Oct. 25, 1949. G. G. SOMERVILLE 2,486,220

MAGNETIC CORE

Filed Oct. 18, 1947 3 Sheets-Sheet 1

Fig. 1.

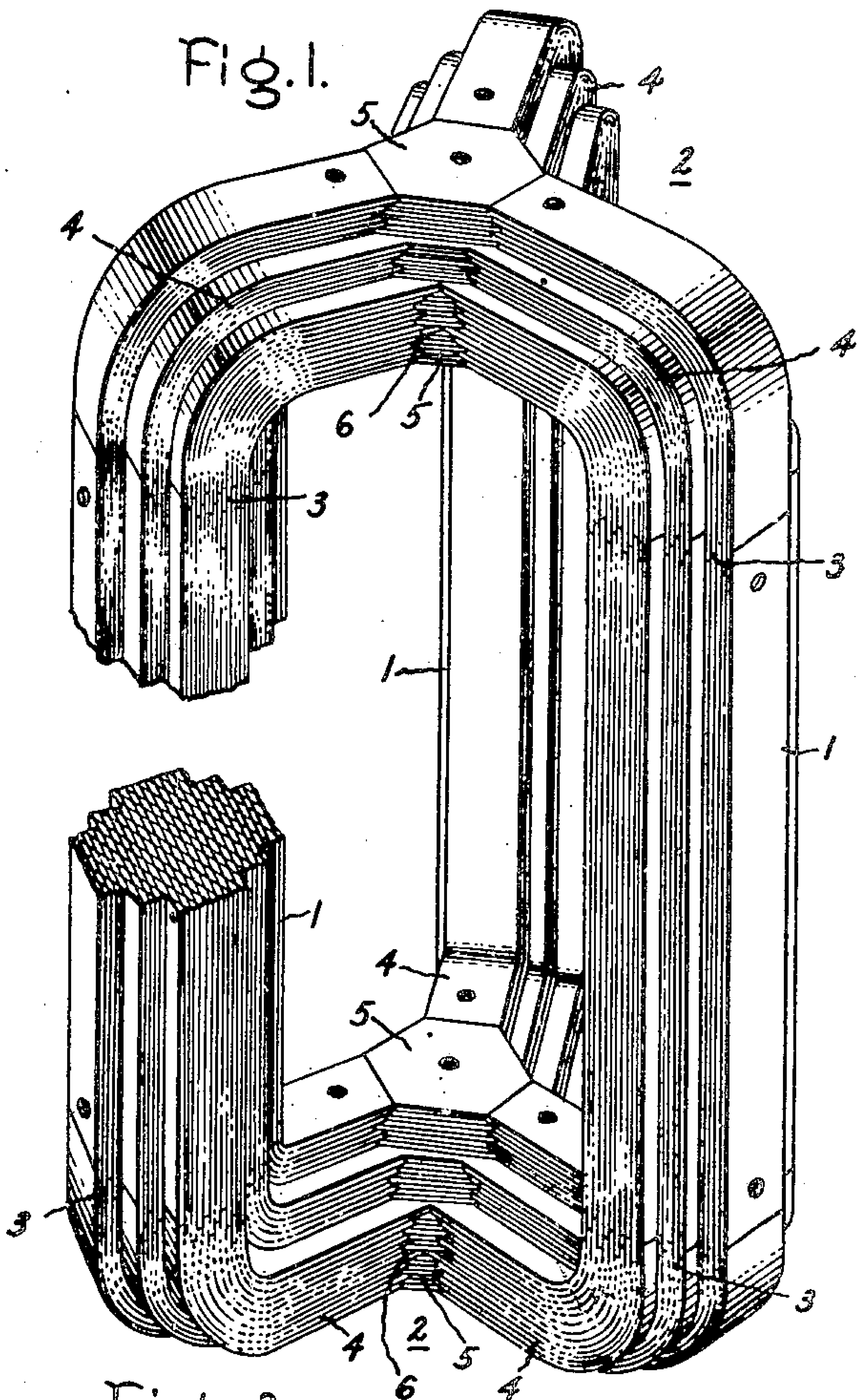


Fig. 2.

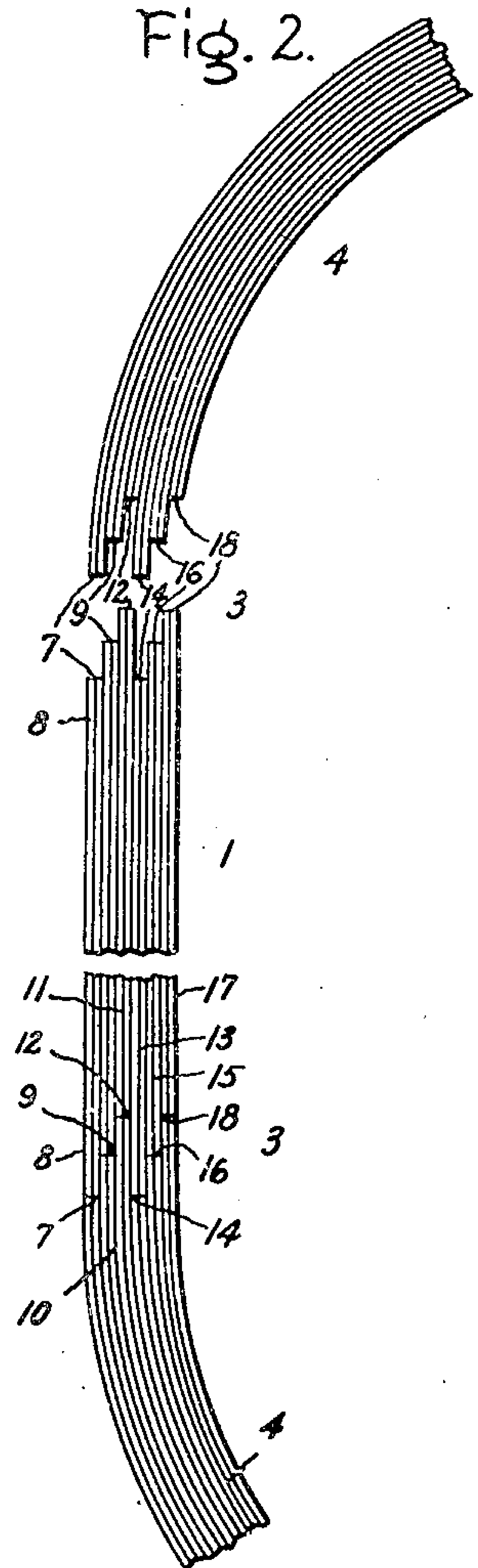


Fig. 3.

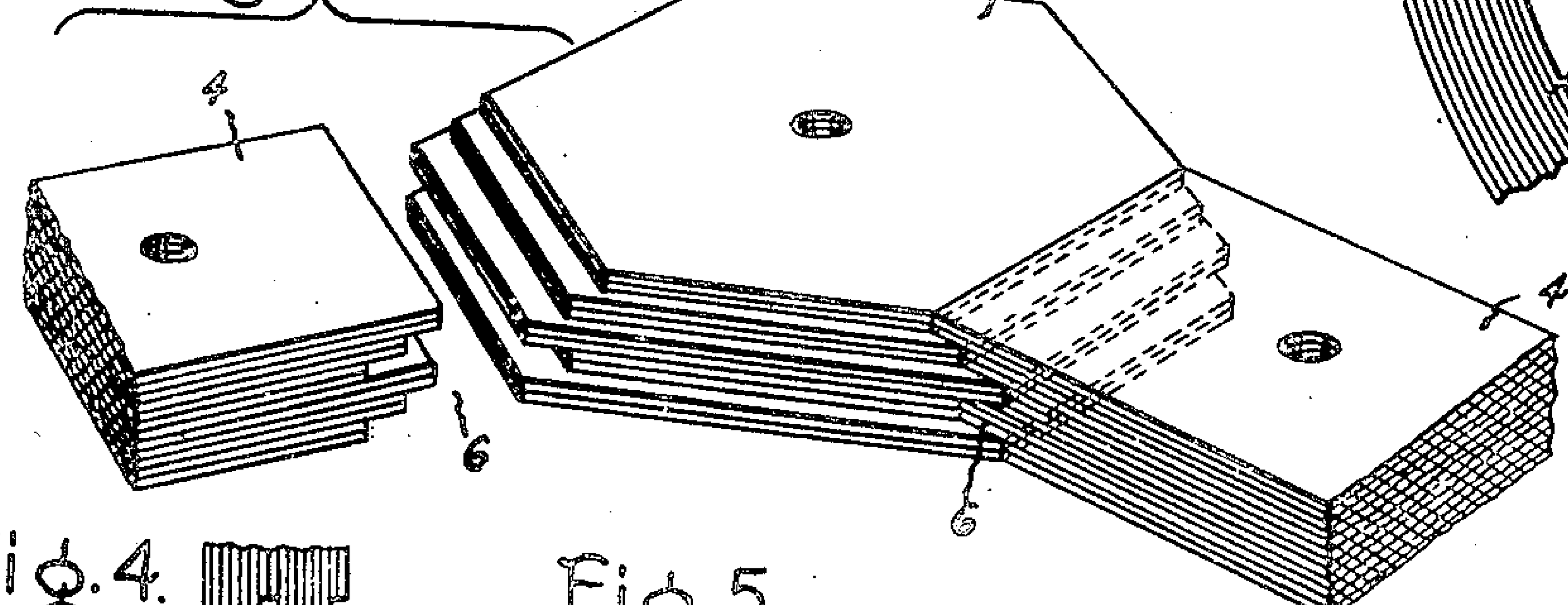


Fig. 4.

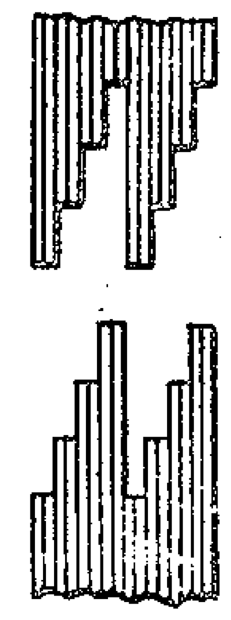
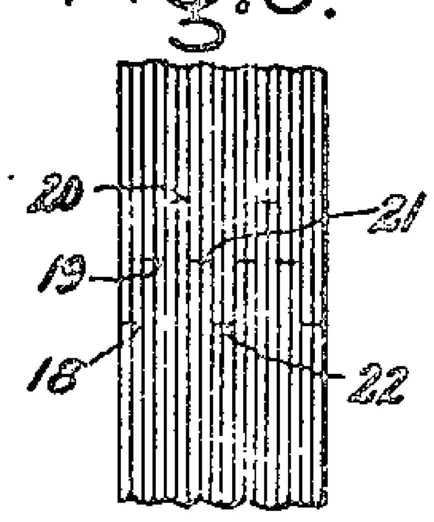


Fig. 5.



Inventor:
Gareth G. Somerville,
by Ernest C. Britton
His Attorney.

Oct. 25, 1949. G. G. SOMERVILLE 2,486,220

MAGNETIC CORE

Filed Oct. 18, 1947 3 Sheets-Sheet 2

Fig. 6.

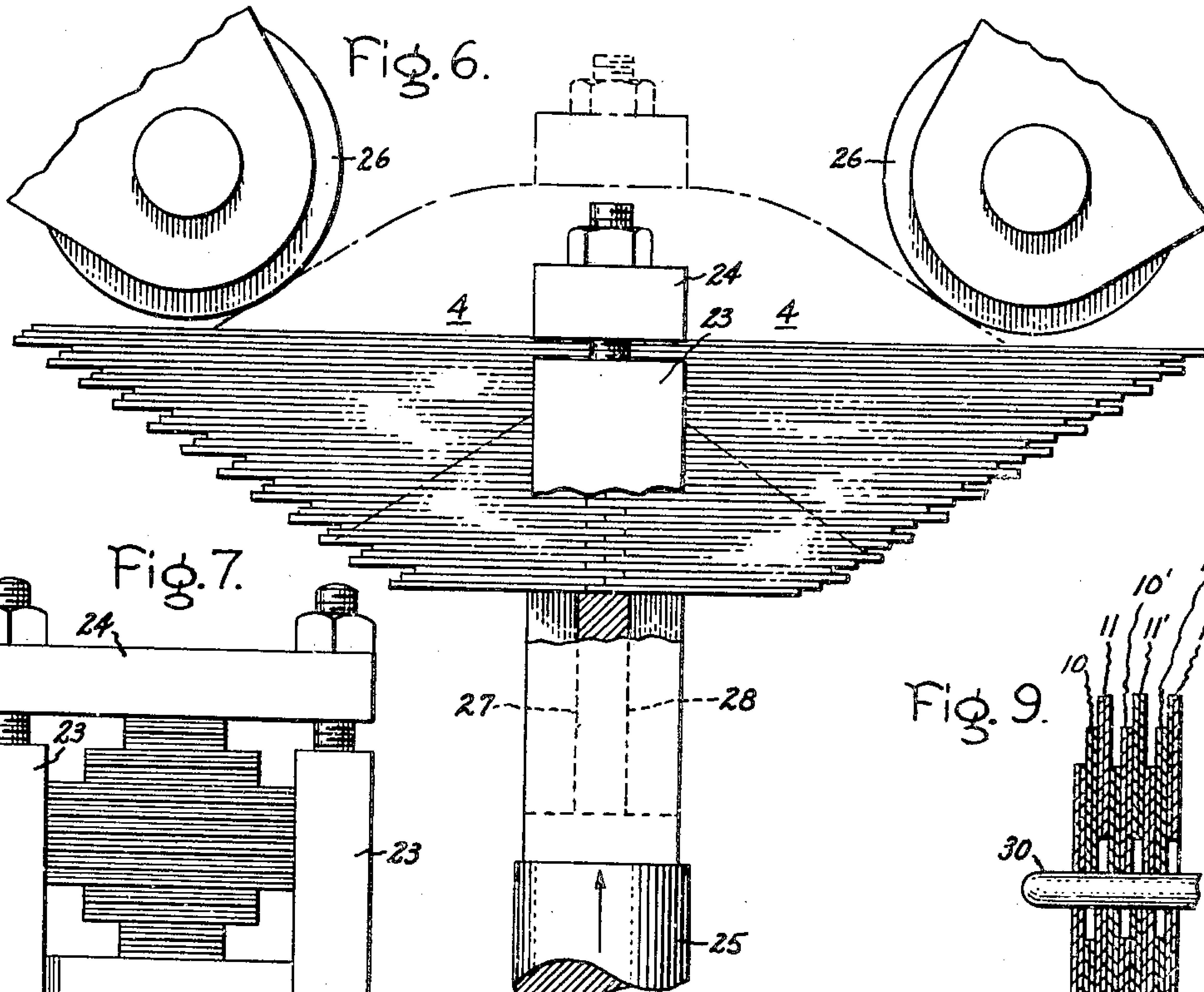


Fig. 7.

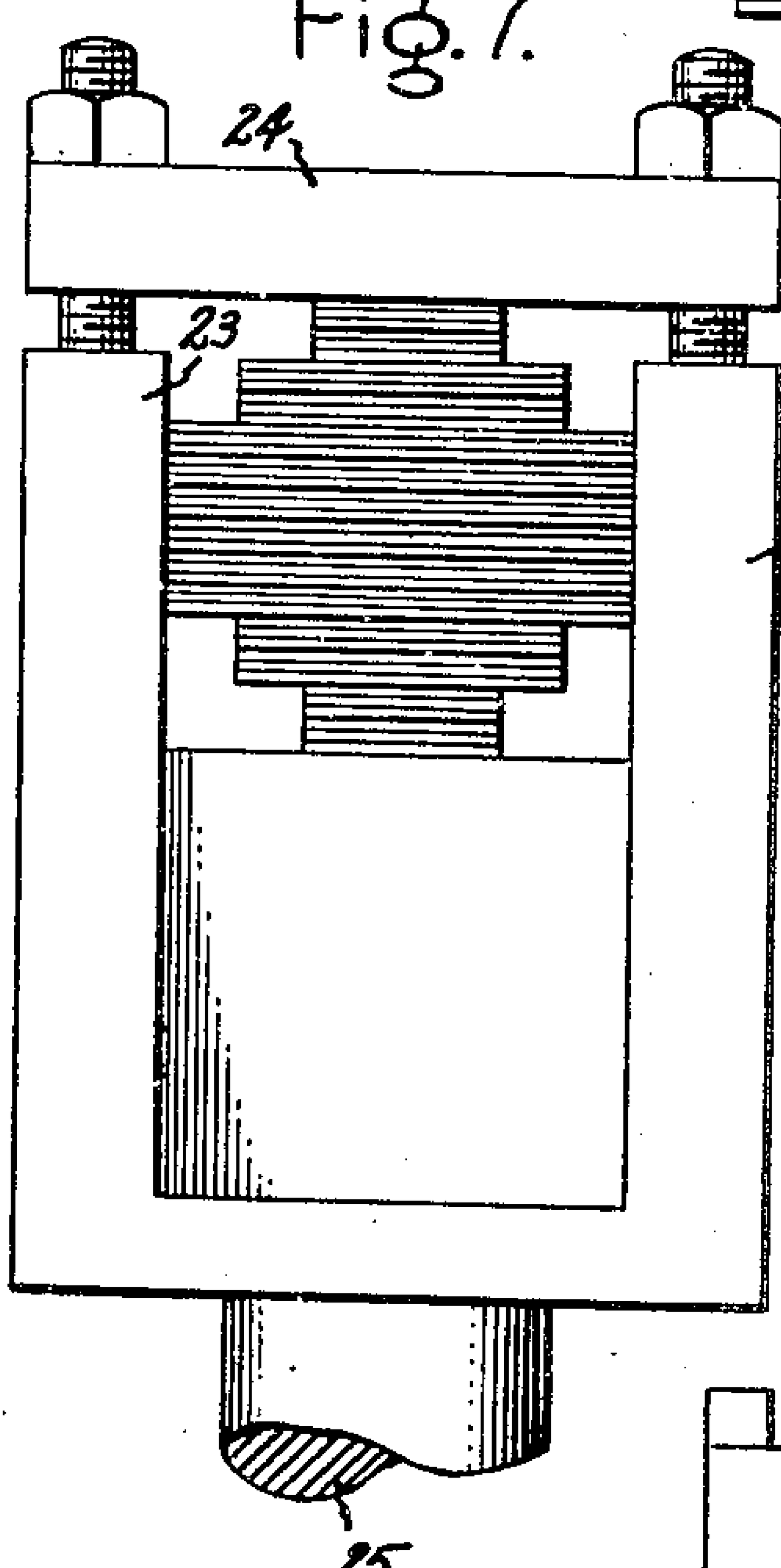


Fig. 8.

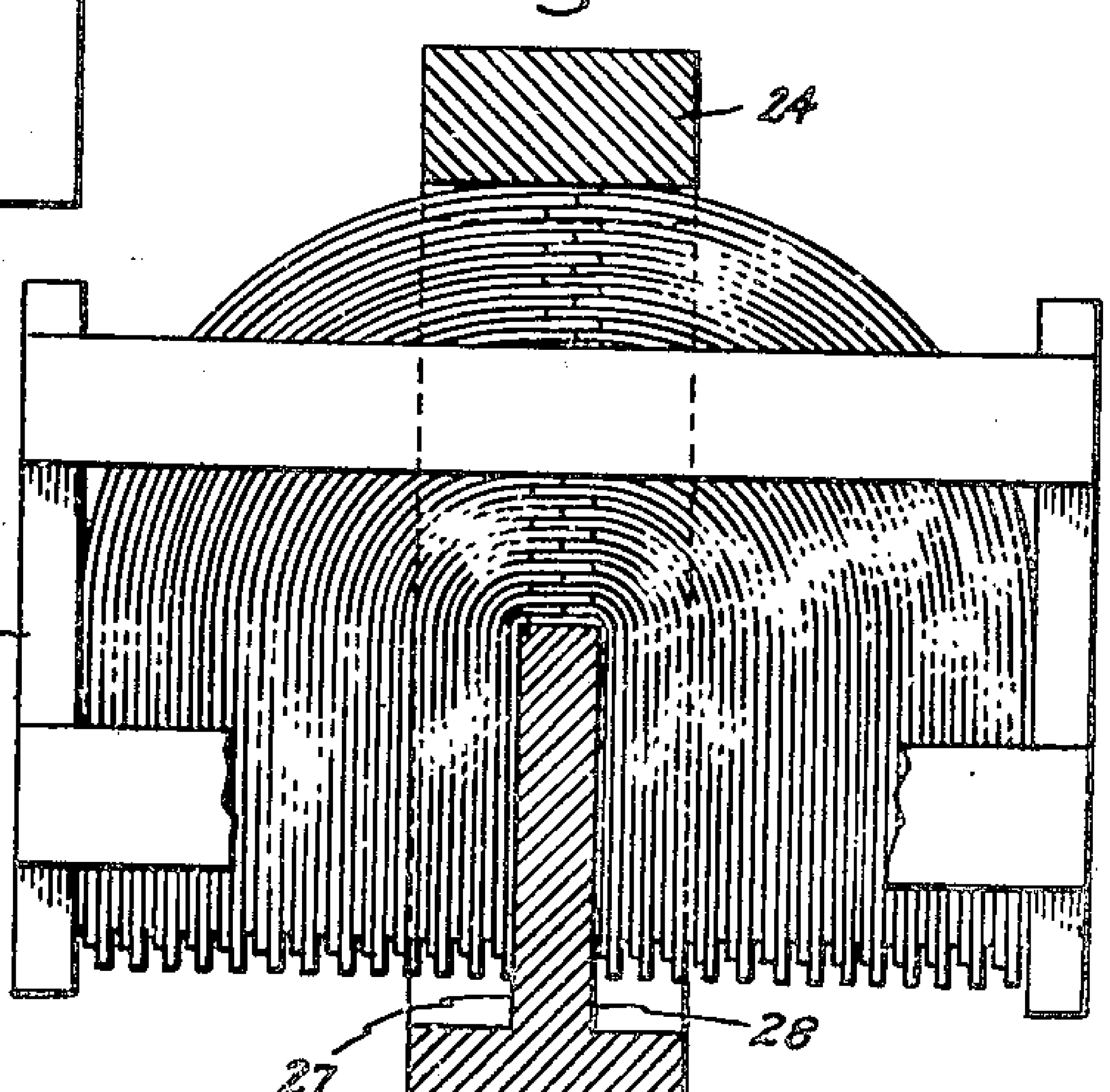
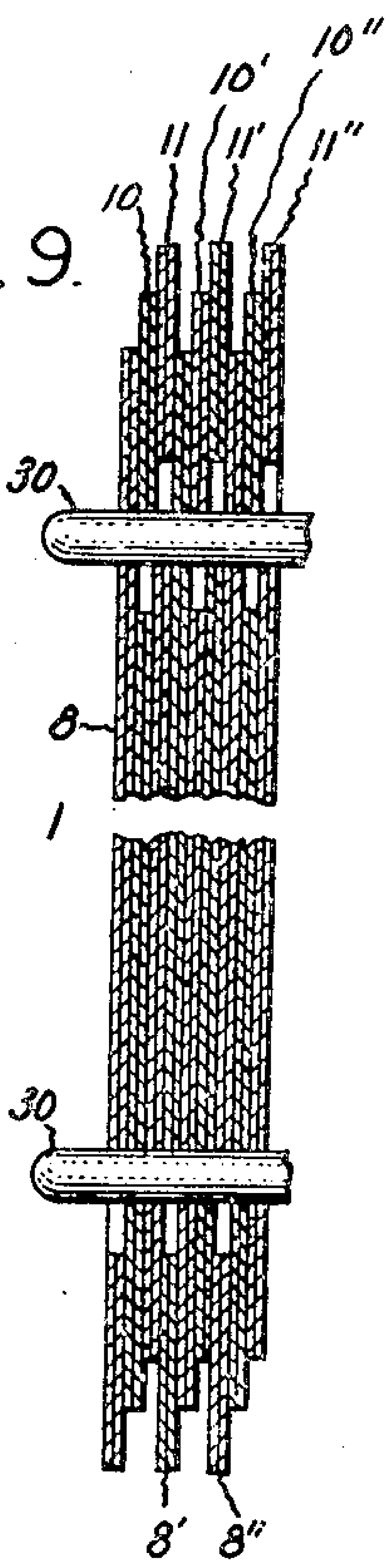


Fig. 9.



Inventor:
Gareth G. Somerville,
by Ernest C. Britton
His Attorney.

Fig. 10.

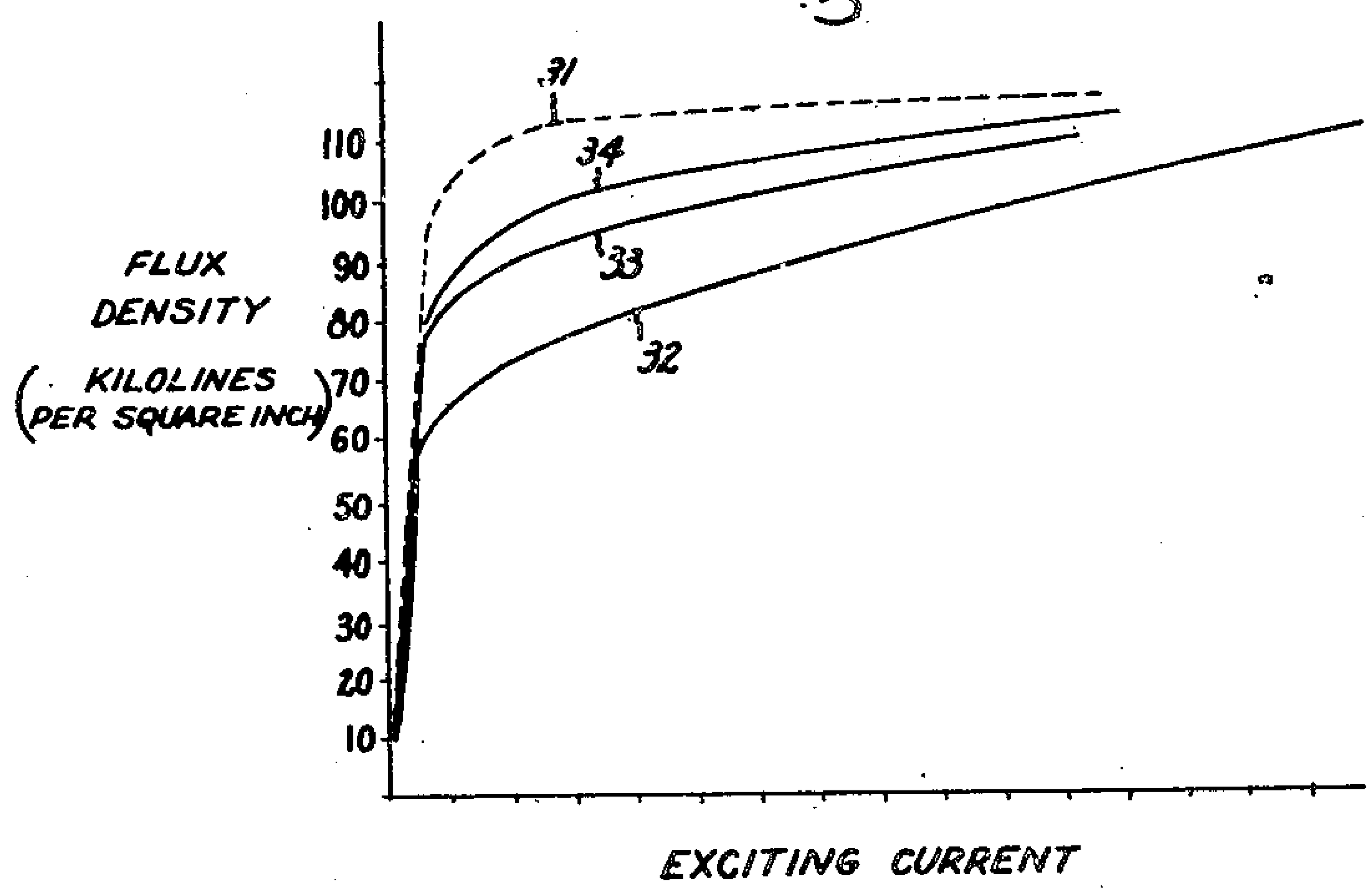


Fig. 12.

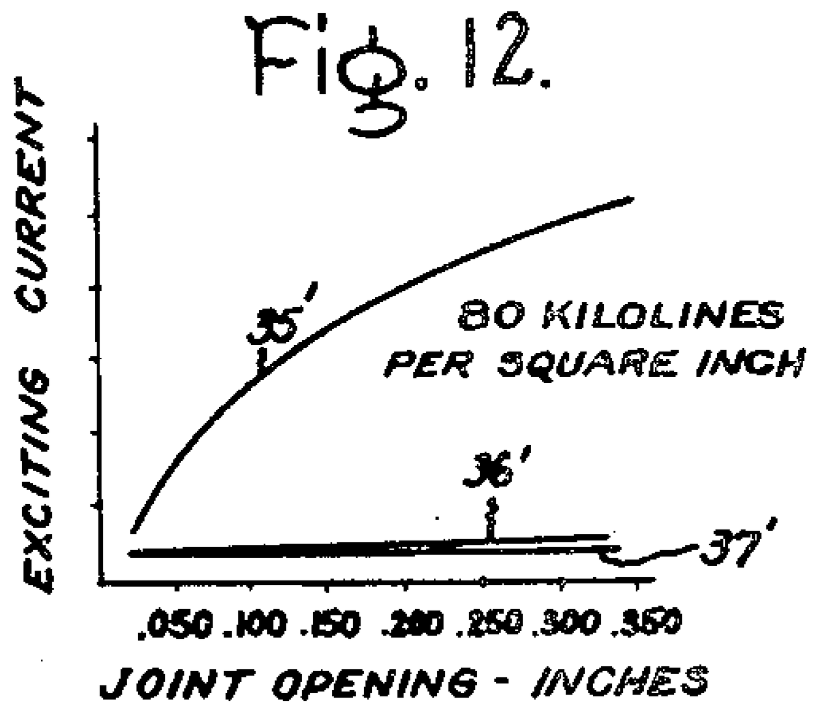


Fig. 11.

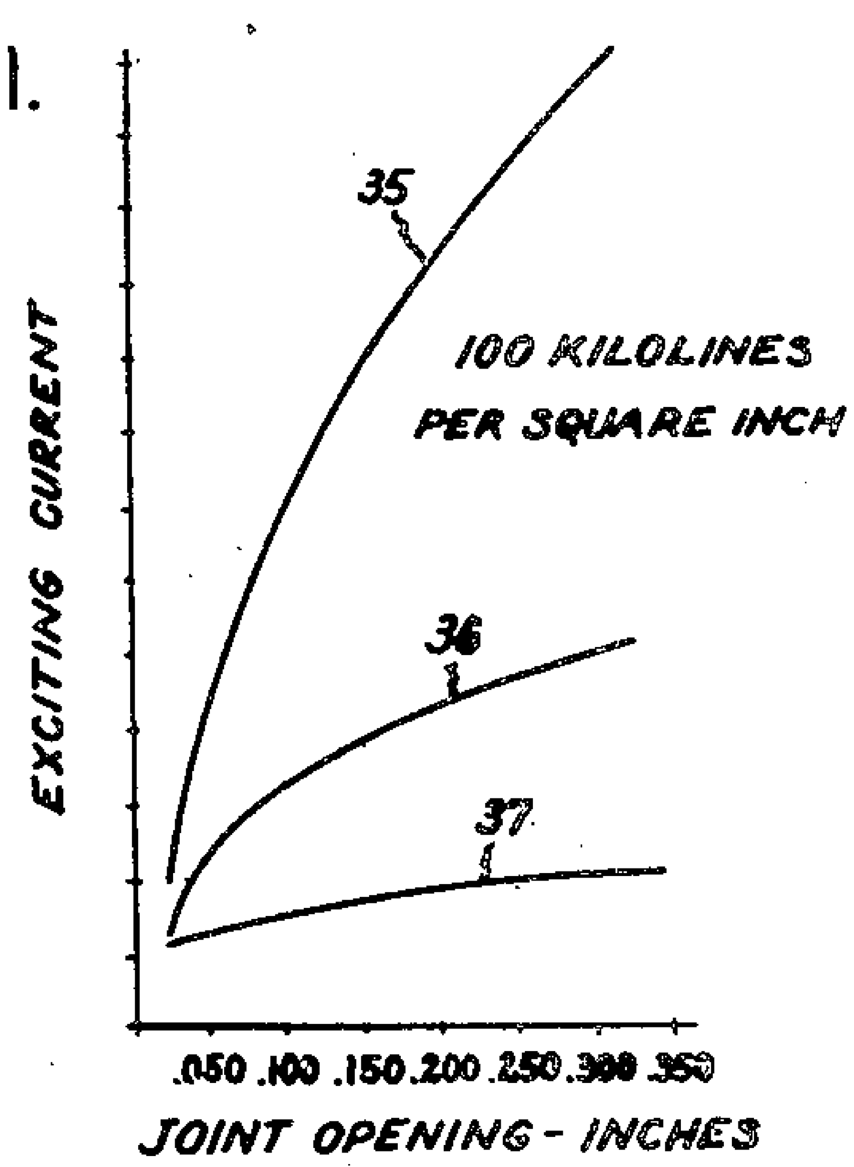
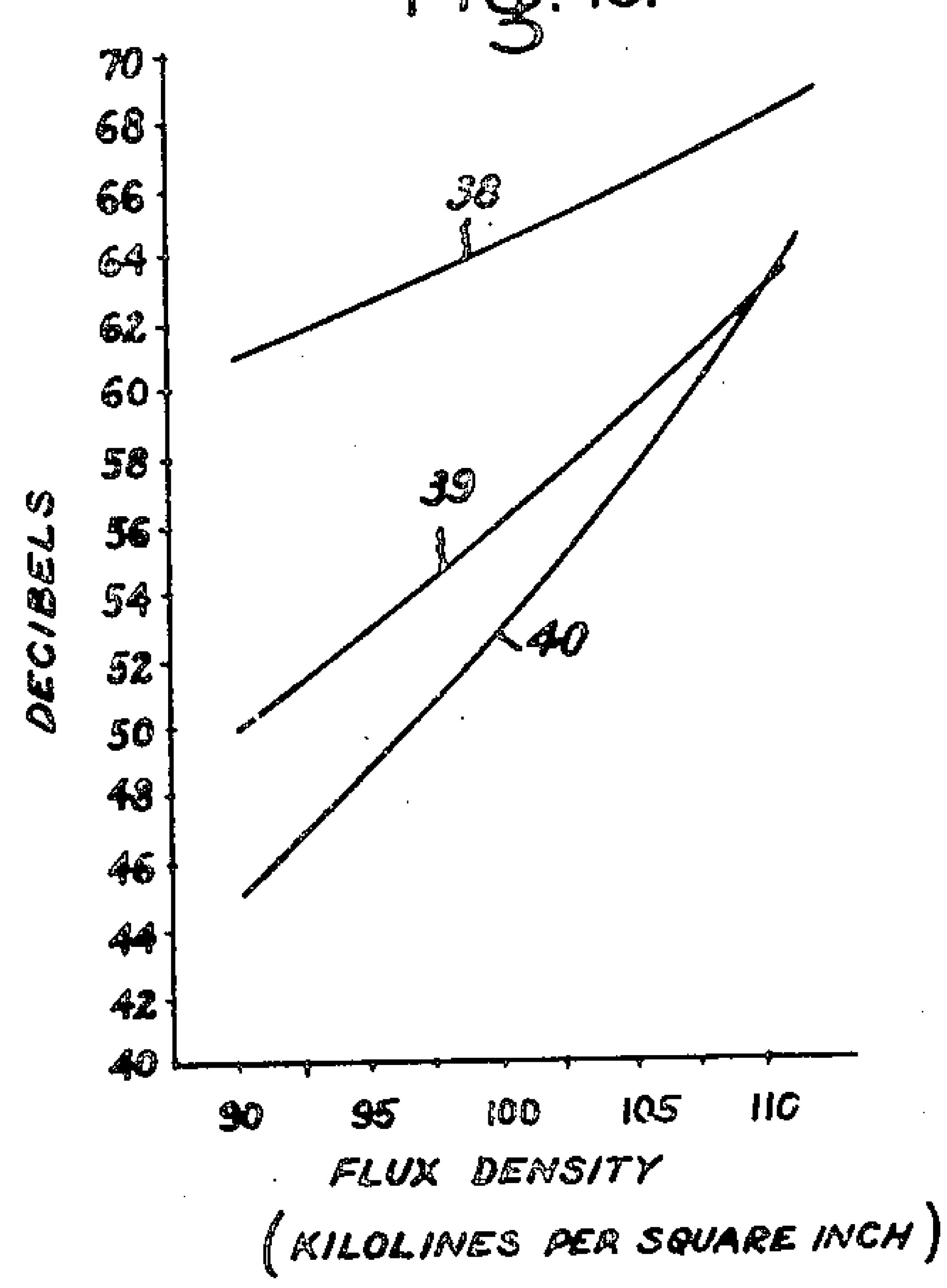


Fig. 13.



Inventor:
Gareth G Somerville,
by Ernest C. Britton
His Attorney.

Patented Oct. 25, 1949

2,486,220

UNITED STATES PATENT OFFICE

2,486,220

MAGNETIC CORE

Gareth G. Somerville, Pittsfield, Mass., assignor to General Electric Company, a corporation of New York

Application October 18, 1947, Serial No. 780,705

7 Claims. (Cl. 175—356)

1

This invention relates to magnetic cores and more particularly to improvements in lap joints for laminated magnetic cores.

It is usually necessary to have one or more joints in closed laminated magnetic cores. In the case of cores which are made by stacking straight flat punchings against each other, joints are necessary at the corners of the core. In the case of bent lamination cores, of either the wound or precut-preformed variety, which are usually characterized by one or more straight winding legs and rounded corners, at least one core joint is desirable in order that standard preformed coils or windings can be fitted onto the winding leg. By the term, "core joint," it is meant that all the individual lamination joints making up the core joint lie close to the same transverse plane through the core, as distinguished from a jointless core in which the joints in the individual lamination layers are distributed widely throughthe length and breadth of the core. A core joint is ordinarily characterized by being openable and closable and it has a relatively short lengthwise extension compared to the length of the core's magnetic circuit, whereas cores having the individual laminations provided with widely separated joints are not openable or separable in any practical sense.

Core joints may be classified as butt joints and lap joints. In butt joints, the ends or sides or both of the laminations forming the joint all lie in the same surface, which is usually a plane. In lap joints, the individual joints in adjacent lamination layers are overlapped, usually in a regular pattern. Each lamination layer is one or more laminations thick. The overlap pattern may either be recurring (i. e. repetitive or cyclic) or nonrecurring. Heretofore, the recurring pattern has been characterized by what may be called "reversibility" i. e. for every overlap or series of overlaps in one direction there is an equal and opposite overlap or series of overlaps in the opposite direction in successive lamination layers. An example of this is the standared so-called two-way overlap core joint in which all the joints in the even numbered lamination layers are in one plane which is offset a given distance from another parallel plane in which lie all the joints in the odd numbered lamination layers. Such reversibly recurring lap pattern core joints, while characterized by good mechanical strength and relatively short length, have rather high reluctance unless quite carefully made and very closely fitted together.

On the other hand, the nonrecurring lap pat-

2

tern core joint has poor mechanical strength, and in cores having a relatively large number of lamination layers, such a joint extends along such a large part of the core length that it is impractical and there is not adequate space for it on the core. This is because the overlap between joints in adjacent lamination layers must ordinarily be of the order of three-quarters of an inch, and in power transformers having hundreds of lamination layers, the total length of a nonrecurring pattern lap joint will be several feet.

In accordance with this invention, there is provided what may be called an irreversibly asymmetrically recurring lap pattern core joint. Such a joint is further characterized by having a three, four, or more way lap. It has remarkably low reluctance even at relatively wide separation or opening and it has good mechanical strength. The very much improved magnetic properties of the irreversibly recurring pattern lap joint make it practical greatly to increase the number of joints in a given magnetic circuit so that hitherto impractical forms of cores are now practical. Other advantages of the improved core joint are that it is relatively easy to put together and it is relatively quiet in operation.

An object of the invention is to provide a new and improved magnetic core.

Another object of the invention is to provide a new and improved joint for a laminated magnetic core.

An added object of the invention is to reduce the reluctance of lap joints of magnetic cores.

A further object of the invention is to provide a core joint whose reluctance is relatively independent of its degree of opening within wide limits.

The invention will be better understood from the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings, Fig. 1 is a perspective view, partly broken away, of a precut-preformed Y yoke three-phase core embodying the invention; Fig. 2 is a detailed view showing in enlarged form certain of the joints of the core shown in Fig. 1; Fig. 3 is an enlarged detail view showing the joint construction at the center of the yoke part of the core shown in Fig. 1; Fig. 4 shows a modified four-way lap joint; Fig 5 shows the wrong way to assemble the laminations so as to provide a reversibly or symmetrically recurring pattern lap joint; Fig. 6 is a front view of a suitable jig for forming the bent yoke cap portions of the core shown in Fig. 1; Fig. 7 is a side view of the structure shown in fig. 6; Fig 8 shows, partly in section, how the jig of Fig. 6 forms simultaneously two of the yoke cap members; Fig. 9 is a sectional view showing how the straight leg laminations may be perforated and assembled so as to provide the three-way lap joint shown in Figs. 1 and 2; Fig. 10 is a set of magnetization curves for comparing the magnetic properties of my improved joint with the magnetic properties of the core steel itself and with a standard three-quarter inch two-way lap joint core; Fig. 11 is a set of curves illustrating the relationship between exciting current and joint opening at a flux density of 100 kilolines per square inch for my improved joint and a standard two way lap joint; Fig. 12 is similar to Fig. 11 except that the flux density is 80 kilolines per square inch and Fig. 13 is a set of curves which compares the noise made by similar cores having different joints.

Referring now to the drawings, and more particularly to Fig. 1, the core may consist of three identical straight winding legs 1 whose corresponding ends are joined together by Y-shaped yokes which are indicated generally by 2. As shown most clearly by the section of the cut-away portion of the left-hand winding leg, the core is of so-called cruciform cross section and it consists of steps of different width laminations. The ends of the legs 1 are connected to the yokes 2 by novel joints 3. The yokes 2 in turn may each consist of identical curved core members 4 and central connector or insert members 5. The joints between the members 4 and 5 are also of the same pattern or configuration as the joints 3 between the legs 1 and the curved members 4. These joints are indicated at 6.

In Fig. 2, some of the laminations of a leg 1 and of two curved members 4 are shown edgewise and enlarged. The upper joint 3 is shown entirely open and the lower joint 3 is shown tightly closed. It will also be seen that each lamination layer consists of two lamination pieces. In practice, it is usual to have several laminations in each lamination layer so as to facilitate handling of the parts as the layers become more rigid and easier to handle when they are built up of two, three, or four lamination members.

Considering the joints 3 which are shown in Fig. 2, it will be seen that there is a joint 7 in the outer layer 8 which is offset in a given direction from a joint 9 in the second layer 10. In the third layer 11, there is a joint 12 which is offset from the joint 9 in the same direction and by the same amount as was the case with respect to the joints 7 and 9. In the next layer 13, there is a joint 14 which instead of being overlapped by the same amount as heretofore is overlapped all the way back to the same transverse location or plane as the joint 7. In the next layer 15, there is a joint 16 which corresponds with the joint 9 in layer 10, and in the last layer 17, there is a joint 18 which corresponds in lengthwise location with the joint 12. The joints 7, 9, and 12 thus form a pattern which pattern is repeated in the joints 14, 16, and 18, but this repetition or recurrence is asymmetrical and not reversible because the step or overlap between adjacent joints 12 and 14 is the full width of the core joint instead of being merely the amount of overlap between the adjacent joints in the pattern 7—9—12 or 14—16—18. This will be explained more fully in connection with Fig. 5 in which the lamination layers are improperly assembled to form a symmetrically reversible pattern lap joint.

One of the things to notice about the joints 3 in Fig. 2 is that although there are six lamination layers shown, the ends of these lamination layers do not all come together at the same time when the joints close. This is clearly shown by the open upper joint in Fig. 2 in which the ends of the lamination layers of the curved member 4 which form the layer joints 7 and 14 have a relatively wide space which in fact is equal to twice their width or that of four lamination layers, in which to adjust themselves transversely as the core joint closes. This is in marked contrast with an ordinary two-way reversible lap pattern joint in which all of the long ends of the lamination layers must come into contact with each other at the same time when the joint is closed.

Another and very important feature of the joint can be seen most clearly in connection with the closed lower joint 3 shown in Fig. 2, that is, that only one-third of the cross section of the core consists of layer butt joints or gaps in any plane and the other two-thirds of the core in that plane is continuous magnetic material. For example, consider the plane containing the layer joints or gaps 7 and 14. Those joints or gaps are in two of the six lamination layers so that in that plane the other four lamination layers are uninterruptedly available for carrying the core flux. The same thing is also true for the plane containing the joints or gaps 9 and 16 and for the plane containing the joints or gaps 12 and 18. Thus, the core is magnetically symmetrical so far as these three planes are concerned, and the magnetic properties of the core are the same in each plane.

The specific reluctance of each of the layer joints or gaps is, of course, higher than the specific reluctance of the iron or steel itself, so that what is believed to happen is that at each layer joint or gap the flux tends to crowd into the adjacent layer or layers, thus increasing their flux density. When it is realized that modern electric induction apparatus operates with its magnetic cores very little below the knee of the saturation curve, it will be seen that not much crowding can take place without raising the flux density in the crowded parts of the core to above the knee of the saturation curve, thus producing local saturation with the result that there is a very marked increase in reluctance and hence in exciting current required to produce the total flux, the value of which is fixed by the voltage of the apparatus.

Fig. 3 illustrates the details of the joints 6 between the center insert members 5 and the curved yoke member 4. The joints 6 between these members are essentially the same as the joints 3. The lamination pieces which make up the leg 1 and the curved yoke members 4 are preferably made of material such as a high reduction cold rolled silicon strip steel which has a highly favorable magnetic direction which coincides with the direction of rolling and which coincides with the direction of normal flux travel in the lamination pieces. As the flux does not always travel in the same direction in the center insert pieces 5, there is not much, if any advantage in using the same kind of material for these inserts. However, if directional material is used it is desirable to rotate successive pieces 5 120°, so that for each of the different directions of flux travel, some of the pieces will have their most favorable magnetic direction in line with the flux.

The three-phase Y yoke core shown in Fig. 1 is a species of the core which forms part of the subject matter of an application Serial No. 722,843, filed January 18, 1947, now Patent No. 2,456,461, issued December 14, 1948, in the name of Cecil G. Dunn, and assigned to the present assignee. Also the generic idea of a core having lap joints between straight stacked winding legs and flatwise curved yoke members is described and claimed in application Serial No. 645,650, filed February 2, 1946, in the name of Ivanhoe H. Sclater, and assigned to the present assignee.

Fig. 4 illustrates a modification of the joint illustrated in the previous figures, and it may be described as a four-way lap joint in contradistinction to the three-way lap joint shown in the previous figures. In the four-way lap joint, there are four spaced planes through the core, each of which contains a number of lamination layer joints or gaps, the number being one-fourth of the total number of lamination layers. In other words, in each plane through the core which contains layer joints or gaps, there is three-quarters of the total cross-sectional core area of metal which is available for carrying the total flux. The four-way lap joint has still better magnetic properties than the three-way joint. However, it has been found that for each increase in the number of steps the corresponding improvement in magnetic properties gets less and less so that the diminishing returns will ordinarily make it uneconomical to increase the number of steps or "ways" substantially above four.

In Fig. 5, there is illustrated a reversibly recurring three-step or three-way lap joint pattern. Thus, individual layer joints or gaps 18, 19, and 20 progress as do joints 7, 9, and 12 in Fig. 2. However, the joint 21 in the next layer overlaps only by the amount of overlap between adjacent joints 18, 19, and 20, so that it is in the same plane with joint 19. Similarly, the next joint 22 is in the same plane with joint 18. Thus the pattern of joints 20, 21, and 22 is just the reverse of the pattern of joints 18, 19, and 20, and these patterns are symmetrically reversibly repeated throughout the thickness of the core. The result is a very uneven distribution of the number of layer joints or gaps in the three different transverse planes through the core which contains these joints. Thus, in the plane containing the joint or gap 20 there are only two joints or gaps, although there are nine layers, whereas in the plane containing the joint 19 there are four joints, while in the plane containing the joint 18 there are three joints. Consequently, the average flux density will be quite different in the iron in these three different planes, it being by far the highest in the middle plane containing the joint or gap 19, because substantially half the area is layer joints and substantially only the other half is magnetic material which is available for carrying the total flux.

Fig. 6 illustrates one way of forming the curved yoke members 4, two at a time. As shown, the individual lamination pieces, which preferably have been automatically precut to the proper length, are stacked in the proper order in a jig which by means of side arms 23 and a clamping bar 24 are held firmly in place with one joint assembled at the center. Fig. 7 shows a side view of the jig with the cruciform cross section core parts clamped in place. The entire jig is carried by a vertically movable rod 25 and a pair of fixed forming rollers 26 are mounted above the assembly of laminations and are laterally spaced from the side surfaces 27 and 28 of the jig by the thickness of the assembled stack of laminations. Consequently, as the rod is moved upward, the ends of the clamped laminations are bent downwardly into the position shown in Fig. 8. A suitable clamp 29 may then be applied to hold the bent laminations in this position, after which the assembly can be removed from the jig and annealed in the usual way. By properly predetermining the lengths of the individual lamination layers, their ends will all form the desired patterns as shown in Fig. 8.

The core legs 1 may be assembled readily by means of a pair of properly spaced pins 30 in combination with suitably spaced perforations in the laminations. Layer 8, which is the same as every fourth layer, such as the layers 8′ and 8″, may be provided with a round hole near one end and a slot near the other end, the hole fitting over the upper pin 30 and the slot fitting over the lower pin 30. The layers 11, 11′, and 11″ are all also the same as each other and, furthermore, they may be exactly the same as the layers 8, 8′ and 8″ except that they are reversed lengthwise so that their round holes fit over the lower pin 30 and their slots fit over the upper pin 30. The intermediate layers 10, 10′ and 10″ are also all alike but they are different from the other layers in that their perforations and particularly the location of the holes to fit snugly over one pin are positioned so as to bring the ends of these intermediate layers 10, 10′ and 10″ into the proper relation to the other layers.

In Fig. 10, the dashed curve 31 is the magnetization curve of the magnetic material from which the core shown in Fig. 1 is made. That is to say, it represents an ideal jointless core made of the same magnetic material. Curve 32 is a curve of the same size core having two standard three-quarter inch two-way lap joints. As will be seen, the exciting current increases very rapidly when the flux density exceeds 60 kilolines per square inch. Curve 33 is for a similar core having two three-way lap joints of the type illustrated in Fig. 2, for example. It will be seen that in this case, the flux density can be carried up to 80 kilolines per square inch before manifestations of saturation appear and the exciting current begins to increase rapidly. Curve 34 is for a similar core but having two four-way lap joints of the type shown in Fig. 4. Here the flux density can be carried up to 90 kilolines before saturation begins Presumably increasing the number of ways or laps will produce a family of curves in between curves 31 and 34.

The data for curves 32, 33, and 34 was obtained from rectangular cores having two winding legs and two curved yokes, the thickness of the core being three inches, its width being four inches, and the dimensions of the central window being 6 inches by thirty-two inches. They contained approximately 267½ pounds of SX10 steel. The joints had an opening of .050 inch. By that it is meant that there was that much gap or opening or separation between the adjacent ends of the laminations in each layer. This is about as far as lap joints can be closed without taking very special care in making the joint and without applying excessive pressure to close it.

In Fig. 11, the curves 35, 36, and 37 show the relation between exciting current and joint opening in inches for the same three cores having respectively the standard reversible pattern two-way overlap and the three and four-way irreversible overlap shown in Figs. 2 and 4. In curve **35** the exciting current goes up very rapidly and practically doubles for each twentieth of an inch of opening. Curve **36** for the three-way lap joint shows that exciting current is no higher with an opening of one-quarter inch (.250) than is the exciting current for the standard core when it is open only .050 inch. Curve **37** for the four-way overlap shows a still further reduction in sensitivity of exciting current to joint opening. All the curves in Fig. 11 were taken at a flux density of 100 kilolines per square inch.

In Fig. 12, curves **35'**, **36'**, and **37'** correspond to curves **35**, **36**, and **37**, except that the flux density is 80 kilolines per square inch. Here it will be seen that there is a marked difference between the standard two-way lap joint on the one hand and the three and four-way lap joints on the other hand. There is practically no difference between the latter two and, furthermore, the exciting current is practically the same for the latter two at an opening of .25 inch as it is when the joint is practically fully closed.

It has also been found that cores which are provided with this novel joint are substantially quieter than similar cores which are provided with the same number of conventional joints such as two-way lap joints. The results of noise tests are shown in Fig. 13, in which curve **38** shows the relationship between core noise in decibels and core flux density for a given size core having two standard two-way lap joints. Curve **39** shows the decibel flux-density characteristic of the same size core which is provided with a four-way lap joint of the type shown in Fig. 4 and it will be seen that the noise which is produced at corresponding flux densities is substantially lower in the case of this joint. Curve **40** is for the same size core which has the joints in the individual lamination layers distributed at random throughout the entire core so that, in effect, the core has no joint. It will be seen from a comparison of curves **39** and **40** that the four-way lap joint is almost as quiet as no joint at all.

While there have been shown and described particular embodiments of the invention, it will be obvious to those skilled in the art that changes and modifications can be made without departing from the invention and, therefore, it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

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

1. In a laminated magnetic core, a closed loop comprising at least six radially nested flatwise curved lamination layers of magnetic strip material, each of said layers having at least two closely adjacent ends of said strip material which between them form a high specific reluctance section, said high reluctance sections collectively comprising a lap joint extending entirely across the core perpendicular to the plane of the laminations and extending along the length of the core parallel with the plane of laminations for a distance which is a small fraction of the total length of the magnetic circuit of the core, said lap joint being characterized by a three step pattern which is irreversibly repeated, the corresponding steps in each three step pattern beginning in the same plane perpendicular to the plane of laminations.

2. In a laminated magnetic core, a closed loop

comprising at least twelve radially nested flatwise curved lamination layers of magnetic strip material, each of said layers having at least two closely adjacent ends of said strip material which between them form a gap, said gaps in successive layers being offset in a pattern which irreversibly repeats at least every fourth layer, the length of the offsets being greater than the separation of the gaps, the repetitive pattern forming at least three groups of longitudinally separated gaps, which groups lie respectively in different planes which are perpendicular to the surface of the layers.

3. The core recited in claim 1 in which there are at least two superposed laminations in each layer.

4. The core recited in claim 2 in which the lengthwise separations of the two outermost of said planes is short in comparison with the radial thickness of said core.

5. In a magnetic core having a plurality of lamination layers, a joint whose length is short in comparison with the thickness of said core, said joint comprising a separated butt joint between the ends of lamination pieces in each lamination layer, said butt joints being staggered in an asymmetrically recurring pattern which includes at least three successive lamination layers so that in a perpendicular plane through any group of transversely aligned separated butt joints at least two-thirds of the cross sectional area of the core will be magnetic material.

6. In combination, a closed magnetic core including a plurality of radially nested, flatwise curved layers of magnetic material, a separable and closable joint in said core, said joint including a gap in each layer, all of said gaps being parallel with each other said gaps in successive layers being offset lengthwise by greater distances than the gap lengths, the offsetting being in a regular pattern which irreversibly repeats at least every fourth layer and at most every sixth layer, said pattern being characterized by arranging all of said gaps into at least three substantially equal numbered groups of gaps, the gaps in each group being aligned in a plane substantially perpendicular to the surface of the layers, the transverse separation between adjacent gaps in each group being equal, the lengthwise separation of said planes being substantially uniform whereby at least two-thirds of the core cross sectional area in each of said planes is magnetic material.

7. The combination recited in claim 5 in which there are at least two superposed laminations in each layer.

GARETH G. SOMERVILLE.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,154,866	Lunnon et al.	Sept. 28, 1915
2,290,680	Franz	July 21, 1942
2,305,650	Vienneau	Dec. 22, 1942
2,456,458	Somerville	Dec. 14, 1948

FOREIGN PATENTS

Number	Country	Date
106,986	Great Britain	June 14, 1917