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Construction and Praxis of Six Sigma DMAIC for Bearing Manufacturing Process

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ABSTRACT

The process capability improvement of a bearing manufacturing process using the Six Sigma-DMAIC approach was performed. A progressive method was adopted by the utilization of statistical techniques such as design of experiments for optimizing process capability. We report the draconian improvement in process capability with present approach. This has led to a diminution in high resource spoilage and rework. In the Define-phase, rejection data was used to identify the critical factors responsible for rejection. Process capability indices were used to evaluate the process performance in the Measure-phase. In the Analyze-phase, the vital root causes responsible for low process capability were identified. Using the Taguchi robust design technique, the Improve-phase focuses on optimizing the critical root causes. Analysis of variance was used to examine the results of the experiment. In the control-phase, Cp and Cpk values were improved from 1.170 and 0.976 to 2.780 and 2.230.

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1. Introduction

In today's competitive era, to sustain for the long run 'performance' is the most important factor. The quality challenge in today's competitive market is to be on the leading edge of producing high quality products at minimum cost, which forces organizations to look for new ways to consistently improve the quality, reduce the manufacturing cost and rejections. This cannot be done without a systematic approach and this approach is contained within what has been called 'Statistical Quality Control' (SQC). The segment of SQC discussed in the present study is "process capability". The importance of process capacity analysis is that it allows one to quantify how well a process can provide acceptable results. As an outcome, a manager or engineer can prioritize the action plan and identify the processes that require immediate process improvement. Process capability study indicates whether a process is capable of producing nearly all acceptable products. If the process is capable, then statistical process controls can be used to monitor the process and conventional acceptance efforts can be reduced or eliminated entirely. This not only results in great cost savings in eliminating nonvalue added inspections but also eliminates scrap, rework and increases customer satisfaction. The benefits of performing process capability studies are certainly worth the efforts in the long run. A process will be classified as capable or incapable when a capability study has been completed. When the process is unable to produce almost all conforming goods, the process is stated to be ineffective, and acceptance sampling or hundred percent inspection must remain a part of the operation.

In the present work, the define-measure-analyze-improve-control (DMAIC) approach is employed to improve the process capability of the bearing manufacturing process at the Auto Component Business group of Kirloskar Oil Engine Ltd. Khadki, Pune, India. The scope of the present work is to identify the vital causes responsible for most of the rejection among many by using Pareto analysis, identify and address processes which are responsible for major rejection, evaluate the process capability of these processes. Then Taguchi's robust design approach was utilized to find out the critical process parameters responsible for the low process capability for which the L27 orthogonal array (OA) was constructed, which uses three factors and levels. Finally, Analysis of Variance (ANOVA) was used to analyze the results of experimentation.

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Nomenclature

Symbol	details
Cp	Capability index
Cpk	Process performance capability index

2. Literature review

2.1. Process capability

The notion of process capability was created by statistician community. It did not become popular until reports of Japanese manufacturing methods appeared in trade and professional periodicals in the United States (Sullivan 1984). The Cp and Cpk process capability indices, as well as their statistical features, such as estimation hypothesis testing reflect that the degree of the process variation in respect to the specification limits is reflected by the Cp index. The index Cpk, on the other hand, considers both the process variance and the position of the process mean. Also, it provided the first discussion of the indices, sampling characteristics and made some suggestions for modifications to the indices. Process capability indices are used for evaluating process performance as they provide a static goal for performance, it measures continuous process improvement, it provides common process performance language, criteria of prioritization for process improvement, directs process improvement activities and it is an indicator of quality system deficiencies [1]. Applications of statistical processes for health monitoring, surveillance in space and time, profile monitoring, auto-correlation of data and the impact of error in estimating were discussed by Woodall and Montgomery [2]. Kotz and Johnson (2002) conducted an inquiry and presented brief remarks and views on process capability indices along with evaluation of most extensively used process capability indices [3]. Sharma and Rao (2014) applied DMAIC methodology to improve the engine crankshaft production process. It was reported that minimizing the critical causes step by step showed improvement in capability index (C_p) and the process performance capability index (Cpk) [4]. The measurement of the capability of a process when the prime requirement is to produce the items within a specific tolerance range and follow the normal distribution, the indices Cp, Cpk, Cpm, and Cpmk are most useful [5]. Sullivan (1984) published descriptions of capability indices with an improvement over previous metrics that were used to describe process capability [6]. Feigenbaum (1951), Juran, Gryna, and Bingham (1974) employed six sigma technique to determine the capability of a process. A process's intrinsic variability was modelled to determine the standard deviation (sigma-σ) [7]. This description gave process capability an interpretation that was independent of customer specifications. There was an implication of inevitability regarding process performance. Juran, Gryna, and Bingham (1974) established a connection between process variability and customer requirements as a way of assessing the requirement for process improvement actions by comparing six sigma with the tolerance width [8]. However, the capability was nevertheless understood independently of the specifications. Finally, J. M. Juran and Gryna (1993) introduced a capability ratio which was the first statistic that linked process variability to customer specifications directly [9].

$$\text{Capability ratio} = 6\sigma \text{ variation/tolerance width} \quad (1)$$

In case of capability ratio, customer specifications are linked directly to process variability, and in doing so, they highlight the importance of the supplier obligation to meet such requirements. Capability indices, on the other hand, have some advantages over capability ratios. As the process performance improves, the value of capability indices rises. This property may be of limited analytical value, but it does provide psychological insight in terms of the natural "bigger is better" predisposition. Furthermore, capability indices specify the relative advantages of improvements both in terms of process location and variation. Reports from Shewhart (1931); Joseph M. Juran, Gryna, and Bingham (1974); and J. M. Juran and Gryna (1993) were the historic imprints on how to determine specification limits using process capability indices [8–10]. In general, they suggested that the tolerance range should be kept to a maximum of six sigma. Palmer and Tsui (1999) summarized the process capability indices and reviewed the fundamentals of index interpretation and process improvement [11]. Comparisons of the indices' behavior under shifting process conditions were described. Finally, recommendations were given for the selection of indices to direct process improvement activities at various levels of process performance. Stoumbos (2002) presented the process capability indices Cp, Cp*, CPL, CPU, CPL*, CPU*, Cpk, Cpk*, Cpm and Cpm* which were linked to process parameters. These indices are used by industries till date all over the world [12]. Brugger (1992) provided a procedure to perform a process capability study to determine the inherent variation in a process and mentioned the benefits of conducting process capability study [13]. Gitlow, Gitlow, and Oppenheim (1989) presented detailed discussion on the process capability and improvement studies with attribute process parameters [14].

2.2. Six Sigma and DMAIC

Six Sigma is a philosophy as well as a method that is extremely rigorous developed by Motorola. It was developed as a technique to minimize process variance and to improve the quality and performance of an organization. The philosophy and methodology were developed to enhance customer satisfaction and profitability by reducing the cost. The methodology is to continuously monitor the process to eliminate errors or failures in the production processes. Performance of a system can be evaluated by measuring the critical to quality (CTQ) characteristics. Any divergence in the CTQ parameters' performance can be regarded a defect [15]. The DMAIC is extensively applied Six Sigma approach for improving the process capability [16]. Antony and Banuelas (2002) identified that DMAIC methodology was effective approach for successful implementation of Six Sigma. Taguchi robust design was employed for analysis of various CTQ characteristics [17]. Srinivasan et al. (2014) implemented Six Sigma as well as Taguchi's robust design to examine various CTQ characteristics. The process parameters were identified and optimized which affect the CTQ characteristics and led to diminished fault rate [18].

2.3. Taguchi robust design

The Taguchi robust design, created by Genichi Taguchi in 1980, is a commonly used statistical method to optimize the process parameters of production process and quality characteristics of products [19]. Gopalsamy, Mondal, and Ghosh (2009) discussed the applications of the Taguchi method for investigating the surface finish and tool life of end milling as a function of various cutting parameters [20]. Li, Al-Refaie, and Yang (2008) concluded that the DMAIC approach involving Taguchi's robust design is an efficient approach for improving the process capability [21]. Pareto analysis is used for separating the 'vital few' from the 'trivial many' causes of rejection [22].

3. DMAIC methodology, results and discussion

3.1. Define-phase

This study was carried out for half engine bearing. The define-phase includes charting the flow of the machining operations. There are thirteen process workstations in all and two inspection points located after the tenth workstation. Table 1 shows the specifications of the bearing manufacturing system.

The time duration for collecting the rejection data was one calendar year. The rejection data sheet was created identifying fifty-nine defects. Out of the fifty-nine defects identified, twenty defects and their proportion with respect to total defects are listed in Table 2. As an industrial convention, the defects which have more than 1 % of total rejection were only considered for further study. To find defects which were contributing most to the rejection, monthly rejection data was collected, which was used as an input for the Pareto analysis. Fig. 1 shows Pareto analysis for defects observed in bearing manufacturing. It can be observed that nine defects contribute to nearly 80 % of rejection.

3.2. Measure-phase

The 'Measure' phase included the evaluation of current performance with respect to critical quality characteristics (CQC). A data collection system was established for collecting data for each CQC.

Table 1
Specifications of bearing manufacturing system.

Sr. No.	Title	Specifications
1	Range of Products	Diameter from 38 to 125 mm, Height up to 70 mm
2	Bearing Material	Bimetallic Bearings, Backing: steel, Lining material: Cu-Pb, Al-Sn
3	Type of Production	Batch Production, Cellular Manufacturing System, Automatic Transfer lines, Product Layout

For attribute parameters, rejection data for 30 days was collected and for variable parameters 60 data points were collected. Classification of defects according to inspection method and process capability study is presented in Table 3.

The parameters selected for process capability study are listed in Table 3. These parameters can be classified as either variables or attributes depending upon, method of evaluation. For attribute parameters, daily production of one cell is considered for thirty days and accordingly P, UCL and LCL were calculated using the P chart. A variable process capability study was performed for measurable parameters using Cp and Cpk values by using standard formulae.

The Table 4 provides rejection in PPM for attribute parameters and Table 5 provides process capability indices for variable parameters. Cp and Cpk values for 'Crush height' and 'Finished width at crown' were found to be above satisfactory level. Cp and Cpk values for 'Finish wall thickness at crown' were below acceptable levels. It is desired to have at least a process capability index of 1.33. Capability of the process for attribute parameters is such that it will produce rejection indicated by the PPM rejection level for that parameter [23]. If the rejection level is above UCL, it is an indicative for presence of assignable causes. Based on the findings of the measure phase, it was decided to undertake process improvement actions for 'Finish wall thickness at crown'. This parameter had the Cp and Cpk values critically lower than the desired value of 1.33. This warrants for significant improvement at 'Auto bore broaching workstation'.

3.3. Analysis-phase

The measure-phase indicated that the performance level of the process being practiced was unacceptable and needed improvement. The critical cause responsible for variation in 'Finish wall thickness at crown' was identified and analyzed. The fishbone diagram was prepared to detect various aspects that contribute to the variation in 'Finish wall thickness at crown'.

The fishbone diagram presented as Fig. 2 reveals common causes and specific causes for variation in 'Finish wall thickness at crown'. The identified common causes like unskilled operators and improper machine settings were eliminated. Parameters like cutting speed and roundness of the cutter were already optimized during the product development phase. Hence, it was not considered for further analysis. The most influential causes which have a decisive role for the 'Finish wall thickness at crown' were identi-

Table 2
Defects and their proportion with respect to total defects.

Sr. No.	Defect	Count	Cumulative Count	Cumulative percentage
1	O.D. Spoil	18,490	18,490	15.00 %
2	Bore Spoil	17,994	36,484	30.00 %
3	Wall plus minus	15,555	52,039	43.00 %
4	Deformed	13,790	65,829	54.00 %
5	Defective Oil Groove	9082	74,911	62.00 %
6	Without Stamping	7536	82,447	68.00 %
7	Double Coining	5222	87,669	72.00 %
8	Crush Height Minus	3849	91,518	75.00 %
9	Finished Width minus	3600	95,118	78.00 %
10	Less Facing allowance	3456	98,574	81.00 %
11	Wrong Stamping	3343	101,917	84.00 %
12	Excess two corner deburr	2851	104,768	86.00 %
13	Width minus	2442	107,210	88.00 %
14	Relief not OK	2388	109,598	90.00 %
15	Width plus	2345	111,943	92.00 %
16	Defective chamfer	2248	114,191	94.00 %
17	Line in bore	1987	116,178	96.00 %
18	Nick spoiled	1875	118,053	97.00 %
19	Defective countersink	1765	119,818	99.00 %
20	Twist	1697	121,515	100.00 %

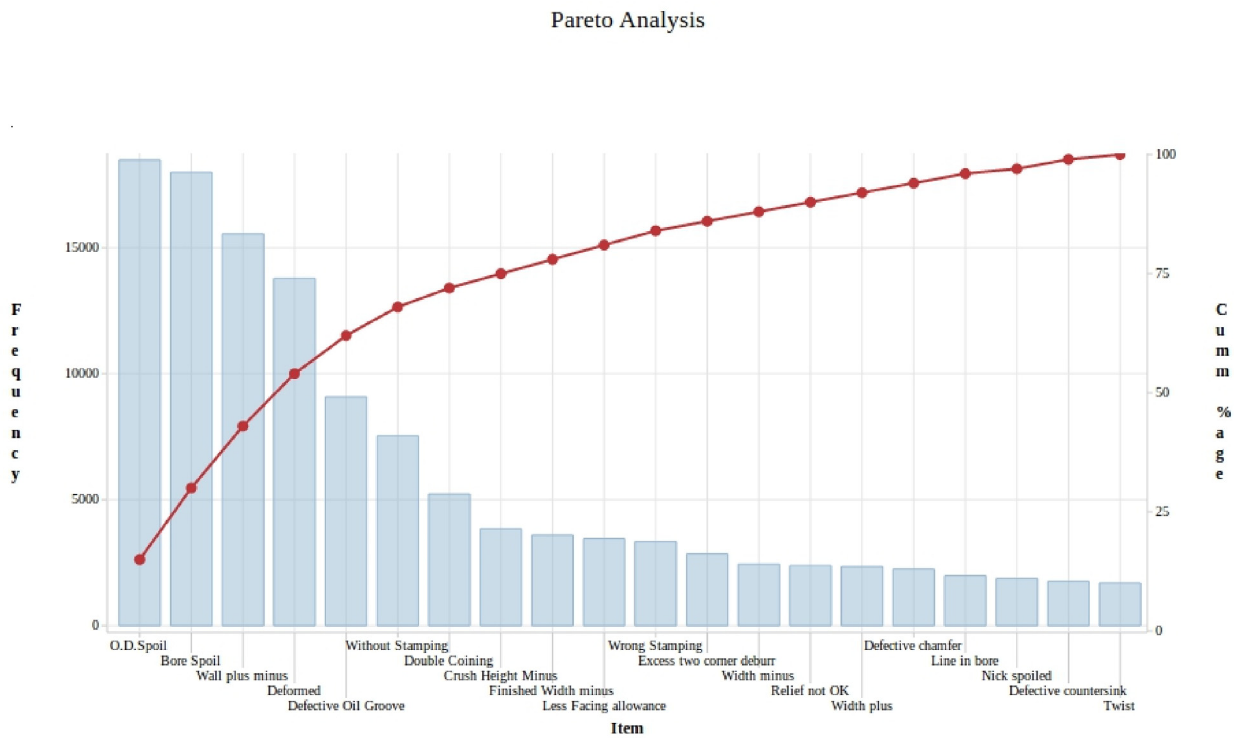

Fig. 1. Pareto analysis for defects.

Table 3
Classification of defects according to inspection method and process capability study.

Sr. No.	Defects	Quality characteristics	Inspection Method	Type of process capability study
1	O.D. spoil	Marks on outer diameter	Visual	Attribute
2	Bore spoil	Bore spoiled	Visual	Attribute
3	Wall plus minus	Finish wall thickness at crown	Wall thickness measurement machine	Variable
4	Deformed	Deformed	Visual	Attribute
5	Defective oil groove	Chip embedded in groove	Visual	Attribute
6	Without stamping	Stamping operation missing	Visual	Attribute
7	Double coining	Double coining	Visual	Attribute
8	Crush height minus	Crush height	Height measurement machine	Variable
9	Finished width minus	Finished width at crown	Micrometer	Variable

Table 4
Rejection in PPM for attribute parameters.

Sr. No.	Attribute parameter	Rejection in PPM		
		Average	UCL	LCL
1	O.D. Spoil	4090	5769	2412
2	Bore Spoil	3814	5434	2193
3	Deformed	2920	4339	1501
4	Defective Oil Groove	747	1466	28
5	Without Stamping	1933	3089	778
6	Double Coining	968	1786	150

Table 5
Process capability indices for variable parameters.

Sr. No.	Parameter	C_p	C_{pk}
1	Finish wall thickness at crown	1.170	0.976
2	Crush height	3.630	2.540
3	Finished width at crown	3.050	1.870

fied as clamping pressure (CP), the worn-out cutter or usage of the cutter (UC) and the length of bimetallic strip (LBS).

3.4. Improve-phase

This phase involved optimizing values of the CP, UC and LBS, which may have a significant impact on the 'Finish wall thickness at the crown'. For optimization, experiments were designed and conducted by developing an OA, and results were analyzed by employing ANOVA. Levels for factors under consideration were selected such as level-I indicates the lower value, level-II indicates the actual value, whereas level-III indicates the higher value of the respective factor.

Three factors and three levels are used to make L27 OA as illustrated in Table 6, whereas Table 7 lists the number of trials carried out as a part of experimentation.

The control over variables to avoid confounding was achieved by randomizing the trials. ANOVA is used to detect the importance of one or more factors by comparing the response variable at the different factor levels. The results of ANOVA with three factors

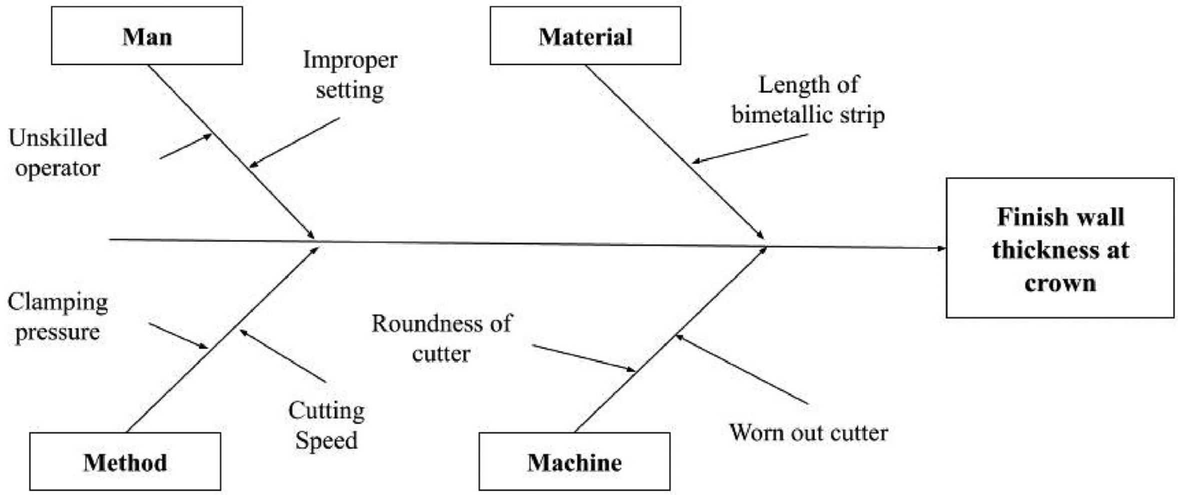

Fig. 2. Fishbone diagram.

Table 6
Factors along with its levels.

	Factor	Unit	Level-I	Level-II	Level-III
A	Clamping pressure (CP)	Bar	4	5	6
B	Usage of cutter (UC)	–	1200	1500	1800
C	Length of bimetallic strip (LBS)	mm	62.78	62.79	62.80

Table 7
Taguchi experimental L27 orthogonal array.

Sr. No.	A	B	C	Finish wall thickness at crown	S/N Ratio
1	4	800	62.78	0	
2	4	800	62.79	0.001	60.0000
3	4	800	62.8	0.001	60.0000
4	4	1000	62.78	0.001	60.0000
5	4	1000	62.79	0.001	60.0000
6	4	1000	62.8	0.002	53.9794
7	4	1200	62.78	0.001	60.0000
8	4	1200	62.79	0.001	60.0000
9	4	1200	62.8	0.002	53.9794
10	6	800	62.78	0.001	60.0000
11	6	800	62.79	0.001	60.0000
12	6	800	62.8	0.002	53.9794
13	6	1000	62.78	0	
14	6	1000	62.79	0.001	60.0000
15	6	1000	62.8	0.002	53.9794
16	6	1200	62.78	0.001	60.0000
17	6	1200	62.79	0.001	60.0000
18	6	1200	62.8	0.002	53.9794
19	8	800	62.78	0.001	60.0000
20	8	800	62.79	0.002	53.9794
21	8	800	62.8	0.004	47.9588
22	8	1000	62.78	0.001	60.0000
23	8	1000	62.79	0.002	53.9794
24	8	1000	62.8	0.004	47.9588
25	8	1200	62.78	0.001	60.0000
26	8	1200	62.79	0.003	50.4576
27	8	1200	62.8	0.005	46.0206

and three levels for ‘Finish wall thickness at crown’ are summarized in Table 8.

It is evident from Table 8 that the parameter ‘Length of bimetallic strip’ strongly influences the ‘Finish wall thickness at crown’ followed by the ‘Clamping pressure’. The impacts on input components were calculated using a tabular value with a 95 % confidence interval, indicating that all three elements influence ’Finish wall thickness at the crown’.

The Fig. 3 shows the response diagram for ‘Finish wall thickness at crown’. It can be observed from Fig. 3, as the ‘Length of bimetallic strip’ increases the magnitude of S/N ratio decreases. ‘Clamping pressure’ also revealed the same trend. There is no significant change in the S/N ratio because of change in the ‘Usage of cutter’.

Table 8
Analysis of variance for finish wall thickness at crown.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Clamping pressure	2	0.0000116	0.0000116	0.0000058	16.19	0
Usage of cutter	2	0.000001	0.000001	0.0000005	1.34	0.284
Length of bimetallic strip	2	0.0000165	0.0000165	0.0000083	22.99	0
Error	20	0.0000072	0.0000072	0.0000004		
Total	26	0.0000363				

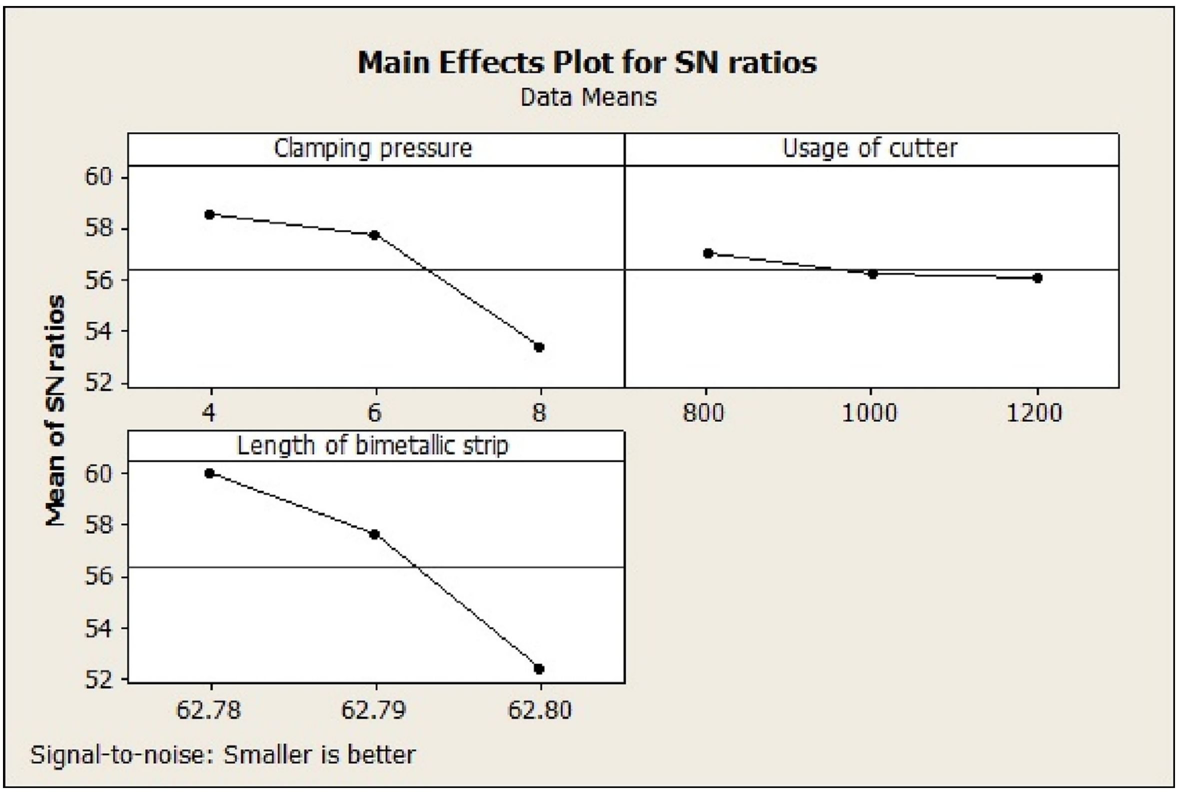

Fig. 3. Main effect plot for SN ratios.

From the response diagram of 'Finish wall thickness at crown', it is possible to get higher value of S/N ratio by setting up the 'Length of bimetallic strip' at 62.78 mm and 'Clamping pressure' at 4 bar. The Fig. 4 shows the residual plot which clearly reveals the existence of linearity between the actual and fitted values. From the standardized residual versus percent graph, it can be observed that the predicted value and experimental value are in near agreement. The experimental data is linearly fit for 'Finish wall thickness at crown'. The residual versus fits plot suggests the appropriateness of the simple linear regression model. It can be observed that the residuals spread randomly around the zero line, which suggested that the assumption that the relationship is linear is reasonable. It also can be observed that the variances of the error terms are nearly equal and there are no outliers.

An interaction plot between the factors 'Length of bimetallic strip' and 'Clamping pressure' is plotted to examine how the interactions affect the relationship between these factors and their responses. Fig. 5 shows the interaction plot for 'Finished wall thickness at crown'. It can be observed from the interaction plot that level 3 values for both the factors were contributing in large variation in the 'Finished wall thickness at crown' and needs to be avoided.

3.5. Control-phase

As an outcome of the Improve-phase, optimal factors and levels for 'Finish wall thickness at crown' were obtained. A trial run with a sample size of 50 units was carried out by setting up the length of the bimetallic strip at 62.78 mm, clamping pressure at 4 bar and 1500 value for cutter usage for optimizing the multiple responses. The appropriate minimum process capability value (Cp and Cpk) for two-sided specifications is 1.33, which guarantees a very low rejection rate (0.007 %) and makes it an effective strategy for inhibition of non-conforming items [23]. Cp and Cpk values for 'Finish wall thickness at crown' were found to be 2.78 and 2.23, which were in the acceptable range. It clearly indicates that the optimal factors and levels selected in the present approach was successful.

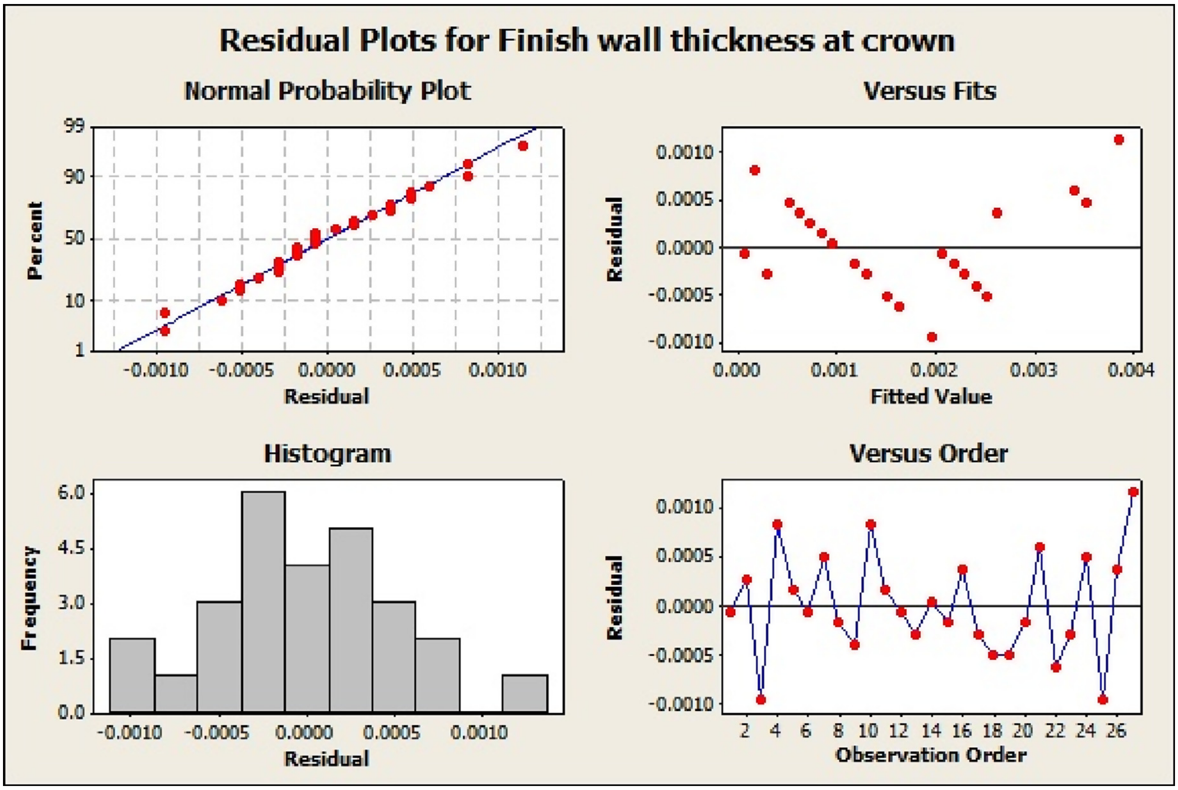

Fig. 4. Residual plots for finish wall thickness at crown.

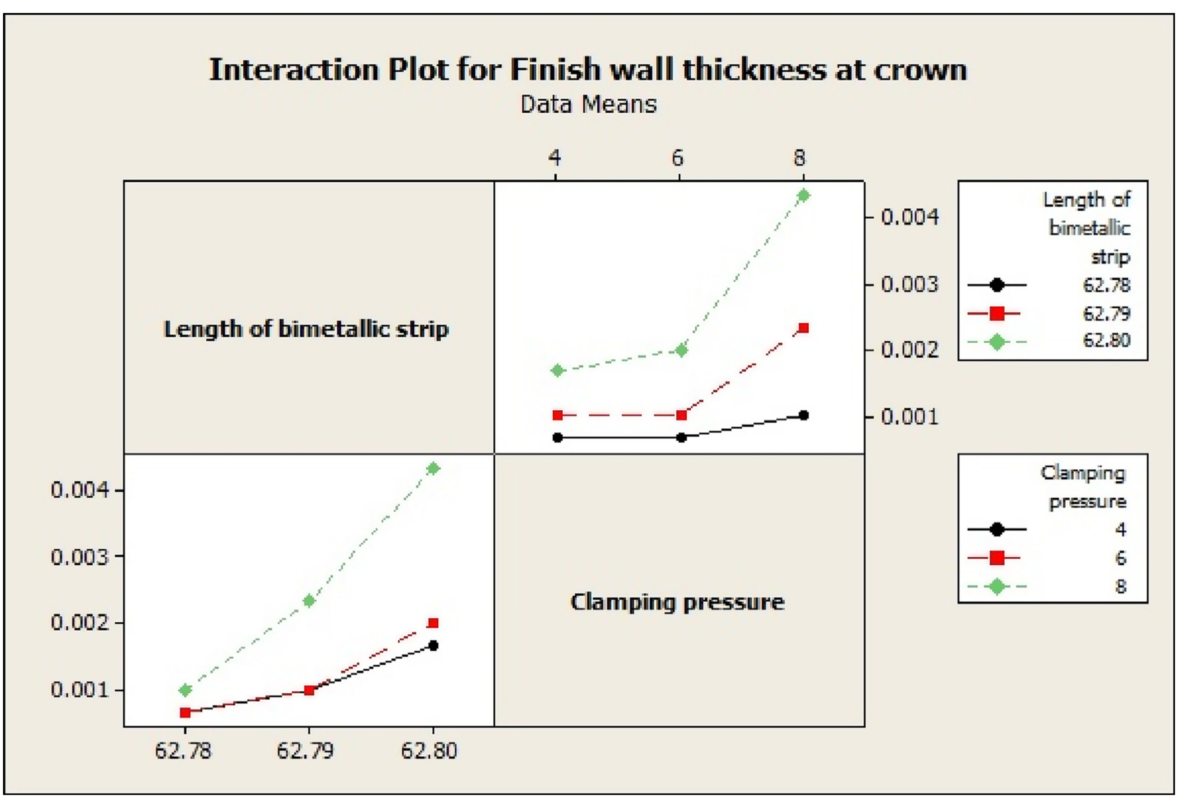

Fig. 5. Interaction plot for Finish wall thickness at crown.

4. Conclusions

The Taguchi method is employed for systematically studying the effects of process parameters on process capability of a bearing manufacturing system using the Six Sigma DMAIC approach. Process capability study was found to be effective in removing the primary cause of rejection, reorganizing the process, and making the process capable by enhancing the Cp and Cpk values of the CTQ characteristics under consideration. The application of the DMAIC approach concludes,

- The 'Define' phase identified critical defects responsible for major rejection. Nine defects contributed to nearly 80 % of rejection.
- The 'Measure' phase involves the measurement of current performance by evaluating process capability indices. Cp and Cpk values for 'Finish wall thicknesses at crown' were below acceptable levels.
- In the 'Analyze' phase, the vital root causes responsible for low process capability were identified using the fishbone diagram. The most influential sources which have a decisive role for the 'Finish wall thickness at crown' are clamping pressure, usage of the cutter and length of bimetallic strip.
- At the end of the 'Improve' phase the L27 orthogonal array was developed with three factors and levels. Experimental results were analyzed by using the ANOVA which identifies interaction of 'length of bimetallic strip' and 'clamping pressure' as a critical parameter.
- In the 'control' phase, the validation run using optimal conditions was conducted. The Cp and Cpk values for 'Finish wall thickness at crown' were improved from 1.170 and 0.976 to 2.78 and 2.23.

CRediT authorship contribution statement

Trishul Kulkarni: Writing – original draft, Formal analysis. **Bhagwan Toksha:** . **Sagar Shirsath:** Software, Validation. **Sandeep Pankade:** Methodology, Investigation. **Arun T. Autee:** Conceptualization, Supervision.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] V.E. Kane, Process Capability Indices, J. Quality Technol. 18 (1) (1986) 41–52, https://doi.org/10.1080/00224065.1986.11978984.
[2] W.H. Woodall, D.C. Montgomery, Some Current Directions in the Theory and Application of Statistical Process Monitoring, J. Quality Technol. 46 (1) (2014) 78–94, https://doi.org/10.1080/00224065.2014.11917955.
[3] S. Kotz, N.L. Johnson, Process Capability Indices—A Review, 1992–2000, J. Quality Technol. 34 (1) (2002) 2–19, https://doi.org/10.1080/00224065.2002.11980119.
[4] G.V.S.S. Sharma, P.S. Rao, A DMAIC approach for process capability improvement an engine crankshaft manufacturing process, J. Ind. Eng. Int. 10 (2) (2014) 65, https://doi.org/10.1007/s40092-014-0065-7.
[5] D. Grau, New Process Capability Indices for One-Sided Tolerances, Quality Technol. Quant. Manage. 6 (2) (2009) 107–124, https://doi.org/10.1080/16843703.2009.11673188.
[6] L.P. Sullivan, Reducing variability: A new approach to quality, Quality Prog. 17 (7) (1984) 15–21.
[7] A.V. Feigenbaum, Quality control: Principles, practice and administration: An industrial management tool for improving product quality and design and for reducing operating costs and losses, McGraw-Hill, 1951.
[8] J.M. Juran, Juran's Quality Control Handbook, McGraw-Hill, New York, 1988.
[9] J.M. Juran, Quality planning and analysis; from product development through use, 1993.
[10] W.A. Shewhart, Economic control of quality of manufactured product, Macmillan and Co Ltd, London, 1931.
[11] K. Palmer, K.-L. Tsui, A review and interpretations of process capability indices, Ann. Oper. Res. 87 (Apr. 1999) 31–47, https://doi.org/10.1023/A:1018993221702.
[12] Z.G. Stoumbos, Process capability indices: overview and extensions, Nonlinear Anal. Real World Appl. 3 (2) (2002) 191–210, https://doi.org/10.1016/S1468-1218(01)00022-0.
[13] R.M. Brugger, Handbook of Statistical Methods in Manufacturing, Technometrics 34 (3) (1992) 360–361, https://doi.org/10.1080/00401706.1992.10485296.
[14] H. Gitlow, S. Gitlow, A. Oppenheim, Tools and Methods for the Improvement of Quality, Irwin, 1989.
[15] G. Eckes, The Six Sigma Revolution: How General Electric and Others Turned Process Into Profits, John Wiley & Sons, 2002.
[16] P. Jirasukprasert, J.A. Garza-Reyes, H. Soriano-Meier, L. Rocha-Lona, A case study of defects reduction in a rubber gloves manufacturing process by applying Six Sigma principles and DMAIC problem solving methodology, in: ProceedIngs of the 2012 International Conference on Industrial EngIneerIng and Operations Management, 2012, pp. 3–6.
[17] J. Antony, R. Banuelas, Key ingredients for the effective implementation of Six Sigma program, Meas. Bus. Excell. 6 (4) (2002) 20–27, https://doi.org/10.1108/13683040210451679.
[18] K. Srinivasan, S. Muthu, N.K. Prasad, G. Satheesh, Reduction of Paint line Defects in Shock Absorber Through Six Sigma DMAIC Phases, Procedia Eng. 97 (2014) 1755–1764, https://doi.org/10.1016/j.proeng.2014.12.327.
[19] P.J. Ross, Taguchi techniques for quality engineering: loss function, orthogonal experiments, parameter and tolerance design, 1996.
[20] B.M. Gopalsamy, B. Mondal, S. Ghosh, Taguchi method and ANOVA: An approach for process parameters optimization ofhard machining while machining hardened steel, JSIR Vol.68(08) [August 2009], Aug. 2009, Accessed: Mar. 07, 2022. [Online]. Available: http://nopr.niscair.res.in/handle/123456789/5301.
[21] M.-H.-C. Li, A. Al-Refaie, C.-Y. Yang, DMAIC Approach to Improve the Capability of SMT Solder Printing Process, IEEE Trans. Electron. Packag. Manuf. 31 (2) (2008) 126–133, https://doi.org/10.1109/TEPM.2008.919342.
[22] F.J. Reh, Pareto's principle-The 80–20 rule, Business Credit-New York then Columbia MD- 107 (7) (2005) 76.
[23] D.C. Montgomery, Introduction To Statistical Quality Control, fourth ed., John Wiley & Sons, 2007.