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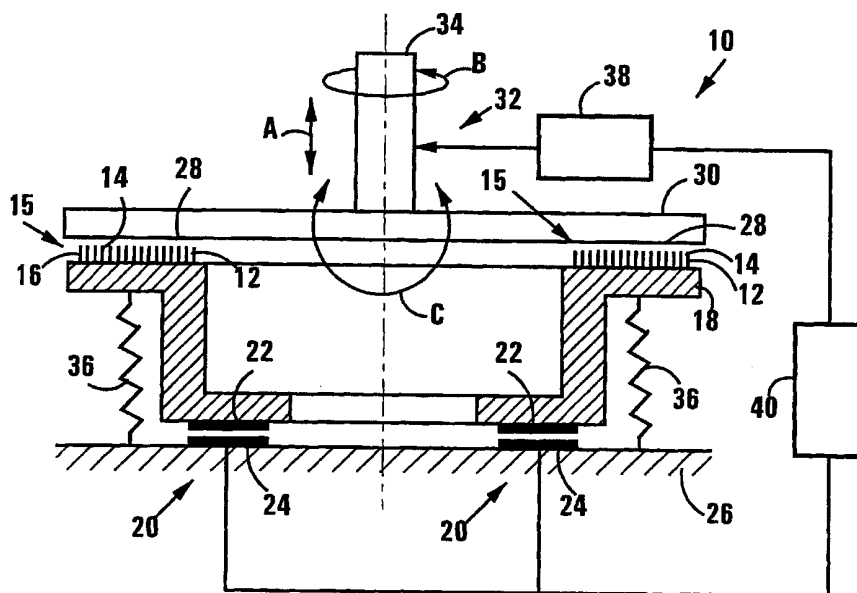
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(54) Title: A SEAL ASSEMBLY



(57) Abstract: A seal assembly (10) includes a first seal element (12) defining a first sealing surface (14); displacement means including at least one electromagnet (20) operatively coupled with the first seal element (12), the displacement means being operable to displace the first seal element (12) via the, or each, electromagnet (20); and a second seal element defining a second sealing surface (16) associated with the first sealing surface (14), the first and second seal elements providing a seal. The invention extends to a combination comprising a gas turbine and a seal assembly. The invention further extends to a method of controlling a spacial relationship between respective sealing surfaces of two seal elements.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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A SEAL ASSEMBLY

THIS INVENTION relates to a seal. In particular the invention relates to
10 a seal assembly. The invention further relates to a method of controlling a spacial
relationship between two sealing surfaces. Still further, the invention relates to a
machine incorporating a seal assembly.

According to a first aspect of the invention there is provided a seal
15 assembly which includes

a first seal element defining a first sealing surface;

displacement means including at least one electromagnet operatively coupled
with the first seal element, the displacement means being operable to displace the first
seal element via the, or each, electromagnet; and

20 a second seal element defining a second sealing surface associated with the first
sealing surface, the first and second seal elements providing a seal.

The seal assembly may include a sensor means for sensing a
displacement of the second element from a first datum position.

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The seal assembly may include control means operably connected to the

sensor means and the displacement means, the control means operable to control the displacement means to maintain the first sealing surface in a predetermined spatial
30 relationship with the second sealing surface.

The seal assembly may include a biasing means for biasing the first seal element in a predetermined direction. The biasing means may bias the first seal element towards the second seal element. Instead, the biasing means may bias the
35 first seal element away from the second seal element. The biasing means may be configured to exert a force which is a function of a displacement of the biasing means from a second datum position.

The displacement means may include a plurality of electromagnets in spaced relationship with respect to one another and the control means may be
40 operable to control each of the electromagnets. Then, the sensor means may include a plurality of sensors, a sensor being associated with each of the electromagnets. The control means may be operable to control each of the electromagnets independently. Instead, the control means may be operable to control sub-sets of the electromagnets
45 in unison.

The first seal element may comprise an annular ring defining an annular first sealing surface and the second seal element may define an annular second sealing

50 surface. Then, the seal assembly may include a rigid carrier member on which the first annular seal element is mounted, the electromagnets being operatively coupled with the carrier member and angularly spaced with respect thereto.

Further, the seal assembly may include a support member, and each of
55 the electromagnets of the displacement means may have a core element displaceable with respect to a coil, one of the core element or the coil being connected to the carrier member of the first seal element and the other of the core element or the coil being connected to the support member.

60 In one embodiment of the invention the seal assembly may provide a seal on a rotating element of a machine. Then, the first seal element may comprise an annular ring defining an annular first sealing surface. The second element may be the rotating element of the machine and may define a second sealing surface which also comprises an annular ring. The first annular seal element may be mounted on a rigid
65 carrier member. The displacement means may include a plurality of electromagnets coupled with the carrier member and angularly spaced on the carrier member. The electromagnets of the displacement means may have a movable core element. The movable core element may be attached to the carrier member of the first seal element. The coils of each electromagnet may be attached to a support member which may be
70 fixed in position. It will be appreciated that by controlling the current in the coil of

each electromagnet the magnetic flux of the electromagnet may be selectively varied thereby selectively varying the force on the core element of the electromagnet. Thus, a lateral force of a preselected strength may be applied to the first seal element at the
75 position of each electromagnet. It will further be appreciated that by selectively varying the lateral force of each electromagnet the entire annular first seal element may be displaced so that a plane defined by the first seal element is displaced in a direction perpendicular to the plane. Instead, the plane may be tilted in a preselected direction with respect to a symmetrical axis of the first seal element.

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In a particular embodiment of the invention, the second seal element may comprise a downstream portion of a power generator gas turbine. It will be appreciated that a turbine rotating on a shaft about a rotation axis may move on its bearings both axially and radially. In addition, the longitudinal axis of the turbine may
85 precess. It will further be appreciated that the gap between a downstream sealing surface defined on a downstream end of the turbine rotor (providing the second seal element) and a sealing surface of an annular seal element (providing the first seal element) sealing on the said downstream sealing surface will vary with the displacement of the turbine rotor. Accordingly, if the said gap is to be maintained
90 within predetermined limits, the first seal element must be allowed to move in a manner related to the movement of the rotating second sealing surface of the turbine rotor. The sensing means may be operable to sense displacement of the turbine shaft

or any rotating components rotatably fixed to the shaft, such as the downstream
95 sealing surface of the turbine rotor. Instead, the sensing means may comprise a
plurality of sensors which sense the distance between the first and second sealing
surfaces at preselected locations.

According to a further aspect of the invention there is provided a
100 combination comprising a gas turbine including a turbine rotor having a downstream
end and a seal assembly as hereinbefore described, the second seal element of the
seal assembly being arranged on the downstream end of the turbine rotor.

Then, the sensing means of the seal assembly may sense displacement
105 of the second seal element from the first datum position directly. The sensing means
of the seal assembly may include a plurality of sensors, each of which being operable
to sense a distance between the first and second sealing surfaces at a respective
preselected location, the position of the first sealing surface at the said location
defining the first datum position.

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Instead, the sensing means of the seal assembly may sense displacement
of the second seal element from the first datum position indirectly by sensing a
displacement from a datum position of a component of the gas turbine mechanically
fast with the rotor thereof.

115

Further, the biasing means may comprise an annular gas impermeable bellows arranged between the carrier member and the support member.

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According to another aspect of the invention there is provided a method of controlling a spacial relationship between respective sealing surfaces of two seal elements, the method including the steps of

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sensing a displacement of one of the seal elements from a datum position; and displacing the other of the seal elements by means of a displacement means including an electromagnet, the said other seal element being operatively coupled with the displacement means via the electromagnet, to maintain a preselected spacial relationship between the two sealing surfaces.

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The datum position may be defined by the sealing surface of said other seal element, and the method may include sensing the distance between the two sealing surfaces and displacing the said one seal element to maintain a preselected distance between the two sealing surfaces.

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The displacement means may include a plurality of electromagnets and the method may include selectively varying the magnetic flux in each of the electromagnets.

The invention is now described, by way of example, with reference to the accompanying diagrammatic drawings.

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In the drawings,

Figure 1 shows a schematic sectional side view of a first embodiment of a seal assembly in accordance with the first aspect of invention;

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Figure 2 shows a schematic sectional side view of a second embodiment of the seal assembly;

Figure 3 shows a sectional side view of a detail of the seal assembly in use on a turbine rotor;

Figure 4 shows a three-dimensional view of a portion of the seal assembly of Figure 3; and

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Figure 5 shows a further three-dimensional view of the portion of the seal assembly of Figure 3.

In the drawings, reference numeral 10 generally refers to a seal assembly in accordance with the invention.

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In Figures 1 and 2, the seal assembly 10 has a first seal element 12 defining a first sealing surface 14. The first seal element is an annular seal 16 which is mounted on a rigid annular carrier member 18. The seal assembly 10, further has

160 a plurality of electromagnets 20, two of which are illustrated schematically in Figures
1 and 2. A movable component 22 of the electromagnets 20 is attached to the
support 18, while a stationary component 24 of the electromagnets 20 is attached to
a fixed support member 26. In the drawings, the first sealing surface 14 is shown
forming a seal 15 in cooperation with a second sealing surface 28, which is defined
165 on a rotating element 30 of a machine 32, being a power generator gas turbine, the
rotating element 30 being mounted on a shaft 34. The seal assembly 10 further
includes a biasing means, indicated schematically in the drawings by the device
labelled 36.

170 In the embodiment of the seal assembly 10 shown in Figure 1, the biasing
means 36 normally urges the annular carrier member 18 away from the support
member 26, so that the first and second sealing surfaces, 14 and 28 respectively, are
normally urged towards one another. The electromagnets 20 are operable to urge the
carrier member 18 towards the support member 26 and, consequently, the first and
175 second sealing surfaces, 14 and 28, away from one another. By controlling the
magnetic flux of the electromagnets 20, the force exerted on the annular carrier
member 18 by the urging means 36 may be balanced by an opposed force exerted on
the carrier member 18 by the electromagnets 20. In this way a predetermined gap
may be maintained between the first and second sealing surfaces 14 and 28.

It will be appreciated that the biasing means 36 may be configured to normally urge the carrier member 18 towards the support member 26 so that the first and second sealing surfaces, 14 and 28 respectively, are normally urged away from one another. Such a configuration is provided in the embodiment illustrated in Figure 2. In this case, the electromagnets 20 are operable to urge the carrier member 18 away from the support member 26.

Generally, the shaft 34 of a machine 32 will not run perfectly true. Thus, while rotating, as indicated by the arrow marked "B" in the drawings, the shaft 34 may move on its bearings in an axial direction, as indicated by the arrow marked "A" in the drawings, or transversely in a radial direction, or both. Further, the shaft 34 may precess about its own axis, as indicated by the arrow labelled "C" in the drawings. Consequently, the gap between the first and second sealing surfaces 14 and 28 will generally vary with each rotation of the shaft 34, if the first sealing surface 12 is fixed in position. In order to reduce the extent of variation in the spacing gap, the movement of the second sealing surface 28 is detected and measured via a sensor, indicated in the drawings by reference numeral 38, which detects displacement of the shaft 34 from a datum position, the displacement of the shaft 34 bearing a known relationship to displacement of the second sealing surface 28. It will be appreciated that displacement of the second sealing surface 28 may be detected and measured directly, as may variation in the gap between the first and second

205 sealing surfaces 14 and 28. A controller, indicated on the drawings by reference numeral 40, is operable to control each of the electromagnets 20 independently by varying the magnetic flux of each electromagnet 20, thereby selectively increasing or decreasing the force exerted by an electromagnet 20 on the carrier member 18. In this way, the entire carrier member 18, and consequently the first sealing surface 14, may be displaced axially, or tilted in any desired direction. The first sealing surface 14
210 may be controlled to mimic the movement of the second sealing surface 28 as it is displaced from its true position. Instead, the first sealing surface 14 may be controlled to maintain a preselected average gap between the first and second sealing surfaces 14 and 28.

215 We now turn to Figures 3 to 5, which show a seal assembly 10 in use on a gas turbine power generator rotor 50. In Figures 3 to 5, with reference to Figures 1 and 2, like components are indicated by like reference numerals, unless otherwise stated.

220 The turbine rotor 50 has a plurality of circumferentially spaced vanes, one example of which is labelled 52, and the seal assembly 10 is located on a downstream end 54 of the rotor 50. The seal assembly 10 is mounted on a fixed support assembly 56 and has sixteen electromagnets 20 evenly spaced about the circumference of the support assembly 56. Each of the electromagnets 20 has a coil 58 and a movable

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core element 60, the coils 58 being mounted on the support assembly 56 and the core elements 60 being mounted on an annular carrier member 18. It will be appreciated that instead the coils 58 of the electromagnets 20 may be mounted on the carrier member 18 and the core elements 60 may be mounted on the support assembly 56.

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An annular labyrinth seal 62 is arranged on an underside 64 of the carrier member 18 and defines a labyrinthine surface 66, which comprises the first sealing surface 14 of the seal assembly 10. The second sealing surface 28 of the seal assembly 10 comprises an annulus defined on the downstream end 54 of the turbine rotor 50. It will be appreciated that the second sealing surface may be in any suitable form so

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that, for example, a second labyrinth seal may be arranged on the downstream end 54 of the turbine rotor 50 to define the second sealing surface 28. The second labyrinth seal may be configured to cooperate with the labyrinth seal 62 of the annular carrier member 18.

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An annular steel bellows 74 is arranged between the support assembly 56 and the carrier member 18, a first end 76 of the bellows 74 being connected to the support assembly 56 and a second end 78 of the bellows 74 being connected to the annular carrier member 18. The steel bellows 74 is configured to provide a biasing means 80, normally urging the labyrinth seal 62 away from the downstream end 54

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of the turbine rotor 50. In this configuration, if power to the electromagnets 20 fails, the labyrinth seal 62 will move away from the downstream end 54 of the turbine rotor

50, thereby avoiding massive damage to the seal 62 which would result from direct contact with the rapidly rotating turbine rotor 50. It is to be appreciated, however, that the biasing means 80 may be configured to normally urge the labyrinth seal 62 towards the second sealing surface 28.

It will be appreciated that on large gas turbine machines, a stream of gas at high pressure flowing from an upstream end 68 of the turbine rotor 50 towards the downstream end 54 of the rotor 50 will create large axial forces on the turbine shaft (not shown). In order to obviate this problem, a flow of gas at high pressure is directed to a downstream region 70 adjacent the downstream end 54 of the turbine rotor 50, to reduce the difference between forces on the downstream and upstream ends, 54 and 68 respectively, of the turbine rotor 50 and balancing the axial forces operative on the turbine shaft. An extendably retractable gas impermeable seal 82 is provided by the bellows 74, between the downstream region 70 and a low pressure region 72, normally at atmospheric pressure. It will be appreciated that in general such an extendably retractable seal, such as the seal 82, will be required to provide an impermeable barrier between the high pressure region 70 and a low pressure region 72 and to provide for axial displacement of the rotor 50, as described above. In order to maintain a relatively high pressure in the downstream region 70, a seal must be maintained closely proximate the rapidly rotating rotor 50 to minimise leakage of gas to the low pressure region 72. However, in order to inhibit rapid seal wear, the sealing

270 surfaces 14 and 28 should not be in contact. Thus, a preselected gap should be
maintained between the sealing surfaces 14 and 28. Generally, as explained above,
the shafts of large machines do not run perfectly true. Consequently, in order to
maintain a preselected gap, or to maintain a gap within preselected limits, the first
sealing surface 14 must be enabled to track the second sealing surface 28. At least
275 one sensor (not shown) is provided for sensing displacement of the turbine rotor 50
from a datum position. A controller (not shown) is operably connected to the sensors
and to the electromagnets 20 and is operable to vary the magnetic flux in the
electromagnets 20 in response to a signal from the sensors on sensing a displacement
of the turbine rotor 50 from its datum position. It will be appreciated that, as required,
280 the controller may control each of the electromagnets 20 independently. Instead, the
controller may control subsets of the sixteen electromagnets 20, for example groups
of four adjacent electromagnets 20 to operate in unison.

CLAIMS

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1. A seal assembly which includes
a first seal element defining a first sealing surface;
displacement means including at least one electromagnet operatively coupled
with the first seal element, the displacement means being operable to displace the first
290 seal element via the, or each, electromagnet; and
a second seal element defining a second sealing surface associated with the first
sealing surface, the first and second seal elements providing a seal.

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2. The seal assembly as claimed in Claim 1, which includes a sensor means
for sensing a displacement of the second element from a first datum position.

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3. The seal assembly as claimed in Claim 2, which includes control means
operably connected to the sensor means and the displacement means, the control
means operable to control the displacement means to maintain the first sealing surface
in a predetermined spacial relationship with the second sealing surface.

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4. The seal assembly as claimed in any one of the preceding claims, which
includes a biasing means for biasing the first seal element in a predetermined direction.

5. The seal assembly as claimed in Claim 4, in which the biasing means is

configured to exert a force which is a function of a displacement of the biasing means from a second datum position.

310 6. The seal assembly as claimed in Claim 3, in which the displacement means includes a plurality of electromagnets in spaced relationship with respect to one another and the control means is operable to control each of the electromagnets.

315 7. The seal assembly as claimed in Claim 6, in which the control means is operable to control each of the electromagnets independently.

8. The seal assembly as claimed in Claim 6, in which the control means is operable to control sub-sets of the electromagnets in unison.

320 9. The seal assembly as claimed in Claim 6, in which the first seal element comprises an annular ring defining an annular first sealing surface and the second seal element defines an annular second sealing surface.

325 10. The seal assembly as claimed in Claim 9, which includes a rigid carrier member on which the first annular seal element is mounted, the electromagnets being operatively coupled with the carrier member and angularly spaced with respect thereto.

11. The seal assembly as claimed in Claim 10, which includes a support
330 member, and in which each of the electromagnets of the displacement means has a
core element displaceable with respect to a coil, one of the core element or the coil
being connected to the carrier member of the first seal element and the other of the
core element or the coil being connected to the support member.

335 12. A combination comprising a gas turbine including a turbine rotor having
a downstream end and a seal assembly as claimed in Claim 11, the second seal
element of the seal assembly being arranged on the downstream end of the turbine
rotor.

340 13. The combination as claimed in Claim 12, in which the sensing means of
the seal assembly senses displacement of the second seal element from the first
datum position directly.

345 14. The combination as claimed in Claim 13, in which the sensing means of
the seal assembly includes a plurality of sensors, each of which being operable to
sense a distance between the first and second sealing surfaces at a respective
preselected location, the position of the first sealing surface at the said location
defining the first datum position.

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15. The combination as claimed in Claim 12, in which the sensing means of the seal assembly senses displacement of the second seal element from the first datum position indirectly by sensing a displacement from a datum position of a component of the gas turbine mechanically fast with the rotor thereof.

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16. The combination as claimed in Claim 12 or Claim 13, in which the biasing means comprises an annular gas impermeable bellows arranged between the carrier member and the support member.

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17. A method of controlling a spacial relationship between respective sealing surfaces of two seal elements, the method including the steps of

sensing a displacement of one of the seal elements from a datum position; and

displacing the other of the seal elements by means of a displacement means

including at least one electromagnet, the said other seal element being operatively

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coupled with the displacement means via the, or each, electromagnet, to maintain a preselected spacial relationship between the two sealing surfaces.

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18. The method as claimed in Claim 15, in which the datum position is defined by the sealing surface of a said other seal element, and the method includes

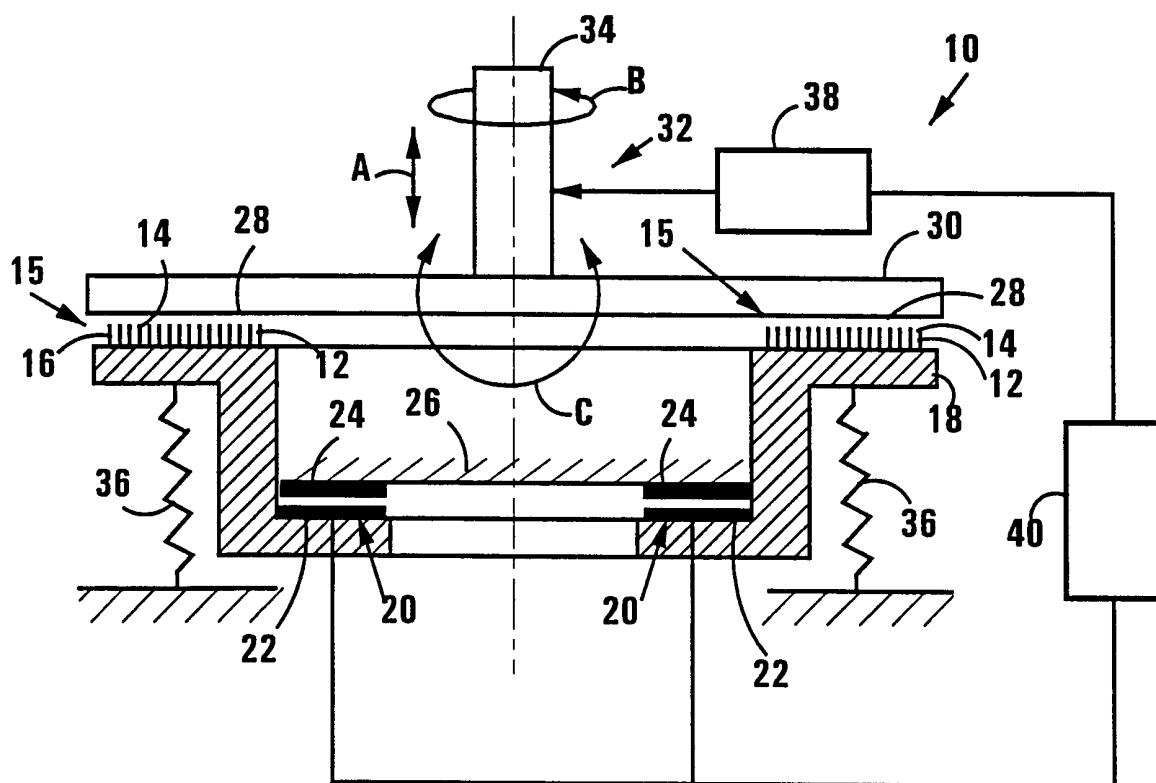
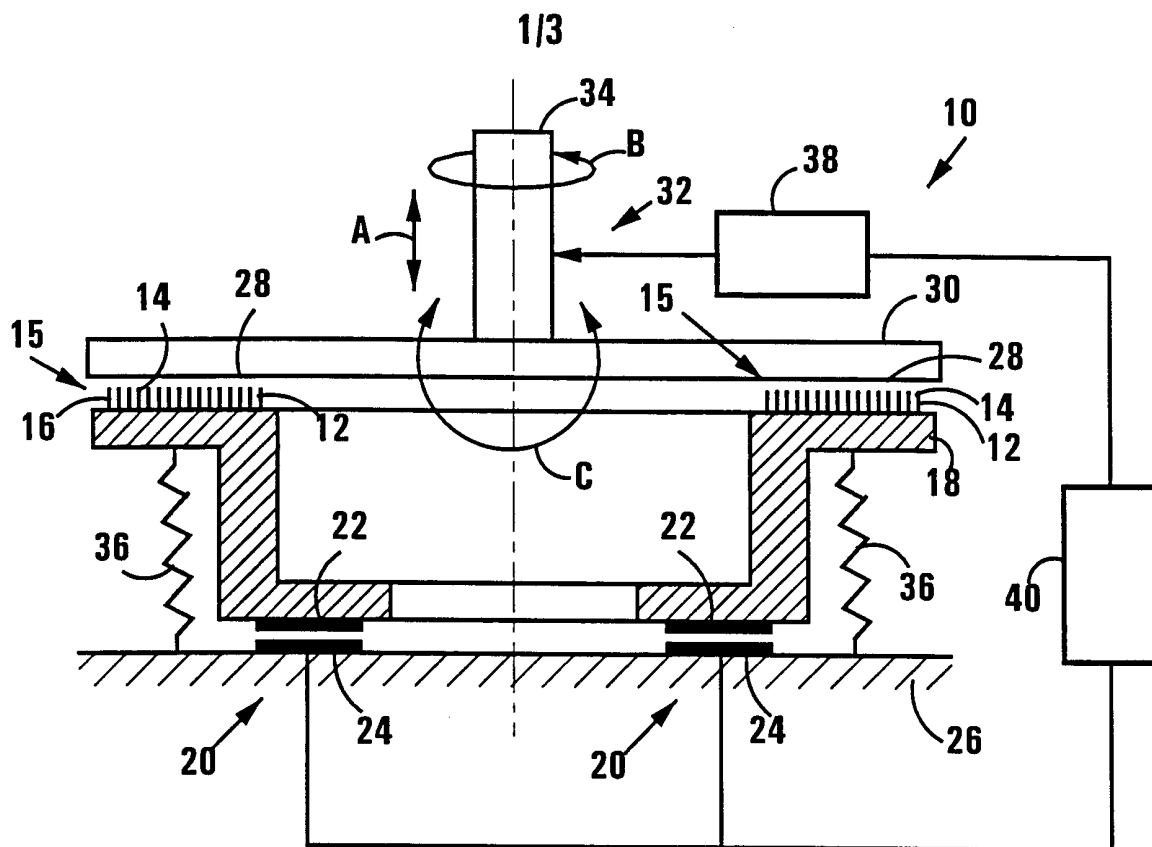
sensing the distance between the two sealing surfaces and displacing the said one seal element to maintain a preselected distance between the two sealing surfaces.

19. The method as claimed in Claim 15 or Claim 16, in which the displacement means includes a plurality of electromagnets and the method includes
375 selectively varying the magnetic flux in each of the electromagnets.

20. A seal assembly substantially as herein described and illustrated with reference to the accompanying diagrammatic drawings.

380 21. A combination comprising a gas turbine including a turbine rotor having a downstream end and a seal assembly substantially as herein described and illustrated with reference to the accompanying diagrammatic drawings.

385 22. A method of controlling a spacial relationship between two sealing surfaces substantially as herein described and illustrated with reference to the accompanying diagrammatic drawings.



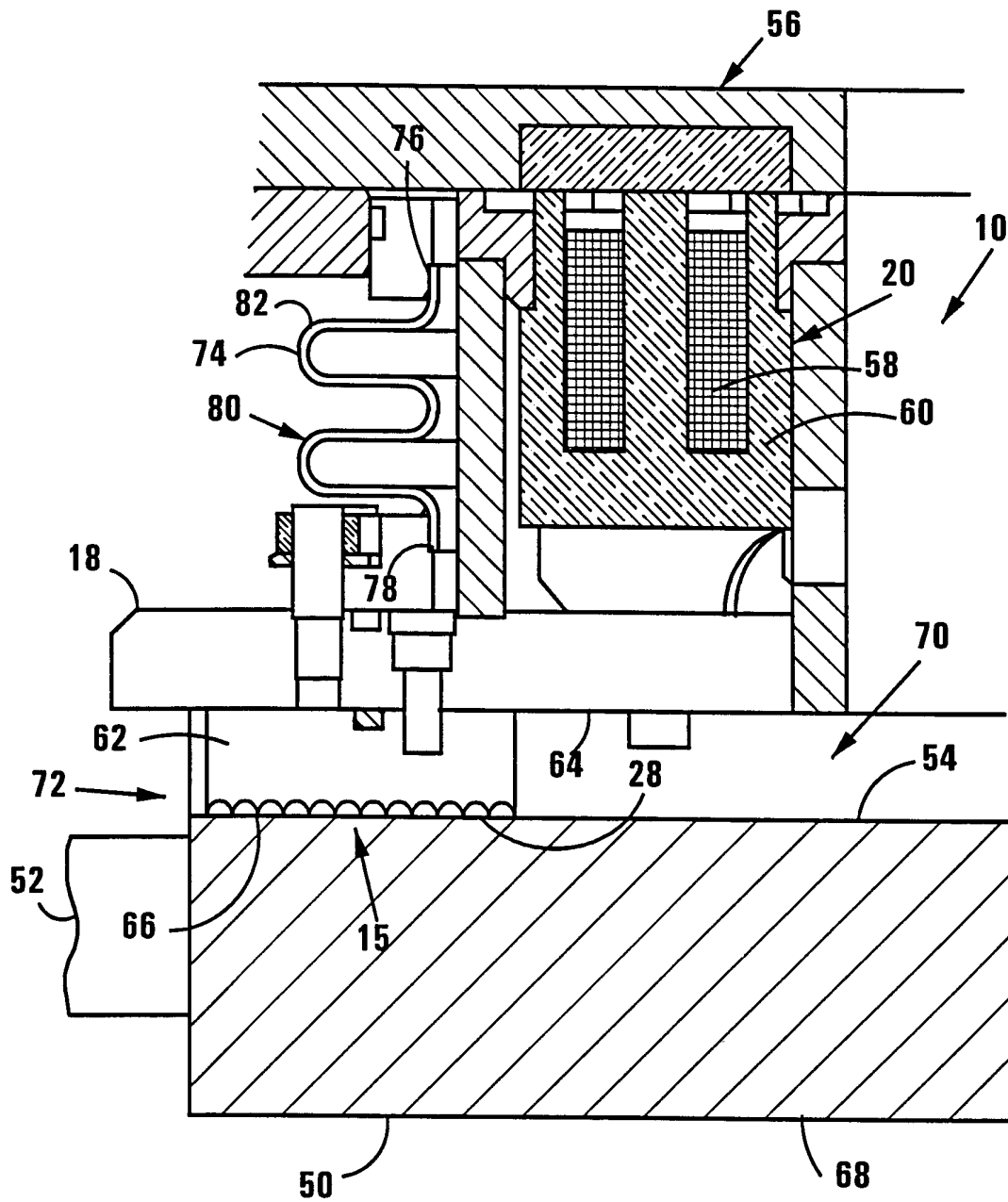


FIG 3

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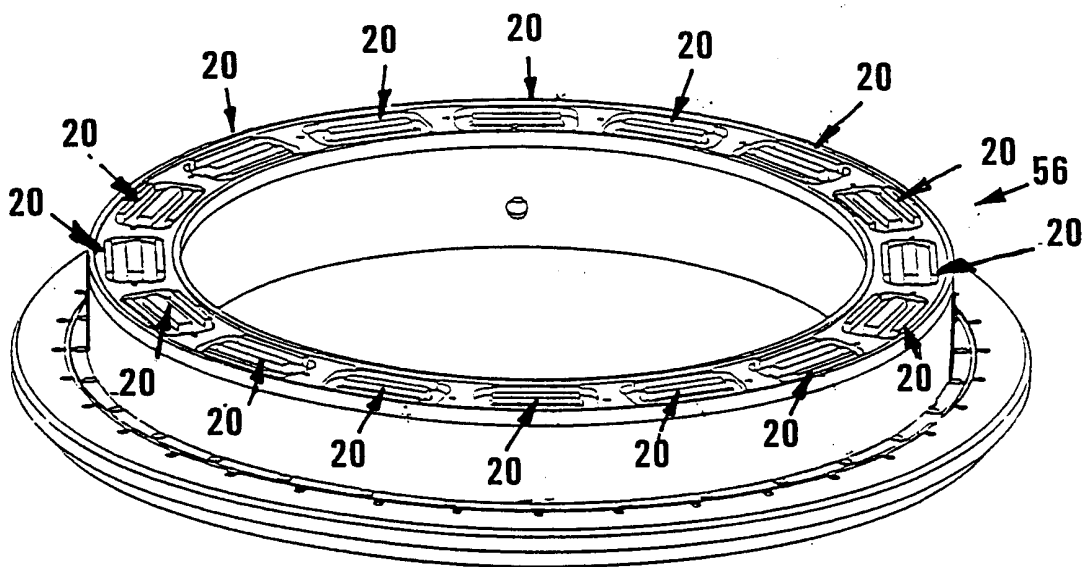


FIG 4

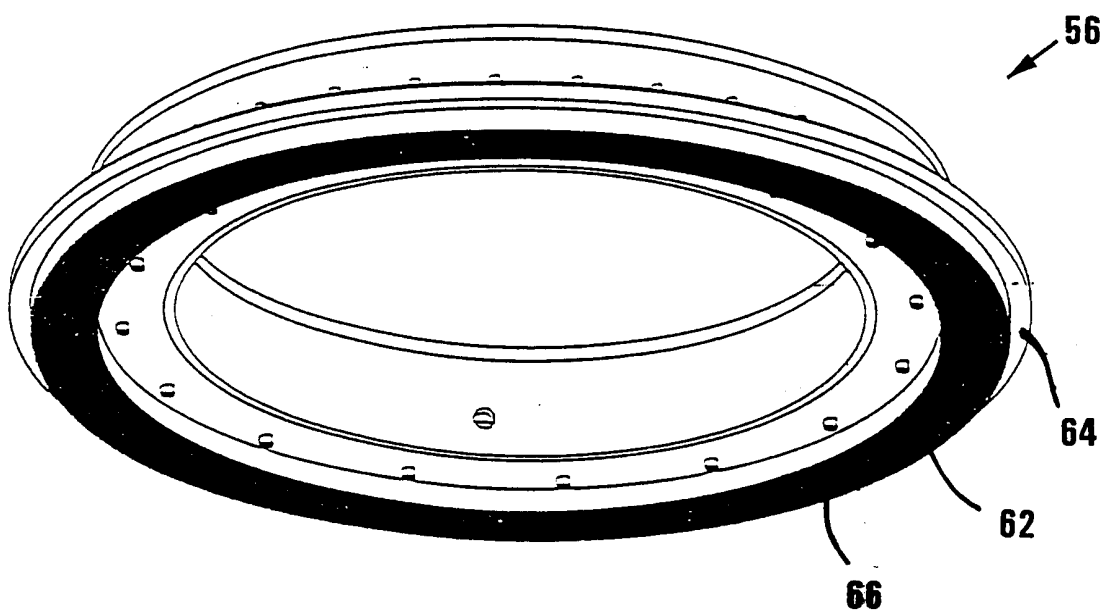


FIG 5

INTERNATIONAL SEARCH REPORT

International Application No

PCT/IB 00/01152

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 F16J15/43 F01D11/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 F01D F16J F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 263 816 A (WEIMER MATTHEW M ET AL) 23 November 1993 (1993-11-23) column 1, line 45 - line 64 figure 1	1-5, 17, 20-22
A	----- DE 35 05 048 A (MOTOREN TURBINEN UNION) 14 August 1986 (1986-08-14) the whole document -----	6-16, 18, 19
A	DE 35 05 048 A (MOTOREN TURBINEN UNION) 14 August 1986 (1986-08-14) the whole document	1-22

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

° Special categories of cited documents :

A document defining the general state of the art which is not considered to be of particular relevance

E earlier document but published on or after the international filing date

L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

O document referring to an oral disclosure, use, exhibition or other means

P document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

* & * document member of the same patent family

Date of the actual completion of the international search

23 November 2000

Date of mailing of the international search report

29/11/2000

Name and mailing address of the ISA

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

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Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5263816	A	23-11-1993	CA 2086170 A,C	23-12-1993
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