Oct. 25, 1960 G. CAMILLI 2,958,058

HIGH VOLTAGE TRANSFORMER

Filed March 21, 1957 3 Sheets-Sheet 1

Fig. 1

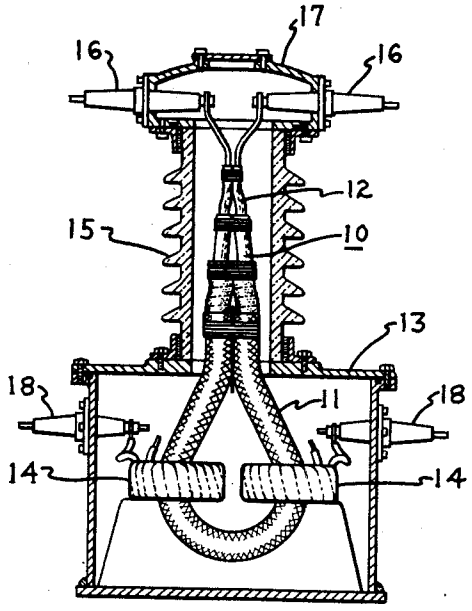


Fig. 2

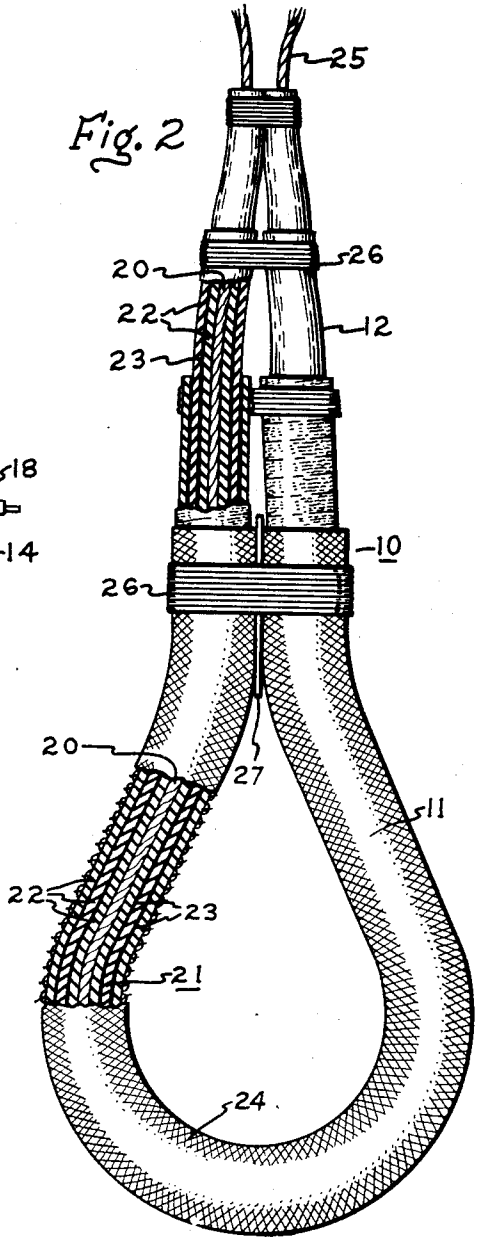
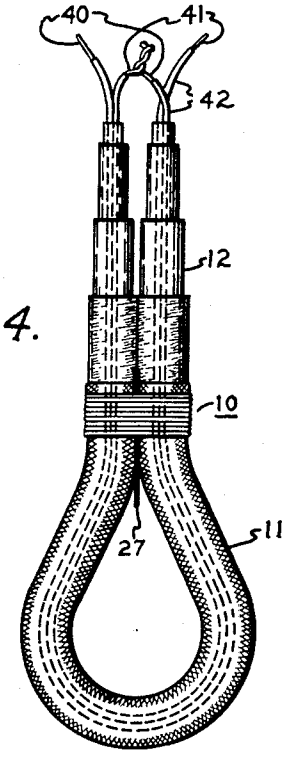


Fig. 4.



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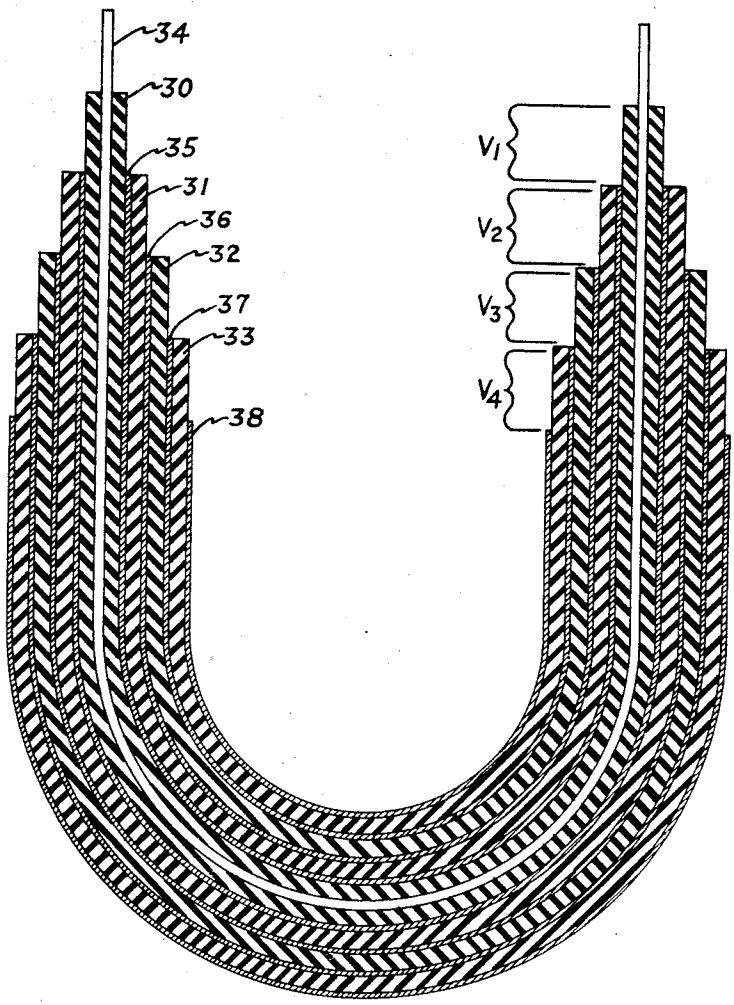


Fig. 3.

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Fig. 5.

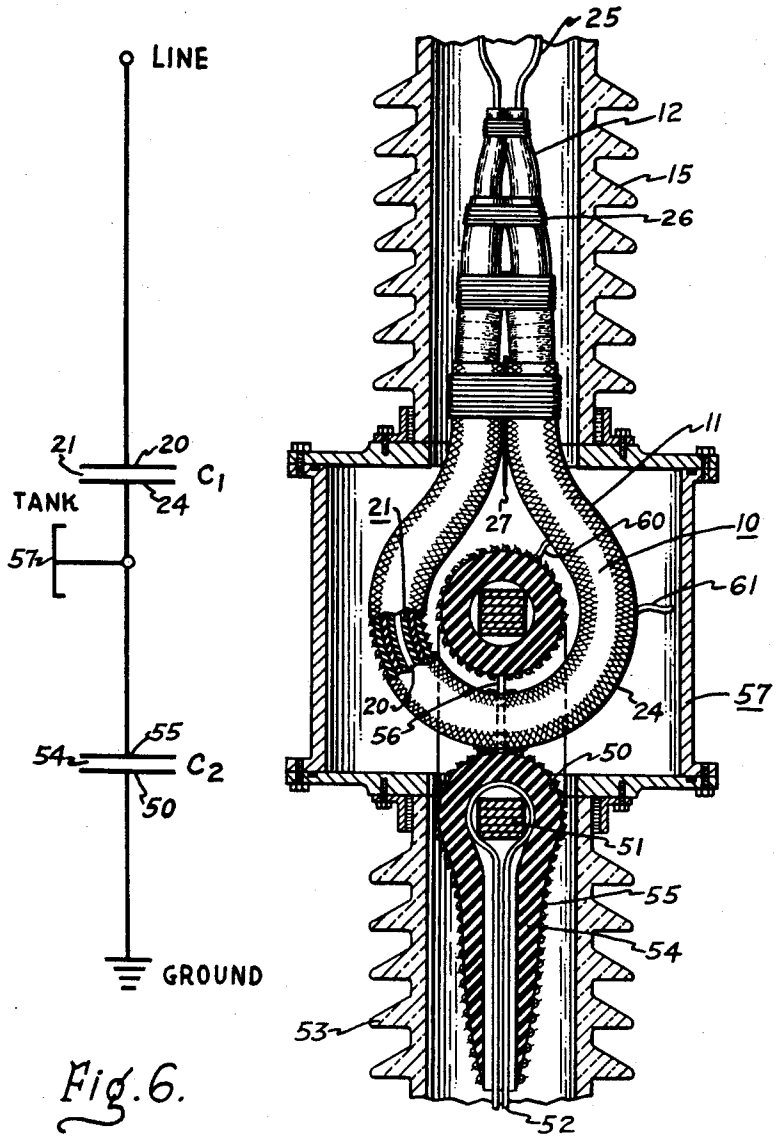


Fig. 6.

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HIGH VOLTAGE TRANSFORMER

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Filed Mar. 21, 1957, Ser. No. 647,719

1 Claim. (Cl. 336—174)

This invention relates to high voltage electrical induction apparatus, and more in particular to an improved high voltage current transformer and a method for making the same.

High voltage current transformers of one type, commonly referred to as the "eye-bolt" type, are comprised of an annular high voltage winding of one or more conductor turns interlinking one or more toroidal low voltage secondary windings wound on annular magnetic cores. The windings are generally enclosed in a dielectric fluid filled tank, and a pair of leads extend from the high voltage winding upwardly from the top of the tank, through an insulating ceramic shell, and are connected to a suitable terminal assembly disposed at the upper end of the ceramic shell. The leads from the low voltage winding or windings may be connected to low voltage bushings disposed in the side walls of the tank.

In the fabrication of transformers of this type, the turns of the high voltage winding are interlinked with the low voltage windings, and in order to provide the necessary insulation for the high voltage winding, the high voltage winding and its associated leads are then manually wrapped with an insulating tape, such as paper tape. Following the taping of the high voltage winding, a ground shield may be provided on the high voltage winding. The manual taping of a high voltage winding in some cases must be accomplished after the high voltage winding has been interlinked with the other windings. Thus, as a result of the configuration of the high voltage winding and the low voltage winding, it is difficult and time consuming to properly insulate the windings, and the cost of the transformer is thereby substantially increased.

It is therefore an object of this invention to provide an improved high voltage transformer and a method for making the same.

It is also an object to provide a high voltage current transformer having such a structure that the necessity for manual insulation of the windings is minimized or eliminated.

Another object of this invention is to provide means for obviation of the necessity of insulating the high voltage winding of the high voltage current transformer subsequent to the interlinking of the high voltage winding with a low voltage winding.

Still another object is to provide a readily fabricated pre-insulated winding for a high voltage current transformer.

A further object of this invention is to provide an improved method for fabricating a high voltage current transformer, the method being characterized by the obviation of the necessity for manual insulation of the windings.

Briefly stated, in accordance with one aspect of my invention, I provide a high voltage current transformer having a high voltage winding comprising a loop of a flexible cable. The cable has one or more central conductors surrounded by a flexible insulating material. As

will be described in more detail in the following disclosure, the insulating material is preferably comprised of a plurality of layers of insulating tape, such as paper tape, having a substantial degree of flexibility axially with respect to the cable. Electrostatic equalizing means are imbedded in the insulating material surrounding the central conductor in order to provide a desirable voltage gradient across the insulating material, and to obtain fairly uniform voltage distribution on a hollow ceramic insulator when the cable is assembled and enclosed within the insulator. The high voltage winding is interlinked with one or more low voltage toroidal windings according to the usual practice.

While the specification concludes with a claim particularly pointing out and distinctly claiming the subject matter which I regard as my invention, it is believed that the invention will be better understood from the following description taken in connection with the accompanying drawing in which:

Fig. 1 is a partially cross-sectional view of a high voltage current transformer and illustrating a high voltage or primary winding according to my invention,

Fig. 2 is an enlarged partially cross-sectional view of the high voltage winding of Fig. 1,

Fig. 3 is a cross-sectional view of a high voltage winding according to my invention,

Fig. 4 is a view of a modified form of the primary winding of Fig. 2 and illustrating means for providing a high voltage winding having a plurality of turns,

Fig. 5 is a cross-sectional view of a modified high voltage current transformer according to my invention, and

Fig. 6 is an equivalent capacitance diagram of the transformer of Fig. 5.

Referring now to the drawing, and more in particular to Fig. 1, therein is illustrated a current transformer of the "eye-bolt" type fabricated according to my invention. A flexible cable **10** is provided having a central loop portion **11** joining relatively straight portions **12**. The loop portion **11** comprises the primary or high voltage winding of the transformer. The high voltage winding is disposed in a dielectric fluid filled tank **13**, and therein is interlinked with one or more low voltage toroidal secondary windings **14**. The low voltage windings **14** may be of the conventional type wound on annular magnetic cores, and it will be obvious that the number of such coils employed may be varied without departing from the spirit or scope of this invention.

A ceramic insulating shell **15** is disposed on the top of the tank **13**, and the straight lead portions **12** of the flexible cable extend upwardly through the top of the tank **13** and through the ceramic shell **15** and are connected in a conventional manner to suitable terminals **16** disposed in upper terminal assembly **17** at the upper end of the ceramic shell **15**. The low voltage winding leads may be connected to low voltage bushings **18** disposed in the side walls of the tank **13**.

Referring now to Fig. 2 the flexible cable **10** is therein illustrated as being comprised of a central conductor **20** surrounded by a flexible insulating material **21**. While other flexible cables may be employed, the cable 10 is preferably of the type disclosed in U.S. Letters Patent 2,607,824 which issued on August 19, 1952 on an application of G. Camilli et al. and assigned to the assignee of the present invention. The cable of the Camilli et al. patent is comprised of a plurality of layers of crepe paper tape spirally wound about a conductor, the crepe paper tape having two crepings substantially perpendicular to each other. In this type of cable, the insulating material has a substantial degree of stretchability in the axial direction with respect to the cable, thereby permitting the cable to be bent on a small enough radius to enable its

use as a high voltage winding of a high voltage current transformer. Referring still to Fig. 2, the insulating material **21** is preferably comprised of a plurality of layers **22** of insulating material separated by electrostatic equalizing layers **23**. The equalizing layers may be comprised of flexible metallic shielding, or any other flexible conductive material. The cable **12** is also preferably provided with an outer conductive shielding **24** surrounding the insulating material for the purpose of providing a ground shield for the primary winding.

From the previous disclosure, it is obvious that the cable **12** may be formed in long lengths by conventional cable forming techniques, the equalizing layers **23** being imbedded in the insulating material during the forming of the cable, the desired lengths of cable for use in a current transformer may be severed from the long length that is thus formed. In this manner, the necessary insulation and shielding for the high voltage winding is provided prior to the forming of the winding, and manual insulation thereof is minimized or entirely eliminated.

Referring still to Fig. 2, the insulation and shielding of the straight lead portions **12** of the flexible cable is removed in steps, with progressively decreasing insulation thickness toward the ends **25** of the cable. This results in the ends of the equalizer layers being progressively increasing distances from the ends of the cable radially outwardly of the conductor **20**, or in other words, the equalizers are progressively longer toward the central conductor.

As illustrated in Fig. 2, the straight portions **12** of the flexible cable are preferably taped together by suitable insulating tape **26**. To eliminate the flow of circulating current through the shield **24** or the equalizer members **23**, however, conducting parts of the contacting portions of the straight portions of the cable **10** should be insulated from each other. This may be provided for the internal shielding by stepping the shielding to the same extent as the adjacent radially outward insulation, and a strip of insulating material **27** may be provided to prevent contact between the ends of the outer shielding **24**.

The layers of electrostatic shielding in the cable insulation act as a capacitance voltage divider, and distribute the electric stress throughout the cable in inverse proportion to the capacities between shielding layers. By stepping the electrostatic shielding the area of the outer capacitances is reduced, and the electric stress is thereby more nearly equalized throughout the cable. The equalization of stress in the insulation makes possible the use of a flexible cable in a high voltage current transformer, since the equalizing of stress permits a reduction in the radial thickness of the insulation, and as a result a cable having sufficient flexibility to form a loop within the confines of a reasonably sized transformer structure may be readily provided.

Referring now to Fig. 3, therein is illustrated a cross-sectional view of a cable loop for a typical high voltage winding of a current transformer according to my invention. In this illustration, the cable has four concentric layers of insulation **30**, **31**, **32** and **33** surrounding a conductor **34**. (The lower numbered layers of insulation being closer to the conductor.) Between the layers **30**, **31**, **32** and **33** are thin layers of flexible conducting material **35**, **36** and **37** respectively. A conducting shield **38** surrounds the outer insulation layer **33**. As in the high voltage winding of Figs. 1 and 2, the ends of the equalizer layers and insulation layers are stepped, with the layers toward the conductor being progressively longer. The insulation layers have the same length as the next adjacent radially inward equalizer layer, and the outer shield is shorter than the insulation layer **33**. The distance between the end of the outer shield and the end of inner insulation layer **30** is referred to as the scarf. In tests on the winding loop of Fig. 3, (see Table I) with the exposed portions of the insulation layers **30**, **31**, **32** and **33** being equal, it was shown that the voltage stress in the layers of insulation is not appreciably affected by either the length of the cable or by the length of the scarf. In Table I, the voltages V_1, V_2, V_3, and V_4 are respectively the voltages across the insulation layers **30**, **31**, **32** and **33**, and the total length of the cable is the distance around the loop between the ends of inner insulation layer **30**. (See Table I.)

In view of the slight independence of voltage stress on cable and scarf length, the stepping of the insulation and conducting layers in the scarf may be designed primarily from the standpoint of obtaining uniform voltage distribution on the ceramic insulator which surrounds the ends of the loop.

Table I

Total Length of Cable (Feet)	Scarf Length on each end (Inches)	Voltage in Percent of Total Voltage Between the Conductor and Outer Shield			
		V_1	V_2	V_3	V_4
4	12	33.9	24.5	21.2	20.3
	15	31.5	23.7	21.8	22.9
6	12	36.6	25.2	20.4	17.8
	15	35.4	24.8	20.8	18.9
8	12	37.8	25.4	20.0	16.9
	15	36.9	25.2	20.3	17.7
12	12	38.9	25.5	19.6	16.0
	15	38.4	25.4	19.7	16.4

Referring now to Fig. 4, therein is illustrated a modification of the winding of Fig. 2 in which the cable **10** is provided with two central conductors **40** and **41**, the conductors **40** and **41** being provided with separate insulation **42** one end of each of the conductors **40** and **41** are electrically joined by any suitable means at the ends of the cable **12**, so that they are serially connected. By this means, the primary winding may be provided with two turns. It will be obvious, of course, that any number of turns may be provided in the primary winding in a similar manner by providing a plurality of insulated conductors in the cable, and serially connecting the ends of the conductors.

In order to fabricate the current transformer of my invention, the desired number of low voltage toroidal secondary coils are wound on annular magnetic cores, and these low voltage windings are taped with suitable insulating tape, and may also be provided with ground shields. Then a loop of the previously disclosed flexible cable is interlinked with the low voltage windings. If more than one primary turn is desired, the flexible cable may be provided with a plurality of central conductors, and these central conductors then serially connected in the manner illustrated in Fig. 4.

Referring now to Fig. 5, in a modified form of the current transformer of my invention, a primary winding **10** consisting of a loop of cable is provided, the winding being of the same construction as the primary winding of Figs. 1 and 2. The loop **11** of the high voltage winding is interlinked with a toroidal low voltage winding **50**. According to conventional practice, the low voltage may be wound on an annular magnetic core **51**. The leads **52** of the low voltage winding extend downwardly through a ceramic insulator **53**, and are connected to low voltage terminals on the transformer (not illustrated). The low voltage winding is adapted, in operation, to be substantially at ground potential. Insulation **54** is provided surrounding the low voltage winding, the insulation also extending into the ceramic insulator **53**. The insulation **54** may be formed of manually wrapped layers of insulating tape. A metallic shield **55** is provided surrounding the insulation **54**, and the shield **55** may be provided with a gap **56** to prevent the flow of circulating currents therein.

The interlinked high and low voltage windings are surrounded by a tank **57**, the tank extending between the ceramic insulators **15** and **53** and being sealed to the insulators so that a dielectric fluid may be contained therein.

Electrical connection is made between the outer shield **24** of the high voltage winding and the outer shield **55** of the low voltage winding, for example, by a lead **60**. Electrical connection is also made between the tank **57** and outer shield **24** of the high voltage winding, such as by a lead **61**.

The equivalent capacitive circuit of the transformer of Fig. 5 is illustrated in Fig. 6, wherein capacitances C_1 and C_2 are illustrated serially connected between a power line and ground reference. Capacitor C_1, connected to the power line, represents the capacitance between the central conductor **20** of the high voltage winding and the outer shield **24** of the high voltage winding. The insulation **21** of the high voltage winding corresponds to the dielectric of capacitor C_1. Capacitor C_2, connected to the ground reference, represents the capacitance between the outer shield **55** of the low voltage winding and the low voltage winding **50**. The dielectric of capacitor C_2 represents the insulation **54** of the low voltage winding.

From the illustration of Fig. 6, it is seen that the proportion of the total line voltage that is developed across the high voltage insulation **21** and the low voltage insulation **54** depends upon the relative values of capacitors C_1 and C_2, C_1 being the conductor to outer shield capacitance of the primary winding and C_2 being the conductor to outer shield capacitance of the low voltage winding.

The transformer arrangement of Fig. 6 while having the advantages of the transformer of Fig. 1, has the additional advantage that it lends itself to higher voltage application than the transformer of Fig. 1. Thus, in the arrangement of Fig. 6, the required high voltage winding insulation depends upon the proportion between C_1 and C_2, and thus it is not necessary to insulate the cable for the full line voltage. For example, the cable insulation may be made suitable to withstand only one-half of the full line voltage, and the low voltage winding would also be insulated to withstand only one-half of the line voltage, if the capacitances C_1 and C_2 are equal. The windings of the transformer of Fig. 5 may be made by the same method as the windings of the transformer of Fig. 1.

It will be understood, of course, that while the forms of the invention herein shown and described constitute

preferred embodiments of my invention, it is not intended herein to illustrate all of the possible equivalent forms or ramifications thereof. It will also be understood that the words employed are words of description rather than words of limitation, and that various changes may be made without departing from the spirit or scope of the invention herein disclosed, and it is aimed in the appended claim to cover all such changes as fall within the true spirit and scope of the invention.

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

A high voltage current transformer comprising a tank, a single bushing supported by said tank, a toroidal low voltage winding in said tank, a high voltage winding formed from a length of cable having pre-wound insulation that has sufficient flexibility axially of said cable to allow said cable to be bent into a loop that passes through said toroidal low voltage winding within the confines of said tank, end portions of said cable forming relatively straight leads from said high voltage winding that extend into said single bushing only, said cable having at least one central conductor, the pre-wound insulation of said cable comprising a plurality of layers of insulating tape having two crepings perpendicular to each other, a plurality of flexible electrostatic equalizers imbedded in said insulation and concentric with said conductor, said equalizers being insulated from said conductor and from each other, and the ends of said equalizers being at progressively increasing distances from the ends of said cable radially outward of said conductor.

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