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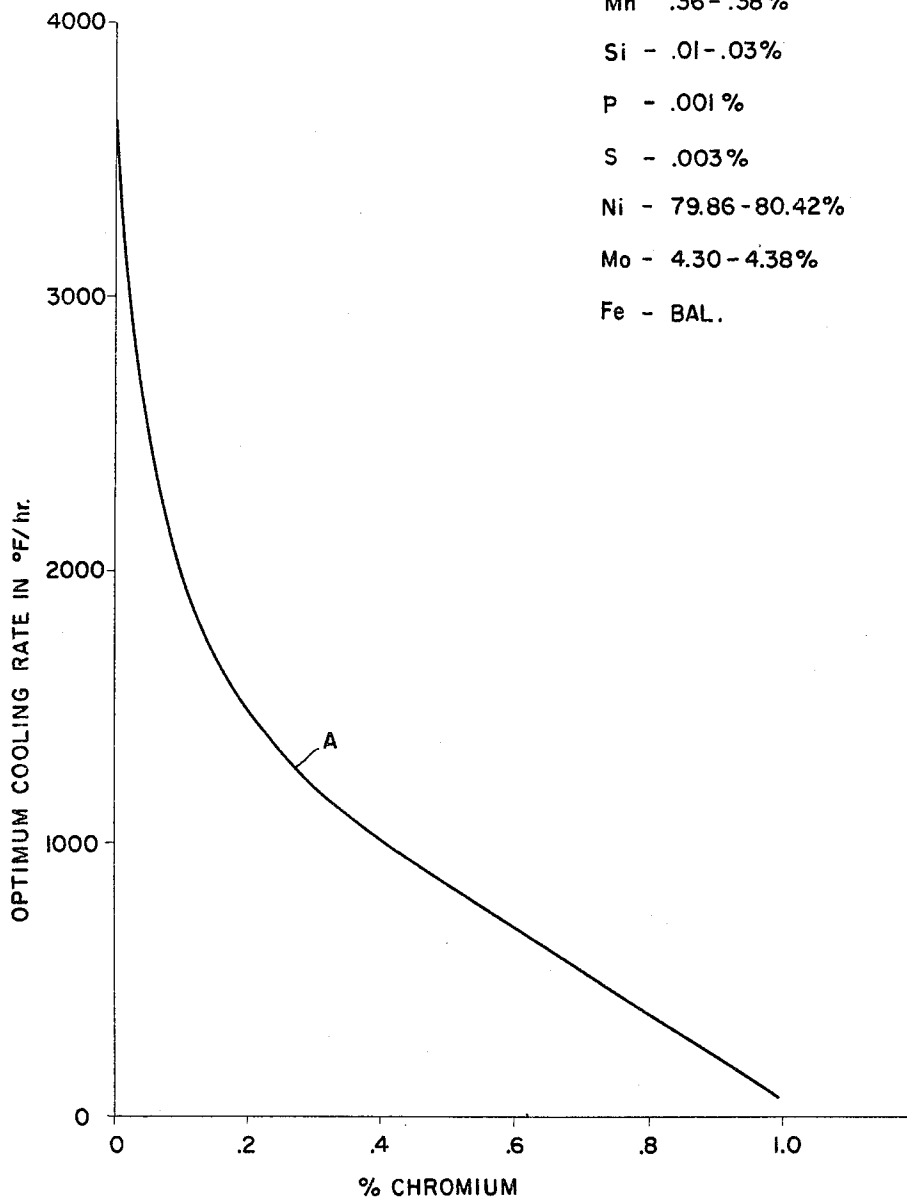
A. A. LYKENS ETAL

3,269,834

MAGNETIC ALLOYS

Filed Sept. 28, 1962

C - .003-.005%
Mn .36-.38%
Si -.01-.03%
P -.001%
S -.003%
Ni - 79.86-80.42%
Mo - 4.30-4.38%
Fe - BAL.



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MAGNETIC ALLOYS

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This invention relates to magnetic alloys and more particularly to magnetic alloys and a method for making the same, having improved initial permeability at a small magnetizing force with relatively low hysteresis loss which is more readily attained than heretofore by commercial parts fabricators.

Magnetic alloys have long been known and used to make parts for use where high initial permeability is an important property. One such alloy is set forth in United States Patent No. 1,768,443, and is commercially available as an alloy containing 0.05% carbon, 0.50% manganese, 0.15% silicon, 79.0% nickel, 4.50% molybdenum and the balance iron. This alloy is normally melted in an electric arc or induction melting furnace and processed into strip ranging from about 0.001 to 0.020 inch in thickness. Laminations and parts are formed from the strip as by blanking or deep drawing and annealed at about 2050° F. for a period of four hours in an oxygen free atmosphere of dry hydrogen, followed by cooling at a controlled rate through the critical ordering temperature range, from about 1100° F. down to about 550° F.

It has been the general experience in the industry that considerable difficulty is encountered in achieving high initial permeability in such materials on a consistent basis. In practice, the initial permeability varies widely from one heat to another and as a result a relatively low commercial standard value of 20,000 has been adopted as the minimum acceptable initial permeability. The commercial standard of 20,000 for initial permeability represents a substantial compromise because values as high as 50,000 or higher are attainable although not consistently.

It has also been found that higher values of initial permeability may be obtained by melting in vacuum an alloy containing somewhat more molybdenum, that is, up to about 5% total molybdenum, and then annealing the strip material at a temperature of about 2400° F. Considerable difficulty has been encountered in obtaining consistent results with this vacuum melted and high temperature annealed material. Furthermore, the high temperature anneal at 2400° F. materially increases the cost of the product.

Considerable effort has been expended toward obviating the difficulties surrounding the manufacture and fabrication of parts from high permeability alloys. It has become generally understood that a major factor contributing to the difficulties encountered in obtaining consistent results resides in the sensitivity of the magnetic property to even relatively small variations in analysis of the composition. As a result, considerable effort has been expended in developing such techniques as vacuum melting and annealing procedures in controlled atmospheres which have added materially to the cost of the materials but thus far have had but little effect upon the difficulty of obtaining consistent results.

A very small variation in the composition of highly purified nickel-iron-molybdenum magnetic alloys has been found to have a large effect upon the cooling rate required to bring out the highest attainable initial permeability in a given specimen. A difference in analysis of as little as a few tenths of a percent by weight or even less in the amount by which an element is present may result in a shift in the required cooling rate by hundreds or even thousands of degrees per hour.

The furnaces in use in the field for annealing and cooling commercial quantities have limited capabilities both as to the maximum annealing temperature and as to the rates at which controlled cooling can be carried out. Cooling rates of up to about 1500° F. per hour are commercially practical but many furnaces in use in commercial establishments are capable of maintaining cooling rates of no greater than up to about 1000° F. per hour. Ideally, the cooling rate required to bring out the maximum attainable initial permeability in a given material is one which falls within the capabilities of the furnaces in use in the field by those who fabricate parts from these magnetic alloys.

Our experiments have shown that when such alloys as exemplified by the aforementioned nickel-iron-molybdenum alloys are refined toward increasing purity as by commercial vacuum melting techniques, the optimum cooling rate required to obtain the highest initial permeability of which the material is capable ranges from approximately 2000° F./hr. to 4000° F./hr. Such rapid cooling rates are not suited to the equipments in commercial use. Thus, the maximum attainable initial permeability is not realized in practice. Furthermore, consistent results are not achieved because very small changes in the analysis of the material from one heat to another causes a wide fluctuation in its initial permeability for a given cooling rate.

We have discovered that by adding small but definite amounts of certain elements to the composition primarily made up of nickel, iron and molybdenum, a unique degree of stability is achieved in that the span of cooling rates required to bring out the maximum attainable initial permeability is kept well within the capabilities of commercially used equipment. Furthermore, the compositions provided in accordance with our present invention are characterized by initial permeability values markedly higher than those consistently attainable hitherto on a commercial basis.

It is therefore a principal object of our invention to provide a magnetic alloy having significantly improved initial permeability which may be consistently and readily achieved by commercial parts fabricators.

Another object of our invention is to provide a method for inhibiting the cooling rate required to bring out in the magnetic composition its maximum attainable initial permeability and at the same time desensitizing the material to changes in composition whereby to minimize the effect of variations in composition, including those incidental to good commercial practice, upon the cooling rate required to bring out the highest attainable initial permeability values of the composition.

Further objects and advantages of our invention will be apparent from the following description thereof and the accompanying drawing which is a graph showing the effect of up to about 1% variations of chromium upon the optimum cooling rate required to bring out the maximum attainable initial permeability in the nickel-iron-molybdenum magnetic alloy.

In this application, by permeability it is intended to refer to the standard value represented by the ratio of the flux density, measured in gauss, produced in the composition to the magnetizing force in oersteds producing this flux density. The initial permeability values set forth herein were obtained with a flux density of 40 gauss (B_{40}) induced by a 60 cycle per second current, but it is to be understood that use of the composition and the method of our invention is not limited thereto because other flux densities and direct or alternating current may be used.

Magnetic alloys, with which the present invention is concerned, contain from about 75% to 85% nickel, 3% to 5% molybdenum with the balance consisting essen-

tially of iron, conveniently termed the "base" composition or analysis. The highest initial permeability is obtained when the nickel content is kept within the preferred range of about 79% to 80.5%. Molybdenum is most effective when present in amounts of from about 3.75% to 4.5%. Because the magnetic properties of such compositions have been found to be sensitive to the presence of impurities and are detrimentally affected thereby, care is exercised to keep impurities to a minimum. However, customary commercial practices result in various elements that are not deliberately added, being present in quantities which may vary from a few thousandths of a percent to a few hundredths of a percent. For example, phosphorus and sulfur each may be present in amounts less than 0.01%, while an element such as chromium when not deliberately added may be present in amounts less than 0.05%. Various elements not necessary to the achievement of the desired magnetic properties and which do not adversely affect the magnetic properties to an undesirable extent may be included when their presence is beneficial in connection with the melting or working of the alloy or for other reasons. Thus, it is intended by the foregoing expression "consisting essentially of iron" to include in the aforementioned base composition as well as in the alloys of the present invention, the foregoing and additions of other elements such as silicon and manganese which do not objectionably affect the desired magnetic properties but are beneficial for other purposes.

Because carbon appears to adversely affect the desired magnetic properties, it is limited to not more than 0.10% and preferably is limited to not more than 0.04%. Silicon and manganese are included in such compositions for the purpose of maintaining fluidity in the melt and to improve the hot workability of the composition. For this purpose, up to 1% manganese and up to 1% silicon is helpful but each is preferably limited to no more than .5% for best results.

We have determined that the hitherto encountered difficulty in obtaining consistent results in providing magnetic materials having high initial permeability results primarily from the fact that the heat treatment required to bring out the maximum attainable initial permeability of said base composition is widely affected when there is a relatively small variation in the composition of the material. This is illustrated by the steepness of the slope of the extreme left hand portion of Curve A in the drawing where the optimum cooling rate in degrees Fahrenheit per hour to bring out maximum attainable initial permeability is plotted along the vertical axis and the chromium content from a trace up to about 1% is plotted along the horizontal axis. As indicated for ready reference in the drawing, the alloy, in addition to chromium, consisted essentially of .003-.005% carbon, .36-.38% manganese, .01-.03% silicon, .001% phosphorus, .003% sulfur, 79.86-80.42% nickel, 4.30-4.38% molybdenum, and the remainder iron.

The portion of Curve A to the left of the .2% addition of the fourth element of which chromium is illustrative, demonstrates the extreme sensitivity of the alloy to relatively small changes in analysis. The alloy is sensitive not only to variations in the content of the fourth element but also to variations in the nickel and molybdenum content. Variations from heat to heat may be as much as about .3% in the nickel content and about .1% in the molybdenum content even when good commercial practices are followed in processing the alloy within extremely narrow melting limits. Thus, in the absence of a fourth element addition in accordance with the present invention, the optimum cooling rate may vary by as much as 1000° F. per hour or more because of differences in content of up to one or two tenths percent from heat to heat and the required cooling rate is usually beyond the capabilities of the furnaces found in the field.

The underlying causes of this phenomenon are not fully understood but the wide variation in the cooling rate resulting from very small variations in composition from one heat to another has thus far prevented the consistent attainment on a commercial basis of the high initial permeability values which may be obtained experimentally.

In accordance with our present invention, we utilize from about 0.2% to up to about 1% of a fourth element selected from the group chromium, columbium and titanium to stabilize the heat treatment required to bring out in the material the maximum attainable initial permeability. When such a deliberate addition is made to the base analysis, the slope of the cooling rate versus maximum initial permeability curve is markedly reduced as illustrated by Curve A, with the result that minor variations in the composition of the material now only have an insignificant effect on the cooling rate required to attain optimum initial permeability. Preferably, one of the elements selected from the group of chromium, columbium and titanium is utilized in amounts ranging from about 0.3% up to 0.8% while best results are achieved by such an addition in an amount ranging from 0.4% to 0.65%. Not only is the cooling rate which is required to bring out the optimum initial permeability of the material stabilized to a remarkable degree by such additions but also higher initial permeability values are achieved than could be achieved with the base material in the absence of such additions.

When present in amounts above about 1%, the elements chromium, columbium and titanium have the undesirable effect of depressing the maximum attainable initial permeability values. In addition, when any one or more of these elements is present in such large amounts as more than 1%, then the required cooling rate for achieving the maximum attainable initial permeability becomes so slow that the time required to carry out a single annealing treatment is excessive. When chromium, columbium and titanium are present in amounts below about 0.2%, the cooling rate required to achieve maximum attainable initial permeability is not sufficiently stabilized for practical purposes and the maximum attainable initial permeability is not beneficially affected.

Tests have shown that the base analysis in the absence of a deliberate addition of chromium, columbium or titanium in the amounts stated, has an ultimate attainable initial permeability ranging from about 40,000 to about 55,000 for the various heats tested which can be realized only when a cooling rate of about 3000 to 4000° F. per hour is utilized. On the other hand, controlled additions of the elements chromium, columbium and titanium in accordance with the present invention have resulted in initial permeability values ranging from about 65,000 to about 93,000 with cooling rates below 1000° F. per hour.

In preparing the various compositions, a charge was made up of electrolytic iron, plate nickel and metallic molybdenum, which is melted in a crucible in the desired proportions. To this melt, metallic silicon, electrolytic manganese, as well as ferrochromium, ferrocolumbium, or ferrotitanium, as the case may be, were added in the proper proportions. The melting, refining and teeming of the metal were all carried out in a vacuum furnace. The ingots which were formed were stripped from their molds and allowed to cool in air. The ingots were reheated to about 2300° F. and hot worked into a slab. The slab, after being surface ground, was reheated to 2300° F. and by hot rolling was formed into 0.187 inch strip. This strip was cleaned to remove the mill scale and was then cold rolled to a final thickness of 0.006 inch. The following examples which were all prepared in accordance with the foregoing, are illustrative of our composition and of our method of stabilizing the cooling rate.

Example 1.—For use by a parts fabricator having an annealing furnace capable of providing good control of the cooling rate in the range of from about 800° F./hr.

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to about 1500° F./hr., an alloy was prepared having the following analysis:

	Percent
Carbon	.005
Manganese	.38
Silicon	.01
Phosphorus	.001
Sulfur	.003
Nickel	79.86
Molybdenum	4.30
Chromium	.34
Iron	Balance

Rings having an outside diameter of 1½ inches and an inside diameter of 1 inch were formed from 0.006 inch strip of this analysis. A number of stacks of thirty of such rings, each stack weighing about 25 grams, were formed and were annealed at 2050° F. for three hours in a dry hydrogen atmosphere having a dew point of -50° F. or less. Then each specimen was cooled at a predetermined rate in the dry hydrogen atmosphere down through the critical ordering temperature range. After each specimen had been demagnetized, it was subjected to an increasing 60 cycle per second magnetizing force until a flux density of 40 gauss was obtained. The energizing current producing this flux density was measured and the initial permeabilities calculated therefrom.

The cooling rates utilized were varied in nine steps from the very slow rate of 14° F./hr. to the extremely fast rate of about 8000° to 10,000° F./hr. The specimens having the analysis of Example 1 gave an initial permeability value of 80,500 at a cooling rate of 1080° F./hr. and were characterized by values of initial permeability consistently greater than 65,000 when the cooling rate ranged from about 800° to 1500° F./hr. Furthermore, stabilization of the composition against sensitivity to variations in cooling rate was demonstrated by the fact that even when the cooling rate was as low as 350° F./hr., the initial permeability of the specimen tested was found to be 64,200, a value significantly greater than that attainable with the aforementioned base analysis.

Example 2.—For use by a parts fabricator, having equipment adapted for maintaining cooling rates somewhat slower than that of Example 1, an alloy was prepared having the following analysis:

	Percent
Carbon	.003
Manganese	.37
Silicon	.03
Phosphorus	.001
Sulfur	.003
Nickel	80.14
Molybdenum	4.30
Chromium	.62
Iron	Balance

Stacked rings of the analysis of Example 2 were prepared and tested as was described in connection with Example 1. With cooling rates of from about 350° to 700° F./hr., the specimens of Example 2 were found to have initial permeabilities of from 88,100 to 93,600. When as low a cooling rate as 165° F./hr. was used, the specimens continued to give a value of initial permeability above 70,000. It was not until the cooling rate was reduced below 100° F./hr. that the initial permeability of the specimens of this example fell below 55,000, the maximum attainable initial permeability for the base analysis at its optimum cooling rate of approximately 3500° F./hr.

Additions of columbium or titanium in accordance with the present invention, like chromium, also have the effect of not only making possible attainment of improved initial permeability values, but also have a similar effect in stabilizing the optimum cooling rate required to bring out improved values of initial permeability. However, the smaller amounts of columbium or titanium below about 0.35% appear to be somewhat less effective

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than like amounts of chromium in retarding the cooling rate. Nevertheless, within the broad ranges stated herein both columbium and titanium are effective at any given cooling rate in raising the value of the attainable initial permeability above that attainable with the base analysis at the same cooling rate.

Example 3.—An alloy was prepared having the following analysis:

	Percent
Carbon	.007
Manganese	.36
Silicon	.04
Phosphorus	.001
Sulfur	.003
Nickel	80.08
Molybdenum	4.25
Chromium	.02
Columbium	.26
Iron	Balance

This alloy was processed and formed into specimen stacks and then tested for initial permeability with different cooling rates as was described in connection with the alloy of Example 1. Values of initial permeability consistently above about 55,000 were obtained with cooling rates ranging from about 350° to 1500° F./hr. as compared to the maximum initial permeability of about 44,000 to 45,000 over the same range of cooling rates obtained from specimens of an alloy identical to that of Example 3 but containing no more than a trace of columbium.

Example 4.—An alloy was prepared having the following analysis:

	Percent
Carbon	.008
Manganese	.37
Silicon	.07
Phosphorus	.002
Sulfur	.003
Nickel	79.84
Molybdenum	4.39
Chromium	.02
Columbium	.56
Iron	Balance

Specimens of this alloy were prepared and tested as was described in connection with Example 1. Initial permeability values consistently greater than 75,000 were obtained over a range of cooling rates from about 350° to 1500° F./hr. An initial permeability value of 90,000 was obtained with a cooling rate of about 1080° F./hr. With this alloy, the attainable initial permeability is not brought below about 60,000 until the cooling rate utilized is depressed below about 150° F./hr.

Example 5.—An alloy was prepared having the following analysis:

	Percent
Carbon	.008
Manganese	.39
Silicon	.05
Phosphorus	.002
Sulfur	.003
Nickel	80.06
Molybdenum	4.37
Chromium	.02
Columbium	.86
Iron	Balance

Specimens of this alloy were prepared and were tested as was described in connection with Example 1. Cooling rates ranging from about 50° F. to about 1500° F. per hour consistently gave values of initial permeability greater than about 50,000 and with cooling rates ranging from about 150° F. to about 700° F. per hour, the initial permeability ranged at about 70,000 with a high value of 77,500 being obtained with the cooling rate of 165° F./hr.

Example 6.—An alloy was prepared having the following analysis:

	Percent
Carbon	.007
Manganese	.36
Silicon	.06
Phosphorus	.001
Sulfur	.005
Nickel	79.82
Molybdenum	4.31
Chromium	.01
Titanium	.26
Iron	Balance

Specimens of this alloy were prepared and tested as was described in connection with Example 1. Initial permeabilities of 50,000 or above were consistently obtained with cooling rates ranging from about 350° to 1500° F./hr. as compared to initial permeabilities of about 40,000 obtained from specimens of the same analysis but containing no more than a trace of titanium, the maximum attainable initial permeability of which was found to be about 47,000 at a cooling rate of about 3500° F./hr.

Example 7.—An alloy was prepared having the following analysis:

	Percent
Carbon	.006
Manganese	.36
Silicon	.02
Phosphorus	.003
Sulfur	.004
Nickel	80.00
Molybdenum	4.35
Chromium	.02
Titanium	.57
Iron	Balance

Specimens of this alloy were prepared and tested as was described in connection with Example 1. Initial permeability values of from about 60,000 to 70,000 were consistently obtained with cooling rates ranging from about 150° to 1200° F./hr., the maximum value attained being 70,300 at the cooling rate of 1080° F./hr.

The optimum cooling rate for obtaining maximum initial permeability for the base analysis is approximately 3500° F./hr. and is so fast that it could not be achieved with the standard commercial equipment normally in use in the field and requires relatively expensive equipment designed especially for such a purpose. Furthermore, a relatively small change in the analysis of the base composition results in a relatively large shift in the cooling rate required to bring out the maximum initial permeability in the slightly modified base analysis and this optimum cooling rate must be determined empirically for each heat. On the other hand, in accordance with the present invention, the cooling rate is not only stabilized but is shifted downward to a range which can be readily maintained by conventional equipments normally encountered in the field.

Consistently higher values of initial permeability are obtained in accordance with the present invention without the requirement of cooling rates any faster than about 1500° F./hr. A fabricator provided with equipment in which the work pieces can be cooled at a predetermined rate falling within the faster portion of the practical band of cooling rates can now produce products which are consistently characterized by much higher values of initial permeability than hitherto when our compositions containing the smaller additions of the elements chromium, columbium and titanium are utilized. On the other hand, when the equipment of the fabricator is of such nature that it can only accurately maintain the slower cooling rates, then utilization of our compositions containing the larger additions of chromium, columbium and

titanium in the fabrication of parts required to have high initial permeability, also makes possible consistent attainment on a commercial basis of much higher values of initial permeability than hitherto.

While the highest values of initial permeability are attainable when the alloys are vacuum melted as was described in connection with the foregoing examples, the present invention is also applicable to those alloys when they are prepared by other processes or are air melted as in arc or induction melting furnaces. When alloys were prepared as was described in connection with the examples set forth herein except that they were melted in an air induction furnace, then annealed at 2050° F. until magnetically stabilized, the additions of chromium, columbium or titanium in accordance with the present invention were found to be effective to shift the cooling rate required to bring out the maximum attainable initial permeability to rates well within the range readily maintained by parts fabricators. At the same time, the values of initial permeability attained with our alloys at the slower cooling rates were consistently equal to or higher than the maximum initial permeabilities attainable at the fast cooling rate required for the base analysis.

Best results are achieved when one of the elements, chromium, columbium or titanium, alone is added in the amounts indicated. However, certain of the benefits and advantages of the present invention may be achieved when two or more of these elements are included in our composition. When two or more of the elements chromium, columbium or titanium are included in our composition, the total content of these elements should not depart from the hereinabove stated range for one of them.

The objects of the present invention are best achieved when the amounts of chromium, columbium or titanium added to the base analysis is carefully controlled so as to fall in the narrow range of about 0.4% to 0.65%. In this preferred range, initial permeabilities of as high as 90,000 or more are readily obtained with additions of chromium or columbium and of 70,000 or more with titanium. Furthermore, when chromium, columbium or titanium is added to the base analysis in an amount ranging from 0.4% to 0.65%, the optimum cooling rate required to bring out the maximum obtainable initial permeability is best stabilized and falls within the preferred range for commercial practice.

It is an advantage of our alloys that their high initial permeability values are achieved with the relatively low annealing temperature of 2050° F. However, if higher values of initial permeability are desired, they are obtainable with a higher temperature annealing treatment.

It should also be noted that when a parts fabricator is equipped with a relatively large annealing furnace in which only relatively low cooling rates can be achieved, for example, below about 150° F./hr., then additions of chromium, columbium or titanium ranging from about 0.8% up to about 1% are utilized to control the cooling rate and at the same time raise the attainable value of the initial permeability of the material.

The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed.

We claim:

1. A magnetic alloy consisting essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, up to about 0.1% carbon, up to about .01% phosphorus, up to about .01% sulfur, up to about 1% manganese, up to about 1% silicon, from about 0.2% to 1% of an element selected from the group consisting of chromium, columbium and titanium, and the balance essentially of iron.

2. A magnetic alloy consisting essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, up to about 0.1% carbon, up to about .01% phosphorus, up to about .01% sulfur, up to about 1% manganese, up to about 1% silicon, from about 0.2% to 1% chromium, and the balance essentially of iron.

3. A magnetic alloy consisting essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, up to about 0.1% carbon, up to about .01% phosphorus, up to about .01% sulfur, up to about 1% manganese, up to about 1% silicon, from about 0.3% to 0.8% chromium, and the balance essentially of iron.

4. A magnetic alloy consisting essentially of about 79% to 80.5% nickel, about 3.75% to 4.5% molybdenum, up to about 0.04% carbon, up to about .01% phosphorus, up to about .01% sulfur, up to about 0.5% manganese, up to about 0.5% silicon, from about 0.4% to 0.65% chromium, and the balance essentially of iron.

5. A magnetic alloy consisting essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, up to about 0.1% carbon, up to about .01% phosphorus, up to about .01% sulfur, up to about 1% manganese, up to about 1% silicon, from about 0.2% to 1% columbium, and the balance essentially of iron.

6. A magnetic alloy consisting essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, up to about 0.1% carbon, up to about .01% phosphorus, up to about .01% sulfur, up to about 1% manganese, up to about 1% silicon, from about 0.3% to 0.8% columbium, and the balance essentially of iron.

7. A magnetic alloy consisting essentially of about 79% to 80.5% nickel, about 3.75% to 4.5% molybdenum, up to about 0.04% carbon, up to about .01% phosphorus, up to about .01% sulfur, up to about 0.5% manganese, up to about 0.5% silicon, from about 0.4% to 0.65% columbium, and the balance essentially of iron.

8. A magnetic alloy consisting essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, up to about 0.1% carbon, up to about .01% phosphorus, up to about .01% sulfur, up to about 1% manganese, up to about 1% silicon, from about 0.2% to 1% titanium, and the balance essentially of iron.

9. A magnetic alloy consisting essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, up to about 0.1% carbon, up to about .01% phosphorus, up to about .01% sulfur, up to about 1% manganese, up to about 1% silicon, from about 0.3% to 0.8% titanium, and the balance essentially of iron.

10. A magnetic alloy consisting essentially of about 79% to 80.5% nickel, about 3.75% to 4.5% molybdenum, up to about 0.04% carbon, up to about .01% phosphorus up to about .01% sulfur, up to about 0.5% manganese, up to about 0.5% silicon, from about 0.4% to 0.65% titanium, and the balance essentially of iron.

11. In the method of making a nickel-molybdenum-iron magnetic alloy article the maximum attainable initial permeability of which is dependent upon an optimum cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.2% to 1% of an element selected from the group consisting of chromium, columbium and titanium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from at most 1500° F. and at least about 50° F. per hour so that values of initial permeability at least equal to about said maximum value are attained independent of variations in said cooling rate over said range of 1500° F. to about 50° F., making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1500° F. per hour and at least about 50° F. per hour.

12. In the method of making a nickel-molybdenum-

iron magnetic alloy article, the maximum attainable initial permeability of which is dependent upon an optimum cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.2% to 1% chromium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from about 50° F. to at most 1500° F. per hour so that values of initial permeability in excess of about 55,000 are attained independent of variations in said cooling rate over said range of 50° to 1500° F. per hour, making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1500° F. per hour and at least about 50° F. per hour.

13. In the method of making a nickel-molybdenum-iron magnetic alloy article, the maximum attainable initial permeability of which is dependent upon an optimum cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.3% to 0.8% chromium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from about 75° F. to at most 1500° F. per hour so that values of initial permeability in excess of about 60,000 are attained independent of variations in said cooling rate over said range of 75° to 1500° F. per hour, making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1500° F. per hour and at least about 75° F. per hour.

14. In the method of making a nickel-molybdenum-iron magnetic alloy article, the maximum attainable initial permeability of which is dependent upon an optimum cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.4% to 0.65% chromium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from about 150° F. to at most 1000° F. per hour so that values of initial permeability in excess of about 60,000 are attained independent of variations in said cooling rate over said range of 150° to 1000° F. per hour, making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1000° F. per hour and at least about 150° F. per hour.

15. In the method of making a nickel-molybdenum-iron magnetic alloy article, the maximum attainable initial permeability of which is dependent upon an optimum cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.2% to 1% columbium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from about 100° F. to at most 1500° F. per hour so that values of initial permeability at least equal to about said maximum value are attained independent of variations in said cooling rate over said range of 100° to 1500° F. per hour, making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1500° F. per hour and at least about 100° F. per hour.

16. In the method of making a nickel-molybdenum-iron magnetic alloy article, the maximum attainable initial permeability of which is dependent upon an optimum

cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.3% to 0.8% columbium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from about 150° F. to at most 1500° F. per hour so that values of initial permeability at least equal to about said maximum value are attained independent of variations in said cooling rate over said range of 150° F. to 1500° F. per hour, making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1500° F. per hour and at least about 150° F. per hour.

17. In the method of making a nickel-molybdenum-iron magnetic alloy article, the maximum attainable initial permeability of which is dependent upon an optimum cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.4% to 0.65% columbium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from about 150° F. to at most 1500° F. per hour so that values of initial permeability in excess of about 60,000 are attained independent of variations in said cooling rate over said range of 150° to 1500° F. per hour, making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1500° F. per hour and at least about 150° F. per hour.

18. In the method of making a nickel-molybdenum-iron magnetic alloy article, the maximum attainable initial permeability of which is dependent upon an optimum cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.2% to 1% titanium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from about 150° F. to at most 1500° F. per hour so that values of initial permeability at least equal to about said maximum value are attained independent of variations in said cooling rate over said range of 150° to 1500° F. per hour, making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1500° F. per hour and at least about 150° F. per hour.

19. In the method of making a nickel-molybdenum-iron magnetic alloy article, the maximum attainable initial permeability of which is dependent upon an optimum cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.3% to 0.8% titanium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from about 150° F. to at most 1500° F. per hour so that values of initial permeability at least equal to about said maximum value are attained independent of variations in said cooling rate over said range of 150° to 1500° F. per hour, making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1500° F. per hour and at least about 150° F. per hour.

20. In the method of making a nickel-molybdenum-iron magnetic alloy article, the maximum attainable initial permeability of which is dependent upon an optimum cooling rate at which it is cooled from an annealing temperature down through its critical ordering temperature range, the steps of preparing an alloy which consists essentially of about 75% to 85% nickel, about 3% to 5% molybdenum, about 0.4% to 0.65% titanium and the remainder consisting essentially of iron so as to control and retard the optimum cooling rate to a rate of from about 200° F. to at most 1500° F. per hour so that values of initial permeability in excess of about 60,000 are attained independent of variations in said cooling rate over said range of 200° to 1500° F. per hour, making an article of said alloy, and cooling said article from its annealing temperature down through the critical ordering temperature range of the alloy at a rate of at most 1500° F. per hour and at least about 200° F. per hour.

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