METHOD AND DEVICE FOR MAGNETIZING ANNULAR DISCS IN RADIAL DIRECTION
11 Claims, 2 Drawing Figs.

ABSTRACT: A method of radially magnetizing an annular disc includes covering a part of at least one flat face of the disc with a ring of soft-magnetic material having a diameter not greater than the inner diameter of the disc and having an outer diameter less than that of the disc and magnetic flux is passed radially through the disc between the outer and inner circumferential areas. The ring is removed from the disc and magnetic flux is again passed radially through the disc.

Device for carrying out the method includes a magnetic coil for generating a magnetic field. The coil has a core for conducting the flux of the field. A mandrel of magnetically permeable material mechanically engages the core and accommodates the disc and ring in the magnetic field. The core has a peripheral surface of which a portion is spaced from the mandrel. A yoke of magnetically permeable material is provided and magnetically communicates with the core of the surface portion of the latter spaced from the mandrel. The yoke conducts the flux to the outer peripheral surface of the annular disc to be magnetized.
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METHOD AND DEVICE FOR MAGNETIZING ANNULAR DISCS IN RADIAL DIRECTION

My invention relates to a method and device for magnetizing annular discs in radial direction.

The annular discs which are magnetized according to the method of the invention are used primarily as field-generating components of a permanently magnetized lens in cooperation with aperture discs magnetized in rotational symmetry. It is known, for example, from British Patent 522,377, to use such annular discs, magnetized in radial direction, as electron-optical lenses whose central opening serves as the passage for the electron beam to be acted upon. Lenses constructed in this manner can also be built in on other particle beam devices, such as in diffraction devices or ion microscopes.

Tests and experiments have demonstrated that this magnetization of annular discs in radial direction creates difficulties, at least when the material should be magnetized completely. Because the material cross section available to the magnetic flux is considerably smaller in the region of the inner diameter of the disc than in the region of the outer diameter thereof. It has been found that insofar as the annular disc is subjected, in the absence of other steps, to a magnetizing field, the magnetic flux passing through the disc is not high enough to secure a complete magnetization of the outer regions of the annular disc which is due to a premature magnetic saturation of the material in the inner region of the disc.

It is the object of my invention to provide a method and means suitable for magnetizing annular discs which affords complete magnetization of all regions of the disc.

According to a feature of the invention, magnetization of an annular disc is performed from its outer periphery. More specifically, the disc is subjected to a magnetic field which acts in the plane of the disc in radial direction between the outer and inner peripheral areas of the disc. First, at least one of the flat surfaces of the disc is covered by a ring of soft-magnetic material in the region whose limits are defined by a circle having an inner diameter not larger than the inner diameter of the disc and a circle having an outer diameter less than that of the disc. The elevation of the soft-magnetic ring increases with radial distance measured inwardly from the outer circle to the inner circle. The annular disc is subsequently subjected to the magnetic field without the soft-magnetic ring.

According to more specific features of the invention, while magnetization takes place, saturation of the inner region of the annular disc is prevented, whereas its outer region becomes magnetized because magnetic shunts are provided in parallel with the inner region, so that the magnetic flux which passes through the outer region is not restricted by saturation of the inner region. In order to reliably obtain a complete magnetization of the material of the inner region of the annular disc as well, the disc is subjected in a subsequent step to the magnetic field without having the soft-magnetic ring disposed thereon.

According to another embodiment of the invention, the magnetization of the annular disc is performed in more than two steps by exposing the disc to the magnetic field; first, by sequentially covering the regions of at least one of its front faces with several soft-magnetic rings or ring pairs having a smaller outer diameter than that of the previously used rings or pairs of rings. Thus, several soft-magnetic rings are used having respective outer diameters which become smaller with each successive method step while the inner ring diameter has the same value in each instance. This produces a step-by-step magnetization of the disc proceeding from the outside inwardly, so that saturation in the inner region of the disc cannot produce an adverse effect upon the magnetization of the outer region. As a final step, these method steps are followed by the magnetization of the inner region of the disc in the absence of the soft-magnetic rings which served as magnetic shunts.

The method of the invention affords the advantage of allowing annular discs to be magnetized along desired radii, as well as effecting a rotation-symmetrical magnetization, the latter being of particular importance where, for example, the discs are used as excitation elements of permanent-magnetic lenses. To preclude unavoidable tolerances from acting as disturbing deviations from the rotational-symmetry of the magnetization, it is preferable for achieving rotation-symmetrical magnetization of the annular discs to rotate the latter in several positions with and without the cover rings and to subject the same to the magnetic field in these positions.

The device for performing the method of the invention must be constructed to supply the magnetizing flux to the inside circumference of the discs to be magnetized as well as to the soft-magnetic rings and be able to receive the flux at the outer circumference of the disc or covering.

A device for performing the method of the invention which fulfills the above-mentioned criteria has a mandrel upon which the annular discs to be magnetized are placed together with the rings which are sometimes needed. The mandrel is made of a material having a low magnetic resistivity or high permeability and has longitudinal extensions which extend into the centric openings of the coils that produce the magnetic field. The extensions serve as cores for the coils and have respective peripheral surfaces of which a portion is spaced from the mandrel. These surface portions are connected with a magnetic yoke which extends into the region of the outer circumference of the annular disc.

In the method of the invention, the member used to hold the annular disc to be magnetized as well as the soft-magnetic rings also delivers the magnetic flux to the inner peripheral areas of the disc and rings.

The yoke portion of the magnetic circuit does not necessarily have to bear upon the outer surface of the disc for it to be magnetized, rather, a good magnetizing effect is achieved even when an airgap is present between the magnetic yoke and the annular disc. I have found to be most effective a device wherein the yoke is provided with a yoke plate which surrounds the outer peripheral area of the annular disc and which has a thickness greater than that of the disc, at least on the outside. In addition, the plate tapers to lesser thickness in the direction of the disc.

Hence, while the elevation of the soft-magnetic rings which bear as shunts upon the inner regions of the disleads to be magnetized, is preferably reduced in a radial outward direction, the thickness of the yoke plate diminishes in the opposite radial direction so that its value at the contact point with the outer peripheral area of the annular disc corresponds approximately to the thickness of the disc. This dimensioning of the soft-magnetic rings and the yoke plate was found to be advantageous in regard to reducing stray flux in the vicinity of the annular disc.

It is possible to provide an embodiment of the device for performing the invention which involves an asymmetrical construction and produces the magnetic flux used to effect magnetization with one or more windings arranged only to one side of the annular disc to be magnetized. However, for securing the best feasible homogeneity of magnetization in the disc with respect to rotational symmetry of magnetization as well as with respect to the center plane of the disc which extends parallel to flat surfaces thereof, it is preferable to position the disc in the device turned once or several times by 180° and to subject the disc to magnetization in each such position.

This expedient becomes unnecessary if each side of the mandrel is provided with a magnetic coil and core which drive aligned magnetic fluxes via a common yoke through the annular disc as well as the rings which are sometimes used. In the mandrel, the coils produce mutually opposed magnetic fluxes which extend in the same directions in the annular disc to be magnetized.

As already discussed, it is desirable for obtaining a rotation-symmetrical magnetization to rotate the annular discs to several positions and to subject them to the magnetic field. A feature of the magnetizing device of the invention is that the mandrel is rotatable about its longitudinal axis during the magnetization process. Rotation of the mandrel can be effected manually as well as by a relatively slow rotating electric motor.
The magnetizing device is preferably subdivided at a place suitable for inserting and removing the annular disc and the rings. Also the mandrel with the discs and the rings when used are rotatably positioned in the direction of the longitudinal axis of the mandrel to facilitate the removal of the annular discs from the vicinity of the yoke plate.

The invention will be further elucidated with reference to the accompanying drawings showing by way of example an embodiment of a magnetizing device according to the invention.

FIG. 1 is a sectional view of a device for magnetizing annular discs in accordance with the method of the invention.

FIG. 2 is a sectional view of the magnetizing device when viewed from lines II-II in FIG. 1.

In FIG. 1 annular disc 1 to be magnetized is held by the mandrel 2 whereof is a material having low magnetic resistivity. The mandrel 2 butts against the annular disc on the right end, the latter extending into coil 4. Coil 4 produces a north pole N at the end of the magnet core 3 which faces the mandrel 2.

The left end of the mandrel 2 extends into pole piece 5 at magnet core 6, the latter extending into coil 7. This arrangement establishes a connection between the mandrel 2 and the magnet core 6 is detachable along the interface 6a by moving the magnetic core 3 to the right.

The magnetic circuits close over the yoke 8 which is common to coils 4 and 7 as well as over yoke plate 9 which bears upon the outer peripheral area of the annular disc 1 to be magnetized.

Referring to FIG. 2, the magnetic yoke 8 is essentially comprised of two struts 10 and 11. The yoke plate consists of two halves 13, 14 divided at the junction interface 12 which lies on a line passing through the axis of the mandrel 2. Plate halves 13, 14 are detachably joined together by screws or other suitable means after the disc 1 to be magnetized, is placed in position.

FIGS. 1 and 2 illustrate the disc 1 after the inner regions thereof have been covered by soft-magnetic rings 15, 16 according to a step of the method of the invention, the rings 15, 16 functioning to prevent limiting the magnetic flux which crosses the disc 1 because of saturation within the inner region of the latter.

The positioning of the annular disc 1 and rings 15, 16 and their subsequent removal from the magnetizing device becomes especially simple if there is no permanent connection between the mandrel 2 and the magnetic core 3 and if instead only a bearing surface is provided as illustrated. The annular disc 1 and when required, rings 15, 16 are first threaded on the mandrel outside the device. The assembly thus formed is placed in the magnetizing device while the yoke plate 9 is opened, for example, by removing plate half 14. A good contact between the annular disc 1 and core 3 is established by shifting the latter. The plate half 14 of the yoke plate 9 is then screwed or otherwise secured to plate half 13.

Even if the magnetic return circuit is not rotationally symmetric, a uniformity in the magnetizing flux is still effected along the yoke plate 9, since the circuit has only the two strut-like parts 10, 11, so that a rotation-symmetrical magnetization of the annular disc is obtained. Stray flux in the vicinity of the annular disc 1 is held at a minimum because of the tapered construction of the yoke plate 9 indicated by reference numerals 17 and 18. At 17 and 18, the thickness of the plate 9, is conically reduced to correspond approximately to the thickness of the disc 1. The thickness of the soft-magnetic rings likewise decreased with radial distance to keep stray flux at a minimum.

When the magnetization of the annular disc 1 is not effected in rotational symmetry, but only along specific radii, the mandrel 2 and the yoke plate 9 are constructed so as not to bear upon the disc 1 along the entire inner and outer circumferential areas respectively of the latter, but only in the regions corresponding to the desired radii. The annular disc does not necessarily have to be an annular disc, but can have, for example, outer boundary areas, which are planar such as a polygon.

Upon study of this disclosure it will be obvious to those skilled in the art that my invention permits of a great variety of modifications in a manner analogous to the above-mentioned magnetizing method and device. For example, the mandrel and magnetic cores can together constitute a single member. I claim:

1. The method of radially magnetizing an annular disc which comprises covering a part of at least one of the flat faces of the disc with a ring of soft-magnetic material having an inner diameter not greater than the inner diameter of said disc and having an outer diameter less than that of said disc, passing magnetic flux radially through the disc between its outer and inner circumferential areas, removing said ring from said annular disc and, again passing magnetic flux radially through the disc.

2. The method according to claim 1, which comprises sequentially covering a part of at least one of the flat surfaces of the annular disc with a plurality of said rings, one at a time, each succeeding ring having an outer diameter less than the outer diameter of the preceding ring, passing magnetic flux radially through said disc while covering said disc with a first one of said rings, and passing magnetic flux through said disc at least once more with another one of said plurality of said rings having an outer diameter less than the outer diameter of the first of said rings.

3. The method according to claim 2, wherein each of said rings has a thickness which increases with radial distance from its outer periphery to its inner periphery.

4. The method according to claim 1, wherein said disc is magnetized in rotational symmetry, said method comprising rotating said disc with said ring to a plurality of angular positions, passing magnetic flux radially through said disc at a first one of said positions, and passing magnetic flux through said disc at least once more at another one of said plurality of positions, and after removing said ring form said disc, again rotating said disc to a second plurality of angular positions, and passing magnetic flux through said disc at a first one of said second plurality of positions, and passing magnetic flux through said disc at least once more at another one of said second plurality of angular positions.

5. A device for radially magnetizing an annular disc with the aid mandrel, ring means made of soft-magnetic material, said device comprising magnetic coil means for generating a magnetic field, said coil means having core means for conducting the flux of said field, a mandrel of magnetically permeable material for accommodating the disc and ring means in said magnetic field, said mandrel magnetically engaging said core means, said core means having a peripheral surface of which a portion is spaced from said mandrel, and a yoke of magnetically permeable material magnetically communicating with said core means at said surface portion and being adapted to conduct said flux to the outer peripheral surface of the annular disc to be magnetized.

6. In a device according to claim 5, said yoke having a plate surrounding the outer peripheral surface of the disc, said plate having a thickness at its outermost region greater than the thickness of the disc, said thickness decreasing with radial distance measured inwardly toward the disc.

7. In a device according to claim 5, said core means being two coil cores disposed at the axially opposite ends of said mandrel, each of said cores having a peripheral surface, a portion of which is spaced from said mandrel, said coil means being two coils surrounding said cores respectively, and said yoke magnetically communicating with each of said cores at said surface portion thereof for directing said flux in symmetrical distribution through the disc and ring means in the same direction.

8. In a device according to claim 5, said mandrel and said core means having coupling means for establishing a disconnectable connection therebetween and so permit placement and removal of the disc and ring means on said mandrel.

9. In a device according to claim 6, said plate consisting of two parts disconnectable along a junction interface disposed on a line passing through the longitudinal axis of said mandrel.
10. In a device according to claim 5, said core means being rotatably disposed in said coil means so as to permit rotation of said mandrel about its longitudinal axis.

11. In a device according to claim 5, said core means and said mandrel having a common longitudinal axis, said mandrel with the disc and ring means being displaceable along said axis.