Watchmaking,

the American System of Manufacturing

and

Mass Production

2nd Edition

Richard Watkins

Second edition of *Watchmaking and the American System of Manufacturing,* 2009.

Acknowledgements

I started writing *Cook Rice and Potatoes* in 2010 as an addendum to the first edition of this book. However, at that time I was unable to access the court records for the Boston Watch Company insolvency, because the carton containing them had been mislaid. I decided that, without these documents, I could not complete the article and I put it to one side. It was not until 2018 that the documents were located.

In 2018 Bob Frishman went to Boston and photographed a selection of the most important court documents and sent them to me in Australia. Ron Price joined him and provided me with some additional photographs. Without their work and advice the article, and consequently the second edition of this book, would not have been written.

And I would like to thank the Benson Ford Research Center for promptly supplying me with data about Ford's production, and Wolfegang's Collectibles giving permission to reproduce a photograph of a sewing machine.

Finally, but not least, my partner Georgina was a willing participant, happily sitting at her treadle sewing machine while I watched and tried to understand the workings of this complex machine. And she bought a buttonhole attachment from an opportunity shop that was useless for her but enlightening for me.

Richard Watkins

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Introduction

Getting From One Place to Another, Part 1

I once heard a deceptively simple hypothesis, perhaps attributed to Bertrand Russell, that *the development of civilisation is the development of the ability to move things from one place to another*.

At its most basic, this hypothesis draws a distinction between hunter/gatherer societies, where the people moved to the food, and farming societies, where the food moved to the people.

In the context of transportation the hypothesis might be considered trite. The development from horses, to external combustion engines, steam engines, to internal combustion engines, and the corresponding development of roads, canals and railway tracks is obvious and might not warrant serious study. But the hypothesis leads to more interesting aspects of moving things.

For example the London sewage system, developed in the 19th century, can be seen as a solution to London's serious health problems by moving effluent from one place (the city) to another (the Thames estuary).[1] So, although this fits with the hypothesis, I doubt if any books on transportation would include it. And I do not expect they cover reticulated water and electricity, both of which are moved large distances from their sources.

At the time of writing this, two other modern examples are the corona virus covid19, and heart/lung and other transplants.

Similarly, the development of watches in the late 15th century enabled time to be moved from place to place, even though this was hampered by the lack of time zones, which were not created until the end of the 19th century. But knowing the correct time was sometimes important, not just to sailors, and the Belville family carried Greenwich time around London in a watch and charged a fee for it.[2]

And *transportation*, the movement of convicts, was (and is?) an important aspect of the development of civilisation by exporting the un-civil elsewhere and importing others as un-civil or slave labour.

There are many other examples, including the internet and postal services, so meditating on this hypothesis is useful.

The purpose of this book is also deceptively simple, having the objective of moving the reader's mind from one viewpoint to another.

The primary purpose is to define the term *The American System of Manufacturing* as the *manufacture of machines by unskilled labour*. That is, I want to shift the focus away from large-scale production, factories and interchangeability, the three corner-stones of all explanations of the system that I have read. This is because large-scale production, factories and interchangeability are all necessary consequences of using unskilled labour, so this definition is inclusive of all other definitions.

Also the book briefly examines the relationship between the American System of Manufacturing and mass production, a transition that is not clear from other sources, because what I have read about mass production is vague and sometimes contradictory.

With respect to research, it is somewhat unfortunate that I live in Tasmania, a state of Australia, where access to objects and books is very limited, and the time and expense of travel prohibits many areas of study. Consequently, although the proposed definition of the American System of Manufacturing could perhaps be explained in just a few pages if it were done in the context of clock-making and armoury practice, I am limited to two other areas. First, my main interest is watchmaking, and I have a collection of books, tools and watches to examine. Second, my partner Georgina has a small collection domestic

1 Wikipedia, 2020c.

2 Mercer, 1972, pages 83-84.

sewing machines and many of their attachments. So it is natural that I focus on these two machines, even though they were relative late-comers in American manufacturing, both occurring about 1850.

The later development into watchmaking is not surprising, because the manufacture of watches is far more difficult than the manufacture of clocks and guns. Not only are components of the machine much, much smaller, but the accuracy with which the machine must function, and hence the accuracy of the parts, is significantly greater.

The generally accepted view is that the successful application of the American System of Manufacturing to watchmaking took place at the Boston Watch company between 1850 and 1856, under the auspices of Edward Howard and Aaron Dennison; that is

> *the use of machinery to turn out interchangeable parts for watches on a large scale was first achieved in America by the Boston Watch Company.*[3]

However, some writers claim that it was applied earlier by other makers, some of whom were not Americans. And also, there are different opinions as to what was actually achieved.

In contrast, I will argue that the system was not successfully applied until 1857, after Royal Robbins had taken over the Waltham factory.

The emphasis on watchmaking is because it is the industry with which I am most familiar, but it creates a problem in that readers who have little knowledge of watches may not understand parts of my argument. Indeed, this is a problem with all histories of industries and, as a result, most studies are quite general in order to avoid their readers' eyes glazing over!

However, I would rather not generalise, because often generalisations obscure important details and allow wrong conclusions to be derived. And so I have included details, particularly in the appendixes, with which the reader might not be familiar.

For the reader who wants to learn more about watches I suggest three sources:

First, Wikipedia contains the majority of the information necessary, but some searching is required because the information about watches is fragmented into many articles and some articles contain dubious statements.

Second, two useful books are Cutmore *The Pocket Watch Handbook* (1985) and Watkins *Practical Watch Collecting* (2012).

For those seeking more information, there is a bibliography of books and articles pertaining to watches.[4]

The examination of domestic sewing machines is simply the result of my wife having a small collection of them, and because they are the subject of a chapter in another book.[5] Again some detail is provided in an appendix because these machines have an important property, adaptability.

This book is in four sections.

Part 1 examines the conventional definition of the American System of Manufacturing and then looks at relevant American attempts at watchmaking up to the beginning of 1857; that is, the Pitkin brothers and Dennison and Howard.

Part 2 examines the events at Waltham in 1857 and establishes my alternative definition of the American System of Manufacturing. In doing this I also look at the work of Japy and Ingold.

Part 3 considers the concept of mass production and its consequences for later watch manufacturing.

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3 Price, 2005, page 1.
4 Watkins, 2016a.
5 Hounshell, 1984.

The fourth section consists of seven appendices which provide the justifications for the main points in my argument. This information has been separated out so that the reader can gain an overall understanding without being interrupted by the lengthy and technical detail which underlies my research.

This second edition incorporates the information in my article *Cook Rice and Potatoes*,[6] and it also includes many changes and additions to the original text and the appendices. In particular, my methods of assessing the rate of production achieved by the Boston Watch Company and the American Watch Company are completely different and much improved, but the conclusions are the same.

Most of this book simply provides a convenient summary of the known evidence and interprets it in ways that, to my knowledge, are generally acceptable. However my emphasis is different, the sole objective being to examine watch production and in particular *rate of production* (man-days per unit), for it is rate of production that provides the best clues to company success.

It must be noted that there are significant contradictions and inaccuracies in many sources, and some writers make statements for which there are no apparent provenances. And quite often these views are repeated in later works.

This variety of opinion means that it is necessary to very carefully examine and assess the different claims.

To do this I have taken care to provide complete citations, although some repetitions of statements have not been included. The footnotes in this book are reserved for the references and can be ignored by the reader unless he or she wishes to check the original sources. Unfortunately too many of these sources fail to provide details of where they derived their information. Sometimes their statements are obviously wrong, but in others the information is credible and useful. However their lack of citations can cast doubt on their reliability.

Because I expect some readers, like myself, are not Americans, the following map of part of Massachusetts and Connecticut has been included. Until I had seen it I had no idea of the relationships between the principle towns which participated in the early period of American watchmaking.

Monetary Values

It is useful to be able to compare the amounts, in the 1850s in particular, with current values. For example, if a watch cost $30 in 1857, how much would it be worth in 2018, the latest date for which data is available at the time of writing?

There are several ways in which this comparison can be made.[7]

The most conservative is to use the consumer price index (CPI), in which case the watch would be worth about $890 today.

However, a better comparison is to use the labour value, in which case the completely hand-made watch would be worth about $13,900 today. This is because the labour in making a watch is vastly larger than the cost of the materials and is probably about $28 of the total cost of $30. The comparison used is the *production worker compensation*, recognising that watchmakers were skilled workers.[8]

The difference between these two measures is, in part, due to changing expectations. The worker in 1857 did not buy white-goods, cars, mobile phones, etc. that are now considered essential, and our expectations in other areas, such as housing, have also changed. Consequently wages were relatively much lower.

In addition we need to consider discretionary spending; in 1857 how much income was available to buy desirable, but unnecessary items after paying for the essentials of food, rent, heating, etc?

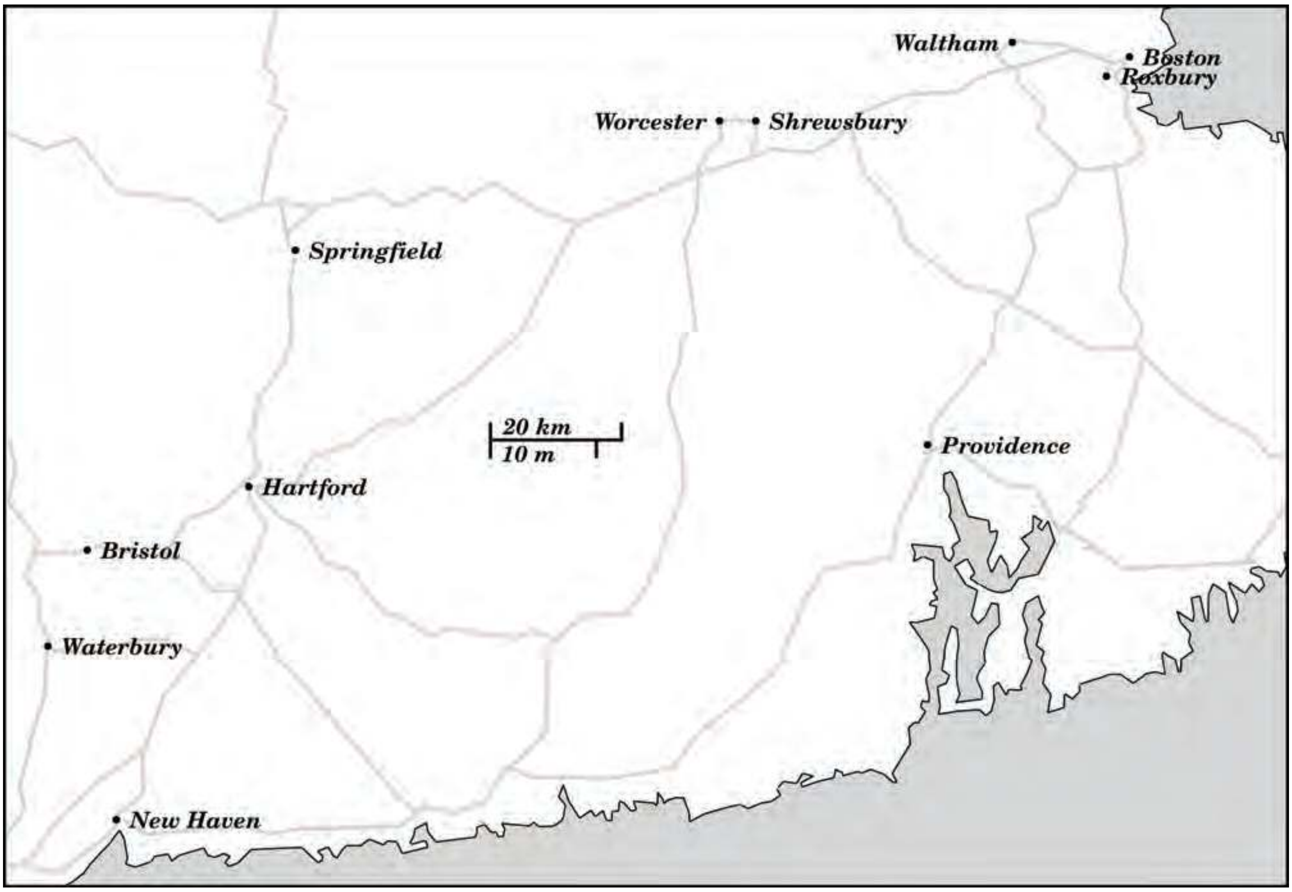
6 Watkins, 2019.
7 Measuring Worth, 2019.
8 Officer, 2011.

For a skilled worker earning perhaps $2 per day, the Boston Watch Company watch cost more than 2 weeks income, but there was little available money. A reasonable guess is that at most 10% of income was discretionary and so it would take about 6 months to earn the price of the watch; this is based on 25 working days in a month, 6 days per week, and allowing for 3 holidays, that is 310 days per year working.[9]

Clearly watches were luxury goods at that time.

A skilled worker at the Waltham factory earned about $610 per year and this translates into about $283,000 per year in 2018.

In addition, at that time labour was the main component of manufactured goods such as tools (and even buildings) and comparing wages is probably a better measure than other figures; it was not until later that sophisticated machinery changed the balance and reduced costs relative to wages.



9 Whaples, 2019.

Part 1: From Cottage To Factory

The Origin of the Species

The *American System of Manufacturing* is often described in rather vague terms that gloss over and obscure necessary details. It is not that such statements are wrong (most are not), it is that broad generalisations often only express one aspect of the system.

Trowbridge defines the *American interchangeable system* as

> *The art of making complete machines or implements, each part of which may be introduced into any machine of the same kind, and especially the adaptation of special tools, by which handwork in fitting the parts is often entirely avoided.*[10]

He goes on to say that

> *it is possible to furnish such machines at low prices only by ... assembling the parts which are required for a complete machine at a single and separate operation.*[11]

Similarly, Hounshell provides the definition

> *the sequential series of operations carried out on successive special-purpose machines that produce interchangeable parts.* [12]

In contrast, and in the context of horology, Clint Geller writes that it is:

> *the development and first practical demonstration of truly efficient mass-production methods for watches.*[13]

In fact, implicit in Trowbridge's definition is the need for large-scale production, for the building of many complete machines from parts requires a stockpile of those parts. But the reverse is not necessarily true and large-scale production need not inevitably lead to interchangeability.

For example, in the late 18th and early 19th centuries, the Swiss and English produced ebauches (rough watch movements) on a large scale, but the accepted viewpoint is that the products were not interchangeable. And as Buffat points out, even as late as the 1870s Roskopf movements were manufactured in batches of 2,000 movements, apparently large-scale production.[14] But these movements required hand fitting and I would not regard them as interchangeable.

I have deliberately used the term "large-scale production" instead of "mass-production" because in Part 3 I will discuss the differences in these two terms.

So Geller is right in that large-scale production is involved, but it cannot be the central, key feature of the American system.

Richard Meibers gives yet a fourth definition:

> *Industrialization brought all these workers together into* ***manufactories****, creating a new way of life and what became known as the American System of Manufacture.* [15]

Even though Trowbridge does not say so, also implicit in his explanation of the American system is the use of factories. Wright, in his history and analysis of the development of factories, states that the first

> *perfect factory, the scientific arrangement of parts for the successive processes necessary for the manipulation of raw material till it came out finished goods*

10 Trowbridge, 1883, page 615.
11 Trowbridge, 1883, page 615.
12 Hounshell, 1984, page 15.
13 Geller, 2005, page 1.
14 Buffat, 2007, page 15.
15 Meibers, 2002, pages 23 and 31.

was the cotton factory built at Waltham in 1814, which received raw cotton and produced finished cloth.[16] Such a factory

> *is an association of separate occupations conducted in one establishment in order to facilitate the combination of the processes into which most branches of manufactures are divided.* [17]

Although the language is archaic, the essence is clear: the effective organisation and control of *multiple trades* under one roof.

But again we have a one-way relationship. A factory need not produce interchangeable parts, but large-scale production of interchangeable parts without a factory is unlikely.

It should be noted that the term *"factory"*, as used above, means a single, distinct place where *all* processing takes place. As Waldo puts it,

> *The American system ... means the establishment of working facilities for the entire manufacture. That everything is made on the premises, not according to the plans or ideas of individual workmen, but under the direct supervision of a company's foreman ...*[18]

This is the model adopted by American watch-makers. In contrast, twentieth century Swiss watchmaking achieved large-scale production of watches using interchangeable parts made by a large number of small, independent organisations, which were an extension of the previous établissage industry. For example, Glasmeier notes that in 1955 there were 2,316 companies, with an average of 22 workers each, and 7,867 home workers.[19] And even large, factory-based companies such as Longines made use of small suppliers and home workers.[20] Many of these companies could not be called factories according to the definitions of Wright and Waldo because they did not produce complete watches, making, for example, just balance springs. So the Swiss system differed from the American system in at least this respect.

Finally, also implicit in these views, and sometimes explicitly stated, is the use of *machinery*. Although this may seem obvious, there is a danger that ignoring the obvious may lead to misconceptions. For example, the machinery used by the English cottage industry may have been the same as used by any individual watchmaker; basic lathes and other tools for hand work. So even if they achieved large-scale production of interchangeable parts, which they did not, there could be qualitative differences in the methods and organisation.

Whether such differences are important remains to be considered, but it is necessary that we examine the *type* of machinery used rather than just its mere existence.

Thus Trowbridge seems to be correct in placing the emphasis on interchangeability, and it may be the fundamental corner-stone upon which the American system is built. However, all four aspects are needed, and so we should define the American system as *the large-scale production in a factory of products from interchangeable parts by the use of machinery*. It is this definition, with minor variations, that forms the basis of the analyses by Hoke,[21] Glasmeier and others. Because all four aspects are intimately related, it is almost impossible to discuss one in isolation; any argument must necessarily invoke all because you cannot have one without the other.

So far, I have deliberately ignored a fundamental point.

Implicitly or explicitly, all the discussions of the American System of Manufacturing are predicated on its originality. Indeed, it is called the *American* system, not the interchangeable system, for that very reason; as Trowbridge says, it *"is, I believe, of American origin"*.[22]

But what is original about it?

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16 Wright, 1883, pages 539-540.
17 Wright, 1883, page 533.
18 Waldo, 1886, page 189.
19 Glasmeier, 2000, page 200.
20 Marti, 2007, pages 194-197.
21 Hoke, 1990.
22 Trowbridge, 1883, page 615; see also Hounshell, 1984, page 17 and page 333.

Large-scale production had been carried out long before the Americans developed it and, irrespective of the method or the results, the Swiss, French and English had successfully manufactured watch movements by large-scale production at the end of the 18th century. Certainly Japy achieved large-scale production of movements, supposedly making at least 40,000 a year in the 1790s with only 50 workers, using machines designed and patented by Japy.[23]

Factories existed in England and on the continent which pre-date American factories. For example, those for cotton manufacture and Japy's watch and clock factory in Beaucourt. To some extent, Trowbridge avoids this problem by defining the American system to be the *"art of making complete machines or implements"*, so excluding cotton manufacture. But the problem still remains: there is little or nothing original to the Americans.

Machinery for watchmaking had been developed by Japy, Ingold and others prior to or contemporaneously with the Americans.[24]

And *interchangeable parts* had been used in the 1780s. Rolt points out that interchangeable parts for guns were made by Le Blanc in 1785 and Bodmer in 1806, both in France. Of the latter, it was written

> *Mr Bodmer invented and successfully applied a series of special machines by which the various parts … were shaped and prepared for immediate use, so as to insure perfect uniformity.*[25]

This, with the omission of the word "American", is just what I have defined above. Also, Japy achieved a degree of uniformity that we must regard as interchangeable if we are also to accept the claims put forward for the Pitkins and others.

About the only thing we might be left with is the *combination* of all four aspects in a single entity. But even the originality of this is dubious to say the least, as the factories of Bodmer and Japy fit this requirement. Admittedly Cutmore notes that Japy's movements were *"identical"* but the parts were not interchangeable in that they required hand finishing, and after finishing *"the parts would still not be interchangeable"*.[26] But much depends on how the word *interchangeable* is defined. If we follow the example set by Hoke, which I will discuss shortly, then Japy's movements were definitely interchangeable.

So what we do know is that the very existence of the American system appears to rest on a quicksand of half truths and its originality in America is dubious to say the least. Indeed, the phrase *the American System of Manufacturing* appears to be a mythical creature, a mirage, and the closer we try to get to it, the further away it is, until it vanishes and we are left with nothing.

But this is untenable. The system does exist.

So what are we missing? There is no doubt that *all* the commentators can't be wrong and there *is* something which sets the American system apart. But it cannot be the conventional aspects of factories, machinery, large-scale production and interchangeability.

The Holy Grail

In a TV interview, the famous American economist J.K. Galbraith once said:

> *There are some advantages in being right. You don't have to change your mind.*

Unfortunately, being right is not that easy! In reality differences of opinion coupled with the ambiguity of most historical information make any sort of absolute rightness impossible. All that we can hope to do is to follow Morpurgo's advice, that professional historians are

> *those people who, by the use of documents* [and artefacts] *and their own intelligence and knowledge, pursue a matter to its core, but not those who blindly repeat the opinions of others.*[27]

23 Cutmore, 1989, page 19, Harrold, 2005, page 28; but see Watkins, 2010.
24 Japy, 2006, Penny, 2005.
25 Rolt, 1986, page 148.
26 Cutmore, 1989, page 20.
27 Morpurgo, 1954, page 56.

That is, it is necessary to question everything and allow nothing to be taken for granted. For we are at greatest risk of erring when we gloss over what seems obvious, only to find out later that the obvious was in fact obscure. Or the obvious was not obscure, but so generalised as to allow any interpretation and any circumstance to fit. Either way we risk drawing conclusions that are at best unhelpful and at worst wrong.

In the context of the American system, this requires us to carefully examine every aspect of our definition and expose the consequences of different interpretations and choices.

Of the four factors, large-scale production, factories, interchangeability and machinery, it is interchangeability that creates the most problems. Large-scale production and factories are a question of degree, how much and how big, and achieving some consensus should not be too difficult. And machinery can be examined, categorised and its behaviour specified. But the word "interchangeable" is often used without any attempt to define it, and without specifying what is interchangeable.

Yet interchangeability is the holy grail of manufacture and especially of watchmaking. Fitting parts, and finishing and adjusting movements takes a large amount of time, and requires the most skilled and most highly paid of all watchmaking workers. What if parts could be made so accurately that they required no fitting or finishing, and they could simply be taken, put in a watch and work? What if parts could be made so accurately that the watch would work without needing to be adjusted for isochronism, temperature and positions?

Hoke is one of the few writers who has defined the term interchangeability:

> *In fact, every nineteenth century manufacturer of complex mechanisms designed these mechanisms to be adjusted at the time of assembly. Thus the interchangeable parts were interchangeable, but only to the degree necessary, the degree stipulated by the design of the product.*[28]

And he states, with regard to Waltham:

> *Watches were also interchangeable within the confines of this new definition of interchangeable. Most parts ... were completely and fully interchangeable, while some parts were interchangeable until assembly.*[29]

As he points out:

> *The segregation of partially finished watches was critically important, because, at certain points in the manufacturing operation, some of the parts of each watch were machined with respect to each other and had to be kept together.*[30]

This weak definition, which forms the basis of Hoke's book, has been used by many writers. For example, Torrens, with respect to manufacture in Prescot, England, says

> *parts for any particular size of movement of the same maker were interchangeable within the limits set by the condition and the rate of wear of the tools.*[31]

And Glasgow, writing about Wycherley's late 19th century factory in England, states

> *the wheels, barrels, and other parts are practically interchangeable* ***in their unfinished state****.* [my emphasis][32]

But there are two serious problems with this approach.

First, it is a cart-before-the-horse argument. Parts were *not* made interchangeable "only to the degree necessary", but as interchangeable as the machines and techniques allowed. And the manufacturing process was dictated by lack of interchangeability and not the other way around.

28 Hoke, 1990, page 308, note 5; Hoke, 1991, page 60, note 96.
29 Hoke, 1990, pages 262-263.
30 Hoke, 1990, page 244.
31 Torrens, 1947, page 177.
32 Glasgow, 1885, page 42.

To take the most extreme case, consider the balance, balance staff, balance spring and balance jewels in a pocket watch. Hoke says

> *As with typewriters, watches required adjusting as an integral part of their manufacture.*[33]

This is true, but it is true because it was (and still is) *impossible* to make these parts with sufficient accuracy. If that could have be done then the months of laborious testing and meticulous adjustments would have been unnecessary and high quality watches would have been far cheaper.

A clearer illustration of this is the end-shake tool described in Appendix E (see page 118). We know from Jacques David and others that both the length of arbors (from pivot shoulder to pivot shoulder) and the diameters of pivots varied so much that jewel holes had to be chosen to suit a particular arbor and then set into the plate by varying amounts to suit the arbor length, the latter being done using the end-shake tool.[34] Thus the plates were adjusted to suit the arbors, resulting in non-interchangeable arbors and non-interchangeable plates, plates which may have been interchangeable before finishing!

(However, there is some evidence of size variations in plates which suggests that in the early years at Waltham plates may not have been interchangeable.[35] This may be because they were manufactured by Scoville in Waterbury, with less quality control, and not in house; although, at least in later years, the dies were supplied by the watch company.[36] Out-sourcing plates is sensible, because punching blanks takes very little time. For example, if 50 workers could make 3 watches simultaneously, at about 16 man-days per watch, then the person making the plate blanks would cut out the plates needed for 3 movements, taking less than a day, and then be idle for the rest of the 16-day cycle. So, unless he could perform other tasks he would either have an extremely low, inadequate piece-rate income or be paid for doing nothing. Obviously it would be far better to get Scoville workers to do this work, workers who would have been used to cut out flat brass for a number of different clock and watch companies and so be fully employed.)

Hoke's argument suggests that in 1876 Waltham had deliberately designed watches to use non-interchangeable arbors so that they could be fitted by the end-shake tool. This is patently silly. The end-shake tool was invented only because Waltham could *not* make interchangeable arbors and not the other way around. Indeed, the entire history of American watchmaking is a century long struggle to develop better and better machines to make parts to smaller and smaller tolerances. It was *not* a struggle to design watches for poorly made parts.

If we accept Hoke's definition, and allow final adjustments to be made to "interchangeable" parts, then we must also conclude that Japy made interchangeable parts, because his movements required some final adjustments. And so the Pitkins and the Boston Watch Company were many years after the first large-scale production of interchangeable parts. The problem is the vagueness of the statement. How much and what sort of finishing is acceptable?

To make this clear, let me suggest the following: Dogs have legs. Insects have legs. Therefore dogs are insects. This argument is obviously absurd. But consider another example: Interchangeable parts require fitting. In 1763 Ferdinand Berthoud made watches with parts that required fitting.[37] Therefore Berthoud made interchangeable parts. The problem is that dogs are only one type of creature that has legs, and interchangeable parts are only one type of parts that require fitting. There are things with legs that are not dogs and fitted parts that are not interchangeable. So, if we set the hurdle too low, then Berthoud made interchangeable parts, but I doubt if anyone would accept this. And if we set the hurdle too high, then interchangeability was not achieved until about the 1930s, 80 years too late. And strictly speaking, complete interchangeability has never been achieved, because even today escapements, balances and balance springs of fine watches have to be individually adjusted.

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33 Hoke, 1990, page 210.
34 David, 2003, page 62.
35 Price, 2005, pages 4-5.
36 David, 2003, page 39; Fitch, 1883, page 60 (page 676).
37 Berthoud & Auch, 2005.

As another example, I have heard statements about people taking several watches of the same model and grade, mixing up the parts and then successfully re-assembling the watches. One example, cited by Sauers, is

> *if you completely dismantle 100 Hamilton watches of the same model, you could mix up all the parts and reassemble 100 watches that would all run perfectly* ***with little or no adjusting****. The amazing thing is that you could do this with every model they ever made. I don't know of another watch company that can make this claim.*[38]

Perhaps Hamilton was far in advance of other American companies, for my own experience has been quite different. I once had two Waltham movements of the same model and grade, but manufactured in different batches a few years apart around 1890. Neither worked, so I tried to build up one good movement using parts from both. I could not. The escapements were not interchangeable and it was not possible to get the balance from one to function with the lever from the other. This surprised me because both were low grade watches and surely the larger tolerances would make it easier, not harder to interchange parts?

But Jacques David makes it clear that reject parts, which were outside acceptable tolerances, were used in low grade movements where larger tolerances were acceptable.[39] And so individual fitting was also necessary with those movements, but presumably it was done with less care.

Of course, with a bit of good luck it might be possible to swap parts.

But swapping is not enough. Not only must the part fit, but it must fit *within the required tolerances* for the grade of movement, and tolerances vary with the part. It is probably quite easy to physically swap barrel bridges, for example, but unless the holes for the barrel arbor are the correct size we may well find there is too much or too little side shake. An escape wheel or balance is far more critical and our chances of a successful swap are very small; the watch might run, but it is very unlikely that it can be adjusted to the required accuracy. In which case we must regard the swap as a failure. And because balances and balance springs were carefully matched to each other, it is not possible to switch balance springs and expect the watch to function correctly. This was the case at least until 1895,[40] but well into the twentieth century *balances complete* were being sold that were comprised of matched balances and balance springs.

An interesting example of the lack of interchangeability is the use of adjustable banking pins in American watches; see Figure A6, page 85. Mounting the banking pins eccentrically on screws makes it much easier to set up escapements in which the parts are not interchangeable. And the extra cost and complexity, compared with fixed banking pins, is offset by reduced labour and time. In this case the solution lay not in improved machinery and improved accuracy, but in the design of the watch; just as the Pitkins used screwed in conical bearings to overcome variations in arbor lengths.

The general use of screwed banking pins at Waltham commenced about 1861.[41] However, Howard used them on his return to Roxbury.[42] In addition, Price lists two Boston Watch company movements (Nos. 628 Samuel Curtis and 1351 DH&D) and four American Watch Company movements (No. 1423, PSB made in 1857; Nos. 1871 and 1878 made in 1858; and No. 14748 made in 1859-60. (There is one other odd movement but it dates from 1863.) Making these banking pins would require some sort of machine to form the eccentric pin on the end of the screw and it seems unlikely that these early movements actually had them. However, such a machine might have been built just before the insolvency and taken to Roxbury; which would explain Howard's use of them.

Another example of the careless use of "interchangeability" is the standard WW 8 mm watch-makers' lathe. In reality there is little or no interchangeability of parts. I have a collection of split chucks from

38 Sauers, 1992, page 94.
39 David, 2003, page 29.
40 Houriet, 1895, pages 23-24, see page 120 for a description.
41 Price, 2005, pages 77 and 99.
42 Price, 2005, pages 156-157

a number of makers. Despite being *standard* 8 mm split chucks, there is considerable variation in body diameter and length, thread diameter and thread pitch. Some have to be forced into the head stock. At least two have thread diameters so small that the draw bar slides over them. And several cannot be screwed into the draw bar because of thread pitch or diameter problems. Whether lathe makers did not try to make interchangeable parts, or they simply could not do so, is a question that needs to be answered.

The easiest way to tackle the problem of interchangeability is to start with the strictest possible view:

> *The criterion of interchangeability is the ability to choose any part in a pile and insert it in its place, **where it functions without further adjustment or treatment**.* [my emphasis][43]

This definition forbids any manipulation of the part or the place where it is located. Further, the part must not merely fit but must function correctly; by which I mean the fit of the part must be within prescribed tolerances. For example, the end and side shakes for a balance staff must be neither too large nor too small for the grade of watch; clearly the shakes for a railroad grade watch must be far better controlled than those for a dollar watch. If a part fits but is outside the required tolerances then it is not interchangeable.

The advantages of this definition are very important. First, it is fairly easy to decide which parts are interchangeable and which are not. And second, as a consequence, it is easy to define *partial interchangeability* where some pieces are interchangeable and others are not. With this definition we can determine the degree of interchangeability achieved in different places or at different times. But to do this, we need to strip down and accurately measure all parts in a number of movements. As far as I know, no one has ever done this.

As I have indicated, the majority of writers explicitly, or more often implicitly, weaken this definition in two respects. First, they do not distinguish between partial and complete interchangeability and use the unqualified word irrespective of the degree of interchangeability achieved. Second, they allow parts to be fitted and still regard them as interchangeable. However, no one specifies just how many parts need to be interchangeable or just how much fitting should be allowed for the word "interchangeable" to be applicable. It is this vagueness that leads to the diverse opinions regarding the Pitkins and other watch manufacturers. By insisting on the strict definition it is possible to remove the vagueness by quantifying the degrees of interchangeability and fitting, and so enable a sensible comparison of different watchmaking endeavours.

Has the Jury Considered its Verdict?

One serious problem faced by historians is the lack of conclusive evidence. Very rarely do we have the contemporary documents and artefacts to enable a definitive assessment of people and events. Consequently, historical research has much in common with juries. Jurors are presented with incomplete and conflicting information about events and asked to come to a conclusion about what really happened. Like us, they have to work on the *probability* that certain things occurred. By carefully examining the possibility of different explanations, they and we can decide that one view is much more likely than another and so reach a reasonable decision. Unfortunately some people do not understand, or are unwilling to accept, the validity of such a process and they require absolute certainty, which is almost never possible. Others cling to preconceptions or irrational preferences and attempt to justify their decisions by explanations that often have such a low probability as to make them effectively impossible. But the majority of us have at least a vague understanding of the significance of probabilities and so can reach a sensible, likely outcome, beyond reasonable doubt.

We can liken the various articles and books published over a period time to the opinions of a number of one-man juries. Some provide credible, well argued assessments of the facts and draw likely, satisfying conclusions. A few express opinions that, on careful examination, are simply incredible and unacceptable.

Like the law, later writers often rely upon the precedents set by previous judgements. These people accept some earlier interpretation and repeat it, perhaps with some variations. Which is fine if the person being

43 Landes, 2000, page 491, note 1.

relied upon got it right, but it is disastrous if an unlikely, unsafe verdict is used. The repetition of such precedents produces myths, statements which, as a result of frequent regurgitation, are taken as true when they are not.[44]

The Pitkins provide an interesting example of the need to behave like a jury. There is very little concrete evidence and what we know has been used to produce contradictory statements about what they achieved and their role in the development of the American system. Thus they provide a good place to start our examination of that system.

The most important history of the Pitkins' endeavours is the first, written by Crossman in 1885.[45] His account is credible because of the considerable detail of their manufacturing methods and watch designs. The Pitkins manufactured watches in Hartford between late 1838 and late 1841, when they moved to New York. The five known watches from this period, with serial numbers from 46 to 164, confirm the generally accepted view that they made at most 200 watches. The Pitkins, together with four apprentices, established themselves in a building, designed and constructed machinery, and then made watches. Although their watches have a number of interesting features, the two most important are the type of pivots (and their holes) and the use of lantern pinions. According to Crossman three different pivot designs were used. However, all of the 4 illustrated watch movements are stated to use the one design of *pivot screw*: conical pivots running in steel, conical holes on the ends of screws. Although he does not explain, Crossman is quite emphatic when he writes

> *the movements were not interchangeable.*[46]

Twenty years later, Abbott added a little. He quotes Ambrose Webster, who said that the Pitkins

> *attempted to make uniform interchangeable watches.*[47] [Note the strange use of "uniform".]

Then we have to wait nearly fifty years for Small to expand our knowledge.[48] To a large extent, Small bases his article on Crossman and Abbott, but he also makes statements which are not derivative. According to him, around 1820 the Pitkins were probably apprenticed to Jacob Sergeant, a master of both silversmithing and watchmaking. However, their later demonstration of watchmaking abilities suggests they learned far more about silversmithing and Sergeant was probably a watch repairer, not maker; a view supported by Crossman. Small believes the

> *Pitkin brothers were the pioneers in the original and revolutionary system of watchmaking which evolved into what has become known as the 'American Plan'.* [49]

And he goes on to say that

> *there is evidence that* [Pitkin] *had given some thought to standardization and interchangeability of parts ... That was a natural conclusion, since he was working within the sphere of influence of the Springfield Armory, where Eli Whitney's ideas of mass-production were then receiving there highest fulfilment.*[50]

But guns are utterly different from watches, both in size and structure. As Fitch shows, the making and boring of barrels is so different that the methods are not applicable. Other than the general principles of presses for lock parts and machining, there is nothing relevant to watchmaking.[51] It is interesting that Fried states:

> *Even the Civil War helped these young companies: Elgin purchased gun-making machinery cheaply near the end of the war and converted it to watchmaking.*[52]

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44 Watkins, 2005; Watkins, 2010.
45 Crossman, 1885, pages 4-7.
46 Crossman, 1885, page 5.
47 Abbott, 1905, page 51.
48 Small, 1954.
49 Small, 1954, page 251.
50 Small, 1954, page 255.
51 Fitch, 1883, pages 6-12 (pages 622-628) and pages 19-29 (pages 635-645).
52 Fried, 1994, page 10.

But this is not credible. The only useful machinery would have been general metal shaping tools that could have been used to make watchmaking machinery; the presses, lathes and tools being far too large for manufacturing watch parts. A more startling failure to understand the differences between watches and other manufactured items is that of the 1870 tool supplier to the Swiss company Eterna who used an American automatic nail making machine as the basis for the design of watchmaking machinery. Not surprisingly

> *the new machines, however, functioned miserably* [53]

A number of other writers come after Small. Most base what they write on earlier opinions, adding nothing new. Many of these rely on Crossman and don't need to be considered. And some are not credible. For example, Meibers says the Pitkins

> *manufactured about 500 complete watches with fusees ... prior to 1842.*[54]

But all the early watches made in Hartford had going barrels, as does the New York watch illustrated by Wingate.[55]

The most notable feature is the attitude to interchangeability. At the opposite extreme to Crossman is, for example, Bruton who writes

> *they made parts that were interchangeable.*[56]

But the majority equivocate, saying the parts were interchangeable but with qualifications. Cutmore, for example, informs us that the Pitkins' watch was

> *the first to be made by machine with reputably interchangeable parts although there is no doubt that the interchangeability would require considerable fitting skills.*[57]

The other substantive article is by Wingate, who includes some interesting photographs of watches. Although he relies on Crossman and Small, Wingate has embellished the gaps with statements like:

> *After weeks of being confined to bed with a high fever ... he returned to his shop* [and] *was overwhelmed to see Stratton operating the machinery that stamped out plates for his new watch.*[58] [Stratton will reappear later on page 34.]

These and other myth-making statements are derived from Rosenberg. But, unlike Rosenberg, Wingate presents them as facts; Rosenberg states at the beginning of his article:

> *I have taken the liberty of fictionalizing this meagre data ... where facts are few and imagination must fill in the voids.*[59]

Finally, and more recently, Jon Hanson has stated:

> *Several 'experts(?)' have mentioned from time to time that these watches were not interchangeable but this is simply not true. Although these were essentially hand made (actually fitted) and finished, many of the parts* ***are*** *interchangeable.*[60]

So it is hardly surprising to find some people state adamantly that the Pitkins produced watches with interchangeable parts whereas others insist nothing they made was interchangeable. It may be that both groups are correct, because they define the word "interchangeable" in different ways and so allow different interpretations. Such a range of opinions can only be resolved if we enter the jury room and decide what, in all probability, reasonable people like the Pitkins actually did. And this is not all that hard if we compare the Pitkins' achievements with our understanding of the American system.

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53 Brunner, Pfeiffer-Belli & Schild, 2006, page 21.
54 Meibers, 2002, page 59.
55 Wingate, 1982, pages 386-391.
56 Bruton, 1979, page 184.
57 Cutmore, 1989, page 25.
58 Wingate, 1982, page 384.
59 Rosenberg, 1963, page 582.
60 Hanson, 2019.

Large-scale manufacture: In three years the Pitkins and four apprentices produced at most 200 watches. Can this be described as large-scale?

A useful indicator of productivity is *the number of man-days required to make one complete watch,* ignoring the work in progress. The main reason for this measure is because at least some information about completed watches is available for the different watch manufacturers. In contrast, we know very little, if anything, about the work in progress, which ranged from basic, rough components to complete movements being assembled and adjusted prior to sale.

The exclusion of work in progress means that the actual rate of production is faster than the estimated man-days per watch for *all* manufacturers. However, it is much more important to use a consistent measure that enables meaningful comparisons of the production achieved by different makers.

Assuming a six-day working week, or about 310 work-days per year (allowing 3 holidays), the 66 watches per year made by the Pitkins each required about 28 man-days of work. Of course the number of workers throughout this period is not known and the figure could be as low as 19 man-days (four people) and so it seems fair to take an intermediate figure of 23.5 man-days.

To make matters worse, such a figure can only be compared with another, from a different time and place, if the length of the days are the same. For example, Rosenberg suggests the Pitkins had a 12-hour working day.[61] But later 10-hour days were used, and so the Pitkins took about 34, 28 or 23 10-hour days to make a watch, depending on the number of workers. Clearly the number of man-hours to make a watch would be a better figure, but it is almost impossible to determine and no one has used this.

What is important is that these figures correspond to those for making watches by hand; although hard to quantify, it seems that traditional watch-making methods took about 25 to 30 man-days per watch.

Factory: 6 people in a small building constitute a *workshop*, not a factory.

Machines: The only machines that we know they used were presses for plates and other flat work. But, if it took a generous 5 minutes to press out one plate, then the 600 plates and balance cocks for 200 watches could be made in less than 5 days. (The watches do not use a barrel bridge and there are no bridges on the dial plate; see Figures 4 and 5 on page 23.) So what did they do for the rest of the three years?

The answer is simple. Marsh notes that

> *an ordinary watch movement is composed of upwards of one hundred and fifty distinct pieces, and a careful list of the distinct operations required to complete them all show the number to be over 3,700 or an average of twenty-five operations for each piece.* [62]

Fitch provides some useful details of different processes.[63] Harrold suggests a total of 1,200 operations.[64]

This is based on estimating 8 operations per part, which is too low; for example, making an 8 "leaf" lantern pinion requires at least 40 operations. In Appendix A (page 82) I provide a third estimate based on the common design of a 7-jewel movement, together with a summary of the different operations involved; it agrees quite well with Marsh's estimate.

But only 12 flat parts can be pressed out of brass and steel, including the wheels, lever and balance. Each of these require a different set of dies and the resulting blanks then require considerable further processing.

For example, the under-dial photographs of watches number 46[65] and 164 (see Figure 5, page 23), show four circular cut-outs (three eccentric) which do not go through the pillar plate and so cannot be pressed out. So these have to be turned with the plate held eccentrically on a mandrel or cemented to a wax chuck; remembering that these watches were made long before the versatility of the WW lathe was available.

61 Rosenberg, 1963, page 583.
62 Marsh, 1890, page 13.
63 Fitch, 1883, pages 63-67 (pages 679-683).
64 Harold [2], page 26.
65 NAWCC, 1976, page 41 and Hanson, 2019; permission to reproduce photographs of this watch was refused.

Even holes passing through plates may not have been punched out. Harrold states:

> *Top plates were stamped with windows in them ... From subtle variations in window shapes, it may be inferred that dies were periodically being re-sharpened, and late watches had no windows at all.*[66]

But periodic sharpening of dies within a run of only 200 plates seems unlikely, and the absence of windows suggests entirely new dies. A far more likely explanation is that the dies cut plain brass disks and the windows were added later by hand.

Anyway, punching parts is the *least* used process, and is insignificant when compared with the 3,688 other operations (or 1,188 if you prefer Harrold's figure) of drilling, turning, wheel cutting, finishing (deburring, smoothing and polishing), and shaping irregular parts, like potences, which cannot be turned or punched out. So the vast majority of the work must have been done using other tools and machines.

Most importantly, the watches themselves are crude. Compared with the hand work of the late 18th and early 19th centuries,[67] which is the standard of work expected from any apprentice watchmaker of the time, the arbors, pinions, pivots and pivot holes used by the Pitkins stand out as not only unusual, but indicative of serious inadequacies. If the Pitkins were competent watchmakers then it would be much easier and far better to turn arbors from pinion wire on hand lathes than to make tiny lantern pinions and hardened steel screws with conical depressions. As they must have been importing some parts (such as balance springs, mainsprings and dials, which were still being sourced overseas in the 1850s) supplies of pinion wire should not have been a problem. Crossman (repeated by Small) writes that

> *several experiments were tried in order, if possible, to* ***improve*** *on the old method in which pivots run in the plates or jewels set in the plates.* [my emphasis][68]

But what the Pitkins did was certainly not an improvement, and I suspect Crossman was showing their experiments in a better light than they deserve.

Harrold sensibly suggests

> *lantern pinions and screw pivots were logical extensions of clock practice,*[69]

with which the Pitkins would have been familiar and which would be a much more likely source of ideas than Small's suggestion of the Springfield Armory,[70] although I am not aware of screw, conical holes being used prior to modern, cheap clocks. Harrold suggests they were used to

> *avoid the difficulties and bottleneck of machining pinions from solid* [and to avoid the] *numerous or complicated lathes for performing the many machining operations required to make solid arbors and pinions.*[71]

But this is incorrect, because pinion wire was universally used and, as Berthoud and Auch show, easily "machined" using files and turns.[72] And pinion wire was still being used in 1856.[73] Compared to using pinion wire, making tiny lantern pinions, involving drilling small disks and riveting in small wires, would be much more difficult and would require much more skill. It may make sense if the Pitkins' experience led them to make small clocks rather than watches, but it cannot have been easier and certainly was not better.

One fascinating feature of watches number 46[74] and 164 (Figure 5, page 23) needs to be mentioned here. It is clear from the under-dial views that the cannon pinion and the minute wheel have conventional

66 Harrold, 2005, page 37.
67 Berthoud & Auch, 2005; Vigniaux, 2011.
68 Crossman, 1885, pages 4-5; Small, 1954, page 256.
69 Harrold, 2005, page 37.
70 Small, 1954, page 255.
71 Harrold, 2005, page 37.
72 Berthoud & Auch, 2005, pages 30-32, 89-91.
73 Waltham Sentinel, 1856, page 144.
74 NAWCC {2}, page 41 and Hanson, 2019; permission to reproduce photographs of this watch was refused.

pinions, whereas I assume the train uses lantern pinions. Why? If the Pitkins had pinion wire and could make a cannon pinion, why didn't they use the same, superior pinions elsewhere? And if they had these skills, why not use superior, conventional pivots? As a juror, I can conceive of no credible explanation other than that they imported the motion work. Although 30 years earlier, David Cooper provides a list of imported tools and material, which includes dials, hands, pinion wire, canon pinions, verges, balances and *"motions"* (which I presume means the minute and hour wheels).[75] Most if not all was still being imported in the 1850s.

Thus it is probable that, other than presses, the work was done with simple hand tools, such as English turns, mandrels and the like. This view is supported by Small, who quotes Abbott quoting Ambrose Webster:

> *they attempted to make ... all parts interchangeable as far as possible with the* ***crude*** *appliances of those days.* [my emphasis][76]

And other authors also refer to *"simple devices"* and *"crude"* machines. Except for presses, the only other concrete mention of a tool is by Hoke, who suggests they had *"an embryonic gauging system"*.[77] Although Crossman mentions a gauge for grinding pallets, I suspect Hoke is simply deducing gauges from the supposition of interchangeability. Anyway, gauging has always been a part of watchmaking, and evidence that the Pitkins' gauges were qualitatively different is needed before we can regard them as significant.

The strongest evidence to support my contention that the Pitkins had no machinery other than presses is the *absence* of any information. There can be no doubt that what the Pitkins did was of great interest to other watchmakers and was talked about. This is clear from the fact that Crossman, writing nearly 50 years later, is able to provide so much detail about their methods, including a precise explanation of how they made the pallets. So we can expect that if the Pitkins used any other novel tools and techniques it would be known and documented. But there is no such information and we can only conclude that there were no other features of their manufacturing process worth talking about.

The importance of this is made clear by my quote from Marsh above and Appendix A (page 82), specifying the number and types of operations to make a watch. We know the Pitkins used presses to perform a very small number of operations, but how did they carry out the other processes? How did they drill holes, turn arbors, make screws, pillars, pins, and make lantern pinions? We do not know, but we can be confident that these tasks were performed by conventional methods. Consequently, as Hanson states, the Pitkin watches *"were essentially hand made"*[78] and not made by machinery.

Interchangeability: The fourth criterion of the American system is interchangeability. Unfortunately there is very little evidence, because (with one exception) the Pitkin watches have not been stripped and examined. But there is simply no reason to suppose the Pitkins achieved any degree of standardisation deserving of the word interchangeable. Most importantly, there are only two reliable statements, by Crossman and then Webster in Abbott; one flatly denies interchangeability while the other makes it sound most unlikely.[79]

The Pitkins' use of screwed pivot holes was probably a *necessity* and not a *desired* design choice. With them it would be possible to allow for significant variations in arbor length (maybe half a millimetre or more, depending on the thickness of the plates). So built into the design is a way of *hiding* the dissimilarity of the parts. Of course, these conical holes do not help with the depthing of the wheels and the pinions they mesh with, and variations in wheel and pinion diameters would still have to be remedied by re-cutting teeth or altering the positions of holes in the plates. However, the depthing of lantern pinions is far less critical than the depthing of normal pinions, and so there could be some variations in the wheels without it causing problems.

75 Cooper, 2002, page 27.
76 Small, 1954, page 255; Abbott, 1905, page 51.
77 Hoke, 1991, page 63.
78 Hanson, 2019.
79 Crossman, 1885, page 5; Abbott, 1905, page 51.

A second feature, mentioned by Small,[80] is that the early balance pivots were held by a pair of half jewels which could be moved to adjust side shake. This comes from Crossman, but the relevant text and illustrations were omitted from the first edition of his book. Crossman states:

> *At that time, however, they were unable to make jewels of the regular kind, even if they had desired to use them. ... before the regular style of balance jewels were used, they used a device of which a cut is given, much enlarged [Figure 1]. The slides having jewels in them similar to a balance jewel cut in half that would slide up to the pivots, barring side shake necessary for freedom, of course, and then they were set fast by the screw at the bottom. The movement, of which a cut is given [Figure 2], has this arrangement in it also. Just when it was dropped for the regular style of balance jewelling the writer is unable to ascertain.*[81]

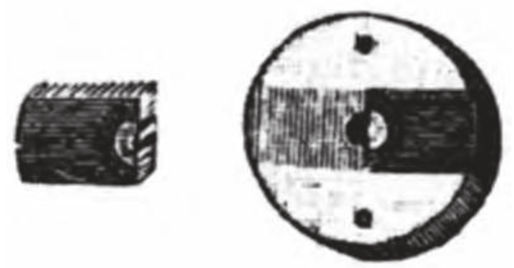

Figure 1 (Reproduced from Crossman & Dawes, 2002, page 2)

Figure 2 (Reproduced from Crossman & Dawes, 2002, page 3)

This method of jewelling is very dubious!

(a) If the balance pivot diameter is smaller than the effective diameter of the jewels and the two jewels are exact halves, then the jewels must be pressed against each other and side-shake depends on how much smaller the balance pivot is. If the jewels are less than exact halves, then the side-shake will be larger parallel to the meeting faces than perpendicular to the faces.

(b) If the balance pivot diameter is larger than the effective diameter of the two jewels, then there must be a space between the two jewels and side-shake is determined by the corners of the round jewel holes. If these are sharp they will cut the pivot.

The serial number in Figure 2 and the watch number 164 (next page) suggest that most of the Pitkins' production used this form of jewelling.

Crossman's explanation for the use of this type of balance jewelling is most likely wrong. At the time jewels were imported and supplies of hole and endstone jewels should have been available. Also, the jewels in Figure 1 could *not* be bought off-the-shelf and would have to be made, and they would probably be harder to make than regular hole jewels. The only reason to use this method of jewelling would be as a poor way of overcoming a lack of interchangeability.

I am sure the Pitkins did their best, commensurate with their skills and machinery. But their best was to make similar, but not interchangeable parts and produce hand finished watches. There was still a long road to tread before anything deserving of the name of the American System of Manufacturing was produced.

All this is conjecture based on probabilities. If we wish to, we can say 66 watches a year is large-scale production; some presses and turns constitute machinery; 6 people in a building is a factory; and parts that need significant finishing are interchangeable. If so, the Pitkins used the American System

80 Small, 1954, page 256.

81 Crossman & Dawes, 2002, pages 2-3.

of Manufacturing. But only if we relax our definition even more. Trowbridge defines it as the making of *complete* machines and most certainly the Pitkins did not make balance springs, mainsprings, jewels or dials; all were imported. Should we really accept a process that relied on imported, finished parts? Perhaps we have to, otherwise the Boston Watch Company has to be excluded too; after all, the name the "American Horologe Company"

> *was continued but a few months, it being too suggestive, as they were obliged to send across the water for much of the material they used.*[82]

(Dennison denied this name was used,[83] but Howard stated it was.[84])

Even if we feel uncomfortable with this watering down of the concept of the American system, there is nothing to prevent us deciding that the Pitkins created a prepubescent version or prototype which evolved into the system during the rest of the 19th century.

I have deliberately avoided mentioning two other important pieces of evidence, because I wanted to focus on what we could learn about the Pitkins from documents. But in addition to the books there are illustrations of five Pitkin watches made in Hartford (numbers 46, 66, 91, 148 and 164)[85] and one watch has been taken apart and examined.

Figures 3 to 5 show two extant watch movements with serial numbers 148 and 164, Figure 5 being the under-dial view of number 164. Top plate and under-dial views of watch number 46 are available,[86] but permission to reproduce photographs of this watch was refused.

Figure 3 (Reproduced from Hoke [2], page 62)

From these photographs we can see a number of important features:

(a) The movements were hinged to the case in the English style; both the hinge and the catch are visible in Figure 3 and the catch and its spring in Figure 5.

(b) The cut-outs in the top pates in Figure 3 and watch number 46 are very different and the differences are far larger than would occur if the one die was re-sharpened. So the cut-outs must have been made by hand.

(c) In Figures 2 and 4 (and in watch number 46) it appears that the two small screws on the balance cock do not overlap and hold in place a loose collet for the endstone and regulator. This is definitely the case with the bottom endstone in Figure 5.

    That is, the endstones are fixed directly into the cock and the plate, and the two screws hold the hole-jewel collet (Figure 1). In which case, the two half jewels are held in place by friction, being sandwiched between the collet and the cock or plate.

(d) The center-wheels in Figures 2, 3 and watch number 46 have conventional pivots in the top plate, whereas there is a screw pivot in Figure 4.

82 Crossman, 1885, page 16.

83 Dennison, 1886.

84 Howard, ca1883.

85 No. 46, NAWCC, 1976, page 41 and Hanson, 2019; No. 66, Abbott, 1888, page 25, Small, 1954, page 252; No. 91, Crossman & Dawes, 2002, page 3 and Ehrhardt & Meggers, 1987, page 168; No. 148, Hoke, 1991, page 62 and Wingate, 1982, page 382; No. 164, NAWCC, 2005, page 12.

86 NAWCC, 1976, page 41; Hanson, 2019.

Figure 4 (Reproduced from NAWCC [1], page 12)

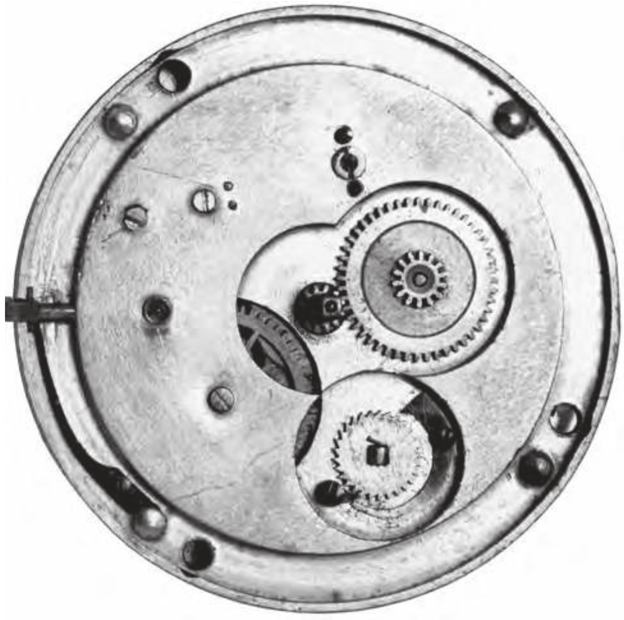

Figure 5 (Reproduced with permission of David Penney and Don Wing)

(e) The center-wheels have kidney-shaped cut-outs instead of normal spokes.

(f) The teeth on the center-wheels in Figure 4 and watch number 46 are triangular in shape and nothing like the correct form for meshing with either ordinary pinions or lantern pinions.[87] The other visible wheels appear to have more conventional teeth.

(g) In watch number 46, the center, 3rd and 4th wheels have conventional pivots in the pillar plate. In watch number 164 the center and 4th wheels appear to have conventional pivots. This means that for some pivots the only purpose of the corresponding screw pivots is to adjust end-shake.

(h) The escape wheel and lever have screw pivots in both the top and pillar plates. So these screw pivots can be used to adjust the relative heights of the roller jewel, pallets and escape wheel teeth as well as adjusting end-shake.

(i) In watch number 46 the barrel ratchet is screwed onto the barrel arbor whereas it is pinned in Figure 5.

In addition, watches 46, 148 and 164 have sub-seconds above VI on the dial. This constrains the design of the train and the 4th wheel must revolve once in 60 seconds. So it is very likely that all three watches have identical calibres.

As well as these photographs, we have concrete information about one watch. In 1989 David Penney examined watch number 164 and made drawings of it. Unfortunately Penney has not yet published the details of his examination, but in a letter to me, he made the following observations:[88]

First

> *Pivots and bearings in the frame are* ***not*** *conical. The brass seatings hold a steel screw with a jewel at the end for adjusting endshake.*

This method is described by Crossman as being *"used until they commenced jeweling in the regular way"*;[89] presumably the change occurred when they moved to New York. In contrast, Tom McIntyre states that

> *The pivots of the train wheels are held and adjusted for end-shake with hardened steel screws. The screws have conical recesses in their tips that mate with the conical ends of the wheel pivots.*[90]

87 Camus & Hawkins, 1837, pages 28-49.
88 Penney, 2006.
89 Crossman, 1885, page 5.
90 NAWCC, 2005, page 12.

I presume McIntyre was not able to disassemble the watch and he assumed there were conical pivots on the basis of statements by other writers. A consequence of the screws holding end-stones is that the pivot holes must be in the plate and must be quite thin.

Second,

> *Lantern pinions are crudely made and obviously took great effort to produce. As finished steel pinions were readily available, I believe that they were used so that the depthing of the train was not critical, rather than just an ambition to 'make it all themselves'.*

Third,

> *The frame and train are crudely made and finished ... There are many signs of hand finishing.*

Fourth,

> *From this and other features in the watch, such as a* [balance] *cock designed so that it could be adjusted slightly (a single screw in the circular foot and single steady pin) and endshake adjustable pivot settings, it is clear to me that interchangeability was **not** part of the Pitkin's plan and that the lack of ability to manufacture to close tolerances forced them to adopt a system that could tolerate this - effort that would no doubt have been better put to improving manufacture.*

In addition, Penney notes that this watch has a Massey lever type 3 escapement.[91]

Thus this watch confirms the previous deductions. As it is reasonable to assume that the Pitkins skills and techniques improved over time, we can conclude that all watches up to number 163 can be no better made than watch 164. That is, all were hand made.

Before moving on, I should comment on the Pitkins' New York watches. According to Wingate, in 1841

> *only a few weeks after the young company had been set up in New York, the first New York model Pitkin rolled of the assembly line.* [92]

Wingate also states that

> *confusion still exists over why the Pitkins built two distinctly different models of watches ... I personally believe that the changes were made because of improvements,*

and that

> *after ... examining the New York model, and observing the accurate finishing of the pinions, I find it hard to believe that, with the machinery they had, they could have finished it so well.*[93]

Anyway, it would seem from serial numbers that the Pitkins could have sold up to another 200 watches in the 4 years before Henry took his own life. However, Crossman suggests that watch number 378 *"is undoubtedly one of the first produced after their removal"*[94] and it may be that only about 50 watches were made with numbers between 350 and 400; so the total production of the Pitkins could have been less than 250.

Whatever opinion we hold, there is a significant difference in the design and manufacture of the New York watches compared with the Hartford watches: three-quarter plate compared with full-plate with sunk balance; steel pinions compared with lantern pinions; and standard pivots compared with conical pivots and pivot screws. Consequently little if any of the Hartford machinery, if it was more sophisticated than turns, mandrels and other simple hand tools, could have been used and the Pitkins *must* have built entirely new machinery for the new watch. Also, there must have been a substantial improvement in the Pitkins' skills or they employed someone better trained than themselves. Even if we discount Wingate's *"a few weeks"*, this is simply not credible. Compare the time frame and the number of people, with how

91 Choi, Frederick, 2003, page 52; Treherne, 1977.
92 Wingate, 1982, page 385.
93 Wingate, 1982, pages 388-389.
94 Crossman, 1885, page 7.

long it took Dennison, with far greater resources, to get his watch manufacturing up and running. Sad to say, a jury, taking into consideration that the English did make some going barrel watches, would find it hard not to decide that the Pitkins used imported English movements. Hoke supports this view, but unfortunately does not say why.[95]

For Eight Days Shalt Thou Labour

The next important contribution to American watchmaking was that of Aaron Dennison.

In 1830, some 8 years before the Pitkins started making watches, Aaron Dennison was apprenticed to a clockmaker. From that moment to the beginning of 1857 he was a motivating force behind the development of an American watch, and he has frequently been called the "Father of American Watchmaking". I don't know where this epithet came from, but the earliest use, that I know of, is by Favre-Perret in 1876.[96]

We know precisely when Dennison ceased to be a major force. On 28th February 1857 the collapse of his dream began, and on 9th May Royal Robbins bought the remains of the Boston Watch Company.[97]

Although he was still needed, he lost control of the company. He lasted until 1861 when he was dismissed. So it is during the 26 years from 1830 to 1856 that Dennison must have made his mark, and he must have done something significantly different from what went before. Fortunately there is enough information on this period for us to get a fairly good picture of events.

In somewhat flowery language, Abbott says that it was during his apprenticeship that Dennison was supposed to have

> *first thought of making watches by machinery. With absolutely no practical knowledge of machines excepting that gained at his master's bench with a watchmaker's lathe* [turns or mandrel], *he saw possibilities which only the brain of a mechanical genius could conceive.*[98]

This is wrong, and Price notes correctly that at this time

> *Dennison first envisioned making cheap brass clocks incorporating his ideas for interchangeable parts,*[99]

a statement Dennison himself makes in his biographical sketch.[100] And he was clearly not thinking of large-scale production in a factory, but the manufacture of a small number of uniform clocks simultaneously so that the work could be done more efficiently. There is nothing particularly original in this, as large-scale production of clocks was well under way.

Not only did he think about it, according to Moore, repeated by Hauptman, it was while an apprentice that

> *... he invented an automatic cutter for making the wheels which ... form the gear train of a watch.*[101]

Again this is wrong and Cutmore, citing Dennison, says correctly that

> *he made a model of an automatic machine for cutting clock wheels during this period.*[102]

However, Marsh makes it clear that automatic machinery is very complex and was not developed until the 1860s or later.[103] This, with the lack of concrete evidence, indicates that Dennison may have built a modified wheel cutting engine that could cut a stack of wheels, but it would have been in no sense

95 Hoke, 1990, page 309 note 15.
96 Favre-Perret, 1876, page 172.
97 Price, 2005, pages 8-9.
98 Abbott, 1905, page 33.
99 Price, 2005, page 1.
100 Dennison, ca1877, page 1.
101 Moore, 1945, page 5; Hauptman, 1963b, page 923.
102 Cutmore, 1989, page 26.
103 Marsh, 1896.

automatic and was probably similar to the machine patented by Japy in 1799, shown in Figure 6.[104] This uses a fixed cutter ***L*** and a stack of wheel blanks ***C*** mounted on a moving carriage. There is no dividing plate. Instead an endless screw mounted on the handle ***L*** meshes with the wheel ***F*** to rotate the wheels.

Dennison's later attempt to use such a machine for watch making failed miserably,[105] so despite Dennison writing that *"I constructed an automatic wheel cutting machine which I set up and operated ... "*,[106] it was not automatic and it is unlikely that it was successful.

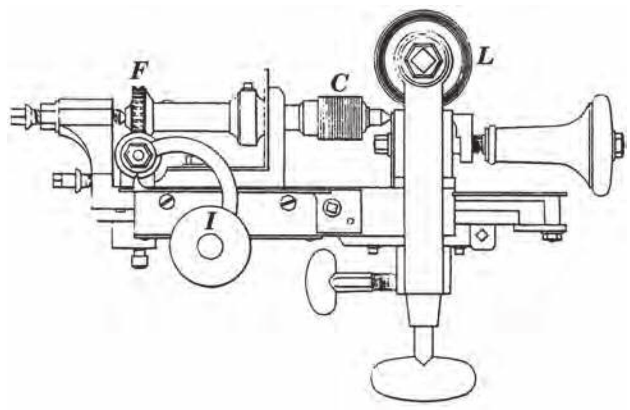

Figure 6 (reproduced from Japy, page 6)

Dennison's brother wrote the following:

> *He drew the logical conclusion that, if watches were to be improved, only making them by machinery could accomplish it; but this involved making each of the parts on a separate machine and assembling them, which meant that similar parts of any two watches must be interchangeable. So he proved that watches made with interchangeable parts would run, by clamping together six forms of brass and thus cutting out the parts in gangs of six, and immediately turned his mind to the development of watch making machines.*[107]

This makes some sense if it refers to cutting clock wheels, or making the plates for cheap brass clocks, but the accuracy needed in watch work could not be obtained. Dennison's brother also wrote:

> *In this idea of interchangeable parts Aaron only saw an added advantage to come to the repairer, although the rest of his trade regarded it as an insurmountable difficulty.*

As we will see later, an advantage to the repairer required detailed records, because the necessary interchangeability could not be achieved, and these records were not kept before 1857; see page 63.

Dennison's master during his apprenticeship was James Cary, who was presumably a watch and clock repairer, but it is clear that Dennison only learned a little about watches and the emphasis was on clocks. Dennison makes this point in his biographical sketch, when he writes

> *Mr Cary, having offered me a partnership interest in his business after I had been to Boston to get some experience in watch repairing under some superior workman. Upon this offer I abandoned the clock scheme and went to Boston.*[108]

So he went to Boston, where

> *he offered his services free gratis to Messrs, Currier & Trott* [109]

for three months. After which, in 1838

> *he went to New York City and ... he was able to gain from Swiss and English workmen ... a large amount of information about the various methods of doing fine work.*[110]

Dennison is rather dismissive of his stay in New York, saying

> *aside from case making and mainspring making and the usual jobbing of replacing the broken parts of movements, there was little done.*[111]

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104 Japy, 2006, pages 5-6.
105 Crossman, 1885, page 19.
106 Dennison, ca1877, page 1.
107 Dennison, 1909.
108 Dennison, ca1877, page 1.
109 Crossman, 1885. page 11.
110 Crossman, 1885, page 11.
111 Dennison, ca1877, page 2.

This is rather peculiar. I very much doubt if mainsprings were made, unless he means cutting to length and hooking in to the barrel. And case making was a trade entirely separate from watch making, about which he could only have learned the basic principles in the time he was there.

So much of the ten years from 1830 to 1840 was spent educating himself in the traditional craft of watchmaking. Later events (in particular his 8-day watch design) indicate that his education was less than perfect, and we can be confident that he did not think of watch factories and automatic machines in the early 1830s.

During this time, Dennison devised

> *a gauge upon which all the different parts of a watch could be accurately measured ... which I was in the habit of supplying my customers.*[112]

Dennison went on to write:

> *It will be observed that this system of accurate gauging is one of the principle points of interest in the establishment of watch manufacture in the United States, but for this purpose I concluded that it would be best to adopt for a basis the French measure owing to its having a scientific basis, dividing the millimetre into 100ths.*[113]

And his gauge was later described as

> *an article indispensable to every watch-maker, who, may by its use, size wire or plate to all the sizes indicated by any Stubb's gauge, also the diameter of wheels and pinions, most perfectly.*[114]

However, a detailed examination of Dennison's "combined" and mainspring gauges, which I assume he was referring to as there are no other extant gauges, shows that they are based on the English imperial inch and they are definitely not metric.[115] Which did not stop people pretending they were metric and

> *in regard to mainspring thickness, the Dennison gauges equal approximately 13/16ths of a tenth of a millimeter or about 0.008mm.*[116]

Anyway, measurements made with such a gauge can only be approximate and it would be far too inaccurate for interchangeable parts other than those, like mainsprings, which have reasonably large tolerances.

There is no evidence that Dennison ever used the metric system, unless it was after he left Waltham in 1861; the change in gauging under Robbins was driven by Ambrose Webster.

Most sources date Dennison's interest in watch manufacture to the 1840s and Abbott quotes Dennison himself saying that it was around 1839 that

> *... as far as I can recollect what my plans then were as to system and methods to be employed, they were identical with those in existence at the principal watch factories at the present time.* [117]

This, as I will show later, is not true. I have no quibble with him conceiving the idea, but what he envisioned and what he did has little in common with the watch factory of 1860. But certainly by 1845, as Crossman states,

> *his mind was still intent on the plan of establishing watchmaking on the well known system of interchangeability as practiced at the Springfield Armory and among the Connecticut clockmakers ... He visited the* [Springfield] *armory and did a great deal of planning ...,*[118]

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112 Dennison, ca1877, page 2.
113 Dennison, ca1877, page 3.
114 Sherwood, 1892, page 66.
115 Watkins, 2009a, pages 27-34.
116 WMDAA, 1957, page 9.
117 Abbott, 1888, page 11; Abbott, 1905, page 35 (quoting Waldo, 1886, page 187, quoting Dennison, 1876, page 1).
118 Crossman, 1885, page 12.

and according to Abbott he

> *predicted, in the year 1846, that within 20 years the manufacture of watches would be reduced to as much system and perfection and with the same expedition that fire-arms were then made in the Springfield armory.*[119]

Just what Dennison learned from his visits to the armory and clockmakers is a matter for conjecture. Fitch, comparing the early attempts by Whitney with the practice in 1880, makes a very important point:

> *If gun parts were then called uniform, it must be recollected that the present generation stands upon a plane of mechanical intelligence so much higher ... that the very language of expression is changed. Uniformity in gun-work was then, as now, a comparative term; but then it meant within a thirty-second of an inch or more, where now it means within half a thousandth of an inch. Then interchangeability may have signified a great deal of filing and fitting, and an uneven joint when fitted, where now it signifies slipping in a piece, turning a screw-driver, and having a close, even fit.*[120]

Certainly by 1845 things had improved considerably from the early 1800s, but progress took time and Dennison would have seen a manufacture somewhere between these two extremes.

Most importantly, just as the Pitkins discovered ten years earlier, both at the armory and at the Connecticut clockmakers he would have seen machines and manufacturing methods of little use in watchmaking. The difference in scale and the different requirements for uniformity mean that only the most general principles would be transferable; the principles of a factory using some sort of machinery to produce uniform parts, with considerable hand finishing to satisfy the requirements of gauging.

So when he persuaded Edward Howard to help him set up a watch factory, Dennison had a reasonably good grounding in the traditional "art and mystery" of watchmaking, no training as a machinist, and some vague idea that it could be done by machinery. Consequently it is hardly surprising that he failed.

There is no question that he failed. As Crossman puts it, in the fall of 1849

> *Mr Dennison commenced to experiment and to build machinery after his own ideas.* [He built an upright lathe] *to form the watch plates, with all their cuts and cavities at one moment* [and] *a set of dies and punches whereby all the holes could be punched out at one time.* [121]

Apparently these were the only tools built then, but according to Hauptman, by the summer of 1850

> *several other pieces of equipment were partially completed and a hand made model of the watch they hoped to produce by machinery was finished.* [122]

So they started making watches, only to discover that their preparations were hopelessly inadequate. The plate presses did not produce plates with holes *"alike and in the same place every time"*. And a wheel cutting engine designed to cut several wheels at once, was so bad that *"no two wheels ever came out of the machine the same size"*.[123] So, according to Hauptman, they got an ordinary English wheel-cutting engine to use until they could perfect their own.[124] It is probable the plate lathe was no better. Unfortunately there is no information about other machinery, but we can be pretty sure the rest consisted of conventional lathes and mandrels.

Crossman quotes Howard saying

> *Mr Dennison was a very fine watchmaker, but as a machinist and builder of watch machinery he was certainly not a success.*[125]

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119 Abbott, 1888, page 35.

120 Fitch, 1883, page 2 (page 618).

121 Crossman, 1885, page 14, quoting Howard, ca1883.

122 Hauptman, 1963b, page 924.

123 Hauptman, 1963b, page 927; Crossman, 1885, page 19.

124 Hauptman, 1963b, page 927.

125 Crossman, 1885, page 14.

Abbott and Moore simply say

> *Mr Dennison's machinery was not a success,* [and] *the company had no choice but to redesign Dennison's original equipment and build new machines.*[126]

So

> *one of Mr Howard's men was detailed to help Mr Dennison, and after numerous attempts, they finally succeeded in getting together a few tools and machines of anything but perfect construction.*[127]

In fact Dennison admitted this in a letter to Crossman:

> *There is one other item which I should have preferred not to have seen in print (though true enough) as it did not seem called for and that is my friend Howard's opinion of my abilities as a machinist or tool maker. I never made any claim in that direction and being put in that way it looks as though I had.*[128]

This summary of events overlooks two major points.

First, neither of the two original machines described by Crossman make sense. The most obvious problem is that it is *not* possible to have *"a set of dies and punches whereby all the holes could be punched out at one time."* Perhaps this might done with brass clocks, having thin plates and relatively large holes. but surely Dennison was sufficiently aware of the problems to realise that it was out of the question for watch plates. A punch is a punch and a drill is a drill, and the two are utterly different. So we must presume Crossman is describing two types of "dies"; one type to press out plates, and a second type to act as a master-plate guide for drilling holes.

The upright lathe is equally confusing. At first I thought Crossman meant that the lathe arbor was mounted vertically, but this is both pointless and inconvenient. A much better interpretation is that the lathe was an *uprighting lathe* which enabled cuts in one plate to be made directly over a corresponding point in another plate. But this is simply a mandrel, or a lathe with a face plate, which allows a piece to be mounted eccentrically and positioned by a steel point passed through the mandrel's arbor; see page 74. Indeed, the term *upright tool* was used for the mandrel in the eighteenth century.[129] Crossman's description does suggest something more sophisticated and it reads as though Dennison made a tool equivalent to Ingold's plate lathe, which is described by Carrington and Penney.[130] This plate lathe was not automatic and "the degree of 'interchangeability' of the plates therefore depended upon the accuracy with which the operator could reproduce the pre-arranged series of settings".[131] But Dennison denied having any contact with Ingold[132] and the actual form of his upright lathe remains a mystery. However, in 1877 Henry F. Piaget wrote

> *For it is certainly a fact that the machinery of Ingold (who is still living in Switzerland), was first used in Boston in the year 1852 where the first American watches were made.*[133]

Unfortunately Piaget did not add any details. Being a Swiss in New York, it is possible that he met Ingold and had good reason for this statement. But his avowed Swissness, together with the almost irrational attacks on Americans in his book, must cast doubt on what he has written, and I am not sure that we should place too much weight on his claim that Ingold's machinery formed the basis for the Roxbury factory. Equally, how much weight can we place on Dennison's denial? After all, to admit to the use of Ingold's machinery would have seriously impaired his reputation.

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126 Abbott, 1905, page 17; Moore, 1945, page 16.
127 Abbott, 1905, page 17.
128 Dennison, 1886.
129 Martin, 1813, pages 576-577.
130 Carrington & Carrington, 1978, pages 700-706; Penney, 2005, pages 12-15
131 Torrens, 1947, page 178.
132 Penney, 2005, page 18; Waldo, 1886, page 188; Torrens, 1947, page 178..
133 Piaget, 1877, page 51.

But one point supports the view that Dennison's upright lathe *was* Ingold's plate lathe or based on it. And that is that Dennison was, on his own admission, not capable of designing machines. Such a lathe requires considerable skill and experience which he did not have.

The second point that I have overlooked is, it is clear that, as with the Pitkins, the machinery we know about performs just a tiny fraction of the tasks involved in making a watch. Once again, the only parts of a watch made by machinery are the plates and wheels, and the huge number of other processes and parts are simply not mentioned. And once again, we should assume that Crossman's silence on other machinery means that there was no other special machinery; to imagine Crossman failing to even mention other machines is not credible. Indeed, Torrens suggests that at Roxbury

> *there was very little in the way of tools and machines at all.*[134]

In addition, such dies and guides must be designed to suit a *particular* calibre, in this case Dennison's first 8-day watch. And, just as most of the Pitkins' tools would have been useless for making their New York watches, most of Dennison's tools would be useless for making the 30-hour watch that followed.

There is considerable confusion regarding the first watch, because there were *two*, quite different eight-day watches, and many authors do not distinguish between them. Crossman is one of the few authors who describe these watches correctly.

The *first*, which was the *only* watch that we are certain was designed by Dennison, was an eight-day watch with a single mainspring barrel. To cite Crossman, Dennison

> *designed it to run for eight days, but it proved a failure from the start... the* ***barrel*** *was not large enough to take a spring that would run it through the whole period of seven days on correct time, as it would loose three or four hours towards the latter part of the week.* [my emphasis][135]

Because punches and dies must be made for a particular calibre, this watch must have been designed in 1850 or earlier.

But the watch Dennison designed was no more successful than his machines. Crossman says

> *Mr Dennison made his model to a large extent after the Perry English movement.*[136]

However Priestley suggests that

> *in his autobiography, Aaron writes that he based the general layout of the first Roxbury watches on a Joseph Johnson fusee.*[137] [See page 82 for an example of a Joseph Johnson fusee movement.]

But

> *it would be impractical to make fusee chains in quantity in the U.S., importing one for each watch would be severely restrictive and expensive,*[138]

so the fusee was probably dropped for practical reasons rather than because of a considered design change. Either way, the English watches would have been standard 30-hour movements and why Dennison attempted to convert the model to run for 8 days is a mystery. And it proved to be a total failure because of isochronal errors.

All that we know about the first 8-day watch comes from Crossman: it was approximately 18-size, based on an English full plate 30-hour movement; it had a single mainspring barrel; and it had an additional wheel and pinion to provide the extra 8:1 reduction necessary for eight days running. At least one model of this watch must have been made and tested, but there are no surviving examples. However, it is possible to deduce some important points about its design from this meagre information.

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134 Torrens, 1947, page 183.
135 Crossman, 1885, page 17.
136 Crossman, 1885, page 16.
137 Priestley, 2005, page 98, possibly citing Torrens, 1947, page 183.
138 Priestley, 2005, page 99.

First, the size of the barrel is restricted to about half the diameter of the movement. The barrel in this 8-day watch must be slightly smaller, because it must clear the center wheel pinion instead of meshing with it. It is possible to have a larger barrel, and Roskopf did so by utilising a novel train which did not have a center wheel.[139] Also, the barrel can be made larger if the center wheel is moved so that it is no longer in the center of the movement, requiring an off-set dial or special motion-work. But Dennison's design was based on a traditional calibre, and neither of these arrangements is possible. As he stated,

> *a solid English full-plate watch was the thing most in favour by dealers in the United States ... and the mass of wearers desired a good large size ... I concluded that, in order to succeed, an establishment should be confined in the first instance to the production of such a class of watch exclusively.*[140]

So a larger barrel could not be achieved by using an unusual calibre.

Second, in order for the barrel to drive the train for 8 days, it is necessary either to have a mainspring about 6 times longer or to insert an extra wheel and pinion between the barrel and the center wheel. Because of the size of the barrel, we can be confident that this extra mobile would have to produce an 8:1 reduction. Although such a reduction enables the use of a short mainspring, with about 7 or 8 turns, it requires a much stronger spring in order to transmit enough power to the escapement. As Berner points out, the strength of a spring is primarily dependent on its thickness, the height having much less influence.[141] Consequently, the spring for such an 8-day watch must be much thicker than one for a 30-hour watch.

Third, the torque produced by a spring varies with its winding state. The line ***H*** in Figure 7, adapted from Berner,[142] shows the variation in torque of a normal 30-hour mainspring, and the line ***N*** illustrates the way in which the torque in a much stronger spring will vary.

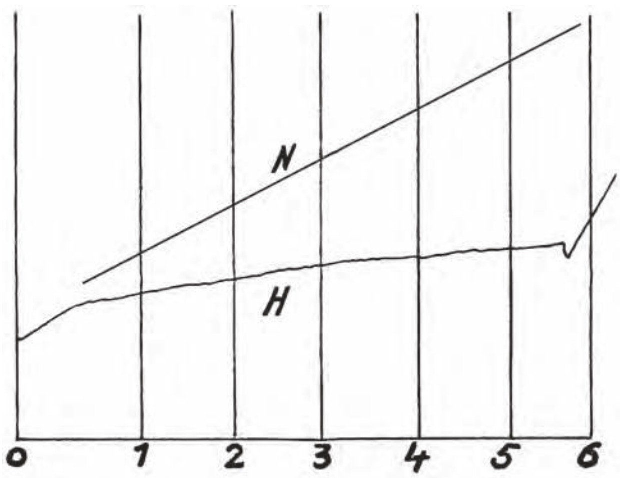

Figure 7 (Modified from Berner, page 12)

We can draw a number of conclusions from these points. First the barrel has to be appreciably larger than that for a 30-hour watch to allow for the increased thickness of the mainspring. Second, in order that the barrel does not extend too far outside the plates, the size of the watch must be increased; despite Crossman's statement, it is very unlikely that it could have been 18 size. Third, a lack of isochronism will be a much greater problem due to the much larger variation in mainspring torque; that is, there would be a much greater variation in the rate of the watch caused by the balance taking different times with different arcs of vibration.

Equally important is that Crossman's discussion of this watch, which has been rather carelessly repeated by some later writers, is wrong in one respect. He writes that Stratton (who did not join the company until 1852) utilised the stock of parts:

> *the changes were to cut the barrel bridge in the center* [and use the two halves for the barrel bridges of two 30-hour movements] *... and, of course, throw aside the extra set off wheel and pinion, which had been used to make it run eight days ... the third wheel, which previous to this had run under the center wheel after the English style, was now raised to run over the center wheel ....*[143]

From this it is clear that at least part of the train had to be discarded as re-arranging the third wheel could only be done by making a new arbor and pinion. Also, it is simply not possible to cut the barrel bridge in

139 Buffat, 2007.
140 Dennison, ca1877, page 3.
141 Berner, 1948 page 17.
142 Berner, 1948, page 12.
143 Crossman, 1885, page 17.

half and create two bridges for 30-hour watches. Irrespective of whether the 8-day watch was 18 size or larger, the barrel bridge would not cover much more of the top plate than one in a 30-hour watch. At best it could be made a little narrower and turned a little smaller to fit the new top plate.

(I must insist that we do not throw the baby out with the bath water. Crossman is one of the few, I think the only author who provides useful accurate detail that can be relied upon, and his book is vastly superior to the other early accounts of American watchmaking. The occasional error should be accepted.)

Later, perhaps towards the end of 1852, the brothers Oliver and David Marsh designed a *second* eight-day watch with two barrels. E. A. Marsh, not related to the designers, incorrectly states:

> *Lacking the judgment, which years of experience would have developed, the two young men* [Dennison and Howard] *decided to create a movement which would run eight days with one winding. Such a model was made, indeed several reproductions were made, but a brief trial sufficed to demonstrate the fact that owing to the varying power of the mainsprings (**of which two were provided**) it was found impossible to secure a constant rate of motion throughout the long interval between windings* [my emphasis].[144]

So Marsh, like others, has merged the two, quite different eight-day watches into one and much confusion has resulted. Although later, in 1909, Marsh almost corrected this error by writing

> *it was an early, if not the original, proposal to manufacture a watch designed and constructed to run a week at a winding. A **couple of models** of this kind were made, but its construction was wisely abandoned as being unsuitable for pocket use, and a full plate model of 18 size one day movement was adopted* [my emphasis].[145]

The second 8-day watch was made near the end of 1852. Crossman is vague in that he does not state who designed this watch, but

> *they were completed before any of the regular watches were ready for market.*[146]

Hauptman states

> *Dennison still would not admit defeat regarding the ability to produce an eight-day watch. While he and most of the staff were fabricating machinery required to manufacture the thirty-hour movements, he induced Howard to agree to let O.B. Marsh and his brother D.S. Marsh ... make a model of an eight-day movement that was entirely different than the first ... if they would do the work in over time.*[147]

Also, Price writes that the Marsh brothers

> *were assigned to model a new watch with two large mainspring barrels.*[148]

Abbott is more precise:

> *While Dennison was a pretty fair watch repairer, he did not consider that he was equal to the task of making a model for the proposed watch, and this work was intrusted to two brothers, Oliver and David Marsh.*[149]

This movement was about 22 size and had two mainspring barrels, Figure 8.

The first feature to note is that, when viewed from the *back* of the watch, the positions of the barrel clicks show that both barrel arbors rotate anti-clockwise during winding and so the barrels rotate *anti-clockwise* during running. Thus Crossman is correct when he writes there was *"an extra set off wheel and pinion*

144 Marsh, 1921, page 6.
145 Marsh, 1909, page 9.
146 Crossman, 1885, page 18.
147 Hauptman, 1963b, page 929, citing Crossman, 1885, page 18.
148 Price, 2005, page 2.
149 Abbott, 1905, page 48.

of course" [150]. The mobile driven by the barrel must rotate clockwise when viewed from the back and so anti-clockwise when viewed from the dial side, which means it cannot be the center-wheel pinion.

So each barrel must contain a relatively weak mainspring, but the total torque of the two mainsprings is sufficient to drive the train. Consequently, the torque produced will be similar to the line ***N*** in Figure 9, and lack of isochronism should be no more serious than that in a 30-hour watch.

Figure 8

The second point is that Crossman's description of adapting parts to suit a 30-hour watch make sense if he is referring to this two-barrel watch. From Figure 8 it is clear that there is a single barrel bridge for both barrels, which runs under the balance cock foot. This bridge could be cut in half and trimmed to make two single-barrel bridges. However, its shape is nothing like the shape of the bridges used in early 30-hour watches, and so even this possibility seems unlikely. Even if the bridges were punched out as plain blanks and the cut-out for the click and spring done later, it is unlikely they would be usable.

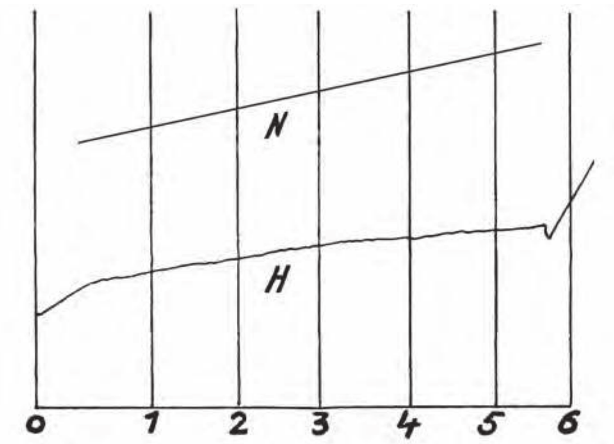

Figure 9

Although this second 8-day watch was apparently successful, in that it kept time reasonably well, it was a failure in commercial terms and very few were made. (This was probably due to the cost of manufacture being too high. It is likely that they cost more than $60, which is about $27,900 in today's money; see page 7.)

Price believes 19 were made, two prototypes and 17 production watches.[151] But if Crossman is right, many more were started and then cannibalised for the 30-hour watch; Hauptman says 100 were started,[152] but we can assume that Howard refused to transfer workers from the 30-hour watch to complete them.

Anyway, even if it had worked they couldn't sell the watches! Dennison had gone to England in 1850

> *for information, and particularly to learn the art of frosting and gilding watch movements. He reported on his return that he had succeeded, and no further attention was given the matter till the time came for doing that work. When he (Dennison) attempted to do the gilding he found himself unable. He and some others worked according to the knowledge he had, and all the reasoning that could be brought to bear on the subject for a long time, without success.*[153]

So there was a small pile of movements "in the grey" and no way of finishing them. (This may be an exaggeration; Hauptman states that Dennison could gild plates, but they *"looked very poor"*.[154] Either way, the watches were not saleable, except perhaps at a loss.)

150 Crossman, 1885, page 18; the extra wheel and pinion are indicated by the two symmetrical jewels on either side of the balance cock.
151 Price, 2005, page 2.
152 Hauptman, 1963b, page 930.
153 Howard, ca1883.
154 Hauptman, 1963b, page 930.

At this point it would not be surprising if the infant American watch industry had died prematurely. All that Dennison had achieved in two years was to spend a lot of money building some completely inadequate machines and designing a watch that was worthless. But Dennison and Howard were rescued by two people with far greater watch and machinery design skills.

The Road to Oblivion

In 1852 Charles Moseley arrived at Roxbury. Although he knew nothing about watch making, he *did* know about machines, having worked for many years on machinery for wool and rifles.[155] If nothing else, he has a permanent place in history for replacing the dead-center and wax-chuck lathes which had been used up to then by the hollow draw tube, split-chuck lathe that has dominated watchmaking ever since. From the time of his arrival there was some chance that the machinery might work.

And also in 1852, N.P. Stratton joined the work force. As Hauptman puts it,

> *Stratton immediately found himself at loggerheads with Dennison* [over the first 8-day watch design, and] *with the aid of Howard he convinced him ... and they decided to change it to a 30-hour movement.*[156]

And then, in the fall of 1852 Stratton went to England to learn what Dennison had failed to, how to gild, and on his return the company could at last produce something that could be put on the market.

Abbott indicates Stratton and Dennison had worked together before this time, and it is worth quoting him:

> *In 1836,* [Stratton age 16] *was indentured apprentice to Henry and J.F. Pitkin ... In the fall* [of 1837] *Henry Pitkin conceived the idea of manufacturing watches, and Mr Stratton commenced work on tools and machinery for this enterprise, continuing work during the remainder of his apprenticeship ... After the discontinuation of the Pitkin factory, Mr Stratton worked at various mechanical pursuits until 1849, when he entered the employ of A.L. Dennison as a watch repairer. In this position he stayed but a short time, as Mr Dennison had arranged with Howard and Davis to engage in the making of watches by machinery. It has been suggested by those who were very conversant with the early history of watchmaking in this country that it is very possible that Mr Dennison got the idea of interchangeable watch parts from N.P. Stratton.*[157]

According to Crossman, after Stratton left the Pitkins he worked at the Springfield armory and as a watch repairer before joining Dennison at Roxbury.[158]

There is one problem with this story: Why didn't Dennison invite Stratton to join him at Roxbury in 1850 or before? Or, if he did, why didn't Stratton accept? It seems quite possible that there was some animosity between them before the events of 1852. Whatever the reason, Stratton arrived in the nick of time, probably at the behest of Howard, to help Moseley rescue the critically ill company.

From the beginning of 1853 to its demise in early 1857 the Boston Watch Company finished about 4,800 movements; see Appendix C, page 97.

According to Crossman, there were 100 employees producing 6 watches per day (16.6 man-days per watch),[159] and Abbott says that in 1854:

> *the company was making about 5 watches per day, and employed about 90 hands* [18 man-days per watch].*[160]*

155 Abbott, 1905, page 82.
156 Hauptman, 1963b, page 926.
157 Abbott, 1905, page 51.
158 Crossman, 1885, page 198.
159 Crossman, 1885, page 24.
160 Abbott, 1905, page 19.

Webster, quoted by Niebling, also says

The daily output at the factory at that time [1856-57] *was five watches per day.*[161]

Although a bit vague, these figures suggest a rate of about 17 or 18 man-days per watch throughout the four years 1853-56, which is consistent with Marsh's figure of 18 man-days per watch.[162] Of course, the workforce would not have been constant and according to an article in the Waltham Sentinel, it was about 75 in March 1856.[163]

However, at this rate the company could have made 5,000 watches in about 2.8 years instead of the approximately 4⅓ years that it actually took. Looking at it in reverse, 5000 watches made in four years by 90 people is a rate of 22 man-days per watch; I am assuming a 310 day working year of 52 six-day weeks. Compared to the Pitkins, this is a marginal improvement. Not only that, consider how long it would take competent 18th century watchmakers like Berthoud, Auch and Vigniaux to make a watch by hand.[164] Excluding the fusee and chain, it is hard to imagine that the process would take any longer, and the Boston Watch Company had invested large amounts of money in tools and building a factory simply to keep up with the methods that Dennison and Howard were trying to replace with something supposedly much more efficient.

One figure appears to contradict this evidence. In March 1856, about 13 months before the company ceased production:

Messrs. Dennison, Howard and Davis, have been five or six years in establishing themselves in their business ... and in that brief time have succeeded in perfecting machinery and educating workmen to such a degree as to make daily ***ten or a dozen*** *elegant and excellent watches ... They employ about* ***seventy-five*** *hands ...*[165] [my emphasis].

This suggests the company was making watches at a rate of 6.25 to 7.5 man-days per watch, and so there must have been a significant change in methods, tools and machinery to reduce the rate by 11 man-days.

However, in Appendix C (page 97) I show that such a rate of manufacture is *impossible* and that the company probably did no better than about 16 man-days per watch.

This does not mean the above quote is wrong. It means that watches were being *finished at that rate on those days*. The distinction is very important. Production was, and never is, uniform. So, even though it took 16 days to make a watch, there would be times when many (or few) watches were being *finished*.; see page 104. Which is why Crossman could note that:

The company then had about one hundred employees ... The company were struggling to make ***ten*** *watches a day, but it was more frequently that* ***six*** *only were produced, and very often at the end of the month it was found that not more than one hundred* [less than **four** per day] *had actually been completed and put on the market* [my emphasis].[166]

That is, rates of 10, 16.7 and 25 man-days per watch. This very large variation is primarily due to variations in the numbers of watches available for finishing.

It is important to note the type of movement manufactured at that time. From Price's data it is clear that all had plain balances with flat balance springs.[167] Such a movement cannot be adjusted for temperature and the expected rate variation makes adjusting for positions or isochronism pointless. These watches, and the English equivalents from which they were derived, are a long way from the later railroad watches. So we can be confident that "finishing" simply involved setting up the escapement and bringing the watch

161 Niebling, 1968, page 634.
162 Marsh, 1921, page 11.
163 Waltham Sentinel, 1856, page 144.
164 Berthoud & Auch, 2005; Vigniaux, 2011.
165 Waltham Sentinel, 1856, page 144.
166 Crossman, 1885, page 24.
167 Price, 2005, pages 53-67.

to time. It was not until much later that compensation balances were introduced so that adjusting could be meaningful. Ignoring watch number 5000, which was clearly a special prototype movement and not a production watch[168], the earliest movement signed Dennison Howard & Davis with a compensation balance is dated November 1857, which is after the insolvency,[169] but other grades were using plain balances well into 1858 or later; with 3 exceptions the Wm. Ellery grade had a plain or uncut balances right through to late 1877. And nowhere is there any mention of overcoil balance springs in Price's data.

The type of movement is important because the most time consuming, most skilled work is setting up the escapement and adjusting it, a process that could take weeks of on and off work for a high-grade movement. This work, more than any other, dictates the lower limit to the number of man-days to complete a watch.

So, with the exception of the number of jewels, all watches would have taken about the same time to manufacture, and very little, if any, of the discrepancies in Crossman's figures above can be attributed to the type of watch.

What is apparent is that Dennison, just like the Pitkins before him, manufactured watch parts with inadequate machinery that turned out similar *but not interchangeable* parts. Other than plate presses and a few other tools, much of the work was almost certainly based on trying to streamline and systematise the use of hand tools.

Balances were made by Mr Brown, an English balance maker, who would have used turns, files and burnishers.[170] And according to Marsh,

> *the* [screw] *threads used in early Waltham watches are said to have been obtained from Swiss 'jam plates'.*[171]

Pinions were hand made from pinion wire:

> *Here we saw the singularly ribbed pinions cut to proper lengths, turned to proper diameters in their various parts, the leaves recut and polished, and the whole pinion pass through successive polishings until the microscope could detect no lack of lustre.*[172]

More important is Crossman's description of setting jewels, which deserves to be quoted in full:

> *The bottom plates were cemented up and the settings cut for the jewels by hand. The jewels were generally set flush with the upper side of the* [bottom] *plate, then the train and escapement were put in, the top plate laid on, having of course, first drilled the holes through the top plates where the jewels were to be set. Mr Lynch would then sight through on the under side of the top plate and in order to arrange the end shake, he had slips of paper for each movement, and, by means of a few hieroglyphics which he used, he would indicate the location for the jewels in the top plate.*
>
> *When the shoulder was above the lower side of the plate, he would raise the top plate a little on one side until he could see the shoulder, and then measure the distance on the pillar. This seems a very primitive method indeed as compared with the automatic jewel setting and end shaking tools of today; but from long experience the jewelers of that period became very expert.*[173]

So not only were the lengths of arbors and the diameters of their pivots all different and not interchangeable, but the crudest methods requiring great skill were used to adjust the once-similar plates into unique but correctly fitting ones.

Some further information which confirms the view that there was little interchangeability, can be found in the tables provided by Price. In them he lists known, existing watches, and includes much additional

168 Geller, 2000, pages 21-22; Price, 2005, page 72.
169 Price, 2005, page 74.
170 Crossman, 1885, page 21.
171 Marsh, 1896, page 95.
172 Waltham Sentinel, 1856, page 144.
173 Crossman, 1885, pages 19-20.

data about them where possible. Although limited to visible features and plate diameters, there are a large number of variations listed. As far as plate diameters are concerned, the best that Price can say is that *"all measure nearly the same"*.[174] And illustrations of train layouts show clearly that different arrangements were used at different times.

So it seems that that all Stratton and Moseley did was to provide a life-support system which allowed the ailing Boston Watch Company to live a little longer. But death was probably inevitable, and as the financial crisis (the panic of 1857) occurred in September, after the company had collapsed, it cannot be used as an excuse for failure. The methods were inadequate and the time to make a watch was far too long. Indeed, from the very beginning the company was on a down-hill slide into oblivion.

What was desperately needed was drastic, invasive surgery, a change both rapid and profound to enable the hopes of many people to be realised. Without it, the Boston Watch Company was simply a resurrection of the Pitkins, but larger.

When I began my discussion of Dennison I wrote: "From that moment to the beginning of 1857 he was a motivating force behind the development of watchmaking in America." However, this is not correct. If we ignore our desires and simply look at the facts we know, then Dennison ceased to be a motivating force in 1852. From the beginning in 1850 his ambition was to make machines to manufacture his design for an 8-day watch, and after two years of completely unsuccessful struggles, it was clear that he had failed in all respects. We can presume that it was Howard, Curtis and Davis, seeing their investments about to vanish, who brought in Moseley and Stratton and forced the infant company to change direction, build new machinery and make a standard, 30-hour watch. It is at this point that Dennison's role changed from creator to manager, and from then on his role was reduced to supervising and running the factory.

There are two events that support this view.

First, why was the second 8-day watch designed and built? The most likely reason is that it was Dennison's swan-song, his final attempt to exert control and send the company in the direction required by his personal ambitions, perhaps amounting to delusions of grandeur. Indeed, his conflict with Stratton would have been an attempt to stop development of a 30-hour watch and keep resources focused on an 8-day model. So he refused to be reduced to a manager and forced resources to be diverted from the 30-hour watch to another Dennison idea. He could only do this if much of the development was done outside work hours, because there was a limit to what Howard, Curtis and Davis could accept. It is likely that he was allowed to do so from lingering respect and because of his pivotal role in the company. But this watch also failed and from then on Dennison ceased to be a watchmaker.

(It should be noted that Dennison's later attempts at watchmaking also failed. He did not achieve any sort of success until he moved to England and joined a firm that was in the far simpler activity of case making.)

Second, after Dennison was finally dismissed in 1861 the board of the company explained why this action was taken. An abbreviation of the board's resolution, given in full by Moore, reads:

> *A.L. Dennison, Superintendent of the Mechanical Department, omitted and neglected to perform the various duties incumbent on him, and has discharged his duties in an unsatisfactory and disagreeable manner, and he has offensively intermeddled with other departments.*[175]

It is clear that this condemnation resulted from a conflict that had been going on for some time, most likely since the takeover in 1857.

Dennison had been kept on as a superintendent and he was needed in this role because of his knowledge. But there can be little doubt that his life-long ambition, to be *the* watchmaker who built an industry, would have created tensions and conflicts as the company moved further and further in a different direction.

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174 Price, 2005, page 5.

175 Moore, 1945, page 44.

But in one respect this view of Dennison is actually generous. The Boston Watch Company failed because of his totally inadequate understanding of watchmaking. That is, Dennison attempted to build an industry based on the traditional master-apprentice system of education and skilled hand work with simple tools. But such a system could *never* achieve the rates of production necessary for success.

Aaron Dennison had a vision. Sadly, he lacked the insight and the skills to turn that dream into reality.

So on Wednesday, 15th April 1857, the Suffolk County Court of Insolvency issued warrants to Samuel Curtis, David Davis, Edward Howard and Aaron Dennison as insolvent debtors.[176] These warrants were to take possession of their real and personal estates both as individuals and as members of the Boston Watch Company.

The failure of the Boston Watch Company was mainly due to its failure to manufacture watches at a low enough price, but it was also undoubtedly due to the policy of Aaron Dennison. Until the eventual failure in April 1857, Dennison, instead of giving up in an orderly fashion, poured every cent he could raise into keeping the factory functioning and manufacturing watches. This single-minded approach included not making the regular payments on the mortgages held and loans advanced by the Waltham Improvement Company.[177] This continued until the Waltham Improvement Company forced the Boston Watch Company into insolvency because of its failure to satisfy its mortgage obligations, and on 3rd March 1857 it took "peaceful" possession.[178]

Indicative of Dennison's policy is that Tracy notes that Dennison purchased gold cases from Tracy & Baker on account and promptly pawned them to a Boston bank for their gold content, thus raising cash to keep the factory running.[179] In doing so he borrowed about $14,000 against assets worth $8,000 ($6,510,000 against assets worth $3,720,000)! And it seems he did this for most of 1856-57. Together with the mortgages over the material and tools in the factory (discussed below), Dennison probably raised about $27,000 (about $12,500,000 today).

In 1883, an article was published lauding Dennison as the "Father of American Watchmaking".[180] This so upset William Keith, who had been the president of the Waltham Improvement Company and then president of the American Watch Company, that he immediately wrote a 269 page manuscript providing his view of the history of the Boston Watch Company and the events at Waltham, rebutting the claim that Dennison was the "father" of American watchmaking.[181]

If the word "father" is used in the sense of *earliest*, then it is incorrect, because the Pitkin brothers preceded Dennison. If the word is used in the sense of the *creator of an industry*, then it is also incorrect as the next section shows.

Either way, Dennison is not entitled to be the "Father of American Watchmaking".

176 Suffolk County Court of Insolvency, 1857-58.
177 Keith, 1883, pages 23, 36.
178 Waltham Improvement Company, 1854-1864.
179 Tracy, 1886; see Marsh, 1889, page 15.
180 Waltham Weekly Record, 6th April, 1883, "Timely Topics", page 5.
181 Keith, 1883.

Part 2: Making The Most Of Time

A Roller-Coaster Ride

To repeat the question I posed near the beginning: What are we missing? There is something which sets the American system apart, but it is not the conventional aspects of factories, machinery, large-scale production and interchangeability. And it is not found in the work of the Pitkins or Dennison. Both missed it, whatever it is, and someone else discovered it.

We can see that graphically. Moore produced a chart of the number of man-days to make a watch at different times; see Figure 10.[182] In it, Moore has simplified and idealised reality, creating two smooth curves to illustrate the difference between the watchmaking practices in Europe and America. And in doing so he has hidden several important features, two of which I shall mention now.

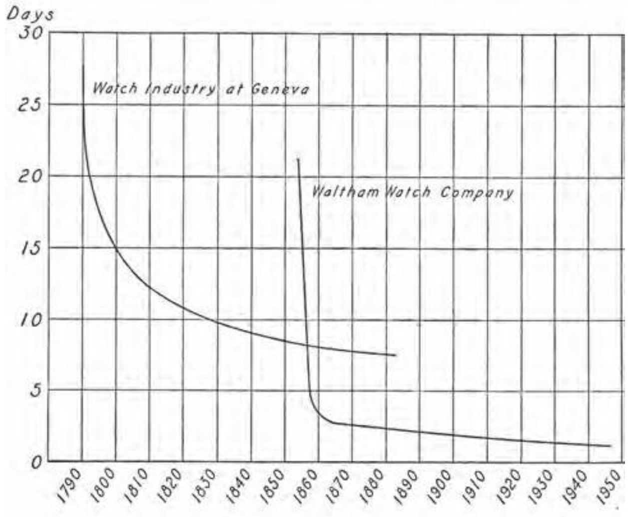

Figure 10

First, for most of the 17th and 18th centuries the time to make a watch might have dropped slowly, but would have been fairly constant. Throughout this period techniques and tools did not change much and Berthoud's, Auch's and Vigniaux's descriptions of watchmaking would apply to almost any watchmaker at any time.[183] But in the late 1700s Japy and others established factories, and centers like that around Liverpool became major producers. So the rate of watch making began to improve and this continued until the limit of productivity of the tools and labour was approached.

Second, if we consider what happened at Roxbury and Waltham between 1850 and 1857 we have to draw a significantly different picture, as shown in Figure 11. For throughout this period, Dennison and his workmen struggled to make watches and failed to reduce the number of man-days significantly. Then, very suddenly, the time to make a watch plummeted from about 18 man-days to 5 or even less. It was not a gradual change, not an improvement grafted by hard work. It was a stunning and dramatic free fall.

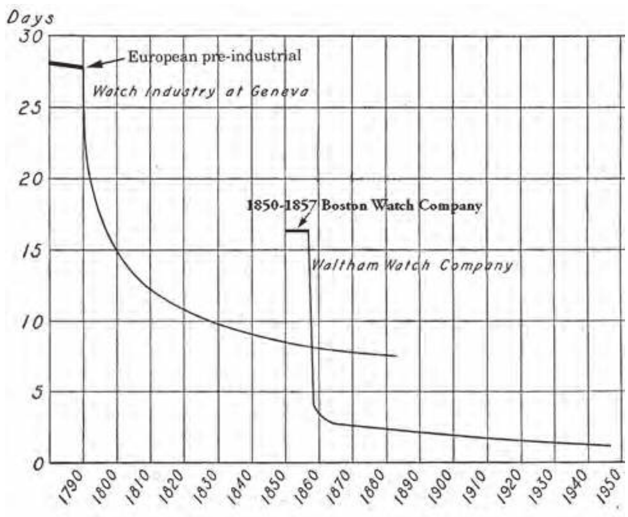

Figure 11

This graph is confirmed by what we know of production. Appendix D (page 106) analyses production of the American Watch Company for 1857 and 1858, and it shows that the rate reached about 5 man-days per watch by January 1858 if not earlier. That is, the rate dropped by about 11 man-days (from 16 to 5) in the space of a year.

Moore's graph and Appendix D have another, equally important implication. Not only does it illustrate the labour involved in making a watch, but it also reflects the *cost* of that watch. At a time when the tools and machines were relatively simple, the dominant factor in manufacturing was labour. If average wages were $1.00 per day (an annual income today of about $144,000) then Dennison and Howard had to

182 Moore, 1945, page 233.
183 Berthoud & Auch, 2005; Vigniaux, 2011

charge about $23 for each movement just to cover costs, including materials and the case, about $10,700 today. But after 1857 this figure dropped to about $10 ($4,650). And so the affordability and potential for sales of watches altered dramatically even though we can see that they still remained expensive, luxury items. This can be seen from the Waltham sales records;[184] although the sale prices are surprisingly erratic, they reflect this much lower cost.

The precise figures are not important. What does matter is that there was a *rapid, very large change*. And this change simply could *not* have occurred if the factory had continued production using the same methods, tools and staff that had existed before the Boston Watch Company became insolvent.

All that we need to know is: what happened?

A Spanner in the Works

A spade is a pretty dumb tool; in fact the dumbest tool I can think of. But it is very useful and can be employed to make holes of all sorts of shapes and sizes. Not only that, anyone who isn't badly disabled can use one. A tiny amount of care is desirable, to avoid cutting off toes, but otherwise the operator can be as dumb as the tool. Well nearly. Not long ago a man dug a big, deep hole in the sand on an Australian beach and lay down in it. Unfortunately the sides collapsed and he suffocated. But the problem had nothing to do with the tool, which had performed its function admirably.

Another dumb tool is the watchmaker's turns; see page 73. What could be simpler than two female centers to hold something and a horse-hair bow to turn the something? The only complication is the addition of a rest to help support a graver while turning. Indeed, it is so dumb you can make one from a few bits of wood and a couple of nails; even making a simple lathe is not much harder.[185] But unlike a spade, the turns are definitely *not* easy to use. It takes considerable skill and a large amount of experience before someone can successfully make watch parts with it. And there are many dumb tools like the turns. For example, a file. Simple, easy to use badly, but quite difficult to use well. Apprenticeships and other watchmaking courses begin with endless filing of taper pins and squares simply because the experience and the development of skills are essential.

A spade might be dumb, but its modern equivalent, a back-hoe or mechanical digger, most certainly is not. Its complex combination of engine, wheels, hydraulic arms and a bucket make it vastly superior to the spade in both speed and power. But otherwise it is the same; just about anything you can do with a back-hoe you can do with a spade, it just takes a bit longer. The big differences are that a back-hoe is *very* expensive and that the operator needs to be trained and experienced or else a disaster is certain to ensue. But a skilled operator can either caress the ground or rip it apart, such is the control and power available.

My fourth and last example of a tool is the digital camera. Turn it on, point it at something and press a button, and the camera does the rest. It focuses on the subject, adjusts the exposure, turning on the flash unit if necessary, and takes a picture. Knowledge of photography and cameras is not needed, there is no skill required, and the dumbest amongst us can accidentally take as good a photograph as a well educated professional.

These four examples of tools illustrate the various ways in which we have created machines to enhance out abilities and our productivity. They show an important relationship between the dumb or complex tool and its dumb or skilled operator. And they explain why every early attempt to achieve large-scale production of watches with interchangeable parts either failed miserably or achieved a minimal success.

Machines and tools are created by people. And what people create is strongly influenced by their past experiences and their perceptions.

In watchmaking, these experiences and perceptions derived from more than 300 years of a master-apprentice system controlled by guilds. This closed system is exemplified by the London Clockmakers

184 Hawkins, 1983, pages 4-67.
185 Whiten, 1979, pages 43-44.

Company, whose goal was to protect the *Art and Mystery* of the craft. The art is the skill and experience, and the mystery is the knowledge and understanding. Both were passed down from master to apprentice, and the apprentices who proved their competency by making a "master piece" became the next generation of masters and continued the secretive, tightly controlled distribution of education.

Apprentices entered their chosen trade when about 14 years old, and after 7 years they became journeymen, able to work but not yet competent to be masters; indeed, large numbers remained journeymen throughout their lives, working for masters or for factories. This organisation meant that the only education watchmakers or any other tradesmen received was dictated by their masters. The type of education and its content was directed to practical watchmaking and practical experience dominated. Very few people in such a system had the opportunity or inclination to study in areas outside those provided by their masters, and consequently the same information and skills were passed down from one generation to the next with little modification. This closed-shop system rewarded watchmakers by providing a stable, fairly safe working situation, but it actively discouraged and prevented change.

The only significant alteration to this educational structure was the result of splitting up the activities of watchmaking into a large number of sub-crafts. But these derivative trades followed the same educational organisation, using the master-apprentice system to propagate knowledge and skills in each sub-craft in the same way, and so produced journeymen, graduate apprentices, specialising in plate making, wheel cutting and 50 or more branches of watchmaking.

A good example of the effects of this system is the "mystery" of wheel cutting. From the beginning until well into the 19th century, wheel teeth and pinion leaves were shaped like thumbs and bay leaves respectively in a tradition handed down from one generation to the next, and despite a translation of Camus' 1750 work on gears by Hawkins, knowledge of epicycloid gearing was almost totally absent.[186]

These different trades involved varying degrees of knowledge and skill, but all required on-the-job training and all journeymen had significant, specialist skills.

Not all workmen were competent. In 1804 Crespe had to warn his reader to check the number of teeth on wheels in case there were too few or too many! So even the relatively simple wheel cutting engine was misused.[187]

Also, the system was abused. As a House of Commons committee noted, apprentices worked in factories in Coventry with 30 or more under the supervision of a single journeyman, and they received minimal, inadequate training. They were basically cheap, unskilled labour producing cheap, badly made watches. When they had completed their seven year's apprenticeship, they were dismissed because, as journeymen, their wages would be higher. But, because their education was so poor, they could not find jobs elsewhere.[188]

An important effect of this closed system was that it produced blind and irrational opinions to support it. A relevant example from 1860 is a letter by "one who admires good work":

> *I have seen a National watch from America, and confess I could discover nothing very alarming for English watchmakers in any part of it, especially as it was to a great extent merely a rough and tasteless agglomeration of parts manufactured in England, apparently got up for the purpose of turning national vanity to account; and I should be sorry to see Englishmen drawn by any such ruse to abandon the vantage ground time has granted to them, for I am confident that the genius that originated and gradually brought to its present perfection the art of chromometry may be excused from copying every sample of trash that roughly measures time.*[189]

(This is confusing because the Elgin company was not started until 1864. However the sentiments are what concern me, and clearly the author had not seen a Waltham watch.)

186 Camus & Hawkins, 1837.

187 Crespe, 2006, page 79.

188 House of Commons, 1817, pages 43, 73-76, 82, 84.

189 Anon, 1860, in response to Anon, 1858.

Originally all the skill lay with the watchmaker. Wheels and pinions were divided by hand and the leaves and teeth filed into shape. By the time of Berthoud, Auch and Vigniaux the machines were becoming marginally more intelligent. But even then teeth were hand shaped. And correct depthing, the distance between a wheel and the pinion that it meshes with, was achieved by plugging all the holes in the plates and re-drilling them in the right positions. The point is that although these machines improved productivity they still required highly trained operators, and watchmaking was firmly based in the skill and knowledge of the masters. So, although large-scale production and a degree of standardisation was achieved there was one insuperable barrier to progress: the machines were dumb. Almost the entire skill of watch making rested with the highly trained journeyman, and so the original factories recreated the watchmaker's bench en mass in factories to gain the benefits of the co-ordinated manufacture of similar parts.

The earliest factory of which we have some details is that set up by Frederic Japy in Beaucourt. Fortunately Japy decided to patent his machines and so we have precise descriptions of them.[190] There were ten machines: a circular saw, a plate lathe, a wheel cutting engine, a pillar lathe, two presses to punch out balances and wheels, a drilling guide, a tool to rivet pillars, another to slit screw heads, and a draw bench.

It has been stated by Cutmore, and repeated by Harrold, that Japy manufactured about 40,000 movements per year with 50 workers,[191] but these figures are patently ridiculous. They suggest that Japy made movements at a rate of about 0.39 man-days per movement; this figure is based on workers labouring for 310 days a year (6 day weeks with only 2 holidays). But Moore, using far more precise data, shows that the rate of production at Waltham was about 3 man-days per movement 1865, 2.5 in 1876 and not going below 2 man-days until after 1889.[192] Even if we accept that Japy produced rough, unfinished movements, ebauches, the figures just do not add up. To suggest he made watches over five times faster than the highly automated, streamlined factory of 1876 is not sensible. However, Cutmore's mythological statement is derived from David Landes, who actually wrote:

> *By 1780, we are told, Japy was employing and housing some fifty 'apprentices',* ***plus numbers of journeymen****, and turning out 43,200 pieces* [my emphasis].[193]

Assuming his ebauches took a credible 10 man-days, then there must have been around *1,290* journeymen. Landes also suggests the figure of over 40,000 is far too high, but even 20,000 at 10 man-days would require some 645 journeymen. We cannot get around the fact that Japy did produce large quantities of watches before America, but if a serous comparison is to be made we need much more convincing information.

Of the ten machines patented by Japy we can dismiss four immediately. The circular saw, pillar lathe, drilling guide and draw bench are crude, dumb tools which do not represent a significant advance over older hand tools like hacksaws, turns and free-hand drilling. The drilling guide is a good example. A piece is clamped in the tool and a drill, which is mounted on a runner in a tube and turned by a bow, is used to make a hole perpendicular to the face of the piece. But there is no way to clamp the piece in the right position other than by advancing the drill to touch it while moving the piece with one hand and clamping it with the other hand when it is in position; as Japy notes, use of the chest as well as two hands is desirable! So the chances of drilling two plates alike is minimal. Of the remainder, the two presses and the wheel cutting engine, which could cut a stack of wheels, are undoubtedly useful advances, but they are in no sense automatic, require skill to use, and speed up processes which represent only a fraction of the tasks in watchmaking. And the remaining three tools are of dubious utility.

The screw head slitting tool enables a number of screw heads to be slit at the one time. The screws are held in a clamp and a hand-operated slitting file moved repeatedly over them. Japy provides no information on how the screws are held in exactly the right position and height, and it is clear that setting up the tool would take some time. Again, it is a dumb machine which enables one task to be done a little faster, but

190 Japy, 2006.

191 Cutmore, 1989, page 19; Harrold, 2005, page 28.

192 Moore, 1945, page 232.

193 Landes, 2000, page 280.

there is no mention of corresponding tools to turn and thread the screws in the first place. Thus only a small part of the task has been improved.

The pillar riveting tool is simply a jig by which the frame and its pillars can be held while a hammer is used to rivet. It would probably be slower than doing the task by hand, but it may be a bit more accurate. However, a much greater problem than riveting is ensuring that the four pillars are turned to exactly the same length; otherwise the top plate would bend when it is fastened. The description of the pillar lathe tells us that it is simply a mill attached to a lathe; whether the result is square or round depends on whether the brass rod for the pillar, mounted in the lathe, is indexed or allowed to rotate freely. This is fine as far as it goes, but nowhere does Japy explain how the two pivots are made on the ends of the rod and consequently how the length of the pillar is controlled. Under these circumstances I would expect that free-hand turning and square filing would be just as easy and probably faster.

Finally, the plate lathe holds and turns a plate while cutters, one mounted in a slide and the other pivoted at the side, are used to shape the edge of the plate and cut a central recess. Plates are located by their pillar holes, the reference system, but presumably cemented to the chuck. By substituting other cutters, the lathe can be used to make other verge watch components, such as the slide and the rack. The most serious defect of this lathe is that there is no way to mount the plate eccentrically and so cut an off-center feature. In addition, play in the lathe components and the reference holes, and wear of the cutters would make producing interchangeable parts virtually impossible. But here we have a machine with a little intelligence built into it, although a skilled operator is still required.

We can now see two very interesting trends. First, the most useful of Japy's tools, presses and a wheel cutting engine, are the same tools that Dennison built some 50 years later. I am not implying that Dennison copied Japy's ideas, although he might have, rather that the common thread points to the fact that it is easier to make such tools than machines to do other tasks. Second, the vast majority of watchmaking tasks (plate drilling, screw making, arbor turning, etc.) must still be done using traditional hand methods requiring skilled journeymen; which we can see from the more sensible estimates of Japy's workforce given above. (Also see Appendix A, page 82.)

Consequently, the most that Japy could have done was to organise a manufacture that moved tradesmen from cottages to a single building without significantly reducing the number of man-days to make a watch. But he probably didn't even do that. There is some information on his factory in Allix (1974) which suggests that it would be simply impossible to house the more than 600 workers in the building. Most likely the majority were still working in their cottages.

The other European attempt to manufacture watches before Dennison was by Pierre Frederic Ingold, a contemporary of the Pitkins. Ingold is championed by many outside the United States, and David Penney takes his life in his own hands by daring to suggest

> *the American System of Watchmaking should perhaps be renamed the Ingold System of Watchmaking.*[194]

However, it is clear that this suggestion is not acceptable; if we are to agree with the argument then it must be called the Japy System of Watchmaking as Japy takes precedence.

But what do we know of Ingold's tools and machines? As Penney and Carrington point out,[195] Ingold invented and patented two machines in 1842 and 1843. The first is his fly press for producing wheel blanks. Although an improvement on Japy's presses, it also only assists with a minor part of watchmaking.

Ingold's second machine was his plate lathe. This undoubtedly ingenious hollow mandrel, or face-plate lathe, had an eccentric chuck which enabled any part of a watch plate to be centered according to a pre-set indexing plate and a slide screw. Because the mandrel ran on a hollow tube, cutters could be fed through this hole to form the other side of the plate. Thus sinks and holes could be cut and drilled anywhere on

194 Penney, 2005, page 22.
195 Carrington & Carrington, 1978.

the plate. And because the last step was to separate the plate from its oversize blank, there was no problem clamping it to the head-stock. The difference between this and the traditional method lay in the single chucking of the plate instead of a number of separate mountings on a wax brass or a face plate. And it is clearly far more versatile than Japy's plate lathe. But although some time may have been saved, just about as much skill and training would be needed by the operator as when he made plates the old way. Further, it is very unlikely that interchangeable plates could be produced. Certainly they would be very similar, but the accuracy of the settings, wear on drills and cutters, and the operator's involvement make it very likely that small differences would occur and some finishing would be needed.

It must not be forgotten that the tolerances for some parts, such as pivot holes, must be measured in hundredths of a millimetre, both in diameter and position. And the more parts a tool has, the more problems there will be with play and other variations. So a little play in the head-stock, a little more in the indexing system, yet more in the tool mount, and a slightly worn tool can add up to an appreciable error. It is precisely such problems which made it impossible for Waltham to make interchangeable arbors as late as the 1880s, so what chance did Ingold have?

But again, just as with Japy, the tools and machines we know about perform only a fraction of the tasks in watchmaking; see Appendix A, page 82. However, unlike Japy, Ingold never got past the drawing board. As Waldo notes, quoting a watchmaker who visited Ingold's London premises,

> *of the two hundred men said to be employed, the number I saw did not exceed six or eight, these were occupied in making watches without the aid of machinery, employing only the tools generally in use.*[196]

So all of them, Japy, Ingold, the Pitkins and Dennison, developed the same types of tools. And in all four cases we are faced with the same questions: How were arbors and pinions made? How were screws and escape wheels made? How was the train assembled with correct depths and end shakes? And so on!

But the critical point is that the approach of Japy, Ingold, the Pitkins and Dennison was that of the master watchmaker, which Japy and Ingold were, and the Pitkins and Dennison attempted to be. Mechanisation was seen from that point of view and central to it is the *trained artisan*. And it is safe to say that the majority of tools and methods were designed with the apprentice and journeyman in mind. Thus, all four attempted large-scale watchmaking within the confines of traditional methods enhanced by a few, inadequate machines. Three (and I think Ingold as well if he had ever managed to set up and run a factory for long enough) only managed to reduce the man-days per watch by a small amount. All except Japy failed, and it is probable that he only succeeded because he was much earlier and he produced unfinished ebauches for a hungry Swiss industry.

At least one useful conclusion can be drawn from this examination. And that is, no one beat the Americans to it, whatever it is. Nothing done by Japy, Ingold, the Pitkins or Dennison changed watchmaking in the way that events in 1857 must have. Something that was distinctly different caused an abrupt change in how watches are made, and it is that which makes The American System of Manufacturing original and so very important.

What Dennison Missed

Really, Ingold never had a chance. Even if he visited Japy's factory he would have seen machines doing rough work and menial tasks, and people doing the difficult bits using simple tools. But both the Pitkins and Dennison might have seen the light. Both were in easy reach of the clock factories and both visited the Springfield Armory. But they both missed the crucial point of armory and clockmaking practice.

When Dennison went to the Springfield armory he saw a way to manufacture watches by assembling people to work with machines in a controlled factory environment. But other than presses, there is nothing in the manufacturing process for guns that can be applied to watches. And there is nothing in the system of go/no-go testing of components that is relevant to watchmaking.

196 Waldo, 1886, page 187.

When Dennison went to the Springfield armory he thought he saw interchangeability. But what he should have seen were reject parts that failed the go/no-go tests, parts that had to be discarded or refinished by hand. He saw a process of *standardisation* of parts that tried to minimise waste but produced waste nonetheless.

From this he could construct a vision of a similar factory peopled by tools and workmen making watches. A factory where similar parts could be created and then massaged into usability, just as had been done in the past. So he and Howard built such a factory and it promptly failed.

It failed, because what Dennison completely missed at the armory was a manufacture that had been *dumbed down*.

One thing that America lacked was enough skilled craftsmen. The number of gunsmiths was simply too small to produce enough rifles to invade the west and equip armies. The number of watchmakers was probably just sufficient to maintain and repair imported watches without worrying about trying to make them.

Contrast this with England and Europe. By the 1850s, there was at least 200 years of watchmaking and 200 years of apprenticeship training. And in both places there were established industries based on manufacture by skilled artisans. And there were enough of these journeymen, perhaps even a glut.

Also it seems that America had few labourers and, as Rolt notes, in the early 1850s an English commission reporting on America stated that

> *the labouring classes are relatively few in number*

and there was apparently

> *a widely held and long-cherished belief that the American System originated solely because of a shortage of labour and the high wage rates consequent upon such a shortage.*[197]

But the machines were too simple to have any significant impact on the number and type of people required, and trained watchmakers were in short supply.

From the 1850 US census,[198] the population of the US was 21,191,875, of which there were 1,181 clockmakers and 2,901 watchmakers, including 837 clockmakers in Connecticut, most presumably employed in clockmaking factories. That is, there was one watchmaker for every 7,305 people, and less than 0.014% of the population were watchmakers. Of these, 59 clockmakers and 213 watchmakers lived in Massachusetts.

Ten years later,[199] the population of the US was 31,443,321, of which there were 1,157 clockmakers and 4,538 watchmakers. That is, there was one watchmaker for every 6,929 people, and less than 0.015% of the population were watchmakers. Of these, 74 clockmakers and 417 watchmakers lived in Massachusetts.

It would be much better if these people had the correct titles of *clock-repairer* and *watch-repairer*, because there is no doubt that they were fully occupied in selling and servicing, and they probably had never made a clock or a watch; except perhaps for Massachusetts in 1860 where many of the 417 "watchmakers" would have worked at the American Watch Company, and it is likely that some of these were ordinary workers in the factory and called themselves watchmakers for the purpose of the census.

However Rolt is wrong and one thing America had was an ample supply of *unskilled labour*; there was a wealth of young men and enthusiastic girls with not much education and no skills beyond tending farm animals and crops, and many of these came from Ireland.

During the great famine caused by the repetitive failure of the potato crop, from 1841 to about 1851, the population of Ireland dropped by about 2 million people, and it has been estimated that of these

197 Rolt, 1986, page 155.
198 US Census, 1850, section 1850a-12.
199 US Census, 1860, section 1860a-19.

about 1 million died of starvation and disease and 1 million emigrated, the majority to America, Figure 12.[200] And the Irish population continued to fall until it had halved when compared to the pre-famine population.

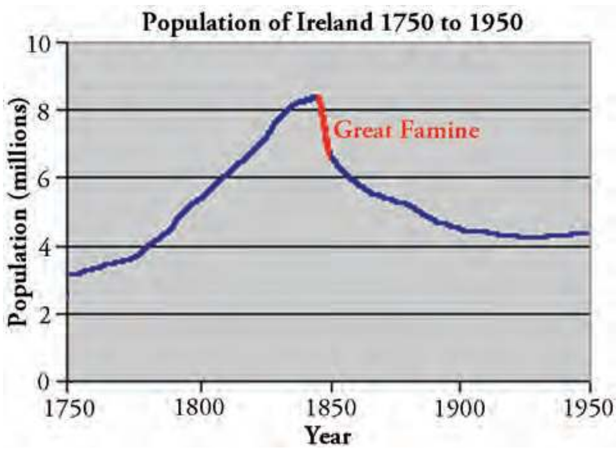

Figure 12

In addition:

> *Unlike the pre-famine exodus, which was mainly the better-off peasants, these were mostly the poorer people in Ireland.*[201]

And:

> *In Ireland almost half of the population lived on farms that produced little income. ... Over two million Irish eventually moved to the United States seeking relief from their desolated country. Impoverished, the Irish could not buy property. Instead, they congregated in the cities where they landed, almost all in the northeastern United States.*
>
> *In the decade from 1845 to 1855, more than a million Germans fled to the United States to escape economic hardship. They sought to escape the political unrest caused by riots, rebellion and eventually a revolution in 1848. ... Unlike the Irish, many Germans had enough money to journey to the Midwest in search of farmland and work.*[202]

The 1850 and 1860 censuses of the United States provide a little more information:

(a) In 1850 immigrant occupations are given for only three years: 1845, 1847 and 1852.[203] Over 36% of immigrants were farmers and labourers, and there was only one watchmaker and no clockmakers. And about 50% of immigrants were *unknown, mostly female*.

That is, about 86% of immigrants were unskilled. In addition, about 7.9% of immigrants were mechanics; I have not found a definition of what these people did, but they were probably machine repairers and not machine makers.

(b) In 1850 day labourers in Massachusetts earned $1.09 without board, confirming estimates I have used.[204] It is interesting to note that the American Watch Company did not give a higher wage as an incentive to attract workers; it didn't need to.

(c) Of the occupations for immigrants arriving between 1851 and 1860, over 32% were farmers and labourers, and 54% were *not stated* but presumably mostly women. Mechanics accounted for about 6.3%.[205]

(d) With regard to Massachusetts, in 1860 78.87% of the population was born in the US, 15.07% were immigrants from Ireland, and only 6.06% were from elsewhere.[206]

However, the populations of main cities, Boston, Cambridge and Lowell, were 25.9%, 17.5% and 25.7% Irish born; that is 45,991, 4,558 and 9,460 persons respectively.

In 1860 Waltham had a population of 6,397.[207] It is obvious that there was a glut of unskilled immigrants in Massachusetts needing employment and, unlike skilled workers, the American Watch Company would have had no trouble getting suitable people and training them.

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200 Ireland, 2018, Demographics.
201 Ireland, 2018, The Winter of 1846 to 1847.
202 US History, 2018.
203 US Census, 1850, section 1850a-12.
204 US Census, 1850, section 1850c-05.
205 US Census, 1860, section 1860c-02.
206 US Census, 1860, section 1860a-02.
207 US Census, 1860, section 1860a-19.

But unfortunately clocks, guns and watches require skilled artisans ...

But they do not! At the core of the American System is the realisation that *complex, sophisticated products can be manufactured by unskilled labour*.

As Fitch notes

> *Whitney ... systematized the work, and by making the parts in lots of large numbers,* ***employing unskilled labour*** *for filing them to hardened jigs, and by close personal supervision, succeeded in executing a contract under circumstances which caused the failure of other contractors, who employed skilled craftsmen, filers and gunsmiths to do the work.*[208]

Or, to put it another way, Whitney *dumbed down the workers*.

Although writing about a much later time, Alft & Briska drive home the truth of these statements. An employee at Elgin is quoted:

> *I worked for the Elgin company nearly ten years ... and I don't know any more about watch making than millinery.*[209]

And another employee:

> *who had been making canon pinions, didn't know where in a watch the part belonged. It is not necessary that she should ... she could not make them any better or any worse if she did, because she simply tends the machine which does the work.*[210]

These clearly stress the central feature of post 1857 watchmaking in America, the use of minimally trained, unskilled labour. For the employees, watch making is a mystery, knowledge of which is irrelevant.

A third statement in the same book is also important:

> *because 'interchangeable' parts often had to be 'fitted' by finishers, they were among the factory's most skilled employees.*[211]

Indeed, we could reasonably say that finishers were almost the *only* skilled employees, other than the machine makers. And by 1886

> *the great questions ... of determining what kind of labor - whether of boys or girls, or men or women - was most efficient in any department had been settled.*[212]

and these labourers had

> *no specific knowledge of horology.*[213]

There is a world of difference between filing a part to an accuracy of one thirty-second of an inch and turning a balance staff to within one hundredth of a millimetre. And wooden parts for clocks made with simple jigs also have tolerances which enable fairly crude workmanship to be quickly finished and fitted so that similar parts take on an air of interchangeability. Whether Dennison completely missed the point or found he was unable to transfer it to watchmaking is uncertain. But Abbott strongly supports my contention that Dennison entirely missed this vital factor: About 1843:

> *Mr Dennison now began to turn his thoughts to ... the 'Interchangeable System', and here it may be well to state that, among the objects which spurred Mr Dennison on was the need of the masses ... to be supplied with a reliable timekeeper at a price within his means ... and further, he desired to establish a fine mechanical industry in our country which would tend to* ***raise the standard of skilled labour and give employment to talented mechanics*** [my emphasis].[214]

208 Fitch, 1883, 2 (page 618).

209 Alft & Briska, 2003, page 32.

210 Alft & Briska, 2003, page 32.

211 Alft & Briska, 2003, page 46.

212 Waldo, 1886, page 189.

213 Waldo, 1886, page 189.

214 Abbott, 1905, pages 34-35

And that is exactly what he tried to do.

As Abbott wrote, in 1850

> *a small factory was built ... and some **English and Swiss watchmakers** were put to work.* [my emphasis].[215]

So he gathered together some 50 journeymen fresh from overseas, supplied a few primitive machines to supplement the traditional turns, files and burnishers, and tried to achieve large-scale production of watches. They *had* to be journeymen simply because the tools and machines were dumb; or even if they had some sort of inbuilt intelligence, they required skilled operators.

Indeed, Dennison was so concerned about the comfort of his journeymen that Crossman notes

> *the wings of the buildings were divided into small rooms or stalls ... The reason for this arrangement was that Mr Dennison thought the European workers, **who had been accustomed to work in their own homes** would be better satisfied to have separate rooms and thus in a measure overcome the jealousy which would exist among them. This plan was, however, found impracticable, and after being in use for about a year the partitions were removed.* [my emphasis] [216]

These descriptions of a factory reliant on traditional, craft-based labour are confirmed by what happened immediately after the insolvency in 1857. Robbins, needing to restart the factory as soon as possible, was reliant on Dennison's experience and knowledge to do this. So

> *The next day after the sale Mr. Dennison started for England for the purpose of obtaining material which was required and also to arrange for the manufacture of dials there* [with the new company name].[217]

And Moore notes that Dennison went to England

> *trying to get materials and skilled craftsmen.*[218]

In Dennison's own words

> *there had existed the necessity ... for the purpose of stocking up a little or to obtain some help or both.*[219]

To which Moore adds:

> *The need for factory hands was also a matter of concern, but the attempt to recruit craftsmen in England was not successful.*[220]

(It appears that Dennison was happy to be away from Waltham because

> *I know* [of Robbins] *only enough to discover that under all the circumstances, if he was to have much say about the business, the sooner I could make it convenient to leave the better.*[221]

Which was prophetic of later events.)

Dennison's failure to recruit English workers was because

> *we can hardly offer any inducement for an Englishman to emigrate, as workmen in our line, as well as most trades similar such as jewelry manufacture &c &c, are getting quite as good pay and have every reason to be happy here as they could with us.*[222]

These statements confirm that watchmaking in Waltham had been based on trained journeyman. Consequently, I must disagree with Hauptman when he writes:

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215 Abbott, 1905, page 17.
216 Crossman, 1885, page 15.
217 Crossman, 1885, page 38.
218 Moore, 1945, page 25.
219 Moore, 1945, page 22.
220 Moore, 1945, pages 28-29.
221 Moore, 1945, page 23
222 Moore, 1945, page 29.

> *Dennison with Howard proved the machine-made watch and the machines that made it to be mechanical successes.*[223]

Their manufactory was not significantly different to that of Japy and was based on traditional watchmaking augmented by simple machines. What Dennison with Howard actually proved was that *such a factory with its excessive man-days per watch and expensive, skilled labour was a failure*. Don't forget, the insolvency of the Boston Watch Company not only occurred long before the panic of 1857, which started in September, but it had probably been foreseen by the middle of 1856 or earlier. The failure was just the inevitable end result of a company that simply could not achieve its aims.

To summarise: The point I am making is that the one essential feature of the American System of Manufacturing, which sets it apart from everything that had gone before, is that it uses *unskilled labour*; it *dumbed down* technical, guild-based crafts to the point where the craftsmen were almost redundant.

Although large-scale production can be seen as a second motivating factor, everything is a *consequence* of dumbing down and not a cause: the development of intelligent machines able to be used by people with just a little on-the-job training; the relocation of machines and people into factories so that these unskilled workers could be supervised; the emphasis on large-scale production, because that is the only way the cost of expensive machines and their maintenance could be justified and recouped; and the inevitability that such machines would produce very uniform and, eventually, interchangeable parts.

It could be argued that Japy understood and acted upon this fundamental point. His patent description begins

> *The following machines produce the principle parts of a watch, with rapidity and precision, by employing only not very skilful workmen, and can even be operated by children.*[224]

This view is re-expressed by Allix when he wrote

> [Japy's] *outstanding endeavours ... gave work to many people who previously had depended upon the soil for their livings.*[225]

There is no doubt that some of his machines could be used by unskilled people, but these machines perform only a small fraction of the tasks involved in making a watch, and several of them would need considerable skill to use correctly. It is quite clear that Japy was simply speeding up some of the rough work while the majority of the labour had still to be done by journeymen. He was doing exactly the same as Ingold, the Pitkins and Dennison; which is to say, he was not dumbing down watchmaking, but rather he was trying to improve the efficiency of craft-based methods.

Like Ingold, he never had a chance, simply because his cultural and educational environment was that of guilds and craftsmanship, and he was unable to see outside this framework. So I have no doubt that everyone before 1857 missed the essential point of unskilled labour, which is not to supplement, but to *eliminate* the craftsman.

Thus the American System of Manufacturing is *the manufacture of machines by unskilled labour*.

Three Cheers for Charlie and Bill!

Events don't just take place. They occur because some confluence of conditions create a moment which enables dramatic change. The founding of Australia is one such event and, perhaps an heretical view, it was a consequence of the American War of Independence. England was sinking under the weight of petty criminals who filled to overflowing the rotting hulks on the Thames. But there was a simple solution; ship them off to the North Americas, to that vast colony with room to spare for the unwanted convicts. Unfortunately, the free Americans got sick and tired of the "mother country" and kicked England out.

223 Hauptman, 1963a, page 691.
224 Japy, 2006, page 1.
225 Allix, 1974, page 142.

What to do? Easy. Send Captain Cook off to locate Terra Australis, claim it and ship the rubbish there instead; which is why, ignoring the 60,000 years of Aboriginal settlement, Tasmania started out as a penal colony.

It wasn't quite that simple, because there were other factors. One was John Harrison. Through his work the English could see a way not only to accurately map the world but, more importantly, to dominate it; which they did. And so finding Australia killed two birds with one stone; the colonisation of a substitute land to replace America and making a map covered with British flags. I am sure historians will list many other factors, but the point is, if the Americans hadn't gained independence it is unlikely that England would have bothered with Australia.

The same is true of American watchmaking. It took the coming together of a particular set of circumstances at a particularly propitious moment to cause an industry to be created.

The right time was the result of some twenty-six years of attempts and failures by the Pitkins, Dennison and Howard.

The right circumstances were the selling of a nearly *empty factory* to someone who knew *nothing about watchmaking* but who had the will to succeed.

I have argued, and I think demonstrated, that past failures were primarily due to the inability to dumb down watchmaking. No one had been able to make the leap, to look at the task from a completely different perspective, because all the people involved were *watchmakers*, educated within the narrow confines of the traditional art and mystery. To be able to view watchmaking from a totally different aspect required someone who was not a watchmaker and who was not burdened by preconceptions.

The empty factory was vital. If it had not been empty, the new owner, Royal Robbins, and his employees would have inherited a working factory and would almost certainly have attempted to continue what Dennison and Howard had started. If that had happened the Waltham company would have failed yet again and almost certainly died, bringing America's experiment with watchmaking to an abrupt and premature end.

But Robbins, although he didn't see it that way, was rescued by Charles Rice and William Cook.

In a letter to C.N. Thorpe, Mr. E. Tracy states:

> *In the fall of 1856, Dennison, with the knowledge of his firm, began looking around to get someone to put some money into his enterprise of watchmaking, and early in the Fall of 1855, or Spring of 1856, Mr. Charles Rice, a shoemaker of Boston, loaned the money, which Dennison, Howard & Davis secured by* ***chattel mortgage on all the material, tools, machinery, etc*** *in the watch factory.* [my emphasis] [226]

However, this view of events ignores the information given in the 1857 Boston Watch Company insolvency,[227] and it only makes sense if the dates are the Fall of 1856 and the Spring of 1857.

It is important to note that there is no case number for the Boston Watch Company in the Insolvency Court documents. That is, the Boston Watch Company was not formally a company and was merely the trading name under which Curtis, Davis, Howard and Dennison made and sold watches. Consequently these four people were individually liable. The Boston Watch Company is frequently mentioned and is the name in which many financial transactions occur, but it is a convenient and not legal name.

However, at some time before the insolvency case, Davis, Howard and Dennison handed over all the assets and liabilities of the Boston Watch Company to Curtis. For example, on 29th October 1857 Dennison submitted an affidavit to the court in which he states:

> *I, A. L. Dennison Insolvent debtor in said proceedings being duly sworn say that more than six months previous to the petition being filed in said proceedings I sold out all my interest in the Boston Watch*

226 Tracy, E., 1886; see Marsh, 1890, page 15.

227 Suffolk County Court of Insolvency, 1857-58.

Co. to Samuel Curtis who agreed to pay and hold me harmless from all liabilities of or on account of said Company …[228]

In addition, Rice and Howard were asked when Curtis and others were aware that the Boston Watch Company was insolvent, suggesting that the finances were deliberately organised before the court case:

22 When did you [Rice] first suspect or believe that said Curtis, Howard and Dennison, respectively, were insolvent. State as to each respectively. [229]

19 When did you first suspect that you & Curtis were insolvent? [230]

These questions are interesting in the light of Dennison's affidavit above, and the answer is probably that they were aware that the Boston Watch Company was insolvent in October 1856 and they prepared for the inevitable failure; this was about 11 months before the panic of 1857. Why Curtis was made the fall-guy is not known, but the result is that all the assets and liabilities of the Boston Watch Company were the responsibility of Curtis alone.

The Waltham Improvement Company took over the factory on 3rd March 1857, and on 15th April 1857 the Suffolk County Court of Insolvency formally issued warrants to the four partners to take possession of their real and personal estates, both as individuals and as members of the Boston Watch Company. The involvement of the Waltham Improvement Company is limited to a single entry stating that it was a creditor of Curtis for $6,000, about $2,790,000 today.[231] This was secured by collateral, presumably the mortgages held over the buildings.

At the time of the insolvency, the only assets of the Boston Watch Company were the buildings and their contents worth about $43,000, about $20,000,000 today. In contrast, the amount owed to creditors of the company was $105,344.01, about $48,900,000 today, and on 15th September 1857 the creditors received 20 cents in the dollar from the distribution of the proceeds of the sale of the property.[232] (A second amount of 4⁷⁄₁₀ cents in the dollar was distributed, but there are no details of it.) Charles Rice was a creditor of Curtis for $33,833.24 and he received only $6,766.64. William Cook was also listed as a creditor of Curtis for $7,000 secured by collateral but this amount is not explained anywhere.[233] In the distribution of dividends from the proceeds of the sale on 15th September 1857 Cook is not mentioned. However, it appears that half of the last page of this document is missing and Cook might have been mentioned there.

After the Waltham Improvement Company took over it leased the factory to Charles Rice:

13 Did not the Waltham Improvement Company enter upon said Watch Factory and premises to foreclose a mortgage about March 1857…? Did you [Rice] not take a written lease of the same premises from said Waltham Improvement Company about the same time? [234]

April 11: Watch Factory Estate: Rent paid to April 3rd by Charles Rice of Boston: $52.50. [235]

The lease of the factory terminated on 9th May 1857 when the factory was sold at auction:

May 31: Watch Factory Estate: Seven days rent up to May 9th at which time the premises were sold: $12.04. [236]

In addition to leasing the factory, Rice did not act on his mortgage until the day of the sale, because up to then he and his associates expected to buy the factory:

228 Suffolk County Court of Insolvency, 1857-58, Document 119-028.
229 Suffolk County Court of Insolvency, 1857-58, Document 116-153.
230 Suffolk County Court of Insolvency, 1857-58, Document 118-056.
231 Suffolk County Court of Insolvency, 1857-58, Document 116-003.
232 Suffolk County Court of Insolvency, 1857-58, Document 116-164.
233 Suffolk County Court of Insolvency, 1857-58, Document 116-003.
234 Suffolk County Court of Insolvency, 1857-58, Document 116-153.
235 Waltham Improvement Company, 1854-1864.
236 Waltham Improvement Company, 1854-1864.

After the failure in Waltham, Mr. Howard anticipated buying in the property and continuing there ... but the amount bid far exceeded their expectations and he returned to Roxbury ... and started up the old watch factory ... The watch factory was now conducted by Mr. Howard in the interests of Mr. Charles Rice. [237]

The insolvency court documents show that, contrary to Tracy's letter, Charles Rice only had a mortgage on the watch movements and parts in the factory. In them there are 11 pages of *interrogatories* (questions asked of Charles Rice *on complaint of* Tracy Baker) and 10 pages of interrogatories (questions asked of Edward Howard on complaint of Tracy Baker) to both of which are attached a copy of the 2nd February 1857 *Inventory of stock in workmen's hands;* [238] see Appendix B, page 92. (The complaint is in the name of Tracy Baker presumably because Royal Robbins purchased the Boston Watch Company factory on behalf of Tracy Baker, and he was not directly a party to the case. There are no answers, presumably because they were oral statements in a court session, but some answers are obvious.)

However, none of the questions refer to tools or machinery and from this we can conclude that Tracy (quoted above) was wrong. When Edward Howard returned to Roxbury to manufacture watches, the early watches were signed Howard & Rice, thus confirming that whatever Rice removed from the factory was moved to Roxbury.

The purpose of the 23 interrogatories to Rice was primarily to determine if he had a legal right to remove stock, materials and watches as described in the inventory. The questions are very complex and obscure because it was necessary to ensure that Rice answered correctly. For example, if he was asked "did you have a contract ...?" then he might legitimately answer "no" because he had an agreement that, in his eyes, was not a contract. To illustrate this, one question was:

5 If you paid, lent or advanced money or other property, or notes or credit at any time, to said Howard Dennison or Curtis, or either of them, in connection with said Watch Company or otherwise, please state the time & amount of each and every such payment lending or advance, separately - what were the several considerations thereof, whether money, or other & what property, and how much of each - when such considerations were given - and how much was ever repaid you on the same by said Howard, Dennison and Curtis severally, & the exact times of such payments - Please state fully in order of time in a schedule & show which of the same are now due - State fully & particularly from the beginning down to the time of insolvency?

As suggested by this question, Rice's involvement was much greater than the $7,510 in the inventory, and in the 29th April 1857 list of the creditors of Curtis[239] Rice was owed a total of $32,130.56, about $14,900,000 today, (There are some discrepancies in the amounts in different documents.) Rice answered the question by providing promissory notes and receipts, and about $26,556 of this was owed by the Boston Watch Company,[240] about $12,300,000 today.

Up until the insolvency Rice appears to have had a legal right to the materials and stock. However, the warrant of 15th April 1857 [241] authorised the assignee appointed by the court, Nathan W. C. Jameson, to take possession of the assets of Curtis including the Boston Watch Company. At this point Rice became a creditor and, at the time of the sale of the factory on 9th May 1857, Rice should have had no legal claim to the contents of the factory. This is the significance of interrogatories 16 to 20:

16 Did you not take or some one for you or by your orders from said Watch Factory between the time of said Curtis' filing his petition in this case and the assignee's sale of said factory premises materials stock etc. certain stock, materials tools and fixtures or some & which [when?] and which thereof? If

237 Crossman, 1885, page 55.

238 Suffolk County Court of Insolvency, 1857-58, Document 116-153, dated 25th August 1857; Document 118-056, dated 27th August 1857.

239 Suffolk County Court of Insolvency, 1857-58, Document 116-003.

240 Suffolk County Court of Insolvency, 1857-58, Document 116-175.

241 Suffolk County Court of Insolvency, 1857-58, Document 116-002.

so state the time or times of such taking, and particularly the items of such stock materials tools & fixtures - and …

17 If any such stock materials tools or fixtures were taken by you as mentioned in the last interrogatory, where did you take them? Where are they now? Has the Assignee made any claim for them or any of them of you? Have you not bought the Assignee's interest in them or some of them? If so when & what did you give the Assignee for them?

18 Did you give the Assignee three hundred dollars or some other & what sum for his interest in same property taken by you or by your order as mentioned in the last two interrogatories? What interest in what property did you purchase of the said Assignee therefor.

19 What relation to you are the Assignee Mr Jameson … Does not said Assignee have a desk and do business in the same office with you or in your office? …

20 Did not you … take property from said Watch Factory the night before the assignee's sale aforesaid or within two or three days of said sale or soon after said sale? If so what property was so taken … Was it not watch movements from No 4891 to 4910 inclusive or some other and what number?

Similarly, Howard was asked:

18 Did not said Rice or you … between the time of said Curtis' or your petition in insolvency before this court and the delivery of the said factory or premises & stock, tools & fixtures by Mr Jameson the assignee to the purchaser after said assignee's sale thereof, take away stock, materials, tools and fixtures …

When were such stock, materials, tools or fixtures taken and where are they now? Are they not, or some of them in your or Rice's possession now? … Have not you and said Rice or said Rice alone, commenced watch manufacturing at what you call the old factory in Roxbury …? … And are not the said stock, materials, tools & fixtures there in said old factory or are the not intended therefore? Did the assignee make any claims for said stock materials tools or fixtures? [242]

Clearly Robbins thought that there was corrupt collusion between Howard, Rice and the assignee Jameson.

Although ambiguous, the above indicates that Rice had an interest in only the stock. So what happened to the tools and machinery? This question is answered by the Waltham Improvement Company.

The Waltham Improvement Company owned the watch factory estate, including the building and had sold it to the Boston Watch Company with a mortgage over it. So when Curtis, Howard, Davis and Dennison failed to make repayments on 24th February and 2nd March 1857 of $6,000 (about $2,790,000 today), the Waltham Improvement Company took over on 3rd March 1857:

February 24, 1857: Information was given them from the Waltham Bank of the non-payment of notes of the Boston Watch Company due January 9/12th for $2000 - also, one due February 13/16 for $2000 - both guaranteed by the Waltham Improvement Company, with request of payment of the same. Another like note for $2000 would be due in March 2/7. [243]

These are *promissory notes* (as, for example, in Figure 13 top on page 55) where a person guarantees to pay cash to someone else at some time in the future.

When a promissory note has been dishonoured by non-acceptance or non-payment, the holder may get the dishonour noted and certified by a notary public. Such a certificate is called a protest, and it allows the holder to legally force payment from the assets of the issuer.

So by March 1857 the Boston Watch Company had dishonoured three, four-month notes which were written in September, October and November 1856.

242 Suffolk County Court of Insolvency, 1857-58, Document 118-056.

243 Keith, 1883, page 32.

On 10th March 1857 the Waltham Improvement Company protested the notes, and before 25th March it took possession of the machinery and tools in the factory by its rights under the debt. [244]

But on 9th April 1857 it transferred the $6,000 debt to William Cook:

> *To Bills Receivable: For the payment by the hand of Wm J. Cook of Boston of three notes as follows, viz one dated Sept 9th 1856 one dated Oct 13th 1856 and one dated Nov 3rd 1856 given by Curtis, Howard and Dennison for $2000 each, which were acknowledged by us upon the back as being held as collateral with a mortgage of machinery & tools at the Watch Factory. Which mortgage has this day been assigned to said Cook, and the three notes so held, were surrendered to said Howard. The three protested notes, the payment of which we had guaranteed to the Waltham Bank and paid by us, were surrendered with the mortgage to said Cook. $6000.* [245]

Although obscure, Cook paid the debt of the Boston Watch Company and received a mortgage on the machinery and tools in exchange.

The final transaction relating to Cook's mortgage was on 15th April 1857:

> *April 15, 1857: To Boston Watch Co: For the amount of expenses which we paid on account of the mortgage of machinery and tools which sum was received of Wm J. Cook of Boston." $234.72.* [246]

And on the same day the members of the Boston Watch Company went before the Suffolk County Court of Insolvency and became insolvent. However, the Waltham Improvement Company was probably not aware of this until the next day when the assignee Nathan Jameson advertised the insolvency in newspapers.[247]

These entries answer one question, why the inventory of 2nd February 1857 only covers materials. Charles Rice did not have a mortgage on the tools and machinery, and so he could only remove materials from the factory to take back to Roxbury.

William Cook is also listed as a creditor of Curtis for $7,000 secured by collateral,[248] but this amount is not explained anywhere.

However, there are two unanswered questions: Who was William J. Cook? And what happened to the tools and machinery?

I was unable to find out who Cook was. I don't know if he was acting independently, but the most likely explanation is that Cook was acting for, or transferred his mortgage to Rice or Howard; this is necessary to fit with the generally accepted view that Rice had a "chattel mortgage on all the material, tools, machinery, etc. in the watch factory."

The only thing we know for certain is that Cook mysteriously disappeared, just as he had mysteriously appeared.

The interrogatories add a little additional information:

> *19 What relation to you [Rice] are the Assignee Mr Jameson and William J. Cook? Does not said Assignee have a desk and do business in the same office with you or in your office? What is said Cook's business? Where does said Jameson reside?* [249]

Again, there is a suggestion that Charles Rice, the assignee Nathan Jameson, and probably William Cook corruptly colluded. This is likely because in February and March 1857 Charles Rice gave the Assignee Nathan Jameson $5,093 in the form of three promissory notes, of which one is shown in Figure 13 top.[250]

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244 Waltham Improvement Company, 1854-1864.
245 Waltham Improvement Company, 1854-1864.
246 Waltham Improvement Company, 1854-1864.
247 Price, 2005, page 8.
248 Suffolk County Court of Insolvency, 1857-58, Document 116-003.
249 Suffolk County Court of Insolvency, 1857-58, Document 116-153.
250 Suffolk County Court of Insolvency, 1857-58, Document 116-175.

This note and its receipt provide an example of why the Boston Watch Company owed Charles Rice about $34,000 (about $15,800,000 today) for money he gave the company between April 1856 and March 1857.

The note reads "Febry 5th 1857 Six months after date I promise to pay to the order of N W C Jameson Two Thousand & fifty dollars Payable at Bank of N America Boston."

The receipt, Figure 13 bottom, reads "Boston Mch 3rd 1857 Received of Chas Rice his note for Two Thousand & fifty dollars on account. due Aug 5/8 1857 for our accommodation and to be paid by us when due. Boston Watch Co."

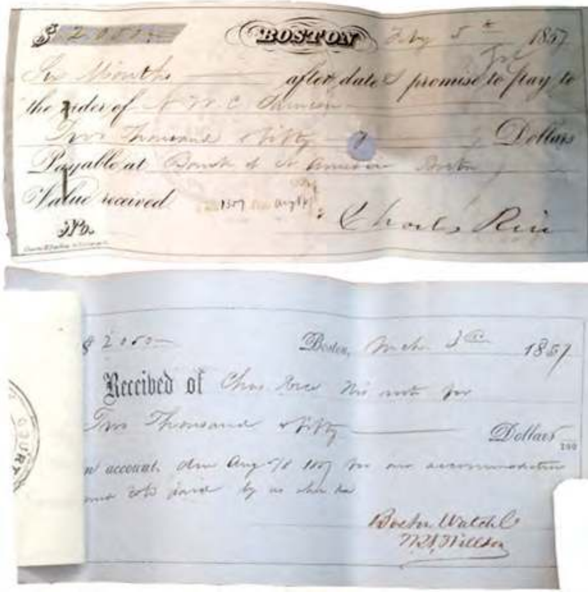
BOSTON
after date I promise to pay to
Dollars
Payable at
Value received
Received of
Dollars

Figure 13

Instead of paying Jameson directly, Rice gave $2,050 and the promissory note to the Boston Watch Company, and the company agreed to pay the note in six months time.

Promissory notes can also be endorsed on the back so changing the person who is the recipient. The note in Figure 13 is endorsed with Jameson's signature, "pay to the order of A J Frothingham", and Frothingham's signature. However, the endorsements on the notes involving the Boston Watch Company are not dated and so it is not possible to know when they were endorsed.

Just what Rice (and Cook) took away is subject to debate. Harrold suggests that it

> *is unlikely that many machine tools were taken, for they would have been neither easily portable nor of ready cash value. More likely involved were some small factory tools and semi-completed movements which could be finished using traditional methods.*[251]

However, four points contradict this view.

First, why would Rice, who was owed about $34,000, take only *some* of the chattels, worth about $7,500, when it appears he was entitled to the lot? I simply cannot imagine him leaving anything behind that could removed reasonably easily and which would help compensate him for the loss of his investment. Indeed, any sensible person would take as much as possible to maximise the cash value and the chance of recouping his money. As Rice was bidding for the factory at the auction, we might assume he left much in the buildings in anticipation of taking them over. But every writer states that he did take much away and it seems unlikely that he would risk loosing everything if he failed to win the auction bidding.

Second, virtually all of the watchmaking machinery and tools were in fact small and portable. Marsh makes it clear that the early machinery was light and delicate and some

> *occupy a space of considerably less than six inches each way.*[252]

Even later machinery was often quite small, simply because of the size of what was being manufactured. For example, the lathes necessary to make screws, arbors and other parts would not have been significantly different in size to their very portable, modern counterparts.

About the only large items would have been the power plant, the transmission and the machines used to *make* the watchmaking machinery. But even much of the heavy machinery used to make the watch-making tools was probably quite small and portable. Lathes, metal planes and other machinery to make

251 Harrold, 1999, page 584.
252 Marsh, 1896, page 55.

objects the size of those specified by Japy and Ingold need only be a few feet in dimension and could have been moved by some people and horse-drawn carts.

Anyway, there was not much machinery, as Appendix A (page 82) shows. A few punches for flat pieces, wheel-cutting machines, small lathes to turn parts, and not much else other than hand tools for drilling, files, etc. Even in the unlikely event that every worker had his own tool there would only be about 75 machines.

Third, Rice wasn't acting in isolation and the "cash value" of what he took was not the only consideration. The shoemaker was acting with Edward Howard, who knew full well that such machinery was very time-consuming and expensive to buy or to make, and that the Waltham factory was the *only source* of such machinery. It is clear that Howard wanted to continue making watches, and when he and his "front man" Rice failed to get the buildings they were still in a very good position. They simply moved as much as they could back to Roxbury:

> *Mr. Howard commenced in Roxbury with a force of some fifteen workmen, the greater part of whom had come with him from Waltham. Work commenced at once on the tools and machinery that were necessary, aside from those which Mr. Rice brought from Waltham.*[253]

Some new tools and machinery were needed because Howard designed a radically different watch from that made at Waltham. However, much of the machinery of that time would have been quite simple and so readily adaptable, and it is highly likely that many of Howard's new tools and machinery were built from those rescued from Waltham.

And fourth, Robbins himself, in an address to the Watch Factory Foremen's Association quoted by Marsh, states that

> *the bidding proceeded by a hundred dollars at a time, until my principals, much to their alarm and disgust, became the owners, at the price of $51,000, I believe, plus a mortgage of $7,500. We found we had got the wooden buildings,* ***but not much besides*** *... However, with a few grimaces, we shouldered our burden and determined to make the best of it* [my emphasis].[254]

The company of Tracy Baker became the new owners. Early in May 1857, Robbins gave them $33,000 and Tracy And Baker contributed $7,500 each. Then Tracy Baker paid $8,500 for the real estate (and took over a mortgage of $7000 on it[255]) and $33,000 for the contents of the factory.[256] In today's values he had paid about $15,300,000 for the contents that had been removed and $7,200,000 for the factory buildings. The figures given by Robbins are similar if his "price" includes the mortgage and the cost was $43,500. Jameson's statement of account for the sale gives $37,500 for both the real and personal estate, plus $491.90 *from collections*.[257] This amount less expenses is confirmed by document 116-164, the distribution of dividends to creditors. The differences between these amounts have not yet been explained.

However, with respect to what he had got for his money, Robbins was actually more precise, and in his speech he said

> *We found we had got the wooden buildings, but not much besides. Most of what little machinery there was and most of the stock in process which we thought we had bought, had been carried off the night before the sale,* ***and the balance the night after****, by parties whom I will charitably say were unknown to us.* [my emphasis] [258]

And he goes on to say that in 1857

> *I kept the factory going, principally in the construction of tools and machinery.*[259]

253 Crossman, 1885, page 55.
254 Marsh, 1921, page 12.
255 Price, 2005, page 9.
256 Tracy Baker, 1857a, page 3.
257 Suffolk County Court of Insolvency, 1857-58, Document 116-139.
258 Robbins, 1883, page 2.
259 Marsh, 1921, page 12.

Robbins, not surprisingly, was incensed and wanted the stock and tools handed back to him.

Although Robbins may not have had any rights over the machinery and stock removed before the auction, he would most certainly have felt he owned whatever was in the factory after the sale, and

> *Mr. Robbins started legal action against Mr. Rice and Mr. Howard. The suit was settled by return of some of the material* [but apparently no machines].[260]

As I have noted, the buildings would not have been completely empty. The engine house, transmission shafts and furniture would have been in place, and perhaps some large and heavy machinery used for tool making. But there can be little doubt that Robbins had bought a near empty shell together with responsibility for some 60 unemployed workers who were left behind by Howard and who still lived in Waltham and the Waltham Improvement Company houses.

I expect one of the main reasons for supposing Howard and Rice had left machinery behind, is the problem of explaining how Robbins got the factory back to work. But I believe there would have been sufficient *non-company* tools around. It must be remembered that the original Roxbury factory was based on employing journeymen watchmakers. But during their apprenticeships, such people bought and made a set of *personal tools* with which they worked. As a House of Commons report notes, in times of desperation workmen pawned their own tools to get money for food. But having done so, they could no longer work at their trade.[261] Although this report is forty years earlier, the same system existed, almost unchanged, into the twentieth century. And the Waltham factory was established on the basis of transferring the Roxbury equipment and *skills* from a town with amenities to the country with nothing. Indeed, Marsh makes a point of stating that:

> *Having found a satisfactory location for the factory, the next thing was to make it evident to the employees that country life was a thing to be greatly desired. Accordingly, Mr. Dennison used to plan excursions into the country, the objective point, of course, being a certain pasture on the south bank of the Charles River. And then he would endeavor to awaken in his companions a little of the enthusiasm which always seems to have possessed him by pointing out to them some of the very charming locations on which to build houses.*[262]

And so part of the tooling of the Waltham factory belonged to the employees and could not have been removed by Rice (the employees had probably removed them to the safety of their homes before that time anyway). In which case Robbins would have had little difficulty in finishing the stock returned by Rice and Howard. But watchmakers did not have their own machines, like wheel-cutting engines, and we can be sure that he had no way to make *new* watches; the machines and tools for basic operations being certainly part of the company's chattels.

There are four further points to note.

First, there can be no doubt that the "fifteen workmen" who went back to Roxbury would have been amongst the most highly skilled at Waltham, and they were almost certainly mechanics and skilled watchmakers. So the biggest problem facing Robbins would be getting mechanics to build new machines.

Second, *Dennison stayed behind*. Why? After all, his partner, some of the best workmen, much of the material and some of the equipment had gone back to Roxbury. So what prompted Dennison to remain in Waltham? This is the second time something peculiar had happened to him, the first being the relationship with Stratton some years earlier (see page 34).

The most likely reason for Dennison staying at Waltham is that Howard did not want him. If we consider Howard's experiences with Dennison in the seven years from 1850 to 1856, we can see a succession of disasters. Howard found out that Dennison couldn't build effective machinery, couldn't design watches, and his "system" of watchmaking had collapsed into insolvency with horrendous debts.

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260 Hawkins, 1983, page 1.

261 House of Commons, 1817, pages 6, 37, 62.

262 Marsh, 1890, page 4.

There is good reason to believe that Dennison was a "difficult" person. In addition to a probable rift with Howard, there are the documented conflicts with Stratton and Robbins. And Moore notes friction between him and William Keith, who was *"very critical of Dennison's methods"*.[263]

Both Moore and Tremayne mention that he was called the *"Boston Lunatic"* because of his schemes for manufacturing watches,[264] but such an epithet is indicative of the person as well as his ideas. I have no doubt that Dennison was charismatic and possibly had delusions of grandeur. How else could he have persuaded Howard to bankroll and build a factory for his project? And how else could he persuade Rice to lend him about $34,000? Both were successful business men and should have foreseen the risks. But they were not watchmakers, and so Dennison could paint a grand picture of a humming factory producing watches and, more importantly, producing a profit. However he created a factory that limped along, producing too few watches and producing losses.

In addition, it is apparent that Dennison had an inflated view of his importance and value. His brother, E.W. Dennison, wrote:

> *Previous to the sale, Messrs Tracy & Baker who were the largest creditors arranged to purchase the concern and also beforehand arranged with my brother (ALD) to conduct the manufactory at 1/3 profit.*[265] [Actually by far the largest creditor was Charles Rice.]

Which explains why Tracy wrote:

> *Before the assignment Dennison & Howard had differences as to how or in what manner they should proceed. Howard wanted Rice to get possession* [he wanted the chattels]*, but Dennison strenuously opposed and he came to Baker and me to become purchasers.*[266]

There can be little doubt that Dennison was playing one group off against the other to get the best possible outcome for himself.

However, E.W. Dennison's description is certainly wrong, because it amounts to Tracy & Baker making Dennison an equal partner, but without Dennison contributing any capital or taking on any of the risk. Dennison himself gives a much more realistic picture:

> *I was to have the general superintendence of the business and to have 5 pr ct. on the manufacture with a guarantee that the same should not fall below 3000$ a year and there was a dead certainty in my mind that with any decent management of financial matters, I should realize from 4 to 5,000$. This is just what I felt was my just proportion of the business.*[267]

That is, Dennison wanted between $1,860,000 to $2,320,000 in today's money. Dennison's manoeuvres to maximise his personal gain almost failed, but fortunately Robbins needed him. With no experience of watch making and having to get a factory up and running quickly, Robbins had no choice but to cave in to Dennison's demands. E.W. Dennison wrote:

> *You can imagine his disappointment when on his return from Europe, he was met with a proposition to assume the superintendence for $1000 a year, Mr. Robbins disowning any arrangement with Tracy & Baker to the contrary - of course this offer was rejected as pitiable - Mr. Robbins increased his offer to $1500, then $2000 and finally $2500 was fixed upon. ... My brother was reduced to almost the extremity at that time that he is at the present moment ... for which reason he was forced to take the above pittance.*

The suggestion that Dennison's rate of pay was an insult is patently silly, because $2500 was about *eight times* the rate for skilled watchmakers and was, at about $1,160,000 today, a substantial income.

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263 Moore, 1945, page 29.

264 Moore, 1945, page 3; Tremayne, 1912, page 2.

265 Dennison, 1871, page 2.

266 Tracy, E., 1886; see Marsh, 1890, page 15.

267 Moore, 1945, page 23.

Despite Dennison disliking Robbins and considering such a low wage an insult, he had burnt his bridges and had no option but to accept. So it is hardly surprising that these two men had little respect for each other, and hardly surprising that Robbins got rid of Dennison at the first opportunity.

Third, Howard went back to Roxbury, designed a new watch, built and modified machinery, and started producing small numbers of high grade movements using the same methods that had been used at Waltham. And he produced about 125,000 movements in 44 years, whereas in only the 27 years from 1857 to 1884 the Waltham factory produced 2,356,000 watches, about 19 times as much in a bit more than half the time.[268]

Marsh offers an interesting insight into Howard's activities:

> [Howard] *soon started a second watch factory in the building in which he was manufacturing clocks. The machines and tools which he used were* ***practically like those used at that time in the Waltham factory****, and do not seem to have been essentially modified during the entire life of the factory. It is generally, and doubtless correctly understood, that at no time was he able to obtain any profit from watchmaking, but that the losses in watchmaking were more than covered by the profits of clock manufacturing. It was Mr. Howard's aim to produce high grade watches, but the accomplishment of that end involved the work of* ***skilled watchmakers*** *to eliminate the original manufacturing defects, and so much labor and expense were involved in the production of the watches of desired high quality that their selling price did not insure a profit* [my emphasis].[269]

This provides further confirmation of my description of events. Rice did remove some of the tools from Waltham. The tools were dumb, produced parts which were not interchangeable and required skilled journeymen. And the excessively high number of man-days per watch inherent in such machinery made it impossible to produce watches profitably.

And fourth, we must view what happened in the light of what had been achieved before and after the insolvency. As I have pointed out in Appendix C (page 97), the pre-insolvency factory could only produce watches at a rate of about 16 man-days per movement, but the post insolvency factory could make one about every 5 man-days (Appendix D, page 106). Such a dramatic change could not have occurred if Robbins simply continued on with inherited workmen and tools, and it requires a significant difference in the methods used from 1857 onwards.

This significant change was made possible by Charles Rice and William Cook gutting the Waltham factory before it was sold.

There is an interesting consequence. If we draw a genealogical tree of watchmakers, then Dennison and Howard gave birth to only one descendant, the Howard Watch Company. Indeed, Howard

> *regarded his own firm, and not that of Appleton Tracy & Co., as the rightful successor to the Boston Watch Co.*[270]

In contrast, what was to become the great Waltham Watch Company had a virgin birth in 1857, in an empty building. And it spawned the American watchmaking industry.

Farewell to the Watchmaker

Although the empty factory was vital, it was just an empty factory that had to be filled. Most importantly, a *new management* was needed to decide what to do and how to do it, while the 60 odd journeymen watch-makers were finishing off the old stock.

Which brings us to the second requirement for the post-insolvency success:

> *The key managers were business men and mechanics, not watchmakers.*

268 Geller, 2000, page 1.
269 Marsh, 1909, page 10.
270 Geller, 2000, page 1.

First Robbins, who was a business man and not a watchmaker. Moore and Priestley note that:

> *Robbins was familiar with the English trade - in 1841 he had worked for his uncle, Chauncey Robbins, in the Birmingham, England, firm of Robbins & Martin as head of the watch department* [at age 17]. *By 1846 at the age of 22, he was back in the US in New York importing watches ....*[271]

So although he was technically ignorant, he had a strong business interest in watches. What we do know, from Moore's book, is that Robbins was a consummate business man and an excellent administrator who ran the Waltham plant with great skill, very quickly turning it from a failure to a resounding success.

Second, sitting in a near empty factory, with little knowledge of watchmaking, the first task facing Robbins was to make the machinery necessary to manufacture watches. He knew even less about machinery than watchmaking and, either by sheer luck or a stroke of genius, he employed Ambrose Webster as his head mechanic; he was the first machinist hired.[272]

Webster had been an apprentice in the machine shop of the Springfield Armory. He then worked for the Springfield Tool Company where, in 1855, E. A. Marsh worked with him as an apprentice.[273]

In 1857 he was hired by Robbins, and Webster himself states:

> *My first acquaintance with the Waltham factory was in May 1857* [immediately after Robbins took over].[274]

And when

> *Mr Webster took charge of the machine shop of the Waltham factory it was as crude as could well be imagined. There was absolutely no system, no appreciation of the fact that the machine shop was the foundation of the manufactory. The proprietors* [Dennison and Howard] *had not learned that to successfully run a factory they must build up a machine shop large enough, and under a competent head, to build and repair all the tools and machines needed in the business. Anything approaching an automatic machine was frowned upon. ... there were no less than nine classes of measuring units or gauges, which he changed to one.*[275]

But this quickly changed.

> *Aside from Mr. Webster's abilities as a machinist, he possessed the valuable qualification or ability to realise the imperative need of 'system' in creating and maintaining a successful manufacturing enterprise.* [At Waltham] *he had his first opportunity to urge the adoption of an initial system ... He also endeavored to emphasize the vital dependence of the entire factory to the Machine Department.*[276]

As Collord picturesquely expresses it,

> [Webster] *stood before management and said, 'Listen, you've got to stop regarding the machine shop as a burden to this factory, but rather as the foundation upon which the works will stand.' He went ahead and built the first successful semi-automatic machine used in the factory.*[277]

The importance of Webster cannot be underestimated. It is apparent that previous machinists, like Moseley, were competent mechanics, but it seems they did not understand the central role of the machine and the need for "system". Or they simply produced what was asked of them. In contrast, Webster not only understood, but he had the opportunity to implement his ideas because Robbins trusted him.

In the environment of the time,

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271 Moore, 1945, page 26; Priestley, 2005, page 103.
272 Abbot [1], page 79.
273 Marsh, 1921, page 15; Hoke, 1990, pages 189-191; Abbott, 1905, pages 77-79.
274 Niebling, 1968, page 633.
275 Abbott, 1905, pages 79-80; Abbott, 1888, page 28.
276 Marsh, 1921, page 15.
277 Collord, 2005, page 52.

the great variety of work which comes to the American boy early gives him practice in solving new problems without considering precedents. He is obliged to face new difficulties constantly, and he has no one to appeal to for help ... he cares little for trade practices, for custom, for what is old.[278]

Similarly, Webster and Robbins were forced to solve problems without considering precedents, to make watches without regard for trade practices, for custom, for what was old. They had to begin afresh. And this is undoubtedly the beginning of the long, difficult task of transferring skill from the workers to the machines. A substantial, qualitative change in machinery must have taken place. And this change was initiated and driven by Ambrose Webster with the support of Royal Robbins.

Unfortunately, we know only a little about the tools and machines developed in the period of interest, 1857-1858. E. A. Marsh joined Waltham in 1866 and, writing thirty years later in 1896, he says

it would be interesting to review the various forms of machines which have successively be used ... such a review is, however, impossible. Most of the discarded or displaced machines have been destroyed.[279]

However, Webster's creativity is well documented and includes the first watch factory lathe with hard spindles and bearings;[280] the first interchangeable parts for lathes;[281] the use of levers to control turning;[282] a semi-automatic escape wheel cutter;[283] an automatic pinion cutter (in 1865);[284] and a train wheel cutter (in 1865).[285]

Also, there is enough information for us to see something of the changes that occurred.

First, the outstanding 19th century invention that revolutionised watch making was the split chuck and the hollow draw-tube lathe. Until its creation, parts to be turned had to be mounted between centers, held on wax chucks or mounted on the face-plate of a mandrel. So the huge numbers of arbors, balance staffs, screws, pillars, canon pinions, barrels and so on, had to be turned using slow, difficult-to-use lathes which required skilled workmen. And so Charles Moseley's invention, which formed the basis of all lathes from that point on, completely changed watch making. Indeed, without it, it is very unlikely that Robbins and Webster could have succeeded.

Abbott, repeated by others, states that the split chuck was invented in 1857 or 1858.[286] Because this idea had such an enormous impact and was so central to manufacturing, it is more likely that the date was 1857.

Abbott's date is supported by Daniel Leary. He started work at Waltham in 1856 as a 14-year old. Describing jeweling he says

The chucks we used were steel tapers, sawed at right angles, and a friction collar driven on to hold the jewel ... the draw-in spindle had not then been invented.[287]

However Marsh dates the invention to about 1854:

Credit [for the split chuck] *doubtless belongs to Mr. C. S. Moseley, who introduced it while the original of the Waltham watch factory was located in Roxbury, Mass.*[288]

This is probably confusing two inventions. Howard wrote:

The most important tool, although a simple one, and which has been of more service than any other one tool in developing and carrying forward watch-making was the spring chuck. That chuck was

278 Waldo, 1886, page 186.
279 Marsh, 1896, page 12.
280 Abbott, 1905, page 80.
281 Abbott, 1905, page 80.
282 Marsh, 1896, page 31.
283 Marsh, 1896, page 81.
284 Abbott, 1905, page 80.
285 Marsh, 1896, page 73.
286 Abbott, 1905, page 84.
287 Small, 1953, page 28.
288 Marsh, 1896, page 15.

invented by Mr. Edward Howard, and was used in the clock factory of Howard & Davis sometime prior to any attempt to watch-making.[289]

It is probable that Howard is referring to the chucks described by Leary and not those designed by Moseley, but Moseley's invention was probably derived from Howard's, and the later date is more likely.

There is some doubt about the date of second, well-documented tool, the end-shake tool (described in Appendix E, page 118). This replaced the very difficult process of jewelling plates by a far simpler method using an intelligent tool. Abbott provides a biography which is again vague about dates, but it seems the inventor, Napoleon Bonaparte Sherwood, went to Waltham around 1855 where he was put in charge of the jeweling department and

under his charge the jeweling department soon made a complete revolution.[290]

Abbott says he left *"the employ of Mr. Howard in the fall of 1858"*, but he also says incorrectly that the tools were built *"as far back as 1860"*.[291]

Small says Sherwood arrived at Waltham in late 1854. He quotes Daniel Leary:

[Sherwood] *first got up a lathe for opening jewels, then he devised a lathe with tail-stock and spindle, next the caliper rest. ... Mr Sherwood invented the end-shaker, which was considered by all the most wonderful invention that had been made in our business.*[292]

Unfortunately we do not know *when* he invented it.

It is clear that Sherwood was one of the employees who returned to Roxbury with Howard after the insolvency. In which case the end-shake tool, the last of the three he designed at Waltham, was most likely invented before May 1857. But the dates are critical. If Sherwood left immediately, and remembering that Rice took away the chattels, Robbins and Webster would have had neither the inventor nor the tool. But there is no doubt that the end-shake tool was used at Waltham after the insolvency.

Small also states vaguely that

Under the combined direction of Howard and Sherwood, first at Waltham and later, following the return to Roxbury, new ideas and systems were introduced, new machines were designed and made.[293]

However, it is likely that Sherwood did not return immediately, but worked at Waltham for a short time after the insolvency. Certainly he was still there about 20th May, ten or more days after the sale:

We learn also, that since the sale of the above mentioned property, efforts have been made to start another establishment of the same kind, either here or in Roxbury, and that a meeting of the employees of the old establishment was called a few evenings since, at the residence of N. B. Sherwood, Esq., for the purpose of ascertaining how many of them would pledge themselves to the interests of the new establishment, and that a very respectable number of the old hands did so pledge themselves, including Mr. Sherwood, Mr. Messer, and others.[294]

Although I have no evidence, it is possible that Sherwood, apparently having his own residence at Waltham, would have preferred to stay, but Howard enticed him back to Roxbury, because he paid him

nearly double the wages he paid the best of his other employees.[295]

Certainly, as it is the last tool mentioned by Leary, it would have been either shortly before or shortly after the events of 1857. Accuracy in transcribing is critically important. The above quote of Leary separates out mention of the end-shake tool into a separate sentence and this separates its development from the others, implying it was made later. But it may not. Only the person who spoke to him could know.

289 Howard, ca1883.
290 Abbott, 1888, pages 18-20.
291 Abbott, 1888, page 24.
292 Small, 1953, page 28.
293 Small, 1953, pages 82-83.
294 Waltham Sentinel, 1857, page 59?
295 Small, 1953, page 84.

The endshake tool is central to the problem of non-interchangeable pivots, jewels and arbors which continued to at least 1898 and was the reason for the *Record*, Waltham's watch records, described by Jacques David:

> *Recording consists of noting in a table the diameters of the 2 pivots of the 5 mobiles ... and the lengths of these pivots. ... Even if a movement is to have only top plates jewels, or some mobiles are not to be jewelled at all, the sizes of the pivots are noted ... The Record also notes the size of the impulse pin, or the fork notch, so that a replacement lever or roller can be sent for with the same ease as with pivoted mobiles.*[296]

Unfortunately David's detailed description of watchmaking, written in French in 1876, was not published until 1992, when it was produced in a limited edition of 1,000 copies. Worse, an accessible English translation did not appear until 2003. However, the Record was described in 1858:

> *The sizes of the several pivots and jewels in each watch are carefully recorded under its number, so that if any one of either should fail in any part of the world, by writing to Waltham, or to Robbins & Appleton, ... and giving the number of the watch, the part desired may be replaced, so as to be a working match.*[297]

Also, Fitch mentions the Record in what is just a passing comment without any details.[298] And Hoke quotes a Scientific American advertisement of 1884 saying that Waltham

> *kept accurate records of all its watches* [and] *the owner need only send on the number of the movement to enable the factory to supply an exact duplicate of a part.*[299]

However, it seems that the full implications of these statements have not been recognised and the Record and the end-shake tool have been overlooked. The implication often drawn was that the movement number was only needed to pick an interchangeable part for the correct calibre, rather than enable a non-interchangeable part to be made.

One important point is that the Record did not commence until after the takeover in 1857. This is supported by the preface to a hand-written serial number list [300] which states:

> *Around 1900 the company had ledger books prepared from what appears to be inventory cards. The whereabouts of the original cards is not known.*[301]

This list commence at serial number 1001, but all are post 1857 watches; see Figure D8, page 117. (Also, see Price for a mention of the re-use of serial numbers below 5000[302].) It is likely that the original cards were the watch records described by Jacques David and Fitch. Small notes that the E. Howard & Co. instructions for ordering material read:

> *in ordering material for any movement numbered below 30,000, always send old parts.*[303]

Clearly Howard did not record the necessary details for watches before 1879.

A consequence of the Record is that a repair department was necessary, not only for requests from outside, but also to fix problems in production. I suspect that the repair department was probably closed when Ezra Fitch arrived at Waltham in 1883, and so there was no longer a reason to record details of watches; this is confirmed by the hand-written list, whose last page includes movements dated 1881-1883. However the Record and the repair department may have continued to about 1898.

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296 David, 2003, page 60.
297 Anon, 1858.
298 Fitch, 1883, page 61 (page 677).
299 Hoke, 1990, page 246.
300 American Watch Company, ca1900.
301 NAWCC, 2009; I cannot find another source for this information.
302 Price, 2005, page 14.
303 Small, 1953, page 82.

The necessity of this shift of emphasis from watchmaker to business manager and mechanic was recognised from then on, and when Elgin was set up:

> *The seven recruits from Waltham became known as the Seven Stars. ... A significant characteristic of the Seven Stars was that five of them came to the watch business ... as mechanics.*[304]

The consequence of this shift in focus was a corresponding shift in employment:

> *The second factor that assisted in the adjustment of the new Company to the trying conditions of 1857 was the personnel policy. When the Company was founded by Dennison, it was recognized that the mechanical problems were difficult and every effort was made to hire the best craftsmen that could be found. Under Robbins ...* ***workers from old New England families*** *were given preference when new jobs were filled* [my emphasis].[305]

And, as discussed on page 45, Moore continued:

> *A* ***considerable number of the factory hands were unskilled workers****, many of them young women who lived at home ... The remainder were largely skilled craftsmen ... Since Waltham was a small town of about 6,000 population, it is probable that many workers were drawn from the surrounding farms* [my emphasis].[306]

These points are reinforced by Moore's comment that:

> *there is no record of serious difficulty from a lack of skilled labour during this period.*[307]

Which was more to do with the shift to unskilled workers than a sufficiency of skilled journeymen.

Moore also cites John Swinton who, writing in 1888, notes that

> *the workshops are filled by* young men and women of the soil*, almost wholly of New England lineage.*[308]

It is here that we see the beginning of the change in employees that was highlighted by Alft & Briska; see page 47.

From the start, Dennison would have employed a few unskilled workers to perform unskilled tasks, such as running errands and clerical jobs. But his factory was dominated by trained journeymen. In contrast, Robbins and Webster shifted direction and under them preference was given to local farm hands who would have had no knowledge of watchmaking and most certainly never undertook an apprenticeship. But such a shift in employment policy is only possible if there is a corresponding shift in manufacturing processes. Farm hands may be cheaper than craftsmen, but they would have nothing to do unless the processes had been dumbed down by the creation of much more intelligent and sophisticated machinery.

Of course Robbins did employ skilled watchmakers, but the proportion of such people fell. Let us assume Dennison employed 60 skilled journeymen and 15 unskilled people to do other tasks like moving materials around the factory. Then we can conclude that Robbins inherited some 45 journeymen who outnumbered the 15 unskilled workers by 3 to 1. Then, once new, more intelligent machinery had been made, the journeymen were probably ample for the skilled tasks in the increased production. So if the workforce rose to about 100 at the end of 1858 (Appendix D, page 106) we can guess that there would have been roughly 50 skilled and 50 unskilled employees, a 1 to 1 ratio. And this ratio continued to drop from then on until the journeymen were vastly outnumbered by the unskilled workers using automatic machines.

If we need to use the title of the "Father of American Watchmaking" (see page 38), then it must be given to Royal Robbins and Ambrose Webster jointly.

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304 Alft & Briska, 2003, page 13.
305 Moore, 1945, pages 30-31.
306 Moore, 1945, page 31.
307 Moore, 1945, page 29.
308 Moore, 1945, page 315, note 12.

Part 3: Lego Land At Last

Getting From One Place to Another, Part 2

I must admit that I have a simplistic streak in my brain. I like simple hypotheses because I can understand them and I can understand the arguments for and against them. And when I am reading books by other people, particularly books within the discipline of the "history of technology" I search for hypotheses to give me something that I can relate to, and by which I can understand their often complex arguments.

That is why I have defined the American System of Manufacturing as *the manufacture of machines by unskilled labour*. Yes, it is simplistic, but it enables me to put other definitions into context and interpret the apparently complex views of other authors. And it enables me to understand why factories, machines and interchangeability go hand-in-hand with it; so I have a clearer interpretation of the importance, and the inevitability, of these four aspects being united within one definition.

I have read a few histories of manufacturing industries. Each examines the histories of some particular manufacturers and almost all the words within them are concerned with painting a picture of the history of representative companies.

But underlying them is a purpose, a reason for choosing those companies because they illustrate the aims of the authors. But usually those aims are not obvious and have to be teased out; and when they are teased out I find equally simplistic hypotheses are the basis of the arguments. Not that I think simplicity is bad, indeed I find it admirable, for it inevitably leads one to a surprisingly rich understanding.

So what is *mass production*? And what distinguishes it from the American System?

The index in Hounshell (1984) provides seven references to the definition of "mass production." They are:

(a) Page 1: *The focussing of the Principles of Power, Economy, Continuity and Speed.* This is a vague motherhood statement that could apply to many things; for example, steam locomotives.

(b) Page 3: *In origin mass production is American and recent,* which doesn't tell us anything useful, but Hounshell also suggests that interchangeable parts are fundamental.

(c) Page 122: *The historian may quibble ... interchangeability of parts ... had now become critical for mass production,* and, on the same page, Ford's criterion that *in mass production there are no fitters.* But interchangeable parts are a natural extension of the American System, so is mass production just the American System refined?

    Anyway, I very much doubt if the Swiss watch industry could have in any sense been called mass production, but they achieved a high degree of interchangeability.

(d) Page 217: After quoting Ford's opinions, as in (a) above, there is mention of a slaughterhouse's *disassembly lines* as source for Ford's assembly lines.

(e) Page 228: Again Ford's opinions are quoted, as in (a) above, and added is *their first experiment with an assembly line*.

(f) Page 263: *Ford had given ... the assembly line.*

(g) Pages 307-8: *... the super factory system ... Mass production is not simply large scale production ...* [it], *therefore, is production for the masses.* Again we have a vague motherhood statement of no real value because it does not describe *how*.

In addition, on page 244 there is the very interesting statement "every*thing* was put in motion and every *man* brought to a halt," and this requires an assembly line.

The only part of these "definitions" that is useful is the *assembly line*, and that must be Hounshell's hypothesis:

> *Mass production is the assembly (of machines) using assembly lines to achieve continuous flow.*

And consequently mass production started, as Hounshell wants us to believe, with Ford motor cars.

However, there are two serious problems with this hypothesis.

First, Hounshell appears to have "shot himself in the foot," because the third chapter of his book is titled "Mass Production in American Woodworking Industries".[309] However, nowhere in this chapter is there any mention of assembly lines! Indeed, the only features to be gleaned from it are very large-scale production of sewing machine cabinets and a vague hint of dubious interchangeability. But apparently Hounshell believes that quantity is not the deciding factor to distinguish the American System from mass production, although the discussion of wood working seems to contradict this.

The point I am making is that, according to Hounshell, some "mass production" was performed without assembly lines. Or, having no other distinguishing aspect, mass production is separated from the American System by an artificial criterion. However, assembly lines are probably a better criterion than any other, as later developments are largely, perhaps always, dependent on them.

Second, *actual physical assembly lines* are only necessary if the objects being manufactured, like Ford cars, are too big or too heavy to be man-handled. Even the example of slaughterhouse disassembly lines is accompanied by illustrations of *large animals* that would be very difficult to be carried by men.[310] And Nasmyth, Gaskell and Company used railway tracks and cranes to move the machines being built through the factory.[311]

OK, Hounshell also gives an example of an 1885 canmaking assembly line where the items are small,[312] but the point is important. For example, standard practice in watchmaking was to use batches of ten for which the parts conveniently fit in a small tray with divisions. And, obviously, a man could carry 100 watches, ten trays comfortably. So why spend the money creating an assembly line when cheap labour can be used?

There has to be some very good reason for creating assembly lines; and I suspect, from Hounshell's illustration, that the canmaking line, very sparsely occupied by workers, was probably created to remove faulty cans rather than to make them by performing successive operations on them.

However, we have missed an important point. The assembly lines used in the slaughterhouse are *not automatic*. The hooks carrying the carcasses dangle from small wheels carried by fittings in the ceiling, and they are moved by the workers. Whereas the assembly lines used by Ford and the canmaker are propelled by machines and are "conveyor belts". So Hounshell's hypothesis should be:

> *Mass production is the assembly (of machines) using automatic conveyor systems to achieve continuous flow.*

And this is a satisfactory way of distinguishing mass production from the American System.

But what is the watch plate lathe designed in about 1894 by Duane Church? This consisted of 7 machines, and there were 8 transfer arms that could rotate and invert brass disks as necessary. At one end there was a hopper holding the brass disks. The first transfer arm took a disk and loaded it into the first machine, which then drilled and milled some holes. Then the second transfer arm moved the disk to the second machine that drilled and milled more holes. And so on, until the last transfer arm took the finished watch plate and put it into a hopper. So when running 7 watch plates were machined simultaneously.[313] Except for loading and unloading the hoppers we have a *fully automatic* system with *continuous flow* from one station to the next by much more sophisticated transfers than an ordinary assembly line can achieve.

309 Hounshell, 1984, pages 125-151.
310 Hounshell, 1984, page 242.
311 Wikipedia, 2019a.
312 Hounshell, 1984, page 243.
313 Abbott, 1905, pages 63-65; Hoke, 1990, pages 237-240.

Is this mass production? Possibly not, because Hounshell appears to carefully distinguish between *assembly* systems and *manufacturing* systems. But the basic feature permeating his book is conveying the machines past the workers; or in Church's case, past machines that can be viewed as the precursor of the robots used today.

Three points should be made in the comparison of motor cars, with an automatic assembly line, and watches, with a *human* assembly line:

First, the continuous flow is extremely slow, about six feet per minute on Ford's main assembly line, to give the hands at each station enough time do their work; that is, a car was produced about every 120 seconds. In contrast in the human assembly line the flow stutters and the watches remain in one place while operations are performed on them.

Second, the time to do the work at each station of an automatic or human assembly line has to be roughly the same, or some workers will be idle whilst other workers finish their tasks.

Third, if work at one station of automatic assembly line halts because of some problem, the entire assembly line must halt and all workers will be idle until the problem is fixed. However, this is not true of a human assembly line, where work can bank up at one station for at least a short time.

So size matters. A manual or an automatic conveyor system is necessary for something as large as a car in order to move it past the workers. In contrast, a watch is about 1½ by ½ inch (38 by 13 mm) and can be easily carried by a human conveyor system.

Hounshell's chapter on Ford is primarily a history of the development of assembly lines and how they decreased the time taken to manufacture cars, so that, quoting Fred Colvin,

> *a complete Model T emerged from the factory every forty seconds of the working day.* [314]

This estimate actually refers to the rate of production *before* assembly lines were introduced and, if Colvin is correct, cars were produced three times faster than on the assembly line.

Ford's system was based on:

> *the design, construction, or procurement of large numbers of special- or single-purpose machine tools. This is what the American system of manufactures was all about.* [315]
>
> *Every critical part of the Model T was machined in standard fixtures* [that insured the correct positioning of the part] *and checked by standard gauges both during and after ... the factory maintained essential accuracy* [316]
>
> *The Ford testing method is unique and simple, but thoroughly practical, and secures satisfactory results. … Each unit is built in standard fixtures and inspected by standard gages, before being assembled. Every unit is tested before being assembled to any other unit. … instead of the usual block test, … the engine is simply run in by electric motor … to know positively that the parts run well together, and that the transmission is right in every way. This being so, the motor simply must run when given proper gas and spark.* [317]

Unfortunately there is no mention of under-sized parts (that presumably could largely be avoided by machining parts slightly over-size and grinding them or otherwise reducing them), and what "essential accuracy" means, and how noncritical parts were treated. But the standard fixtures and gauges were designed so that they could be used by unskilled machine tenders.[318]

One of the first assembly lines (and there were several as well as the final chassis assembly line) was for magnetos:

314 Colvin, 1913.
315 Hounshell, 1984, page 227.
316 Hounshell, 1984, page 229.
317 Colvin, 1913, page 761.
318 Hounshell, 1984, page 230.

Twenty-nine workers who had each assembled 35 or 40 magnetos per day at the benches (or about one every twenty minutes) put together 1,188 of them on the line (or roughly one every thirteen minutes and ten seconds per person) ... Within the next year ... the engineers achieved an output of 1,335 flywheel magnetos in an eight-hour day - five man-minutes. [319]

And Hounshell quotes other examples of the effect of assembly lines: "eighteen man-minutes to nine minutes and twelve seconds"; and "lowering engine assembly from 594 man-minutes to 226 man-minutes". And the chassis assembly line dropped the time to build a car from 12½ man-hours to 5⅚ man-hours and then to 93 man-minutes.[320]

Similar reductions in time occurred with all the assembly lines.

However, although very impressive, such figures can be misleading. As Colvin notes:

The assembly of the various parts from the different departments or from storerooms, if the parts have [been] *assembled in their particular departments and come to the final, or chassis, assembly as complete parts ready to be coupled together into a complete car. These units may be divided into the rear axle, the front axle, the frame, the radiator, the motor, the dash and the gasoline-tank assemblies, all of which are easily coupled, leaving only such parts as wheels, exhaust pipes, mufflers, fenders and bodies to be attached.* [321]

That is, the final chassis assembly line created a car from only 12 sub-assemblies. But a Model T has about 1,481 parts,[322] and these have been reduced to 12 "parts" and a few screws and bolts to hold them all together. And so the "40 seconds per car" and the other figures above are misleading.

In addition, Ford did not make every part at there main factory. Nuts and bolts were out-sourced to the National Acme Mfg. Co. who, in 1913, provided 1,250,000 per week, on average 5 tons per day of small parts.[323] Carburettors were purchased from Kingston and Holley.[324] And wheels and the bodies were brought in.[325]

Date	Production	Workers	Man-Days	Ratio
1910	20,727	2,773	38.1	2.6
1911	53,488	3,976	21.2	1.5
1912	82,388	6,887	23.8	1.6
1913	182,809	14,366	22.4	1.5
1914	260,720	12,880	14.1	1.0
1915	355,276	18,892	15.2	1.0
1916	577,036	32,702	16.2	1.1

Table 1

Ignoring these out-sourced parts, the total time to make a Model T can be estimated from production and the numbers of workers, as in Table 1.[326] This is based on employees working 5½ days per week. The reason for the reduction between 1910 and 1911 is not clear. But the reduction between 1913 and 1914 is undoubtedly due to the self-propelled assembly lines.

A crude comparison with watch production is possible, as in the last column of Table 1. Model T cars have about 1,481 parts and watches have about 102 parts, and this ratio applied to the car man-days gives the corresponding man-days for a watch. However, from 1910 to 1916 at Waltham the man-days per watch was consistently around 1.6,[327] and the ratio shows the improvement of efficiency at Ford's factory.

If, as Colvin states, in 1913 a complete car was produced every 40 seconds, then there must have been about 20,000 workers in the factory, 6,000 more than the actual figure, and Colvin's estimate must have been journalistic fervour. Also, it is clear that Hounshell's figures only apply to specific segments of production.

319 Hounshell, 1984, page 248.
320 Hounshell, 1984, pages 254-255.
321 Colvin, 1915, page 365.
322 Anon, 1956.
323 Colvin, 1913, page 757.
324 Peterson, 2019.
325 Colvin, 1915, page 365.
326 Hounshell, 1984, page 224; Nevins & Hill, 1954.
327 Moore, 1945, page 232.

Why Bother?

Automatic assembly lines require interchangeable parts so that the machines can be assembled without any delays. But are assembly lines, and hence mass production, necessary?

The basis of Hoke's book (see page 12) is the hypothesis that

> *machines were made as interchangeable as necessary.*

However, as I have shown, the real problem was that interchangeability simply could not be achieved, and the decision to make parts interchangeable or to not make them interchangeable was irrelevant.

It is clear that the watch factory at Waltham simply could not make some parts to be interchangeable, and fitting and adjusting were forced upon them. Certainly I have no doubt that if they had found methods to produce interchangeable parts they would have used them; after all, fitting and adjusting were the most expensive processes employing the most expensive, highly skilled labour.

For example, it was impossible to make watch balances of exact weight and balance springs of exact strength, and small variations have a significant effect on the rate of a watch. So balances and balance springs had to matched with each other.

I presume this is the reason why, up to the middle of the twentieth century and perhaps later, Swiss watch factories would sell a "balance complete". That is, the factory matched balances and balance springs, adjusted them and sold the balance staff, balance and spring as a complete unit that could be dropped into a wristwatch and the watch would run quite accurately without adjusting.

The problem is in the detail. A very good watch (including American "railroad" watches) should be accurate within about 2 seconds per day, a minute per month. Normally the balance oscillates 5 times per second, or 432,000 times in one day. So a difference of 2 seconds, 10 oscillations, is an error of 1:43,200 or 0.0023%, and interchangeable balances and balance springs would have to be that accurately made. It was impossible.

The solution was to "match" balances with balance springs so that when the watch was assembled it would be fairly easy to do the final adjustment. This process is described in Appendix F, page 120.

So, although enticing, I think Hoke's hypothesis is wrong, because it assumes interchangeability was achievable when, in fact, it was not.

However, my analysis is in the context of watchmaking. Watches are very small, very complex machines and fitting parts was a difficult, time-consuming process. If methods had been found to make interchangeable parts then I have no doubt that watchmakers would have jumped at the opportunity. In addition, watches were often dropped resulting in damage to the small parts, and both manufacturing and after-sales servicing were the reason for the Record (page 63) that overcame the lack of interchangeability.

But I have ignored two important questions:

> *What parts need to be interchangeable? And when do they need to be interchangeable?*

For example, there are significant benefits to making watch plates interchangeable during manufacture so that less fitting is needed. But after the watch is sold the only way the plates need to be replaced is if catastrophic damage occurs to bend them, and such damage would mean almost every part in the watch would be damaged and so the watch could not be repaired; buying a new one is the only option. Whether the plates are interchangeable or not is irrelevant to the end user.

This becomes clear if we look at another machine.

For a long time Singer based its large-scale production of sewing machines on hand finishing non-interchangeable parts,[328] and from 1858:

328 Hounshell, 1984, pages 82-123; Singer, 1914, page 45.

for the next fifteen years at least, ... Singer compromised with the European method by employing many cheap workmen in finishing pieces by dubious hand work ... assembling was very expensive; and after a machine was adjusted and in sewing order, all of the parts were kept by themselves ... as they were far from interchangeable.[329]

During this time, Singer manufactured about 882,000 sewing machines, 1858 to 1873 inclusive,[330] although a data base of serial numbers suggests the company made 1,349,999 in this time.[331]

No prices are given, but another company's sewing machine sold, circa 1853, for $125, or $58,900 today (using production worker income); that is, a worker would have to labour for 125 days (about 5 months) to earn enough money to buy it.[332] In 1914 a sewing machine cost £9-10-0 and a worker earned £0-10-0 per week, And so it required about 114 days work to buy it; £3,141.00 and £165.30 respectively today.[333]

So for many years Singer could not, or did not try to make interchangeable parts, instead making expensive products and creating an ethos of desirability. This is clear from the company's business model:

To insure success only two things are required: 1st to have the best machines and 2nd to let the public know it. [334]

And about 1876:

Singer's army of agents continued "peacefully working to conquer the world". [335]

This policy, focused on advertising and high quality, was coupled with the development of hire purchase,[336] and initially it enabled Singer to sell machines at five to ten times the cost of production.[337]

That the parts were not interchangeable is clear, because it took about 6 man-days to put the parts together and this must have included a large amount of fitting.[338]

In addition, the cost of making or buying the machinery to produce interchangeable parts, illustrated by Fitch,[339] would have been large and time-consuming, so initially it may have been more expensive than producing and fitting non-interchangeable parts with the existing workforce.

However, at some time between 1873 and 1914, probably in the 1880s, Singer moved from artisanal production and started manufacturing interchangeable parts:

One of the most important departments of the modem Singer factory is that for designing and constructing the tools required accurately to make the thousands of different kinds of sewing machine parts so that every one of a kind shall be exactly duplicate and interchangeable with its fellow. ...

With the advancement of mechanical art through the general use of machine tools, absolute precision in the execution of its processes was made possible. But the assembling system requires this perfect accuracy to be exactly uniform on each piece. In order to preserve a perfect uniformity of the dimensions of each corresponding part, it is necessary to use gauges that shall test the truth of each, as compared with its standard, to such a minute fraction that it seems hardly possible for the senses to detect it.

Such gauges are systematically and rigidly used at every point in the construction of a Singer sewing machine, and each part is numbered. [340]

329 Hounshell, 1984, page 91.
330 Hounshell, 1984, page 89.
331 ISMACS, 2020.
332 Hounshell, 1984, page 69.
333 Askaroff, 2019.
334 Hounshell, 1984, page 85.
335 Hounshell, 1984, page 122.
336 Hounshell, 1984, page 91.
337 Hounshell, 1984, page 107.
338 Hounshell, 1984, page 94.
339 Fitch, 1883, pages 33-43 (pages 649-659).
340 Singer, 2014, pages 73-74.

Figures 15 and 16 are of a "young" Singer 201K manufactured in 1936. Figure 15 is cluttered to show that the machine is in use now, nearly every day, by a person who was also born in 1936. Figure 16 shows the shafts and linkages underneath the machine, and Figure 17 is a diagram of the machine. [341]

What should be clear is that every component is substantial and, provided a little oil is given, nothing will wear out.

Indeed, this sewing machine could last another hundred years or more of use without it failing; unless, of course, it is dropped on a hard surface and the castings break. How many other machines will last for 83 years, let alone over a hundred years?

There are only two parts that need to be interchangeable: the needle and the thread.

A third part, the bobbin, is interchangeable because it is convenient to have more than one bobbin with different coloured threads. *Nothing else needs to be interchangeable because nothing else needs to be replaced.*

So whether Singer did or did not make interchangeable parts is simply irrelevant to the end user but, of course, it was very relevant to the manufacturer.

In this context, Hoke's definition, that machines were made as interchangeable as necessary, appears to be correct.

However, his definition only applies to the American System of Manufacturing.

Mass production requirements are different, because the workers take parts from a supply and, as the assembly line cannot be stopped, they must be interchangeable. So watch and sewing machine manufacture are sophisticated uses of the American System of Manufacturing, and Ford's car making is mass production.

Figure 15

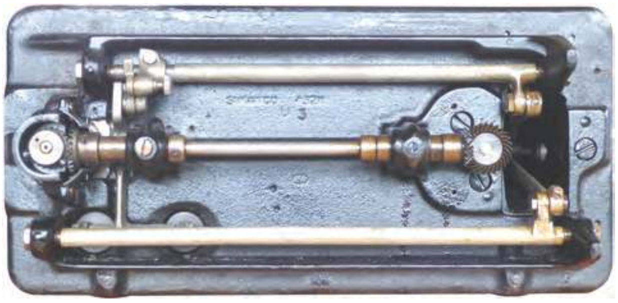

Figure 16

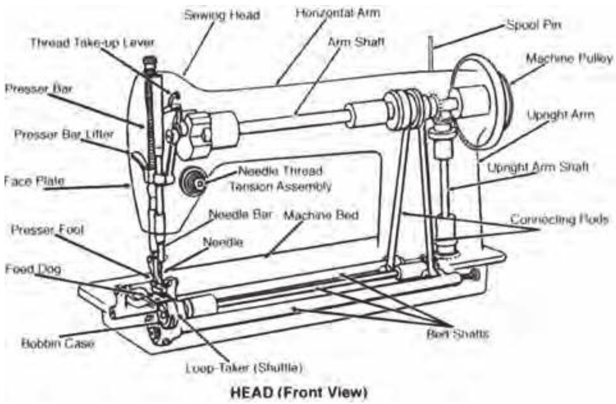

Figure 17

Adapting to Different Circumstances

Unlike the histories of technology that I have read, I have referred to the end users, the purchasers of the machines. The focus of the American System of *manufacturing* and mass *production* is on the way that companies *made* machines, but this strict approach largely ignores the requirements of the buyer. Some consideration is given, illustrated by the Waltham Watch Company's Record and the advertising of Singer, however it does not form part of hypotheses and arguments developed by the authors.

This oversight is not surprising, because the majority of machines are *single-purpose* and the user cannot, or is not expected to modify the behaviour of the machines. For example, clocks, watches and typewriters serve only a single function and, except for servicing and repair, they cannot be modified by the user. Other than winding the former and putting paper and carbon in the latter they are closed systems. An

341 Wikipedia, 2019b.

owner cannot convert the dial and mechanism of a watch from a 12-hour to a 24-hour display and cannot change a typewriter to type the Cyrillic alphabet.

This also applies to steam engines, bicycles, arms and cars. A railway engine cannot plough a field. A bicycle cannot transport two tons of bricks. A rifle cannot be converted into a machine gun. A car cannot transport people across lakes. Indeed, almost every machine that has been invented is limited to a single task.

The criterion for adaptability is that it must be easy to remove parts and add other parts so that the machine performs a different task; and, obviously, it must be easy to return the machine to its original configuration. There are two common machines designed to be modified by the user to perform different tasks. (I can think of a third, domestic machine that is adaptable, but I suspect these are the only three.)

The first is the watchmaker's lathe and perhaps other metal working lathes.

The basic principle of any lathe is that it can only turn round things and, in that sense, it is very simple. Indeed, pole lathes for turning wooden chair legs (often used in the forest) and the horsehair-bow driven watchmaker's turns are simply two centers to hold the work and a hand-held chisel or graver to reduce its size appropriately. But ...

Figure 18 is a circa 1880 watchmaker's/clockmaker's lathe. It consists of a triangular bed ***1*** and eight attachments that are mounted onto the bed, ***2-9***.

Number ***2*** is the *turns head-stock* with a block under it to mount the lathe in the supplied stand. It and the *turns tail-stock* ***3*** are used to hold the 13 *runners* at the left of the drawer; the runners having different ends to perform different functions.[342] In addition, the turns tail-stock can be used with the lever ***11*** to hold and center a drill or other small tool.

Figure 18

The other attachments are:

(a) ***4:*** *Graver rest* for free-hand turning (in two parts, one on the bed and one beneath the lathe head-stock ***7***).

(b) ***5:*** *Universal tail-stock* with 12 chamfered holes and a stop to align each hole with the center of the bed.

(c) ***6:*** *Taper holding tail-stock* for the four male and female tapers under the wheel chucks.

(d) ***7:*** *Lathe head-stock* with draw-in tube to hold the 12 split chucks and 5 wheel chucks in the middle of the box. The pulleys were driven by a foot or hand treadle.

(e) ***8:*** Compound slide-rest.

(f) ***9:*** Bed mounted safety pulley for center turning (in the drawer).

(g) ***10:*** Face plate, for eccentric mounting of the work, which attaches to the lathe head-stock.

(h) ***11:*** Hand operated lever that mounts in the tail-stock ***3*** in which are held the rose cutters (below the wheel chucks).

(h) Various *cement chucks* where the piece is held in the right position by shellac; they screw into a special chuck for use in the lathe head-stock.

342 Crom, 1980, page 492; de Carle, 1952, page 36; Saunier, 1924.

In addition, there are 4 extra split chucks and 4 extra cement chucks in the drawer.

Obviously all these components have to be precisely centered and I have no doubt that much hand finishing was required to ensure each piece correctly interacted with all the other pieces.

So here we have a *multipurpose machine* in which the user can arbitrarily choose different pieces to suit the needs of the task, and then re-configure the machine to perform another task. However, this interchangeability is *within* the machine and, like the WW lathe mentioned on page 14, it need not be interchangeability *between* machines.

In Figure 19 the lathe has been set-up as *turns*. The English word *turns* applies to turning between *dead centers*, centers that cannot rotate. Here a *turning arbor* with its ferrule (pulley) ***A*** has been used to create another ferrule ***B***. A piece of hammer-hardened brass has a hole drilled into the center and then it is mounted on the turning arbor and turned to the correct shape. In addition to being used on turning arbors, ferrules are often attached to other parts so that they can be shaped in the turns.

The inset photograph shows three other turning arbors with ferrules that are used for different purposes.

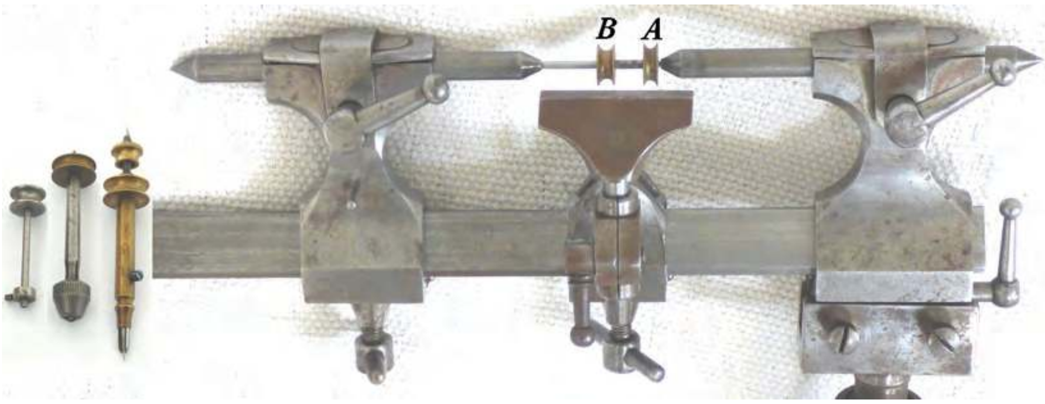

Figure 19

Figure 20 is also a form of turns. A brass rod ***A*** with a female center is placed between the special chuck ***B*** and a suitable chamfered hole in the universal tail-stock ***C***. Instead of using a ferrule to rotate the work, a *carrier* ***D*** is attached to the work and it is rotated by the small brass rod between ***B*** and ***D***, so that the rotation of the lathe head-stock can be used.

Although the male center in ***B*** rotates with the head-stock, it acts like a dead center with respect to the work; without the carrier any friction on ***A*** would stop it rotating.

All the following photographs show the lathe being used as a *lathe*, where the rotation of the head-stock is used to rotate the work.

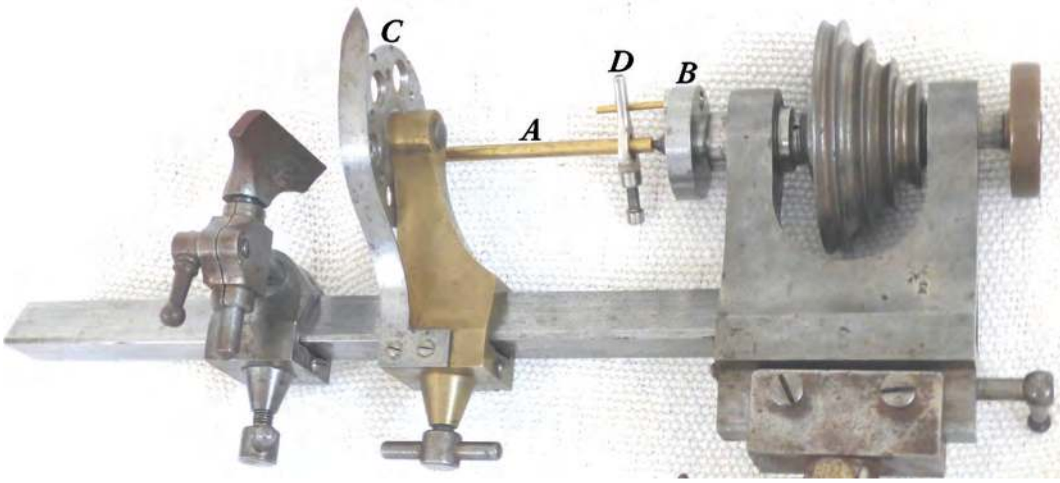

Figure 20

Figure 21 has a brass rod mounted in a split chuck in the lathe spindle and the pulleys in the lathe head-stock ***7*** must be used to rotate the work. Here the turns tail-stock is used with the hand-operated lever ***11*** and a rose cutter to form a pivot on the end of the rod. The inset shows an enlargement of the work, and the metric ruler is included to give an idea of the size of the lathe.

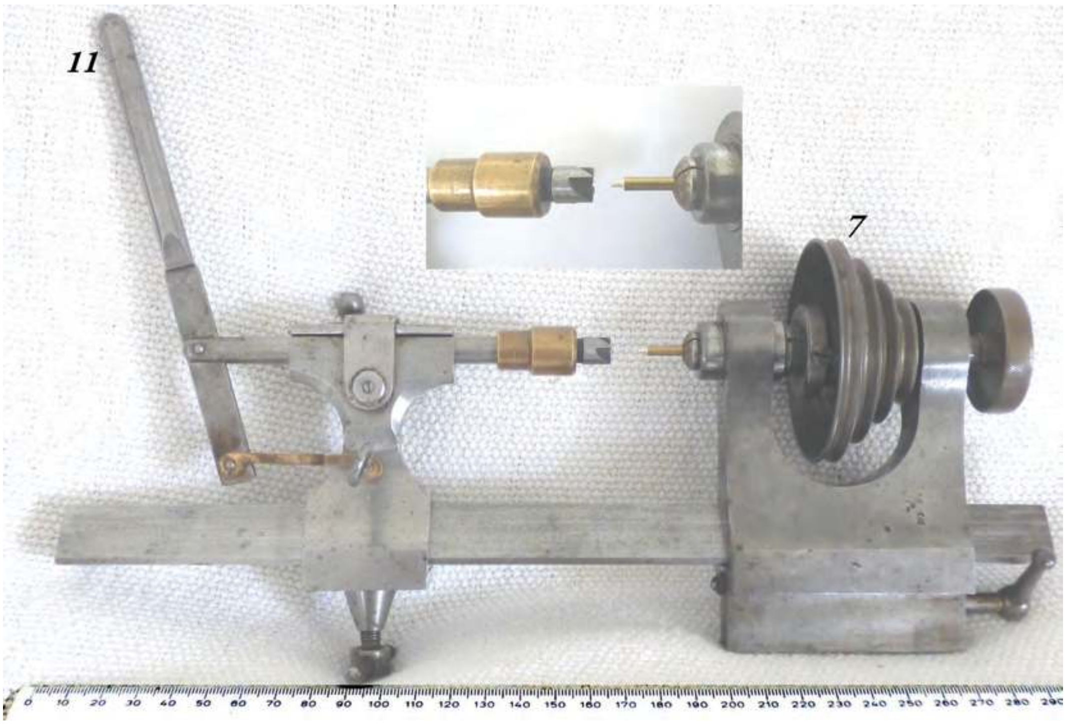

Figure 21

In Figure 22 the lathe head-stock ***7*** has the face plate ***10*** mounted on it. The faceplate is being used to hold a Joseph Johnson movement that is centered on the barrel pivot hole in the pillar plate so that the large concentric cut-out in the top plate can be made. The rest for the graver ***4*** has been moved away to show the watch plates.

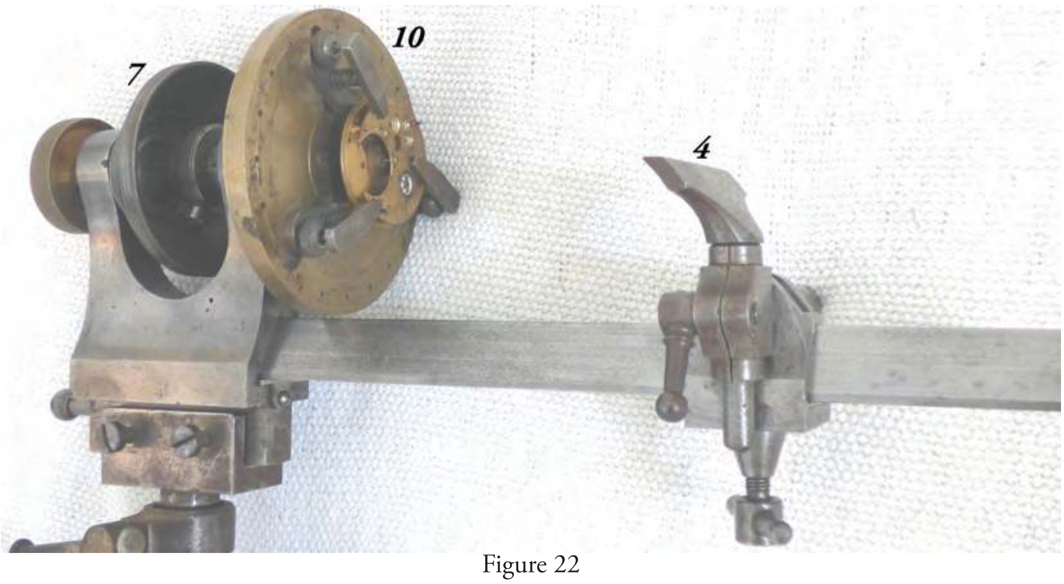

Figure 22

The face plate has a male center in it so that the work piece can be correctly aligned with the lathe's center.

Figure 23 shows a different lathe set-up. The barrel of the Joseph Johnson movement is held on a cement chuck and the slide rest is used to finish its shape. Alternatively, as in the inset photograph, a wheel chuck can be used to hold a wheel so that the center hole in the wheel can be enlarged concentrically with the teeth.

Figure 23

The barrel can also be made using the turns set-up in Figure 19, as was done in the 18th century.[343]

Consequently, this circa 1880 lathe can be configured in at least five different ways to perform many different tasks. Yes, all these tasks involve rotating the work while a cutter removes some material. But they are quite different and require different ways of setting up the lathe to accomplish them.

Of course, not all watchmaking machines are adaptable and not all lathes are large. Figure 24 shows a *pivot turns*, used to replace broken pivots on watch arbors. The wheel with its arbor is held between a runner ***A***, with a loose ferrule ***B*** on it, and a chamfered hole in ***C***; ***C*** contains many sizes of chamfered holes and the selected hole is locked in place by a pin at ***D***. The wheel and its arbor are rotated by a horse-hair bow while a drill, mounted in the runner at ***E***, is used to form a hole in the end of the arbor for the new pivot. There are 15 different drills at F and, when not in use, these are stored in the base of the turns covered by the thumb screw.

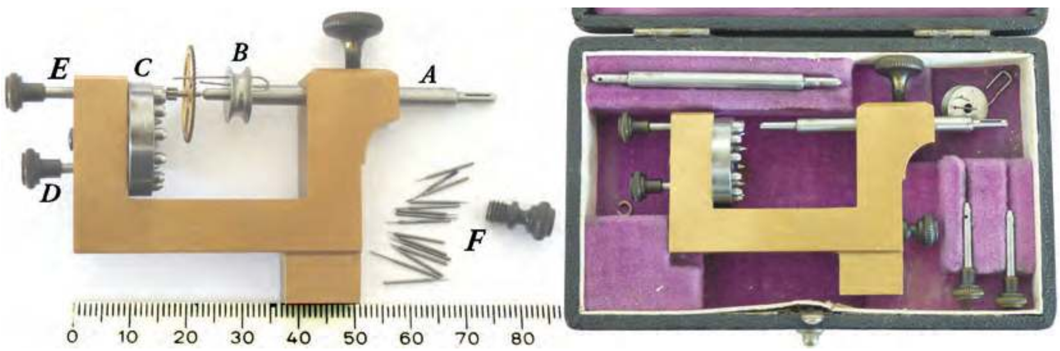

Figure 24

Another watchmaking "lathe" that cannot be adapted is the *rounding-up tool* in Figure 25. This very complex machine is used to correct the shapes of wheel teeth.

The wheel and a suitable cutter are mounted at right angles on separate slide rests, and they are adjusted. Then the handle is turned and the machine automatically cuts every tooth on the wheel so that they are of the correct shape and of exactly the same size. The cutter has a special form so that, after cutting one tooth, it turns the wheel to the next tooth.

343 Berthoud & Auch, 2005, pages 36 and 99; Vigniaux, 2011, page 55.

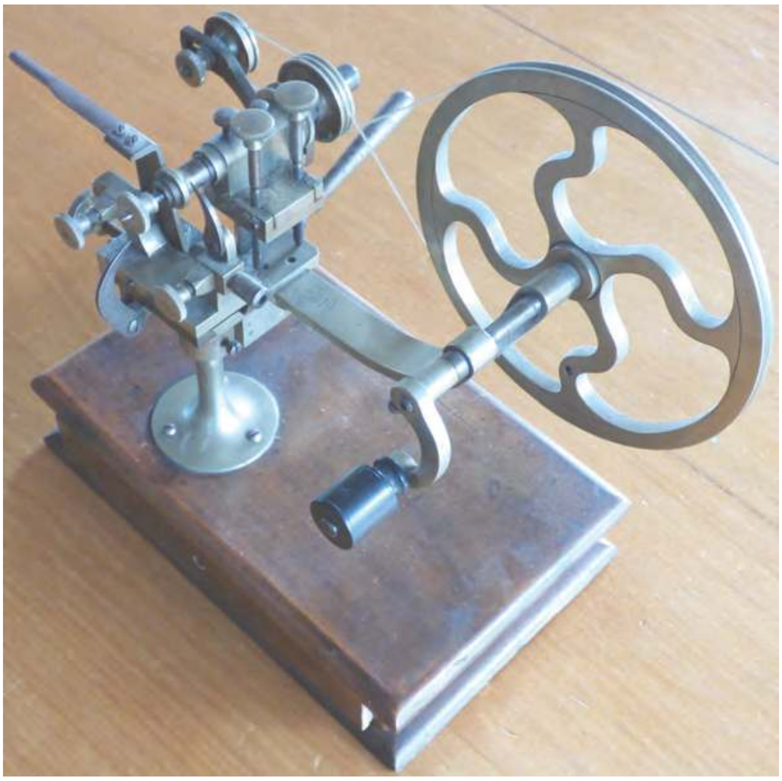

Figure 25

The second machine that can be adapted for different circumstances is the domestic sewing machine.

Mechanical sewing machines can perform only one action, to make stitches of uniform length in a straight line. So they are basically as simple as a lathe. But ...

The most interesting of their few interchangeable parts is the *presser-foot*.

With the normal presser-foot the machine can only sew in a straight line. However, there are presser-feet that adapt the sewing machine to sew in sophisticated ways, and this versatility is similar to the metal lathe. Although there are many descriptions of how to *use* presser-feet, I have found no descriptions of how they *work*, but in Appendix G (page 121) the mechanisms of some presser-feet are explained.

For example, one problem with material is that the cut edge of it will fray. And so the second most important activity of the user, behind joining pieces of material together in a straight line, is to *hem*; that is, to fold the edge of the material over twice (so that the edge is hidden) and then stitch the hem. Indeed, this function is so important that it was probably the first activity to warrant special treatment, by providing a dedicated *presser-foot*, and other hemming attachments.

It is noteworthy that the only activity mentioned by Hounshell is hemming;[344] and Fitch also mentions the hemmer, stating that it took 70 operations to make one.[345]

Figure 26 shows this presser-foot and its use. The material is put under the foot and then wound around the spiral to form the hem, which is then stitched.

However, as explained in Appendix G, presser-feet are interchangeable *between* the machines, even of different brands and different manufacturing dates.

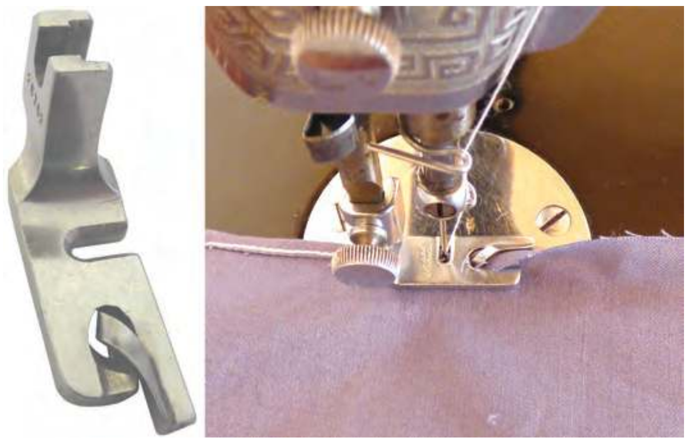

Figure 26

344 Hounshell, 1984, page 98.
345 Fitch, 1883, page 37 (page 653).

Decline and Fall

As I have stated, the American system is the manufacture of machines by unskilled labour. Well, that is how it started. In fact, it became obvious at a fairly early date that the development of automatic machinery of increased accuracy not only enabled the use of unskilled labour but it also reduced the number of labourers needed. Around 1860 each worker at Waltham could manufacture 50 watches in a year, and by the early 1900s this had risen to around 500 watches for each worker. That is, *fewer* people were needed to achieve the same production and, consequently, at lower costs.

The process of increasing machine complexity has continued without abatement. Landes outlines the development of the Swatch watch in the 1980s and he notes that

> *the production line ran automatically, and all one saw was robotic hands and pincers tirelessly coming and going and ministering to the components wafted along by the mechanized belt.*[346]

And this was quickly followed by error detecting systems to automatically weed out faulty modules.

Likewise, at the Seiko plant in Japan

> *a large room, about eighty metres square, filled with many dozens of automatic machines, a moving belt carries components from station to station, assembling watches as it goes. ... The room is almost empty of humans: a few inspectors, mostly women ... a few mechanics ....*[347]

Both Swatch and Seiko used mass production. But the important difference from the practices at Waltham is that the *assembly was done by machines, not humans*, and the machines required an automatic assembly line to function.

At present the production of quartz watch modules is in the billions per year. These watches require no watchmakers and only a few machinists and computer systems engineers. The human has been all but eliminated and production per person must be of the order of a million watches per year.

So at some time watchmaking passed through a stage when increased productivity exceeded demand and consequently employee numbers fell. Of course the relationship between production and employee numbers is far more complex than I am suggesting, but this simple view is sufficient for my purposes, which is to briefly look at post 1860 watchmaking in America.

Not long after the second world war the few remaining American watch companies disappeared and left the market to the Swiss and later the Japanese. On the surface it seems that the American system had failed, for watches anyway. In contrast, the Swiss manufacturers survived through one crisis after another and even the quartz revolution could not kill off their industry, although it went close. What was the difference?

Undoubtedly one factor was relative importance. No matter how much we might admire American watchmaking, it was always a tiny, even trivial part of the American economy, dwarfed by other industries. So, although its continued existence might be a matter of pride, its absence, other than in war time, made not a jot of difference to the wealth of the Unites States. In contrast, the Swiss industry was a huge part of the economy and entire regions depended on it for their livelihoods. It is hardly surprising that any crisis was met with national concern and frantic attempts to support watch companies.

But more important is an underlying difference in business culture. The United States had developed an attitude to business akin to Darwin's theory of evolution, the survival of the fittest. One aspect of this is the approach to competition and anti-trust laws. The business culture believed that there should be minimal, preferably no impediments to competition, and if companies wanted to engage in price wars they should be allowed to do so. Indeed, they were effectively *forced* into such wars, because any attempt to set up a cartel to stabilise prices would immediately bring down the wrath of the law.

346 Landes, 2000, page 390.

347 Landes, 2000, page 391.

This situation, discussed by Moore, meant that the profits of watchmaking companies fell and significant cost-cutting measures were needed simply to survive.

The Swiss political and business culture was completely different, and consequently their reaction to problems were the reverse of that taken in America. For example, after the first world war the Swiss watch industry collapsed, sales dropping from 18 million watches in during the war to around 8 million in 1921, and unemployment in the industry rising to around 28,000. Drastic measures were taken to support the industry, as explained by Landes:

> *The first step was the creation of a number of trade associations ... to defend the interests of makers and sellers of watches. ... The next step was the acceptance, beginning in 1928, of collective agreements governing output, pricing and export policies of all producers in the industry, with provision for enforcement and compulsory arbitration.*[348]

Even so, the Wall Street collapse produced another depression and, to quote Fallet,

> *At the end of 1929 sales collapsed. The export of machines and tooling, the transfer of labour abroad and the sale of half-finished movements (known as chablons) came to the fore again.*[349]

More collective agreements were signed and the final step

> *was government intervention ...* [creating] *a super 'holding' ASUAG ... followed in 1934 by a federal statute giving the watch cartel's private agreements the force of law and imposing new restrictions on output and technique.*[350]

The Swiss deliberately inhibited competition, controlled prices, and prohibited export of machinery and unfinished watches.

These laws had teeth, as the Oris Watch Company found out:

> *Because of the Swiss Watch statute, protecting the monopoly of a limited number of manufacturers, Oris* [was] *initially unable to produce precision watches with lever escapements.*[351]

So the company was forced to stay in the low quality, pin-lever market.

Another example is Tissot. To summarise the history provided by Fallet,[352] both Omega and Tissot had been weakened by the crisis after World War I that eventually led to the federal statute legalising the watch cartels. In 1930 Tissot and Omega joined together under the SSIH umbrella. Both remained separate companies, but instead of competing without constraint they co-operated. SSIH, which other companies subsequently joined, was the final expression of an agreement reached in 1924. This agreement not only included production co-operation (in 1925 it was arranged for a new Omega calibre to be made by Tissot), but administrative collaboration as well, with Omega appointing Paul Tissot as a director. A later example is that the Omega Speedmaster movement, the "moon watch", was designed and manufactured by Lemania, which had also joined SSIH[353].

As well as the prevention of cartels, the American business culture has another aspect. This is that the needs of shareholders is often in conflict with the needs of the company and its customers. A basic tenet of private industry is that it should return an adequate compensation to shareholders through dividends, as payment for their provision of capital. Generally, company boards take a long-term view and balance dividends against company viability, preferring to reduce dividends at times when the company needs capital for survival or development. But the lack of constraints inherent in a free market economy allows boards to give preference to the short-term demands of shareholders, even if this risks long-term

348 Landes, 2000, page 353.
349 Fallet, 2003, page 152.
350 Landes, 2000, page 353.
351 Oris, 2004, page 12.
352 Fallet, 2003, pages 151-160.
353 Omega, 1995, pages 36-42.

existence; indeed, some countries force companies to maximise dividends. At its extreme, this becomes asset stripping, where cash is depleted and even fixed assets are sold to boost dividends, until the company goes bankrupt. Companies are most in danger when a single person has a controlling interest, which was the case with both Robbins and Dumaine at Waltham. Landes provides strong evidence (supported by indirect statements by Moore) that Dumaine asset-stripped Waltham for personal gain, and sold the company just before it collapsed.[354]

Although this divergence of cultures goes a long way to explaining why the American watchmakers failed, there is a much more important factor. *The Americans stopped dumbing down*.

Unfortunately, the only company for which there is sufficient information is Waltham. But in that case there is some striking and all but conclusive evidence. Perhaps the clearest is a statement by Henry Fried. In a preface he wrote:

> *Some of the earlier machines were so efficient and advanced that I saw them still in use at the Waltham factory in the 1950's when I used to visit there.*[355]

And Church's plate lathe was still being used in 1954, although "it was worn out and sadly out of date".[356] Although this is a testament to the designers and machinists, it is a damning condemnation of management. Whereas the Swiss industry continually advanced, with a never-ending stream of new machine designs and techniques, Waltham had stood still, relying on outdated equipment and ideas. The Swiss, and later the Japanese competition may have eventually crushed Waltham, but management made sure it had no chance.

Again, Moore's chart of man-days per watch hides important features. Although only a rough approximation (but better than Moore's idealised, smooth curves) and simply to give a comparison, Figure 27 displays the main events.

Not long after 1876, the shock and knowledge, brought back to Switzerland from the Philadelphia Exhibition by Jacques David, started having an impact. At that time, the rate of production in Switzerland was 40 watches per year by each workman (about 7.75 man-days per watch), as against 150 (2.1 man-days) in America.[357] The Swiss changed direction from craft based comptoirs to machine based factories. And so the man-days per watch fell in Switzerland to match the American factories. But it did not end there. Unlike the Americans, who had a captive market and little need to improve on what they had done so successfully, the Swiss continued along the path of dumbing down. Machines with more and more sophistication and intelligence were developed to increase productivity and lower costs. Most importantly, while the American industry was still based on the railroad pocket watch, the Swiss took to wrist watches with a vengeance.

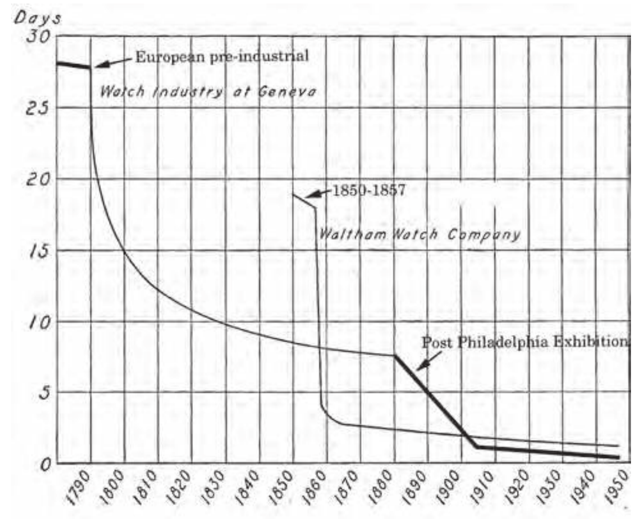

Figure 27

The trouble at Waltham, which is analysed with care by Moore, dates back to the death of Royal Robbins in 1902 and Duane Church in 1905. Moore notes that

> *the management of war and business is normally conducted along purely autocratic lines.*[358]

354 Landes, 2000, pages 356-360.
355 Marsh, 1896, page 6.
356 Hoke, 1990, page 240.
357 Fitch, 1883, page 61 (page 677).
358 Moore, 1945, page 91.

And he points out that Robbins

> *was a dictator only by virtue of* [the shareholders] *unfailing confidence in his ability.*[359]

But after his death, the new management lacked ability and lost direction. Eventually, when Dumaine took over, management moved from ruling for the benefit of the company to ruling for some other source of gain.

To make this clear, let me quote from Moore:

> *When the company was founded in 1850, it was purely a research organization. Dennison had an idea ... but he had neither the process nor the equipment. ... The new plant was built at Waltham in 1854 and ... the erstwhile inventors took over the responsibility for production and also continued with their search for better equipment and methods.*[360]

Although glossing over the discontinuity which occurred in 1857, this is a fair enough summary of what drove the company in the early days. Moore continues:

> *Dennison left the company in 1861, but it continued to be dominated by inventors: Ambrose Webster, Fogg, Vander Woerd, and others. This state of affairs continued until the promotion of Ezra Fitch to the position of general manager in 1883 bought a marked change in general policy; then the inventors ... had to subordinate their wishes to the dictates of the Sales Department. Notwithstanding ... the inventors remained in positions of authority in the factory and continued to exert a powerful influence on Company affairs.*[361]

The last date in the NAWCC copy of the first volume of the watch records kept by Waltham is 1883,[362] and it might be supposed that this indicates Waltham achieved full interchangeability at that time. However, Ezra Fitch took over in 1883 and it is more likely that the record ceased as a result of cost cutting measures (see page 116). As Jacques David points out, Waltham maintained a repair department, without which there would have been no point in keeping watch records. It is probable that Fitch closed down this expensive service and Waltham ceased to provide individualised spare parts, handing over the problem of fitting parts to retail watch repairers.

Moore's choice of the words *"research"* and *"inventor"* are excellent. Throughout these early, vibrant years, Robbins kept the focus on these crucial machinists, all of whom were employed after 1857. That is, he made the continual and progressive dumbing down of watchmaking the prime goal of the company. A dumbing down achieved by increasingly sophisticated automatic machines working to increasing accuracy.

In the 20 years from 1860 to 1879 Robbins spent about $3,482,000 on machinery (including some furniture and fixtures), an average of about $174,000 per year.[363] In contrast, Moore notes that Dumaine spent $1,288,000 on new machinery in the 20 years from 1923 to 1942, an average of about $65,000 per year or 1.5% of the value of machinery.[364] Kenison (quoting William Kilbourn, a division manager under Dumaine) notes the single motor, shafts and belts used to drive all machines were replaced by individual electric motors on each machine and the floors were replaced throughout the factory.[365] But there is no indication of how much of the $1,288,000 this took and hence how much was actually spent on retooling.

Also, there is no allowance for inflation in these raw figures, and the decreasing value of the dollar between 1860 and 1942 means that the difference, in real terms, is much, much greater. For example, in today's money Robbins spent $3,827,762 in the year 1879 and Dumaine spent $81,823 in 1942; so Robbins

359 Moore, 1945, page 91.
360 Moore, 1945, page 237.
361 Moore, 1945, page 237.
362 American Watch Company, ca 1900.
363 Hoke, 1990, page 249.
364 Moore, 1945, page 197; Landes, 2000, page 358.
365 Kenison, 2000, page192.

invested nearly *47 times* more than Dumaine on machinery. Even if nothing else had changed the amount spent by Dumaine is alarmingly low, but as he switched Waltham from making pocket watches to wrist watches, which would require substantial retooling, it is patently ridiculous.

Moore, attempting to show Dumaine in a good light, offers a different explanation:

> *The available data do not warrant any conclusions as to the adequacy of this rate of replacement. The rate of obsolescence on watch-manufacturing equipment may be much lower than is the case for other industries. Visitors to the Waltham plant are shown equipment in operation which is reputed to have been designed fifty years ago by Church. The continued use of this equipment is a tribute to Church's genius, but it may also signify that further improvements in this old and highly developed industry are too difficult to be profitable. Where progress has been very rapid, it may be advisable to rest until the associated mechanical arts have made parallel advances.*[366]

This is shown up to be a feeble excuse, by an anecdote given by Kenison which deserves repeating because it reflects the inherent problems at Waltham:

> *New England in the 1930s was a leader in medical advances, just as it is today. Apparently one of our best known surgeons had come up with an idea to save a certain kind of brain injury patient through a revolutionary surgical procedure. It required the sewing of a very small severed nerve in the brain. The doctor needed a very small gold needle that would allow the nerve to be sewn together in much the same way as a seam-stress would work on a hem. Massachusetts General Hospital contacted F.C* [Dumaine] *on the theory that if such a needle could be made, Waltham Watch could do it. It took three months and the only way the eye of the needle could be constructed was to taper the 'fat end' and bend it around into a loop. The needle worked, the operation was successful and the patient lived a normal life. Everyone involved with the project was proud of Waltham's accomplishment.*
>
> *The 'Old Man' had a needle packaged and sent to one of the heads of the watchmaking industry in Switzerland, together with a newspaper account of its creation and success. Also included was a note offering the following challenge: 'Match this if you can'. About 90 days later a package from Switzerland arrived. It contained Waltham's needle split laterally three ways, drilled and threaded. No note accompanied it.*[367]

This clearly demonstrates that Waltham's machinery and research skills were sadly out-of-date and inadequate as early as the 1930's.

One company, Hamilton, lasted longer, going out of watch production in 1969, and its survival makes an interesting comparison. First, during the Second World War it was the only company to successfully manufacture marine chronometers. Not only did Waltham and Elgin fail ignominiously, but Hamilton designed arguably the best marine chronometer ever built. Second, the company produced a number of striking and sophisticated wrist watch designs. And third, it diversified into other precision engineering areas. The inescapable conclusion is that Hamilton maintained a focus on research and development long after other watch companies had opted for stagnation and death.

366 Moore, 1945, page 232.

367 Kenison, 2000, pages 181-182.

Appendix A: Operations To Make A Full-Plate Movement

Calibre Features

It is not possible to understand watch manufacturing without some knowledge of the design of movements and how they are made, and this book requires the reader to have at least a basic understanding of a key-wound, full-plate watch with just a going train, 7 or 15 jewels and no complications. Whether made by hand or by sophisticated machinery, the parts and the problems remain the same. The only significant variations result from the layout of the train and the design of the two plates.

Detailed descriptions of how to make a watch by hand are given by Berthoud, Auch and Vigniaux.[368] Because they are concerned with the typical continental verge watch with a fusee, a few things they describe are not relevant, but the majority of the steps apply to almost any watch.

Figures A1 to A4 are of a Joseph Johnson English watch with a lever escapement, the same type that was used to model the Boston Watch Company's movements.

The train, Figure A1, consists of the fusee ***f***, which is the 1st wheel, the center-wheel ***2***, the third-wheel ***3***, the fourth-wheel ***4***, the escape-wheel ***e***, and the lever (***l*** is the lever's pivot hole). It is constrained to less than half of the plate by the barrel ***b*** and the fusee; the fusee chain, connecting it to the barrel is not shown.

Figure A1 Pillar plate inside.

The center-wheel and the third-wheel overlap the fusee and the barrel and have to be placed underneath them. For the movement to be reasonably slim, it is normal to cut a recess into the middle of the pillar plate so that the center-wheel can run underneath the barrel and fusee and, because it is sunk below the level of the pillar plate, the third-wheel pinion must be sunk even lower to avoid the barrel.

Although there are many variations, a common arrangement is to cut two overlapping *eccentric* holes and a third, separate hole in the pillar-plate and cover them with a train bridge mounted on the outside under the dial, Figure A2 ***t***.

Then the third-wheel is placed under the center-wheel and the fourth-wheel pinion placed beside it, also supported by the train bridge, as is the escape wheel pivot ***e***.

Figure A2 Pillar plate outside.

English lever escapements, which were used by the Boston Watch Company, are right-angle escapements; that is, a line from the balance staff (under the ruby jewel in the balance cock in Figure A3) to the lever is at a right-angle to the line joining the lever's pivot to the escape-wheel pivot.

368 Berthoud & Auch, 2005; Vigniaux, 2011.

Figure A3 Top plate outside.

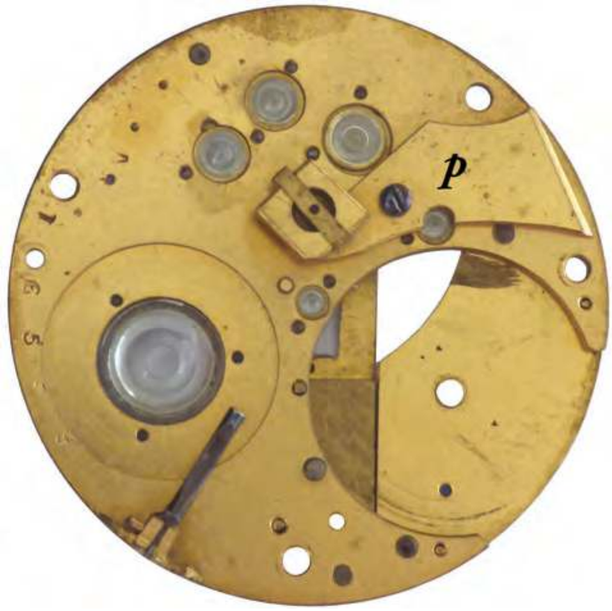

Figure A4 Top plate inside.

And so the position of the balance cock (and the balance that is not shown) is constrained to the position in Figure A3. But the size of the center-wheel (whose pivot can be seen under the window in the balance cock) means that the balance staff cannot go through to the pillar plate, and its bottom pivot must be supported by a potence ***p*** attached to the underside of the top plate as in Figure A4.

It appears that Dennison and Stratton simply copied a full-plate fusee movement, similar to the Joseph Johnson watch, and omitted the fuse while retaining the layout. This included copying the "Liverpool windows," excessively large jewels on the top plate to help sell the watch, and much smaller jewels elsewhere.[369] (The Joseph Johnson movement has 19 jewels, probably quartz or glass, the normal 15 plus 4 on the center-wheel and fusee pivots.)

Often the Boston Watch Company movements had a 16th jewel, a large and visible Liverpool window, moved from the fusee to the barrel.[370]

If a going barrel is used and the fusee omitted, as in the Waltham watch in Figure A5, there is much more space for the train, and so only the center-wheel has to be sunk below the barrel and the third and fourth wheels can be between the plates; however, the third-wheel pinion must be sunk to the level of the center-wheel, requiring a thick pillar plate or a bridge for it.

Even so, early Boston Watch Company watches used a train bridge under the dial, and later movements also used a train bridge even though the third-wheel was not sunk.[371] The watch in Figure A5 (and Figures A6 and A9) is of a later, 15-jewel Waltham watch and it does not have a train bridge.

To a large extent, the positions of the pillars are dictated by these features and they are arranged asymmetrically; there are four in the fusee watch but only three in the Waltham watch, presumably to cut costs.

Figure A5 Pillar plate inside.

369 Kemp, 1979, pages 51-52.
370 Price, 2005, page 7.
371 Price, 2005, pages 5 and 7.

Total Operations

The parts that make up a watch movement and the number of operations required to make them are based on the table at the end of this appendix. This table was constructed by examining a movement, noting down all visible components and estimating the number of operations to make each part. In addition to listing parts, the table gives the number of plain holes (*P holes*), threaded holes (*T holes*) and pinions. Note that not all arbors have pinions and not all pinions have arbors.

The total number of distinct parts is 102.

The number of operations depends on the methods used. For example, if a pin is simply pushed into a hole and riveted, then there are fewer operations than if the pin is threaded, the hole tapped and then the pin is screwed in and riveted. I have been very conservative in estimating the number of operations.

I have divided the operations into 7 groups. In order from most to least frequent they are:

(a) Teeth cutting (360, 33.6%): Cutting teeth on the barrel, train, motion-work and barrel ratchet using a wheel-cutting engine.

(b) Turning (305, 28.4%): All operations done on a lathe. Some of these involve eccentric turning requiring a face plate or a wax chuck.

(c) Shaping (177, 16.5%): Shaping parts which cannot be turned; for example pins, screw slots, the barrel click and the potence. These parts require special treatment by filing or cutting to produce their correct form.

(d) Drilling (134, 12.5%): Drilling and counter-sinking holes. There are 102 holes. Some holes have steps (for example, to countersink screws) and I have included oil sinks here.

(e) Thread cutting (52, 4.8%): Cutting threads on the 26 screws and in their holes.

(f) Riveting (27, 2.5%): Attaching pillars, steady pins and so on.

(g) Punching (18, 1.7%): Punching out flat pieces with presses and dies. This includes the plates, wheels, etc.

Thus a total of 1073 operations are required to make the 102 parts. This is a good estimate, not an exact figure. Some variations in design, such as having 2 screws to hold the potence, and minor errors in my calculations mean the figure may be a little smaller or larger. However, the *relative* number of operations in each group is unlikely to vary much.

A large number of tools are needed. Different teeth cutters are required for each wheel; most holes need drills of different sizes, each punching operation requires a different press and die; and so on.

Also, I have not attempted to estimate the relative difficulty of operations. For example, drilling is much easier to do than turning, which is easier than shaping. So the amount of skill and time varies considerably.

Finishing

Nearly every operation performed in making a watch has to be followed by one or more finishing operations. Some examples are:

(a) Drilling: The holes usually have burrs that must be removed, and many holes need to be smoothed internally.

(b) Turning: Most turning operations do not produce a perfect surface, so grinding or smoothing and polishing is necessary.

(c) Shaping: Irregular shapes have to be formed using files or special cutters and they then need finishing. The barrel click spring, for example, can only be roughly shaped at first, after which it must be hardened, tempered, thinned to the right strength and then polished.

(d) Bluing: Steel parts are polished and blued not only for appearance, but also to inhibit corrosion.

(e) Gilding: All brass parts are gilded to prevent corrosion. This involved meticulous cleaning, preparation of the surfaces and then gilding. After which, because the gold is deposited on all surfaces, all plain and threaded holes have to be cleaned out.

A conservative guess as to the amount of finishing involved is to *double* the basic number of operations. As a result, the total number of operations including finishing is about 3,219.

Note that I have omitted all indirect operations; for example, engraving, the fact that the movement is assembled twice, before and after gilding, and adjusting.

The above figure fits very well with Marsh's total of over 3,700 operations[372]; much of the difference will be due to the later addition of keyless work and compensation balances, and to changed methods, for example machining pinions instead of making them from pinion wire.

Screws, Pins and Holes

There are about 26 screws of different sizes. Each screw requires a number of operations performed on a piece of steel wire held in a lathe:

(a) Face the end of the wire. If the end of the screw is visible it is often slightly domed rather than left flat.

(b) Turn the body of the screw to the required diameter.

(c) Cut the thread with a die.

(d) Turn the head the required diameter.

(e) Cut off the screw and face the head.

(f) Cut the slot in the head.

In addition, the head (and end if visible) must be ground and polished. If necessary the screw is then blued. So there are about 182 operations to make the 26 screws.

In addition to screws there are about 22 pins:

(a) *Steady pins*: When a sub-plate, such as the balance cock, is attached to a plate there are two steady pins. These pins should be called alignment pins because they hold the sub-plate in the correct position; the screws are generally quite free in their holes and cannot be used for alignment. These pins are quite thick and can be turned and cut off in a lathe. They can be made slightly tapered so that they are forced into the corresponding hole and riveted. Or they can be threaded like a screw, put in and riveted.

(b) *Joining pins*: Pins can be used instead of screws to join parts together; for example, early watches had their dials held on by tapered pins running through the dial feet. These pins are generally very thin and cannot be turned because they would flex under the cutter.

(c) *Banking pins:* Normally a lever escapement has two banking pins for the lever to butt against. Often these are two simple pins that are bent for adjustment, but the Waltham watch in Figure A6 has eccentric pins mounted on screws (indicated by the arrows).

(d) *Other pins*: A few pins have different functions. For example, I have included as pins the stud for the minute wheel, the guard pin on the lever and the hooks on the barrel and its arbor for the mainspring; all of which start life as pins.

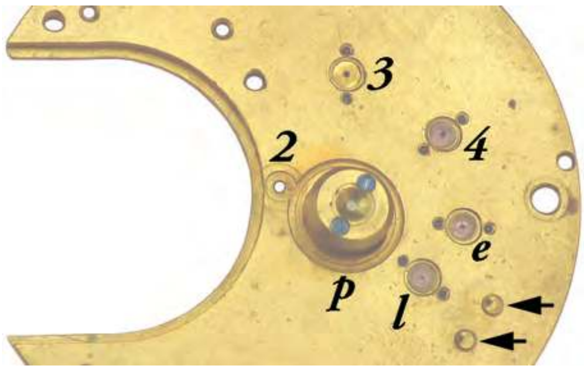

Figure A6 Top plate inside.

372 Marsh, 1890, page 13.

Although obvious, it must be remembered that for each screw there are two holes, a plain hole in the piece to be attached and a threaded hole. Some of these holes are stepped so that screws can be countersunk and so they cannot simply be drilled.

There are about 103 holes in a watch, including pivot holes, but because some are stepped at least 121 operations are required to make them.

To drill the holes for pivots and other attachments it is essential that there be some method of aligning the partially completed plates and sub-plates accurately. The holes have to be in the correct positions and upright; for example, the holes in the top plate must be perpendicularly above the corresponding holes in the pillar plate. The holes have to be drilled as most are far too small to punch. And after drilling they must be deburred and smoothed.

The tolerances for pivot holes, both in position and diameter are very small. The old method, used in hand work, was to drill pilot holes in approximate positions and later to plug these holes and re-drill them. This was necessary because of variations in wheel and pinion diameters and in the sizes of their teeth due to the finishing operations.

The only practical way to drill pivot holes in sub-plates is to first attach the sub-plates to the top and pillar plates. So they need to be clamped in position and the holes for the steady pins and retaining screws drilled; then the steady pins turned, threaded, inserted and riveted in place.

To locate holes correctly, some form of master plate is necessary. This plate could have small, raised points to mark hole positions on the plates, which may be the method used by Japy, or it could be drilled through with guide holes. Either way there has to be some way to accurately align the watch plates with the master plate.

If the plates are plain blanks then there is no problem. The two plates are simply clamped together and *all* holes drilled at the one time. This method means that the holes for the barrel and train bridges must be marked and cut out later; they cannot be punched out first.

If the plates already have asymmetric features, such as the bridge or pillar holes, then there must be a very good alignment system.

The four pillar holes can be used for this purpose because they are disposed asymmetrically around the edge of the plates and so provide a unique reference system. However, as I have already noted, the tolerances for pivot holes is very small and the pillar holes must be very accurately located and reamed out to an exact size.

The Top Plate and its Attachments

Given suitable dies, it would be possible to punch out the top plate with its eccentric hole for the barrel; there is no strict size requirement for the hole and so it could be punched fairly easily. However, with the possible exception of the holes for the pillars, the other holes must be drilled; fine, hard steel pins to punch out small holes would snap off the dies and the holes would be poorly formed. Other than drilling these holes, tapping some for screws and any necessary finishing, the top plate is complete.

There are five pieces attached to the top plate:

(a) Balance cock: This could probably be punched out, but it has a vertical profile that must turned. To hold it while turning requires a wax chuck or special clamps. Both the jewel and screw holes are countersunk. It has two steady pins.

 The balance jewels (and plate jewels if there are any) are mounted in brass chatons. As the jewels were purchased they may have already been mounted. However the chatons would have to be turned to fit the holes in the cock, potence and plates.

(b) Barrel bridge: This is punched out. It has two countersunk screws and two steady pins. Attached to it is the dust guard which would be turned from brass rod.

(c) Potence: In older watches the potence ***p***, Figure A4, which holds the lower balance-staff jewels, is similar to the balance cock, having a foot and a raised section holding the jewels. Thus, although it may be possible to punch it out, it has a profile that must be turned or filed. There are two steady pins and one or two screws. The potence must be positioned so that it does not obstruct any arbors and the end of the lever can reach the roller jewel.

In contrast, the potence in Figure A6 is riveted in place.

(d) Regulator: In the watches we are considering, the regulator consists of a steel bar ending in a large, split circle, Figure A7. The split circle clips into the hole in the top plate which surrounds the balance staff. (The regulator is missing in Figure A3, but it is of this type and its position can be deduced from the regulator scale engraved into the top plate.) The rod is thinned and flattened from this circle to the outside diameter of the balance spring, and two small steel pins inserted in it, the curb pins. The remainder of the rod is often rounded on top and tapered to a rectangular block, left there for moving the regulator by a finger nail or tool. The end of the rod tapers to a point over the index scale (either engraved in the top plate or an engraved arc of steel screwed to the plate).

Figure A7

Because of its shape, this piece, which is made from hardened and tempered steel, is difficult to make. As can be seen from Figure A7, it has a very complex profile. The underneath of the split ring is tapered and it fits into a correspondingly tapered hole around the balance staff; this is essential to hold the regulator in place. The tip, which the pointer to the regulator scale on the top plate, is rounded on top. And the entire piece has to be polished.

The only way to make the regulator, before sophisticated machine tools, is by hand filing, grinding and polishing. It is quite likely that they were imported from England.

Note that this regulator is for an undersprung watch where the balance-spring is between the balance and the top plate.

(e) Balance spring: The balance spring is often attached to the top plate by a simple round or square stud with a pivot that fits friction tight into a hole in the top plate; the Joseph Johnson movement has such a stud under the balance cock. Although easy to make, it has the disadvantage that it is difficult to remove the balance spring for servicing. Figure A8 shows a much better stud which is attached to the top plate by a screw and one steady pin. Although making it much easier to handle the balance spring it is difficult to make.

Figure A8

The collet, to attach the balance-spring to the balance staff, is turned from a drilled brass rod. Then it is split and the hole for the balance spring drilled through one side.

The Pillar (Bottom) Plate and its Attachments

The pillar plate and its eccentric hole for the train bridge can be punched out of brass sheet. However, the eccentric hole is often made up of two intersecting round holes, one for the third-wheel and the other for the fourth-wheel pinion. It may be that these are not punched out. Instead the hole for the fourth-wheel pinion is drilled, after which the plate is mounted on a face-plate or wax chuck and the third-wheel hole turned out.

In addition the plate must have a recess for the center-wheel, and the whole of the dial side, except for a narrow rim, is recessed to make room for the motion work and barrel ratchet under the dial, as in Figure A9. These recesses must be turned. (Alternatively, as is common with old English watches, the dial side of the pillar plate can be left flat and the dial mounted on a separate dial plate. This dial plate is cut out to provide the room for the under-dial parts.)

With the possible exception of the holes for the pillars and the dial feet, the other holes must be drilled.

There are 7 pieces attached to the pillar plate:

(a) Train bridge: This is punched out. Its shape is arbitrary except for providing space for two screws and two steady pins.

(b) Barrel ratchet, click and click spring: The barrel ratchet is a steel wheel squared onto the barrel arbor. In principle it should have ratchet teeth, but often it has ordinary teeth, probably because they are easier to cut, as in Figure A9.

The barrel click has an irregular shape. It might be punched out but it would need finishing, including drilling the screw hole for a shoulder screw.

The click spring, as noted above, is roughly shaped and the foot drilled for the screw and perhaps a steady pin. It is then hardened, tempered and the spring ground down to the required thickness.

(c) Barrel cock: The barrel ratchet can be pinned to the barrel arbor to keep in place. This creates a problem: the barrel cannot be removed to replace the mainspring without first removing the dial and unpinning the ratchet.

The alternative, that may have been used in early Boston Watch Company watches,[373] is to have the barrel ratchet loose on the arbor and hold it in place by a barrel cock, Figure A9. This cock does not have a pivot hole for the barrel arbor; that is in the pillar plate. Instead the hole in the cock is over size and simply makes room for the end of the arbor. Because the position of this piece is not critical, it has no steady pins and is held by a screw. In principle, it is now possible to remove the barrel without taking off the dial. But personal experience shows that it is almost impossible to put the barrel back in, because the ratchet inevitably moves and no longer lines up with the square on the arbor.

Figure A9

(d) Pillars: Pillars are turned from brass rod. One end has a pivot with a flat shoulder to be riveted to the dial plate. The other end has a pivot and flat shoulder to which the top plate can be pinned or screwed. When pinned, the pivot protrudes, its end is rounded and a small hole is drilled through level with the top plate. When screwed, the pivot is cut off below the surface of the top plate, leaving enough to accurately locate the plate, and it is drilled with a blind hole and tapped. In this case the screws can be set above or countersunk into the plate. The early American movements often used two of the screws going into pillars to also hold the barrel bridge.

(e) Dial: Dials were purchased and were attached to the pillar plate by pins running through the three feet. Because the plates may vary in thickness, these holes cannot be pre-drilled.

The Train

The train consists of a barrel, three brass wheels, a brass or steel escape-wheel, the lever and the balance, together with their arbors and pinions.

(a) The barrel: The barrel must be turned from brass rod, leaving a boss for the arbor bearing when it is hollowed out. A groove for the snap to hold the lid on must be made.

373 Price, 2005, page 7.

The barrel lid can be punched out, but it then requires turning to thin the inside, leaving a boss for the arbor bearing, and to make the snap. In addition, an eccentric hole must be made on the edge of the lid, although this could be punched out by the die that roughed out the cover. No matter how these parts are made, the arbor hole *must* be concentric with the rim.

(b) Wheels: Wheels can be punched out. Again the arbor hole *must* be concentric with the rim.

It is common to attach wheels to their pinions; the end of the pinion is cut down, the hole in the wheel enlarged, and then the wheel pressed on and riveted to what remains of the leaves. This method of attaching the wheel is restricting in that it limits the position of a wheel in the frame to just above or just below the other wheel that meshes with its pinion. Alternatively, the wheel can be riveted to a collet which fits tightly on the arbor. This is less satisfactory because it is possible for the wheel to rotate independently of the arbor.

The English lever, pointed tooth, escape wheel can be cut in a wheel cutting engine. The cutter has to be angled and shaped for the task.

(c) Teeth cutting: Cutting teeth on the wheels and the barrel is done by a wheel cutting engine. It is essential that the piece is held exactly on center to ensure the teeth will be concentric with the arbor. Wheels could be cut in stacks if a sufficiently accurate and rigid machine was used, but it is unlikely that barrels could be treated this way. The teeth should be epicycloid. However, it is extremely difficult to shape the very small cutters correctly and the teeth were probably good approximations to the correct shape, usually circular.[374]

Note that this is the most common task, there being about 360 individual teeth to be cut.

(d) Lever: The lever and its pallets, Figure A10, are two separate pieces which can be punched out of steel stock and then finished. (Originally the pallets were filed by hand.[375]) The pallets are aligned with the lever by a common center, the arbor, and one or two pins or screws going through holes drilled in the lever and pallets. In addition, the lever is drilled for the guard pin. The pallets must be slit, using a file or a saw, to take the jewels. After forming, the parts need to be hardened, tempered, ground and polished; the tools of early watchmaking could not shape hardened steel.

Figure A10

(e) Balance and roller: The balances in the watches we are considering were plain balances made from steel, brass or gold. The basic shape could be punched out, however the top of the rim and spokes are rounded and this rounding cannot by done by a punch or on a lathe. The underneath is left flat but, as in Figure A11 (at the top to the right of the arm) the rim can be filed away to poise the balance.

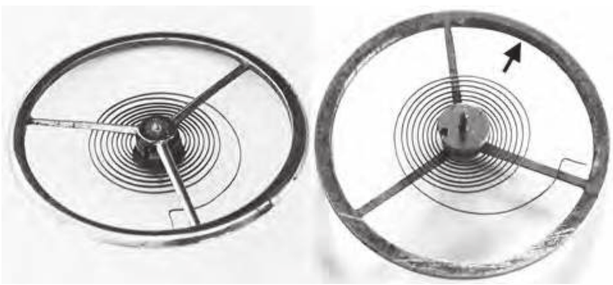

Figure A11

The roller in a single roller escapement is simply a disk which can be punched out or turned, and the hole in it for the balance arbor is made and enlarged to a very good friction fit. The hole for the impulse jewel can be drilled and then shaped appropriately with a punch. This means the roller must be hardened, tempered and finished after the basic work has been completed.

(f) Arbors and pinions: Except for the barrel, balance and lever, arbors were made from drawn pinion wire. The diameter of the wire and the shape of the leaves formed on it were only approximate and had to be finished.

374 Tarasov, 1964, page 160; David, 2003, page 51.

375 Crossman, 1885, page 19.

Making an arbor involves taking a piece of pinion wire and breaking off the leaves from most of it. Then it is pointed at both ends, mounted in a turns or dead-center lathe, turned to size and the pivots and their shoulders formed.[376]

The barrel arbor is turned from steel wire. It then has to be drilled through in the middle to take the hook, which is also made from steel wire, and a square formed on both ends to take a key and the click work.

Both the balance staff and the lever arbor are plain rods with pivots and are turned from steel wire. Both must have extremely accurate diameters so that the balance, roller and lever can be attached by a good friction fit. Note that using plain rods enables the heights of the balance, roller and lever to be adjusted and so overcome variations in the arbors.

(g) Pivot holes: A major problem with early watchmaking is that is was not possible to turn pivots to specific diameters; neither machines nor hand work could reproduce them to the required accuracy of about 0.01 mm. To overcome this, pivot holes in plates needed to be drilled undersize and then broached out to suit particular arbors. And likewise, balance jewels had to be chosen to suit the balance staff.

Ignoring the balance, all 12 pivot holes have oil sinks. I presume these are milled out after centering the hole.

The Motion-Work

The motion work consists of the canon pinion and the minute and hour wheels.

(a) Cannon pinion: Although the cannon pinion is also made from pinion wire, it has to be considered separately. It must be drilled through for the post on the center wheel arbor, and then this hole made slightly taper to match the taper on the center wheel post. Finally, the end is cut square for the hand setting key.

It is likely that canon pinions were purchased.

(b) Minute and hour wheels: Minute wheels would be punched out, have their teeth cut and then be mounted on a pinion with a hole for the minute-wheel stud. Hours wheels are the same, except they are riveted to a pipe which would be turned from brass rod.

Table of Parts, Holes and Teeth in a Watch

Part	Sub part	Screws	Pins	P holes	T holes	Jewels	Arbors	Teeth	Pinion
	Total	**26**	**22**	**76**	**26**	**7**	**7**	**360**	**6**
Top plate	plate								
	case screws	2		2					
	pillar holes			4					
	banking pins		2	2					
	balance cock holes			2	1				
	pivot holes			5					
	oil sinks								
	balance spring stud hole			1					
	potence holes			2	1				
	barrel plate holes			2	2				
Balance cock	balance cock								
	screws	1		1					
	steady pins		2	2					
	jewels					2			
	pivot hole			1					
	chatons	3			3				

376 Marsh, 1896, page53; Berthoud & Auch, 2005, pages 30-32, 89-91; Vigniaux, 2011, pages 45-47.

Part	Sub part	Screws	Pins	P holes	T holes	Jewels	Arbors	Teeth	Pinion
Balance spring	balance spring (buy)								
	collet		1	2					
	stud		1	1					
Regulator	regulator			1					
	pins		2	2					
Balance	balance								
	staff						1		
	roller			2		1			
Potence	potence	1	2	1					
	pivot hole			1					
	jewels					2			
	chatons	2			2				
Barrel bridge	plate	2		3	3				
	barrel dust guard	3		1					
	steady pins		2	2					
Pillar plate	plate								
	pillars	4		4	4				
	minute wheel stud		1	1					
	case screws				2				
	pivot holes			4					
	oil sinks								
	barrel cock holes				2				
	center wheel sink								
	holes for train bridge			2	2				
	barrel click holes				1				
	barrel click spring holes			1	1				
	motion-work sink								
	dial feet holes			3					
Barrel click		1		1					
Click spring		1	1	2					
Train bridge	bridge	2		2					
	steady pins		2	2					
	pivot holes			2					
	oil sinks								
Barrel cock	cock								
	screws	2		2					
	pivot hole			1					
Barrel	barrel		1	1				60	
	arbor with square		1	1			1		
	lid with notch			1					
	mainspring (buy)								
Center wheel	wheel							64	
	canon pinion with square								1
	arbor						1		1
Third wheel	wheel							64	
	arbor						1		1
Fourth wheel	wheel							45	
	arbor						1		1
Escape wheel	wheel								
	arbor						1	15	1
lever	lever		1	3					
	pallets with slots	2		1	2	2			
	arbor						1		
Minute wheel								40	1
Hour wheel	with pipe							36	
Barrel ratchet	with square							36	
Dial (buy?)			3	3					

Appendix B: Boston Watch Company Inventory and Costs

Inventory of Stock in Workmen's Hands, February 2nd 1857

There are two copies of this inventory; one attached to document 116-153 and one attached to document 118-056.[377]

The following tables are not transcripts of the inventory. Instead I have changed the layout and the wording to make the information more readable. Question marks indicate text for which the interpretation is dubious. The text in italics are my comments.

The per item values are dollars in the first and third tables and cents in the second table. There are some errors in amounts that have not been corrected.

No.	Type	State	Unit cost $	Total cost $
30	Movements	4 pairs ready to gild lacking dials say ⅞ done	$20⅛	603.50
30	Movements	4 pairs with all materials selected except dials ¾ done	17¼	517.50
30	Movements	4 pairs less balance jewels & dials say ⅝ done	14⅜	423.50
10	Movements	Plain less balances & dials say ½ done	10	100.00
				1644.50
		Less 20 per cent		328.90
				1315.60
620	Frames	4 pairs, job? 30, stock 8, ex 4	0.42	260.40
150	Frames	Plain, job? 30, stock 8, ex 4	0.42	63.00
400	Frames	4 pairs ¾ done	0.28	112.00

No.	Part and state	Unit cost ¢	Total cost $
850	3rd pinions	$0.25	212.50
850	4th pinions	25	212.50
1000	5th (escape) pinions	25	250.00
1325	Balance arbors	25	331.25
1187	2nd (center) pinions	37½	445.12
600	Cannon pinions (½ done)	12½	75.00
200	2nd (center) pinions with wheels staked on	50	100.00
1650	Barrels	10	165.00
275	Finished ratchets	4	11.00
10	Barrels	10	1.00
51	2nd (center) wheels	50	25.50
670	Minute wheels	6	40.20
2950	Hour wheels	6	177.00
131	Dozen second hands gold? - silver?	25	32.75
3162	Pair gold hands	6	189.72
675	Balance spring collets	3	20.25
320	Pallets finished	75	240.00
176	Pallets ½ finished	37½	66.00
225	Forks finished	5	11.25
200	Forks ¾ finished	4	8.00
2500	Forks ¼ finished	1	25.00

377 Suffolk County Court of Insolvency, 1857-58.

No.	Part and state	Unit cost ¢	Total cost $
4300	Forks some work done		10.00
47	Pairs? jewels ¾ finished		30.00
550	Jewels ready to set		8.25
204	Balances finished *(Also described as rollers)*	14	28.56
228	Balances ⅔ finished *(Also described as rollers)*	10	22.80
292	Balances ⅓ finished *(Also described as rollers)*	5	14.60
337	Regulators finished	14	47.18
500	Regulators broached		5.00
700	Hair spring studs drilled		7.00
1400	Clicks drilled		10.00
350	Clicks ½ done		7.00
427	Click springs drilled		3.00
1087?	Ratchets filed		5.00
55	Caps? ⅔ done		1.54
587	Pallet arbors	25	146.75
700	Pallet arbors ⅔ done	1/? *(16⅔)*	116.66
464	Rollers with pins	19	88.16
241	Rollers without pins	14	33.74
56	Balances with arbors	50	28.00
57	Balances without arbors	1/? *(16⅔)*	9.50
198	3rd wheels with pinions	37½	74.25
141	4th wheels with pinions	37½	58.87
136	5th (escape) wheels with pinions	37½	51.00
416	5th (escape) wheels gilt without pinions	6	24.96
1432	5th (escape) wheels not gilt without pinions	3	42.96
61/10	Gro? watch glasses	2.50	16.47
100	Finished balances	1/? *(16⅔)*	16.66
300	Balances ½ done	6	25.00
500	Set screws ⅔ done	*(16⅔)*	83.33
300	3rd upper jewels opened & set	15	45.00
87	3rd upper jewels opened too large	6	5.22
633	4th upper jewels opened & set	15	94.95
144	5th (escape) upper jewels opened & set	15	21.60
357	5th (escape) upper jewels opened too large	6	21.42
31	Cock and potence (balance) jewels	12½	3.87
97	Cock and potence jewels (balance) opened large	6	5.82
770	Bar jewels in settings	10	77.00
124	Bar jewels opened too large	6	7.44
950	Jewel (roller) pins	4	38.00
	Jewel holes not opened say 500	8	40.00
1650	2nd (center) pinions cut off		16.50
3200	3rd pinions cut off	½	16.00
3106	4th pinions cut off	½	15.53
8000	5th (escape) pinions cut off	½	40.00
3634	Cannon pinions cut off	½	18.17
2500	Minutes pinions cut off	½	12.50

No.	Part and state	Unit cost ¢	Total cost $
3300	2nd (center) pinions cut off ½ B...? work done	1½	49.50
6300	3rd pinions cut off ½ B...? work done	1½	94.50
2241	4th pinions cut off ½ B...? work done	1½	33.61
550	Cannon pinions ½ B...? work done	1½	8.25
340	Minute pinions ½ B...? work done	1½	5.10
1540	Hour wheels B...? ½ done	2	30.80
1252	Balance staffs B...? ½ done	2	25.04
1100	Barrel arbors B...? ½ done	2	22.00
809	2nd (center) wheels finished	2	16.18
90	3rd wheels finished	2	1.80
840	4th wheels finished	2	16.80
200	Minute wheels finished	2	4.00
2049	Hour wheels finished	2	40.98
1089	Balance arbors finished	3	32.67
500	Barrel arbors finished	5	25.00
2000	4th settings	½	10.00
1215	3rd bridge settings	½	6.07
1200	Cock & foot settings	½	6.00
374	Pallets	75	280.50
43	Pallets not suitable for present? drilling		32.25
50	Good forks		2.50

No.	Part and state	Unit cost $	Total cost $
9	Silver 2½ oz cases polished to pin up. Estimated 9⁄10 done	6.65	59.85
25	Silver 2½ oz cases jointed not sps? Estimated ½ done	5.25	131.25
20	Silver 2½ oz cases part sps? ½ done	5.25	105.00
18	Silver 2½ oz cases in hands of jointer ½ done	5.25	94.50
20	Silver 2½ oz cases turned ¼ done	4.37½	87.50
46	Silver 2½ oz cases ready for turner ⅛ done	3.94	181.24
	Estimated 1½ oz chips to come off the last named 46 cases say 69 oz	1.25	86.25
	Chips about lathe say 20 oz		25.00
	A very few sweeps and washings about the shop estimated		25.00
	Add 69 oz silver in the above for under estimate of weights		86.25

	Total value of the inventory		***$7510.49***

Unfortunately some entries in the above inventory are obscure, and have not been interpreted. However:

(a) *Prices.* In the inventory, the unit prices of movements, cases and silver are in dollars. All other unit prices are in cents. The total value of the inventory is $7,510.49 after allowing a discount of 20% on the value of the movements; as the majority of the total value is labour, it is equivalent to about $3,490,000 today.

Case data is inconsistent. Finished cases contained 2.5 ounces or $3.13 worth of silver and probably cost $7.40 for open face cases and $10 for hunter cases; $3,440 and $4,650 today respectively.

A finished movement with 15 jewels is priced at $23, making a complete watch $30.40. Watches in silver cases were sold for $30 to $50,[378] and the inventory value of $30.40 must be the cost of manufacture for a selling price of around $40 to $50 (between $18,600 and $23,200 today).

378 Waltham Sentinel, 1856.

In contrast, a plain, 7 jewel, movement is priced at $20 and the complete watch about $27.40. Assuming these sold for $30, there was very little profit. The small difference in price compared with 15 jewel movements, only $3, reflects the fact that the only additional cost and time is in adding 8 jewels. This is about $1.00 for the jewels and so $2.00 labour. (Jewels in settings cost 15 cents.)

(b) *Movements*. There are only 100 unfinished movements. The finished movements (with or without cases) are not listed because they were no longer stock in the workmen's hands; they were probably stored in an office.

(c) *Frames*. There are 1,170 frames. These presumably include all brass work: 2 plates with pillars, barrel bridge, balance cock, potence and third-wheel bridge. They may not have had the various holes drilled. It is reasonable to assume that the frames had serial numbers punched into them. That is, there was a total of 1,270 movements in different stages of manufacture.

(d) *Excessive production*. There are 9,136 escape-wheel pinions, including 136 mounted on escape wheels. At the rate of production up to 1857, this represents something like ten-years supply! However, there are only 1,984 escape wheels, 7,152 too few for the pinions but 814 too many for the number of frames.

Even more ridiculous is that there are 10,548 third-wheel pinions, but only 288 third-wheels to mount on them. And there are 7,275 forks (levers), but only 870 pallets. (In these watches, like their English equivalents, the lever and pallets were two, separate pieces joined together by pins or screws.)

An important question that cannot be answered is: How many of these parts were scrap? The inventory lists jewels "opened too large" which could not be used, and it is likely that there were other components which could not be used.

(e) Insufficient production. In order to convert the 1,170 frames into movements there needs to be equivalent numbers of all other components. However, there are only 288 third-wheels, 882 too few; and 870 minute wheels, 300 too few. Also, there are only 500 sets of screws. (There are about 29 screws in a 15-jewel movement. These screws are for: balance jewel settings, 5; four top-plate jewels in settings, 10; balance cock, 1; barrel bridge, 2; barrel dust cap, 3; pillars, 2; potence, 1; third-wheel bridge, 2; ratchet bridge, 2; and click, 1.[379])

Consequently, it would be impossible to complete all of the new movements until these components were made. This is most important for imported parts which, unless already on the way from England, would take several weeks to obtain. The obvious problem is that there are no balance springs or mainsprings listed, but these imported parts might have been held in a store.

(f) Dials. There are no dials listed. Consequently, none of the 1,270 movements and frames could be finished. Dials were apparently made locally, but it would take appreciable time to produce so many.

It is interesting to note that when Royal Robbins took over, Dennison was sent to England and, amongst other things, ordered 3,000 dials signed Tracy Baker & Co., none of which were used.[380] This might indicate that dials never were manufactured at Waltham, but it might show that the dial makers employed by the BWC were amongst the workers that Howard took with him back to Roxbury after the insolvency; I think the latter is more likely.

There is one important conclusion from the above. It is clear that Dennison's approach to manufacturing was irrational and he had no understanding of quantity control, the production of matching numbers of components. It is not excessive to say that Dennison was incompetent.

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379 See Price, 2005, pages 5 - 7.

380 Tracy, 1886; see Marsh, 1889, page 17.

Estimated Cost of a Watch, 1857

The following table, derived from the inventory given above, gives the approximate cost of a watch movement, case and glass. Note that:

(a) Some values in the inventory are vague and/or inconsistent and the table below uses best estimates.

(b) Values for the main and balance springs are not given, presumably because they were purchased. In 1880 and in 1897 mainsprings were about 8 cents and balance springs about 2 cents.[381] The exchange rate was approximately £1 = $5 so that one penny was worth about 2¢.[382]

(c) The total cost of the rough movement is about $8.00 including the main and balance springs. This figure includes the labour used to make and finish the components. As the raw materials are very cheap and labour cost about $1.00 per day, the labour amounted to about 6 man-days.

(d) The inventory values a *finished* 15-jewel movement at $23.00 and consequently $15.00 was spent in assembling, fitting, testing and adjusting. As this work was specialised, the labour would be about $2 per day, and so it took about 7.5 man-days to create the finished movement.

(e) The cost of the finished case and glass is about $7.43. The value of silver in the 2.5 ounce case is $3.12 and the labour component is about $4.28, probably about 3 man-days. So the total labour for a cased movement is about 16.5 man-days, which fits the independent estimates given next.

(f) The total cost of a finished watch is about $30; that is, more than a month's pay for an ordinary worker earning $1.00 per day. However, we do not know if this amount is the cost price or the wholesale price.

Part	Cost cents	Part	Cost cents
Frame	42	Lever (fork)	5
Barrel	10	Pallets with jewels	75
Barrel cap	3	Pallet arbor	25
Barrel arbor	5	Balance	25
Barrel ratchet	4	Balance staff	25
Barrel click	4	Roller	14
Click spring	1	Roller jewel	5
Mainspring	***8***	Balance jewels	12.5
Center wheel	25	Balance spring collet	3
Center pinion	37.5	Balance spring stud	1
Third wheel	12.5	Balance spring	***2***
Third pinion	25	Regulator	14
Third wheel upper jewel	15	Minute wheel	6
Third wheel bar jewel	10	Minute pinion	1.5
Fourth wheel	12.5	Hour wheel	6
Fourth pinion	25	Canon pinion	25
Fourth wheel upper jewel	15	Screws 25c per set	25
Fourth wheel bar jewel	10	Dial	200
Escape wheel	12.5	Hour & minute hands	6
Escape pinion	25	Seconds hand	2
Escape wheel upper jewel	15	Case	740
Escape wheel lower jewel	10	Glass	2.5

381 Silber & Fleming, 1880, page 455.
382 Measuring Worth, 2019.

Appendix C: Boston Watch Company Production Rate 1850-1857

Estimate of Production

Estimating Boston Watch Company production must be done indirectly because there are no company records. However, we do have the February 1857 inventory and some information about watches completed by Robbins and Howard. These allow us to form a possible picture of production.

Because of the lack of data, it is impossible to determine the precise rates of production during the seven years 1850 to 1856 inclusive and the four months, January, February, March and April 1857, before the sale of the factory to Royal Robbins.

Two points must be made before examining the evidence.

First, large scale watch manufacture is based on sequential production. When made, the structural components, the frames, are stamped with a serial number. And throughout the process each numbered movement was kept separate from others to ensure all parts were correctly matched.

Normally the movements were manufactured in order of serial number and they progressed through the factory in sequence, in small batches usually of 10 movements. The American Watch Company used batches of 10; although some entries have groups of 100, this number is much too large to be a single batch;[383] see page 116. Occurrences of out-of-order finishing do happen, but these usually concern special or very high quality watches. Sometimes these were started, but put on hold until there was sufficient demand to warrant finishing them. Or sometimes they were never finished as the particular model was no longer viable.

All the movements manufactured by the Boston Watch Company are of the same type, simple full-plate movements with 7 or 15 jewels. (Some watches were made with a 16th jewel on the barrel arbor, but most had the standard 15 jewels.) Although Hawkins has a few discrepancies and errors,[384] it appears that the Boston Watch Company manufactured watches in batches of 10, with batches of 7 and 15 jewel movements intermingled. Consequently, there is no reason why movements would be manufactured out-of-order and we can assume watches with lower serial numbers were completed before watches with higher serial numbers. Because the frames had serial numbers stamped on them, it is likely that the inventory counted them correctly.

Second, unless some changes were made, movements started by the Boston Watch Company and finished by the Boston Watch Company must be indistinguishable from movements started by the Boston Watch Company and finished by someone else. Thus, the only way we know that some movements were finished by the American Watch Company is from Tracy Baker (1857b) and Hawkins (1983); without this information we would be unable to tell who finished the movements. However, it is possible to examine *probable* rates by making some assumptions.

Most important is that I have tried to *maximise* production in the period 1853 to 1856 inclusive and, as a consequence, *minimise* the number of man-days per watch. So I will assume that *zero* watches were produced in the first 3 years, 1850 to 1852 inclusive, even though we can be sure some watches were at least partially completed. Stratton, who designed the first 30-hour watch, joined the company in March 1852.[385] About a year later (around March 1853) watches were completed.[386] And so there were about 9 months production of watches in 1852, although none were finished because the could not be gilded.[387]

383 American Watch Company, ca1900.
384 Hawkins, 1983, pages 22-24.
385 Abbott, 1905, page 51.
386 Crossman, 1885, page 19.
387 Crossman, 1885, page 18.

That is, up to 639 watches could have been made in nine months in 1852 (assuming 50 workers, 230 days at 18 man-days per watch) and I ignore this production.

The company was *forced* into insolvency against its will, because it had failed to make mortgage repayments, and insurance and tax payments to the Waltham Improvement Company who took over the factory on 3rd March 1857.[388] It continued to try to raise capital until it finally filed for insolvency on 15th April 1857.[389] As the company was trying to remain solvent up to this date, there is no reason to suppose production ceased until the very last moment.

As noted on page 51, after the Waltham Improvement Company took over on 3rd March 1857 it immediately leased the factory to Charles Rice.

So the question is: How many complete watches did the Boston Watch Company make up to 9th May 1857?

We know without doubt that some Boston Watch Company movements were finished by the American Watch Company, the company that Robbins established when he took over the Waltham factory. The Tracy Baker & Co. sales records for June 1857 to December 1858,[390] which provided the data for Hawkins (1983), show that Tracy Baker & Co. sold, on behalf of Royal Robbins, watches with serial numbers 4081 to 4199 inclusive, and 4223. In addition, in September 1857 watch 4219 was sold, but this is not listed by Hawkins. Of these watches, about half had 7 jewels and the rest had 15/16 jewels.

These were probably not complete, finished watches when Robbins acquired them for two reasons:

First, Tracy Baker lists with no date (but probably 21st May) "Expense for material and work not finished $2,359.82",[391] and the only available "work not finished" would have to come from the factory or stock removed by Charles Rice. This is confirmed by Tracy:[392]

> *Rice had taken all, or nearly all of the stock in the factory. This left from twelve to twenty finished movements, material, silver, and sundry articles in the silver case department, which items we purchased for $2,500 to $3,000 ... however, all of the finished movements were spirited away by whom we do not know, although we had strong suspicions.*

In today's money the purchase would have cost between $1,160,000 and $1,390,000.

Hawkins states "Mr. Robbins started legal action against Mr. Rice and Mr. Howard. The suit was settled by the return of some of the material".[393] In contrast, Hackett writes "Rice started negotiations with Robbins to resell the movable goods to him but the deal fell through when they could not agree on a price".[394] Either way, the indications are that Rice sold part of the materials. If Robbins had to pay about $16 each for the movements that the American Watch Company finished and sold (about $7,430 today), then they cost $1,952 and he bought about $408 in other stock, including cases and silver.

Second, if these had been complete watches we can be sure Robbins would have sold them immediately to raise cash for the watch company. Indeed, all 29 that were completed in June 1857 were sold to Robbins & Appleton; that is, Robbins purchased them himself as a means of transferring cash into the company; throughout 1857 Robbins was pumping money into the fledgling company to keep it running, and clearly this would have been better rather than by borrowing from elsewhere. Indeed, between 26th June 1857 and 27th February 1858 Robbins contributed $35,150.00 to the company.[395] (I have no information for later dates.) But the rest of these movements, with a few exceptions, were sold between

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388 Price, 2005, page 8.
389 Price, 2005, page 8.
390 Tracy Baker, 1857b.
391 Tracy Baker, 1857a, page 3.
392 Tracy, E., 1886; see also Marsh, 1889, page 16.
393 Hawkins, 1983, first page.
394 Hackett, 1962, page 10.
395 Tracy Baker, 1857a.

July and September, a delay which can only be explained if they were bought unfinished and required varying amounts of additional work. This view is also supported by the fact that Robbins purchased 660 ounces of coin silver to make cases in May and June 1857.

There are two separate issues regarding the Boston Watch Company material which Rice and Howard took back to Roxbury.

First, there are no records relating to Edward Howard which are equivalent to the Tracy Baker & Co. sales records. That is, except for the movements discussed below, we do not know if Howard finished and sold Boston Watch Company movements with serial numbers less than 5000. Such movements would have no features which would distinguish them from any other Boston Watch Company movements, and there is no way of telling if a particular movement was finished at Waltham or at Roxbury, let alone who sold it. Price states that Howard completed about 500 watches.[396]

Second, there is some evidence which suggests the Boston Watch Company actually started movements with serial numbers greater than 5000 and that these were finished by Howard.

Ron Price[397] notes that some Howard & Rice movements with serial numbers within the range 6000 to 6500 have different numbers under the top plate, and most of these are in the range 14927 to 15217; there are also some movements with only 2 digits under the top plate. As many of these are signed "Boston Watch Company" he sensibly suggests that these numbers are original Boston Watch Company serial numbers prefixed by "1"; that is, Boston Watch Company movements in the range 4927 to 5217. These Howard & Rice movements have escapements with vertical pallets on the levers, a style never used by the Boston Watch Company. So there can be little doubt that they were unfinished when Howard & Rice acquired them.

As watches with serial numbers 4081 to 4199 were finished by the American Watch Company, and as it is likely that movements were made in order of serial numbers, this necessarily implies that the movements with serial numbers 4200 to 5220 were also started. This large stock of unfinished movements at the time of the inventory is possible, because there were 1,170 frames in the inventory and there are 1,140 movements with serial numbers 4081 to 5220.

We need to distinguish between the status at the time of the inventory on 2nd February and the status at the time of the sale on 9th May:

(a) There are about 82 work days in the period from the inventory in February and the sale in May. Assuming the Boston Watch Company produced movements up until the day before the sale, and assuming 60 workers finished partially completed movements at 10 man-days each, about 492 could have been finished in this time, leaving 578 unfinished frames. The list of creditors of Curtis,[398] includes 61 people who were owed wages. This includes NB Sherwood and NP Stratton and so there were about 59 workers in the factory at the time of the insolvency.)

    I am assuming no more frames or parts were made, and all workers were employed finishing movements. This is credible, because Dennison employed skilled artisans and there would be few, if any, unskilled or semi-skilled workers unable to do this type of work.

    That is, if the maximum serial number on the frames was 5220 (from the movements that Howard finished), then the maximum serial number of the 492 finished watches must have been 4642; that is, 5220 - 578.

(b) As mentioned above, 122 movements were apparently finished by the American Watch Company and the first sales in June 1857 consisted of 29 movements without cases sold to Robbins & Appleton in two batches.[399]

396 Price, 2005, page 9.

397 Price, 2005, pages 48-49.

398 Suffolk Insolvency Court, 1857-58, document 116-003.

399 Tracy Baker, 1857b, page 3.

However, now we have a serious problem! Why were the ordinary movements with serial numbers 4081-4199 unfinished when *ordinary movements with serial numbers up to 4642 were finished*? Surely this is impossible if the factory processed movements *in order in small batches*? There is no explanation, unless Robbins delayed sales of them for some unknown reason.

So in May there might have been an additional 122 hidden, unfinished movements. That is, there were frames numbered 4081-4199 (+3) and frames numbered 4765-5220 making up the 578 frames that were unfinished. And consequently the last finished movement would have been number 4764 and Howard finished numbers 4765 to 5220, 456 movements. This agrees with Price's assessment.

(c) As mentioned above, Tracy stated that "... This left from twelve to twenty finished movements ... however, all of the finished movements were spirited away".[400] And the interrogatories specifically mention finished movements numbered 4891 to 4910.[401] This implies that, at the time of the sale in May, the Boston Watch Company had finished an additional 146 movements, about one month's worth of production, and Howard and Rice only finished 310 movements. However, as with the American Watch Company movements, these 20 movements might have been finished out of sequence and they could be misleading.

The above analysis suggests that the Boston Watch Company made 4,650 or 4,765 or 4,910 finished movements. As there is no way of choosing between these, a reasonable estimate is 4,800.

Finally, an important point needs to be made:

These figures range from -3.1% to +2.3% of the mean value 4,800. These are *very small variations* and, in the context of estimating the rate of production in man-days they simply cannot produce any significant changes.

Estimating the Rate of Production

Estimating the rate of production, the number of man-days per watch, requires three things:

(a) The number of watches produced. Despite the above, I will assume 4,900 watches were made in order to reduce the number of man-days.

(b) The number of workers. This is discussed below.

(c) The number of days worked. There were 310 working days per year; that is 52, 6-day working weeks with 3 holidays, an average of 25.8 days per month. Thus watches were manufactured for 1,240 days, 1853 to 1856 inclusive and for a further 77 days in 1857, making a total of 1,317 days.

The number of man-days to produce a watch continually *declines*. Assume that with existing machines, tools and methods it takes 18 man-days to make a movement. Then it is inevitable that after this point in time machines, tools and methods either remained the same or improved. And so the number of man-days either remained the same or decreased.

The number of man-days could increase, but only if a different type of watch movement was made. This did not happen; except for some variations in train layout and the number of jewels, all movements were simple timepieces with plain balances and flat balance-springs, and so there can be minimal variation due to adjusting. These were the only watches made by the Boston Watch Company.

And so the initial number of man-days per watch is important because it gives a *maximum* to the rate of production.

400 Tracy, E., 1886; see also Marsh, 1889, page 16.
401 Suffolk Insolvency Court, 1857-58, document 116-153-11, repeated in document 118-056-11.

According to Crossman, in late 1854,

> *The company then had about one hundred employees ... The company were struggling to make ten watches per day, but it was more frequently that six only were produced ...* [and] *very often at the end of the month it was found that not more than one hundred* [watches] *had been completed and put on the market.*[402]

Crossman's figures give rates of 10, 16.6 and 25.8 man-days per watch. And Abbott states that in 1854 production was 5 watches per day with 90 workers, giving 18 man-days.[403] Marsh also gives the figure of 18 man-days for late 1854.[404] The lowest and highest rates will be ignored, because they are probably the result of batch processing (see page 104), and so an initial figure of 18 man-days per watch in 1853 is sensible.

By far the greatest expense in making a watch was labour. To be more precise, if a watch takes x man-days to make with $x - 2$ days at $1 per day, and two days of skilled labour at $2.00 per day, then the labour cost c is:

$$c = (x - 2) + 4$$

or $20 for 18 man-days.

Estimating materials at $4,[405] the total cost of production is $24. This is confirmed by the 1857 inventory, which independently produces a cost of $23 (see page 96).

Also Crossman indicates that about 1853

> *movements cased in silver cost the company $18.00 for the work and material.*[406]

Using the above formula, this is a rate of about 16 man-days per watch at that time.

Also note that the cost of manufacture can only be reduced significantly by reducing the number of man-days of work.

We also have good estimates for the sale price. In 1853 watches "were sold at $40"[407] and in 1856 watches were "worth in silver cases from 30 to 50 dollars each".[408] This is a mark-up of about 73% for 18 man-days per watch which is feasible. (In today's money the sale price would be between $13,900 and $23,200.[409])

So the number of man-days to make a watch was initially about 18 and then dropped or remained static.

(The March 1856 Watham Sentinel article suggests a rate of between 6.25 and 7.5 man-days per watch; 75 workers producing 10 or 12 watches per day.[410] This is not credible and can only be an error or the result of batching.)

Two factors influence the number of employees. First, the company failed primarily because it did not repay its mortgage debts; that is, all borrowed money was put into production. Second, there were no work opportunities for skilled watchmakers outside the watch factory and if they were laid off they would leave the district. Consequently it was imperative that such people be continuously employed. Any reduction in employee numbers would preferably come from laying off unskilled labour, of which there were only a few.

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402 Crossman, 1885, page 24.
403 Abbott, 1905, page 19.
404 Marsh, 1921, page 11.
405 Harrold, 1999, page 596.
406 Crossman, 1885, page 21.
407 Abbott, 1905, page 18; Abbott, 1888, page 17; Marsh, 1921, page 7
408 Waltham Sentinel, 1856, page 144.
409 Measuring Worth, 2019.
410 Waltham Sentinel, 1856, page 144.

According to Crossman, in late 1854 the Waltham factory had 100 employees,[411] and according to Abbott the number was 90 at that time.[412] Marsh does say that in 1854 there were only 50 hands,[413] but later he states there were 90 workers at that time (30 watches per week at 18 man-days per watch).[414] All these figures may be correct if the workforce varied. Initially it was probably 50 (mainly transferred from Roxbury), but it built up to around 100 during the first few months at Waltham.

Estimated Man-Days per Watch

In the first edition of this book I went through many tedious and long methods for estimating the Boston Watch Company's production, but I have realised that none of the previous calculations were necessary and a simple approach to the problem is much better. Figure C1 summarises the method.

First, The man-days per watch started at 18 at the beginning of 1853 and then continuously dropped.

Second, the production was 4,900 watches; This is the highest feasible number to reduce the man-days per watch.

Third, the three years 1850 to 1852 and the month of April 1857 are ignored, again to reduce the number of days and so reduce the man-days per watch.

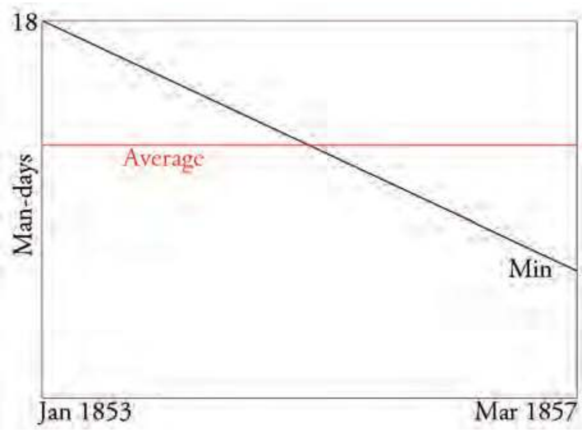

Figure C1

Fourth, the average man-days per watch over the 4¼ years can be estimated from the total number of days worked and the number of employees. As reducing the number of employees reduces the man-days per watch, *the work-force is made as low as possible*. For this reason, I will ignore Crossman, Abbott and Marsh and assume the Watham Sentinel article is correct and there were no more than 75 workers at any time. That is:

(a) Initially the rate was 18 man-days per watch.

(b) Taking into account the estimates of Crossmann, Abbott and Marsh, there were probably 75 or more workers for an extended period of about 2½ years from mid 1854 to the beginning of 1857, and 50 workers before then.

(c) Or, if the Watham Sentinel article is taken literally, and it refers to February 1856, there were 75 workers for 11 months, from February 1856 to the beginning of 1857, and 50 workers before then.

(d) At all other times there were 50 employees.

Table C1 is based on these estimates. The columns in it show, from left to right:

(1) Total number of months (4¼ years).

(2) The minimum number of workers (50).

(3) The number of workers employed (75) for part of the time, assuming the minimum number of workers at other times.

(4) The number of months for which the workers in (3) were employed.

(5) The total number of man-days worked.

411 Crossman, 1885, page 24.
412 Abbott, 1905, page 19.
413 Marsh, 1890, page 4.
414 Marsh, 1921, page 11.

(6) The number of watches produced.

(7) The average man-days per watch.

(8) The minimum man-days per watch achieved. This is an estimate assuming uniform production and is based on a maximum number of 18 man-days per watch; it is 2 x Average - 18.

Months	Min Workers	Workers	For months	Total Days	Production	Average Man Days	Min Man days	Notes
51	50	75	51	98813	4900	20.2	22.3	A
51	50	75	30	85250	4900	17.4	16.8	B
51	50	75	24	81375	4900	16.6	15.2	C
51	50	75	11	72979	4900	14.9	11.8	D

Table C1

Notes:

(A) There were 75 workers for the entire 4¼ years. This is impossible because the number of man-days increases when it should decrease or remain constant. So for at least part of the time there must have been fewer workers.

(B) Based on (b) above, there were 75 workers for 2½ years and 50 workers at other times. If this is correct, then the man-days per watch dropped by 1.2 man-days over the 4¼ years, from 18 to 16.8.

(C) The same as (B), but there were 75 workers for only 2 years and 50 workers at other times. If this is correct, then the man-days per watch dropped by 2.8 man-days over the 4¼ years.

(D) Based on (c) above, there were 75 workers for 11 months and 50 workers at other times. Here there is a substantial reduction of 6.2 man-days. However 14.9 man-days is not credible, because the 1857 inventory indicates a figure of about 19 man-days per watch (see page 96).

The spreadsheet from which Table C1 is derived can be changed arbitrarily to test other scenarios, from the sensible to the ridiculous. Table C2 shows one other probable permutation:

(a) The time is increased to 4½ years to include April 1857 when Charles Rice was leasing the factory.

(b) The minimum number of workers is increased to 60 to make a little more sense of the figures given by Crossmann, Abbott and Marsh.

(c) The production is reduced to 4,800 which is a more credible figure.

(d) The maximum man-days per watch is increased to 19, in line with the 1857 inventory.

Months	Min Workers	Workers	For months	Total Days	Production	Average Man Days	Min Man days	Notes
52	60	75	51	100363	4800	20.9	22.8	A
52	60	75	30	92225	4800	19.2	19.4	B
52	60	75	24	89900	4800	18.7	18.5	C
52	60	75	11	84863	4800	17.7	16.4	D

Table C2

Although open to debate, I think that the figures in Table C2 are closer to being correct than the figures in Table C1, and consequently best that the Boston Watch Company achieved was a rate of about 16.4 man-days per watch.

Conclusions

First, the only sensible conclusion to be drawn is that the Boston Watch Company never achieved a production of 10 watches per day. Indeed, it is most likely that production peaked at about 4.5 watches per day at a rate of about 16.5 man-days per watch.

Second, as production commenced at around 18 or 19 man-days per watch, the basic method of manufacturing watches did not change significantly, and the marginal improvement of about 1.5 man-days per watch would be due to minor changes in production methods or watch design, or simply a calculation error.

Batch Processing

It remains to explain the figures in the Waltham Sentinel article and Crossman. As noted above, Crossman gives three figures for production in late 1854 of 10, 16.6 and 25 man-days per watch. And the Waltham Sentinel article indicates a rate of 7.5 man-days per watch. How do we reconcile these figures with the above assessment, that rates of production of 7.5 or 10 man-days per watch could never have been achieved?

This apparent contradiction is, in fact quite easy to explain. Over extended periods of time average values are probably valid. However they need not apply to short periods because watches were produced in *batches*.

Although much later, Fitch provides a good description of batching:

> *The custom generally prevails of starting watches in large lots, say 1,000 of one kind or grade, 1,000 of another grade being started when these are out of the way, and so on. But the watches are not finished in the same order, the partly-finished portions being kept in store and given out in job lots of ten for assembling. ... Thus, while one lot of a thousand watches remains in the works, many subsequent lots may be completed. It is stated at some factories that the usual average time of completion is about five months, including the testing; it being obvious that no such time is required in the simple fabrication of the movement.*[415]

(This was written in 1880 when the rate of production was about 2.5 man-days per watch. That is, watches spent on average about 148 days in store!)

As a simple example, assume watches are made in batches of 100 at a rate of 16 man-days per watch. That is, the time needed to complete a batch would be 1,600 man-days. If there were 60 employees then the batch would take about 26.5 days to finish, assuming there was no other work to undertake. Now assume the watches pass through 4 steps of 4 man-days, each step employing 15 people and each step completed before the next step begins. Then:

(a) Step 1 takes 400 man-days or 26.5 days, after which the 15 people start on another batch.

(b) Step 2 takes 26.5 days and the batch is passed on to step 3 after 53 days.

(c) Step 3 takes 26.5 days and the batch is passed on to step 4 after 79.5 days.

(d) Step 4 takes 26.5 days during which time all 100 watches are finished.

Thus, the first watch is completed 83.5 days after work started (79.5 + 4 days) and the last after 106 days.

The total amount of work is 1,600 man-days. But, production (output of completed watches) is *zero* for 83.5 days and the 100 watches are completed in 22.5 days at a rate of 2.25 man-days per watch; that is, the apparent production in this period is about 4.5 watches per day when the overall production rate (100 watches in 106 days) is only 0.94 watches per day.

415 Fitch, 1883, page 61 (page 677).

Of course, as Fitch states, batches overlap. The above suggests the people performing step 1 work for 26.5 days and then are idle for 79.5 days, which is ludicrous. It also assumes each group of 15 people cannot perform other tasks. If, for example, all of the workers who performed step 3 were transferred to performing step 4 then the last phase would take 30 people only half the time, 11.25 days, at a rate of 8.9 watches per day.

Although this example is artificial, it indicates that *significant* rate variations can occur for short periods of time, and that apparently very high or very low rates of production are possible compared to the overall average rate; which is why Crossman could cite three very different figures.[416] It is only when production is examined over a longer period of time that representative figures can be determined.

Thus the high figures cited by the Waltham Sentinel article and Crossman need not conflict with the above analysis of long-term production.

Another, simpler explanation, and I think more likely to be correct, is that the figures provided to the Waltham Sentinel and to Crossman were simply advertising hype and were never actually achieved.

416 Crossman, 1885, page 24.

Appendix D: American Watch Company Production Rate 1857-1858

Sources of Data

As with the Boston Watch Company, the primary purpose of this analysis is to estimate the monthly rate of production, the man-days per watch, which is *Ed/W*, where *E* is the number of employees, *d* is the number of days worked in the month, and *W* is the watch production. In addition, the cost of a watch *C* is estimated. Because the number of employees is not known it has to be calculated from the payroll figures.

As with the Boston Watch Company, the original analysis in the first edition of this book was overly complex and, in parts, wrong.

In contrast to the production of the Boston Watch company, we have reasonably precise information about the production of the American Watch Company in its first two years. Table D1 summarises:

Month	Watches *W*	Costs *C*
5/57		
6/57		3000
7/57	100	3375
8/57	250	4978
9/57	150	4140
10/57	130	1307
11/57	470	4016
12/57	260	3993
1/58	540	4672
2/58	550	4957
3/58	690	6754
4/58	720	6197
5/58	700	6870
6/58	720	6465
7/58	710	6425
8/58	590	6043
9/58	600	6406
10/58	510	5789
11/58	600	6149
12/58	729	6665

Table D1

(a) Watch production:[417] This data only includes *new* production. Although the finishing of Boston Watch Company watches would have occupied employees during the first few months, this has been ignored. Except for two entries for which the year is uncertain, these figures are exact. Although the possible error caused by the two doubtful figures might noticeably change the November 1858 production, the overall effect is about 1.1% which is not significant. The total production is 9,019 watches.

(b) Production costs. These are based on data provided by Harrold;[418] see page 110.

To calculate *E* we need to know the average rate of pay and the payroll. There are three different ways to estimate the average rate of pay and consequently three different estimates for *E* and the man-days per watch.

Payroll Figures

The monthly payroll figures are given in Table D2, and they are used to determine the man-days per watch and to generate the graphs. For convenience, the spreadsheet that is used to generate the following graphs is based on the *daily payroll* for full-time workers. As a consequence, when there is part of a month or part-time work, I calculate figures for the equivalent full-time daily activity.

Originally I used Moore's payroll data.[419] However, despite Moore's vague disclaimer that "payroll does not necessarily indicate employment for the month since payments were sometimes curtailed" his data is misleading and contains a number of important errors. Initially, the Tracy Baker Cash Book [420] has entries such as "Manuf. Charges paid hands ...", clearly distinguishing the employees *E* from other staff. Later entries simply state "Manufacturing Charges", but obviously refer to employees.

The major errors in Moore's data are:

417 American Watch Company, ca 1900.
418 Harrold, 1999, page 596.
419 Moore, 1945, page 315.
420 Tracy Baker, 1857a.

(a) Moore states that the payroll in May 1857 was $822.90; this payment was made on Saturday 23rd May. However, there was also a payroll payment of $619.54 on Saturday 30th May which Moore has omitted.[421] So the total payroll for May was $1,442.44.

(b) Likewise, Moore gives the payroll for October 1857 as $417 when it was, in fact, $1,886.70.

(c) In many months there are a number of small payments in addition to the main payroll payments. In general, Moore has omitted these, although there is no justification for doing so. Some of these payments are, in fact, important; for example the payment of $44.95 on 4th August 1857 represents a significant amount of work when it is remembered that wages were around $1 per day.

(d) By simply presenting amounts in the months in which they were paid has produced misleading data. For example, Moore states the payroll in June 1858 was $6,171 and zero in the following month,[422] and both figures are inexplicable unless the dates of payment are analysed.

Payroll 1857-1858 ($)		
Month	Moore	Tracy Baker
5/57	823	1,442
6/57	Not given	3,117
7/57	2,575	2,827
8/57	3,728	3,087
9/57	3,190	3,269
10/57	417	1,820
11/57	1,316	1,349
12/57	2,713	3,343
1/58	2,552	2,756
2/58	2,257	2,548
3/58	3,499	4,022
4/58	2,817	4,488
5/58	3.570	4,999
6/58	6,171	3,770
7/58	0	3,184
8/58	3,183	3,783
9/58	3,506	*3,800*
10/58	Not given	*3,800*
11/58	Not given	*3,800*
12/58	Not given	*3,800*

Table D2

The most difficult and important of these problems is (d) above. From Tracy Baker (1857a) it is apparent that workers were paid weekly on Saturdays, and this is true for nearly all major payments to the end of November 1857. But after that date, pay days become erratic, the date commonly slipping into the next week, but this probably indicates that Robbins had cash flow problems rather than a change in the payment regime. It was probably influenced by the panic of 1857.

The obvious problem occurs with June and July 1858, but examination of the pay dates explains these two figures, In fact, $2,400.31 was paid out on 1st June and obviously belongs to the May payroll, leaving a credible $3,770.44 for June. Similarly, $3,183.66 was paid out on 3rd August and most or all has to be accounted for in July.

Simply moving $2,400.31 to May 1858 creates the same type of problem for that month. But $1,169.84 paid out on 4th May should be allocated to April. And so on. Similar problems occur with the 1857 figures.

Strictly speaking, because payroll payments were weekly, allocation to months should be done by splitting some payments between months. Although this is possible for 1857, payments in 1858 were erratic and it is not possible to be sure to which weeks they actually refer. This, and the fact that estimating the number of workers from the payroll is only approximate, makes a detailed analysis both very difficult and probably unnecessary. So for most entries I have simply re-allocated payments to the previous months, giving an adequate picture of activity.

The significance of the smaller payroll payments is not known, so they have been included in the same way. The resulting values are given under the head "Tracy Baker" in Table D2 together with Moore's original figures.

The final transactions in Tracy Baker (1857a) are for $3507 on 4th September (allocated to August) and $26 on 6th September. At this point:

421 Tracy Baker, 1857a.

422 Watkins, 2009b, page 63.

Tracy and Baker, perhaps snuffing the financial storm just ahead, abandoned all the capital, some $15,000, they had put into the venture, and in fact, abandoned by agreement the whole enterprise to me ...[423]

And so the accounts stopped and Robbins became the sole owner of the watch factory.

I could not find payroll information for September to December 1858 elsewhere. Previously I had guessed payrolls of $3,500 for October to December,[424] but the new figure of $3,800 is probably more realistic. (Also this increases the number of workers and hence the man-days per watch, which I am trying to do.)

In addition to the payroll for "hands", the Tracy Baker cash book includes payments to specific individuals. Moore notes one of these in his table of May 1857 expenses: "May 23 Merchandise Pd. Lynch for jewels $8.58", but there are many other such payments. The largest and most important of these are:

(a) A. L. Dennison: He received $1,454.52 over 14 months, an average of $103.89 per month. This is much less than his salary of $2,500 or $208.33 per month (see page 58), but I have no explanation for the difference, although he might have been forced to take a pay cut while the business was in difficulties.

(b) N. P. Stratton: He received $1,268.00 over 12 months, an average of $105.67 per month. Stratton's payments appear to have been based on $24 per week, rising to $25 per week.

(c) J. Appleton Jr: He was the brother of the partner in Robbins & Appleton,[425] and he received $1,536.57 over 6⅓ months, an average of $242.74 per month, significantly more than either Dennison or Stratton.

(d) C. G. Robbins: He received $590.81 over 7¾ months, an average of $76.23 per month. His role is unknown.

It is likely that these people were singled out because they were in managerial positions as superintendents in the factory but, although the roles of Dennison and Stratton can be guessed, the role of Appleton is a mystery.

In contrast, over about 4⅔ months Louis Felix received only $146.89, an average of $31.52 per month, but why such low payments were singled out by Tracy Baker is also a mystery.

The glaring omission is Ambrose Webster who is never mentioned in the cash book! Surely he would have been paid a fairly large salary as manager of the machine shop? Although he was not just a "hand", we must assume that his salary was included in the "Manufacturing Charges".

Royal Robbins kept a separate cash journal about which my notes simply say "nothing interesting", [426] but perhaps it includes relevant entries.

Production

Figures D1 and D2 show the production and cumulative production of finished watches. It is based on the Record,[427] and it is used to calculate the man-days per watch.

The November 1857 production is 470 watches, including 400 watches with serial numbers 1,001 to 1,400 (see page 117), but this large number is unlikely to be correct, especially as the employees only worked for 3 weeks. I have assumed that this is an error in the Record and I have moved 200 of the watches to December because that month's production appears to be too low.

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423 Robbins, 1883.
424 Watkins 2009b, page 62.
425 Moore, 1945, page 25.
426 Robbins, 1857.
427 American Watch Company, ca 1900.

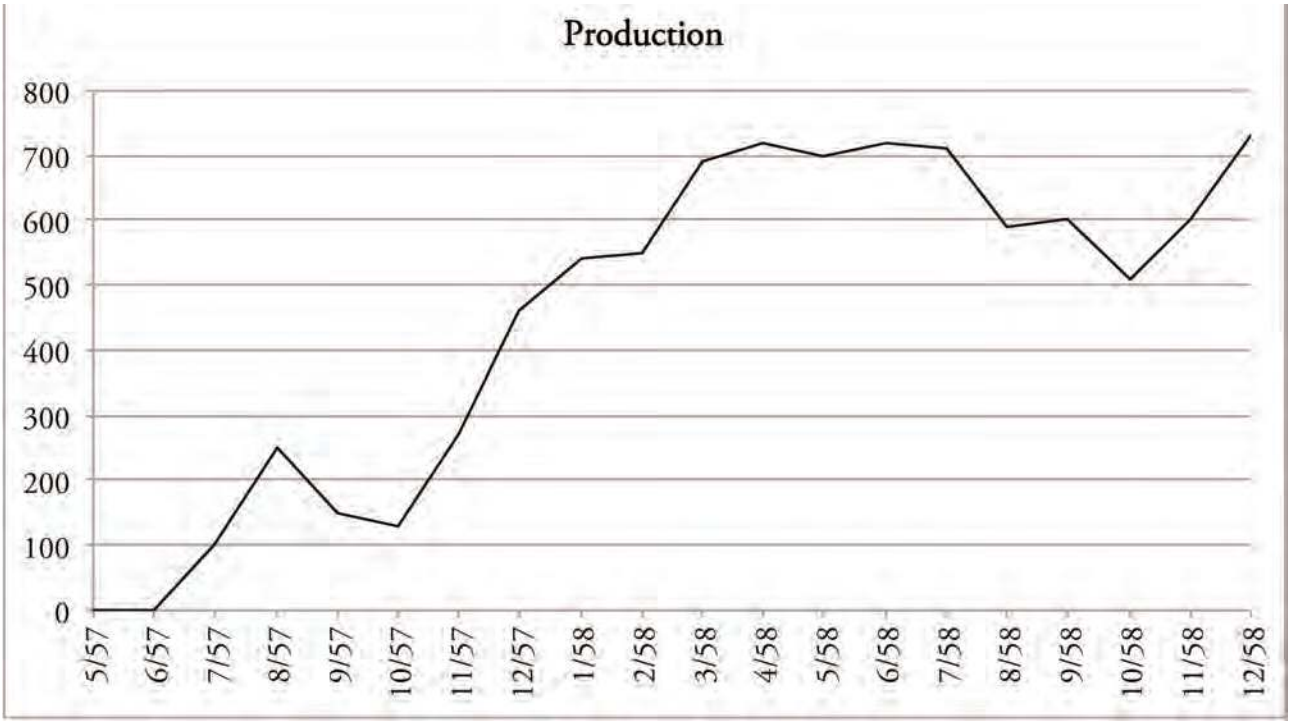


Figure D1

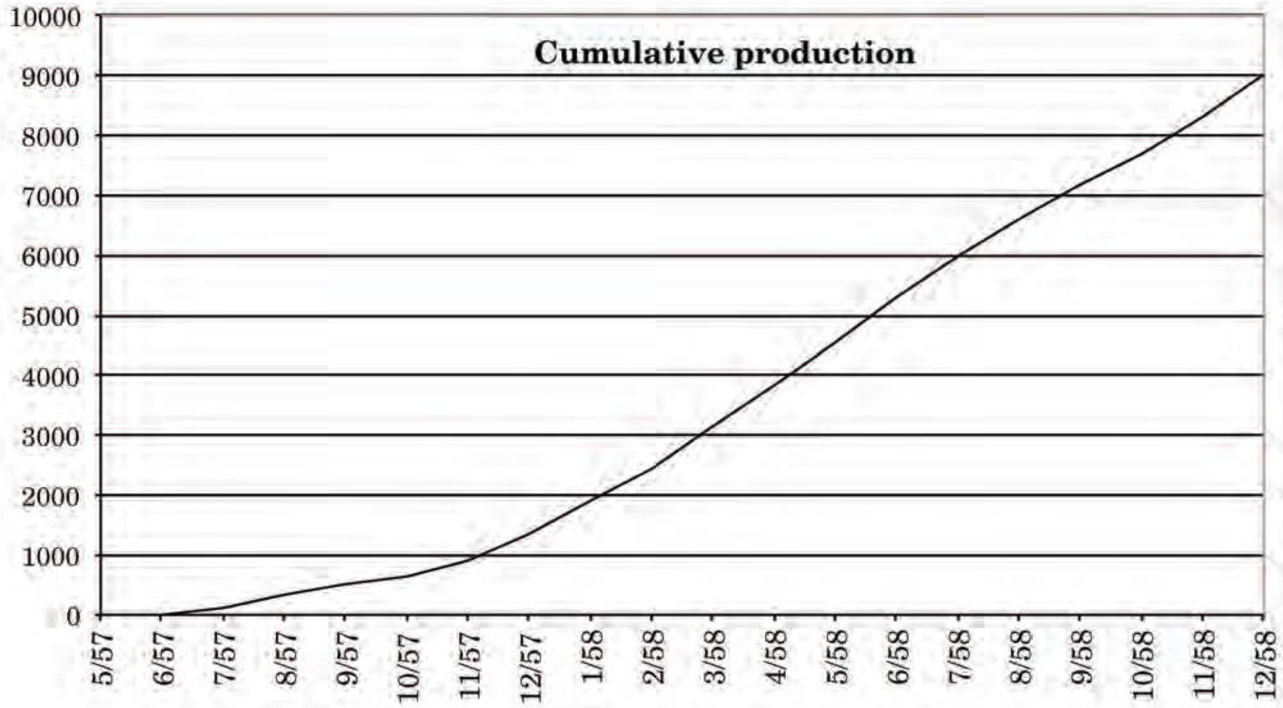


Figure D2

The Cost of a Watch

The costs in Table D1 are based on Harrold's data.[428] He estimated the total cost of production to be *payroll + overheads + materials + case* and I have used his estimates.

Thus the unit price is calculated independently of the number of man-days required to make a watch. The total cost of production *T* in any month is:

payroll + $500 + xW

where $500 is a constant allowance for overheads, *x* is the cost of materials, which is based on $1 for watch materials and $3 for the case, and *W* is the production in that month. However, Harrold takes into account that some movements were sold uncased and so *x* varies; it is 3 for June 1857 to January 1858 and 4 for the remaining time.

Both Harrold and I determine production cost per watch by simply dividing the total cost of production for a month by the number of watches made in that month, *C/W*. I use the actual payroll, the Tracy Baker figures in Table D2, and ignore the first two months.

In Figure D3 the initial cost figures vary, but after that they settle down to a fairly stable value around $10. The high early figures are the result of few watches have reached the stage where they could be completed; May and June 1857 have been omitted because they are misleading as there is a high payroll with few finished products.

A better idea of cost is obtained by using a cumulative average, Figure D4. The graph calculates the unit cost in month *M* as (*sum of costs for months June 1857 to M*) divided by (*sum of production for months June 1857 to M*). This evens out the monthly variations and gives a better idea of the way unit costs changed. Again the initial figures are too high, demonstrating the fact that production was in full swing but no or few movements were ready for finishing; in particular, about 60 people were employed in May but zero watches were produced!

As a result the July cumulative figure has about 72 people working for 2 months and producing only 100 watches. However, later figures give a good view of production with the final cost being about $11.

A major component of the overheads is advertising costs. The 1859 annual report includes $4,559.36 or $380 per month for advertising.[429] There may be some doubt about this figure. Robbins also gives $24,457.53 for the payroll,[430] but this is much too low, not only because it disagrees with the figures in Table D1, which add up to $65,004, but also because the number of employees would be too low for the number of watches produced; it represents production at the average rate of 2.0 man-days per watch which is not possible. So perhaps the advertising costs are also too low?

Just what other "overheads" should be included is a matter of opinion. It is common practice to separate out direct costs of production (cost of sales) from indirect costs (expenses), but Robbins does not do this.[431] Some expenses, such as machinery furniture and buildings, have to be averaged over the life of the item. Also, expenses associated with unfinished work cannot be included. Unfortunately Robbins is vague. For example, he states that the "Material goods in progress" to be $45,000, which is an enormous figure.[432] Presumably it is not the *cost* of work in progress but the *potential sales value* of it, in which case it corresponds to about 2,250 partially completed movements, a sensible number.

The cost data published by Harrold will not be considered further, because his production figures, presumably from Hawkins,[433] are clearly too low, the total being 7725 watches including 125 Boston Watch Company movements. However, except for a few instances, it shows the same trends and produces very similar conclusions.

428 Harrold, 1999, page 596.
429 Robbins, 1859, page 2.
430 Robbins, 1859, page 2.
431 Robbins, 1859, pages 2-3.
432 Robbins, 1859, page 2.
433 Hawkins, 1983.

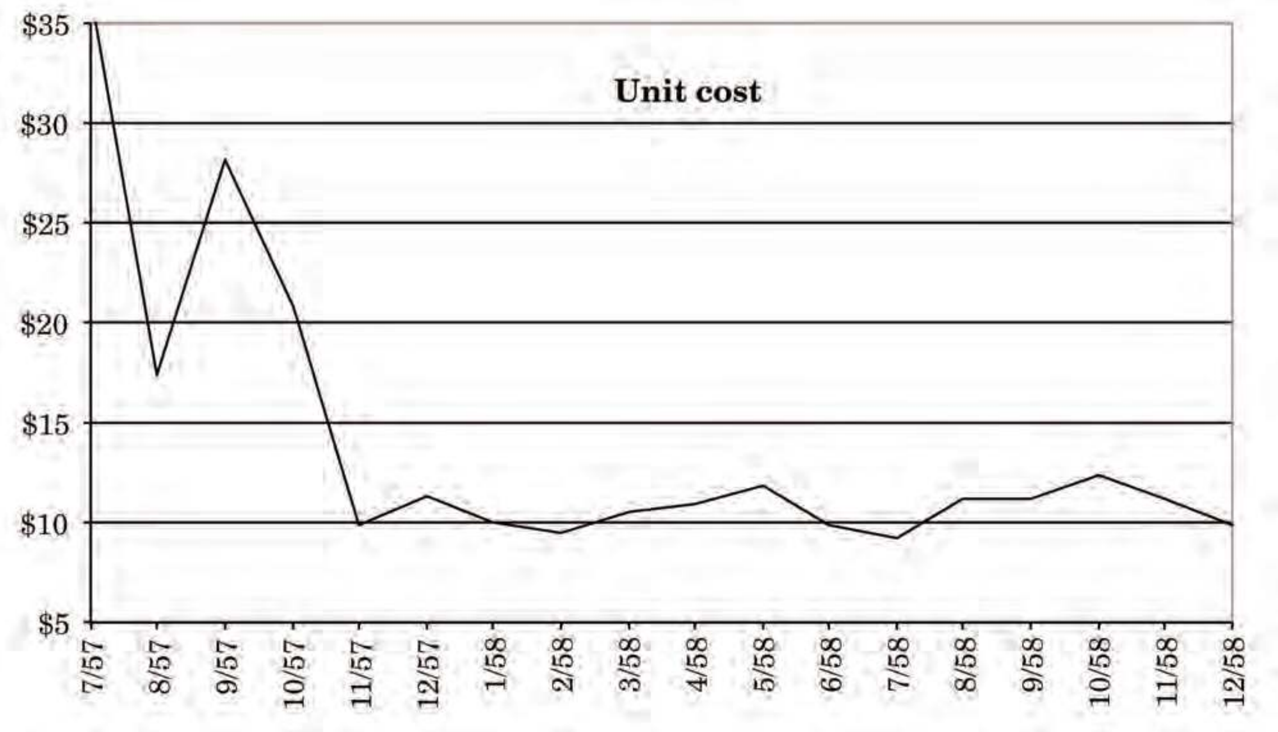


Figure D3

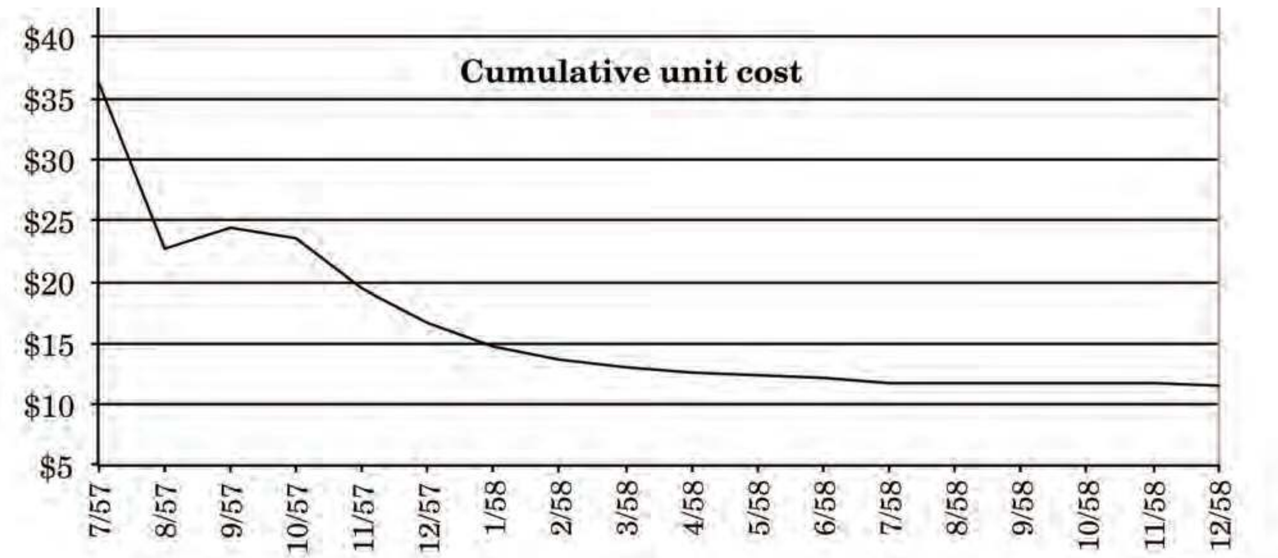


Figure D4

Days Worked and Payroll

Because three months are exceptional, it is easier to base the calculations on the daily figures.

The daily payroll P is used to calculate the number of employees and $P = p/d$, where p is the Tracy Baker payroll in Table D2 and d is the number of days worked in the month. The days worked in a normal month is 25.8 days (see page 100).

The three exceptional months are May, October and November 1857:

(a) Using the actual calendar for May 1857, there are 18 work days from Monday 11th May. However, we do not know how long it took Robbins to restart the factory, and I will assume that took one week. And so $d = 12$. This is largely irrelevant, because no watches were produced in the month, but it does impact on the number of people in the work force.

(b) According to Crossman,[434] in October 1857 "the time of the employees was reduced in October to one-half, with half pay and the factory was running this way for a few weeks. Then it was decided that still another reduction must be made ..."

Although vague, it appears that this reduction occurred for the whole of October 1857.

However, the payroll figures in Table D3 contradict this view.[435]

October 1857	Total	Saturday 3	Saturday 10	Friday 16	Saturday 24	Friday 30
	$1,819.54	$67.17	$5.33	$283.50	$670.58	$792.96
November 1857	Total	Saturday 7	Saturday 14	Saturday 21	Monday 30	
	$1,349.42	$430.41	$435.91	$449.91	$33.19	

Table D3

This shows that the employees worked full-time for 2 weeks (17th to 30th October), one week on probably 2/5 pay (10th to 16th October), and were furloughed for the first week. (When a worker is furloughed they do not work and receive no pay, but they are guaranteed their jobs and are re-employed when conditions improve.)

So the best estimate of the number of employees is derived from the daily payroll for the two weeks when they worked full-time.

(c) For 3 weeks in November 1857 there was a 50% wage cut,[436] and during this time the workers were employed ¾ time.[437]

Again from Table D3, employees were on half pay for 3 weeks and were furloughed for the last week. So the number of employees is best derived from the daily payroll for 3 weeks.

Employee Numbers

In order to determine the rate of production (man-days per watch) we need to know the number of employees E in each month; this is $E = P/R$, where P is the daily payroll and R is the average daily rate of pay per day. However, calculating R is not simple, because different workers would have had different rates of pay depending on their different skills. And so some assumptions have to be made.

The number of workers earning particular rates of pay can, in principle, be estimated from Fitch:

> *The percentage of the numbers of persons in the various duties of watch-making is here given roundly in an average of the practice at several factories, viz: The springing and finishing, including train finishing, 17½ per cent.; the pinion roughing and finishing, 15½ per cent.; the screw, flat steel, and escapement work, 12½ per cent.; the jewel making, 7½ per cent.; the jeweling, 7½ per cent.; the plate work and engraving, 7½ per cent.; the balance making, etc., 7 per cent.; the machine-shop work, 6½ per cent.; the dial work, 6 per cent.; the carpenter and blacksmith work, clerical work, watching and time-keeping, 6 per cent.; the stoning and gilding, 3½ per cent.; the mainspring making, 1½ per cent.; the nickel-finishing, 1½ per cent. ... The percentage of female operatives to the whole number ... for the whole work, from 33 to over 40 per cent.*[438]

Although Fitch was writing in 1880 and there were some changes in the types of watches manufactured which would alter these percentages, they at least provide a starting point.

It would be too difficult to estimate wages for each group, and so I will assume there were only two *average* rates of pay, one for skilled workers and one for the rest of the employees.

Assume E_U unskilled employees earn on average P_U ($ per day) and E_S skilled employees earn on average P_S. So the total daily payroll P is:

434 Crossman, 1885, page 39.
435 Tracy Baker, 1857a.
436 Crossman, 1885, page 39, Moore, 1945, page 315.
437 Crossman, 1885, page 39, Keith, 1883, page 36.
438 Fitch, 1883, page 62 (page 678).

$P = E_U P_U + E_S P_S$

Assume the fraction of workers earning the lower rate P_U is e_U and the fraction of workers earning the higher rate P_S is e_S; then $e_U + e_S = 1$. That is, if E is the total number of employees then:

$E_U = e_U E, \quad E_S = e_S E$ and so $P = e_U E P_U + e_S E P_S$

Consequently $E = P/(e_U P_U + e_S P_S)$

and the average daily payroll is $P_{AV} = e_U P_U + e_S P_S$

However, the values of e_U and e_S vary over time, and I shall make two assumptions about them.

First, the Boston Watch Company had about 75 employees at the time of the insolvency, most were skilled watchmakers, and Howard took some (about 15?) with him to Roxbury; we can be confident that Howard took the most skilled workers, those that he could not easily get elsewhere.. Consequently, a reasonable assumption is that $e_1 = 0.3$ and $e_2 = 0.7$, about 70% of employees were skilled, and so there were approximately 53 watchmakers and 22 unskilled workers.

If that is correct, the post insolvency American Watch Company inherited 38 skilled and 22 unskilled workers, and so the relative numbers changed to about $e_U = 0.4$ and $e_S = 0.6$. Robbins would not have wanted to significantly reduce the work-force when he took over. If he had, many people with hard-to-replace skills would have left the area and so, just as Dennison had to do, it was necessary to maintain the work-force, either by furloughing them or by employing them and suffering a significant payroll without any money coming in. Equally, Robbins needed to keep costs as low as possible until new machinery had been made and production of new watches started. Hence he would not have hired any new workers unless they were absolutely essential. From the available data, Robbins had to support the work-force during May and June 1857 before any new work was completed and could be sold. Consequently, the number of employees at the start of the period we are considering (May 1857) should not be more than about 60.

Second, over time the American Watch Company reduced the relative number of skilled employees and increased the relative number of unskilled workers. I assume that e_U increased by 0.01 each month, starting at 0.40 in May 1857 and ending at 0.59 in December 1858; that is, 40% to 59% unskilled.

In the following I calculate the number of workers using three different estimates of the average rate of pay P_{AV}. All assume that $P_U = \$1.00$.

(a) "Waltham": These figures are based on $P_U = \$1$, $P_S = \$3$ and they, I think, represent the upper limit for P_S as Stratton, one of the most valuable employees, earned about \$4 per day.

(b) Moore: Moore calculated that in August 1859 124 workers were employed at an average wage P_{AV} of \$1.546.[439] That is, a payroll of about \$192 per day and \$4,946 per month. If we assume $P_S = \$2.50$ then $e_U = 0.64$ and $e_S = 0.36$.

Using these figures, in December 1858 $e_U = 0.59$ and $P_{AV} = \$\ 1.62$; that is, over the next 8 months e_U increased by 0.5 and P_{AV} dropped by \$0.08, and these are consistent with the other figures generated by the spreadsheet.

(c) Harrold: In contrast, Harrold indicates factory wages P_U were \$1 per day and *"trained and skilled employees received about \$1.50 per day"*.[440] However Moore's figures above show that such a low value for P_S is impossible, because his average pay requires P_S to be at least \$2. However, I have included Harrold's data for comparison with the other two estimates.

Using these three estimates we can calculate the number of employees for each month, using the daily payroll, as in Figure D5.

The Waltham data and Moore's data give initial work-forces of 55 and 63 which are about the correct initial work force. However, Harrold's rates of pay produce a high initial work force of 92.

439 Moore, 1945, page 315

440 Harrold, 1999, pages 585-586.

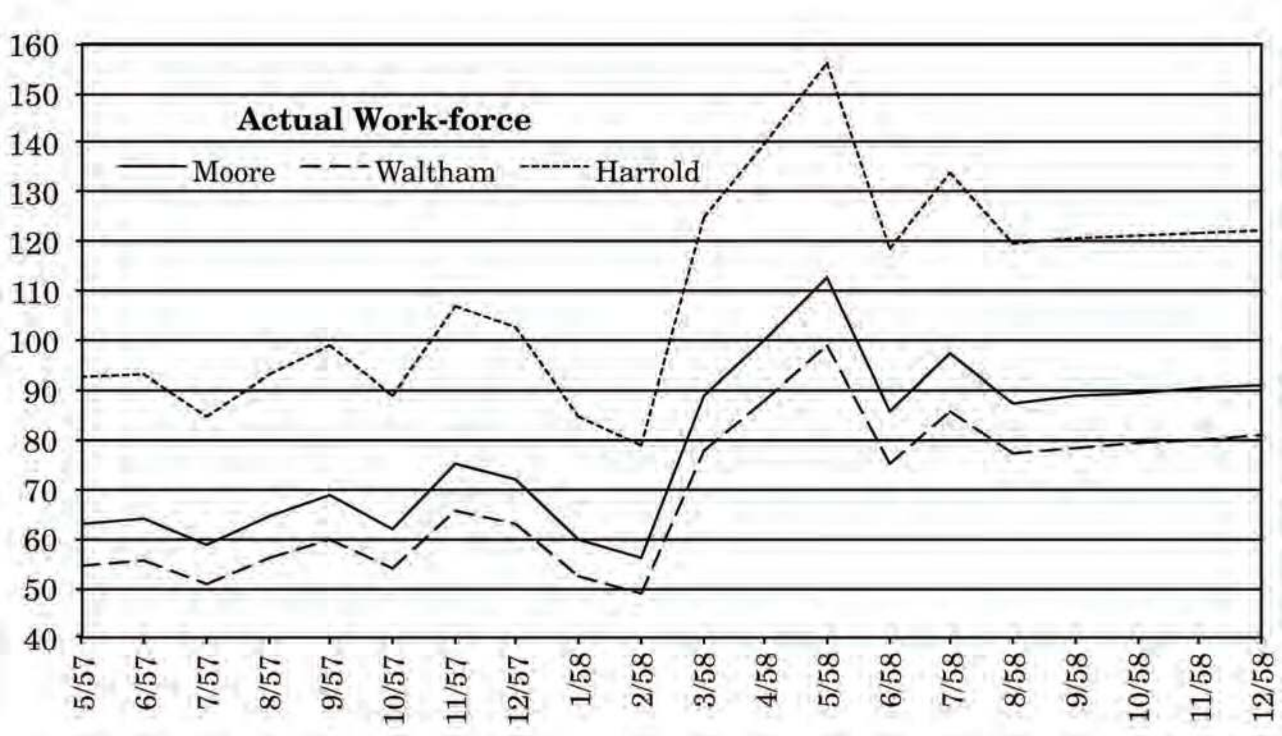


Figure D5

Two features need comments:

(a) In July 1858 the payroll is low and it suggests that employees worked for 3 out of 4 weeks. The daily payroll has been adjusted to reflect this in the same way that October and November 1857 were adjusted (page 109).

(b) The May 1858 work-force is too high, but I have no explanation for it. It might have included back-pay for January and February, which would result in a smoother upwards trend, but there is no evidence for this.

(c) As above, in the following graphs the Moore estimates are between the estimates based on "Waltham" and Harrold. I suspect, but of course cannot prove, that the Moore figures are closest to being correct.

Man-Days per Watch

For each month the man-days per watch is *Ed/W*, where there are *E* employees working for *d* days and manufacturing *W* watches manufactured in that month.

The number of days worked in most months is simply the number of days in that month; as before, I assume a 310 day working year and so the average working days per month is 25.8. However the number of days in May, October and November 1857 (see page 111), and July 1858 are less. May and June 1857 are omitted, because very few watches were manufactured.

From this and the production data we get Figure D6.

The figure for August 1857 is low, suggesting that the workers were finishing a stock of watches.

Although the figures for the first few months are high, the cumulative average, Figure D7, provides a more realistic picture overall. The under-production of finished watches in September and October is probably explained by batching, discussed at page 104.

What is important is to note that the significant differences in the methods of estimating the rate of pay P_{AV} make very little difference to the outcome.

According to Moore, in the next year 1859 there were 200 workers producing 50 watches per day, 4 man-days per watch.[441] These figures fit with the above analysis.

However, these figures are embarrassing. With the Boston Watch Company our problem was to try to reduce the number of man-days per watch without reducing the number of employees to an unrealistic level. However, with the American Watch Company the problem is the exact reverse; how can we increase the number of man-days per watch without increasing the number of employees. But the consistent values from January to December 1858 clearly show normal production at a rate of about 4 to 5 man-days per watch.

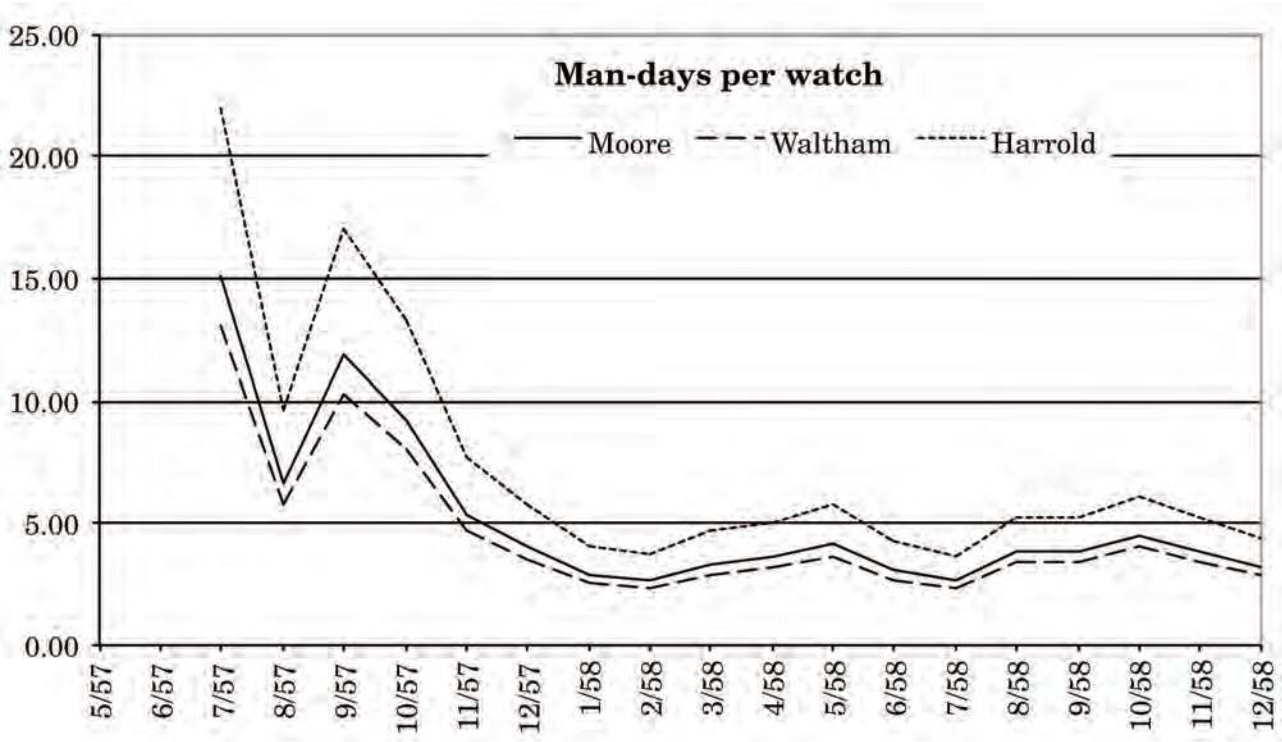


Figure D6

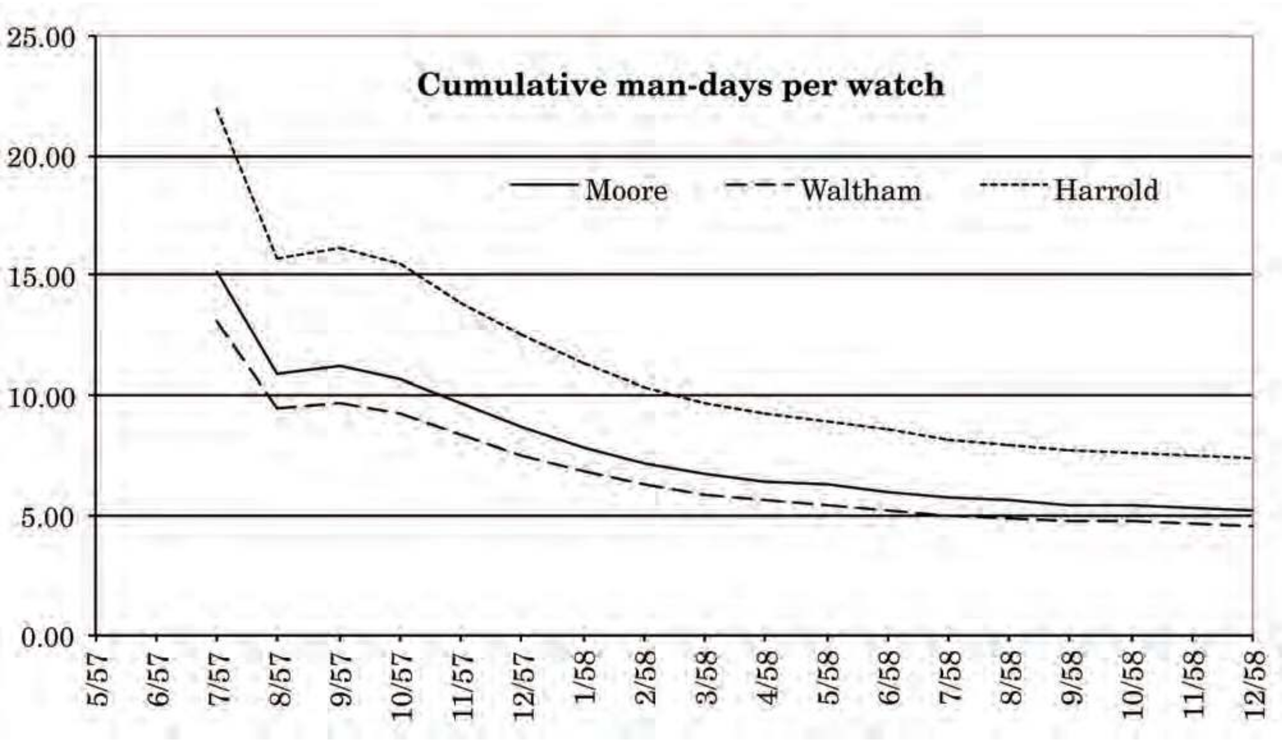


Figure D7

441 Moore, 1945, page 56,

Record of Watches, Page 1

The *Record* consisted of detailed descriptions of every movement made in Waltham from 1857 to about 1898, probably written on cards. It was created to enable the factory to make replacements for parts that were not interchangeable (see page 63 on).

It appears that two volumes were created from the Record, summarising the production of the company. Volume 1 goes from 1857 to May 1883, serial numbers 1,001 to 1,500,000. Volume 2, in different hand writing, continues up to September 1898 and serial number 6,513,495.[442]

In 1883 Ezra Fitch took over as general manager and shifted the focus of the company to sales.[443] In 1898 Robbins had a stroke and began relinquishing control to Fitch.[444] The dates may be coincidences, but I do not think so.

The following facsimile of page 1, volume 1 of the Record of Watches was provided by the NAWCC library. Page 1 is included here for the following reasons:

(a) From serial number 5501 onwards the watch record shows that movements were manufactured in batches of 10 (see page 97). It is likely that the preceding entries summarise production.

(b) The number column states "numbers started with 1000" and this is confirmed by Hawkins (1983). Serial numbers 1001 to 2200 are Model 57 movements made by the American Watch Company.

(c) According to Hawkins serial numbers 2201 to 5000 were not made by the American Watch Company;[445] however, there is one stray movement number 2328, but it is not known if this is genuine or an error in Hawkins's data.

(d) Serial numbers 2201 to 2600 are listed as not made by the American Watch Company, and Price (2005) confirms this gap. However, movements with these serial numbers were made by the Boston Watch Company.[446]

    Price is equivocal but assumes this entry is a "filler" to complete the sequence of serial numbers and is of the opinion (with which I agree) that the entry is not significant.[447]

(e) As in (d), serial numbers 2601 to 5000 were not made by the American Watch Company, but they are listed as "Dennison, Howard & Davis" with the annotation that "The Dennison, Howard & Davis Co finished work on this last hundred." But the annotation does not make sense, as it is referring to a group of 2,400 movements, although it may be stating that the Boston Watch Company completed movements up to serial number 4900. That interpretation is possible as Robbins, from the interrogatories, was aware of some movements with serial numbers about 4900 (see page 53).

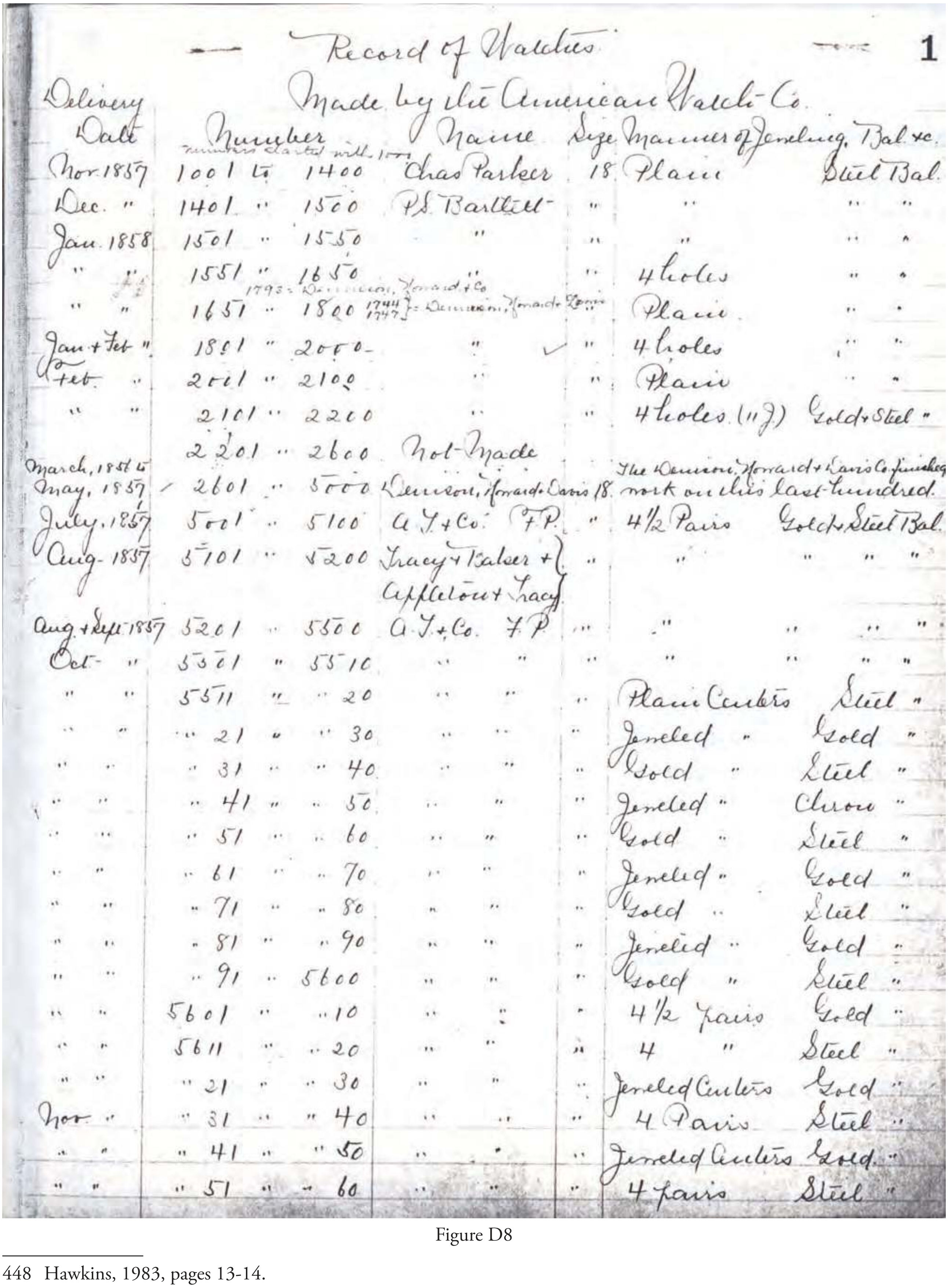
    These movements are listed as completed between March 1856 and May 1857. However, assuming 60 workers, the 2,400 movements would have to be manufactured at a rate of about 9 man-days per movement, which is about double the average rate achieved by the Boston Watch Company. Consequently, the dates must be wrong. Again, this entry is probably a "filler" to complete the sequence of serial numbers. But why these movements are distinguished from the group in (d) is unknown.

(f) The record of watches reports that three movements with serial numbers 1744, 1747 and 1793 were made by Dennison, Howard & Davis. However, movements with serial numbers 1651 to

442 American Watch Company, c1900
443 Moore, 1945, pages 75-76, page 237.
444 Moore, 1945, pages 86.
445 Hawkins, 1983, pages 22-25.
446 Price, 2005, pages 60-61.
447 Price, 2005, pages 45-46.

1800, including these three serial numbers, were Model 57, PS Bartlett movements made by the American Watch Company.[448]

I think that the only possible reason for these three movements to be listed is because the American Watch Company came into possession of them. Either they were left in the factory when Robbins purchased it or they were given to Robbins by Charles Rice.



Record of Watches — 1

Made by the American Watch Co.

Delivery Date	Number	Name	Size	Manner of Jeweling, Bal. &c.	
	(numbers started with 1001)				
Nov. 1857	1001 to 1400	Chas Parker	18	Plain	Steel Bal.
Dec. "	1401 " 1500	P.S. Bartlett	"	"	" "
Jan. 1858	1501 " 1550	"	"	"	" "
" "	1551 " 1650	"	"	4 holes	" "
" "	1651 " 1800 (1793 = Dennison, Howard & Co; 1744, 1747 = Dennison, Howard & Davis)			Plain	" "
Jan + Feb "	1801 " 2000	"	"	4 holes	" "
Feb. "	2001 " 2100	"	"	Plain	" "
" "	2101 " 2200	"	"	4 holes (11 J)	Gold + Steel "
	2201 " 2600	Not Made			
March, 1856 to May, 1857	2601 " 5000	Dennison, Howard & Davis	18	The Dennison, Howard & Davis Co finished work on this last hundred.	
July, 1857	5001 " 5100	A. T. & Co. F.P.	"	4½ Pairs	Gold & Steel Bal.
Aug. 1857	5101 " 5200	Tracy & Baker & Appleton & Tracy	"	"	" " "
Aug + Sept 1857	5201 " 5500	A. T. & Co. F.P.	"	"	" " "
Oct. "	5501 " 5510	" "	"	"	" " "
" "	5511 " " 20	" "	"	Plain Centers	Steel "
" "	" 21 " " 30	" "	"	Jeweled "	Gold "
" "	" 31 " " 40	" "	"	Gold "	Steel "
" "	" 41 " " 50	" "	"	Jeweled "	Chron "
" "	" 51 " " 60	" "	"	Gold "	Steel "
" "	" 61 " " 70	" "	"	Jeweled "	Gold "
" "	" 71 " " 80	" "	"	Gold "	Steel "
" "	" 81 " " 90	" "	"	Jeweled "	Gold "
" "	" 91 " 5600	" "	"	Gold "	Steel "
" "	5601 " " 10	" "	"	4½ Pairs	Gold "
" "	5611 " " 20	" "	"	4 "	Steel "
" "	" 21 " " 30	" "	"	Jeweled Centers	Gold "
Nov. "	" 31 " " 40	" "	"	4 Pairs	Steel "
" "	" 41 " " 50	" "	"	Jeweled Centers	Gold "
" "	" 51 " " 60	" "	"	4 Pairs	Steel "

Figure D8

448 Hawkins, 1983, pages 13-14.

Appendix E: The Endshake Tool

The following description is taken from Jacques David[449]; the text in brackets are my insertions. The tool is also described by Sherwood and Watkins.[450] Sherwood's explanation is obscure and inadequate, partly because it is described in the context of repair. David's description shows that its primary use was for manufacture, the repetitive processing of batches of watches after the tool had been set up with a standard arbor Unfortunately, Sherwood does not mention how or when he invented this tool.

The mobile pivots do not have exactly the same length, either because of turning or as a result of polishing. [Elsewhere David points out that considerable care was taken to ensure that the overall length of arbors was constant. The variations in pivot length result from variations in their shoulders.] *These errors are rectified in the following way, by an operation as delicate as it is ingenious.*

The chatons of the top plate are set up and the top plate is mounted on the pillar plate.

The difference between pivot lengths is allowed for by the chaton of the pillar plate. A shoulder is turned on it in order to insert it further into the plate if the mobile pivots are short and to insert it less if the mobile it must receive has long pivots. To be turned in this way, the chaton is gripped in a chuck to the left of the slide rest [shown in Figure E2].

A is the left edge of the graver which turns the shoulder of the chaton. B is a center which rests against the jewel. The distance between A and B varies according to the lengths of the mobile's pivots. The movement is placed between the centers e and g, with the top plate resting against g. The center f rests against the flat face of the top plate jewel; for that to happen f passes through the hole in the pillar plate.

In the same way the center e rests on the shoulder made for the chaton in the pillar plate hole. Thus the distance between the ends of e and f is the distance of the planting of the 2 jewels.

If a correctly pivoted (standard) mobile is put between c and d, the position of the graver can be adjusted with respect to the point B in such a way that the graver A finds the edge of the chaton slightly higher than the jewel [as indicated in Figure E1]. *The difference between m and n will give end play to the mobile.*

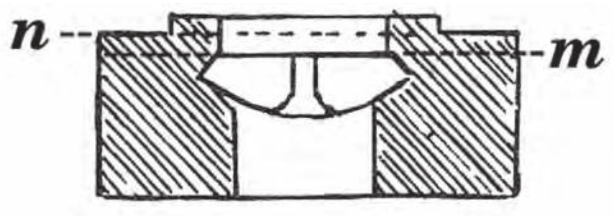


Figure E1 (reproduced from David, page 62)

This first adjustment of the relative positions of A and B being done, it should be understood that if a mobile is introduced which has long pivots, the point B will overlap the graver A and the shoulder turning will be shallower than with the correctly pivoted mobile. This chaton when put in place will descend into the hole less than the normal chaton.

If, on the contrary, a mobile is introduced which has pivots shorter than the standard, the point B will be held behind the graver and the graver will remove more material from the chaton. The chaton, when set up in the plate, will descend further than the normal chaton and the mobile will not have too much end play, even though it pivots are too short. The shoulders of all the chatons which go in the pillar plate are turned in this manner.

If there are no jewels, which happens in ordinary movements, end play is given by placing the wheels and testing them. The plate is recessed more or less to suit, using a hand-held or preferably a fixed graver.

449 David, 2003, pages 62-63.
450 Sherwood, 1892, pages 85-91; Watkins, 2004, pages 298-299.

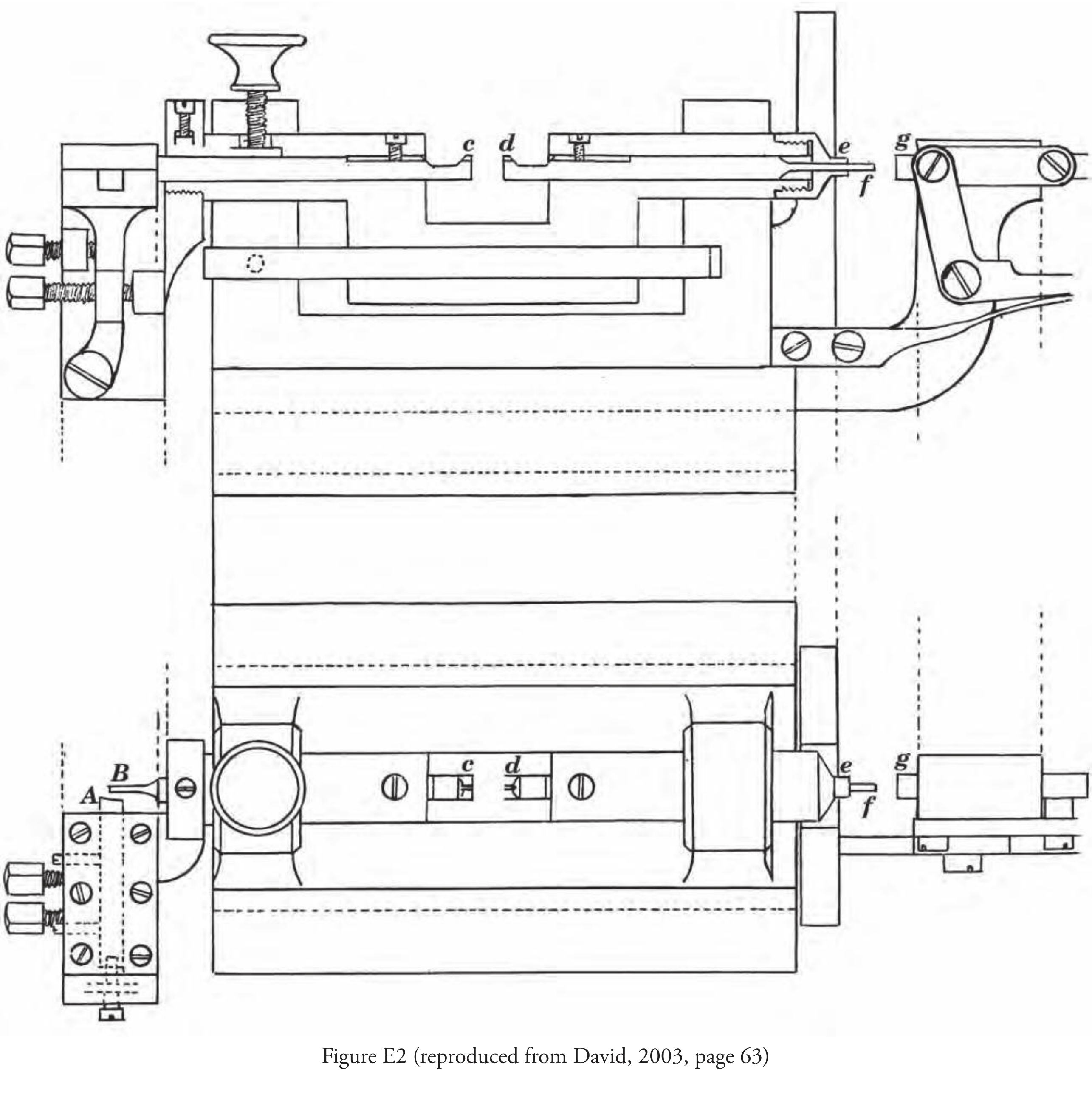


Figure E2 (reproduced from David, 2003, page 63)

Appendix F: Balance And Spring Matching

Houriet describes the process of matching balances and balance springs for watches, and Figure F1 and the following edited description are from that source: [451]

*This consists of three apparatuses **a**, **b**, **c**, all quite similar, which are used: first, to classify the balance springs according to the number of vibrations which they give with a standard balance; second, to classify in the same way balances against a balance spring; and third to determine the length of the blade, the balance and the balance spring being joined together.*

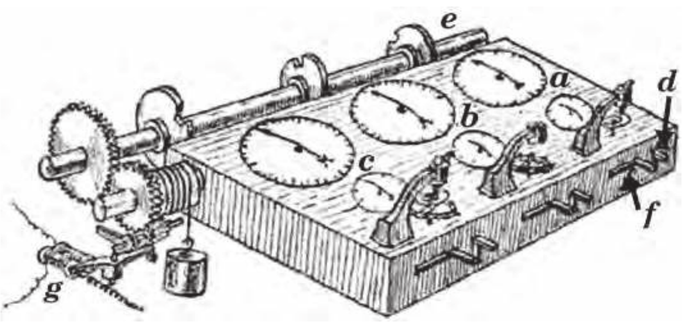


Figure F1

These apparatuses are automatic meters. They are independent of each other, and each one has a special movement having its engine (weight or spring), with a large and small hand assembled on the axes of the mobiles, an escapement and a balance axis whose end rises up under the brackets.

*This end is arranged so that one can fix at **a** a balance spring, at **b** a balance, and at **c** a balance carrying a balance spring.*

*With the apparatus **a**, under the table the axis carries a balance of a given diameter and weight; the balance spring to be tested is held at its end by tweezers, as with our vibrators. While stationary, the two hands are on zero: it is started by the lever at **d** which acts on the cam **e**. It rotates in a fixed amount of time, then the lever engages in the notch and the movement stops instantly. The two hands then indicate the number of vibrations that the balance spring has made during this time, and it is classified and put in a numbered rack.*

*The same operation is done for balances with the apparatus **b**.*

*One then chooses from the rack balances and balance springs which will definitely go together, by taking for example a balance which gives two vibrations less than the desired number and a balance spring which makes two more of them. This balance, provided with the balance spring, is fixed by a small grip on the axis of the apparatus **c** where, after some tests, the worker, by giving more or less length to the blade, will be able to make it beat the desired number of vibrations as indicated by the hands. He marks the blade at the place where the stud must be attached.*

*Before each operation, the hands are brought back to zero on the dials, like those of a stop watch, using the lever **f**. The accuracy of their indications depends on the rotating cams; for that, the axle on which they are fixed by friction is moved by a weight which runs a train ending in a flirt which is released automatically every second. The regularity of this release is controlled by the seconds pendulum of a precision regulator which, while running, opens the current of an electrical circuit magnetising the reel **g**.*

*At the factory, a certain number of apparatuses **a**, **b** or **c** are joined together; a worker has fifteen of them to supervise.*

The balance spring is attached to the stud by means of a small tool that the worker holds in one hand; the balance and the stud are held in the position that they occupy relative to each other under a cock; the balance can rotate so that the balance spring can be put in the hole of the stud without twisting the it, and without having to worry about putting it out of flat or eccentric.

If, after the operation of counting on the machine, the perfection of the adjustment is not sufficient, it is fixed by the timing screws which the balances carry, they often have four of them.

451 Houriet, Ch, 1895, pages 23-24.

Appendix G: Domestic Sewing Machine Presser-Feet

Simple Presser-Feet

Mechanical, lock-stitch domestic sewing machines can only stitch in a straight line. Figure G1 shows the basic mechanism of a "modern" Singer 201K made in 1948.[452] A spring loaded *presser-foot* above the material presses it firmly onto the saw-tooth *feed-dogs* in the base of the machine. The feed-dogs have, in the photograph, a left, down, right and up motion, which draws the material past the needle, allowing a line of stitches to be produced.[453]

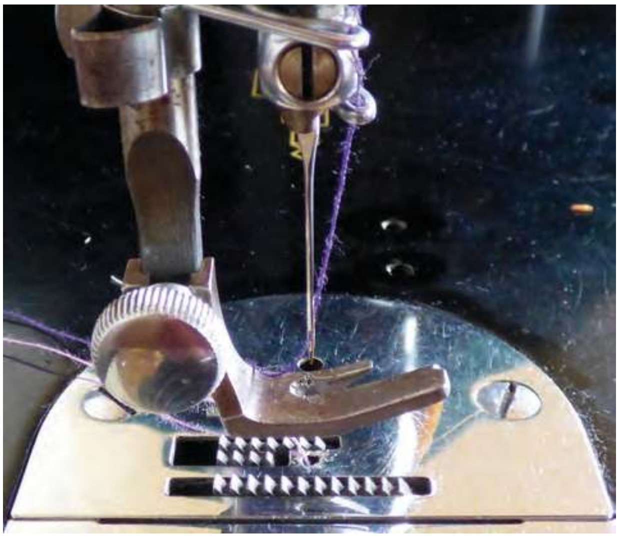


Figure G1

These feed-dogs were patented by Allan Wilson in 1854.[454]

Figure G2 shows the mechanism in the head of the same machine. The left rod ***A*** controls the presser-foot; the lever ***B*** on the outside raises it, as in Figure G1. It is free but held down by a spring. The center rod ***C*** has the needle attached to it and it can only move vertically, controlled by the linkage ***F*** that attaches it eccentrically to the drive shaft ***D*** running from the back of the machine. (A second linkage ***G*** is attached to a lever at the upper right to control the thread tension.) The counter-weight ***E*** is to avoid vibration. Clearly the needle cannot move sideways and the only variation possible is the stitch length, which is controlled by the distance the feed-dogs move.

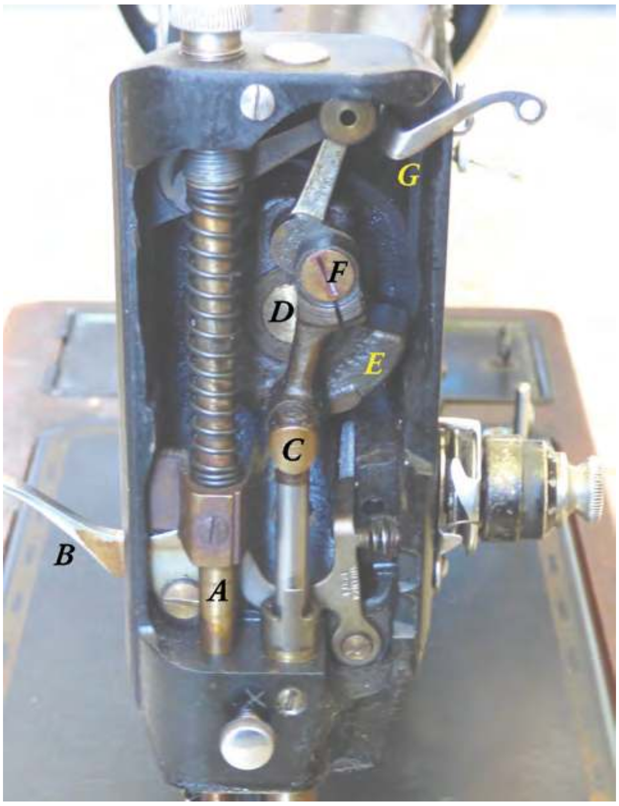


Figure G2

There are several ways to form the *lock stitch*, when the thread in the needle is inter-twined with the second thread in the base of the machine, and these mechanisms are described in detail elsewhere.

Although there are many instructions on how to *use* presser-feet, I have found no explanations of how they *work*, even though they are probably the most important features of sewing machines. This is because they enable the machine to perform complex tasks easily, tasks that would otherwise be very difficult and time consuming; for example, the hemmer foot illustrated on page 76.

In addition, most photographs of sewing machines do not display the presser-feet or how they are joined to the rod or square bar that holds them. And of the few useful photographs, the machines in them are not dated and the chronology of changes in the design of presser-feet is very hard to quantify.

452 Askaroff, 2019.
453 Wikipedia, 2019b.
454 Warren, 2020.

Consequently, the history of presser-feet is largely unknown.

In Figure G1 the presser-foot is *side-clamped* and held on by a large thumb screw, so it can be easily replaced by another presser-foot. But early machines did not have this feature and were limited to one or a few similar designs. For example, some photographs indicate that the presser-foot is fixed onto the presser-foot rod and cannot be removed. And other designs appear to have the foot held by an ordinary countersunk screw or nut threaded onto the rod.

However, there is some documentation of Singer sewing machine presser-feet. This is because from about 1888 Singer produced *style boxes* which held a set of presser-feet; these style boxes are commonly called *puzzle boxes* because of the way they unfold.[455] The majority of these were produced in the 19th century because the style 11 box is dated 1901.[456] It retailed for $5, about $1,150 now.

Figure G3 is a style 1 box dated 1888,[457] and Figure G4 is probably a style 12 box dated about 1905;[458] both are for vibrating shuttle machines. In Figure G3 the parts are held in place by small thumb screws, but in Figure G4 they slip under metal clamps.

The important feature is the method of attaching the feet:

(a) Style 1 box, Figure G3: The left arrow in Figure G3 (pointing to the ruffler 12) clearly shows that the machine used side-clamping and, although difficult to see, the three feet 7, 8 and 9, with the top arrow pointing to 7, are also side-clamping. However, in the second compartment from the right, the five *hemmers* 1 - 5 and the *binder* 6 have long, curved posts and are back-clamping! (This is easier to understand by comparison with Figure G4 that has the same parts but they are attached differently.)

    This is why there is a complex *attachment foot* 7 highlighted by the top arrow. The attachment foot is side-clamped onto the presser-rod, and the attachment has a slot that fits between the lever and the base of the foot. Then the lever is raised up to lock it into place, as in Figure G5.[459]

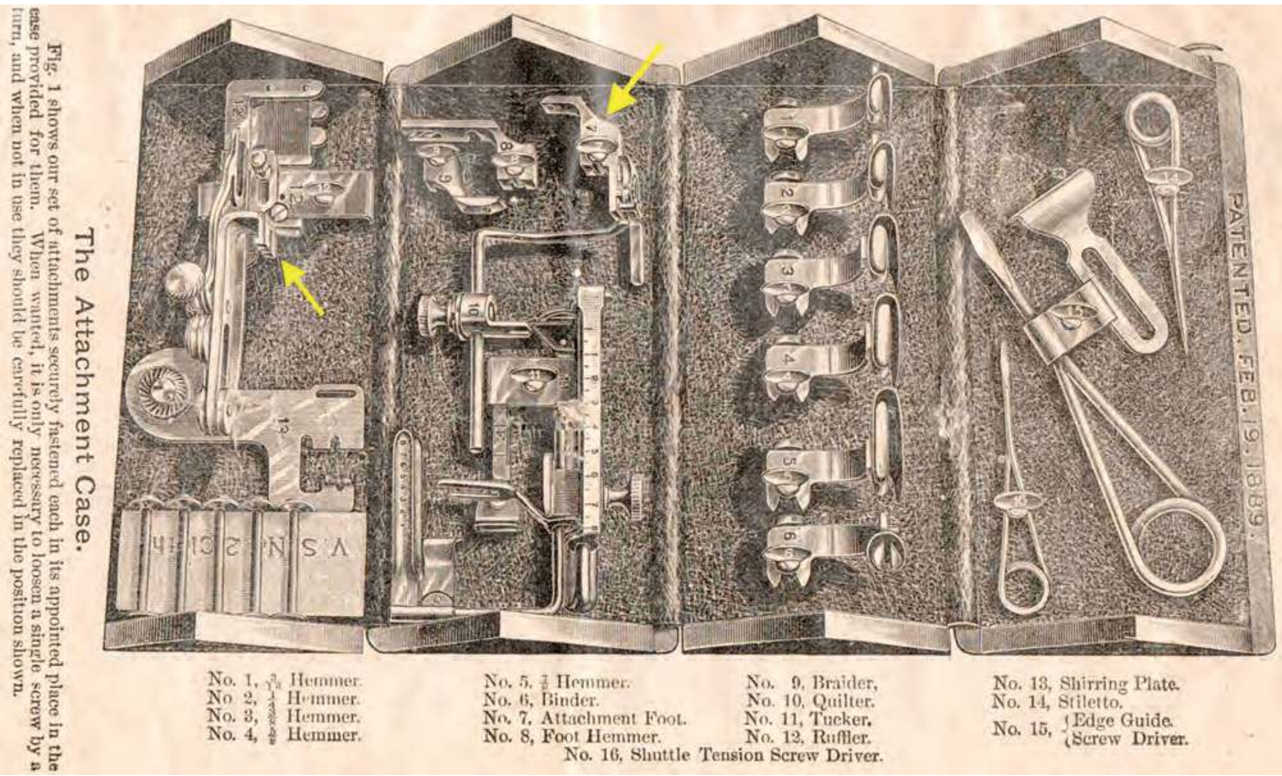


Figure G3

455 Singer, 2020a; Wikipedia, 2020b.

456 Singer, 1901.

457 Singer, 1889.

458 Watkins, 2020.

459 Phillips, 2008.

(b) Style 3 box, Figure G4: This uses side-clamping, but again the five hemmers and the binder do not attach directly. Instead these accessories terminate in a rod that is inserted into the attachment foot and fixed with a thumb screw. Figure G4 might be of a style 7 box, because they are very similar.

Figure G4

However, the contents of the different style boxes is not clear, as many images of them appear to have an assortment of parts that actually belong to different styles and the boxes are often missing parts. For example, a photograph of a "style 14 box" [460] might actually be an incomplete style 3 box.[461]

All these presser-feet are simple in that their purpose is to make it easier to manipulate the material while sewing in a *straight line*, the only thing that these sewing machines can do. (It is possible to sew in a curve by turning the material after each stitch, but this is freehand stitching is relatively difficult.)

For example, Figure G5 shows the use of a hemmer attachment and the way it is mounted on an 1888 vibrating shuttle machine:

> *Substitute the attachment foot for the ordinary presser-foot, and attach the wide-hemmer to it as shown above. … Enter the right-hand edge of the cloth into the hemmer, turning it to the left until it fills the scroll. Lower the presser-foot and commence to sew, being careful to hold the goods so as to keep the scroll full.* [462]

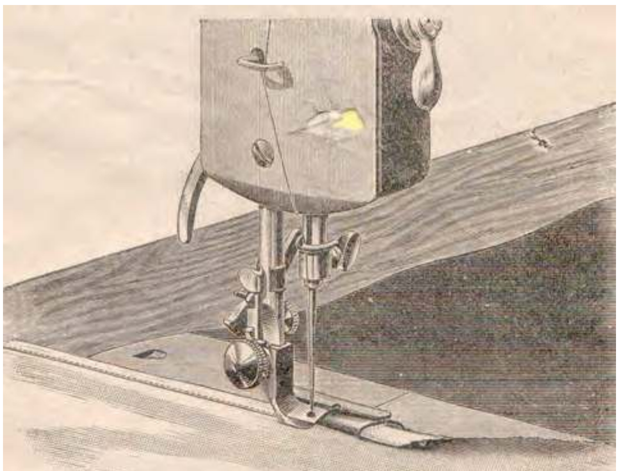


Figure G5

The hemmer is very important because it is used to stop the edge of the material fraying. Similarly the binder foot attaches a separate, narrow piece of

460 Wikipedia, 2020a.
461 Singer, 2020a.
462 Singer, 1889, page 15.

material to the edge of the main material. And many other presser-feet achieve other common tasks which are very difficult to do free-hand.

Figure G6 shows the same type of hemmer, but with a later method of attachment to another vibrating shuttle machine.[463] This form of attachment would have been included in a style box, but there is no information about it (perhaps it is style 2 as I think it probably comes between the other two methods of attachment). However the hemmer is Singer Part No. 25509 and it is attached by the braiding foot, Singer Part No. 25510.[464]

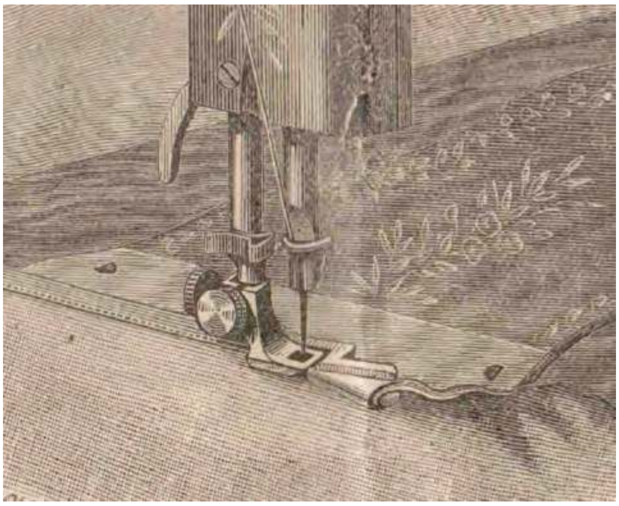


Figure G6

In addition, Figure G7 shows the attachment method used in the style box in Figure G4.

There is no doubt that the presser-foot rod and its side-clamping flat and screw hole were standardised at some time before 1888. But also the distance between the presser-foot rod and the needle rod must have been standardised, so that the needle can go down through the foot and into its hole in the bed of the machine.

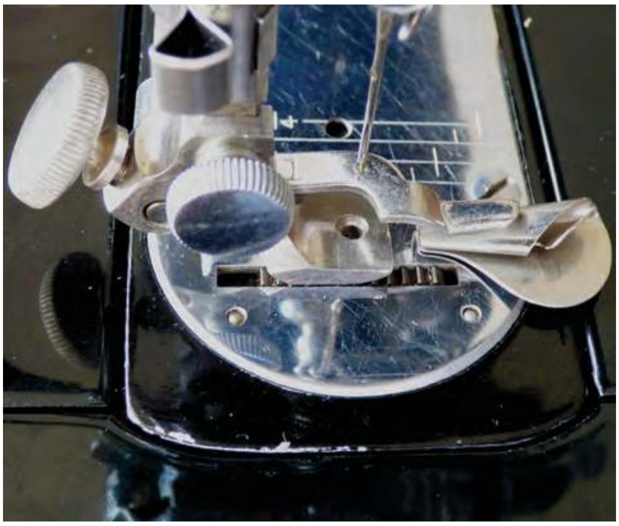


Figure G7

The style 3 box was made in 1892 and the style 11 box was made in the early years of the 20th century. However, the attachments fit onto the 1948 Singer 201K, and Figure G7 shows the style 3 box attachment foot and a hemmer fixed to a Singer 222K manufactured in February 1957. That style also fits a Singer Model 27, circa 1900.

And, although perhaps unnecessary, these presser-feet and attachments also fit a Janome Memory Craft 7700 computerised sewing machine that was made about 2010.

When Singer standardised their design is not known, but it was probably some years before the style boxes were produced. Certainly the style 1 box was made to hold an existing collection of attachments, as the style box itself was patented in 1889, but the attachments in it are dated 1888.

So it is likely that Singer standardised at least the critical dimensions in 1885 when the Vibrating Shuttle No. 1 machine was produced.[465] (It is interesting that Singer's 1891 publication actually describes two different machines with different bed shapes.[466])

In addition, there are two photographs of two different Singer Model 12 machines that are dated 1871, and they show that it has side-clamping presser-feet with a square presser-foot rod as in Figure G8, reproduced with permission of Wolfgang's Collectibles. Although not certain, later presser-feet would probably fit it, pushing back the date of standardisation, of the presser-foot attachment and the presser-foot rod and needle rod distance, by 14 years.

This standardisation is very important, because the end-user can use presser-feet and attachments on one machine even though they were originally made for a different machine.

463 Singer, 1891, page 19.
464 Singer, 2020b.
465 Wikipedia, 2020a.
466 Singer, 1891, pages 2-3 and page 13, for example.

An example of the importance of this is the Singer model 66 that was manufactured from 1907 to 1956.[467] Early model 66 machines used back-clamping presser-feet and attachments, rather than the common side clamping used on other models. It is clear that this was a significant blunder, because it was quickly changed to side-clamping on later model 66 machines!

Figure G8

Another, quite early attempt to make interchangeable presser-feet was the 1876 Wheeler & Wilson sewing machine.[468] It had a fixed presser-foot into which inserts could be placed, Figure G9, but these were conveniences to help the user make ordinary straight stitches, and the only "clever" foot was the hemmer, again illustrating the importance of that design.

Figure G9

Using the Motion of the Needle: The Walking Foot and Levers

A third feature of these sewing machines that appears to have been standardised in the 19th century is the method of attaching the needle.

Figure G10 (of a Singer Model 201K) shows a horizontal boss into which there is the thumb screw holding the needle in place.

Figure G10

A similar design is used in the circa 1900 Singer Model 27 and from Figure G5 we can see that the a similar design was used in 1888.

The Singer Model 12 in Figure G8 is different, having a large, cylindrical screw holding the needle, similar to the screw holding the presser-foot. The ruffler in Figure G17 would fit it, but the later zig-zag and buttonhole feet may not.

However, the important feature of all these machines is that *the needle rod has a useful point of attachment* and this can be used by presser-feet.

Some early domestic and some industrial machines used a *vertical feed* or *walking foot*. Instead of feed dogs in the base of the machine, the feed dogs are in the foot and there was a mechanism in the head to provide the up-down, backward-forward motion. However, the common walking feet for domestic sewing machines use the feed dogs in the base of the machine as well as motion of the foot itself. Although used in

467 Singer, 2020c.
468 Wheeler & Wilson, 1876.

several situations, a primary purpose of walking feet is when sewing two layers of material together. In that situation, especially if the top layer is smooth, the feed dogs in the base might move the bottom layer but the top layer may be stationary or move a different distance. The purpose of a walking foot is to overcome this problem; as the walking foot moves it shifts the top layer of material along with it.[469]

Figure G11 shows a "cheap and nasty" walking foot that falls apart when the clip-on cover and a single screw is removed, and consequently it is very hard to reassemble it without some sort of third hand.

Figure G11

The feed-dogs ***3*** are attached to a metal strip ***10***. It is screwed to a block ***11*** that runs in a slot in the body ***12***, so that the feed-dogs are loose and can move backwards and forwards. And there a small spring under the holding screw so that the feed-dogs are continually being pressed up. The foot ***2*** is mounted between the cover plates ***4*** and ***5***.

There are three levers to control the motion of the feed-dogs, Figure G12. The needle arm ***1***, that is fitted around the needle attachment point, is a lever pivoted at ***1′***. It has two fingers ***7*** and ***9*** to control the positions of the levers ***6***, pivoted at ***6′***, and ***8***, pivoted at ***8′***.

When the needle arm rises, the finger ***7*** forces the lever ***6*** to rotate anti-clockwise and the pad at the end of that lever tries to force the feed-dogs ***3*** down to below the surface of the presser-foot. However, when the lever ***6*** rotates, the feed-dogs cannot drop, because they are stopped by the machine's feed-dogs and

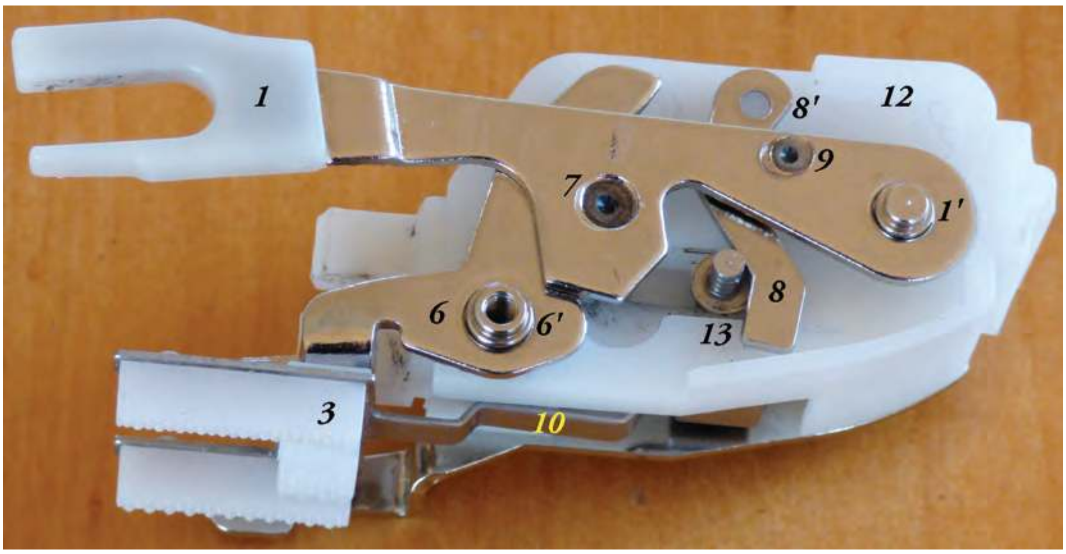


Figure G12

469 Wikipedia, 2019b.

the material, and it actually causes the whole body ***12*** and the foot ***2*** to *rise up*, as in Figure G11 left. This is possible because the presser-foot is only held down by the spring at ***A***, Figure G2 (page 121). At this point the material is clamped only by the two sets of feed-dogs. As the machine's feed-dogs are up and move the material, the feed-dogs ***3*** can move in unison, because the lever ***8*** is loose and the metal strip ***10*** is free to move in its slot in the body.

When the needle arm drops, the lever ***6*** is loose and the feed-dogs are free so that the body ***12*** drops down again and the foot ***2*** holds the material in position. At the same time the machine's feed-dogs have dropped.

Also when the needle arm drops, the finger ***9*** moves the lever ***8*** clockwise. The pin ***13*** is at the end of a rod to which the feed-dogs are screwed via the metal strip ***10*** and the screw at ***11***. So the lever ***8*** forces the pin ***13*** and the feed-dogs to the left, which moves the feed-dogs out to the front of the presser-foot. This is possible because the feed-dogs are only held by the spring under the screw at ***11***, which lifts the feed-dogs up so that there is no or only light contact with the material under them. When the needle arm rises, the lever ***8***, and hence the feed-dogs, are free to move to the right.

So when the needle arm is up and the machine's feed-dogs are active, the top piece of material is firmly pressed against the bottom piece by the feed-dogs ***3*** and both sets of feed-dogs can move the material without the friction of the presser-foot ***2*** holding it back.

And when the needle drops the presser-foot holds the material in place while both sets of feed-dogs move forward, but out of contact with the material, ready for the next stitch.

Figure G13 shows a Singer "Penguin" walking foot.[470] It has a similar action to the foot in Figure G11 and the three labels ***1***, ***2*** and ***3*** are the same.

When forming a stitch the foot ***2*** is forced down and holds the material firmly, because the needle arm ***1*** is under the needle clamp, while the "feed-dogs" ***3*** move out but above the material. And when the machine's feed-dogs move the material, the foot ***2*** rises and the "feed-dogs" ***1*** press down on the material and move back in unison with the machine's feed-dogs.

The important difference between these two walking feet is that there are actually no feed-dogs under ***1*** in the Penguin foot and it has a smooth surface, relying on friction to move the top material. This is necessary because, unlike Figure G11 where the feed-dogs are loose and can move an arbitrary amount, the corresponding "feed-dogs" in the Penguin walking foot are moved a fixed distance. But most sewing machines can vary the number of stitches per inch by varying the movement of the machine's feed-dogs and if the Penguin foot had feed-dogs it would force the upper piece of material to move a different distance from the lower piece.

Figure G13

Finally, the Singer Penguin foot is rare and absurdly expensive, about $1,000 if you can get one. Although better made (even so, it has a fault in the design[471]) a large number of the walking feet in Figure G11, enough to last several lifetimes, can be bought for the same outlay. We will never have one!

470 Singer, 1953.
471 Featherweight Shop, 2020.

Using the Motion of the Needle: The Tuck and Ruffler Feet

Another foot that uses the motion of the needle is the tuck marker that is included in the early style boxes, and is only discussed here for that reason. Although appearing to be complicated, Figure G14, it is actually quite simple.

This foot is a guide to ensure all the tucks are of the same width and with uniform spacing.

A is the tuck scale, the width guide that the folded material is pressed against. ***B*** is the space scale that marks the position of the next tuck, consisting of a ***V*** slot and a blunt knife edge ***K***, as in the inset photograph; the material is placed between them. The spring ***S***, which acts as a lever and goes under the needle clamp, presses ***V*** and ***K*** together, making a mark in the material at every stitch. Only the downward motion of the needle is used.

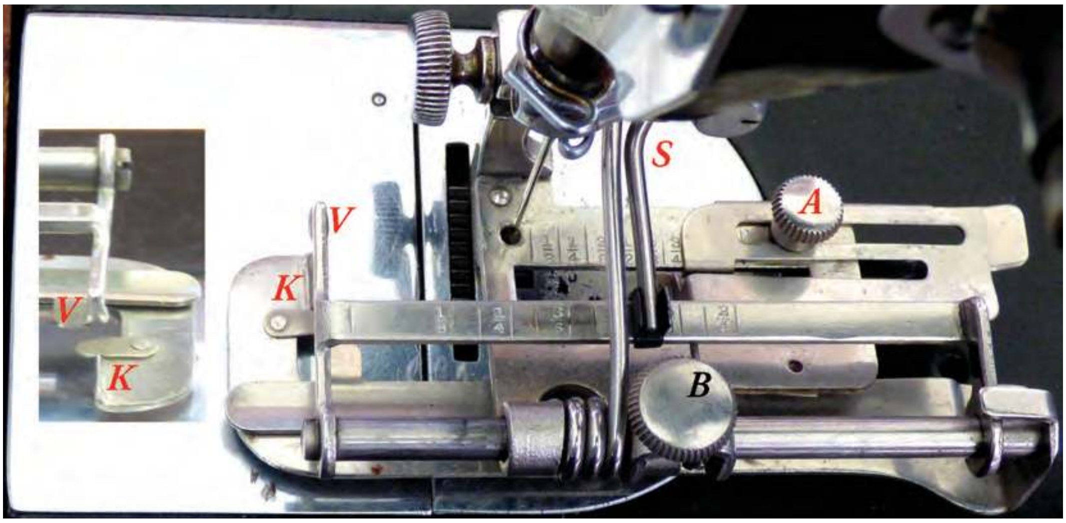


Figure G14

Figure G15

Figure G15 is a sample piece with three tucks and, at the top, the mark in the material for the next tuck.

In tucks the material is stitched *down* the folds. In ruffles and pleats the material is stitched *across* the folds.

Figures G16 and G17 show a Singer 26156 *ruffler foot* circa 1901 and what it produces.

The ruffler is attached to the presser-foot rod and the needle arm ***1*** is positioned around the needle clamp. The material is inserted between the two blued-steel blades at ***2****;* the upper blade is shorter and has a serrated edge to grip the material.

When the needle rises after forming a stitch, the lever ***1***, pivoted at ***4***, rotates clockwise and it rotates the lever ***5***, also pivoted at ***4***, clockwise. That lever has a third lever ***6*** hinged to it, that can only move horizontally to the left because of the three blades ***7*** attaching it to the base ***8*** of the presser-foot. This lever has the upper blade attached to it and moves that serrated blade forward, to the left, so that it folds the material before the next stitch is made.

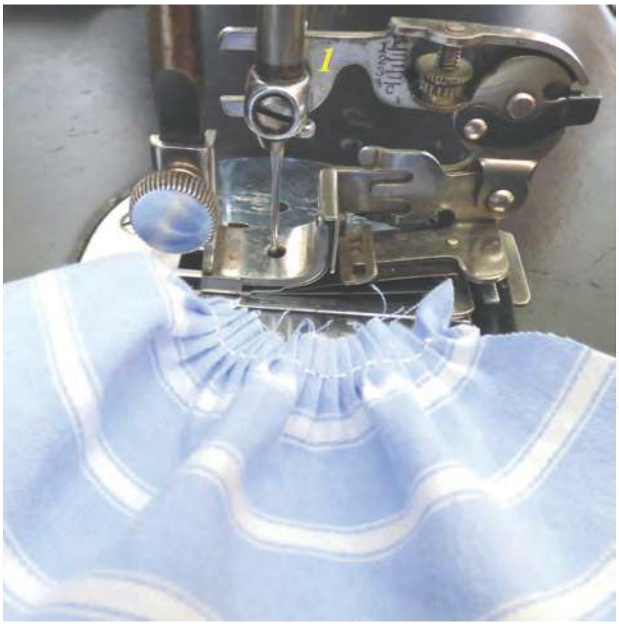


Figure G17

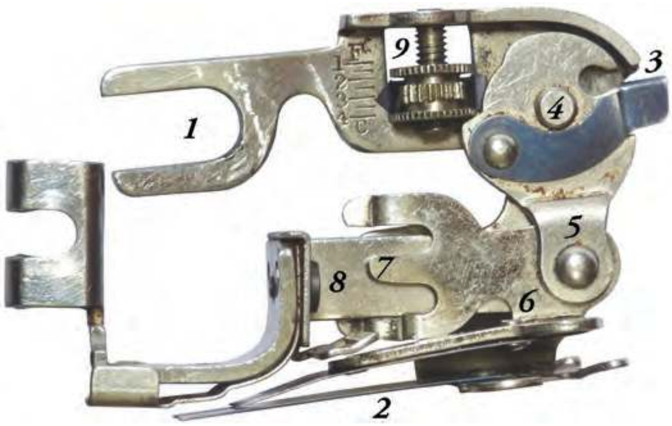


Figure G17

This movement clockwise cannot be varied. However, when the needle arm ***1*** drops, the thumb-nut ***9*** butts against the lever ***5*** and rotates it anti-clockwise, moving the lever ***6*** and the upper blade back to the right. By changing the position of the thumb-nut, this motion can be varied to change the length of the ruffle.

It is no surprise that this ruffler will also fit onto a Janome Memory Craft 4000 computerised sewing machine circa 1997.

Replacing the Feed-dogs: The Zig-Zag Foot

Fundamental to the domestic sewing machines considered here is that the needle cannot move laterally, and its only motion is up and down to form a stitch.

Also, the motion of the material, and hence the stitch length, is controlled by the feed-dogs that move it in a straight line from front to back, as in Figures G1 and G10. And consequently, the machine can only sew in a straight line and, as the needle cannot move sideways, if we want to move the material in other directions then the feed-dogs have to be replaced by another mechanism.

As a result, a basic requirement of most *zig-zag* and *buttonhole* presser-feet are:

(a) A cover-plate that is screwed to the bed of the sewing machine covering the normal feed-dogs so that they cannot move the material; Figure G18.

(b) Feed-dogs in the presser-foot to move the material; that is, a *walking foot*.

(c) Cams or other mechanisms in the presser-foot that move its feed-dogs, and hence the material, sideways and backwards as well as the normal forward motion.

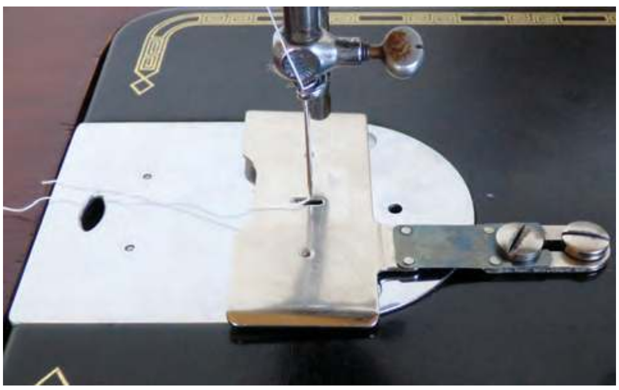


Figure G18

Figures G19 and G20 give four views of a Singer 160990 *zig-zag* presser-foot made in Switzerland; it uses the needle arm ***3*** to control its action.

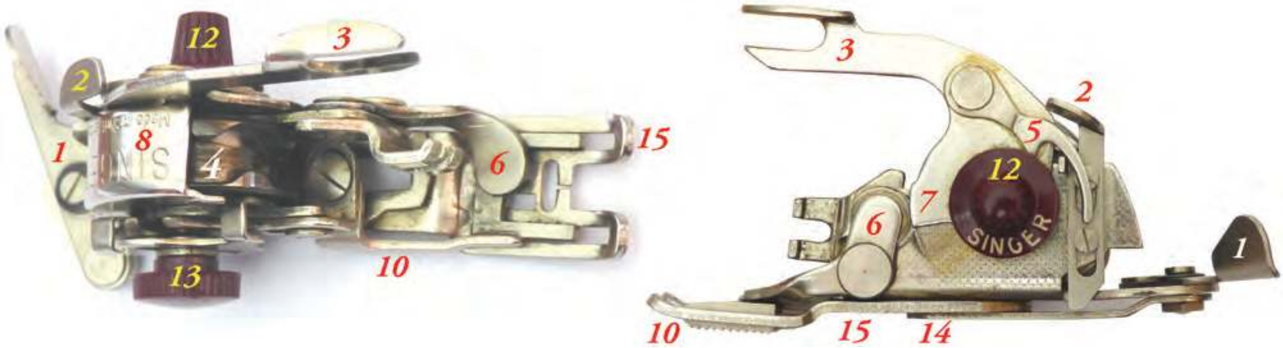


Figure G19

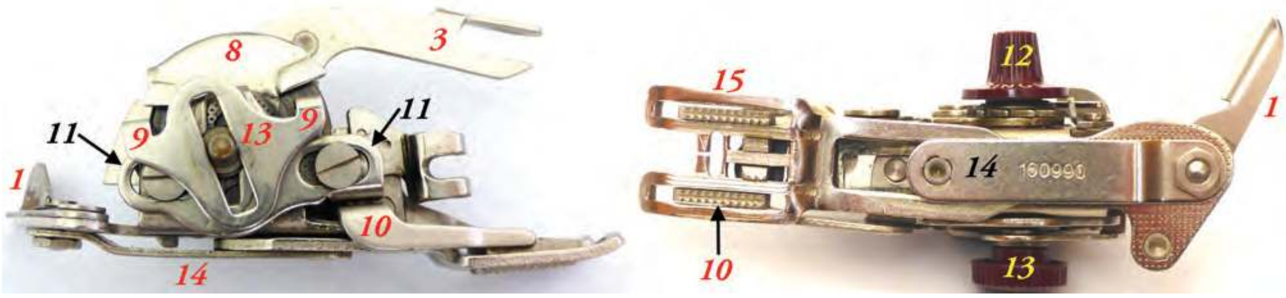


Figure G20

This presser-foot is a walking foot with its own feed-dogs ***10***, and the cover-plate is needed to stop the sewing machine's feed-dogs being active. It is controlled by the rotation of the main cam ***4*** (Figure G19 left) that moves the feet ***15*** and the material sideways, and the lever ***1*** adjusts that distance and so the width of the zig-zags.

At every stitch, the pawl ***5***, Figure G19 right, is moved by the motion of the needle and it rotates a fixed, uniform ratchet, under the "SINGER" thumb screw ***12***, which in turn rotates the main cam ***4***; there is a spring under the pawl's mounting disk to ensure it is always in contact with the ratchet. The main cam moves the feet sideways. The feed-dogs ***10*** are pivoted and, because they fit in gaps in the feet, they and the material also move sideways to form the zig-zag pattern.

This foot normally produces a zig-zag, but the "throw-out" lever ***2*** can be used to raise and so disable the pawl ***5*** and the action of the cam, and then it will produce ordinary, straight-line stitches.

The feet ***15***, Figures G20 right and G21, are at the end of a lever that reaches to the finger ***f*** that is under the main cam and hidden by the bar ***14***. The fulcrum of this lever is at ***14***, a boss on the bar that is linked to the adjustment lever ***1***, and moving the bar left or right moves the fulcrum ***14***, changing the amount that the feet move sideways.

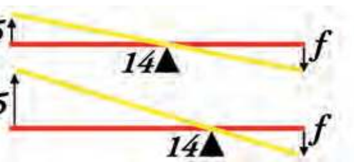


Figure G21

The red thumb screw ***13***, removed in Figure G20 left, adjusts the stitch length by changing the movement of the feed-dogs ***10***. The feed-dogs are loose, but every time the needle rises the pad ***6***, Figure G19, forces the feed-dogs down allowing them to advance the material. This is done by the protuberance ***7*** acting on a roller wheel under ***6*** forcing the pad to rotate. As with the walking presser-foot discussed earlier, the feed-dogs cannot move down, because they are pressed against the cover plate, and the pad ***6*** raises the whole presser-foot up so that the material is only held in place by the feed-dogs and the feet ***15*** are above the material.

The cover ***8***, Figure G19 left, that is over the main cam ***4***, is not decorative. It is fixed to the needle arm ***3*** and rotates with the movement of the needle. On the left side, Figure G20 left, the cover ***8*** has two pads that cause the stitch length lever ***9*** to rock.

The stitch length lever ***9*** is a U shaped piece, Figure G22, with one arm inside the body ***16*** and that arm is pivoted at the bottom. The feed-dog lever ***11***, which has the feed-dogs ***10*** at the end of it, is sandwiched between the stitch length lever and the body and held onto the body by two screws that run in elongated holes in the lever allowing it to move sideways.

The screw under the thumb screw ***13***, Figure G20 left, has a rectangular base that fits into the slot in the stitch length lever ***9***, and a circular extension that fits into a corresponding slot in the feed-dog lever ***11***.

Consequently, as the stitch length lever ***9*** rotates it moves the feed-dog lever backwards and forwards to move the material. The thumb screw ***13*** can be moved up and down the slot in the stitch length lever ***9*** to change the amount by which the feed-dog lever ***11*** and the feed-dogs ***10*** move.

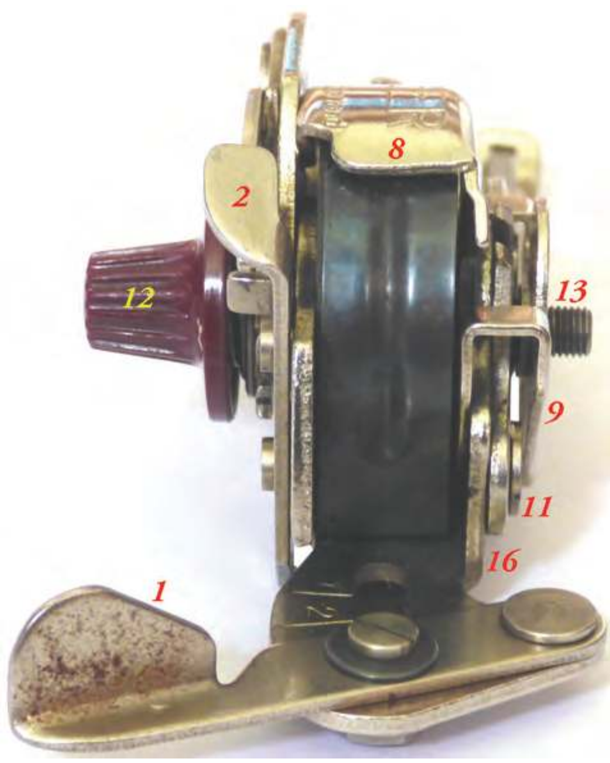


Figure G22

The pattern cams, Figure G23, are ratchets that are put under the "SINGER" thumb screw and are held friction-tight by a spring integral with the thumb screw, but they are free to rotate. By interacting with the fixed ratchet they produce a variety of zig-zag patterns as shown in Figure G24; this figure uses paper piercing by the needle to show the pattern produced.

The fixed ratchet produces the pattern ***0***. The pattern cams, that are placed over the fixed ratchet, have some steps that are larger in diameter than the fixed ratchet. Consequently, when the pawl ***5*** meets a large step it rotates the pattern cam but it does not rotate the fixed ratchet, and so the main cam ***4*** does not rotate and a number of stitches are produced in a straight line.

Note that once the lever ***1*** has been set, the widths of all the patterns are the same and the only variation is when the sideways movement occurs.

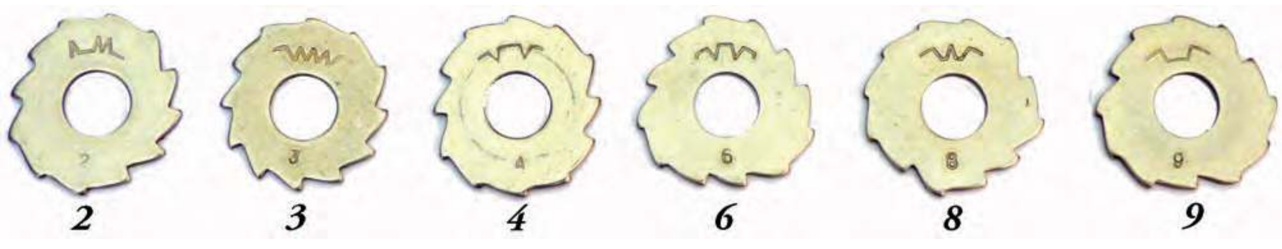


Figure G23

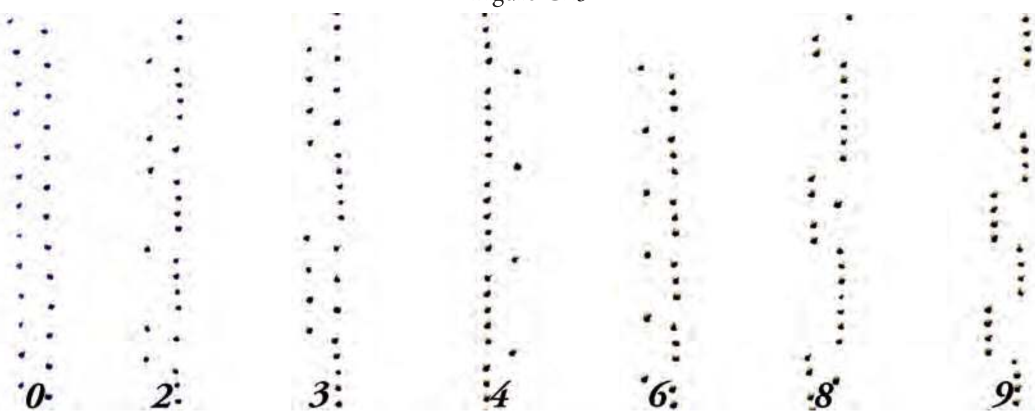


Figure G24

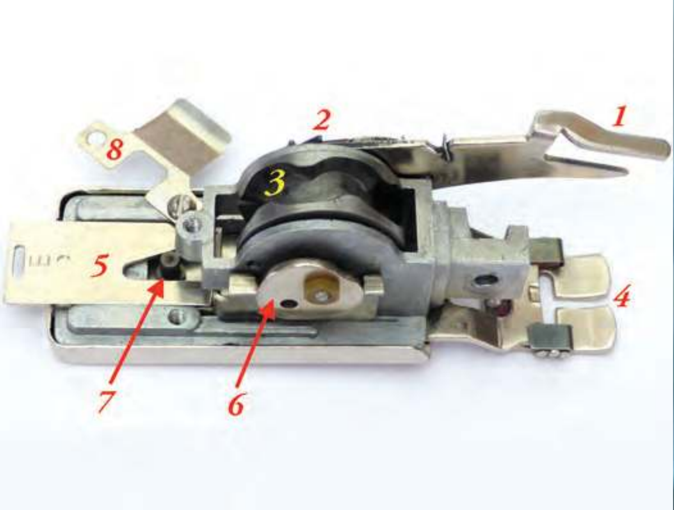


Figure G25

Figure G26

Figure G25 is a later Asian YS-7 zig-zag presser-foot with its cover removed to show the main cam ***3***. It also uses the needle arm ***1*** to rotate the uniform ratchet ***2*** and the main cam ***3*** to move its feed-dogs from side to side.

There are seven pattern plates for it, Figure G26, that go into the back of the foot at ***5***; plate ***E*** is installed in Figure G25; the cover plate 8 has been moved to show the mechanism under it. These pattern plates change the pattern of the zig-zags; without a pattern plate it produces straight stitches. Note that, unlike the Singer zig-zag foot, with the pattern plates ***C*** and ***E*** the width of the zig-zag changes throughout. However, unlike the Singer, there is no way that the basic width can be changed.

These pattern plates fit into a carrier that is moved forward and backward by the heart cam ***6***.

This zig-zag presser-foot is interesting because it does not use a plate to cover the normal feed-dogs and its feed-dogs ***4***, integrated in the foot, only have a sideways motion. Instead it uses the machine's feed-dogs and the machine's stitch length regulator for the forward motion.

This is possible because the feed-dogs ***4*** in the zig-zag foot have teeth that are at right-angles to the machine's feed-dogs, going from front to back, as in Figure G27. Also the teeth face outwards, the left teeth facing left and the right teeth facing right. (In contrast, the Singer zig-zag presser-foot has pointed feed-dog teeth that can move the material in all directions.)

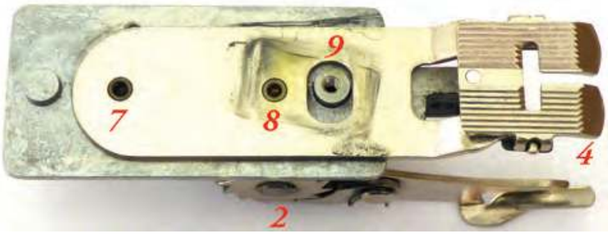


Figure G27

The foot ***4*** is loose, free to move sideways but limited by a slot ***9*** in the base of the presser-foot, and so it is only held in position by the material and can rotate around its center ***8***, which is the finger acting on the main cam ***3***. This finger also acts in a slot in the base.

The needle arm ***1*** rotates the main cam ***3*** and the heart cam ***6***. By the finger ***8***, the main cam moves the presser-foot sideways, but this movement is limited by the finger ***7*** that fits into the slot of the pattern plate. Because the presser-foot is loose some of the sideways movement caused by the main cam then forces the front of the presser-foot sideways to make a zig-zag.

When there is no pattern plate the finger ***7*** is completely free to move and the presser-foot oscillates without moving the material.

Replacing the Feed-dogs: The Buttonhole Foot

The buttonhole presser-foot is a more sophisticated zig-zag foot. This presser-foot is also a walking foot with its own feed-dogs, like the Singer zig-zag presser-foot, and a cover-plate is needed to stop the sewing machine's feed-dogs being active.

Figure G28 shows the left side of the presser-foot; it is complete except that its cover has been removed. The *zig-zag cam* ***1*** makes the small zig-zag stitches that form the buttonhole, and the *buttonhole cam* ***2*** moves the feed-dogs ***3*** to form the buttonhole. Because the gap in the feed-dogs is necessarily very large, an additional finger ***4*** is used to ensure the material does not move. The wing-nut ***5*** can be used to position the presser-foot before starting to sew.

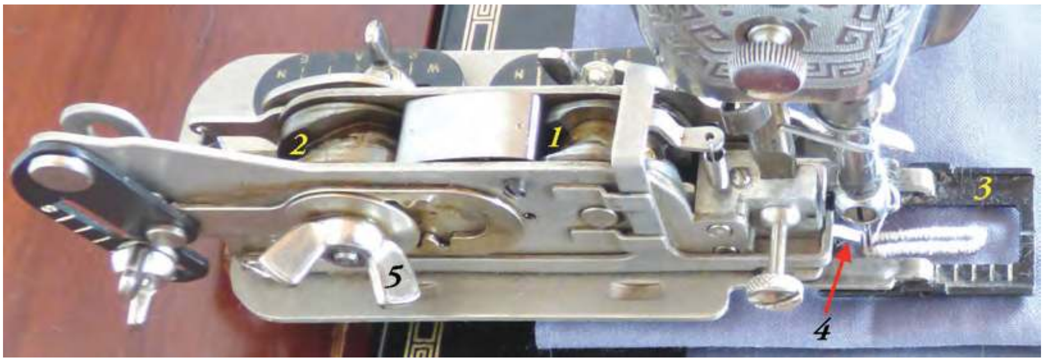


Figure G28

Figure G29

Figure G29 shows the left side of the presser-foot with the wing-nut ***5*** and the covering disk removed.

Under the wing-nut there is a three-tooth wheel ***6*** that rotates with the buttonhole cam ***2***. It moves the double-sided rack ***7*** which is linked to the buttonhole length adjustment ***8***.

The base plate ***10*** is loose, Figure G30. It is held in position by the plate and screw ***11***, by the fingers ***13*** and ***14*** and by the rod at ***8***. The slots in the base plate allow it to move backward and forward, and the wide slot allows it to move sideways.

As shown in Figure G31, the pieces ***7***, ***8*** and ***9*** form a lever pivoted to the body ***12*** at the fulcrum ***9***. The movement of the base plate ***10*** can be adjusted by the wing-nut and rod ***8***, and so the length of ***9-8*** can be varied from short ***s*** to long ***l***, as shown in Figure G29.

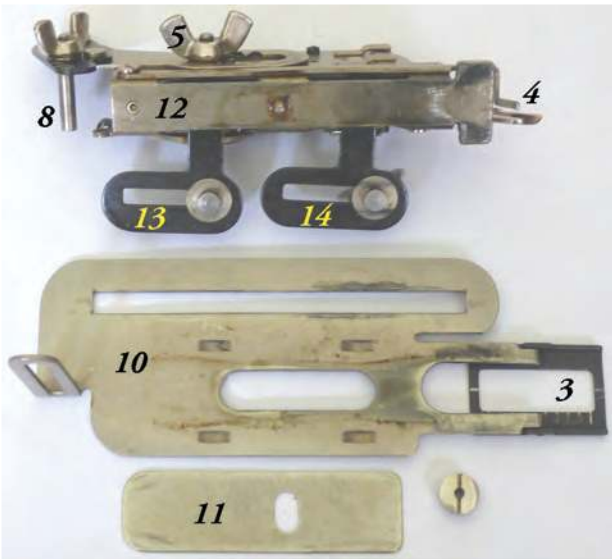


Figure G30

Consequently the motion of the rack *7* will move the base plate ***10*** different amounts depending on the position of the wing-nut ***8*** and so form different lengths of buttonhole.

Figure G31

At the end of stitching one side of the buttonhole the finger under the buttonhole cam ***2*** moves sideways and moves the base plate to start the other side.

During this process the three-tooth wheel ***6*** fits into the end of the rack *7* and its teeth rotate while moving the base plate forward or backward a small amount until the teeth slot into the other side of the rack so that the zig-zag cam ***1*** can form the end of the buttonhole.

The pieces ***13*** and ***14***, Figure G32, are also levers, but the mechanism is hidden within the body of the Singer presser foot and cannot be exposed because the components of the body are riveted together; but see Figure G35.

The lever ***13***, Figure G32, moves when the finger for the buttonhole cam ***2*** is pushed to one side or the other, and it moves the base plate sideways by varying amounts depending on the position of its wing-nut. This changes the space between the two rows of zig-zag stitches.

This happens twice for every rotation of the buttonhole cam and, as noted above, the base plate only moves forward or backward a small amount during this process.

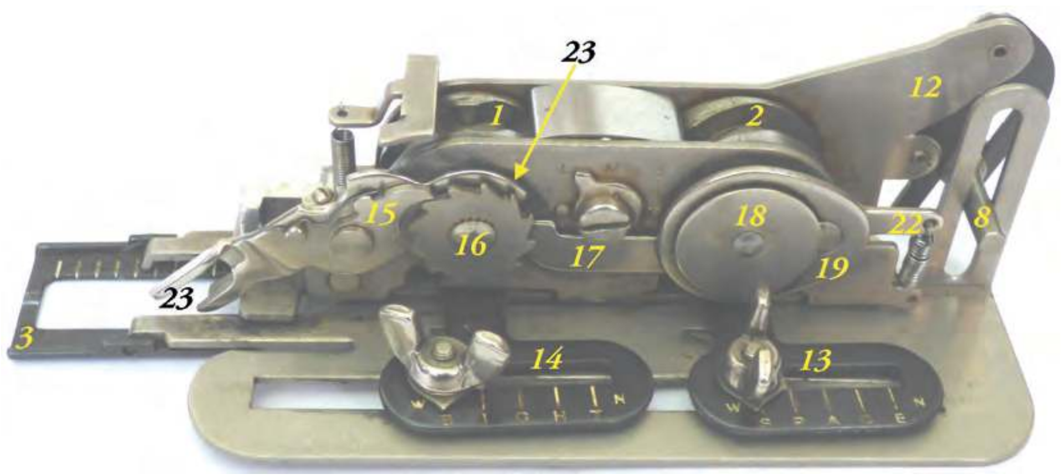


Figure G32

The lever ***14*** is similar, but it responds to the position of the zig-zag cam ***1***. That cam is turned by the needle arm ***23*** via the spring-loaded pawl ***15*** that rotates the ratchet ***16***, as in zig-zag presser-feet. At every stitch the finger under the zig-zag cam moves the base plate sideways by an amount set by the wing-nut on ***14*** and this varies the width of the zig-zag stitches.

Thus the length, spacing and width of the zig-zag stitches that form the buttonhole can be adjusted.

Finally, how is the buttonhole cam ***2*** rotated?

The pawl ***15*** rotates the ratchet ***16*** and zig-zag cam ***1*** clockwise. The lever ***17***, and consequently the buttonhole cam ***2***, is rotated anti-clockwise by the needle arm ***23***. The cover plate on the Singer presser-foot, ***18*** in Figure G32, cannot be removed, and I assumed that the lever ***17*** was a pawl that rotated a ratchet. However, the mechanism is quite different and, although rather crude, it is effective.

Figures G33, G34 and G35 are of a YS-4455 industrial buttonhole presser-foot, made in China, that will not fit onto a domestic sewing machine. Although there are a few differences in layout, it is basically identical to the Singer buttonhole foot and uses the same methods.

Three obvious differences are:

(a) The three-tooth wheel and the rack (***6*** and *7*, Figure G29) are replaced by an oval cam and a bar linking the cam to the lever ***8***, ***9***, ***10***.

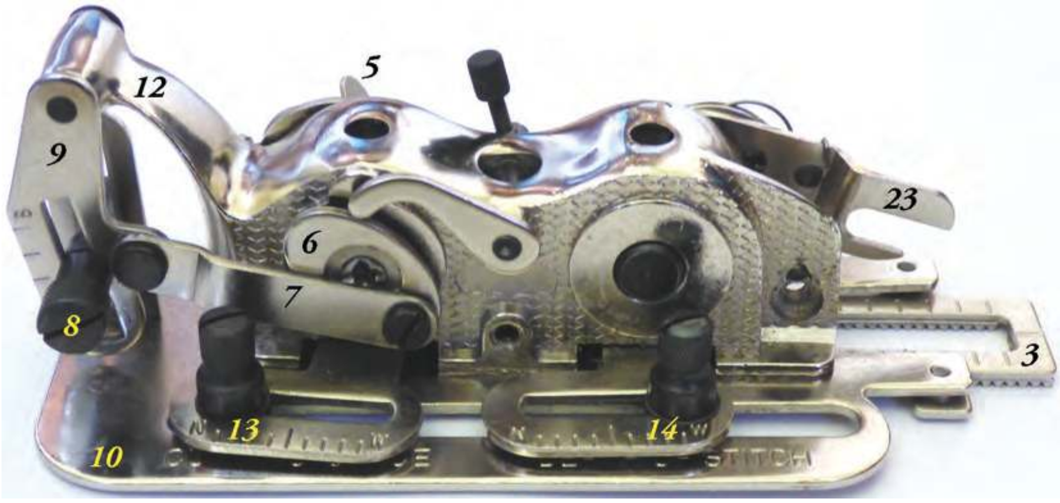


Figure G33

(b) The wing-nut (***5***, Figure G28) has been moved to the other side of the presser-foot.

(c) The two levers ***13*** and ***14*** are moved from the right side of the presser-foot to the left side.

However on this presser-foot, Figure G34, the wing-nut ***5*** and the cover ***18*** can be removed. In both the Singer and YS presser-feet, the needle arm ***23*** rotates the lever ***17*** on every stitch. This lever is very loose and the hole in it is much larger that the pivot it surrounds! In addition, it has a boss ***19*** that is semi-circular but angled slightly so that only the top edge butts against the disk ***21***; that disk is fixed to the buttonhole cam ***2***. The piece ***20*** fits tightly over the boss ***19*** and the disk ***21*** and, because of the boss, it prevents the lever ***17*** from moving sideways and it can only rotate.

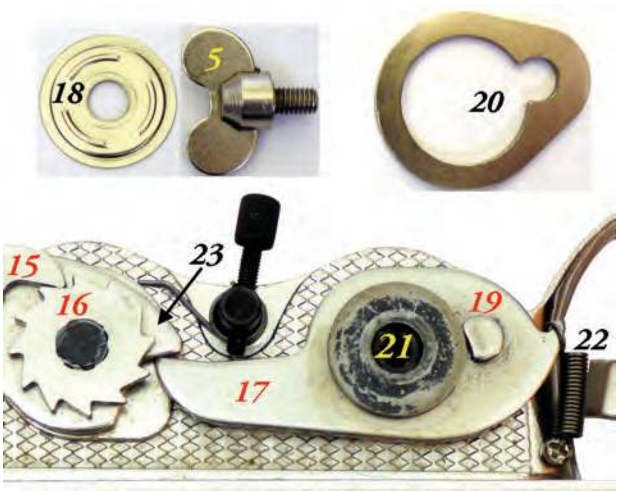


Figure G34

When the lever ***17*** rotates anti-clockwise the boss has enough friction to rotate the disk ***21*** and the buttonhole cam. And when the needle arm ***23*** rotates anti-clockwise, freeing the lever ***17***, the spring ***22*** rotates the lever clockwise ***17*** and the boss ***19*** slides over the edge of the disk ***21*** without rotating it.

Finally, Figure G35 shows the two levers ***13*** and ***14*** that control the cutting space of the buttonhole and the width of the zig-zag stitches respectively, varying them from narrow ***N*** to wide ***W***.

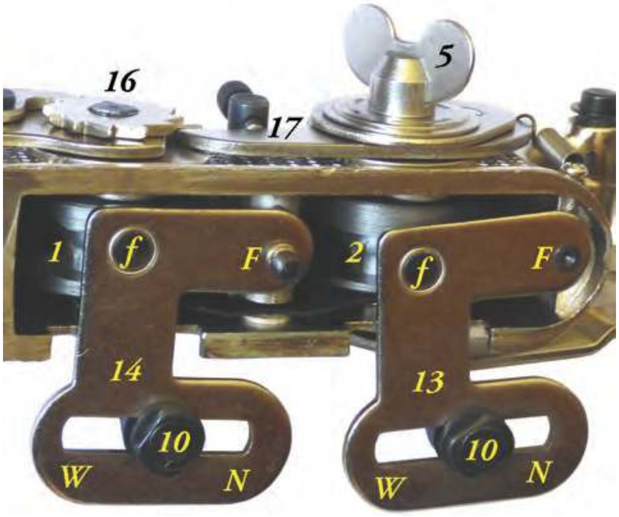


Figure G35

The distance that the base plate moves depends upon the positions of the wing-nuts ***10***. The distances of the fingers ***f*** from the fulcrums ***F*** are fixed, but the distances of the wing nuts varies from ***F-N*** up to ***F-W*** thus changing the distance the base plate moves. Figure G36 shows the two positions of lever folded (as in Figure G35) and straightened out.

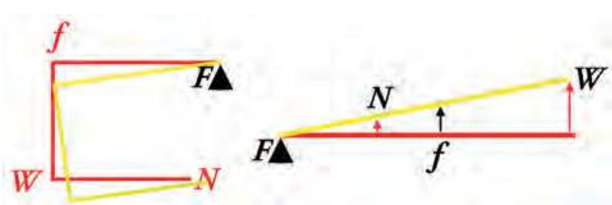


Figure G36

Postscript: Getting From One Place to Another, Part 3

Moving Time

I began this book with the suggestion that *the development of civilisation is the development of the ability to move things from one place to another*. Although the Ford assembly line is the most obvious development, most of this book can be seen in that light, including the migration of Irish to America, which affected the culture in that land, and the development of industrial watchmaking..

However, it is apparent that improved movement of goods (and the Irish can be seen in as goods) was coupled with *a decrease in the costs* of those goods. So I suspect that if Ford was unable to lower the cost of his cars the assembly line may have failed in its primary objective, and the social change wrought by motoring for all would not have occurred until later.

Equally, the dissemination of portable time required that the cost of watches was in the reach of many more people, and the developments at Waltham must be viewed in that light. That is, a fundamental consequence of my definition of the American System of Manufacturing (the manufacture of machines by unskilled labour) is the reduction in the prices of the goods being made. The most obvious example of this point is related by Chauncey Jerome, circa 1842, when he exported shipments of clocks to England, valuing them at $1.50 each or less than £1 (about $751.00 today):

> *I had always told my young men over there to put a fair price on the clocks, which they did; but the* [customs] *officers thought they put them altogether too low, so they made up their minds that they would take* [purchase] *a lot, and seized one ship-load, thinking we would put the prices of the next cargo at higher rates. They paid cash for this cargo, which made a good sale for us. A few days after, another invoice arrived which our folks entered at the same prices as before; but they were again taken by the officers paying us cash and ten percent in additions, which was very satisfactory to us. On the arrival of their third lot, they began to think they had better let the Yankees sell their own goods and passed them through unmolested, and came to the conclusion that we could make clocks much better and cheaper than their own people.*[472]

So the movement of things from one place to another was very profitable! Unfortunately Jerome does not tell us what the officers did with their warehouse-full of clocks.

And, as the result of advances in technology and mass production, a watch can now be bought for about $10 and a clock is not much more.

Moving Food

I have previously described two adaptable machines, machines that can be easily configured to perform different functions; they are the watchmaker's lathe, based on rotation, and the domestic sewing machine, based on levers.

I have thought about other adaptable machines, but I can only think of one, the Kenwood Chef domestic food processor, which is also based on rotation. The following is a brief description of its main features. (There is another brand of food processor that has similar features, but it is not as flexible.)

Food processing is necessarily different from steel, brass and material processing. The latter are *coherent*, in the sense of not falling apart. In contrast, most food is *incoherent*; for example, flour, and eggs and other liquids. In addition, some processes involve breaking down coherent, solid substances to make them incoherent, such as mincing meat and chopping nuts. However, the processes performed actually involve moving substances from one place to another, albeit sometimes simply rotating them in a bowl.

472 Bailey, 1975, page 149.

The Kenwood Chef has a whisk or beater that, while rotating, pirouettes around the bowl. This action is achieved by the gears in Figure K1, a simplified form of planetary gears.[473] (This diagram was produced using *Gear Generator*.[474])

There is no sun gear in the center, and instead the rotation of the motor shaft turns the carrier ***c***. The annulus ***a*** has 50 teeth, $Na = 50$, and it is fixed to the casing and cannot rotate. The planet gear ***p*** has 15 teeth, $Np = 15$, and it is free to rotate on the carrier ***c***.[475] This gear has a socket under it for holding attachments that follow the motion of the gear.

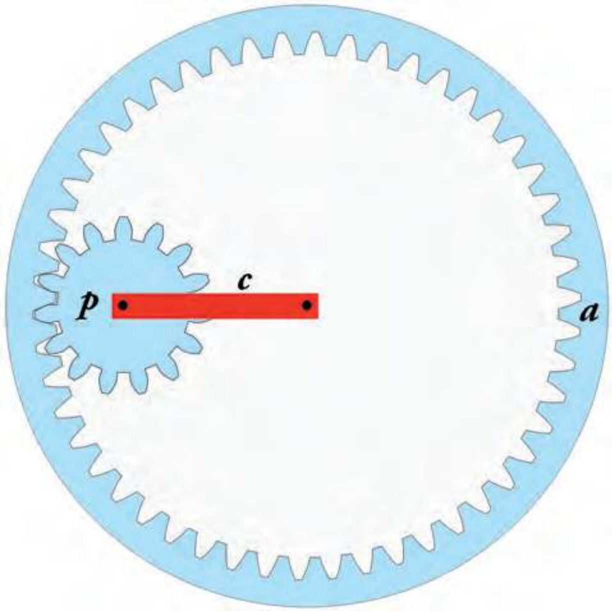


Figure K1

The easiest way to understand the motion of the planet gear is to use its relative motion.[476] Instead of viewing the system from the outside, when the turns of the annulus $Ta = 0$ and the carrier rotates, it is better to view the system from the point of view of the carrier, when $Tc = 0$ and the annulus rotates in the opposite direction.

In this case, when the annulus is rotating the planet gear, $Tp = (Na/Np)Ta$.

So $Tp = (50/15)Ta = 3\frac{1}{3}\ Ta$.

That is, the whisk or beater rotates *31/3* times while it pirouettes around the bowl once in the opposite direction. (Seen from above, the carrier rotates anti-clockwise so the beater pirouettes anti-clockwise, while the planet gear and the beater rotate clockwise.)

It is essential that the sun gear is omitted because with it $Ta = 0$, $Ts = Tc$ and consequently:[477]

$Ts = Tc = Ta = Tp = 0$

That is, the system is locked, nothing will rotate and the motor will burn out.

Attachments

In addition to the planetary gears, the Kenwood Chef has a complex set of gears to enable the rotation of the motor to be used in several different ways,[478] as in Figure K2 (this is a wide angle photograph with some distortion). These gears are:

A is the normal whisk or beater operating from the planet gear (the bowl is omitted).

B is a slow speed horizontal outlet shown with a mincer attachment.

C is a high speed vertical outlet shown with the blender or liquidiser.

D is another vertical outlet.

There are 14 different attachments that can be used with these outlets for the rotation of the motor:

473 Watkins, 2018.
474 Vincze, 2020.
475 Batten, 2019.
476 Watkins, 2016b.
477 Watkins, 2018, page 3.
478 Kenwood, ca 1971.

A: Potato peeler, colander & sieve (in addition to the normal beater, whisk and dough hook).

B: Coffee grinder, mincer, sausage filler, pasta maker, slicer & shredder (there are two different types), bean slicer & pea sheller, cream maker, can opener.

C: Juice separator, liquidiser.

D: Juice extractor.

However, current models have many more attachments.

These different attachments necessarily process food differently, depending on the quantity and the consistency.

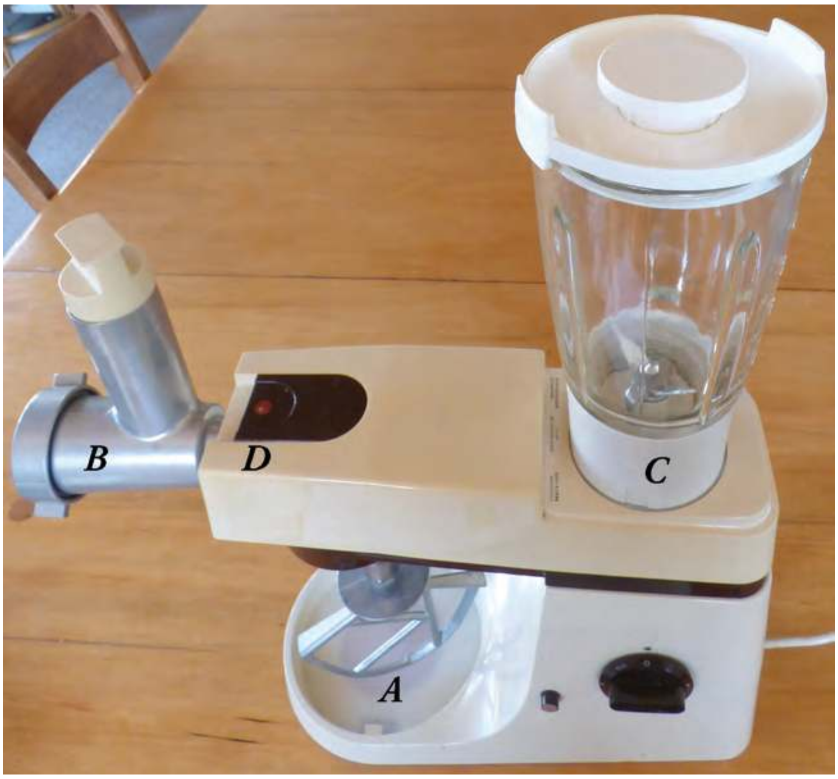


Figure K2

What Next?

Modern machines are based on computerisation, where most of the flexibility comes from electronic chips performing functions that are largely impossible in simple machines with motors and gears. But they do not interest me, as I am firmly stuck in the early 20th century.

So are there others? That is, are there other adaptable machines that have been designed to perform several different functions, and are easily converted from one function to another?

Despite thinking about this question for some time, I can only think of the three that I have described.

So I end with a question: Are there any more?

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There are four *case numbers*: 116, 117, 118 and 119 for the four debtors Samuel Curtis, David P. Davis, Edward Howard and Aaron L. Dennison respectively; this is the allocated number of the case in 1857. The *document numbers* are hand-written on the documents. The *photograph number* is the number of the photograph as taken by Bob Frishman and Ron Price, and these are usually in the obvious order for the pages. For example the warrant issued to Samuel Curtis is 116-002-01 and 116-002-02.

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