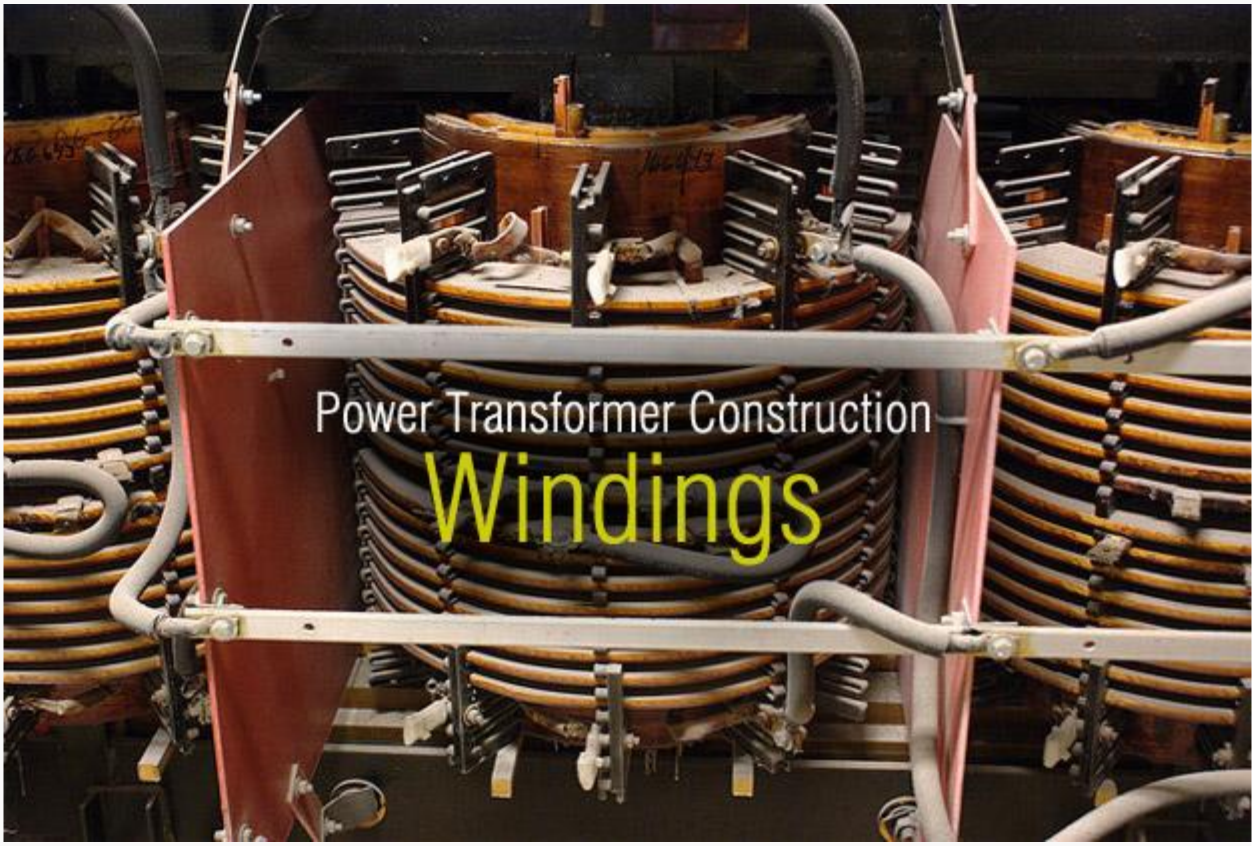
Power Transformer Construction – Windings



750kVA dry type transformer windings

Continued from tech. article: ***Power Transformer Construction – Core***

Construction

The **windings** consist of the ***current-carrying conductors wound*** around the sections of the core, and these must be properly insulated, supported and cooled to withstand operational and test conditions.
The terms winding and coil are used interchangeably in this discussion. Copper and aluminum are the primary materials used as conductors in power-transformer windings.

While aluminum is ***lighter*** and generally ***less expensive*** than copper, a larger cross section of**aluminum conductor** must be used to carry a current with similar performance as copper. Copper has higher mechanical strength and is used almost exclusively in all but the smaller size ranges, where aluminum conductors may be perfectly acceptable.

In cases where extreme forces are encountered, materials such as silver-bearing copper can be used for even greater strength.

The conductors used in power transformers are typically stranded with a rectangular cross section, although some transformers at the lowest ratings may use sheet or foil conductors. Multiple strands can be wound in parallel and joined together at the ends ofthe winding, in which case it is necessary to transpose the strands at various points throughout the winding to prevent circulating currents around the loop(s) created by joining the strands at the ends.

Individual strands may be subjected to differences in the flux field due to their respective positions within the winding, which create differences in voltages between the strands and drive circulating currents through the conductor loops.

Figure 1 - Continuously transposed cable (CTC)

Proper transposition ofthe strands cancels out these voltage differences and eliminates or greatly reduces the circulating currents. A variation ofthis technique,involving many rectangular conductor strands combined into a cable, is called ***continuously transposed cable (CTC)***, as shown in ***Figure 1***.

In core-form transformers,the windings are usually arranged concentrically around the core leg, as illustrated in ***Figure 2***, which shows a winding being lowered over another winding already on the core leg of a three-phase transformer.

A schematic of coils arranged in this three-phase application was also shown in ***Figure 1*****(article ‘Power Transformer Construction – Core’)**.

Shell-form transformers use a similar concentric arrangement or an inter-leaved arrangement, as illustrated in the schematic ***Figure 3*** and the photograph in ***Figure 7***.

Figure 2 - Concentric arrangement, outer coil being lowered onto core leg over top of inner coil

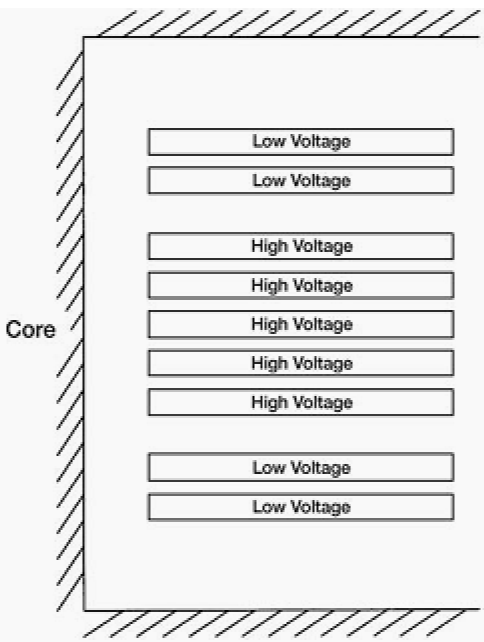


Figure 3 - Example of stacking (interleaved) arrangement of windings in shell-form construction

With an interleaved arrangement, individual coils are stacked, separated by insulating barriers and cooling ducts. The coils are typically connected with the inside of one coil connected to the inside of an adjacent coil and, similarly, the outside of one coil connected to the outside of an adjacent coil. Sets of coils are assembled into groups, which then form the primary or secondary winding.

When considering concentric windings, it is generally understood that circular windings have inherently higher mechanical strength than rectangular windings, whereas rectangular coils can have lower associated material and labor costs.

Rectangular windings permit a more efficient use of space, but their use is limited to small**power transformers** and the lower range of medium-power transformers, where the internal forces are not extremely high. As the rating increases, the forces significantly increase, and there is need for added strength in the windings, so circular coils, or shell-form construction are used.

In some special cases, elliptically shaped windings are used.

Concentric coils are typically wound over cylinders with spacers attached so as to form a duct between the conductors and the cylinder. The flow of liquid through the windings can be based solely on natural convection, or the flow can be somewhat controlled through the use of strategically placed barriers within the winding.

Figures 4 and ***5*** show winding arrangements comparing nondirected and directed flow. This concept is sometimes referred to as ***guided liquid flow***.

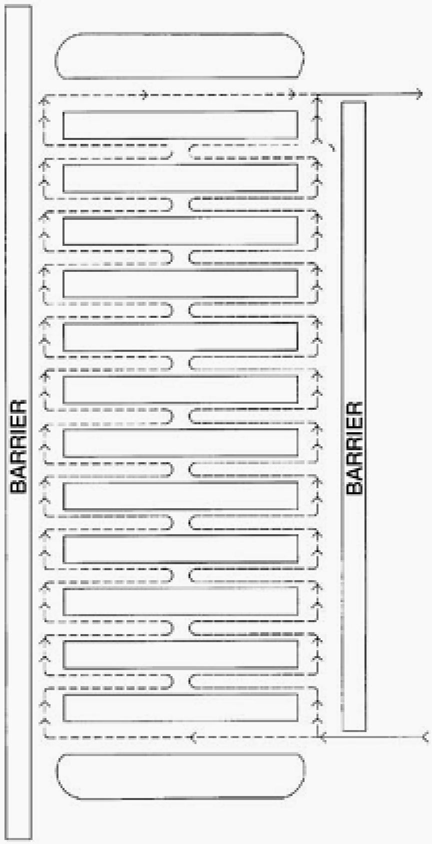


Figure 4 - Nondirected flow

A variety of different types of windings have been used in power transformers through the years. Coils can be wound in an upright, ***vertical orientation***, as is necessary with larger, heavier coils; or they can be wound ***horizontally*** and placed upright upon completion.

As mentioned previously, the type of winding depends on the **transformer rating** as well as the core construction. Several of the more common winding types are discussed below.

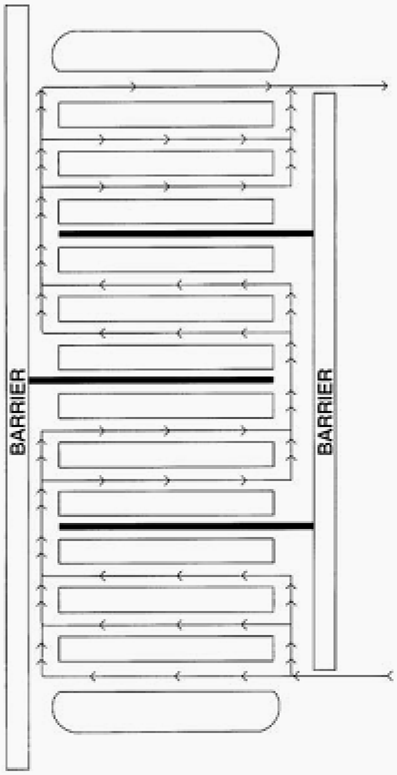


Figure 5 - Directed flow

Pancake Windings

Several types of windings are commonly referred to as "***pancake***" windings due to the arrangement of conductors into discs. However, the term most often refers to a coil type that is used almost exclusively in ***shell-form transformers***.
The conductors are wound around a rectangular form, with the widest face of the conductor oriented either horizontally or vertically. ***Figure 6*** illustrates how these coils are typically wound. This type of winding lends itself to the interleaved arrangement previously discussed (***Figure 7***).

Figure 6 - Pancake winding during winding process

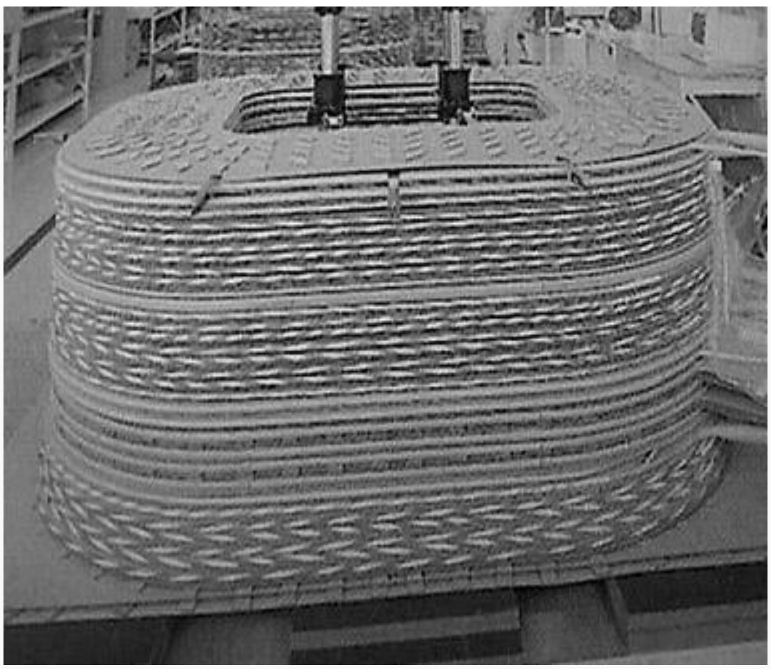


Figure 7 - Stacked pancake windings

Layer (Barrel) Windings

Layer (barrel) windings are among the simplest of windings in that the insulated conductors are wound directly next to each other around the cylinder and spacers.
Several layers can be wound on top of one another, with the layers separated by solid insulation,ducts,or a combination. Several strands can be wound in parallel ifthe current magnitude so dictates.

Variations of this winding are often used for applications such as tap windings used in ***load-tap-changing (LTC) transformers*** and for tertiary windings used for,among other things,third-harmonic suppression.

Figure 8 shows a layer winding during assembly that will be used as a regulating winding in an LTC transformer.

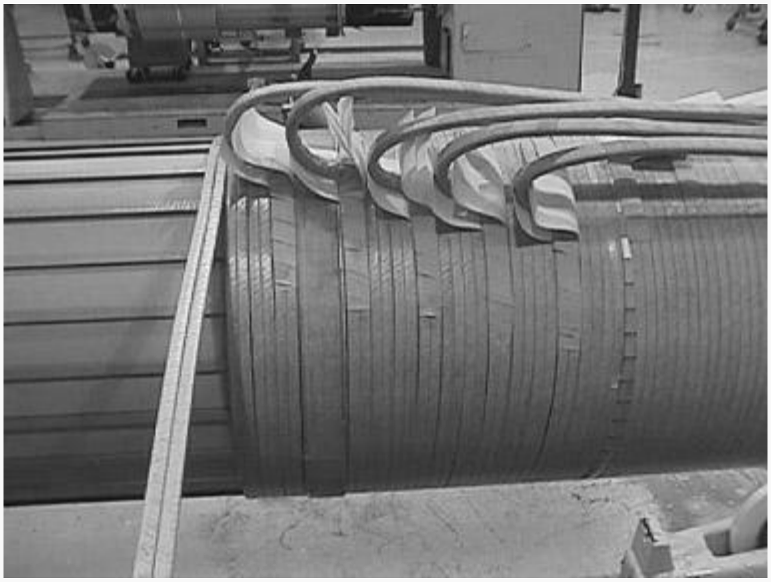


Figure 8 - Layer windings (single layer with two strands wound in parallel)

Helical Windings

Helical windings are also referred to as screw or spiral windings, with each term accurately characterizing the coil’s construction.
A helical winding consists of a few to more than 100 insulated strands wound in parallel continuously along the length of the cylinder, with spacers inserted between adjacent turns or discs and suitable transpositions included to minimize circulating currents between parallel strands.

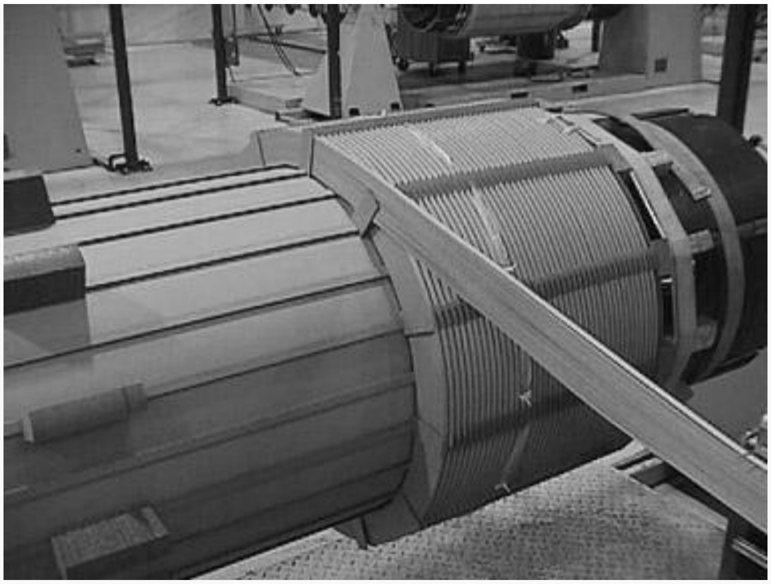


Figure 9 - Helical winding during assembly

The manner of construction is such that the coil resembles a corkscrew. ***Figure 9*** shows a helical winding during the winding process. Helical windings are used for the higher-current applications frequently encountered in the lower-voltage classes.

Disc Windings

A disc winding can involve a ***single strand*** or ***several strands*** of insulated conductors wound in a series of parallel discs of horizontal orientation, with the discs connected at either the inside or outside as a crossover point. Each disc comprises multiple turns wound over other turns, with the crossovers alternating between inside and outside.

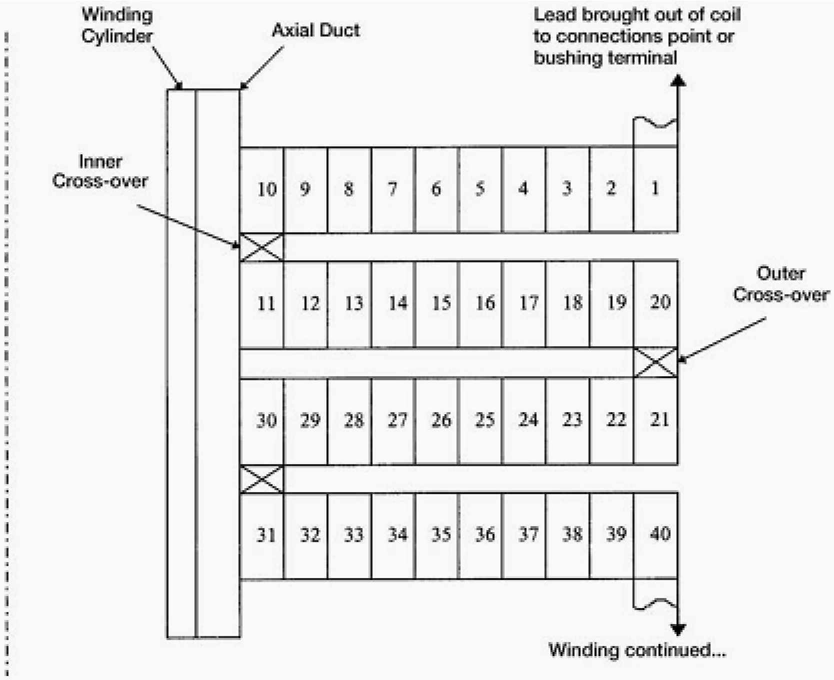


Figure 10 - Basic disc winding layout

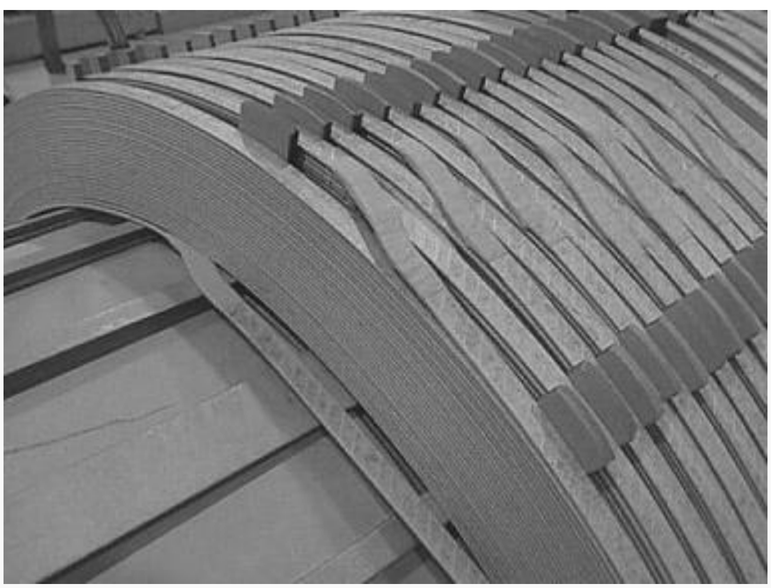


Figure 11 - Disc winding inner and outer crossovers

Figure 10 outlines the basic concept, and ***Figure 11*** shows typical crossovers during the winding process.

Most windings of 25-kV class and above used in core-form transformers are disc type. Given the high voltages involved in test and operation, particular attention is required to avoid high stresses between discs and turns near the end of the winding when subjected to transient voltage surges.

Numerous techniques have been developed to ensure an acceptable voltage distribution along the winding under these conditions.

Reference: *Electric Power Transformer Engineering, published May 16, 2012 by CRC Press // chapter Power Transformers authored by H.J. Sim and S.H. Digby (**Get this ebook from CRC Press**)*

Source:

http://electrical-engineering-portal.com/power-transformer-construction-windings