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Bearing Endplay Verification: Oscillation Analysis

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Abstract

The purpose of this study is to determine if the current non-oscillating endplay verification method is sufficient to meet the design specifications or if oscillation of the taper roller bearings needs to be added to the method. Adding oscillation to the method of verifying the endplay will require additional capital for equipment, will increase the manufacturing cycle time, and will increase the complexity of t the manufacturing process.

BEARING ENDPLAY VERIFICATION:
OSCILLATION ANALYSIS

Technology Research Paper

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CHAPTER 1

INTRODUCTION:

In industry, an important aspect of building mechanical equipment is ensuring that bearings are adjusted and verified to meet the intended product specifications. Bearings are utilized on rotating components so that loads can be transferred and friction can be reduced. Depending on the product design, the type of loads, and the amount of loads, different types of bearings can be used. This research focuses specifically on taper roller bearings. Taper roller bearings are generally used in sets because each end of the rotating component has a bearing on it. "Tapered roller bearings are one of the most important components used in rotating machinery. When operated under satisfactory load, alignment, and contaminant free conditions, a lasting service life is expected" (Craig, 2009).

A set of taper roller bearings can be adjusted so that the bearings are in endplay or in preload. "Endplay is the amount of axial or end-to-end movement in a shaft due to clearance in the bearings" (Timken Bearing Terms Glossary, 2014). Figure 1 illustrates where the amount of axial or end-to-end movement is measured on a taper roller bearing. Endplay is measured by applying an axial force in both directions and measuring the distance the bearing traveled. The amount of axial force that is required to move any given assembly will vary with the mass of the assembly, material of the assembly and bearings, and the design of the housing the assembly resides in. The force must be great enough to move the assembly but it is important that the force is low enough to ensure that deflection of any single component does not occur. Figure 2 illustrates a simple indicator gauge which is located on the end of a shaft with taper roller bearings. The value on the gauge changes when the shaft is moved axially from end-to-end resulting in endplay verification. Preload occurs when the endplay value is zero and the amount of preload increases as the amount of interference increases.

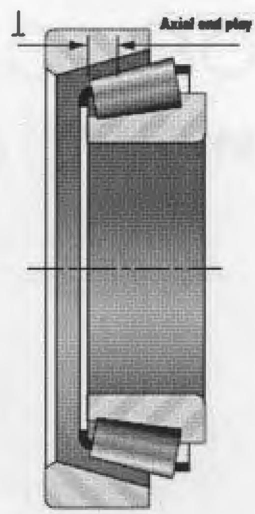

Figure 1. Taper Roller Bearing (Timken Industrial Bearing Maintenance Manual, 2014)

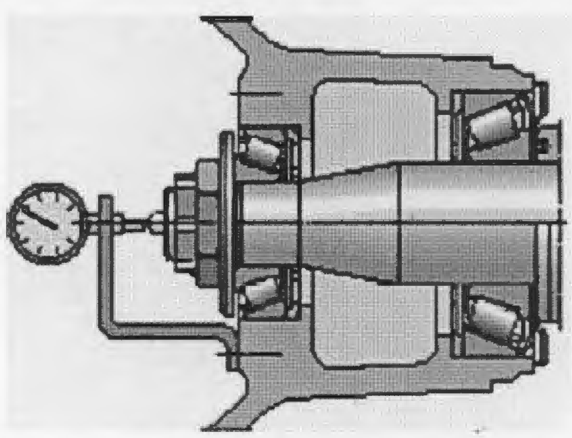

Figure 2. Simple Endplay Gauge (Koyo Training Manual, 2014)

The amount of preload or endplay is critical to the product to ensure that a premature failure does not occur and that the product life goals are met for the designed application. Each set of taper roller bearings are required to be adjusted differently based on the amount of loads, direction of loads, speed, amount of lubrication, system temperature, and other design specific applications. This research is intended to focus on the verification methods of taper roller bearing endplay, to ensure the taper roller bearings have been adjusted to meet the intended product specifications.

Statement of the Problem:

A specific shaft assembly at a manufacturing company consists of a shaft with gears, shifting components, and taper roller bearings on it. This shaft assembly rotates a drivetrain system between two housings and the taper roller bearings are adjusted in an endplay range of 0.0041" to meet the manufacturer's design specification. The current process for verifying the amount of endplay on a given set of taper roller bearings has variations as a result of the measuring method, part tolerances, and the design. The product specification for the intended endplay on a set of taper roller bearings is extremely small. As a result of the extremely small endplay specification, all variation reduction is important to ensure the quality of the product. There is a concern that the current verification process is not capable to meet the extremely small endplay specifications. Currently making changes to the product design or to adjust part tolerances may not being pursued due to the increase in product cost and dedication of resources is not available.

"In all critical applications axial and radial clearances should be checked with feeler gages or dial indicators to insure mounted clearances within tolerances established by the design engineer". "For precision applications . . . taper roller bearings . . . are employed to provide careful control of radial and/or axial clearances. This practice requires skill and experience as well as initial assistance of the bearing manufacturer" (Oberg, 2004). Timken, Koyo, SKF, NTN, and RBC are all manufacturers of bearings and are recognized by industry. The ideal process to verify the amount of endplay for a set of taper roller bearings is stated below by the Timken Bearing Company®:

> Locate a dial indicator against the end or shoulder on the shaft to measure the amount of axial movement. Load the shaft in one direction and oscillate it several times while the load is applied. A handle can be mounted on the shaft to make it easier to apply the load while oscillating the shaft. Oscillate the shaft at least 20 times to firmly seat the bearings and ensure an accurate reading. After seating the bearings in one direction, set the indicator to zero. Then apply the load in the opposite direction, oscillating the shaft as before, and read any movement on the indictor. The difference between the two readings is the end play. (Timken Industrial Bearing Maintenance Manual, 2014)

The Koyo Company® supports this process of endplay verification and has stated the following:

> If the bearings are to have a specific axial clearance setting, it is necessary to check the axial movement of the shaft which indicates the amount of axial clearance in the bearings. To accomplish this procedure, a dial indicator should be mounted against the end of the shaft to measure the axial movement. The shaft should be loaded in one direction and oscillated a number of times in each direction while the load is applied to get an accurate measurement, the indicator should be then set to 0. The load should then be reversed and the shaft oscillated again for an axial movement reading and bearing clearance measurement. (Koyo Training Manual, 2014)

The steps for the current endplay verification in the manufacturing company where the research is conducted are to attach a gauge to the assembly, activate the gauge's pneumatic cylinder to push the shaft with bearings in a downward direction, zero the indicator, activate the gauge's pneumatic cylinder to pull the shaft with bearing in an upward direction, read the endplay value on the indicator, and remove the gauge from the assembly. The current taper roller bearing endplay verification process follows the methods described by Timken and Koyo except that there is currently no ability to oscillate the taper roller bearings. If oscillating the taper roller bearings is required then the current equipment will need to be modified or replaced.

The Timken Industrial Bearing Maintenance Manual (2014) and the Koyo Training Manual (2014) both describe the importance of oscillation during the endplay verification process. When a taper roller bearing is in endplay there is a gap between the bearing's cone, rollers, and cup. When the force is applied in either direction the bearing's cone, rollers, and cup come into contact. If the bearing is not allowed to oscillate when the force is applied the rollers will bind. When oscillation is added the rollers rotate between the cup and cone and can fully seat allowing a more accurate endplay reading. When oscillation is not present the bearing's rollers do not fully seat in both directions resulting in the endplay verification value to be smaller than the actual endplay amount.

Purpose of the Study:

The purpose of this study is to determine if the current non-oscillating endplay verification method is sufficient to meet the design specifications or if oscillation of the taper roller bearings needs to be added to the method. Adding oscillation to the method of verifying the endplay will require additional capital for equipment, will increase the manufacturing cycle time, and will increase the complexity of the manufacturing process.

Need of Study:

While conducting a computer search / literature review the author found that the bearing manufacturing companies are the leaders in the field of taper roller bearing endplay verification methods and specifications. Typically taper roller bearings are specified to be adjusted in preload. Bearing company SKF states the following reasons why it is important to adjust taper roller bearings in preload:

> The main reasons to apply bearing preload are to enhance stiffness, reduce running noise, enhance the accuracy of shaft guidance, compensate for wear and settling (bedding down) processes in operation, and provide long service life. (SKF Application of Bearings, 2014)

SKF explains the importance of preload to a bearing but there are design reasons for specific applications where endplay is chosen over preload. One reason that a taper roller bearing may be put into endplay instead of preload is if there is not adequate lubrication on the bearing. Preload creates an increase in friction which results in an increase in temperature. If there is not adequate lubrication to cool the bearing then the bearing's life will be negatively impacted. RBC Bearing Corporation states the following reasons why precision bearing verification is important:

> Adjustment of the bearings is critical to achieving the best possible bearing life. As shown in the graph, a slight amount of preload provides maximum life, but it falls off dramatically if too much preload is applied. Many applications recommend a small amount of end play in the final adjustment because preload is hard to measure without equipment specifically designed for that purpose, and that equipment is not normally available in the field. (RBC Bearing Corporation, 2014)

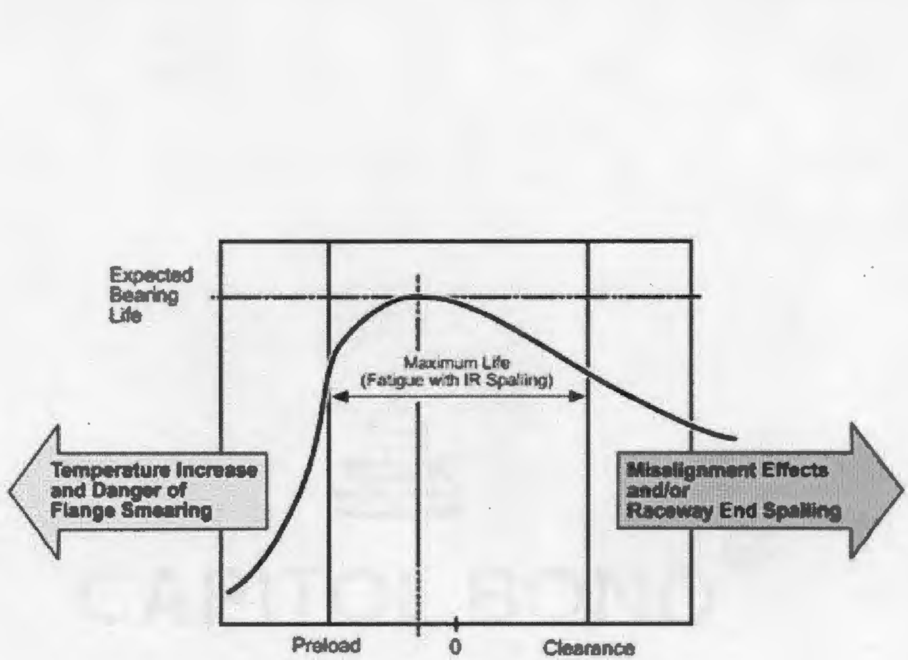

Figure 3. Effect of Preload on Life and Failure Mode (RBC Bearing Corporation, 2014)

Figure 3 does not have any numerical values on it to compare bearing life and preload / endplay because the size, shape, loads, speeds, and lubrication are different for each of the applications. Figure 3 does show that expected bearing life can be drastically reduced if the adjustment is off slightly.

The need / justification for this study is to conduct an experiment to see if the current non-oscillating verification method will produce the same result for a given taper roller bearing as the oscillating verification method. The Timken Industrial Bearing Maintenance Manual (2014) and the Koyo Training Manual (2014) both describe that oscillation ensures that a bearing is fully seated during the endplay verification. This study will determine if the current method of manufacturing is fully seating the bearings during the endplay verification and if the methods yield different results. If the data from this study shows that there is no variation between the oscillation and non-oscillation bearing endplay verification methods, then the current non-oscillation method should continue to be used which will result in a significant cost avoidance. If the data shows that variation exists between the two methods, then a business case to justify if the additional capital and cycle time increase to implement the oscillation bearing endplay verification will need to be evaluated.

Hypotheses:

The author hypothesizes that a non-oscillating bearing verification method will yield the same result an oscillating bearing verification method.

$H_O: \mu_1 = \mu_2$

Where μ_1 is the population mean of the non-oscillating bearing verification method and μ_2 is the population mean of the oscillation bearing verification method.

Limitations:

This study will be conducted in the view of the following limitations:

a. The information gathered from this experiment cannot be generalized for other taper roller bearing sets because each bearing set has different characteristics. The diameter, length, pitch, and number of the needle rollers will affect the endplay verification process differently.

Definition of Terms:

The following terms are defined to clarify their use in the context of the study.

- Axial load: A type of load on a bearing that is parallel to the axis of rotation" (Timken Bearing Terms Glossary, 2014).
- "Bearing: A machine part in which another part (as an axle or pin) turns" (Merriam-Webster, 2004).
- "Brinelling: A small surface indentation generated either on the raceway through plastic deformation at the contact point between the raceway and rolling elements,

or on the rolling surface from insertion of foreign matter, when heavy load is applied while bearing is stationary or rotating at a low rotation speed" (Koyo Training Manual, 2014).

- "Cone: The bearing's inner ring that is fixed to and/or pressed onto a rotating shaft" (Timken Bearing Terms Glossary, 2014).

- "Contamination: Any foreign or unwanted substance in the lubricant that can have a negative effect on bearing operation and fatigue life" (Koyo Training Manual, 2014).

- "Cup: The bearing's outer ring that sits on the housing and remains stationary during rotation" (Timken Bearing Terms Glossary, 2014).

- "Endplay: The amount of axial or end-to-end movement in a shaft due to clearance in the bearings" (Timken Bearing Terms Glossary, 2014).

- "Friction: The force that resist relative motion between two surfaces in contact" (Koyo Training Manual, 2014).

- "Needle Roller: Cylindrical roller with large length to diameter ratio. The length is between three and ten times the diameter, which does not usually exceed 5 mm. The ends of the needle roller may be one of several shapes" (Timken Bearing Terms Glossary, 2014).

- "Preload: Preload is an initial load or "negative clearance" given to a bearing before or during operation. This results in the rolling element and raceway surfaces being under constant elastic compressive forces at their contact points. This has the effect of making the bearing extremely rigid so that even when load is applied to the bearing, radial or axial shaft displacement is minimized" (NTN Bearing Corporation of America, 2014).

- "Radial Load: Force on a bearing from a load perpendicular to the shaft centerline" (Koyo Training Manual, 2014).

- "Spalling: pitting or flaking away of bearing materials" (Folger, 2014).

- "Taper Roller Bearing: A friction reducing bearing that is made up of a cup, cone and tapered rollers, which rotate around the raceway of the bearing" (Timken Bearing Terms Glossary, 2014).

- "Tolerance: The permissible range of variation in a dimension" (Timken Bearing Terms Glossary, 2014).

CHAPTER II

LITERATURE REVIEW:

Function of bearings:

The main function of any bearing is to reduce the amount of friction between objects. "Friction is the force that resists relative motion between two surfaces in contact" (Koyo Training Manual, 2014). There are numerous types and styles of bearings that can be adapted to a manufactured product to reduce the amount of friction between objects. Bearings can vary from simple to complex with a wide variety of tolerances and are a cost effective solution to reduce friction. Reducing friction will also reduce the amount of force to drive the moving components and will reduce wear from the objects resulting better performance and added reliability.

Oberg (2004) advises that bearings are made to high quality standards of accuracy and with close metallurgical control. Balls and rollers are normally held to diametral tolerances of 0.0010 inch or less within the single bearing. In most cases bearings are manufactured to adhere to meet an industry standard. There are multiple standards for the different load and speed specifications. For instance, roller bearings can have the following standards, RBEC-1, RBEC-3, RBEC-5, RBEC-7, and RBEC-9 where the RBEC-9 have the more precise tolerances and fits. In order to be interchangeable most bearings that are used follow the standard dimension, tolerances, and fits which are specified by the Anti-Friction Bearing Manufacturers Association (AFBMA) Standards (p.2269). There are different categories or series within the standards to ensure that the load and speed specifications are met which allow interchangeability to be possible. In general, the bearing vendor's representative can help to choose the proper bearing and bearing series to ensure the bearing will meet the intended functional requirements and specifications.

There are several advantages to utilizing bearings that adhere to the Anti-Friction Bearing Manufacturers Association (AFBMA) Standards. The main advantage is cost reduction because it allows larger batch sizes with common components to be manufactured which drives the piece price down. Larger batch sizes and common components will also support the bearing manufacturers to be able to keep up with the demand. If demand for a bearing that meets the AFBMA standards becomes an issue, bearings from other vendors can be substituted as long as all of the bearings meet the same standard. Another advantage to using bearings that meet the AFBMA is that there is usually a higher performance bearing that is the exact same size that can be used if failures and/or warranty occur. The higher performance bearing will cost more but can be interchanged if the additional performance is needed without changing the design of the product. Designing a product to utilize standard bearings will decrease cost and improve availability which are both important in manufacturing.

Types of bearings:

There are many different types of roller bearings and the differences can be determined by the shape of the rolling element. Figure 4 illustrates the basic types of roller bearings. The size and direction of loads, speed, amount of lubrication, and design of the product will help to drive the best choice of the bearing to be used.

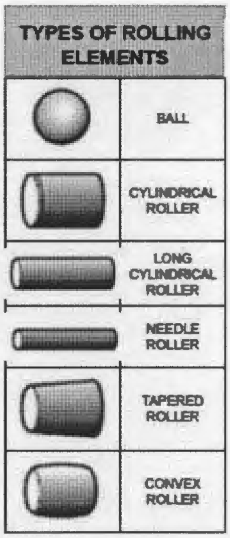

Figure 4. Types of Rolling Elements (Koyo Training Manual, 2014)

The major roller bearing types are ball, cylindrical roller, needle roller, taper roller bearing, convex / spherical roller, and thrust bearings. "Ball bearings consist of an inner and outer ring with a cage containing a complement of precision balls. Ball bearings support high axial loads and provide optimum performance in high precision, harsh operating environments" (Timken Industrial Bearing Maintenance Manual, 2014).

"Cylindrical roller bearings consist of an inner and/or outer ring, a roller retaining cage and a complement of controlled contour cylindrical rollers. Cylindrical roller bearings have a heavy radial load capacity which extends bearing life while reducing maintenance time and costs" (Timken Industrial Bearing Maintenance Manual, 2014).

"Needle roller bearings are a complement of needle rollers held in place with a cage. The mating shaft and housing are normally used as inner and outer raceways. Needle roller bearings have high load capacity which lengthens bearing live and reduces maintenance and replacement costs" (Timken Industrial Bearing Maintenance Manual, 2014).

"Taper roller bearings consist of four interdependent components: the cone (inner ring), cup (outer ring), tapered rollers (rolling element) and cage (roller retainer). Taper roller bearings have the ability to manage both thrust and radial loads providing enhanced performance in demanding applications" (Timken Industrial Bearing Maintenance Manual, 2014).

"Spherical roller bearings consist of an inner ring, outer ring, cage, and center-rounded rollers. Spherical roller bearings manage high radial loads even under misaligned conditions which extend bearing life. Unit design simplifies bearing handling, installation, and maintenance" (Timken Industrial Bearing Maintenance Manual, 2014).

"Thrust bearings can have a complement of balls, spherical rollers, cylindrical rollers, or taper rollers in a cage. Thrust bearings are designed specifically to manage heavy thrust loads and provide high-shock-load resistance for maximum bearing life and load capacity" (Timken Industrial Bearing Maintenance Manual, 2014).

Bearing storage and handling

The Timken Industrial Bearing Maintenance Manual (2014) and the Koyo Training Manual (2014) both describe that bearings are an important component in any manufactured product that has rotating parts. Problems with bearings can result in costly downtime, product damage, and equipment breakdowns. Damage to bearings as a result of improper handling practices can reduce the life of bearings which will impact a product's ability to perform and meet the consumer's expectations. This reduction in bearing life will negatively impact the overall cost of the product and to the business.

In order to minimize the cost to the business the Timken Industrial Bearing Maintenance Manual (2014) and the Koyo Training Manual (2014) both suggest that several techniques that can be utilized when bearings are packaged and stored. Bearings are generally manufactured from materials that can corrode so it is important to clean the bearing thoroughly and apply a rust preventative. This will help to protect the bearing from rusting while in storage. Bearings are then packaged in an impact resistant cardboard box and palletized in a manner to prevent a pallet from being stacked on top of another pallet of bearings to reduce potential transportation damage. Bearings should not be stored in an environment where the temperature is below 70° F and / or relative humidity levels are greater than 65 percent. Folger (2014) adds that the high surface finish of bearings makes them extremely vulnerable to etching or corrosion if moisture is present. Bearings should always be stored upright in the original boxes and must not sit directly on the ground. Bearings can be stored for several years if the manufacture's packaging is preserved.

The Timken Industrial Bearing Maintenance Manual (2014) and the Koyo Training Manual (2014) both describe the importance of handling bearings to ensure that the bearing's performance is not negatively impacted. A bearings surface finish is precisely ground and the bearing is heat treated to ensure that imperfections are minimized. Any nick or high point on one of the bearings surfaces will damage the mating bearing surface as the rollers rotate within the bearings cup and cone. If a bearing is dropped or impacts another object while it is being handled should be inspected to ensure that the cup, cone, cage, and rollers are not cracked, dented, or Brinelled prior to being used. When proper storing and handling bearing techniques are used the less likely premature failures will occur over the life of the bearing.

Bearing damage:

Folger (2014), the Timken Industrial Bearing Maintenance Manual (2014) and the Koyo Training Manual (2014) all state that bearing damage can occur due to inadequate lubrication, contamination, overload, improper handling, installation, and bearing setting. The biggest contributor to bearing damage is a result of inadequate lubrication due to overfilling, underfilling, incorrect specification, mixing or incompatibility, incorrect lubrication intervals, deteriorated grease or oil, water contamination, and particulate contamination. When the proper lubrication is used, the lubrication creates a film on all of the components of the bearings to keep them separated, protected from corrosion, and helps to dissipate heat that is caused by friction. The two main types of lubrication are grease and oil. Grease and oil have different characteristics which require a review of the bearing's application, operating conditions, and lubrication system prior to determining which type of lubrication to use.

Contamination is also a major contributor to bearing damage. Contamination can be in the form of dust, dirt, sand, scale, shavings, or debris can pass between the bearing's cup, cone, and rollers. This contamination can cause the bearing components to wear, pit, or bruise as the bearing rotates. Once one of the bearing's components is damaged, the damage will cause additional damage the mating bearing component with every rotation of the bearing. For example if a shaving that passes between a bearing roller and the bearing cup, the shaving could cause an indentation in the cup and a high point on the roller. Since the roller rotates between the cup and cone, the high point on the roller will make a slight indentation on the cup and cone on every rotation. This indentation may be very small but a bearing can rotate hundreds or thousands of times per minute causing the indentations to continuously get worse. Contamination can also be in the form of water or other substances that become mixed in the bearings grease or oil. The water that is in the grease or oil can cause the bearings components to corrode resulting in an imperfection in the surface finish of the component. Any imperfection on the surface of a bearing component will reduce the overall life of the bearing.

Jiang (2010) and Folger (2014) suggest that damage can occur when bearings are overloaded. Bearing overload occurs when a bearing is being used in an application when the load or speed is beyond the rated specifications. As the speed or load of a bearing increase, the temperature of the bearing also increases, often exceeding the lubrication systems ability to cool the bearing. Excessive temperatures can quickly reduce the life of a bearing. Excessive loads and speeds can also increase the amount of vibration in the bearings and other rotating components which can cause premature failures.

Folger (2014), the Timken Industrial Bearing Maintenance Manual (2014) and the Koyo Training Manual (2014) all stress the importance of handling and installing bearings in a manner not to introduce bearing damage. Technicians should always use the proper methods and equipment when working with bearings to ensure bearings are properly aligned on a shaft or in a housing. If a bearing is misaligned when it is installed or set the load the bearing is carrying may not evenly be distributed among the bearing's rollers. If the bearing is impacted while being seating the mild steel bearing cage that holds the rollers on the bearing cone can be damaged. Another form of damage as a result of impacts is Brinelling which is a small indentation on the bearing cup or cone from the roller while the bearing is being seated.

Bearing damage can also occur if bearings are not set into the proper endplay or preload specification. The amount of preload or endplay is critical to the product to ensure that a premature failure does not occur and that the product life goals are met for the designed application. Each set of taper roller bearings are required to be adjusted differently based on the amount of loads, direction of loads, speed, amount of lubrication, system temperature, and other design specific applications. The criticality of ensuring the bearings are set in the proper endplay or preload specification often drives the manufacturers to perform a verification process after the setting is complete. This verification process helps to ensure the setting procedure remains capable and the final product is assembled correctly.

CHAPTER III

METHODOLOGY

Outline of procedures to be employed:

The procedure to measure the value of the taper roller bearing endplay for this study will be as follows:

a. Inspect the current production endplay gauge is calibrated to ensure it is functioning correctly.
b. Develop a method to add oscillation to the endplay gauge process for this research project.
c. Perform endplay verifications with both processes 3 times each and record the results for 32 random assemblies.
d. Analyze the data
e. Provide endplay verification method recommendations

The endplay verification gauge that is being used in this study is the manufacturer's production gauge that was designed and fabricated by the manufacturer and is unique to this specific assembly. This gauge resembles the gauge in figure 2 on page 3 of this research paper. The gauge does have a pneumatic actuator that can push and pull the shaft with taper roller bearings to verify the amount of endplay which is not shown in figure 2. An inspection and calibration of the production gauge was conducted prior to the start of the taper roller bearing endplay verification study and the gauge was found to be in good working condition.

The method to obtain the endplay verification values with the non-oscillation method is as follows:

1. Attach the production endplay verification gauge to assembly's shaft.
2. Activate the pneumatic cylinder to push the shaft in the downward direction.
3. Zero the digital indicator.
4. Activate the pneumatic cylinder to pull the shaft in the upward direction.
5. Record the endplay value from the digital indicator.
6. Remove the production endplay verification gauge from the assembly.
7. Repeat steps 1 – 6 until 3trials have been recorded.

The method to obtain the endplay verification values with the oscillation method is as follows:

1. Attach the production endplay verification gauge to the same assembly's shaft.
2. Activate the pneumatic cylinder to push the shaft in the downward direction.
3. Mark a spot on the shaft and manually oscillate the shaft a minimum of 10 full rotations by turning the gear on the shaft.
4. Zero the digital indicator.
5. Activate the pneumatic cylinder to pull the shaft in the upward direction.
6. Manually oscillate the shaft a minimum of 10 full rotations by turning the gear on the shaft.
7. Record the endplay value from the digital indicator.
8. Remove the production endplay verification gauge from the assembly.
9. Repeat steps 1 – 8 until 3trials have been recorded.

Both methods were completed on 32 shaft assemblies which were chosen at random equally over 3 production days. The same assembly inspector was chosen to conduct the study for all 32 of the assemblies and the endplay data is shown in Table 1. The manual oscillation method was reviewed by one of the manufacture's quality engineers to ensure the endplay verification values were not affected as a result of the new oscillation method.

Two common types of analyses that are used to determine if the means of two groups are the same or different from each other are a t-test and an Anova test. There are multiple types of t-tests and Anova tests available which will depend on the characteristics of the data and the hypothesis that is being tested. T tests are generally used only when there are two groups to compare and if the data has a normal distribution. If there are more than two groups, multiple t-tests can be performed which would result in an increased chance of committing a statistical error. If there are more than two groups to compare or if the groups are independent an Anova test is generally used for the statistical analysis because the amount of error is reduced.

The author has chosen to test the hypothesis by using a t-test. A t-test is a ratio of the difference between groups (means) and the normal variability with the group. If the t value is large, the difference between the groups is much bigger than the normal variability within the group resulting in the two groups being significantly different from each other. If the t value is small, the difference between the groups is much smaller than the normal variability within the group resulting in the two groups not being significantly different from each other.

There are multiple types of t-tests and for this analysis a paired two tailed t-test will be used. A paired t-test is generally used to compare two small sets of quantitative data when the data samples are related and not independent. The hypothesis is comparing if the population mean of the non-oscillation process and the population mean of oscillation process are equal. Table 2 shows the population means for the 32 random samples for both the oscillation and non-oscillation bearing endplay verification processes. A two tailed t-test is generally used when the hypothesis allows for differences in either direction. All of the calculations that were performed in this study were done with an Excel spreadsheet. Excel is a common program that is readily available and has the capability to perform all of the required calculations.

Table 1. Endplay Data

Random Assembly Number (Sample)	Endplay Reading Trial #1 No Oscillation (in.)	Endplay Reading Trial #2 No Oscillation (in.)	Endplay Reading Trial #3 No Oscillation (in.)	Endplay Reading Trial #1 With Oscillation (in.)	Endplay Reading Trial #2 With Oscillation (in.)	Endplay Reading Trial #3 With Oscillation (in.)
1	0.0075	0.0070	0.0065	0.0070	0.0080	0.0075
2	0.0050	0.0050	0.0055	0.0060	0.0060	0.0060
3	0.0045	0.0050	0.0045	0.0055	0.0060	0.0050
4	0.0035	0.0045	0.0035	0.0040	0.0040	0.0050
5	0.0055	0.0055	0.0065	0.0055	0.0070	0.0065
6	0.0050	0.0045	0.0055	0.0050	0.0060	0.0055
7	0.0065	0.0070	0.0070	0.0070	0.0070	0.0070
8	0.0040	0.0040	0.0035	0.0050	0.0045	0.0040
9	0.0065	0.0065	0.0065	0.0070	0.0075	0.0065
10	0.0045	0.0040	0.0045	0.0050	0.0050	0.0050
11	0.0060	0.0070	0.0070	0.0070	0.0075	0.0065
12	0.0035	0.0040	0.0040	0.0040	0.0055	0.0050
13	0.0060	0.0055	0.0055	0.0065	0.0065	0.0070
14	0.0055	0.0050	0.0050	0.0045	0.0055	0.0055
15	0.0050	0.0050	0.0055	0.0060	0.0055	0.0065
16	0.0035	0.0040	0.0040	0.0040	0.0045	0.0045
17	0.0050	0.0050	0.0050	0.0060	0.0065	0.0055
18	0.0045	0.0040	0.0040	0.0045	0.0045	0.0045
19	0.0055	0.0050	0.0060	0.0070	0.0060	0.0060
20	0.0055	0.0055	0.0055	0.0060	0.0065	0.0070
21	0.0045	0.0050	0.0050	0.0055	0.0065	0.0055
22	0.0050	0.0045	0.0040	0.0040	0.0055	0.0050
23	0.0050	0.0050	0.0050	0.0060	0.0065	0.0050
24	0.0040	0.0040	0.0035	0.0055	0.0040	0.0040
25	0.0070	0.0060	0.0060	0.0070	0.0070	0.0070
26	0.0070	0.0065	0.0070	0.0080	0.0075	0.0075
27	0.0065	0.0065	0.0070	0.0080	0.0075	0.0070
28	0.0040	0.0040	0.0035	0.0045	0.0050	0.0045
29	0.0060	0.0055	0.0055	0.0070	0.0065	0.0065
30	0.0055	0.0050	0.0055	0.0055	0.0055	0.0060
31	0.0070	0.0070	0.0065	0.0075	0.0080	0.0075
32	0.0050	0.0055	0.0050	0.0065	0.0060	0.0060
All measurements recorded using an indicator with 0.0005" resolution.						

Table 2. Population Means

Random Assembly Number (Sample)	Endplay With Oscillation Population Mean (in.)	Endplay With No Oscillation Population Mean (in.)
1	0.0070	0.0075
2	0.0052	0.0060
3	0.0047	0.0055
4	0.0038	0.0043
5	0.0058	0.0063
6	0.0050	0.0055
7	0.0068	0.0070
8	0.0038	0.0045
9	0.0065	0.0070
10	0.0043	0.0050
11	0.0067	0.0070
12	0.0038	0.0048
13	0.0057	0.0067
14	0.0052	0.0052
15	0.0052	0.0060
16	0.0038	0.0043
17	0.0050	0.0060
18	0.0042	0.0045
19	0.0055	0.0063
20	0.0055	0.0065
21	0.0048	0.0058
22	0.0045	0.0048
23	0.0050	0.0058
24	0.0038	0.0045
25	0.0063	0.0070
26	0.0068	0.0077
27	0.0067	0.0075
28	0.0038	0.0047
29	0.0057	0.0067
30	0.0053	0.0057
31	0.0068	0.0077
32	0.0052	0.0062

Table 3. t-Test: Paired Two Samples for Means

	Oscillation data	No Oscillation data
Mean	0.0059375	0.005260729
Standard Deviation	0.00105473	0.001039615
Variance	1.11246E-06	1.0808E-06
Observations	32	32
Hypothesized Mean Difference	0	
df	31	
t-stat	13.98383091	
t Critical two-tail	2.039513446	

CHAPTER IV

DATA ANALYSIS AND CONCLUSIONS:

Data analysis:

The author hypothesizes that a non-oscillating bearing verification method will yield the same result an oscillating bearing verification method.

$H_O: \mu_1 = \mu_2$

Where μ_1 is the population is mean of the non-oscillating bearing verification method and μ_2 is the population mean of the oscillation bearing verification method.

The first step of the t test is to calculate the t-stat which is a measure of how reliable of a difference between the two processes. Table 3 shows that the t-stat for the data is 13.984. The second step of the t test is to determine what confidence level is to be used in the calculation. A confidence level refers to the percentage of all possible samples that can be expected to include the true population parameter. For this study the author has chosen to use a 95% confidence level. A 95% confidence level implies that 95% of the confidence intervals would include the true population parameter. The third step of the t test is to determine the t critical value for the t test based off of the 95% confidence level and the degrees of freedom. Since there are 32 samples the degree of freedom is 31. Table 3 shows that the t critical is 2.040. If the t-stat value is larger than the t critical value there is a significant difference between the two processes.

The analysis shown in table 3 indicates that to have a 95% confidence level that the population means are equal, the t value would have to be less than or equal to 2.040.

Since the t-value is 13.984 the author should reject H_O. The author is 95% confident that population means between the oscillation and non-oscillation method are not the same.

Recommendations:

The recommendation of the author is to create a business case to justify if the additional capital and cycle time increase that is needed to implement the oscillation bearing endplay verification process is worth pursuing. The result of the analysis shows a large amount of variation between the 2 different processes, but does not quantify the return on investment of implementing the oscillation bearing endplay verification process.

This business case should capture both quantitative and qualitative factors pertaining to implementing a new process change. Some of the quantitative factors would be the amount of capital required to implement the new process, the cycle time increase in dollars per unit, any system cycle imbalances due to the process change, and the amount of time to implement the new process with potential openings in the production schedule. Some of the qualitative factors would be what the quality risk with the current process is, how much risk the new process mitigates, and if the customer willing to pay more for the final product built with the new process.

The business case to implement the bearing endplay verification process with oscillation will need to be reviewed by the manufacturer to see what the return on investment will be. If the return on investment is positive, the manufacturer should implement the new process. If the return on investment is not positive then the current process should continue to be used.

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