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Original Research Paper

Analysing Process Capability for Maintaining Gear Dimensions By Knowing External Diameter Deviation

Engineering

KEYWORDS : Gage R&R, Process Capability, Monte Carlo Simulation, Measurement System

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ABSTRACT

Currently, the manufacturing industry faces difficult competition. Competition has increased because of increased customer demands. Even though most of manufacturing industries focus on improving the quality of products in order to enhance their customers' satisfaction, the productivity is not achieved because of the errors in measurement system. In order to improve productivity, the companies should calibrate their instruments and measurement method before operating inspection to achieve precise and accurate data.

The present study performs the Gage R&R analysis for a manufacturing organisation, whose major product is gears of various sizes used in transmission system. The problem faced by the company is that they are getting frequent rejections from the customer due to non-conformance of gear dimensions. Initially the thorough analysis of manufacturing and measurement process of the company has been carried out. The Gage R&R analysis study of the gear dimension measurement system has been carried out. The study show serious issues regarding measurement procedures.

1.1 Introduction

Currently, the manufacturing industry faces difficult competition. Competition has increased because of increased customer demands. The manufacturing industry has to actively perform improvement in order to improve their customers' satisfactions. Even though most of manufacturing industries focus on improving the quality of products in order to enhance their customers' satisfaction, the productivity is not achieved because of the errors in measurement system. The measurement errors occur from variations of instruments, measurement methods, and operators. In order to improve productivity, the companies should calibrate their instruments and measurement method before operating inspection to achieve precise and accurate data. Quality improvement projects are often characterized by their objective to reduce variability and achieve zero-defect production. If a product fails to conform to these standards, analysts generally blame the process and then act to improve process capability.

Figure 1 shows the measurement errors and their causes.

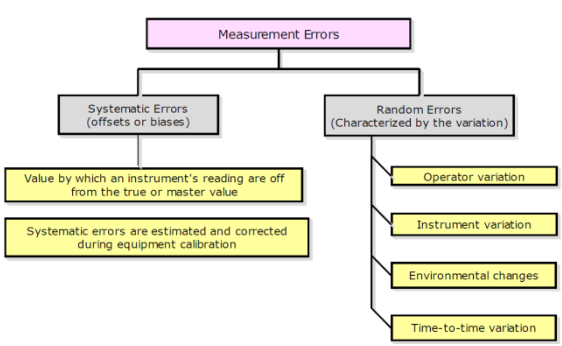

Figure 1 Measurement Errors

Therefore, when trying to determine and understand errors in mechanical testing results, one must examine the testing system in both a qualitative, physical manner and a quantitative manner. For the former, all elements of the fishbone diagram must be considered and evaluated.

1.2 GAGE RELIABILITY AND REPRODUCIBILITY (GAGE R&R)

It is a kind of Measurement System Analysis (MSA), is an important step before analysing the measurement data. It is a process to check tools, equipment's, or operators if they are nonconforming. Results of Gage R&R can define causes of the measurement errors. After analysing the results, the measurement system will be more precise and more accurate. Gage repeatability and reproducibility (R&R) study involves breaking the total gage variability into two portions: repeatability and reproducibility. Gage R&R study is used to measure the amount of variation in an observed process. It is due to measurement system variation and breaks down the measurement system variation into repeatability and reproducibility.

Acceptable regions of gage R&R as defined by the Automotive Industry Action Group (Measurement Systems Analysis Workgroup, Automotive Industry Action Group, 1998) are as indicated in Table 1.

Table 1 Acceptable regions of Gage R&R.

Gage R & R Range	Action Required
< 10 %	Gage Acceptable
10 % < Gage R & R < 30 %	Action required to understand variance
30 % < Gage R & R	Gage unacceptable for use and requires improvement

There are two most common method types used and supported by statistical software: *average and range method* and *analysis of the variance*. The difference between the two methods is the methodologies to calculate them.

Average and Range method - The Average and Range method is quite simple to use in that it avoids a lot of complicated calculation and can be run by hand. The Average and Range method is a method used to conduct Gage R&R. It involves finding the average measurements of parts and operators, then finding the range of results from the parts and operators.

Analysis a/the variance - The ANOVA is more complicated. It can test contribution of control factors and interactive effects between the different factors. The ANOV A can be extended to analyse the data from an experiment and to estimate the appropriate components of gage variability. The technique finds the sum of squared distances of results from the overall average, the average of operators

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and parts to assess where variation is found. This will then show how many variations are found in the measurements from parts, operators, and also interactions between parts and operator.

A big difference between the two methods is that the Average and Range method will not show interactions between how operators measure parts, but the ANOVA will show this. The Average and Range method breaks down the overall variation into three categories; (i) part-to-part, (ii) repeatability, and (iii) reproducibility (refer figure 1.4). In order to compare to ANOV A, the ANOV A method goes one step further and breaks down reproducibility into its operator, and operator-by-part, components.

1.2 RESEARCH PROBLEM

The conclusions drawn from the statistical methods depend on the accuracy of data. If the measuring instrument and the measurement method are not capable of making accurate and repeatable measurements, the data can have significant measurement error. In such cases, the conclusions drawn from the data are inaccurate and misleading. The purposes of this study were to determine if the measurement system could produce precise and accurate data, and if the precision and accuracy could solve the complaint problems by proving the measurement data to the customer. In addition, this study could evaluate the reliability of the measurement system that the manufacturing plant had recently applied in their production processes.

1.3 Experimental Setup and Procedure

A successful gauge capability study is one that provides reliable estimates of the components of variation in the measurement process and identifies the factors that are most influential. The study should also provide information about the potential effectiveness of the gauge as a measurement tool. Consequently, the design of the experiment is very important. Poor statistical design of the experiment can lead to a situation where the true variation in the measurement process is underestimated, and these results in an overly optimistic conclusion regarding gauge capability. Some important statistical design issues include the number of parts to be used in the study, the number of measurements per part, how the parts are selected, and ensuring that true replicates are actually obtained as opposed to repeat measurements.

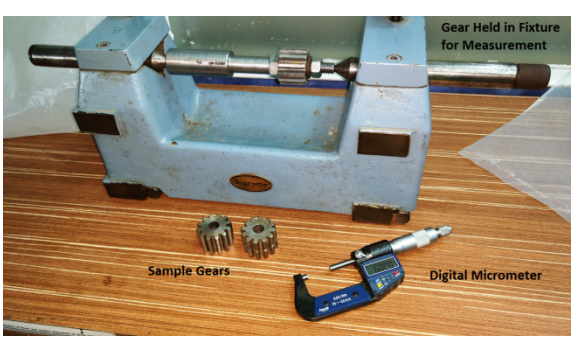


Figure 2 Experimental Setup

Figure 2 shows the photograph of complete experimental setup showing sample pieces (gears), test specimen holding device and measuring instrument.

Before carrying out the measurement exercise on the test specimens using standard measuring instruments one has to follow certain assumptions. The assumptions of the study given below are appropriately considered while doing the measurement procedure.

Assumptions of the Study

This study had assumptions as following;

The digital micrometre is in good condition and was always calibrated before using.

The digital micrometre measured the gear diameter dimensions precisely and accurately.

Operators who perform the inspection were trained well and experienced.

The inspections were implemented under normal conditions and same environment.

All sample items were mixed both good and bad over the entire specification.

All sample items were measured randomly, and the operators could not remember the items when they re-measured them again.

The quality manager understood this study and provided everything as needed.

Data collecting method was operated correctly, no variation occurred in the system.

Following figure 3 shows the detailed dimensioned drawing of a gear used in transmission system. The critical diameter of the part to be measured is gear diameter. The designed value of the gear diameter is 38 ± 0.1.

Figure 3 A 2 Dimensional Drawing of Gear with Solid Model

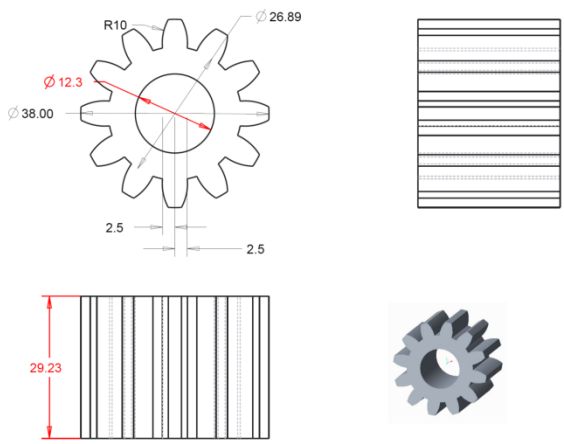
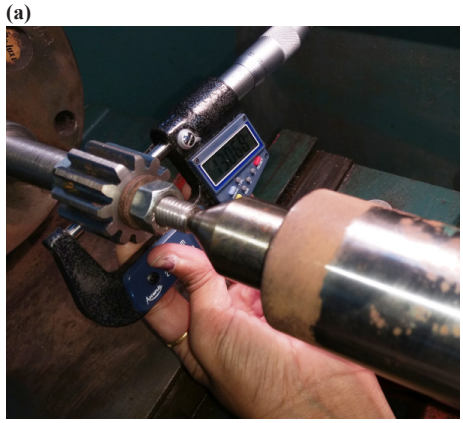
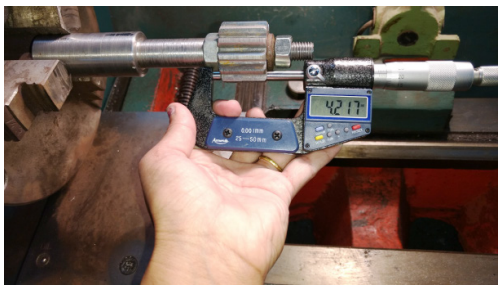


Figure 4 shows the photograph of measurement process. (a)





(b)

Figure 4 Gear Dimension Measurement – (a) Diameter (b) Width

The measurement results of the gear dimensions are given in Table 2, Table 3 and Table 43 for part I, II and III respectively.

Table 2 Observation Table – Part I

Obs. No.	Operator A			Operator B			Operator C		
	Time			Time			Time		
	10 am	2 pm	5 pm	10 am	2 pm	5 pm	10 am	2 pm	5 pm
1	38.035	38.010	38.052	37.990	38.094	38.015	38.025	38.020	38.032
2	38.029	38.092	38.019	38.017	38.074	38.017	38.039	38.092	38.029
3	38.018	38.019	38.018	38.092	38.081	37.993	38.028	38.019	38.013
4	38.050	38.100	38.110	38.019	38.056	38.107	38.052	38.000	38.012
5	37.990	37.992	38.015	38.018	38.010	38.057	37.970	37.972	38.025
6	38.017	38.110	38.017	38.092	38.092	38.092	38.027	38.010	38.027
7	38.092	38.094	37.993	38.035	38.019	38.052	38.072	38.064	37.973
8	38.019	38.074	38.107	38.029	38.100	38.019	38.017	38.044	38.007
9	38.018	38.081	38.057	38.018	37.992	38.018	38.028	38.031	38.037
10	38.092	38.056	38.092	38.050	38.110	38.110	38.072	38.026	38.062

Table 3 Observation Table – Part II

Obs. No.	Operator A			Operator B			Operator C		
	Time			Time			Time		
	10 am	2 pm	5 pm	10 am	2 pm	5 pm	10 am	2 pm	5 pm
1	37.970	37.792	38.007	38.015	38.010	37.990	37.970	38.064	38.025
2	38.017	38.010	37.933	38.017	38.090	38.017	38.027	38.044	38.027
3	38.035	38.074	38.102	37.993	38.017	38.092	38.072	38.031	38.032
4	38.029	38.064	38.047	38.107	38.100	38.019	38.017	38.026	38.029
5	38.018	38.071	38.082	38.057	37.982	38.018	38.028	38.020	38.013
6	38.031	38.010	38.042	38.092	38.100	38.092	38.072	38.092	38.012
7	38.042	38.042	38.015	38.052	38.092	38.035	38.025	38.019	38.032
8	38.019	38.019	38.013	38.019	38.072	38.029	38.039	38.000	38.029
9	38.018	38.090	38.110	38.018	38.080	38.018	38.028	37.972	38.013
10	38.072	37.962	38.011	38.110	38.050	38.050	38.052	38.010	38.012

Table 4 Observation Table – Part III

Obs. No.	Operator A			Operator B			Operator C		
	Time			Time			Time		
	10 am	2 pm	5 pm	10 am	2 pm	5 pm	10 am	2 pm	5 pm
1	38.007	38.010	37.970	37.990	37.792	38.015	38.042	38.062	38.011
2	37.933	38.090	38.017	38.017	38.010	38.017	38.023	38.017	38.037
3	38.102	38.017	38.035	38.092	38.074	37.993	38.034	38.020	38.039
4	38.047	38.100	38.029	38.019	38.064	38.107	38.028	37.972	38.013
5	38.082	37.982	38.018	38.018	38.071	38.057	38.052	38.010	38.012
6	38.042	38.100	38.031	38.092	38.010	38.092	37.920	38.034	38.025
7	38.015	38.092	38.042	38.035	38.042	38.052	38.017	38.034	38.017
8	38.013	38.072	38.019	38.029	38.019	38.019	38.062	38.032	38.032
9	38.110	38.080	38.018	38.018	38.090	38.018	38.013	38.016	38.029
10	38.011	38.050	38.072	38.050	37.962	38.110	38.022	38.010	38.013

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1.4 GAGE R & R ANALYSIS

Gage R&R study provided information on measurement system performance by analysing measurement error from various sources. If a large amount of variability was presented in a measurement system, this could lead to poor quality product being shipped to customers by not being able to use the measurement system to differentiate between conforming and nonconforming parts.

1.4.1 Gage Run Chart

A gage run chart is a plot of all of your observations by operator and part number. A horizontal reference line is drawn at the mean, which can be calculated from the data, or a value you enter from prior knowledge of the process. You can use this chart to quickly assess differences in measurements between different operators and parts. A stable process would give you a random horizontal scattering of points; an operator or part effect would give you some kind of pattern in the plot.

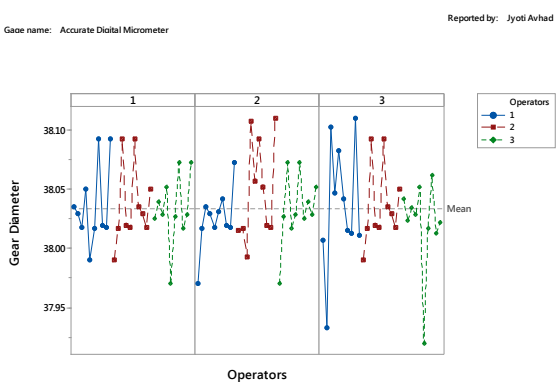

Figure 5 Gage Run Chart of Gear Diameter by Parts, Operators Measurements carried out at 10 am

1.4.2 Gage Linearity and Bias Study

Gage linearity tells you how accurate your measurements are through the expected range of the measurements. It answers the question, "Does my gage have the same accuracy for all sizes of objects being measured?"

Gage bias examines the difference between the observed average measurement and a reference or master value. It answers the question, "How biased is my gage when compared to a master value?

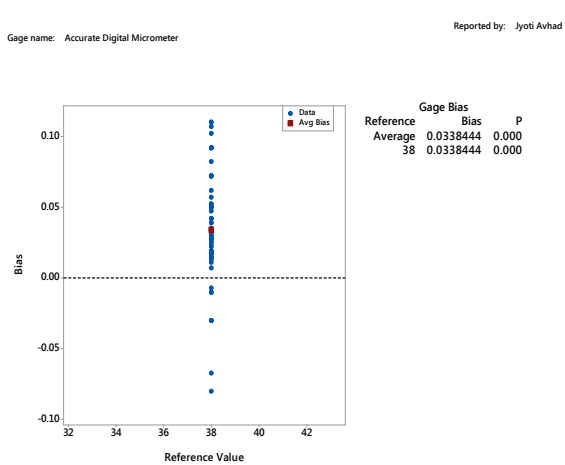

Figure 6 Gage Linearity and Bias Report for Gear Diameter Measurements carried out at 10 am

1.4.3 Gage R&R Study (Crossed)

Any time you measure the results of a process you will see some variation. This variation comes from two sources: one, there are always differences between parts made by any process, and two, any method of taking measurements is imperfect - thus, measuring the same part repeatedly does not result in identical measurements. A crossed gage R & R study determines how well the measurement system distinguishes between parts and how much variation is due to the measurement system when each part is measured multiple times by each operator. Use Gage R&R to determine what portion of the variability in measurements may be due to the measurement system. Measurement system variability includes both variation due to the gage and operator-to-operator variability.

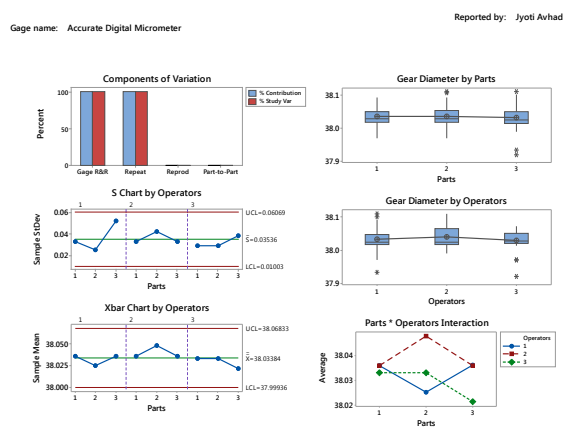

Figure 7 Gage R&R (ANOVA) Report for Gear Diameter Values Measured at 10 am

Table 5 ANOVA of Gear Diameter Values Measured at 10 am

Source	DF	SS	MS	F	P
Parts	2	0.000325	0.0001623	0.27577	0.772
Operators	2	0.001872	0.0009359	1.58975	0.310
Parts * Operators	4	0.002355	0.0005887	0.44898	0.773
Repeatability	81	0.106207	0.0013112		
Total	89	0.110758			

Table 6 Gage R&R of Gear Diameter Values Measured at 10 am

Source	VarComp	% Contribution (of VarComp)
Total Gage R&R	0.0012772	100.00
Repeatability	0.0012772	100.00
Reproducibility	0.0000000	0.00
Operators	0.0000000	0.00
Part-to-Part	0.0000000	0.00
Total Variation	0.0012772	100.00

1.4.4 Normal Distribution and Probability Plot

Many statistical analyses assume that the data are sampled from a larger population with a specified distribution. Quite often, the distribution of this larger population is assumed to be normal (in reliability and survival work the underlying distribution is assumed to be exponential or Weibull). This is often called the normality assumption. (Note that the normal distribution is sometimes called the Gaussian distribution to avoid confusion with its common definition. The normal probability plot is a graphical technique for assessing whether or not a data set is approximately normally distributed.

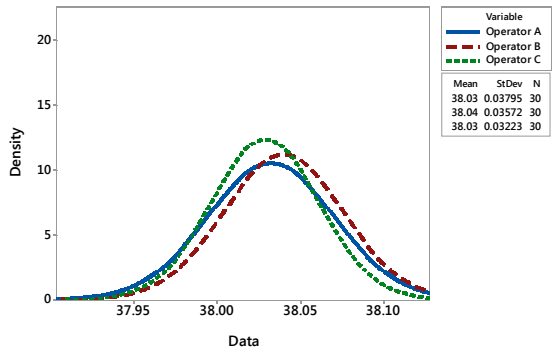

Figure 8 Normal Distribution Plot for the Data obtained from the Measurement carried out at 10 am

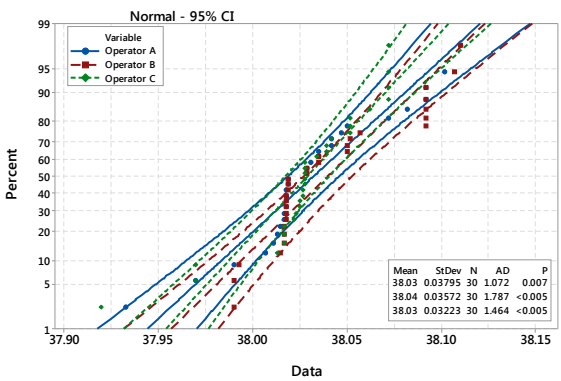

Figure 9 Probability Plot for the Data obtained from the Measurement carried out at 10 am

1.5 Process Capability

A process may produce a large number of pieces that do not meet the specifications, even though the process itself is in a state of statistical control This may be due to the lack of centering of the process mean in other words, the actual mean value of the parts being produced may be significantly different from the specified nominal value of the part. If this is the case, an adjustment of the machine to move the mean closer to the nominal value may solve the problem. Another possible reason for lack of conformance to specifications is that a statistically stable process may be producing parts with an unacceptably high level of common-cause variation, even though the process is centered at the nominal value.

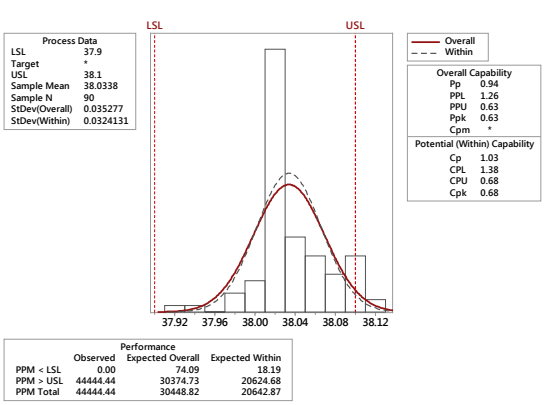

Figure 10 Process Capability Analysis for Measurement Carried out at 10 am

1.6 CONCLUSIONS

The present work is an attempt to improve the existing system of gear dimension measurement process. The organisation, who is manufacturing the gears used for transmission system, is having problem of rejections from the customers due to dimensional non-conformance. Gage R&R study has been carried out to understand the process variance; i.e. to know the source of variation is whether part, operator, gage or interaction between these. From the Gage R&R and the extended process capability study following conclusions were made.

Based on Gage Repeatability and Reproducibility Analysis From the Gage Run chart it is observed that irrespective of the timings of measurement the performance of the operator C is good. This states that there is a need of training the other operators who are playing the role in measurement.

From the Gage Linearity and Bias it is clear that the timings of measurement and an operator plays vital role in measurement and influences the outcome.

The Gage R&R crossed ANOVA study shows that there are serious problems observed in the measurement system, which are highlighted from the range of Gage R&R % contribution values crossing the limit of 30 %.

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