Statistical Quality Control in the Gear Manufacturing Industry

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Abstract. Statistical quality control is process combines various techniques to control, monitor and improve the quality of products and services. An absolute essential for an industry, regardless of its size, to produce goods or services with inherent quality. Choosing the right statistical control process for the industry helps to identify the root cause of defects or deviation from process, control them which routes to high-quality products or services which in turn enhances the industry's image in the market and increase the cost-benefit. This study involves collection of data for selected assembly line factors from gear manufacturing industry, analyzing the data using quality control tools, and identifying the defects or process deviation.From the results obtained the potential regions were immediate attention is needed, where the process deviates from the specification limits are identified and highlighted for action to the industry. Based on the inferences obtained gear manufacturing industry would be suggested to apply the techniques to make appropriate changes in its lines to improve the quality of the spur gears manufactured. The implementation depends on the company, whether to apply or not.

Keywords: Quality, Quality Control Tools, Productivity

1 Introduction

Statistical Quality Control (SQC) process involves monitoring, controlling, and improving the quality of the product or service. SQC provides an industry with tangible benefits and outcomes in terms of quality and costs. To study a process or service, data related to it is collected and analyzed. The analysis can be carried out using various statistical control tools like Check Sheets, histograms, Pareto analyses, Cause and effect or Fish-bone Diagrams, Scatter plots, Control charts, and Flowcharts. The potential areas of attention identified during the analysis help to eliminate the root cause of any defects, making the product or service inherently non-defective or producing fewer defects. Quality is an essential characteristic of any industry, industries that fail to take up quality as a priority cannot survivein the market. Therefore, it is must for any industry to integrate statistical quality control techniques into its processes to achieve higher quality and productivity. Quality control and Quality assurance are two different terminologies. Quality control ensures that no defective products reach the customer, while quality assurance refers to preventing defects in products as well as

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controlling the defects produced. Design and product development infused together with quality is a more efficient way than trying to improve it later. So, fewer defects are identified during the quality checks. Product Quality control focuses on improving the product, while Process Control focuses on creating an environment that focuses on quality. This study was conducted in a gear manufacturing industry, where data related to the defects in the spur gear diameters with several samples and observations were obtained, along with the various types of defects occurring in spur gears. Appropriate quality control tools were applied to the data obtained, and observations were analyzed which will be discussed in this study.The collected data relates to the gear manufacturing industry, where the spur gears are manufactured. The main objective of this study is to identify appropriate quality tools suitable for the industry, highlight areas in need of attention based on results, and inform the industry.

2 Methods

Table 1 contains 60 observations on diameter of spur gear used in lathe machine tool. In total 15 samples of 4 observations each are shown in the table 1. The diameter data tabulated in Table 1 is measured using a Vernier caliper with the least count of 0.02 mm and an uncertainty of 0.01 mm. Quality control tools such as Control Charts ($\overline{X}$-R Chart and P-chart), histograms, ANOVA (Analysis of Variance), and Cause and Effect diagrams are widely used in the industry to reducedefects and improve product quality. The mean or average changeover time is shown by the $\overline{X}$ - R Chart, while the range of the subgroup change over time is shown in the R Chart, which measures subgroup variability and uses the range of the data.

2.1 Control limit for $\overline{x}$ chart

Upper control limit (UCL) $=\overline{\overline{X}} + A_2\overline{R}$ (1)

Central line (CL) $=\overline{\overline{x}}$ (2)

Lower control limit (LCL) $=\overline{\overline{X}} - A_2\overline{R}$ (3)

2.2 Control limit for R chart

Upper control limits (UCL) $=D_4\overline{R}$ (4)

Central line (CL) $=\overline{R}$ (5)

Lower control limit (LCL) $=D_3\overline{R}$ (6)

The p-chart is acontrol chart thatmonitors the proportion of nonconforming units in a sample. Thenonconforming sample proportion is the ratio of the number of nonconforming units to the sample size n.The p-chart only accommodates "pass"/"fail"type inspection as determined by go or no-go tests.

2.3 Control limit for p-chart

$\overline{p} = \Sigma D_i /(m)(n) = 0.438$ (7)

$UCL = \overline{p} + 3 \sqrt{\overline{p}(1-\overline{p}) / n}$ (8)

$LCL = \overline{p} - 3 \sqrt{\overline{p} (1-\overline{p}) / n}$ (9)

A histogram is a graphical representation of the distribution of values, its pattern, and shape. This shape would determine the nature of the data sets statistically. This provides the frequency distribution magnetically, where the height responds to the countof each point within the range. Data Collection gathers a dataset of values or observations you want to analyze. Data Binningdivides the range of data values into a set of continuous and non-overlapping intervals, called bins or classes. The number of classes and their size are determined based on the data and the desired level of detail. Counting frequenciesfind how many data points fall into each class interval. This represents the frequency of values within each bin.On the graph, the x-axis represents the ranges of values, and the y-axis represents the frequency (The number of spur gears lying in each interval). Each interval is represented by a bar, and the height of the bar corresponds to the frequency of data points in that interval. A histogram provides insights into the distribution of data. It can reveal whether the data is normally distributed, skewed to the left or right, bimodal (having two peaks), or exhibiting other characteristics. It helps you understand the central tendency (mean, median, mode) and the spread of the data.

One-way ANOVA is a statistical test that compares the means of three or more groups and determines whether there are statistically significant differences between the groups and assesses the variation between groups. The null hypothesis is that all group means are equal, and the alternative hypothesis is that at least one group means is different from the others.The ANOVA test calculates an F-statistic value, and if the F-statistic value is significantly different from what you'd expectthe null hypothesis is rejected and concludes that there are significant differences between the groups. If the null hypothesis is rejected, post-hoc tests can be used to identify which specific groups differ from each other. The grand mean is a weighted average of the individual sample means. The Mean of the Squares (MS) is the variances, often with an accompanying variable MS(B) or MS(W).The significance level is the sample mean distance from the null hypothesis, so it could be considered statistically significant.The confidence level is how close distance the confidence limits are to the sample mean.A degree of freedom (df) for each value is how much it could vary before the rest of the values are predetermined.

$$MS = SS/df \quad (10)$$

$$Variance = Variance/df \quad (11)$$

A fishbone diagram is a useful management tool to identify the causes of a problem also known as a cause-and-effect diagram. The tool helps users group potential causes into categories and provides a structured way to display them. By breaking down the problem into smaller pieces or "bones," a fishbone diagram can help in quality control. It can also help to figure out the reasons for defects, variations, or failures within a process. The spine of a fishbone diagram (large horizontal arrow) points to the problem box. The lines thatdiagonally point to the spine are the main categories of potential problem causes.

3 Results and discussion

For a product to meet the needs and expectations of customers, it should be produced through a process that is consistent and reliable. This means that the process should be able to operate with minimal variation around the desired quality characteristics of the product. To achieve this, Quality control tools are a set of tools that are highly effective and can help stabilize the process and reduce variability. In end improving the product's overall capability.

In a base period, 15 spur gear samples were taken, and their diameter was measured in mm for 4 observations, converted to inches, and tabulated in Table 1.

Table 1. Gear Diameter Observation

	Observation (in inch)			
Sample No.	**1**	**2**	**3**	**4**
1	4.9	5	5.1	5.3
2	4.8	5.8	5.4	5.3
3	4.7	5.8	4.6	4.9
4	4.4	4.6	4.8	5.4
5	4.4	5.3	5.1	5.5
6	4.8	5.8	5.8	6
7	5.9	4.7	5	5.8
8	5.4	5.2	4.6	5.7
9	5.2	5	6.1	5.8
10	5.3	5.9	5.2	4.8
11	4.6	4.9	4.5	5.7
12	4.3	4.9	4.7	5.5
13	5.1	5.9	4.8	5.2
14	5	4.9	4.5	5.3
15	4.3	4.6	4.7	4.5

3.1 $\overline{X}$-R Chart

From Table 1, the mean value ($\bar{x}$) is calculated for each sample along with the range, that is the difference between the large and smaller values is calculated as shown in Table 2. It acts as the base for the $\overline{X}$-R Chart.

From Table 2, the control limits are calculated below,

Table 2. Data for $\overline{X}$ - R Chart

Sample No.	Observation (in inch)				X bar
1	4.9	5	5.1	5.3	5.075
2	4.8	5.8	5.4	5.3	5.325
3	4.7	5.8	4.6	4.9	5
4	4.4	4.6	4.8	5.4	4.8
5	4.4	5.3	5.1	5.5	5.075
6	4.8	5.8	5.8	6	5.6
7	5.9	4.7	5	5.8	5.35
8	5.4	5.2	4.6	5.7	5.225
9	5.2	5	6.1	5.8	5.525
10	5.3	5.9	5.2	4.8	5.3
11	4.6	4.9	4.5	5.7	4.925
12	4.3	4.9	4.7	5.5	4.85
13	5.1	5.9	4.8	5.2	5.25
14	5	4.9	4.5	5.3	4.925
15	4.3	4.6	4.7	4.5	4.525

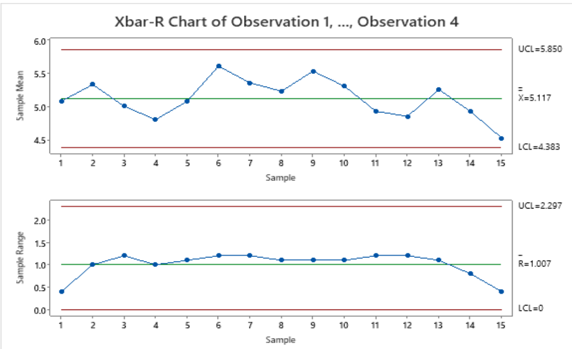

Figure 1. $\overline{X}$ - R Chart for Gear Diameter

Control limits for the $\bar{x}$ chart
Upper controllimit,

$$UCL=\bar{\bar{x}}+A_2\bar{R}= 5.1166+0.483\times1.007=5.850$$

Centerline, $CL=\bar{\bar{x}}=5.117$

Lower control limit,

$$LCL=\bar{\bar{x}}-A_2R \quad =5.1166 - 0.483\times1.007 =4.383$$

Control limit for R chart

Upper control limit, UCL = $D_4\bar{R}$ = 2.004$\times$1.007
Centerline,CL=$\bar{R}$ = 1.007
Lower control limit,LCL=$D_3\bar{R}$ = 0 $\times$ 1.007 = 0

The chart contains a center line that represents the average value of the quality characteristic corresponding to the in-controlTwo other horizontal lines are called the upper control limit (UCL) and the lower control limit (LCL). These control limits are chosen so that if the process is incontrol, nearly all the sample points will fall between them. As long as the points plot within the control limits, the process is assumed to be in control and no action is necessary. However, a point that plots outside of the control limits are interpreted as evidence that the process is out of control, and investigation and corrective action are required to find and eliminate the assignable cause or causes responsible for this behavior. In our observation, we found that all the plots are within the control limits and no action is necessary from Figure 1.

3.2 Histogram

From Table 1, The maximum and minimum value is identified, and the range is determined. The number of intervals is calculated. Followed by the width of classes and the diameter values are split up into intervals, and the number of values lying between the range is noted in Table 3. The frequency ofvaluesbetween each interval is obtained. Subsequently, the cumulative frequency, relative frequency, and cumulative relative frequency are also calculated.

Table 3. Data for Histogram

Diameter Range (inch)	Tally	f	Cumm. f(%)	Rel. f (%)	Cumm. Rel. f (%)
4.3-4.5	IIII	4	4	0.06	0.06
4.5-4.7	IIIII III	8	12	0.133333	0.193333333
4.7-4.9	IIIII IIII	9	21	0.15	0.343333333
4.9-5.1	IIIII IIII	9	30	0.15	0.493333333
5.1-5.3	IIIII II	7	37	0.116667	0.61
5.3-5.5	IIIII III	8	45	0.133333	0.743333333
5.5-5.7	II	2	47	0.033333	0.776666667
5.7-5.9	IIIII III	8	55	0.133333	0.91
5.9-6.1	IIII	4	59	0.066667	0.976666667
6.1-6.3	I	1	60	0.016667	0.993333333

Maximum value = 6.1
Minimum value = 4.3
Range= 6.1 - 4.3 = 1.8
Numberofintervals =$\sqrt{(n)}$ = 9
ClassWidth = 1.8/2 = 0.2

From Table 3, the histogram graph is created and shown in Figure 2.

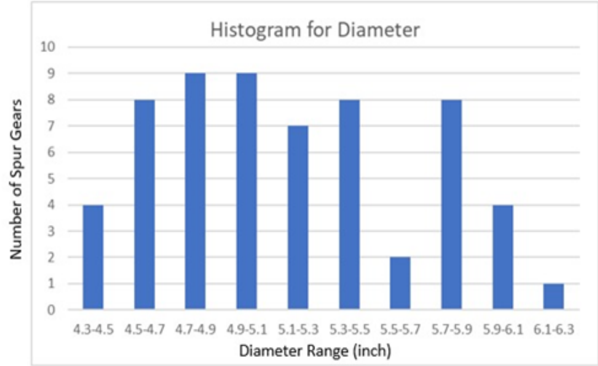

Figure 2. Histogram for Diameter values

From Figure 2, we can interpret that there is variation in the diameter of gears manufactured, few lying between 4.3 to 4.5 inches and most lying between the range of 4.7 to 5.1 inches. There are gears whose diameter is above 5.9 inches. Therefore, it is concluded that the variability in the gear diameter is relatively high.

3.3 One-way ANOVA

A One-way ANOVA test was conducted for the observed gear diameter values as per the hypothesis assumptions made. From the entered data set of diameter values as the factors.

The calculated F valuecan be compared with the 'f' critical value in the table.Suppose your calculated value of 'f' is larger than the 'f' table value. In that case, you can reject the null hypothesis with 95 percent confidence that the variance between your two populations isn't due to random chance.

The following Figure 3depicts the results of the One-way ANOVA Test, from which it observed that the p-value is less than the f-value. Thus, we canreject the Null Hypothesis.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	2.317	0.7722	3.66	0.018
Error	56	11.807	0.2108		
Total	59	14.123			

Figure 3. ANOVA

Means

Factor	N	Mean	StDev	95% CI
Diameter 1	15	4.873	0.456	(4.636, 5.111)
Diameter 2	15	5.220	0.492	(4.983, 5.457)
Diameter 3	15	4.993	0.474	(4.756, 5.231)
Diameter 4	15	5.380	0.411	(5.143, 5.617)

Pooled StDev = 0.459166

Figure 4. Means

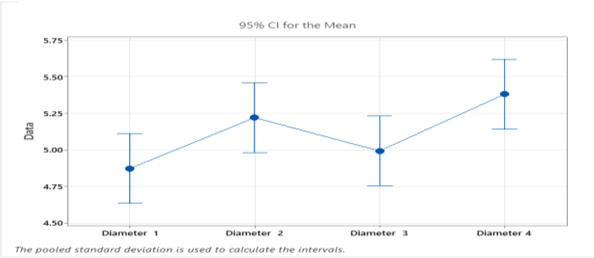

Figure 5. Interval Plot

Figure 4 shows us that there is a difference in all the mean values, and Figure 5 represents the variation graph in the diameter means.

From the Model Summary, we can see that 16.40% of the variation in the response. The S indicates the Standard deviationbetween the data points and fitted values is approximately 0.459 units.

3.4 P chart

The data representing the number of failures present in each of the lot samples is observed and noted along with the fraction of non-conforming is also determined and is given in Table 4.

Table 4. Data for p-chart

Sample	No.of Failures	Fraction nonconforming
1	2	0.05
2	0	0
3	1	0.025
4	1	0.025
5	2	0.05
6	3	0.075
7	1	0.025
8	1	0.025
9	3	0.075
10	2	0.05
11	1	0.025
12	1	0.025
13	1	0.025
14	2	0.05
15	1	0.025

Control limit for p-chart

1. $\bar{p} = \Sigma D_i/(m)(n) = 0.0978$
2. $UCL = \bar{p} + 3\sqrt{\bar{p}(1-\bar{p})/n} = 0.3278$
3. $LCL = \bar{p} - 3\sqrt{\bar{p}(1-\bar{p})/n} = 0$

The chart represents the nonconforming units in the sample. The chart contains two horizontal lines known as upper control limit and lower control limit. This P chart plots the proportion of defective items (also called nonconforming units) for each subgroup. It shows the amount of variation that is expected in the subgroup proportions.
In these results, the average proportion of defectives is approximately 0.0978. The process does not appear to be in control because the two subgroups each failed at least one test.

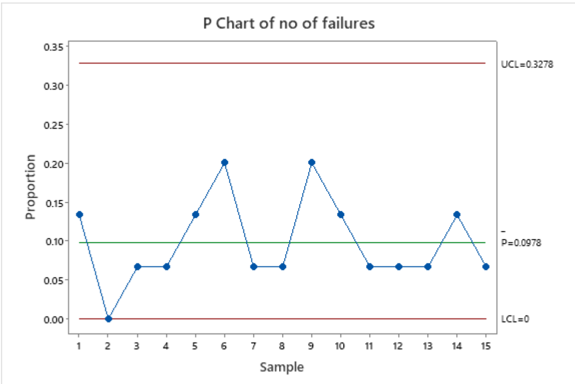

Figure 6. P-chart for Gear failures

3.5 Cause and effect Diagram (Fishbone Diagram):

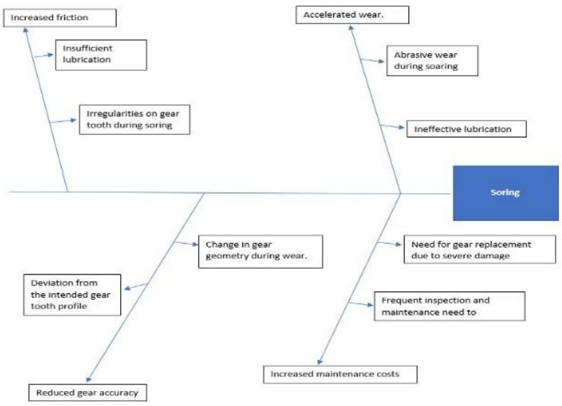

Figure 7. Fish Bone Diagram for soring

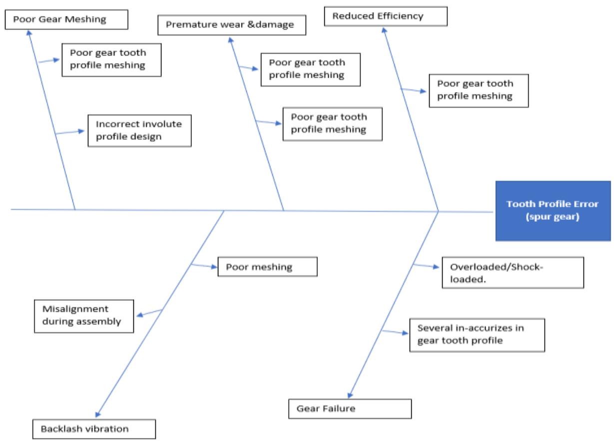

Figure 8. Fish Bone Diagram for Tooth Profile Error

3.6 Root Cause Analysis (Why Analysis)

The gear manufacturing sector provided the case for the why analysis done on the defects in produced gear. It is apparent that from the shortlist of Undersized holes, Porosity is analyzed for its root causes.

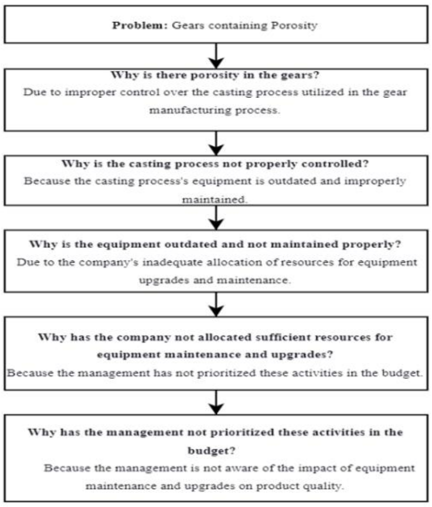

Figure 9.WHY Analysis for porosity

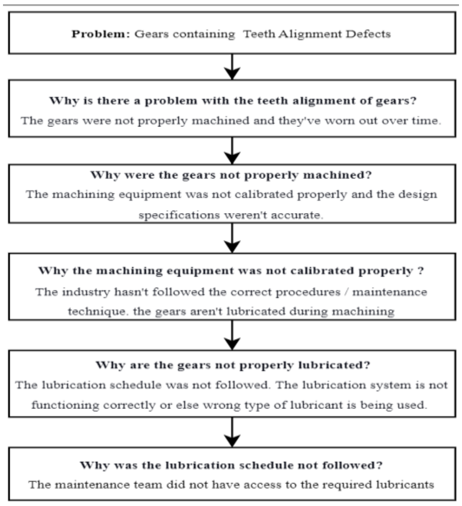

Figure 10. WHY Analysis for Tooth Alignment Defects

4 Conclusion

This study was conducted on a gear manufacturing company to improve the quality of the gears produced using statistical quality control. While using all quality tools and sampling plans is an expensive procedure, using a control chart, histogram, WHY analysis, and Cause and effect diagram is a cost-efficient way for quality testing. The results of the gear diameter observation using quality control tools indicate there is deviation in processes and defects arising. The major reason for arising diameter variation is due to improper cutting of gears which affetcs the outside diameter of the spur gears manufactured causing variations. The root cause of defects in spur gears is identified using fish bone and WHY analysis. All the areas identified using quality control processes require crucial attention in the gear manufacturing industry. This would significantly increase the productivity and quality of the industry.

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