United States Patent

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[33] **Germany**
[31] **P 18 10 005.5**

[54] **TEMPERATURE-COMPENSATED PERMANENT MAGNET**
7 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **335/217,** 335/302
[51] **Int. Cl.** **H01f 1/00**
[50] **Field of Search** 335/217, 302, 303, 306; 308/10

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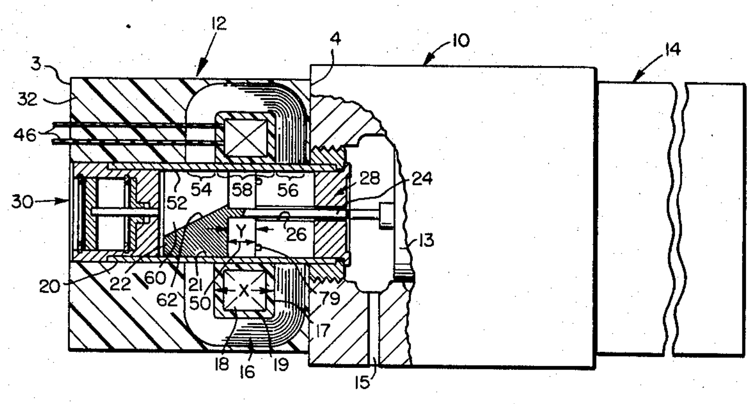
ABSTRACT: A temperature-compensated permanent magnet comprising a generally thin, permanent magnet body having first and second surfaces and magnetized to provide magnetic poles on at least one of the surfaces. Temperature-compensation means are carried by the body for maintaining a substantially constant magnetic flux. The magnet body is configured to have large surface areas and a relatively small thickness.



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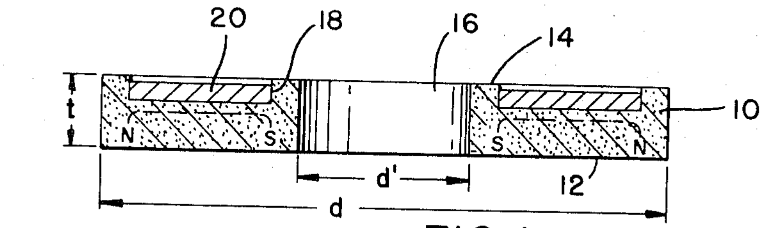

FIG. 1

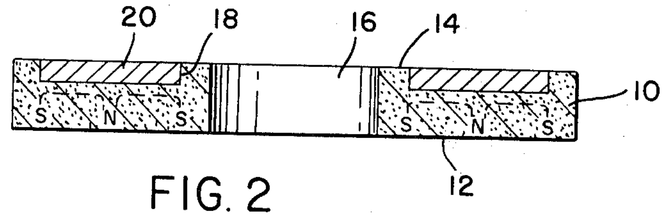

FIG. 2

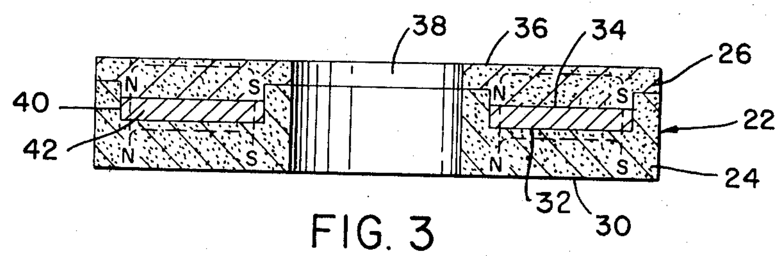

FIG. 3

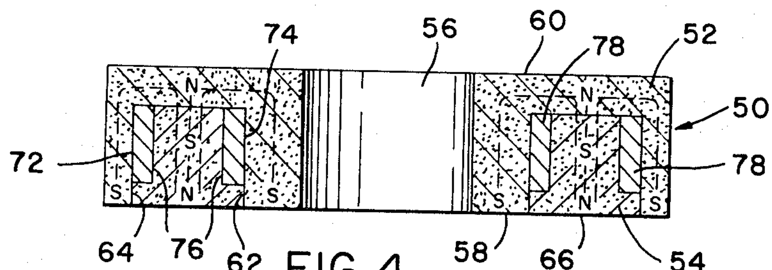

FIG. 4

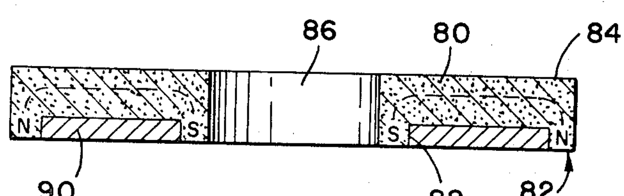

FIG. 5

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TEMPERATURE-COMPENSATED PERMANENT MAGNET

This invention pertains to the permanent magnet art and more particularly to a temperature-compensated permanent magnet.

The invention is particularly applicable to permanent magnet bearings and will be described with specific reference thereto; however, it is to be appreciated that the invention has broader applications and may be used with a variety of devices such as electric measuring equipment and the like.

Magnet bearings are commonly used in a variety of devices wherein the repelling forces between like magnetic poles are used for rotatably supporting one member of the device with respect to another member of the device which is generally fixed to define an air gap therebetween. These bearings are comprised of a pair of magnetic bodies formed from permanently magnetic material having a negative temperature coefficient of induction. Examples of such materials are oxides of iron which include preselected amounts of cobalt, barium, lead or strontium oxide. Temperature-compensation means are carried by the magnet bodies which are formed from magnetizable material having a low Curie point. In most instances iron alloys containing approximately 30 percent nickel are used for this purpose. The temperature compensation means is arranged to define a shunt in the useful magnetic field. In this manner, when the surrounding temperature increases, the magnetic resistance of the temperature-compensation means rises to the same extent as the induction of the magnet bodies decreases, whereby a constant magnetic flux is maintained in the air gap.

When the magnet bodies are constructed from permanent magnet material having a relatively high permeability, temperature compensation is an easy task, because the lines of magnetic force inside the permanent magnet material are generally well conducted through the material towards the temperature compensation means. Being more specific, in the case of permanent magnet material having a relatively high permeability, such as alnico, nearly all the lines of magnetic force originating therefrom are controlled by the temperature compensation means which has the effect of a magnetic shunt, whereby efficient temperature compensation is possible.

In magnets made of the above-mentioned materials the length of the lines of magnetic force between the poles is relatively long and the pole surfaces are relatively small. Furthermore, magnetization is preferably in the direction of the largest dimension, that is, in the axial direction. Thus, for example, in the case of a cylindrical magnet, the north pole is on one end surface and the south pole is on the opposite end surface, the temperature compensation means being disposed on the lateral area of the cylinder intermediate the surfaces.

For many applications, however, it is desirable to construct the magnet bodies from permanent magnet material having a high coercive force and low permeability. Examples of such materials are barium, strontium and lead ferrite. Due to the low permeability of these ferrites, sufficient temperature compensation cannot be obtained. Being more specific, the low permeability of the magnet material does not conduct the lines of magnetic force, but instead acts like air. Therefore, if a magnetic body of cylindrical shape, as heretofore discussed, were made of such permanent magnet material and temperature compensation is carried out in the above-described way, only the lines of magnetic force originating from the rim zone would be short circuited by the temperature compensation means. As such, it has not heretofore been possible to adequately compensate magnetic bodies constructed from low permeability magnet material for changes in temperature.

The present invention contemplates a new and improved magnetic arrangement which overcomes all of the above referred problems and others, and provides a temperature-compensated permanent magnet which may be constructed from magnetic material having a low permeability.

In accordance with the present invention there is provided a temperature-compensated permanent magnet comprising: a generally thin, permanent magnet body having first and second surfaces, the distance between the surfaces defining the thickness of the body; a body being magnetized to provide magnetic poles on at least one of the surfaces; temperature compensation means carried by the body for maintaining a substantially constant magnetic flux; the ratio of the area of either of the surfaces to the thickness of the body being at least equal to 25.

The principal object of the present invention is to provide a temperature-compensated permanent magnet which may be constructed from permanent magnetic material having a low permeability.

Another object of the present invention is to provide a temperature-compensated permanent magnet formed from low permeability magnetic material which is capable of accurately compensating for changes in surrounding temperature.

A further object of the present invention is to provide a temperature-compensated permanent magnet which may be easily manufactured by a variety of processes such as injection molding.

Yet another object of the present invention is to provide a temperature-compensated permanent magnet which is simple and economical to manufacture.

These and other objects and advantages will become apparent from the following description used to illustrate the preferred embodiments of the invention when read in conjunction with the accompanying drawings in which:

FIG. **1** is a cross-sectional view of a temperature-compensated permanent magnet illustrating a preferred embodiment of the present invention; and

FIGS. **2–5** are cross-sectional views of alternative embodiments of the invention.

Referring now to the drawings wherein the showings are for the purpose of illustrating the preferred embodiments of the invention only and not for the purpose of limiting same, FIG. **1** shows a generally thin permanent magnet body **10** having a first surface **12** and a second surface **14**. The magnet body **10** is preferably disc shaped and includes a central opening **16** for securing the body to a support member (not illustrated). Although the magnet body **10** has been shown as being disc shaped, it is to be appreciated that any variety of configurations would be suitable, depending upon the particular use for which the magnet is intended.

The magnet body **10** is magnetized to provide a pair of radially spaced concentric magnetic poles, designated by the letters N and S. The poles are formed on the first surface **12** and as such, the first surface is more particularly defined as the pole surface. As shown by a dashed line, the lines of magnetic force in the interior of the magnet body **10** form a bow which extends from one pole to the other pole. An annular recess **18** is provided in the second surface **14** of the magnet body **10**. There is further provided temperature compensation means for maintaining a substantially constant magnet flux which may take a variety of forms; however, in the present embodiment it is shown as a temperature compensation ring **20** which is disposed within the recess **18**. Preferably, the temperature compensation ring comprises a magnetizable material having a low Curie point, preferably within a range from 65° to 90° C.

The distance between the first surface **12** and the second surface **14** defines the thickness of the magnet body **10** and is represented by the dimension t. The disc-shaped magnet body **10** has a diameter which is represented by the dimension d and the central opening **16** has a diameter which is represented by the dimension d'. As such, the area A of either surface **12**, **14** may be represented by the equation

$$A=\frac{\pi d^2}{4}-\frac{\pi d'^2}{4}$$

In order that the magnet body **10** may be formed from magnetic materials having a low permeability, such as the ferrite materials, barium, strontium and lead ferrite, the surface area A must be substantially greater than the thickness t. Being more specific, the ratio R of the area of either of the surface **12**, **14** to the thickness t of the magnet body **10** must be at least equal to 25. This ratio is represented by the equation $R \geqq A/t = 25/1$ Furthermore, in those instances where the magnet body **10** is disc shaped (as shown in the embodiment of FIG. **1**), the ratio R' of the diameter of the disc *d* to the thickness of the disc *t* must be equal to at least 3.5. This ratio is represented by the equation $R' \geqq d/t = 3.5/1$. Thus, when *R* is at least equal to 25 and *R'* is at least equal to 3.5, it is possible to construct a temperature-compensated permanent magnet from magnetic material having a low permeability. If the magnet body is rectangular, a hypothetical cylindrical magnet body having a surface area equal to the surface area of the rectangular body should be employed as a basis for establishing a value for the diameter *d*.

The magnet body **10** is preferably formed from a mixture of powdered permanent magnet material of high coercive force and low permeability and a plastic binder. This mixture is shaped to the desired configuration, namely that of a magnet body **10** having a large surface area *A* in contrast to a relatively narrow thickness *t*, by injection molding under the influence of a magnetic orienting field. This method of production yields a homogeneous distribution and aligning of the permanent magnet particles in the binder, whereby upon subsequent magnetization the pole surfaces have a homogeneous field distribution over the entire surface. A homogeneous field distribution is of special importance when the temperature-compensated permanent magnets are to be used for magnetic bearings, inasmuch as even rotation is assured and magnetic irregularities are avoided which might otherwise prevent the proper operation of the device in which the magnetic bearings are employed.

Reference is now made to FIG. **2**, wherein there is shown another embodiment of the temperature-compensated permanent magnet. In this embodiment, which is quite similar to the embodiment illustrated in FIG. **1**, the first surface **12**, which is more precisely defined as the pole surface, includes three radially spaced concentric poles. As shown by the reference letters N and S, the north pole is disposed intermediate a pair of south poles. The concentric pole surfaces of the south poles are equal to the concentric surface of the north pole. Furthermore, as shown in dashed lines, the lines of magnetic force in the interior of the magnet body **10** again form bows from pole to pole. The ratios *R* and *R'* discussed in conjunction with the embodiment illustrated in FIG. **1** are equally applicable to the present embodiment.

Referring now to FIG. **3**, wherein there is shown another embodiment of the temperature-compensated permanent magnet. In this embodiment, there is provided a disc-shaped magnet body, designated generally by the reference numeral **22**, having a first body portion **24** and a second body portion **26**. The portions **24**, **26** are configured to fit together to define the unitary magnet body **22**. The first portion **24** includes a first surface **30** and a second surface **32** and the second portion **26** includes a first surface **34** and a second surface **36**. Accordingly, the thickness *t* of magnet body **22** is the distance between the first surface **30** and the second surface **36**. As in the foregoing embodiments a central opening **38** is provided.

Both portions **24**, **26** have been provided with radially spaced concentric poles, designated by the reference letters N and S, on their respective first surfaces **30**, **34**, which are more precisely referred to as the pole surfaces. Although a pair of concentric poles have been shown, it is to be appreciated that more than two poles could be employed depending upon specific magnetic needs. Furthermore, as shown in dashed lines, the lines of magnetic force on the interior of the body portions **24**, **26** again form bows which extend from pole to pole.

The first portion **24** includes an annular recess **40** in the second surface **32** in which is carried a temperature compensation ring **42**. The temperature-compensating effect of the ring **42** is equally applicable to the poles carried on both the first and second portions **24**, **26**. The first surface **34** of the second portion **26** defines a projection which is configured to engage the recess **40** for the purpose of accurately locating the second portion **26** on the first portion **24** when the portions are fitted together. The ratios discussed with respect to the embodiment illustrated in FIG. **1**, namely that *R* is at least equal to 25 and *R'* is at least equal to 3.5, are also applicable and essential for the successful operation of the temperature-compensated permanent magnet illustrated in the present embodiment.

Referring now to FIG. **4**, wherein there is shown another embodiment of the temperature-compensated permanent magnet. In this embodiment, there is provided a disc-shaped magnet body designated generally by the reference numeral **50**, having a first body portion **52** and a second body portion **54**. As in the foregoing embodiments, the magnet body **50** includes an axially extending central opening **56**. The first portion **52** includes a first surface **58** and a second surface **60**, the distance between these surfaces defining the thickness *t* of the magnet body **50**. The second portion **54** includes a pair of opposed axial surfaces **62**, **64** and a radially extending surface **66**. The portions **52**, **54** are configured to fit together to define the unitary magnet body **50**. In the fitted together position, the radially extending surface **66** is in alignment with the first surface **58** and the opposed axial surfaces **62**, **64** are in contact with a pair of opposed internal surfaces **72**, **74** which define a circumferential slot in the first portion **52**.

A radially spaced concentric recess **76** is provided in each of the opposed axial surfaces **62**, **64** of the second portion **54**. Disposed in each of the recesses **76** is a temperature compensation ring **78**. As shown by the reference letters N and S, the first portion **52** has been magnetized both in the axial and radial directions to provide a pair of south poles on the first surface **58** and an intermediate north pole facing the second surface **60**. The second portion **54** has only been magnetized in the axial direction and includes a north and south pole located intermediate the opposed axial surfaces **62**, **64**. When the portions **52**, **54** are fitted together to form a unitary magnet body **50**, the resulting magnetization is one of radially spaced concentric poles with the temperature compensation rings **78** disposed in the shunt of the magnet portions, whereby effective temperature compensation is achieved. As in the foregoing embodiments, the lines of magnetic force in the interior of the magnet portions **52**, **54** as shown in dashed lines, form bows from pole to pole.

The ratio requirements as set forth in the explanation of the embodiment illustrated in FIG. **1** are equally applicable to the present embodiment. As such, the ratio *R* must at least be equal to 25 and the ratio *R'* must at least be equal to 3.5.

Reference is now made to FIG. **5**, wherein there is shown another embodiment of the temperature-compensated permanent magnet. In this embodiment there is provided a thin permanent magnet body **80** having a first surface **82** and a second surface **84**. The distance between the surfaces **82**, **84** defines the thickness *t* of the magnet body **80**. There is further provided an axially extending central opening **86**. The first surface **82** includes an annular recess **88** in which is disposed a temperature compensation ring **90**. A pair of radially spaced concentric poles, designated generally by the reference letters N and S, have been provided on the first surface **82**, which more precisely may be defined as the pole surface. As shown in dashed lines, the lines of magnetic force in the interior of the magnet body **80** forms bows from pole to pole. Furthermore, the ratio requirements as more particularly set forth in the discussion of the embodiment illustrated in FIG. **1** are equally applicable to the present embodiment.

In this embodiment the temperature compensation ring **90** is located on the pole surface **82** of the magnet body **80**, whereas in the embodiment illustrated in FIG. **1**, the temperature compensation ring **20** is not located on the pole surface **12** but instead is adjacent the second surface **14** and between the magnetic poles. By attaching the temperature compensation ring **90** to the magnetized surface **82**, that is, the surface facing the air gap (not illustrated), when the magnet body **80** is used as a magnet bearing, increases in the surrounding temperature will cause a corresponding decrease in the permeability of the temperature compensation material, such that the permeability is practically equal to that of the air. Thus, in this embodiment, the temperature compensation material has the effect of increasing the air gap.

The foregoing embodiments illustrate various arrangements for a temperature-compensated permanent magnet and each includes a specific polar arrangement. It is to be appreciated however, that variations in the number and arrangement of poles may be made without effecting the overall operability of the permanent magnet.

Although the invention has been described with reference to specific embodiments, variations within the scope of the following claims will be apparent to those skilled in the art.

Having thus described my invention, I claim:

1. A temperature-compensated permanent magnet comprising: a generally thin, permanent magnet body molded from a high coercive force, low-permeability material having first and second surfaces, the distance between said surfaces defining the thickness of said body; said body being magnetized to provide magnetic poles on at least one of said surfaces with the lines of magnetic force interior of the body extending in bowed paths between the poles; temperature compensation means carried by said body for maintaining a substantially constant magnetic flux; said means being in a position where at least a majority of the lines of magnetic force in their normal path exterior of the body pass therethrough, the ratio of the area of either of said surfaces to the thickness of said body being at least equal to 25.

2. The temperature-compensated permanent magnet defined in claim 9, wherein said magnet body is a disc, the ratio of the diameter to the thickness of said disc being at least equal to 3.5.

3. The temperature-compensated magnet defined in claim 2, wherein said disc has at least two radially spaced concentric magnetic poles disposed on said first surface and said second surface includes an annular recess in which is carried said temperature compensation means.

4. The temperature-compensated permanent magnet defined in claim 2, wherein said disc has a first surface including at least two radially spaced concentric magnetic poles and an annular recess in which is carried said temperature compensation means.

5. The temperature-compensated permanent magnet defined in claim 2, wherein said disc comprises first and second portions configured to fit together to define a unitary magnet body, each of said portions including said first and second surfaces, at least two radially spaced concentric poles disposed on one of said surfaces of each of said portions, one of said portions including an annular recess in which is carried said temperature compensation means, said recess being located intermediate said portions.

6. The temperature-compensated permanent magnet defined in claim 2, wherein said disc comprises first and second portions configured to fit together to define a unitary magnet body, said first portion including said first and second surfaces and said second portion having opposed axial surfaces in contact with said first portion when said portions are fitted together, said second portion further having a radially extending surface in alignment with one of said first portion surfaces when said portions are fitted together, a radially spaced concentric recess disposed in each of said opposed axial surfaces, in which is carried said temperature compensation means, one of said portions being magnetized in the radial direction and the other of said portions being magnetized in both the radial and axial directions, and all lines of magnetic force being curved between opposite polar surfaces.

7. The temperature-compensated permanent magnet defined in claim 1, wherein said temperature compensation means comprises a magnetizable material having a low Curie point.

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