

Sept. 18, 1956

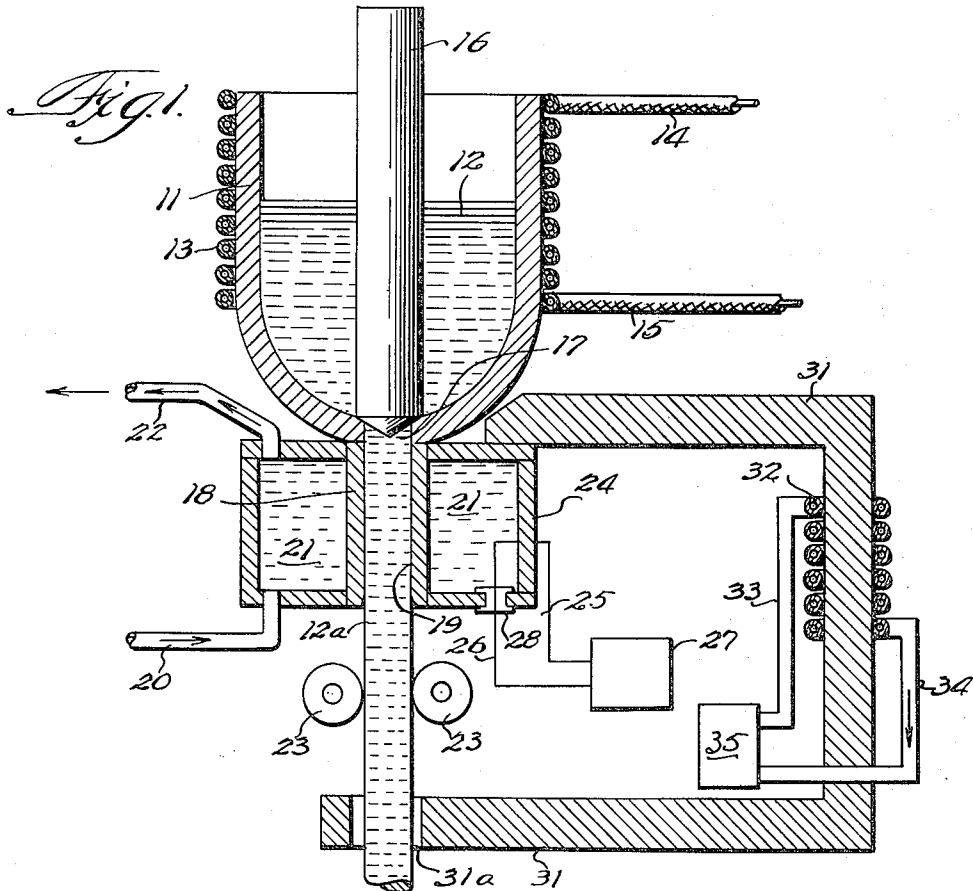
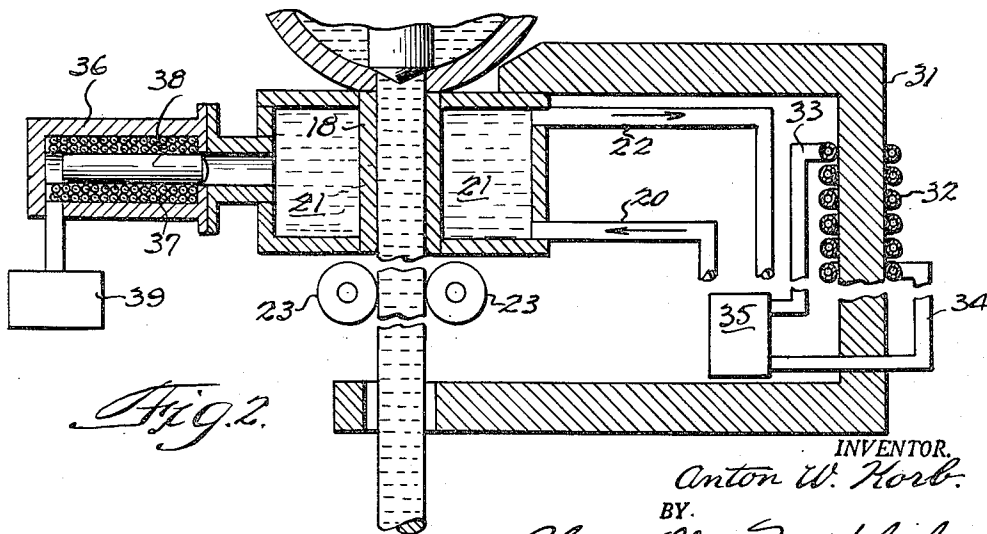
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2,763,040

METHOD AND APPARATUS FOR FORMING MATERIALS

Filed July 31, 1951

3 Sheets-Sheet 1



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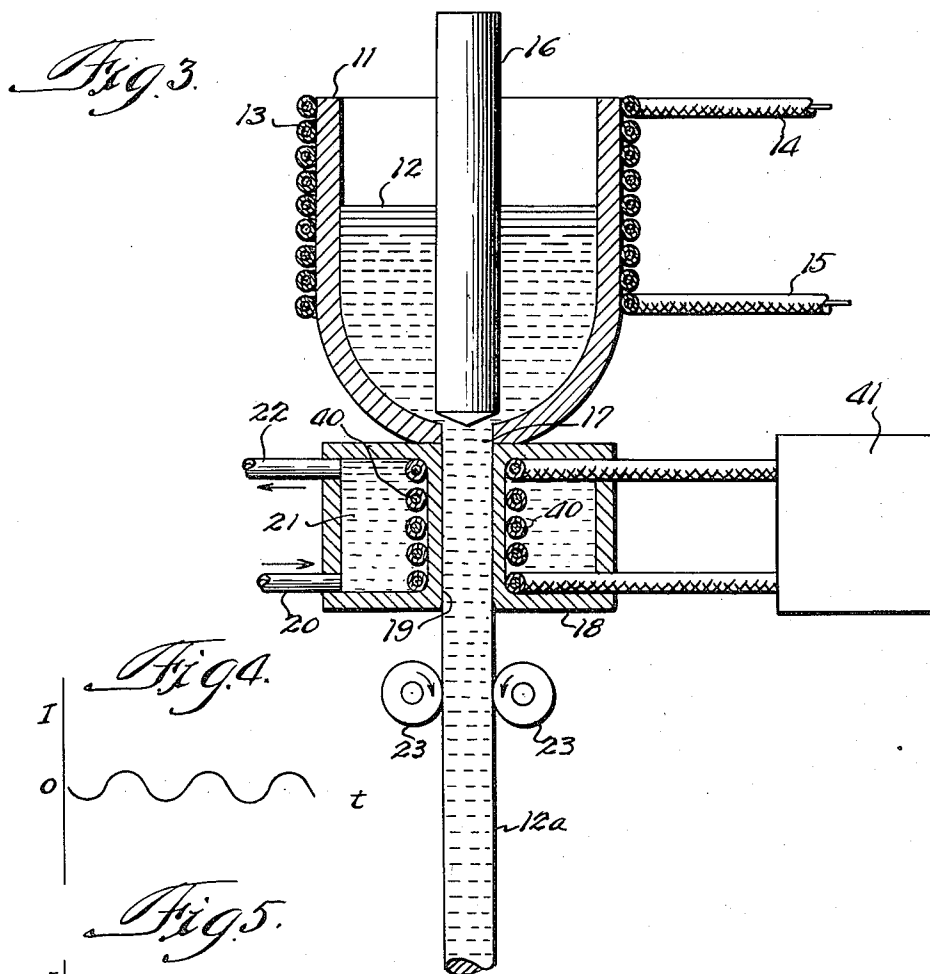
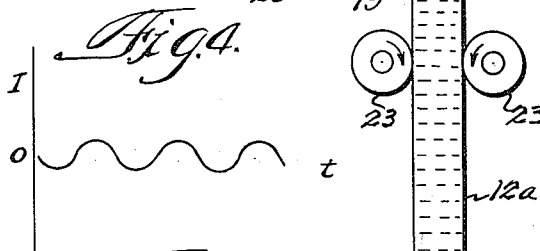
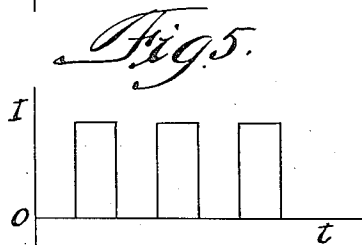
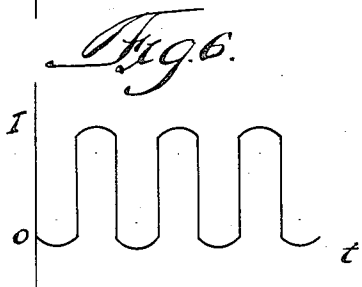
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METHOD AND APPARATUS FOR FORMING MATERIALS

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3 Sheets-Sheet 2



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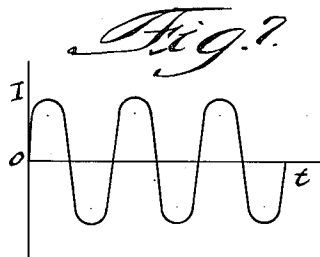
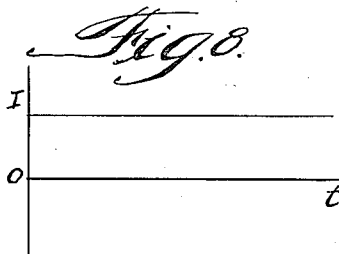
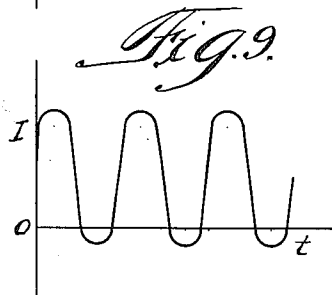
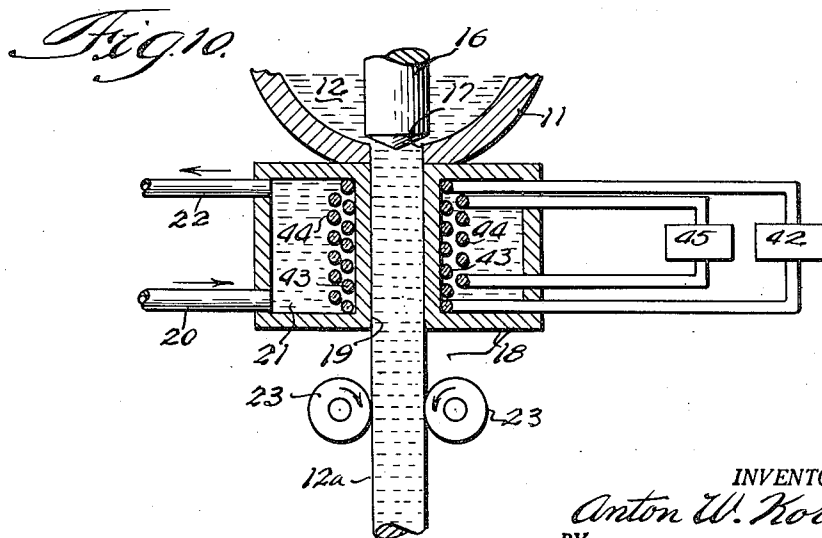
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METHOD AND APPARATUS FOR FORMING MATERIALS

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3 Sheets-Sheet 3



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2,763,040

METHOD AND APPARATUS FOR FORMING MATERIALS

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5 Claims. (Cl. 22—57.2)

This invention relates to a method and apparatus for forming materials and to the products obtained therefrom. It is an object of the invention to provide materials and an improved method and apparatus of that character.

It is another object of the invention to provide an improved method and apparatus for producing castings in a continuous operation.

It is another object of the invention to provide an improved method and apparatus for producing stronger magnets from a given material than has heretofore been possible.

It is another object of the invention to provide an improved permanent magnet which is stronger than previously known magnets formed of the same materials.

In accordance with one feature of the invention, a method and apparatus are provided whereby the casting of material may be carried on continuously and whereby the material is subjected to high frequency vibration as it cools. Castings are thereby produced very economically (several steps of the conventional methods being eliminated) and, at the same time, the castings are greatly improved in quality, particularly, it is believed, in grain size and molecular structure, all as will be explained subsequently in detail.

The invention is well adapted to the making of magnets, of both the permanent type and the electromagnetic type. That is, the invention is of particular value in producing both permanent magnets and the cores of electromagnets. In accordance with another feature of the invention, a D. C. field is applied to the material (which in this instance must be permanently magnetizable) in conjunction with the high frequency vibration referred to above, as the material cools, whereby permanent magnets of great magnetic strength are produced. Preferably, but not necessarily, this method and apparatus provide for continuous casting, as suggested above.

It is a well recognized principle in the art of producing permanent magnets that if the magnetic material from which a magnet is to be produced is heated above its Curie point and then allowed to cool while a magnetizing force is applied thereto, the resultant magnet will be stronger than if the material were subjected to a magnetizing force only while cool or below its Curie point. According to a generally accepted theory the reason for this is that the heating of the material to a temperature above its Curie point, and preferably to a molten or semimolten state, relaxes the crystalline structure of the material such that the individual magnetic particles, commonly called spins or magnetic domains, are no longer tightly bound together with their magnetic axes in any fixed relative orientation and may be brought more completely into alignment by application of a magnetizing force than would otherwise be possible. After the material has been allowed to cool below its Curie point with the magnetizing force continuously applied, the magnetic domains again become locked into position but with their axes to a substantial degree aligned.

This applies, of course, only where the material used is susceptible of permanent magnetization. If a material such as soft iron, for example, is subjected to such a magnetizing operation, a permanent magnet is not produced since the crystalline structure of such material

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will not lock the individual magnetic domains, or any large percentage of the same, into any particular orientation with respect to each other. However, where the material employed is one which is capable of being permanently magnetized, the crystalline structure is such as to lock the axes of the individual magnetic domains, or at least an effective percentage thereof, into definite aligned orientation.

It is believed that the degree to which the magnetic domains are liberated one from the other by elevation of the temperature of a material above its Curie point is limited. The extent to which the individual magnetic domains are so liberated is probably dependent upon the degree to which original groups of associated magnetic domains are broken down by the application of heat into smaller groups of varying size, the individual magnetic domains presumably being more nearly free to align themselves with an applied magnetic field where they are included in small residual groups. In any event, it is believed that the extent to which the axes of the individual magnetic domains may be aligned even when the material is heated above its Curie point is one of degree.

According to the last-mentioned feature of the invention this effect of raising the temperature of a magnetic material above its Curie point is augmented by rapid vibration of the magnetic domains thereof, a second factor thereby being introduced which tends to liberate the individual magnetic domains within the material from each other such that they may be aligned to a greater degree by an applied magnetizing force. It is another object of the invention to provide an improved method and apparatus for producing stronger permanent magnets by more completely aligning the axes of the individual magnetic domains than has heretofore been possible.

Where permanent magnets have been produced in the past by heating permanently magnetizable material above its Curie temperature and then subjecting the material to a magnetizing force while the material is being cooled, a batch process has been employed, usually involving the use of molds and necessarily involving a substantial amount of labor. According to another feature of the invention magnets are produced in a continuous process with flowable (i. e. molten or semimolten), permanently magnetizable material being withdrawn from a container and subjected to a magnetizing force while being cooled, the entire process being continuous as long as the supply of molten material is available.

It is another object of the invention to provide an improved method and apparatus for producing permanent magnets continuously as opposed to producing them in batches.

In accordance with one embodiment of the invention which incorporates all of the features of the invention referred to above, the material of which castings are to be made is heated to a molten state in a vessel and is allowed to escape through an opening in the bottom thereof and pass through a continuously cooled die which forms the rapidly hardening material to the desired cross section. As the material first enters the die it is in a molten state but as it passes through the die it cools with sufficient rapidity that when it leaves the die it is at least self-supporting and, where permanent magnets are being made, well below the Curie temperature for the particular material.

Means are provided for causing rapid vibration of the material as it leaves the vessel and enters the die, the vibrations preferably being of supersonic frequency. Such vibration of the material results in castings of finer grain and greater homogeneity than can otherwise be obtained. Where permanent magnets are being made, means are provided for producing a powerful magnetic

field within the die for magnetizing the material as it cools. Finally, means are preferably provided for continuously drawing the completed product out of the die.

As will subsequently be explained in greater detail magnets produced by this method, more specifically in which the material forming the magnets is subjected to supersonic vibrations during the simultaneous cooling and magnetizing operations, are substantially stronger magnetically than magnets produced by the conventional or previously known methods. Also magnets may be produced continuously by such a method and apparatus whereby a substantial saving is effected in labor cost as compared to methods and apparatus based upon a batch process.

Accordingly, it is another object of the invention to provide an improved method and apparatus for producing in a continuous operation permanent magnets of great magnetic strength.

This invention, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings, in which like parts are designated by like reference numerals,

Fig. 1 is a cross-sectional view, partially schematic, of apparatus, constructed in accordance with one embodiment of the invention, for continuous production of castings, and, more specifically, permanent magnets;

Fig. 2 is a partial cross-sectional view of apparatus similar to that disclosed in Fig. 1 but illustrating another embodiment of the invention;

Fig. 3 is a view similar to Fig. 1 but illustrating still another embodiment of the invention;

Figs. 4, 5 and 6 are graphs showing one form of the magnetizing and vibrating current and its components which may be employed in the apparatus shown in Fig. 3;

Figs. 7, 8 and 9 are graphs showing another form of magnetizing and vibrating current which may be employed in the apparatus shown in Fig. 3; and

Fig. 10 is a partial cross-sectional view of apparatus similar to that disclosed in Fig. 3 but illustrating still another embodiment of the invention.

The embodiments of the invention disclosed in Figs. 1, 2, 3 and 10 are complete with means which are needed only in the production of permanent magnets, and the following description of the various illustrated embodiments includes the steps of one method and the portions of the apparatus used only in the making of permanent magnets. However, the invention is not limited in application to the production of magnets but has application to the production of castings in general, in which case certain steps of the disclosed method and certain portions of the disclosed apparatus are unnecessary.

The apparatus disclosed in Fig. 1 includes a crucible 11 containing a quantity of material 12 from which castings, and, in particular, permanent magnets, are to be formed. The material 12 may be of any suitable metal which is capable of being permanently magnetized and, in accordance with the illustrated embodiment of the invention, is brought to a molten or semimolten state through induction heating by a current passing through a coil 13 which surrounds the crucible. The leads 14 and 15 of the coil 13 are of course connected to any suitable source of relatively high frequency electric current, such source not being illustrated in the drawings.

A valve in the form of a rod 16 of a suitable refractory material extends down through the molten metal 12 to control the flow of metal through an opening 17 in the bottom of the crucible. Located immediately below the opening 17 is a die 18 having an opening 19 there-through which is of the same cross section as that desired in the magnet or magnets to be produced.

The die 18 is preferably hollow in order that it may

be cooled by water or any other suitable cooling medium. The cooling medium may be pumped through a pipe 20 into a cooling chamber 21 within the body of the die 18 and drawn off through a pipe 22.

When the metal in the crucible 11 has been heated to the proper temperature by the coil 13 the rod 16 may be raised permitting the molten metal 12 to escape through the opening 17 and pass through the die opening 19. The metal 12 is cooled rapidly as it passes through the die and is in a solid state as it leaves the die. The solidified metal bar or rod 12a then passes between a pair of rollers 23 which are driven by any suitable power means, not illustrated in the drawings, such that they draw the solidified metal bar or rod downwardly. In starting such an operation, it is desirable that a short length of rod or bar, not shown in the drawings, be used as a lead to retard the initial flow of the molten metal 12 through the die opening 19. Such a bar or rod may be inserted upwardly between the rollers 23 and into the die opening 19 and is preferably only slightly smaller in cross section than the die opening. When the rod 16 is raised allowing the molten metal 12 to flow down to the upper end of the lead bar the rollers 23 can be started and will withdraw the lead bar and, subsequently, the metal bar 12a at such a rate as to permit the molten metal 12 to solidify before it passes completely through the die.

A portion of the outer wall of the cooling chamber 21 comprises a transducer 24 for transmitting physical vibrations through the water in the cooling chamber and through the inner wall of the die 18 to the material 12 within the die opening 19. The transducer 24 is energized electrically through a pair of leads 25 and 26 and a high frequency electrical generator 27, the lead 26 passing through a suitable insulating grommet 28 in one wall of the die structure. The transducer 24 may be of various materials, for example, a titanate ceramic. The principal characteristic of the transducer required in this application is that it is capable of producing mechanical vibrations of high frequencies upon suitable electrical energization thereof. Many materials capable of producing this result are well-known in the art and accordingly, the transducer will not be further described herein.

The high frequency vibrations, which are preferably supersonic in frequency, transmitted to the molten and semimolten material 12 within the die opening 19 by the transducer 24, break up the crystalline structure of the material during the solidifying of the material. The result is the production of castings having a very fine grain and hence having much greater strength. Furthermore, this is accomplished in a single step, that is, without the necessity of additional handling or reheating of the material.

Where the end product is to be permanent magnets, the high frequency vibration of the material produces not only a finer grain but magnetically stronger magnets. This may be explained on the theory that the vibration tends to break up the residual groups of magnetic domains into smaller units, whereby a larger percentage of the magnetic domains contained within any given portion of the material 12 may be aligned with an applied magnetic field.

Means for producing such a magnetic field are illustrated in Fig. 1 and include a yoke 31, a coil 32 having leads 33 and 34, and a D. C. generator 35. The output of the D. C. generator 35 passes through the coil 32 and sets up a strong magnetic field within the yoke 31. It will be noted that the yoke is substantially U-shaped, the upper arm terminating alongside the upper wall of the die structure 18, and the lower arm extending to a position below the die 18 and having an opening 31a through which the completed product may pass. Preferably, the upper wall of the die structure is of magnetic material and the inner wall of nonmagnetic material, whereby the magnetic flux lines tend to pass from the

end of the upper arm of the yoke to the material within the die opening 19. The flux lines then pass downwardly through the molten, semimolten, and finally the solidified portions of the material and to the lower arm of the yoke 31 across the air gap within the opening 31a.

In accordance with this embodiment of the invention, as applied to the production of permanent magnets, the material of which the magnets are to be formed is subjected to high frequency vibrations originating from the transducer 24 during the time that the material is solidifying and cooling to a temperature below its Curie temperature, the material being subjected to a powerful, continuous magnetic field throughout the entire process. The permanent magnets produced by this apparatus and by the method described are stronger magnetically, for any given permanently magnetizable material, than can be obtained by presently known apparatus and methods.

Where castings are desired of any nature other than permanent magnets the magnetizing means 31-35 are, of course, unnecessary. The transducer 24 along with the means for energizing the transducer are desirable, however, since the high frequency vibration of the casting material during its solidification produces fine grain structure with a minimum of apparatus and with no additional handling of the material.

The apparatus disclosed in Fig. 2 is very similar to that disclosed in Fig. 1 and described above but differs in the form of the transducer. In Fig. 2 an electromagnetic transducer 36 is employed which comprises a coil 37 and a movable core or armature 38. The coil 37 is energized by a high frequency generator 39 which causes the armature 38 to vibrate at the same high frequency. The vibrations of the armature are transmitted through the water in the cooling chamber 21 and through the inner die walls to the molten and semimolten material, the same as in the apparatus disclosed in Fig. 1. Two forms of transducer are therefore shown in Figs. 1 and 2, respectively. However, the invention is obviously not limited thereto but includes within its scope any form of apparatus or device capable of causing high frequency mechanical vibrations to be transmitted to the material contained within the die opening 19.

The apparatus disclosed in Fig. 3 is generally similar to that disclosed in Figs. 1 and 2 and described above but differs substantially in the form of apparatus employed for breaking up the crystalline structure of the material and, in the case of permanent magnet production, for breaking up the residual groups of magnetic domains into smaller units. In this embodiment of the invention there is arranged within the cooling chamber 21 of the die 18 and closely adjacent the die opening 19, an electric coil 40 which is connected to electrical apparatus designated by the numeral 41 and shown in block form in Fig. 1. The electrical apparatus 41 may comprise merely a source of D. C. voltage, the direct current obtained therefrom, upon passing through the coil 40, establishing a magnetic field within the die opening 19 and thereby magnetizing the metal passing therethrough by aligning the magnetic domains thereof. It will be recognized that the metal forming the die 18, or, at least that portion of the die forming the opening 19, should be nonmagnetic, since the magnetic field within the die opening 19 would otherwise be very weak or even negligible.

As previously indicated, when magnetizable metal is in a molten state or above its Curie temperature the magnetic domains of the metal are relatively free to change the orientation of their axes and therefore may be more completely aligned by a magnetic field than when the same material is at a temperature below its Curie point. Accordingly, a magnetic field of given strength will produce a stronger magnet when the field is applied to the magnet metal in a molten state and the metal permitted to cool within the field, than when the field is applied to metal at a temperature below its Curie point.

The method and apparatus so far described in connection with Fig. 3 are particularly desirable as they take advantage of this principle while still being adapted to a continuous rather than a batch operation.

Conventionally, molten or semimolten material is poured or forced into a mold or die until the latter is filled, after which the material in the mold or die is subjected to a magnetizing force until it is cooled below its Curie temperature. Such a process may be classified as a batch process and is relatively expensive since the individual magnets so formed must be handled a number of times after the pouring operation. In the case of the method and apparatus so far described a continuous magnetic bar is formed which may subsequently be divided into a large number of individual magnets, the entire bar being formed in a continuous operation. A bar of any desired length may be produced by this method if means are made available for providing a continuous flow of molten metal. For example, molten metal may be added to the crucible 11 or solid metal added and the coil 13 made of such capacity as to melt the metal as fast as it is withdrawn through the opening 17. Whether or not the supply of metal in the crucible is replenished the process so far described is considered a continuous process as opposed to a batch process. Where the term "continuous process" is employed herein it is intended that it be so construed.

The method and apparatus so far described, then, in connection with Fig. 3 effect a substantial saving in the labor cost previously involved in the production of magnets. The substantial reduction in the cost of magnets thereby obtained is a vital matter where a large number of magnets are employed in a device, such as a refrigerator, in a highly competitive field.

In accordance with another feature of the invention the electrical apparatus 41 causes a current to flow through the coil 40 which is not a direct current of constant value but is instead of a character whose effect, at least, is similar to that of the current indicated in the graph comprising Fig. 6, in which current, I , is plotted against time, t . The wave form of the illustrated current is essentially that of a square wave pulsating direct current, such as is illustrated in Fig. 5, having superimposed thereon an inphase alternating current, such as is illustrated in Fig. 4.

A wave shape such as that shown in Fig. 6 may be produced by any one of various well-known or obvious expedients and since the particular method or apparatus used to produce the desired current is not, in itself, a part of the invention, the apparatus is not shown or described in detail herein. The desired characteristics of the current wave are that the current value alternates rapidly between a substantial value of one polarity and a relatively small value of the opposite polarity, the frequency of the alternation being rapid and preferably in the range of supersonic frequencies.

One form of apparatus for producing such a wave form is a square wave generator and a source of high frequency alternating current such as an oscillator, the output of the latter being of the same frequency and in phase with the output of the square wave generator. This phase relationship may be accomplished by driving the D. C. generator and an A. C. generator at the same effective speed or by providing a suitable control circuit whereby the alternating current voltage triggers the source of square wave direct current. Another obvious expedient involves the combination of an alternating current of substantial peak value, see Fig. 7, and a steady state direct current whose value is somewhat less than the peak value of the A. C., see Fig. 8. The resultant wave form would be that illustrated in Fig. 9 where it is seen that the wave has the same desired characteristics as the wave illustrated in Fig. 6, namely the current alternates rapidly between a substantial value of one polarity and a relatively small value of the opposite polarity.

The beneficial effect of such a wave form will be explained in accordance with the theory previously presented. When the metal 12 enters the die opening 19 and while it is still molten or semimolten, or in any event while it is still above the Curie temperature of the material, the magnetic domains of the metal are contained probably within relatively small and loosely associated groups of domains. Accordingly, the axes of the domains are responsive to the weak magnetic field established by the relatively small negative half cycle of the current through the coil 40 (referring to either Fig. 6 or Fig. 9) as well as to the much stronger magnetic field produced by the positive half cycle of the current flowing in the coil. As a result the individual magnetic domains are rapidly oscillated presumably through an angle of substantially 180 degrees, and thereby tend to shake themselves loose from any remaining influences within the metal which may tend to lock them in a given orientation either with respect to the body of the metal or with respect to other associated magnetic domains. In other words, the application of the rapidly alternating magnetic field to the soft metal for even a very short period of time tends to break up any remaining groups of magnetic domains or to break down any other restraining influences which may be present in the metal, and thereby to render the individual magnetic domains relatively free to align themselves more perfectly with any applied magnetic field or force.

As the metal passes through its Curie temperature the magnetic domains begin to lock into a given orientation with respect to the body of the metal. Under these conditions the relatively weak field produced by the small negative half cycle of the current wave fails to cause a substantial movement or reorientation of the individual magnetic domains, while the relatively strong field produced by the positive half cycle of the current wave still forces the individual magnetic domains to align themselves with that field.

It will be apparent, then, that a single coil carrying an alternating current of which alternate half cycles are of substantially greater magnitude than the other alternate half cycles, can serve the dual purpose of oscillating the magnetic domains of metal above its Curie temperature and aligning the magnetic domains of the same metal as it passes through its Curie temperature.

In accordance with the embodiment of the invention illustrated in Fig. 10 an alternating voltage derived from a suitable source 42 is applied to a coil 43, through the field of which molten or semimolten metal passes. A second coil 44 is arranged over the coil 43 and is connected to a suitable source 45 of direct current voltage.

The voltage of the two sources 42 and 45 are of such value that the peaks of the A. C. current wave through the coil 43 are of slightly greater value than the value of the D. C. current in the coil 44. The effect is then the same as in the previously described embodiment. Namely, the metal within the die 18 is subjected to a magnetic field which alternates rapidly between a substantial value and a relatively weak value.

In accordance with either of the embodiments disclosed in Figs. 3 and 10, the metal which is to form the ultimate magnet or magnets is subjected while above its Curie temperature to a rapidly alternating magnetic field which tends to liberate the individual magnetic domains to a greater degree than is accomplished by merely heating metal above its Curie temperature. The magnets so produced from any given permanently magnetizable material are stronger magnetically than magnets produced of the same material by any previously known method or apparatus.

It will be apparent from the foregoing that the invention includes a number of associated features. By way of example, it is pointed out that the invention includes a novel method and apparatus for continuous production of castings having a fine grain structure. It also includes

a novel method and apparatus for producing stronger permanent magnets, which method and apparatus may or may not provide for continuous casting of the magnets. Still further, the invention covers improved permanent magnets and improved castings in general.

It will be apparent that the invention may be varied in its physical embodiment without departing from the spirit of the invention, and it is desired, therefore, that the invention be limited only by the prior art and the scope of the appended claims.

The invention having thus been described, what is claimed and desired to be secured by Letters Patent is:

1. The method of producing permanent magnets which comprises, subjecting permanently magnetizable material to a magnetizing force and vibrating such material at ultrasonic frequency while cooling the material from a temperature at which the material is substantially nonmagnetic to a temperature at which the material is magnetic.

2. The method of producing permanent magnets which comprises continuously driving permanently magnetizable material through a magnetizing field while simultaneously vibrating such material at ultrasonic frequency and cooling the material from a temperature at which the material is substantially nonmagnetic to a temperature at which the material is magnetic.

3. Apparatus for producing permanent magnets which comprises means for creating a magnetic field which comprises a steady state field and a larger field alternating at ultrasonic frequency whereby the net field alternates at ultrasonic frequency between a substantial value in one direction and a relatively small value in the opposite direction, means for heating permanently magnetizable material to a temperature at which such material is substantially nonmagnetic, means for advancing such material through said field, and means for cooling the material while in said field to a temperature at which the material is magnetic.

4. Apparatus for producing permanent magnets which comprises an electrical coil, electrical means for producing in said coil an electric current comprising a direct current and a larger current alternating at ultrasonic frequency whereby the net current alternates at ultrasonic frequency between a substantial value in one direction and a relatively small value in the opposite direction, means for heating permanently magnetizable material to a temperature at which such material is substantially nonmagnetic, means for advancing such material through said field, and means for cooling the material while in said field to a temperature at which the material is magnetic.

5. Apparatus for producing permanent magnets which comprises means for heating permanently magnetizable material at least to a temperature at which said material is semimolten, a die for continuously forming said material to a desired cross section as said material passes therethrough, means for creating a magnetic field within said die, means for vibrating said material within said die at ultrasonic frequency, and means for cooling said material while in said field to a temperature at which the material is magnetic.

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