This invention relates to inductive devices, such as transformers and reactors, and to magnetic core structures therefore, and more particularly to inductive devices having coaxial magnetic core structures.

Inductive devices, such as transformers and reactors, are used to modify either the voltage or current of an alternating current system; transformers serving to increase or decrease the voltage and reactors serving to limit the current. A special type of transformer, referred to as a high reactance transformer, serves not only to modify the voltage of the system, but also limits current by virtue of its internal reactance. High reactance transformers are commonly used for starting and operating discharge devices such as fluorescent lamps or mercury vapor lamps.

Inductive devices used in alternating current systems of relatively low frequency, i.e., 60 cycles, commonly comprise a magnetic core structure with one or more coils or windings positioned thereon. These core structures conventionally include a portion on which the coils are arranged and an outer or yoke portion surrounding the coils thereby providing a return path for the magnetic flux. High reactance transformers may additionally have shunts formed of magnetic material arranged between the primary and secondary coils for providing a path for leakage flux.

In the past, the core structures for inductive devices have conventionally been formed of a stacked plurality of relatively thin laminations of magnetic material. These laminations have generally been punched from a sheet of magnetic material thus involving a considerable waste of the material in the punching operation. In addition, the coils used on the cores of this type have generally had a rectangular configuration thus giving the core and coil assembly a somewhat cruciform cross-section; in turn requiring that the core and coil assembly be housed in a case having a rectangular cross-section thus involving considerable waste space. Such constructions have thus required considerably more material than is theoretically necessary thus adding appreciably to the overall cost of the device.

It is therefore desirable to provide an inductive device having a core structure which can be formed essentially without waste of material. Such a construction should be adaptable for use in a high reactance transformer in which instance it should also permit the use of magnetic shunts and the series and shunt air gaps well known in the prior art.

An object of this invention is therefore to provide an improved inductive device incorporating the desirable features set forth above.

Further objects and advantages of my invention will become apparent by reference to the following description and the accompanying drawing and the features of novelty which characterize this invention will be pointed out with particularity in the claims annexed to and forming a part of this specification.

In its broadest aspects, this invention provides new magnetic structures and new coaxial core inductive devices generally comprising central magnetic core portions with one or more electrical windings arranged thereon, and magnetic outer yoke core portions surrounding the windings thereby providing a return path for the magnetic flux. The coaxial core of these devices is generally constructed about an elongated or rod-shaped central core portion and, as compared with prior inductive devices of similar rating, is more economical in materials and thus involves a lower overall cost.

The features of my invention, which I believe to be novel, are set forth with particularity in the appended claims. My invention, itself, however, both as to its organization and method of operation, together with further objects and advantages thereof may best be understood by reference to the following description and the drawings in which

Fig. 1 is a cross-sectional side elevation view of a low reactance transformer according to my invention;

Figs. 2a through 2f show end and partial side elevation views of center coil supporting structures;

Fig. 2k illustrates in plan view a portion of a lanced strip of magnetic material used in forming the center coil supporting structure of Figs. 2i and 2j;

Figs. 3a through 3n and 3p show various views of outer yoke structures;

Figs. 4a through 4l show various views of magnetic end structures;

Figs. 5a and 5b are cross-sectional side elevation views and end views respectively of another inductive device of my invention;

Figs. 6a and 6b are cross-sectional side elevation and end views respectively of still another inductive device according to my invention;

Figs. 7a and 7b are cross-sectional side elevation and end views respectively of an audio transformer made in accordance with my invention;

Figs. 8a and 8b are cross-sectional side elevation and end views respectively of another audio transformer according to my invention;

Figs. 9a through 9e are cross-sectional side elevation views of a high reactance ballast transformer or parts of such a transformer according to my invention, and

Fig. 10 shows a coaxial core type solenoid made according to my invention.

Referring now to the drawing, there is shown in Fig. 1 a simple coaxial core low reactance transformer 1 made according to my invention. This transformer has a center magnetic core portion 2 of specific structure to be discussed hereinafter. Surrounding the rod-like center core portion 2 are a primary winding or coil 6 having leads 4 and 5 adapted to be connected to an external source of alternating current (not shown), and a secondary winding or coil 3 having leads 7 and 8 adapted to be connected to a load (not shown). While the windings are shown as concentrically wound they may be arranged in any desired manner according to any particular requirements which are to be met. Surrounding windings 3 and 6 and forming a protective shell therefor is a magnetic yoke portion whose structure will be discussed below. Completing the magnetic circuit between inner core portion 2 and outer yoke portion 9 are magnetic end pieces 10.

It will be realized that the transformer of Fig. 1 is to be taken as illustrative only of inductive devices which will be discussed herein of which low reactance transformers, high reactance transformer ballasts, solenoids and reactors, among other devices, are typical.

Refferring to Figs. 2a through 2k there are shown various configurations of center magnetic cores which are useful in the practice of my invention. Fig. 2a and
Fig. 2b are end and partial side views respectively of a center core portion comprising a plurality of wires or rods 12, of magnetic material, such as iron, circular or otherwise, with their axis parallel to that of the core. This construction, which is useful for many purposes, has low eddy current loss. The stacking factor, that is, the relationship of the quantity of magnetic material in the core to the internal air gaps, can be increased by using wires or rods of small diameters or of nesting shapes. The rods 12 may be insulated one from the other as well as held in final shape by a thin coating thereon of insulating varnish or resin. Alternatively the oxide film on the rods which occurs either naturally or by reason of handling may be utilized for insulation, the rods being held together in a desired core shape by winding thereon. It will be understood that all core elements discussed hereinafter may be insulated or bound together as described above.

Figs. 2c and 2d show end and partial side views of another typical center core portion 13 made up of parallel-arranged relatively thin laminations 14 of magnetic material such as iron or steel, cut into proper widths and properly placed to form a core preferably of round cross-section, though any cross-sectional shape may be used here as in all other magnetic structures described herein. This core again is characterized by low eddy current loss. These laminations are cut from a strip of magnetic material thus involving essentially no waste or scrap.

Core portion 15 shown in end and partial side views in Figs. 2e and 2f is a preferred embodiment for a center magnetic core portion. This core portion comprises a series of relatively thin laminations of magnetic material of various widths nested together in quadrants of a circular cross section as shown, although again other shaped cross sections may be used. The widest laminations 16 are equal in width to the radius of the core cross-section and delimit one side of the quadrant while the other delimiting or bounding lamination 17, the thickness of one lamination narrower than lamination 16 is buttressed against the latter lamination as shown. Successively narrower laminations are nested in perpendicular V-shaped fashion as shown, conforming to the desired periphery of the core to form a quadrant of magnetic material which is repeated for the rest of the core section. Core elements of other shaped cross-sections may be divided into similar sections having spacers at the longitudinal axis of the core.

Since all of the laminations of the core portion 15 are substantially disposed in a radial direction, the eddy current losses are reduced over that of core portion 13 with its parallel laminations. For the same reason losses due to fringing flux are substantially reduced. Furthermore, the stacking factor can be maintained at a high level by using thin laminations and precise nesting. The core portion 18 shown in end view in Fig. 2g and partial side view in Fig. 2h is characterized by reduced eddy current loss and fringing flux loss because its laminations 19, 20, 21, 22, etc., all formed of relatively thin magnetic material are all disposed radially outwardly from the center of the core. Here the cross-section of the core portion may be of any shape and is divided into as many sectors or sections as desired, each sector or section being bounded by laminations 19 equal in width to the radius or dimension of the core, the intervening laminations being of varying widths depending on their thickness and the stacking factor to be obtained. The laminations may also be tapered toward the core center to permit a higher percentage of magnetic material in the core.

Core portion 23 shown in end view in Fig. 2i and partial side view in Fig. 2j is very desirable from the point of view of low fringing flux loss and low eddy current loss. Core portion 23 is made by coiling relatively thin lanced magnetic sheet material 24 lanced or slit as at 25, 26, and 27 of Fig. 2k. These lancings or slits may be as numerous as desired and in any pattern so long as the sheet is still capable of being physically handled. If desired, the slits may be spread apart and the edges thereof insulated as with a varnish.

From the point of view of overall usefulness, taking into account their losses such as those due to eddy current and fringing fluxes, as well as relatively high stacking factors, the center core portion of Figs. 2e–2k are preferred.

The center core portions described above are easily adaptable to mass production. The laminations of Figs. 2a through 2k are readily fed from spools or other sources through a die which is in the shape desired. The core of Figs. 2l through 2k may be made by coiling or rolling up sheet 24 in any length or width desired and cutting off to size.

Useful outer yoke core structures are depicted in Figs. 3a through 3p. Outer yoke core portion 28 shown in end view in Fig. 3a and in partial side view in Fig. 3b is comprised of a plurality of wires or rods 29 of magnetic material, such as iron, circular or otherwise shaped in cross-sections which are parallel to the longitudinal axis of the core. The elements 29 of the outer yoke can be separated by an insulating varnish to lower the eddy current loss or the natural oxide film thereon may be utilized for this purpose. The core portion may be fabricated much as certain of the center core portion by feeding the magnetic stock from reels and through a die over the windings on the center cores. As is also the case with the center core portion made of similar elements, the stacking factor may be improved by using wire shapes which nest closely together.

Outer yoke core portion 30 shown in end view in Fig. 3c and partial side view in Fig. 3d is comprised of a plurality of relatively thin laminated parallel to the longitudinal axis of the core portion. The widths of laminations 31 may be directed radially outward or oriented at any desired angle to the radius, as shown, for example, in the drawing. By orienting the laminations at various angles the thickness of the core may be varied within wide limits for any particular width laminations. Such a core is characterized by low eddy current loss as well as low loss due to fringing flux. The laminations of this core may be especially insulated, if desired.

Figs. 3e and 3f show a different outer yoke core portion 32 comprising corrugations 33 of magnetic material, the corrugations or folds running parallel to the longitudinal axis of the core portion. While, for the purpose of illustration, corrugations or folds 33 are shown spread apart or open, they can be compressed to various degrees to provide a desired stacking factor or concentration of magnetic material. Since the corrugations are oriented essentially in radial directions, the eddy current loss and the loss due to fringing flux is low. As with core portion 30 such corrugations may be oriented outwardly to various degrees.

The outer yoke core portion 34, an end view of which is shown in Fig. 3g and a partial side view which is illustrated in Fig. 3h is quite similar to outer yoke core portion 32 except that the corrugations or folds 35 are disposed radially. As in the previous structure, the corrugations may be compressed as desired to obtain various stacking factors. This core structure width may be coated with an insulating varnish as above. Since the outer side of the corrugations are radially oriented the losses due to eddy current and fringing flux are favorably low.

The outer yoke core portion 36 shown in end view in Fig. 3i and partial side view in Fig. 3j consists of a series of annularly or concentrically arranged laminations 37 of magnetic material having one or more air gaps 38 to reduce the eddy current and other core losses. Laminations as in the previous case may be especially insulated as desired. Laminations 37 may also be in the nature
of a continuous coil in which at least one air gap is formed.

Shown in Fig. 3k in end view and in Fig. 3f in partial side view is an outer yoke core portion formed by coiling a lanced sheet of relatively thin magnetic material such as that shown in Fig. 2k with the laminations 25, 26, 27, etc., disposed parallel to the longitudinal axis of the core. It will be realized, of course, that the laminations or slats may also be disposed circumferentially, the primary consideration being to divide the core in a radial manner in order to reduce eddy current and fringing flux losses. Again the number of laminations may be varied according to the particular requirements to be met. Instead of forming core 39 by coiling a sheet upon itself it may build up of a plurality of distinct lanced sheets, with each sheet forming one or more layers of the core. From the fabricating point of view, and particularly with respect to mass production the use of one continuous sheet is preferred.

Figs. 3m, 3n, and 3p illustrate a variation of core 34 of Figs. 3g and 3h. This outer yoke core portion 40 is formed of corrugations 41. The folds in such corrugations being at the ends of the core and the folds compressed to give any desired stacking factor. A particular feature of outer yoke core portion 40 resides in the end structure 42 which extends at right angles to the main body of the core to form a winding and closing structure which may also be utilized to form a magnetic path to the center core structure. Such an outer yoke core 40 may conveniently be made out of a punched strip 43 of relatively thin magnetic material as shown in Fig. 3p, which is folded at lines 44, outer yoke core portion 40 having its laminations disposed radially and again characterized by low eddy current and fringing flux losses. It will be realized that end structures similar to 42 may be obtained with other core structures such as those shown in Figs. 3a through 3f by bending the core structures, such as rods 29, or by providing proper end structures in the case of laminations 31, corrugations 33, etc.

Generally in coaxial core inductive devices of the type described above, some means must be provided for completing the magnetic circuit between the inner or coil supporting portion and the outer yoke portion of the core. As described above, this may be accomplished by extending the ends of the outer core inward to contact the inner core. In many cases it may be more convenient to provide a separate angular piece or end structure such as is shown in Figs. 4a through 4f. Shown in Figs. 4a and 4b in end and side views respectively is a molded magnetic end structure 45 which is comprised of divided magnetic material 36, such as iron powder suspended in a resin 47. Such magnetic material and resin compositions are well known in the art and may be made using various resins and various percentage of the magnetic filler, the resin binding the magnetic particles together to form a solid structure. Furthermore, such end structures may be molded in place between the center and outer cores and firmly bonded thereto so that an improved magnetic path is provided. The above end structures can also be formed of suitable sintered material.

Referring to Figs. 4e and 4d, end structure 48 is comprised of a plurality of laminations 49 of relatively thin magnetic material insulated from one another by surface oxide or applied insulating material with their edges oriented in a radial direction to reduce eddy current and fringing flux losses. The folded portion of outer yoke core portion 30 of Fig. 3c, the laminations 49 may also be disposed at various angles thus making it possible to obtain end structures of different radial thicknesses, using laminations of one standard width.

The new end structure 50 of Figs. 4e and 4f is comprised of corrugations 51 of relatively thin magnetic material similar to those of Fig. 5e, the folds of said corrugations being disposed parallel to the length of the structure with the folds disposed generally radially outward. The corrugations may be compressed as desired to obtain any particular stacking factor and magnetic material contact. The eddy current and fringing flux losses of this end structure are low.

Shown in Figs. 4g and 4h in end and side views respectively is an end structure 52 which is similar in general construction to outer yoke core portion 34 in Figs. 3g and 3h. Here the corrugations 53 of relatively thin magnetic material have their folds at the ends of the structures, and disposed radially outwardly and may be compressed again to obtain any particular stacking factor. Since the elements of the end structures are radially oriented the losses due to eddy current and fringing flux are again low.

The end structure 54 shown in end view in Fig. 4i and side view in Fig. 4j is comprised of a plurality of washer type laminations 55 of magnetic material each of which has a plurality of radially oriented laminations therein resulting in a corrugated structure for each washer lamination. These laminations 56 may be varied in number increasing to the point where the washer 55 is just capable of being handled physically. It will be realized, of course, that increasing the number of laminations lowers the losses due to eddy current and fringing flux.

End structures according to this invention may also be fabricated by other means than those shown. For example, an end structure may be made similarly to the outer cores shown in Figs. 3a and 3b. The outer yoke core portions shown in Figs. 3a and 3b and 3f through 3l may also be used as end structures simply by reducing their diameter and length. The end structures made in these manners may also be varied as described above in connection with outer cores. In particular end structures, according to Figs. 3k and 3l are characterized by low core losses. In general, any of the structures shown for a center core portion or an end structure may be adapted for any of the other two elements depending upon the characteristics desired and losses which may be tolerated. Thus the magnetic metalized material 47 of Figs. 4a and 4b may be used in center cores and outer cores in many applications. Other adaptations will be apparent to those skilled in the art.

As pointed out above, the new and useful magnetic elements of my invention may be used in a wide range of inductive devices, either in combination one with the other or in conjunction with known magnetic elements, the typical ones of which have been described above, to provide new and useful combinations.

Referring again to Fig. 1 which shows a coaxial low reactance transformer made according to my invention, for lowest core losses I prefer to utilize a center core portion of the types shown in Figs. 2e through 2k. It will be noted that these cores are all laminated in a generally outward or radial direction which reduces eddy current losses as well as fringing flux losses. In low power applications where the core losses are not so important a factor as when higher power is used, the cores shown at 11 and 13 are useful with that at 13 generally preferred of these two structures.

The outer yoke core portions shown in Figs. 3a through 3n and 3p are all very useful for general transformer devices, the cores of Figs. 3e, 3b, 3f, and 3l being most used where core losses are not of great importance. From the point of view of reducing core losses to a minimum I prefer outer yoke core portion shown in Figs. 3e, 3p, and 3l, since here the laminations or elements are all directed edgewise in a generally outward or radial direction.

Insofar as end structures are concerned I prefer reducing core losses to a minimum with end structures shown in Figs. 4e through 4j. An end structure patterned after outer yoke core portion 59 of Fig. 3k is also very useful. Here again the outward orientation of the laminations,
together with the high obtainable stacking factors dictate the preference. Where low power applications are to be made an end structure of the molded type shown in Fig. 4a may be used. The core 45 shown here has the advantage that it may be molded in place between and to the center and outer cores thus attaining a tight magnetic circuit.

The various magnetic elements described may be used in any desired combination. However, insofar as control transformers which generally have a lower power rating and low core loss factor are concerned, I prefer from the point of view of ease of manufacture and performance, to employ first a center core portion 13 which is easily made and has suitably low power core loss along with a combination outer yoke core portion and end structure 40 or an outer core 35 and an end structure 52. Also preferred for control or low power rating transformers is one having a center core portion 18, a combination outer yoke core portion and end structure 40, or an outer yoke core portion 35 and an end structure 52. Another preferred embodiment for such transformers is one having a center core portion 13, combination outer yoke core-end structure 40, or an outer yoke core portion 35 and an end structure 48. Combinations of center core portion 13, end structures 48 and outer yoke core portion 30 or 36 are also useful for small transformers as well as audio transformers. It is to be realized that many other combinations of magnetic structures as well as combinations of old structures with my new structures may be used for control transformers or those of low power rating.

In general, all of the center core portions shown are useful in varying degrees as are the outer yoke core portion and end structures, though those utilizing my new structures are preferred and particularly the examples given above.

For power transformers in which the power rating and core losses are relatively higher I prefer to use magnetic structures whose structure is such as to reduce core losses due to eddy currents and fringing flux. A preferred power transformer structure based on Figs. 1 has a center core portion 15, an outer yoke core portion 30, and an end structure 52 or a combination outer yoke core portion and end structure 49. Also preferred is a power transformer having a center core portion 18, an outer yoke core portion 30 and an end structure 52 or again a combination outer yoke core portion-end structure 48. A third preferred construction for power transformers is that comprising a center core portion 23, an outer yoke core portion 36, and an end structure 52 or a combination outer yoke core portion and end structure 40. Other combinations of magnetic structures to provide efficient low core loss power transformers will occur to those skilled in the art. In general cores 15, 18, and 23 are preferred for the center core portion of power transformers while preferred outer yoke core portions are cores 30, 32, 34, 39, and 40. Preferred end structures are 48, 50, 52.

These structures all have low core losses which are important in power applications. The magnetic connection between the magnetic elements may be improved by binding them at their points of contact with a thin film of resin filled with divided magnetic material.

Returning now to Figs. 5a and 5b, there is illustrated means for providing an improved magnetic circuit as desired for inductive devices. Shown is a low resistance transformer 57 having a center core portion 58 of the type shown in Figs. 2e and 2f, an outer yoke core portion 59 similar to that shown in Figs. 3c and 3d and an end structure 60 such as that of Figs. 4e and 4d, along with primary and secondary windings 61 and 62. The elements of transformer 57 are illustrative only and may be varied as desired in accordance with my invention. As shown, the ends of center core 58 are accurately tapered and the inner periphery of end structure 60 also tapered to substantially mate with the taper on core 58. This construction provides an improved magnetic path of low reluctance for the transformer which requires a relatively low magnetizing current. It is very useful in power distribution transformers.

Another useful type of low reactance transformer construction is shown in Figs. 6a and 6b which eliminates the need for a separate magnetic end structure and has only two magnetic joints instead of the usual three. Transformer 63 has a center core portion 64 of wires or rods formed of magnetic material, the wires being flared outwardly at the ends of the core to form a spread to accommodate windings 65 and 66. After the flared portion 67, the direction of the rod is altered to run parallel to the center core portion 64 and in the process spread or flattened out to form an annulus or cylinder 68. While not essential, if the annulus 68 is bound together as with a resin or varnish, a non-magnetic end disk 69 may be utilized to maintain the shape of the annulus and partially support it. Outer yoke core portion 70 may conveniently be of any construction of my invention and is shown here as similar to that shown in Figs. 3c and 3d. The above construction eliminates magnetic end structures. Another advantage resides in the manner in which the flux traverses the wires at annulus 68. In any center core of magnetic wire the flux in the central wires must traverse the wires at the end of the center core. However, in the structure shown in Figs. 6a and 6b the flaring of the wires and forming of the annulus 68 reduces the depth of the core wires or elements and the magnetic path from the center core to the outer core is lessened and losses reduced. The two magnetic joints or junctions being at points where the joint area of magnetic material is relatively large and the flux density therefrom low further contribute to a device which has low core loss and low magnetizing current.

The magnetic structures of my invention are also very useful in making audio transformers which are typically used as coupling media between the last audio stage and loud speaker in electronic sound systems. Such transformers in order to have a wide frequency range should have good low frequency response as well as good high frequency response, and be small in size or economical of material. Low frequency response varies directly with the primary inductance which latter resolves itself into a matter of obtaining an optimum air gap length to air gap area ratio 40. A thin air gap transformers the area of the air gap is determined by the cross-sectional area of the core. However, in a coaxial core type transformer, the air gap length or the distance along the core is not determined by the core cross-sectional area but utilizes the circumference of the core. As compared with an "E" and "I" type core of the same cross-sectional area to obtain an equal air gap area in a coaxial type construction the length of the air gap need be only one-quarter the diameter of the core. To double the air gap area the air gap length need be lengthened only one-quarter of the core diameter. On the other hand, since the area of an "E" type core the cross-section must be doubled and hence the amount of magnetic material doubled.

High frequency response varies indirectly with the leakage reactance, that is the lower the leakage reactance the higher the frequency response. Whereas in "E" and "I" core transformers coupling is relatively poor; that is, any wire in a primary winding is relatively distant from a wire similarly situated in a secondary winding, close coupling and low leakage reactance is obtained in a coaxial type construction because here the primary and secondary windings are relatively thin or spread out and are concentrically arranged one with the other.

A novel and useful low reactance coaxial core transformer is shown in Figs. 7a in cross-sectional side view and 7b in end view. Here transformer 71 has a center core portion 72 of longitudinally disposed wires or rods formed
of magnetic material. Surrounding the core portion 72 are two primary windings 73 and a secondary winding 74. Surrounding the windings and conforming to their shape and that part of center core portion 72 which extends beyond the windings is outer yoke core portion 75. Outer core portion 75 may typically be made of one or more coils of a lanced sheet of magnetic material such as shown in Fig. 3k with the laminating extending longitudinally. Providing the core is somewhat thicker than a single sheet and may be of any greater thickness desired. Outer core portion 75 which is longitudinally and radially segmented may also be conveniently made up of a plurality of round, square, or otherwise shaped wires of magnetic material which are bent to shape. The outer core is held in place on the center core by cementing it thereto and can also be fixed thereto by collars 76 and other means.

Another embodiment of an audio transformer is shown in Figs. 8a in side cross-sectional view and in Fig. 8b in end view. Here transformer 77 has a center core portion 80 of wire or rods of magnetic material about which are wound concentrically primary winding 79 and secondary winding 80. If desired, a binding collar 81 may be used to hold the center core wires in place at the places where it extends beyond the windings. Outer yoke core portion 82 is comprised in this instance of a punched strip 87 folded along lines 44 in accordion fashion as shown in Fig. 3n and placed around the windings and the center core, the strip having been precurved to conform exactly to the windings and center core. The outer core 82, as in other similar structures, may be compressed as desired to provide any particular stacking factor. In lieu of a preformed collar 81, resins filled with magnetic material or other means can be used to hold the center core 78 together and bind it to the outer core 82.

While the preceding audio transformers have been described with respect to magnetic structures and elements of certain types, it will be realized that various other combinations of my newly disclosed structures as well as combinations of these structures with old structures may be used. Thus such a transformer of good performance may be made using a center core portion of the construction shown in Figs. 2c and 2d and a conforming outer yoke core portion of the type shown in Figs. 5m, n, and p or Fig. 7a. It will be understood that all the center core portions shown herein may be used as may all outer yoke core portions, the outer core portion being easily altered as required to conform to the windings and center core thus eliminating separate end structures.

The magnetic structures of my invention are also most useful in fabricating high reactance ballot transformers for use in starting and operating arc discharge devices such as fluorescent and mercury vapor lamps. In operating arc discharge devices, it is desirable to provide a relatively high starting voltage to initiate an electrical discharge in the lamps. Additionally, all arc discharge devices have a negative resistance characteristic, and current limiting means must be provided to maintain the current therethrough at a non-destructive level. These functions can be provided by a high starting voltage and after starting of limiting the current to a safe value are provided by the so-called high leakage reactance ballot transformer. In the past such ballot transformers have conventionally been constructed with a laminated "E" and "I" type core having therein loosely coupled primary and secondary windings. Such configurations are shown in the windings for the passage of the leakage flux. Air gaps at the magnetic shunts serve to limit the secondary current to the proper level.

A characteristic of conventional ballot transformers is the extra core loss due to fringing flux. This loss occurs because an appreciable amount of the fringing flux traverses the laminations of the "E" and "I" type core at right angles to the laminations. It is highly desirable that this loss be reduced as much as possible and such a reduction may be made using the magnetic structures of this invention. Additionally, whereas in conventional ballot transformers a magnetic shunt must be provided between the primary and secondary windings for the leakage flux, with a coaxial core type construction I have found that an outer concentric core completely surrounding the center core so increases the area of the leakage path between the center and outer cores that a magnetic shunt may not be necessary. Magnetic shunts may however be incorporated in construction in accordance with this invention. In ballot transformers made according to my invention the reluctance of the leakage path between the center and outer cores is adjusted as desired by varying the relative diameter of the center core, the inside diameter of the outer core and the length of the cores. Hence, the current may be limited to any desired value.

Shown in Fig. 9a is a side elevation sectional view of a typical high reactance ballot transformer according to my invention. This transformer has a center core portion 83 on different parts of which in spaced relationship and thus loosely coupled fashion are wound, a primary winding 84 with its leads 85 and 86 adapted to be connected to an external source of alternating current (not shown) and secondary winding 87 with its leads 88 and 89 adapted to be connected to an arc discharge device. Separating the primary and secondary winding is a thin non-magnetic washer 90. Completely surrounding the windings and extending beyond them is a magnetic outer yoke core portion. Between the extending portions of the center and outer cores is provided the magnetic path therebetween are magnetic end structures 92.

The center core portion 83 may be any of those set forth in this application. However, I prefer those center core portions shown in Figs. 2e through 2j since these are laminated in a generally outward or radial direction, thus reducing eddy current loss as well as lowering fringing flux losses. Outer yoke core portion 91 can be any of those disclosed herein, but again I prefer those set forth in Figs. 3c through 3h and Figs. 3k and 3l. The end structure 92 can be of any of the embodiments shown although I prefer those of Figs. 4e through 4f. If caps 93 of any suitable insulating material may be provided, as well as an outer casing 94. Washer 90 may be of any insulating material, such as fiber, resin, and the like to serve as a barrier between the windings 84 and 87.

Optimum design considerations may require that magnetic shunts be placed between the windings of a high reactance ballot transformer such as that shown in Fig. 9. This is particularly true in lagging current circuits where exciting flux and leakage flux are additive in the leakage path in contrast to leading current circuits in which the exciting flux and leakage flux are subtractive in the leakage path. Fig. 9b is similar to Fig. 9a except for a magnetic shunt 95 between primary winding 84 and secondary winding 87. This shunt 95 can conveniently be of any of the structures shown in Figs. 4a through 4j although again those of Figs. 4e through 4f are preferred. Spacer 96 of non-magnetic material is placed as shown to separate shunt 95 from outer yoke 91 and provide the shunt air gap.

In leading current circuits, that is, in those having a capacitor in series with the arc discharge device load a series air gap may be required in the region of the core adjacent the leading current secondary winding. Such configurations are shown in Figs. 9c and 9d. If a spacer 96 is placed between end structure 92 and outer yoke 91 while in Fig. 9d the series gap is provided by placing a spacer 96 between end structure 92 and the center core 83.

In still other cases it may be desirable to utilize a bridged series air gap as discussed in Patent 2,598,399, H. W. Lord, assigned to the same assignee as this appli-
cation. Here as shown in Fig. 9e, a portion of the end structure 92 is cut away to define an air gap 97 suitably located.

I prefer from the point of view of ease of manufacture and low core losses ballast transformers having a center core portion as shown in Figs. 2e and 2f, and outer yoke core portion as shown in Figs. 3e and 3d and an end structure as shown in Figs. 4e and 4d, 4e and 4f or 4e and 4h. Also, preferred are such devices having a center core portion as in the examples above as shown in Figs. 2e and 2f, an outer yoke core portion as shown in Figs. 3g and 3h and end structures as shown in Figs. 4c and 4d, 4e and 4f, and 4g and 4i. In addition to the above preferred embodiments any desired combination of center core portions, outer yoke core portion, and end structures may be used, including those of my invention as well as all structures in combination with those of my invention. Using the basic structural features taught herein high reactance ballast transformers having any number of windings may be made. For example, two-lamp ballast transformers having one primary and two secondary windings are readily made incorporating the features set forth.

The magnetic elements or structures described herein may also be applied to other inductive devices such as solenoids, a typical one being shown in Fig. 10. The solenoid 98 of Fig. 10 has a fixed center core portion 99, end structure 100, outer yoke portion 101 and winding 102 all fixed together as shown. Mounted in lines with fixed center core 99 and inside the winding 102 for reciprocating motion therein is a movable center core 103 having fixed thereto an end structure 104. The various components of solenoid 98 are constructed similarly to analogous parts of the various devices shown hereinbefore.

The inductive devices and core structures of my invention offer many advantages over those of conventional design. Where losses must be reduced to a minimum, my new magnetic core structures can be combined to provide inductive devices with very low losses. Where such losses are not of the essence as in low power devices, my structures may be used in combination one with the other or with known structures to provide new and useful devices.

My inductive devices make maximum use of materials. For example, my generally circular inner or center core portion as compared to rectangular laminated cores of conventional design permit a unit length of copper to enclose a greater core area. Neither do my windings require special insulation as at the corners of rectangular coils where danger of insulation damages is present. Thus said in insulation thus occasioned permits an increased core area.

There is very little or no scrap in the fabrication of my core elements as compared to conventional "E" and "I" type cores. For the same inductance one may use the same length of winding and use lower permeability magnetic material than with "E" and "I" type cores. Likewise, using the same quality magnetic material, the same number of turns requires less wire with my coaxial core construction.

My magnetic devices are accompanied by reduced noise since all parts are closely bound together in compact fashion. My devices are further well protected against weathering, etc., the outer core and end pieces protecting the windings and serving as a shield therefore as well as acting as a magnetic element of the device. My devices, being relatively long and slender as compared to conventional devices, have a proportionately larger heat dissipating surface with a resultant lower operating temperature and longer life. Their compactness also reduces the heat path to the exterior of the device and thus enhances the heat transfer characteristic.

In certain cases as where molded magnetic end structures are utilized or where the center core portion is expanded at the ends, separate winding spools and the like are obviated.

The elimination of separate layers of paper insulation between winding layers except where used purposely to provide specific reactance characteristics represents a saving in cost and bulk.

Inductive devices made according to my invention provide substantial reductions in size and weight. For example, when a conventional transformer about twenty-four inches long and twelve inches in diameter was redesigned in accordance with the invention the size was reduced to a cylinder twelve inches long and six inches in diameter.

High reactance ballast transformer which for compactness of installation are made as small as possible may be substantially reduced in size and weight over conventional "E" and "I" type cores by utilizing my invention.

As pointed out above, my magnetic structures and devices are further well adapted to continuous mass production and assembly.

While I have described certain specific embodiments of my invention, I wish to be understood that I desire to protect in the following claims all changes or modifications thereto which fall within the spirit and scope of those claims.

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

1. A magnetic structure comprising corrugated magnetic material, the corrugations being compressed together and in the form of an annulus, the folds of said corrugations being parallel to the axis of said annulus.

2. A magnetic structure comprising a plurality of magnetic laminations, said structure being divided into longitudinally extending sections each having an apex at the longitudinal axis of said structure, said sections being abutting and respectively bounded and filled with generally outwardly extending laminations of such widths as to conform to the shape of said structure.

3. A magnetic structure comprising a plurality of longitudinally extending sections having apexes at the longitudinal axis of said structure, said sections being abutting and respectively bounded and filled with outwardly extending and inwardly tapered laminations of such widths as to conform to the desired periphery of said structure.

4. A magnetic structure comprising a plurality of longitudinally extending sections, said sections being abutting and respectively defined by bounding radially extending laminations and filled with radially extending laminations of varying widths.

5. A magnetic structure having a generally circular cross section comprising a plurality of longitudinally extending sections, said sections being defined by radially extending bounding laminations, said sections being filled with radially extending filler laminations of varying widths, said filler laminations and said bounding laminations being tapered at their inward portions to provide for substantial filling of said sections.

6. A magnetic structure comprising a plurality of longitudinally extending radially abutting sections having apexes at the longitudinal axis of said structure and defined by interlocking bounding laminations, said sections being respectively filled by interlocking filler laminations, said filler laminations being respectively shorter than alternately parallel with one and then the other of said bounding laminations.

7. A magnetic structure having a circular cross section comprising a plurality of longitudinally extending radially abutting sections, said sections being bound by interlocking bounding laminations forming a V-shape and extending to the periphery of said structure, the sectors between said bounding laminations being filled with interlocking filler laminations, said interlocking filler laminations being
respectively shorter than and alternately parallel with one and then the other of said bounding laminations.

8. An inductive device comprising an integral segmented inner magnetic core member of generally circular cross-section each longitudinal quarter of the core taken in a transverse direction comprising flat strips of magnetic material arranged in successively smaller V-sections proceeding from, and with the apexes thereof toward, the center of said core, at least one winding on said core, said inner core member having parts respectively extending beyond the ends of said winding, and at least partially radially segmented magnetic outer yoke core portion surrounding said winding and having parts respectively extending beyond the ends thereof, said parts of said outer core extending inwardly at the ends of said winding and terminating respectively adjacent said parts of said inner core.

9. An inductive device comprising a cylindrical segmented magnetic center core portion encompassing and including the longitudinal axis of the device, at least one winding on said center core, said center core having parts respectively extending beyond the ends of said winding, and at least partially radially segmented magnetic outer yoke core portion surrounding said winding and having parts respectively extending beyond the ends thereof, said parts of said outer core extending inwardly at the ends of said winding and terminating respectively adjacent said parts of said inner core.

10. An inductive device comprising a segmented magnetic center core portion, at least one winding on said center core, said center core having parts respectively extending beyond the ends of said winding, an at least partially radially segmented magnetic outer yoke core portion surrounding said winding and having parts respectively extending beyond the ends thereof, and divided resin-bonded magnetic material respectively positioned between said parts of said center core and said outer core portions.

11. An elongated inductive device comprising a magnetic center core member of generally circular cross-section, each longitudinal quarter of the core comprising separate laminations of magnetic material arranged in successively smaller V-shaped configurations proceeding from the center of said core, at least one winding on said core, said core having parts respectively extending beyond the ends of said winding, a magnetic outer yoke core member surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core comprising magnetic laminations arranged in a generally radial edgewise direction, and annular magnetic structures positioned respectively between said parts of said center and outer cores comprising corrugated magnetic material with the folds thereof parallel with the longitudinal axis of said center core.

12. An inductive device comprising a magnetic center core member of generally circular cross-section, each longitudinal quarter of the core taken in a transverse direction comprising separate laminations of magnetic material arranged in successively smaller V-shaped configurations proceeding from the axis of said center core, at least one winding of said center core, said center core having parts respectively extending beyond said winding, a magnetic outer yoke core member surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core comprising magnetic laminations arranged in a generally edgewise direction, and annular magnetic structures respectively positioned between said parts of said center and outer cores comprising laminations arranged in a generally radial direction.

13. An inductive device comprising an integral magnetic center core member of generally circular cross-section, said cross section being divided into longitudinally extending sectors, said sectors being abutting and respectively bounded by radially extending magnetic laminations and filled with radially extending laminations, at least one winding on said center core, said center core having parts respectively extending beyond the ends of said winding, an integral outer yoke magnetic core member surrounding said winding and having parts respectively extending beyond the ends thereof, and said outer core comprising corrugated magnetic material with folds directed in a radial direction.

14. An inductive device comprising a center core portion of generally circular cross section comprising a coiled sheet of magnetic material, said sheet having there-in longitudinally extending slits, at least one winding on said center core, said center core having parts respectively extending beyond the ends of said winding, an outer yoke core portion surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core comprising magnetic laminations extending in a generally radial direction, with folds directed in a radial direction, and annular magnetic end structures positioned respectively between said parts of said center and outer cores comprising corrugated magnetic material with folds extending in a radial direction.

15. An elongated inductive device comprising a magnetic center core member of generally circular cross section, each longitudinal quarter of the core comprising separate laminations of magnetic material arranged in successively smaller V-shaped configurations proceeding from the center of said core, at least one winding on said core, said center core having parts respectively extending beyond the ends of said winding, a corrugated magnetic outer yoke core member surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core comprising magnetic laminations extending in a generally radial direction with folds therein directed in a radial direction, and annular magnetic structures positioned respectively between the extending portions of said outer and center cores comprising corrugated magnetic materials with folds therein directed in a radial direction.

16. An inductive device comprising a magnetic center core portion of generally circular cross section comprising a coiled sheet of magnetic material having longitudinally extending slits therein, at least one winding on said core, said center core having parts respectively extending beyond the ends of said winding, a magnetic outer yoke core portion surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core comprising magnetic laminations extending in a generally radial direction with folds therein directed in a radial direction, and annular magnetic structures positioned respectively between said parts of said center and outer cores comprising corrugated magnetic material with folds therein directed in a radial direction.

17. An inductive device comprising a magnetic center core portion of generally circular cross section, said cross section being divided into longitudinally extending sectors, said sectors being abutting and respectively bounded by radially extending magnetic laminations and filled with radially extending magnetic laminations, at least one winding on said center core, said center core having parts respectively extending beyond the ends of said winding, a magnetic outer yoke core portion surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core comprising corrugated magnetic material with folds therein directed in a radial direction.

18. An elongated inductive device comprising an integral magnetic center core portion of generally circular cross section, said center core being comprised of parallel arranged magnetic laminations, at least one winding on said center core, said center core having parts respectively extending beyond the ends of said winding, a magnetic outer yoke core member surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core comprising corrugated magnetic materials with folds therein directed in a radial direction.
material with folds oriented in a radial direction, and annular magnetic structures positioned respectively between said parts of said outer and center cores and respectively comprising magnetic laminations oriented edgewise in a generally radial direction.

19. An inductive device comprising a magnetic center core portion of generally circular cross section, said cross section being divided into a plurality of longitudinally extending sectors, said sectors being abutting and respectively bounded by radially extending laminations and filled with radially extending laminations, at least one winding on said center core, said center core having parts respectively extending beyond the ends of said winding, a magnetic outer yoke core portion surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core comprising corrugated magnetic material with folds oriented in a radial direction, and annular magnetic structures positioned respectively between said parts of said outer and center cores and comprising corrugated magnetic material with folds therein oriented in a radial direction.

20. An inductive device comprising a magnetic center core portion formed of parallel disposition wires, at least one winding on said center core, said center core having parts respectively extending beyond said winding, a magnetic outer yoke core portion surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core conforming to the shape of said winding and said parts of said center core, said outer core comprising segmented magnetic material with the folds therein directed in a radial direction.

21. An elongated inductive device comprising a magnetic center core member of generally circular cross section, each longitudinal quarter of the core comprising separate laminations of magnetic material arranged in successively smaller V-shaped configurations proceeding from the center of said core, at least one winding on said core, said core having parts respectively extending beyond the ends of said winding, a magnetic outer yoke core member surrounding said winding and having parts extending respectively beyond the ends thereof, said outer core comprising magnetic laminations arranged in a generally radial edgewise direction, and annular magnetic structures positioned respectively between said parts of said center and outer cores comprising corrugated magnetic material with the folds therein directed in a radial direction.

22. An inductive device comprising a generally circular segmented magnetic inner core member, each longitudinal quarter of said inner core taken in a transverse direction comprising separate laminations of magnetic material arranged in successively smaller V-shaped configurations proceeding from and with the apexes thereof toward the center of said inner core, at least one winding on said core, said inner core having parts respectively extending beyond the ends of said winding, a magnetic outer yoke core member at least partially segmented in a generally radial direction and having parts respectively extending beyond said winding, and magnetic end structure material at least partially segmented in a radial direction positioned respectively between said parts of said inner and outer cores, said parts of said inner core being tapered, said end structure having surfaces respectively mating with said tapered parts of said inner core.

23. An inductive device comprising a generally circular segmented inner core member, each longitudinal quarter of said inner core taken in a transverse direction comprising separate laminations of magnetic material arranged in successively smaller V-shaped sections proceeding from and with the apexes thereof toward the center of said inner core, at least one winding on said inner core, said inner core having parts respectively extending beyond the ends of said winding, an outer yoke core member of magnetic material at least partially segmented in a radial direction surrounding said winding and having parts respectively extending beyond the ends thereof, and annular magnetic end structures at least partially segmented in a radial direction positioned respectively between said parts of said inner and outer core portions.

24. An inductive device comprising an inner core portion formed of a plurality of magnetic rods, the end portions of said rods being bent outwardly to form banked structures beyond a central winding receiving portion of said core and terminating in flanges parallel to the central portion of said core, magnetic material between the outwardly bent portions of said inner core, at least one winding on said central portion of said inner core, and an outer magnetic core at least partially radially segmented surrounding said winding and said inner magnetic core.

25. An inductive device comprising a magnetic center core member having an outer perimeter substantially circular with reference to a longitudinal axis, said center core including a plurality of radially extending laminations and generally outwardly extending laminations in abutting relationship interposed between said radially extending laminations and disposed so as to occupy the space bounded by said outer periphery; at least one winding on said core, said core having parts respectively extending beyond the ends of said winding; a magnetic outer yoke core member surrounding said winding and having parts respectively extending beyond the ends thereof, said outer core comprising magnetic laminations arranged in a generally radial edgewise direction, and annular magnetic structures positioned respectively between said parts of said center and outer cores and having thin sections of magnetic material parallel with the longitudinal axis of said center core.

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