

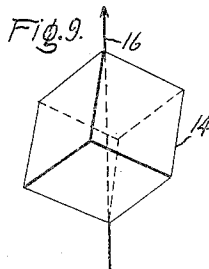
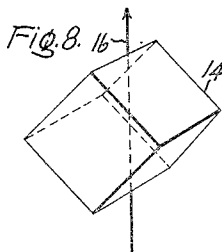
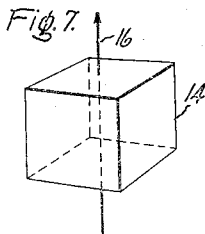
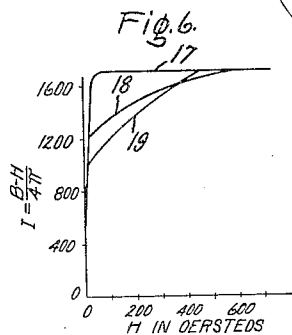
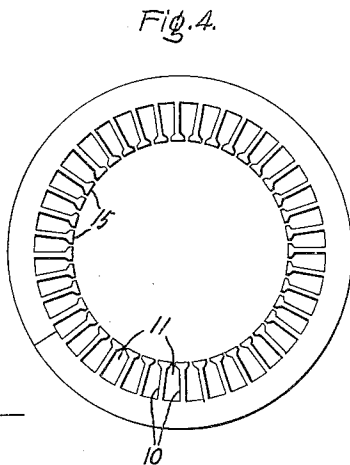
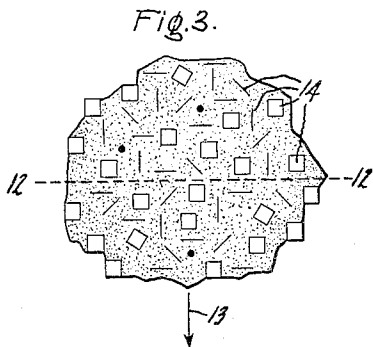
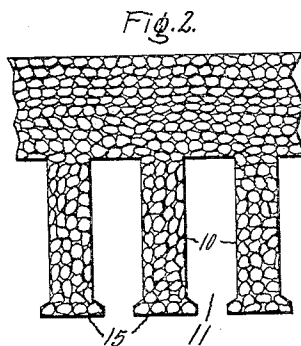
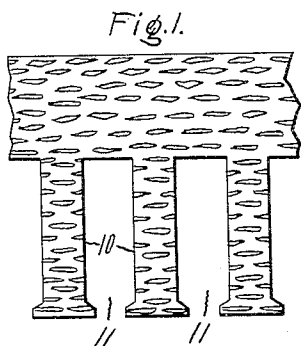
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R. M. PFALZGRAFF

2,053,162

CORE FOR DYNAMO-ELECTRIC MACHINES

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Inventor:
Ross M. Pfalzgraff,
by *Harry E. Dunham*
His Attorney.

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CORE FOR DYNAMO-ELECTRIC MACHINES

Ross M. Pfalzgraff, Lynn, Mass., assignor to
General Electric Company, a corporation of
New York

Application February 18, 1936, Serial No. 64,491

14 Claims. (Cl. 171-252)

My invention relates to laminated cores for dynamo-electric machines.

This application is a continuation in part of my applications, Serial No. 730,875, filed June 16, 1934, and Serial No. 14,781, filed April 5, 1935.

In cores for dynamo-electric machines, or other electrical apparatus, in which the windings are placed in slots in the surface of the core, the flux in the teeth is subject to high frequency pulsations caused by relative rotation of the teeth on the rotating and stationary members of the machine, and these flux pulsations cause a tooth-tip core loss which forms a substantial part of the total core loss of the machine. Hence, in analyzing the core losses in such apparatus, attention must be given both to the losses due to eddy-currents caused primarily by high frequency pulsations, and also to hysteresis losses due primarily to low frequency pulsations. Considering first the losses due to high frequency pulsations, if the core is constructed by edgewise winding hot-rolled silicon steel strip, the tooth-tip core losses due to the high frequency flux pulsations are higher than would be expected from the standard low frequency Epstein test. In making the Epstein test the iron to be tested is made part of the magnetic circuit of a transformer, and the iron losses are determined by exciting the transformer with a 60-cycle voltage to produce a 60-cycle flux of standard density. The losses of the cores made from edgewise wound hot-rolled silicon steel strip are also higher than would be expected from comparison with cores made from laminations punched to the desired shape from the hot-rolled sheets. This increased loss is due in part to the fact that the grain structure of hot-rolled silicon tends to be elongated in the direction of rolling, and when the strip is edgewise wound, the elongated grains in each of the teeth are arranged substantially perpendicular to the length of the teeth and are in the position for maximum loss under high frequency flux pulsations. When the core laminations are punched in the final shape from hot-rolled sheet steel, the elongated grains are not arranged in the same position in each of the teeth so that the core loss is not as greatly increased by unfavorable grain structure as is the case with edgewise wound laminations. The effect of grain structure on the high frequency core losses is not indicated by the Epstein tests, because in this test, half of the iron to be tested is arranged so that the flux passes across the grain, and the other half of the iron is arranged

so that the flux passes with the grain. The directional effect of grain structure is, therefore, not indicated by this test. As the Epstein test is conducted at low frequency, it does not indicate the losses which would be obtained at high frequencies occurring in the teeth of a core of a dynamo-electric machine. I find that if the grain structure of the steel is not elongated, but is more nearly equiaxed, the high frequency tooth-tip core losses of edgewise coiled laminations are lower, even though the Epstein test does not indicate that this reduction could be expected.

From a consideration of the magnetic properties and the losses resulting primarily from low frequency pulsations, it is known that the magnetic properties of ferro-magnetic material are greatly improved and the losses reduced when the crystals have a face substantially normal to the direction of the magnetic flux with a crystal cube edge substantially in the direction of the magnetic flux. Better magnetic properties also are obtained with a crystalline orientation, such that a crystal cube edge is normal to the direction of the magnetic flux, over a random crystal orientation. It also has been found that further improvement is obtained by the orientation of the crystals so as to produce a crystalline arrangement in a strip of material wherein the corresponding faces of the crystals are parallel. This improvement due to crystalline orientation is particularly noticeable in the permeability and hysteresis of the ferro-magnetic material. Such a crystalline arrangement is most easily obtained and generally occurs with steel having a substantially equiaxed grain structure, although such a granular arrangement is not necessary for the preferred crystalline arrangement. A small and equiaxed grain structure is also beneficial, as it reduces the losses due to eddy currents resulting from high frequency flux pulsations, as above explained.

An object of my invention is to provide an improved core for electrical apparatus having low core losses and improved magnetic properties. I reduce the core losses due to eddy currents and hysteresis and improve the permeability by employing a core material having a substantially small and equiaxed grain and a particular orientation of the crystalline structure. This orientation of the crystalline structure is preferably obtained by a final heavy cold reduction of the core material, and a subsequent normalizing treatment.

Further objects of my invention will become

apparent in the following description referring to the accompanying drawing, and the features of novelty which characterize my invention will be pointed out with particularity in the claims annexed to and forming a part of this specification.

In the accompanying drawing, Fig. 1 is a fragmentary view illustrating the grain structure of a strip of hot-rolled silicon steel such as may be used for forming cores by edgewise winding; Fig. 2 is a fragmentary view illustrating the grain structure of a strip of silicon steel having a substantially equiaxed grain structure suitable for forming cores by edgewise winding; Fig. 3 is an enlarged view of the arrangement of cubical crystals within a grain of silicon steel utilized in my improved magnetic core; Fig. 4 is an end elevation of a completed core embodying my invention; Fig. 5 is a side view of the edgewise wound helical core illustrated in Fig. 4; Fig. 6 is a graph of the magnetization curves of iron along the three directions indicated in Figs. 7, 8, and 9; and Figs. 7, 8, and 9 illustrate various relations of the direction of flux to the crystals of the grain structure.

Referring to Fig. 1 of the drawing, I have shown a strip of hot-rolled silicon steel containing from $2\frac{1}{2}\%$ to 3% silicon which has teeth 10 and slots 11 along one of its edges and may be used in forming a core for a dynamo-electric machine by edgewise winding the strip in the form of a fine-pitch close-wound helix. Fig. 1 illustrates the grain structure elongated in the direction of rolling, which is characteristic of hot-rolled silicon steel strip. The individual grains are in the form of elongated polyhedrons. When the strip shown in Fig. 1 is edgewise wound to form the completed core shown in Figs. 4 and 5, the elongated grain structure extends perpendicular to the length of the teeth and causes higher tooth-tip core losses than would be expected from the standard Epstein core loss test. If the core were made by stamping a blank of the shape shown in Fig. 4 from this sheet of hot-rolled silicon steel, the elongated grain structure of the steel would not extend uniformly perpendicular to the length of the teeth, but would vary from a position perpendicular to the length of the teeth, which would cause high tooth-tip core losses, to a position along the length of the teeth which would cause low tooth-tip core losses. Therefore, in cores which are constructed by cutting the blank to the desired shape from a sheet of steel, the grain structure is not as important, because the tooth-tip core loss obtained is an average of the core losses resulting from different grain positions. In cores which are constructed from edgewise wound strip, the grain structure of the steel is more important because the grain structure in each of the teeth is identical and there is no averaging effect.

In Fig. 2 I have shown a fragmentary view of a strip of silicon steel having from $2\frac{1}{2}\%$ to 3% silicon and a substantially equiaxed grain structure, and formed so that it is suitable for making cores by edgewise winding. Steels containing from 2% to 4% silicon, such as are used in cores for dynamo-electric machines, may be used. Fig. 2 illustrates the substantially equiaxed grain structure of the strip, each grain being roughly a symmetrical polyhedron. Each of the grains has a crystalline arrangement, as shown in Fig. 3, which is drawn from an etched photomicrograph, the longitudinal axis of the strip being indicated by the dotted line 12-12 and the direction of the teeth by the arrow 13. As here illustrated, the crystal-

line orientation is such that the major portion of the crystals 14 have a crystal edge substantially parallel to the longitudinal axis 12 of the strip, which corresponds to the direction of rolling, and a substantial portion of the crystals 14 have a face substantially parallel to an edge of the strip in a direction normal to the direction of cold rolling.

The silicon steel having an equiaxed grain structure and the desired crystalline orientation is preferably made by subjecting the steel to a final heavy cold reduction of from 50% to 80% by rolling the strip perpendicular to the axis of the teeth. After the heavy cold reduction, which produces strains in the steel, the steel is subjected to a suitable heat treatment which recrystallizes the steel, relieves the cold rolling strains, and causes the grain structure to become substantially equiaxed. I prefer to normalize the steel by this heat treatment in which the steel is quickly heated above the temperature at which grain growth occurs and maintained at this temperature for a period of time, in the order of a few minutes, and then quickly cooled. Subsequent to the final cold reduction and normalizing, the steel strip is annealed to remove any strains remaining in the material due to the working process and to obtain a more stable granular and crystalline structure. I prefer to anneal the core after it has been edgewise wound, thereby also removing strains set up in the steel by the winding process. This cold reduction should form the final step in the reduction process, for its advantages are lost by a subsequent hot rolling. Tests show that this heavy cold rolling of the steel strip longitudinally thereof and subsequent heat treatment produces a crystalline orientation in which the major portion of the crystals, approximately 58%, have a crystal cube edge within $\pm 10^\circ$ of being parallel to an edge 15 of the strip, and with a substantial portion of the crystals, approximately 36%, with a face within $\pm 10^\circ$ of being parallel to the edge 15 of the strip. The normalizing heat treatment of the steel strip produces a rapid grain growth throughout the strip, and the grains tend to mutually limit their growth, thereby providing a substantially equiaxed, uniform grain structure.

By edgewise winding a toothed strip to form a helix, as shown in Figs. 4 and 5, from which the teeth extend radially, a core is obtained in which the major portion of the crystals are oriented with a crystal edge substantially normal to the direction of the flux, and a substantial portion of the crystals with a face substantially normal to the direction of the flux. Such a crystalline arrangement provides a core structure having greatly improved magnetic properties. The advantages of such an arrangement can be readily understood from a consideration of Figs. 6, 7, 8, and 9. Fig. 6 shows the magnetization curves of a single ferro-magnetic cubical crystal 14 and in which the direction of the flux is indicated by an arrow 16, in Figs. 7, 8, and 9. The most desirable magnetic properties of a magnetic material are obtained when the direction of the flux is normal to a face and an edge of the crystal of the material, as illustrated in Fig. 7 and indicated by curve 17 in Fig. 6. A crystal of magnetic material presenting an edge of the crystal normal to the direction of the magnetic flux, so that the flux enters the crystal at a lesser or greater angle than normal to the crystalline face, as shown in Fig. 8, possesses slightly less desirable magnetic properties, as indicated by curve 18 in Fig. 6. The least desirable magnetic properties are pos-

5 sessed by an arrangement of a crystal of magnetic material in which the crystal presents a corner to the direction of the magnetic flux, as shown in Fig. 9, as indicated by the magnetization curve 10 in Fig. 6. A core of ferro-magnetic material constructed according to my invention possesses the desirable characteristic of having a major portion of the crystals with an edge substantially parallel to an edge of the helical strip, and therefore substantially normal to the direction of the magnetic flux and a substantial portion of the crystals with a face and an edge substantially parallel to an edge of the helical strip and therefore substantially normal to the direction of the magnetic flux. It will thus be seen that I utilize a very advantageous arrangement of the granular and crystalline structure of the core material.

20 Although I have shown and described a particular embodiment of my invention, I do not desire my invention to be limited to the construction described, and I intend in the appended claims to cover all modifications which do not depart from the spirit and scope of my invention. 25 What I claim as new and desire to secure by Letters Patent of the United States is:

1. A core for dynamo-electric machines comprising a thin strip of silicon steel in the form of a fine-pitch helix and arranged with an edge thereof presented toward the axis of said core, said strip of steel having slots in one edge thereof forming a series of teeth in axial register, said strip of silicon steel also having a substantially equiaxed grain.

35 2. A core for dynamo-electric machines comprising a thin strip of ferro-magnetic material in the form of a fine-pitch helix and arranged with an edge thereof presented toward the axis of said core, said strip of ferro-magnetic material having slots in one edge thereof forming a series of teeth in axial register, said strip of ferro-magnetic material also having a substantially equiaxed grain.

45 3. A core for electrical apparatus comprising a strip of ferro-magnetic material having an edge thereof presented toward the axis of said core, said helical strip having a series of slots in an edge thereof forming a series of teeth in axial register, said helical strip having a crystalline formation wherein the crystals are oriented so that a major portion of the crystals have a crystal cube edge substantially parallel to an edge of said helical strip.

55 4. A core for dynamo-electric machines comprising a thin strip of silicon steel in the form of a fine-pitch helix and arranged with an edge thereof presented toward the axis of said core, said strip of steel having slots in one edge thereof forming a series of teeth in axial register, said strip of steel having a substantially equiaxed grain and the grains making up said strip having a crystalline formation wherein the crystals are oriented so that a major portion of the crystals have a crystal cube edge substantially parallel to an edge of said strip and a substantial portion of the crystals have a face substantially parallel to an edge of said strip.

70 5. A core for dynamo-electric machines comprising a thin strip of silicon steel in the form of a fine-pitch helix and arranged with an edge thereof presented toward the axis of said core, said strip of steel having slots in one edge thereof forming a series of teeth in axial register, said strip of steel having a substantially equiaxed grain and the grains making up said strip hav-

ing a crystalline formation wherein the crystals are oriented so that at least 50% of the crystals have a cube edge substantially parallel to an edge of said strip and at least 30% of the crystals have a face substantially parallel to an edge of said strip.

6. A core for electrical apparatus comprising a strip of ferro-magnetic material having an edge thereof presented toward the axis of said core, said helical strip having a series of slots in an edge thereof forming a series of teeth in axial register, said helical strip having a crystalline formation wherein the crystals are oriented so that at least 50% of the crystals have a crystal edge substantially parallel to an edge of said helical strip and a substantial portion of the crystals have a face substantially parallel to an edge of said helical strip.

7. A core for electrical apparatus comprising a strip of ferro-magnetic material having an edge thereof presented toward the axis of said core, said helical strip having a series of slots in an edge thereof forming a series of teeth in axial register, said helical strip having a crystalline formation wherein the crystals are oriented so that at least 30% of the crystals have a face substantially parallel to an edge of said helical strip.

8. A core for electrical apparatus comprising a helical strip of ferro-magnetic material arranged with an edge of said strip presented toward the axis of said core, said strip having a series of slots in an edge thereof forming a series of teeth in axial register, said strip having electrical and magnetic properties characteristic of said ferro-magnetic material when subjected to a final cold reduction of from 50% to 80% by rolling in a direction perpendicular to the length of said teeth and having been normalized.

9. A core for electrical apparatus comprising a helical strip of ferro-magnetic material arranged with an edge of said strip presented toward the axis of said core, said strip having a series of slots in an edge thereof forming a series of teeth in axial register, said strip having electrical and magnetic properties characteristic of said ferro-magnetic material when subjected to a final cold reduction of from 50% to 80% by rolling in a direction perpendicular to the length of said teeth and normalized during said final cold reduction.

10. A core for electrical apparatus comprising a helical strip of ferro-magnetic material arranged with an edge of said strip presented toward the axis of said core, said strip having a series of slots in an edge thereof forming a series of teeth in axial register, said strip having electrical and magnetic properties characteristic of said ferro-magnetic material when subjected to a final cold reduction of from 50% to 80% by rolling in a direction perpendicular to the length of said teeth and normalized during said final cold reduction and subsequently annealed.

11. A core for electrical apparatus comprising a helical strip of ferro-magnetic material, said strip having a series of slots in an edge thereof providing a series of teeth arranged in axial registry, said ferro-magnetic material being characterized by electrical and magnetic properties produced by a final cold reduction of from 50% to 80% by rolling in a direction perpendicular to the length of said teeth and by subsequent heat treatment producing a substantially equiaxed grain structure and producing an orientation of the crystalline formation such that a major por-

tion of the crystals have a crystal edge substantially parallel to an edge of said strip.

12. A core for electrical apparatus comprising a helical strip of ferro-magnetic material, said strip having a series of slots in an edge thereof 5 providing a series of teeth arranged in axial registry, said ferro-magnetic material being characterized by electrical and magnetic properties produced by a final cold reduction of from 50% 10 to 80% by rolling in a direction perpendicular to the length of said teeth and by subsequent heat treatment producing a substantially equiaxed grain structure and producing an orientation of the crystalline formation such that a substantial 15 portion of the crystals have a face substantially parallel to an edge of said strip.

13. A core for electrical apparatus comprising a helical strip of ferro-magnetic material, said strip having a series of slots in an edge thereof 20 providing a series of teeth arranged in axial registry, said ferro-magnetic material being characterized by electrical and magnetic properties produced by a final cold reduction of from 50% to 80% by rolling in a direction perpendicular to

the length of said teeth and by subsequent heat treatment producing an orientation of the crystalline formation such that a major portion of the crystals have a crystal edge substantially 5 parallel to an edge of said strip and a substantial portion of the crystals have a face substantially parallel to an edge of said strip.

14. A core for electrical apparatus comprising a helical strip of ferro-magnetic material, said strip having a series of slots in an edge thereof 10 providing a series of teeth arranged in axial registry, said ferro-magnetic material being characterized by electrical and magnetic properties produced by a final cold reduction of from 50% to 15 80% by rolling in a direction perpendicular to the length of said teeth and by subsequent heat treatment producing a substantially equiaxed grain structure and producing an orientation of the crystalline formation such that a major portion 20 of the crystals have a crystal edge substantially parallel to an edge of said strip and a substantial portion of the crystals have a face substantially parallel to an edge of said strip.

ROSS M. PFALZGRAFF.