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Fig.1

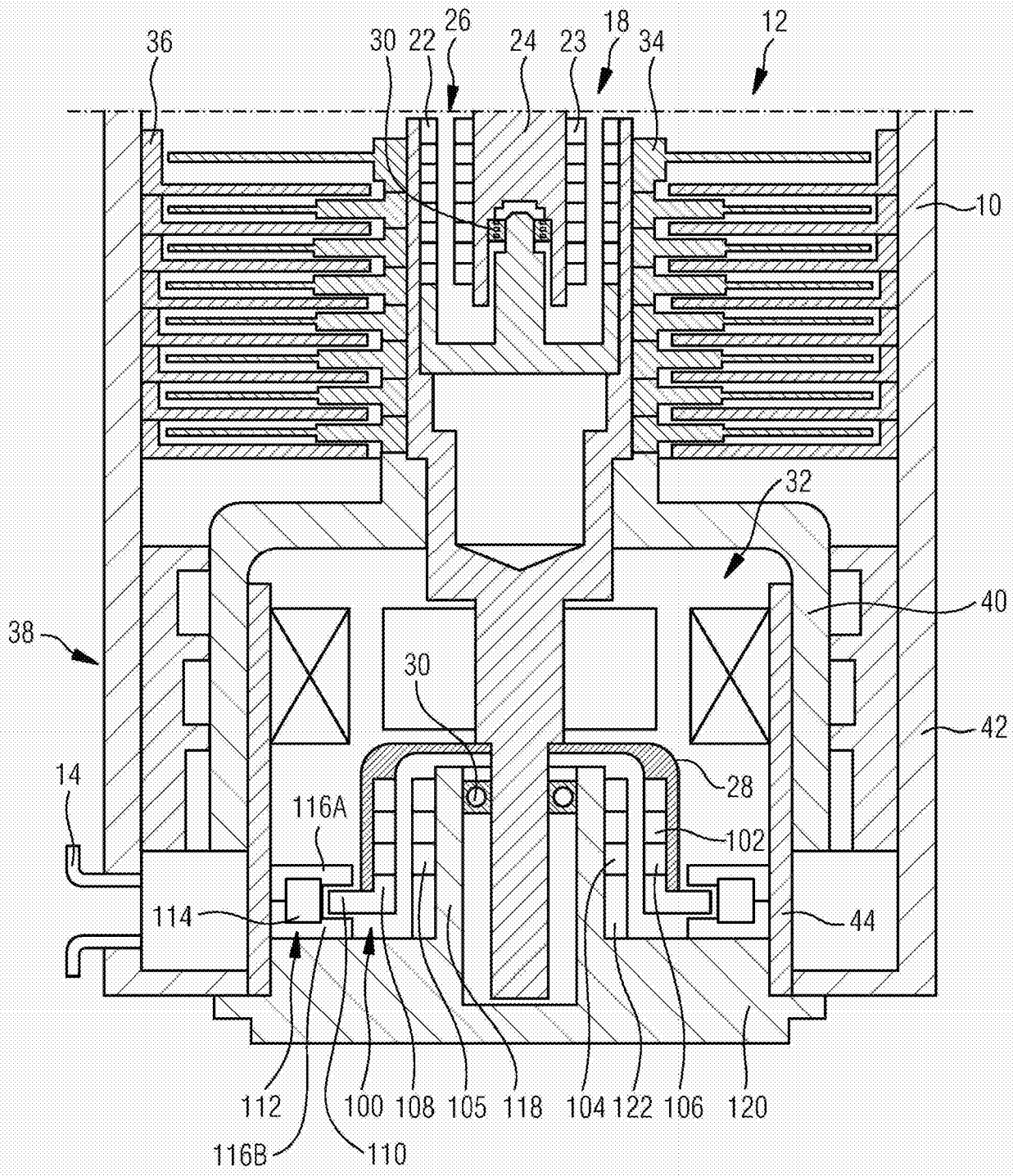

36
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116A
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116B
110

Fig.2

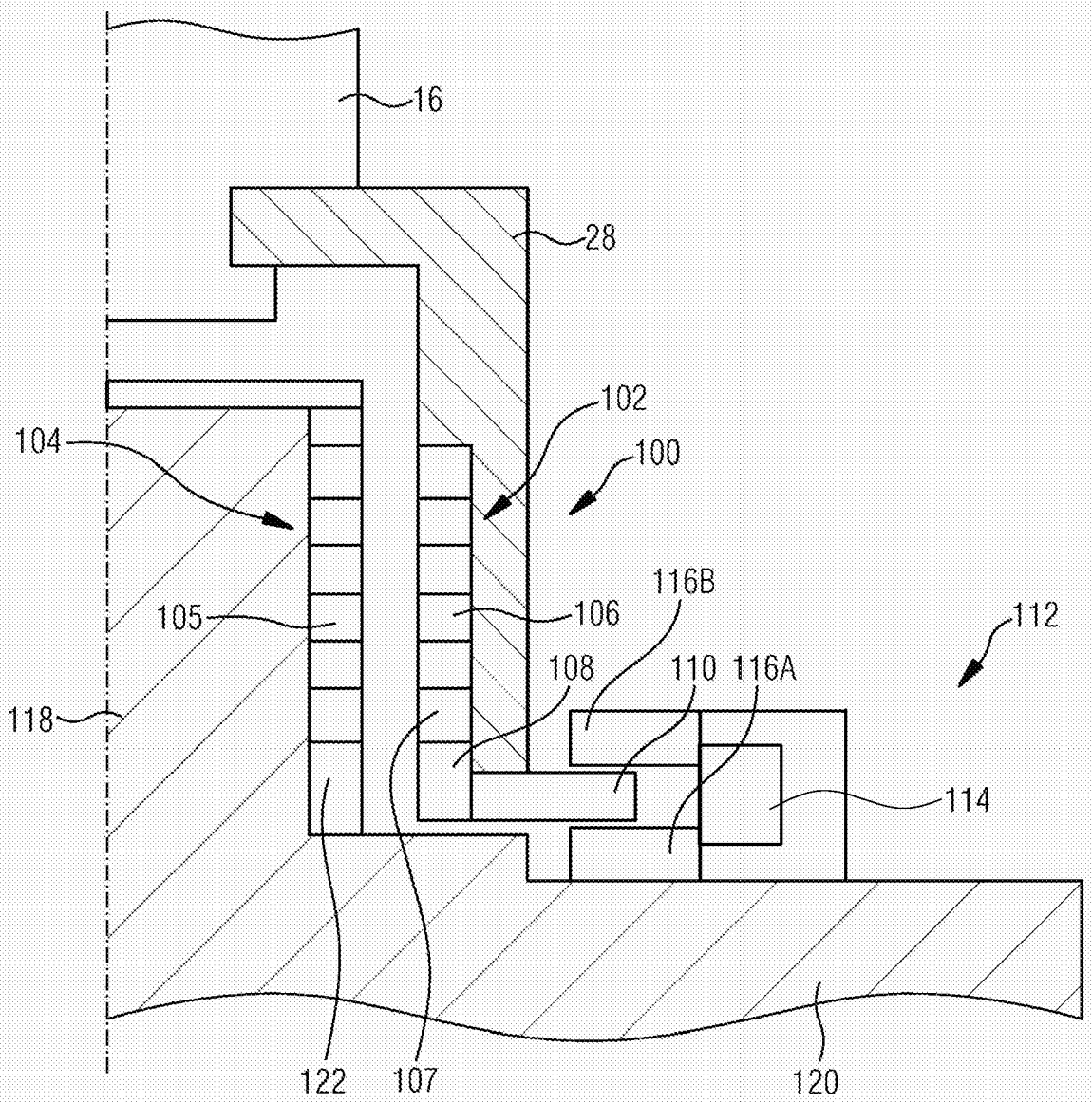

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Fig.3

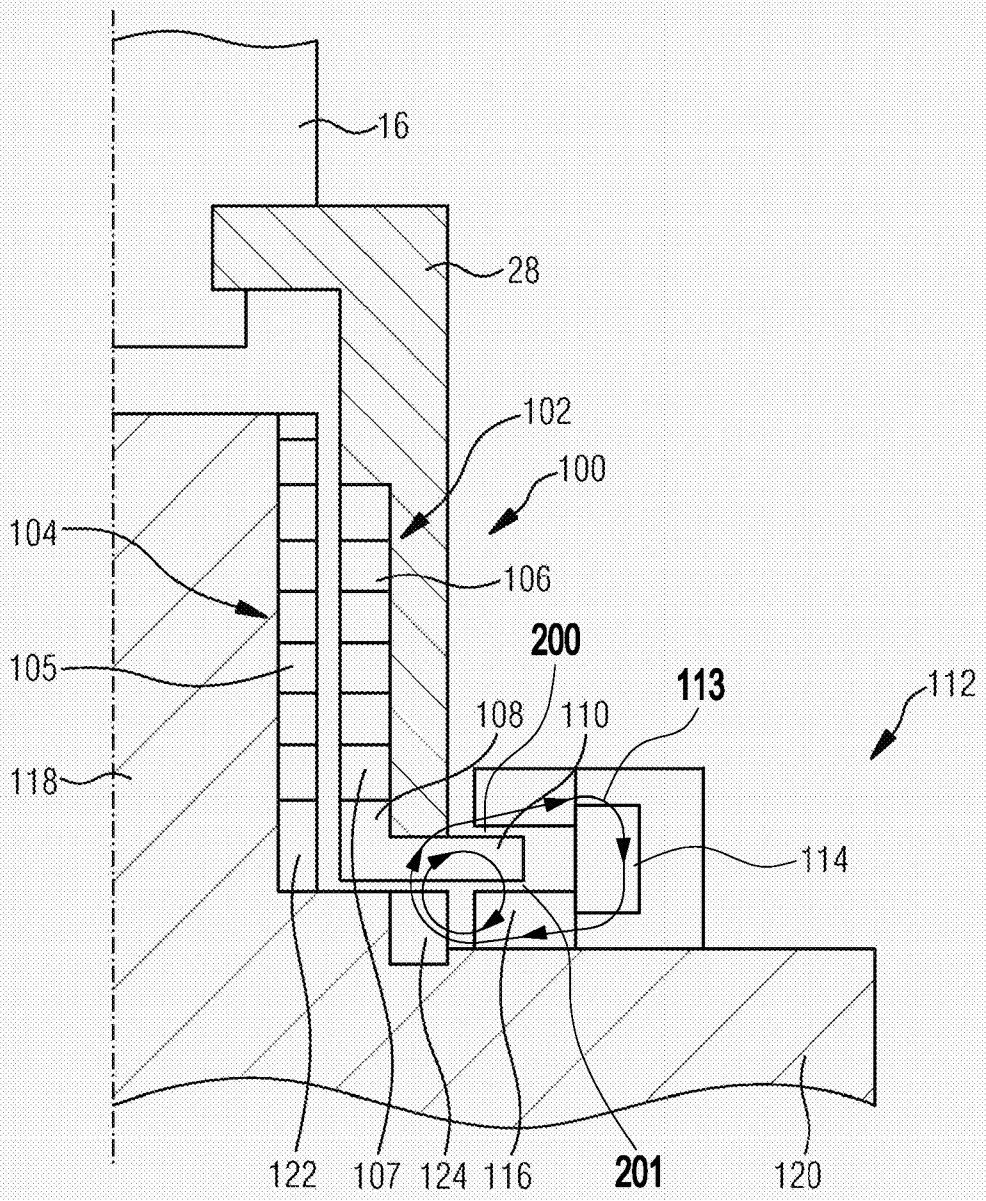

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Fig.4

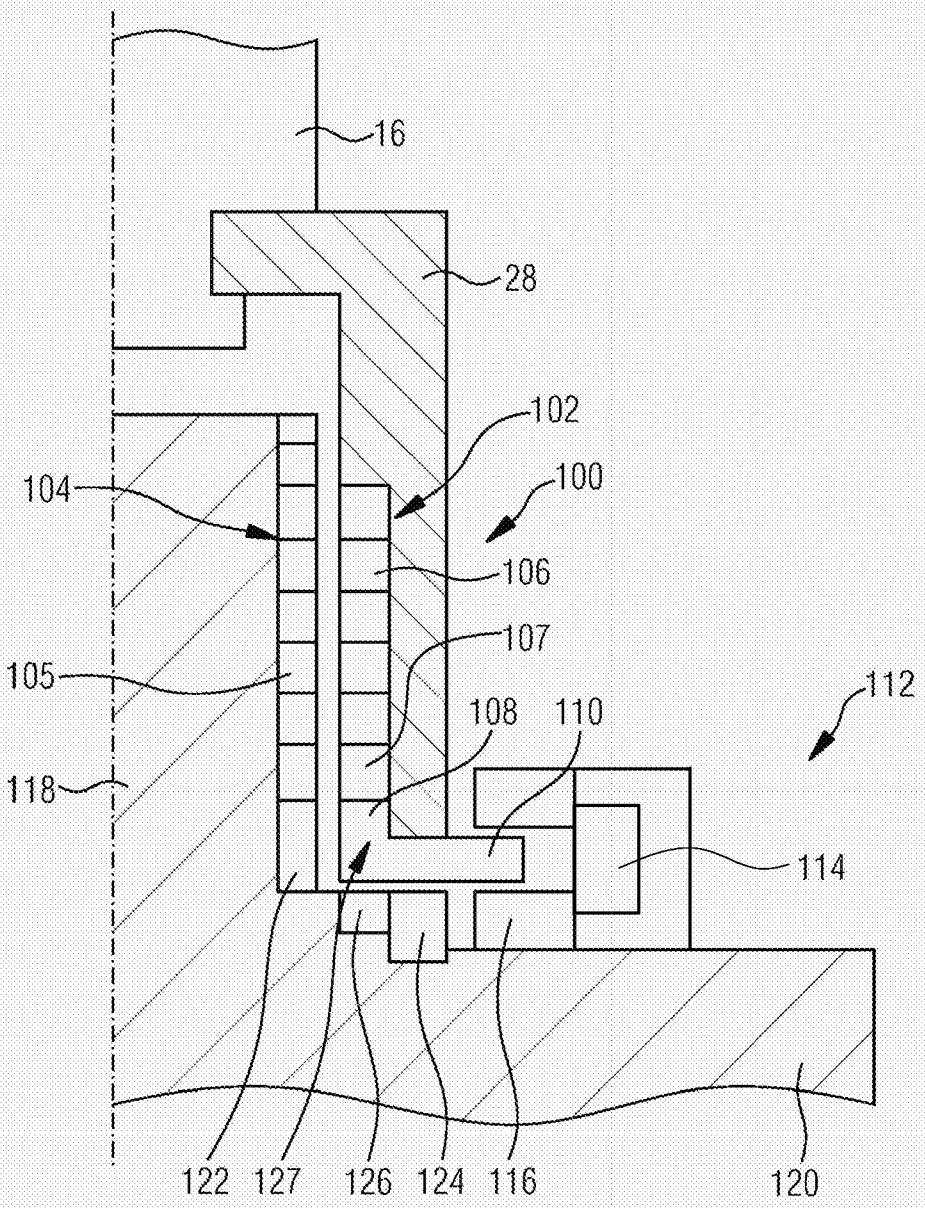
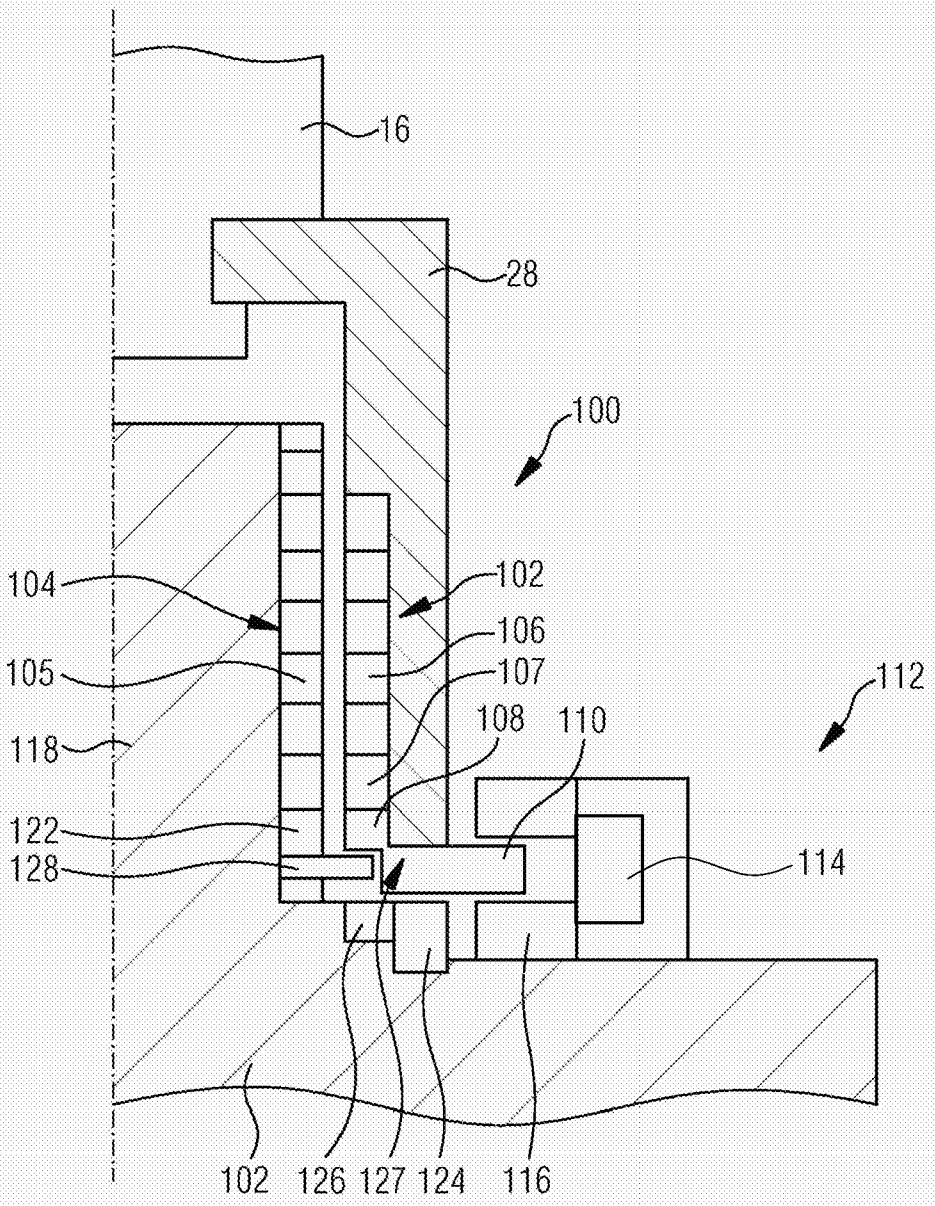

16
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Fig.5


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# MAGNETIC BEARING AND VACUUM PUMP

The present invention relates to a magnetic bearing for a vacuum pump and in particular for a turbomolecular pump. Further, the present invention relates to a vacuum pump and in particular to a turbomolecular pump with such a magnetic bearing.

Vacuum pumps comprise a housing having an inlet and an outlet. A rotor including a rotor shaft is disposed in the housing wherein at least one rotor element is connected to the rotor shaft and rotated by an electromotor. In the case of a turbomolecular pump a plurality of vanes are connected to the rotor shaft as pump elements interacting with a plurality of vanes of a stator connected to the housing. Upon rotation of the rotor a gaseous medium is conveyed from the inlet to the outlet. Therein, the rotor shaft is rotatably supported by one or more bearings.

It is known to use permanent magnetic bearings which are contact free and thus are not subject to wear. However, permanent magnetic bearings are usually employed for radial support wherein these bearings must be complemented by an axial bearing supporting the rotor shaft in the axial direction. In particular, if both or all bearings supporting the rotor shaft are built as permanent magnetic radial bearings, axial support of the rotor shaft is necessary. However due to the additional axial bearing, the space requirements increase, increasing the overall size of the vacuum pumps.

Thus, it is an object to provide a compact built magnetic bearing and vacuum pump with such a magnetic bearing.

The problem is solved by a magnetic bearing according to claim 1 and a vacuum pump according to claim 8.

In a first aspect a magnetic bearing for a vacuum pump and in particular for a turbomolecular pump is provided. The magnetic bearing comprises a radial permanent bearing having a static magnetic element to be connected to a housing of the vacuum pump and a rotated magnetic element to be connected to a rotor of the vacuum pump arranged radially next to each other and in mutual magnetic repulsion to each other to provide radial support. Therein a terminal ring is attached axially next to the rotated magnetic element. By the terminal ring, which is usually made from a hard metal such as steel, the brittle permanent magnetic rings of the rotated magnetic element should be protected during the process of inserting the rotor shaft into the housing of the vacuum pump. The terminal ring does not contribute to the radial support of the rotor shaft and in addition to the provided protection maintains the axial position of the rotated magnetic element of the permanent magnetic bearing.

In accordance with the present invention, the magnetic bearing comprises a magnetic axial bearing including an electromagnet or coil in order to create an adjustable magnetic field. Further, the terminal ring comprises a protrusion extending in a radial direction and being arranged next to the electromagnet such that an axial magnetic force can be applied by the electromagnet to the protrusion of the terminal ring. Thus, by the adjustable axial force applied to the protrusion of the terminal ring, axial support of the rotor shaft is provided. Thus, by the protrusion of the terminal ring, the radial bearing and the axial bearing are integrated thereby reducing the space requirements of the magnetic bearing and consequently the minimum space requirements of the vacuum pump comprising such a magnetic bearing.

Preferably, the protrusion and even more preferably also the terminal ring are made from a ferritic material. Since the terminal ring is in direct contact with the outermost ring magnet of the rotated magnetic element, by the ferritic material the magnetic field is permeating the protrusion and increasing the magnetic field at the electromagnet increasing the efficiency of the axial bearing.

Preferably, the electromagnet is connected to a yoke element extending in a radial direction and being arranged axially next to the protrusion of the terminal ring in order to create a magnetic field at the position of the protrusion. Preferably, the yoke has a U-shape. Thus, on both sides of the protrusion of the terminal ring in the axial direction parts of the yoke are disposed. Thus, by the yoke a gap is created in order to enhance the magnetic field created by the electromagnet wherein in this gap the protrusion of the terminal ring is arranged.

Preferably, the protrusion and the terminal ring are built as one piece, i. e. integrally formed.

Preferably, a sensor coil is arranged axially next to the protrusion and connected to the housing, i. e. being non-rotated or static. By the sensor coil the axial position of the protrusion can be directly measured. Preferably, the sensor coil is used as eddy-current sensor and can detect the axial position of the rotor shaft over the entire circumference. This design offers the advantage of not detecting possible tilt vibrations of the rotor thus not generating any damaging coupling or interference between radial and axial movements of the rotor shaft. In particular, the sensor coil is part of a resonant circuit wherein shift of the resonance frequency relates to a change of the axial position.

Preferably, a bias magnet is connected to the housing and arranged at least partially axial next to the protrusion to apply a bias force to the magnetic axial bearing. Thus, by the bias magnet built as magnetic ring, a biasing force in the axial direction is applied to the protrusion and the rotor shaft. In addition, by the biasing attracting and repulsive magnetic forces can be applied by the electromagnet to the protrusion of the terminal ring in order to reliably adjust the axial position of the rotor shaft. In particular, the bias magnet comprises the opposite pole orientation than the outermost ring magnet of the rotated

magnetic element being next to the terminal ring. By this configuration the bias effect of the bias magnet is enhanced due to the additional magnetic field of the last magnet ring of the rotated magnetic element next to the terminal ring permeated by the protrusion.

Preferably, the sensor coil is arranged within the bias magnet. Thus, the space requirement can be reduced by this arrangement and at the same time can be easily assembled. Further, the detection is close to the position of force acting on the rotor. Therein, the sensor coil is positioned outside the main flux of the magnetic field and thus less affected by the magnetic axial bearing placed next to the sensor coil.

Preferably, a static terminal ring is arranged axially next to the static magnetic element, in particular directly next to the outermost magnetic ring of the static magnetic element. Therein, the static terminal ring is disposed at the same side as the terminal ring attached axially next to the rotated magnetic element.

Preferably, a conductive disc is connected to the static terminal ring and the disc is at least partially arranged axially next to the rotated magnetic element such that eddy-currents are induced in the conductive disc by the magnetic field of the rotated magnetic element. Thus, by the conductive disc made from a conductive material such as copper, aluminum or the like, an eddy-current damper is created utilizing the magnetic field provided by the outermost rotated magnetic element of the permanent magnetic bearing. In particular, the disk is extending in a radial direction to be arranged axially next to the rotated magnetic element.

In another aspect of the present invention a vacuum pump and in particular a turbomolecular pump is provided comprising a housing and a rotor shaft disposed in the housing and rotatably supported by at least one permanent magnetic bearing as described before.

Preferably, the vacuum pump comprises two bearings wherein the second bearing might be built as conventional permanent magnetic bearing or as roller bearing. Alternatively, the second bearing is also built as permanent magnetic bearing as described before including an additional/second axial bearing to combiningly provide axial support for the rotor shaft.

Preferably, the permanent magnetic bearing according to the present invention is arranged at the exhaust side of the rotor shaft. Alternatively or additionally, the permanent magnetic bearing according to the present invention is provided at the inlet side of the rotor shaft.

Preferably, the static magnetic element is connected to a trunnion extending into a recess of the rotor shaft wherein the rotated magnetic element is connected to an inner surface of the recess radially opposite to the static magnetic element.

In the following the present invention is described in more detail with refence to the accompanying figures.

The figures show:

Figure 1 a first embodiment of a vacuum pump according to the present invention,

Figure 2 a detailed view of the magnetic bearing according to the present invention,

Figure 3 a detailed view of a further embodiment of the magnetic bearing according to the present invention,

Figure 4 a detailed view of a further embodiment of the magnetic bearing according to the present invention,

Figure 5 a detailed view of a further embodiment of the magnetic bearing according to the present invention.

Referring to figure 1 showing a vacuum pump built as turbomolecular pump. The vacuum pump comprises a housing 10 including an inlet 12 and an outlet 14. A rotor 16 is disposed in the housing and supported by a first radial bearing 18 built as permanent magnetic bearing, and a second radial bearing 100 also built as permanent magnetic bearing. The first radial bearing 18 comprises a plurality of magnet rings 22, 23. Therein the static magnet rings 23 of the first radial bearing 18 are attached to a trunnion 24 extending into a recess 26 of the rotor shaft 16. The rotated magnet rings 22 are arranged at the inner surface of the recess radially next to the static magnet rings 23. For the second radial bearing 100 the rotated magnet rings 106 are attached inside a bell-shaped element 28 radially next to the static magnet rings 105 connected to the housing. Therein, the static magnet rings 23 of the first radial bearing 18 are in mutual repulsion to each of the rotated magnet rings 22 of the first radial bearing 18, similar, the static magnet rings 105 of the second radial bearing 100 are in mutual repulsion to each of the rotated magnet rings 106 of the second radial bearing 100, respectively, thereby providing a rotatably support of the rotor 16 within the housing 10

Further, the first radial bearing 18 and the second radial bearing 100 comprise emergency running bearings 30 built as ball bearings. The rotor shaft 16 is driven by electromotor 32. Attached to the rotor shaft 16 are a plurality of pump elements 34 built as vanes interacting with stator elements 36 connected to the housing 10 of the vacuum pump and arranged alternating with the pump elements 34. In addition, the vacuum pump of figure 1 comprises a Holweck stage 38 comprising a rotating cylinder 40 interacting with a threated stator 42

connected to the housing. By rotating of the rotor shaft 16 a gaseous medium is conveyed from the inlet 12 of the vacuum pump towards the outlet 14.

Referring now to the lower magnetic bearing 100 shown in figure 1 and shown in detail in figure 2. Therein, it is referred to the axial direction, coinciding with the rotational axis of the vacuum pump, and the radial direction being perpendicular to the axial direction.

The magnetic bearing 100 according to present invention comprises a first or rotated magnetic element 102 and a static magnetic element 104. Therein the rotated magnetic element is connected to the rotor shaft 16 via the bell-shaped element 28. The static magnetic element 104 is connected to a trunnion 118 of the housing 10. The rotated magnetic element 102 and the static magnetic element 104 both comprise ring magnets 106, 105 arranged radially next to each other and in mutual repulsion in order to provide radial support of the rotor shaft 16. Therein a terminal ring 108 is connected to the rotated magnetic element 102 and directly connected to the outermost ring magnet 107 of the rotated magnetic element 102. The terminal ring 108 is usually made of steel and provided in order to protect the relatively brittle ring magnets 107, 106 from damage upon insertion of the rotor shaft 116 into the housing 10 or alternatively insertion of the cap element 120 of the housing 10 thereby introducing the trunnion 118 into the recess formed by the bell-shaped element 28. In addition also a static terminal ring 122 can be implemented radially next to the terminal ring 108 of the rotated magnetic element 102. By the static terminal ring 122 the axial position of the ring magnets 106 the static magnetic element 104 is maintained/fixed. Preferably, the static terminal ring 122 is made from plastic.

In accordance to the present invention the terminal ring 108 comprises a radial protrusion 110 which in the given example extends outside the bell-shaped element 28. Further, the magnetic bearing 100 comprises an axial bearing 112. The axial bearing 112 comprises an electromagnet 114 or coil in order to create

an adjustable magnetic field. Connected to the electromagnet 114 are yoke elements 116A, 116B which are arranged on both sides of the radial protrusion in the axial direction. Thus, by the yoke elements 116A, 116B a gap is formed extending radially wherein the radial extending protrusion 110 is disposed in this gap. Thus, by the yoke elements the magnetic field created by the electromagnet 114 is applied to the radial protrusion 110 thereby applying an axial force to the protrusion 110 and consequently to the rotor shaft 16. Thus, the radial magnetic bearing and the axial magnetic bearing are integrated reducing the space requirements and providing an effective axial and radial support of the rotor shaft.

Although shown in figure 2 as two elements, the terminal ring 108 and the radial protrusion 110 can be built as one piece being integrally formed. In particular the terminal ring 108 and/or the protrusion 110 are formed from a ferritic material such that the magnetic field of the outermost ring magnet 107 is transferred by the ferritic material of the terminal ring 108 and the protrusion 116 enhancing the axial force applied to the protrusion 110 by the axial bearing 112.

Now referring to figure 3 showing another embodiment of the present invention. Therein same or similar elements are indicated by the same reference signs. Therein, the description is limited to the differences between the embodiment of figure 2 and figure 3.

In particular, in the embodiment shown in figure 3 a bias magnet 124 is connected to the cap element 120 of the housing 110. By the bias magnet 124 built as ring magnet, a bias flux is generated in the axial airgaps 200 between the protrusion 110 and the one yoke element 106B and the axial airgap 201 between the protrusion 110 and the other yoke element 106A. In addition, the magnetic field of the bias magnet 124 permeates the protrusion 110 and enhances the magnetic interaction between the protrusion 110 and the magnetic field created by the electromagnet 114.The bias magnet 124, built as permanent

magnet, is arranged next to the protrusion 110. Therein, the bias magnet 112 is magnetically connected to the yoke elements 106A, 106B to create a magnetic circuit. As indicated in figure 3, a magnetic flux 113 is provided by the bias magnet 124. In dependence on the magnetic orientation of the bias magnet 124, the flux of the electromagnet 110 or coil weakens the magnetic flux in one airgap 200 (or airgap 201) and strengthens the magnetic flux in the respective other airgap 201 (or 200). Thus, the force applied to the protrusion 110 can be provided in both axial directions depending on the current direction in the electromagnet 114 or coil. Therein, preferably, the pole orientation of the bias magnet 124 and the outermost ring magnet 107 of the rotated magnetic element 102 are in the opposite direction thereby enhancing the bias effect. As a consequence, the bias magnet 124 can be built smaller while still maintaining sufficient axial bias of the bias magnet 124.

Referring to figure 4, a sensor coil 126 is provided along the complete circumference of the trunnion 118. The sensor coil 126 is disposed axially next to the protrusion 110 wherein a sensor element 127 is connected to the protrusion 110. The sensor element might be a permanent magnet in order to induce eddy currents into the sensor coil 126. Alternatively, the sensor element 127 is made from a conductive material such as copper or aluminum and a magnetic field is induced into the sensor element by the sensor coil 126 itself. The sensor coil 126 serves as eddy-current sensor for detecting the axial distance between the sensor coil 126 and the rotor shaft 16 used to control the magnetic field created by the electromagnet 114 in order to apply an axial force to the protrusion 110 and the rotor shaft 16. Thereby, the axial position of the rotor shaft 16 can be controlled/maintained. Since the sensor coil 126 is built as ring tiling of the rotor shaft has no influence or only little influence on the sensor signal since it averages out from the sensor signal detected along the complete circumference. Further, due to positioning the sensor coil radially within the bias magnet 124 a compact design can be achieved while the sensor coil is outside the main flux of

the axial bearing 112. Thus, mutual influence of the position sensor and the axial bearing is reduced.

Referring to figure 5, the terminal ring 122 of the static magnetic element 104 is directly connected to a conductive disc 128 extending radially. The conductive disc 128 is made from a conductive material such as copper, aluminum or the like. By the disk 128 an eddy-current damper is provided acting directly to the end of the rotor shaft 16 for damping radial vibration of the rotor shaft 16. Therein, the magnetic field of the outermost ring magnet 107 induces eddy-currents into the disc 128 creating a magnetic force as restoring force damping the radial vibration of the rotor shaft 16. Thus, the outermost ring magnet 107 has a double function for radial support of the rotor shaft 16 and for the eddy current damper.

Although figure 5 shows the magnetic bearing 100 having an eddy-current damper, a sensor coil 126 and a bias magnet 124, different combination of these features in different embodiments is feasible. Thus, in one embodiment only an eddy-current damper 128 is implemented together with the sensor coil 126 and without a bias magnet 124. In another embodiment an eddy-current damper 128 is implemented together with a bias magnet 124 without a sensor coil 126. In another embodiment an eddy-current damper is implemented without a sensor coil 126 and without a bias magnet 124. In another embodiment the bearing 100 according to the present invention comprises only a sensor coil without an eddy-current damper and without a bias magnet 124. Thus, in addition to the embodiments shown in the figures, all different combinations of eddy-current damper 128, sensor coil 126 and bias magnet 124 can be implemented into the magnetic bearing 100 according to the present invention in order to provide a compact and efficient magnetic bearing providing radial and axial support at the same time.

## CLAIMS

1. Magnetic bearing for a vacuum pump, in particular a turbomolecular pump, comprising

   a radial permanent magnetic bearing having a static magnetic element and a rotated magnetic element arranged radially next to each other and in mutual repulsion to provide radial support;

   a terminal ring attached axially next to the rotated magnetic element,

   a magnetic axial bearing comprising an electromagnet,

   wherein the terminal ring comprises a protrusion extending in radial direction and being arranged next to the electromagnet such that an axial magnetic force can be applied by the electromagnet to the protrusion of the terminal ring.

2. Magnetic bearing according to claim 1, wherein the protrusion and preferably also the terminal ring a made from a ferritic material.

3. Magnetic bearing according to any of claims 1 or 2, wherein the protrusion and the terminal ring a one-piece.

4. Magnetic bearing according to any of claims 1 to 3, wherein a sensor coil is arranged axially next to the protrusion to detect the radial position of the protrusion.

5. Magnetic bearing according to any of claims 1 to 4, comprising a bias magnet arranged at least partially axially next to the protrusion to apply a bias force to the magnetic axial bearing.

6. Magnetic bearing according to any of claims 1 to 5, wherein a static terminal ring attached axially next to the static magnetic element.

7. Magnetic bearing according to claim 6, wherein a conductive disk is connected to the static terminal ring and the disk is at least partially arranged axially next to the rotated magnetic element such that eddy currents are induced into the conductive disk by the magnetic field of the rotated magnetic element.

8. Vacuum pump, in particular turbomolecular vacuum pump, comprising a housing and a rotor shaft disposed in the housing and rotatably supported by at least one permanent magnet bearing according to any of claims 1 to 7.

9. Vacuum pump according to claim 8, comprising a second bearing built as permanent magnetic bearing or as roller bearing.

10. Vacuum pump according to claims 8 or 9, wherein the magnet bearing is arranged at the exhaust side of the rotor shaft and/or the inlet side of the rotor shaft.

11. Vacuum pump according to claims 8 or 9, wherein the static magnetic element is connected to a trunnion extending into a recess of the rotor shaft, wherein the rotated magnetic element is connected to an inner surface of the recess.