A Gage Repeatability and Reproducibility Analysis of Transmission Gear Dimension Measurement System

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ABSTRACT

Currently, the manufacturing industry faces difficult competition. Competition hasincreased because of increased customer demands. Even though most of manufacturing industries focus on improving the quality ofproducts in order to enhance their customers' satisfaction, the productivity is not achievedbecause of the errors in measurement system. In order to improveproductivity, the companies should calibrate their instruments and measurement method beforeoperating 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. The corrective measures have been proposed and implemented. The new improved measurement system is compared on the basis of Gage R&R and Process Capability Analysis. Further the study is extended by using Monte Carlo Simulation to develop a reliable and redundant measurement system.

1.1 Introduction

Currently, the manufacturing industry faces difficult competition. Competition hasincreased because of increased customer demands. Even though most of manufacturing industries focus on improving the quality ofproducts in order to enhance their customers' satisfaction, the productivity is not achievedbecause of the errors in measurement system. The measurement errors occur from variations ofinstruments, measurement methods, and operators. In order to improveproductivity, the companies should calibrate their instruments and measurement method beforeoperating 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.

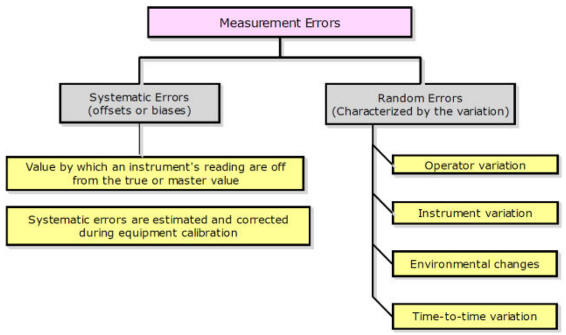

Figure 1Measurement Errors

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.

1.2Gage Repeatability 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 gagevariability into two portions: repeatability and reproducibility. Gage R&R study is used tomeasure the amount of variation in an observed process. It is due to measurement systemvariation and breaks down the measurement system variation into repeatability andreproducibility.

Acceptable regions of gage R&R as defined by the AutomotiveIndustry Action Group as

Table 1Acceptable 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 statisticalsoftware: *average and range method* and *analysis of the variance*. The difference between thetwo methods is the methodologies to calculate them.

Average and Range method - The Average and Range method is a method used to conduct Gage R&R. It involves finding theaverage measurements of parts and operators, then finding the range of results from the parts andoperators.

Analysis a/the variance -The ANOVA can beextended to analyse the data from an experiment and to estimate the appropriate components ofgage variability.

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, andoperator-by-part, components.

1.3Research Problem

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.

1.4Experimental Setup And Procedure

A successful gauge capability study is one thatprovides information about the potential effectiveness ofthe gauge as a measurement tool. Consequently, thedesign of the experiment is very important. Someimportant statistical design issues include the number ofparts to be used in the study, the

number ofmeasurements per part, how the parts are selected, andensuring that true replicates are actually obtained asopposed to repeat measurements.

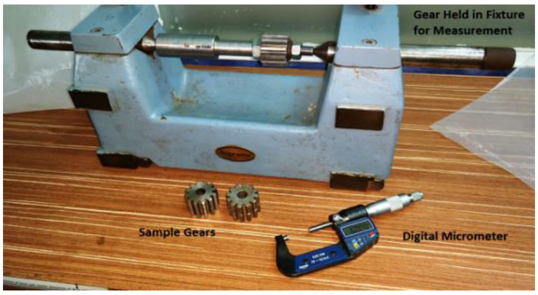

Figure 2Experimental Setup

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

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

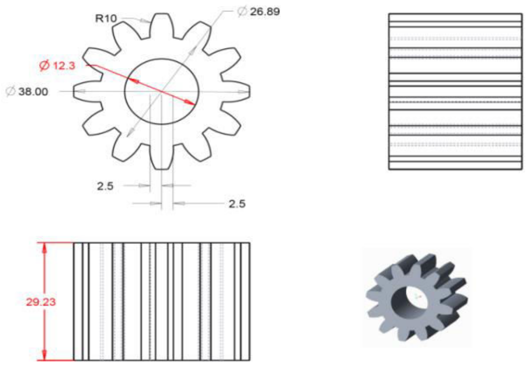

Figure 3A 2 Dimensional Drawing of Gear with Solid Model

(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 4 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

1.5Gage R & R Analysis:

1.5.1 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.

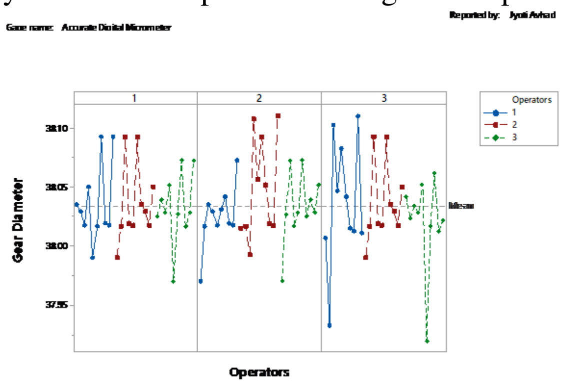

Figure 5 Gage Run Chart of Gear Diameter by Parts, Operators Measurements carried out at 10 am

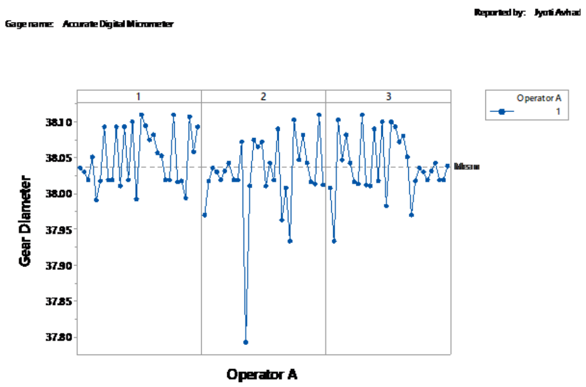

Figure6Gage Run Chart of Gear Diameter for Operator A

1.5.2 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?

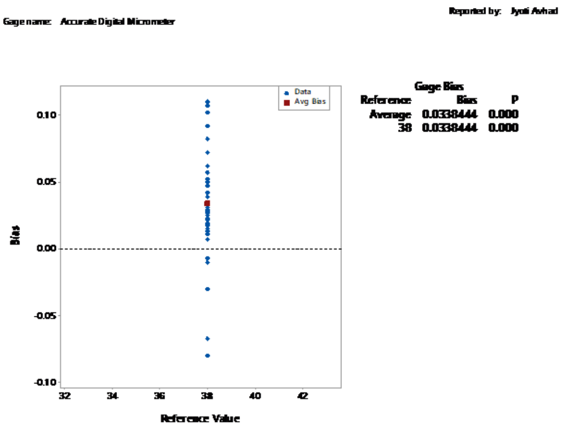

Figure 7Gage Linearity and Bias Report for Gear Diameter Measurements carried out at 10 am

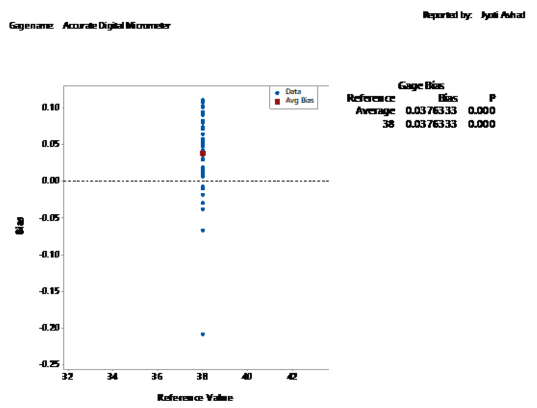

Figure 8Gage Linearity and Bias Report for Operator A

1.5.3 Gage R&R Study (Crossed)

. 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.

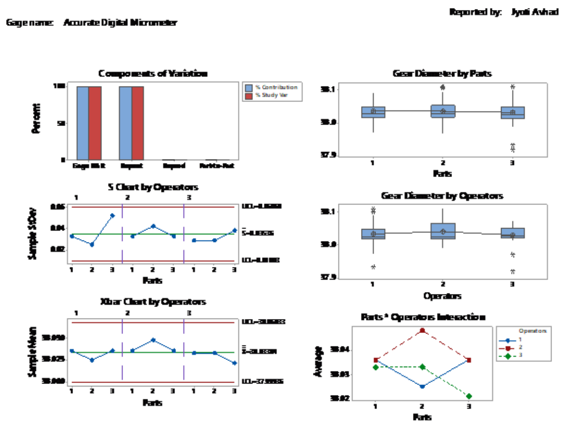

Figure 9 Gage R&R (ANOVA) Report for Gear Diameter Values Measured at 10 am

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

1.5.4 Normal Distribution and Probability Plot

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 The normal probability plot is a graphical technique for assessing whether or not a data set is approximately normally distributed.

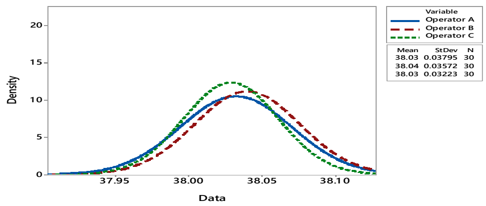

Figure 10Normal Distribution Plot for the Data obtained from the Measurement carried out at 10 am

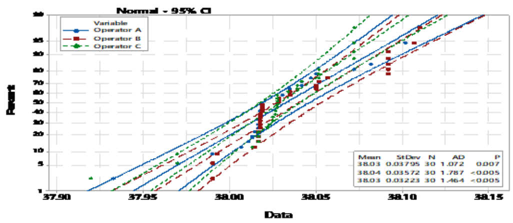

Figure 11 Probability Plot for the Data obtained from the Measurement carried out at 10 am

1.6Process 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.

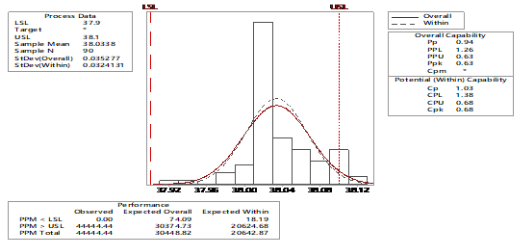

Figure 12 Process Capability Analysis for Measurement Carried out at 10 am

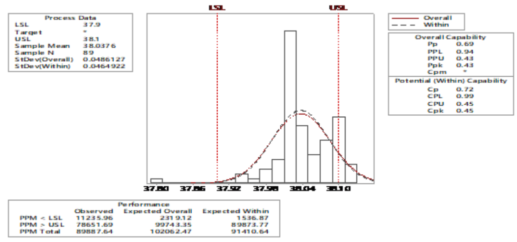

Figure 13 Process Capability Analysis for Measurement Carried by Operator A

1.7 Monte Carlo Simulation

The Monte Carlo method is a probabilistic technique based on generating a large number of random samples.The Monte Carlo simulation is categorized as a sampling method because the inputs are generated randomly from probability distributions to simulate the process of sampling from an actual population.Five basic stepsare as follows:

Step 1: Generate a model with parameter $y = f(x_1,x_2, \ldots, xq)$

Step 2: Generate a set of random number inputsx_{i1}, $x_{i2}, \ldots, xiq$

Step 3: Evaluate the model with the saved result yi

Step 4: Repeat Steps 2 and 3, $i = 1$ to n

Step 5: Analyse the statistical results andconfidence intervals

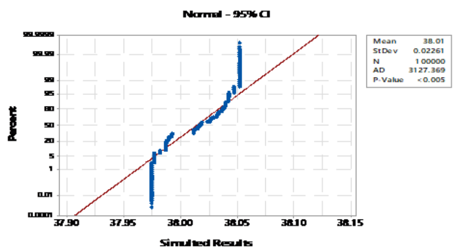

Figure 14 Probability Plot for 100000 measurement values generated using Monte Carlo Simulation

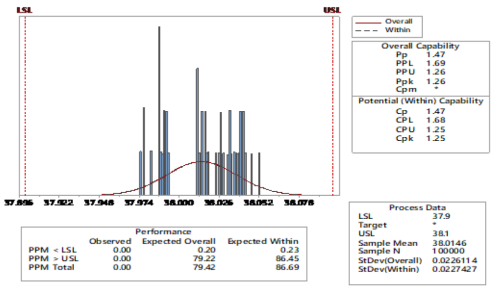

Figure 15 Process Capability Analysis of 100000 measurement values generated using Monte Carlo Simulation

1.8 SUMMERY

1.GageLinearity And Bias Study

Table 7 Comparison for Gage Linearity and Bias Study

Data	Gear Diameter Measure at / by						
	10 am	2 pm	5 pm	Operator A	Operator B	Operator C	After Improvement
Bias	0.0338444	0.0385889	0.0342444	0.03763333	0.0430556	0.0256111	0.0147556
P	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.Gage R&R Study (Crossed)

Table 8Gage R&R (% Contribution)

Source	Gear Diameter Measure at / by			
	10 am	2 pm	5 pm	After Improvement
Total Gage R&R	100.00	99.26	100.00	4.61
Repeatability	100.00	98.16	93.34	4.61
Reproducibility	0.00	1.09	6.66	0.00
Operators	0.00	1.09	6.66	0.00
Part-to-Part	0.00	0.74	0.00	95.39

3. Process Capability

Table 9 Process Capability Analysis

Source	Gear Diameter Measure at / by							
	10 am	2 pm	5 pm	Operator A	Operator B	Operator C	After Improvement	Monte Carlo Simulation
C_P	1.03	0.60	1.02	0.72	0.71	1.43	2.23	1.47
C_{PL}	1.38	0.84	1.37	0.99	1.01	1.80	2.56	1.68
C_{PU}	0.68	0.37	0.67	0.45	0.40	1.07	1.90	1.25
C_{PK}	0.68	0.37	0.67	0.45	0.40	1.07	1.90	1.25

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&Rstudy 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. The Gage R&R crossed ANOVA study shows that there is a noticeable change in the measurement system and the % contribution of Gage R&R is about 5% only. Which shows that the developed system is producing results within acceptable limit.

Based on Process Capability Analysis: The process capability calculated for the measurements taken at different timings and by different operators' shows that the existing measurement system is not acceptable because all the Cp values are nearly below the expected value of 1.

The improved measurement system gives a very high process capability value for different indices, and giving the Cp values beyond 2.

Based on Monte Carlo Simulation:

Over 100,000 measurement results are generated using simulation. This amount of data will certainly predict the forthcoming probability and capability of the new system. The Cp values obtained from this data is around 1.5 which shows that the measurement system is stable and sound in performance. Also the linear nature of the data is observed in probability plot.

1.7 REFERENCES

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