

# TEXTILE WEAVING



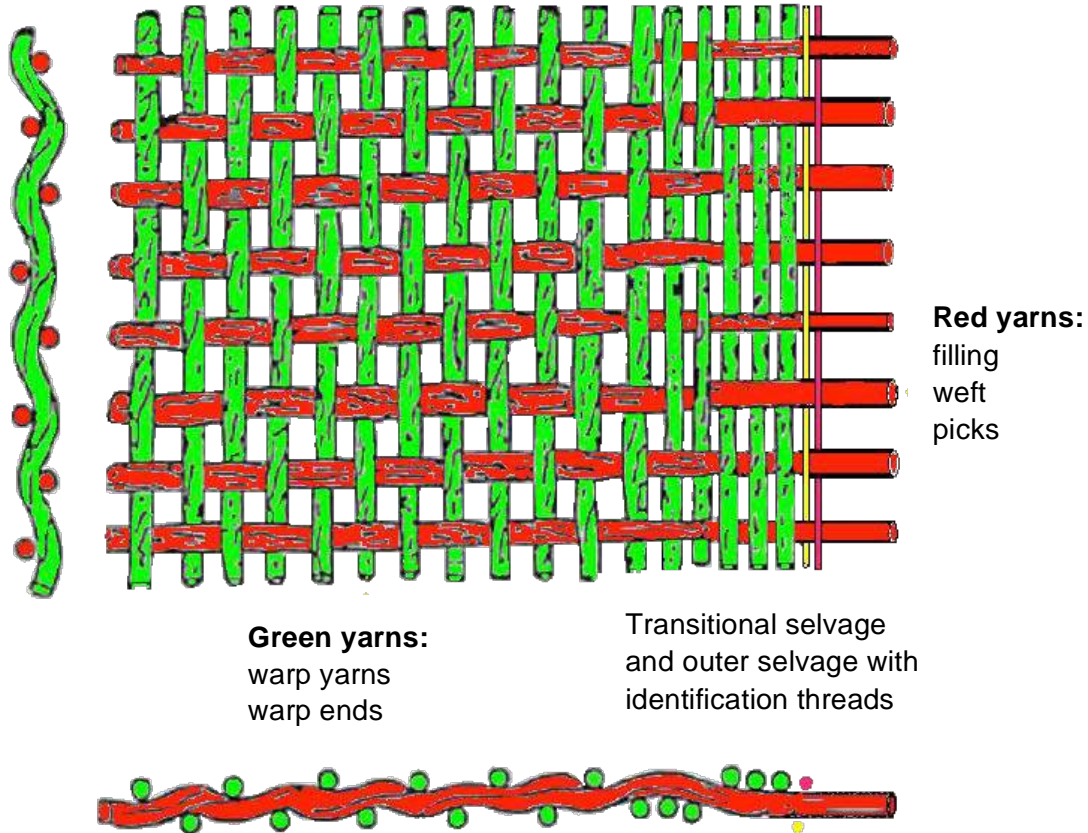
COTTON INCORPORATED

# Textile Weaving

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## 1 INTRODUCTION

Weaving is the process of **interlacing** sets of yarns together to form a woven fabric structure. As diagrammed in Figure 1, one set of yarns run along the fabric length or machine direction; these are called **warp yarns, warp ends,** or simply **ends**. The other set of yarns run along the fabric width and are called **weft yarns, picks,** or **filling yarns**.



**Figure 1. Components of a woven fabric structure**

The warp yarns unwind from a **loom beam** and move forward at a fixed rate as the woven fabric is formed. The weft yarns typically are inserted one at a time across the warp yarns. The warp yarns are under tension and undergo stress, strain, and abrasion as they move up and down and follow a path through the various parts of the loom. The tension is necessary in order to form a clear opening, or **shed**, for insertion of the weft yarns.

This booklet covers the preparation of the warp yarns for weaving, the basic motions of a weaving machine, and basic woven designs.

## 2 WARP PREPARATION

Because the warp yarns are under high tension, are in very close proximity to one another, and go through various weaving machine elements, they must be properly prepared for the rigors of weaving. The warp yarns go through several processing steps before being wound onto a loom beam that will be inserted at the back of a weaving machine. The processes to prepare the warp yarns for efficient weaving comprise what is called **warp preparation**; they include **warping**, **slashing**, and **drawing-in** or **tying-in**.

### 2.1 Direct Warping

This method of warping transfers yarns from many cones or tubes and winds them simultaneously onto a **section beam** in a parallel arrangement called a **yarn sheet**. The yarn packages are held on a device called a **creel**. For spun yarns, a creel typically holds 400 to 800 yarn packages, while filament yarn creels can hold over 1,000 yarn packages. Each section beam contains the same number of yarns. Because most woven fabrics contain well over 2,000 warp yarns, several section beams are needed to provide the required number of warp yarns for a given fabric construction. For a fabric requiring a total of 4,000 warp yarns, 10 section beams need to be formed, each containing 400 warp yarns.

It is critical that the warp yarns be wound with equal tension, that they not be crossed or rolled over one another, and that none be lost (broken and not tied back together) or missing. Various elements of the warping machine, such as tension devices, static eliminators, broken yarn detectors, wild yarn (yarn waste) detectors, eyelet boards, and expansion combs help ensure that the warping machine forms high-quality beams. For most fabrics, all section beams must have identical yarn tension, uniform yarn count, and equal numbers of yarn ends.

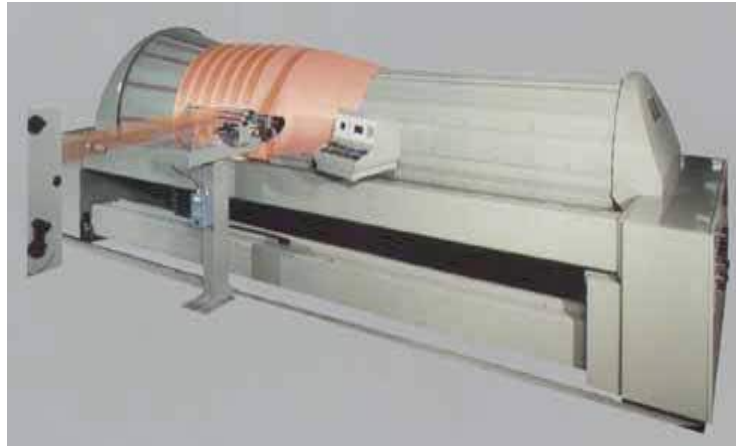
The warping operation shown in Figure 2 is transferring 400 yarns from cones onto a section beam. In the background is the creel holding the yarns as they make their way to the warper. Above the section beam is an expansion comb, which helps to keep the yarns straight and parallel as they wind onto the section beam.

### 2.2 Indirect Warping

This method of warping uses smaller creels with fewer yarn packages and therefore requires less space. Bands or sections of parallel yarns are wound onto a **pattern drum**. The bands are wound parallel to one another, contain the same number of yarns, and are identical in make-up. Indirect warping is preferred for sample work, short runs, and fabrics with pattern stripes. The total required number of warp yarns is wound onto the drum, eliminating the use of section beams. However, the yarn on the pattern drum must be then be rewound onto a flanged loom beam suitable for use in further processing.



**Figure 2. Direct warping from yarn packages to a section beam**

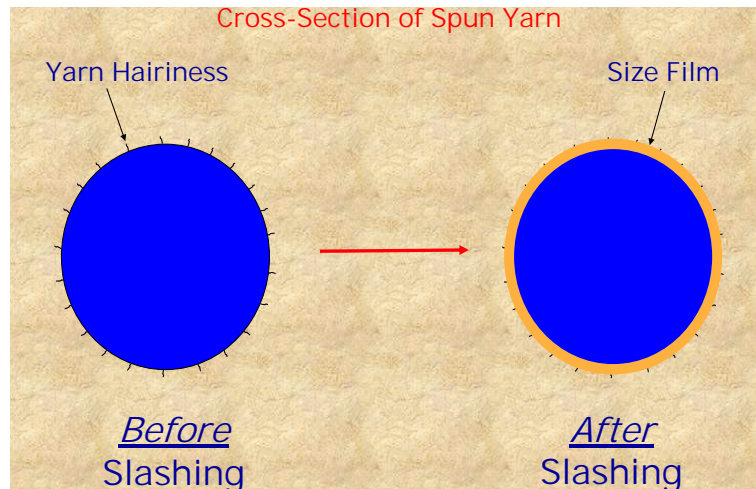


**Figure 3. Indirect warping of bands or sections of yarn onto a pattern drum**

### **2.3 Slashing**

The purpose of slashing spun yarns is to encapsulate the yarn in a film of **size** in order to reduce yarn hairiness, improve yarn abrasion resistance, and increase yarn strength. Figure 4 illustrates how slashing reduces the hairiness of spun yarns. For spun cotton yarns, size is typically starch or a blend of starch and polyvinyl alcohol (PVA). In the case of filament yarns, the size is formulated not to encapsulate the yarn, but to hold or glue the individual filament together. PVA is commonly used as size for filament yarns.

Slashing may be omitted with coarse plied spun yarns or heavier-denier filament yarns, or in production of fabrics with a low-density warp (in which the yarns are not close to one another).



**Figure 4. Reduction of yarn hairiness by slashing**

In the case of direct warping, the required number of section beams are placed on a **slasher creel**. Figure 5 shows section beams loaded on a slasher creel for the weaving of denim. To produce a yarn-dyed woven fabric with a striped pattern, section beams of yarn are dyed on a special beam and then placed on the slasher creel, as shown in Figure 6. The different colors of yarn are aligned in an expansion comb at the front end of the slasher in the correct order to form the desired color pattern in the fabric.

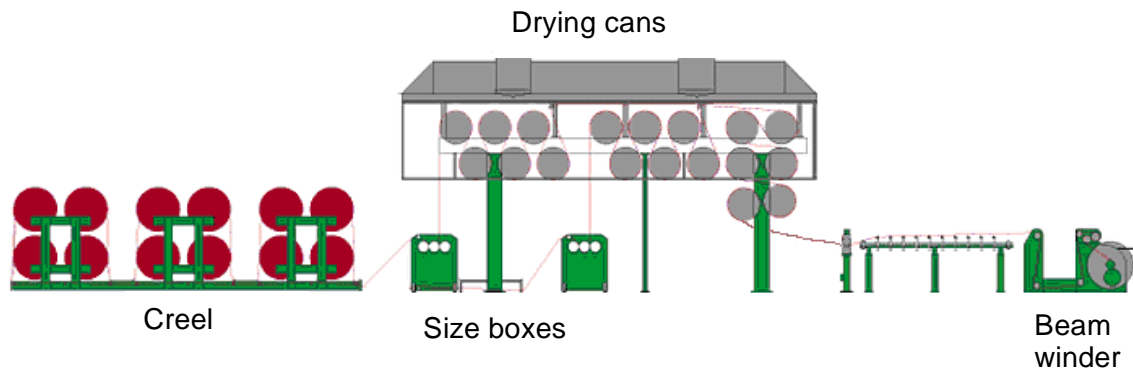


**Figure 5. Slasher creel loaded with 12 section beams for weaving denim**



**Figure 6. Slasher creel loaded with beam-dyed yarns for a warp-striped fabric**

From the creel, the yarns flow through the **size box**, where where the liquid size solution is applied to the yarn. Size concentration, viscosity, and temperature must be constantly controlled. Yarn tension and yarn speed on the slasher must also be controlled. Squeeze rolls above the size box remove excess size, and the pressure of these rolls helps control size add-on. The yarns are then dried as they move over steam-heated cylinders or cans. All of the warp yarns are then laid in parallel fashion through an expansion comb and wound onto a loom beam. The size remains on the warp yarns through the weaving process and then is removed from the fabric in a preparation process known as **desizing**. Some sizes, such as PVA, can be reclaimed, but starch cannot be reclaimed. The schematic in Figure 7 shows the path of yarn through the slasher.



**Figure 7. The general parts of a slasher**

## 2.4 Drawing-In

The last warp yarn preparation step is to draw each warp yarn through the appropriate loom elements, as illustrated in Figure 8. If a given yarn breaks, the associated **drop wire** makes an electrical contact that stops the weaving machine. The **heddles** are necessary to control the weave design, and the **reed** helps to space the yarns equally and provide a means of pushing, or **beating**, each weft yarn into the fabric. Each opening or space in a reed is called a **dent**. Drawing-in is sometimes done by hand (as shown in Figure 9), but can be done electronically. If all yarns are drawn in properly, then weaving will be more efficient, fabric design will be accurate, and the overall fabric appearance will be acceptable.

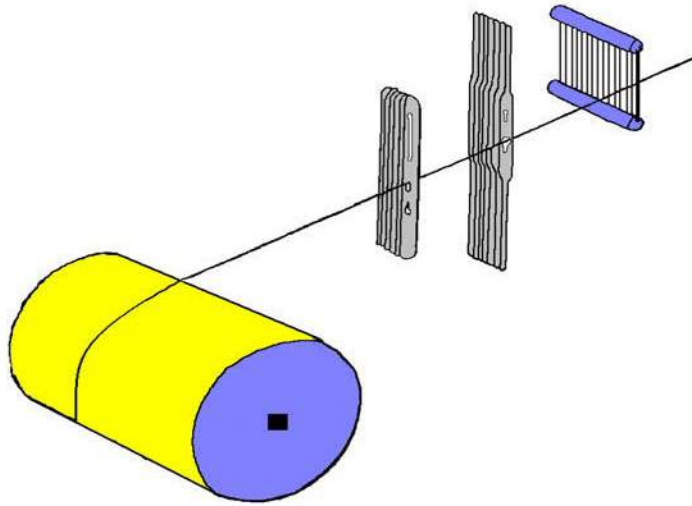


Figure 8. A warp yarn drawn through a drop wire, heddle, and reed dent

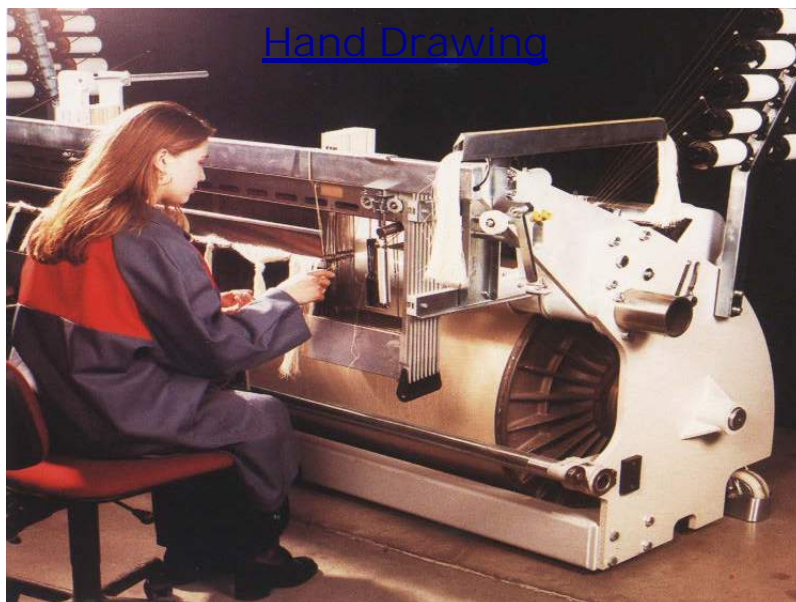


Figure 9. Hand or manual drawing-in



## 2.5 Tying-In

In mass production of a fabric in the same fabric design, it is not necessary to redraw the warp yarns in order to replace a loom beam that has run out with a new beam of the same style. Instead, the much faster process of **tying-in** can be used. A tying-in machine takes each end of warp yarn on the existing loom beam and ties it to the associated yarn on the replacement loom beam.

## 3 WEAVING

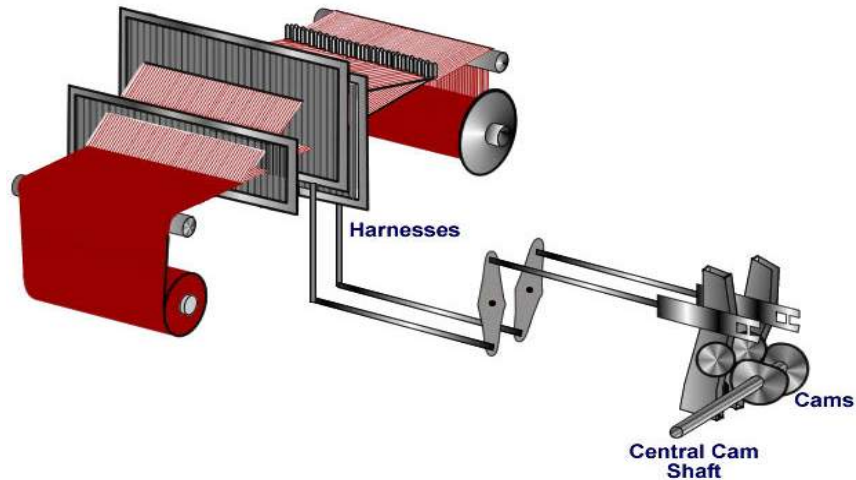
Forming a woven fabric requires five basic loom functions or motions: **shedding, filling insertion, beat-up, let-off, and take-up**. The first three motions take place in a set time interval and follow one another sequentially. Because these motions cannot happen simultaneously, conventional weaving is a single-phase process. Some machines can insert a number of picks almost simultaneously into a number of shed openings and beat each pick into the fabric. However, these multiphase (multished) machines have limited design potential and generate more lint when weaving spun yarns.

### 3.1 Shedding

This loom function separates all the warp yarns into a **weave shed** (opening) formed between a **top shed** (yarns that are raised) and a **bottom shed** (yarns that are not raised). Each weft yarn is inserted into the opening created by shedding of the warp yarns. Devices called **harnesses** contain a certain number of heddles through which warp yarns are drawn (see Figure 8, above). Harnesses are raised and lowered to produce a particular woven design. There are three general methods of shedding, each with specific design capabilities.

#### 3.1.1 Cam Shedding

**Cam shedding** typically uses 6 to 8 harnesses, though sometimes up to 12. As illustrated in Figure 10, each harness is controlled by a rotating cam that forces the connected harness to move up and down in a prescribed manner to produce a particular fabric design. The profile or shape of each cam and its position on the camshaft dictate the movement of the connected harness. With cam shedding, designs are limited to basic weaves such as **plain weave**, simple **twill weaves**, and common **satins weaves**.



**Figure 10. Cam shedding (courtesy of NC State College of Textiles)**

### 3.1.2 Dobby Shedding

**Dobby shedding** typically uses 12 to 32 harnesses, which allows for a broader range of woven designs than with cam shedding. In addition to the basic weaves, dobbie shedding makes it possible to weave small geometric figures, spot weaves, and more complex pattern stripes. Many machines with dobbie shedding use plastic sheets with punched holes to direct the harnesses to be lifted in a certain sequence to produce a given design. A punched hole allows a pin to penetrate the sheet and initiate lifting of the associated harness. The weave design is thus controlled by the positioning of the holes in the pattern sheet. Figure 11 shows a weaving machine using this type of dobbie shedding.



**Figure 11. Dobby shedding**

Today, many weavers are investing in electronic dobbie shedding machines that work in a much simplified manner, with no punched sheets. Connected with a computer-aided design system, these machines can quickly download and weave a developed design. Figure 12 shows an electronic dobbie shedding machine.

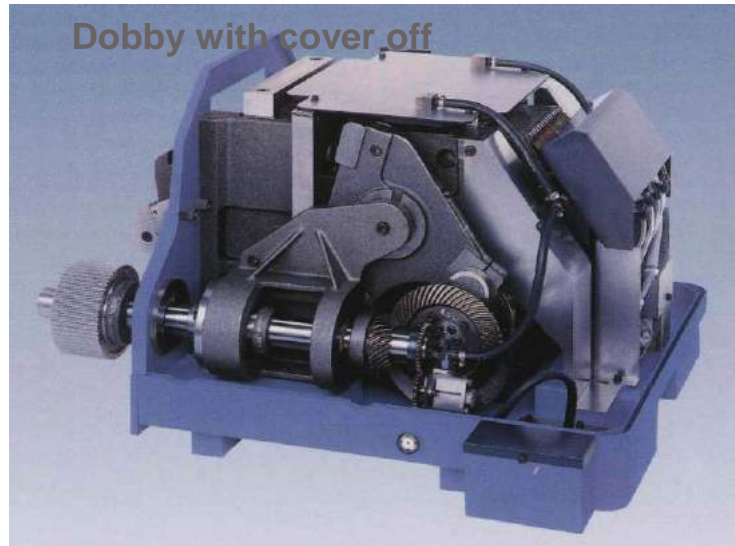


Figure 12. Electronic dobby shedding machine with cover removed

### 3.1.3 Jacquard Shedding

Instead of using harnesses to control the weave design, **Jacquard shedding** employs **draw cords** that drop down from a **Jacquard head**; each cord is connected to an individual heddle or a small group of heddles. This type of control makes it possible to form large design repeats and very intricate designs. A given Jacquard machine will have a certain number of hooks that control the lifting of warp yarns. Having more hooks makes it possible to weave larger design repeats and more intricate designs. Figure 13 shows a Jacquard machine and its associated draw cords.

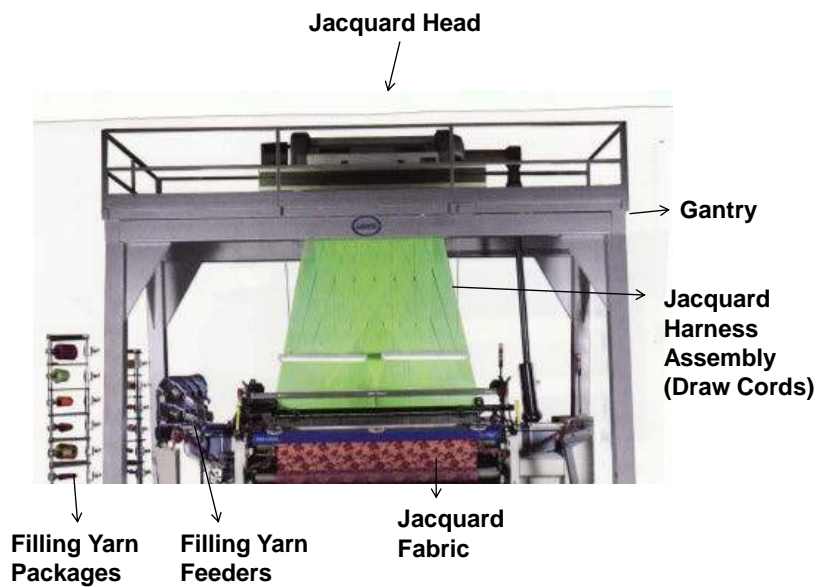


Figure 13. Weaving machine with Jacquard shedding (courtesy of Picanol)

### 3.2 Filling Insertion

The filling, or weft yarn, can be inserted into the woven fabric by various methods. The oldest method, using a **shuttle**, has been replaced today by various **shuttleless** methods, which include **rapier**, **projectile**, **air jet**, and **water jet** filling insertion.

### 3.3 Shuttle Weaving

Shuttles typically are inserted at the rate of 180 to 220 times per minute, referred to as **picks per minute**. The shuttle contains a **quill** on which a small amount of filling yarn is wound. The yarn unwinds from the quill as the shuttle goes back and forth through the separated warp yarns. A fresh quill of yarn is inserted just before the current quill is completely empty. Some shuttle machines are still in operation, weaving vintage denim and specialty fabrics. Figure 14 shows a shuttle with an empty quill inserted. The shuttle is tapered on each end for easy entrance into and exit and out of the weave shed. Figure 15 shows a shuttle machine manufactured in the late 1940s, with elements made of iron, wood, and leather.



Figure 14. A weaving shuttle



Figure 15. Rear view of a shuttle loom

### 3.3.1 Rapier Filling Insertion

Rapiers are rigid bars or flexible tapes with an attached gripper system to grip the yarn and insert it across the warp shed. The grippers typically are opened and closed with the aid of cams or springs. Most rapier weaving machines use a left-hand and a right-hand rapier. As illustrated in Figure 16, one rapier (the **giver**) inserts the weft yarn halfway across the weave shed, where it meets the other rapier (the **taker**), which enters the weave shed from the opposite direction, and the weft yarn is transferred from the giver to the taker. Each rapier then retracts from the weave shed to complete the process. The insertion process is typically repeated 350 to 600 times per minute, depending on machine width and model.

At least one manufacturer still produces single-rapier machines, which insert the rapier across the complete width of the fabric and return it empty before insertion of the next weft yarn. This makes for a simpler operation and requires less critical timing, because successive picks are not exchanged from one rapier to another.

Because rapier machines can insert a wide range of yarn types, from steel wire yarns to all kinds of novelty yarns, rapier filling insertion is the most flexible insertion method. **Rigid rapier machines** are excellent for weaving rip-stop fabrics, in which several yarns are inserted simultaneously to help prevent the propagation of tears in the fabric. Rigid rapier machines are shown in Figures 17 through 19. In Figure 17, the rounded pipe-like devices at the front of each machine are where the rigid right-hand rapiers are recessed after leaving the weave shed. Figure 19 shows two rapiers exchanging the weft yarn as it is woven into a novelty-yarn woven fabric.

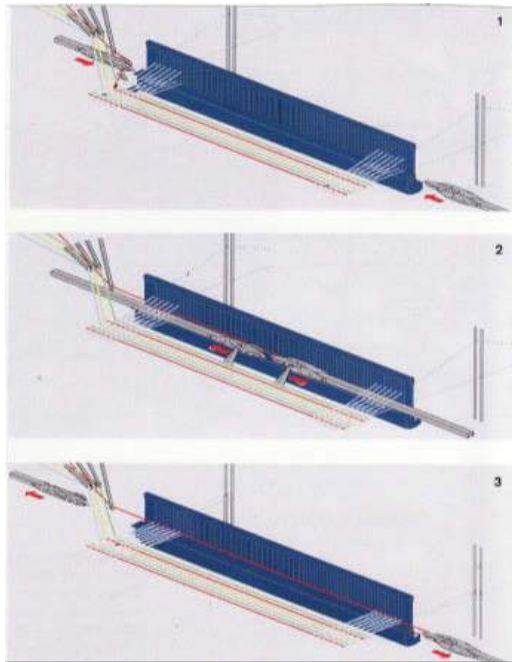


Figure 16. The sequence of operations on a double-rapier machine



**Figure 17. Rigid rapier machines with Jacquard shedding (courtesy of Dornier)**



**Figure 18. Rigid rapier machine with selection of 12 weft yarns (courtesy of Dornier)**



**Figure 19. Double rigid rapier machine (courtesy of Dornier)**

### 3.3.2 Projectile Filling Insertion

Projectile weaving machines (illustrated in Figure 20) contain a gripper that holds the filling yarn as the projectile is shot across the weave shed. A torsion bar stores up energy as it is twisted; when the energy is released, a connected lever strikes the projectile, propelling the yarn across the machine. A given machine will contain several projectiles, typically one per 10 inches of machine width. Projectiles are returned to the picking side of the machine via a type of conveyor-belt system; at any one time, several projectiles will be on the belt. Projectile filling insertion machines typically run at 300 to 550 insertions per minute. With fewer moving parts, they require less maintenance than rapier machines. Double-width projectile machines can make two separate fabrics with the same set of projectiles, thus doubling the speed of weaving. Projectile machines can produce denim-weight fabrics, as well as shirting weight.

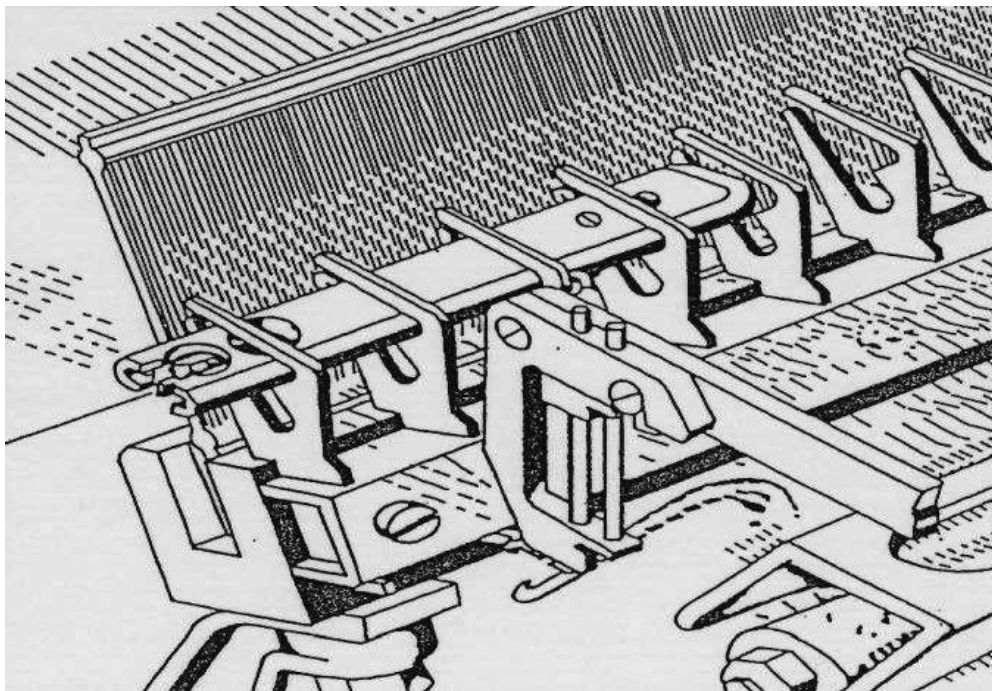


Figure 20. Projectile filling insertion (courtesy of Sulzer Textil)

### 3.3.3 Air Jet Filling Insertion

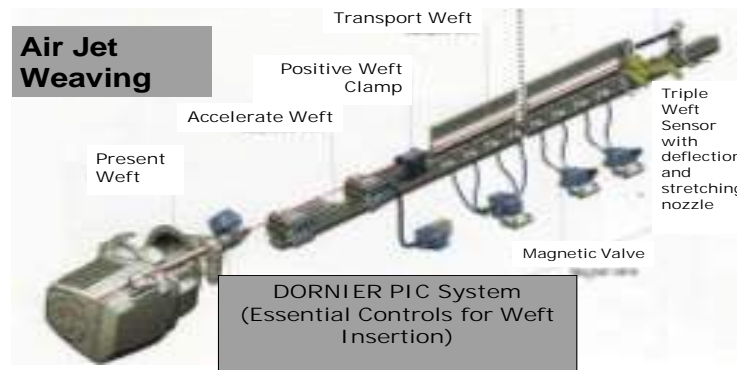
Air jet weaving machines use a burst of compressed air from an air nozzle to initially propel the filling yarn across the weave shed. Because the air disperses very quickly, additional relay air nozzles are evenly spaced across the width of the weave shed (as shown in Figure 21) to allow for weaving of wider fabrics. Air jet machines use a special **profile reed** to create a tunnel configuration through which the air and filling yarn travel across the weave shed.

Air jet weaving machines can insert relatively coarse yarns, such as yarns for heavy bottom-weight denim; however, yarns any heavier than that would be difficult and more costly to weave, because of the high air pressures required. These machines can also

weave finer spun yarns, but not ultra-fine yarns that might be blown apart. Spun yarns and textured filament weft yarns run well on these machines, but not slick flat filament yarns, because of their low surface friction. Air jet machines have lower maintenance requirements and fewer replacement parts than do rapier and projectile machines. Insertion rates ranging from 600 to 1200 per minute are typical for air jet machines. Figure 22 shows the layout of the main nozzle and relay nozzles.



**Figure 21. Relay nozzles on an air jet weaving machine**



**Figure 22. Air jet weaving weft insertion system (courtesy of Dornier)**

### 3.3.4 Water Jet Filling Insertion

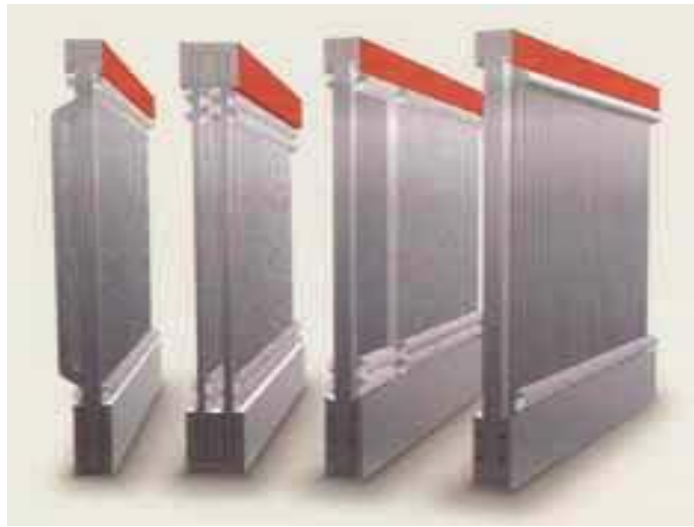
In water jet weaving, only hydrophobic fibers and yarns can be used, such as polyester, nylon, and olefin fibers. Most of the fabrics woven on these machines are made of filament yarns, which are less absorbent than spun yarns. A vacuum slot on the front of the machine front helps to remove any residual water from the fabric. All machine parts must be made of non-corrosive materials. Water jet weaving machines have insertion



rates of 800 to 1200 picks per minute. The fabric most commonly made on water jet machines is mattress ticking.

### 3.4 Beat-Up

In the third basic motion of weaving, the reed pushes, or beats, the weft yarn into the woven fabric. The reed moves backwards as the filling yarn is inserted in front of it and forward to beat the yarn into the fabric. Reeds are designated by **reed number**, which indicates the number of dents or slots in the reed per inch of width. For example, a 24 reed number means that the reed contains 24 dents per inch. Ends per inch in the fabric divided by ends per dent in the reed equals the reed number. Weavers typically have an inventory of different reeds to accommodate various fabric styles with different numbers of ends per inch and warp-yarn sizes. The space between dents must be wide enough to allow any slubs or thick places in the warp yarn to pass through. Therefore, each reed has a required amount of air space depending on whether filament or spun yarn is used; spun yarns require more air space because of their unevenness. Figure 23 shows several reeds.



**Figure 23. Various reeds for different fabric constructions**

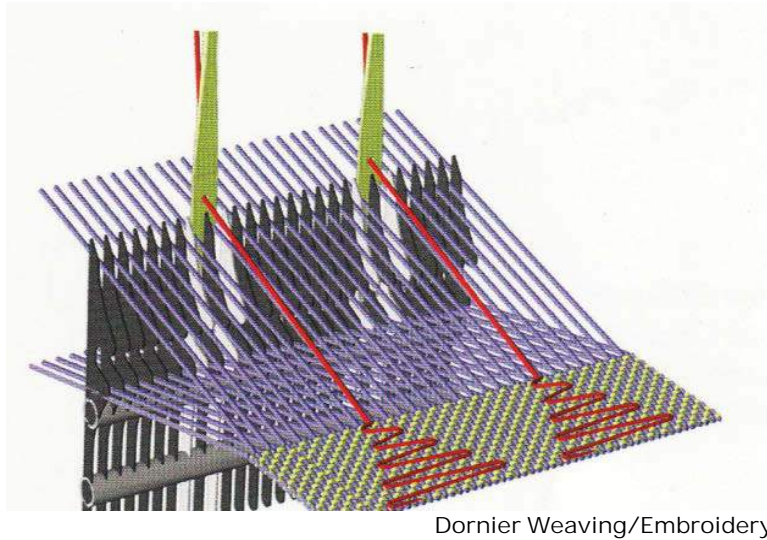
### 3.5 Let-Off and Take-Up

In the basic fourth motion of weaving, let-off, the warp yarn is unwound from the loom beam. The rate of let-off must be controlled so that the warp yarns are not under excessive tension during shedding, which would result in warp yarn breakage. The fifth basic motion of weaving is take-up, or removal of fabric from the weaving machine. The rate of take-up thus controls the number of picks per inch inserted into the fabric. Slower take-up allows insertion of more weft yarns per inch, while faster take-up allows insertion of fewer weft yarns per inch and results in a higher production rate.

### 3.6 Weaving in Combination with Embroidering

At the 2011 International Textile Machinery Association exhibition in Barcelona, Spain, Dornier demonstrated integration of embroidery in the weaving process to enable

simultaneous weaving and embroidery. As shown in Figure 24, the embroidery unit on the weaving machine consists of needle-like devices with eyelets located behind the reed for threading extra yarns that serve as the embroidery yarns. Figure 25 shows the location of the embroidery yarns above the weaving harnesses, and Figure 26 shows samples of fabric woven and embroidered through the use of this technology.



**Figure 24. Weaving and embroidery performed simultaneously**

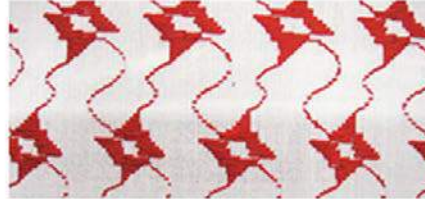


**Figure 25. Weaving and embroidering integrated machine (courtesy of Dornier)**

Pattern produced with  
one stitching axis



Pattern produced with  
two stitching axes



**Figure 26. Fabric produced with integrated weaving and embroidery technology**

## 4 BASIC WOVEN DESIGNS

The three basic weave designs are **plain**, **twill**, and **sat**in. All other weave designs are built around these three basic weaves. More complex weave designs may combine two or more of the basic weave designs.

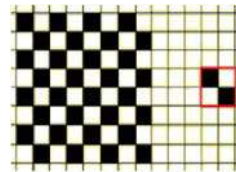
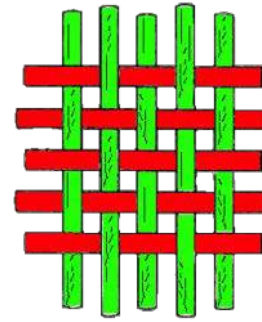
### 4.1 Plain Weaves

Plain weave is the most commonly used weave design and the simplest. Figure 27 illustrates how one warp yarn weaves over one weft yarn and under the next one, and the adjacent warp yarn weaves in the opposite manner, under one weft yarn and over the next one. Figure 27 also shows how the design is presented graphically on **point paper** or a computer screen. In the sketch, each vertical column of blocks represents a warp yarn and each horizontal row of blocks represents a weft yarn. When a warp yarn weaves over a weft yarn and appears on the face of the fabric, a block is filled in or marked with a symbol such as an X. Thus, each filled-in block represents a warp yarn showing on the face of the fabric, and each block left blank represents a weft yarn showing on the front of the fabric. Thus, for the plain weave design, each vertical column has a filled-in block followed by an empty block.

The plain weave can be represented by the notation 1/1, meaning that each warp yarn goes over one individual weft yarn and then under the next successive weft yarn. Adding the numbers 1 plus 1, we can say that the plain weave design repeats on 2 warp yarns and 2 weft yarns. Figure 27 also shows how the **weave repeat** is represented on point paper.

The plain weave has more interlacing or crossover points than the other basic weaves. Plain-weave fabrics therefore tend to be stiffer, with less drape. However, the fabric is very stable, resulting in few issues with skew, seam slippage, picking, or snagging. Some common plain-weave fabrics are chambray, broadcloth, canvas, and sheeting.

- The plain weave is one of the oldest, simplest, and most widely used weaves.
- It repeats on two ends and two picks.
- Two harnesses are needed to produce the plain weave.



One Repeat

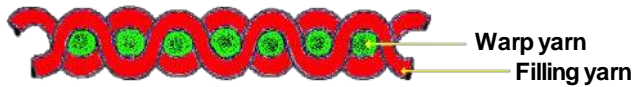
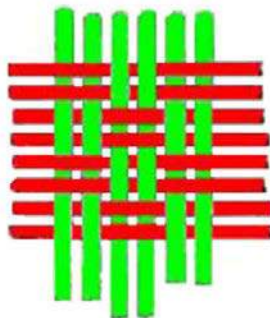


Figure 27. The plain weave

#### 4.1.1 The Basket Weave

The **basket weave**, shown in Figure 28, is a derivative of the plain weave with groups of yarns weaving over and under one another. In the example shown, each group consists of two yarns, and the pattern is classified as a 2 x 2 basket weave design. Fabric woven in this design has more texture and better drape, but is not as stable as the simple plain-weave fabric.

- The basket weave is a derivative of the plain weave.
- The most common basket weave is the 2 x 2 basket.
- This has a repeat of four ends and four picks.
- Two ends weave over two picks as one.



One repeat

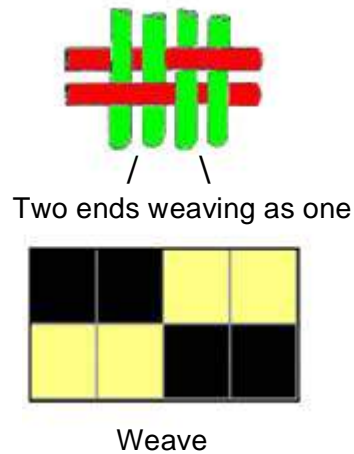
Figure 28. The 2 x 2 basket weave

### 4.1.2 The Oxford Weave

The **Oxford weave** design, illustrated in Figure 29, is sometimes referred to as a 2 x 1 basket weave. A derivative of the plain weave, the Oxford weave is a common weave design for shirting. The basic Oxford weave design usually uses thicker weft yarns and finer warp yarns, typically with the filling yarn left natural and the warp yarn dyed.

**Pinpoint Oxford** fabric uses yarns of the same size for the warp and weft, and the yarns tend to be much finer, producing a finer woven structure than the basic Oxford weave fabric. As shown in Figure 29, pairs of warp yarns weave together, typically drawn through the same heddle, weaving over and under individual weft yarns.

- The Oxford weave is a derivative of plain weave.
- Two warp ends weave as one, over and under single picks.
- Most Oxford fabrics have about twice as many ends per inch as picks per inch and a finer warp yarn with a heavier filling yarn.



**Figure 29. The Oxford weave**

## 4.2 Twill Weaves

Twill weaves are characterized by a diagonal pattern, or **twill line**, in the fabric. If the diagonal line rises to the left, the fabric is classified as a **left-hand twill**, and if it rises to the right, the fabric is classified as a **right-hand twill**.

### 4.2.1 The 2 x 1 Twill Weave

Figure 30 shows a 2 x 1 right-hand twill design represented in point-paper notation using X marks in blocks to represent where the warp yarn floats over the weft yarn. This design repeats on 3 warp yarns and 3 weft yarns and requires at least 3 harnesses to weave. The number of harnesses needed to weave a given design often must be a multiple of the minimum number of harnesses required. Examples are 4, 6, 8, or 10 harnesses for plain weave and 6, 9, 12, or 15 harnesses for a 2/1 twill. Of course, more harnesses means more weaving expense. However, weaving costs for producing left-hand and right-hand twill fabrics should not differ.

- The 2/1 is the **counter**.
- The top number designates how many picks each warp end will float over, and the bottom number designates how many picks each warp end will float under.
- Each end weaves over two picks and under one pick.

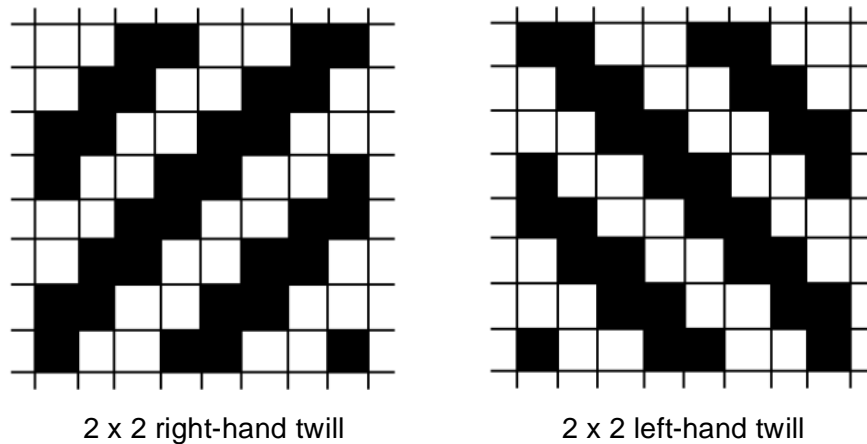
	X	X		X	X
X	X		X	X	
X		X	X		X
	X	X		X	X
X	X		X	X	
X		X	X		X

**One Repeat  
2/1 RHT**

**Figure 30. Point-paper notation for 2/1 right-hand twill (RHT)**

#### 4.2.2 The 2 x 2 Twill Weave

Figure 31 shows examples of **balanced twills**, where each warp yarn goes over two weft yarns and then under two weft yarns. This results in a balance of warp and weft yarns showing on the face of the fabric. Adding 2 plus 2 to get 4 means the weave repeat is on 4 warp yarns and 4 weft yarns. Therefore, this weave design requires at least 4 harnesses or some multiple of 4 as needed to accommodate more warp ends. Changing the way the warp yarns are drawn through the harnesses and heddles can convert a 2 x 2 twill to a **herringbone** or **chevron** design, as illustrated in Figure 32.



**Figure 31. 2 x 2 right-hand and left-hand twill designs**

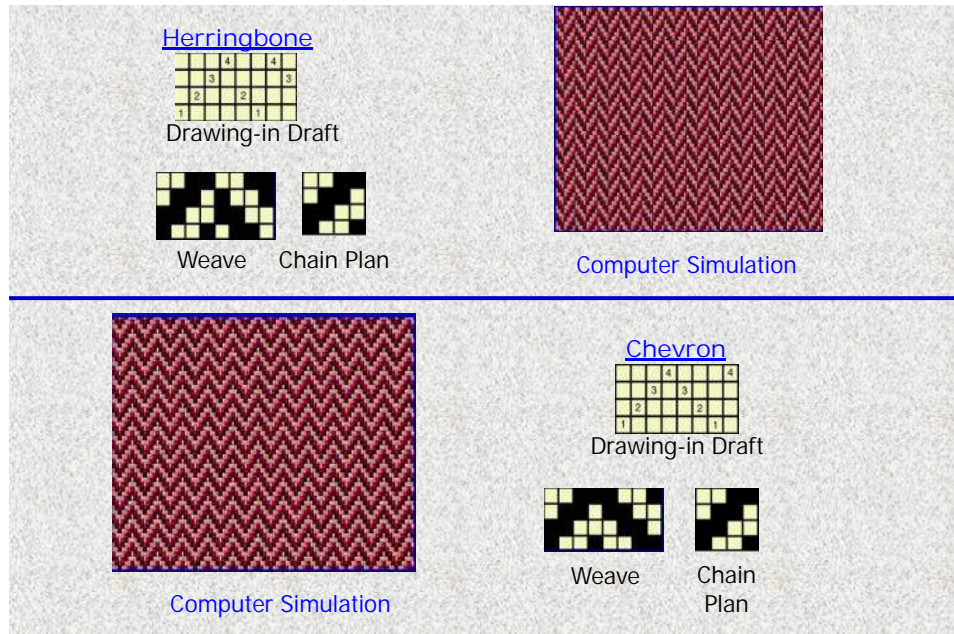


Figure 32. 2/2 right-hand twill variations

#### 4.2.3 The 3 x 1 Twill Weave

A 3 x 1 twill design is illustrated in Figure 33. Here, each warp yarn goes over 3 weft yarns before going under the next individual weft yarn. Thus, the **weave floats** are longer, creating fewer **interlacing points** in the fabric. This weave design produces fabrics with higher tear strength and is used to make heavier bottom-weight fabrics, such as denim, chino, and gabardine. The weave design repeats on 4 warp yarns and 4 weft yarns and requires at least 4 harnesses.

The 3/1 twill is the most common twill in bottom-weight fabrics.

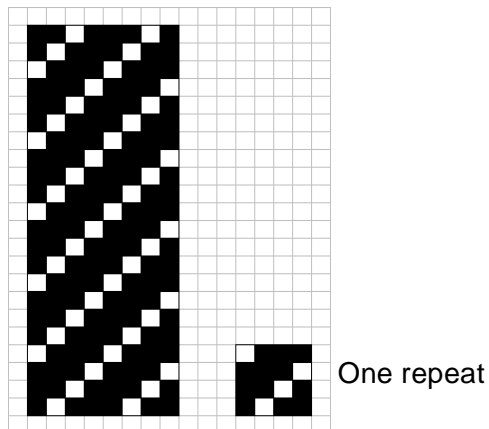
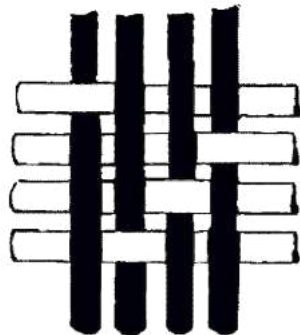


Figure 33. 3 x 1 twill

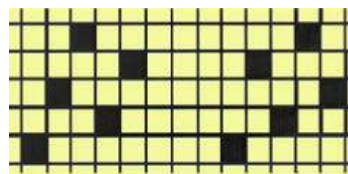
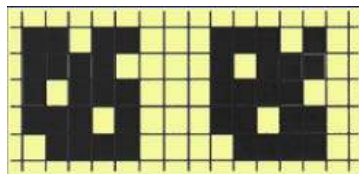
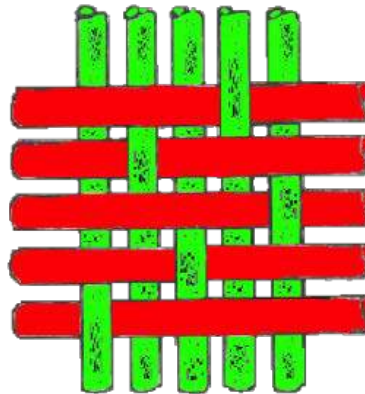
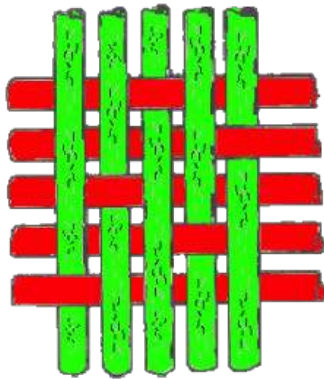
### 4.3 The Satin Weave

The satin weave is known for its smooth and lustrous surface. This is due to the many long floats in the fabric design, where no interlacing points touch one another. Satin weaves are classified by the number of harnesses used to weave them. The simplest satin weave (as shown in Figure 34) uses 5 harnesses. Satin-weave fabrics have excellent drape but can have problems with picking, snagging, skew, and seam slippage.

**Satin fabrics** are defined as fabrics woven with silk yarns in a satin design, and **sateen fabrics** are defined as fabrics woven in a satin design with any fiber other than silk. However, in some countries, warp-face satin is referred to as a “satin fabric” and filling-face satin as a “sateen fabric.” As shown in Figure 34, warp-face satin fabric has long floats in the warp direction, and filling-face satin (or sateen) fabric has long floats in the filling direction.

Warp-face satin with 2 as pick counter

Filling-face satin with 3 as pick counter



2 as Counter

3 as Counter

2 as Counter

3 as Counter

Figure 34. Five-harness satin weaves



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