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PROCESS CAPABILITY IMPROVEMENT FOR SWINGARM BORING OPERATION: A CASE STUDY

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Keywords:

Process capability indices; Control charts; Statistical process control; Quality improvement; Control limits.

ABSTRACT

A swingarm is the most crucial component of modern motorcycles use to provide suspension, hold the rear axle firmly, manage load distribution and maintain the centre of gravity. Boring is one of the most critical operation in swing arm manufacturing. The objective of this research work is to conduct a case study on process capability and its improvement for the most critical operation in swingarm. The boring operation was performed on swingarm using CNC boring machine and observations were recorded. $\bar{X}$ *and R Control charts were plotted and commented on process control. The process capability indices Cp, Cpk, Cpm and Cpmk were calculated using MINITAB 19 statistical software. Among all indices, Cpmk was found to be more trustworthy with respect to the process output. Process improvement was suggested by changing the process mean towards the goal. Further analysis of such data is possible using Taguchi's loss function for quality improvement.*

1. INTRODUCTION

In any manufacturing operation, variability is inevitable and manifested due to variations in raw material properties, processes, machines used, tools, operators and inspectors. Quantifying the variability in order to reduce it is the main objective of every quality management system. In this regard, various quality improvement using process capability analysis have been suggested by various researchers through different case studies (Hung & Sung, 2011; Sharma et al., 2013), (Chen et al., 2001; Wu et al., 2009; Rajvanshi & Belokar 2012).

A process capability study refers to the ability of the process to produce parts to the technical specifications (Ramakrishnan et al., 2001; Montgomery, 2005). Significant amount of case studies on improving quality of product and effectiveness of process using process capability analysis have been made. Process control refers to stability of the process over a period of time. Several capability indices have been broadly used in industries such as *Cp, Cpl, Cpk, Cpm, Cpmk* etc. Several control charts, histograms, normal probability charts and run charts were plotted using statistical software. It has been observed that *Cpmk* provides more capability as compare to *Cpk* and *Cpm* (Yerriswamy et al., 2014). A process capability analysis for multi-process product composed of bilateral tolerances and other quality attributes have been carried out for continuous improvement on the process and considered to be Product Capability Analysis Chart (PCAC) (Chen et al., 2001). A case study was carried out in company producing spare parts and found that the process is inadequate can be improved the quality by shifting the target value and spread in the process (Rajvanshi & Belokar 2012).

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Cumulative distribution function of PCI was discussed (Wright, 2000).

A swingarm is the foremost part of the rear suspension in modern motorcycles and All Terrine Vehicles (ATV). It is used as a fixture for rear axle and helps to administer the vibrations. Another major task of the swingarm is to provide the suspension. Apart from this, the swing-arms of the bikes helps to distribute the load of the bike uniformly and adjust the centre of gravity. A swigarm must have proper stiffness as well as handling comfort. Having a lightweight swingarm reduces the total weight of the bike as well as un-sprung mass at the rear. This improves the overall handling of the motorcycle. Hence manufacturing of critical operations of swingarm to the specifications is of prime importance and boring is one of them.

Figure 1. Photograph of Swingarm

Figure 1 depicts the photograph of swingarm used in most of the motorcycles and manufactured by S M Auto Engineers at Pune in India.

The objective of this work is to conduct process capability analysis for a boring operation of a swing arm bt using *Cp, Cpl, Cpk, Cpm, Cpmk* process capability indices and propose a methodology for by shifting of mean value and take continuous measures for improvement.

2. METHODOLOGY

Process capability analysis is one of the most proven methodologies to improve the process yield. According to Montgomery (2005) the few assumptions are essential and taken into consideration. The observed values are taken at random and independent of each other. The process has to be statistically control. Normal distribution was observed. In the case of equal bilateral tolerances, the process average is at the center of limits.

In order to study and analyze process capabilities following methodology was adopted as shown in figure 2. It is essential to know the basic concepts of process capability analysis and its measurement. In step one, analysis of the product drawing was made to identify critical operations. Swingarm bore on the bush is identified as one of the critical operation. Step two is determination of sample size and data collection. In step three, calculate $\bar{X}$ and R values and plot control charts.

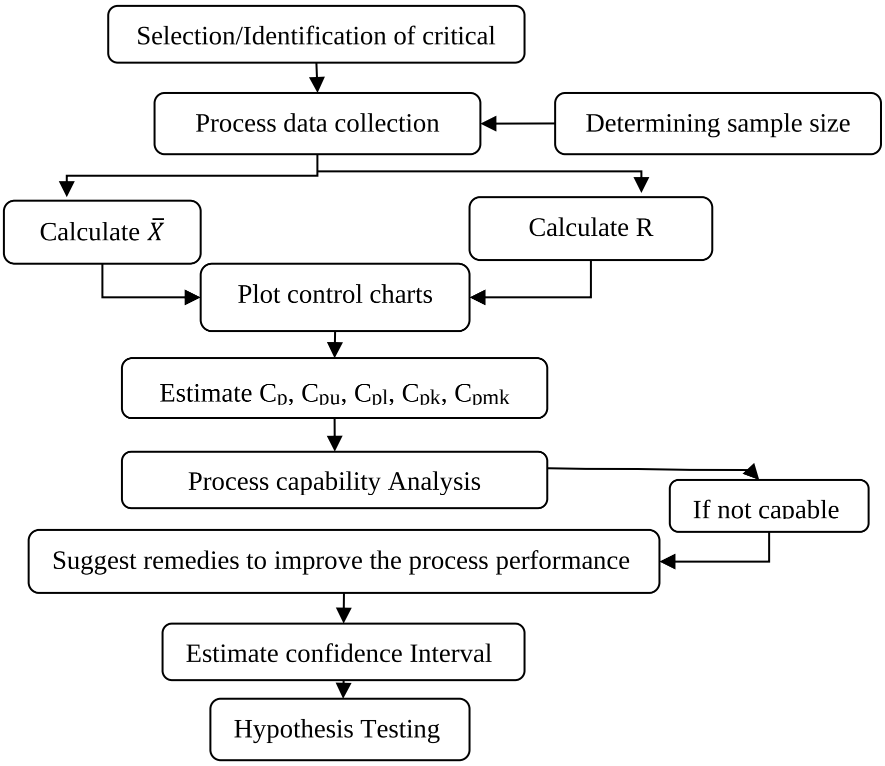

Figure 2. Methodology to Adapt Process Capability Study

Step four is to estimate standard deviation and process capability indices under a set of assumptions made. Step five is analyzing the source of variation and find out route cause of process variations. If the process is not capable, find out the reason and take corrective actions to improve the process. Step six is calculating confidence intervals on process capability ratios and set the tolerances in order to meet the overall system requirements.

Furthermore, process improvement can be done by incorporating various quality improvement tools such as plotting cause and effect diagram, fault-tree diagram, FMEA and FMECA, seven quality tools, Poka-yoke, PDCA circle, 5S, Kaizen, zero defect etc.

3. BASIC CAPABILITY INDICES

Cp: It is used to identify whether the process is capable of producing the parts with mean focused on Target. $Cp \geq 1.33$ indicates that the process is adequate to meet the specifications. If $1.33 \leq Cp \geq 1.00$ indicates the adequacy of the process provided that it is under close control. If value of $Cp < 1.00$ then the process hardly capable.

Cpu: Process capability related to upper specific limit only.

Cpl: Process capability related to lower specific limit only.

Cpk: It is used to evaluate process average and its spread based on location. Cpk measures how well the process mean is centered within the specification limits, and percentage of products within the specification limit. The assumption made is that the process data shows Gaussian distribution. For perfectly centered process, Cpk = Cp.

Cpm: Cpm is based on Taguchi Loss function. It estimates process capability around a target T is always greater than zero. It is assumed that process data shows bell shaped distribution. Cpm is more consistent as compared to cpk.

Cpmk: Here also it is assumed that the process data shows Gaussian distribution. It estimates process capability around a target value and accounts for an off-center process mean.

Table 1 depicts the equations quantifying various process capability indices.

Where:

- UCL: Upper Control Limit
- LCL: Lower Control Limit
- $\bar{X}$: Average within the batch
- σ : Standard deviation of the process
- $\bar{\bar{x}}$: Process Mean

Table 1. The Equations Quantifying Process Capability

Index	Estimated Equation
Cp	$(UCL\text{-}LCL)/6\sigma$
Cpu	$(UCL\text{-}\bar{\bar{x}})/3\,\sigma$
Cpl	$(\bar{\bar{x}} - LCL)/3\,\sigma$
Cpk	$MIN\{(UCL\text{-}\bar{\bar{x}})/3\,\sigma\,,\,(\bar{\bar{x}} - LCL)/3\,\sigma\,\}$
Cpm	$(UCL\text{-}LCL)/6^{*}\sqrt{\sigma^2 + (\bar{\bar{X}} - T)^2}$
Cpmk	$Cpk/\sqrt{1 + (\frac{\bar{\bar{X}}-T}{\sigma})^2}$

4. DATA COLLECTION

A case study was conducted on swingarm manufactured by S. M. Auto Engineering pvt. Ltd., India for process capability analysis. The product description is mentioned in Table 2.

Table 2. Product description

Company name	S.M Auto Engineering Pune, India
Part name	Swingarm
Material	Mild Steel
Operation	Boring
Instrument use	Pneumatic Bore gauge (Digital)
Specification	$26.087^{+0.02}_{-0.02}$

The company is engaged in production of number of automotive components in India. Critical dimension of the swingarm is bore diameter to be produced in a bilateral tolerance of $\pm 0.02\,mm$. The originating processes have been performed using some forming techniques. The machining operations were performed on hydraulic boring machine having spindle speed around 1900 rpm with carbide tip tool. The machine used is having very good prime accuracy and producing accuracy as well. The number samples to be selected at random are decided by using single sampling plan. The data was collected over a period of month to get 5 observations in a batch size of 100 each. Likewise, data was collected from 20 subgroups. The bore diameters were measured with specially designed digital plug gauge. The measured values are depicted in Table 3.

5. PROCESS CAPABILITY ANALYSIS

5.1 Construction of $\bar{X}$ and R charts

Variations are inevitable and the variability is monitored through mean value and its spread around the target. Process variability can be examined through control charts based on standard deviation in $\bar{X}$ Charts, and range in R chart. From the observed data, first of all the control limits are calculated based on grand average ($\bar{\bar{x}}$) and $\bar{R}$ as shown in eq. (1) to (4). To construct the control limits for $\bar{X}$ Charts, mean value and standard deviation were calculated and for R chart the range of the sample is calculated from Table 2.

Table 3. The measured values of Bore diameter

Sample Number	1	2	3	4	5	$\bar{X}$	R
1.	26.092	26.099	26.092	26.094	26.089	26.0932	0.010
2.	26.089	26.095	26.099	26.094	26.092	26.0938	0.010
3.	26.093	26.089	26.087	26.086	26.087	26.0890	0.007
4.	26.094	26.290	26.092	26.087	26.088	26.0902	0.007
5.	26.084	26.089	26.087	26.086	26.092	26.0876	0.008
6.	26.095	26.089	26.092	26.088	26.089	26.0906	0.007
7.	26.092	26.089	26.087	26.089	26.084	26.0882	0.008
8.	26.088	26.092	26.094	26.089	26.090	26.0906	0.006
9.	26.099	26.094	26.089	26.085	26.089	26.0912	0.014
10.	26.098	26.089	26.086	26.089	26.092	26.0908	0.012
11.	26.090	26.093	26.085	26.089	26.087	26.0880	0.008
12.	26.098	26.099	26.084	26.091	26.093	26.0930	0.015
13.	26.089	26.085	26.090	26.089	26.094	26.0890	0.009
14.	26.087	26.085	26.094	26.091	26.092	26.0890	0.009
15.	26.084	26.091	26.094	26.093	26.089	26.0902	0.010
16.	26.092	26.099	26.087	26.088	26.090	26.0912	0.012
17.	26.082	26.087	26.081	26.099	26.085	26.0868	0.018
18.	26.094	26.091	26.096	26.085	26.093	26.0918	0.011
19.	26.089	26.088	26.089	26.096	26.098	26.0920	0.010
20.	26.087	26.093	26.092	26.098	26.095	26.0930	0.011

Control limits for $\bar{X}$ Chart and R charts have been calculated. Where, $n = 5$, $A_2 = 0.577$, $d_2 = 2.326$, $D_3 = 0.00$ and $D_4 = 2.114$.

Control limits for $\bar{X}$ Chart

UCL= $\bar{\bar{x}} + A_2 \bar{R}$ = 26.0963 (1)
LCL= $\bar{\bar{x}} - A_2 \bar{R}$ = 26.0846 (2)

Control limits for R Chart

UCL=$D_4\bar{R}$ = 0.02135 (3)
LCL=$D_3\bar{R}$ = 0 (4)

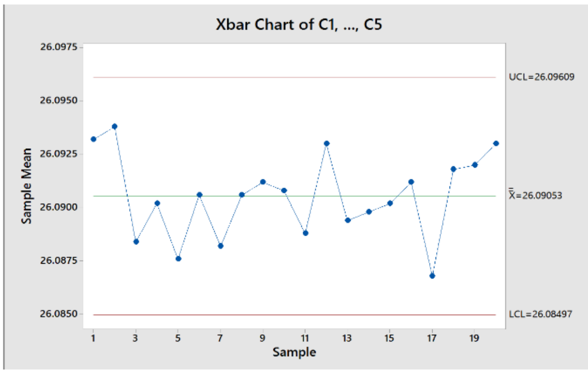

Figure 3. $\bar{X}$ Control Chart

It has been observed from figure 3 and figure 4, that the process is in control. There is no indication of shift occurred in $\bar{X}$ Chart; however in R chart slight shift after sample number size was observed. Hence, It depicts that the process is under control and no external factor is influencing on the process thus the process is stable and operating under only random variations.

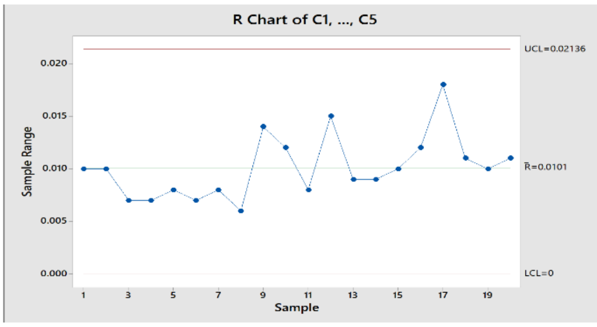

Figure 4. R Control Chart

5.2 Histogram and Normal Probability Plot

Figure 5 and Figure 6 depicts histogram and normal probability plot for the observed data. There is no abnormality observed in the sample data.

5.3 Construction of Run Chart

A run chart displays the process performance over a period of time. Run chart as shown in figure 7 depicts that the variation are random and not due to assignable cause. There is no upward or downward trend and abnormality was observed.

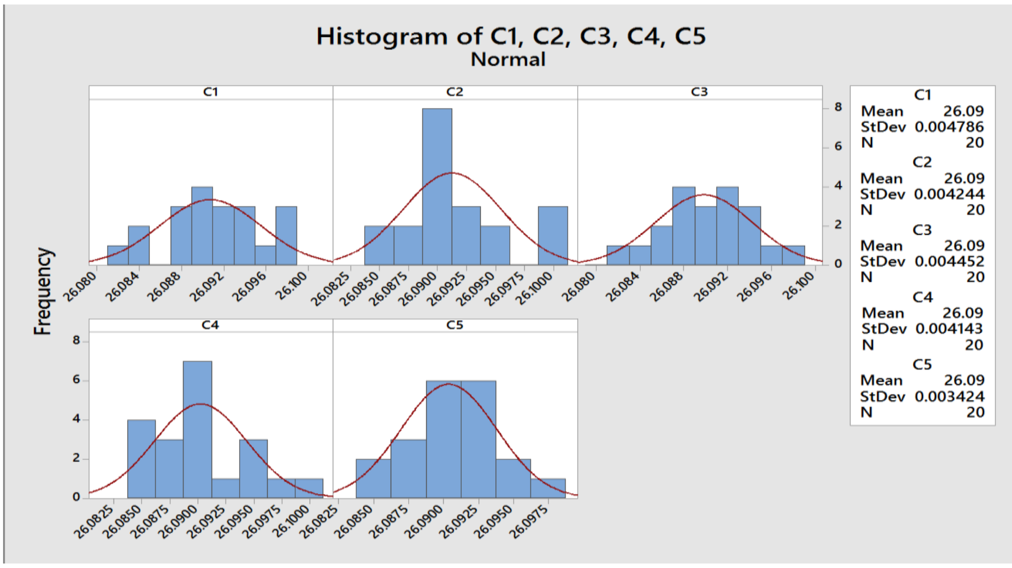

Figure 5: Histogram for Each Data Set

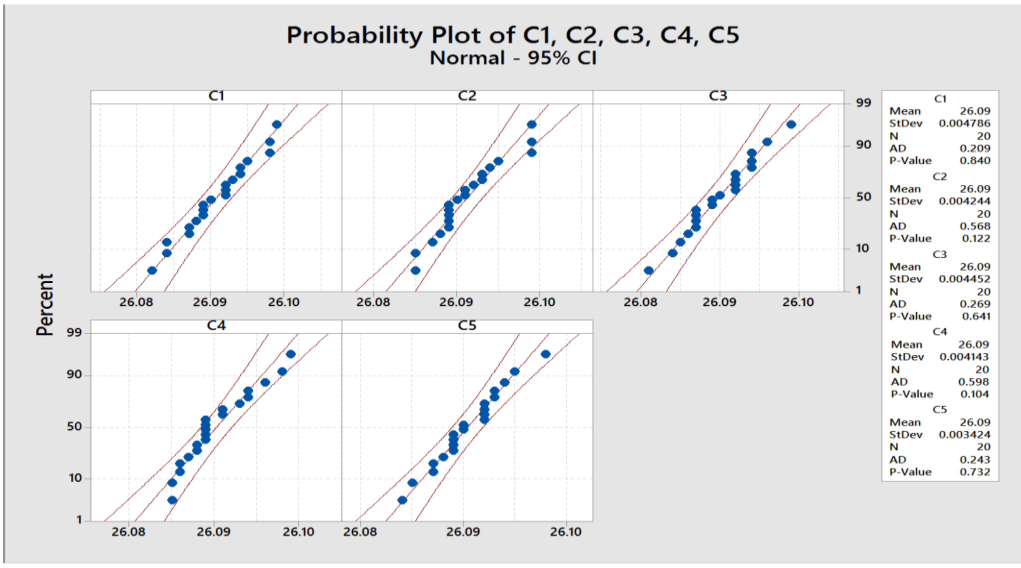

Figure 6: Normal Probability Plot for Each Data Set

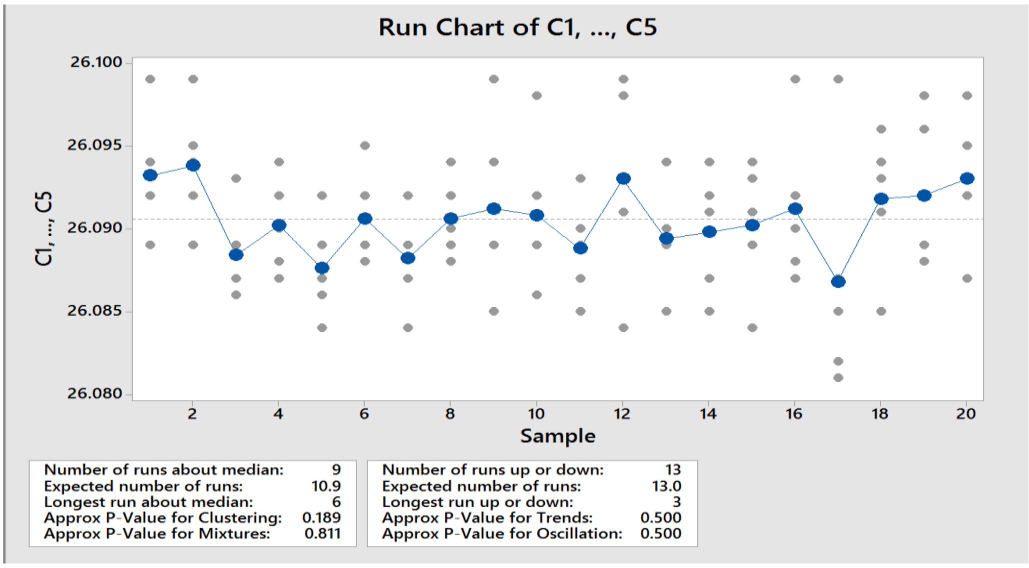

Figure 7. Run Chart

6. ESTIMATION OF PROCESS CAPABILITY INDICES

Since $\bar{X}$ chart and R chart depicts the stability of the process. The process capability indices *Cp, Cpk, Cpm* and *Cpmk* were calculated to understand whether the process is capable or not as shown in equation (5) to (10).

Based on standard deviation and upper and lower specific limits, Cp value was calculated.

$$\sigma = \sqrt{(\sum(Xi - \bar{X})^2)/N} = 0.0019333 \qquad (5)$$

$$Cp = (UCL – LCL)/(6\ \sigma) = 1.008 \qquad (6)$$

The specification band used by the process can be calculated as:

$$Cr = \left(1/_{Cp}\right) \times 100 = 94.30\ \% \qquad (7)$$

$$Cpk = \min\left(\frac{UCL-\bar{\bar{X}}}{3\ \sigma}, \frac{\bar{\bar{x}}-LCL}{3\ \sigma}\right) = \min(1.00, 1.017) \qquad (8)$$

Hence, Cpk is 1.00

$$Cpm=(UCL\text{-}LCL)/6\sqrt{\sigma^2 + (\bar{\bar{X}} - T)^2} = 0.489 \qquad (9)$$

$$Cpmk=Cpk/\sqrt{1 + (\frac{\bar{\bar{X}}-T}{\sigma})^2} = 0.4834 \qquad (10)$$

From the above calculations the value of *Cp* is between $1.33 \leq Cp \geq 1.00$ and the value of Cpk is 1.00 indicates that process is marginally capable and slightly away from centre. Also the value of *Cp* is closer to 1.000 the process needs to be observed under close control.

7. PROCESS CAPABILITY IMPROVEMENT BY SHIFTING MEAN

The foremost aim of this study was to examine the capability of the process and use of existing machine to produce desired tolerances. The process capability analysis shows that the *Cp* and *Cpk* values are close to each other hence the process mean is not shifted too much, however process needs close control. Further improvement in capability is possible by shifting process mean. Following calculations were done by shifting process mean to 26.089. New process capability indices *Cp, Cpk, Cpm* and *Cpmk* are calculated as shown in equation (11) to (17). However; calculations of repetitive nature and voluminous data is avoided here.

Control limits for $\bar{X}$ - Charts

$$UCL= \bar{\bar{x}} + A_2\ \bar{R} = 26.0963 \qquad (11)$$

$$LCL= \bar{\bar{x}} – A_2\ \bar{R} = 26.0846 \qquad (12)$$

Standard deviation with new mean

$$\sigma = \sqrt{(\sum(Xi - \bar{X})^2)/N} = 0.001933 \qquad (13)$$

$$Cp = (UCL – LCL)/\ (6^*\ \sigma) = 1.0088 \qquad (14)$$

$$Cpk = \frac{UCL-\bar{X}}{3\ \sigma} = 1.26 \qquad (15)$$

$$Cpm = (UCL\text{-}LCL)/6\sqrt{\sigma^2 + (\bar{\bar{X}} - T)^2} = 0.701 \qquad (16)$$

$$Cpmk = Cpk\ /\sqrt{1 + (\frac{\bar{\bar{X}}-T}{\sigma})^2} = 01.008 \qquad (17)$$

After shifting the mean, *Cpk*, *Cpm* and *Cpmk* values have been increased drastically.

8. RESULTS AND DISCUSSION

Process capability indices (PCI) *Cp*, *Cpk*, *Cpm* and *Cpmk* were calculated. The process capability indices before and after mean shift have been depicted in Table 3. Before adjusting the process mean, it was observed that the process is marginally capable based on *Cp*, *Cpk* value; however it is inadequate based on *Cpm* and *Cpmk*. After adjusting the process mean and taking another set of observations, it was observed that *Cpmk* index changed from 0.4834 to 1.0080. As $1.00 \leq Cpmk \leq 1.33$; indicates that the process becomes marginally capable. The percentage increase in process capability indices after shifting to the new mean are shown in Table 4. It is observed that *Cp*, *Cpk* values changes by 7.93 % and 26 %; however drastic change was observed in *Cpm* and *Cpmk*.

Table 4. Quantified values of

Index	PCI before mean shift	PCI after mean shift	Percentage increase in PCI
Cp	1.0080	1.0088	07.93 %
Cpk	1.0000	1.2600	26.00 %
Cpm	0.4870	0.7010	43.94 %
Cpmk	0.48340	1.0080	100 %

9. CONCLUSION

A case study was conducted on process capability improvement of swingarm (an automotive component) boring operation. Adequate number of samples was selected. Almost 100 observations were recorded over a period of a month at random intervals. Control charts were plotted to learn whether the process is in control or not. Afterwards the process capability indices were calculated using MINITAB 19 statistical software for monitoring variations. By shifting the mean value, the observations and subsequent calculations of *Cp, Cpm and Cpmk* indices were changed by 26 %, 43.94 % and 100%. Among all indices *Cpmk* is more trustworthy with respect to the process output. Thus, the process capability analysis can be successfully used to understand the variations and tendencies of the systems during manufacturing and improving the product quality. Further in-depth analysis of such data is possible using mean square deviations and signal to noise ratios as in Taguchi's quality loss function.

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