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APPARATUS FOR MAGNETIZING PERMANENT MAGNET MATERIALS TO FORM BAND-LIKE POLES THEREON

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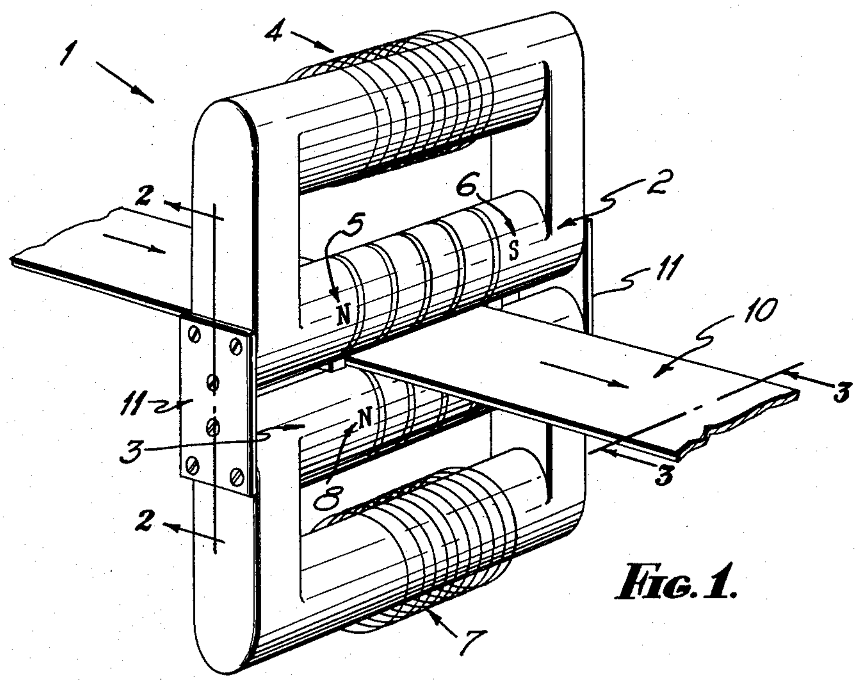

FIG. 1.

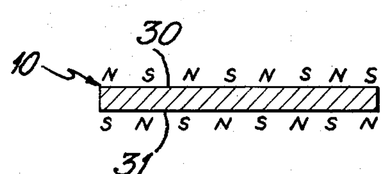

FIG. 3.

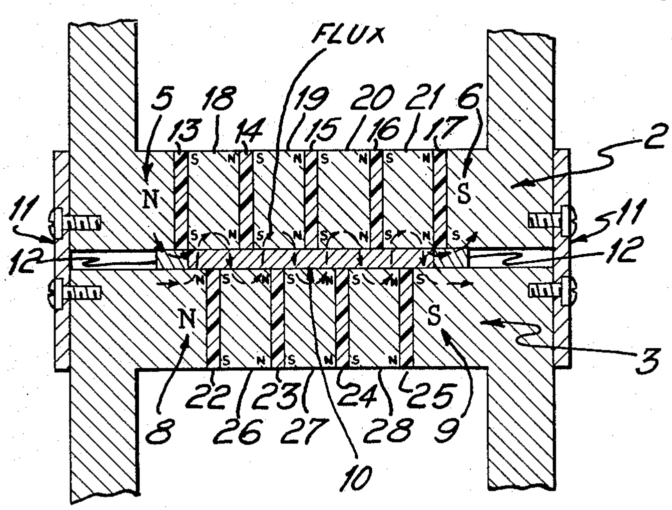

FIG. 2.

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APPARATUS FOR MAGNETIZING PERMANENT MAGNET MATERIALS TO FORM BAND-LIKE POLES THEREON

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This invention relates to the magnetization of ferromagnetic materials, and in particular to apparatus for the magnetization of permanent magnet materials to form band-like poles thereon.

It is frequently desired to magnetize permanent magnet materials of strip or sheet form in such fashion that the magnetic north and south poles are disposed on the two large surfaces of the strip or sheet, that is, on the top and bottom surfaces, as opposed, for example, to providing the magnetic poles at the opposite ends of the piece. Some of the newer types of strips and sheets formed of magnetizable materials with which industry has recently been supplied, the so-called high anisotropy aligned fine particle composition materials, are particularly amenable to the disposition of poles on their large surfaces, being, in fact, more strongly magnetizable in that manner than otherwise; for this reason, these new materials are said to possess a "preferred direction of magnetization" which is directed perpendicularly to their large surfaces.

It is perhaps simplest to effect such magnetization of strip and sheet form materials by subjecting them to a substantially homogeneous magnetic field directed perpendicularly to their large surfaces. If the sample undergoing magnetization is small, it may be possible to magnetize it all at once; if it is physically larger than the region over which the magnetizing field can be maintained, then the sample may be moved through a localized field, for example, between the poles of an energized electromagnet. In any event, a sample magnetized in this manner has its north pole distributed over one entire large surface, while the south pole extends over the entire area of its opposite surface.

Strips and sheets magnetized in this straightforward manner are characterized by a disadvantageously large "air gap" between their north and south poles: the magnetic flux established by a piece thus magnetized extends through space from the north pole, on the one surface of the magnet, around the edge of the piece, to the south pole, on the other surface. It can be seen that this air gap is relatively great as compared with the "length" of the magnet (which can be no greater than the thickness of the piece), a factor which causes the magnet to display substantially less holding power than a magnet of similar material and volume but with a shorter air gap.

As a means of shortening the air gap between the poles of a strip or sheet form magnet while still arranging the poles on the large surfaces of that magnet, it has been found desirable to so magnetize the piece such that its poles are in the form of a number of parallel, alternate north-south bands which extend longitudinally or transversely on each of its large surfaces. The air gap of a piece so magnetized is only the average or effective distance between adjacent bands on the same side of the piece, which, it will be appreciated, is considerably shorter than the distance from one surface around the edge of the piece to the other surface, and as a result the piece displays considerably improved holding power.

It is not so easy a process to form these "alternate band" poles on the surfaces of a piece of magnetic material as it is to form a single pole extending over each entire surface of that piece, particularly where the poles

are to be very closely spaced to minimize the air gap between them. Heretofore it has been accomplished, as one example, by positioning the sample to be magnetized adjacent a specially shaped electric conductor and then passing a very large current through the conductor, which current establishes a momentary electromagnetic flux cutting the sample in a manner effective to establish the alternate magnetic bands thereon. If a long strip is to be magnetized, however, the limited surface area over which the conductor can be extended necessitates magnetizing the strip in sections along its length, which in turn very greatly increases the amount of time required to completely magnetize it. Moreover, the closeness of the poles is limited by the physical diameter of the current-carrying conductor which must of necessity be large to accommodate the heavy current to which the conductor is subjected.

No method has been known in the past for quickly and continuously magnetizing long strips or sheets to provide very closely spaced, alternate, band-like poles simultaneously on both surfaces thereof. This application is directed to apparatus whereby this result may be attained.

Briefly put, the apparatus I have invented comprises two spaced, opposed assemblies. Each assembly comprises a north primary pole piece and a south primary pole piece which are spaced from each other. Between the primary pole pieces of each assembly there are arranged in alternate order a plurality of nonmagnetic spacers and ferromagnetic secondary pole pieces, the secondary pole pieces being spaced from each other and from the primary pole pieces by the spacers. Electromagnetic means, when energized, establish a magnetic potential difference between the primary pole pieces of each assembly, so that north and south magnetic poles are induced respectively at the north and south primary pole pieces.

The two assemblies are positioned parallel to each other, in such relationship that like primary poles will oppose each other, the spacing between the assemblies corresponding to the thickness of the sheet or strip material which is to be magnetized. The apparatus is further characterized in that the secondary pole pieces and spacers are so arranged between their respective primary pole pieces that the secondary pole pieces of each assembly are staggered or misaligned with those of the other assembly, and are substantially centered diametrically opposite the nonmagnetic spacers of the other assembly.

With the electromagnets energized, the material to be magnetized is drawn between the two spaced assemblies, the surfaces of the material on which the poles are to be formed preferably being facially adjacent the respective assemblies. Alternate magnetic poles are formed simultaneously on each side of the strip or sheet at positions corresponding to the positions of the secondary pole pieces.

That such an apparatus will effect the formation of alternate band-like poles on a piece of magnetizable material is contrary to what theory would lead one to expect from a consideration of the individual assemblies of the apparatus. The application of a magnetic potential difference across a single assembly of north and south primary pole pieces, secondary pole pieces and spacers of the type described, in the absence of a second such assembly, would establish a flux extending from the primary north pole to the primary south pole in a series of loops between the secondary pole pieces. Presumably, the presence of a second such assembly polarized similarly to the first and adjacent to it should bring about no merging of their individual flux patterns, because like poles repel each other (i.e., the primary polarization of each assembly opposes that of the other); no magnetic potential difference exists between the assemblies to cause a merging interaction of their individual flux patterns. The two should, in fact, only repel each other. In consequence of this, theory would suggest that only shallow imperfect surface magnetization of magnetizable material between the assemblies should be effected. Moreover, if the secondary pole pieces of the two assemblies are not staggered but rather are aligned with one another, and if dissimilar primary poles are positioned adjacent each other, then only superficial surface magnetization is effected as theory does in fact suggest. But theory to the contrary notwithstanding, if the assemblies are so arranged that like primary poles are opposed to and repel each other, the formation of a number of closely spaced band-like poles on both surfaces of a piece of magnetizable material positioned between the two assemblies can readily be accomplished by substantially centering the secondary pole pieces of each assembly diametrically opposite the spacers of the other.

The invention can best be further explained with reference to the accompanying drawings, in which:

FIGURE 1 is a perspective diagrammatic view of preferred magnetizing apparatus incorporating the principles of my invention, showing a strip of magnetizable material being passed between two opposed assemblies, across each of which a magnetic potential difference is impressed, to form alternate north and south bands thereon;

FIGURE 2 is an enlarged partial sectional view taken on line 2—2 of FIGURE 1 showing the relationship of the alternately arranged secondary pole pieces and spacers of the assemblies; and

FIGURE 3 is a sectional view taken on line 3—3 of FIGURE 1 showing in a general way the longitudinally extending band-like poles on both surfaces of the magnetized strip.

In FIGURE 1 there is shown a perspective view of a preferred magnetizing apparatus **1** in accordance with my invention. The apparatus comprises an upper assembly **2** and a lower assembly **3** of generally similar construction but with certain differences which will be described in detail hereinafter. Assembly **2** includes a north primary pole piece **5** and a south primary pole piece **6** which is spaced from the north pole piece **5**, between which a magnetic potential difference is or can be established by suitable means such as an electromagnet having a coil **4**. Similarly, the lower assembly **3** includes a north primary pole piece **8** and a south primary pole piece **9** which is spaced from the north pole piece **8**. Means such as an electromagnetic coil **7** are effective to establish a magnetic potential difference between the primary pole pieces **8** and **9** of assembly **3**.

The two assemblies **2** and **3** are arranged in spaced relationship such that the two north primary pole pieces **5** and **8**, and the two south primary pole pieces **6** and **9**, respectively oppose one another. The assemblies **2** and **3** are spaced by an amount corresponding to the thickness of the strip or sheet **10** of material which is to be magnetized between them, as for example, by means of connecting plates **11** suitably fastened to the assemblies. These connecting plates **11** prevent the upper assembly **2** from being repulsed away from the lower assembly **3** by the force exerted on it when the opposing primary pole pieces **5** and **8**, and **6** and **9**, are energized. The coils **4** and **7** of the electromagnets are energizable from a suitable source which is not shown. Guides **12** position the magnetizable material **10** in the horizontal plane between the two assemblies.

An enlarged partial sectional view of the preferred arrangement of secondary pole pieces and nonmagnetic spacers is shown in FIGURE 2 of the drawings.

Between the primary pole pieces **5** and **6** of the upper assembly **2** there are disposed a number of nonmagnetic spacers designated as **13**, **14**, **15**, **16**, and **17**, in alternate order with ferromagnetic secondary pole pieces designated as **18**, **19**, **20**, and **21**, the secondary pole pieces being separated from each other and from the primary pole pieces **5** and **6** by the spacers. The secondary pole pieces are made of a nonmagnetic material such as plastic, aluminum, or brass. As shown in the figure, the secondary pole pieces and spacers are preferably of circular cross-sectional configuration similar to that of the primary pole pieces **5** and **6** between which they are disposed, and thus are engageable in line contact with the magnetizable material **10**. The secondary pole pieces are preferably substantially wider than the spacers.

The bottom assembly **3** is provided with a plurality of spacers **22**, **23**, **24**, and **25**, arranged alternately with secondary pole pieces **26**, **27**, and **28**, both preferably of the same generally types and dimensions as those of the upper assembly **2**. However, in the preferred embodiment, the primary pole pieces **8** and **9** of the lower assembly **3** are positioned or dimensioned so that the lower spacers **22**—**25** are centered substantially diametrically opposite the respective upper secondary pole pieces **18**—**21**. Thus, the secondary pole pieces of the upper and lower assemblies are misaligned or staggered with respect to each other but are aligned with respect to the spacers of the opposite assembly.

The strip **10** of material which is to be magnetized is positioned between the assemblies **2** and **3** with its upper and lower surfaces **30** and **31**, on which the poles are to be formed, in juxtaposition to the secondary pole pieces and spacers of the upper and lower assemblies respectively, as shown in FIGURE 2. With the coils **4** and **7** of the electromagnets energized, the strip **10** is drawn through the magnetizing apparatus in the manner indicated by the arrows in FIGURE 1.

I have empirically found that the alternately arranged, out of alignment sequence of secondary pole pieces of the opposite assemblies is effective to cause the magnetic flux to follow a path between the primary poles of the assemblies such that alternate north-south magnetic poles are formed on the magnetic material **10**. Without intending to limit the invention, it is believed from the results obtained that in the region between the poles of the two assemblies the magnetic flux traverses or "threads" the strip **10** from the two north primary pole pieces **5** and **8** to the nearest secondary pole piece **18**, then downwardly through the strip **10** to secondary pole piece **26**, then upwardly to secondary pole piece **19**, and so on back and forth to the south primary pole pieces **6** and **9**, approximately as shown diagrammatically in FIGURE 2. But whatever the exact pattern of the field, the strip **10** is magnetized as a result of its passage through the opposed assemblies **2** and **3** of the apparatus with a plurality of alternate north and south poles extending longitudinally along both of its surfaces **30** and **31**, as shown in FIGURE 3. The width of these bands, and consequently the length of the air gap between the bands is a function of the width and spacing of the secondary pole pieces.

With this apparatus I have found that it is possible, on a thin sheet of magnetizable material, to form pole bands which are as narrow as $\frac{1}{32}$ of an inch, or less. In general, the secondary pole pieces may be about $\frac{1}{16}$ inch in width or wider, depending on the desired spacing of the pole bands on the material. The spacers are preferably considerably narrower than the secondary pole pieces; for example in the embodiment pictured, the spacers are about $\frac{1}{4}$ as wide as the secondary pole pieces. The width of the spacers is preferably somewhat greater than the thickness of the particular piece which is to be magnetized, for example, about 25% greater, for reasons which will be explained. The spacing of the primary pole pieces of each assembly and the number of secondary pole pieces and spacers between them should, of course, be greater where wide materials are to be magnetized than for narrow widths of material. The utilization of round secondary pole pieces and spacers offers the advantage that the magnetic flux between the assemblies is thereby concentrated around the very line at which the magnetic material engages the secondary pole pieces.

As previously explained, it is preferred that the spacers of each assembly be arranged so that they are substantially or exactly centered or aligned with respect to the secondary pole pieces of the opposite assembly, each secondary pole piece overlapping at its ends the secondary pole pieces which are on either side of the proximate spacer of the opposite assembly. Otherwise put, the arrangement of the secondary pole pieces and spacers should be such as to cause the magnetic flux to "thread" the strip upwardly and downwardly at evenly spaced locations across its surfaces. The formation of band-like poles does not, of course, instantly cease as the secondary pole pieces and spacers are shifted slightly out of alignment with each other, but on the whole, the magnetization of the strip may be most efficiently conducted with the relatively least expensive apparatus, if the secondary pole pieces of each assembly are centered diametrically opposite the spacers of the other and overlap the two secondary pole pieces on either side of that spacer.

This condition may perhaps be more exactly expressed by reference to the magnetic potential differences between the secondary pole pieces. For most effective practice of the invention, it is preferred that, when a magnetic potential difference is impressed across the primary pole pieces, the magnetic potential difference between a secondary pole piece of one assembly and the proximate secondary pole piece of the other be not substantially less than that between proximate secondary pole pieces of the same assembly (taking into account the permeabilities of the material to be magnetized and of the spacers), in order that the flux will extend through the thickness of the material from one surface to the other rather than extend in loops between proximate secondary pole pieces of the same assembly. Thus, if the "air gap" between proximate secondary pole pieces of the same assembly is less than the effective air gap between proximate secondary pole pieces of opposite assemblies, the major part of the magnetic flux will extend along the shorter path within the assembly from which it originates, and will achieve only imperfect surface magnetization of the material. By employing very large electromagnetic coils, it is conceivable that "spill-over" flux could be made to effect the formation of band-like poles on the piece, but certainly such a process would not be efficient from the standpoint of the size and cost of the apparatus required, or from the standpoint of power consumption.

If desired, the secondary pole pieces and spacers may be assembled on a rotatable shaft so that the strip 10 can be driven by the secondary pole pieces and spacers themselves, in preference to pulling it endwise through the apparatus.

From the foregoing, it will be appreciated that while I have described the preferred embodiment of my invention, it is susceptible of variations and changes falling within the scope and spirit of the claims which follow.

Having described my invention, I claim:

1. Apparatus for the continuous magnetization of permanent magnet material in strip form for simultaneously inducing a number of alternate band-like poles on both surfaces thereof, said apparatus comprising, two spaced assemblies, each assembly comprising, a north primary pole piece and a south primary pole piece which are spaced from each other, a plurality of nonmagnetic spacers and ferromagnetic secondary pole pieces disposed between the north and south primary pole pieces of each assembly in alternate order, said secondary pole pieces being spaced from each other and from the primary pole pieces by said spacers, and electromagnetic means for establishing a magnetic potential difference between primary pole pieces of each assembly whereby north and south magnetic poles can be induced in said north and south primary pole pieces respectively, the north and south primary pole pieces of each assembly being opposed respectively to the north and south primary pole pieces of the other assembly, the spacers of each assembly being substantially centered diametrically opposite the respective secondary pole pieces of the other assembly, the secondary pole pieces and spacers of both assemblies defining a region between them through which material to be magnetized may be passed.

2. Apparatus in accordance with claim 1, in which the width of said spacers is less than the width of said secondary pole pieces.

3. Apparatus in accordance with claim 1 in which the width of said spacers is a fraction of the width of said secondary pole pieces.

4. Apparatus in accordance with claim 1 in which said secondary pole pieces and said spacers are round and are of equal diameter.

5. Apparatus in accordance with claim 1 in which the width of said spacers is greater than the thickness of the material which is to be magnetized.

6. Apparatus in accordance with claim 1 in which the width of said spacers is about 25% greater than the thickness of the material which is to be magnetized.

7. Apparatus in accordance with claim 1 in which each of a substantial portion of the secondary pole pieces of each assembly overlaps the two secondary pole pieces on either side of the spacer of the opposite assembly with which each of said portion of secondary pole pieces is centered.

8. Apparatus for the continuous magnetization of elongated permanent magnet material for simultaneously inducing a number of alternate band-like poles on both surfaces thereof, said apparatus comprising, two spaced assemblies, each assembly comprising, a north primary pole piece and a south primary pole piece, said pole pieces being spaced from each other, a number of nonmagnetic spacers and ferromagnetic secondary pole pieces arranged in alternate order between the north and south primary pole pieces of each assembly, said secondary pole pieces being spaced from each other and from their primary pole pieces by said spacers, electromagnetic means for establishing a magnetic potential difference between the primary pole pieces of each assembly whereby north and south magnetic poles can be induced in said north and south primary pole pieces respectively, and means positioning said assemblies such that like primary pole pieces are opposed to each other, the dimensions and positions of said secondary pole pieces and spacers being such that each of at least a substantial portion of the secondary pole pieces of each assembly is substantially centered opposite to the proximate spacer of the other assembly and overlaps the two secondary pole pieces on either side of that spacer, the secondary pole pieces and spacers of both assemblies together defining a region between them through which material to be magnetized may be passed.

9. Apparatus in accordance with claim 8 in which the width of said secondary pole pieces is at least about $\frac{1}{16}$ inch, and in which the width of said spacers is at least about $\frac{1}{32}$ inch.

10. Apparatus for the continuous magnetization of permanent magnet material for simultaneuosly inducing a plurality of closely spaced alternate band-like poles on both surfaces thereof, said apparatus comprising, two spaced assemblies, each assembly comprising, two primary pole pieces which are spaced from each other, a number of nonmagnetic spacers and ferromagnetic secondary pole pieces arranged in alternate order between said two primary pole pieces, said secondary pole pieces being spaced from each other and from the primary pole pieces by said spacers, means positioning said assemblies in opposed spaced parallel relationship, said assemblies defining a region between them through which material to be magnetized may be passed, and energizable electromagnetic means effective when energized to establish a magnetic potential difference between the primary

pole pieces of each assembly such that like magnetic poles are induced in the proximate primary pole pieces of opposite assemblies, the secondary pole pieces of each assembly being arranged with respect to the spacers of the other assembly in such position that the magnetic potential difference between proximate secondary pole pieces of the same assembly is not substantially greater than the magnetic potential difference between proximate secondary pole pieces of opposite assemblies.

11. Apparatus in accordance with claim 10 in which the magnetic potential difference between proximate secondary pole pieces of the same assembly is less than the magnetic potential difference between proximate secondary pole pieces of opposite assemblies when permanent magnet material is positioned in said region.

12. Apparatus for the continuous magnetization of permanent magnet material in strip form for simultaneously inducing alternate band-like poles on both surfaces thereof, said apparatus comprising, first and second electromagnets, each electromagnet having a north pole and

a south pole, said poles being spaced from each other, and a plurality of nonmagnetic spacers and ferromagnetic secondary pole pieces mounted between said poles in alternate order, said secondary pole pieces being spaced from each other and from the poles of their corresponding electromagnets by said spacers, the north and south poles of said first electromagnet being respectively opposed to the north and south poles of said second electromagnet, the secondary pole pieces of each electromagnet being substantially opposed to the respective spacers of the other electromagnet, the ferromagnetic elements and spacers of both said electromagnets together defining a region between them through which material to be magnetized may be passed.

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