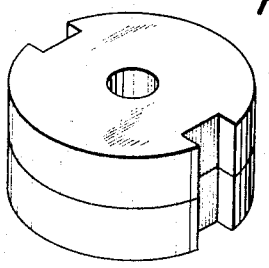
April 18, 1967 KOUJI KAWAHARA ETAL 3,315,196

POT TYPE MAGNETIC CORE FOR TOROIDAL COIL

Filed June 16, 1964

FIG. 1



PRIOR ART

FIG. 2

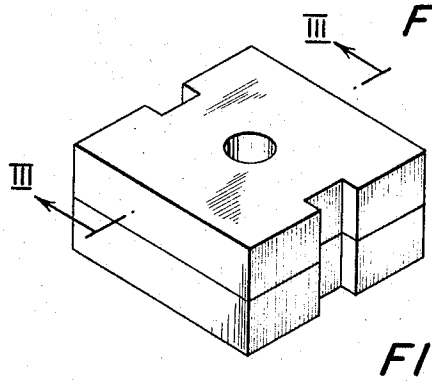
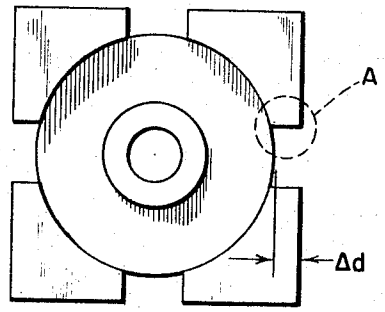


FIG. 7



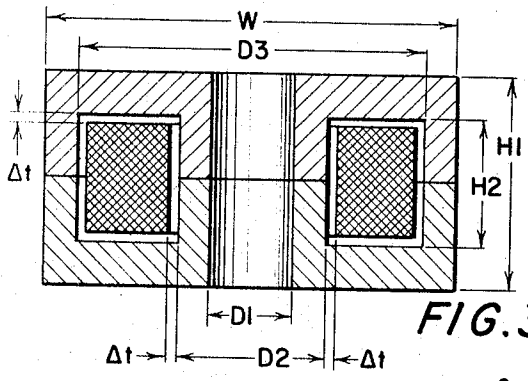


FIG. 3

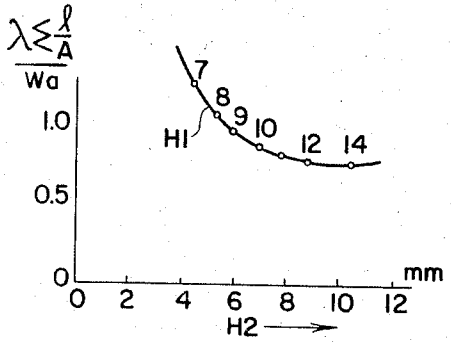


FIG. 4

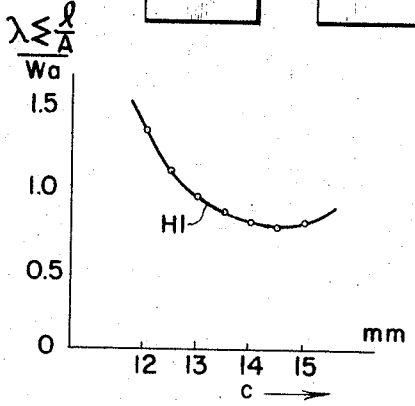


FIG. 5

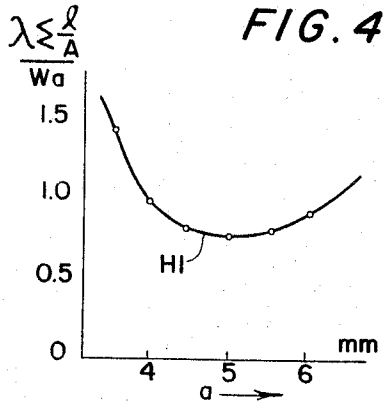


FIG. 6

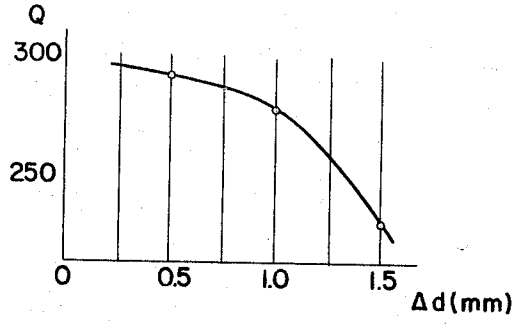


FIG. 8

United States Patent Office 3,315,196 Patented Apr. 18, 1967

3,315,196

POT TYPE MAGNETIC CORE FOR TOROIDAL COIL

Kouji Kawahara, Kawasaki-shi, and Misao Takahashi, Tokyo, Japan, assignors to Fujitsu Limited, Kawasaki, Japan, a corporation of Japan

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Claims priority, application Japan, June 20, 1963, 38/32,357
7 Claims. (Cl. 336—83)

The present invention relates to a magnetic core for a toroidal coil. More particularly, the invention relates to a miniature magnetic core.

There is a recent tendency toward miniaturization of various communicating equipment so that miniaturization of coil and transformer becomes indispensable. There are various problems which arise in the use of a tubular shape pot-type magnetic core of conventional type. The value of Q drops due to an increase of D.C. resistance loss, and stability may be lost due to such increase. Furthermore, a reduction of coil space increases magnetic resistance and magnetic loss. Miniaturization requires high quality material and this causes an increase in the cost of manufacture. Miniaturization has been limited by poor magnetic concentration in the core.

The present invention concerns a magnetic core in which such problems are entirely resolved and in which the magnetic concentration is improved although the core is of small size. Furthermore, the core will provide an efficient and effective coil or transformer without the use of high-quality material.

The principal object of the present invention is to provide a new and improved miniature magnetic core.

One of the characteristics of the magnetic core of the present invention is that it is a rectangular parallelopiped. The rectangular parallelopiped configuration of the core improves its magnetic concentration. If, however, its size ratio is not properly selected, various problems may occur in the manufacturing of the magnetic core and it becomes impossible to assure expected characteristics. Therefore, in order to obtain good results with the rectangular parallelopiped magnetic core, including a manufacturing process free of problems, consideration should be given to the size of each part of the magnetic core.

Another of the characteristics of the magnetic core of the present invention is that the size of each part is selected in accordance with predetermined equations.

In order that the present invention may be readily carried into effect, it will now be described with reference to the accompanying drawings, wherein:

FIG. 1 is a perspective view of an embodiment of a known type of magnetic core;

FIG. 2 is a perspective view of an embodiment of a magnetic core of the present invention;

FIG. 3 is a section of the magnetic core of FIG. 2, taken along the line III—III;

FIGS. 4, 5 and 6 are graphical presentations of the magnitude

$$\frac{\lambda \Sigma \frac{l}{A}}{Wa} \text{ versus } H2$$

FIG. 7 is a top view of a modification of the embodiment of FIG. 2; and

FIG. 8 is a graphical presentation of the quality factor Q versus Δd.

In the miniaturization of carrier equipment it is generally most effective to make the frequency band small. When a small size magnetic core is operated in the frequency band of 12 to 24 kilocycles, 70 to 80% of the coil loss is due to the coil wire loss and most of the coil wire loss is due to D.C. resistance loss. Therefore, the most suitable size of magnetic core can be obtained from the condition of minimum D.C. resistance loss as follows.

The magnetic core of the present invention comprises a substantially rectangular parallelopiped having spaced substantially parallel top and bottom faces. A first pair of spaced substantially parallel sides is substantially perpendicular to the top and bottom faces. A second pair of spaced substantially parallel sides is substantially perpendicular to the top and bottom faces and to the first pair of sides. Each of the top and bottom faces has four edges of substantially equal length W forming a substantially square face. Each of the sides of the first pair of sides and each of the sides of the second pair of sides has top and bottom edges of substantially equal length W and side edges of substantially equal length H1 forming a substantial rectangular parallelogram of each side.

The magnetic core has formed therein a substantially toroidal recess for accommodating a substantially toroidal coil. The toroidal recess has spaced substantially parallel top and bottom faces substantially parallel to the top and bottom faces of the rectangular parallelopiped and spaced a distance H2 from each other. A first substantially cylindrical side is substantially perpendicular to the top and bottom faces of the toroidal recess and of the rectangular parallelopiped and has a diameter D2. A second substantially cylindrical side is coaxial with and spaced from the first side of the toroidal recess and is substantially perpendicular to the top and bottom faces of the toroidal recess and of the rectangular parallelopiped and has a diameter D3. Each of the top and bottom faces of the toroidal recess has an inner circular edge formed by the first side of the toroidal recess and an outer circular edge formed by the second side of the toroidal recess.

The magnetic core has formed therethrough an aperture of diameter D1 substantially perpendicular to the top and bottom faces of said magnetic core and centrally located substantially equidistantly from the sides of the first and second pairs of sides thereof.

In the embodiment of FIG. 2, the magnetic core has formed in each side of one of the first and second pairs of sides thereof a notch extending from the top face to the bottom face of said magnetic core substantially parallel to the sides of the other of the first and second pairs of sides thereof and to the H2 edges of the sides.

In the modification of FIG. 7, a notch similar to those of the embodiment of FIG. 2, is formed in each side of the magnetic core. Each notch has a bottom substantially juxtaposed with the second side of the toroidal recess at a distance Δd from each corresponding side of the first and second pairs of sides of the magnetic core.

In FIG. 3, the size and description of each part in millimeters is:

W is the length of the outer side of the magnetic core.
D1 is the diameter of the central aperture through the core.
D2 is the inside diameter of the toroidal recess formed in the core.
D3 is the outside diameter of the toroidal recess formed in the core.
H1 is the thickness of the magnetic core.
H2 is the thickness of the toroidal recess formed in the core.
Δt is the clearance between the coil and the toroidal recess formed in the core.

The D.C. resistance loss is defined by the equation:

$$\frac{Rdc}{\omega L}=\frac{1}{\mu'\cdot f\cdot fcu}\cdot\frac{D3+D2}{D3-D2}\cdot\frac{\rho}{8\pi(H2-2\Delta t)}\sum\frac{l}{A}\cdot 10^{9}$$

where:

μ' is the effective magnetic permeability.

fcu is the concentration rate of copper.

L is the inductance of the coil or winding (H).

l is the mean length of the flux path in cm.

f is the frequency in cycles per second.

ρ is the specific resistance of the winding or coil in ohm-cm.

A is the cross-sectional area of the core in cm.^{2}.

$$\frac{\pi(D3+D2)}{2}$$

is the average length of a single winding.

$(D3-D2)(H2-2\Delta t)/2$ is the cross-sectional area of the toroidal recess.

If the average length of the winding is defined by λ and the cross-sectional area of the toroidal recess is defined by W*a*, the D.C. resistance loss will be

$$\frac{Rdc}{\omega L}=\frac{1}{\mu 1\cdot f\cdot f\cdot fcu}\cdot\frac{\rho}{8\pi}\times 10^{-7}\frac{\lambda\cdot\Sigma\frac{l}{A}}{Wa}$$

where ρ is the specific resistance of the coil. Thus, copper has a ρ of 1.76×10^{-6} ohm/cm.

As is evident from this equation, the term which relates to core size is only

$$\frac{\lambda\cdot\Sigma\frac{l}{A}}{Wa}$$

If

$$a=\frac{D1+D2}{2}$$

$$b=\frac{D2-D1}{2}$$

$$c=\frac{\frac{W}{\sqrt{\pi}}+D3}{2}$$

$$d=\frac{\frac{W}{\sqrt{\pi}}-D3}{2}$$

Then,

$$\sum\frac{l}{A}=\frac{H1+H2}{2\pi}\left\{\frac{1}{a(a-D1)}+\frac{1}{c\left(\frac{2W}{\sqrt{\pi}}-c\right)}\right\}+\frac{4.62}{\pi(H1-H2)}\log\frac{c}{a}$$

$$Wa=\left\{(c-a)-\left(\frac{W}{\sqrt{\pi}}-\frac{D1}{2}\right)-2\Delta t\right\}\{H2-2\Delta t\}$$

$$\lambda=\pi\left\{(c+a)-\left(\frac{W}{\sqrt{\pi}}+\frac{D1}{2}\right)\right\}$$

Therefore,

$$\frac{\lambda\cdot\Sigma\frac{l}{A}}{Wa}$$

is obtained by the equation

$$\frac{\lambda\Sigma\frac{l}{A}}{W}=\frac{\left(c-a-\frac{W}{\sqrt{\pi}}-\frac{D1}{2}\right)}{(H2-2\Delta t)\left(c-a-\frac{W}{\sqrt{\pi}}+\frac{D1}{2}-2\Delta t\right)}\left[\frac{H1+H2}{2}\left\{\frac{1}{a(a-D1)}+\frac{1}{c\left(\frac{2W}{\sqrt{\pi}}-c\right)}\right\}+\frac{4.62}{H1-H2}\log\frac{c}{a}\right]$$

If W is assumed to be 14.0 mm., D1 is assumed to be 3.0 mm., and Δt is assumed to be 0.2 mm., the calculation of

$$\frac{\lambda\Sigma\frac{l}{A}}{Wa}$$

is illustrated in FIGS. 4, 5 and 6, each of which illustrates

$$\frac{\lambda\Sigma\frac{l}{A}}{Wa}$$

versus the magnitude of H2 in mm.

The D.C. resistance loss *Rdc*/ωL, as indicated hereinbefore, is proportional to the reluctance of the magnetic core and is inversely proportional to the winding or coil space. A minimum *Rdc*/ωL value condition may thus be determined by appropriate determination of the core reluctance and the coil space. Thus, a suitable value of *H1*/*H2*, as well as suitable values of H1 and H2, should be determined. The calculation for determining these values results in the curve of FIG. 4.

In FIGS. 4, 5 and 6,

$$\frac{\lambda\Sigma\frac{l}{A}}{\omega L}$$

is the ordinate in mm. In FIG. 4, H2 is the abscissa in mm., for different values of H1. In FIG. 5, *c* is the abscissa in mm., for different values of H1. In FIG. 6, *a* is the abscissa in mm., for different values of H1. These curves enable the determination of the value of H2 which provides the minimum value of

$$\frac{\lambda\Sigma\frac{l}{A}}{\omega L}$$

with respect to H1. This results in the selection of H1 and H2 values for minimum D.C. resistance loss.

If *a*, *c*, H1 and H2 are selected as follows, a good result is obtained:

H1=11 to 14 mm.
H2=8 to 10 mm.
a=4.8 to 5.2 mm.
c=14 to 15 mm.

A desirable size in practical use is obtained if W is 14 mm. However, in actuality manufacturing problems should be taken into consideration. In a rectangular parallelopiped type magnetic core of the present invention, Δd shown in FIG. 7, presumably creates a manufacturing problem.

The cross section of the outside ring portion is not uniform, as opposed to conventional magnetic cores. Thus, during the manufacture of a magnetic core, a part may break or crack and may thus affect the electrical characteristics of the core. Accordingly, it is desirable that the value of Δd be as large as possible. It is, however, undesirable to make the value of Δd too large, since too large a value of Δd causes a drop in the magnitude of the quality factor Q.

The relation between Δd and Q is shown in FIG. 7, and from the curve of FIG. 7, the value Δd=0.8 mm. can be selected. The size of the magnetic core is obtained from the aforementioned results. In general, the size of the magnetic core follows similarly to the aforedescribed calculations. Therefore, if the aforedescribed size ratio is applied to another core of different size, the various size ratios for the magnetic core may be immediately obtained. These preferred size ratios are:

$W/D3$=1.00 to 1.15
$W/D2$=1.50 to 2.40
$W/H1$=0.90 to 1.60
$H1/H2$=1.20 to 1.50
Δd=0.4 to 0.8 mm.

The magnetic core of the present invention for a toroidal coil may be used in a wide range, such as for a filter, or loading coil, etc. The following is an example in which the core is used with a band pass filter element and toll line loading coil and is of small size with little loss. The transformer D.C. resistance loss $Rdc/\omega L$ is reduced about 30% over that of a conventional magnetic core of same size. The magnetic core of the present invention has a wide range of utilization and application.

In an application with a band pass filter.

Size of magnetic core in mm.:
14ϕ x 8.4
11 x 11 x 9.6
18ϕ x 14
Q at 20 kc. where L=50 mh.:
270
320
340

where ϕ is the diameter in mm. of the magnetic core and 14ϕ x 8.4 is a magnetic core having a diameter of 14 mm. and an altitude of 8.4 mm.

In an application as a channel filter:

Item	Size of magnetic core		Note
	30ϕ x 19	21 x 21 x 21	
Inductivity	100 mh./37 mh. (Side Cct.) (Phantom Cct.).	100 mh./37 mh.	
Effective resistance, 1,800 c./s.	16.6Ω	15.8Ω	Side.
Do	8.2Ω	7.7Ω	Phantom.
Hysteresis factor, ΔR 800 c./s.	0.15Ω/ma.	0.12Ω/ma.	Side.
Do	0.035Ω/ma.	0.03Ω/ma.	Phantom.
Magnetic stability	0.90%	0.17%	

We claim:

1. A magnetic core for a substantially toroidal coil, comprising a substantially rectangular parallelopiped having spaced substantially parallel top and bottom faces, a first pair of spaced substantially parallel sides substantially perpendicular to said top and bottom faces and a second pair of spaced substantially parallel sides substantially perpendicular to said top and bottom faces and to said first pair of sides, each of said top and bottom faces having four edges of substantially equal length W mm., each of the sides of said first pair of sides and each of the sides of said second pair of sides having top and bottom edges of substantially equal length W mm. and side edges of substantially equal length H1 mm., said magnetic core having formed therein a substantially toroidal recess for a substantially toroidal coil, said toroidal recess having substantially parallel top and bottom faces substantially parallel to the top and bottom faces of said rectangular parallelopiped and spaced a distance H2 mm. from each other, a first substantially cylindrical side substantially perpendicular to the top and bottom faces of said toroidal recess and of said rectangular parallelopiped and having a diameter D2 mm. and a second substantially cylindrical side coaxial with and spaced from the first side of said toroidal recess and substantially perpendicular to the top and bottom faces of said toroidal recess and of said rectangular parallelopiped and having a diameter D3 mm., each of the top and bottom faces of said toroidal recess having an inner circular edge formed by the first side of said toroidal recess and an outer circular edge formed by the second side of said toroidal recess, the ratio $W/D3$ ranging in value from 1.00 to 1.15, the ratio $W/D2$ ranging in value from 1.50 to 2.40. the ratio $W/H1$ ranging in value from 0.90 to 1.60 and the ratio $H1/H2$ ranging in value from 1.20 to 1.50.

2. A magnetic core as claimed in claim 1, wherein said magnetic core has formed therethrough an aperture substantially perpendicular to said top and bottom faces thereof and centrally located substantially equidistantly from the sides of said first and second pairs of sides thereof.

3. A magnetic core as claimed in claim 1, wherein said magnetic core has formed in each side of one of the first and second pairs of sides thereof a notch extending from the top face to the bottom face of said magnetic core substantially parallel to the sides of the other of said first and second pairs of sides thereof.

4. A magnetic core as claimed in claim 1, wherein said magnetic core has formed in each side of each of the first and second pairs of sides thereof a notch extending from the top face to the bottom face of said magnetic core substantially parallel to the sides of the other of said first and second pairs of sides thereof.

5. A magnetic core as claimed in claim 4, wherein each notch has a bottom substantially juxtaposed with the second side of said toroidal recess.

6. A magnetic core as claimed in claim 1, wherein said magnetic core has formed therethrough an aperture substantially perpendicular to said top and bottom faces thereof and centrally located substantially equidistantly from the sides of said first and second pairs of sides thereof and wherein said magnetic core has formed in each side of one of the first and second pairs of sides thereof a notch extending from the top face to the bottom face of said magnetic core substantially parallel to the sides of the other of said first and second pairs of sides thereof.

7. A magnetic core as claimed in claim 1, wherein said magnetic core has formed therethrough an aperture substantially perpendicular to said top and bottom faces thereof and centrally located substantially equidistantly from the sides of said first and second pairs of sides thereof and wherein said magnetic core has formed in each side of each of the first and second pairs of sides thereof a notch extending from the top face to the bottom face of said magnetic core substantially parallel to the sides of the other of said first and second pairs of sides thereof.

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LEWIS H. MYERS, *Primary Examiner.*

L. EASKIN, T. J. KOZMA, *Assistant Examiners.*