

## PERMANENT MAGNETIC BEARING INSERT

### Field

- 5 [001] The present invention relates to a magnetic bearing insert for a vacuum pump, a vacuum pump, particularly a turbomolecular pump, comprising the same, and a method of manufacturing a vacuum pump. The invention further provides the use of a neodymium magnet alloy in a permanent magnetic bearing insert or vacuum pump.

### 10 Background

[002] A vacuum pump typically comprises an impeller in the form of a rotor mounted on a shaft for rotation relative to a surrounding stator. In a turbomolecular pump, for example, sets of moving rotor blades are located on a shaft and are separated and  
15 moveable between stationary blades, in use, to compress gas and typically deliver it to an outlet pump, e.g. a rotary pump.

[003] A shaft is supported by two bearing arrangements located at or intermediate respective ends of the shaft. Typically, the upper bearing (that nearest the pump inlet)  
20 may be in the form of a magnetic bearing, and the lower bearing is in the form of a rolling bearing.

[004] The magnetic bearing is typically a passive magnetic bearing comprising an inner stator bearing half and an outer rotor bearing half, the outer rotor bearing half  
25 forming a part of the rotor shaft of the vacuum pump. The outer rotor bearing half typically comprises one or more ring shaped permanent magnets coaxially aligned with the axis of rotation of the rotor shaft and the inner stator bearing half.

[005] Typically, the permanent magnet rings in the inner stator bearing half and outer  
30 rotor bearing half are magnetised and disposed relative to each other in order to create repulsive forces between the two halves. Thus they may suspend the rotor radially.

[006] Typically, the permanent magnet rings are made from a samarium–cobalt alloy, such as SmCo<sub>5</sub>. Advantageously, these magnets are extremely resistant to demagnetisation, and show good temperature stability with maximum use temperatures typically between 250°C and 550 °C, and a Curie temperature from 700 °C to 800 °C.

[007] There is however a desire to move towards other magnet alloys, such as neodymium magnets, as they are magnetically stronger, facilitating the use of small magnets and ultimately more compact vacuum pump designs. Known vacuum pump designs and methods of manufacture have however been found to be unsuitable for successfully accommodating these alternative magnets in their bearings.

[008] The present invention addresses at least to a degree some or all of these problems with the prior art.

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## Summary

[009] Thus, in a first aspect, the present invention provides a vacuum pump, preferably a turbomolecular pump, comprising a rotor shaft configured to have one or more rotor blades coupled thereto and the rotor shaft defining a bearing well containing, in an interference-fit configuration, a permanent magnetic bearing insert.

[010] The magnetic bearing insert comprises one or more permanent magnet alloy rings of a rotor bearing half of a permanent magnetic bearing and a radially outwardly extending sleeve coupled thereto around an outer circumference of the or each said permanent magnet alloy ring.

[011] An outer surface of the permanent magnetic bearing insert engages with an inward facing wall of the bearing well to provide an interference fit.

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[012] Preferably, the radially outwardly extending sleeve has a coefficient of thermal expansion that is at least substantially the same as (i.e. the same or greater than),

preferably substantially the same as, the coefficient of thermal expansion of the material of the rotor shaft defining the engaged bearing well wall.

[013] In a related aspect, the invention further provides permanent magnetic bearing  
5 insert for a vacuum pump, the vacuum pump comprising a rotor shaft having one or more rotor blades coupled thereto and the rotor shaft defining a bearing well configured to receive the magnetic bearing insert in an interference-fit configuration.

[014] The magnetic bearing insert comprises one or more magnetized permanent  
10 magnet alloy rings of a rotor bearing half of a permanent magnetic bearing and a radially outwardly extending sleeve coupled thereto around an outer circumference of the or each said permanent magnet alloy ring.

[015] An outer surface of the permanent magnetic bearing insert is configured to  
15 engage with an inward facing wall of the bearing well following insertion therein.

[016] Typically, the sleeve of the permanent magnetic bearing insert will be generally tubular. The sleeve may extend from a proximal end to a distal end. When *in situ* in the rotor shaft of the vacuum pump, the proximal end is typically located towards a low  
20 pressure end of the rotor, whereas the distal end is typically located towards a relatively higher pressure section of the rotor.

[017] The sleeve of the permanent magnetic bearing insert may be a substantially plain cylinder or may include other features.  
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[018] One end of the sleeve may include a radially inwardly extending annular flange, or other abutment, for retaining the permanent magnet alloy ring(s). In use, a permanent magnet alloy ring may directly abut against the radially inwardly extending annular flange or other abutment. In some applications, this end may be the proximal or  
30 low pressure end.

[019] Such radially inward extending annual flange or abutment may be integral part of the sleeve or may be in the form of a ring, or other insert, inserted in the sleeve to provide an abutment for the or each magnet(s). Said ring or insert may be held by a  
35 snap-fit or interference fit or other permanent or semi-permanent fixation.

[020] In some applications an abutment ring, or other abutment insert, may be inserted at the opposite end to that of an integral ring to provide abutment to the magnet(s) so as to provide an abutment either side of the magnetic ring(s). Likewise,  
5 in some applications two abutment rings, or abutment inserts, may be inserted, each at the opposite ends of the sleeve. This arrangement may provide abutment to the magnetic ring(s) at both ends also.

[021] One end of the sleeve may include a funnelled entrance. This may assist with  
10 pushing the permanent magnet alloy rings into the funnel and/or forming an interference fit. In some applications the funnelled entrance may be at the distal or higher pressure end of the sleeve. Typically, before the permanent magnet alloy rings are inserted, the funnelled entrance is such that the internal diameter of the sleeve decreases from a diameter greater than that of the permanent magnet alloy ring(s) to  
15 a diameter that is smaller than that of the of the permanent magnet alloy ring(s). Once *in situ* the rings will typically be in an interference fit. An abutment ring, or other abutment insert, may be inserted through the funnelled entrance once the permanent magnet alloy ring(s) are *in situ* to improve the retention thereof.

[022] An end of the sleeve may include a tapered and / or stepped outer surface. This may assist with pushing the sleeve and/or bearing insert into the rotor shaft bearing well. In some applications the tapered and/or stepped outer surface may be located at the distal or higher pressure end of the sleeve. However, in other applications, for instance a bell-shaped rotor, the tapered and/or stepped outer surface may be located  
25 at a proximal or lower pressure end of the sleeve. Typically, before the sleeve and/or bearing insert is inserted into the bearing well, the tapered outer surface is such that the outer diameter of the sleeve increases from a diameter less than the inner diameter of the bearing well to a diameter greater than the diameter of the bearing well. This may assist with pushing the sleeve and/or bearing insert into the bearing well and/or  
30 forming an interference fit.

[023] When *in situ* in the bearing well of the rotor shaft, an end of the bearing insert directly may abut against a radially inwardly extending annular flange formed within the rotor shaft. This may assist with the correct alignment of the rotor half of the  
35 permanent magnet bearing with the stator half of the permanent magnet bearing.

[024] When the bearing insert is *in situ* in the bearing well of the rotor, an additional abutment ring or similar abutment insert(s) may be inserted in the rotor well so as to abut against the sleeve and/or the magnets. The additional abutment ring, or abutment  
5 insert, may compliment the interference fit between the sleeve and well to better hold the sleeve and/or the magnet rings in place.

[025] The bearing well is typically in the form of a cavity or recess in the rotor shaft.  
10 Typically, the bearing well is located at or towards a proximal, or lower pressure, end of the rotor shaft. Although, in embodiments, bearing well may be present at or towards the distal, relatively higher pressure, end of the rotor shaft, or at or towards both ends of the rotor shaft.

[026] The bearing well may be configured to slidably receive the bearing insert to achieve an intimate engagement about the entire circumference of the bearing insert. Typically, the bearing well has a generally circular cross-section along a length thereof. The fit between the bearing well and the bearing insert may be permanent or semi-permanent. The fit may however be sufficient to maintain the position of the permanent  
15 bearing magnets during normal use of the vacuum pump.  
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[027] Typically, the bearing insert may comprise from about 1 to about 10 permanent magnet alloy rings, more preferably from about 2 to about 6 permanent magnet alloy rings, 2 to 4 permanent magnet alloys are particularly preferred.

25 [028] Preferably, the permanent magnet alloy ring(s) comprise a Neodymium Iron Boron ('neodymium') magnet, preferably  $\text{Nd}_2\text{Fe}_{14}\text{B}$ ; or Samarium Cobalt, preferably  $\text{SmCo}_5$ , or  $\text{Sm}_2\text{Co}_{17}$ . Neodymium magnet(s) are particularly preferred. Typically, where a plurality of magnet alloy rings are present, each comprise substantially the  
30 same material.

[029] Preferably, the radially outwardly extending sleeve has a coefficient of thermal expansion that is at least substantially the same as the coefficient of thermal expansion of the material of the rotor shaft defining the engaged bearing well wall,  
35 preferably their coefficient of thermal expansion is substantially the same.

[030] The invention further provides a rotor for a vacuum pump comprising a rotor shaft having one or more rotor blades coupled thereto and the rotor shaft defining a bearing well containing magnetic bearing insert in an interference-fit configuration.

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[031] The magnetic bearing insert comprises one or more permanent magnet alloy rings of a rotor bearing half of a permanent magnetic bearing and a radially outwardly extending sleeve coupled thereto around an outer circumference of the or each said permanent magnet alloy ring.

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[032] Preferably, the radially outwardly extending sleeve has a coefficient of thermal expansion that is at least substantially the same as the coefficient of thermal expansion of the material of the rotor shaft defining the engaged bearing well wall.

15 [033] Advantageously, the permanent magnetic bearing insert of the aspects of the invention facilitates the inclusion of a neodymium permanent magnet, and others, in the magnetic bearing of a vacuum pump.

[034] As will be appreciated, permanent magnets are typically brittle and cannot  
20 withstand high tensile loads without fracture. In order to contain tensile stress, rotor bearing half magnets are typically inserted into the rotor with an interference fit, generating an inward radial compressive fit on the rotor bearing half magnets.

[035] The material properties and sizes of the permanent magnets and the rotor are  
25 such that the magnets expand less with temperature and centrifugal force than the rotor, which is typically made from aluminium. This results in a decrease in the amount of compression exerted by the rotor on the rotor magnets during use.

[036] However, as will be understood, for the bearing to operate as intended the  
30 residual compressive action at maximum speed and temperature must still be sufficient for the rotor bearing half magnets to be retained by the rotor, all while keeping the tensile strain below a maximum allowed value for a given magnet (this may be referred to as a minimum compressing action).

[037] In addition, the magnets may have a minimum fit requirement. The minimum fit between magnets is the fit that at maximum temperature and speed generates the minimum compressing action as described above.

- 5 [038] Additionally, tolerances in the magnets and in the rotor result in a max fit which may be defined as '*the minimum fit requirement*' plus manufacturing tolerances.

[039] When the max fit condition occurs, the compressive stress on the magnets and the overall stress in the rotor are highest. This will typically be encountered when the  
10 rotor is not rotating and when the ambient temperature (and consequently the temperature of the rotor and bearing) is low (e.g. room temperature).

[040] Additionally, the magnets are typically inserted into the rotor by a press, with the rotor heated to a high temperature to minimise the press force required. The  
15 magnets may also be cooled to very low temperatures, such as in liquid nitrogen, to minimise the pressing force required. The maximum temperature the rotor can be heated to is often limited by material science issues and the pressing forces can also be limited by stress and practical considerations. Therefore, there is a limit in the max fit that can be achieved, which in turn limits the minimum fit requirement.

20 [041] The inventors have found that the use of neodymium, NdFeB, magnets especially, poses a particular challenge because of their relatively very low coefficient of thermal expansion and their susceptibility to demagnetisation at relatively low temperatures (e.g. from about 120 °C, depending on the grade).

25 [042] The minimum fit requirement is therefore much higher than with magnets like NdFeB, and the max fit that can be achieved is reduced because cooling the magnets during the fitting operation does not help (because of their negligible or negative coefficient of thermal expansion) and, depending on the rotor material, by the  
30 maximum temperature they can be exposed to before significant demagnetisation takes place.

[043] The use of a sleeve may allow increased compression of the magnets, particularly when the magnets are inserted in the sleeve first and then the assembly  
35 formed by the sleeve and magnets is inserted into the rotor.

[044] However, permanent magnetic bearing inserts made from materials having a relatively low coefficient of thermal expansion, like titanium, or, more specifically, lower than the rotor material (like stainless steel with an aluminium rotor), as seen in prior art, have been found to be inadequate for accommodate NdFeB magnets in rotor bearing wells, particularly aluminium rotor bearing wells.

[045] In fact, whilst the thermal expansion of these materials relative to the Neodymium magnets may be contained, the heating temperature required to shrink the magnets inside the sleeve and/or the pressing force required for the max fit condition may be inappropriately high and / or may lead to demagnetisation of the magnets. Likewise, the heating temperature required for the rotor to ensure the sleeve remains in contact during operation, particularly if the rotor is made in aluminium, may lead to weakening of the rotor.

[046] The inventors have found that by providing a permanent magnetic bearing insert comprising a radially outwardly extending sleeve which has a coefficient of thermal expansion that is at least substantially the same as the coefficient of thermal expansion of the material of the rotor shaft defining the cavity configured to receive the magnetic bearing insert, then appropriate levels of compression may maintained during and out of use, whereas an acceptable press-fit insert force may be employed without necessitating excessive heating of the magnets, sleeve and/or rotor. The invention may therefore facilitate the use of neodymium magnets in magnet bearings of vacuum pumps, in particular turbomolecular pumps, reducing the size of the magnets required and potentially the size of the bearing and/or vacuum pump.

[047] References herein to the coefficient of thermal expansion refer to the linear coefficient of thermal expansion (CLTE) measured at 20 °C ( $t_0 = 20^\circ\text{C}$ ,  $t_1 = 100^\circ\text{C}$ ). Throughout the specification, unless stated otherwise, all measurements are taken at 20 °C and standard atmospheric pressure (101325 Pa).

[048] The sleeve may have a coefficient of thermal expansion that is at least substantially the same as the coefficient of thermal expansion of the material of the rotor shaft defining the bearing well wall, preferably substantially the same as the

coefficient of thermal expansion of the material of the rotor shaft as a whole. More preferably, the sleeve is made from the material defining the bearing well wall.

[049] Herein, substantially the same as may mean within about 10% of the given parameter, preferably within about 5% of the given parameter, more preferably within about 1 % of the given parameter.

[050] Preferably, the sleeve may have a coefficient of thermal expansion that is within about  $1.5 \times 10^{-6} \text{ K}^{-1}$ , preferably within about  $0.25 \times 10^{-6} \text{ K}^{-1}$  of the coefficient of thermal expansion of the material of the rotor shaft defining the bearing well wall.

[051] In embodiments, the coefficient of thermal expansion of the material of the rotor shaft defining the engaged bearing well wall is about  $8.6 \times 10^{-6} \text{ K}^{-1}$  or greater, preferably about  $10.1 \text{ K}^{-1}$  or greater, preferably about 17.3 or greater, more preferably about 23  $\text{K}^{-1}$  or greater.

[052] Preferably, the sleeve comprises a material with a linear coefficient of thermal expansion of about  $20 \times 10^{-6} \text{ K}^{-1}$  or greater, preferably about  $23 \times 10^{-6} \text{ K}^{-1}$  or greater.

[053] Preferably, the sleeve comprises a material with a linear coefficient of thermal expansion of about  $20 \times 10^{-6} \text{ K}^{-1}$  or greater, preferably about  $22 \times 10^{-6} \text{ K}^{-1}$  or greater, and the material of the rotor shaft defining the engaged bearing well wall a linear coefficient of thermal expansion of about  $23 \times 10^{-6} \text{ K}^{-1}$  or greater, preferably about  $23 \times 10^{-6} \text{ K}^{-1}$  or greater.

[054] Typically, the sleeve is made from a non-ferromagnetic material.

[055] In embodiments, the sleeve is aluminium. Typically, the cavity is defined by an aluminium portion of the rotor shaft, preferably a high strength aluminium alloy.

[056] In particularly preferred embodiments both the insert sleeve and portion of the rotor shaft defining the rotor cavity for receiving the same are made from aluminium, preferably substantially the same aluminium alloy. For the avoidance of doubt, references to aluminium herein include aluminium alloy, that is to say an alloy in which aluminium is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin, nickel and zinc. The aluminium may be anodized

or coated. 2000 and 7000 series aluminium alloys may be particularly suitable for the invention. Preferably substantially all of the rotor shaft is made from aluminium.

[057] Typically, the or each permanent magnet alloy ring is coupled to the sleeve by an interference fit. Preferably, the permanent magnet alloy ring(s) is coupled to the sleeve prior to the sleeve being inserted into the cavity of the pump rotor.

[058] In embodiments, the magnetic bearing insert is machined after the permanent magnet alloy ring is coupled to the sleeve, typically a radially outermost wall of the sleeve is machined once the magnet alloy ring is coupled to the sleeve. Typically, this *in situ* machining is the final machine of the sleeve. Machining the sleeve once the magnet is *in situ* may enable tighter tolerances to be achieved when compared to machining the individual components prior to their assembly.

[059] Similarly, the rotor may be machined once the insert is *in situ*. Typically, this will be the final machine of the rotor. Again, machining the rotor once the insert (including the ring magnet(s)) is *in situ* may enable tighter tolerances to be achieved when compared to machining the individual components prior to their assembly.

[060] For the avoidance of doubt, in all embodiments and aspects, the or each permanent magnet alloy ring may be magnetic. In embodiments, the or each permanent magnet alloy ring comprises a neodymium magnet alloy.

[061] A Neodymium magnet (also known as NdFeB, NIB or Neo magnet) is a permanent magnet made from an alloy of neodymium, iron, and boron to form typically the Nd<sub>2</sub>Fe<sub>14</sub>B tetragonal crystalline structure. A Neodymium magnet is magnetised.

[062] In embodiments, the rotor shaft and one or more rotor blades are monolithic, i.e. in the form of a single piece of material. The rotor blades may extend radially outwardly from the rotor shaft in a series of axially separated substantially planar arrays. Rotor shafts of this construction may be referred to as a monobloc rotor(s).

[063] Alternatively, one or more of the rotor blades may form a part of an annular rotor blade array, or arrays, coupled to the rotor shaft by an interference fit. Typically, the annular rotor blade array(s) are coupled to the rotor once the bearing insert is *in situ*. Advantageously, this may facilitate introducing further compression to the

permanent magnetic ring. Preferably, the rotor shaft is machined once the magnetic bearing insert is *in situ* but prior to coupling the rotor blade array(s) to said rotor shaft. Rotor shafts of this construction may be referred to as a multiblock rotor(s).

- 5 [064] Often permanent magnets demonstrate anisotropic thermal expansion, whereby the value of the coefficient of the thermal expansion depends on the direction considered. Often the coefficient of the thermal expansion that has the most influence on the expansion of the diameters of the ring is the one in the circumferential or hoop direction. Preferably, the permanent magnet alloy ring has a coefficient of thermal expansion in such direction that is less than about  $16 \times 10^{-6} \text{ K}^{-1}$  More preferably below  $4 \times 10^{-6} \text{ K}^{-1}$  and even more preferably below  $1 \times 10^{-6} \text{ K}^{-1}$ . Preferably, such permanent magnet alloy rings are made in Neodymium Iron Boron. Preferably, the rings are magnetised either axially or radially.
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- 15 [065] In a further aspect the invention provides method of manufacturing a vacuum pump, preferably a turbomolecular pump, according to the previous aspect. The pump comprises a rotor shaft configured to have one or more rotor blades coupled thereto and the rotor shaft defining a cavity for receiving a magnetic bearing insert.
- 20 [066] The method comprises the steps of a) providing a permanent magnetic bearing insert according to first aspect of the invention and b) inserting the magnetic bearing insert into the cavity of the rotor of the vacuum pump for receiving the same and forming an interference fit.
- 25 [067] In embodiments of the method, the permanent magnetic bearing insert is preassembled prior to step a) by inserting the permanent magnet alloy ring or rings into the sleeve to form an interference fit.
- [068] In embodiments relating to multiblock rotor(s), one or more rotor blades are coupled to the rotor shaft, preferably using an interference fit, following step b). Preferably, the rotor shaft is machined after step b) in an intermediate step before the one or more rotor blades are coupled to the rotor shaft.
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[069] In embodiments, the permanent magnetic bearing insert is cooled and/or the portion of the rotor defining the cavity is heated prior to inserting the insert into the cavity.

- 5 [070] In a further aspect the present invention provides the use of a neodymium magnet alloy in a permanent magnetic bearing insert or vacuum pump, in particular in an insert or vacuum pump as previously described herein. The neodymium magnet alloy may be magnetic.

### Figures

- 10 [071] The invention will now be described with reference to the following figures, which are intended to be non-limiting.

Fig. 1 shows a magnetic bearing insert according to the invention *in situ* in a monobloc turbomolecular pump rotor.

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Fig. 2 shows a magnetic bearing insert according to the invention.

Fig. 3 shows a magnetic bearing insert according to the invention *in situ* in a multiblock turbomolecular pump rotor.

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Fig. 4 shows a rotor bearing comprising a bearing insert according to the invention.

### Detailed Description

- [072] As illustrated in Fig.1, the present invention provides a permanent magnetic bearing insert (2), preferably for a turbomolecular pump rotor (1). In the illustrated example, the magnetic bearing insert (2) is located towards a relatively low pressure end (6) of the rotor (1). The insert (2) is slidably installed in a magnetic bearing well (7) formed in the rotor (1). The bearing insert (2) is held in position within the bearing well (7) by an interference fit.

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[073] In the illustrated embodiment, an interference fit is formed between a longitudinally extending, radially outwardly facing circumferential wall of the insert and a longitudinally extending radially inwardly facing wall of the bearing well. Typically, the interference fit is

such that the bearing insert and/or the or each magnetic ring is in compression across the operating temperature range of the of rotor, for instance from about ambient temperature (e.g. 20 °C) to about 90 °C, or to about 120, for other applications. Typically, the interference fit is such that the bearing insert and/or the or each magnetic ring is in  
5 compression across the across the operating rotational speed of the rotor, for instance up to about 100000rpm.

[074] The illustrated bearing well (7) includes a radially inwardly extending annular shoulder or ledge (15). Once inserted into the well, a distal end of the insert positively  
10 engages the shoulder or ledge (15). This may assist with the precise position of the bearing insert (2), and therefore the or each magnet ring (3, 4, 5), within the rotor (1). The bearing insert (2) is typically pushed into the bearing well (7) through the bearing well opening using a press.

[075] As better illustrated in Fig. 2, the sleeve opening may be in the form of a funnel (13). The opening of the funnel having an inner diameter substantially the same as or  
15 larger than the outer diameter of the or each magnet ring prior to insertion therein. The funnel end may have an inner diameter smaller than the outer diameter of the or each magnet ring prior to insertion therein. The funnelled entrance (13) to the sleeve facilitates  
20 inserting the or each magnet ring (3, 4, 5) into the sleeve.

[076] Similarly, in embodiments and as illustrated in in Fig. 2, the end of the sleeve may have a tapered (14) or stepped leading edge. The leading edge of the sleeve tapering  
25 from an outer diameter which is smaller than the inner diameter of the opening of the bearing well to an outer diameter which is greater than the inner diameter of the opening of the bearing well prior to insertion therein. Again, the tapered leading edge of the sleeve facilitates inserting the sleeve (16) into the bearing well (7).

[077] The sleeve (16) may further comprise a radially inwardly extending annular lip (12)  
30 at a second end opposite sleeve entrance (13). The annular lip (12) provides an abutment against which a magnet ring (3) of the bearing insert (2) may abut. This may assist with the accurate placement of the or each magnet ring within the sleeve, rotor and vacuum pump.

[078] The rotor (1) illustrated in Fig.1 is of a monolithic construction. That is to say the rotor (1), including rotor blades (8), rotor shaft (9) and the rotor bearing well wall (10) are all formed from a single piece of material. In this instance, an aluminium alloy. A multicomponent rotor is also contemplated in which the rotor blades are coupled rotor shaft by an interference fit, typically once the bearing insert is *in situ* in the rotor bearing well. In said embodiments, the rotor shaft may be machined while the bearing insert is *in situ* but prior to coupling the rotor blades to the rotor shaft. This may improve tolerances.

[079] The rotor blades (8) are arranged in a series of annular arrays extending radially outwardly from the rotor shaft (9). The size and pitch of the rotor blades will be determined according to the specific requirements of the pump in question; however, generally both the size and pitch of the rotor blades decrease from the lower-pressure end (6) of the rotor shaft (9) towards the relatively higher-pressure end (11) of the rotor shaft (10). The bearing well (7) is located towards the lower-pressure end of the rotor shaft (9) in the illustrated embodiment. The bearing insert and magnet ring(s) being held such they are essentially coaxial with the rotational axis (A) of the rotor shaft. In use, the bearing insert and magnet ring(s) rotate about the rotational axis (A) of the rotor shaft.

[080] The permanent magnetic bearing insert comprises a plurality of permanent magnet alloy rings (3, 4, 5), in this instance three. The exemplified permanent magnet alloy rings are made from a ferromagnetic material.

[081] Typically, the sleeve is a monolithic structure. Typically, the sleeve consists substantially of a single material, although, in embodiments, it may be coated and/or anodised.

[082] Preferably, the sleeve comprises, consists essentially of, or consists of aluminium, preferably an aluminium alloy selected from 2000 or 7000 series.

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[083] Preferably, the or each magnet alloy ring comprises, consists essentially of, or consists of a ferromagnetic material, preferably Nd<sub>2</sub>Fe<sub>14</sub>B (neodymium magnet), SmCo<sub>5</sub>, Sm(Co, Fe, Cu, Zr)<sub>7</sub>, preferably Nd<sub>2</sub>Fe<sub>14</sub>B or SmCo<sub>5</sub>. A neodymium magnet is particularly preferred, particularly sintered neodymium alloy. The or each magnet alloy

ring may be coated or plated, such as nickel or zinc plating, or a polymer and/or lacquer coating may be employed.

[084] Preferably the permanent magnet bearing and/or vacuum pump is configured such  
5 that the or each magnet alloy ring does not exceed about 120 °C during use.

[085] Preferably the magnet alloy has a Curie temperature from about 310 °C to about 370 °C.

10 [086] As described earlier, the invention further provides method of manufacturing a vacuum pump, preferably a turbomolecular pump. The pump comprises a rotor shaft configured to have one or more rotor blades coupled thereto and the rotor shaft defining a cavity for receiving a magnetic bearing insert.

15 [087] The method of the invention will generally comprise the steps of providing a permanent magnetic bearing insert according to the invention and inserting the magnetic bearing insert into the passive magnetic bearing cavity of the rotor of the vacuum pump to form an interference fit.

20 [088] Typically, the permanent magnetic bearing insert is preassembled prior to step being inserted into the rotor by first inserting the or each permanent magnet alloy ring into the sleeve and forming an interference fit therebetween. Typically, the or each ring is pushed into the sleeve using an external press. In embodiments, the permanent magnetic bearing insert is cooled and/or the portion of the rotor defining the cavity is  
25 heated prior to inserting the insert into the cavity.

[089] The sleeve may be machined once the magnet alloy rings are *in situ*. Typically, the surface of the sleeve which may form the interference fit with the rotor bearing well is machined, for instance a radially outwardly facing circumferentially extending outer  
30 face of the sleeve. Performing this machining step once the rings are *in situ* may reduce tolerances and/or ease manufacturing. Typically, this may be the final machining of the sleeve.

[090] Prior to insertion in the rotor, the insert may be cooled to a temperature below  
35 about 0 °C, preferably below about -50 °C, preferably below about -75 °C, for instance

using either dry ice or liquid nitrogen. Preferably, the portion of the rotor defining the cavity is heated to a temperature of from about 100 °C to about 150 °C. Once in position the or each magnet alloy ring and the sleeve are allowed to reach ambient temperature.

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[091] The rotor shaft may be machined once the insert is *in situ* therein, for example the surface of the rotor shaft which receives an annular array of rotor blades is machined in multiblock rotors. Performing this machining step once the insert is *in situ* may reduce tolerances and/or ease manufacturing. Typically, this may be the final machining of the rotor. Figure 3 shows a multiblock rotor according to the invention.

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[092] In embodiments, one or more rotor blades, typically in the form of one or more annular arrays, are coupled to the rotor shaft, preferably using an interference fit, once the permanent magnetic bearing insert is *in situ*.

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[093] A suitable vacuum pump for use with the permanent bearing inserts and rotor shafts described herein is the nEXT made by Edwards Vacuums.

[094] Figure 3 shows an embodiment of the invention in which the rotor (1) is a multiblock rotor. Similar or identical features are identified with corresponding numerals to Figures 1 and 2 respectively. In the illustrated embodiment of Figure 3, the rotor (1) comprises a rotor shaft (9) and plurality of separately formed annular arrays (17) of rotor blades (8) coupled thereto with an interference fit. The rotor blade annular arrays (17) may be provided as a single monolithic structure or a plurality of blocks of one or more annular arrays. The or each annular array block may itself be muti-array, having two or more arrays in a single monolithic structure, or a mono-array, having a single annular array.

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[095] As described above, the preferably, in a multi-block rotor the rotor blades are coupled to the rotor shaft once the magnetic bearing insert is *in situ*. As this may allow for improved compression of the permanent magnetic bearing ring(s).

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[096] Figure 4, shows an assembled permanent magnetic bearing comprising a bearing insert according to the invention.

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- [097] As illustrated, the magnetic bearing comprises an inner stator bearing half and an outer rotor bearing half, the outer rotor bearing half forming a part of the rotor shaft of the vacuum pump. The illustrated outer rotor bearing half comprises three ring shaped permanent magnets (3,4,5) provided in a permanent magnet bearing insert according to the invention. The bearing insert, and ring-shaped magnets, are substantially coaxially aligned with the axis (A) of rotation of the rotor shaft (9). The bearing further comprises an inner stator bearing half also comprising three ring shaped permanent magnets (18,19,20).
- 10 [098] The illustrated permanent magnet rings (18, 19, 20) in the inner stator bearing half and permanent magnet rings in the outer rotor bearing half (3, 4, 5) are magnetised and disposed relative to each other in order to create repulsive forces between the two halves. Thus they suspend the rotor shaft (9) radially.
- 15 [099] It will be appreciated that various modifications may be made to the embodiments shown without departing from the spirit and scope of the invention as defined by the accompanying claims as interpreted under patent law.

**Key**

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|----|-----------|-------------------------------|
|    | <b>1</b>  | Turbomolecular pump rotor     |
|    | <b>2</b>  | Magnetic bearing insert       |
| 5  | <b>3</b>  | Magnet ring                   |
|    | <b>4</b>  | Magnet ring                   |
|    | <b>5</b>  | Magnet ring                   |
|    | <b>6</b>  | Low pressure end of the rotor |
|    | <b>7</b>  | Bearing well                  |
| 10 | <b>8</b>  | Rotor blade                   |
|    | <b>9</b>  | Rotor shaft                   |
|    | <b>10</b> | Rotor bearing well wall       |
|    | <b>11</b> | High-pressure end             |
|    | <b>12</b> | Annular lip                   |
| 15 | <b>13</b> | Funnelled entrance            |
|    | <b>14</b> | Tapered sleeve end            |
|    | <b>15</b> | Shoulder / ledge              |
|    | <b>16</b> | Sleeve                        |
|    | <b>17</b> | Annular array                 |
| 20 | <b>18</b> | Magnet ring                   |
|    | <b>19</b> | Magnet ring                   |
|    | <b>20</b> | Magnet ring                   |

**What is claimed:**

1. A vacuum pump, preferably a turbomolecular pump, comprising a rotor shaft configured to have one or more rotor blades coupled thereto and the rotor shaft defining a bearing well containing, in an interference-fit configuration, a permanent magnetic bearing insert, wherein  
5 the magnetic bearing insert comprises one or more permanent magnet alloy rings of a rotor bearing half of a permanent magnetic bearing and a radially outwardly extending sleeve coupled thereto around an outer circumference of the or each said permanent magnet alloy ring, and  
10 an outer surface of the permanent magnetic bearing insert engages with an inward facing wall of the bearing well to provide an interference fit, wherein the radially outwardly extending sleeve has a coefficient of thermal expansion that is at least substantially the same as the coefficient of thermal expansion of the material of the rotor shaft defining the engaged bearing well wall.  
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2. The vacuum pump according to claim 1, wherein the radially outwardly extending sleeve has a coefficient of thermal expansion that is substantially the same as the coefficient of thermal expansion of the material of the rotor shaft defining the engaged bearing well wall.  
20
3. The vacuum pump according to claim 1 or claim 2, wherein the or each permanent magnet alloy ring is coupled to the sleeve by an interference fit.
- 25 4. The vacuum pump according to any preceding claim wherein the permanent magnet alloy ring is coupled to the sleeve prior to the sleeve being inserted into the bearing well of the pump rotor.
- 30 5. The vacuum pump according to any preceding claim wherein the magnetic bearing insert is machined after the permanent magnet alloy ring is coupled to the sleeve.
6. The vacuum pump according to any one of claims 3 or 4, wherein the rotor is final machined after fitting the insert.

7. The vacuum pump according to any preceding claim, wherein the bearing well is defined by an aluminium portion of the rotor shaft; and/or wherein the sleeve is aluminium.
- 5
8. The vacuum pump according to any preceding claim, wherein the permanent magnet alloy ring has a coefficient of thermal expansion in the circumferential direction of less than about  $4 \times 10^{-6} \text{ K}^{-1}$ .
- 10
9. The vacuum pump according to any preceding claim wherein the or each permanent magnet alloy ring comprises a neodymium magnet magnetised either in the axial or radial direction.
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10. The vacuum pump according to any preceding claim wherein the rotor shaft and one or more rotor blades are monolithic, and/or wherein one or more of said rotor blades forms a part of an annular rotor blade array coupled to the rotor shaft by an interference fit.
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11. A method of manufacturing a vacuum pump, preferably a turbomolecular pump, according to any one of claims 1 to 10, the pump comprising a rotor shaft configured to have one or more rotor blades coupled thereto and the rotor shaft defining a bearing well for receiving a magnetic bearing insert, the method comprising the steps of:
- 25
- a. providing a permanent magnetic bearing insert comprising one or more permanent magnet alloy rings of a rotor bearing half of a permanent magnetic bearing and a radially outwardly extending sleeve coupled thereto around an outer circumference of the or each said permanent magnet alloy ring, and
- 30
- b. inserting the magnetic bearing insert into the rotor bearing well of the vacuum pump rotor and forming an interference fit, and
- wherein the radially outwardly extending sleeve has a coefficient of thermal expansion that is at least substantially the same as, preferably substantially the same as, the coefficient of thermal expansion of the material of the rotor
- 35
- shaft defining the engaged bearing well wall, optionally wherein the

permanent magnetic bearing insert is cooled and/or the portion of the rotor defining the bearing well is heated prior to inserting the bearing insert into the bearing well.

- 5        12. The method of claim 11 wherein the permanent magnetic bearing insert is preassembled prior to step a) by inserting the permanent magnet alloy ring into the sleeve and forming an interference fit, and/or wherein one or more rotor blades are coupled to the rotor shaft following step b).
- 10       13. A permanent magnetic bearing insert for a vacuum pump, the vacuum pump comprising a rotor shaft having one or more rotor blades coupled thereto and the rotor shaft defining a bearing well configured to receive the magnetic bearing insert in an interference-fit configuration, wherein
- 15       the magnetic bearing insert comprises one or more permanent magnet alloy rings of a rotor bearing half of a permanent magnetic bearing and a radially outwardly extending sleeve coupled thereto around an outer circumference of the or each said permanent magnet alloy ring, and
- 20       an outer surface of the permanent magnetic bearing insert is configured to engage with an inward facing wall of the bearing well following insertion therein, wherein the radially outwardly extending sleeve has a coefficient of thermal expansion that is at least substantially the same, preferably substantially the same, as the coefficient of thermal expansion of the material of the rotor shaft defining the engaged bearing well wall.
- 25       14. A vacuum pump according to any one of claims 1 to 10 comprising a permanent magnetic bearing insert according to claim 13.
- 30       15. The use of an neodymium magnet alloy in a vacuum pump according to claims 1 to 10 or 14 or permanent magnetic bearing insert according to claim 13; or the use of a neodymium magnet in a vacuum pump according to any one of claims 1 to 10.