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TO ACHIEVE QUALITY STANDARDS BY REDUCING DEFECTS THROUGH SIX- SIGMA (DMAIC) METHODOLOGY

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Abstract *–In present era of competition, Six-Sigma has been considered as a powerful business strategy that employs a well-structured continuous improvement methodology to reduce rejections within the manufacturing processes usingeffective application of statistical tools and techniques. This paper presents the implementation of Six-sigmamethodology for reducing rejection of automobile part in an industry. The DMAIC methodology has been used toachieve quality level. During this process, data for all possible causes were collected analysed and thereby conclusionswere drawn. Implementation of six sigma resulted in reduction of rejection and therefore reduced the Defect perMillion Output (DPMO) from 35000 to 15000. This increased the Sigma level from 3.2 to 3.67, with optimal solution.Finally, implementation of Six-sigma methodology has resulted increase in quality level of camshaft of the engine.*

Key Words:**Six Sigma, DMAIC, DPMO, Quality improvement, Camshaft**

1. INTRODUCTION

Six-Sigma is the most popular quality and process improvement methodology which strives for elimination of defects in the processes whose origin is traced back to the pioneering and innovation work done at Motorola and its adoption by many companies including GE, Ford, General Motors, Xerox etc. The primary objective of Six Sigma is to reduce variations, in products and processes, to achieve quality levels of less than 3.4 defects per million opportunities (DPMO). [3]

This paper presents six sigma implementation conducted in an automotive parts producing industry with the aim of reducing rejection, and thereby increasing its sigma level, using Six-Sigma methodology. The application of the Six-sigma problem solving methodology, DMAIC (define– measure – analyse –improve – control), reduced the rejection and thereby improved quality level. Various statistical techniques were applied to analyse the data and to identify solution[4, 5]. For performing this research work various topic related literatures were studied and cases also discussed in table 1. After performing the literatures study and case discussion related to the topic, an understanding has been made for performing the research & it also felt that the need and importance of six sigma in today's manufacturing environment. But unfortunately less research has been conducted in this area of implementing six sigma in camshaft manufacturing automotive industries in India. Therefore it was needed to investigate the implementation of six sigma in an automotive industry. In this study an effort has been made to implement six sigma with engine camshaft manufacturing automotive industry. To carry out this study, an automobile industry located in Pithampur, India has been selected.

2. RESEARCH PROBLEMS & OBJECTIVES

In this study the research problem is to implement the six sigma DMAIC method for the reduction in high rejections of automobile part camshaft in an automobile parts manufacturing industry. Detailed research problems are as follows.

1. High rejection of camshaft due to face hole diameter
2. High Defect per Million Output (DPMO) that is 35000.
3. Low process sigma level which is only 3.2 Globalization has opened the doors of world market to Indian organizations, which in turn forcing them to bring their products & services to world class level. For that, along with various tools Six Sigma is becoming popular in India.

Considering specific need of Indian companies to implement Six Sigma effectively; the main objectives of this research work are;

1. Understand the need of Six Sigma in an Organization.
2. Reduce the rejection of camshaft in an automotive industry.
3. Reduce the Defect per Million Outputs (DPMO).
4. Increase the process sigma level of that particular process of camshaft manufacturing.
5. Evaluate and compare Six Sigma and the existing way of working.

To achieve the above mentioned objectives DMAIC methodology has been used in present research.

Table 1: Summary table of discussed case

Sr. No.	Author name	Problem	Method used	Supporting tools	Results
1	Yadav and Sukhwani, 2018	Reduction of clutch rejection in auto industry due to variation of keyway depth.	Six sigma DMAIC	Process map Pareto chart Ishikawa (fishbone) diagram	Sigma level comes at 3.86 from 2.99
2	Patidar and Madan, 2018	Rejection issues in cab mounting bracket and actuator mounting bracket	Six sigma DMAIC	Cause and effect diagram ANOVA DOE	Sigma level comes at 3.16 from 2.90 of cab mounting bracket and 3.09 from 2.88 for actuator mounting bracket
3	Darshan D. Patel et al,2014	Reduction of production cost & process in bearing manufacturing industry	Six sigma DMAIC	Cause and effect diagram Process capability analysis	Sigma level comes at 3.76 from 2.47
4	Jirasukprasert et al, 2014	large amount of rubber gloves had been rejected by the customers due to defective gloves	Six sigma DMAIC	Process map Pareto chart Ishikawa (fishbone) diagram	Sigma level comes at 2.9 from 2.4
5	MehdiuzZaman et al, 2013	Rejection of welding electrodes in Manufacturing industry	Six sigma DMAIC	Process map Pareto chart Ishikawa (fishbone) diagram	Sigma level comes at 4.43 from 3.41
6	PrabhakarKaushik et al,2012	Rejection of bush in bicycle chain manufacturing company	Six sigma DMAIC	Brain storming Process map Pareto chart Ishikawa diagram	Sigma level comes at 5.46 from 1.40

3. Methodology

The paper deals with an application of Six Sigma DMAIC (Define– Measure- Analyse- Improve- Control) methodology.

3.1. Define phase

As the first step, a Six Sigma project team was formed in the investigation company. The members of this team were the production manager, supervisor, operator and the author of this thesis. These members analyzed the past six-month data after COVID-19 lockdown period concerning the manufacturing of camshaft in the investigation company. There is no production in the months of April-2020 and May 2020 due to the COVID- 19 lockdown. But due to very few productions of previous orders in the month of June- 2020, due to this we consider after lockdown data in the calculation. Bar graph of defects produces in different month in figure 1.

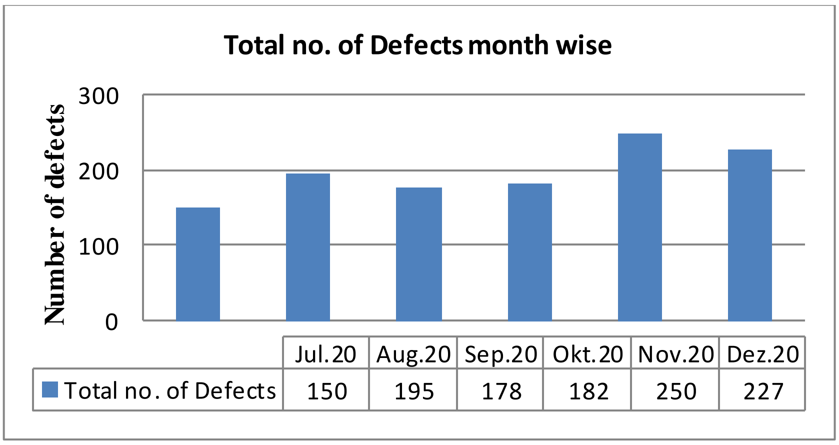

Figure 1: Month wise defects of camshaft

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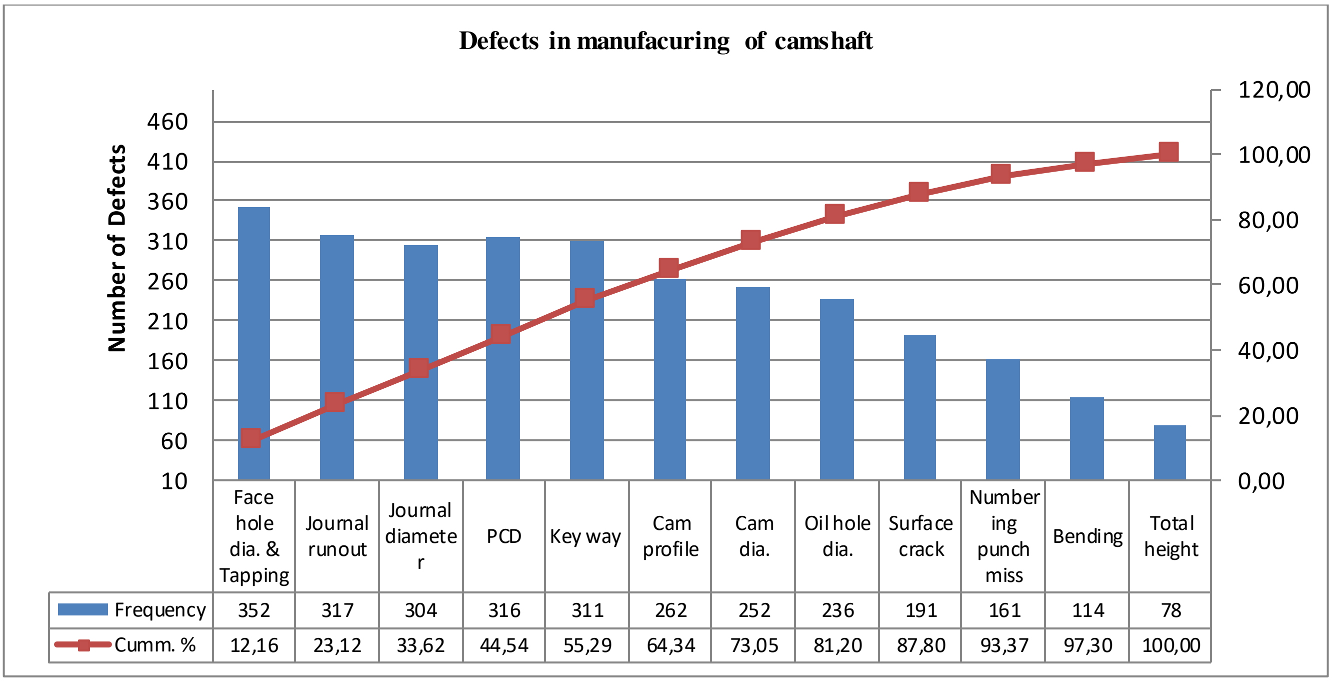
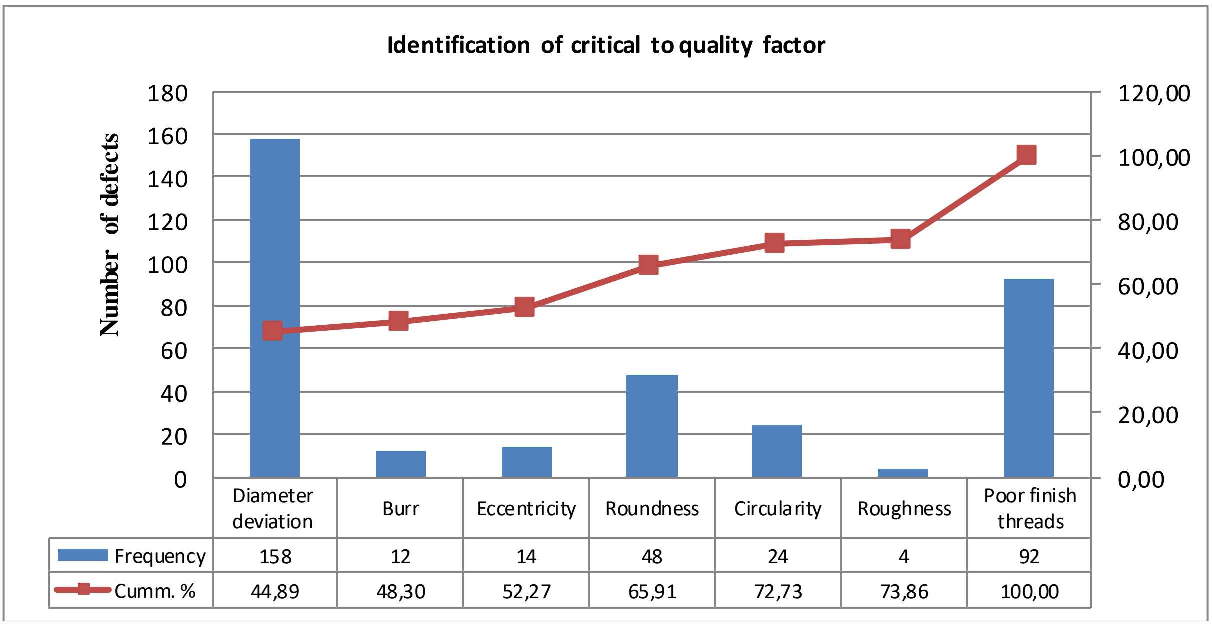
Then, Pareto analysis was conducted. The use of Pareto analysis in the application of DMAIC phases can further be studied. The outcome of conducting the Pareto analysis is depicted in Figure 2.



	Face hole dia. & Tapping	Journal runout	Journal diameter	PCD	Key way	Cam profile	Cam dia.	Oil hole dia.	Surface crack	Numbering punch miss	Bending	Total height
Frequency	352	317	304	316	311	262	252	236	191	161	114	78
Cumm. %	12,16	23,12	33,62	44,54	55,29	64,34	73,05	81,20	87,80	93,37	97,30	100,00

Figure 2: Defects of manufacturing of camshaft

As it can be viewed in Figure 2, the most commonly observed problem was theoccurrence of defects during the drilling of the camshaft hole. As the result of this finding,'drilling of the camshaft hole' formed the scope of the investigation. Consequently, thefailure to accurately drill the camshaft hole was considered as the problem of theinvestigation. Subsequently, the past one year data were gathered for identifying the CTQfactors concerned with 'drilling of camshaft hole'. In this background, Pareto analysis wasconducted. The results of conducting this Pareto analysis are shown in Figure 3.



	Diameter deviation	Burr	Eccentricity	Roundness	Circularity	Roughness	Poor finish threads
Frequency	158	12	14	48	24	4	92
Cumm. %	44,89	48,30	52,27	65,91	72,73	73,86	100,00

Figure 3: Identification of critical factor

As shown in Figure 3, the percentage of defects is highest in the case of deviation ofhole diameter (from the targeted diameter of 11 mm) in the camshaft. As it can beobserved in Figure 3.5, this defect accounted to 44.89% of the total number of defects.Subsequently, the project charter was developed. This project charter is shown in Table 2.

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As indicated, the VOC is that, 'A large amount camshaft has been rejected at final inspection station by quality inspector due to they have deviation in face hole diameter. This type of losses is not good for any company because for this time, materials, capital as well as create customers dissatisfaction, which negatively affects the company image'. The CTQ factor is the diameter of the camshaft hole. Thus, Six Sigma project was defined by developing the project charter. After developing the project charter, the SIPOC diagram pertaining to the manufacturing of camshaft was developed. This SIPOC diagram can be viewed in Figure 4. As shown in this Figure, the camshaft manufacturing section was identified as the supplier. The inputs are raw material, drawing, operator and radial drilling machine.

Table 2: VOC Chart

Project objective	To achieve six sigma level quality in the manufacturing of engine camshaft.
Problem description	Deviation in the face hole diameter affects the performance of the engine camshaft sub-assembly.
VOC	A large amount camshaft has been rejected at final inspection station by quality inspector due to they have deviation in face hole diameter. This type of losses is not good for any company because for this time, materials, capital as well as create customers dissatisfaction, which negatively affects the company image.
Metrics	Number of pieces returned by the customer and sigma level.
CTQ parameter	Face hole diameter of the engine camshaft.
Six Sigma tools	Pareto chart, SIPOC diagram, cause and effect diagram, DOE and OA.
Expected Savings in one year	INR 0.1 million
Six Sigma team members	Production Manager, Supervisor, Operator and the author of this thesis.

The process involved was drilling. The output was the drilling of the camshaft hole to the specification of 11±0.05 mm. The manufacturing unit was identified as the customer. The development of SIPOC diagram facilitated to realize that the drilling operation is the core operation and hence, it should be subjected to investigation for achieving six sigma level quality in the case of manufacturing camshaft.

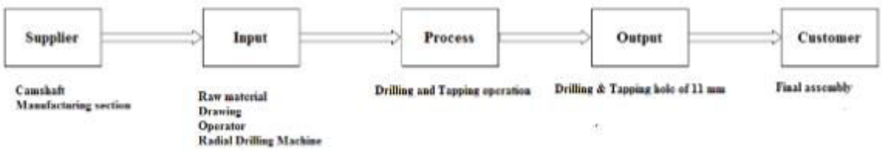

Figure 4: SIPOC chart

3.2. Measure phase

The members of the Six Sigma project team conducted gemba study to measure thevariation in the hole resulting from the drilling operation. In this investigation company,vernier caliper was used to measure the deviation in the hole diameter drilled byemploying radial drilling machine while manufacturing camshafts. A sample consisting of50 camshafts was subjected to gemba study for identifying the number of camshaftsrejected due to deviation in the hole diameter. Out of these 50 camshafts, seven of themwere rejected due to deviation in the diameter of the camshaft hole. In order to check theaccuracy of the measurement system employed in this phase, the measurement data wereentered into Minitab19software for conducting Gauge R & R studyis shown in Table 3.

As shown, the Total Gauge R & R of the measurement system employed in this phase is 20.78 percent. According to the research establishment, if the value of Total Gauge R & R falls between 10 percent and 30 percent, then it can be construed that the measurement system facilitates to obtain accurate results. Since the Total Gauge R & R shown in Table 3 falls between 10 percent and 30 percent, the measurement system employed in this phase of DMAIC facilitated to obtain accurate results.

Table 3: Gauge evaluation

Gauge Evaluation		
Source	**Standard deviation**	**Percentage study variation**
Total Gage R & R	0.0103276	20.78
Repeatability	0.0092561	18.64
Reproducibility	0.0045808	9.22
Part -To-Part	0.0485819	97.81
Total Variation	0.0496676	100

3.3. Analyze phase

The results of the gemba study revealed that there was a significant deviation in thediameter of the camshaft hole. This deviation caused the improper supply of fuel into theoil fired furnace. Hence, subsequently, the key variables of the radial drilling operationwere identified in which the camshaft hole is drilled. Then, the Six Sigma project teamparticipated in brainstorming sessions and identified the causes and key variables thatimpact the drilling of the camshaft hole accurately. These causes and key variables werepictorially plotted using a cause and effect diagram. The cause and effect diagram is depicted in Figure 5.

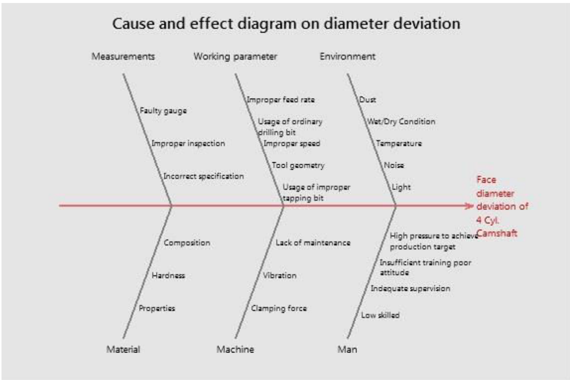

Figure 5: Cause and Effect diagram

As it can be viewed on the cause and effect diagram, the factors that impact diameterdeviation while drilling the camshaft hole using radial drilling machine are grouped underthe key variables, namely working parameter, man, environment, machine, measurementand material. After participating in brainstorming sessions, the Six Sigma team membersdecided to concentrate on the factors listed under 'working parameter'. The Six Sigmateam members excluded other key variables from further consideration as these variableseither have insignificant impact on the diameter deviation or are uncontrollable due tovarious reasons. At the end of this phase, the Six Sigma team members decided to considerfour factors, namely speed, feed rate, drill bit and tool geometry under the 'working parameter' variable. These factors were considered as the opportunities of drillinginaccurately the camshaft hole by using the radial drilling machine. After recognizingthese four opportunities, the initial sigma level was calculated. The steps of thiscalculation are presented below.
Number of camshaft inspected= 50
Number of camshaft rejected due to the deviation in the hole diameter= 7
Number of opportunities that cause the deviation in the diameter of the camshaft hole= 4
(Opportunity 1- Speed, Opportunity 2- Feed rate, Opportunity 3- Drill bit, Opportunity 4- Tool geometry)

DPMO= Number of defects/ (Number of units x Number of opportunities) x 10^6 --------------------(Equation1)

$$DPMO = \left[\frac{7}{50 \times 4}\right] \times 10^6 = 35000$$

By using Six Sigma conversion table, the sigma value for the DPMO of 35,000 is found tobe 3.2.

3.4. Improve phase

The Six Sigma team members participated in brainstorming sessions to identify theoptimum values of the four factors, namely speed, feed rate, drill bit and tool geometry. Inthe initial brainstorming sessions, the Six Sigma team members suggested the replacementof the drill bit in the radial drilling machine to overcome the deviation in the diameter ofthe camshaft hole. This suggestion could not be considered further as the management wasnot willing to implement this solution due to financial concerns. Because of this hurdle,the Six Sigma team members decided to consider only the speed and feed rate to overcomethe problem of diameter deviation in the case of drilling the camshaft hole. Hence, at thisjuncture, the scope of this investigation was restricted to identifying the best combinationof the values of these factors, so as to reduce the diameter deviation of the camshaft holewhile drilling it in the radial drilling machine. In this situation, the Six Sigma teammembers decided to design and conduct the experiments. The factors and levels chosen todesign these experiments are shown in Table 4.

Table 4: Factors

	Speed (rpm)	Feed rate (mm/revolution)
Level 1	180	0.2
Level 2	250	0.3
Level 3	300	0.4

In this Table 4, where level 2 of factor 'speed' indicates the speed at which currently the operators operate the radial drilling machine while drilling the camshaft hole. Levels 1 and 3 of the factor 'speed' indicate the preceding and succeeding speeds available in the radial drilling machine. The operators were not adopting any specific feed rate while drilling the camshaft hole in the radial drilling machine. Hence, the Six Sigma team members carefully observed the feed rate at which the operators drilled the camshaft hole using radial drilling machine. After making this close observation, the Six Sigma team members chose 0.2mm/revolution, 0.3 mm/revolution and 0.4 mm/revolution respectively as levels 1, 2 and 3 of the factor 'feed rate'.

Designing and conducting of experiments After choosing the factors and levels, the experiments were designed by following Taguchi's method. In this process, L9 orthogonal array was used. The experiments thus designed and conducted are shown in Table 3.4. As it can be viewed in Table 3.4, each experiment was replicated thrice. That is, while conducting each experiment, the holes in three specimens of camshaft were drilled using radial drilling machine. After drilling, the hole diameter in each specimen was measured. The data thus measured are presented in Table 3.4. Subsequently, the deviation in the hole diameter and S/N ratio in each experiment was calculated. These values are also presented in Table 5.

Table 5: Design of experiments

Experiment Number	Speed (rpm)	Feed rate (mm/rev)	Design specification of diameter 'A' (mm)	Diameter measured in mm			Mean diameter 'B' (mm)	Diameter deviation = Mod [A-B] (mm)	S/N ratio (dB)
				Specimen 1	Specimen 2	Specimen 3			
1	1450	0.2	11.00	11.02	11.03	11.03	11.027	-0.0267	-20.8489
2	1450	0.3	11.00	11.03	11.02	11.02	11.023	-0.0233	-20.8463
3	1450	0.4	11.00	11.04	11.03	11.04	11.037	-0.0367	-20.8568
4	1800	0.2	11.00	11.02	11.03	11.02	11.023	-0.0233	-20.8463
5	1800	0.3	11.00	11.01	10.99	11.01	11.003	-0.0033	-20.8305
6	1800	0.4	11.00	11.04	11.02	11.03	11.03	-0.0300	-20.8515
7	2500	0.2	11.00	11.05	11.05	11.04	11.047	-0.0467	-20.8646
8	2500	0.3	11.00	11.02	11.03	11.04	11.03	-0.0300	-20.8515
9	2500	0.4	11.00	11.01	11.02	11.01	11.013	-0.0133	-20.8384

Since the deviation in the camshaft hole diameter is required to be minimum, the 'smaller the better, characteristic was used to calculate the S/N ratios.

$$SN_s = -10\log\left(\sum_j \frac{y_j^2}{n}\right) \qquad \text{………………………… (Equation 2)}$$

As shown in Table 5, the S/N ratio is highest in the case of experiment number. In this case, the value of S/N ratio is -20.8305. This observation indicates that the deviation in the camshaft hole diameter can be minimized to the best possible extent while drilling the camshaft hole by employing radial drilling machine at the speed of 1800 rpm and feed rate of 0.3 mm/revolution. These data were fed into the Minitab software. Using this software, the response table and the main effect plots for S/N ratios presented in Table 3.5 and Figure 3.8 respectively were generated. The response diagram shown in Figure 6 corroborates the inferences drawn by referring to the Table 5.

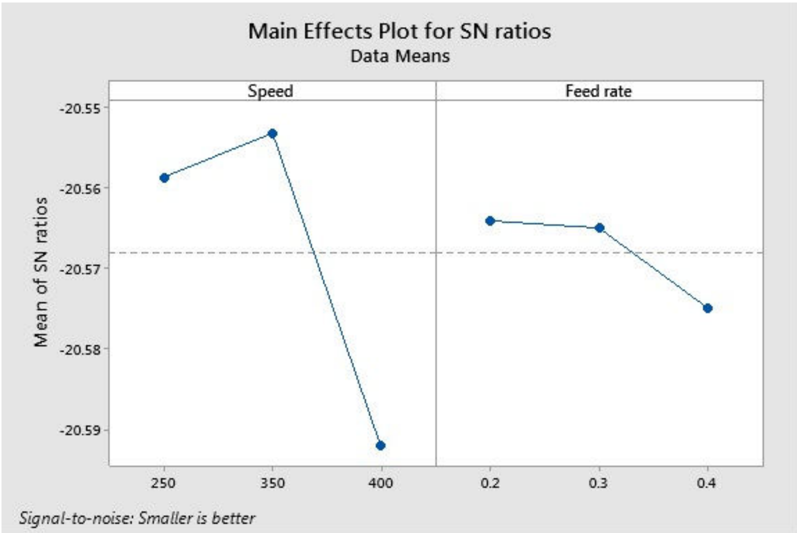

Figure 6: SN ratio

Subsequently, the operators drilled holes in the camshaft by using radial drilling machine at the speed of 1800 rpm and the feed rate of 0.3 mm/revolution. The holes in 50 camshafts thus drilled were inspected. Among these, three camshafts were rejected due to deviation found in the hole diameter. With this data, the sigma value was calculated.
Number of camshaft inspected= 50
Number of camshaft rejected due to the deviation in the hole diameter= 3
Number of opportunities that cause the deviation in the diameter of the camshaft hole= 4
(Opportunity 1- Speed, Opportunity 2- Feed rate, Opportunity 3- Drill bit, Opportunity 4- Tool geometry)
From equation 1.

$$DPMO = \left[\frac{3}{50\times 4}\right]\times 10^6 = 15000$$

DPMO find from the equation 1 is 15,000. From the Six Sigma conversion table (Gibbons and Burgess 2010), the sigma value for the DPMO of 15,000 is found to be 3.67. In this background, it is construed that the suggested levels of the factors, when applied while drilling the camshaft hole by using the radial drilling machine, facilitate to increase the sigma value from 3.31 to 3.67.

3.5. Control phase

The final stage of Six Sigma's DMAIC framework is control phase. In Six Sigma implementation, the control phase is carried out to sustain the improvements achieved in the improve phase. As mentioned in the previous section, the operators are required to operate the radial drilling machine at the speed of 1800 rpm and feed rate of 0.3 mm/revolution to reduce the rejection rate of camshaft due to deviation in the hole diameter. In order to sustain this implementation, two actions were carried out in the investigation being reported here. First, the belt connecting the pulleys was fixed so that the radial drilling machine was always operated at the speed of 1800 rpm. Second, the feed rate of 0.3 mm/revolution was maintained in the radial drilling machine. Besides these two actions, in order to ensure that the knowledge of these levels of factors is exposed in a sustained manner, a circular containing these details was displayed in front of the radial drilling machine. This circular is shown in Figure 7.

Name of the Organization	:	XXXXXXXXXXXXXXXXX
Name of the Machine	:	Radial drilling machine
Name of the Supervisor	:	YYYYYYYYYYYYYYYYYYYY

Operators are requested to operate the radial drilling machine at the speed and feed indicated in the Table shown below while drilling the camshaft hole.

Speed	1800 rpm
Feed	0.3 mm / revolution

Note: The supervisors are requested to check twice in a day to ensure that the operators comply with the above stipulations.

Figure 7: Circular for instructing the operators and supervisors

As shown, the operators are requested to operate the radial drilling machine at the speed and feed rate indicated in the circular while drilling the camshaft hole in the radial drilling machine. As shown, the supervisors are also requested to check whether the operators are pertaining to the technical specifications stipulated in the circular.

4. RESULT

In this background, it is construed that the suggested levels of the factors, when applied while drilling and tapping the camshaft hole by using the radial drilling machine, facilitate to increase the sigma value from 3.2 to 3.67. Thus, the application of the best levels of the factors has resulted in quality improvement. However, the increase in sigma value indicates the possibilities of achieving still higher degree of quality.

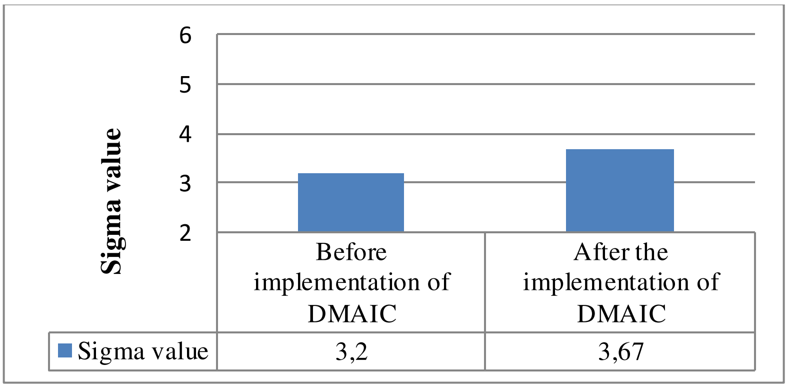

Figure 8: Sigma value

Lastly this partial achievement is due to two main reasons. The first main reason is that due to the paucity of time and money, all the factors that impact the deviation of diameter in the camshaft hole could not be considered. The second main reason is that the top management of the candidate company is not inclined to take any immediate action requiring significant investment.

5. CONCLUSIONS

This research is concerned with the analysis of the camshaft rejection problem in the small and medium-sized automotive industry because of the variation in the diameter of the camshaft hole and reducing it by the Six Sigma DMAIC, after making important conclusions

1. Results of this study suggest that the implementation of Six Sigma can lead to a breakthrough improvement in the automotive industry.
2. It has been found that speed and feed rate is found to be the significant factor. The best results (smaller is better) would be achieved with optimum parameter Speed=350 rpm, and Feed rate= 0.3 mm/rev.
3. The number of defective items also decreased from the 50 samples 9 to 3.
4. The percentage of rejection decreases from the 50 samples 18 % to 6%.
5. Sigma Level improves after study from 3.2 to 3.67.
6. Rejection trend after study decreases.

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