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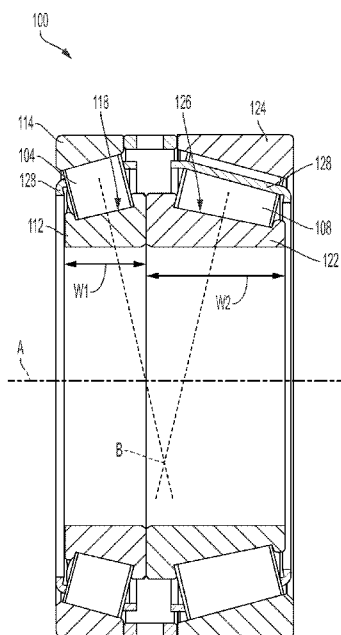


FIG. 2

(57) Abstract: A multi-row tapered roller bearing assembly for a wind turbine gearbox includes first and second axially adjacent inner bearing races including respective raceway surface that are oppositely skewed with respect to a central rotation axis of the bearing assembly. Also provided are first and second axially adjacent outer bearing races, and respective first and second sets of tapered rolling elements supported for rolling between the respective inner and outer bearing races. Less than all the bearing races are constructed of a stainless steel.



## BEARING ASSEMBLY WITH STAINLESS STEEL RACE

### RELATED APPLICATIONS

**[0001]** This application claims the benefit of U.S. Provisional Patent Application No. 63/053,330 filed July 17, 2020, the entire content of which is hereby incorporated by reference herein.

### BACKGROUND

**[0002]** The present invention relates to bearings, and more specifically to rolling element bearings in which multiple rows of rolling elements are provided, along with separate, axially-adjacent races.

### SUMMARY

**[0003]** In one aspect, the invention provides a multi-row tapered roller bearing assembly for a wind turbine gearbox, the bearing assembly including first and second axially adjacent inner bearing races including respective raceway surfaces that are oppositely skewed with respect to a central rotation axis of the bearing assembly. Also provided are first and second axially adjacent outer bearing races, and respective first and second sets of tapered rolling elements supported for rolling between the respective inner and outer bearing races. The second inner bearing race is wider than the first inner bearing race, and the second inner bearing race is constructed of a stainless steel, while the remaining bearing components of the assembly are not.

**[0004]** In another aspect, the invention provides a multi-row tapered roller bearing assembly for a wind turbine gearbox, the bearing assembly including first and second axially adjacent inner bearing races including respective raceway surfaces that are oppositely skewed with respect to a central rotation axis of the bearing assembly. Also provided are first and second axially adjacent outer bearing races, and respective first and second sets of tapered rolling elements supported for rolling between the respective inner and outer bearing races. One of the inner bearing races and one of the outer races are constructed of a stainless steel, and the remaining bearing components of the assembly are made of steel that has a chromium content of less than 2 wt. %.

[0005] In another aspect, the invention provides a multi-row tapered roller bearing assembly for a wind turbine gearbox, the bearing assembly including first and second axially adjacent inner bearing races including respective raceway surfaces that are oppositely skewed with respect to a central rotation axis of the bearing assembly. Also provided are first and second axially adjacent outer bearing races, and respective first and second sets of tapered rolling elements supported for rolling between the respective inner and outer bearing races. The first and second inner bearing races are constructed of a stainless steel, and the remaining bearing components of the assembly are made of steel that has a chromium content of less than 2 wt. %.

[0006] Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Fig. 1 is a sectional view of a multi-stage gearbox for a wind turbine, including several shafts supported for rotation by bearings.

[0008] Fig. 2 is a sectional view of a bearing assembly according to one embodiment of the present disclosure for use in the gearbox as shown in Fig. 1.

[0009] Fig. 3 illustrates exemplary results of laboratory testing of bearings under white etching crack damage mode.

#### DETAILED DESCRIPTION

[0010] 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.

[0011] Fig. 1 illustrates a multi-stage gearbox 20 of a geared wind turbine, including a low-speed planetary stage 24 provided between a rotor shaft 26A and a low-speed shaft 26B, and two parallel stages: an intermediate-speed shaft 28 driven by an output portion or shaft of the planetary stage 24 to run at an increased speed compared to the slow-speed shaft, and a high-speed shaft 32 driven by the intermediate-speed shaft 28 to run at yet a higher speed

still. The high-speed shaft 32 is utilized directly or indirectly as the input to the electrical power generator 30 of the wind turbine and may rotate at over 1000 RPM, e.g., between 1500 and 1800 RPM. The various shafts of the gearbox 20 are coupled for rotation through respective gear tooth portions as shown in Fig. 1. Numerous bearings 36A to 36E support rotation of the low-speed planetary stage 24 of the gearbox 20. Likewise, the intermediate-speed shaft 28 is supported for rotation by at least front and rear bearings 40A, 40B, and the high-speed shaft 32 is supported for rotation by at least front and rear bearings 44A, 44B. As illustrated, each of the bearings 36E, 40B, 44B at the rear end is in fact a bearing pair or multi-row tapered rolling element bearing assembly in which two axially spaced sets of tapered rolling elements are provided, oppositely angled from one another.

**[0012]** Although relatively successful in the field, long-term reliability remains a significant industry concern. Turbine gearboxes may be capable of lasting 20 years or more with proper inspection and maintenance, but significant percentages of these gearboxes may fail well short of 20 years of service life, and moreover, it is often impossible to predict with accuracy when a gearbox will fail, even given good data on which to perform statistical analysis. A combination of high speeds, stresses and strains, vibration, foreign matter, additives or moisture contained in the lubrication oil can all contribute to component failure through material degradation within the gears and/or bearings of the gearbox 20. One significant failure mode is known as white etching cracks, which can damage the raceways of one or more turbine gearbox bearings and cause premature bearing failures. These bearing failures interrupt the wind turbine operation and replacing fresh bearings is needed to resume the turbine operation. White etching cracks refer to subsurface crack networks that form within the microstructure of bearing steel and eventually propagate to the surface to cause raceway surface spalling and bearing damage or failure. White etching cracks are known to damage the bearings within 10% of their designed lives. White etching cracks get their name from the white appearance of the microstructure of a polished, etched sample when viewed under a microscope. While the white etching crack problem is well documented and understood within the art, complete determination of the root causes and damage mechanisms are still under exploration. Due to their massive size and associated complexity, replacing the damaged bearings top of the wind tower cause very high maintenance costs. In addition, productive time of the wind turbines is shortened.

**[0013]** Solutions to prevent white etching cracks are of high importance to expand the wind turbine power capacities. It was found that bearing races made of stainless steels prevent the white etching cracks and offer very long bearing lives. This is proven through laboratory testing of bearings under white etching crack damage mode. These results are shown in Fig. 3.

**[0014]** Fig. 2 illustrates a bearing assembly 100 for installation in the position of one of the bearings 40B, 44B of Fig. 1, particularly the rear bearing position on the intermediate-speed shaft 28 or the rear bearing position on the high-speed shaft 32. The terms front and rear refer to the positioning within the gearbox 20 where the rotor shaft 26A is at the front end and the generator 30 is toward the rear. The bearings at these positions are subject to both high loads and high speeds and have been identified as having higher susceptibility to white etching cracks. The bearing assembly 100 is a pair of tapered rolling element bearings placed one opposite to the other and having axially-spaced first and second rows of tapered rolling elements 104, 108. As seen in the drawing and discussed further below, the two rows of rolling elements 104, 108 are of different sizes such that the bearing assembly 100 is asymmetrical. On the left side of Fig. 2, the first row of tapered rolling elements 104 are held captive between radially inner and outer rings or races 112, 114 that define the respective raceway surfaces along which the rolling elements 104 roll. The conical raceway surface 118 of the inner race 112 is labeled for reference. On the right side of Fig. 2, the second row of tapered rolling elements 108 are held captive between radially inner and outer rings or races 122, 124 that define the respective raceway surfaces along which the second (larger) set of rolling elements 108 roll. The conical raceway surface 126 of the inner race 122 is labeled for reference. Respective rolling element separators, or “cages,” 128 are provided amongst the rolling elements 104, 108 on each side of the bearing assembly 100. The two inner races 112, 122 are directly axially adjacent and opposite to each other, and in some constructions, both have identically sized inner cylindrical surfaces for receiving the appropriate gearbox shaft. In some other constructions, the two adjacent inner races 112, 122 are fixed on the shaft opposite to each other and may be separated by a distance.

**[0015]** Although the bearing assembly 100 bears the shaft loads and supports shaft rotation about a central axis A, the tapered nature of the rolling elements 104, 108 means that the inner ring raceway surfaces 118, 126 are not oriented parallel to the central axis A, but rather are angled or skewed in relation thereto. On one side of the bearing cross-section

(sectioned along a plane in which the axis A lies), reference lines are provided perpendicular to the two inner ring raceway surfaces 118, 126. The reference lines are angled in opposite directions, and in some constructions are provided at opposite but equal angles with respect to the central axis A. The bearing assembly 100 is constructed such that the two reference lines intersect (at point B) when extended to the radially inner side of the bearing cross-section. In other constructions, the taper angles of the two rows of rolling elements 104, 108 can be reversed such that two similar reference lines intersect when extended to the radially outer side of the bearing cross-section.

**[0016]** Each tapered rolling element 104, 108 is constructed as a truncated cone or, in other words, a modified cylinder with one end circle larger than the other. Although not cylindrical, each rolling element 104, 108 defines a central or longitudinal axis extending between the two end circles. An axial length of the rolling elements 108 on the right of Fig. 2 exceeds an axial length of the rolling elements 104 on the left of Fig. 2. The maximum diameter of the rolling elements 108 can, in some constructions, exceed a maximum diameter of the rolling elements 104, although alternate relationships may be provided in other constructions. The larger axial length of the set of rolling elements 108 leads to an extended width W2 (distance as measured along the central axis A) of the corresponding inner race 122 as compared to the similarly measured width W1 of the inner race 112 supporting the rolling elements 104. In some constructions the greater axial width W2 is at least 1.1 times the lesser axial width W1 (or for example at least 1.5 times W1). It can also be expressed that the total surface area of the raceway surface 126 exceeds the total surface area of the raceway surface 118. In some constructions such as that illustrated, the two inner bearing races 112, 122 can have maximum radial thicknesses (measured at an end flange outside the raceway surface 118, 126) that are equal. Although not illustrated, the inner races 112, 122 can be of equal width in another construction ( $W1 = W2$ ) that otherwise conforms the description herein. In a construction with equal inner race widths W1, W2, the overall bearing assembly may be symmetrical about a central bisector plane.

**[0017]** The material construction of the bearing assembly 100 may be unique in that the inner race 122 of the larger portion can be constructed of stainless steel with chromium content of 5 wt. % or more, or 10 wt. % or more. For example, the inner race 122 can be AISI 440C stainless steel having chromium content of 16 to 18 wt. %, e.g., X108CrMo17, X47Cr14, X65Cr14, X40CrMoVN16, or X89CrMoV18 grade steels. In some constructions,

the inner race 122 can be the only component of the bearing assembly 100 constructed of this material. The material of the inner race 122 can have a hardness of at least 55 HRC to a minimum depth of 0.5 mm. The material of the inner race 122 can be surface treated to enrich the steel surface with one or more of nitrogen, carbon, phosphorous, and oxygen (e.g., nitriding, carburizing, carbonitriding, phosphating, black oxidation). The rolling elements 104, 108 and the remaining three bearing races 112, 114, 124 can be constructed of one or more types of non-stainless bearing steel (e.g., 52100 or other steel grades which typically have the chromium content of less than 3 wt. %, or in some constructions less than 2 wt. %). The material of the rolling elements 104, 108 and the remaining three bearing races 112, 114, 124 can have a hardness of at least 55 HRC to a minimum depth of 0.5 mm. In some constructions, the use of ceramic material for the rolling elements 104, 108 with one or more high-chromium stainless steel (e.g., chromium content of 5 wt. % or more, or 10 wt. % or more) races can also be used in combination to dramatically reduce the occurrence of white etching cracks. In some other possible constructions similar to the bearing assembly 100, one inner race (e.g., 112 or 122) and one outer race (e.g., 114 or 124) is made of stainless steel and the remaining components are made of non-stainless steel.

**[0018]** In spite of the fact that the bearing assembly 100 has non-uniform material construction among the races 112, 114, 122, 124, the bearing assembly 100 as a whole is rendered largely impervious to early life failure through white etching cracks. The stainless steel of the large inner race 122 is immune to the white etching crack damage due to its  $\text{Cr}_2\text{O}_3$  surface passivation layers. The placement and loading conditions of the remaining bearing components may be fundamentally less susceptible to white etching cracks, and thus additional cost associated with the use of stainless steel may be avoided. In other constructions, stainless steel (e.g., the same as or similar to that of the large inner race 122 – see description above) may be used for the two inner races 112, 122 of the bearing assembly 100, while remaining components in the bearing assembly are made of non-stainless steel.

## CLAIMS

What is claimed is:

1. A multi-row tapered roller bearing assembly for a wind turbine gearbox, the bearing assembly comprising:

first and second axially adjacent inner bearing races including respective raceway surfaces that are oppositely skewed with respect to a central rotation axis of the bearing assembly;

first and second axially adjacent outer bearing races;

a first set of tapered rolling elements supported for rolling between the first inner bearing race and the first outer bearing race; and

a second set of tapered rolling elements supported for rolling between the second inner bearing race and the second outer bearing race,

wherein the second inner bearing race has a width measured along the central rotation axis that is larger than a width measured along the central rotation axis of the first inner bearing race, and wherein the second inner bearing race is constructed of a stainless steel while the remaining bearing components of the assembly are not.

2. The bearing assembly of claim 1, wherein the second inner bearing race has a chromium content of at least 5 wt. % and the first inner bearing race has a chromium content of less than 3 wt. %.

3. The bearing assembly of claim 1, wherein the second inner bearing race has a chromium content of more than 10 wt. % and the first inner bearing race has a chromium content of less than 2 wt. %.

4. The bearing assembly of claim 1, wherein the second inner bearing race is made of AISI 440C stainless steel.



5. The bearing assembly of claim 1, wherein the second inner bearing race width is at least 1.1 times the first inner bearing race width.
6. The bearing assembly of claim 1, wherein the second inner bearing race width is at least 1.5 times the first inner bearing race width.
7. The bearing assembly of claim 1, wherein the raceway surfaces of the first and second inner bearing races are skewed at equal and opposite angles with respect to the central rotation axis.
8. The bearing assembly of claim 1, wherein the material of the second inner race is surface treated to enrich the stainless steel surface with one or more of: nitrogen, carbon, phosphorous, and oxygen.

9. A multi-row tapered roller bearing assembly for a wind turbine gearbox, the bearing assembly comprising:

first and second axially adjacent inner bearing races including respective raceway surfaces that are oppositely skewed with respect to a central rotation axis of the bearing assembly;

first and second axially adjacent outer bearing races;

a first set of tapered rolling elements supported for rolling between the first inner bearing race and the first outer bearing race; and

a second set of tapered rolling elements supported for rolling between the second inner bearing race and the second outer bearing race,

wherein one of the first and second inner bearing races and one of the first and second outer races are constructed of a stainless steel, and the remaining bearing components of the assembly are made of steel that has a chromium content of less than 2 wt. %.

10. The bearing assembly of claim 9, wherein the second inner bearing race has a width measured along the central rotation axis that is the same as a width of the first inner bearing race, also measured along the central rotation axis.

11. The bearing assembly of claim 9, wherein the second inner bearing race has a width measured along the central rotation axis that is at least 1.1 times a width of the first inner bearing race, also measured along the central rotation axis.

12. The bearing assembly of claim 9, wherein the second inner bearing race has a width measured along the central rotation axis that is at least 1.5 times a width of the first inner bearing race, also measured along the central rotation axis.

13. The bearing assembly of claim 9, wherein the raceway surfaces of the first and second inner bearing races are skewed at equal and opposite angles with respect to the central rotation axis.

14. The bearing assembly of claim 9, wherein the stainless steel inner race and the stainless steel outer race are surface treated to enrich the stainless steel surface with one or more of: nitrogen, carbon, phosphorous, and oxygen.

15. A multi-row tapered roller bearing assembly for a wind turbine gearbox, the bearing assembly comprising:

first and second axially adjacent inner bearing races including respective raceway surfaces that are oppositely skewed with respect to a central rotation axis of the bearing assembly;

first and second axially adjacent outer bearing races;

a first set of tapered rolling elements supported for rolling between the first inner bearing race and the first outer bearing race; and

a second set of tapered rolling elements supported for rolling between the second inner bearing race and the second outer bearing race,

wherein the first and second inner bearing races are constructed of a stainless steel, and the remaining bearing components of the assembly are made of steel that has a chromium content of less than 2 wt. %.

16. The bearing assembly of claim 15, wherein the second inner bearing race has a width measured along the central rotation axis that is the same as a width of the first inner bearing race, also measured along the central rotation axis.

17. The bearing assembly of claim 15, wherein the second inner bearing race has a width measured along the central rotation axis that is at least 1.1 times a width of the first inner bearing race, also measured along the central rotation axis.

18. The bearing assembly of claim 15, wherein the second inner bearing race has a width measured along the central rotation axis that is at least 1.5 times a width of the first inner bearing race, also measured along the central rotation axis.

19. The bearing assembly of claim 15, wherein the raceway surfaces of the first and second inner bearing races are skewed at equal and opposite angles with respect to the central rotation axis.

20. The bearing assembly of claim 15, wherein the first and second stainless steel inner races are surface treated to enrich the stainless steel surface with one or more of: nitrogen, carbon, phosphorous, and oxygen.

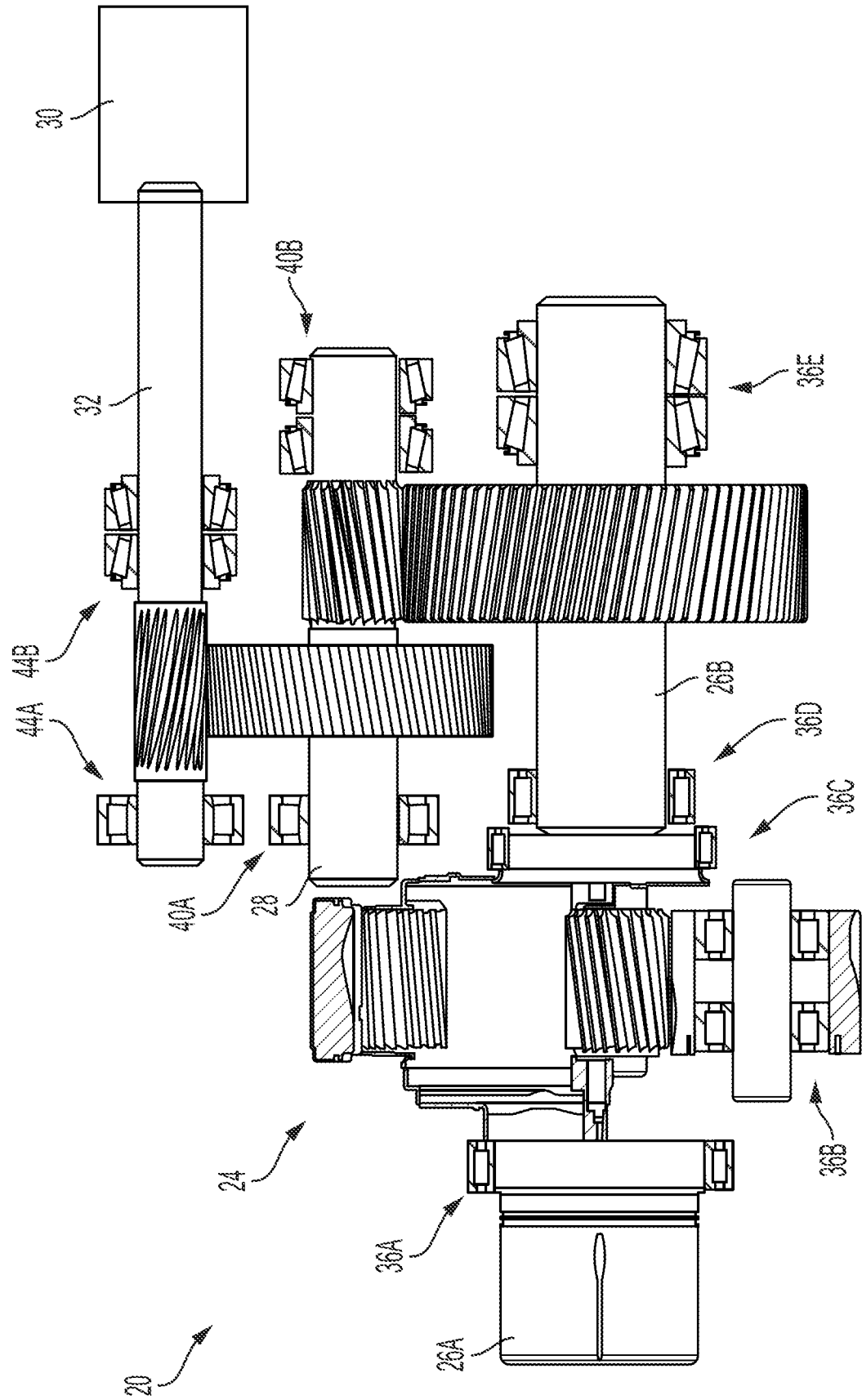


FIG. 1

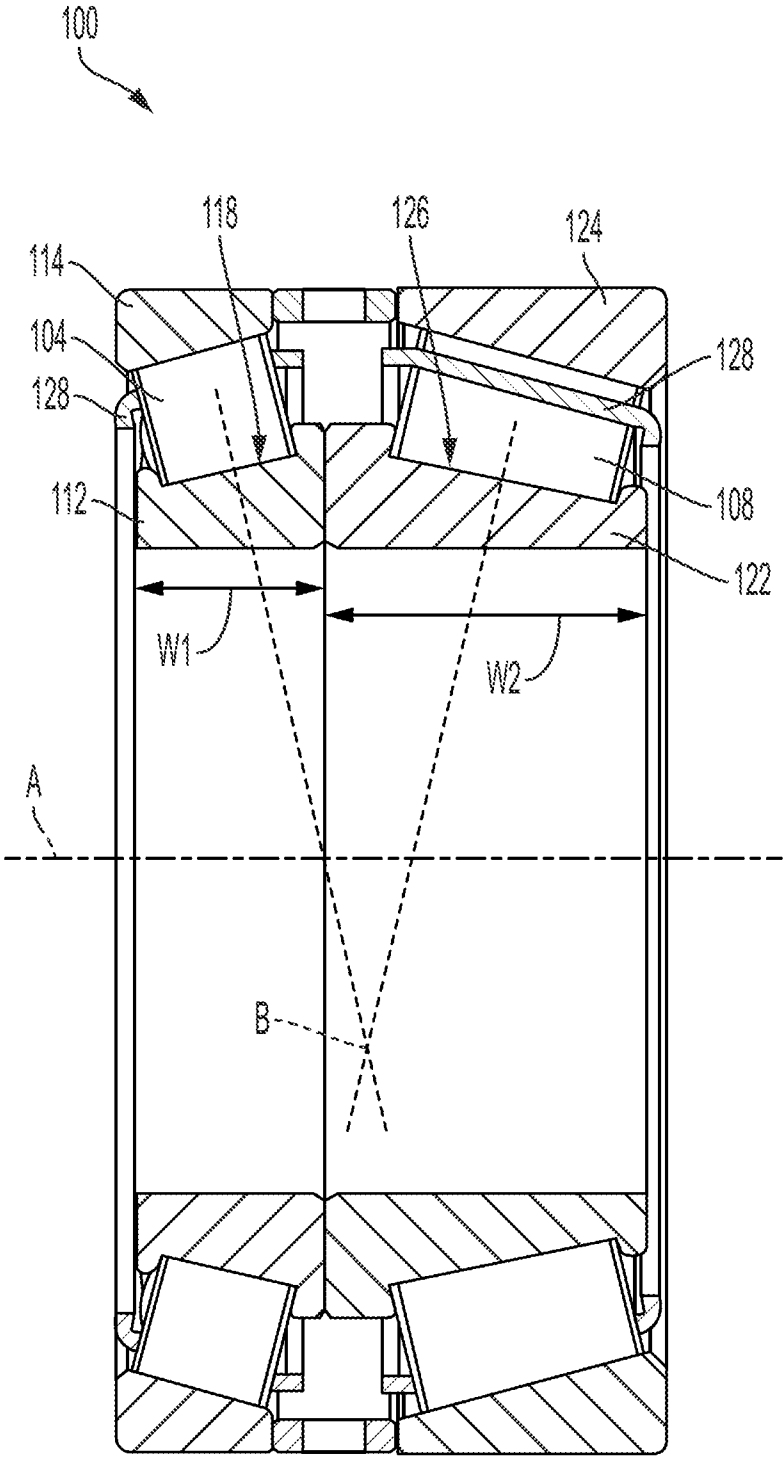


FIG. 2

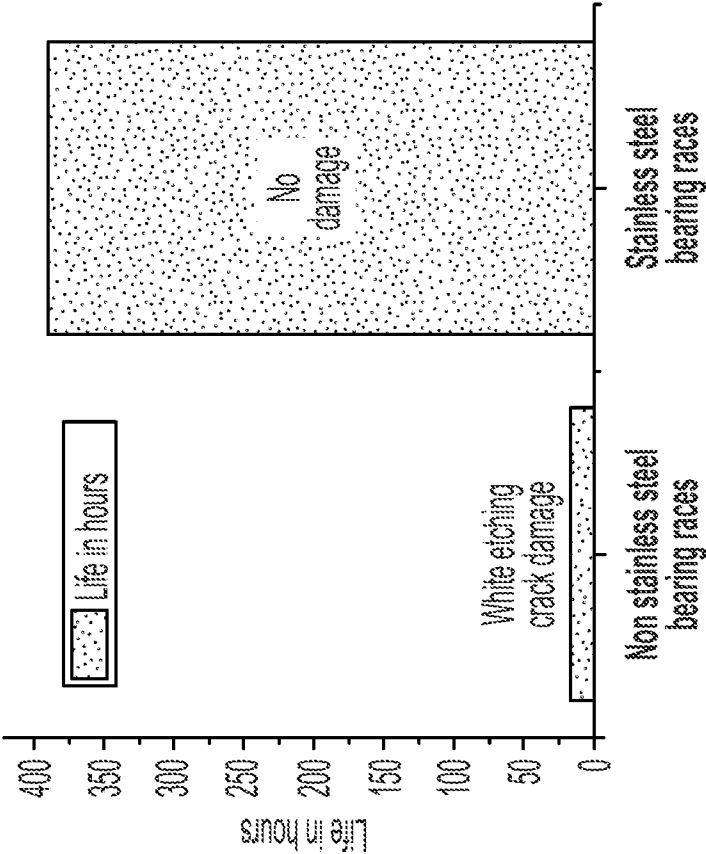


FIG. 3



## INTERNATIONAL SEARCH REPORT

International application No  
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| A. CLASSIFICATION OF SUBJECT MATTER                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                   |                                                                      |
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| INV.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | F16C19/36<br>F03D80/70                                                                                                            | F16C19/50<br>F16C19/54<br>F16C33/62<br>F16C33/30                     |
| 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)<br>F16C F03D                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                   |                                                                      |
| 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)<br>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.                                                |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | US 2008/118344 A1 (MATSUMORI NAOKI [JP] ET AL) 22 May 2008 (2008-05-22) paragraphs [0065] - [0067] figure 6                       | 1-20                                                                 |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | EP 1 705 392 A1 (NTN TOYO BEARING CO LTD [JP]) 27 September 2006 (2006-09-27) paragraphs [0064] - [0068] figures 7, 8             | 1,2,5-20                                                             |
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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | - / - -                                                                                                                           |                                                                      |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                   |                                                                      |
| * Special categories of cited documents :<br>"A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier application or patent but published on or after the international filing date<br>"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)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"P" document published prior to the international filing date but later than the priority date claimed<br>"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<br>"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<br>"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<br>"&" document member of the same patent family |                                                                                                                                   |                                                                      |
| Date of the actual completion of the international search<br><br>29 October 2021                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                   | Date of mailing of the international search report<br><br>10/11/2021 |
| Name and mailing address of the ISA/<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                   | Authorized officer<br><br>Dumont, Marie-Laure                        |

## INTERNATIONAL SEARCH REPORT

International application No  
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| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                          |                       |
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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
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