Effect of Annealing in a Magnetic Field Upon

Iron-Cobalt and Iron-Cobalt-Nickel Alloys

Prepared by Powder Metallurgy

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Iron-cobalt and iron-cobalt-nickel alloys prepared by powder metallurgy have been heat treated in a magnetic field. The 50 pct iron-cobalt alloy exhibits optimum magnetic properties and an essentially rectangular hysteresis loop when subjected to the best magnetic annealing cycle developed. Small amounts of nickel appear to be detrimental in the alloys studied.

Binary and ternary alloys of iron, nickel and iron-cobalt respond to annealing in a magnetic field by a characteristic change in the shape of their hysteresis loop. An increase in retentivity and a decrease in coercive force produced by the magnetic treatment cause the hysteresis loop to approach the appearance of a rectangle.

Materials with a rectangular hysteresis loop have made possible the contact-rectifier and have greatly improved the performance of pulse transformers and magnetic amplifiers. In the best material presently available for these applications, a 50 pct nickel-iron alloy, the desired characteristics are achieved by aligning the preferred crystallographic directions of magnetization along the rolling direction of the tape.

The objective of the present study has been to produce rectangular hysteresis characteristics in materials with inherently high saturation. Iron-cobalt alloys, exhibiting saturation values up to 24,000 gausses appeared to offer promise for the magnetic annealing technique, because they remain magnetic to very high temperatures, exhibit favorable magnetostriction properties, and show zero crystal energy at 42 pct cobalt.

Among the ternary iron-cobalt-nickel alloys, response to heat treatment in a magnetic field is unfortunately limited to alloys having rather low saturation values. It appeared interesting nevertheless, to study a series of compositions connecting the optimum composition (50/50) of the binary iron-cobalt system with the “Perminvar” composition (30 pct Fe, 25 pct Co, and 45 pct Ni).

Very recently, R. Smoluchowski and R. W. Turner, have shown that under certain circumstances magnetic annealing can produce oriented recrystallization. A combination of this technique with the domain orientation utilized in the present study might well result in further improvements.

The advantages of the powder metallurgy technique in preparing magnetic alloys for study have

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Preparation of Specimens: Toroidal core specimens were prepared from the mixed elemental powders by the following sequence of operations:

1. Press mixed powders in die using pressure of 26 tons per in.². Die lubricant to be 3 pct stearic acid in carbon tetrachloride.
2. Pre-sinter green compact at 800-816°C for 10-25 min.
3. Machine to fit die, if necessary.
4. Repress compact at a pressure of 22 tons per in.² or 66 tons per in.².
5. Sinter compact at 1400-1430°C for a total time of 24 hr in atmosphere of purified dry electrolytic hydrogen. Heating rate from 800° to 1400°C to be approximately 3°C per min.

The variations in the pre-sinter and repress operations correspond to changes made to facilitate production of the cores as the work progressed. These changes did not influence the final results obtained.

Magnetic Anneal: After fabrication and preliminary tests, toroidal cores were magnetically annealed in a stream of purified hydrogen. This was accomplished by heating the cores above their Curie points, and cooling in the presence of a magnetic field. Direct electric current was passed through a copper or platinum winding designed to develop a circumferential magnetic field of the desired magnitude. Optimum response in the magnetic field generally involved an interruption in cooling at 900°C for 1½ hr and cooling to 230°C or below in the presence of the magnetic field.

The standard magnetic annealing treatment was therefore established as follows:
1. Heat cores above Curie temperature (1020°C) for 15 min.
2. Cool rapidly with magnetic field of 20 oersteds to 900°C.
3. Hold 1 to 1½ hr with magnetic field at 900°C.
4. Cool rapidly (23°C per min.) to 230°C or below in presence of magnetic field.

Except where noted, this standard magnetic annealing treatment was applied to all cores.
Density Measurements: Density determinations were made on all alloys using the weight in air-weight in water technique. Since the densities generally approached the theoretical value, the cores were not coated prior to immersion in water.

Magnetic Testing: The magnetic properties of the cores were determined by the standard ring method, employing a ballistic galvanometer and dc electric current. The ring dimensions were chosen in such a way as to make the radial thickness small with respect to the diameter.

The following magnetic properties were measured: (1) saturation at 100 oersteds, (2) remanence after magnetization at 100 oersteds, and (3) coercive force. Because of extreme difficulty encountered in demagnetizing magnetic alloys cooled with a magnetic field, no attempt was made to measure permeability.

Variation in Magnetic Anneal Procedure for Iron-Cobalt-Nickel Cores: The standard magnetic anneal procedure already described was used for all iron-cobalt cores. Iron-cobalt-nickel cores were annealed at the Signal Corps Engineering Laboratories, using a somewhat different procedure. This procedure consisted of heating in an atmosphere of purified electrolytic hydrogen to above the Curie temperature or the alpha-gamma transformation temperature of the individual cores in a magnetic field of 20 to 40 oersteds, increasing the field to 70-80 oersteds upon reaching maximum temperature; holding for 5 to 45 min and then cooling at 1.5 to 3°C per min to 500°C followed by continued cooling at approximately 20°C per min to below

Fig. 1—Effect of Magnetic Anneal on the Magnetic Properties of Iron-Cobalt Alloys.

Fig. 2—Hysteresis Loops and Magnetic Properties of 50 pct Iron-50 pct Cobalt Alloy, Before and After Magnetic Annealing.
100°C with the magnetic field. For the cores of the binary alloys, and the alloys containing 10 pct of nickel, the faster cooling rate was applied at 800°C rather than at 500°C.

Experimental Results and Discussion

Response of Iron-Cobalt Alloys to Magnetic Annealing: Since the alloys of iron and cobalt containing approximately 30 to 55 pct cobalt possess the highest saturation values known for magnetic materials, binary alloys of iron and cobalt were prepared in this range of composition to determine the optimum magnetic properties and response to magnetic annealing.

The effect of composition on the magnetic properties of iron-cobalt alloys before and after magnetic annealing is shown in fig. 1. The properties plotted show the variation in the saturation induction measured at 100 oersteds, the retentivity, and the coercive force caused by the magnetic anneal. Magnetic saturation values given by G. W. Elmen:* These values are credited to Elmen by Bozorth in ref. 14; they are somewhat at variance with those reported by Elmen in ref. 7.

for a field strength of 1500 oersteds are plotted for comparison.

The marked influence of magnetic annealing upon the magnetic properties of iron-cobalt alloys is clearly demonstrated by fig. 1. In general, magnetic annealing causes a large increase in retentivity, an insignificant increase in saturation (H = 100), and a decrease in the coercive force for the alloys studied. The optimum response to magnetic annealing occurs at a cobalt concentration of approximately 50 pct.

The spread in experimental data for the alloys having a composition close to 50 pct iron-50 pct cobalt appears significant. Since almost no variation in magnetic properties occurred for alloys with lower cobalt concentrations, the spread noted for alloys containing approximately 50 pct cobalt appears due to the sensitive behavior of the latter alloys, rather than to any variation in processing variables. This sensitive behavior is most probably associated with the formation of the superlattice in this range of composition.

The 50 pct iron-50 pct cobalt alloy, after annealing, also shows the best magnetic properties characteristic of materials which develop a rectangular hysteresis loop, i.e., a high ratio of retentivity to saturation and a low coercive force. Fig. 2 shows typical hysteresis loops before and after magnetic annealing cores of a 50 pct iron-50 pct cobalt alloy prepared from commercial cobalt powder.

It is significant to note that the 58 pct iron-42 pct cobalt alloy shows the smallest increase in retentivity as the result of magnetic annealing. This result is surprising, since the 42 pct cobalt alloy was initially selected as the most promising for study after an analysis of the important parameters for optimum response to magnetic annealing. Fig. 3, for example, shows that the 42 pct cobalt alloy is magnetic to a very high temperature (980°C); has a high linear magnetostriction value (67.0 x 10^-9) at room temperature and zero crystal anisotropy:*
Similar conditions in the iron-nickel system are associated with an excellent response to magnetic annealing. Poor response to magnetic annealing in the 42 pct cobalt alloy, and optimum response in the 50 pct cobalt alloy are difficult to explain. A comparison of the magnetic constants for these two alloys shown in fig. 3, however, is interesting. The crystal energy of the 50 pct cobalt alloy is considerably greater than that of the 42 pct cobalt alloy. However, the abrupt increase in the volume magnetostriction at the 50/50 composition and the known presence of a superlattice formation in this range appear to be more than a coincidence, and seem to exert a controlling influence on the behavior of the iron-cobalt alloys in the magnetic anneal.

**Effect of Nickel on the Magnetic Properties of Iron-Cobalt Alloys:** Certain binary alloys of iron and nickel provide interesting magnetic characteristics and have achieved commercial prominence. A large number of these alloys respond to heat treatment in a magnetic field and exhibit rectangular hysteresis loops and a low coercive force after magnetic annealing.

Since the binary alloys of iron and cobalt studied showed a comparatively high coercive force after magnetic annealing, it appeared desirable to determine the influence of nickel on the magnetic properties of iron-cobalt alloys.

Two series of iron-cobalt-nickel alloys were therefore fabricated, magnetically annealed, and tested (1) containing 0 to 50 pct nickel and equal amounts of iron and cobalt and (2) containing 0 to 50 pct nickel and an iron content exceeding the cobalt content by 10 pct. Table III gives the composition of the alloys prepared and their sintered density. In addition, cores corresponding to the commercial alloy Perminvar (30 pct iron, 25 pct cobalt, and 45 pct nickel) were prepared in an effort to confirm the response of this alloy to magnetic annealing. All iron-cobalt-nickel cores were fabricated in the standard manner except that they were repressed at 66 tons per in. and sintered at 1375°C, rather than at 1400°C. Magnetic annealing and testing were conducted at the Signal Corps Engineering Laboratories in accordance with the technique already discussed.

The saturation induction, the retentivity and the coercive force before and after magnetic annealing are shown in fig. 4 for the series of iron-cobalt-nickel alloys containing equal amounts of iron and cobalt.

The data presented show a sharp decrease in saturation induction and in retentivity; and an exceedingly sharp increase in the coercive force as the nickel content is increased from 0 to 10 pct. While the coercive force decreases rapidly to a low value with a further increase in nickel content, the saturation and retentivity of the alloys containing more than 10 pct nickel are considerably less than the saturation and retentivity of the 50 pct iron-50 pct cobalt alloy.

The primary influence of heat treatment in the magnetic field appears to be an increase in the retentivity. It is interesting to note from fig. 4 that this increase is pronounced for the alloys containing zero per cent nickel and 30 to 50 pct nickel, but is very small for the alloy containing 45 pct iron, 45 pct cobalt and 10 pct nickel. The failure of iron-cobalt-nickel alloys containing 10 to 20 pct nickel to show appreciable response to magnetic annealing confirms the work of Bozorth and Dillinger. It may be explained by the simultaneous presence of two phases for alloys of this composition when they are cooled to room temperature. The large coercive force also is the result of this fact.

The saturation induction, the retentivity and the coercive force before and after magnetic annealing are shown in fig. 5 for the series of iron-cobalt-nickel alloys in which iron exceeds cobalt by 10 pct. In general the effect of nickel in the iron-rich alloys is similar to its effect in the alloys containing equal amounts of cobalt and iron; although the minimum values of saturation induction and retentivity after magnetic annealing, and the maximum value of the coercive force occur at a somewhat higher nickel content, i.e., 20 pct nickel. This is most probably due to the location of the boundaries of the heterogeneous two phase field in the iron-cobalt-nickel system extending from the 78 pct cobalt point on the iron-cobalt side to the binary iron-nickel alloys with 20 to 30 pct nickel.

It is interesting to note in fig. 5 that the coercive force is a maximum after the magnetic anneal for the 20 pct nickel alloy. This observation is contrary to the decrease in coercive force resulting from the magnetic anneal experienced with all other iron-cobalt-nickel cores. The anomalous behavior of the 20 pct nickel alloy is most probably associated with the effect of heat treatment upon the development of the heterogeneous alloy containing two phases.

The magnetic properties before and after magnetic annealing of a Perminvar core prepared by powder metallurgy are given in table IV. This table also shows the approximate results obtained by Bozorth and Dillinger by heat treating Perminvar in a magnetic field. The results are in fair agreement and confirm the response of this alloy to heat treatment in a magnetic field. The results also demonstrate that alloys prepared by powder metallurgy give results comparable to those prepared by conventional methods.

For the iron-cobalt-nickel alloys studied, the results presented demonstrate the undesirable influence of nickel upon the magnetic properties after heat treatment in a magnetic field. Unfortunately, a reduction in the coercive force is obtained only with nickel contents which cause a considerable decrease in the values of saturation and retentivity. Because of the sharp increase in coercive force with low nickel concentration, it appears that the presence of nickel as an impurity in the cobalt powder may be very detrimental.

**Influence of Variables in the Magnetic Anneal:** The influence of a number of variables in the magnetic annealing treatment was studied to determine an optimum cycle.

**Field Strength:** Experiments to determine the influence of field strength during cooling were conducted over a range of 1 to 20 oersteds, using a 50 pct iron-50 pct cobalt alloy. The subsequent tests conducted on iron-cobalt-nickel alloys, using a field strength of 70-80 oersteds during cooling, did not
appear to alter the conclusions reached from the experimental work using lower field strengths.

The influence of field strength on the retentivity and the coercive force after magnetic annealing is shown in fig. 6. Also plotted in this figure is the influence of field strength during magnetic annealing upon the ratio of retentivity to saturation in per cent. This ratio is an indication of the magnetic orientation achieved by magnetic annealing, and of the approach to a rectangular hysteresis loop. In these tests the cores were prepared from commercial cobalt powder, and were treated in accordance with the standard magnetic anneal cycle except that a slow cooling rate (3°C per min) was used to cool from the holding temperature of 900°C. Since subsequent experiments showed the beneficial effect of cooling more rapidly, particularly with respect to the coercive force, the properties shown in fig. 6 should not be considered optimum.

The rapid increase in retentivity upon cooling in a magnetic field as weak as 1.5 oersted is striking. It is also notable that the retentivity as well as the coercive force show little change as the field strength is increased from 10 to 20 oersteds. For this reason, all subsequent cores, except the iron-cobalt-nickel alloys, were cooled in a magnetic field of 20 oersteds.

It is interesting to note that Kelsall also obtained excellent response to magnetic annealing for iron-nickel and iron-cobalt-nickel alloys using a field strength of one oersted. Apparently, only low field strengths are required to develop sufficient magnetostrictive stresses for good response to magnetic annealing in those alloys which do respond.

**Cooling Method:** The formation of a superlattice known to form in 50 pct iron-50 pct cobalt alloys under favorable conditions of cooling from above the α-γ transformation (see fig. 3), and the possible influence of the superlattice formation upon the magnetic properties, after magnetic annealing, made a study of the influence of cooling rate very desirable.

Three approximate cooling rates were used, (1) 3°C per min, (2) 23°C per min, and (3) 48°C per min, all cooling rates being determined over the temperature range 900 to 100°C. The influence of cooling rate may be seen by a comparison of magnetic properties after the magnetic anneal shown in Table V. The results shown are an average of four cores heat treated in accordance with the standard magnetic anneal procedure described, except that the cooling rate was varied.

The principal effect of rapid cooling in the presence of a magnetic field is a decrease in the coercive force, without an appreciable change in the retentivity or saturation. This effect appears most pronounced when the cooling rate is increased from 3 to 23°C per min and seems less pronounced and consistent when it is increased to 48°C per min.

The decrease in coercive force resulting from a
### Table VI. Effect of Interrupting Cooling

<table>
<thead>
<tr>
<th>Time at 900°C (Hrs)</th>
<th>Cooling Rate 3° C per min</th>
<th>Cooling Rate 23° C per min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( B_s ) per ( B_r ), Pct. ( H_c ), oersteds</td>
<td>( B_s ) per ( B_r ), Pct. ( H_c ), oersteds</td>
</tr>
<tr>
<td>1</td>
<td>82.6</td>
<td>0.94</td>
</tr>
<tr>
<td>0</td>
<td>79.9</td>
<td>1.06</td>
</tr>
</tbody>
</table>

### Table VII. Influence of Magnetic Field in Cooling

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Magnetic Properties ( B_s ) per ( B_r ), Pct. ( H_c ), oersteds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Applied During Cooling 1020° to 900° C only</td>
<td>71.1</td>
</tr>
<tr>
<td>Field Applied During Cooling 1020° to 230° C</td>
<td>80.9</td>
</tr>
</tbody>
</table>

more rapid cooling rate during magnetic annealing appears associated with the suppression of the superlattice which may form in the 50 pct iron-50 pct cobalt alloy. Actually, it appears doubtful whether cooling rates as high as 48°C per min would produce an appreciably disordered structure. Recently Goldman and Smoluchowski have shown that a 50 pct iron-50 pct cobalt alloy may show slight ordering even after a quench in cold water. Unfortunately, any explanation for the behavior exhibited, based upon metallurgical effects such as a dispersed phase appear to require additional experimental work.

The effect of interrupting cooling to maintain a constant temperature of 900°C for 1 hr in the presence of the magnetic field before further cooling with the field is illustrated by the data tabulated in table VI. The holding period at 900°C causes a consistent though small increase in the ratio of retentivity to saturation, and a decrease in the coercive force. This effect appears to be associated with a metallurgical change and may well be attributed to an increase in grain size caused by the time of holding at a temperature just below the \( \alpha \rightarrow \gamma \) transformation. Since these effects are beneficial, a holding period was included in the standard magnetic anneal procedure described.

The important influence of the magnetic field in cooling through the range of temperature 900° to 230°C is illustrated by the fact that 50 pct iron-50 pct cobalt cores cooled from 1020°C to 900°C with the magnetic field, and then to 230°C without the field gave decidedly inferior re-

Fig. 5—Influence of Nickel on the Magnetic Properties of Iron-Cobalt Alloys, Before and After Magnetic Annealing, pct Fe = pct Co + 10 pct.

Fig. 6—Effect of Field Strength During Magnetic Anneal on Magnetic Properties of a 50 pct Iron-50 pct Cobalt Alloy. Commercial Cobalt Powder, Furnace Cool (3°C per min) from Holding Temperature.
results. This is illustrated in table VII. The ratio of retentivity to saturation is considerably lower and the coercive force appreciably higher for the core cooled without the magnetic field from 900°C.

The results presented in table VII agree with those of Bozorth and Dillinger,1 who showed that maximum response in the magnetic anneal is associated with cooling in the presence of the magnetic field to a threshold temperature above which the alloy is plastic enough to be affected by the forces of magnetostriction.

**Holding Temperature:** Since the experiments concerning cooling method showed consistent improvement for a 1 hr holding period at 900°C with the magnetic field during cooling, additional experiments were conducted to determine the effect of other holding temperatures. The influence of a 1 hr holding period at various temperatures during the magnetic anneal upon the magnetic properties developed is shown in fig. 7 for a 50 pct iron-50 pct cobalt alloy. All cores were heat treated with the magnetic field in the standard manner, except that cooling was interrupted for a 1 hr period at the temperature shown.

The holding temperature appears to play a significant role in the ultimate properties to be derived from the magnetic anneal. The data indicate that the magnetostrictive forces are most effective at a temperature close to the transformation temperature where the increased plasticity allows optimum orientation of the magnetic domains. Since plasticity increases with temperature, the importance of a high Curie temperature is evident.

**Holding Time:** The influence of holding time at a temperature of 900°C while cooling with the magnetic field is shown in fig. 8. The results shown were obtained by using the same cores for each holding time. Between experiments the cores were heated above the $\alpha$-$\gamma$ transformation temperature, i.e., to 1020°C for 15 min and cooled slowly without the field to eliminate the effect of the previous magnetic anneal.

The data of fig. 8 show that little improvement is realized by increasing the time of holding with the magnetic field at 900°C beyond ½ hr. This is the anticipated behavior in the light of the good plasticity of the metal at higher temperature.

Although the results indicate that a holding period of 30 min was sufficient to develop optimum magnetic properties in cores repeatedly heat treated, subsequent work indicated that new cores magnetically annealed for the first time did not develop optimum response until the holding time was increased to 1½ hr. For this reason, 1½ hr was selected as the holding period at 900°C for the standard magnetic anneal procedure.

**Influence of Variables in Core Preparation:** The relative ease of preparing numerous new alloys of definite composition by the powder metallurgy technique is clearly demonstrated in this study. The ability to prepare cores directly, without resorting to fusion, hot working and cold working, or machining allows rapid study of alloy systems.

The magnetic properties produced in cores prepared by the powder metallurgy technique are in good agreement with those produced by fusion. This is illustrated in fig. 9. The somewhat lower values
of saturation induction are probably the result of the lower density exhibited by the powder metallurgy alloys. In this respect, it may be noted that the maximum discrepancy in saturation occurs for those alloys which show the greatest difference in density between the fused alloy and the powder metallurgy alloy.

Since all of the alloys studied were prepared by the powder metallurgy technique rather than by fusion, no information was available concerning the influence of processing variables unique to powder metallurgy upon the magnetic properties of the alloys studied. Experiments were therefore conducted to determine the influence of different lots of commercial iron and cobalt powders, mixing time, repressing pressure and rates of heating and cooling, during sintering, upon the ultimate magnetic properties.

**Fabrication Variables:** The influence of different lots of commercial powder, mixing times from hand mixing to machine mixing for 72 hr, repressing pressures from (0 to 66 tons per in.²), and rapid vs. slow heating and cooling rates during sintering, upon the ultimate magnetic properties produced, was found to be insignificant in the range of variables studied. Small changes in magnetic properties caused by processing variables generally fell within the deviation expected for a single group of cores prepared in accordance with the standard procedure finally developed. The small effect of the processing variables studied upon the ultimate magnetic properties can be attributed to the long sintering treatment at a temperature just below the solidus for the alloys. All iron-cobalt alloys were sintered at 1400-1420°C for a total time of 24 hr. Such a sintering treatment would tend to mask the effects of other processing variables.

**Raw Material:** Although experiments showed little variation in the magnetic properties of cores procured from the different lots of commercial cobalt powder used in this investigation, the rather large amounts of impurities present in the commercial cobalt powder used (table I) suggested the possibility that purer cobalt powder might give better magnetic properties. The striking and detrimental influence of small amounts of nickel upon the coercive force of iron-cobalt alloys, appeared to strengthen this possibility.

Hysteresis loops and magnetic properties are shown in fig. 10 for a 50 pct iron-50 pct cobalt core prepared from the special cobalt powder reported to contain 99.13 pct nickel and 0.50 pct oxygen. The properties shown are the optimum achieved to date in this study. It will be noted by comparison with fig. 2 showing the typical magnetic properties for 50 pct iron-50 pct cobalt cores prepared with commercial cobalt powder, that the retentivity after magnetic annealing is appreciably higher, and the coercive force considerably lower for the core made with the special cobalt powder. Although the study to determine the influence of small amounts of impurity in iron-cobalt alloys upon the magnetic properties is in the initial stages, it is believed the improvement shown by cores made from the special powder is due to less impurities.

**Summary and Conclusions**

Rectangular hysteresis loops have been developed for binary alloys of iron and cobalt prepared by powder metallurgy and annealed in a magnetic field. The pronounced influence of magnetic annealing on the ultimate magnetic properties produced in a 50 pct iron-50 pct cobalt alloy are shown in fig. 2 and 10.

Response to magnetic annealing and the ultimate magnetic properties are a function of the composition. The optimum retentivity and minimum coercive force after magnetic annealing occur at a cobalt concentration of approximately 50 pct.

The optimum magnetic properties of the 50 pct iron-50 pct cobalt alloy are: saturation (H = 100) equals 22,400 gausses, retentivity equals 19,000 gausses and coercive force equals 0.68 oersteds; and were obtained with a specially prepared cobalt powder. The 50 pct iron-50 pct cobalt composition coincides with a high α-γ transformation temperature, a high linear magnetostriction, and maximum volume magnetostriction, but not with minimum crystal anisotropy.

The addition of small amounts of nickel (0 to 10 pct) to iron-cobalt alloys with approximately equal amounts of iron and cobalt, causes a striking increase in the coercive force, and a sharp decrease in the retentivity and saturation. Although greater amounts of nickel (10 to 50 pct) cause a rapid decrease in the coercive force to a low value, the saturation (H = 100) and the retentivity of the iron-cobalt-nickel alloys after magnetic annealing remain considerably below those obtained for the 50 pct iron-50 pct cobalt alloy.
The high coercive force, and the failure of iron-cobalt-nickel alloys containing 10 to 20 pct nickel to respond to magnetic annealing are associated with the heterogeneous two phase field known to exist for iron-cobalt-nickel alloys in this range of composition; and the results confirm those of Bozorth and Dillinger. Likewise, the magnetic properties obtained in this study after magnetic annealing the alloy Perminvar (30 pct iron-25 pct cobalt-45 pct nickel) are in close agreement with those presented by Bozorth and Dillinger.

Studies have been conducted to determine the influence of field strength, cooling method, holding temperature and holding time during cooling in a magnetic field upon response to magnetic annealing. Results of these studies indicate that cooling from above the α-γ transformation temperature in a magnetic field of 20 oersteds to 900°C, followed by a hold of 1½ hr at 900°C with the magnetic field, and then cooling at a rate of 20 to 25°C per min to below 230°C with the magnetic field provides an optimum response for the 50 pct iron-50 pct cobalt alloy.

Finally, the suitability and ease of powder metallurgy as a technique for preparation of numerous alloys for magnetic analysis has been demonstrated.

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