

Form-Wound Coils Random-Wound Coils

A typical low-voltage generator is built with multi-turn stator coils, ranging from one to 16 turns per coil. These coils can either be form wound (where the wire is square or rectangular and the turns are systematically arranged) or random wound (where the wire is round and the arrangement between the turns is not definite).

With units less than 1,500 kW, the size of the stator and the minimum wire thickness usually do not allow form-wound coils. However, in some cases, either form-wound or random-wound coils can be used.



Generators with random-wound coils can be made at a reduced cost, and their capability to withstand severe environmental conditions can be enhanced through the use of vacuum-pressure impregnation (VPI). Still, performance, capability and endurance to the environment make units with form-wound coils superior. This report analyzes construction feature and advantages of the two type of windings.



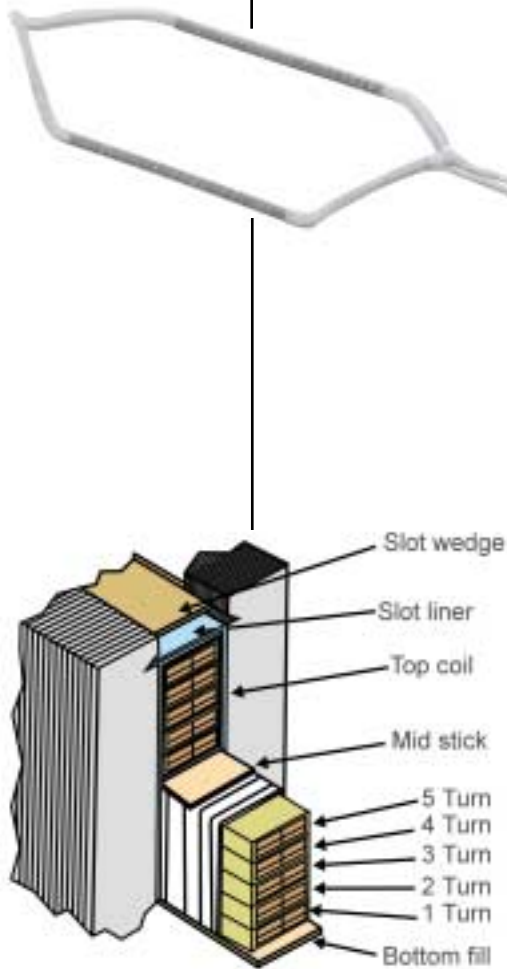
Form-wound coils

A form winding uses square or rectangular magnet wire. The wire insulation is designed to handle operating turn-to-turn voltages as well as maximum surge or impulse voltages. Kato Engineering Inc.'s standard magnet wires have 200° C heavy film coat covered with dacron glass or mica turn tape.

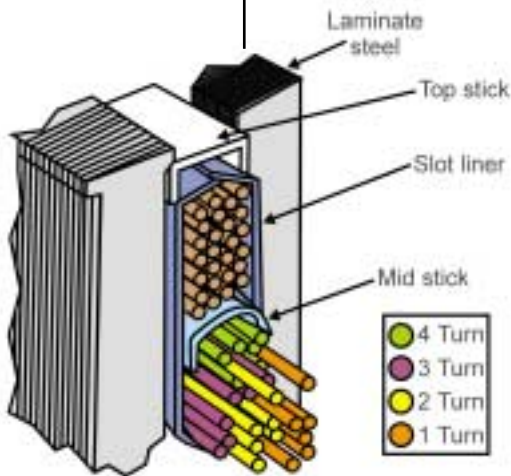
The coil winding process begins with skeining (looping) of the magnet wire. Because of the difficulty to form wire of high width-to-thickness ratio, several wires in parallel may make one turn. Individual turns are arranged in precise location with respect to each other. That is, turn one is always next to turn two, turn two is always next to turn three, and so on.

The skeined coils are shaped in a forming machine to the final configuration that they will occupy in the stator. The coils then have mica groundwall tape applied, which provides both electrical-withstand strength and protection from mechanical damage. During coil insertion, the coils are held in place in the slot with insulated wedges and liners. Felt pads and ropes are inserted in the end windings to allow spacing for air circulation while maintaining a rigid system that prevents coil movement under abnormal operating conditions. The coil-to-coil connections and lead connections are made and insulated.

The stator then undergoes vacuum-pressure impregnation. The vacuum removes air and moisture from the coils. Resin is then applied under pressure to uniformly saturate the windings. The stator is then baked to cure the resin, making a rigid mechanical and electrical winding.



Random-wound coils



When the arrangement between turns is not definite during coil skeining or insertion, the windings are called “random.” That is, for example, turn one can be touching turn four.

Random windings are used on lower kW machines where it is impractical to use form coils. Random windings are made from a lower cost magnet wire that is film coated and round. With random windings, the mechanization of manufacturing is also increased to add to a lower cost. Generally, several spools of wire are used to form one turn. A special fixture is used to produce coils that are diamond or oval shaped. Complete phase grouping can be made from a single operation, so coil-to-coil connections do not have to be made.

A cross-section of the coil shows that turns are randomly distributed and can be in close proximity to a number of other turns. Throughout the axial length of the coil, wires can migrate during manufacturing and take new positions with respect to other coils. When migration occurs, the electrical stresses between turns increases. This condition will be compounded by non-linear loads, such as silicon controlled rectified (SCR)-type loads.

The stator slots with random windings have small openings compared to the open slots in stators with form coils. Inserting random-wound coils requires separation of the strands of wire and random feeding through the small slot opening. This process again increases the chances of random location of the wires.

During stator winding, the coils are separated with insulating material and positioned to clear the inside diameter of the stator. The stators can be either dipped in resin or, as is done at Kato Engineering Inc., vacuum-pressure impregnated. During the vacuum-pressure impregnation process, the resin fills pockets and seals any openings that occurred in the end windings.



Advantages of form-wound coils

The primary advantage for manufacturing generators with random windings is economics: lower cost wire and mechanized construction. However, without vacuum-pressure impregnation (VPI), the life expectancy of random windings is drastically reduced under severe environmental conditions or with applications involving non-linear loads, such as silicon-controlled-rectified (SCR)-type loads. Kato Engineering Inc.'s experience with such applications has shown that form windings with VPI treatment are far superior to varnish dipped, random wound systems.

SCR type loads induce high turn-to-turn surge voltages into the windings, as high as twice the normal operating voltage. In the case of random windings, the ability to withstand operating turn-to-turn voltages, which can be marginal for normal operation, will cause failures within a few hours under SCR type loads. For example, a four-pole generator rated 600 kVA and 600 volts may have four turns per coil and peak turn-to-turn voltage of 38 volts. For a random-wound design if turn one and turn four are touching, this voltage can be as high as 114 volts (38 volts x a three-turn difference), and can be amplified by SCR loads. That is why random coils may prematurely fail. A similar form-coil design would have a peak voltage of only 38 volts because turns one and four would never be next to each other.

For salt or other chemical laden environments, the end windings are the most susceptible area, especially with random windings. Moisture and contaminants promote tracking and deterioration that can lead to failure. Tracking failures are caused by small partial discharge currents, which develop localized heating and cause chemical decomposition of any weak insulation barrier. Arcs of relatively high currents develop additional heating, which will carbonize (track) the resin surface. This is the start of most winding failures.

The end windings of form coils have large openings for air circulation, which prevent contamination build up. Therefore, the likelihood of tracking-type

failures is minimized. In addition, the insulating tape on the coils provides additional environmental protection. The inherent rigidity of the rectangular wire coupled with the lacing of the end turns and VPI ensures a rigid insulation system. A rigid coil structure is very important to minimize movement at the coil-lamination interface when there are high surge currents, such as motor starting loads or short circuit faults. These can exert extreme forces between the coils.

Form windings have uniform temperature distribution as well as resin build up, which minimize the chance of localized hot spots. Insulation systems are categorized by temperature limits of the materials. For example, a class F system is designed to withstand an overall temperature of 155° C. This temperature is made up of ambient air plus average temperature of the windings with allowance for hot spots. The average winding temperature is determined by measuring the dc resistance, which includes end windings, the coolest part of generators with form coils.

While very few specifications require hot spot measurements, test data on prototype units have shown that hot spot temperatures can be as high as 30° C above the average winding temperature. With form wound machines the hot spot is always in a predictable location at the slot portion of the laminations. The hot spot temperature can be measured and duplicated from unit to unit. However, for random windings, because of uneven resin build up, the hot spot location can vary in duplicate units. In continuous duty applications, premature winding failures of identical units having random coils is a prime example of localized excessive hot spots.



Summary of differences

Form-wound coils

1. Magnet wire is rectangular or square with double dacron glass cover or mica turn tape over 200° C heavy film. The wire is more costly and inventory costs are increased because many different sized wires are used.
2. Individual turns are systematically arranged throughout the coil.
3. Coils employ insulation tapes.
4. The slots have uniform copper fill. Individual wires are tightly held in the slot.
5. Coil-to-coil connections are usually required.
6. End windings are shaped to form a basket with large openings between the coils to promote cooling and reduce coil contamination.
7. There is uniform resin build up in VPI and uniform temperature distribution.
8. There is uniform turn-to-turn voltage stress.
9. There is minimum potential for wire damage during assembly or disassembly.

Random-wound coils

1. Round wire with 200° C heavy film is used. Fewer sizes need to be kept on hand, and the wire is more economically priced.
2. Turns have a random location; wires from a turn can touch any other turn.
3. Coils are not taped.
4. Wires may be loose and vibrate with respect to each other, depending upon the resin treatment.
5. Only phase connections are required.
6. End windings are completely covered. Excessive resin can build up and seal all openings. Moisture and contaminants can easily be accumulated.
7. Resin builds up unevenly based upon the looseness of the wires in the slots. Localized hot spots can occur due to internal voids.
8. Turn-to-turn voltage can be as high as $(\# \text{ of turns} - 1) \times \text{volts/turns}$.
9. There is a high potential of wire damage during assembly or disassembly.

Conclusion

It is imperative that form-wound coils are used on SCR-type loads and in harsh environments: those laden with salts and other harsh chemicals. However if random windings are used, the maximum voltage-per-turn stresses must be within the insulation capability of the wire, and the windings must receive vacuum-pressure impregnation.