Gage Repeatability and Reproducibility Study

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Abstract:-

The Measurement System Analysis (MSA) is a significant method which is used to analyze the measurement capability of a measurement system. It's considered the early steps in production control and one of the quality enhancement techniques. Gage Repeatability and Reproducibility (GR&R) is a process to examine the non-conforming of tools, equipment, and operators. The Gage study tell the operators if the measurement system is acceptable for its purposed use, also shows which part of the system is contributing the most variation of the measurements, so this will help the operator to improve the measurement system. The aim of the MSA is to qualify a measurement system for use by quantifying its precision, accuracy, stability and minimizing their contribution in process variation through including method such as ANOVA. This paper study ANOVA method, using MINITAB (16) to calculate Gage R&R through taken ten samples of Aluminum shafts , and three operators to measure the outer diameter of samples by using micrometer outer diameter device. The measurement results show the variance component for gage repeatability and reproducibility is acceptable, and the excessive variance was in the Part-To- part variations.

Keyword: Gage R&R, Repeatability, Reproducibility, ANOVA

1. Introduction

The measurement system analysis is usually known as Gage R&R Study [6]. Measurement System Analysis (MSA) is a comprehensive set of tools for the measurement, agreement, and errors analyses which includes topics such as Statistical Process Control. It focuses on emphasize variations in the data are considered the actual variations in what to measure and not to variations in measurement techniques. The objective of measurement system analysis is to find if a measurement system produce precise quality information, and if precision is appropriate to reach the objectives. Potential roots of difference can be discovered by analyzing stability, linearity, repeatability and reproducibility of the measurement system [8]. Manufacturing environment depends on two kinds of measurements to confirm the quality and to quantify the performance: (1) measurement of its products, and (2) measurement of its processes. This requires precise and accurate measurement methods. Actually all the measurements included error, understanding and managing "measurement error", commonly called Measurement Systems Analysis (MSA) [4].

Zhang.et.al (2008) Described methods and principles of Repeatability and Reproducibility in measurement system analysis (MSA), utilized the measurement system analysis techniques in Non-Destructive Testing (NDT) field depending on an example of ultrasonic testing, the value of Repeatability and Reproducibility is calculated, and the results show that measurement system analysis technique can evaluate the measurement capability of ultrasonic testing system, also can be applied in other nondestructive testing system [12].

Kazerouni.et.al (2009) Determining the requirement and assurance of comprehensive development in analyzing measurement systems, essentially with the use of Gage Repeatability and Reproducibility (GR&R) to improve physical measurements [4].

Wang.et.al (2010) the aim of the study is to determine whether measurement steps and tools is adequate for monitoring the performance of a process. The Bootstrap method and control chart are used to get the confidence intervals of the gage variability. An example is utilized to display the application of this control chart with the Bootstrapping method, and the result is compared with three experimental design procedures in terms of confidence intervals for gage R&R variability [10].

Huang.el.al(2012) the aim of this research is to check the Repeatability and Reproducibility (R&R) of an optical measurement system [3].

Yadav.et.al (2016) the purpose of this paper is to outline Measurement System Analysis (MSA) and study Analysis of Variance (ANOVA) method through a real-time shop floor experiment [11].

2. Measurement System Analysis Components

2.1 Accuracy

It denotes how close instrument's average value is to true value (i.e. it represents the closeness of observed value to the true value) [11]. It includes:-

a- Bias

In measurement situation, bias is "the difference between a population mean of measurement and true value". Bias leads to an over or under estimate of the true value. Measurement bias at most due to incorrect measuring device or procedures and it doesn't disappear away by increasing samples. Sampling bias occurs mainly due to under representative sampling of target data pool and cannot be decreased by increased sampling [11].

b- Linearity

"Is the measure of accuracy or bias of the measurements through the expected range of measurements". The linearity determines if the gage has similar accuracy for several sizes of the measured parts. It also shows how the size of the part impacts in the accuracy of the measurement system [6].

2.2 Stability

Stability refers to degree of measure to which system can produce same mean over extensive periods of time with no variation using the same gage and operator to frequently measure the same part. In statistical process control (SPC) It can be determined by using control charts (X bar and R chart), given the appraiser measure the same way as others over an extended period of time meaning absence of "special cause" variation [9].

2.3 Precision

It refers to degree of closeness between repeated measurements taken from the same system in unchanged conditions. It is the opposite of variance/ variability and unlike bias its magnitude only depends on observed (measured) value and is independent of true value. If a system has precision error it creates spread error in result of measurements [5]. It includes:

a- Repeatability

"It refers to the variation in measurements acquired when one measuring device used several times by an operator while measuring similar characteristics of the same part [11].

b- Reproducibility

It is the difference in the mean of measurements made by different operator using the same device, while measuring similar characteristics of same part. Also called as between system variation or appraiser variation (AV). Fig. (1) illustrate measurement system analysis component [11].

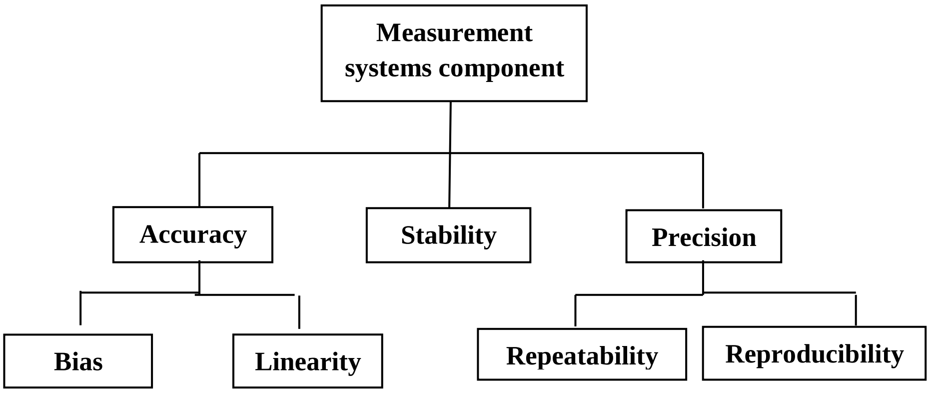

Fig. 1 Measurement System Analysis Component [11]

3. Measurement Error

Measurement error "is the estimated amount that a measured value is different from its reference or master value". The errors can be caused by devices, appraiser, types of test and differ than other parameters. Measurement error estimation based on accuracy and precision. The equation (1) used to determine the accuracy and precision of a measurement system.

$$Accuarcy = \overline{X_m} - X \dots\dots\dots \boldsymbol{Eq.(1)}$$

Where

X_m: Average of measurements

X: True value

In order to maximize the measurements accuracy, the errors should be minimized. The measurement readings are assessment of valid measured values. Measurement suspicion can be defined as the probability that a reading will fall in the interval that includes the reference value. Measurement instruments may not give a true reading because of problems due to accuracy and precision. Fig. (2) shown difference between accuracy and precision, where Fig. (2(a)) shows an accurate series of repeated measurements because their average is close to the true value , which is at the center. In Fig. (2(b)) repeated measurements in the series are precise (very close together), but are not close to the true value. Fig. (2(c)) shows the series of repeated measurements tightly grouped around the true value, and these measurements are both accurate and precise [1].

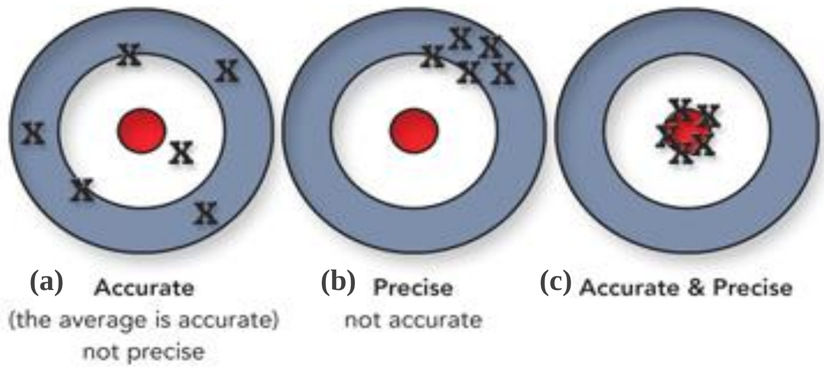

Fig. 2. Difference between Accuracy and Precision [1]

4.Gage Repeatability and Reproducibility Calculation Method

In the GR&R studies, repeatability and reproducibility notes explain how much the variations of production process belong to the measurement system dispersion. Different methods used to calculate an instruments Repeatability and Reproducibility index such as:

1. Range method: this method utilized to determine a rapid estimation of the measurement system variation. The disadvantage of range method is the disability to partition the variations into Repeatability and Reproducibility (R&R) [3].
2. Average and Range method (X bar & R): this method includes determining the average measurements (X bar) of the samples and appraisers, then determining the range (R) of the results from these samples and appraisers. This method can be run by hand so it's considered very simple because its avoids a lot of sophisticated calculation [8].
3. Average and Standard deviation method: this method has the same characteristics as the average and range method [3].
4. Analysis of Variance (ANOVA): this method has a more widespread usage. It's more sophisticated than other methods. This method can experiment the effects of "control factors" and the interaction affects between the various factors. ANOVA can be expanded to analysis the data from an experiment, also to evaluate suitable

components of gage variability [7].Table (2) shows the formulas used to conduct the ANOVA analysis.

Table 1. Formulas Used to Conduct the ANOVA Analysis for GR&R [2]

Variability	Sum of Squares (SS)	Degrees of Freedom (DOF)	Mean of Squares (MS)	F Statistics
Operator (a)	SS_a	a-1	$MS_a = \frac{SS_a}{a-1}$	$F = \frac{MS_a}{MS_E}$
Part (b)	SS_b	b-1	$MS_b = \frac{SS_b}{b-1}$	$F = \frac{MS_b}{MS_E}$
Interaction (operator×part)	SS_{ab}	(a-1)(b-1)	$MS_{ab} = \frac{SS_{ab}}{(a-1)(b-1)}$	$F = \frac{MS_{ab}}{MS_E}$
Error	SS_E	ab(n-1)	$MS_E = \frac{SS_E}{ab\,(n-1)}$	
Total	SS_T	a.b.n-1	**Where:** **a: Number of Operators** **b: Number of parts** **n : Number of trails**	

5.Experimental Work

The experimental work of this paper will be illustrating through the practical application of MINITAB 16 for the shaft diameters data which is taken from Training and Workshops Center /University of Technology. Ten samples of shafts were taken and measured by Micrometer outer diameter device in the Dimensional laboratory of the department of Production Engineering and Metallurgy. Fig. (3) shows the dimensions of the shaft, Fig. (4) shows the Ten shafts (Samples), Fig. (5) shows the measurement tool (Micrometer) and Fig. (6) shows Samples measured By Micrometer.

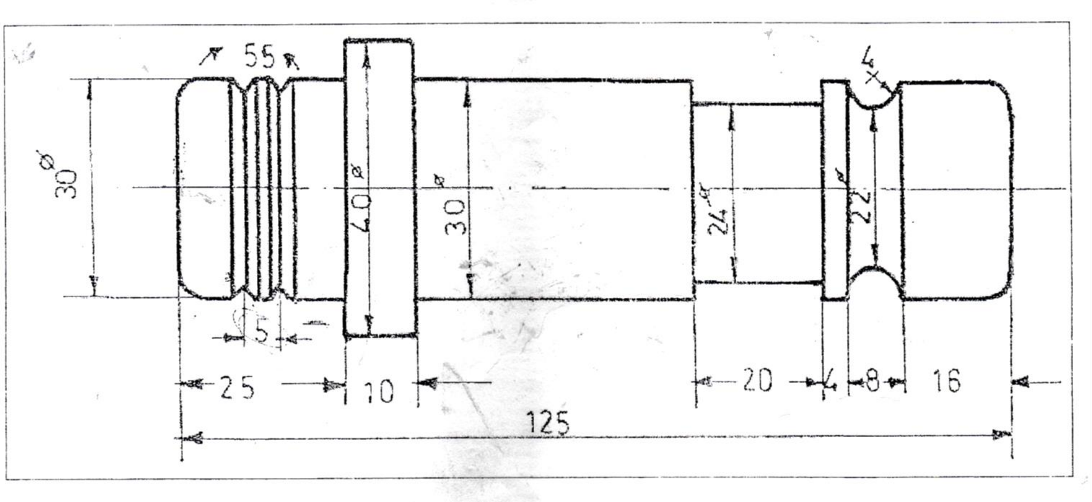

Fig. 3 The Dimensions of the Shaft

Fig. 4 Ten Shafts (Samples)

Fig. 5 Micrometer (Outer Diameter)

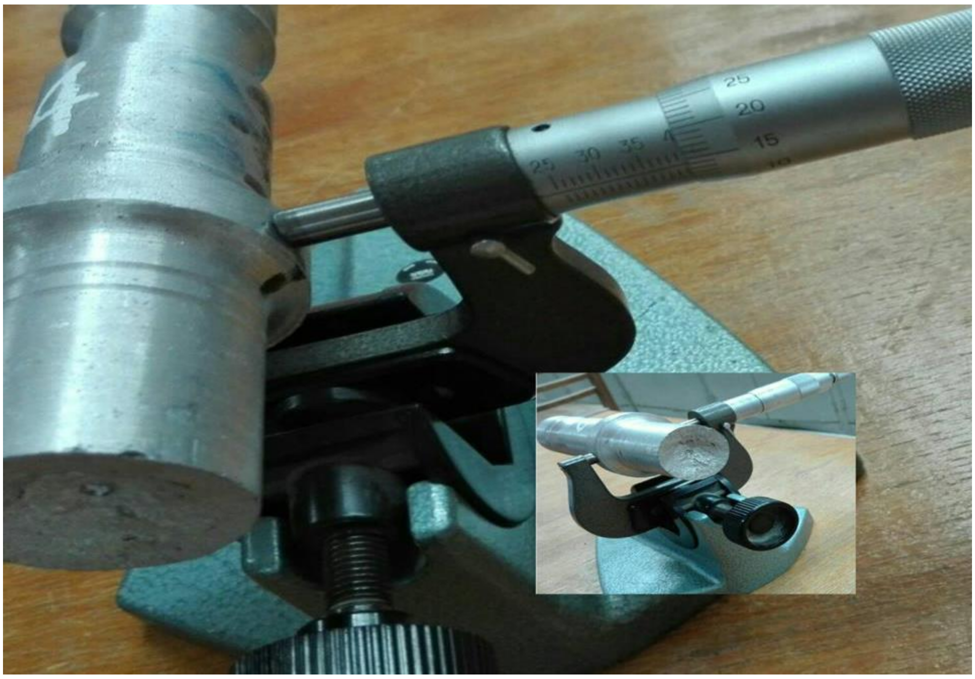

Fig. 6 Samples Measured by Micrometer

6. Application

In this paper the gage R&R (crossed) ANOVA method used by utilizing the statistical software MINITAB (16) to facilitate the gage repeatability and reproducibility calculations. Crossed analysis used to evaluate the variation in the measurement system when every operator measures every part multiple times. The data of the measured samples are shown in table (2). The procedure to measure samples is detailed as follows:

1. Take out a sample of ($n > 10$) parts that represent the factual or predictable range of process variation.
2. Operator (A) measures all the (10) parts and record the data in row (1).
3. Operator (A) repeated the measurements in a different order and enters the results in rows (2).
4. The same procedure will be done by operators (B) and (C).

By entering the measured data in MINITAB, the results will appear separately in the session window and the graphic window as shown in Fig. (7) and (8).

Table 2. The Data of the Measured Samples

Operator(A):

Trial\Sample	1	2	3	4	5	6	7	8	9	10
1	40.31	40.44	36.83	40.40	41.18	40.12	40.21	43.88	40.90	44.85
2	39.85	40.34	36.85	40.39	41.17	40.20	40.23	43.85	40.11	44.80

Operator(B):

Trial\Sample	1	2	3	4	5	6	7	8	9	10
1	40.35	40.44	36.88	40.47	41.22	40.17	40.30	43.97	40.20	44.83
2	40.34	40.43	36.87	40.43	41.23	40.21	40.31	43.98	40.19	44.98

Operator(C):

Trial\Sample	1	2	3	4	5	6	7	8	9	10
1	40.32	40.41	36.86	40.38	40.67	40.70	40.26	43.83	40.13	44.70
2	40.27	40.37	36.85	40.39	41.23	40.10	40.28	43.68	40.10	44.68

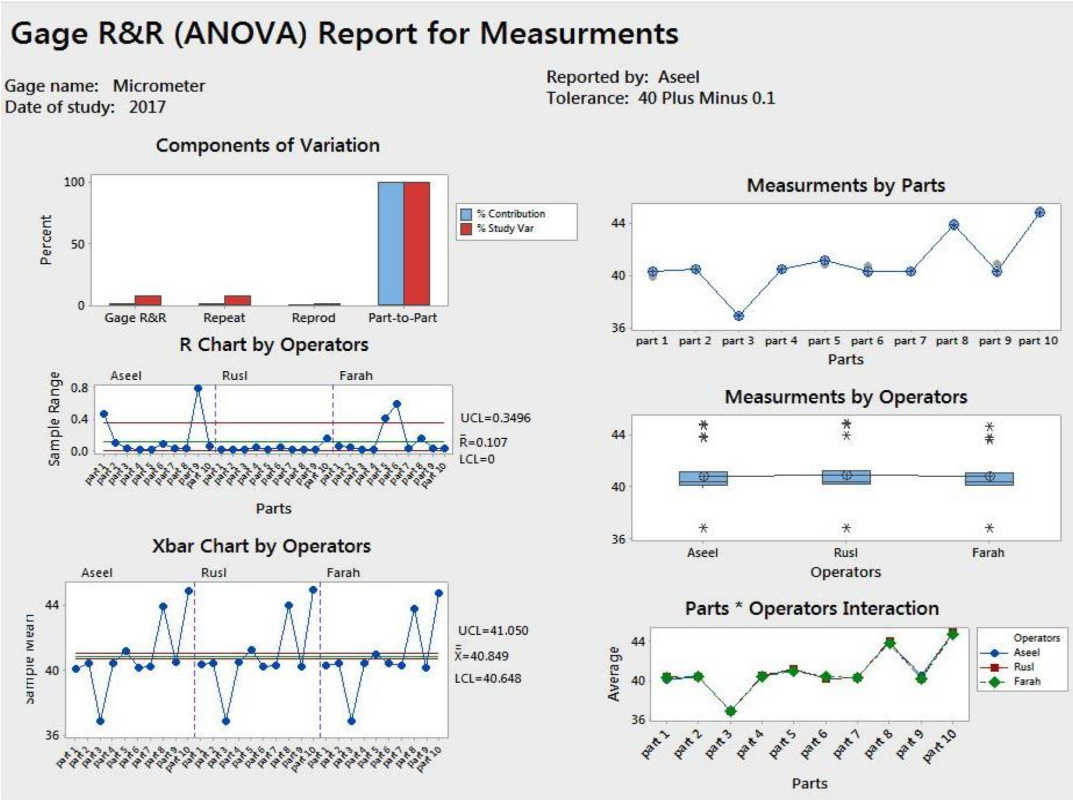

Fig. 7 Gage Repeatability and Reproducibility ANOVA Report for Measurements (graphic window)

Session

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.02457	0.52
Repeatability	0.02425	0.51
Reproducibility	0.00032	0.01
Operators	0.00032	0.01
Part-To-Part	4.72555	99.48
Total Variation	4.75012	100.00

Source	StdDev (SD)	Study Var (5.15 * SD)	%Study Var (%SV)
Total Gage R&R	0.15673	0.8072	7.19
Repeatability	0.15571	0.8019	7.14
Reproducibility	0.01785	0.0919	0.82
Operators	0.01785	0.0919	0.82
Part-To-Part	2.17383	11.1952	99.74
Total Variation	2.17948	11.2243	100.00

Fig. 8 Gage Repeatability and Reproducibility ANOVA Report for Measurements (Session Window)

7. Results and Discussion

The measurement results should be reviewed to decide if the instrument that used in measurement is acceptable for its purposed function. The most acceptance guidelines to explain the results are established by Automotive Industry Action Group (AIAG) which is considered as a standard for interpreting the measurement system analysis. Table (3) shows the AIAG standards.

Table 3. The AIAG Standards [2]

Measurement System	***% Study Variation***
acceptable	%10 or less
May be acceptable for some Application (Marginal)	%10-%30
Un acceptable	%30 or greater

From the result in the session window which is shown in Fig. (8) we notice that the percent contribution of the variance component (% contribution) for gage repeatability and reproducibility is (0.52) this variation due to both repeatability (measuring device) and reproducibility (operators). This value is less than 10% so the measurement system is acceptable. Also the % contribution of Part –To-Part is (99.48), so it is clear that there is excessive Part –To-Part variations.

8. Conclusions

1. Gage repeatability and reproducibility studies are important to guarantee the validity of data, which is essential to other researches.

2. The effectiveness of a measurement system is with relationship to the accuracy of measurement tool. The familiar measurement tools such as micrometers and calipers are the ones that could cause the most worry with their incorrect use.

3. The measurements processes and tools should be controlled fitly to ensure getting the suitable data. So, the using of the Measurement System Analysis (MSA) would be a great support for emphasis the accuracy of activities.

4. The used method can simplify the measurement problems effectively, thus, the measurement analyses could be named as a tracing way for

the significant causes of process variances.

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دراسة التكرارية وامكانية تكرار النتائج

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الخلاصة:-

تحليل نظام القياس هو الخطوة الاولى من مراقبة الانتاج و تقنية تحسين الجودة و هو طريقة هامه تستخدم لتحليل القدرة على القياس الاحصائي و قدرة القياس لنظام القياس , مقياس التكرار وامكانية تكرار النتائج هو عملية للتحقق من الادوات , المعدات , او العاملين اذا كانت غير مطابقة . نتائج مقياس التكرار و امكانية تكرار النتائج ممكن ان توضيح اسباب اخطاء القياس . ان الغرض من تحليل نظام القياس هو تأهيل نظام القياس لاستخدامه من خلال قياس دقته , الانضباط , و الاستقرار و تقليل مساهمتها في عملية الاختلاف من خلال عدة طرق مثل (ANOVA).في هذا البحث تم دراسة طريقة الانوفا , و ذلك باستخدام برنامج MINITAB(16) لحساب مقياس التكرار وقابلية تكرار النتائج من خلال اخذ عشر عينات و قياسها باستخدام جهاز مايكرومتر الاقطار الخارجية. وقد اظهرت نتائج القياس ان التباين في التكرارية وامكانية تكرار النتائج مقبول وان التباين المفرط يعود الي التغيرات من جزء الى اخر.