Measurement of Inline Tooth Space Runout Gauge for Soft Machining of Transmission Parts using Xbar and R Method

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Abstract - **Accuracy of gear closely monitors its main geometric features to resemble theoretical design. Gears are complex in geometric shapes and are therefore specified by a range of appropriate closed dimensions. Gear accuracy are considered as the deviation of selected dimensions from the theoretical design. The dimensions are also evaluated within certain tolerance levels. Close monitoring during its manufacture is important for operational requirements, detecting and monitoring problems during manufacturing related to the machine tools and their operation. Measurement system analysis (MSA) is a useful quality tool used to evaluate the acceptability of gauge variation to ensure the quality of the measurement system and their product quality. MSA depends on measurement error so it must be implemented prior to any process improvement activities for minimizing the measurement errors. The capability of each quality system is related to the accuracy of its measurement system. Measurements are required to maintain the consistent quality of all finished products in a production line. The work is proposed for assessing a measurement system using gauge repeatability and reproducibility (GR&R). Usually, GR&R study need to be carried out prior to the process capability analysis for assessing the adequacy of gauge variation. GR&R study followed the standard automotive industry action group (AIAG) study to evaluate the tooth space runout gauge measuring performance. The obtained GR&R percent was 9.1 which is acceptable for measurement.**

Keywords:* *Gear accuracy, Tooth space runout, Gauge R&R, AIAG

I INTRODUCTION

In modern day transportation consumer preferences for automobiles have been focused on both performance and quality. In particular, consumers look for improved driving, comfort, safety, power performance, stability of the steering system, and fuel economy. The transmission, which is a major component of the automobile, is developed to satisfying the more stringent requirements of high capacity, high endurance, compact size, and low vibration/noise. An automotive transmission consists of shafts, helical gears, bearings, gearmotor systems, a case, etc. All forms of motorized transport, including vessels and aircraft, need transmissions to convert torque and rotation. There are contrast between transmissions according to their function and intended use, for example gearboxes, steering boxes and power take-offs. The function of a vehicle transmission is to make the traction available from the drive unit to suit the vehicle, the surface, the driver and the environment. The main boundary is technical and economic competitiveness. The transmission has a conclusive effect on the reliability, fuel consumption, ease of use, road safety and transportation performance of passenger cars and commercial vehicles. Vehicle transmission components are now themselves undergoing a process of evolution. The development of components such as gearwheels, shafts, bearings, synchronizers and clutches, as well as electronic controls A measurement system is a process that includes standards and methods in obtaining measurements of some quality characteristics. Measurement system analysis (MSA) is the most important quality tools used for evaluating the acceptability of gauge imbalance in order to make sure the quality of the measurement system and related products. The motive of MSA is to specify accuracy, precision and stability of a measurement system. MSA is used to set measurement errors by evaluating sources of deviation including measuring instruments, appraisers, and parts [1]. If the measurement results are not accurate, poor-quality products will be delivered to customers. MSA is used to find the extent of the observed variation caused by an equipment, to identify the source of variation in a testing system and to evaluate the capability of the equipment [2]. MSA plays an important role in Six Sigma and the ISO/TS 16949 standards for the reliability evaluation of the input and output data in the manufacturing process, the review of variations caused by evaluator, machines, methods, materials, and environment and the analyses of data for process improvements [3].

MSA determines measurement errors from various sources of variation in a process. Figure 1. illustrates the observed process variation including actual process and measurement variations [4,5]. Measurement variation consists of part-to-part variation, variation due to gauge and variation due to appraiser. Firstly, part-to-part variation is the difference of product feature due to manufacturing process. Secondly variation due to gauge includes linearity, stability, bias and the variance of the measurements obtained while measuring the characteristics of a measuring equipment (e.g., gauge repeatability). Lastly, variation due to evaluator is defined as the variance of the medium of the measurements obtained by different evaluator in measuring the same characteristics of the same part with the same measurement equipment (e.g., gauge reproducibility) [6].

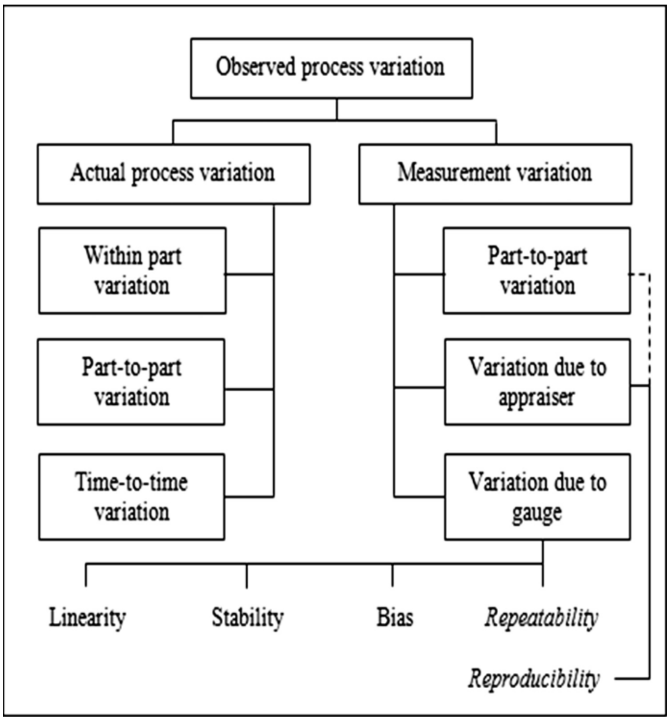

Figure 1. Variation in the process

II LITERATURE REVIEW

Generally, gauge repeatability and reproducibility (GR&R) will be studied before the process capability analysis by determining the capability of measurement system [7–9]. If the measurement system difference is relatively small compared with the process variation, the measurement system will be considered capable [10]. The procedure for standardizing the capabilities of measurement systems and manufacturing processes by conducting GR&R study with four measures consisting of the precision-to-noise ratio, signal-to-noise ratio, discrimination ratio and process capability index in order to reduce the measurement and product variabilities [11]. The measuring system review for mould-injected plastic parts [12] and the assessment of gear-diameter measuring system using an optical comparator [13].

GR&R is generally judged by three techniques including range, average and range (Xbar & R), and analysis of variance (ANOVA) methods. The range and Xbar & R methods are based on information that can be acquired from control charts using the sample ranges to estimate variability [10]. These methods compute reproducibility, repeatability and part-to-part variabilities by calculating the range of the average measurement from each appraiser, the average range across all parts, and the range of the average measurement from each part before determining the variance components for reproducibility, repeatability and Measurement system analysis (MSA) is a systematic procedure that identifies the components of variations in the precision and accuracy assessments of the measuring part-to-part variabilities. GR&R study using the Xbar & R method to supervise the process variation and evaluate the changeability of measurement system for a cast dimension in a foundry [5].

The GR&R tool is used to assess the reproducibility of the two different waveform generators by measuring their rise or fall times with a single evaluator. It was found that there was no statistically significant change between the rise and the fall time but there was significant interaction between the rise time fall times and the waveform generators at the significant level of 0.05, indicating the dependability of the measurement systems. This approach should be applied to assess the rendering of mechanical machining tools such as lathe and milling machines. The studies show that using process capability analysis indicate that the inaccuracy of machine tools is one of the most significant sources of variation in mechanical manufacturing process [15].

MSA is based on measurement error lied in any process measurement method. Therefore, it should be considered as the representative process of any quality measurement system [16]. MSA determines measurement errors via the testing of multiple sources of change in a process. These changes consist of the difference resulting from the measurement system, the operators, and the parts themselves Since statistical measures are computed by data obtained by sampling, they are usually undependable. In this case, it is required to be mentioned that a measured value is enclosed summation of two variables, the quantity of measured value and corresponding error (ei) as

$$Y_i(\text{Measured Value}) = Xi(\text{True Value}) + e_i \qquad (1)$$

The measurement system increases the total observed variability (σ^2_{obs}) of the measured parts. In any measuring, some of the observed variability is due to variability in the process(σ^2_p), whereas the rest of the variability is due to the measurement error or gauge variability (σ^2_{msa}). The variance of the total observed measurements can be expressed as Eq. (2). It means that total variability equals to the sum of process variability and measurement variability [17].

$$\sigma^2_{obs} = \sigma^2_p + \sigma^2_{msa} \qquad (2)$$

Gauge variability (σ^2_{msa}) contain two types of error they are called repeatability and reproducibility. Repeatability ($\sigma^2_{Repeatability}$), which was determined by measuring a part for several times, determine the variability in a measurement system resulted from its gauge [18,19]. Reproducibility ($\sigma^2_{Reproducibility}$), which was driven from the variability created by several operators measuring a part for several times, quantifies the variations in a measurement system resulted from the operators of the gauge and environmental factors [20]. Square root of σ^2_{msa} is called gauge repeatability and reproducibility (GR&R) which formulated the all errors related to the gauge. It can be shown as

$$\sigma^2_{msa} = \sigma^2_{Repeatability} + \sigma^2_{Reproducibility} \qquad (3)$$

instruments used in a measurement system [13]. The aims of MSA are to: (1) determine the extent of the observed variability caused by a test instrument, (2) identify the

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sources of variability in a testing system, and (3) assess the capability of a test instrument [14].

MSA is used to evaluate the reliability of some important input and major output data in the manufacturing process, understanding the variations caused by people, machines, materials, methods, or the environment, and then using the analysed data as a reference for improvements. Summary of GR&R is presented in Table 1

Table -1 Acceptable general proportions for precision width error

Source: AIAG MSA Manual [10]

P/T ratio	Decision
P/T ≤ 10%	The measurement system is considered to be acceptable
10% < P/T ≤ 30	The measurement system is considered to be marginally acceptable (may be acceptable for some applications)
P/T ≥ 30%	The measurement system is unacceptable

III METHODS AND PROCEDURE

The workpiece material was SCM 20 forged steel as shown in Figure 2. which was step turned to the close dimensions as per the customer requirement. The material undergoes several machining operations to generate gear teeth as shown in Figure 3. In this study, the standard AIAG GR&R study is used in order to assess the tooth space runout for gear counter performances using the X bar & R methods containing following steps:

Figure 2. Gear counter raw material

Figure 3. Gear counter after machining

a) The gear counter forged raw material was taken form bin
b) The sequence of machining operation is performed which is shown in Figure 4.
c) After gear shaving operation is completed the component needs to be checked for its tooth space runout
d) For this purpose, a mechanical gauge tester was used
e) For every two hours randomly, a part was taken by the technician for its tooth space runout measurement and values are noted
f) The X bar &R method was used to analyse the performances of the gear counter part

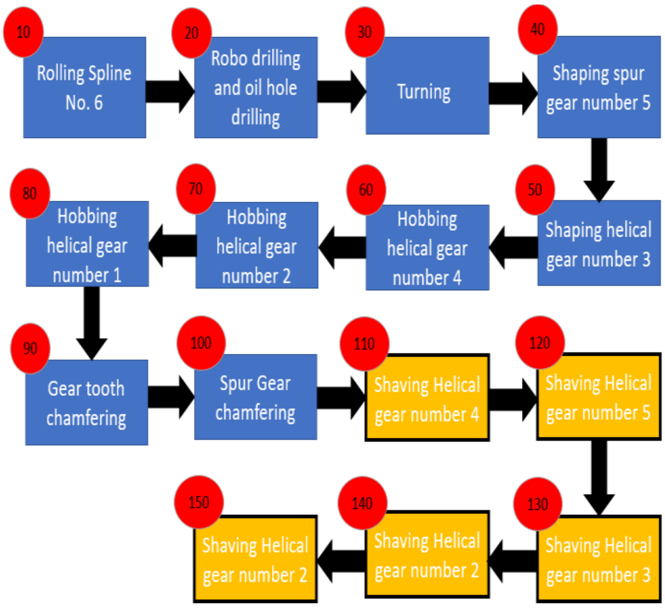

Figure 4. Gear counter after machining and nomenclature

IV RESULTS

The data Table 2 shows the three different appraisers are responsible for part measurements at three different time measured the tooth space runout values for 10 samples and 2 trials. The average of each sample with respect to trial is calculated and if any change in between the maximum value and minimum value is present then the range is calculated. The average of each trial sample is also calculated. Then X bar and R bar for each appraiser is calculated. The part average is done at the last cell in order to calculate X doublebar and R doublebar. The range of part averages (Rp) and Range of Appraiser averages (Ro) is also tabulated.

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Table -2 The data table used in this GR&R study.

VARIABLE MSA - GAUGE R & R - DATA ENTRY

Appraiser (A): ABC

Trial\Sample	1	2	3	4	5	6	7	8	9	10	Average	
1	8.00	9.00	12.00	15.00	18.00	13.00	9.00	12.00	10.00	12.00	11.80	
2	8.00	8.00	12.00	15.00	18.00	13.00	9.00	12.00	10.00	12.00	11.70	
3	7.00	8.00	11.00	15.00	18.00	13.00	9.00	12.00	10.00	12.00	11.50	
Average	7.67	8.33	11.67	15.00	18.00	13.00	9.00	12.00	10.00	12.00	Xbar(A)	11.67
Range	1.00	1.00	1.00	-	-	-	-	-	-	-	Rbar(A)	0.30

Appraiser (B): DEF

Trial\Sample	1	2	3	4	5	6	7	8	9	10	Average	
1	9.00	12.00	10.00	11.00	14.00	12.00	10.00	14.00	15.00	10.00	11.70	
2	8.00	12.00	10.00	11.00	14.00	12.00	10.00	14.00	15.00	10.00	11.60	
3	8.00	11.00	9.00	11.00	14.00	12.00	10.00	14.00	15.00	10.00	11.40	
Average	8.33	11.67	9.67	11.00	14.00	12.00	10.00	14.00	15.00	10.00	Xbar(B)	11.57
Range	1.00	1.00	1.00	-	-	-	-	-	-	-	Rbar(B)	0.30

Appraiser (C): XYZ

Trial\Sample	1	2	3	4	5	6	7	8	9	10	Average	
1	8.00	10.00	14.00	12.00	12.00	12.00	12.00	13.00	9.00	14.00	11.60	
2	7.00	11.00	14.00	12.00	13.00	11.00	12.00	13.00	9.00	14.00	11.60	
3	8.00	10.00	14.00	12.00	13.00	11.00	12.00	13.00	9.00	14.00	11.60	
Average	7.67	10.33	14.00	12.00	12.67	11.33	12.00	13.00	9.00	14.00	Xbar(C)	11.60
Range	1.00	1.00	-	-	1.00	1.00	-	-	-	-	Rbar(C)	0.40

Part Average	7.89	10.11	11.78	12.67	14.89	12.11	10.33	13.00	11.33	12.00	$X_{doublebar}$	11.61
											$R_{doublebar}$	0.33
										Range of Part Averages	R_p	7.00
										Range of Appraiser Averages	R_o	0.10

The Table 3 shows tabulation of repeatability of Equipment Variation (EV), reproducibility of Appraiser Variation (AV), Gauge Repeatability and Reproducibility (GR&R), Product variation (PV) and Total Variation (TV). There are two methods used to calculate GR&R they are Component Variance Method (CVM) and Automotive Industry Action Group (AIAG) method

Table -3 The data table shows the tabulation of quality parameter using Xbar and R method

VARIABLE MSA - GAUGE R & R - RESULTS

MoreSteam Recommended Alternative →

	Component Variance Method: % of Total Variation	AIAG Method: % of Total Variation	AIAG Method: % of Tolerance
REPEATABILITY - EQUIPMENT VARIATION (EV)			
EV = $R_{doublebar} / d_{2\,EV}^{*}$	%EV = EV^2/TV^2	%EV = EV/TV	%EV = EV/Tol
EV = 0.1968892 micro meter	%EV = 0.8%	%EV = 8.9%	%EV = 3.0%
REPRODUCIBILITY - APPRAISER VARIATION (AV)			
AV = $\{[R_o / d_{2\,AV}^{*}]^2 - [EV^2 / (n \times p)]\}^{0.5}$	%AV = AV^2/TV^2	%AV = AV/TV	%AV = AV/Tol
AV = 0.0380654 micro meter	%AV = 0.0%	%AV = 1.7%	%AV = 0.6%
REPEATABILITY & REPRODUCIBILITY (GRR)			
GRR = $(EV^2 + AV^2)^{0.5}$	%GRR = GRR^2/TV^2	%GRR = GRR/TV	%GRR = GRR/Tol
GRR = 0.2005351 micro meter	%GRR = 0.8%	%GRR = 9.1%	%GRR = 3.0%
PRODUCT VARIATION (PV)			
PV = $Rp / d_{2\,PV}^{*}$	%PV = PV^2/TV^2	%PV = PV/TV	%PV = PV/Tol
PV = 2.2012579 micro meter	%PV = 99.2%	%PV = 99.6%	%PV = 33.0%
	Σ = 100%	Σ <=> 100%	
TOTAL VARIATION (TV)			
TV = $(EV^2 + AV^2 + PV^2)^{0.5}$			
TV = 2.2103734 micro meter			

The Table 4 shows that the results of Component Variance Method in which Product variance is 99.2 percent. This means that system is acceptable for measurement and will be the excellent quantifier of process improvement. The accuracy (Bias) has a goal that all appraiser averages should be within the control limits. The value which I had got contain no appraiser bias.

Table -4 below shows the results of Component Variance Method

Interpretation of Results for the Component Variance Method

Relative Utility: Goal - at least 80% of measurement is error attributable to the product

Range of % PV	Actual %PV	This Means:
>= 80%	99.2%	The measurement system is acceptable for measurement and will be an excellent quantifier of process improvement.
50% <= %PV < 80%		
20% <= %PV < 50%		
< 20%		

Bias: Goal - all appraiser averages within Bias Chart control limits

Value	Result:	This Means:
0	All appraisers averages are within the Bisas Chart control limits	There is no appraiser bias present
1 or 2*		
# appraisers		

The values below show the results of Automotive Industry Action Group (AIAG) method in which Gauge Repeatability and Reproducibility (GR&R) is 9.1 percent. This means that it is generally considered as an acceptable measurement system. The measurement system has adequate resolution to detect part to part variation.

Table -5 below shows the results of Automotive Industry Action Group (AIAG) method

Interpretation of Results for the AIAG Method

Relative Utility: Goal - gauge R&R% is less than 10%

Range of % GRR	Actual GRR%	This Means:
<= 10%	9.1%	The measurement system is acceptable
10% < %GRR <= 30%		
> 30%		

System Resolution: Goal - all appraisers have at least 50% of average values outside the Averages Chart control limits

Value	Result:	This Means:
# Appraisers	All appraisers have at least 50% of averages outside the Averages Chart control limits	The measurement system has adequate resolution to detect part-to-part variation
< # Appraisers		

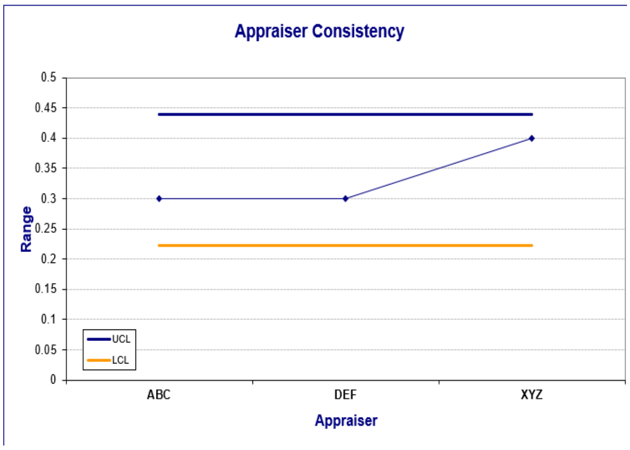

Figure 5. The Bias with respect to appraiser

If all the data points are within the control limits, there is a 95% probability that there is no operator bias present

Control limit calculation

Appraiser Bias Chart

$X_{doublebar}$	+	($R_{doublebar}$	X	ANOME)	=	UCL
11.6111	+	0.3333	X	0.192	=	11.675

$X_{doublebar}$	-	($R_{doublebar}$	X	ANOME)	=	LCL
11.6111	-	0.3333	X	0.192	=	11.547

The Minitab tabulation shown in below contain 9.07 percent of total gauge repeatability and reproducibility and part to part variation 99.59 percent.

```
                               %Contribution
Source             VarComp     (of VarComp)
Total Gage R&R     0.04023             0.82
  Repeatability    0.03879             0.79
  Reproducibility  0.00144             0.03
Part-To-Part       4.84843            99.18
Total Variation    4.88866           100.00


                                 Study Var  %Study Var
Source             StdDev (SD)    (6 × SD)       (%SV)
Total Gage R&R         0.20057      1.2034        9.07
  Repeatability        0.19694      1.1816        8.91
  Reproducibility      0.03800      0.2280        1.72
Part-To-Part           2.20192     13.2115       99.59
Total Variation        2.21103     13.2662      100.00


Number of Distinct Categories = 15
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Figure 6. Minitab software results

The gage R&R graph from Minitab results

Figure 7. summary of graph for Xbar and R

V CONCLUSION

The work proposed the use of MSA to evaluate the performance of randomly selected gear counter of automotive transmission that was produced on machining centres. The performance of evaluators was zero biased based on their readings. The proposed GR&R study from the standard AIAG study was successfully implemented for all the gear counters using the Xbar & R. According to the results, there was a statistically important interaction between parts and machines, indicating that the part dimensions and measurement results by an evaluator depended considerably on the machine performance. This led to the suggestion that the periodic machine maintenance and proper corrective actions were necessary to ensure the quality of machined parts. The machine performance assessment using GR&R analysis would be useful for the measurement system acceptance test. This could also provide important guidelines for improving machine performances in other industrial systems.

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