Rectification of the improper mating of the rack and valve assembly using Six Sigma methodology at a steering manufacturing & assembly plant.

Aftab .A. Pathan and Vijayaragavan. E
Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu 603203, India

Email: ¹aapathan007@gmail.com, ²vijayare@srmist.edu.in

Abstract. Precision automobile components and the automobile assembly systems are found to be the building element of any automobile, thus it is evident for the stakeholders to take utmost care and ensure that the most superior quality is delivered to the market. The minus cost principle says that when the quality is assured the time taken for the production is more which results in low volumes and where the volume is concerned the quality is compromised. Thus, focusing on one parameter results in the disturbance of the other. Hence, it should be balanced in such a way that the quality achieved is superior and with high volumes. While concentrating on the two parameters the parameter which is often neglected is the cost and it is found to be one of the most significant parameters for which the stakeholders have to focus upon. The following study illustrates how the quality factor was accounting for the heavy loss in a steering manufacturing company and how was the problem addressed with the most optimized solution thus eliminating the cost of poor quality. During the assembly of the steering system, three major components; the rack gear, the pinion gear and the housing are clustered and allowed to fit perfectly according to the design specification. Thus the method adopted to achieve the results was Six Sigma DMAIC Methodology. The DMAIC is an acronym for the Define Measure Analyze Improve and Control which is widely used in industries to address the problems when the problem is not easily identifiable.

1. Introduction
The need to address the problem aroused when the number of rejected samples rose substantially and caused noticeable errors for the end product. As discussed earlier precision automobile components are expected with the utmost quality standards since none of the manufacturers has the tendency to compromise on quality. Each operation has a particular quality standard to be achieved, every detail has to be customised according to the customer specification. This customer specification is called a spec limit and further this data is compiled in a reference guide with which each operation is executed and the end result is counter checked. This data is known as Standard Operating Procedure abbreviated as SOP. Majority of the problems in the industry are addressed by a systematic way of approach which is widely practised in all the industries to which popularly known as the SIX SIGMA; a tool, a methodology, a technique and a philosophy to resolve any of the problems persisting in the industries. Widely popular as a process improvement tool but serves best to reduce the variation in any process.
Variation is the major source of all the problems, therefore a controlled behaviour is required to ensure that the processes are optimum with minimum variation. Similarly, this problem too was dealt with the Six Sigma DMAIC approach, DMAIC stands for Define, Measure, Analyze, Improve and Control which are the five phases in a standard Six Sigma project respectively. The scope of the project, financial statement, cost of poor quality, financial impact and other important aspects are taken into consideration in the define phase. The magnitude of the problem, quality standards, design standards, measuring parameters and operational standards are taken into consideration and account for the measure phase. The root cause analysis, technical analysis, study of the error report and the Design of Experiments (DOE) are carried out in the analysis phase. Based on the inputs and feedback the necessary changes in the design, technical specifications, mechanical comprehension and quality measures are made in the improve phase. Further, it is made sure that all the alterations and amendments are maintained over a period of time and sustained thereafter in the control phase. Also, it is made sure that the issue does not reoccur in future.

2. Method of Approach

A brief introduction of the Six Sigma DMAIC approach has been discussed earlier, the step by step proceeding with reference to the phases (Define, Measure, Analyze, Improve and Control) is illustrated further. Each phase has its own set of tools and techniques which is used based upon requisite conditions.

2.1 Define Phase

2.1.1 Problem statement. The rack gear and pinion gear manufacturer using a number of manufacturing techniques is brought together for the assembly, the rack gear is present in the housing and the pinion gear is allowed to mate in the housing and mesh with it. The meshing is inefficient, noisy in operation, not smooth which contributes to the rejection of the entire steering assembly.

2.1.2 Project objectives

- To eliminate the obstruction during the meshing of rack and valve.
- To obtain smooth rack and valve insertion.
- To eliminate the sound produced during the process of rack and valve insertion
- To reduce the cost of poor quality.

2.1.3 Cost of poor quality. The cost of poor quality is the financial estimation of the losses occurred to the company and a preliminary amount that can be estimated to be saved.

No of systems assembled per day: 50
No days of the assembly line running: 25
Cost of one steering system: 3000/- (INR)
No of systems rejected per day: 2-3
Cost of poor quality = Number of rejections per day = 6000/- (INR)

2.2. Measure Phase

A standard tool of the measure phase is the 4M method. The 4M method allows an individual to identify and group causes that impact to a specific effect properly. 4M stands for Material, Man, Method and Machine.

2.2.1 Step 1 - Material. In the material phase, all the dimensions of the housing, pinion and rack were checked with Coordinate Measuring Machine (CMM). The dimensional turbulence in face width of gear housing was found and analyzed further. 100 housings were inspected and a random sample of 20 housings was taken off the analysis. The mean variable chart is plotted for the 20 samples and checked the housings under the company’s range of face width measurement. The figure 1 shows the diagram of
the housing. The face width is the diameter of the entry points of both the gears in millimetres (mm). The table 1 contains the data of the face of the 20 samples which were taken for monitoring.

Figure 1. Diagram of the Gear Housing.

| Sample No. | Measurement |
|------------|-------------|
| 1          | 35.183      |
| 2          | 35.155      |
| 3          | 35.212      |
| 4          | 35.168      |
| 5          | 35.176      |
| 6          | 35.227      |
| 7          | 35.189      |
| 8          | 35.151      |
| 9          | 35.177      |
| 10         | 35.201      |
| 11         | 35.244      |
| 12         | 35.183      |
| 13         | 35.194      |
| 14         | 35.157      |
| 15         | 35.189      |
| 16         | 35.232      |
| 17         | 35.251      |
| 18         | 35.174      |
| 19         | 35.163      |
| 20         | 35.248      |
The figure 2 shows the control chart of the 20 random samples. Since the housing is under the accepted range of the dimensional specification, all the housings were QC passed at an elementary level and sent at the assembly station. Being firm with the QC of the material it was found that the problem of improper mating still persists. Therefore it could be concluded that the material was not the root cause of the problem and it requires further investigation to find the root cause.

2.2.2 Step 2- Man. A significant factor which influences the production scenario is the workforce and labor. An unskilled operator may leave the loopholes or fail to match the standard operating procedures when compared to skilled labor. This error may lead to repeatability and reproducibility errors.

2.2.3 Step 3- Machine & Method Analysis. It can be concluded that the problem is solely because of the assembly error since the analysis of materials and man is concluded to be insignificant. Assembly method is observed in sequence and categorized on the basis of internal & external assembly. The problem statement is based on the internal assembly so the assembly operation of the internal section is revisited. The following table 2 displays a data of parameters involved for the perfect fit of the rack and pinion gear during the assembly operation.

The specification or the spec limit for each of the parameters is calculated and expected that it remains under the limit. Exceeding the spec limit may lead to rework and error and increase in the cycle time of the assembly line. The perpendicularity of the rack gear should be ensured before the insertion of the pinion during the assembly. The perpendicularity was not satisfied as it was exceeding the spec limit derived for it. The following figure 3 is the diagram of the rack gear which shows the perpendicularity of the gear.
2.3 Analysis Phase
The data obtained from the measure phase is further utilized for the analysis of the root cause of the problem and efforts are taken to eliminate it.

2.3.1. Reverse Analysis. The reverse analysis is the method of analysing the processes, data and rules in a backward format to understand the loopholes and escape clauses persisting in the existing processes. For the concordance, reverse analysis is employed to analyse the magnitude of the problem and relevant measures to counter it. The reverse analysis in this scenario is studied in stages. Stage one starting with the bearing and seal insertion followed by the dolly washing of rack and pinion and then insertion of rack & pinion and finally input of the rack seal. It was found that the problem persisted in stage three of the assembly process. Hence it was evident to find the root cause of the problem in stage 3. Further analysis of the supporting elements involved in the assembly lines was analyzed and necessary measures were taken.

2.3.2. Gemba Analysis. The word Gemba is a word of Japanese origin and means ‘Actual place’ (a place where a particular process or operation is executed). Gemba analysis in literal terms means going to the actual place and observing the process and identifying the problems on the ground. This is a lean concept and often used in the analysis phase. Lean is a systematic approach of eliminating the wastes and unwanted activities that do not add any value to the process.
Hence, Gemba analysis proves to be a significant tool in the analysis phase. The Gemba analysis concluded that the pinion guide rod home position is found to deviate from the specified dimension. Guide rod air pressure is low to insert the pinion to its respective position. Since there is no specific air pressure range stated, direct feed of 2 to 3 bar is given to the guide rod actuator. The figure 4 shows the pinion guide rod which was found to be deviated from its actual position.

2.3.3. Cause and Effect Relationship. The Cause and Effect Relationship or the Failure mode effect analysis is a pictorial representation of the causes and effects pertaining to a specific problem or an obstacle. The causes are displayed on a diagram which resembles the structure of a fishbone hence it is also known as the fishbone diagram. The following figure 5 displays the fishbone diagram in which the effect side is at the extreme right and to the left of it are the probable causes and their root causes.
The fishbone diagram, why-why analysis, 4M method are the major tools used to analyse the root cause along with a few brainstorming sessions. The major factor which massively contributed to the extent of the problem were: 1. Guide rod pressure. 2. Spring tension and 3. Rack straightness. Hence, these parameters were further employed to analyse and suggest the optimum values in order to eliminate the issue occurring during the assembly.

2.4 Improve & Control Phase

2.4.1 Design of Experiments (DOE). Design of Experiments or the DOE is performed to determine the point of optimal performance by identifying the root and analysing further by using DOE for a better solution. The root cause of having different specifications is statistically analysed to find the best combination. Using the L9 orthogonal array, the following data tabulated in table 2 was analysed and the main effects plot for mean was plotted as shown in the figure 6.

| Code | Factor                     | Units | Level 1 | Level 2 | Level 3 |
|------|----------------------------|-------|---------|---------|---------|
| A    | Guide rod pressure         | Bar   | 4       | 3       | 2       |
| B    | Spring Tension             | N     | 14      | 17      | 20      |
| C    | Straightness value         | mm    | 0.1     | 0.05    | 0.08    |

Since the factors are of 3 levels, we found the L9 orthogonal array is suitable to analyze the above table. Using L9 orthogonal an array has been formed with the above data. With the above array in place, 5 trials of each combination is performed at the workstation 3. The following table 3 contains the data of the response variable for the DOE.

| Guide Rod Pressure (BAR) | Spring Tension (N) | Straightness Value (MM) |
|-------------------------|--------------------|-------------------------|
| 2                       | 14                 | 5                       |
| 2                       | 17                 | 7                       |
| 2                       | 20                 | 8                       |
| 3                       | 14                 | 7                       |
| 3                       | 17                 | 8                       |
| 3                       | 20                 | 5                       |
| 4                       | 14                 | 8                       |
| 4                       | 17                 | 5                       |
| 4                       | 20                 | 7                       |
2.4.2. Taguchi Optimum Result. The Taguchi Method often referred to as robust design methods involve identification of optimum control factors of any process. Taguchi refers to the experimental style as "off-line quality control" as a result of it's a way of guaranteeing sensible performance within the style stage of merchandise or processes. Some experimental styles, however, as once utilized in biological process operation, are used on-line whereas the method is running. By the Taguchi Analysis, The Optimum predicted values are 4 bar, 17N & 0.08 mm respectively. The figure 7 displays the optimum values of the response variables by using the taguchi method in Minitab 2019. Therefore, the above countermeasure is implemented and thoroughly checked to avoid the Improper mating of Pinion and Rack.

| Prediction         |        |        |        |
|--------------------|--------|--------|--------|
| S/N Ratio          | -34.297| 44.6667| 31.6108|
| Mean               |        |        |        |
| StDev              |        |        | 3.42712|
| Ln(StDev)          |        |        |        |

| Settings           | SPRING | TENSION | STRAIGHTNESS |
|--------------------|--------|---------|--------------|
| GUIDE ROD PRESSURE |        | 4       | 17           |
| TENSION (N)        |        |         | 8            |
| STRAIGHTNESS (mm)  |        |         |              |

**Figure 6.** Main Effects Plot for Means.

**Figure 7.** Taguchi optimum results.

3. Conclusion

Using the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) approach the significant root causes were identified and DOE was performed to determine the most significant factors which
impact the most. The Taguchi optimum results were implemented and necessary changes with due reference to the Design of experiments were made. The predicted values by the Taguchi method are:
1. Guide rod pressure - 4 bar
2. Spring Tension - 17 N
3. Straightness value - 0.08 mm
Based on the data obtained the frameworks and Standard Operating Procedures were revised and the Quality check was made based on new references. The objectives were fully satisfied with zero rejections and cost of poor quality due to this particular problem drastically reduced and found close to zero. The obtained standards were maintained and data was recorded for future references.

4. References
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