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# VIRGINIA TRANSFORMER CORP.

220 GLADE VIEW DRIVE • ROANOKE, VA 24012

PHONE 540-345-9892 • FAX 540-342-7694

www.vatransformer.com

## The Performance Advantages Of Circular Windings

### Introduction / Summary

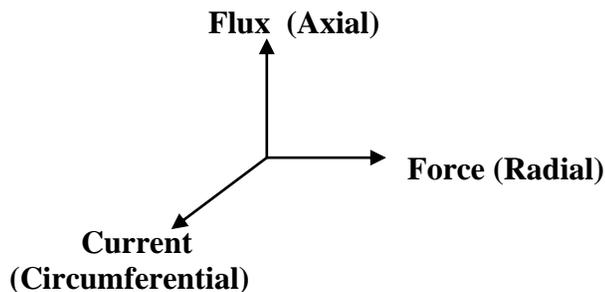
Staying at the leading edge of technology in the transformer industry requires a complete understanding of the major advantages of circular windings over rectangular windings. To develop a proper evaluation of why circular windings are better than rectangular windings, Virginia Transformer Corporation has examined the nature of forces generated in windings and how each of these two types of windings copes with these forces. Circular windings can be a major asset to VTC customers when they are developing specifications for transformer above 5000 KVA. The following simplistic explanation can help to educate VTC present and potential customers as to the advantages.

Under the short circuit, the rectangular coil design transformer will undergo substantial geometry changes in the coil shape leading to coil/insulation damage because it wants to become circular. The impedance change is up to 7.5%.

The circular coil on the other hand remains circular, the natural shape and suffers no change in geometry and impedance.

### How Forces are generated in Transformer Windings

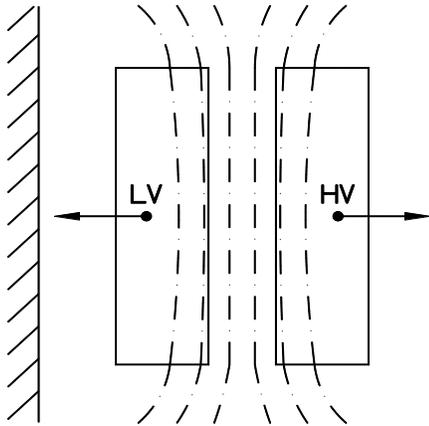
When the windings of transformer carry current, a leakage flux field is produced between the concentric windings (i.e. high voltage and low voltage windings). The principal component of the leakage flux is axial. The current carried by the winding conductors (circumferential direction) interact with the leakage flux and produces forces.



**Fig 1. Direction of Forces generated due to interaction of Flux and Current**

## **Radial Forces**

The nature of the leakage flux is such that it is mostly in the axial direction (except in the ends of the windings) and hence the maximum radial force occurs around the mid-height of the coils. Radial forces act outward on the outer winding and inward on the inner winding (see Fig 2).



**Fig 2. Leakage Flux Pattern and Direction of Forces Acting on HV and LV.**

## **Axial Forces**

Near the ends of the windings, a large part of the leakage flux bends towards the core leg and thereby causes a radial component of the flux. The interaction of this radial component of flux with the winding current produces axial forces that tend to compress (or telescope) the winding conductors along the vertical axis.

In short, there are both radial forces and axial forces generated in a transformer winding.

## **Short-Circuit Conditions result in Very Large Forces**

During the short circuit condition, large amount of currents flow through the windings. The forces generated in a transformer subject to short circuit conditions are magnified many times more compared to those under normal operating conditions. For example, a transformer with 6 percent of leakage impedance will carry 16 times the rated current during short circuit and this will result in forces more than 250 times those under normal operating conditions. Also, the peak forces are much higher than the RMS forces. As an example, the radial forces in a 10 MVA transformer can exceed 100,000 lbs.

## **Circular Windings remain Circular under Short-Circuit – No Change in the Geometry**

In circular coils any radial forces tend to be distributed uniformly along the circumference of the coil. In circular windings the radial forces are resisted by the strength of the winding conductors, and in some cases the low-voltage winding tubes. The axial forces are resisted by the stiffness of the radial spacers and the beam strength of the conductors.

In circular coils the forces are limited to that particular phase coil and are borne by the coil itself, which is suitably designed to withstand the forces on its own strength. There is no change in the performance of the coils. The impedance changes during short circuit test is typically 1% or less.

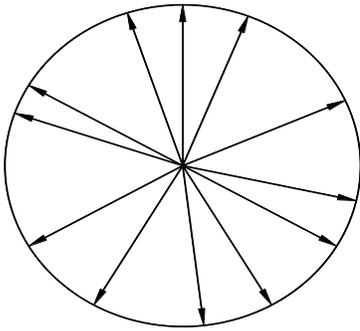


Fig. 3 (A circular winding remains circular)

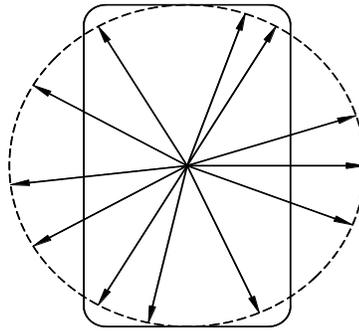


Fig. 4 (A rectangular winding tends to become circular)

## **Rectangular Windings try to Become Circular**

The forces generated in the rectangular coil transformers are very similar to those in circular coil transformers. The radial forces tend to separate the inner winding from the outer winding. The inner winding tries to crush inwards. The outer winding tries to arch or bow away from the flat surfaces of the inner winding and the high-low gap.

**Under radial forces the rectangular windings tend to become circular (see Fig 4). This results in substantial change in geometry and the impedance.**

For rectangular coils, the radial forces tend to concentrate at the corners of the coil and cause greater stresses in those regions.

By restraining the outer winding (mechanically) from moving, the forces on the inner winding greatly increased. If the inner winding happens to be a sheet winding, it tries to get displaced towards the corners.

The phase-to-phase gaps between rectangular coils are sometimes packed to restrain movement of coils in that area. Unfortunately, under such arrangement, **the forces generated by one coil are passed on to the adjacent phase coil and hence the forces are compounded.** The insulation may be damaged (coil failure) due to the mechanical restraint on windings/coils.

### Change in High-Low Gap in Rectangular Winding

The short circuit forces in the rectangular windings tend to separate the windings and consequently increase the high-low gap. This increase results in variation of impedance. The standards allow 7½% variation of impedance after the short circuit test. In other words, a transformer will be deemed “passed” if the variation is within 7½ %.

In this section we shall show that the actual change in the high-low gap is nearly 20% when the overall change is 7½%.

The ends (front and back) of rectangular windings are somewhat oval in shape and can be expected to undergo lesser change than the flat sides. For this analysis we have assumed 3 percent change in the ends. Also, of the total length of the high-low gap about 60% is on the flat side and 40% is on the ends.

Let us assume that the high-low gap was “G” before the short circuit test.  
Overall change = change in the ends + change in the flat sides (say “X”).

$$G * 1.075 = (40\% \text{ of “G”}) * 1.03 + (60\% \text{ of “G”}) * “X”,$$

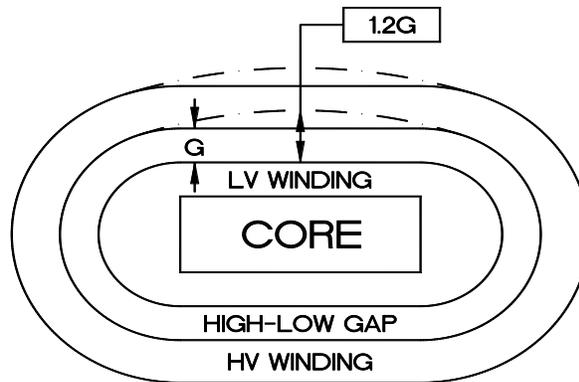
$$\text{Or, } 1.075 G = 0.412 G + 0.6 G * X$$

Solving for “X”, we get:

$$X = 1.105 \quad (\text{i.e. } 10.5\% \text{ change in High-Low gap}).$$

Further, the figure below shows the nature of the deformation of high-low gap, which is like an arch and the highest reflection occurs in the center. Using trigonometry, it can be seen that the **deflection in the center of the arch is nearly twice** as much as of the average change.

In other words, **the percentage change in the high-low gap would be as much as 20%** (even though the average change may be within 7 ½ %).



**Fig 5. Change in High-Low Gap in Rectangular Windings is Very Large.**

### **Summary**

- Rectangular designs may be fine for distribution application typically less than 5000 KVA. Ratings above 5000 KVA should be circular.
- Rectangular windings tend to become circular under radial forces. This results in conductor movement, change in performance and risk of failure.
- If the outer coils of a rectangular winding are restrained from moving, the forces on the inner winding are greatly increased, thereby increasing the risk of conductor movements.

By: Subhas Sarkar,  
MSEE, P.E.,  
Sr. Member IEEE

### **Bibliography**

- (1) J & P Transformer Book, 11th Edition.
- (2) IEEE Std C 57.12. 90- 1993, Part II, Guide for Short- Circuit Testing of Distribution and Power Transformers.
- (3) IEEE Guide C 57.12.125 – 1991, Guide for Failure Investigation, documentation and Analysis for Power Transformers and Shunt Reactors. (presently out of circulation).