Jan. 29, 1957 W. M. JOHNSON ET AL 2,779,926

TRANSFORMER WITH FIVE-LEG CORE

Filed Jan. 25, 1954

Fig. 1.

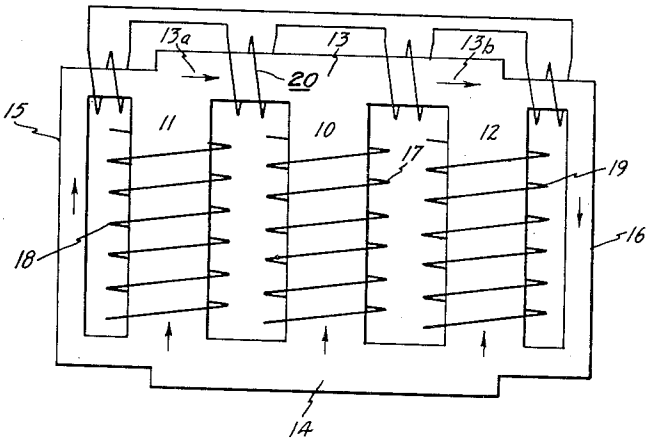


Fig. 2.

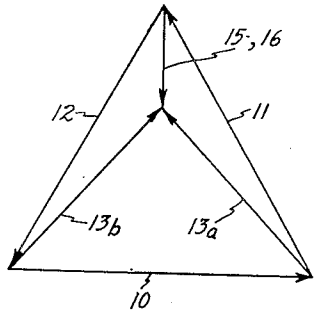
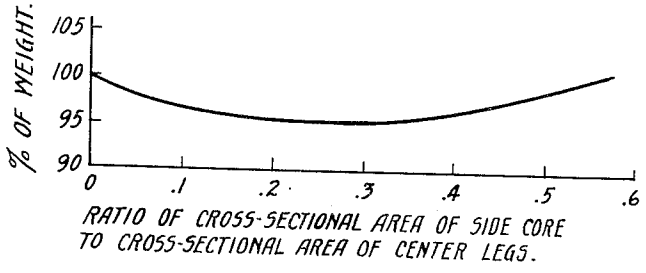


Fig. 3.



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TRANSFORMER WITH FIVE-LEG CORE

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6 Claims. (Cl. 336—5)

This invention relates to a five-leg magnetic core. More particularly the invention relates to a three-phase transformer with a five-leg core arranged for the efficient use of core materials.

As the transmission voltages of electric power have increased and the output of generating equipment has increased, there has been a demand for larger and larger power transformers to handle these steadily increasing loads. Railroad clearances have limited the height of power transformers to be shipped by rail and in recent years efforts have been directed toward increasing the capacity of power transformers without increasing their overall height.

One type of transformer which has provided increased KVA without an increase in height has utilized a magnetic core with five legs with windings on just the inner three legs. This has reduced the yoke height of the core thereby providing a five-leg transformer with greater window height than a conventional three-leg transformer having the same overall height.

It is an object of the present invention to provide a five-leg transformer which not only has the same KVA rating with less overall height than a three-leg-core transformer but has a core weighing less than a conventional three-leg core with the same KVA rating.

It is another object of the invention to provide an efficient five-leg core in a three-phase transformer having a harmonic flux suppression winding.

Other objects of the invention will be apparent from the following specification taken in connection with the accompanying drawing in which Fig. 1 is a diagrammatic view of a three-phase transformer constructed in accordance with this invention; Fig. 2 is a vector diagram of the fluxes in a five-leg core constructed in accordance with this invention; Fig. 3 is a graph illustrating the saving in core weight in a transformer constructed in accordance with Fig. 1.

Briefly stated, in accordance with one of its aspects, this invention is directed toward a five-leg magnetic core assembly comprising a main core including a center leg and two side legs defining two main core windows having similar rectangular profiles, and a side core extending outward from each of the side legs, the side cores having the same window height as the main core windows and having a cross-sectional area between 1/10 and 1/2 the cross-sectional area of each side leg.

Referring to Fig. 1, the magnetic core is seen to consist of a center leg **10** and two side legs **11** and **12** positioned between a pair of yokes **13** and **14**, two sections, **13***a* and **13***b*, being indicated for the yoke member **13**. Extending outward from each of the side legs **11** and **12** is a side core **15** and **16** respectively. The entire five-leg structure including the three main legs **10**, **11** and **12** and side cores **15** and **16** is preferably composed of a magnetically oriented material such as silicon steel in laminated form. The side cores **15** and **16** need not be of the same thickness as the rest of the core as long as their cross-sectional area bears the relationship to the core to be

described hereinafter. Each of the legs **10**, **11** and **12** has a magnetic winding **17**, **18** and **19**, respectively. While only a single winding is shown for each leg, there may be in actual practice more than one such winding on each leg.

In order to prevent a third-harmonic flux from circulating through the yoke members **13** and **14** and side cores **15** and **16**, a flux control winding **20**, which is short-circuited, is wound around various portions of the side cores **15** and **16** and the yoke member **13**. A plurality of arrows indicating the direction of flux flow at a particular instant are shown on Fig. 1. These arrows have reference to the vector diagram illustrated in Fig. 2.

Referring to Fig. 2, the balanced three-phase fluxes in the legs **10**, **11** and **12** are represented by the three sides of an equilateral triangle which are designated by the numbers **10**, **11** and **12** to represent the flux in the similarly numbered parts of Fig. 1. Other numbered vectors of the diagram relate to the flux in similarly numbered parts of Fig. 1. The yoke fluxes are represented by vectors which connect from the corners of the triangle to a common point inside the triangle. This point may be located any place along a line from the center of the triangle to the apex. If it is located at the apex, the fluxes in the outside cores are zero and the core becomes a three-leg core. If the point is located in the center of a triangle the core is a conventional five-leg core with side cores and top and bottom yokes both having 57.7% of the cross-sectional area of the main legs **10**, **11** and **12**. For an intermediate position of the common point, the other cores **15** and **16** have a lesser cross-sectional area than in the conventional five-leg core and it is preferred that the cross-sectional area of the side cores **15** and **16** be from 1/10 to 1/2 the cross-sectional area of the main legs **10**, **11** and **12**. Within this range it is preferred that the side cores have a cross-sectional area of about three-tenths that of the main legs. Any decrease in cross sectional area of the side cores **15** and **16** is compensated by an increase in the cross sectional area of the yoke members **13** and **14** as determined by the relationship shown in Fig. 2. The relationship shown in Fig. 2 represents the cross-sectional areas of the associated core members, since in order to determine the core configuration having the optimum weight for given core characteristics a constant flux density must be assumed for each core part. Then from the triangle of Fig. 2, the ratio A of the cross-sectional area of a yoke member **13** or **14** to the cross-sectional area of a main leg **10**, **11** or **12** is substantially equal to:

$$A=\sqrt{(0.5)^2+(0.866-B)^2}$$

where B is the ratio of the cross-sectional area of a side core **15** or **16** to the cross-sectional area of a main leg **10**, **11**, or **12**.

The effect of the cross-sectional area relations mentioned above may be seen in the graph of Fig. 3. In Fig. 3, the per cent of weight of a typical core is plotted against the ratio of the cross-sectional area of outer cores such as **15** and **16** to the cross-sectional area of the main legs such as **10**, **11** and **12**. At a ratio of zero, the core becomes a conventional three-leg core having an arbitrary weight of 100%. At a ratio of 0.58, which is the ratio of a conventional five-leg core, the total core weight is approximately 101.5%, which is slightly greater than the weight of a standard three-leg core. Between the range of 0.1 and 0.5 the weight is less than for either a conventional three-leg or a conventional five-leg core, and at a ratio of 0.3 the weight of a five-leg core constructed in accordance with this invention is approximately 95.3% of the weight of a conventional three-leg core of the same capacity. In a transformer weighing many tons, this saving in weight is appreciable. The curve of Fig. 3 is typical but for different core proportions the curve will vary.

With a five-leg core there exists two paths in the yoke for the flux from each leg, and because of the saturation of the iron, the division between paths will vary during each cycle. The net result is that there will exist a large third harmonic of flux which circulates in the yoke and the side cores but does not enter the main legs. The short-circuited flux control winding 20 consists of a cable wound around the yoke with the turns in each phase adjusted to force the desired flux division as indicated by Fig. 2. A number of turns in each phase is used such that when the desired flux distribution is obtained the fundamental frequency voltages induced in the winding add up to zero. The core will function without the flux-control winding but it has been found that suppression of the third-harmonic flux reduces the noise produced by the transformer.

While the present invention has been described with reference to particular embodiments thereof, it will be understood that numerous modifications may be made by those skilled in the art without actually departing from the invention. Therefore, we aim in the appended claims to cover all such equivalent variations as come within the true spirit and scope of the foregoing disclosure.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A five-leg magnetic core assembly comprising three main core legs and two yoke members, said legs being positioned at spaced intervals between said pair of yoke members, said three legs and two yoke members defining a pair of main core windows of similar profile, and a side core extending outward from each of the outer main core legs, the side cores having the same window height as the two main core windows and having a cross-sectional area of between one-tenth and one-half the cross-sectional area of each of the main core legs, the ratio A of the cross-sectional area of each of said yoke members to the cross-sectional area of each of said core legs being substantially

$$A=\sqrt{(0.5)^2+(0.866-B)^2}$$

where B is a ratio of the cross-sectional area of each of said side core members to the cross-sectional area of each of said yoke members.

2. A five-leg magnetic core assembly comprising a main core including a center leg and two side legs defining two main core windows having similar rectangular profiles, and a side core extending outward from each of said side legs, the side cores having the same window height as the main core windows and having a cross-sectional area between one-tenth and one-half the cross-sectional area of each side leg, the ratio A of the cross-sectional area of each of said yoke members to the cross-sectional area of each of said core legs being substantially

$$A=\sqrt{(0.5)^2+(0.866-B)^2}$$

where B is the ratio of cross-sectional area of each of said side core members to the cross-sectional area of each of said yoke members.

3. A five-leg magnetic core assembly comprising a main core including a center leg, two side legs and a pair of yoke members defining two main core windows having similar rectangular profiles, and a side core extending outward from each of said side legs, the side core windows having the same height as the main core windows and said side cores having a cross-sectional area of about one-third the cross-sectional area of each side leg, the ratio A of the cross-sectional area of each of said yoke members to the cross-sectional area of each of said core legs being substantially

$$A=\sqrt{(0.5)^2+(0.866-B)^2}$$

where B is the ratio of cross-sectional area of each of said side core members to the cross-sectional area of each of said yoke members.

4. A five-leg magnetic core assembly comprising a main core including a center leg, two side legs and a pair of yoke members defining two main core windows having similar rectangular profiles, a side core of rectangular profile extending outward from each of said side legs, the side cores having the same window height as the main core windows and having a cross-sectional area of between one-tenth and one-half the cross-sectional area of each side leg, and a short-circuited flux control winding around at least one of said yoke members of said assembly, the ratio A of the cross-sectional area of each of said yoke members to the cross-sectional area of each of said core legs being substantially

$$A=\sqrt{(0.5)^2+(0.866-B)^2}$$

where B is the ratio of cross-sectional area of each of said side core members to the cross-sectional area of each of said yoke members.

5. A five-leg magnetic core assembly as claimed in claim 4 wherein the cross-sectional area of the side cores is about one-third the cross sectional area of each side leg.

6. A five-leg three phase transformer comprising a main magnetic core including a center leg, two side legs and a pair of yoke members defining two main core windows having similar rectangular profiles, a side core of rectangular profile extending outward from each of said side legs, the side cores having the same window height as the main core windows and having a cross-sectional area of about one-third the cross-sectional area of each side leg, at least one inductive winding on each of the three legs of the main magnetic core, and short-circuited flux control winding around the yoke members of said transformer on one side of said inductive windings, the ratio A of the cross-sectional area of each of said yoke members to the cross-sectional area of each of said core legs being substantially

$$A=\sqrt{(0.5)^2+(0.866-B)^2}$$

where B is the ratio of cross-sectional area of each of said side core members to the cross-sectional area of each of said yoke members.

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