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Process Improvement Using Six-Sigma (DMAIC Process) in Bearing Manufacturing Industry: A Case Study

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Abstract. Propagation, development of technologies and increasing customer demands switch the approach of existing work in the industries. To overcome barricades, the six-sigma DMAIC (define, measure, analyse, improvement, control) approach is trendy along with being advantageous. This approach decreases the variation and set up the way for up gradation in the manufacturing companies. This paper contains the Six-Sigma DMAIC approach that was used to decrease the process variation of inner and outer races of ball bearing for enhancing product quality. Define phase of DMAIC approach begins by difficulty detection through the voice of internal and external customers. The later stage constitute of measuring the data of bearing parts of existing process. This stage followed by the analyze as well as improvement stage, where the Six-Sigma quality improvement tools i.e. statistical process control (SPC), Control charts, MINITAB 18.0 software, fish bone diagram along with significant study of alive process were imposed to identify root causes and minimizing process variability. The improvement stage minimized the assignable causes for variability. The control phase called to maintain the improved process till further improvement.

This work expected that the Six-Sigma DMAIC methodology was effective for increasing the sigma level, decreasing the value of standard deviation and also decreasing the expected part per million (PPM) out of specification limits. Values of capability indices i.e. (Cp, Cpk and Cpm) were improved. A Six-Sigma DMAIC methodology is well-known and is capable of playing an efficient role in manufacturing industry by reducing variability in the bearing part process.

Introduction

In manufacturing, bearing sector is the most demanding in our country. Manufacturer faces critical challenge to minimize variability in dimensions of bearing components manufacturing. Over 95% of equipment use bearings and the failure might possibly go ahead to breakdown of that equipment. Bearing is considered as a critical part in industrial appliances. For that reason, the bearing quality plays a key role in the high production volume system.

If a firm wants to improve their product quality, process control play a key role [1]. Manufacturing industries need to analyze, watch and make up improvement of their existing processes to meet the requisites with the market competition. The industries use numerous techniques, approaches and tools for implementation of programs used for regular enhancement in terms of quality [2]. The industries faced the problem of variations in each stage of process of every product. The variability that occurs during the manufacturing process is investigated in any organization using quality tools like Six-

Sigma DMAIC, process capability analysis (PCA), control charts, process capability indices (PCIs), which assist the organization to examine and assess the potential of the process [3].

PCA provides a baseline intended for us to be aware of how the process is performing relatively to the pre specified limits. PCA is the initial concept, which gives information that how variability affects the process. Process capability studies make us aware about the best situations of process performance for achieving target [4]. PCA helps in statistical analysis of PCIs. If the value of these PCIs is low, it means higher rejection rate and higher values of PCIs means minimum rejection rate [5].

Literature review

Industries use various approaches, techniques and tools for regular enhancement of their overall quality. More to point these, every organization chooses an accurate mixture of these tools, and techniques [1]. If a firm works in the direction of implementation of six-sigma practically with enhancement in process capability and consumer happiness it is considered six sigma implementing firms [6]. Some well known successfully six sigma implemented industries like Motorola, General Electric, Honeywell, Sony, L&T, TCS etc. Are a motivation to others [7], [8]. Six-Sigma purpose is to attain excellence in every stage of production in an industry [9], [10]. Six-Sigma means DPMO or rate of success with 99.997%. [11]. Many organizations work according to level of 3σ, that means 93% success rate or 66,800 DPMO. According to present market demand organizations need to review their existing process. Six- sigma DMAIC approach helps them to reduce rejection rate and enhance their success rate up to 99.997% [12]. Six-sigma DMAIC is a benchmark to check the process or product quality, also having ability for improving efficiency and quality of product [13]. DMAIC is a systematic and fact based methodology and provides best results when the process is flexible. Literature review shows the six- sigma DMAIC methodology is the outstanding exercise for enhancing the quality of process in manufacturing industries [14], [15]. Six-sigma DMAIC methodology gives an effective results in printed circuit boards (PCB) and integrated circuits (IC) [16], [17]. Six sigma DMAIC approach applied in various processes for improvement in manufacturing industries i.e. food processing industry, IC engine parts manufacturing firms, TFT LCD screen manufacturing firms [18], [19], [20], [21]. Six-sigma DMAIC approach is extremely important for Telecom and other service sectors for process and quality improvement [22]. Ford automobile company saying ‘Quality Job is first’ and taken an initiative of six sigma in year 2001. Companies reported significant economic benefits and product or process quality improvement using six sigma DMAIC approach [23]. Hence, the recent work concentrate on the effective utilization of six-sigma DMAIC methodology expected for enhancement of capability of the bearing part manufacturing industry.

Company Profile: Firm A was the topmost manufacturer and supplier of ball bearing components in Rajasthan. Firm started in the year 1995, its first and second both manufacturing plant are located at Jaipur.

Methodology: In this work, using six-sigma DMAIC methodology focus is to get better quality level and process capability for bearing part manufacturing. If DMAIC approach is properly applied it gives targeted products at right time with minimum cost [24]. DMAIC steps in this work were explained:

Define phase

The aim of this phase is to improve the existing process. The main goal was acquired using the customer and firm employee voice method. This would be useful for the quality improvement of the firm. In addition, the goal will minimize the defect level or reduce process variability and improve productivity for a particular process. The present work focused to enhance the process of CNC machining where the forge bearing races were machined with specified size with tolerance ±0.05mm given by customers. CNC machining plays an important role in the process of bearing race manufacturing, because it is shaping the critical dimensions of bearing races. Both races are shown in fig. 1.

Figure 1: Inner race (IR) and outer race (OR) of ball bearing

The basic operations parameter taken in this work is bore diameter of IR and OR of ball bearing.

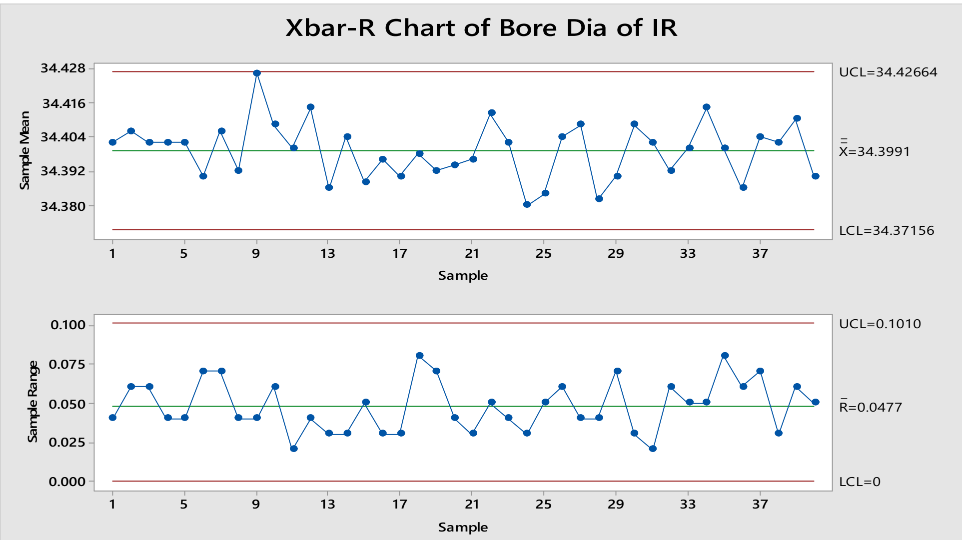
Measure Phase
In measurement phase of DMAIC measured existing process data of ball bearing bore diameter of IR and OR which are shown in Table 1. This collection of data has 200 observations. These 200 observations converted into 40 samples. Each sample contains 5 observations.

Table: 1 Observations of bore diameter of inner and outer races of existing process

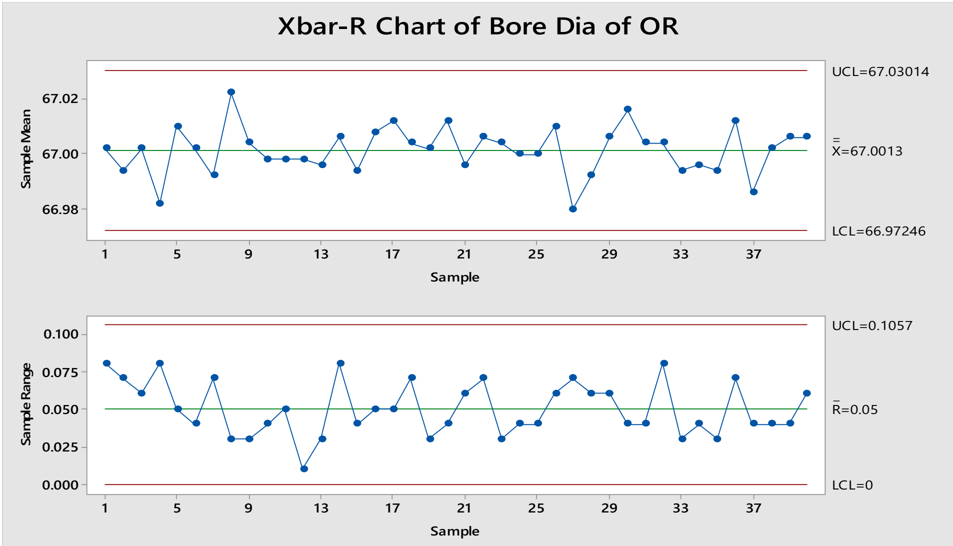
S. No.	Bore diameter of inner race 34.40±0.05 mm					Bore diameter of outer race 67.00±0.05 mm				
	1	2	3	4	5	1	2	3	4	5
1	34.40	34.41	34.40	34.42	34.38	67.01	67.02	67.04	66.98	66.96
2	34.40	34.37	34.41	34.42	34.43	66.95	66.99	67.00	67.02	67.01
3	34.44	34.38	34.39	34.42	34.38	67.03	67.01	67.00	66.97	67.00
4	34.42	34.41	34.38	34.39	34.41	66.99	66.95	66.96	66.98	67.03
5	34.38	34.42	34.38	34.41	34.42	67.04	67.01	67.00	66.99	67.01
6	34.38	34.39	34.36	34.43	34.39	67.00	67.02	66.99	66.98	67.02
7	34.40	34.45	34.41	34.38	34.39	67.03	66.96	66.98	66.99	67.00
8	34.37	34.38	34.40	34.41	34.40	67.01	67.02	67.02	67.02	67.04
9	34.42	34.42	34.43	34.41	34.45	67.00	67.01	67.02	66.99	67.00
10	34.41	34.39	34.40	34.45	34.39	66.99	67.02	66.98	67.01	66.99
11	34.41	34.39	34.40	34.41	34.39	67.00	67.02	66.97	66.99	67.01
12	34.40	34.42	34.41	34.44	34.40	67.00	67.00	66.99	67.00	67.00
13	34.38	34.40	34.37	34.40	34.38	67.01	67.00	66.99	66.98	67.00
14	34.40	34.41	34.42	34.39	34.40	67.03	67.01	67.01	66.95	67.03
15	34.39	34.36	34.40	34.38	34.41	67.01	66.97	67.00	66.98	67.01
16	34.38	34.39	34.40	34.41	34.40	67.02	67.00	67.03	67.01	66.98

17	34.38	34.39	34.41	34.39	34.38	67.02	67.00	66.99	67.04	67.01
18	34.43	34.35	34.39	34.40	34.42	67.05	67.00	66.99	67.00	66.98
19	34.40	34.42	34.41	34.38	34.35	67.01	67.00	67.01	66.98	67.01
20	34.41	34.40	34.40	34.37	34.39	67.03	67.02	67.00	67.02	66.99
21	34.38	34.40	34.39	34.41	34.40	67.00	66.96	66.99	67.01	67.02
22	34.44	34.42	34.39	34.40	34.41	67.00	66.97	67.00	67.02	67.04
23	34.40	34.39	34.42	34.38	34.42	67.00	67.01	67.02	67.00	66.99
24	34.39	34.38	34.38	34.39	34.36	67.00	66.98	67.02	67.00	67.00
25	34.37	34.38	34.37	34.38	34.42	66.99	67.00	66.98	67.01	67.02
26	34.43	34.42	34.37	34.40	34.40	67.05	67.02	66.99	67.00	66.99
27	34.39	34.40	34.41	34.43	34.41	66.96	66.98	66.95	66.99	67.02
28	34.39	34.36	34.38	34.40	34.38	67.01	66.99	67.00	67.01	66.95
29	34.42	34.35	34.38	34.39	34.41	66.98	67.04	67.01	67.00	67.00
30	34.42	34.39	34.41	34.42	34.40	66.99	67.03	67.01	67.03	67.02
31	34.41	34.40	34.39	34.41	34.40	66.98	67.02	67.01	67.02	66.99
32	34.39	34.40	34.42	34.36	34.39	67.00	66.97	67.05	66.99	67.01
33	34.42	34.41	34.39	34.37	34.41	66.98	66.99	66.99	67.00	67.01
34	34.44	34.43	34.39	34.42	34.39	67.00	67.00	67.01	66.97	67.00
35	34.38	34.37	34.45	34.40	34.40	66.99	66.98	67.01	67.00	66.99
36	34.38	34.35	34.40	34.41	34.39	67.00	67.05	67.01	67.02	66.98
37	34.44	34.39	34.41	34.37	34.41	66.99	67.00	66.98	67.00	66.96
38	34.40	34.39	34.40	34.40	34.42	66.98	67.01	67.02	67.00	67.00
39	34.41	34.42	34.38	34.40	34.44	66.99	67.00	67.00	67.03	67.01
40	34.40	34.41	34.36	34.40	34.38	67.04	67.00	67.01	66.98	67.00

After observing above data, for diagnosing process to see whether the process is under statistical control or not and for assessing process capability, X-bar R charts were prepared for IR and OR using MINITAB 18.0 software shown in figure 2.



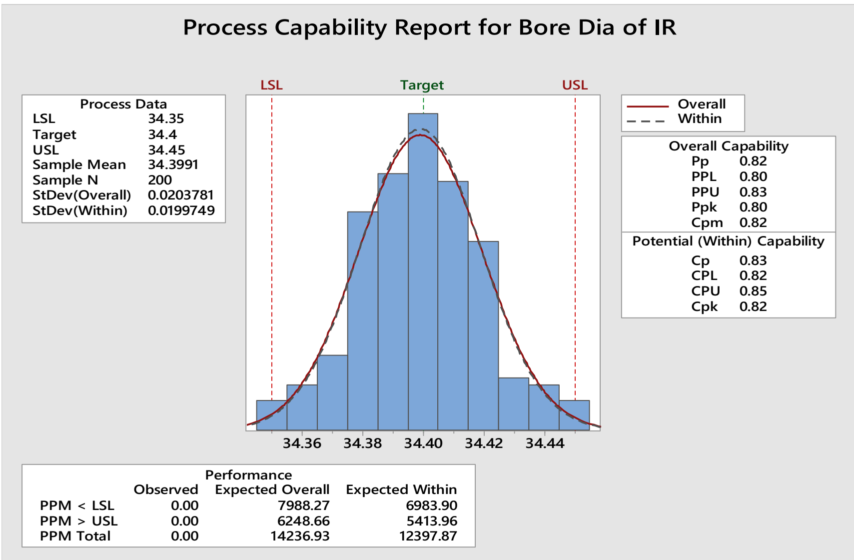
(a)



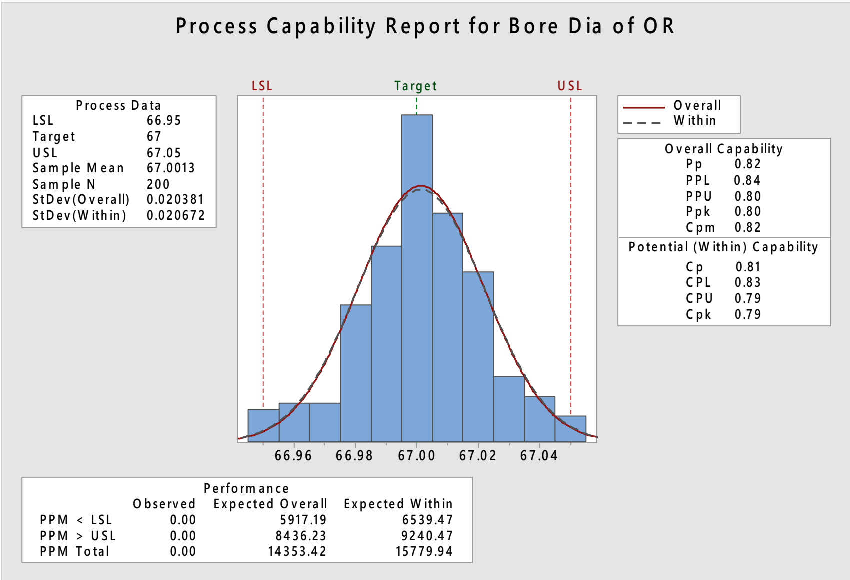
(b)

Figure 2: X-bar R charts of bore diameter of (a) inner and (b) outer race for existing process

From X-bar R chart analysis showed that the process is under statistic control, all sample points were inside the lower and upper control limits furthermore go for PCA using again MINITAB 18.0 software. The analysis of process is shown in figure 3.



(a)



(b)

Figure 3: Process capability report of bore diameter of (a) inner race and (b) outer race for existing process

From the PCA, found the values of PCIs (Cp = 0.81 & 0.83, Cpk = 0.79 & 0.82 and Cpm = 0.82) and standard deviation (0.02067 & 0.01997). The values of capability indices are less than one (<1), that means the process is not capable.

Analysis Phase

In this phase of DMAIC identify responsible assignable causes for poor quality or variability in the existing process. These responsible causes are mentioned in cause and effect diagram figure 4.

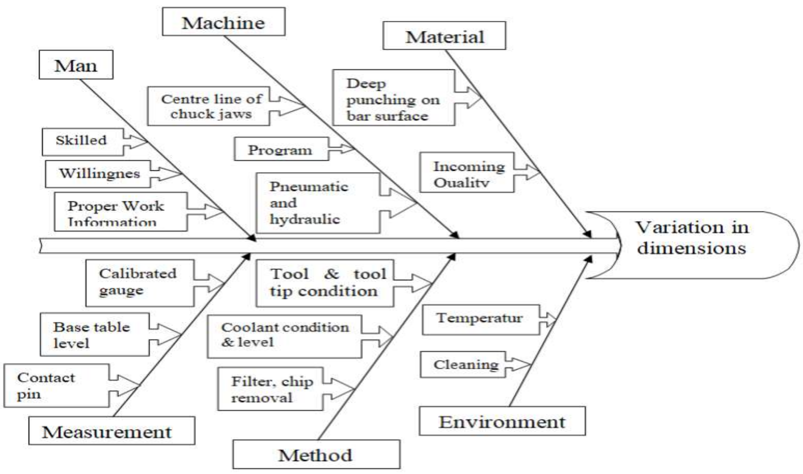


Figure 4: Cause and effect diagram

The role of possible causes identified in cause and effect diagram for variability were analyzed using survey opinion of 60 employees of the various bearing part manufacturing companies. Analysis of survey questionnaire is shown in figure 5.

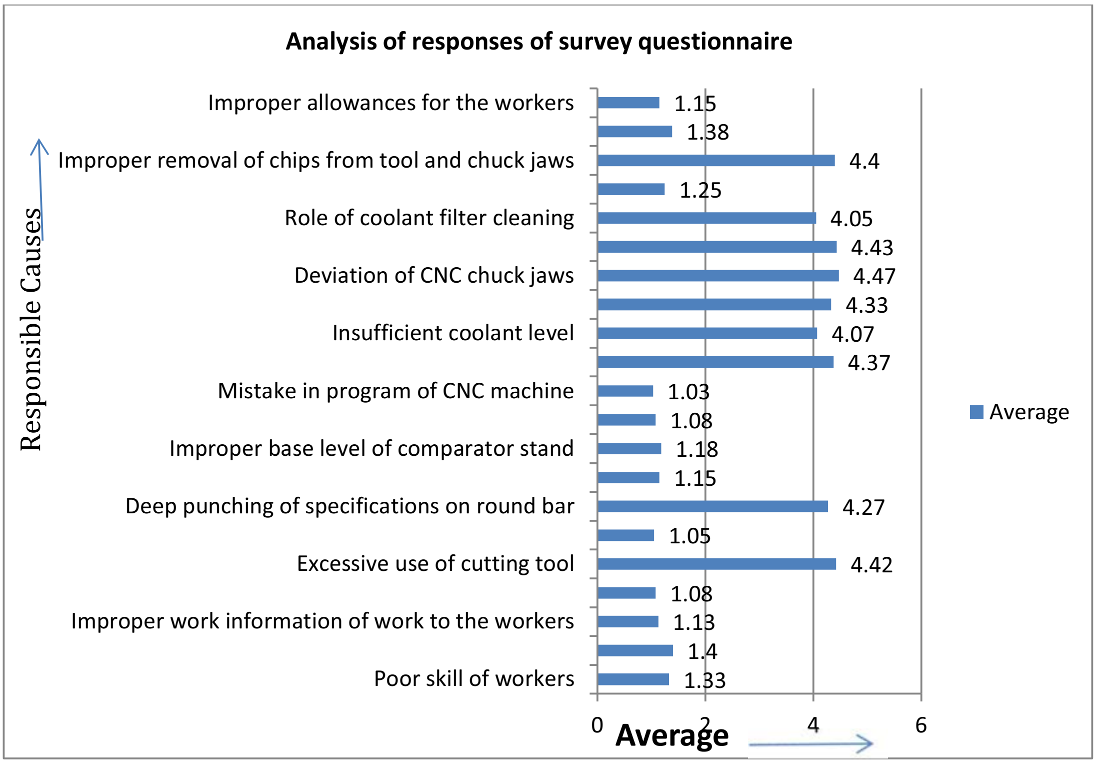


Figure 5: Analysis of responses of survey questionnaire

On the basis of analysis of survey questionnaire, following causes have been found playing major role in variations of dimensions of bearing components as shown in table 2.

Table 2: Major responsible causes

S. No.	Major responsible cause of variation
1	Excessive use of cutting tool
2	Deep punching of specifications on round bar
3	Improper tool and tool tip condition of CNC machine
4	Insufficient coolant level
5	Excessive use of coolant
6	Deviation of CNC chuck jaws
7	Role of coolant filter mesh size
8	Improper removal of chips from tool and chuck jaws

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Improve Phase

In this phase of DMAIC, after finding the responsible causes some corrective actions were implemented.

- Proper removal of chips from cutting tool and chuck jaws after every machined product shown in figure 6 (a)
- The tool life should be closely monitored. Tool should be changed not after ongoing production batch, in between the ongoing production batch to minimize the possible variation.
- Due to tiny chip particles mixed in coolant shown in figure 6 (b), replacement of existing coolant filter with smaller mesh size (5 microns to 4 microns). The coolant and coolant filter changed after specified duration or machine run time. Also clean the coolant filter after every production batch and check the level of coolant in tank.
- Before start the production check all the setting of machine every day. Specifically check chuck jaws were centered or not to prevent ovality.
- Use sticker on raw material steel round bar for specifications shown in figure 6 (c).

(a) (b) (c)

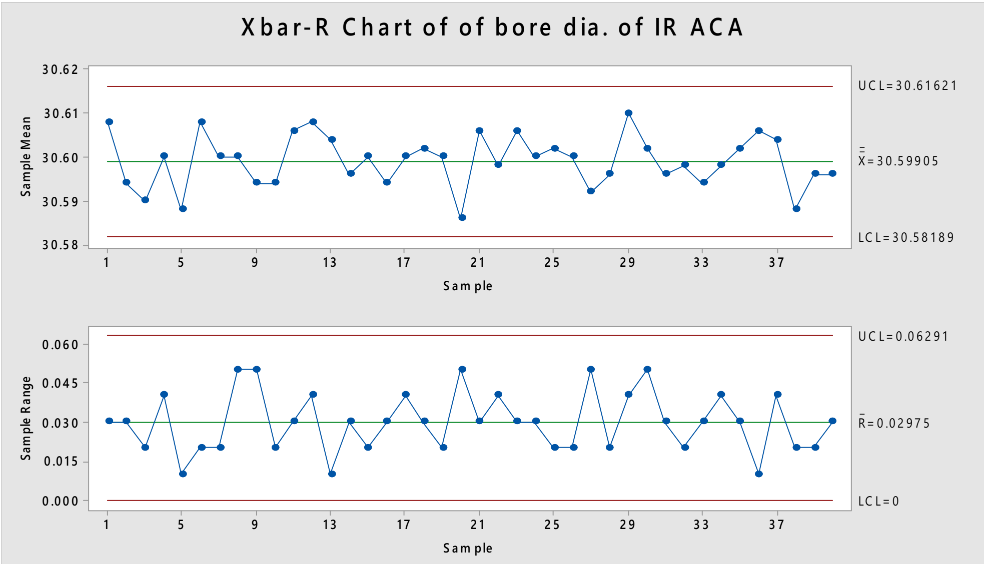
Figure 6: (a) Cutting chips, (b) chips mixed in coolant and (c) raw material with stickers

After taking above corrective actions may be the improved process is better than existing process in terms of productivity, quality and cost effective. Machining data were again collected and analyzed for bore diameter of inner race. Collected data for bore diameter of inner race and outer race after taking corrective actions has shown in table 3. This collection of data has 200 observations.

Table 3: Observations of bore diameter of inner and outer races of improved process

S. No.	**Bore diameter of inner race 30.60±0.05 mm**					**Bore diameter of outer race 62.95±0.05 mm**				
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1	30.61	30.60	30.62	30.59	30.62	62.96	62.97	62.95	62.96	62.94
2	30.58	30.61	30.60	30.60	30.58	62.93	62.95	62.96	62.93	62.95
3	30.59	30.59	30.60	30.58	30.59	62.94	62.95	62.94	62.94	62.93
4	30.58	30.60	30.60	30.60	30.62	62.97	62.95	62.95	62.93	62.95
5	30.59	30.59	30.58	30.59	30.59	62.94	62.93	62.94	62.94	62.95
6	30.60	30.61	30.62	30.60	30.61	62.96	62.97	62.94	62.95	62.95
7	30.60	30.60	30.60	30.59	30.61	62.96	62.95	62.95	62.95	62.94
8	30.62	30.60	30.61	30.60	30.57	62.92	62.96	62.95	62.97	62.95
9	30.60	30.62	30.59	30.57	30.59	62.94	62.96	62.97	62.95	62.92
10	30.60	30.60	30.58	30.59	30.60	62.95	62.93	62.95	62.95	62.94
11	30.61	30.60	30.59	30.61	30.62	62.97	62.94	62.95	62.96	62.96
12	30.62	30.63	30.59	30.60	30.60	62.95	62.94	62.98	62.97	62.95
13	30.60	30.61	30.61	30.60	30.60	62.95	62.96	62.96	62.95	62.95
14	30.58	30.60	30.60	30.61	30.59	62.94	62.95	62.95	62.93	62.96
15	30.59	30.61	30.61	30.60	30.59	62.94	62.96	62.96	62.94	62.95
16	30.59	30.60	30.58	30.59	30.61	62.96	62.93	62.95	62.92	62.94
17	30.58	30.58	30.62	30.62	30.60	62.95	62.97	62.93	62.93	62.97
18	30.61	30.61	30.60	30.58	30.61	62.96	62.95	62.96	62.96	62.93
19	30.60	30.61	30.60	30.60	30.59	62.94	62.95	62.96	62.95	62.95
20	30.57	30.62	30.60	30.57	30.57	62.92	62.95	62.97	62.92	62.92
21	30.62	30.59	30.59	30.62	30.61	62.96	62.94	62.94	62.97	62.97
22	30.61	30.57	30.61	30.60	30.60	62.95	62.96	62.92	62.96	62.95
23	30.59	30.62	30.62	30.60	30.60	62.95	62.97	62.97	62.94	62.95
24	30.61	30.61	30.61	30.59	30.58	62.94	62.96	62.97	62.96	62.94
25	30.61	30.60	30.61	30.59	30.60	62.95	62.96	62.95	62.96	62.94
26	30.59	30.59	30.61	30.61	30.60	62.95	62.96	62.93	62.94	62.96
27	30.59	30.58	30.62	30.60	30.57	62.92	62.97	62.93	62.94	62.95
28	30.60	30.60	30.60	30.58	30.60	62.95	62.95	62.95	62.95	62.93
29	30.59	30.62	30.60	30.61	30.63	62.98	62.95	62.97	62.94	62.96
30	30.60	30.60	30.60	30.58	30.63	62.98	62.95	62.95	62.95	62.93
31	30.58	30.59	30.59	30.61	30.61	62.96	62.94	62.94	62.93	62.96
32	30.59	30.59	30.61	30.61	30.59	62.94	62.96	62.94	62.94	62.96
33	30.60	30.59	30.58	30.61	30.59	62.94	62.93	62.94	62.95	62.96
34	30.60	30.58	30.59	30.60	30.62	62.97	62.94	62.93	62.95	62.95
35	30.62	30.59	30.59	30.60	30.61	62.96	62.94	62.94	62.97	62.95
36	30.61	30.61	30.61	30.60	30.60	62.95	62.96	62.96	62.96	62.95
37	30.61	30.59	30.63	30.60	30.59	62.94	62.98	62.94	62.96	62.95
38	30.58	30.58	30.59	30.60	30.59	62.94	62.94	62.93	62.93	62.95
39	30.59	30.61	30.60	30.59	30.59	62.94	62.95	62.96	62.94	62.93
40	30.61	30.60	30.58	30.59	30.60	62.95	62.93	62.95	62.96	62.94

After observing above data prepared X-bar R charts for IR and OR using MINITAB 18.0 software shown in figure 7.



(a)

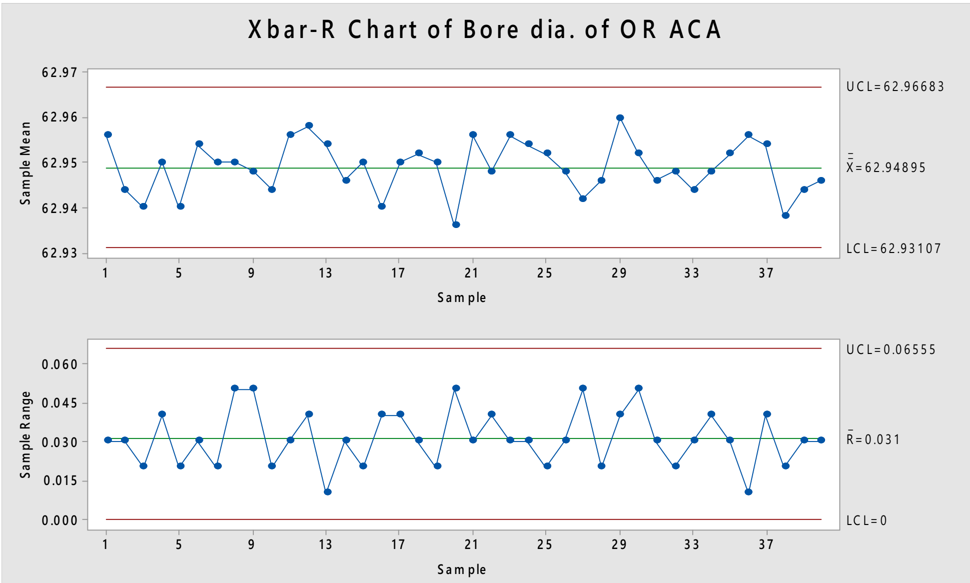
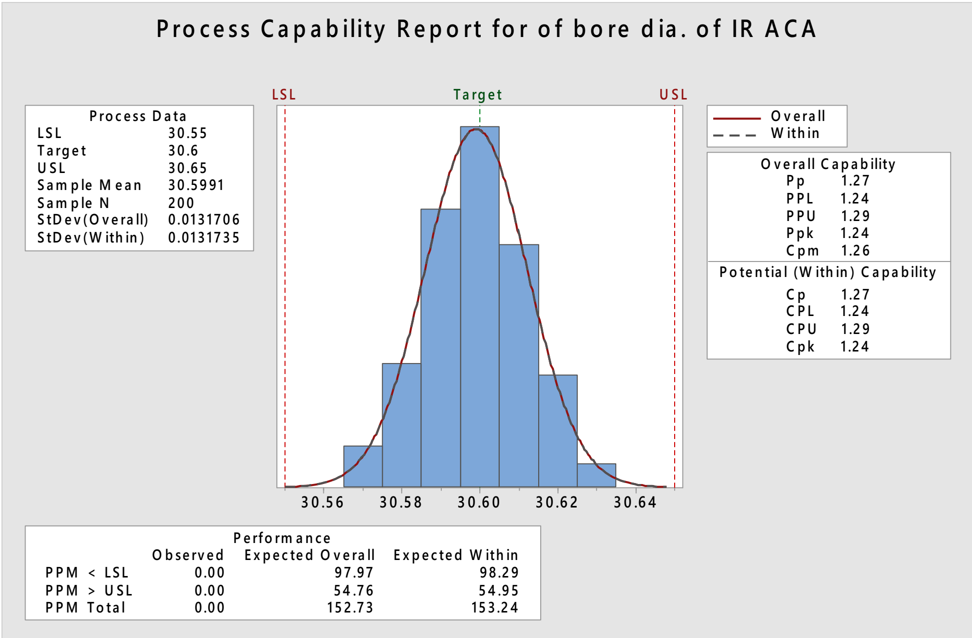
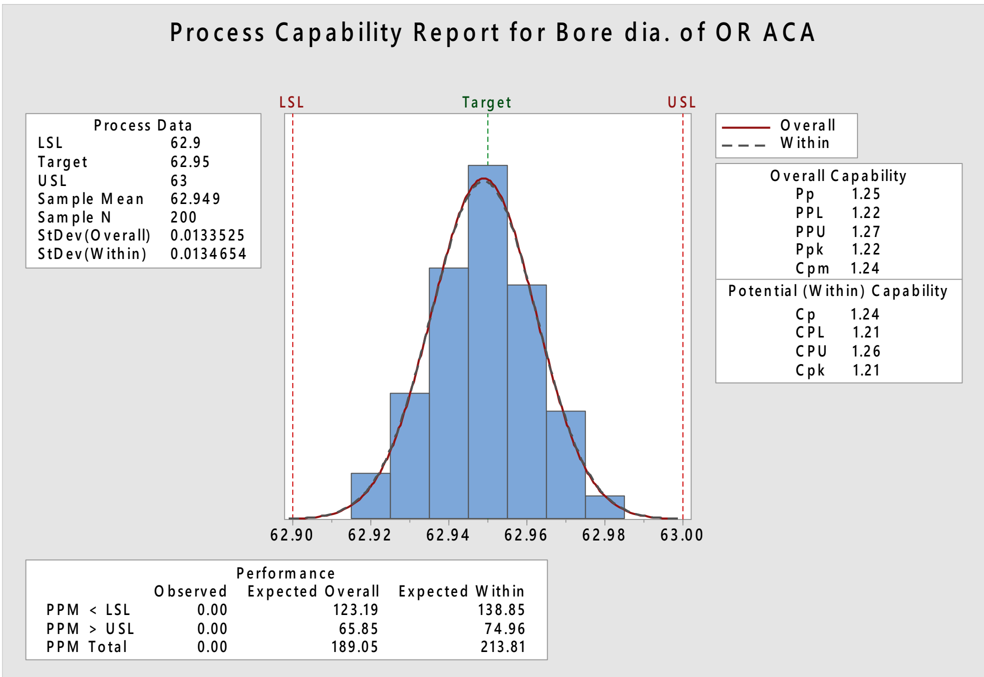


Figure 7: X-bar R charts of bore dia. of (a) inner race and (b) outer race for improved process

From X-bar R chars analyzed that the process is under statistic control, furthermore go for PCA using MINITAB 18.0 software.



(a)



(b)

Figure 8: Process capability report of bore diameter of (a) inner race and (b) outer race for improved process

Found the values of process capability indices (Cp = 1.24 & 1.27, Cpk = 1.21 & 1.24 and Cpm = 1.24 & 1.26) and standard deviation (0.01346 & 0.01317) using MINITAB 18.0. The values of capability indices were improved up to greater than one (>1), that means the improved process is better than the existing process. Comparison of PCIs before and after improvement of the process is shown in table 4.

Table 4: Comparison of process capability indices before and after improvement

		Cp	**Cpk**	**Cpm**	**Std. Dev.**
For Inner Race	Before Improvement	0.83	0.82	0.82	0.01997
	After Improvement	1.27	1.24	1.26	0.01317
For Outer Race	Before Improvement	0.81	0.79	0.82	0.02067
	After Improvement	1.24	1.21	1.24	0.01346

Control Phase

Maintain and continue the improved process for sustaining the firm in competitive market. The improved process runs till further improvement. From the results process/ product variability is reduced and quality and customer satisfaction will be improved.

Results

Using Six-Sigma DMAIC methodology increased the approximate sigma level from 2.5 to 3.5, decrease the value of standard deviation from 0.02067 to 0.01317 and decreased the expected part per million (PPM) out of specification limits from 15780 to 154. Values of capability indices i.e. (Cp, Cpk and Cpm) were improved from 0.81 to 1.27, 0.79 to 1.24 and 0.82 to 1.26 respectively.

Conclusion

Six-Sigma DMAIC is an efficient methodology to find out the actual needs of a process for improvement. Six-Sigma DMAIC methodology also provides practical solution for analysis of data. Results with successful implementation of Six-Sigma in different applications are:

- Reduced costs of poor quality
- Improve process capability
- Process improvement

In this research, Six-Sigma DMAIC methodology was implementing for process improvement in bearing part manufacturing industry. In the first step, values of process capability indices C_p, C_{pk}, C_{pm} and standard deviation for the existing process were calculated. These values were found to be less than one, so to improve the values of process capability indices by reducing the responsible causes of the process variability with the help of cause and effect diagram. In improvement phase, the value of process capability indices were improved and found greater than one after taking corrective actions. We can conclude from this research that quality level or performance level of a process can be improved by implementing Six-Sigma DMAIC methodology. The aim of this research was to reduce the process variability of bearing part manufacturing, which contributes to betterment of the performance. This work provides information about the procedure for reducing the process variability in manufacturing of bearing components and other products also.

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