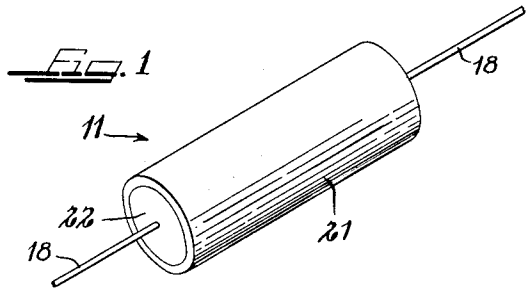
March 21, 1961 L. E. HILL 2,976,502

INDUCTIVE DEVICES

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Fig. 1



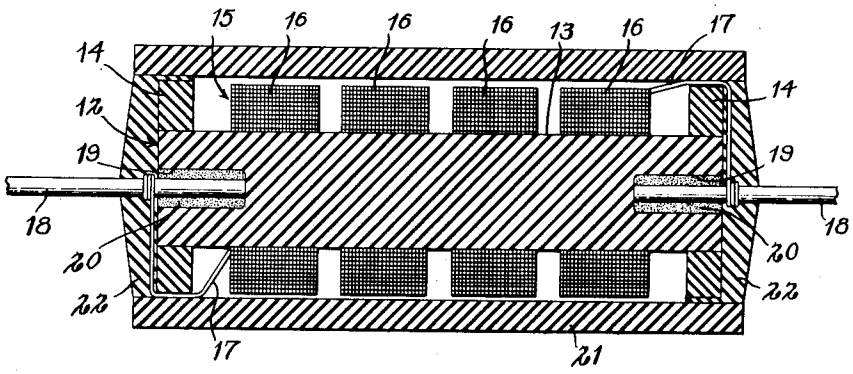




Fig. 2

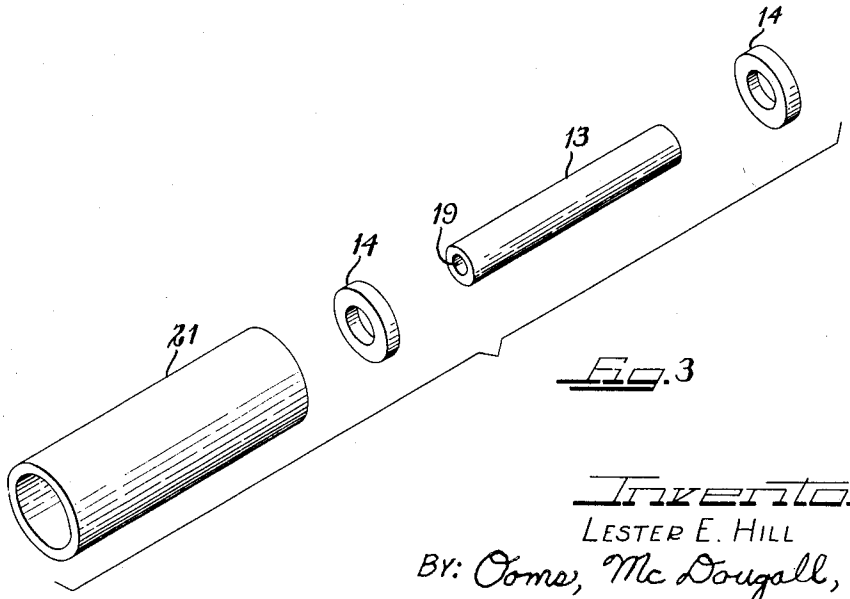



Fig. 3

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INDUCTIVE DEVICES

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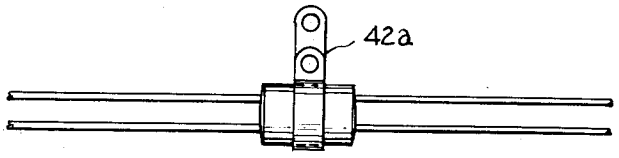



Fig. 4

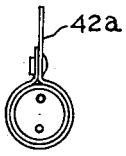



Fig 5

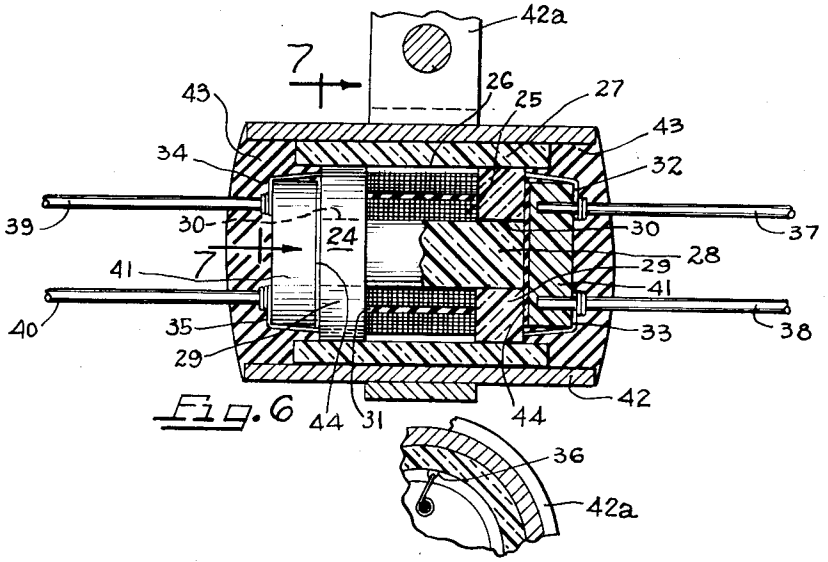



Fig. 6




Fig. 7

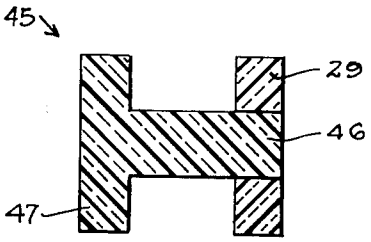



Fig. 8

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Patented Mar. 21, 1961



2,976,502

# INDUCTIVE DEVICES

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Filed Mar. 13, 1958, Ser. No. 721,142

7 Claims. (Cl. 336—83)

This invention relates to inductive devices, such as choke coils, transformers, or the like.

This application is a continuation-in-part of my copending application Serial No. 623,584, filed November 21, 1956, now abandoned, which was a division of my application Serial No. 471,780, filed November 29, 1954.

An object of the invention is to provide new and improved inductive devices having efficient magnetic cores which provide high inductance and low losses.

A further object is to provide a new and improved inductive device having an efficient yet inexpensive spool-shaped core.

Another object of the invention is to provide an improved inductive device having a closed magnetic circuit.

A further object is to provide an improved inductive device of the foregoing character which may be employed to advantage as a transformer or choke at high radio frequencies.

Another object of the invention is to provide an improved radio frequency inductive device which is completely enclosed magnetically and hence is efficient and well shielded.

It is a further object of the invention to provide an improved inductive device which has a closed magnetic circuit, yet is simple in construction and extremely inexpensive to manufacture.

Another object is to provide an improved magnetically enclosed inductive device which provides an extremely high inductance, yet has an extremely low resistance.

A further object is to provide a new and improved inductive device which is magnetically enclosed and hermetically sealed.

Further objects and advantages of the invention will appear from the following description, taken with the accompanying drawings, in which:

Fig. 1 is a perspective view of a magnetically enclosed coil constituting an illustrative embodiment of the invention.

Fig. 2 is an enlarged longitudinal sectional view of the coil shown in Fig. 1.

Fig. 3 is an exploded perspective view of some of the components forming the magnetic circuit of the coil.

Fig. 4 is an elevational view of a modified embodiment, in the form of a transformer, which may be employed as a pulse transformer or the like.

Fig. 5 is an end view of the transformer of Fig. 4.

Fig. 6 is a greatly enlarged elevational view, partly in central longitudinal section.

Fig. 7 is a fragmentary cross-sectional view, taken generally along the broken line 7—7 in Fig. 6.

Fig. 8 is a central longitudinal sectional view showing a modified spool which may be employed in the transformer of Figs. 4–7.

If Figs. 1–3 are considered in greater detail, it will be seen that they illustrate an exemplary inductance coil 11 which is well adapted for use as a choke coil at high radio frequencies.

To provide a magnetic circuit having high permeability,



the coil 11 includes a spool 12 which is preferably made of a bonded finely divided magnetic material so that the spool will be magnetic yet electrically insulating. It will be seen that the spool 12 comprises a cylindrical rod-like core 13 fitted at its opposite ends with disk-like flanges 14.

The conductive or current carrying element of the coil 11 is formed by a winding 15 carried on the core 13. In this instance, the winding 15 comprises a plurality of spaced annular pies 16 which may be universally or otherwise wound in the conventional fashion. As is well known, this arrangement of the winding 15 minimizes the distributed capacitance of the coil. Various other types of windings may be employed. If desired, the core may be provided with two or more transformer windings. Leads 17 are brought out from the opposite ends of the winding 15 and are soldered or otherwise connected to terminal or end leads 18 in the form of short lengths of relatively stiff wire received in recesses 19 formed in the ends of the core 13. Annular solder masses 20 are disposed in the recesses 19 around the terminal leads 18 to anchor the leads in the recesses. The solder is flowed into the recesses around the wires 18 during the course of the assembly of the coil 11. Other anchoring compounds may be employed instead of the solder.

The spool 12 and the winding 15, even when not enclosed with magnetic material, provide a coil with high inductance and low losses. The end disks 14 enhance the efficiency of the magnetic core to such an extent that the inductance of the coil is approximately doubled, over the value obtained when the core 13 is employed alone.

Provision may be made for enclosing the spool 12 and the winding 15. To this end the spool 12 is received within an elongated sleeve 21 which is tubular and cylindrical, as illustrated. The sleeve 21 may be made of various insulating materials. To obtain maximum inductance, however, the sleeve may be made of low-loss, bonded, finely divided magnetic material. It will be understood that the inside diameter of the sleeve 21 is made sufficient to receive the spool 12 and the winding 15. The fit between the sleeve 21 and the flanges 14 may be rather free, as shown, or may be close or snug. Preferably, the length of the sleeve 21 is made somewhat greater than the length of the spool 12.

The ends of the sleeve 21 may be sealed by magnetic, electrically insulating plugs or masses 22 which also serve to form magnetic bridges between the ends of the spool 12 and the sleeve 21. Accordingly, the winding 15 is completely enclosed within a sheath of magnetic material. The magnetic sealing masses 22 may be composed of finely divided or powdered magnetic material carried in a suitable binder such as a polyester or other resinous plastic. It is preferred to add the magnetic sealing plugs 22 by flowing or otherwise introducing the magnetic material into the ends of the sleeve 21 with the binder in a liquid or plastic state. A solvent or other plasticizer may be employed to soften the binder. After the sealing plugs 22 are in place, the binder may be cured, preferably with the aid of heat. It will be appreciated that the masses 22 hermetically seal the winding 15. Moreover, the material of the end masses 22 flows between the ends of the sleeve 21 and the disk flanges 14 so that the magnetic circuit for the winding 15 will be completely closed.

Instead of the magnetic sealing compound, a suitable non-magnetic, electrically insulating compound may be employed. This will not provide magnetic bridges, but will give acceptable results when the fit between the sleeve 21 and the disks or flanges 14 is close. Either sealing

compound seals the coil hermetically and secures it in assembled relation.

In manufacturing the exemplary coil **11**, the spool **12** and the sleeve **21** may be made of any suitable bonded finely divided magnetic material. However, it is preferred to form the spool **12** and the sleeve **21** of nickel ferrite and cobalt ferrite, along with other materials added in minor quantities, generally as disclosed and claimed in the Berge Patents Nos. 2,640,813; 2,656,319; and 2,659,698. The additive materials may include zinc ferrite, vanadium ferrite, zinc oxide, vanadium oxide, iron oxide, magnesium zirconate, and lead titanate in various small proportions. These ferrite based mixtures provide high magnetic permeability, high inductance with a minimum of wire in the coil, high "Q" or factor of merit, low eddy current, and other losses, and low thermal drift in the finished magnetic members.

It is preferred to make the spool **12** by molding the core **13** from a suitable ferrite mixture, prefiring the core, molding the disks **14**, mounting the disks on the ends of the core, and refiring the assembly. It has been found that the disks **14** shrink to a greater extend than the prefired core **13** during the final firing, with the result that the disks and the core are intimately engaged and firmly united in the finished spool **12**.

While the ferrite mixture for molding the core **13** may vary in composition, as discussed in the above-mentioned Berge patents, the mixture may comprise, for example, approximately equal parts by weight of finely divided or powdered nickel ferrite and cobalt ferrite. Either of the ferrites may be in excess of the other up to about 25 percent. In addition, the exemplary mixture may contain a small amount, up to about 12 percent by weight, of finely divided magnesium zirconate; a small amount, up to about 15 percent by weight, of powdered zinc oxide; a small amount, up to about 10 percent by weight, of powdered vanadium oxide; a sufficient amount of finely divided iron oxide to react with the zinc and vanadium oxides to form the corresponding ferrites; and a small amount, up to about 10 percent by weight, of a temporary organic binder. Any binder having suitable adhesive properties may be employed. For example, the binder may be selected from the phenol-aldehydes, melamine-aldehydes, urea-aldehydes, vinyl polymers and copolymers, polyacrylates, polystyrenes, polyesters, and rubber based materials. The binder may be made fluid or plastic with a suitable solvent. About three percent by weight of the binder is usually sufficient.

The core **13** is formed by molding the mixture under high pressure into the desired shape. At this point, the core **13** is fired for about one-half to two hours at a temperature in the range between about 1800 and 2500 degrees Fahrenheit, and preferably in excess of 2000 degrees Fahrenheit. The firing burns away the temporary binder, but develops a bond between the other ingredients. After the core **13** has been cooled, the molded but unfired end disks **14** are slipped over the ends of the core and the assembly is refired in the same temperature range, but preferably this time to a temperature of 2350 degrees Fahrenheit. Differential shrinkage occurs between the disks or rings **14** and the core **13**, with the rings shrinking more than the core, due to the prefiring of the core. The amount of shrinkage of the core in the second firing is inversely related to the prefiring temperature, particularly in the range from 2000 to 2500 degrees Fahrenheit. If the prefiring temperature is much below 2000 degrees Fahrenheit, the shrinkage of the core in the second firing tends to be about the same as if it had not been prefired. By virtue of the two-stage firing, the end disks are united to the core with great firmness.

Alternatively, the disks **14** and the core **13** may be molded and fired separately, whereupon the disks may be slipped on the ends of the core at final assembly. In this case, it is desirable to make the finished disks to fit snugly on the finished core.

After the spool **12** has been completed, the winding **15** is wound on the core **13**. Moreover, the end leads **18** are inserted into the recesses **19** and solder is flowed into the recesses to anchor the leads. The ends of the winding **15** are soldered to the leads **18**.

Next, the sleeve **21** is slipped over the spool **12**. To form the plugs **22**, finely powdered ferrite material, carried in a suitable binder, in applied to the ends of the sleeve **21**. The ferrite material may be similar to that in the finished core **13**. Any suitable binder, such as a polyester resin, for example, may be employed. The ferrite material is applied to one end of the sleeve **21** first, and then the binder is cured, preferably at an advanced temperature of about 125 degrees centigrade. The coil **11** is then inverted so that the ferrite material may be applied to the opposite end of the sleeve **21**. A second curing operation follows. It will be understood that the plastic ferrite material flows into the interstices between the end disks **14** and the sleeve **21**. Thus the finished end plugs **22** completely fill the ends of the sleeve **21** and cover the ends of the spool **12**. Accordingly, the winding **15** is hermetically sealed and magnetic bridges are formed between the sleeve and the ends of the spool **12**. In this way, the coil **11** is provided with a completely closed magnetic circuit. Moreover, the winding **15** is effectively shielded magnetically.

Due to the chemical nature and the finely divided character of the material in the magnetic circuit, the coil **11** may be employed as an effective choke coil or inductance element at high radio frequencies. Because of the insulating nature of the magnetic material, the coil may be employed at high voltages, such as 10,000 volts, for example.

It will be apparent that the winding may be wound by inexpensive simple methods. Moreover, the parts of the magnetic circuit may be easily and inexpensively made and assembled. Accordingly, the cost of the coil as a whole is extremely low.

Figs. 4–7 illustrate a modified inductive device in the form of a transformer **23**, which may be employed as a pulse transformer, or for various other services. As in the case of the first embodiment, the transformer **23** comprises a flanged spool **24**. In this case, the spool **24** is provided with a plurality of windings. Two windings **25** and **26** are illustrated, but it will be understood that additional windings may be provided. A sleeve **27** is employed to surround the spool **24**.

As before, the spool **24** comprises a rod-like core **28** fitted with apertured end disks or flanges **29**. It is preferred to form the core **28**, the end disks **29**, and the sleeve **27** of a bonded finely divided magnetic material which has a high magnetic permeability yet is a good electrical insulator. In this way, the transformer may be employed for extremely high frequencies, while maintaining low losses. The elements **27**, **28** and **29** may be molded from a ferrite mixture and then fired as described in connection with Figs. 1–3. The end disks **29** may be shrunk onto the core **28**, as previously described, by the two-stage firing method. However, in many cases it has been found quite acceptable to form the core **28** and the end disks **29** separately. The disks **29** may then be assembled on the core **28**. In this case, the fit between the disks and the core is made quite close or snug so as to enhance the magnetic permeability of the magnetic circuit. The snug fit between the disks **29** and the core **28** also improves the spool mechanically, so that it may be handled with facility during the winding of the coils **25** and **26** and in the final assembly. In some cases, the disks **29** may be cemented to the core **28** along the joints **30** therebetween.

The coils **25** and **26** are shown as being wound in two separate layers, with an insulating wrapper **31** therebetween. However, the coils may be wound in any other suitable manner.

After the coils **25** and **26** have been wound, the spool

24 is slipped into the sleeve 27. Preferably, the fit between the end disks 29 and the sleeve 27 is made quite close or snug so as to enhance the permeability of the magnetic circuit.

It will be seen that the winding 25 has end leads 32 and 33, while the coil 26 has end leads 34 and 35. The end leads are brought out through notches or grooves 36 (Fig. 7) formed in the periphery of the end disks 29.

The illustrated transformer 23 is equipped with four terminal leads 37, 38, 39 and 40 which are sufficiently heavy to support the transformer. In this case, the leads 37–40 extend in pairs from the ends of the transformer. Each pair is molded into or otherwise secured in an insulating plate 41 at each end of the spool 24. The plates 41 may be made out of a suitable resinous plastic material. The end leads 32–35 may be wrapped around the corresponding terminal wires 37–40 and may be soldered in place. It will be seen that the illustrated plates 41 are partly received in the ends of the magnetic sleeve 27.

In the case of the illustrated transformer 23, the magnetic sleeve 27 is surrounded by an electrically conductive metal sleeve 42 which provides an electrostatic shield. When the transformer is employed in a circuit, the shield 42 may be grounded in any suitable manner, such as by means of a clamp or band 42*a*. It is also feasible to solder a grounding lead to the sleeve 42.

The ends of the transformer 23 are hermetically sealed by plastic masses 43 of sealing compound. In this case, an ordinary non-magnetic sealing compound may be employed to good advantage, because of the close fit between the sleeve 27 and the end disks 29. The plastic masses 43 fill the ends of the metal sleeve 42 and surround the plastic plates 41. It will be apparent that the plastic masses 43 extend into the ends of the magnetic sleeve 27, and surround portions of the terminal wires 37–40. For somewhat greater permeability in the magnetic circuit, the plastic sealing masses 43 may be made of insulating magnetic material, as in the embodiment of Figs. 1–3.

If desired, the plastic lead mounting plates 41 may be cemented to the ends of the spool 24, by means of plastic cement, which may be the same as employed in the sealing masses 43. In Fig. 6, layers of cement or sealing compound between the plates 41 and the spool 24 are indicated at 44.

The core 28, the end disks 29 and the sleeve 27 provide a completely enclosing magnetic circuit for the transformer windings 25 and 26. Thus, the efficiency of the magnetic circuit is high, and there is very little flux leakage. Because of the finely divided, insulating character of the material in the magnetic circuit, the transformer may be used effectively at extremely high frequencies. The transformer is hermetically sealed and thus will withstand extremely high humidity, without loss of efficiency. The enclosing metal sleeve provides effective electrostatic shielding.

With all of these advantages, it will be recognized that the transformer 23 may be readily manufactured at extremely low cost.

Fig. 8 illustrates a modified spool 45 which may be employed instead of the spool 24 in Figs. 4–7. It will be seen that the modified spool 45 has a generally cylindrical rod-like core 46, with a flange 47 formed integrally on one end thereof. The other end of the core 46 may be fitted with one of the end disks 29, which may be the same as in Fig. 6. The flange 47 may be the same in shape as the end disk 29, but is molded and fired integrally with the core 46.

The molding of the spool in three parts, as in Fig. 6, or in two parts, as in Fig. 8, makes it possible to form the spool with truly cylindrical surfaces, without mold marks, parting lines, or other irregularities. The molded parts may be removed endwise from the mold, or, in other words, parallel to the cylindrical surfaces. The sleeve 27 may be molded in a similar manner, so that the inner surface will be truly cylindrical and free from irregularities. In this way, the parts of the magnetic circuit may be fitted closely together to provide high permeability.

Various other modifications, alternative constructions and equivalents may be employed without departing from the true spirit and scope of the invention as exemplified in the foregoing description and defined in the following claims.

I claim:

1. A magnetically enclosed inductive device comprising a cylindrical rod-like magnetic electrically insulating core made of finely divided bonded magnetic material, a wire winding including a plurality of spaced pies carried on said core, said core having axial recesses formed in its opposite ends, a pair of end leads disposed in said recesses and connected to the ends of said winding, solder masses in said recesses around said wires to anchor said wires therein, a pair of magnetic electrically insulating apertured disks made of finely divided bonded magnetic material and tightly received over the opposite ends of said core in intimate engagement therewith, a cylindrical tubular magnetic electrically insulating sleeve made of finely divided bonded magnetic material and surrounding said core, disks and winding, said sleeve extending beyond the ends of said disks and core, and magnetic electrically insulating masses of finely divided magnetic material carried in a polyester plastic binder and received in the ends of said sleeve over the ends of said disks and between said disks and said sleeve to seal in said windings and form magnetic bridges between said disks and said sleeve.

2. A coil, comprising a rod-like magnetic core, a wire winding carried on said core, a pair of magnetic apertured members received over the opposite ends of said core, a magnetic sleeve surrounding said core, members, and winding, said core, members and sleeve being composed of bonded finely divided magnetic material, and magnetic masses of finely divided magnetic material carried in a binder and sealing the ends of said sleeve and forming magnetic bridges between said members and said sleeve.

3. A magnetically enclosed inductive device, comprising a cylindrical rod-like magnetic electrically insulating core made of bonded finely divided magnetic material, a wire winding carried on said core, said core having generally radial flanges at opposite ends thereof and formed of finely divided bonded magnetic material, a tubular cylindrical magnetic electrically insulating sleeve made of bonded finely divided magnetic material and surrounding said core, flanges and winding, and finely divided magnetic material carried in a binder and disposed in sealing relation between the ends of said sleeve and said flanges ot form magnetic bridges therebetween.

4. A magnetically enclosed coil, comprising a cylindrical rod-like magnetic electrically insulating core made of bonded finely divided magnetic material, a wire winding carried on said core, a pair of magnetic electrically insulated apertured disks made of bonded finely divided magnetic material and received over the opposite ends of said core, a tubular cylindrical magnetic electrically insulating sleeve made of bonded finely divided magnetic material and surrounding said core, disks, and winding, and finely divided magnetic material carried in a binder and disposed in sealing relation between the ends of said sleeve and said disks to form magnetic bridges therebetween.

5. A magnetically enclosed inductive device, comprising a cylindrical rod-like magnetic electrically insulating spool with a pair of annular generally radial flanges thereon at the opposite ends thereof, said spool and said flanges being made of bonded finely divided magnetic material, a wire winding carried on said spood between said flanges, a tubular cylindrical magnetic electrically insulating sleeve made of bonded finely divided magnetic material and extending between said flanges around said winding and said spool, and finely divided magnetic mate-

rial carried in a binder and disposed in sealing relation between the ends of said sleeve and said flanges to form magnetic bridges therebetween.

6. A magnetically enclosed inductive device comprising a spool having a cylindrical rod-like magnetic electrically insulating core made of bonded finely divided magnetic material and a pair of magnetic electrically insulating apertured disks made of bonded finely divided magnetic material and received over the opposite ends of said core, a plurality of windings on said spool between said disks, a tubular cylindrical magnetic electrically insulating sleeve made of bonded finely divided magnetic material and surrounding said core, disks and windings, insulating plastic plates mounted at the ends of said spool, leads mounted in said plates, said windings being connected to said leads, and masses of plastic sealing material sealing the ends of said sleeve and embedding said plates.

7. A magnetically enclosed inductive device comprising a magnetic electrically insulating spool with a generally cylindrical rod-like core having a pair of annular generally radial flanges thereon at the opposite ends thereof, said spool being made of bonded finely divided magnetic material, winding means carried on said spool between said flanges, a tubular cylindrical magnetic electrically insulating sleeve made of bonded finely divided magnetic material and extending between said flanges around said winding and said spool, insulating members mounted at the ends of said spool, leads mounted on said members, said winding means being connected to said leads, and masses of plastic insulating material closing the ends of said sleeve and embedding said members.



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