Nov. 19, 1946. C. C. HORSTMAN 2,411,374

MAGNETIC CORE STRUCTURE FOR THREE PHASE TRANSFORMERS

Filed Jan. 7, 1943

Fig. 1.

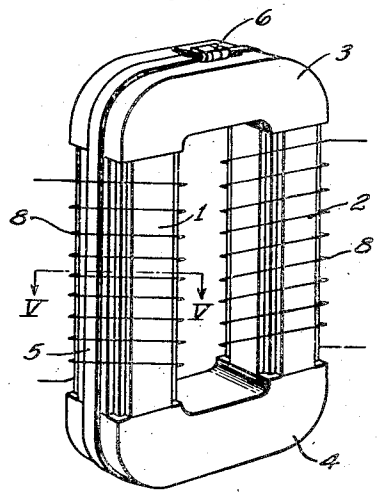


Fig. 2.

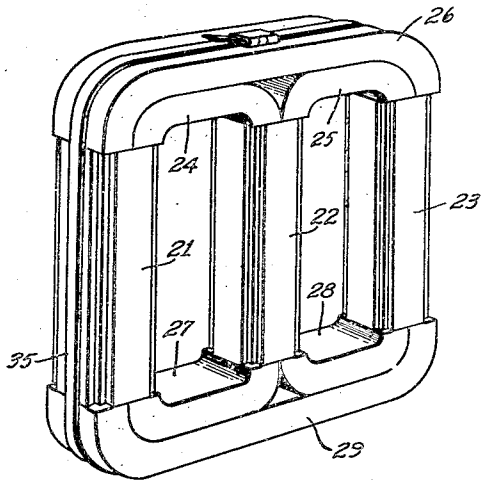


Fig. 3.

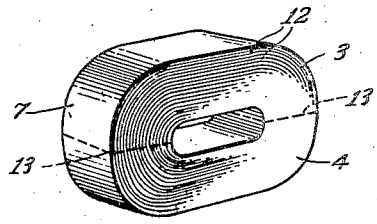


Fig. 4.

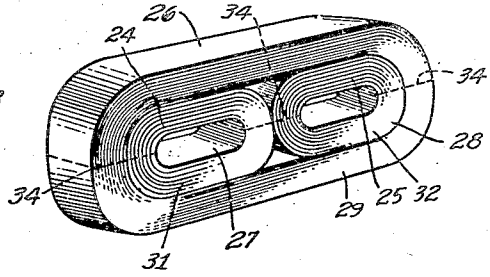
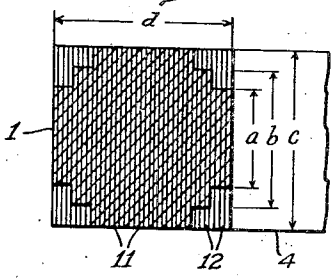


Fig. 5.



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MAGNETIC CORE STRUCTURE FOR THREE-PHASE TRANSFORMERS

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8 Claims. (Cl. 175—356)

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My invention relates to electrical induction apparatus such as transformers, and particularly to the core or magnetic circuit structure thereof and the method of making the same.

Recent developments in the manufacture of electric steel have produced steel having a preferred orientation of the grains in the direction of rolling. By properly cold rolling and annealing silicon steel, the crystals of the steel can be oriented in such manner that substantially all the crystals present a tube edge parallel to the direction of rolling. When the lines of magnetic flux pass through the steel in the direction of rolling, the permeability of such steel is considerably higher at operating densities, say 13 to 18 kilogausses, than the permeability of commercial grades of hot rolled silicon steel at the same densities. Likewise, the watts lost per unit volume or unit weight at operating densities is lower than for commercial grades of hot rolled steel at the same density when magnetized in the direction of rolling. To properly take advantage of the properties of this improved steel, it is necessary that the steel be so used that the direction of magnetization of the steel coincide substantially with the grain of the steel, or direction of rolling, so that the lines of magnetic flux shall not pass through the steel at an appreciable angle from the direction of rolling.

There are many advantages in the manufacture of transformer structures in utilizing preformed current conducting coils for the windings among which are the application of high frequency testing and the inspection of the individual unassembled coils. These coils are wound on separate temporary transformers or mandrels and are then assembled together with a magnetic core structure of the transformer or other induction apparatus with required insulation and spacers.

It has been the usual practice in building core structures for use in distribution or power transformers to employ stacks of layers of thin sheets or laminations of magnetic material shaped as L plates. These L plates are stamped or punched from sheets of silicon steel, and it is necessary that a compromise in the direction of cutting be made which gives poorer magnetic qualities than when the lines of magnetic flux pass in the optimum direction. When a core structure is built up from L-shaped or I-shaped plates, the individual sheets are placed layer upon layer to form the core; those in the winding leg extending through the opening in the winding structure. The joints between the successive layers are

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formed by overlapping the ends of the sheets forming one core member with the ends of the sheets in an adjacent layer forming another core member to form the well known lapped joint. This type of core structure does not lend itself well to the use of the high permeability low watts loss steel which must be used in such manner that the flux passes through the sheets of steel in the direction of rolling.

Magnetic core structures having butt joints instead of the lapped joints have been characterized in general by high iron core losses and high excitation currents which prevent their successful operation at high magnetic flux densities such as are otherwise possible when the improved magnetic steels having preferred orientation are used. Recently ways and means have been discovered to provide low reluctance and low loss butt joints which will enable the building of core structures from stacks or bundles of laminations of predetermined shapes. Patent 2,293,951 issued to J. B. Seastone and myself on August 25, 1942, for induction apparatus and method of core construction therefor, and assigned to the same assignee as this application is directed to a magnetic core and method of making it in which low loss butt joints are employed.

It is an object of the present invention to provide magnetic core structures for electrical induction apparatus in which the leg and yoke portions of the core are separately formed and are so arranged that the lines of magnetic flux pass through all parts of the core in the direction of rolling of the steel sheets of which it is composed.

It is a further object of the invention to provide a magnetic core structure of the above indicated character in which the parts of the core are formed of groups of laminations bonded together as separate units and in which low loss butt joints are provided between the leg and yoke members of the core.

The invention accordingly is disclosed in the embodiments thereof shown in the accompanying drawing and comprises the features of construction, combination of elements, and arrangement of parts which will be exemplified in the constructions hereinafter set forth and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawing, in which:

Figure 1 is a diagrammatic perspective view of a single phase core type transformer having a core structure built in accordance with the teachings of the invention,

Fig. 2 is a diagrammatic perspective view of a three-phase transformer having a core structure built in accordance with the teachings of the invention,

Fig. 3 is a perspective view of a wound coil or loop of magnetic material employed to form the yoke portions of the core in Fig. 1,

Fig. 4 is a perspective view of a wound coil or loop assembly of magnetic material used to form the yoke portions of the core in Fig. 2, and

Fig. 5 is a cross sectional view taken along the line V—V of Fig. 1.

Referring to the drawing, Fig. 1 shows a core structure having two winding legs 1 and 2 which are similar in construction, are placed parallel to each other, and are joined at opposite ends by yoke members 3 and 4. The assembly of the two leg members and two yoke members are shown as held in place by a banding strap 5 and fastener 6 in a known manner, and the entire core assembly may be mounted in end frames for supporting it in place inside of a transformer tank in a well known manner. Windings 8 are shown diagrammatically about the leg members 1 and 2 of the core and would in practice consist of inductively related primary and secondary windings in accordance with well known transformer practice.

Each piece of the core structure is assembled with magnetizable laminations, as 11 in Fig. 5, and 12 in Fig. 3, electrically insulated from each other and solidly held together with intervening bonding layers of an adherent insulating bonding material between the laminations. This bonding material is preferably a chemically inert material such, for example, as one of the well known resinous products which may be applied to the surfaces of the laminations 11 and 12.

The core legs 1 and 2 may be made cruciform in cross section as shown in Figs. 1 and 5 with the laminations running in a plane from the front to the rear of the core structure as viewed in Fig. 1. Certain of the laminations adjacent two opposite sides of the leg have a width *a*, certain others a width *b*, and others the full width *c* of the leg which corresponds to the width of the laminations forming the yoke portions 3 and 4. The laminations or sheets of steel extend from the front to the back of the core in the direction of dimension lines *a*, *b* and *c* as distinguished from the direction the dimension line of line *d* which extends across the stack of laminations. The cruciform shape of the winding legs is desirable from a coil design standpoint in order to permit the more efficient use of round coils.

The sheets or laminations comprising the leg members are coated with a bonding material such as a toluol-alcohol solution of alvar, Vinylite and Bakelite. In practice it has been found satisfactory to utilize a resinous product such as a condensation product of the phenol aldehyde type. To meet different conditions, the phenol aldehyde type resin may be modified by contacts well known in the art. After the bonding material has been applied to the sheets of steel, it is permitted to dry and after drying the punchings are stacked in a jig and heated while pressure is being applied to the stack. The assembly is then cooled under pressure resulting in the punchings being solidly bonded together. When a chemically inert material is applied in this manner, it strongly adheres to bond the laminations between which it is disposed whereby the bundle of laminations is solidly held together in a rigid piece or unit of the core structure, the laminations of the unit being united by the bonding material applied to them.

In order to provide accurately smooth faces on the ends of the leg members 1 and 2 which will cooperate with the corresponding faces on the adjoining portions of the yoke members 3 and 4 to give the desired closely fitting butt joints, the ends of the leg members are either machined or ground or otherwise mechanically worked to present an accurately smooth surface and to provide that the two legs shall be of exactly the same length. It has been found that during the machining or grinding operations to provide the smooth faces, burrs are formed. These burrs are tiny slivers of magnetizable material which may span the bonding layers between adjacent layers of the magnetizable material at the mechanically worked surface, thereby electrically connecting or short-circuiting the adjacent laminations. This increases both the iron losses and the magnetizing current of the electrical apparatus if not removed.

It is, therefore, desirable to remove these burrs in order to provide a commercially acceptable device. The burrs may be removed by applying an etching solution to the faces in any suitable manner. Many different kinds of etching solutions may be employed successfully. It has been found in practice that a 30% nitric acid solution is highly satisfactory. The etching solution may be applied in any suitable manner such as by dipping the face of the worked surface to be etched in the nitric acid solution for about 30 seconds. When the faces are withdrawn from the nitric acid solution, it is desirable to apply sodium carbonate to neutralize the acid. When the acid remaining on the stack has been neutralized, water is applied to remove the particles resulting from the neutralizing process. The above described lightly etched treatment of the working faces removes the burrs without substantially roughening the accurately smooth planed face resulting from the machining or grinding operation.

Structurally the yoke members 3 and 4 consist of arch shaped groups of laminations bonded together by an adherent bonding material between them in the same manner as are the laminations of the leg members 1 and 2 and having similarly worked faces forming accurately smooth surfaces cooperating with the ends of the leg members 1 and 2 to form highly efficient butt joints.

The yoke members 3 and 4 may be formed by winding a continuous strip of oriented grain steel under tension about a mandrel of suitable dimension forming a loop 7, as shown in Fig. 3. Various widths of strip may be used so as to build up a cruciform section if desired, corresponding to the cruciform section of the winding legs 1 and 2. In the embodiment shown, the use of a single width strip is illustrated and has the advantages that it is somewhat simpler to wind and provides widening or an increased cross section of the yoke members over that of the leg members. The width of the strip 12 used would correspond to the width *c* of the widest laminations 11 used in the core leg and the number of turns or laminations used in the yoke would be that required to provide a surface on the yoke having the same dimension *d* as the wide part of the

core leg. After the loop 7 has been wound to the shape shown in Fig. 3, it is then cut along the lines 13 on two opposite sides of the loop to form two U-shaped members 3 and 4. Prior to the cutting of the core members the several layers of the strip 12 have been bonded together in a manner generally similar to that described above with respect to the laminations forming the core legs 1 and 2, so that when the loop 7 is cut along the line 13, two separate yoke units are formed each having an arched or U-shape. The U-shaped members 3 and 4 are in effect stacks or bundles of laminations solidly bonded together similar to the laminations in the leg members 1 and 2 and the cut surfaces will be worked and treated in exactly the same manner. After the faces of the U-shaped members have been worked and treated and the preformed windings shown diagrammatically at 8 have been placed about the leg members 1 and 2, the leg and core members will be assembled to form the unit shown in Fig. 1.

Referring particularly to Figs. 2 and 4, a three-phase transformer core is shown having three winding legs 21, 22 and 23 which are each similar in construction to the legs 1 and 2 in Fig. 1, and each of which accommodate or extend through the primary and secondary windings comprising the windings of one of the three phases of the electrical circuit in a well known manner. The yoke members are constructed similar in principle to the yoke members 3 and 4 shown in Fig. 1, but differ therefrom in that three arch shaped structures are provided both above and below the winding legs. An arch shaped member 24 engages the upper ends of the leg members 21 and 22, an arch-shaped yoke member 25 engages the upper ends of the leg members 22 and 23 and an arch-shaped yoke member 26 engages the upper ends of the leg members 21 and 23. In a similar manner, the arch-shaped member 27 engages the lower ends of the leg members 21 and 22, an arch-shaped member 28 engages the lower ends of the leg members 22 and 23 and an arch-shaped member 29 engages the lower ends of the leg members 21 and 23. The cross sectional area of the several arch-shaped members of the yoke should correspond, to provide three separate paths for the magnetic flux between the three winding legs of the core at each end thereof that are alike in cross sectional area, so that the flux passing between any two winding legs may complete its circuits through corresponding upper and lower yoke arch members 24 and 27, 25 and 28 or 26 and 29.

In forming the yoke members used in the three-phase transformer core shown in Fig. 2, three separate core loops are wound, the loops 31 and 32 being wound about mandrels in the same manner as the loop 7 shown in Fig. 3 to the proper dimension. The two core loops 31 and 32 which are formed of an equal number of turns of the strip of magnetic material are then surrounded by a loop 33 having an equal number of turns or laminations of sheet steel. The three core loops, as shown in Fig. 4, are then cut at three places 34 along the same plane to provide upper and lower yoke members having the same dimensions. The individual turns of all three loops are bonded together in the same manner as in the loop 7 formed in Fig. 3, and the several surfaces formed by cutting along the lines 34 are worked in the same manner to provide cooperating accurately smooth surfaces engaging corresponding accurately smooth surfaces on the ends of the leg members 21, 22 and 23, the entire assembly being

held together by a band 35 and mounted within any suitable frame structure for positioning it in the transformer tank.

In the form of core construction disclosed, the high density flux passing through the winding leg and the yoke portion of the core does not have to pass across the grain of the steel but coincides with the direction of rolling or grain direction of the steel at all points, thus maintaining the lowest watts losses and highest permeability characteristics of the core structure possible. There are no areas adjacent any of the joints in which flux is required to flow across the grain of the steel for even a short distance. The construction lends itself to a ready widening of the cross section of the yoke members to provide a greater cross section in the yoke members than in the leg members if desired. The construction lends itself to the employment of winding legs having cruciform section, thus providing the most economical use of core material with round coils, together with a rectangular cross section for the yoke portions of the core, together with the use of high efficiency butt joints between the core portions. All magnetic material used is active material, thus reducing the required amount of magnetic material to a minimum with a saving of core weight. The core legs are "batch stacked," that is stacked in a bundle rather than placed in position within the preformed conducting coils one sheet at a time as in building up a core from L-shaped punchings, and the yoke portions are wound from a continuous strip, thus reducing the labor required in forming the core below that required for the usual type of built-up core stacks of laminations. The coils may be readily removed from the core for repair since the disassembling of the core structure merely means separating the yoke and leg portions at the butt joints rather than the disassembling of the core sheet by sheet, as in the built-up core type of structure.

Since modifications may be made in the structures illustrated and described within the spirit of my invention, I do not wish to be limited otherwise than by the scope of the appended claims.

I claim as my invention:.

1. In a magnetic core structure for electrical induction apparatus, in combination, a plurality of leg members positioned in parallel relation and having cruciform cross-section and yoke members connecting the corresponding ends of the leg members, the leg members comprising core units formed of stacks of laminations of magnetic material, the laminations of each unit being united by bonding material applied to the laminations and having faces worked on the core leg for making butt joints, certain of the laminations having a different width than others to provide a cruciform shaped core leg, the yoke members comprising portions of a magnetic loop structure formed of magnetic sheet material wound flatwise, the sheet material having the same width throughout the yoke member to provide a greater cross section in the yoke members than in the leg members, the successive turns being bonded together by bonding material applied to the sheet material, and cut to provide two yoke member structures for joining the leg members of the core and having faces worked thereon to provide elements for closely adjoining the cooperating faces of the core leg members to form low loss butt joints.

2. In a magnetic core structure for electrical induction apparatus, in combination, a plurality of leg members positioned in parallel relation and

yoke members connecting the end portions of the leg members together to complete the magnetic circuit, the leg members comprising core units formed of stacks of laminations of magnetic material, the laminations of each unit being united by bonding material applied to the laminations, and faces worked on the opposite ends of the units to provide elements for making butt joints, certain of the laminations of the leg members having a different width than others to provide leg members having cruciform-shaped cross sections, the yoke members comprising arched structures formed of superimposed layers of sheet material bent flatwise to conform to the shape of the arch and bonded together by bonding material applied to the sheet material, the arched structures having faces worked thereon for cooperating with the faces on the units comprising the leg members to form low loss butt joints, the sheet material forming the yoke members having the same width throughout to provide a greater cross section in the yoke members than in the leg members of the core.

3. In a three-phase core structure for electrical induction apparatus, in combination, three leg members positioned in parallel relation and yoke members connecting the end portions of the leg members together to complete the magnetic circuit, the leg members comprising core units formed of stacks of laminations of magnetic material, the laminations of each unit being united by bonding material applied to the laminations, the three winding legs being arranged in a row and having faces worked on the opposite ends of the units to provide elements for making butt joints, the yoke members comprising arched structures formed of superimposed layers of sheet material bent flatwise to conform to the shape of the arch and bonded together by bonding material applied to the sheet material, the arched structures having faces worked thereon for cooperating with the faces on the units comprising the leg members to form low loss butt joints, the yoke members at each end of the leg members comprising three such arch structures, two of the three arch structures being of lesser span than the third and positioned to span from the first to the second and from the second to the third of the three leg members, respectively, and the third one of the three arch structures being dimensioned and positioned to extend from the first to the third of the three leg members.

4. A method of making a magnetic core for an induction device having a plurality of core leg members arranged in parallel relation, and yoke members connecting the corresponding ends of the leg members, said method comprising the steps of building separate leg member pieces each as a solidly held bundle of laminations of magnetizable material with intervening bonding layers of an adherent insulating bond between the laminations, each bonding layer adhering to both of the laminations between which it is disposed whereby the bundle of laminations is solidly held together to constitute one of the plurality of separate leg pieces of the core, mechanically working a plurality of accurately smooth butt joint surfaces on each piece, and in building separate arch shaped yoke members each as a solidly held bundle of laminations of magnetizable material with intervening bonding layers of an adherent insulating b nd between the laminations, each bonding layer adhering to both of the laminations between which it is disposed whereby the bundle of laminations forming the arch shaped yoke member is held solidly together to constitute one of the plurality of separate yoke pieces of the core, the arch shaped yoke members being formed by winding a continuous strip of magnetic material in a plurality of turns, filling the spaces between the several turns with an adherent insulating bonding layer to provide a solid loop structure, cutting and mechanically working the wound and filled core loop to divide it into two yoke members having accurately smooth butt joint surfaces on each piece for closely fitting the matching surfaces of the leg members to provide smooth low loss butt joints between the leg and yoke members of the core, and in assembling the yoke and leg members in final position.

5. A method of making a magnetic core for an induction device having a plurality of core leg members arranged in parallel relation, and yoke members connecting the corresponding ends of the leg members, said method comprising the steps of building separate leg member pieces each as a solidly held bundle of laminations of magnetizable material with intervening bonding-layers of an adherent insulating bond between the laminations, each bonding-layer adhering to both of the laminations between which it is disposed whereby the bundle of laminations is solidly held together to constitute one of the plurality of separate leg pieces of the core, mechanically working a plurality of accurately smooth butt-joint surfaces on each piece so that each of said butt-joint surfaces comprises a plurality of strata consisting of smooth-surfaced lamination-ends separated by insulating adherent bonding layers, said mechanical working operation being performed in such manner and under such conditions as to produce short-circuiting burrs of the magnetizable material spanning the bonding-layers at each butt-joint surface, and subsequently etching away substantially all of said short-circuiting burrs without substantially roughening the smooth-surfaced lamination ends, and in building separate arch shaped yoke members each as a solidly held bundle of laminations of magnetizable material by winding a continuous strip of magnetic material in a plurality of turns, filling the spaces between the turns with bonding layers of an adherent insulating bonding material to provide a solid loop structure, cutting and mechanically working the wound and filled core loop to divide it into two yoke members having accurately smooth butt-joint surfaces on each piece so that each of said butt-joint surfaces comprises a plurality of strata consisting of smooth-surfaced lamination-ends separated by insulating adherent bonding layers, said mechanical working operation being performed in such manner and under such conditions as to produce short-circuiting burrs of the magnetizable material spanning the bonding-layers at each butt-joint surface, and subsequently etching away substantially all of said short-circuiting burrs without substantially roughening the smooth-surfaced lamination ends, and in building separate arch shaped yoke members each as a solidly held bundle of laminations of magnetizable material by winding a continuous strip of magnetic material in a plurality of turns, filling the spaces between the turns with bonding layers of an adherent insulating bonding material, and in assembling the leg and yoke members in final position.

6. In a magnetic core structure for electrical induction apparatus, in combination, a plurality of leg members positioned in parallel relation and

yoke members connecting the corresponding ends of the leg members, the leg members comprising core units formed of stacks of laminations of magnetic material, the laminations of each unit being united by bonding material applied to the laminations and having faces worked on the core leg to provide elements for making butt joints, certain of the laminations of the leg members having a different width than others to provide leg members having cruciform-shaped cross sections, the yoke members comprising portions of a magnetic loop structure formed of magnetic sheet material wound flatwise, the successive turns being bonded together by bonding material applied to the sheet material, and cut to provide two yoke member structures for joining the leg members of the core and having faces worked thereon to provide elements for closely adjoining the cooperating faces of the core leg members to form low loss butt joints, the sheet material forming the yoke members having the same width throughout to provide a greater cross section in the yoke members than in the leg members, the leg members of the core being placed in the assembled structure in such position that the edges of the laminations comprising the leg members and the edges of the laminations comprising the yoke members extend in the same direction in the adjacent faces cooperating to form the butt joints between the leg and yoke members of the core.

7. In a magnetic core structure for electrical induction apparatus, in combination, a plurality of leg members positioned in parallel relation and yoke members connecting the end portions of the leg members together to complete the magnetic circuit, the leg members comprising core units formed of stacks of laminations of magnetic material, the laminations of each unit being united by bonding material applied to the laminations, and faces worked on the opposite ends of the units to provide elements for making butt joints, certain of the laminations of the leg members having a different width than others to provide leg members having cruciform-shaped cross sections, the yoke members comprising arched structures formed of superimposed layers of sheet material bent flatwise to conform to the shape of the arch and bonded together by bonding material applied to the sheet material, the arched structures having faces worked thereon for cooperating with the faces on the units comprising the

leg members to form low loss butt joints, the sheet material forming the yoke members having the same width throughout to provide a greater cross section in the yoke members than in the leg members, the leg members of the core being placed in the assembled structure in such position that the edges of the laminations comprising the leg members and the edges of the laminations comprising the yoke members both extend from the front to the back of, the assembled core structure in the adjacent faces cooperating to form the butt joints between the leg and yoke members of the core.

8. In a three-phase core structure for electrical induction apparatus, in combination, three leg members positioned in parallel relation and yoke members connecting the end portions of the leg members together to complete the magnetic circuit, the leg members comprising core units formed of stacks of laminations of magnetic material, the laminations of each unit being united by bonding material applied to the laminations, the three winding legs being arranged in a row and having faces worked on the opposite ends of the units to provide elements for making butt joints, the yoke members comprising arched structures formed of superimposed layers of sheet material bent flatwise to conform to the shape of the arch and bonded together by bonding material applied to the sheet material, the arched structures having faces worked thereon for cooperating with the faces on the units comprising the leg members to form low loss butt joints, the yoke members at each end of the leg members comprising three such arch structures, two of the three arch structures being of lesser span than the third and positioned to span from the first to the second and from the second to the third of the three leg members, and the third one of the three arch structures being dimensioned and positioned to extend from the first to the third of the three leg members, the leg members of the core being placed in the assembled structure in such position that the edges of the laminations comprising the leg members and the edges of the laminations comprising the yoke members both extend from the front to the back of, the assembled core structure in the adjacent faces cooperating to form the butt joints between the leg and yoke members of the core.

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