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(54) **Title:** WOBBLE RESISTANT SHAFT SEAL

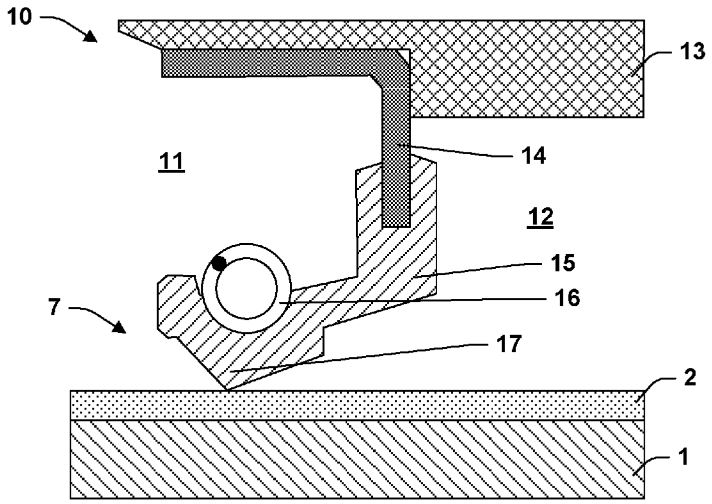

Fig. 4

(57) **Abstract:** A radial shaft seal includes a powder coating on a shaft and a sealing lip that lands on the powder coating. The powder coating is formed of a thermosetting resin and a filler material. The filler material has a melting point above the cure temperature of the thermosetting resin. The powder coating may be porous. The powder coating may be made up of dry powder particles adhered to one-another with spaces in between. The filler may be present in an amount between 15% and 35% within the individual particles. The powder coating is adapted to wear away at locations of maximum interference with the sealing lip but is sufficiently stable to provide a durable seal. This wear behavior compensates for shaft wobble.

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Wobble Resistant Shaft Seal

Field

[0001] The present disclosure relates to radial shaft seals.

Background

[0002] Radial shaft seals are widely employed in machines having rotating or reciprocating shafts. Radial shaft seals are intended to retain lubricants and prevent lubricant contamination while having low friction. Challenges that contribute to radial shaft seals being unable to perform these functions ideally include non-uniform shaft surfaces, shafts that are not perfectly round, and imperfections that cause shafts to wobble about their intended axis of rotation. Maintenance costs and premature wear associated with non-ideal radial shaft seals are enormous, which has created a long felt need for better radial shaft seals.

Summary

[0003] One aspect of the invention is a radial shaft seal that includes a powder coating on a shaft and a sealing lip that lands on the powder coating to form the seal. The powder coating is formed from a powder that includes a thermosetting resin and a filler material. The filler material has a melting point above the cure temperature of the thermosetting resin. The thermosetting resin forms a matrix and the filler material affects hardness of that matrix and imparts desirable wear characteristics. The powder coating is adapted to wear away at locations of maximum interference with the sealing lip but is sufficiently stable to provide a durable seal. This wear behavior can compensate for shaft wobble. In some of these teachings the shaft wobbles as it rotates to produce a radial extent that varies by at least 10 µm as the shaft rotates absent the powder coating.

[0004] In some of these teachings, the powder coating is applied relatively thickly. In some of these teaching the powder coating has a thickness greater than 20 µm. In some of these teachings, the powder coating has a thickness of at least about 40 µm. These thicknesses allow the portion of the powder coating that does not wear away to reshape the shaft compensating for surface defects, non-circularity, and wobble.

[0005] In some of these teachings, the sealing lip to wears a trench into the powder coating. The sealing lip then mates with the trench to provide increased contact area between the lip seal and the powder coating. In some of these teachings, the trench makes the contact area between the sealing lip and the powder coating at least 50 percent greater than it would be if the powder coating had a uniform thickness on the shaft. In some the, trench has a depth that is at least 25% of the trench width. A relatively thick powder coating facilitates the formation of these structures. In some of these structures, the sealing lip is one of a plurality of sealing lips that mate with a plurality of trenches in the powder coating to form a labyrinth seal. This structure may be produced with one sealing ring having multiple sealing lips or by multiple sealing rings each providing one sealing lip.

[0006] In some of these teachings, the powder coating includes a first layer proximate the shaft and a second layer more distal from the shaft. The first layer is more wear resistant that the second layer. This structure may limit the depth to which a trench forms in the powder coating. On the other hand, in some of these teachings the sealing lip is allowed to wear the powder coating down to the shaft.

[0007] In some of these teachings, an elastomeric ring provides the sealing lip. In some of these teaching, a nitrile ring provides the sealing lip. In some of these teachings, the radial shaft seal further comprises a garter spring that biases the sealing lip against the shaft. These elastomeric and spring forces keep space from developing between the sealing lip and the powder coating even as the powder coating wears.

[0008] In some of these teachings, the powder coating is formed from dry powder in which the filler is present in an amount from 15 to 35 volume percent based on the volume of the dry powder. In some of these teachings, the powder coating is formed from a powder of particles that individually have the filler in an amount from 15% to 35% by volume. In some of these teaching, the dry powder is formed from a process that includes melt-mixing the thermosetting resin and the filler material to form a composite, cooling the composite, and breaking up the cooled composite to form the dry powder. In some of these teachings, the powder coating is formed by electrostatic deposition of the dry powder on the shaft. In some of these teachings, the filler is graphite.

[0009] In some of these teachings, the powder coating is porous. In some of these teachings, the powder coating has a porosity in the range from 2% to 80%. In some of these teaching, the powder coating has a porous structure that is formed by the particles of the dry powder adhered to one another with spaces in between. In some of these teaching, that structure is formed by curing the dry powder in such a way that the dry powder particles sinter but do not flow sufficiently to lose their discrete identities. The porous structure allows the powder coating to hold oil and results in lower friction.

[0010] In some of these teaching, a liquid primer is applied to the shaft prior to coating the shaft with the dry powder. The liquid primer includes a second thermosetting resin and a solvent. The dry powder is applied over the liquid primer prior to drying or curing the liquid primer. In some of these teachings, the dry powder is applied over the liquid primer while the liquid primer is still liquid. The dry powder and the liquid primer are cured together to form a dry powder film lubricant. The dry powder film lubricant includes a polymer matrix formed from the first thermosetting resin in a layer proximate the shaft. The dry powder particles adhered to one another form a powder coating in another layer more distal from the shaft. The powder coating that includes the dry powder film lubricant may exhibit superior adhesion and wear properties compared to one formed without the liquid primer.

[0011] The primary purpose of this summary has been to present certain of the inventor's concepts in a simplified form to facilitate understanding of the more detailed description that follows. This summary is not a comprehensive description of every one of the inventor's concepts or every combination of the inventor's concepts that can be considered "invention". Other concepts of the inventor's will be conveyed to one of ordinary skill in the art by the following detailed description together with the drawings. The specifics disclosed herein may be generalized, narrowed, and combined in various ways with the ultimate statement of what the inventor claims as his invention being reserved for the claims that follow.

Brief Description of the Drawings

[0012] Fig. 1 is flow chart of a process that may be used in accordance with some aspects of the present teachings to form a dry powder.

[0013] Fig. 2 is a flow chart of a process for coating a shaft in accordance with some aspects of the present teachings.

[0014] Fig. 3 illustrates a powder coating according to some aspects of the present teachings.

[0015] Fig. 4 illustrates a machine with a radial shaft seal according to some aspects of the present teachings.

[0016] Fig. 5 illustrates the machine of Fig. 4 after the radial shaft seal has broken in.

[0017] Fig. 6 illustrates a shaft with a powder coating according to some aspects of the present teachings.

[0018] Fig. 7 illustrates the shaft of Fig. 6 after the powder coating has worn in to mitigate wobble.

[0019] Fig. 8 illustrates a machine with a radial shaft seal according to some other aspects of the present teachings.

[0020] Fig. 9 illustrates a shaft seal according to some aspects of the present teachings.

Detailed Description

[0021] Fig. 1 is a flow chart of a process 100 for forming a dry powder. The process includes act 101, melt-mixing a thermosetting resin and a filler material to form a composite, act 103, cooling the composite, and act 105, pulverizing the composite to form the dry powder. The resin may be part of a resin system that includes one or more of a curing agent, a hardener, an inhibitor, and plasticizer. Any suitable thermosetting resin may be used. Examples of thermosetting resins that may be used include acrylic, allyl, epoxy, melamine formaldehyde, phenolic, polyamide, polyaryl sulphone, polyamide-imide, polybutadiene, polycarbonate, polydicyclopentadiene, polyester, polyphenylene sulphide, polyurethane, silicone, and vinyl ester resins and mixtures thereof. The composite may have the resin in an amount that is 35% or more by volume.

[0022] The filler material preferably has a melting point above the cure temperature of the thermosetting resin. In some of these teachings, the filler material is a solid lubricant. Examples of solid lubricants that may be used as the filler material include graphite, PTFE, polyamide, polyamide imide, polyimide, boron nitride, carbon monofluoride, molybdenum disulphide, talc, mica, kaolin, the sulfides, selenides, and tellurides of molybdenum, tungsten, or titanium and combinations thereof. The mixture preferably has the filler material in an amount that is 15 to 35 percent by volume. In some of these teachings the filler is at least 60% graphite. In some of these teachings the graphite particles have lengths in the range from 7 to 30 micrometers. Some application benefit from the inclusion of clay in the filler. In some of these teachings, the filler is from 20% to 40% clay by volume. Examples of clays that are suitable for the filler include kaolin, mullite, montmorillonite, and bentonite.

[0023] The composite may be broken up to form the powder by any suitable process such as milling. The resulting powder preferably has a mean particle size in the range from 2 to 200 µm. For purposes of the present disclosure, particle sizes are the diameters of spheres having the same volume as the particles. More preferably, the mean particle size is in the range from 5 to 150 µm. Still more preferably the particle size is in the range from 10 to 80 µm. Smaller particles may be difficult to process. Larger particles may not adhere well when electrostatics are used. Preferably, the filler and the resin are both present in the individual particles of the powder.

[0024] Fig. 2 is a flow chart of a process 120 in which the dry powder is used to form a coating 2 on a shaft 1 as shown in Fig. 3. Process 120 begins with act 121, applying a liquid primer to the shaft 1. The liquid primer is optional, but can improve the adhesion and wear properties of the powder coating. The liquid includes a thermosetting resin. Optionally, the liquid also includes a solvent. The thermosetting resin can be any of the resins given as examples for making the dry powder. The thermosetting resin may make up 35% or more of the liquid primer by volume. The solvent is present in at least an amount sufficient to make the primer liquid if a solvent is needed for that purpose. Low boiling point solvents are preferred as are organic solvents. Examples of solvents that may be suitable for the liquid primer include methyl ethyl ketone (MEK), N-Methyl-2-pyrrolidone (NMP), turpentine, xylene, mineral spirits, turpenoid, toluene, dimethylfomamide, glycol ethers, ethylbenzene, n-butyl acetate, alcohols, acetone and combination thereof.

[0025] Process 120 continues with act 123 in which the dry powder is deposited over the liquid primer. The dry powder is preferably deposited before evaporating the solvent from the primer. The dry powder may be deposited by any suitable process. An electrostatic process is generally preferred for its ability to provide a thick and uniform coating of the dry powder. The dry powder may be sprayed on the shaft or the shaft may be placed in a fluidized bed of the dry powder.

[0026] Process 120 continues with act 125, evaporating the solvent and act 127, curing the liquid primer and the dry powder. Fig. 3 illustrates the powder coating 2 formed by this process. As shown in Fig. 3, powder coating 2 has three layers. A layer 4 closest to the surface 3 of shaft 1 is formed from the thermosetting resin of the liquid primer. A layer 6, which is relatively distal from surface 3, has a structure formed by particles of the dry powder adhered to one another preferably with void spaces in between to produce a porosity in the range from 2% - 80%. Layer 6 by itself may be considered a “powder coating” as that term is used in the claims. Porosity is not strictly required, but generally improves the friction and wear characteristics of powder coating 2. Between layers 4 and 6 is an interfacial later 5 formed by interactions between the dry powder particles and the liquid primer. These interactions may include one or more of sinking, capillary action, and partial dissolution.

[0027] Process 120 continues with act 129, assembling the radial shaft seal 7 to produces a structure as shown in Fig. 4. Radial shaft seal 7 includes powder coating, which coats shaft 1, nitrile ring 15, and garter spring 16. A sealing lip 17 of nitrile ring 15 lands on powder coating 2. Radial shaft seal 7 is shown in a machine 10. Together with housing 13 and mounting piece 14, radial shaft seal 7 maintains isolation between an oil side 11 and an air side 12. The isolation may be sufficient to maintain a pressure differential as well as keep oil in and contaminants out.

[0028] Process 120 continues with act 131, operating shaft 1 to wear a trench 8 into powder coating 2 as show in Fig 5. Trench 8 develops a shape that mates with lip 17. Wearing trench 8 into powder coating 2 greatly increases the contact area between lip 17 and powder coating 2. The depth 18 of trench 8 is preferably on the same order of magnitude as the width 19 of trench 8. More preferably, depth 18 is at least 25% width 19. Preferably, the wear occurs primarily during a short period of operating shaft 1 after which the wear rate greatly diminishes. The wear may become limited in one of several ways. One possibility is that the increase in contact area between sealing lip 17 and powder coating 2 reduces the normal force between sealing lip 17 and powder coating 2 sufficiently to greatly reduce the wear rate. Another is that sealing lip 17 wears trench 8 down to a layer of powder coating 2 that has a higher wear resistance than the uppermost layer of powder coating 2.

[0029] Optionally, powder coating 2 receives two layers of powder, one that produces a low wear resistance upper layer and a second that produces a higher resistance layer underneath. A variety of parameters may be adjusted to produce a desired degree of wear resistance. Useful parameters to adjust include the identity of the thermosetting resin, the cure temperature, the amount of filler, the composition of the filler including the amount of clay the filler contains, and the porosity of the coating, which may be controlled through the size distribution of the dry powder particles.

[0030] In some embodiments, powder coating 2 is adapted to allow sealing lip 17 to wear trench 8 down to shaft 1 resulting in a lip seal 47 having the configuration shown in Fig. 9. In sealing lip 47, nitrile ring 15 has an interface 51 with coating 2 on oil side11 , an interface 53 where coating 2 has worn completely through to the surface underneath, and an interface 55 with coating 2 on air side 12. It has been found that sealing lip 47 is highly effective for preventing sand on air side 12 from working its way through to oil side 11.

[0031] Fig. 6 illustrates how powder coating 2 functions to mitigate wobble of shaft 1. about its ideal axis of rotation. Shaft 1 has an axis 21 that is offset from its ideal axis of rotation 20. This causes shaft 1 to wobble as shown by the outlines 1A and 1B, which illustrate the location of shaft 1 after 120 degrees and 180 degrees of rotation, respectively. Wobble causes a radially fixed location 23 on the surface of shaft 1 to have a radial extent from axis 20 that varies by an amount 22, which may be 10 μm or more. Powder coating 2 may wear to the configuration shown in Fig. 7, whereby the radial variation 22 is reduced to radial variation 24.

[0032] Fig, 8 illustrates machine 10 with radial shaft seal 37, which is a variation on radial shaft seal 7 of Fig. 5. Radial shaft seal 37 differs from radial shaft seal 7 in that radial shaft seal 37 has sealing lips 38, 39, and 40. These sealing lips all land on powder coating 2. Over a short break-in period, sealing lips 38, 39, and 40 wear trenches 41, 42, and 43 into powder coating 2. Sealing lips 38, 39, and 40 then mate with trenches 41, 42, and 43 to form a labyrinth seal.

[0033] The components and features of the present disclosure have been shown and/or described in terms of certain embodiments and examples. While a particular component or feature, or a broad or narrow formulation of that component or feature, may have been described in relation to only one embodiment or one example, all components and features in either their broad or narrow formulations may be combined with other components or features to the extent such combinations would be recognized as logical by one of ordinary skill in the art.

The claims are:

1. A radial shaft seal, comprising:

a powder coating on a shaft; and

a sealing lip landing on the powder coating to form a radial shaft seal;

wherein the powder coating is formed of a thermosetting resin having a cure temperature and a filler material having a melting point; and

the melting point of the filler material is above the cure temperature of the thermosetting resin.

2. The radial shaft seal of claim 1, wherein the powder coating is formed from dry powder in which the filler is present in an amount from about 15 to about 35 volume percent based on the volume of the dry powder.

3. The radial shaft seal of claim 1, wherein the powder coating is formed from a powder of particles in which the filler is present in the individual particles in an amount from about 15 to about 35 volume percent based on the particle volume.

4. The radial shaft seal of claim 3, wherein the filler is a solid lubricant.

5. The radial shaft seal of claim 1, wherein the powder coating is porous.

6. The radial shaft seal of claim 5, wherein the powder coating has a porosity in the range from 2% - 80%.

7. The radial shaft seal of claim 1, wherein the powder coating has a thickness greater than 20 μm.

8. The radial shaft seal of claim 1, wherein the powder coating is the product of a process, the process comprising:

melt-mixing the thermosetting resin and the filler material to form a composite;

cooling the composite;

breaking up the cooled composite to form a dry powder; and

forming the powder coating using the dry powder.

9. The radial shaft seal of claim 1, wherein the powder coating is the product of a process, the process comprising:

applying a coating of dry powder over the shaft, wherein the dry powder comprises particles that each contain the thermosetting resin and the filler material; and

curing the coating of the dry powder to form the powder coating, wherein the powder coating comprises a porous layer formed from the particles of the dry powder adhered to one-another.

10. The radial shaft seal of claim 10, wherein during the curing process the particle sinters, but curing completes without the particles flowing sufficiently to lose their discrete identities

11. The radial shaft seal of claim 10, further comprising:

applying a liquid primer over the shaft;

wherein the liquid primer comprises a second thermosetting resin and a solvent;

applying a coating of dry powder over the shaft comprises applying the coating of dry powder over the liquid primer prior to drying or curing the liquid primer; and

curing the dry powder coating comprises curing the liquid primer and the dry powder coating to form a dry powder film lubricant, wherein the dry powder film lubricant comprises a polymer matrix formed from the first thermosetting resin in a layer proximate the shaft.

12. The radial shaft seal of claim 1, wherein:

the powder coating comprises a first layer proximate the shaft and a second layer more distal from the shaft; and

the first layer is more wear resistant that the second layer.

13. The radial shaft seal of claim 1, wherein:

the sealing lip mates with a trench formed in the powder coating;

the trench has a depth and a width; and

the depth is at least 25% of the width.

14. The radial shaft seal of claim 1, wherein the sealing lip is one of a plurality of sealing lips that mate with a plurality of trenches in the powder coating to form a labyrinth seal.

15. The radial shaft seal of claim 1, wherein:

the sealing lip mates with a trench formed in the powder coating;

the trench makes the contact area between the sealing lip and the powder coating at least 50 percent greater than it would be if the powder coating had a uniform thickness on the shaft.

16. The radial shaft seal of claim 1, wherein the radial shaft seal is the product of a process, the process comprising:

applying the powder coating to the shaft;

placing the sealing lip around the shaft to produce a contact area between the sealing lip and the powder coating; and

operating the shaft to produce wear in the powder coating;

wherein operating the shaft to produce wear in the powder coating increases the contact area between the sealing member and the powder coating by at least 50%.

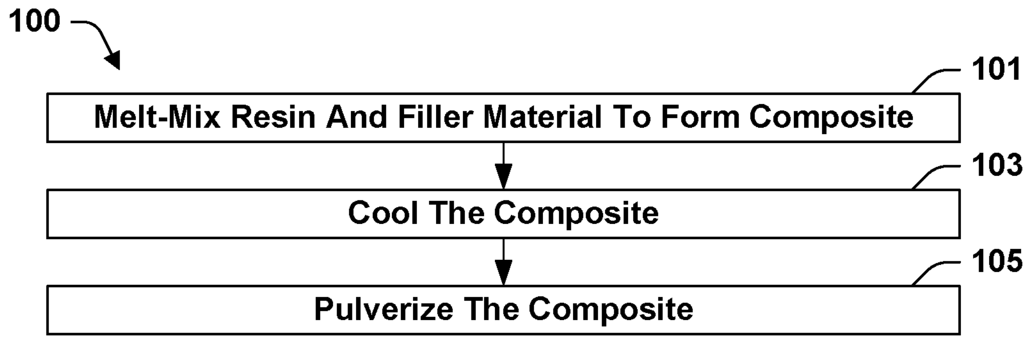

Fig. 1

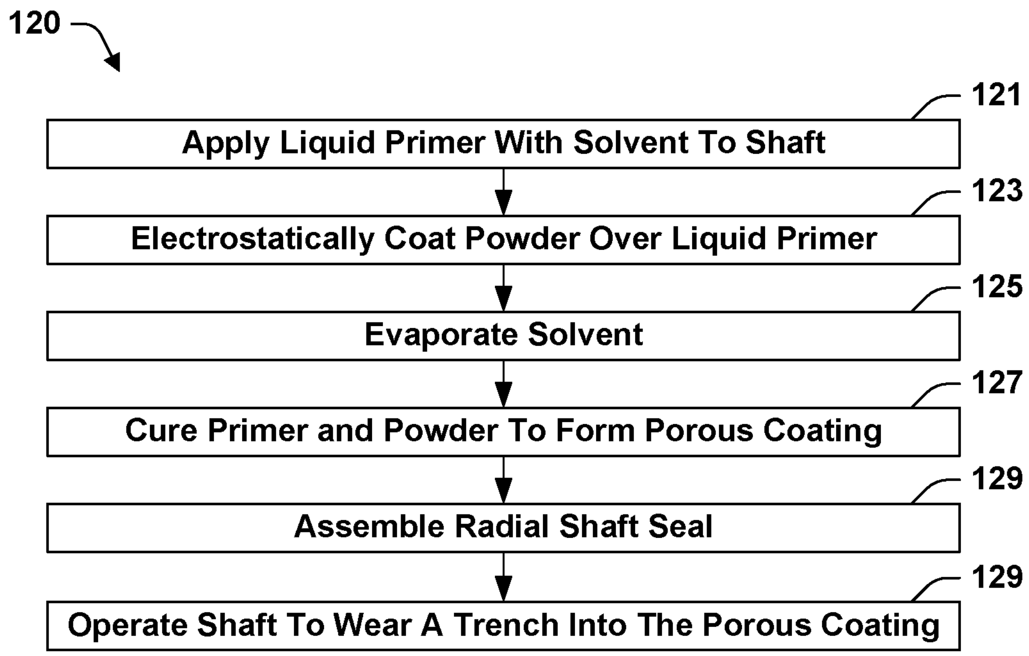

Fig. 2

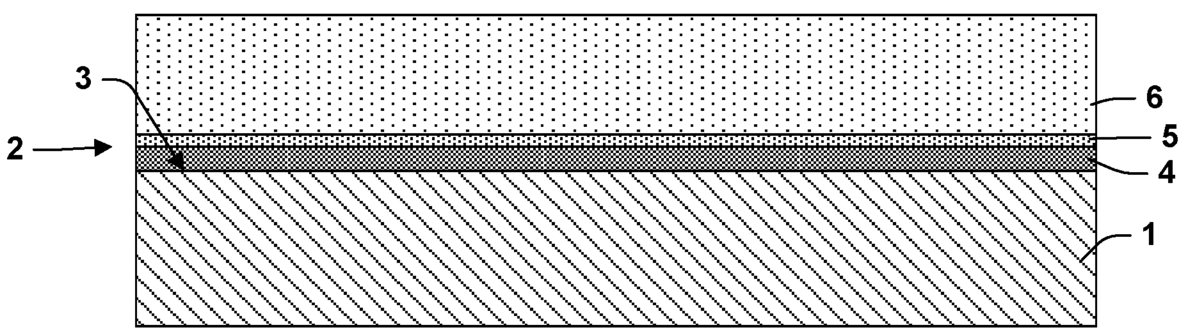

Fig. 3

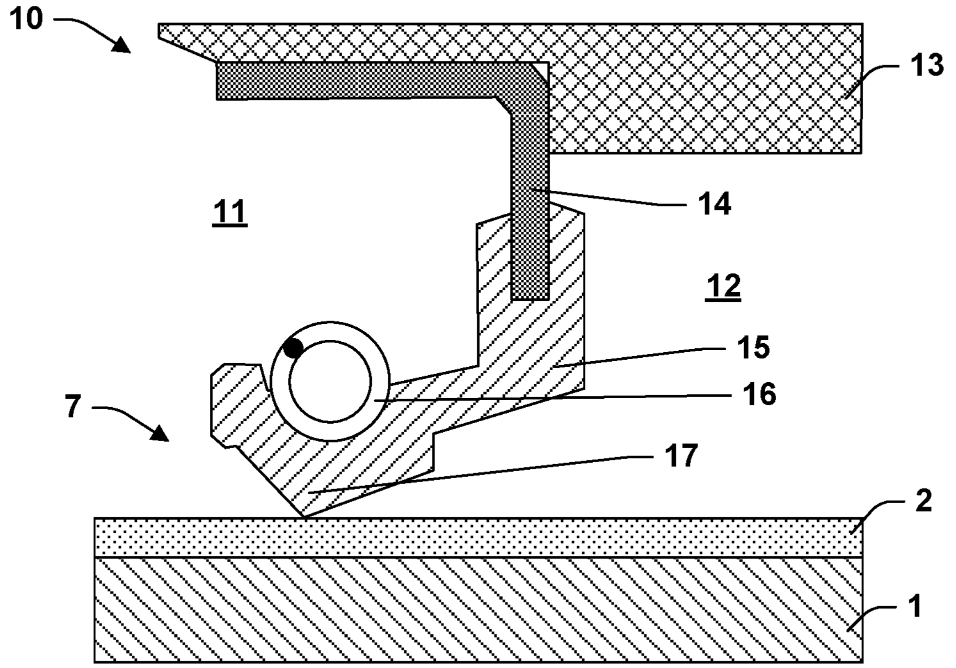

Fig. 4

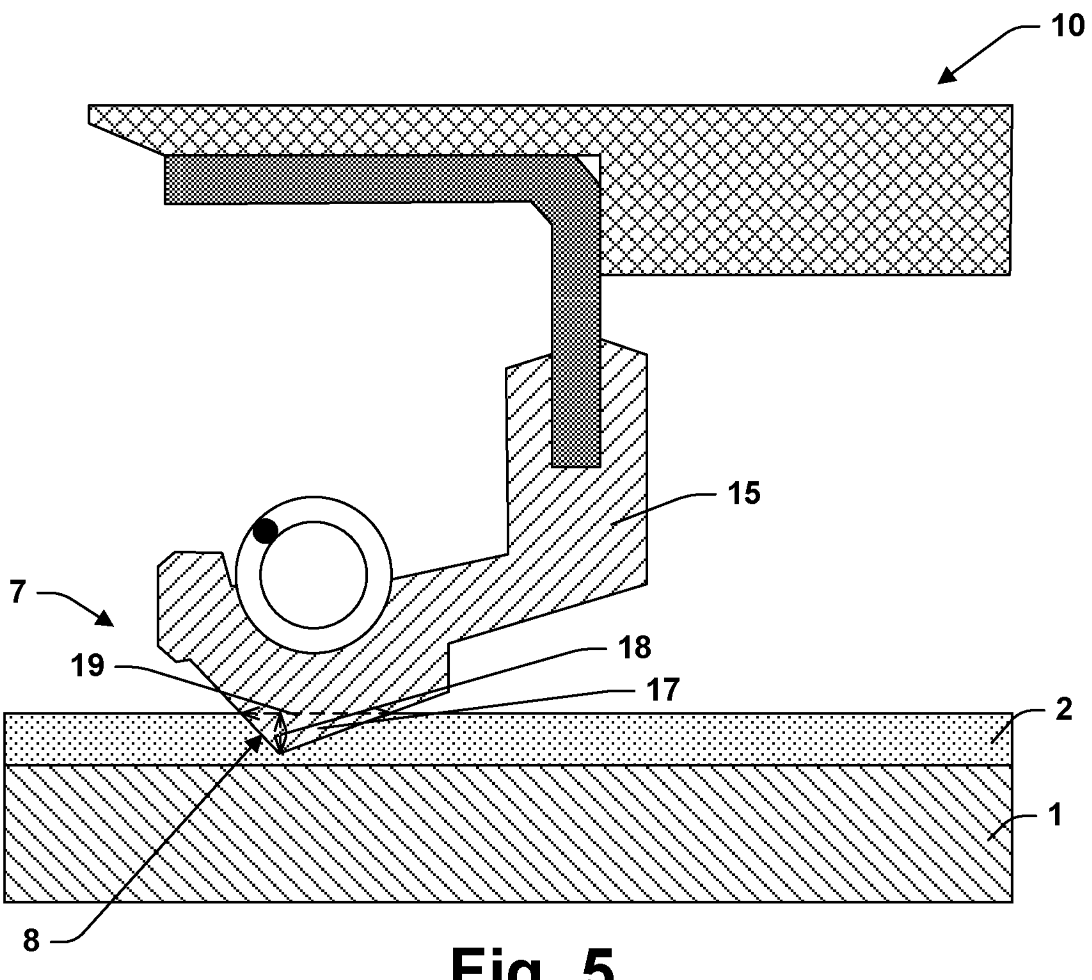

Fig. 5

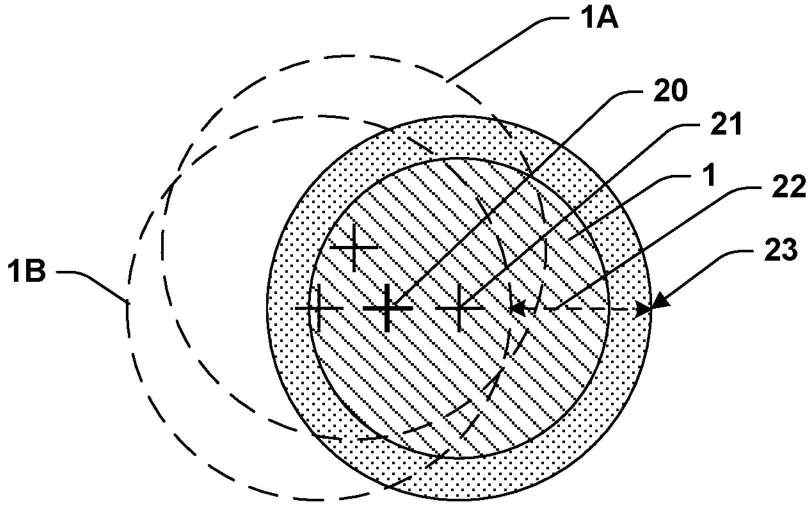

Fig. 6

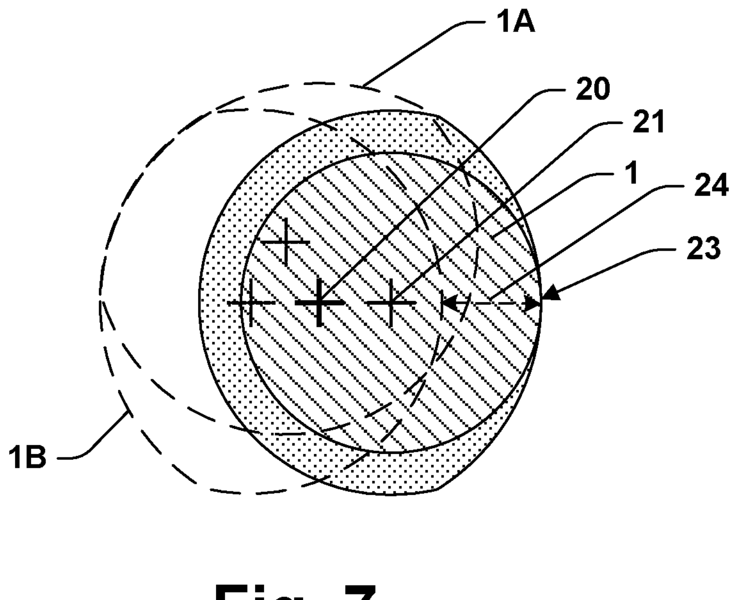

Fig. 7

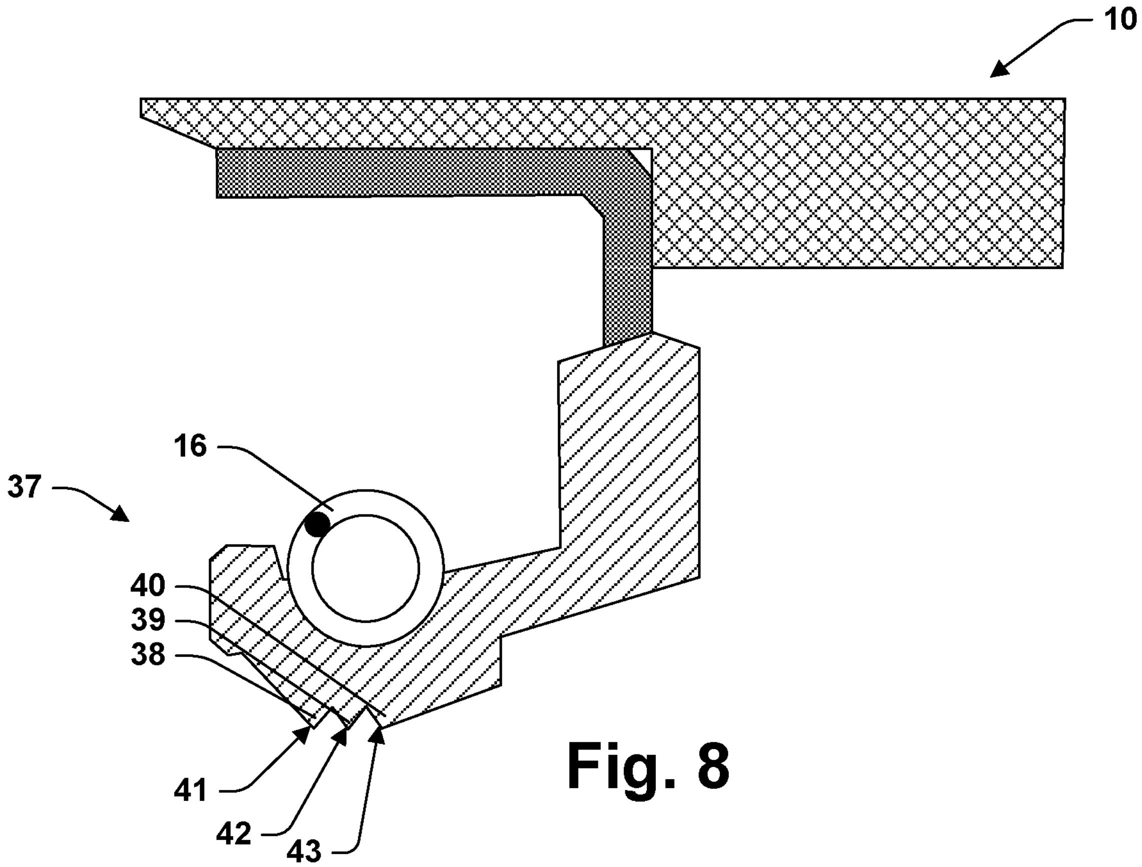

Fig. 8

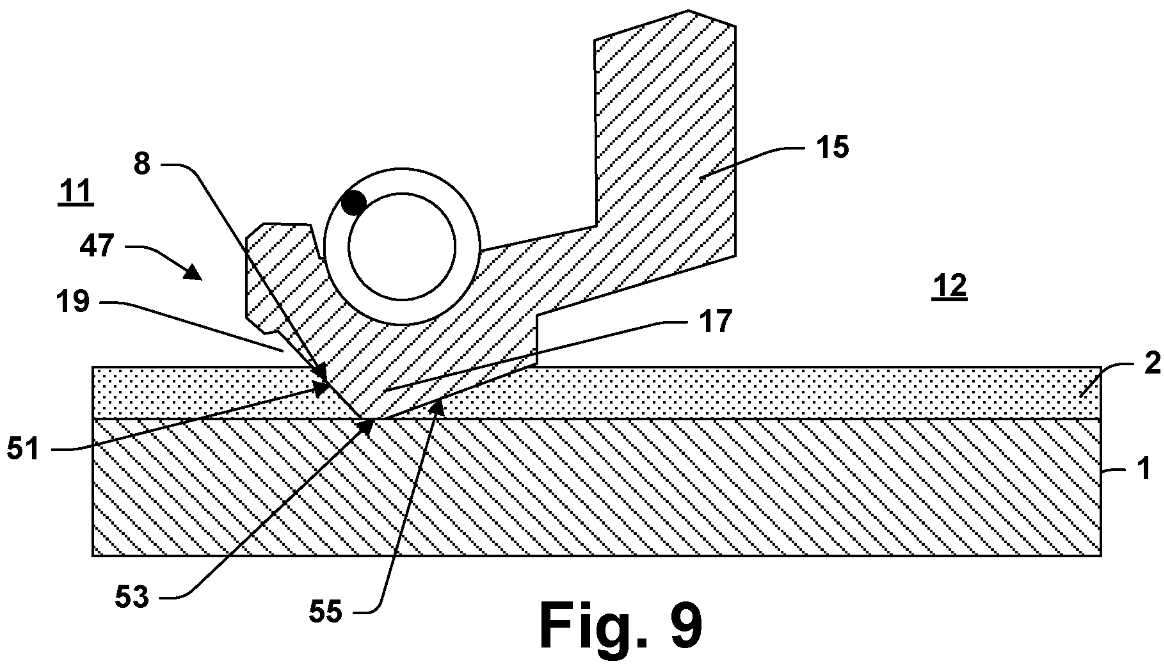

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/055108

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16J15/3212 F16J15/3224 F16J15/328 F16J15/3284 F16J15/54
ADD.

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)
F16J C09G C09D

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 practicable, 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	JP 2006 010019 A (NAT AEROSPACE LAB) 12 January 2006 (2006-01-12) paragraph [0009]; figures 1-3	1-3,5-16
A	US 9 534 119 B2 (SUMAN ANDREW W [US]) 3 January 2017 (2017-01-03) figures 1-3	1-16
A	JP 2000 018264 A (NIPPON SEIKO KK) 18 January 2000 (2000-01-18) figures 1,2,8	1-16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 January 2020	13/01/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kepka, Maciek

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2019/055108

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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