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TOROIDAL CORE FOR HIGH-Q COIL

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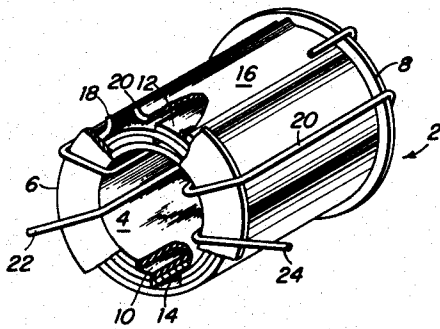


Fig. 1

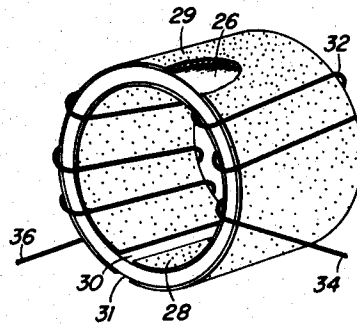


Fig. 2

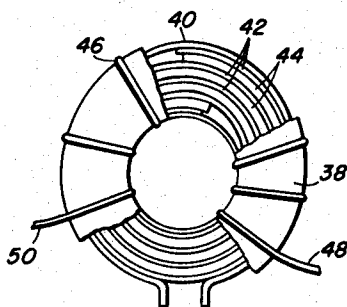


Fig. 3

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TOROIDAL CORE FOR HIGH-Q COIL

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The present invention relates to novel toroidal core configurations for forming high-Q coils and, more particularly, to toroidal iron cores whose hysteresis loss and average permeability are mutually compromised for producing high-Q coils.

The parameter, Q , of a coil is defined as the ratio of its inductive reactance to its resistance. As such, Q represents a figure of merit since its magnitude gives a measure or indication of the quality of the coil as an inductor, the higher the Q , the more pure the inductance. Unless the Q of a coil is reasonably high, it cannot be employed for certain electronic applications, such as saturable reactors and ferroresonant flip-flops.

The Q of an iron core coil is limited by the losses due to hysteresis, eddy currents, and resistance in the wire. The relationship between Q and the limiting Q due to each of these effects is given below in Equation 1:

$$\frac{1}{Q} = \frac{1}{Q_h} + \frac{1}{Q_e} + \frac{1}{Q_w} \quad (1)$$

where Q_h equals Q due to hysteresis losses alone, Q_e is the Q due to eddy current losses alone; and Q_w is the Q due to wire losses alone.

$$Q_h = \pi \left(\frac{HB}{A} \right) \quad (2)$$

Equation 2 shows the dependence of Q_h on the area enclosed by a B-H loop for given limiting values of H and B . In the case of a "square loop" magnetic material, the quantity in parenthesis would be equal to $\frac{1}{4}$, and Q_h would be about 0.8. In order to obtain a high- Q from an iron cored coil, it is essential that the relative area enclosed by the B-H loop be made small. This is usually accomplished by introducing an air gap which has the effect of increasing the value of H required to produce a given magnetic flux.

$$Q_e = E/f \quad (3)$$

Equation 3 indicates the dependence of Q_e on frequency and a constant, E , which varies inversely with the thickness of the magnetic material.

The present technique for producing high-Q coils with iron cores is to subdivide the iron into small spheres held together by a non-magnetic binder. This serves the dual purpose of reducing the thickness of the iron so that Q_e may become large, while simultaneously introducing a large number of small air gaps between the small spheres of iron. These air gaps add up in series to give a large total air gap. The main disadvantage of this method lies in the fact that eddy current considerations (at high frequencies) dictate the use of such small spheres that the total effective air gap introduced is much larger than would have been needed in order to raise Q_h to a reasonably high value. Hence, this air gap needlessly increases the magnetic reluctance of the core so that a relatively low effective permeability is obtained. An additional disadvantage of such cores lies in the difficulty of saturating

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them in non-linear applications. Such applications include ferroresonance and saturable reactors.

In the invention to be described, these disadvantages are avoided by reducing the thickness of the iron to control eddy current losses while maintaining reasonably large dimensions of width and length. The selection of tape thickness is made solely on the basis of eddy current losses and is unrelated to the introduction of an air gap to control hysteresis losses. Then when the air gap is introduced, its dimensions are selected to provide an adequately high value of Q_h while retaining a reasonably large value of average permeability for easy saturation.

According to one embodiment of applicant's invention, the magnetic loop is formed of thin magnetic tape stock which is rolled around the center of a bobbin and its outer end secured. A slot of selected length is then formed across the tape to constitute the air gap and a spring clip employed to maintain the assemblage together. In another embodiment, the magnetic loop is deposited or electro-plated on one or both surfaces of the center of a non-magnetic cylindrical type of bobbin. The air gap is formed by either cutting away the deposited material or by initially placing, prior to the deposition operation, a removable strip of tape, for example, dimensioned identically to the desired slot and then removing this strip after the deposition.

In the final embodiment, a spiral wrap is made of magnetic tape material separated, however, by a non-magnetic tape. By preventing any touching or magnetic shorting from occurring between adjacent loops of the magnetic tape, a distributed type of air gap is achieved, its effective length being a function of the length of the wrap and the thickness of the spacer material. A spring clip is also employed in this embodiment to maintain the assembly together.

Another very important aspect of applicant's invention is the ability to achieve a much higher inductance per volume than is possible in the powdered iron toroidal core art. This is true since the permeability of applicant's toroids may be independently controlled which, as pointed out previously, is not the case for powdered iron toroids.

It is, accordingly, the principal object of the present invention to provide a toroidal core for forming high-Q coils wherein eddy current losses are independently determined and hysteresis loss and average permeability are compromised.

Another object of the present invention is to provide a toroidal core for forming high-Q coils wherein eddy current losses are initially disposed by the thickness of the magnetic material, and the hysteresis loss and average permeability are compromised by the ratio of effective air gap to magnetic path dimensions.

A further object of the present invention is to provide a toroidal core configuration having an air gap whose length when related to the length of the magnetic path provides a design means of mutually adjusting average permeability and hysteresis loss to achieve high-Q coils which are easily saturable.

A still further object of the present invention is to provide a toroidal core having an air gap whose effective dimension enables an adjustment to be made between hysteresis loss and average permeability to achieve

high inductance per volume coils for high frequency application.

Other objects and features of the present invention will be readily apparent to those skilled in the art from the following specifications and appended drawings wherein is illustrated a preferred form of the invention and in which:

FIGURE 1 is a perspective view, with parts broken away, of one toroidal core configuration according to the present invention;

FIGURE 2 is a perspective view, with parts broken away, of another toroidal core configuration according to the present invention; and

FIGURE 3 is also a perspective view, with parts broken away, of a final toroidal core configuration according to the present invention.

Referring now to the drawings, there is illustrated in FIGURE 1 a first embodiment according to the present invention. A bobbin 2, of non-magnetic material is shown broken away in parts to reveal other aspects of the core and coil configuration. This bobbin is of conventional shape, that is, it contains a cylindrical inner shell 4, with outwardly extending flanges 6 and 8 positioned on both edges, respectively of the shell.

A loop or coil 10, of high permeability magnetic tape material, such as moly-permalloy, is wound around the outer surface of shell 4. The outer end 12, of the loop, is affixed to the loop material of the preceding wrap directly under it, as by spot welding or soldering, and a butt-end type of air gap 14, is located diametrically opposite end 12. A spring clip 16, of non-magnetic material, overlaps coil 10 and acts, by spring tension, to maintain the assembly in a sufficiently rigid form for handling, mounting and other required operations. Finally, a coil or winding 20, with leads 22 and 24, is wound in toroidal form around the assembly, some of the loops of the coil being broken away for purpose of clarity.

Consider now, a preferred manner of constructing the core and coil configuration of FIGURE 1. First of all, bobbin 2 is preferably formed of stainless steel. Bobbins of this type are commercially available and are sufficiently rugged to be handled, be placed in and operated on by a toroidal winding machine, and finally, mounted in an electronic circuit package without undue deformation of shape. This handling ability is desirable in order to prevent the magnetic material, constituting loop 10, from being deformed and hence work hardened with a consequent loss of its magnetic properties.

The inner width of the bobbin, that is, the distance between the inner faces of flanges 6 and 8, should be only slightly wider than the width of the coil 10 material in order to provide a snug lateral fit for the ensuing magnetic loop. Finally, the outside diameter of the flanges should be slightly greater than the outside diameter of spring clip 16, measured in its final retaining position around magnetic coil 10, in order to provide a lateral containment of the entire assembly. Too much excess of this outside flange diameter over clip 16 is to be avoided as it unnecessarily increases the air volume enclosed by winding 20.

Magnetic loop 10 is preferably composed of thinstock moly-permalloy material. Its original length will be determined by the outside diameter of shell 4 and the number of wraps desired for the tape loop. This latter quantity will be primarily dependent upon the power handling capabilities dictated for the coil in its ultimate electronic circuit employment. The tape is carefully wrapped around the bobbin shell and its outer end bonded or welded to the tape material directly beneath it on the prior wrap.

A gap 14 is next made in the magnetic coil. This may be done by employing a sandblasting tool of the type manufactured by the S. S. White Company or one of the several ultrasonic impact machines now available.

A spring clip 16, preferably of type 304 stainless steel,

is next snapped into place around magnetic coil 10. Clip 16 is of shorter arcuate length than the outer circumference of the coil, and is also initially fashioned to have a smaller radius than the coil in order to provide spring tension on the assembly under it. Its two ends 18 and 20 may be curved outward, as shown, to facilitate its handling, especially its rotational placement relative to secured end 12 and gap 14.

The length of the gap, formed in the loop, is determined by the compromise to be made between the average permeability of the coil and its hysteresis loss, as discussed previously in some detail, for forming a reasonably high Q coil with a high inductance per volume ratio. Stated differently, the ratio of air gap length to iron path length will be set by the objective of acquiring as high an overall permeability as possible yet consistent with securing a final Q sufficiently high for the ultimate electronic circuit application for the coil. In following this design compromise, as is possible with applicant's invention, required Q's can be achieved with coils which also possess the highest effective permeability. As an example, a gap of one-half mil in a one-half inch circumference loop of magnetic material having a permeability of 16,000, lowers the final permeability to 1000, a figure much higher than any of those quoted previously for various commercially available powdered iron toroids.

The inner diameter of the bobbin will be primarily established by the total number of turns needed for the winding and the size of wire to be employed in forming the winding. The winding capabilities of the machine or person forming the coil will also enter the consideration of this dimension. The total number of wraps constituting the magnetic loop will be determined by the volume of iron needed, in turn, a function of the coil power handling capability requirements.

After gap 14 has been formed and clip 16 added, the assembly is then subjected to an annealing process according to conventional practice, in order to restore the desired magnetic properties into loop 14. This is necessary since the handling, bonding and cutting processes will work-harden the magnetic tape material and radically alter its magnetic properties.

It should be noted that the employment of spring clip 16 is far more desirable for securing the assembly than other possible methods, such as potting, continuous bonding to shell 14, for example where a continuous type of physical constraint would be imposed on the magnetic material. This is due to the highly magnetostrictive properties of moly-permalloy and similar magnetic materials wherein physical motion of the material accompanies applied magnetizing forces. Constraints would act either to adversely affect the magnetic properties of the loop, or would cause mechanical failure of the loop or itself in attempting to restrain the magnetostrictive motion.

The core assembly, as described, is now complete and may be sold to customers who have their own coil requirements and winding capabilities. It is rugged, capable of being handled and wound by hand or machine without the coil material magnetic characteristics being affected. A toroidal winding, generally designated at 20, is, however illustrated with leads 22 and 24.

Another embodiment, according to the present invention, is shown in FIGURE 2. Here, a bobbin 26, of non-magnetic material, is shaped in the form of a thin walled cylinder. Deposits 28 and 29, of magnetic material are made on its inner and outer cylindrical surfaces, respectively. A slot or gap 30 is formed in the inner deposition 28 and extends along the cylinder while a similar gap 31 is formed in the outer deposition and extends parallel to gap 30. A winding, designated generally at 32 is included, with leads 34 and 36.

In this embodiment, bobbin 26 may be readily formed from stainless steel tubing by cutting off tube stock to the desired length. After cutting and deburring the edges, a deposit of magnetic material such as permalloy, is made

on both of its inner and outer surfaces by electroplating or evaporation techniques of conventional practices.

Briefly, in electroplating the deposit, the bobbin would be suspended in either an acid or a base solution, as dependent upon the type of magnetic material, and subjected to a potential of appropriate polarity. The magnetic material, or materials, in case of some alloys, would also be suspended in the solution and subjected to the opposite polarity of potential. Ions, of the magnetic material, would then be attracted through the solution and deposited on the surface of the bobbin. The thickness of the final deposit would be a function of time, current, types of magnetic materials, initial strength of the solution, etc.

In evaporating the deposit, atoms would be effectively boiled off of magnetic materials, for alloy deposition, in a high vacuum by heating. The atoms would then be deposited on the bobbin, also located in the vacuum adjacent the magnetic material, upon contact therewith.

Both of the above processes are, of course, well known in the art and in practice are subject to numerous refinements as determined by the type or alloy of magnetic material to be deposited, equipment available, etc.

Gap 30 may be formed by any one of several different techniques. For example, two pieces of Scotch tape, cut to correspond to the length and width of the desired gaps, may be affixed to the inner and outer surfaces of the bobbin prior to the depositing process. After completion of the process, the tape can be removed, leaving the resulting gaps in the magnetic paths. Alternately, the gaps may be formed by removing some of the deposited magnetic material, as by filing, scraping, super-sonic impact machine, etc.

It will be readily apparent that the deposit may also be extended to include the two edges of the bobbin. If this is done, then the inner and outer gaps must be extended to include the edge material, in which case, they are joined to give a resulting gap which extends completely around the cylinder, and in cross-section, takes a rectangular form.

The relationship between gap length and magnetic path circumference to permeability and hysteresis losses will be similar in this embodiment to that explained in detail for the FIGURE 1 embodiment except that here, control is in addition, had over eddy current losses since the thickness of the deposited magnetic material may be controlled by the deposition process.

In the event the total amount of iron needed is less than that which would be normally deposited on both inner and outer surfaces, assuming the resulting thickness is satisfactory for eddy current control, only one surface need be coated. In this case, it is preferable to coat the inner rather than the outer surface since it naturally is the better protected one of the two and the deposit would suffer less from the possible occurrence of scratches, etc., incurred while handling, winding, etc.

The final embodiment according to the present invention is illustrated in FIGURE 3. It includes a bobbin 38, similar to bobbin 2 of FIGURE 1. Its magnetic element is composed of a sheet or loop 42 of thin magnetic material such as moly-permalloy, similar to loop 10 of the FIGURE 1 embodiment, wrapped spirally in conjunction with a spacer sheet 44 of non-magnetic material. This spacer or wrap 44 is slightly longer than sheet 42 and is symmetrically spaced lengthwise, that is, relative to the ends of element 42, so that a continuous lengthwise separation of wrap 44 is obtained without the occurrence of any "magnetic shorting" taking place between adjacent wraps of loop 42.

A spring clip 40, similar to clip 16 found in the FIGURE 1 embodiment, is employed to maintain the assemblage together. A conventional toroidal winding 46 is shown, partially broken away, with output leads 48 and 50.

In this embodiment, no bonding or securement of the outer end of the magnetic loop is required, as was the

case for the embodiment of FIGURE 1. The same is likewise true for the spacer element since the spring clip acts to maintain the combined wraps in place.

An effective air gap, of a distributed nature, is formed in this configuration through the employment of the spacer material rather than the true butt-end type found in the FIGURES 1 and 2 configurations. This distributed type of air gap may best be realized by viewing, for a moment, the inner-most wrap of loop 42, that is, the wrap nearest the cylindrical inner shell of the bobbin. The flux path between it and all turns of winding 46 is intercepted by a series of wraps of the non-magnetic spacer material forming coil or loop 44 with the result that, for this wrap, an effective air volume, of some measurable value, is interposed between it and the winding. This same effect will be observed between the next outer layer or wrap of spiral loop 42 and the winding except that the non-magnetic volume will be diminished by one wrap of the spacer material. Hence the successive wraps, outward from the innermost one of the loop 42, will include correspondingly smaller volumes of spacer material between them and the winding. These enclosed volumes of non-magnetic material, between the toroidal winding and the individual wraps of the magnetic material behave similarly to an air gap in a closed magnetic path.

In this embodiment, the same compromise between hysteresis loss and average permeability may be achieved, as formerly described, except that, in this embodiment, the compromise is made by mutually adjusting the relative thicknesses of the magnetic and spacer material and their overall lengths since the effective distributed air gap will be a function of these parameters. The distributed air gap, in any event, will have an effective length, compared to the length of the magnetic path which may be adjusted through these parameters to secure the same compromise results stated previously for the prior two core embodiments.

What is claimed is:

1. A toroidal core for forming a high-Q coil having a high inductance per volume for use at high frequencies and having a Q defined by the expression

$$\frac{1}{Q} = \frac{1}{Q_h} + \frac{1}{Q_e} + \frac{1}{Q_w}$$

where Q_h , Q_e and Q_w respectively represent the Q due separately to hysteresis, eddy current, and copper losses, said core comprising a hollow cylindrically shaped bobbin formed of non-magnetic metal and having a cylindrical center portion, at least one thin-layer toroidal path of high permeability strain sensitive magnetic material supported and retained on said bobbin, said path comprising at least one layer of said magnetic material supported on said bobbin in close proximity to said center portion, said layer having an overlapping portion and nonmagnetic means inserted between the overlapping portion, and means for retaining said layer of magnetic material on said bobbin while permitting magneto-strictive motion thereof, said magnetic path having a magnetic discontinuity due to said overlapping layer portion and providing an effective air gap of a distributed nature in the path, said path having its eddy current losses dependent only on the thickness of said layer, said path having its hysteresis losses and average permeability predetermined and proportioned by the ratio of the length of said effective air gap to the length of said magnetic path in accordance with the expression

$$Q_h = \pi \frac{(HB)}{A}$$

where H is the magnetomotive force, B is the flux density, and A is the area of the B-H loop of said magnetic material and is inversely proportional to the length of said air gap.

2. The toroidal core according to claim 1 wherein the

last named means includes a spring clip for maintaining said layer in close proximity to said center portion.

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