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AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

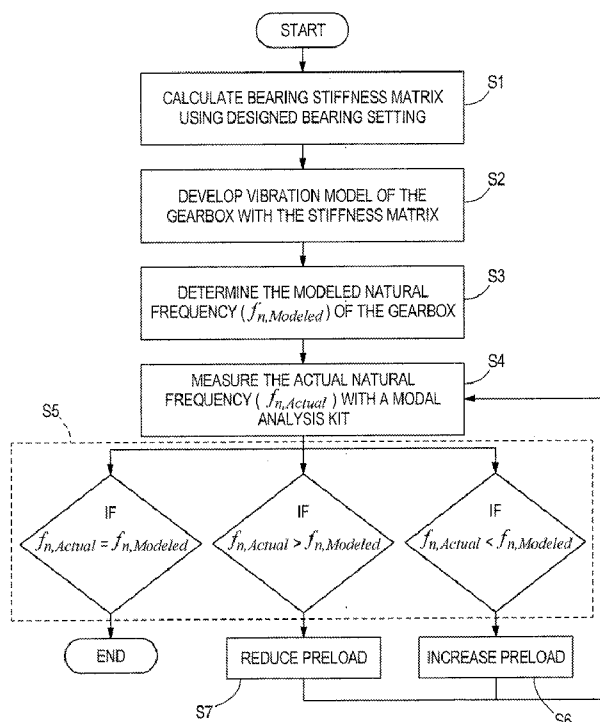
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- (54) **Title:** BEARING ADJUSTMENT USING MODAL ANALYSIS

**FIG. 2**

- (57) **Abstract:** A new setting method for bearings in gearboxes or transmission assemblies uses modeling and modal analysis techniques. The stiffness of bearings varies depending on a set preload or clearance of the bearing. Bearings can be set with varying levels of internal clearance between bearing elements to vary the internal stress or preload of the bearing before the bearings receive an external load. Bearing stiffness affects the natural frequency of the gearbox. It is possible to more accurately and consistently set and adjust the bearing preload or clearance through the comparison of modeled and experimentally determined natural frequencies of the gearbox assembly.



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- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

BEARING ADJUSTMENT USING MODAL ANALYSIS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/912,082, filed on December 5, 2013, the entire content of which is hereby incorporated by reference.

BACKGROUND

[0002] The present invention relates to setting bearing preload or clearance in a transmission assembly.

[0003] A correct setting (e.g., bearing preload or clearance) of bearings is important for bearing life performance and proper functioning of power transmissions, including gearboxes. However, it is very challenging to achieve consistent and reliable bearing setting in complex power transmission and gearbox assemblies due to variations of part geometries. Currently, setting methods based on rolling torque or deflection are widely used. However, the consistency of these methods relies heavily on the experience and skill of the workers who perform the setting. A new setting method that can improve the setting consistency and accuracy is needed in the art.

SUMMARY

[0004] In one aspect, the invention provides a method for setting bearing preload or clearance for a bearing mounted in a transmission assembly. The method includes determining a modeled natural frequency of a vibration model of the bearing and transmission assembly developed using a pre-calculated stiffness of the bearing, performing a modal analysis on an assembled bearing and transmission assembly to determine an actual natural frequency of the assembled bearing and transmission assembly, comparing the actual natural frequency of the assembled bearing and transmission assembly to the modeled natural frequency; and adjusting an actual preload or clearance of the bearing based on the comparison of the actual natural frequency and the modeled natural frequency.

[0005] In another aspect, the invention provides a method for setting bearing preload or clearance for a bearing mounted in a transmission assembly. The method includes calculating a stiffness of the bearing based on a design preload or clearance, developing a

vibration model of the bearing and transmission assembly using the calculated stiffness of the bearing, determining a modeled natural frequency of the vibration model, assembling the bearing into the transmission assembly, performing a modal analysis on the assembled bearing and transmission assembly to determine an actual natural frequency of the assembled bearing and transmission assembly, and comparing the actual natural frequency of the assembled bearing and transmission assembly to the modeled natural frequency.

[0006] In another aspect, the invention provides a method for setting bearing preload or clearance for a bearing mounted in a transmission assembly. The method includes determining a modeled natural frequency of a vibration model of the bearing and transmission assembly developed using a computer modeling software with finite element analysis capabilities and using a pre-calculated stiffness of the bearing. The pre-calculated stiffness of the bearing is determined using computational software, and the modeled natural frequency of the vibration model is determined by the computer modeling software. The method also includes performing a modal analysis with a modal analysis system on an assembled bearing and transmission assembly to determine an actual natural frequency of the assembled bearing and transmission assembly. The modal analysis system includes a vibration sensor, a vibration excitation instrument, and a signal analyzer. Further, the method includes comparing the actual natural frequency of the assembled bearing and transmission assembly to the modeled natural frequency, and adjusting an actual preload or clearance of the bearing based on the comparison of the actual natural frequency and the modeled natural frequency. If the actual natural frequency is less than the modeled natural frequency, the actual preload of the bearing is increased by reducing an internal clearance of bearing components. If the actual natural frequency is greater than the modeled natural frequency, the actual preload of the bearing is decreased by increasing an internal clearance of bearing components.

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

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Fig. 1 is a schematic drawing illustrating a gearbox and modal analysis kit in accordance with an embodiment of the invention.

[0009] Fig. 2 is a flowchart illustrating the steps for setting bearing preload or clearance using modal analysis.

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] The invention presents a new setting method for bearings in gearboxes or other transmission assemblies. The method uses modeling and modal analysis techniques. The stiffness of bearings varies depending on a set preload or clearance of the bearing. Bearings can be set with varying levels of clearance between bearing elements to vary the internal stress or preload of the bearing before the bearings receive an external load. A higher preload on the bearing results in increased bearing stiffness, while a lower preload will result in decreased bearing stiffness. Bearing stiffness influences the natural frequency of the gearbox. It is possible to more accurately and consistently set and adjust the bearing preload or clearance through the comparison of modeled and experimentally determined natural frequencies of the gearbox assembly.

[0012] Fig. 1 illustrates a transmission assembly or gearbox 10 including a bearing 14. The bearing 14 is illustrated as a tapered rolling bearing, but may also be one of various other types of bearings. The bearing 14 receives a first shaft or input shaft 16 in the bearing bore, which may be driven by various means. The bearing 14 includes an inner ring or race 18a and an outer ring or race 18b. The outer ring 18b is coupled to the gearbox 10 so that it does not rotate with the inner ring 18a and the input shaft 16. The rotational movement between the inner ring 18a and the outer ring 18b is facilitated by a low friction interface using various techniques such as, but not limited to, rolling elements.

[0013] The gearbox 10 further includes a second shaft or output shaft 20 and a plurality of gears (not shown) located within a housing 22. The plurality of gears engages with each other to effectively transmit the rotational movement and torque from the input shaft 16 to the

output shaft 20. The plurality of gears may be of various sizes and types to provide a desired gear ratio for a specific application.

[0014] With further reference to Fig. 1, a modal analysis system 24 is illustrated including a vibration sensor 26. The vibration sensor 26 is attached to a computer or signal analyzer 30, for example, through an electrical cord 32. The modal analysis system 24 also includes a vibration excitation instrument 38, which may be an impulse or impact hammer or any other device (e.g., a shaker, modal exciter, etc.) capable of exciting the gearbox 10 to vibrate at its natural frequency. The vibration excitation instrument 38 may be attached to the signal analyzer 30, for example, by an electrical cord 34.

[0015] Fig. 2 illustrates the process a user would follow to use modeling and modal analysis to adjust the setting of the bearing 14 when it is assembled in the gearbox 10. In step S1, the user first calculates a bearing stiffness matrix of the bearing 14 using a designed bearing setting (e.g., preload or clearance). This calculation may be done using traditional analysis using known equations or with available computational software. In step S2, the user develops a vibration model of the gearbox 10 and the installed bearing 14 using the stiffness matrix previously calculated. The vibration model may be created using computer modeling software (e.g., finite element analysis software) which includes vibrational analysis capabilities. In step S3, the user determines a modeled natural frequency of the gearbox 10 and the installed bearing 14 using the created vibration model of the gearbox 10. After the system has been mathematically modeled, the actual bearing 14 is installed in the actual gearbox 10 with an approximate preload or clearance provided to the bearing 14 during installation. In step S4, the user then measures the actual natural frequency of the gearbox 10 and installed bearing 14 using the modal analysis system 24. In operation of the illustrated modal analysis system 24, the user first couples the vibration sensor 26 to the assembled gearbox 10. The vibration excitation instrument or impact hammer 38 is used to induce vibrations of the gearbox 10. The vibration sensor 26, such as an accelerometer, detects the vibration of the gearbox 10 and the vibrational signal is received and recorded by the signal analyzer 30. Through signal processing techniques, the actual natural frequency of the gearbox 10 and installed bearing 14 is determined.

[0016] In step S5, the actual natural frequency of the gearbox 10 and installed bearing 14 is compared to the modeled natural frequency previously determined. If the actual natural frequency of the gearbox 10 and installed bearing 14 is lower than the modeled natural

frequency, the preload on the bearing 14 is too low, and is therefore increased as shown in step S6. As is understood in the art, bearing preload is increased by reducing the internal clearance of the bearing elements relative to each other. For example, in a tapered roller bearing, when axial endplay (i.e., a maximum relative displacement, in a direction parallel to the bearing axis, between the two rings of an unmounted bearing) is reduced, preload is increased. By increasing the bearing preload, the stiffness of the bearing 14 and natural frequency of the gearbox 10 and installed bearing 14 also increase. If the actual natural frequency of the gearbox 10 and installed bearing 14 is greater than the modeled natural frequency, the preload on the bearing is decreased as shown in step S7. Again, as is understood in the art, bearing preload is decreased by increasing the internal clearance of the bearing elements relative to each other. For example, in a tapered roller bearing, when the axial endplay is increased, the preload is decreased. By decreasing the bearing preload, the stiffness of the bearing 14 and the natural frequency of the gearbox 10 and installed bearing 14 also decrease. If the actual natural frequency of the gearbox 10 approximately equals the modeled natural frequency, the preload of the bearing does not need to be changed. In certain applications, the bearing preload may be set to zero (i.e., the bearing elements are not touching) and the bearing elements may be set with a desired clearance or separation. If changes to the bearing preload or clearance have been made, steps S4 and S5 are repeated until the actual natural frequency of the gearbox 10 and installed bearing 14 approximately equals the modeled natural frequency.

[0017] Various features and advantages of the invention are set forth in the following claims.

CLAIMS

What is claimed is:

1. A method for setting bearing preload or clearance for a bearing mounted in a transmission assembly, the method comprising:
 - determining a modeled natural frequency of a vibration model of the bearing and transmission assembly developed using a pre-calculated stiffness of the bearing;
 - performing a modal analysis on an assembled bearing and transmission assembly to determine an actual natural frequency of the assembled bearing and transmission assembly;
 - comparing the actual natural frequency of the assembled bearing and transmission assembly to the modeled natural frequency; and
 - adjusting an actual preload or clearance of the bearing based on the comparison of the actual natural frequency and the modeled natural frequency.
2. The method of claim 1, wherein the actual preload of the bearing is adjusted by changing an internal clearance of components of the bearing.
3. The method of claim 1, wherein if the actual natural frequency is less than the modeled natural frequency, the actual preload of the bearing is increased.
4. The method of claim 1, wherein if the actual natural frequency is greater than the modeled natural frequency, the actual preload of the bearing is decreased.
5. The method of claim 1, wherein the pre-calculated stiffness of the bearing is determined using computational software.
6. The method of claim 1, wherein the vibration model of the bearing and transmission assembly is developed using computer modeling software which includes finite element analysis capabilities.
7. The method of claim 6, wherein the modeled natural frequency is determined by the computer modeling software.

8. The method of claim 1, wherein the modal analysis is performed by a modal analysis system including a vibration sensor, a vibration excitation instrument, and a signal analyzer.
9. The method of claim 8, wherein the vibration excitation instrument is one of an impact hammer and a shaker.
10. A method for setting bearing preload or clearance for a bearing mounted in a transmission assembly, the method comprising:
 - calculating a stiffness of the bearing based on a design preload or clearance of the bearing;
 - developing a vibration model of the bearing and transmission assembly using the calculated stiffness of the bearing;
 - determining a modeled natural frequency of the vibration model;
 - assembling the bearing into the transmission assembly;
 - performing a modal analysis on the assembled bearing and transmission assembly to determine an actual natural frequency of the assembled bearing and transmission assembly;
 - and
 - comparing the actual natural frequency of the assembled bearing and transmission assembly to the modeled natural frequency.
11. The method of claim 10, further comprising adjusting an actual preload or clearance of the bearing based on the comparison of the actual natural frequency and the modeled natural frequency.
12. The method of claim 11, wherein the actual preload of the bearing is adjusted by changing an internal clearance of components of the bearing.
13. The method of claim 11, wherein if the actual natural frequency is less than the modeled natural frequency, the actual preload of the bearing is increased.
14. The method of claim 11, wherein if the actual natural frequency is greater than the modeled natural frequency, the actual preload of the bearing is decreased.

15. The method of claim 10, wherein calculating the stiffness of the bearing is performed using computational software.
16. The method of claim 10, wherein the vibration model of the bearing and transmission assembly is developed using computer modeling software which includes finite element analysis capabilities.
17. The method of claim 16, wherein the modeled natural frequency is determined by the computer modeling software.
18. The method of claim 10, wherein the modal analysis is performed by a modal analysis system including a vibration sensor, a vibration excitation instrument, and a signal analyzer.
19. The method of claim 18, wherein the vibration excitation instrument is one of an impact hammer and a shaker.

20. A method for setting bearing preload or clearance for a bearing mounted in a transmission assembly, the method comprising:

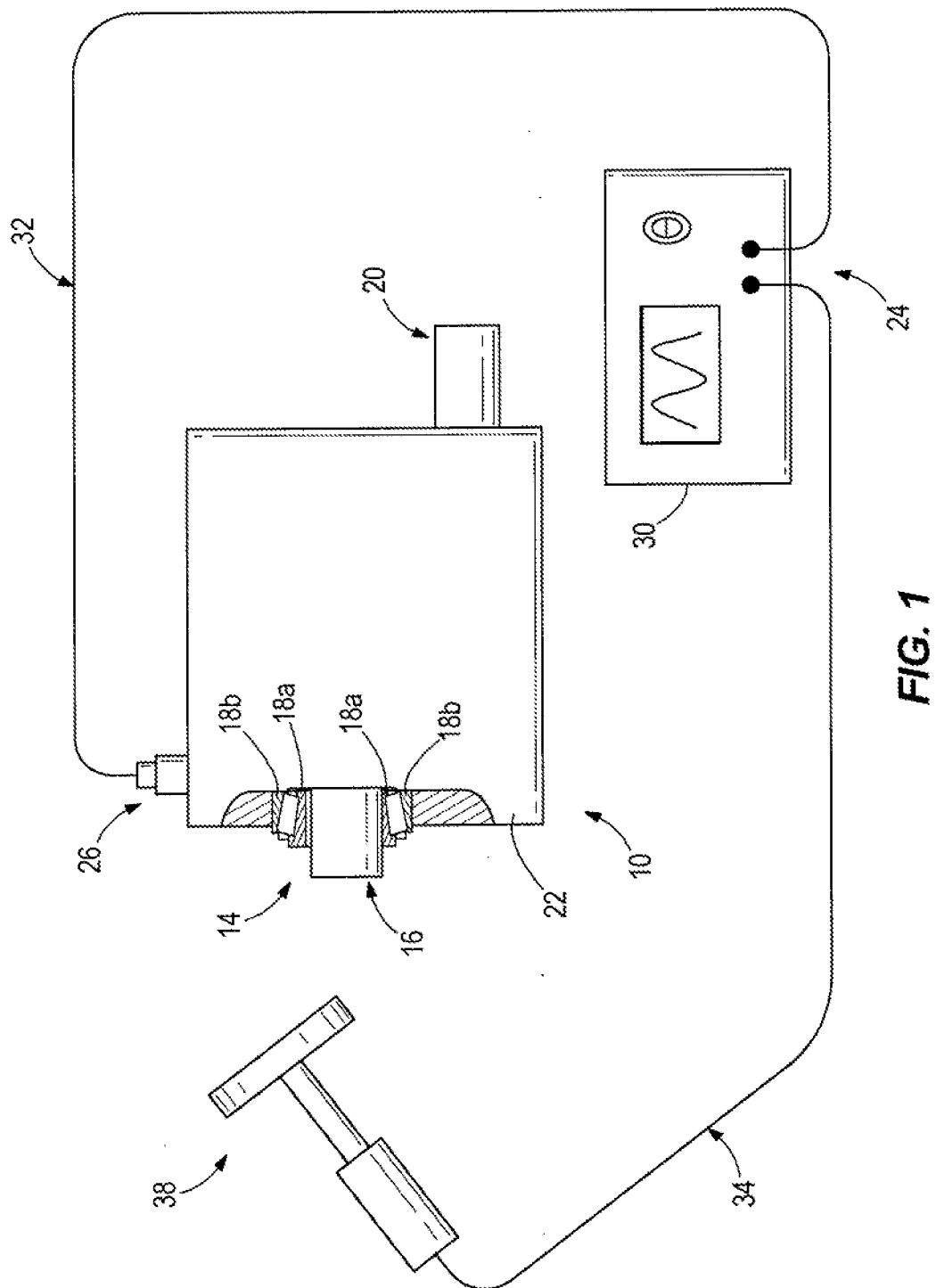
- determining a modeled natural frequency of a vibration model of the bearing and transmission assembly developed using a computer modeling software with finite element analysis capabilities and using a pre-calculated stiffness of the bearing, the pre-calculated stiffness of the bearing being determined using computational software, the modeled natural frequency of the vibration model being determined by the computer modeling software;

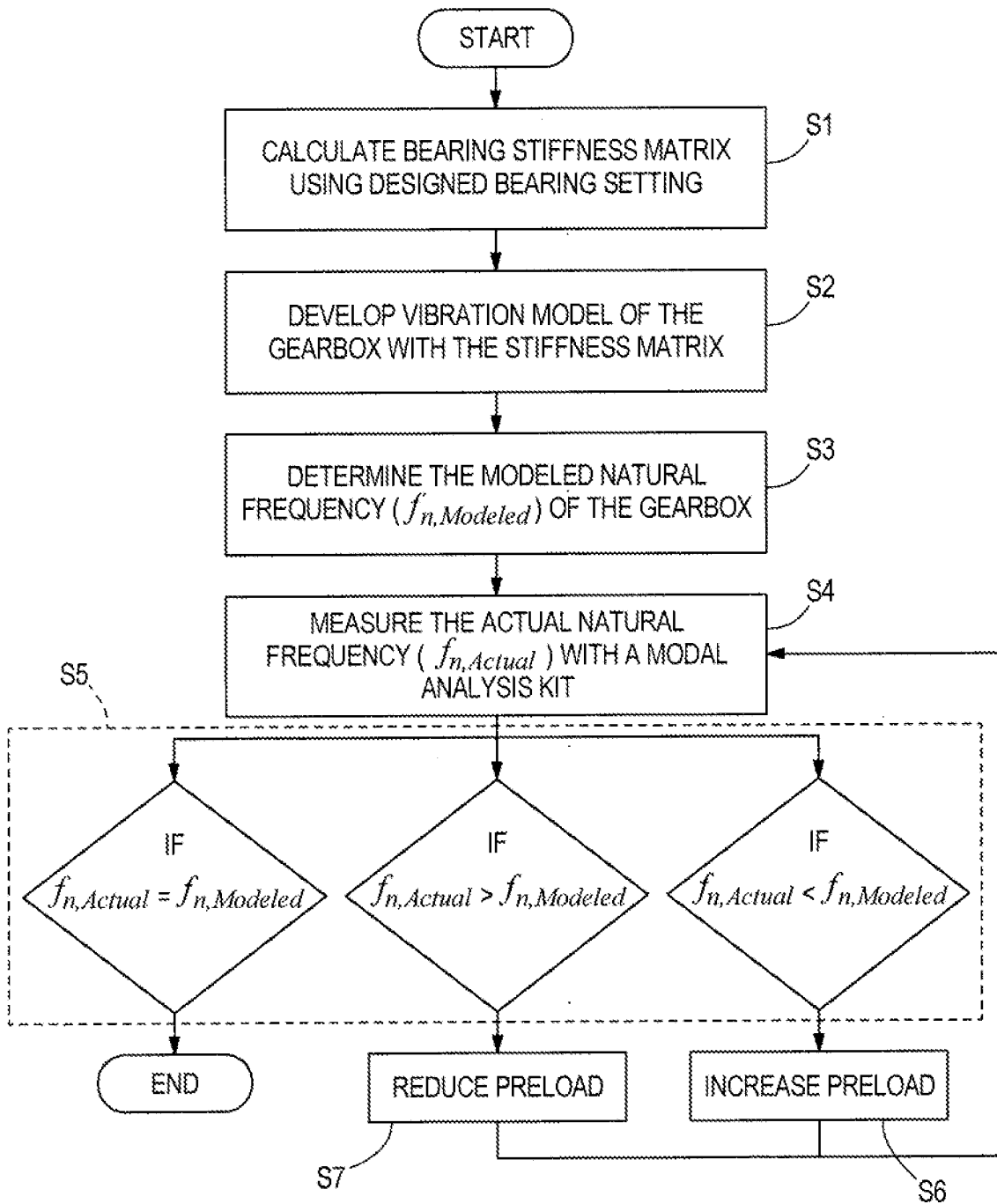
- performing a modal analysis on an assembled bearing and transmission assembly with a modal analysis system to determine an actual natural frequency of the assembled bearing and transmission assembly, the modal analysis system including

- a vibration sensor,
 - a vibration excitation instrument, and
 - a signal analyzer;

- comparing the actual natural frequency of the assembled bearing and transmission assembly to the modeled natural frequency; and

- adjusting an actual preload or clearance of the bearing based on the comparison of the actual natural frequency and the modeled natural frequency, wherein if the actual natural frequency is less than the modeled natural frequency, the actual preload of the bearing is increased by reducing an internal clearance of bearing components, and wherein if the actual natural frequency is greater than the modeled natural frequency, the actual preload of the bearing is decreased by increasing an internal clearance of bearing components.



**FIG. 2**

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/067308

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01M13/04
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)
G01M 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)

EP0-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	DE 10 2005 012914 A1 (KOENIG & BAUER AG [DE]) 5 October 2006 (2006-10-05) paragraph [0001] paragraph [0015] paragraph [0017] - paragraph [0018] paragraph [0020] - paragraph [0021] paragraph [0023] paragraph [0026] - paragraph [0028] paragraph [0031] - paragraph [0032] -----	1-20
X	US 5 341 569 A (TAKAMIZAWA TORU [JP] ET AL) 30 August 1994 (1994-08-30) column 1, line 9 - line 12 column 10, line 3 - line 63 ----- -/--	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

5 March 2015

Date of mailing of the international search report

28/04/2015

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/067308

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP S59 188535 A (NIPPON SEIKO KK) 25 October 1984 (1984-10-25) the whole document figure 3	1-20
A	----- JUI P HUNG ET AL: "Prediction of the Dynamic Characteristics of a Milling Machine Using the Integrated Model of Machine Frame and Spindle Unit", WORLD ACADEMY OF SCIENCE, ENGINEERING AND TECHNOLOGY. INTERNATIONAL SCIENCE INDEX, vol. 6, no. 67, 21 July 2012 (2012-07-21), pages 626-632, XP055171144, ISSN: 1307-6892 Section II B.: FE model of spindle unit Section II C.: Dynamic characteristics of the spindle unit figures 5,6 -----	3,4,13, 14,20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/067308

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102005012914 A1	05-10-2006	NONE	

US 5341569	A	30-08-1994	JP 3419015 B2 23-06-2003
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