METHOD OF PRODUCING NORMAL
GRAIN GROWTH (110) [001] TEXTURED
IRON-COBALT ALLOYS

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Application Data

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Int. Cl. ......................... H01F 1/00
Field of Search .......... 148/120, 121, 122, 31.55, 148/111; 75/123 K

References Cited
UNITED STATES PATENTS
1,247,206 11/1917 Becket ......................... 75/123 K

FOREIGN PATENTS OR APPLICATIONS
1,180,954 1964 Germany ...................... 148/100

Primary Examiner—Walter R. Satterfield
Attorney, Agent, or Firm—R. T. Randig

ABSTRACT
An alloy and a method for producing the same are described in which the alloy is characterized by a primarily recrystallized microstructure having a (110) [001] orientation. The alloy contains from 5% to 35% cobalt, up to 2% chromium, up to 3% silicon, less than 0.005% sulfur and a balance essentially iron with incidental impurities. The method includes a schedule of hot and cold working the latter in limited amounts together with corresponding heat treatments producing the desired improved magnetic characteristics.

11 Claims, 6 Drawing Figures
- 3% Si-Fe ORIENTED

**M849 AND M853—ANNEALED**

48 HOURS AT 900°C

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>THICKNESS (IN.)</th>
<th>PEAK RATIO</th>
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</thead>
<tbody>
<tr>
<td>3% Si-Fe ORIENTED</td>
<td>0.0118</td>
<td>0.342</td>
</tr>
<tr>
<td>M853</td>
<td>0.0121</td>
<td>0.370</td>
</tr>
<tr>
<td>M849</td>
<td>0.0125</td>
<td>0.548</td>
</tr>
</tbody>
</table>

**FIG. 1.**
FIG. 6
METHOD OF PRODUCING NORMAL GRAN GROWTH (110)[001] TEXTURED IRON-COBALT ALLOYS

CROSS REFERENCE TO RELATED APPLICATIONS

This is a division of application Ser. No. 228,071 filed Feb. 22, 1972, now U.S. Pat. No. 3,843,424.

The present application is closely related to application Ser. No. 228,319, filed Feb. 22, 1972 and application Ser. No. 401,766, filed Sept. 28, 1973 each of which application is presently pending.

BACKGROUND OF THE INVENTION

1. Field of The Invention

The present invention relates to iron-cobalt alloys having improved magnetic characteristics and a method for producing said alloys. The alloys are characterized by having a high grain volume of (110) [001] orientation texture, the same having been derived by means of primary recrystallization and normal grain growth.

2. Description of The Prior Art:

The operating inductions of large portions of today's transformers are limited by the saturation value of oriented silicon steel, that is, a steel containing about 3% silicon and which has a high degree of (110) [001] orientation. This saturation value is generally taken to be about 20,300 gauss. Both iron an economic and a technological standpoint this is the highest quality transformer material presently available commercially.

Cobalt functions in iron to significantly increase the saturation value of the iron, and saturation inductions on the order of 24,000 gauss are observed in cobalt-iron alloys containing 25 to 50% cobalt. The alloys containing from about 35 to 50% cobalt have a low magnetocrystalline anisotropy and the lowest values occur in the range of about 50% cobalt. Consequently, high inductions are obtained at low field strengths. It is noted however that when the cobalt content in the alloy is increased to a value ranging from more than about 35% and up to about 80% by weight, with a corresponding decrease in the iron content, the alloy undergoes atomic ordering. Consequently, high cobalt-iron alloys such as the 50% cobalt-iron alloy are quite brittle and can only be cold worked after a drastic quench resulting in high production costs.

While considerable ductility is observed in alloys containing less than 35% cobalt which alloys do not undergo atomic ordering, the high induction values for low field strength have never been observed in this alloy most likely because of their high positive anisotropy values. However, the improved ductility makes the alloys containing between about 5 and about 35% cobalt quite attractive from an economic manufacturing point of view.

Heretofore, there have been commercially available alloys containing about 27% cobalt in an iron base. However, these alloys, while showing some improvement in the overall saturation induction value, nonetheless were deficient from the standpoint of having low inductions at low field strengths. Consequently, such material only found limited use where it was designed for operation at near the saturation value. While the presence of between about 5 and about 35% cobalt in an iron matrix will provide improved saturation values, by the present invention it has been found that proper processing makes it possible to develop grain orientation such that high inductions are obtained at low field strengths without adversely affecting the coercive force or of the saturation induction values. The method as applied to the alloy of the present invention is effective for producing such results which are manifest in the observed magnetic characteristics.

SUMMARY OF THE INVENTION

The present invention relates to an alloy which contains in weight percent between about 5 and about 35% cobalt, up to about 2% chromium, up to about 1% manganese, up to about 3% silicon and the balance iron with incidental impurities. A critical aspect of the invention is recognizing and controlling the sulfur content thereof to a value of less than about 0.005% and preferably less than about 0.002%.

The method for obtaining the improved magnetic characteristics in these alloy compositions includes an initial step of hot working of the metal at a temperature of between about 1000°C and about 1100°C to a desired intermediate gauge and thereafter a critical cold working the alloy in one or more steps to the desired final gauge and a final critical primary recrystallization anneal. While any hot working will suffice since it is not a critical point in the process, hot rolling is preferred. It has been found that in order to develop the desired magnetic characteristics, at least the last cold working operation to final gauge must effect a reduction in the cross sectional area ranging between about 40 and about 75% and the alloy is preferably heated rapidly to the recrystallization temperature and finally subjected to a high temperature heat treatment which results in the development of a primarily recrystallized microstructure having a majority of the grains displaying an orientation described as (110) [001] in Miller Indices, and the majority or a high proportion of the grains have the cube edges of their crystal lattices parallel within 10° to the direction of rolling of the sheet or strip of the alloy. The final high temperature heat treatment to which the alloy is subjected usually takes place at a temperature between about 800°C and the Ar3 temperature of the alloy undergoing the final heat treatment. Preferably the final heat treatment is conducted in a protective atmosphere, such as an atmosphere of substantially pure hydrogen having a dew point of less than about –40°F.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plot on the torque curves of alloys exhibiting various degrees of grain orientation;

FIG. 2 is a photomacrograph at a magnification of 20X of heat M849;

FIG. 3 is a photomacrograph at a magnification of 20X of heat M850;

FIG. 4 is a photomacrograph at a magnification of 20X of heat M851;

FIG. 5 is a photomacrograph at a magnification of 20X of heat M852; and

FIG. 6 is a photomacrograph at a magnification of 20X of heat M853.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Generally speaking, the present invention relates to an alloy having improved magnetic characteristics, and which has a composition containing from about 5 to
about 35% cobalt, at least one element which is effective for raising the volume resistivity such as up to about 2% chromium, and up to about 3% silicon, less than about 0.005% sulfur, up to about 1% mangan- 
cess to form a second phase will improve volume resistivity; however care must be exercised so 
that the other properties are not detrimentally affected. 

By the same token, it has also been found that it is pre-
ferred, although not critically necessary, to have the manganese content at a value of less than about 0.50%. 
Where, however, silicon is added as an alloying compo-
nent, for example, in an alloy with a cobalt content of 
between about 8 and about 20% for improved resistivity, the 
manganese may be quite low — nominally about 0.05%.

While during normal processing of the alloys into fin-
ished gauge material the alloy may be subjected to a de-
carburizing anneal, nonetheless it is preferred to main-
tain the carbon content at less than about 0.030% with a correspondingly low content of oxygen and the bal-
ance of the other incidental impurities. Typical levels of 
these elements may include about 0.003% oxygen, 
about 0.05% manganese, about 0.1% silicon and the 
balance essentially of iron. Such levels of incidental 
impurities are obtained by vacuum induction melting 
however other melting methods may be employed with 
equal success.

The alloy having the desired composition is subjected 
to a hot working operation and one or more cold work-
ing operations in order to reduce the alloy to the de-
sired final gauge thickness. In this respect it has been 
found that good success has been obtained where the 
alloy in ingot form is hot worked as by rolling from a 
temperature within the range between about 1000°C 
and about 1100°C. The material is hot worked at this 
temperature range to any desired intermediate gauge 
thickness such as a hot rolled band gauge of between 
about 0.075 and about 0.150 inches. It will be appreci-
ated that while the intermediate gauge has been set 
fourth, deviations therefrom may be made depending on 
the finish gauge thickness. Thus the intermediate gauge 
thickness is selected with respect to the subsequent 
cool reductions and finish gauge thickness.

Following hot working at a temperature within the 
range between 1000°C and 1100°C the alloy is heat 
treated for a time period of about 10 minutes to about 
60 minutes at a temperature within the range between 
about 600 and 900°C. During such heat treatment it is 
convenient to introduce a hydrogen atmosphere such 
hydrogen atmosphere having a dew point of greater 
than about -40°C in order to decarburize the material. 
It is desired in some cases to decarburize at the inter-
mediate gauge thickness and typical annealing times of 
about 15 minutes at about 700°C in a hydrogen atmos-
phere at approximately a +60°F dew point is effective 
for removing about half of the carbon content remain-
ing in the sample following hot working. However it is 
also contemplated that such decarburizing heat treat-
ment can be delayed to just prior to final heat treat-
ment or at any other step therebetween. After the de-
carburizing anneal, the material is pickled in prepara-
tion for cold working.

Cold working is accomplished in one or more opera-
tions. Preferably, the cold working is accomplished in 
two steps. However, it has been found that it is neces-

silicon is noted for its effect of improving volume resis-
tivity it has been found that other elements such as 
chromium, vanadium, aluminum, titanium and molyb-
denum are more effective where the cobalt content is 
within the range between 20 and 35%. Consequently, 
the alloying silicon addition is preferred only where the 
cobalt is less than about 20%. Any element which is sol-
uble and does not form a second phase will improve 
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volume resistivity; however care must be exercised so 
that the other properties are not detrimentally affected.

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temperature within the range between about 1000°C 
and about 1100°C. The material is hot worked at this 
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carburizing anneal, the material is pickled in prepara-
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Cold working is accomplished in one or more opera-
tions. Preferably, the cold working is accomplished in 
two steps. However, it has been found that it is neces-

necessary that at least the last cold working of the material to finish gauge must effect a reduction in the cross sectional area ranging between about 40 and about 75%. In this respect it has been noted that where the final cold reduction is less than about 40% a sharply defined (110) [001] texture is not obtained as where the material has been subjected to at least a 40% reduction in cross sectional area. While reductions in excess of 75% will not adversely affect the final texture to any marked degree, nonetheless some deterioration has been noted and the degree of recrystallization may be somewhat affected thereby. Consequently it has been found desirable to limit the cold reduction to finish gauge to a value between about 40 and about 75% and outstanding results have been obtained where the final cold reduction has been effected in an amount ranging between about 50% and about 60%.

In this respect it should be noted that the initial cold reduction, if more than one cold reduction stage is contemplated, may be effected by means of a hot-cold working. That is, the material may be heated to a temperature above ambient temperature but at a temperature below the temperature at which spontaneous recrystallization takes place during working. Thus while the material will be warmed well above room temperature it will nonetheless be a cold working and hence has been termed "hot-cold" working. In this respect it has been found that where the intermediate gauge following hot working is for example about 0.100 inches in thickness, warm rolling may be effected at a temperature within the range between about 200°C and about 300°C to reduce the material to a thickness of about 0.040 inches, following which the material is permitted to cool to ambient temperature where it is then further cold rolled to about 0.025 inch. Thus the total reduction from hot rolled band thickness in the first cold rolling stage is effective for reducing the cross sectional area about 75%.

In all cases where more than one cold working operation is performed on the material, an intermediate anneal is preferably employed, said intermediate anneal being conducted for a time period of up to about two hours at a temperature in excess of about 800°C. Preferably, such intermediate anneal is performed in an atmosphere of pure dry hydrogen, that is, a hydrogen content having a dew point of less than about −40°F.

Following such intermediate annealing the material is cold worked to finish gauge, such finish gauge cold working typically effecting a 40 to 75% reduction in cross sectional area and outstanding results have been obtained where the cold reduction has been limited to a range between about 50 and 60% reduction in cross sectional area. Thus the overall processing is not only effective for removing about one-half of the original carbon content but the material has been reduced to finish gauge and thereafter the material may be given the final high temperature heat treatment in order to develop the desired degree of oriented grain texture. In this respect it has been found that annealing the material at a temperature within the range between about 800°C and the $\Lambda_{\text{f}}$ temperature for a time period of between about 12 hours and about 72 hours in an atmosphere of hydrogen having a dew point of less than −40°F followed by furnace cooling has been effective for producing an outstanding degree of grain orientation the same having been accomplished by means of a primary recrystallized grain structure which has undergone normal grain growth. It has been found that orientation textures have been more pronounced where the finish gauge material has been rapidly heated to a temperature of about 800°C. Consequently, the preferred mode of processing includes a strip anneal for five minutes at 800°C followed by a final box annealing at a temperature within the range between 800°C and the $\Lambda_{\text{f}}$ temperature.

In order to more clearly demonstrate the alloy and the method of the present invention reference may be had to the following Table I which includes the chemical composition of a number of heats which were made and tested in accordance with the present invention together with a commercially available material containing an iron base with about 27% cobalt being present and which was processed employing present commercial practices.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>% Co</th>
<th>% Cr</th>
<th>% Mn</th>
<th>% S</th>
<th>% C</th>
<th>% O</th>
</tr>
</thead>
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<tr>
<td>M 849</td>
<td>27.5</td>
<td>—</td>
<td>0.15</td>
<td>0.008</td>
<td>0.015</td>
<td>0.0033</td>
</tr>
<tr>
<td>M 850</td>
<td>27.5</td>
<td>—</td>
<td>0.15</td>
<td>0.011</td>
<td>0.014</td>
<td>0.0030</td>
</tr>
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<td>M 851</td>
<td>27.5</td>
<td>—</td>
<td>0.15</td>
<td>0.021</td>
<td>0.013</td>
<td>0.0023</td>
</tr>
<tr>
<td>M 852</td>
<td>27.5</td>
<td>0.15</td>
<td>0.001</td>
<td>0.009</td>
<td>0.006</td>
<td>0.0034</td>
</tr>
<tr>
<td>M 853</td>
<td>27.5</td>
<td>0.59</td>
<td>0.15</td>
<td>0.001</td>
<td>0.010</td>
<td>0.0019</td>
</tr>
<tr>
<td>Commercial</td>
<td>27.6</td>
<td>0.59</td>
<td>0.37</td>
<td>0.009</td>
<td>0.015</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

These alloys were melted to the foregoing compositions from high purity raw materials resulting in a close control of such elements as sulfur, carbon and oxygen. Following vacuum induction melting, each of the alloy ingots was processed into sheets as follows:

- Hot roll at 1050°C to 0.100 inch;
- Anneal for 15 minutes at 700°C in hydrogen;
- Pickle; warm roll at 260°C to 0.040 inch then cold roll to 0.025 inch;
- Anneal 1 hour at 900°C in dry hydrogen; and
- Cold roll to finish gauge of 0.012 inch. The foregoing processing removed about half of the original carbon but the other additions including sulfur did not change significantly. The finish gauge material was cut into Epstein strips in the rolling direction. In addition a 1 inch diameter torque disc of each of the alloys was annealed for 48 hours at 900°C in dry hydrogen and thereafter furnace cooled.

Reference is directed to Table II which includes the DC magnetic characteristics exhibited by each of the alloys.
In order to complete the comparison, data is also included on a typical commercial heat of a singly oriented 3% silicon steel and a 27% cobalt-iron alloy (unoriented) for comparative purposes. In interpreting the data set forth in Table II it should be noted that the "peak torque" values in the Table represent the average of the absolute values of the large peaks in the curve. The torque ratio represents a ratio of the absolute values of the small peaks to the large peaks for a given curve. Since the commercially processed 27% cobalt material did not have measurable torque peaks and had a $B_m$ value of only 16,100 gauss such values dearly indicate that the grain texture in the commercially processed material is essentially random.

From the data set forth in Table II it can be seen from the torque values as well as the induction at 10 oersted, substantially higher values for $B_m$ have been obtained with each of the compositions. However, the compositions with the lowest sulfur content, that is, heats M 852 and M 853 had outstandingly high $B_m$ values together with peak torque values which closely approach the value for the 3% silicon iron which has a high degree of (110) [001] orientation and is a commercially available material.

This is more clearly demonstrated by reference to FIG. 1 which superimposes the plots of the torque value versus the angle between the field and the rolling direction in degrees for a highly oriented 3% silicon iron as well as for alloys M 853 and M 849. Thus from the value of M 853 it can be seen that by decreasing the sulfur content to a critically low level and by processing the material as set forth hereinbefore torque curves approaching those of the commercially available 3% silicon iron are closely approximated. However, by comparing the saturation values in Table II, that is, the induction values where the field strength is 100 oersted it is clearly seen that much higher saturation induction values are obtained from the cobalt-iron alloys with overall improved magnetic characteristics resulting from the orientation of the material.

Reference is now directed to FIGS. 2 through 6 inclusive which are photomicrographs of alloys identified therein and whose composition is set forth in Table I. These photomacrographs are at a magnification of 20× after annealing the cobalt iron alloy sheets for 48 hours at 900°C, and show a strong correlation between the sulfur content and the final grain size. From FIGS. 2 through 6 it is apparent that the low sulfur levels result in a large grain size by normal grain growth, that is, from a primarily recrystallized microstructure and not as a result of secondary recrystallization and grain growth. These results as well as the shorter annealing times on M 852 and M 853 indicate that the degree of (110) [001] texture is increased by primary grain growth in alloys containing low sulfur. This in direct contrast to the development of a similar oriented texture in 3% silicon iron where controlled high sulfur levels are required for texture development by secondary grain growth. Thus alloys M 852 and M 853 reflect the additional beneficial aspect that the cobalt iron alloys with low sulfur values have low coercive force values. Moreover it appears that the addition of chromium to these cobalt iron alloys appear to improve the texture formation to some degree while increasing volume resistivity.

Another heat of cobalt iron alloy was melted to substantially the same composition as heat M 853. This heat was identified as heat M 903 and was processed employing substantially the same conditions as heat M 853 with the following exception. After annealing for one hour at 900°C at an intermediate gauge of 0.025 inch, the material was cold rolled to final thicknesses of 0.0095 and 0.012 inch.

Reference is directed to Table III which contains the magnetic characteristics of the heat M 903.

### Table II

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Thickness (in.)</th>
<th>$B_m$ (G)</th>
<th>$B_{im}$ (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 849</td>
<td>0.0095</td>
<td>180,000</td>
<td>18,400</td>
</tr>
<tr>
<td>M 850</td>
<td>0.012</td>
<td>123,700</td>
<td>18,400</td>
</tr>
</tbody>
</table>

Domain pattern texture analysis were performed on samples of material from heats M 852 and M 903, the latter having a finish gauge thickness of about 0.0095 inch. It was found that 85% by volume of the grains had the (110) and 7% by volume displayed (100) texture, of which such (110) grains had crystal lattices whose cube edges aligned within 10° of the [001] direction in 80% of the grains. When the deviation from the [001] or rolling direction was measured within 15°, it was found that the edges of the crystal lattices of 88% of the (110) grains were within this limitation.

Heat M 852 was given a final cold reduction of just 50%, consequently, it did not develop as high a texture as heat M 903 rolled to 0.0095 inch thickness. Actual measurements of heat M 852 indicated 61% by volume.
of the grains had the (110) texture while 16% exhibited the (100) texture. Further, 58% of the cube edges of crystal lattices of the grains deviated less than 10° from the (001) direction and 68% of the grains were within 15° of the (001) direction.

In each of the foregoing, the texture developed by means of primary recrystallization and normal grain growth. In each instance the presence of the (100) [001] texture does not detract from the magnetic characteristics exhibited by the alloy containing the preponderating texture (110) [001].

These data appear to indicate that a slightly higher degree of final cold reduction results in an improvement in the texture and that extremely high induction values are obtained. If the $B_{90}$ values as well as the peak torque values for the heat M 903 at the 9.5 mil stage are compared with the commercial oriented 3% silicon steel as set forth in Table II it becomes clear that a higher degree of (110) [001] texture was obtained in heat M 903 than that in the commercial 3% silicon steel. Thus the peak torque values are higher, the $B_{90}$ values are higher and clearly, as would be expected, the saturation values are near the theoretical maximum.

Another series of heats were made in which the sulfur content was controlled to very low limits, that is, a sulfur content of less than 0.001% by weight. Reference is directed to Table IV which includes the chemical composition of three heats which were made and tested.

### TABLE IV

<table>
<thead>
<tr>
<th>Alloy</th>
<th>% Co</th>
<th>% Cr</th>
<th>% Mn</th>
<th>% Si</th>
<th>% C</th>
<th>% S</th>
<th>% O</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 838</td>
<td>27.0</td>
<td>0.59</td>
<td>&lt;0.42</td>
<td>&lt;0.03</td>
<td>0.004</td>
<td>0.0006</td>
<td>0.0058</td>
</tr>
<tr>
<td>M 839</td>
<td>26.8</td>
<td>0.59</td>
<td>0.43</td>
<td>&lt;0.03</td>
<td>0.005</td>
<td>0.0006</td>
<td>0.0042</td>
</tr>
<tr>
<td>M 840</td>
<td>26.8</td>
<td>0.59</td>
<td>0.43</td>
<td>0.13</td>
<td>0.005</td>
<td>0.0006</td>
<td>0.0012</td>
</tr>
</tbody>
</table>

Both disc samples for torque measurements as well as Epstein samples were cut from the material which samples were annealed for 48 hours at 900°C in dry hydrogen.

Reference is directed to Table V which lists the magnetic characteristics of the alloys.

### TABLE V

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Peak Torque (erg/cm²)</th>
<th>Torque Ratio</th>
<th>$H_c$ (Oe)</th>
<th>$B_{90}$ (G)</th>
<th>$B_{perp}$ (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 838</td>
<td>81,500</td>
<td>0.52</td>
<td>0.52</td>
<td>19,100</td>
<td>22,700</td>
</tr>
<tr>
<td>M 839</td>
<td>90,700</td>
<td>0.48</td>
<td>0.89</td>
<td>18,900</td>
<td>22,700</td>
</tr>
<tr>
<td>M 840</td>
<td>81,300</td>
<td>0.41</td>
<td>0.62</td>
<td>19,000</td>
<td>22,800</td>
</tr>
</tbody>
</table>

From the test results set forth in Table V it is noted that high $B_{90}$ values were obtained indicating a high degree of (110) [001] orientation. To substantially the same effect the saturation values were quite acceptable for the alloys although the peak torque values were somewhat lower than obtained with the better materials previously set forth herein. It is believed that the thicker hot rolled band material resulting in substantially higher intermediate cold reductions resulted in the somewhat lower peak torque values. Accordingly, it is desired to limit the cold reduction effected in each step to a value within the range between about 40 and about 75% in cross sectional area.

From the foregoing it may be noted that each of the alloys which were made and tested contained a cobalt content near the upper limit. Having thus found a high degree of orientation being effected by means of the process of the present invention, other cobalt contents were investigated in order to determine the relative level of cobalt which would be effective for obtaining improved induction values commensurate with obtaining the required degree of (110) [001] orientation in a primarily recrystallized microstructure. Reference is directed to Table VI which contains the nominal composition of two alloys which were made and tested in accordance with the teachings of the present invention it being noted that the alloys set forth in Table VI contain 18% cobalt and 10% cobalt with a corresponding amount of silicon of 1% and 2% being added to obtain improved volume resistivity. In these heats, the sulfur content was controlled so as to maintain a level below about 0.003%.

### TABLE VI

<table>
<thead>
<tr>
<th>NOMINAL CHEMICAL COMPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy</td>
</tr>
<tr>
<td>M 883</td>
</tr>
<tr>
<td>M 887</td>
</tr>
</tbody>
</table>

The alloys were processed in accordance with the following schedule: hot roll at 1050°C to 0.080 inch; pickle; anneal 5 hours at 850°C in dry hydrogen; cold roll to 0.025 inch; anneal 5 hours at 850°C in dry hydrogen; cold roll to 0.011 inch finish gauge thickness. Following cold rolling to finish gauge the alloys were strip annealed for about 5 minutes at 850°C in wet hydrogen and then annealed for 40 hours at 940°C in dry hydrogen. The strip anneal was effective for decarburization and the final anneal took place at a temperature near the $A_{c1}$ temperature but below said $A_{c1}$ temperature.

Reference is directed to Table VII which lists the magnetic characteristics for the alloys of Table VI.

### TABLE VII

<table>
<thead>
<tr>
<th>NOMINAL CHEMICAL COMPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>M 883</td>
</tr>
<tr>
<td>M 887</td>
</tr>
</tbody>
</table>

The torque values indicate a high degree of (110) [001] texture. Although the 10% cobalt sample appears to be a little more highly textured, the 18% cobalt alloy has a higher induction value because of its higher saturation value. These samples exhibited only primary
recrystallization and normal grain growth. In other tests, much lower torque values were obtained in similarly processed alloy compositions having sulfur additions of 0.01%. Also samples slowly heated to final annealing temperature, that is, appear to give poorer results.

From the foregoing examples it can be seen that a high degree of (110) [001] texture can be obtained by primary recrystallization and normal grain growth in cobalt iron alloys over a wide range of cobalt, manganese, silicon and chromium contents. The processing schedule is clearly important and should be noted that the final anneal must be kept below the alpha to gamma transformation temperature which is approximately 950°C or, in more precise terms, at a maximum temperature below the A1 temperature. By thus keeping the sulfur content to less than 0.005%, highly (110) [001] textured alloys are obtained through primary recrystallization and grain growth. Accordingly, transformers and rotating magnetic core devices such as motors and generators employing this material can be made with decreased size and weight resulting in significant economic advantages in the production of both the alloy and the apparatus.

We claim:

1. In the method of producing improved magnetic characteristics in iron-cobalt alloys, the steps comprising, melting a composition within the range between about 5% and about 35% cobalt, up to about 3% of an element which improves volume resistivity and the balance iron with incidental impurities and controlling the sulfur content thereof to a value of less than about 0.005%, hot working the alloy material at a temperature within the range between about 1000°C and about 1100°C to an intermediate gauge, subjecting the intermediate gauge material to an annealing treatment at a temperature within the range between about 600°C and 800°C, pickling, cold working the annealed material in one or more steps to the desired finish gauge, at least the last of said cold working steps effecting a reduction in cross sectional area of between about 40 and about 75% and thereafter annealing at a temperature within the range between about 800°C and the A1 temperature, said process being effective for producing a high grain volume of (110) [001] texture by primary recrystallization and normal grain growth.

2. The process of claim 1 in which the cold worked material is reduced in cross sectional area within the range between about 40 and about 75% in each step.

3. The process of claim 1 in which the initial cold working is performed at a temperature of up to about 300°C.

4. The process of claim 2 in which an intermediate anneal at a temperature in excess of 800°C is interposed between each cold working step.

5. The process of claim 4 in which the intermediate anneal takes place in a decarburizing atmosphere.

6. The process of claim 1 in which all anneals take place in a hydrogen atmosphere.

7. In the method of producing improved magnetic characteristics in iron-cobalt alloys; the steps comprising melting an alloy composition within the range between about 26 and about 29% cobalt, up to 1% chromium, up to 1% manganese, up to 1% silicon and the balance essentially iron with incidental impurities and controlling the sulfur content to less than about 0.005%, hot working the alloy at a temperature within the range between about 1000°C and about 1100°C to an intermediate gauge between about 0.080 and about 0.150 inch in thickness, annealing the alloy at a temperature within the range between about 600°C and 800°C, cold working the alloy in one or more steps to the desired finish gauge and thereafter annealing the alloy at a temperature within the range between about 850°C and 950°C, the alloy after such treatment exhibiting a (110) [001] texture by primary recrystallization and normal grain growth.

8. The process of claim 7 in which the cold worked alloy is reduced in cross sectional area between about 50 and about 75% in at least the last reduction to finish gauge.

9. The process of claim 7 in which the initial cold working includes a hot-cold working at a temperature of up to about 300°C.

10. The process of claim 7 in which an intermediate anneal at a temperature within the range between about 700°C and about 900°C is interposed between each cold working step.

11. The process of claim 10 in which an atmosphere of hydrogen having a dew point of at least +40°F is employed in any anneal prior to the final anneal.

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