Development of Outer Diameter Checking Pokayoke for Taper Roller Bearing and Optimization of Process Parameters using Taguchi Design of Experiments
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Abstract—“Pokayoke” is a Japanese improvement strategy for mistake-proofing to prevent defects (or nonconformities) from arising during production processes. Pokayoke is preventative action that focuses on identifying and eliminating the special causes of variation in production processes, which inevitably lead to product nonconformities or defects. Objective of this Pokayoke is to compare the Outer Diameter of Taper Roller Bearing with respect to the Outer Diameter of Master ring. Based on the readings and set value of tolerances, an automatic decision is taken to accept or reject the ring. Accepted or OK rings go further for the next operation whereas rejected rings are collected in rejection bin. This entire system is online i.e. during mass production of rings, this Pokayoke is working. Experimental analysis is carried out for optimizing the input parameters like Ring Clamping Time, Measurement Time, and Pressure of Compressed Air for getting desired output, which is Capability of Measurement. Experimental analysis is accomplished by using Design of Experiments (Taguchi / ANOVA design). For the design, performance and analysis of DOE statistical software (MINITAB 17) is utilized.

Key words: Outer Diameter, Multicasting Routing Protocols

I. INTRODUCTION

It is important to be aware about assembly quality issues due to they represent a significant proportion of quality defects in many companies. Assembly quality issues are commonly analyzed after they occur and are observed that best solutions to eliminate these issues are performing a Pokayoke or error-proofing design in the product or process. The Pokayoke technique developed by Shingueo Shingo has been successfully used to reach zero defects on many companies, this technique help to prevent the occurrence or detect on time defective parts during manufacturing or assembly processes; these improvements are possible by means of product or process design changes[2][3]. In order to detect the Outlier (Oversize and Undersize) in Outer Diameter, a mechanism is developed, which is nothing but a Pokayoke. Development and optimization of this Pokayoke is carried out at SKF India Ltd. Pune.

Pokayoke is comprised of following components.

- Measuring Probe / Transducer (LVDT) - which comes in contact with Outer ring and gets displaced w.r.t. master ring and this displacement in terms of electric signal is the output from LVDT.
- PLC Controller – It controls the function of various components in the system. It takes the electric signal from LVDT, processes it and gives output as Outer Diameter size display.
- Human Machine Interface (HMI) – There is a touch-screen, which helps operator to communicate with Pokayoke.
- Control Panel – It is having different control switches to operate different actuators.
- Mechanism for mounting and guiding the LVDT probe – This mechanism secures the probe and guides it during measurement.
- Machine base and frame – It forms a machine structure and supports all components.

Based on the readings and set value of tolerances, an automatic decision is taken to accept or reject the ring. Accepted or OK rings go further for the next operation whereas rejected rings are collected in rejection bin.

II. PROBLEM STATEMENT

As shown in Fig. 2, Bore of the Inner ring fits on shaft, whereas Outer ring locates in housing. Tolerances of Outer Diameter are designed, selected and manufactured in such a way that Outer Ring is press fitted and secured in housing. During rotation Cone (assembly of Inner ring, Rollers and Cage) rotates with the shaft while Outer ring is stationary.

Fig. 1: Components of Taper Roller Bearing

Fig. 2: Mounting of TRB in Housing

If Outer Diameter of bearing is undersize with reference to desired tolerance, then Outer ring will remain loose and there will be relative motion between Outer ring...
and housing. It will create noise during rotation and it will result into early failure of bearing. In second case if Outer Diameter is oversize then bearing will not at all fit into housing. Both undersize and oversize are not desirable w.r.t Outer Diameter size. It hampers the assembly process at customer end, thereby loss of customer’s production and it generates a customer complaint. So the problem is to generate a detection mechanism which will detect the defect (undersize and oversize) in Outer diameter, before it is being delivered to customer.

III. RESEARCH METHODOLOGY

A. Design and Manufacturing of Mechanism / Pokayoke:
This Pokayoke is mounted in existing Cup Height measurement machine. So considering design of Cup Height measurement machine, Pokayoke has been developed. Pokayoke is having provision to hold and guide the LVDT probe.

B. Identification of Setting Parameters:
For getting the best result for the performance of the Pokayoke or OD measurement following parameters needs to be optimized. [1]
- Ring Clamping Pressure
- Ring Clamping Time
- OD Measurement Time
- LVDT Pushing Pressure

C. Base Line Data Collection:
For any random setting, data regarding Pokayoke performance i.e. Gauge Capability (Cg) is collected. This forms the baseline for further experimentation. Cg(Gauge capability index) = ((K/100) * Tolerance) / L*s
Where K is percentage of tolerance (20 is default)
S is standard deviation of measurements
L is number of standard deviations that represent entire process spread (6 is default) [12].

D. Designing or Formulating Design Of Experiments:
Defining levels or range of setting parameters, Selecting the DOE type (i.e. Taguchi / Factorial), Generating orthogonal matrix containing different sets of setting parameters [4] [5].

E. Experimentation:
- Gathering data of Pokayoke performance i.e. Cg for each set of parameters mentioned in matrix.
- Completing the matrix by consolidating results. [12]

F. DOE Analysis:
- Generating Interaction plot for all parameters and finding out S/N ratio (Larger is Better).
- S/N = -10 log ((1/n) ∑ (1/y^2)) ….. for Larger is Better [4].Where, y is value of response variables and n is number of observations in the experiments.
- Calculating contribution of each parameter in Pokayoke performance
- Generating Optimization plot. [1] [4] [5]
- Finalizing the setting parameters.

G. Confirmation Run:
Putting up finalized parameters on machine and taking confirmation regarding pokayoke performance. Further fine tuning the parameters to get the best results.

H. Standardizing the parameters and compiling the results:
Standardizing the optimized parameters and Compiling the results and preparation of report.

IV. DESIGN AND EXPERIMENTAL SET-UP

As shown in Fig. 4, Mechanism for locating and guiding the probe is mounted on existing Cup Height measurement machine being used for Outer Ring of Taper Roller Bearing. This Cup Height Measurement Machine is connected to previous and next machine by an automated conveyor line. Outer Ring of Taper Roller Bearing is feed through inlet conveyor, and then in-feed pusher locates the ring at measurement station. After ring locating clamping mandrel comes down and clamps the ring. Now LVDT probe is feed towards OD of Outer Ring using mechanism for locating and guiding LVDT probe. Thus LVDT probe touches the OD and determines its size by comparing the measured Outer Diameter with OD of master ring. Reading is
displayed on panel; OK ring passes to outer conveyor whereas bad ring goes to rejection bin.

A. Configuration 1 (Before Measurement):

Fig. 5: Schematic of Experimental Set-up – Configuration 1

As shown in Fig. 5, LVDT probe is mounted in a mechanism, which secures and moves the probe to and fro. This mechanism is having pneumatic actuator and the position of actuator is controlled by a PLC program. A control panel is provided to set various actuators as per the setting procedure. HMI (Human Machine Interface) will interact with the operator to understand the output of the machine, setting parameters and errors in machine. Ring locating and clamping mandrel is controlled by a pneumatic actuator for it’s up and down motion. It locates and secures the work piece at measurement position. As show in the fig. before measurement, ring locating and clamping mandrel is in upward position. LVDT Probe is in unengaged position. Ring is fed at measurement location by in-feed pusher (not show in the fig.). Thus machine is now ready for measurement.

B. Configuration 2 (During Measurement):

Fig. 6: Schematic of Experimental Set-up – Configuration 2

Ring locating and clamping mandrel is moved to its downward position with the help of pneumatic actuator. Now ring is secured and clamped at measurement position. Now LVDT probe approaches the Outer Diameter of the ring with the help of pneumatic cylinder and when cylinder is at leftmost position, probe touches the Outer Diameter of the ring. Displacement of LVDT is calibrated and measured in terms of Diameter reading and displayed on screen. Entire working of the equipment is automatic, controlled by PLC program.

V. EXPERIMENTATION

Values of Process parameters for existing setting are given in Table I. These parameters are not optimized i.e. selection of these parameters is random.

<table>
<thead>
<tr>
<th>Process Parameters</th>
<th>Values</th>
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<td>Ring Clamping Pressure (Bar)</td>
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<tr>
<td>Ring Clamping Time (sec)</td>
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<td>OD Measurement Time (sec)</td>
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</tr>
<tr>
<td>LVDT Pushing Pressure (Bar)</td>
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Table I: Process Parameters for Existing Process

Further 25 readings of Outer Diameter shown by Pokayoke taken and its Gauge Capability is calculated using MINITAB 17 (Statistical software). In current setting Gauge Capability of 1.27 (Cg) is achieved, which is much less than accepted value (2.0) of Gauge Capability Index (Cg) as per six sigma standards[12].

Fig. 8: Gauge Capability for Existing Process Parameters

<table>
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<tr>
<th>DOE Run No.</th>
<th>Ring Clamping Pressure (Bar)</th>
<th>Ring Clamping Time (sec)</th>
<th>OD Measurement Time (sec)</th>
<th>LVDT Pushing Pressure (Bar)</th>
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Table 2: Taguchi DoE Design (4x16 Array)

Taguchi design is selected for carrying out Design of Experiments (DOE). As shown in above Table, 4 process parameters are taken for experimentation. 4 different levels have been defined for each parameter and array of DOE run is generated. Further Gauge Capability is calculated for each DOE run [5].
VI. ANALYSIS OF DESIGN OF EXPERIMENT

Based on the Gauge Capability of each DOE run, SN ration (larger is better) for individual parameter is calculated using Minitab 17 software. As shown in Fig. 9 following values are optimized values for getting larger Gauge Capability.

- Ring Clamping Pressure = 2.0 Bar
- Ring Clamping Time = 2.0 Sec
- OD Measurement Time = 2.0 Sec
- LVDT Pushing Pressure = 1.6 Bar

![Main Effects Plot for SN ratios](image)

Fig. 9: Selection of Optimized Parameters

Ranking of contributing factors are obtained by generating response table. Following is the ranking order of influencing parameters starting from most to least.

- OD Measurement Time
- Ring Clamping Time
- Ring Clamping Pressure
- LVDT Pushing Pressure

![Response Table for Signal to Noise Ratios](image)

Table 3: Response Table for S/N Ratio

VII. RESULTS

After analyzing the main effect plot and response table, values of optimized parameters are obtained; same are given in Table III. Values of optimized parameters are quite different from the values of normal process parameters. It is evident that OD measurement time for getting best result in terms of Gauge Capability is 2.0 sec and before it was 1.0 sec. So for stabilizing the reading/output from LVDT time of 2.0 sec is required. Required Ring Clamping Pressure is 2.0 Bar against 3.0 Bar, i.e. there was excess pressure for ring clamping and ring was getting disturbed due to this excess pressure.

Also the required ring clamping time is 2.0 sec against 1.5 sec, i.e. before ring clamping time was insufficient for clamping the ring firmly.

VIII. CONCLUSION

This paper describes the development of Pokayoke for checking Outer Diameter of Taper Roller Bearing. It also gives insight about process parameter optimization using Taguchi DOE.

Experimental analysis has been carried out using Taguchi design with 16X4 orthogonal array. Following are the finalized value of process parameters 1) Ring Clamping Pressure = 2.0 Bar, 2) Ring Clamping Time = 2.0 sec, 3) OD Measurement Time = 2.0 sec, 4) LVDT Pushing Pressure = 1.6 Bar. For verifying the performance of measurement Pokayoke Gauge Capability has been measured for both current process and optimized process. After optimizing the process parameters using Taguchi DOE Gauge Capability Cg = 3.3 has been achieved against Cg = 1.27, which is for current or un-optimized process.
Further 1 more LVDT probe can be mounted so Outer Diameter of Bearing can be measured at two distinct heights. From this we can measure the taper present in Outer Diameter. Process parameters for 2nd LVDT can be optimized using similar methodology which has been adopted in this paper.

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