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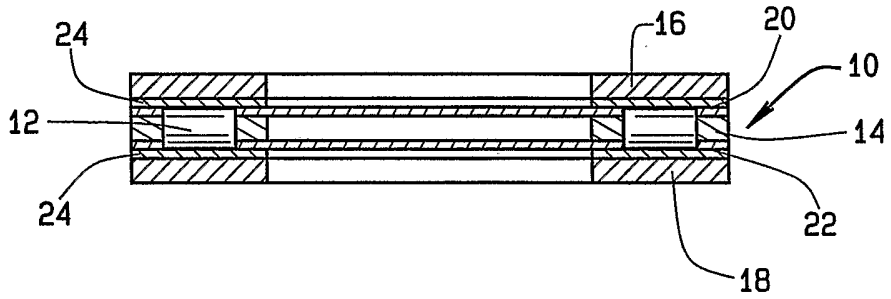
(54) Title: NEEDLE THRUST BEARING WITH MISALIGNMENT TOLERANCE



(57) Abstract: At least one raceway (20) of a needle thrust bearing (10) is coated with a tribological coating (24), preferably, a WC/aC:H coating. The inventors of the present invention have discovered that the application of the coating to the raceways or washers of needle thrust bearings can increase the $L_{15.91}$ fatigue life of misaligned bearings by more than two times (2X) over a misaligned bearing without coated raceways.

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NEEDLE THRUST BEARINGS WITH MISALIGNMENT TOLERANCE

Cross-Reference To Related Applications

This application claims priority to United States Provisional Application No. 60/578,603 filed June 10, 2004 entitled NEEDLE THRUST BEARINGS WITH MISALIGNMENT TOLERANCE and which is incorporated herein by reference.

Technical Field

This invention relates to thrust bearing assemblies, and, in particular, to a coating for the washers or raceways of thrust bearings.

Background Art

It is known in the art that applying tribological coatings to rolling elements of bearings increases the fatigue life and provides wear resistance to rolling element bearings. However, when these coatings have been applied to the raceways of rolling element bearings, no increases in fatigue life or wear resistance have previously been observed. In addition, tribological coatings have not been applied to rolling element bearings to inhibit misalignment-induced fatigue in rolling element bearings.

However, the inventors of the present invention have unexpectedly discovered that certain tribological coatings can be applied to select roller bearing surfaces within a defined domain of application conditions to yield enhanced performance. Until now, the effects of using these coatings on needle and cylindrical thrust bearings, widely employed in many automotive and industrial off highway transmissions, were unknown.

In the accompanying drawings which form part of the specification:

Brief Description of the Drawings

Fig. 1 is an overhead view of a needle thrust bearing;

Fig. 2 sectional view of the needle thrust bearing between thrust washers having tribological coatings;

Fig. 3 is a rear view of a non-rotating washer with shims for testing;

Fig. 4 is a chart illustrating the test results of the coated washers compared to the non-coated washers;

Fig. 5 is a chart illustrating the Weibull analysis;

Fig. 6 is a chart illustrating the surface finish of the coated washers compared to the non-coated washers;

Fig. 7 is a first illustration of the results from a modeling program;

Fig. 8 is a second illustration of the results from a modeling program;

Fig. 9 is a third illustration of the results from a modeling program; and

Fig. 10 is a fourth illustration of the results from a modeling program.

Corresponding reference numerals indicate corresponding parts throughout the several figures of the drawings.

Best Mode for Carrying Out the Invention

The following detailed description illustrates the invention by way of example and not by way of limitation. This description will clearly enable one skilled in the art to make and use the invention, and describes several embodiments, adaptations, variations, alternatives and uses of the invention, including what we presently believe is the best mode of carrying out the invention. Additionally, it is to be understood that the invention is not limited in its application to the details of construction and the arrangements of components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or 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.

Figures 1 and 2 show a needle thrust bearing 10 having rolling elements 12 within a cage assembly 14. The bearing 10 operates between a rotating thrust washer 16 and a non-rotating thrust washer 18. The raceways 20 and 22 of the respective thrust washers 16 and 18 are coated with a tribological coating 24.

The tribological coating 24 is a tungsten carbide reinforced amorphous hydrocarbon coating, such as ES-300 coating available from The Timken Company of Canton, Ohio. Through a testing procedure described below, the inventors of the present invention discovered that applying the coating 24 to the raceways or washers of needle thrust bearings can increase the $L_{15.91}$ fatigue life of misaligned bearings by more than two times (2X), with a 90% confidence level over a misaligned bearing without coated raceways.

The coating is comprised of nanometer-scale (<10 nm in size) crystallites of tungsten carbide embedded in a matrix of amorphous hydrocarbon. Amorphous hydrocarbon materials are also called diamond-like carbon. Specifically, the Timken ES-300 coating is comprised of three layers: (1) a Cr adhesion layer (2) a gradient layer that forms a smooth chemical transition from Cr to the chemistry of the coating layer (3) and a coating layer that can be expressed as WC/aC:H. The coating can be applied to the washers 16 and 18 in any method known in the art.

It is worth noting that it may be technically possible to achieve increased bearing life by coating only the non-rotating washer 24 realizing that an assembly procedure would need to be implemented to ensure that the coated washer was always assembled in contact with the rollers.

The following example documents the testing procedure that was designed to explore the use of Timken's ES-300 coating on a needle thrust bearing. The testing procedure tests the performance characteristics of thrust bearings coated with Timken's ES-300 coating against standard (i.e., uncoated) thrust bearings. In sum, the results of the testing demonstrate that washers coated with Timken's ES-300 coating provide an $L_{15.91}$ fatigue life approximately two times (2X) that of uncoated washers with a 90% confidence level.

Example

The Timken ES-300 coating was applied to the raceways of eight washer sets (Timken p/n JD-76294) that were assembled with standard cage and roller assemblies (Timken p/n FA-35584-R). The coating is applied to a thickness of preferably 5 micrometers or less. The washers were made from AISI 52100, had an inner and outer diameters of 2.5" (63.5 mm) and 3.38" (85.9 mm), respectively, and an axial width of 0.1575" (4 mm). The cage was made from Low Carbon Steel, had inner and outer diameters of 2.5" (63.5 mm) and 3.55" (90.2 mm), respectively, and an axial width of 0.310" (7.8 mm). The bearing had 23 rolling elements, each of which had a length of 0.375" (9.5 mm) and a diameter of 0.3125" (7.9 mm).

As shown in Figure 3, the non-rotating washer 26 was deliberately misaligned by applying 0.004" (100 μm) thick shims 28 to the non-rotating washer 26 to mimic the operating conditions occurring on actual applications. Next, fatigue tests were conducted on both the coated washers and standard non-coated washers in a standard SAE 10W transmission and drive train oil. All fatigue testing was performed at Timken's test lab facility located in Torrington, CT on Automotive Dynamic Thrust Machines 1 & 2.

The following boundary conditions were established for the fatigue testing:

- 2000 RPM, 2700 lbs (12kN) of thrust load

- Oil inlet temp = 194 ± 10° F (90° C ± 12° C)
- Low oil flow = 200 ± 20 cc/min
- Caterpillar Transmission & Drive Train Oil 8T-9568 SAE 10W
- Non-rotating washer (p/n JD-76294) shimmed with two 0.004" (100 µm) thick shims located approximately 90 degrees apart (Figure 3) in order to simulate a severe out of flat condition.
- Rotating washer not shimmed. Standard cage & roller assembly p/n FA-35584-R used for all test cases.
- Running surfaces of both thrust washers coated with Timken ES-300 (for coated samples only).
- Coarse grain spalling greater than or equal to 1mm^2 was defined as the failure criterion.
- Lubricant EHL film thickness is estimated to be approximately 6 µin.
- Lubricant specific film thickness (λ) is estimated to be approximately 0.4.
- Lubricant EHL film thickness and specific film thickness (λ) are estimated using raceway surface finish = 12 Ra (.3 µm) and roller surface finish = 8 Ra (.2 µm).

The fatigue test produced the results listed in the tables below and illustrated in Figure 4:

Table 1: Timken ES-300 Coated Thrust Washers

Test Run	Washer ID	Static / Rotating	Shim / No Shim	Test Begin Date	Test End Date	Rig	Test Hours	Failure / Suspension
5841-1	5-1	Static	Shim	13-Mar-03	07-Apr-03	Dynamic 1	438	Spall
	5-5	Rotating	No Shim					N/A
5841-2	5-2	Static	Shim	24-Mar-03	27-Jun-03	Dynamic 2	1512	Suspended
	5-6	Rotating	No Shim					Suspended
5841-3	5-3	Static	Shim	31-Mar-03	20-May-03	Dynamic 1	827	N/A

	2-5	Rotating	No Shim					Spall
5841-4	5-4	Static	Shim	20-May-03	17-Jun-03	Dynamic 1	549	Spall
	1-0	Rotating	No Shim					N/A
5841-5	3-7	Static	Shim	25-Jun-03	20-Aug-03	Dynamic 2	1153	Spall
	207	Rotating	No Shim					N/A
5841-6	4-8	Static	Shim	21-Aug-03	13-Oct-03	Dynamic 2	1095	Spall
	208	Rotating	No Shim					N/A
5841-13	107	Static	Shim	02-Sep-03	15-Sep-03	Dynamic 1	255	Spall
	209	Rotating	No Shim					N/A
5841-15	109	Static	Shim	06-Oct-03	01-Dec-03	Dynamic 1	974	Spall
	211	Rotating	No Shim					N/A

Table 2: Timken Standard Uncoated Thrust Washers

Test Run	Washer ID	Static / Rotating	Shim / No Shim	Test Begin Date	Test End Date	Rig	Test Hours	Failure / Suspension
5841-7	101	Static	Shim	19-Jun-03	29-Jun-03	Dynamic 1	240	Spall
	201	Rotating	No Shim					Debris dents
5841-8	102	Static	Shim	30-Jun-03	11-Jul-03	Dynamic 1	207	Spall
	202	Rotating	No Shim					N/A
5841-9	103	Static	Shim	11-Jul-03	17-Jul-03	Dynamic 1	134	Spall
	203	Rotating	No Shim					Minor dents
5841-10	104	Static	Shim	15-Oct-03	03-Nov-03	Dynamic 2	399.5	Spall
	204	Rotating	No Shim					Debris dents
5841-11	105	Static	Shim	03-Nov-03	19-Nov-03	Dynamic 2	264	Spall
	205	Rotating	No Shim					N/A
5841-12	106	Static	Shim	21-Nov-03	28-Nov-03	Dynamic 2	162.8	Spall
	206	Rotating	No Shim					Minor dents
5841-14	210	Static	Shim	18-Sep-03	06-Oct-03	Dynamic 1	407	Spall

	108	Rotating	No Shim					Debris dents
5841-16	212	Static	Shim	01-Dec-03	18-Feb-04	Dynamic 1	126	Spall
	110	Rotating	No Shim					N/A

A Weibull statistical analysis of the test results was performed. The data was processed using a "least of one" testing methodology. As shown in Figure 5, the Weibull data shows that at an $L_{15.91}$ life level there is a life increase of 2.4X (90% confidence level) for deliberately misaligned needle thrust bearings using ES-300 coated thrust washers over uncoated washers. The slope of the coated washer population is 1.82 while the uncoated is 2.56.

However, it is not yet understood why the coating provides a fatigue life enhancement to these bearings under a misalignment condition. Current understanding of the functionality of coatings on rolling element bearings cannot explain the ability of coatings such as the ES-300 coating to increase the fatigue life of the misaligned washers in these tests. Therefore, these results were unexpected.

The typical mechanisms by which thin film tribological coatings enhance fatigue life of rolling element bearings are:

1. Polishing of raceway / roller surfaces by coating causing a dynamic improvement in specific film thickness (λ)
2. Barrier to adhesive component of fatigue
3. Von Mises stress reduction due to the coating's reduced coefficient of friction

Increased fatigue life is usually associated with the coating causing the polishing of raceway/roller surfaces. However for the current example, it was found that polishing was not the primary mechanism causing the fatigue life enhancement. Rather, it is more

likely that due to the coating's reduced coefficient of friction, the reduction in the von Mises stress is responsible for the life improvement.

As illustrated in Fig. 6, the ES-300 coating had little impact on the surface finish of the components. The surface finish of several components was measured before and after testing in order to determine the polishing effects of the ES-300 coating. Both coated and uncoated parts were measured in addition to the uncoated rollers. Although a reduction in surface roughness associated with polishing can be a mechanism by which the ES-300 coating reduces bearing damage due to adhesive wear and consequently increases fatigue life, it was not found to be a mechanism contributing to increased bearing life in this test. The effect of ES-300 on bearing performance will vary depending on the amount of rolling and sliding contact present for the type of bearing, magnitude of contact stress, and lubrication.

The results from the above testing procedure is the first evidence that any tribological coating increases the fatigue life of rolling element bearings when the coating is applied to the raceways instead of the rolling elements. The increased life is demonstrated under severe misalignment (high local contact stress), marginal lubrication, and high temperature conditions. It is believed that since a life improvement is realized with aggressive test conditions, a life improvement could also be expected under more rational application conditions.

The test set-up was modeled using a bearing analysis program in order to understand the magnitude of contact stress experienced during the test. The analysis program is a predictive modeling program which predicts the life, stress and lubrication conditions of bearings, utilizing well known ISO and ABMA bearing fatigue life, stress calculation and tribological theory. Those skilled in the art will understand that any appropriate available modeling program can be used to predict the performance of the bearing with the coated raceway.

In the model, each rolling element was assigned a numerical location of 1-23. Raceway out of flatness (OOF) was modeled by introducing a maximum out of flat condition at roller locations 3 and 20, which are approximately 90 degrees apart. Here, OOF is defined as the measurement of the out of flatness condition of the washer at the noted roller location. It was felt that to adequately model the shim's effect on raceway-roller contact pressure a lead in before the shim, and a fade out after the shim, were required. Therefore, the following out of flatness conditions best model the washer stiffness:

Roller location 23 OOF = 0
Roller location 1 OOF = .001" (25 µm)
Roller location 2 OOF = .003" (75 µm)
Roller location 3 OOF = .004" (location of .004" (100 µm) thick shim)
Roller location 4 OOF = .003" (75 µm)
Roller location 5 OOF = .001" (25 µm)
Roller location 6 OOF = 0
Rollers 7 – 16 = 0
Roller location 17 OOF = 0
Roller location 18 OOF = .001" (25 µm)
Roller location 19 OOF = .003" (75 µm)
Roller location 20 OOF = .004" (location of .004" (100 µm) thick shim 90 deg apart from shim 1)
Roller location 21 OOF = .003" (75 µm)
Roller location 22 OOF = .001" (25 µm)
Roller location 23 OOF = 0

After 92 seconds of run time the modeling program analysis converged with a total of 5 iterations. As illustrated in Figures 7-10, the estimated maximum contact stress is located at both rollers 3 and 20, the shimmed locations. The estimated maximum contact stress is approximately 477,000 psi (3290 Mpa). Roller end effect is not present.

As various changes could be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense. Although the invention was described using a bearing assembly of the noted dimensions, the invention will work with other sized thrust bearings as well. What is required is that the thrust bearings (and their components) be sized to be able to withstand at least the anticipated load that will be applied to the bearing.

Claims:

1. A thrust bearing assembly comprising:

a pair of thrust washers defining a raceway on an inner surface of each thrust washer;

a plurality of rolling elements contained within a cage and positioned between the thrust washers with the rolling elements being positioned between the raceways of the thrust washers; and

wherein at least one of said races has a tribological coating.

2. The thrust bearing assembly of claim 1, wherein the coating comprises a tungsten carbide reinforced amorphous hydrocarbon coating.

3. The thrust bearing assembly of claim 2, wherein the coating comprises:

a CR adhesion layer;

a gradient layer that forms the chemical transition from Cr to the chemistry of the coating; and

a coating layer that can be expressed as WC/aC:H.

4. The thrust bearing assembly of claim 2, wherein a thickness of the coating is about 5 micrometers or less.

5. The thrust bearing assembly of claim 1, wherein the coating increases the $L_{15.91}$ fatigue life of misaligned bearings by at least two times.

6. The thrust bearing assembly of claim 1, wherein the rolling elements comprise needle rollers.

7. A method of increasing the $L_{15.91}$ fatigue life of a thrust bearing assembly, the thrust bearing assembly comprising:

a pair of thrust washers defining a raceway on an inner surface of each thrust washers;

a plurality of rolling elements contained within a cage and positioned between the thrust washers with the rolling elements being positioned between the raceways of the thrust washers; and

the method comprising the steps of applying a tribological coating to the raceways.

8. The method of claim 7, wherein the coating comprises a tungsten carbide reinforced amorphous hydrocarbon coating.

9. The method of claim 8, wherein the coating comprises:

a CR adhesion layer;

a gradient layer that forms the chemical transition from Cr to the chemistry of the coating; and

a coating layer that can be expressed as WC/aC:H.

10. The method of claim 8, wherein a thickness of the coating is about 5 micrometers or less.

11. The method of claim 7, wherein the coating increases the $L_{15.91}$ fatigue life of misaligned bearings by at least two times.

12. The method of claim 7, wherein the rolling elements comprise needle rollers.

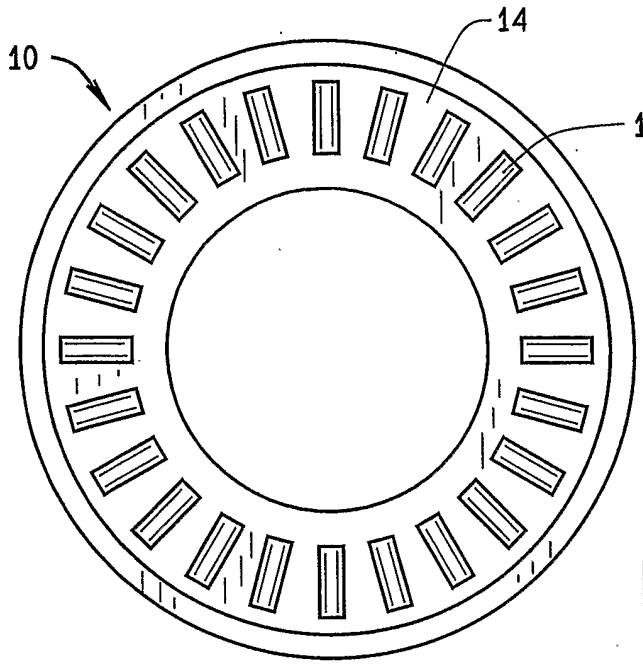


FIG. 1

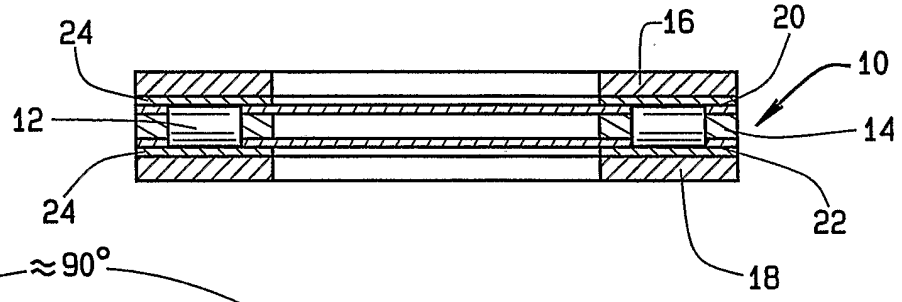


FIG. 2

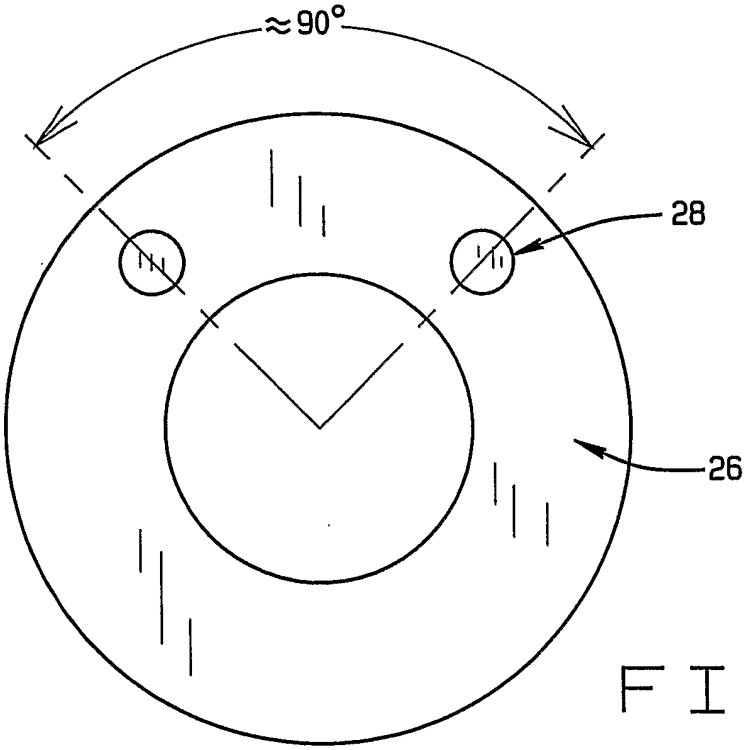


FIG. 3

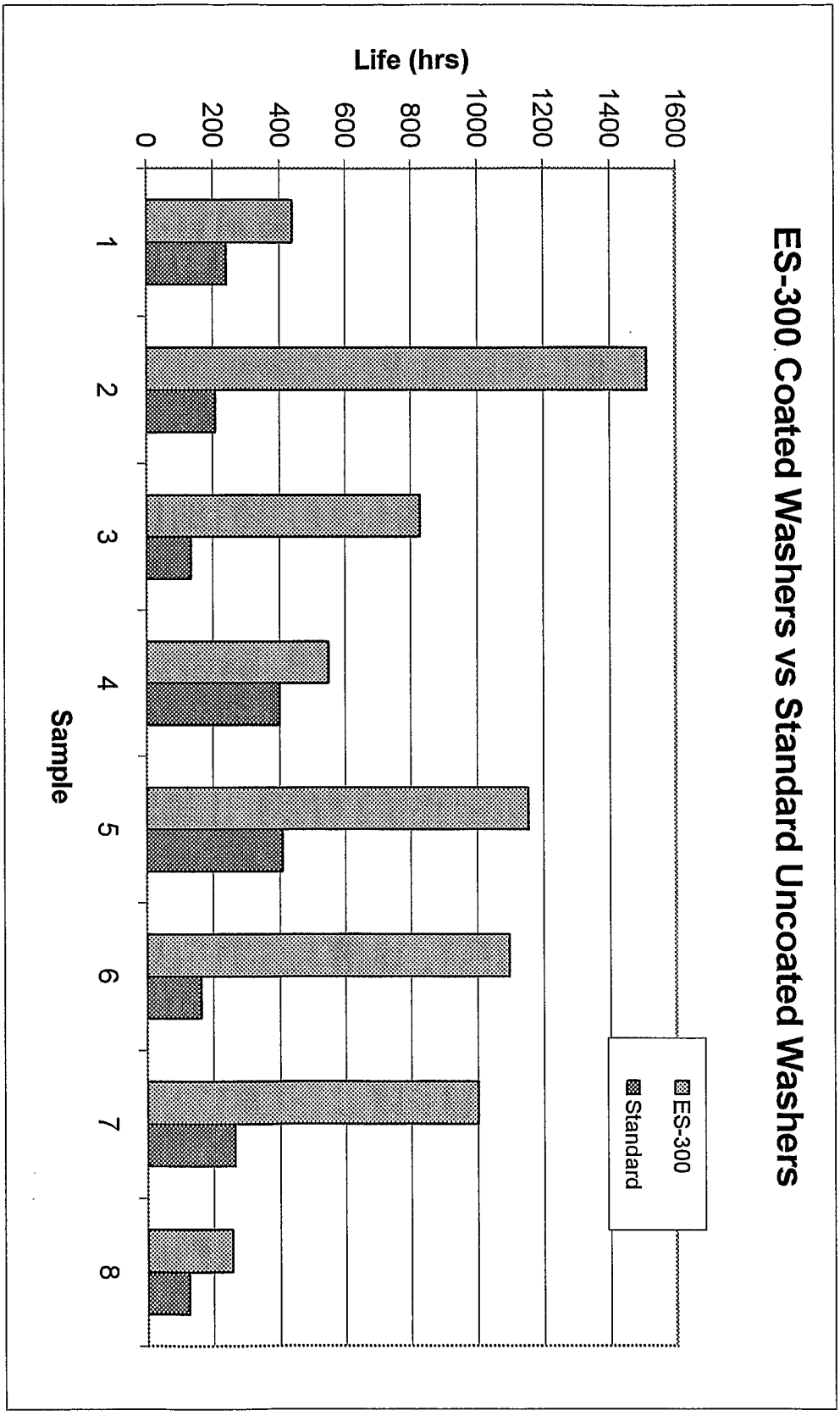
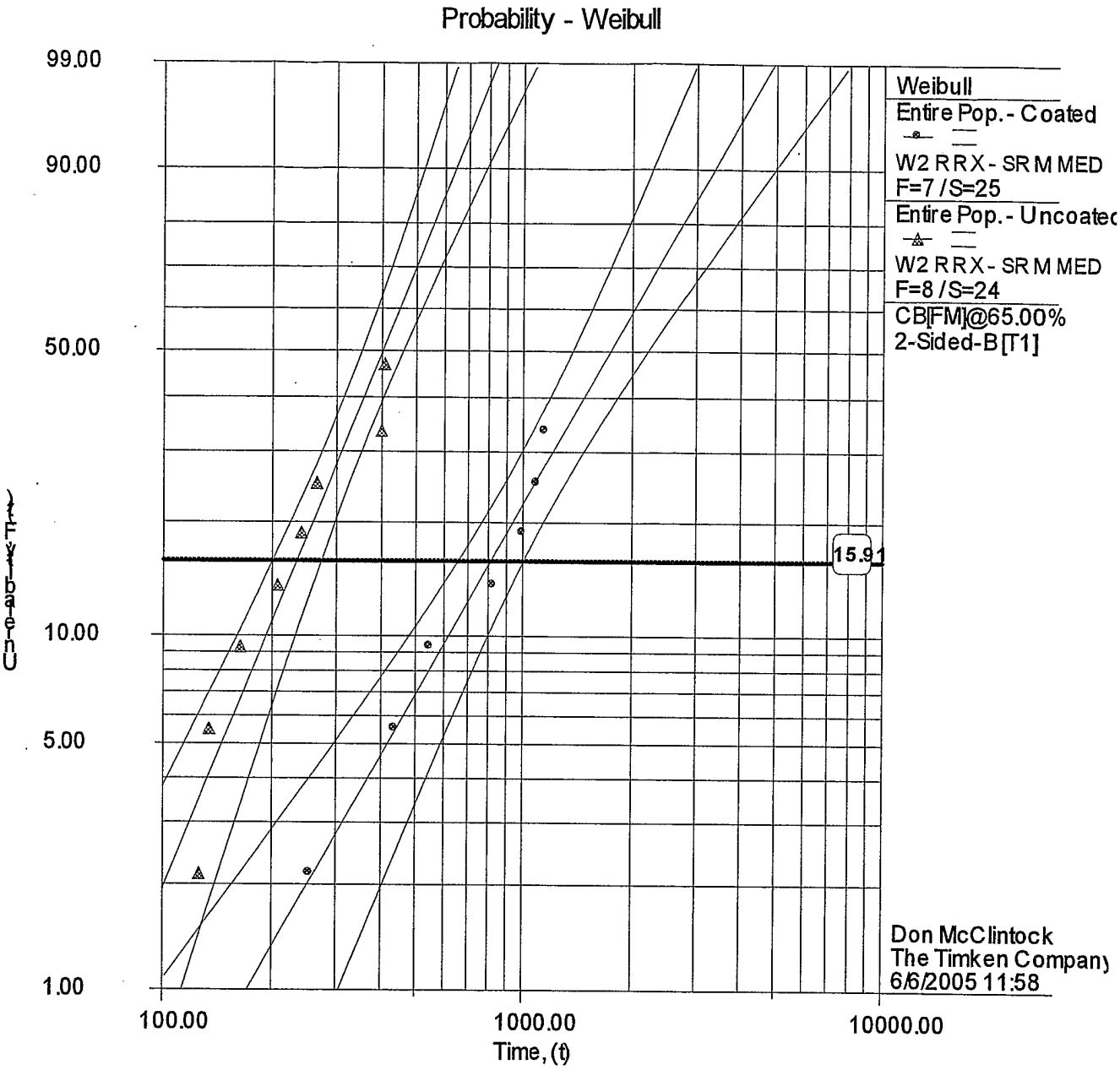

ES-300 Coated Washers vs Standard Uncoated Washers
Life (hrs)
0
200
400
600
800
1000
1200
1400
1600
Sample
1
2
3
4
5
6
7
8
ES-300
Standard

Figure 4



β1=1.8244, η1=2126.0835, ρ=0.9882
β2=2.5581, η2=463.9211, ρ=0.9551

Figure 5

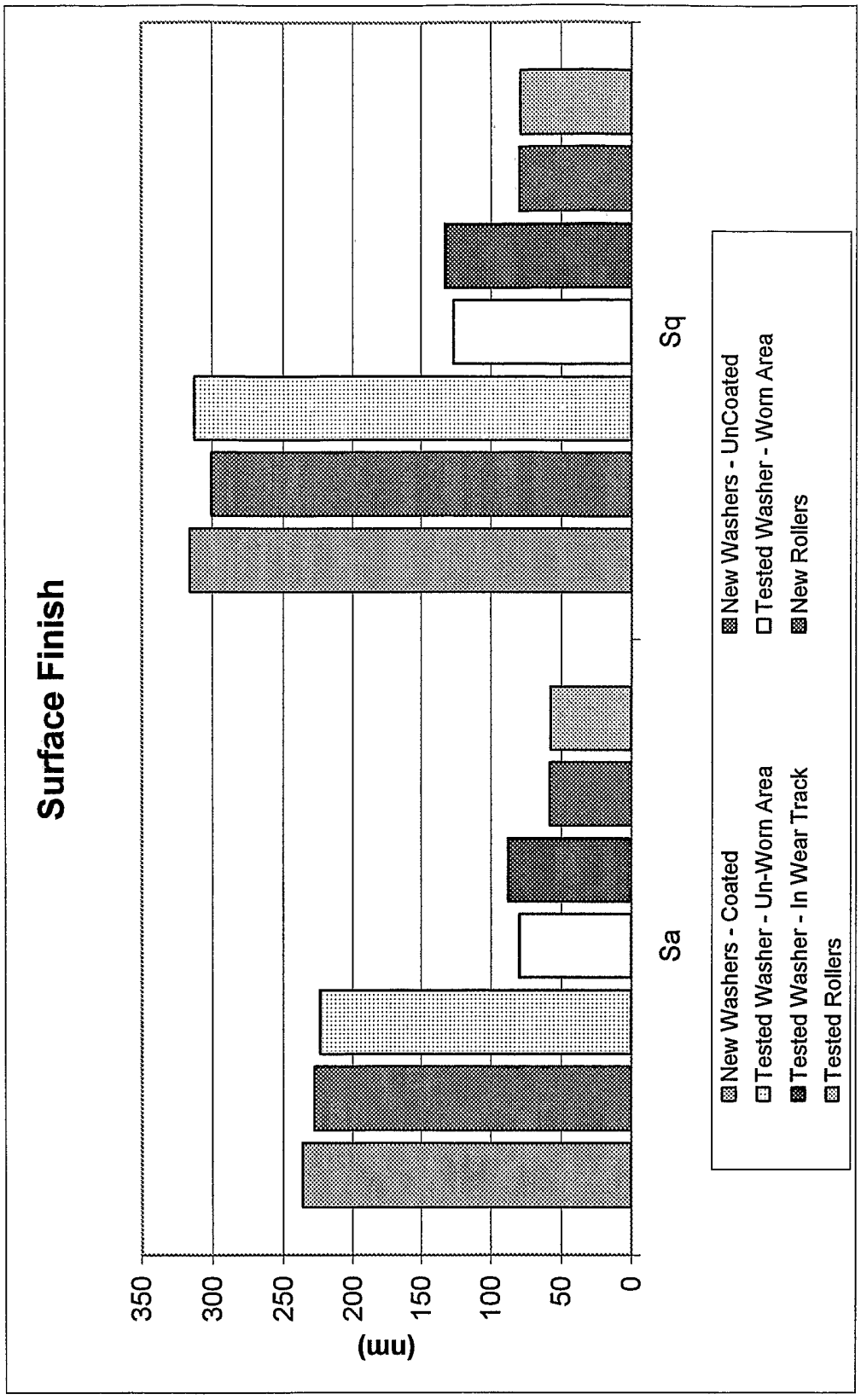

Surface Finish
350
300
250
200
150
100
50
0
(nm)
Sa
Sq
New Washers - Coated
Tested Washer - Un-Worn Area
Tested Washer - In Wear Track
Tested Rollers
New Washers - UnCoated
Tested Washer - Worn Area
New Rollers

Figure 6

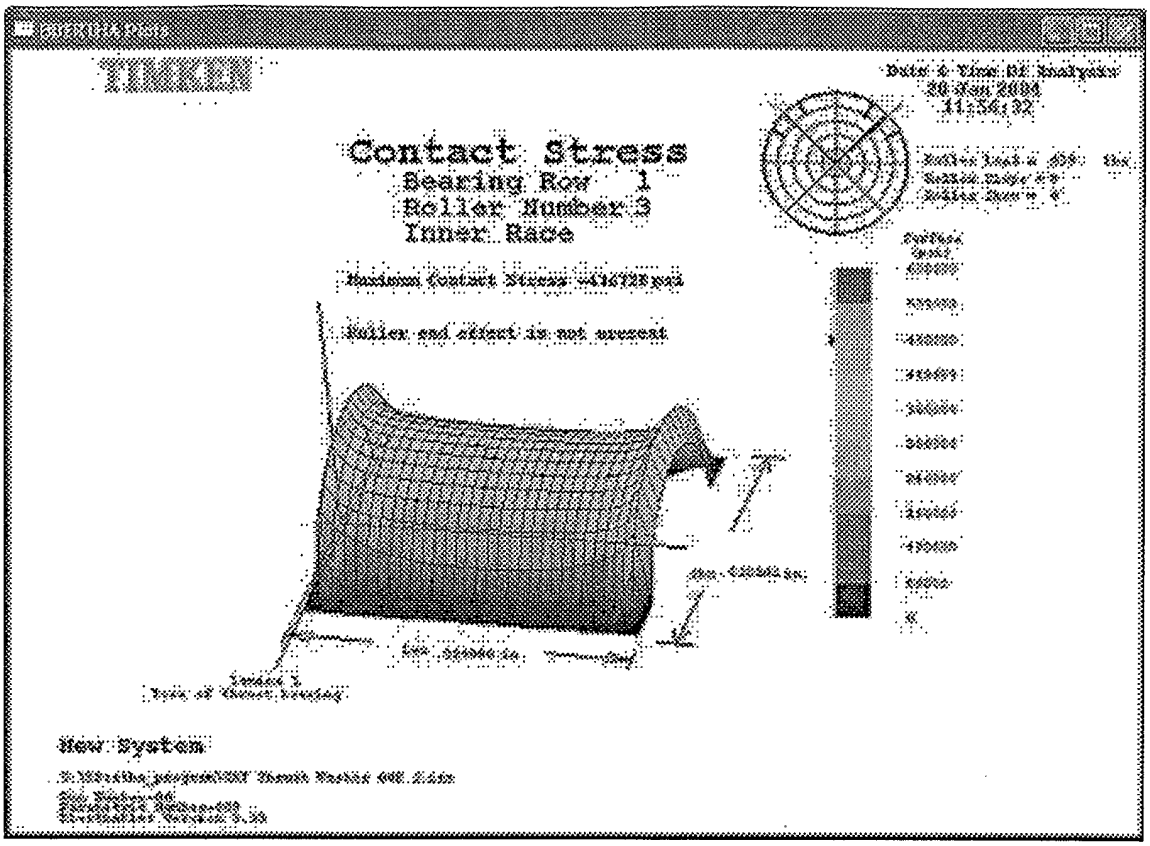


Figure 7

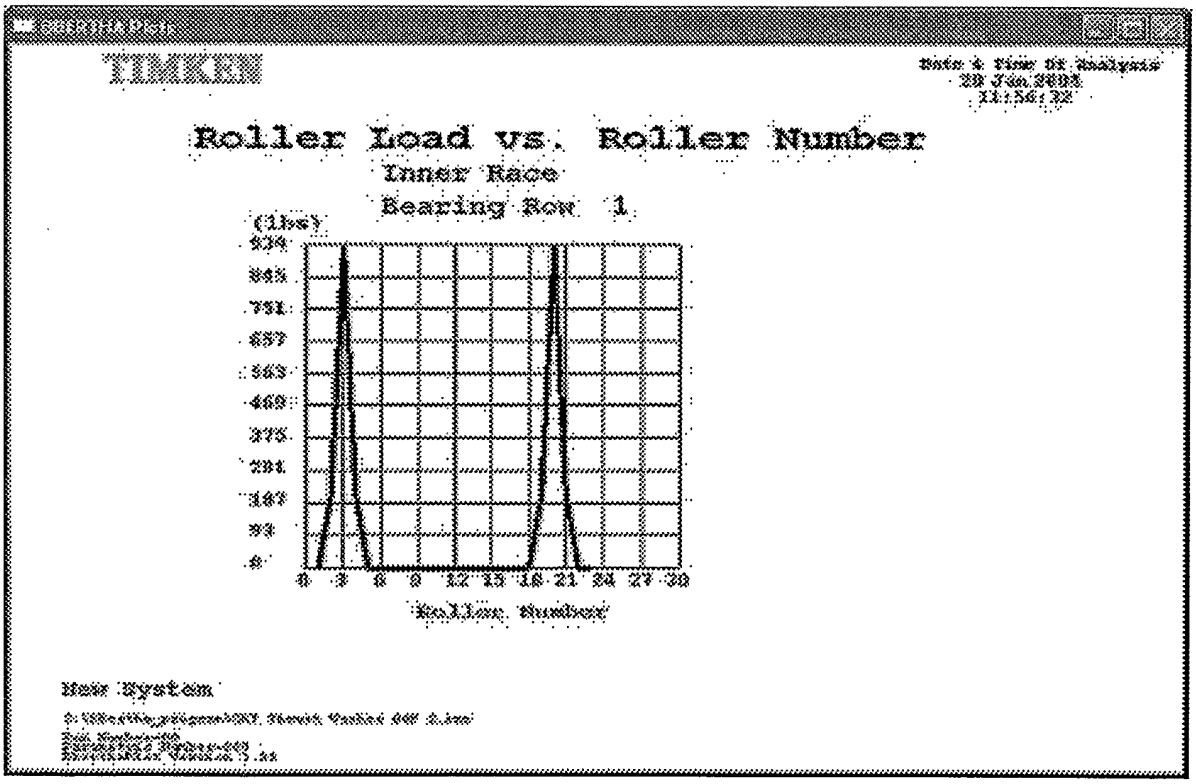


Figure 8

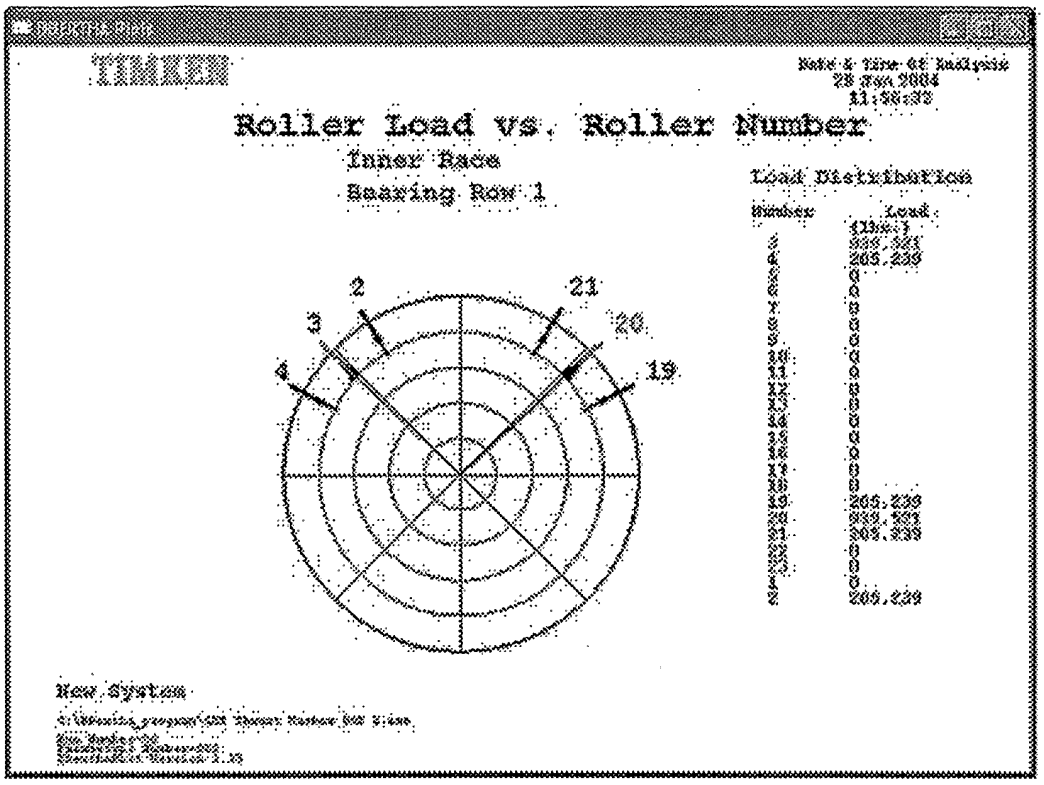


Figure 9

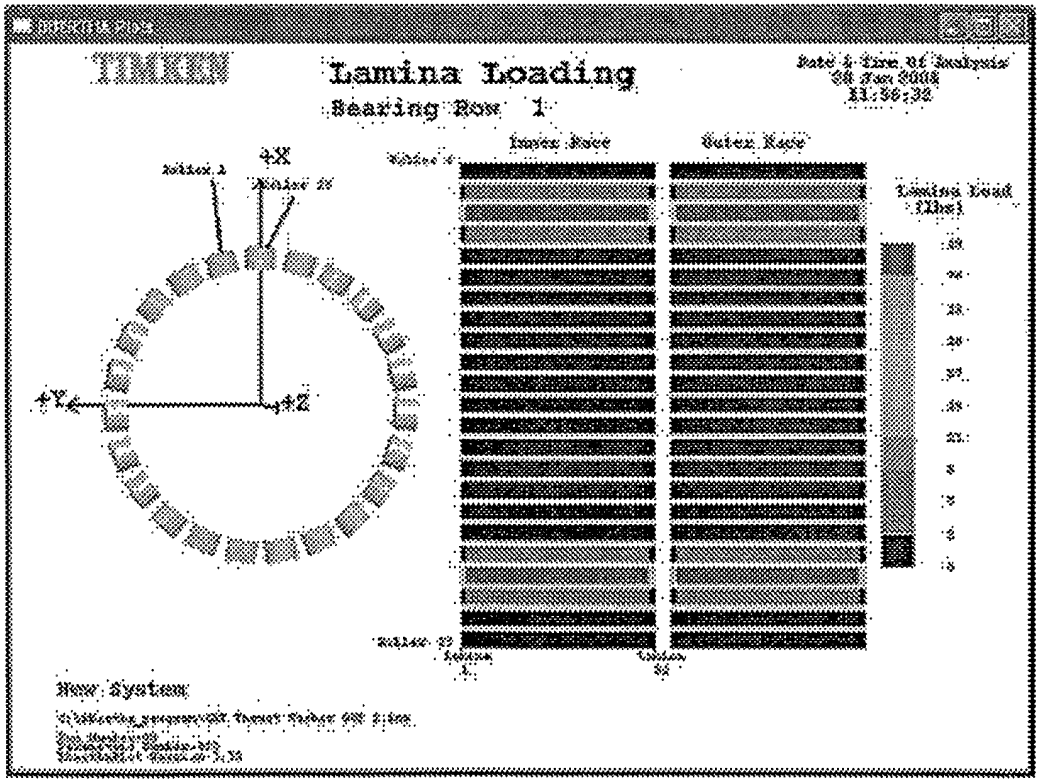


Figure 10

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/020011

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F16C33/62 F16C19/46 F16C19/30

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 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 practical, search terms used)
EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 262 674 A (NSK LTD) 4 December 2002 (2002-12-04) paragraph '0263! - paragraph '0271! paragraph '0288! figures 23,24	1-12
X	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 06, 3 June 2003 (2003-06-03) & JP 2003 056575 A (NSK LTD), 26 February 2003 (2003-02-26) abstract; figures 1,2	1-3,5, 7-9,11

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 September 2005	06/10/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Prieto Sanz, M.D.

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Form PCT/ISA/210 (second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 12, 5 December 2003 (2003-12-05) & JP 2004 060668 A (NSK LTD), 26 February 2004 (2004-02-26) abstract; figures 1,3	1,3,5,7, 9,11
X	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 11, 5 November 2003 (2003-11-05) & JP 2003 214444 A (NSK LTD), 30 July 2003 (2003-07-30) abstract; figures 1,7	1,3,5,7, 9,11
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