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(54) Title: TORQUE SENSING BEARING ARRANGEMENT

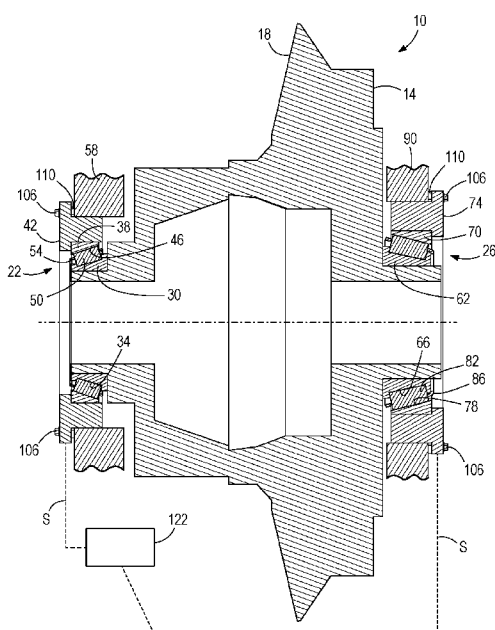


FIG. 1

(57) Abstract: A first bearing supports a shaft assembly with a loading element, and a first support structure is configured to support an outer ring of the first bearing, the first support structure including a plurality of sensor modules configured to produce signals responsive to forces and moments applied to the outer ring of the first bearing. A second adjustable bearing is spaced from the first adjustable bearing and supports the shaft assembly. A second support structure is configured to support an outer ring of the second bearing, the second support structure including a plurality of sensor modules configured to produce signals responsive to forces and moments applied to the outer ring of the second bearing. A processor is configured to receive signals generated by the sensor modules of both the first and second support structures and to output a signal indicative of a dimensional preload of the shaft assembly.

SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN,
GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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TORQUE SENSING BEARING ARRANGEMENT

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 63/338,591 filed May 5, 2022, the entire content of which is hereby incorporated by reference herein.

FIELD

[0002] The present disclosure relates to bearing arrangements, and more particularly to bearing arrangements for adjustable bearings.

BACKGROUND

[0003] Adjustable bearing assemblies, such as tapered roller bearings or angular contact bearings, are known. For tapered roller bearings, the correct and accurate bearing setting (i.e., preload or endplay) can be difficult to achieve using the current techniques.

SUMMARY

[0004] The present disclosure provides, in one aspect, a shaft assembly including a shaft supporting a loading element. A first adjustable bearing supports the shaft, the first adjustable bearing including an outer ring. A first support structure is configured to support the outer ring of the first adjustable bearing, the first support structure including a plurality of sensor modules disposed thereon and configured to produce signals responsive to forces and moments applied to the outer ring of the first adjustable bearing. A second adjustable bearing is spaced from the first adjustable bearing and supports the shaft, the second adjustable bearing including an outer ring. A second support structure is configured to support the outer ring of the second adjustable bearing, the second support structure including a plurality of sensor modules disposed thereon and configured to produce signals responsive to forces and moments applied to the outer ring of the second adjustable bearing. A processor is configured to receive signals generated by the sensor modules of both the first and second support structures and to output a signal indicative of a dimensional preload of the shaft assembly.

[0005] The present disclosure provides, in another aspect, a method of determining a dimensional preload of a shaft assembly. The method includes measuring a strain on a first adjustable bearing supporting a shaft of the shaft assembly, measuring a strain on a second adjustable bearing supporting the shaft of the shaft assembly, providing signals indicative of the strain on the first adjustable bearing and indicative of the strain on the second adjustable bearing to a processor, and using the processor, determining a dimensional preload of the shaft assembly based upon the signals indicative of the strain on the first adjustable bearing and the strain on the second adjustable bearing.

[0006] In yet a further aspect of the method, the method further includes measuring a temperature at the first adjustable bearing, measuring a temperature at the second adjustable bearing, providing signals indicative of the temperature at the first adjustable bearing and indicative of the temperature at the second adjustable bearing to a processor, and using the processor, determining a dimensional preload of the shaft assembly based upon the signals indicative of both the strain on and temperature at the first adjustable bearing, and both the strain on and temperature at the second adjustable bearing.

[0007] Other features and aspects of the invention will become apparent by consideration of the following detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is section view of a first bearing arrangement used with a vehicle differential.

[0009] FIG. 2 is a section view of another bearing arrangement used with an alternative shaft-supported gear arrangement.

[0010] FIG. 3 is a section view of another bearing arrangement used with yet another alternative shaft-supported gear arrangement.

[0011] FIG. 4 is an enlarged section view illustrating one of the bearing assemblies and cup carriers used in the arrangements of any one of FIGS. 1-3.

[0012] FIG. 5 is an end view of the bearing assembly and cup carrier of FIG. 4

[0013] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.

DETAILED DESCRIPTION

[0014] FIGS. 1-3 illustrate three examples in which a pair of tapered roller bearings are mounted in a direct mounting arrangement to support a shaft or shaft assembly. Tapered roller bearings are designed to take both radial and thrust loading. Under radial loads, a force is generated in the axial direction and must be counteracted. As such, a first tapered roller bearing is normally paired with and adjusted against a second tapered roller bearing. When, as shown in FIGS 1-3, a direct mounting arrangement is used, there are two tapered roller bearings supporting the shaft assembly, and the outer ring of each bearing is used to adjust the bearing's setting (i.e., preload or endplay). The outer ring of each bearing is typically mounted in an outer ring carrier, which can also be referred to as a cup carrier or quill.

[0015] FIG. 1 illustrates an example of a shaft assembly 10 for a differential application in a vehicle drivetrain. The shaft assembly 10 includes a shaft 14 that supports a loading element 18. As illustrated, the loading element 18 is a gear (schematically illustrated) through which loading is applied to the shaft 14. In other embodiments, the loading element 18 can be a sprocket or other structure designed to interact with other features (e.g., chains, belts, wheels, etc.) that provide loading to the shaft 14. The shaft 14 is supported on opposite sides of the loading element 18 by first and second adjustable bearings, which are illustrated as first and second tapered roller bearings 22 and 26 mounted in a direct mounting arrangement. Other embodiments for this or the other shaft arrangements shown in FIGS. 2 and 3 could include different adjustable bearings, such as angular contact ball bearings.

[0016] The first adjustable bearing 22 includes an inner ring or cone 30 mounted for rotation with the shaft 14 to define an inner raceway 34, and an outer ring or cup 38 supported in a first support structure or outer ring carrier 42. The outer ring 38 defines an outer raceway 46. A plurality of rolling elements in the form of tapered rollers 50 are supported for rotation on the inner and outer raceways 34, 46. A cage 54 is provided to maintain a predetermined spacing between the rollers 50. The outer ring carrier 42 is supported by a support structure or housing 58 (shown schematically) to remain stationary or fixed relative to the rotating shaft 14. The carrier 42 can be manipulated to adjust the positioning of the outer ring 38 relative to the inner ring 30, to thereby adjust the setting (i.e., preload/endplay) of the first adjustable bearing 22, as will be discussed further below.

[0017] The second adjustable bearing 26 is positioned on the opposite side of the loading element 18 from the first adjustable bearing 22. The second adjustable bearing 26 includes an inner ring or cone 62 mounted for rotation with the shaft 14 to define an inner raceway 66, and an outer ring or cup 70 supported in a second support structure or outer ring carrier 74. The outer ring 70 defines an outer raceway 78. A plurality of rolling elements in the form of tapered rollers 82 are supported for rotation on the inner and outer raceways 66, 78. A cage 86 is provided to maintain a predetermined spacing between the rollers 82. The outer ring carrier 74 is supported by a support structure or housing 90 (shown schematically) to remain stationary or fixed relative to the rotating shaft 14. The carrier 74 can be manipulated to adjust the positioning of the outer ring 70 relative to the inner ring 62, to thereby adjust the setting (i.e., preload/endplay) of the second adjustable bearing 26, as will be discussed further below.

[0018] FIG. 4 illustrates the first adjustable bearing 22 supported in the outer ring carrier 42. The carrier 42 includes an annular wall 94 that surrounds and radially supports the outer ring 38. A base surface 98 of the carrier 42 is adjacent to and radially within the annular wall 94 to abut and support an axial end surface 102 of the outer ring 38. The carrier 42 cannot abut or engage the inner ring 30, and therefore is moveable relative to the inner ring 30. As such, axial movement of the carrier 42 relative to the inner ring 30 causes axial movement of the outer ring 38 relative to the inner ring 30, thereby effecting adjustment of the setting of the first adjustable bearing 22. The carrier 42 includes a plurality of mounting holes 102 located circumferentially about the carrier 42. Mounting fasteners or bolts 106 (see FIG. 1) extend through the mounting

holes 102 and into the housing 58. Shims or spacers 110 (see FIG. 1) are selectively used between the carrier 42 and the housing 58, as is understood, to adjust the axial position of the carrier 42 relative to the housing 58, and therefore, relative to the inner ring 30. In this manner, the setting of the first adjustable bearing 22 can be adjusted as desired. The carrier 74 of the second adjustable bearing 26 includes similar structure, supports the outer ring 70 in the same manner, and is mounted to the housing 90 in the same manner described above with respect to the carrier 42 of the first adjustable bearing 22. The first and second carriers 42 and 74 can be identical to one another when the first and second adjustable bearings 22, 26 are the same, or can be sized differently from one another when the first and second adjustable bearings 22, 26 are different sizes/geometries. However, the structure and functionality of the two carriers 42, 74 is generally the same. As such, only the carrier 42 is shown and described herein in detail.

[0019] FIG. 5 illustrates an end view of the carrier 42 from the side opposite the installed first adjustable bearing 22. As illustrated in FIG. 5, a plurality of sensor modules 114 are circumferentially spaced about the carrier 42. In the illustrated embodiment, the sensor modules 114 are positioned on an axially-facing rear surface 118 of the carrier 42 that faces opposite to a direction of axial extension of the annular wall 94. In other words, if the first bearing assembly 22 is supported within the annular wall 94 on a front side of the carrier 42, the sensor modules 114 are positioned on a rear side of the carrier 42. The specific positioning of the sensor modules 114 can be adjusted as desired based on the particular shaft assembly application, taking into account both forward and reverse direction operation. Specifically, application testing and/or finite element analysis can be used to determine the optimum directional orientation and positioning of the sensor modules 114. Furthermore, while the illustrated embodiment includes three sensor modules 114, fewer or more can be used.

[0020] The sensor modules 114 include transducer-based sensors configured to measure the strain on the first adjustable bearing 22 based on reaction loads. Axial loads, radial loads, and bending moments caused by the loading of the bearing 22 within the housing 58 create reaction loads on the bearing 22, which result in strain at the outer ring 38 that can be measured at the carrier 42 by the sensor modules 114. The sensor modules 114 can utilize full, half, or quarter bridge arrangements, or alternatively a strain and thermo-compensator combination. The sensor modules 114 can also measure temperature, or separate temperature sensors can be used.

By measuring the strain, temperature, and motion at the carrier 42, many calculations can be performed. Likewise, as noted above, the carrier 74 is generally the same and also includes a plurality of sensor modules 114 capable of making the same measurements for the second adjustable bearing 26. The sensor modules 114 of each of the carriers 42, 74 output respective signals S responsive to forces and moments applied to the respective outer ring 38, 70, and indicative of strain and accounting for temperature in the respective first and second adjustable bearings 22, 26. The sensor modules 114 can be wired or wireless. The output signals S from the carriers 42, 74 can be conditioned using known techniques, including amplifiers, data acquisition/converter devices, and the like. The output signals S from both carriers 42 and 74 are sent to a processor 122 (see FIG. 1) that converts the strain and temperature data to torque and/or loading information using correlations from actual physical testing or from analytical testing used to create, for example, microstrain vs torque fit modeling. Modeling or testing data can then be used to correlate the observed torque/load readings to the preload or setting of the bearings 22, 26. The output from the processor 122 is a determination of the overall system setting or preload, deemed the “dimensional setting” or the “dimensional preload,” and is a unit length value such as 0.004 inches or 0.001 inches. With this information, adjustments to the settings of both bearings can be made to optimize the system performance. As will be discussed further below, the readings can be taken during assembly/installation, as well as during operation of the shaft assembly 10. The sensor modules 114 need only be powered on so that the signals S can be sent to the processor 122, which can then perform the analysis to output the dimensional preload.

[0021] The dimensional preload of the shaft assembly 10 is a system variable dependent upon both of the first and second bearings 22, 26. Using the combined strain/torque data obtained from both bearings 22, 26, the dimensional preload of the entire shaft assembly 10 can be determined. The settings of each bearing 22, 26 can be optimized to achieve prolonged bearing life, improved efficiency, and reduced heat generation. The data can assist in understanding axle response to the loading, gear efficiencies, and bearing misalignment and deflection. Understanding the operational bearing loads can help manage powertrain systems and provide protection against over-torque events. Monitoring for predictive or proactive maintenance and gear performance is another functionality achievable with the above system. In

some embodiments, the processor 122 may communicate warnings and predictive maintenance suggestions to the operator via the vehicle's various communication systems. In further embodiments, the collected data can be stored and used in post-damage analysis to assist with warranty and diagnosis issues. For example, after a damage or failure situation, the data could be reviewed to determine if the system experienced a spike in strain or torque (indicative of an impact event or over-torque event) prior to the damage/failure. The processor 122 or another memory/storage device can store the collected data for a predetermined period of time to assist with such diagnostic functions.

[0022] The dimensional preload of the shaft assembly 10 can be monitored and utilized in two important situations relative to the life of the shaft assembly 10. The first situation takes place during the initial assembly and/or installation of the bearings 22, 26. The output in this situation can be referred to as the “mounted dimensional preload,” which does not account for temperature effects or external loading effects. Therefore, the mounted dimensional preload is the tolerance stack-up of the system (e.g., housing widths and tolerance, shaft 14 and spacer 110 widths and tolerance, outer ring and inner ring widths and tolerance), known in industry as the inner and outer ring stand. The mounted dimensional preload also takes into account the interference fitting effects of the inner and outer rings. In this situation, the mounted dimensional preload may be determined on the assembly line during production and/or during installation. The sensor modules 114 can be powered on to output the signals S to a processor 122, which may be a dedicated processor 122 used on the assembly line or during installation (as opposed to a processor associated with the final shaft assembly application). The mounted dimensional preload is the system preload at a static state, with no rotation of the shaft and no external loading. The mounted dimensional preload can be used to determine whether the appropriate spacers 110 have been used to achieve the desired mounted dimensional preload. If not, the spacers 110 can be changed. In other embodiments in which preload adjustment to the bearings 22, 26 is made by varying the torque on a fastener, the mounted dimensional preload can assist with obtaining the appropriate adjustments. This ease of adjustment based on having the mounted dimensional preload value, can allow for tolerance expansion (i.e., relaxing the design tolerances) in the bearing, shaft, and housing components, which can reduce the overall

cost of the parts. The mounted dimensional preload can be set based on the expected operating conditions for the particular shaft assembly 10.

[0023] The second situation takes place during operation of the shaft assembly 10, i.e., during shaft rotation and external loading. The output in this situation can be referred to as the “operational dimensional preload.” In this situation, the output accounts for temperature effects and the applied loading to the system. The temperature effects include growth or shrinkage of the shaft, housings, and bearing rings resulting from temperature changes or differences in the system. Loading effects impact the operational dimensional preload based on axial and radial loadings in the system and could cause one bearing to have more or less preload than the other bearing in the system. During operation, the sensor modules 114 can be powered on to output the signals S to a processor 122, which may be a processor 122 associated with the vehicle (e.g., the ECU) or the particular shaft assembly application. The operational dimensional preload is the system preload at a dynamic state, during rotation of the shaft and under operational external loading. This real-time operational data is useful in showing the actual operational dimensional preload experienced by the shaft assembly 10, and can be more accurate than theoretical modeling used conventionally to estimate the system preload during operation. The output can be monitored continuously or intermittently, as desired, and depending on desired data collection. This data can be used to specify the mounted dimensional preload value for systems being built for the same end use, as there is now actual operational data for that end use. Collecting this operational dimensional preload data is useful to better design and build for the specific application loading and environment.

[0024] The operational dimensional preload output can also account for the direction of rotation of the shaft 14. In certain embodiments, the processor 122 also receives a signal indicative of the direction of rotation of the shaft 14. The signal can be provided by the vehicle’s ECU, or by a controller associated with driving the shaft in other, non-vehicular applications. In yet other embodiments, the directional signal can be provided by the sensor modules 114 if capable of determining shaft direction based on the collected strain data. For example, where the loading element 18 is a helical gear, it is possible to determine the direction of rotation of the shaft 14 based upon the strain data collected by the sensor modules 114. In yet other embodiments, a separate directional sensor could provide the shaft directional rotation signal to

the processor 122. The directional signal can be used in conjunction with the other signals S from the bearings 22, 26 to determine the operational dimensional preload.

[0025] FIG. 2 illustrates an alternative shaft assembly 10' on which the above invention can be practiced. Like parts have been given like reference numerals designated as prime ('). This shaft assembly 10' is illustrative of transmission, gear box, transfer shaft, input shaft or output shaft applications.

[0026] FIG. 3 illustrates another alternative shaft assembly 10'' on which the above invention can be practiced. Like parts have been given like reference numerals designated as double prime ("). This shaft assembly 10'' is illustrative of a situation known as overhung loading, which is common with output shaft belt and chain drive, and power take-off unit applications. Note how both bearings 22'', 26'' are on the same side of the loading element 18''.

[0027] Although the invention has been described in detail with reference to certain preferred embodiments, variations and modifications exist within the scope and spirit of one or more independent aspects of the invention as described. Various aspects of the disclosure are set forth in the following claims.

CLAIMS

1. A shaft assembly comprising:
 - a shaft supporting a loading element;
 - a first adjustable bearing supporting the shaft, the first adjustable bearing including an outer ring;
 - a first support structure configured to support the outer ring of the first adjustable bearing, the first support structure including a plurality of sensor modules disposed thereon and configured to produce signals responsive to forces and moments applied to the outer ring of the first adjustable bearing;
 - a second adjustable bearing spaced from the first adjustable bearing and supporting the shaft, the second adjustable bearing including an outer ring;
 - a second support structure configured to support the outer ring of the second adjustable bearing, the second support structure including a plurality of sensor modules disposed thereon and configured to produce signals responsive to forces and moments applied to the outer ring of the second adjustable bearing; and
 - a processor configured to receive signals generated by the sensor modules of both the first and second support structures and to output a signal indicative of a dimensional preload of the shaft assembly.
2. The shaft assembly of claim 1, wherein the loading element is located between the first and second adjustable bearings.
3. The shaft assembly of claim 1, wherein the first and second adjustable bearings are both located to one side of the loading element.
4. The shaft assembly of claim 1, wherein the first support structure is an outer ring carrier having an annular wall and a base surface that support the outer ring of the first adjustable bearing on a first side of the outer ring carrier, and wherein the plurality of sensor modules are disposed on a second side of the outer ring carrier.

5. The shaft assembly of claim 1, further comprising a housing, the first support structure coupled to the housing in an adjustable manner via fasteners.
6. The shaft assembly of claim 5, further comprising one or more spacers positioned between the housing and the first support structure.
7. The shaft assembly of claim 1, wherein the loading element includes a gear that is part of a vehicle differential.
8. The shaft assembly of claim 7, wherein the processor is a vehicle ECU or another processor on the vehicle that communicates with the vehicle ECU.
9. The shaft assembly of claim 1, wherein the signal output by the processor is a unit length.
10. The shaft assembly of claim 1, wherein the first and second adjustable bearings are both tapered roller bearings.
11. The shaft assembly of claim 1, wherein the shaft assembly is part of a transmission, gear box, transfer shaft, input shaft or output shaft.
12. The shaft assembly of claim 3, wherein the shaft assembly is part of an output shaft belt and chain drive, or a power take-off unit.

13. A method of determining a dimensional preload of a shaft assembly, the method comprising:
- measuring a strain on a first adjustable bearing supporting a shaft of the shaft assembly;
 - measuring a strain on a second adjustable bearing supporting the shaft of the shaft assembly;
 - providing signals indicative of the strain on the first adjustable bearing and indicative of the strain on the second adjustable bearing to a processor; and
 - using the processor, determining a dimensional preload of the shaft assembly based upon the signals indicative of the strain on the first adjustable bearing and the strain on the second adjustable bearing.
14. The method of claim 13, wherein the dimensional preload is determined during assembly and/or installation of the shaft assembly.
15. The method of claim 14, further comprising adjusting a preload of the first and/or second adjustable bearings based on the determined dimensional preload.
16. The method of claim 15, wherein adjusting the preload includes changing a spacer between the shaft assembly and a housing.
17. The method of claim 13, further including:
- measuring a temperature at the first adjustable bearing;
 - measuring a temperature at the second adjustable bearing;
 - providing signals indicative of the temperature at the first adjustable bearing and indicative of the temperature at the second adjustable bearing to the processor; and
 - using the processor, determining a dimensional preload of the shaft assembly based upon the signals indicative of both the strain on and temperature at the first adjustable bearing, and both the strain on and temperature at the second adjustable bearing.
18. The method of claim 17, wherein the dimensional preload is determined during operation of the shaft assembly in which the shaft assembly is rotating and externally loaded.

19. The method of claim 15, further including:
providing a signal indicative of a direction of rotation of the shaft of the shaft assembly;
and
using the processor, determining a dimensional preload of the shaft assembly based upon the signal indicative of the direction of rotation of the shaft assembly as well as the signals indicative of both the strain on and temperature at the first adjustable bearing, and both the strain on and temperature at the second adjustable bearing.
20. The method of claim 19, wherein the dimensional preload is determined during operation of the shaft assembly in which the shaft assembly is rotating and externally loaded.

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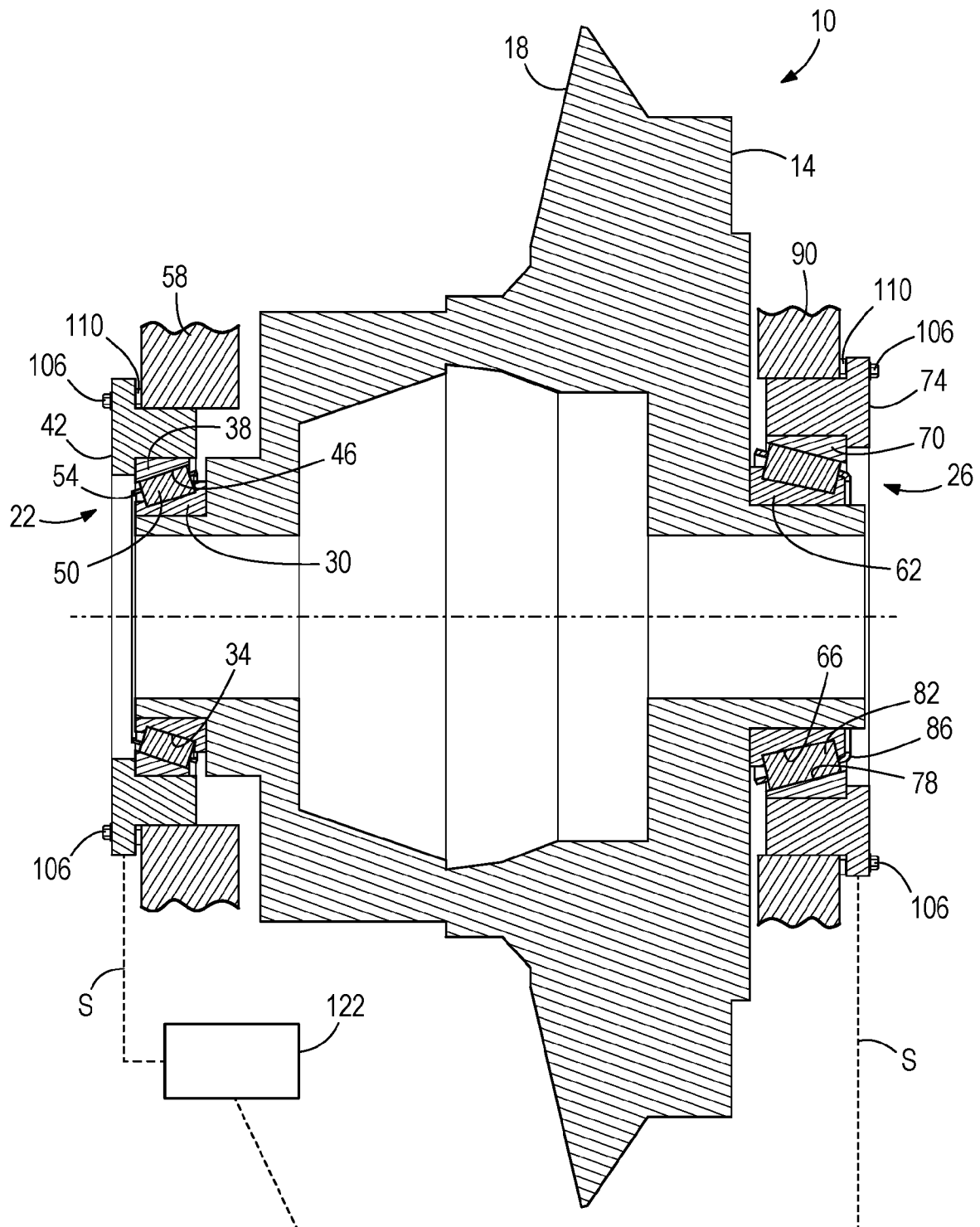
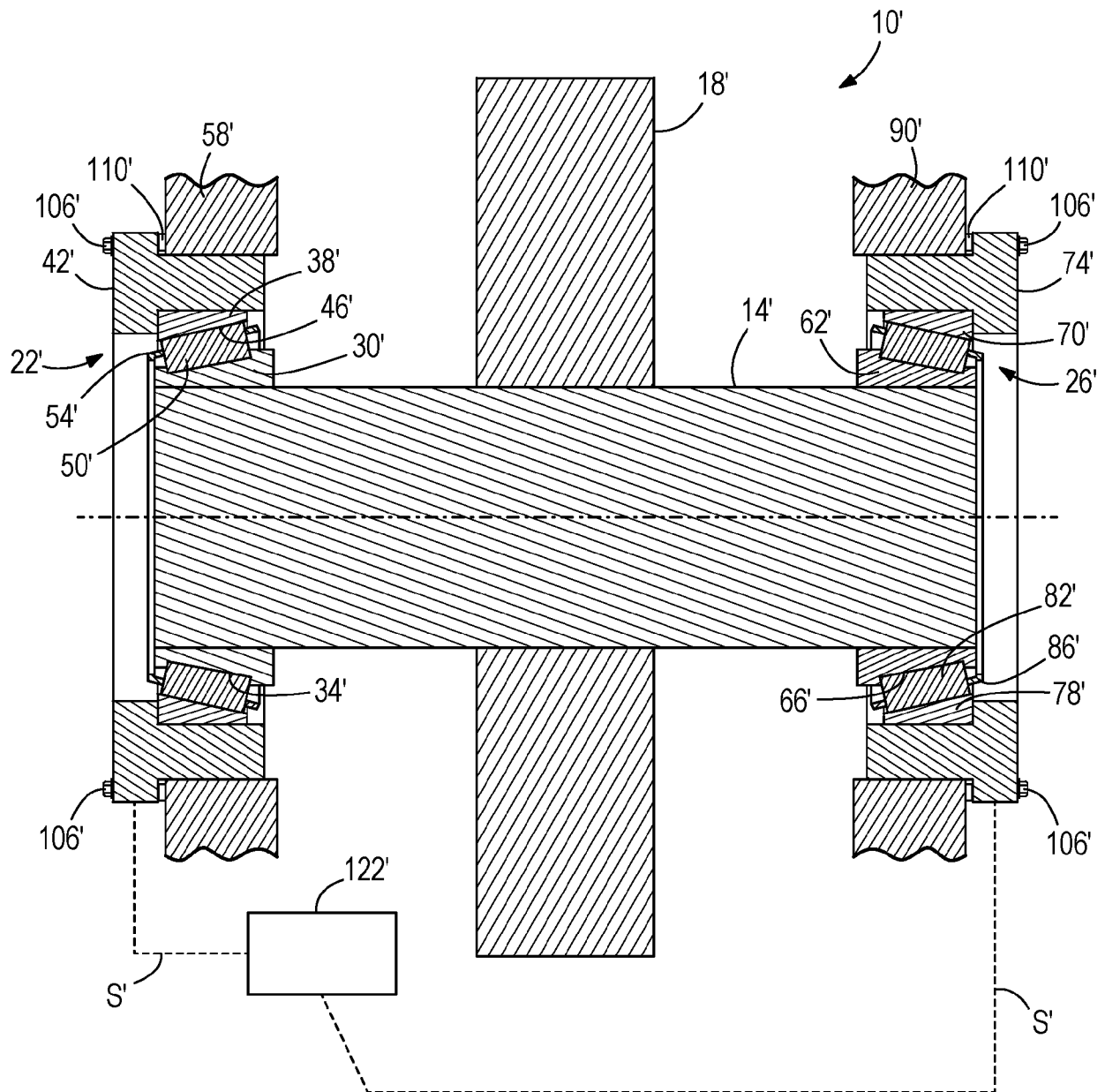


FIG. 1

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**FIG. 2**

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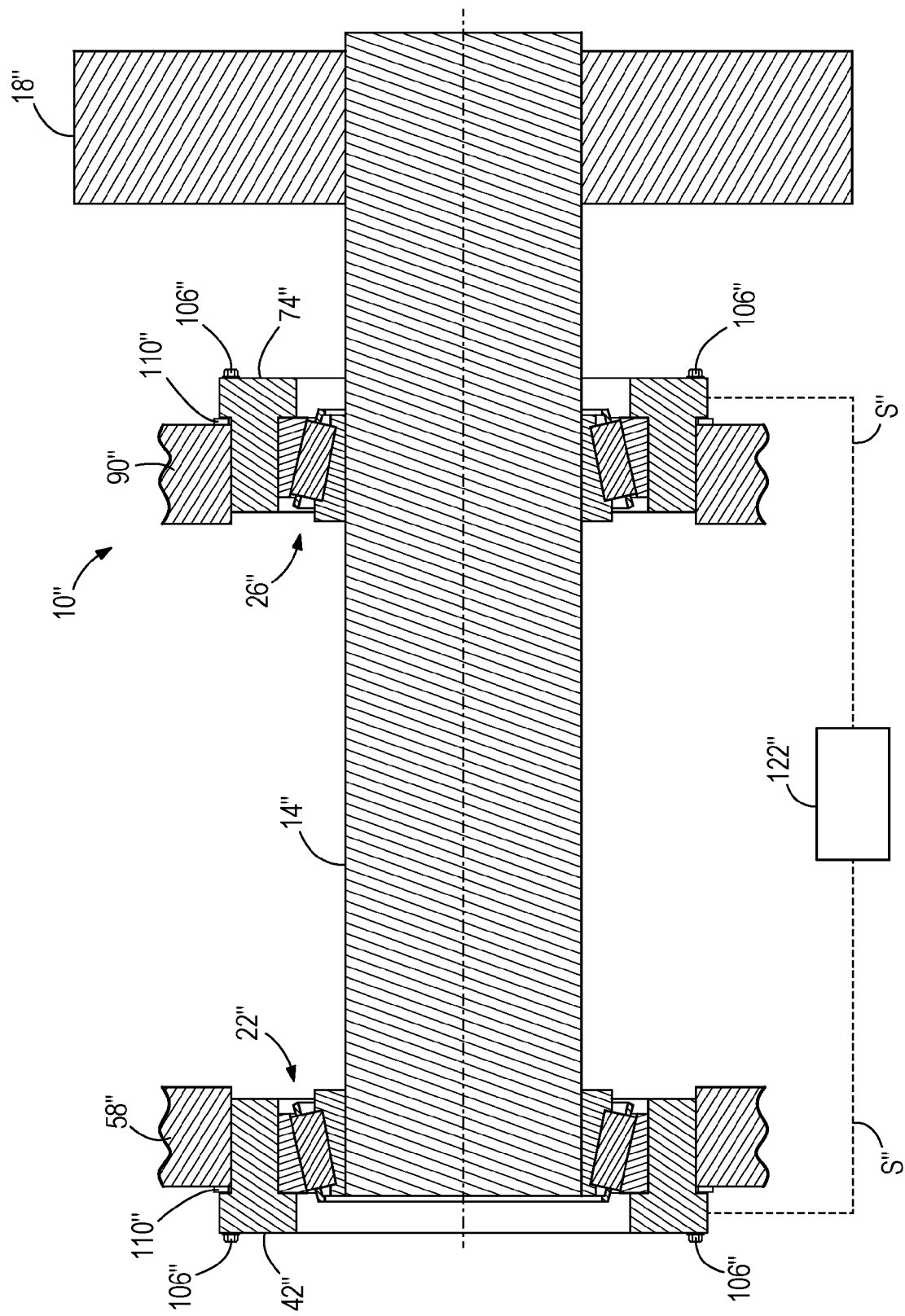


FIG. 3

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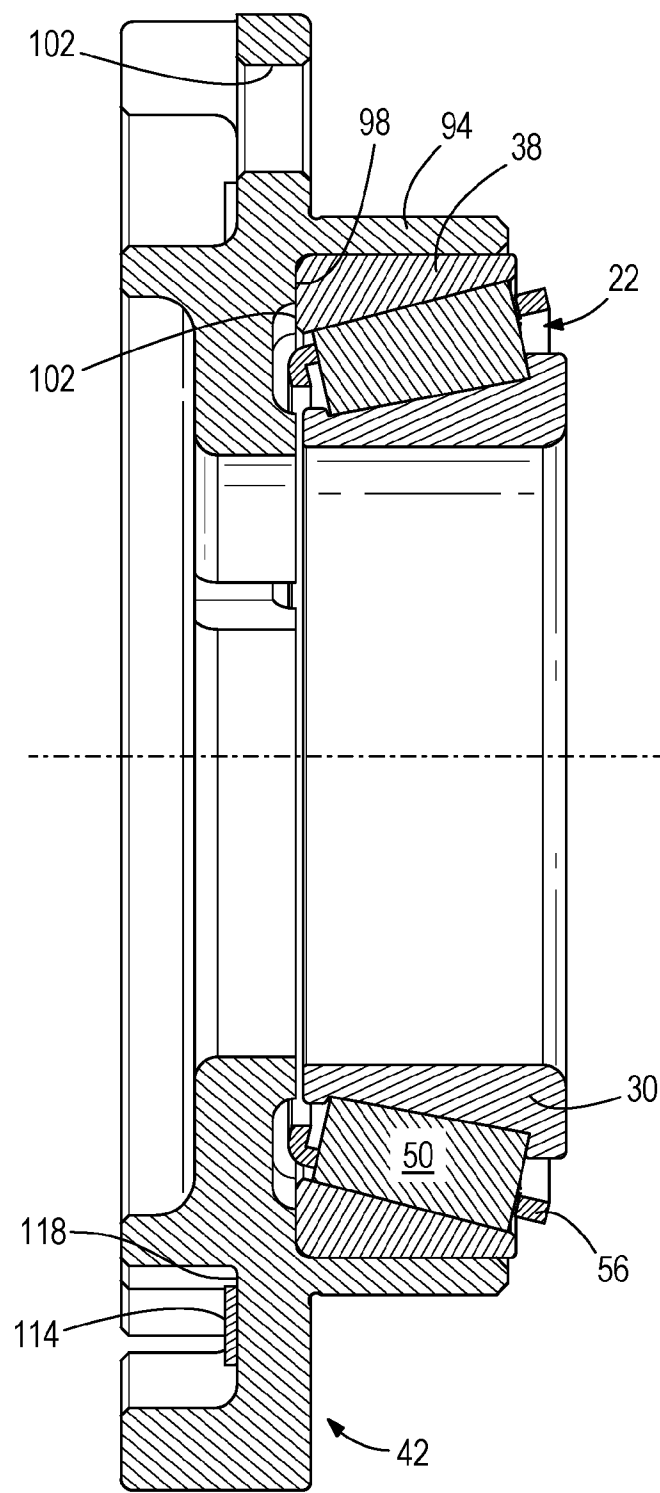


FIG. 4

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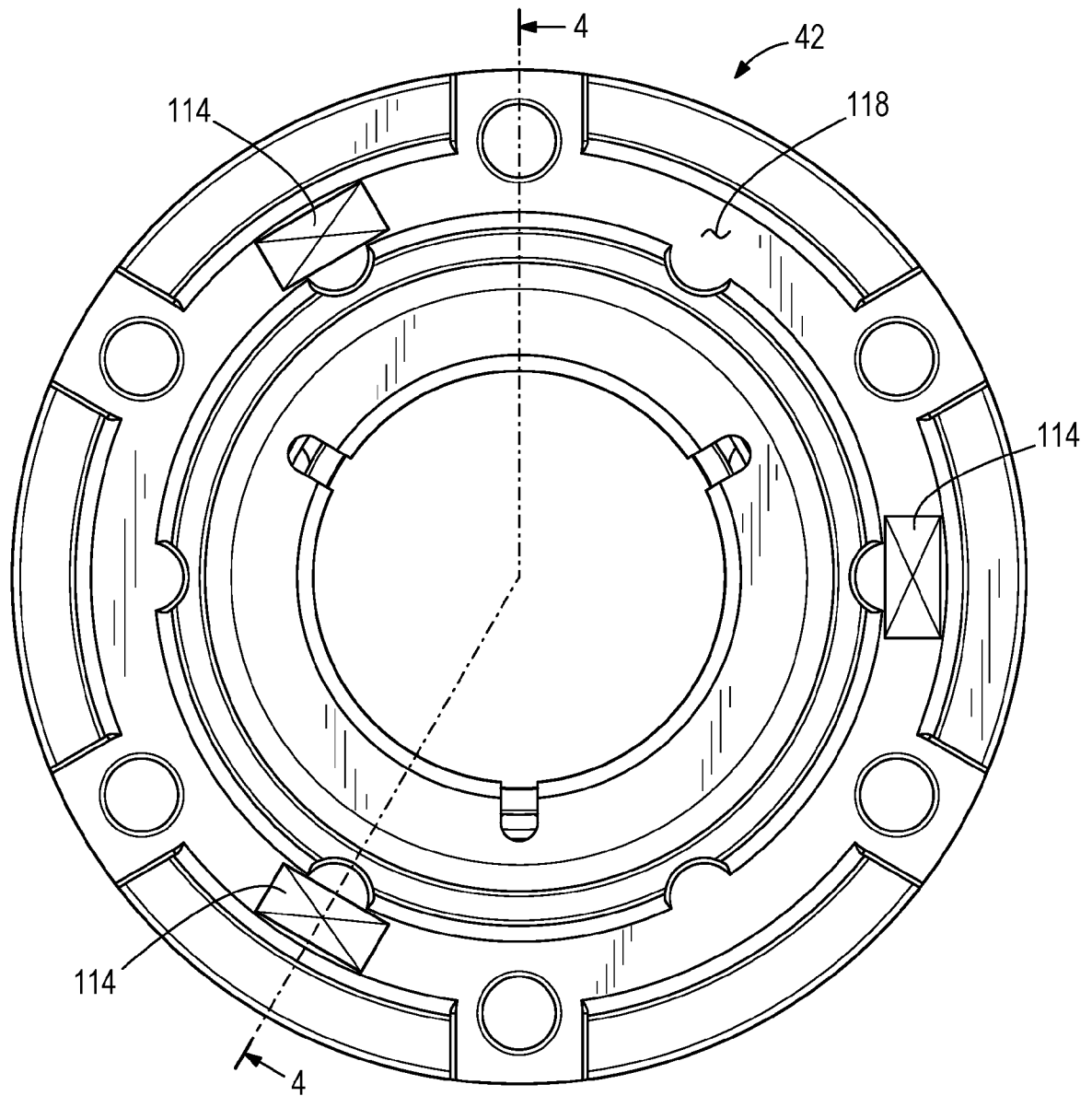


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No

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A. CLASSIFICATION OF SUBJECT MATTER

INV. F16C19/16 F16C19/36 F16C19/54
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)

F16C

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	WO 2014/031905 A1 (AMBER KINETICS INC [US]) 27 February 2014 (2014-02-27)	1, 2, 5-9, 11-16, 19, 20
Y	paragraph [0069] - paragraph [0071]; figures 1, 6, 7 -----	17, 18
X	DE 10 2015 201172 A1 (SKF AB [SE]) 28 July 2016 (2016-07-28)	1, 3-12, 14-16, 19, 20
Y	paragraph [0045]; figure 1 paragraph [0047] - paragraph [0048] -----	17, 18
X	WO 2022/025076 A1 (MINEBEA MITSUMI INC [JP]) 3 February 2022 (2022-02-03)	1, 5-9, 11-16, 19, 20
Y	paragraph [0127]; figure 20 -----	17, 18



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

28 July 2023

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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