Int J Adv Manuf Technol (2014) 71:717–730
DOI 10.1007/s00170-013-5483-y

ORIGINAL ARTICLE

Process improvement through Six Sigma with Beta correction: a case study of manufacturing company

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Received: 23 April 2013 / Accepted: 10 November 2013 / Published online: 11 December 2013

Abstract This article discusses the successful implementation of Six Sigma DMAIC (Define–Measure–Analyse–Improve–Control) methodology along with Beta correction technique in an automotive part manufacturing company. The implementation of Six Sigma approach resulted in reduction of process capability-related problems and improved the first pass yield from 94.86 % to 99.48 %. After studying the baseline performance of the process, a brainstorming session was conducted with all stakeholders of the process for identifying the potential causes of the problem. Data were collected on all the identified potential causes and various statistical analyses like regression analysis, hypothesis testing, and Taguchi methods were performed for identifying the root causes. Solutions were identified and implemented for the validated root causes, and results were observed. The Beta correction technique was introduced for monitoring the process in the control phase. Implementation of Six Sigma methodology with Beta correction technique had a significant financial impact on the profitability of the company. An approximate saving of US$87,000 per annum was reported, which is in addition to the customer-facing benefits of improved quality on returns and sales. This study contributes uniquely by elucidating the synergistic impact of Beta correction for greater effectiveness of Six Sigma programmes in the engineering industry.

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Keywords ANOVA · Beta correction · Main effect plot · Measurement system analysis · *P* value · Regression analysis · Six Sigma · Taguchi methods

1 Introduction

In the attempt to manage change, many large organisations have pursued formalised change programmes or quality initiatives such as Six Sigma that can have a significant impact on the bottom-line and working culture of an organisation. The Six Sigma methodology is becoming one of the most successful quality management initiatives [1]. It has been adopted as a major initiative by some of the leading companies throughout the world [2]. It has gained wide acceptance as an improvement methodology to enhance an organization's competitiveness [3, 4]. It is a breakthrough business strategy used for quality and process improvement by using a set of structured tools and statistical measures to evaluate processes [5]. Six Sigma is a disciplined, project-oriented, statistically based approach for reducing variability, removing defects and eliminating waste from products, processes and transactions [6]. With high profile adoptions by companies such as General Electric, in the mid-1990s, Six Sigma spread like wildfire toward the end of the twentieth century [7]. The interest in this methodology is currently high in organisations [8, 9]. It allows for more careful analysis and more effective decision-making aiming for the optimal solution rather than what is simply 'good enough' [10]. The systematic integration of tools and techniques in Six Sigma makes it different from other problem solving methodologies [11].

In Six Sigma, broadly two approaches are used—DMAIC (Define–Measure–Analyse–Improve–Control) and DFSS (Design for Six Sigma). DMAIC is commonly used for making improvements in existing processes [12]. This approach not only makes use of Six Sigma tools and techniques, it also incorporates other concepts such as financial analysis and project management [13, 14]. Six Sigma has been embraced by manufacturing companies not only for its robust tool set but also because of its well-defined application methodology, the DMAIC. When a new process is required, the DFSS approach is used. DFSS consists of a number of disciplined and rigorous approaches to product, process and service design [15].

Many papers and books have discussed Six Sigma—the concept, its ingredients, its relation to other quality concepts and its benefits, its weaknesses, etc. Articles are also available in topics related to: details of Six Sigma [16]; need for Six Sigma [17, 18]; difference of Six Sigma and other quality initiatives, Six Sigma deployment [19]; critical success factors of Six Sigma implementation [20]; Six Sigma project selection [21]; organisational infrastructure required for implementing Six Sigma [22–24]; and integration of Six Sigma with various initiatives like lean management [25, 26], knowledge management [27], industrial engineering [28], etc.

A well-planned Six Sigma implementation can lead to a rewarding experience and immense benefits for an organisation. On the other side, a flawed implementation may lead to disappointing results—the failure of the entire implementation effort, and a significant waste of time and resources. There is research available in these directions also [29, 30].

The rest of this paper is organised as follows: Section 2 explains the research methodology adopted for this study followed by Section 3, background of the organization with problem description. Section 4 presents the application of DMAIC methodology highlighting the five stages of the methodology. Section 5 presents the lessons learned and managerial implications of the study followed by conclusions in Section 6.

2 Research methodology for the study

In this section, the methodology adopted for this case study is explained. This case study was developed by the researcher while working with the organisation to provide support for the project in Six Sigma methodology. Prior to this project, a literature survey was done to understand various improvement initiatives carried out to address process-related problems [2]. Yin [31] describes a case study as an empirical inquiry that investigates a contemporary phenomenon within its real-life context. In this article, a case study is designed to study the underlying process problem so that solutions can be implemented for process improvement. The extent to which generality can be claimed from a single case study is limited, but by documenting case experiences in the light of existing literature, each case adds to the sum of knowledge available for future practitioners and researchers [31–33].

The team collected data from the process based on a data collection plan and estimated the baseline performance of the process. Based on this information, a project charter was drafted. The data collected during the project were analysed using various statistical techniques. Measurement system analysis [34, 35], regression analysis [36], design of experiments with Taguchi methods [37], hypothesis tests [38], *Beta* correction technique [39], etc. were used for analysing data, and inferences were made. Graphical analyses like histogram, dot plot, control chart, etc., were also utilised for summarising the data and making meaningful conclusions. Management observations and progress were monitored to allow the process to be evaluated.

3 Company background and problem definition

In today's fast-paced global economy, markets demand that companies produce their products more quickly with better quality and at the same time with lesser cost. In order to meet these requirements, organisations adopt various methodologies for process improvement. This article deals with the first-pass yield improvement of a grinding operation in a large manufacturing company in India. They were involved in manufacturing of automobile parts, components and subassemblies for various original equipment manufacturers in India and abroad. Because of the complexity of the manufacturing process and accuracy requirements for the products, the organisation is equipped with high-precision machineries and highly competent work force of around 1,850 personnel. This organisation was having a system of performing value stream mapping (VSM) for the entire process (i.e., from customer order to delivery of product to customer) for identifying the bottleneck areas in the process. VSM not only handles a specific process, but also provides an overall view of the entire system, seeking to optimise it as a whole [40]. This VSM helps the organisation to highlight the problem areas and bottleneck processes which restrict the process flow for meeting the customer requirements [41]. During this analysis, it was identified that the plunger machining process have very low first-pass yield as the rejection and re-work was very high in the process. Hence, this was identified as a priority area for the organisation to focus their efforts for improving the process.

In this article, the authors discuss the study of machining of 'plunger', which is a critical component in fuel injectors used in diesel engines. The first-pass yield of the plunger manufacturing process was as low as 94 percent, leading to rejection of approximately 1,900 components per month. This was creating huge loss to the company in terms of rejection/rework/scrap and delay in product delivery to customer. The estimated financial loss due to rejection and scrap alone was around US$ 95,000 per annum. In addition to this, the dissatisfaction of customers due to violations in on-time delivery was creating negative impact on the reputation of the company. It was clear to the management that an effective solution to this problem would have a significant impact in improving customer satisfaction and reducing rejection/rework and thereby improving the market share of the organisation. Hence, it was decided to address this problem through Six Sigma DMAIC methodology, as the cause and solution to this problem was unknown [42]. All the five phases of the Six Sigma DMAIC methodology was successfully implemented in this project as explained in the following sections of this article.

4 Six Sigma DMAIC methodology

4.1 The Define phase

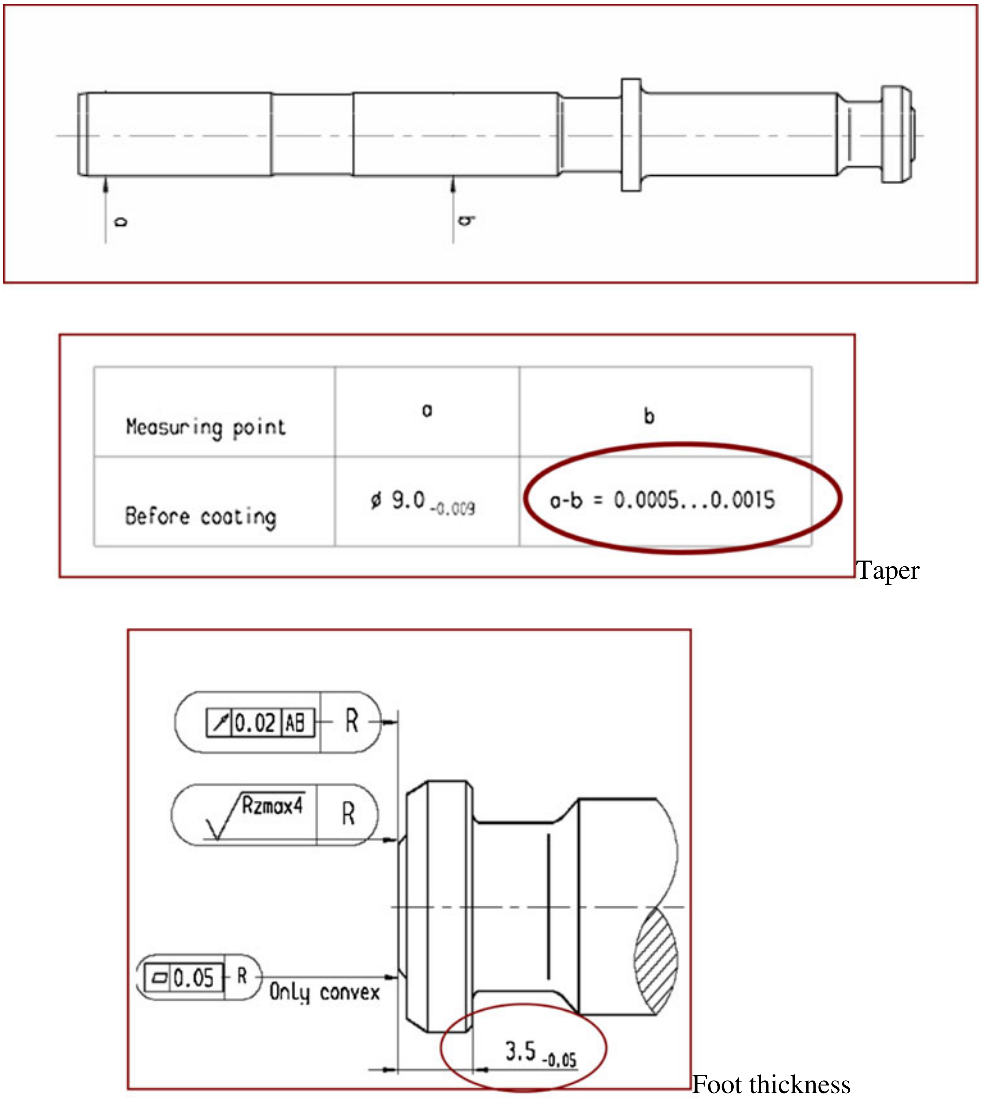
This is the first step in executing a Six Sigma DMAIC project. The aim of Define phase is to define the project with all details including project title, objective, scope, team composition, expected benefits and schedule for the project in terms of the customer requirements and identify the process delivering these requirements [19]. This creates a sense of ownership for the project; it also prevents the delivery of mixed messages between project managers and team members. As a first step, a team was formed with Assistant Manager Production (was the process owner in this case) as the team leader and seven team members associated with the process. The Production Manager was identified as the champion for this project. The team along with the champion had detailed discussions regarding this project and prepared the project charter defining the details of the project (Refer Annex-1 for Project Charter). The project charter is a necessary step in the application of Six Sigma because it indicates not only the ownership of responsibilities of the project team member, but also a commitment from management [28]. Also, this project charter helps everybody to understand the details of the project and keeps the team focused on its objectives with regard to the project [43].

The project team has defined the goal statement of the project as improving the first-pass yield of the plunger manufacturing process from 94 % to 99 %. A process flow chart along with a SIPOC (Supplier–Input–Process–Output–Customer) mapping was prepared to understand the details of the process (refer to Annex-2 for details). The high-level process mapping prepared along with the SIPOC provides the boundaries (start and end points) of the process where improvement activities to be performed. Past data for 1 year were collected to understand the type of defects leading towards low first-pass yield. During the 1-year period under study, 23,453 components were rejected due to different problems. Out of the rejected components, 97.3 % were rejected due to problems at finish size grinding and foot face grinding processes. During finish size grinding, the plunger taper was measured, and during foot face grinding, the foot thickness was measured (refer to Fig. 1). Hence, the team decided to consider the ‘plunger taper’ and ‘foot thickness’ as the critical to quality (CTQ) characteristics. The specification limits for these characteristics were 0.5 to 1.5 microns and 3.45 to 3.5 microns, respectively. Since the tolerance for these characteristics was very narrow, it was a big challenge for the organisation to maintain the manufactured components within these tolerances.

4.2 The Measure phase

The objective of the Measure phase in a Six Sigma project is to evaluate the baseline performance of the process with respect to the CTQs identified during the Define phase [44]. In this project, the CTQs considered were ‘plunger taper’ and ‘foot thickness’. Since the tolerances for both the characteristics were very narrow, the team decided to conduct a measurement system analysis to validate the measurement process related to these characteristics. Two inspectors and ten components were identified for conducting this measurement system analysis study [35]. These two inspectors measured the plunger taper and foot thickness for all the ten components twice [34]. These data were analysed with the help of Minitab software. The total gauge repeatability and reproducibility (GR&R) values were found to be 9.71 % and 4.1 %, respectively, for foot thickness and plunger taper. The Minitab software output of one of the GR&R study is presented in Table 1. Since percentage GR&R values were less than 10 % for both the cases, the team concluded that the current measurement system was adequate for further data collection [34]. After the measurement system study, a data collection plan was prepared with all details of the data required to be collected, including sample size, frequency of sampling, etc. As per the data collection plan, a sample of size 1,500 components was collected from the process across a period of 1 month. The taper and foot thickness were measured for those 1,500 components, and data were recorded. The next step in the Measure phase was to evaluate the base line performance for the selected CTQs with the collected data [2, 45]. For this purpose, the data were tested for normality by Anderson-darling normality test and the *p* values of both the data set were found to be less than 0.05 with *A*-*D* statistic values of 89.827 and 10.403, respectively, for foot thickness and plunger taper, respectively, indicating that the data were from a process that was not normally distributed [46]. Furthermore, the data were tested for all known distributions with the help of Minitab software but failed to identify any specific distribution for this data. The Box-Cox transformation also was tried for the data but was unsuccessful in transforming the data to normality. Since the sample size considered here was very large, any slight deviation from Normality could get detected during the test. Also, these data were collected only to understand the baseline performance of

Fig. 1 Schematic diagram of plunger



Measuring point	a	b
Before coating	$\varnothing\ 9.0_{-0.009}$	a-b = 0.0005...0.0015

the process; the deviation from normality does not affect further analysis in this study.

Process capability analysis was carried out by Minitab software for both the characteristics to get an estimate of the baseline performance of the process in terms of these CTQs. The Minitab output of the process capability analysis is presented in Figs. 2 and 3. The observed performances from these analyses were as follows: The parts per million (ppm) total for foot thickness and plunger taper were 35,333 and 51,333, respectively. Considering these values as the defects per million opportunities (DPMO), the approximate sigma levels were found to be 3.31 and 3.13, respectively. This provides a baseline for both the CTQs [2].

Table 1 Results of gauge R & R study (Minitab output)

Source	Standard deviation	% Study variation
Total Gauge R & R	0.0002509	9.71
Repeatability	0.0002108	8.16
Reproducibility	0.0001361	5.27
Part-to-part	0.0025717	99.53
Total variation	0.0025839	100.00

4.3 The Analyse phase

The objective of Analyse phase in a Six Sigma project is to identify the root causes that are responsible for high variation in the selected CTQs [45]. As a first step towards this endeavour, the team had a detailed study of the process along with other stakeholders of the process including the Champion and Master Black Belt (MBB) of the project. Furthermore, a brain storming session was conducted with all these personnel to identify the potential causes of high variation in the CTQs. The output of the brainstorming session depends to a large extent on the quality and creativity of the session and the knowledge level of the participants [47, 48]. The potential

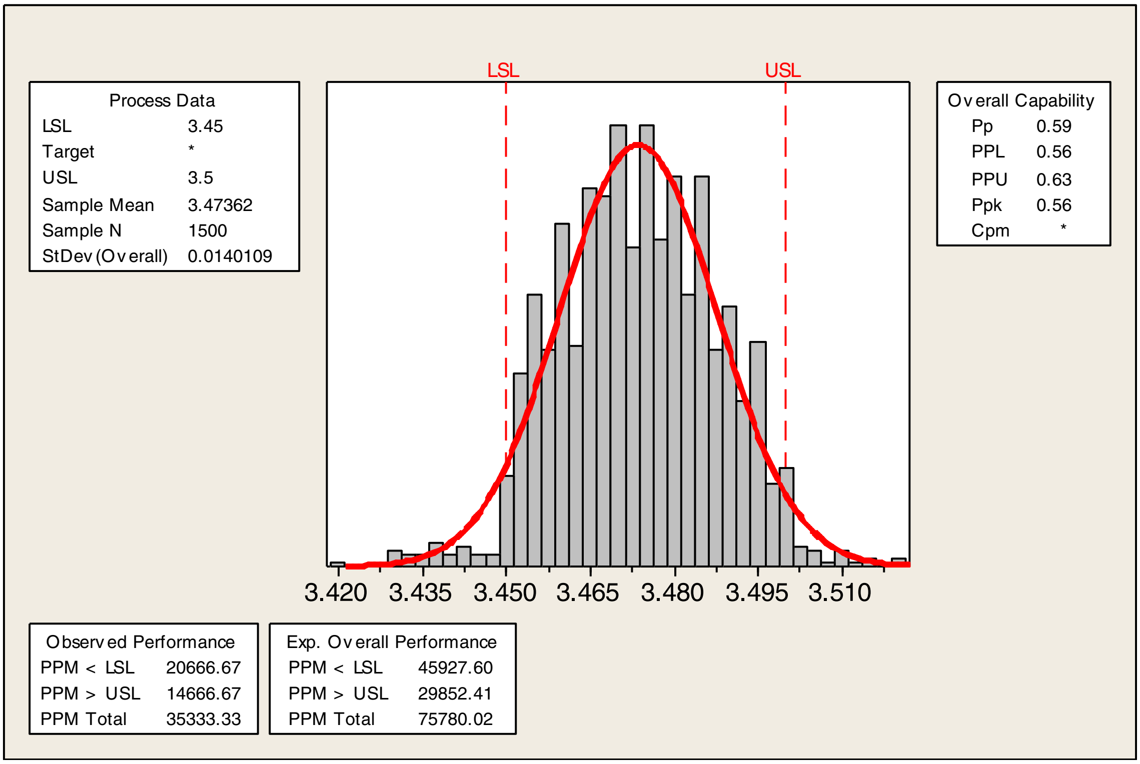


Fig. 2 Process capability for plunger foot thickness

causes generated through the brainstorming session were listed separately for both the CTQs. Those identified potential causes were presented in the form of cause and effect diagrams, as given in Figs. 4 and 5.

From the potential causes listed in the cause and effect diagrams, the root causes to be identified by data based validation of causes. The team had detailed discussions with MBB regarding the availability of data on these causes and

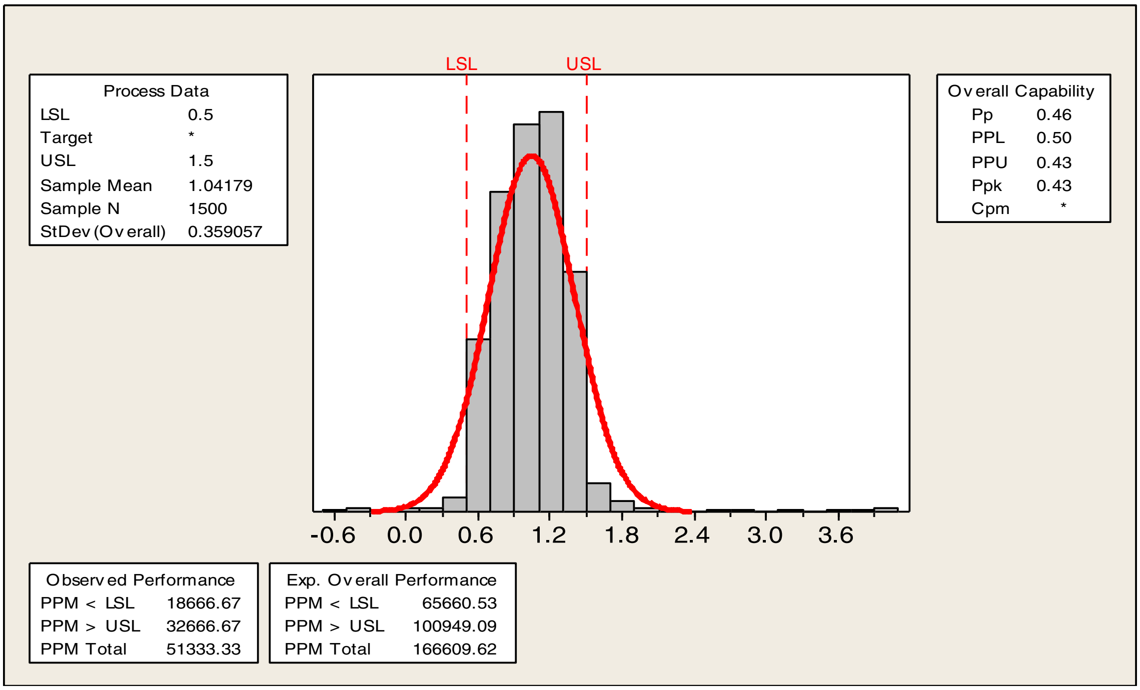


Fig. 3 Process capability for plunger taper

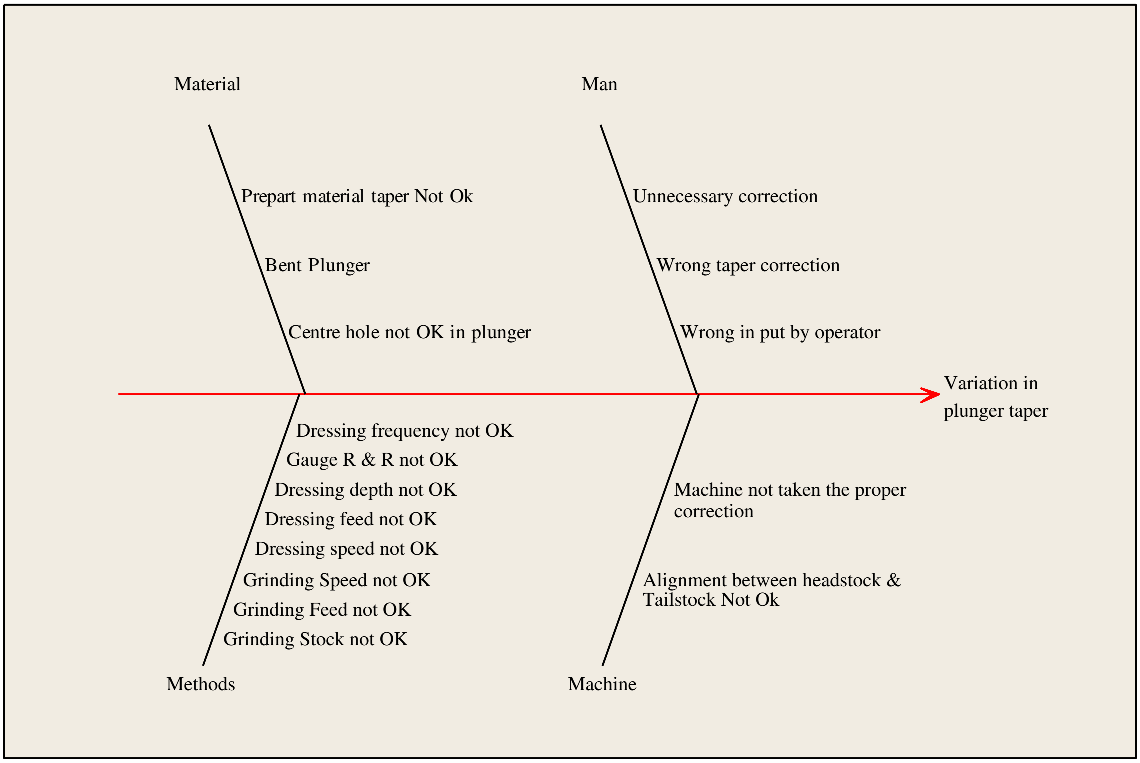


Fig. 4 Cause and effect diagram for variation in plunger taper

prepared a plan for validating all the potential causes. During these discussions, it was identified that there are two categories of causes. For one category, measurable data were possible to collect from the process whereas, for the other category, direct measurable data were not possible to collect. Wherever measurable data were available, appropriate

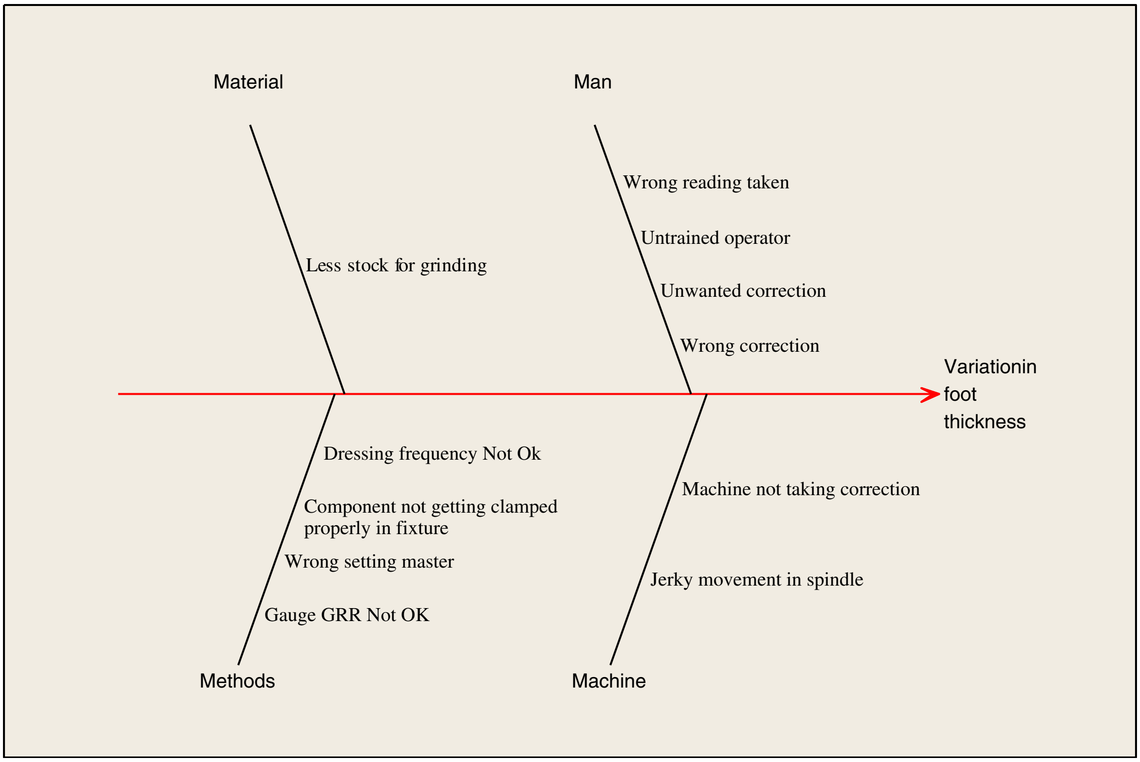


Fig. 5 Cause and effect diagram for variation in foot thickness

statistical techniques were selected for analysis and validation of the potential causes. Wherever direct measurable data were not available, it was decided by the team to validate such causes by process observation or GEMBA analysis [49]. The validation plan in Tables 2 and 3 presents the type of data available and possible analysis to be performed for validation of all potential causes in the cause-and-effect diagram. Based on this validation plan, each potential cause was validated and conclusions were made regarding whether the cause is a root cause or not. The details of validation of the causes are presented in the remaining part of the Analyse phase. The final conclusions regarding these causes are also included in the last column of Tables 2 and 3.

As per the cause validation plan, causes related to input raw material characteristics like *grinding stock*, *pre-part taper* and *pre-part runout* were validated by regression analysis. For this purpose, 116 components in a batch were selected, and data were collected on *grinding stock*, *pre-part taper* and *pre-part runout*. As all these variables are continuous, the effect of these input dimensional characteristics on the plunger taper needs to be validated by a multiple regression analysis. If the regressors are linearly related, the inference based on a regression model can be misleading or erroneous [50]. When there are near linear dependencies between the regressors, the problem of multicollinearity is said to exist [50]. Hence, before performing the multiple regression analysis, the variables were tested for multicollinearity. Multicollinearity can be studied through the variance inflation factor (VIF). The VIF for each term in the model measures the combined effect of the dependencies among the regressors on the variance of that term. One or more large VIF indicates multicollinearity [36]. If any one of the VIFs exceeds 5, it is an indication that the associated regression coefficients are poorly estimated because of multicollinearity [50]. From the VIF of the regression analysis (Table 4), it is evident that multicollinearity is not present in the data [36]. In the regression analysis, the p value for ANOVA and for the regressors Grinding stock and Barrel roundness were found to be less than 0.05 confirming that these two has a significant impact on plunger taper.

In the cause-and-effect diagram, there were few causes related to machine/process parameters. During the team discussion about validation of these causes, it was understood that, at the time of installation of the machine, the machine manufacturer has only provided an operating range for the machine/process parameters for the machine. Hence, during the installation of the machine, all the parameters were set by trial and error method. So far, no scientific approach was adopted to optimise these parameters. Hence, the team decided to conduct a design of experiment (DOE) in the improvement phase to identify the optimum levels for the machine/process parameters.

4.4 The Improve phase

During the Improve phase of a Six Sigma project, solutions were identified for the validated root causes and implemented after a risk analysis. Now, as per the plan in the Analyse phase, it was decided to conduct a design of experiment with the machine/process parameters. After a detailed discussion with the technical personnel of the process, the parameters (factors) identified for experimentation were *dressing frequency*, *dressing feed rate*, *dressing depth*, *grinding feed* and *grinding stock*. The team also felt that the interaction of dressing frequency with grinding stock and dressing depth are important to be estimated. Since the relationship between the selected factors and response was not established as linear, it was decided to experiment all the selected factors at three levels [51, 52]. One of the levels for the selected factors was identified as the existing level and the remaining two levels were selected based on operational feasibility and cost considerations [53]. The factors and respective levels are presented in Table 5.

For conducting a factorial experiment with five factors each at three levels requires quite a large number of

Table 2 Cause validation details for foot thickness

Sl. no	Cause	Observation/validation method	Remarks
1	Wrong setting master	Only one master used	Not a root cause
2	Wrong reading taken	Gemba observation	Not a root cause
3	Dressing frequency not ok	Trend chart	Root cause
4	Unwanted correction	Gemba validation	Root cause
5	Untrained operator	Only trained operator put	Not a root cause
6	Machine not taking correction	Gemba observation, backlash in feed mechanism	Root cause
7	Jerky movement of spindle	Observation & Data collection	Not a root cause
8	Component not getting clamped properly in fixture	Gemba observation, repeatability study.	Not a root cause
9	Gauge GR&R not ok	GR&R study	Not a root cause
10	Less stock for grinding	Data collection	Not a root cause
11	Wrong correction for depth	Data collection, Gemba validation	Root cause

Table 3 Cause validation details for plunger taper

Sl. no	Cause	Observation/validation method	Remarks
1	Grinding stock	Regression analysis	Root cause
2	Prepart material taper not ok	Regression analysis	Root cause
3	Bent plunger	Gemba validation, data collection	Not a root cause
4	Grinding feed	DOE	Root cause
5	Grinding speed	DOE	Root cause
6	Alignment between headstock and tailstock not ok	Gemba validation, observation	Not a root cause
7	Machine not taken the proper correction	Gemba validation, data collection	Not a root cause
8	Unnecessary correction	Gemba validation	Not a root cause
9	Dressing speed	DOE	Root cause
10	Dressing feed	DOE	Root cause
11	Dressing depth	DOE	Root cause
12	Wrong taper correction	Gemba validation	Not a root cause
13	Wrong input by operator	Gemba validation	Not a root cause
14	Gauge R & R not ok	Gauge R & R study	Not a root cause
15	Centre hole not ok in plunger	Gemba validation	Not a root cause
16	Dressing frequency not ok	DOE	Root cause

experiments to be conducted, which would be very costly and time-consuming exercise [54]. Also, the team was interested only in estimating two interactions; it was decided to use fractional factorial experimentation using orthogonal arrays for conducting this experiment [55, 56]. Estimating the main effects of five factors and two interactions require 27 experiments to be conducted using the orthogonal array $L_{27}(3^{13})$ [57, 58]. The design layout for experimentation was prepared by allocating the factors and levels to the $L_{27}(3^{13})$ orthogonal array and is presented in Table 6.

The team decided to replicate each experiment two times. As per the design layout, experiments were conducted in a random sequence, and data were recorded. These data were analysed using Taguchi's signal-to-noise ratio (S/N ratio) method [59]. Since the data collected are of *foot thickness*, *nominal-the-best* type of S/N ratio was selected for analysis. The formula used for *nominal-the-best* type S/N ratio is;

$$S/N = 10\log\left(\frac{\overline{Y}^2}{s^2}\right) \tag{1}$$

Where $\overline{Y}$ is the average and s, the standard deviation for each experiment. These S/N ratio values were calculated for all the 27 experiments, and further analysis was carried out. The S/N ratio values and the raw data were analysed separately to identify the important factors of the process [60]. ANOVA was carried out for the S/N ratio values, and the significance of all factors and interactions were tested (refer to Table 7). From the ANOVA table presented in Table 7, it is clear that the factor grinding feed and the selected interactions are significant at 5 % level. From the main effect and interaction plots of S/N ratio presented in Figs. 6 and 7, the optimum factor level combination was identified [61, 62] and is presented in Table 8.

The optimum combination identified was considered as the solutions to the causes related to machine/process parameters. For the remaining root causes, the team performed a brainstorming session with all the people working on the process, and solutions were identified. After identifying the solutions, the impact of the suggested solutions in the process were discussed with the people working in the process along with the project team to understand any negative side effect of the solutions. The feasibility of some of these solutions, including the ones identified through DOE, was tested through trial implementation. After going through each of these details, the team concluded that there is no risk associated with any of the selected solutions. Hence, an implementation plan was

Table 4 Minitab output of regression analysis

Predictor	Coefficient	SE of coefficient	*t* statistic	*p* value	Variance inflation factor
Constant	0.0011716	0.0001156	10.14	0.000	–
Grinding stock	0.007544	0.002225	3.39	0.001	1.0
Barrel roundness	0.04107	0.01424	2.88	0.005	1.1
Pre-part runout	−0.008743	0.008053	−1.09	0.280	1.0

Table 5 Factors and their levels for experimentation

Sl. no.	Factor	Level		
		1	2	3
1	Dressing frequency	30[a]	40	50
2	Dressing feed rate	80	100[a]	110
3	Dressing depth	30	35[a]	40
4	Grinding feed	1	2[a]	3
5	Grinding stock	35	45[a]	55

[a] Existing levels

prepared for all the solutions with details of responsibility and target date for implementation. All the solutions were implemented as per the plan, and results were observed.

4.5 The Control phase

The idea behind including this phase was to make sure that the benefits and knowledge generated from Six Sigma projects are sustained on a long-term basis [63]. Hence, during the Control phase of a Six Sigma project, the mechanisms for sustainability of the achieved results are introduced in the process. Due to tool wear present in the process, even after the improvement actions, the collected data plotted against time showed an increasing trend in case of foot face thickness. Because of this upward trend in dimension, the operators tend to give corrections in the process for avoiding components produced outside the specification limits. Since tool wear cannot be eliminated from the process, the process adjustments by the operators are necessary for the process. The unscientific way of incorporating corrections in the process was resulting in high variation in the process. Hence the team decided to standardize the process adjustments through scientifically established techniques. Two questions needing to be answered during any process correction are when to give correction and how much correction to be given. These two questions can be answered by the *nested ANOVA* analysis [46] and Beta correction technique [39]. Hence it was decided to apply the Beta correction technique for standardising the corrections. For this purpose, 256 consecutive components from the process were selected without any adjustment, and the foot thickness was measured. A *nested ANOVA* was performed on these data to identify when a significant change happens to the process. From the *nested ANOVA*, it was found that the *p* value between eight components is significant, and hence corrections are required after four components. Now, the corrections/adjustments to be given in the process have to be calculated based on Beta correction technique. In Beta correction method, it is suggested that, instead of giving the full correction, a fraction of the correction be given after taking measurement on the machined component [39]. Hence, as per this method, if 'X' is the measured dimension of the component and 'T' is the centre of the specification, then,

Table 6 The design layout for experimentation

Experiment no	Dressing frequency	Dressing feed rate	Dressing depth	Grinding feed	Grinding stock
1	30	70	30	1	35
2	30	70	35	2	45
3	30	70	40	3	55
4	30	90	30	2	55
5	30	90	35	3	35
6	30	90	40	1	45
7	30	110	30	3	45
8	30	110	35	1	55
9	30	110	40	2	35
10	40	110	30	3	35
11	40	110	35	1	45
12	40	110	40	2	55
13	40	70	30	1	55
14	40	70	35	2	35
15	40	70	40	3	45
16	40	90	30	2	45
17	40	90	35	3	55
18	40	90	40	1	35
19	50	90	30	2	35
20	50	90	35	3	45
21	50	90	40	1	55
22	50	110	30	3	55
23	50	110	35	1	35
24	50	110	40	2	45
25	50	70	30	1	45
26	50	70	35	2	55
27	50	70	40	3	35

$$\text{Correction} = -\beta(X - T) \tag{2}$$

where

$$\begin{aligned} \beta &= 0, \text{when } (X-T)^2 \le \sigma^2 \\ &= 1 - \frac{1}{F}, \text{ otherwise} \end{aligned} \tag{3}$$

where $F = \left(\frac{X-T}{\sigma}\right)^2$

Traditionally, for implementing the Beta correction method, a ready reckoner used to be prepared and displayed near the machine as per the above formula. Since these operations were done on a high-precision and advanced technology machine, in this case, these process adjustment details were incorporated in the machining program itself. As per this programme, whenever the measured dimensions are going out of the specified values, a correction was made to the

Table 7 ANOVA table for S/N ratios

Source	DF	Seq. SS	Adj. SS	Adj. MS	*F*	*P* value
Dressing frequency	2	21.269	21.269	10.635	2.9624	0.109
Dressing feed rate	2	12.637	12.637	6.319	1.7602	0.233
Dressing depth	2	20.702	20.702	10.351	2.8832	0.114
Grinding feed	2	58.64	58.64	29.32	8.1671	0.012[a]
Grinding stock	2	5.173	5.173	2.587	0.7206	0.516
Dressing frequency × dressing depth	4	84.962	84.962	21.241	5.9167	0.016[a]
Dressing frequency × grinding stock	4	100.528	100.528	25.132	7.0006	0.010[a]
Error	8	28.72	28.72	3.59		
Total	26	332.631				

[a] Significant at 5 % level of significance.

process. This has helped the process to maintain the components with less variation in the process.

After implementation of this solution in the process, a sample of size 1,000 units was collected over a period of 2 months time, and the process capability was evaluated for the foot thickness. From the Minitab software output, the observed ppm total was found to be 5,000. Similarly, the data for taper were evaluated, and the observed performance was found to be 5,128 ppm.

All the changes introduced in the process as a part of the solutions were documented in the standard operating procedures, control plans and work instructions in the company. Since the organisation was certified to ISO 9001:2008, all these modifications were brought under document control procedure to ensure that everyone strictly adhered to the revised process. The internal audit checklists were modified to include verification of the results of Six Sigma project. The adherence to these practices and results were closely monitored during the internal audits of ISO 9001 system, which were performed once in 3 months in the organisation. Deviations, if any, were reported, and corrective actions were initiated. Table 9 summarises the improvements achieved from this study. Figures 8 and 9 represent the comparison of process before and after the study.

5 Lessons learned and managerial implications

An age-old problem in the organisation was addressed through this Six Sigma project. As a result of this project, the management got convinced that Six Sigma can do wonders in process improvement, when it is implemented in the true spirit. The top management also understood the time and effort taken by the team for successful completion of this project. Hence, they have introduced a reward scheme for successful Six Sigma projects in the organisation. It was also

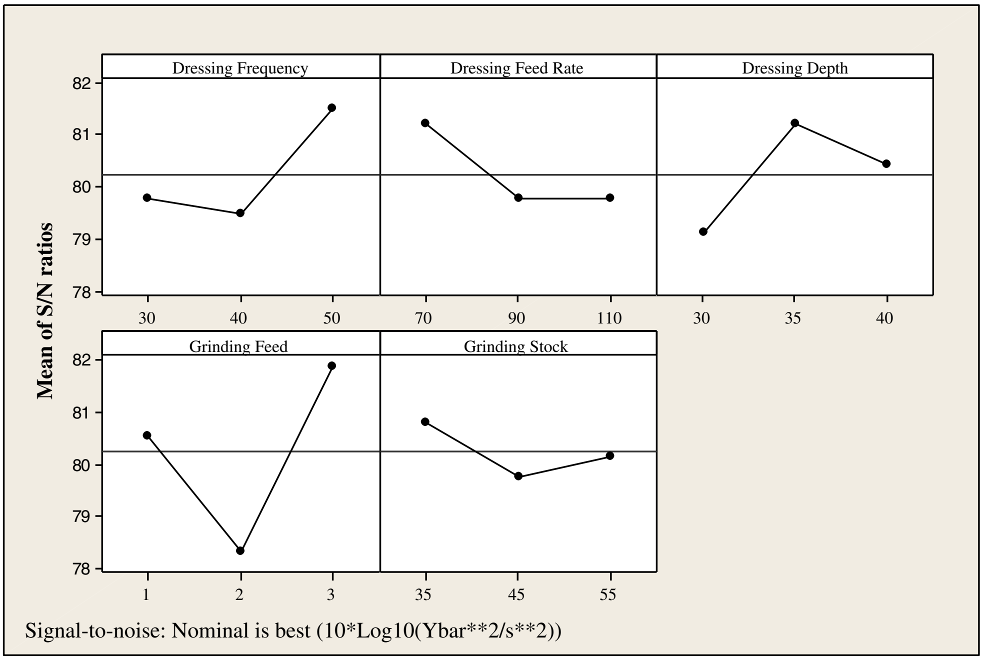


Fig. 6 Main effect plot for S/N ratios

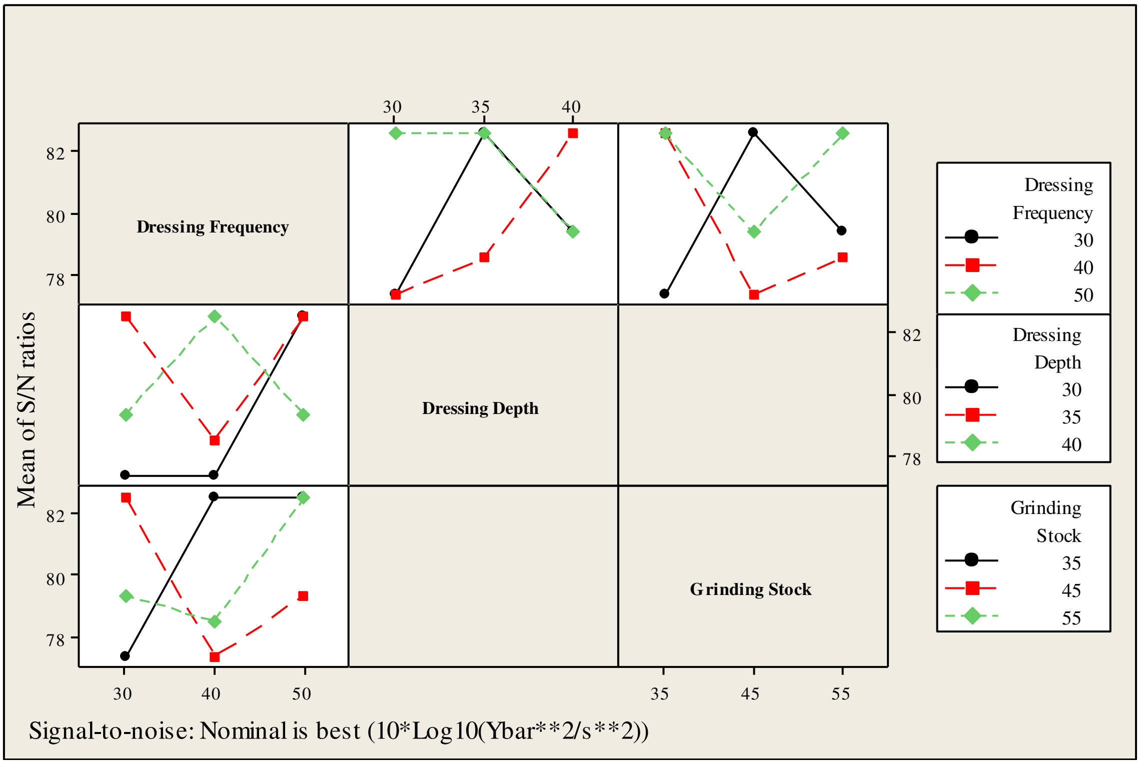


Fig. 7 Interaction plot for S/N ratios

decided by the management to add Six Sigma as an evaluation point in the annual appraisal system for all employees of the company. Based on the level of participation in the Six Sigma projects, scoring were given during the appraisal. All these initiatives from the part of the management have given a big boost for the Six Sigma movement in the organisation. The effectiveness of these actions was evident from the number of projects undertaken in the organisation. During the first wave, only seven projects were selected for implementation where as during the second wave of Six Sigma implementation a total of 42 projects were identified.

The biggest challenge during the Six Sigma implementation was the Black Belt training. Since during the first wave of Six Sigma projects, only seven members were trained as Black Belt, they were sent for training at a training institute outside the company. Availability of these seven persons for the 15 days training outside the organisation was a big challenge. Also, the people in the organisation were so familiar with collecting data from old inspection/production records for any type of analysis; collection of fresh data from the process was a challenge. Another challenge during the project was interpretation of analysis results. Since the statistical software like Minitab and JMP was used for analysis, interpretation of the output was little difficult for the beginners. This problem was taken care by constant intervention of the MBB throughout the project execution process. Getting support from people down the line in the process also was not an easy task for the team. It took a lot of effort by the team to convince these people for the need for participating in the improvement initiatives. All these activities and its success inculcated confidence in the team members as well as for the management to take up similar activities in future.

Another important point was regular project review meetings and briefings enabled both management and employees to share experiences and progress on projects, and factors critical for its success and failure. Also, Six Sigma works best

Table 8 Optimum factor level combination from the experiment

Sl. no	Parameters	Optimum level after DOE
1	Grinding feed, in μ	3
2	Dressing frequency, in Nos	50
3	Dressing depth, in μ	35
4	Grinding stock, in μ	35
5	Dressing feed rate, in mm/min	70

Table 9 Comparison of results, before and after the study

CTQ	Measure	Before	After
Foot thickness	DPMO	35,333	5,000
	Sigma level	3.31	4.08
Plunger taper	DPMO	51,333	5,128
	Sigma level	3.13	4.07

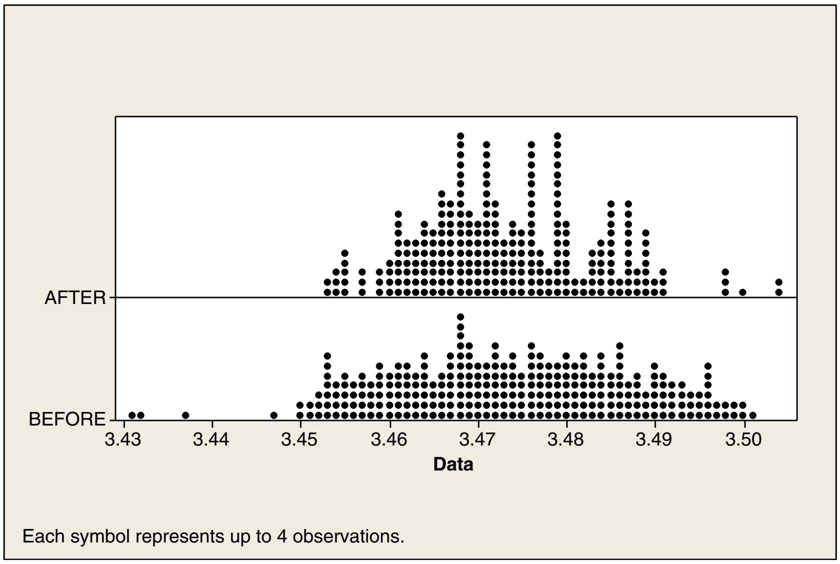


Fig. 8 Foot thickness, before and after the study

with a top-down approach, when the CEO and senior management team own it, support it and drive it.

6 Conclusion

Six Sigma is perceived as a well-structured improvement approach with strong links to an organisation's strategy, high level of management involvement, strong customer focus and strong links to financial results [64, 65]. This article discusses the successful implementation of Six Sigma methodology along with Beta correction technique in an automotive company. As a result of this study, the first-pass yield improved significantly in the process. After achieving the results and maintaining it for a period of 6 months, the team carried out a cost–benefit analysis of the whole project. The team with the help of the finance department estimated the savings resulted from this project. The annualised savings due to reduction in repair, scrap and tool cost was estimated to be around US$87, 000. This has given encouragement for the management and people in the organisation to work in Six Sigma projects. After observing success in this project, the people were more confident in working with Six Sigma methodology.

These results of the effect of implementation of *Beta* correction technique with Six Sigma initiatives make a novel contribution to the growing body of literature. This study contributes uniquely by elucidating the synergistic impact of Beta correction for greater effectiveness of Six Sigma programmes in engineering industry. There has been little, if any, research so far about the effects of simultaneous implementation of Six Sigma and Beta correction. This is highly relevant to

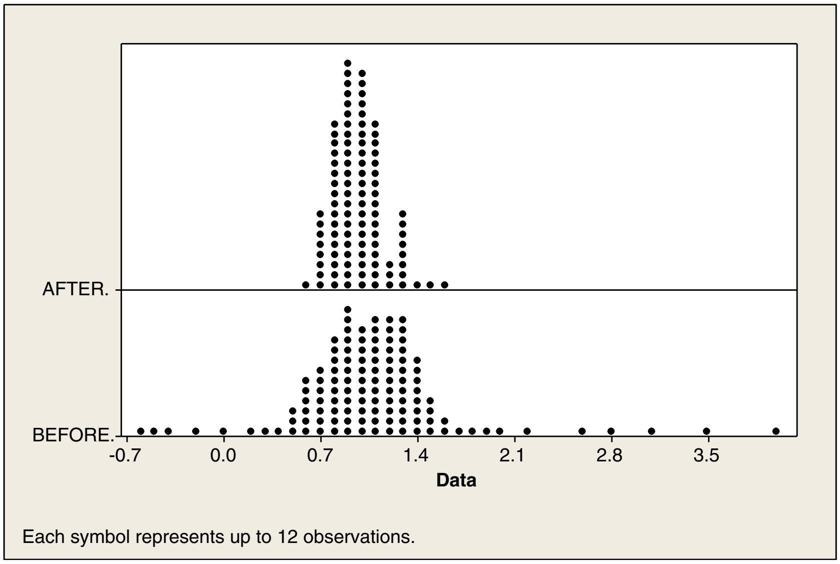


Fig. 9 Plunger taper, before and after the study

machining processes of engineering and manufacturing organisations where tool wear is a major issue. If the process is influenced by tool wear, it necessitates corrections in the process for compensating for tool wear. This is a case study where Taguchi's Beta correction technique was integrated in the Control phase of Six Sigma methodology to have proper monitoring of the process with tool wear. This has helped the process to reduce the variability.

Annexure 1 Project charter

Project Title: First-pass yield improvement in the plunger manufacturing line.

Background and reasons for selecting the project:

This is a high-volume production process utilising costly equipments and tools. The first-pass yield of the process is as low as 94 % resulted in scrapping of around 1,900 components every month. The problem is very complex, and there are too many variables affecting the taper and foot face thickness. The estimated financial loss due to rejection and scrap was around US$ 95,000 per annum.

Aim of the project:

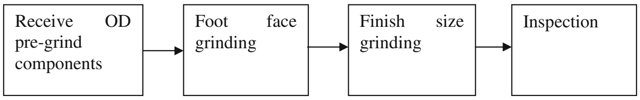
To improve the first-pass yield from 94 % to 99 % in plunger manufacturing line.

Project champion:	Manager–production
Project leader:	Assistant Manager–production
Team members:	Engineer–maintenance Engineer–product planning Supervisor–production Engineer–quality control Operator–shift I Operator–shift II Operator–shift III
Expected benefits:	A saving of approximately US$ 100,000.
Expected customer benefits:	Reduction of customer complaints related to field failure and delay in delivery.
Schedule:	Define, 2 weeks; Measure, 3 weeks; Analyse, 4 weeks; Improve, 4 weeks; Control, 8 weeks

Annexure 2 SIPOC along with process map

Supplier	Input	Process	Output	Customer
Supplier	Pre-machined parts	Foot face grinding and finish size grinding	Finished parts	Stores
Planning department	CNC program		Production and quality reports	Manufacturing department
Calibration department	Gauges			
Planning department	Tooling			

Process steps



References

1. Gutiérrez Gutiérrez LJ, Bustinza OF, Molina VB (2012) Six sigma, absorptive capacity and organisational learning orientation. Int J Prod Res 50(3):661–675
2. Gijo EV, Scaria J, Antony J (2011) Application of Six Sigma methodology to reduce defects of a grinding process. Qual Reliab Eng Int 27(8):1221–1234
3. Lee K-C, Choi B (2006) Six Sigma management activities and their influence on corporate competitiveness. Total Qual Manag 17(7):893–91
4. Mahesh M, Wong YS, Fuh JYH, Loh HT (2006) A Six Sigma approach for benchmarking of RP&M processes. Int J Adv Manuf Technol 31(3–4):374–387
5. Adams C, Gupta P, Wilson C (2003) Six Sigma deployment. Butterworth-Heinemann, Massachusetts
6. Montgomery DC, Woodall WH (2008) An overview of Six Sigma. Int Stat Rev 76(3):329–346
7. Goh TN (2011) Six Sigma in industry: some observations after twenty-five years. Qual Reliab Eng Int 27(2):221–227
8. Tong JPC, Tsung F, Yen BPC (2004) A DMAIC approach to printed circuit board quality improvement. Int J Adv Manuf Technol 23(7–8):523–531
9. Johnston AB, Maguire LP, Mcginnity TM (2008) Disentangling causal relationships of a manufacturing process using genetic algorithms and Six-Sigma techniques. Int J Prod Res 46(22):6251–6268
10. Chen JC, Li Y, Shady BD (2010) From value stream mapping toward a lean/sigma continuous improvement process: an industrial case study. Int J Prod Res 48(4):1069–1086
11. Ellis K (2001) Mastering Six Sigma. Training 28(12):30–35
12. Firka D (2010) Six Sigma: an evolutionary analysis through case studies. The TQM Journal 22(4):423–434
13. Bisgaard S, Freiesleben J (2004) Six Sigma and the bottom line. Qual Prog 37(9):57–62
14. De Mast J (2007) Integrating the many facets of Six Sigma. Qual Eng 19(4):353–361
15. El-Haik M, Roy DM (2005) Service design for Six Sigma: a road map for excellence. John Wiley & Sons, New Jersey
16. Halliday S (2001) So what exactly is Six Sigma? Workforce Manag 15(1):15
17. Pande P, Neuman R, Cavanagh R (2000) The Six Sigma way: how GE, Motorola and other top companies are honing their performance. McGraw-Hill, New York
18. Pande P, Neuman R, Cavanagh R (2003) The Six Sigma way team field book: an implementation guide for process improvement teams. Tata McGraw-Hill, New Delhi
19. Harry M, Schroeder R (1999) Six Sigma: the breakthrough management strategy revolutionizing the world's top corporations. Doubleday, New York
20. Park SH (2003) Six Sigma for quality and productivity promotion. Asian Productivity Organization, Tokyo
21. Snee RD, Rodebaugh WF (2002) Project selection process. Qual Prog 35(9):78–80
22. Snee RD, Hoerl RW (2003) Leading Six Sigma: a step by step guide based on experience at GE and other Six Sigma companies. Prentice-Hall, New Jersey

23. Taghizadegan S (2006) Essentials of lean Six Sigma. Elsevier, New Delhi
24. Treichler DH (2005) The Six Sigma path to leadership. Pearson Education, New Delhi
25. Shah R, Chandrasekaran A, Linderman K (2008) In pursuit of implementation patterns: the context of lean and Six Sigma. Int J Prod Res 46(23):6679–6699
26. Chen M, Lyu J (2009) A lean Six-Sigma approach to touch panel quality improvement. Production Planning & Control: The Management of Operations 20(5):445–454
27. Gowen CR III, Stock GN, Mcfadden KL (2008) Simultaneous implementation of Six Sigma and knowledge management in hospitals. Int J Prod Res 46(23):6781–6795
28. Bunce MM, Wang L, Bidanda B (2008) Leveraging Six Sigma with industrial engineering tools in crateless retort production. Int J Prod Res 46(23):6701–6719
29. Gijo EV, Rao TS (2005) Six Sigma implementation—hurdles and more hurdles. Total Quality Management & Business Excellence 16(6):721–725
30. Gijo EV (2011) 11 ways to sink your Six Sigma project. Six Sigma Forum Magazine 11(1):27–29
31. Yin RK (2009) Case study research: design and methods, 4th edn. Sage, CA
32. Saunders M, Lewis P, Thornhill A (2009) Research methods for business students, 5th edn. Pearson Education Limited, UK
33. Lee TW (1999) Using qualitative methods in organizational research. Sage, CA
34. AIAG (2002) Measurement systems analysis, reference manual, 3rd edn. Automotive Industry Action Group, Southfield, Michigan
35. Montgomery DC (2002) Introduction to statistical quality control, 4th edn. John Wiley, New York
36. Draper NR, Smith H (2003) Applied regression analysis, 3rd edn. John Wiley, New York
37. Wu CFJ, Hamada M (2011) Experiments—planning, analysis, and parameter design optimization. John Wiley, New York
38. Dudewicz EJ, Mishra SN (1988) Modern mathematical statistics. John Wiley, New York
39. Taguchi G (1981) On-line quality control during production. Japanese Standards Association, Tokyo
40. Li YQ, Cui ZS, Ruan XY, Zhang DJ (2006) CAE-based Six Sigma robust optimization for deep-drawing sheet metal process. Int J Adv Manuf Technol 30:631–663
41. Braglia M, Carmignani G, Zammori F (2006) A new value stream mapping approach for complex production systems. Int J Prod Res 44(18):3929–3952
42. Keller PA (2001) Six Sigma deployment. Quality Publishing House, Arizona
43. Hoerl RW (2001) Six Sigma black belts: what do they need to know? J Qual Technol 33(4):391–406
44. Hoerl RW (2004) One perspective on the future of Six Sigma. Int J Six Sigma Competitive Advantage 1(1):112–119
45. Gijo EV, Scaria J (2010) Reducing rejection and rework by application of Six Sigma methodology in manufacturing process. Int J Six Sigma and Competitive Advantage 6(1/2):77–90
46. Montgomery DC, Runger GC (2007) Applied statistics and probability for engineers, 4th edn. John Wiley, New York
47. Ishikawa K, Lu DJ (1985) What is total quality control? The Japanese Way, Prentice Hall, NJ
48. Imai M (1986) Kaizen: the key to Japan's competitive success. McGraw-Hill, New York
49. Womack J (2011) GEMBA walk. Lean Enterprise Institute, USA
50. Montgomery DC, Peck EA (1982) Introduction to linear regression analysis. John Wiley, New York
51. Gijo EV, Scaria J (2011) Application of Taguchi method to optimise the characteristics of green sand in a foundry. Int J Business Excellence 4(2):191–201
52. Goethals PL, Cho BR (2011) Solving the optimal process target problem using response surface designs in heteroscedastic conditions. Int J Prod Res 49(12):3455–3478
53. Li H, Guo Z, Li D (2007) Reducing the effects of weldlines on appearance of plastic products by Taguchi experimental method. Int J Adv Manuf Technol 32:927–931
54. Deng CS, Chin JH (2005) Hole roundness in deep-hole drilling as analysed by Taguchi methods. Int J Adv Manuf Technol 25:420–426
55. Phadke MS (1989) Quality engineering using robust design. Prentice Hall, New Jersey
56. Hwang YD (2006) The practices of integrating manufacturing executing systems and Six Sigma methodology. Int J Adv Manuf Technol 30:761–768
57. Ross PJ (1996) Taguchi techniques for quality engineering. McGraw-Hill, New York
58. Gijo EV, Scaria J (2012) Product design by application of Taguchi's robust engineering using computer simulation. Int J Comput Integr Manuf 25(9):761–773
59. Saravanan S, Meera M, Prakash S, Gijo EV (2012) Efficiency improvement on the multicrystalline silicon wafer through six sigma methodology. Int J Sustain Energ 31(3):143–153
60. Taguchi G (1988) Systems of experimental design, volume 1 and 2. UNIPUB and American Supplier Institute, New York
61. Antony J (2000) Improving the manufacturing process quality and capability using experimental design: a case study. Int J Prod Res 38(12):2607–2618
62. Chan KK, Spedding TA (2001) On-line optimization of quality in a manufacturing system. Int J Prod Res 39(6):1127–1145
63. Kumar M, Antony J, Tiwari MK (2011) Six Sigma implementation framework for SMEs—a roadmap to manage and sustain the change. Int J Prod Res 49(18):5449–5467
64. Van Iwaarden TJ, van der Wiele B, Dale RW, Bertsch B (2008) The Six Sigma improvement approach: a transnational comparison. Int J Prod Res 46(23):6739–6758
65. Gijo EV, Antony J, Hernandez J, Scaria J (2013) Reducing patient waiting time in a pathology department using the Six Sigma methodology. Leadersh Health Serv 26(4):253–267