Evaluating Measurement Capabilities by Gauge R&R Using ANOVA for Reliability

Mr.Ravindra Dhawale *, Prof.Dr.D.N.Raut **
*(M.Tech. Production Engineering Department ,VJTI ,Mumbai- 400019)
** (Prof. Production Engineering Department ,VJTI ,Mumbai- 400019)

ABSTRACT

Gauge Repeatability and Reproducibility i.e. R&R measurement by using ANOVA method is the main step of the production control and quality improvement of the final outputs. This is because, it is necessary for the operators to have particular and accurate data for analyzing and solving problems of the production. This paper underlines the study of Gauge R&R using ANOVA on the Minitab software for checking the tools, equipments, parts, operators if they are not finished. It can also remove the errors of the production that gives the better outputs.

Keywords - *Analysis of Variance (ANOVA), Gauge Repeatability and Reproducibility, Part-Operator interaction, Quality improvement*

I. INTRODUCTION

Most of the quality problems in industries are solved by identifying and correcting inaccurate data and inaccurate measurement process. Despite the quality being a major concern for any sector, experts in manufacturing industries, express their anxiety about the measurement reliability which is used in decision making [1]. The quality of the data measured is vital for appropriate understanding, monitoring or improving a process. If the data is contaminated with errors, it could lead to wrong decisions. The ability to make right decisions depends on the availability of a measurement process, selecting the right measurement process and operating the measurement process in the correct manner. when the data quality is low, the benefits of a measurement system is also low; likewise when the data quality is high, the benefit is high too [2]. A measurement system is the collection of instruments or gages, standards, operations, methods, fixtures, software, personnel, environment and assumptions used to quantify a unit of measure or fix assessment. Because of various reasons, each element of measurement system may lead to bring variation and discreteness into the measurement results, and affect the measurement accuracy. In order to ensure the reliability of measurement system, it's necessary to analyze the measurement system so as to determine and control the variation sources. So far research work on the statistical discreteness in measurement system is rarely implemented. If the discreteness is great, it will increase the measurement error.

II. ERRORS IN A MEASUREMENT SYSTEM

The measurement system errors can be characterized based on its location and spread (variance) [2]. Location error can be categorized by accuracy, bias, stability and linearity. The spread error can be categorized as precision, repeatability, and reproducibility. Fig.1 illustrates measurement system variations.

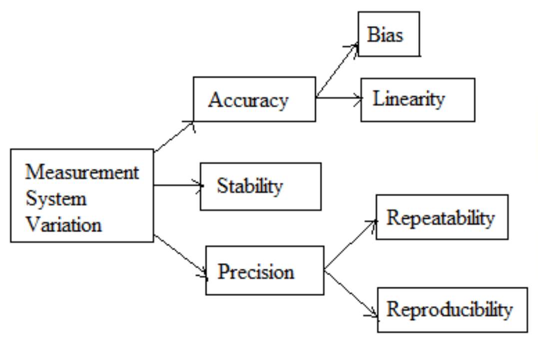

Fig.1. Measurement System Variations

Definitions of accuracy and precision are given as below:

A. Accuracy: It is the difference between the average values of the observed measurement and the actual measurement.

Accuracy can be divided in to three components:

1. Bias: It is the difference between the average observed value and the reference value of the same characteristic on the same part.
2. Linearity: It is the difference in bias values over the expected operating range of the measurement gauge.
3. Stability: It is the variation (differences) in the average over extended periods of time using the same gauge and appraiser to repeatedly measure the same part.

B. Precision: Precision or measurement variation is the variation due to a measurement system and can be divided into two components:

1. Repeatability: It is the ability of measurement system to obtain small variability by repeating the same measurements on the same sample under the same conditions. If the operator gets the same measurement during repeated trials, the Gauge is said to have high repeatability. Poor repeatability could be due to the device being inaccurate, the instructions being faulty, the operator not following the instructions, or a number of other factors. The fig.2 below shows the schematic of repeatability.

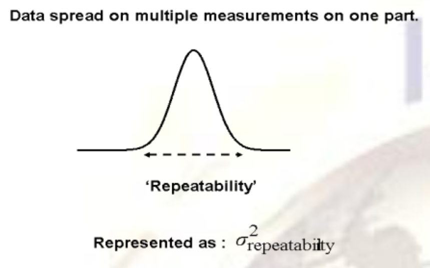

Fig. 2. Schematic of repeatability

2. Reproducibility: It is the ability of measurement system to return consistent measurements while varying the measurement conditions (different operators, different humidity, etc.). If several different operators get the same result when measuring the same object, the measurement device is said to have high reproducibility. Note that this does not mean the device is accurate, but simply that the same result is produced over time. The fig.3 shows the schematic of reproducibility.

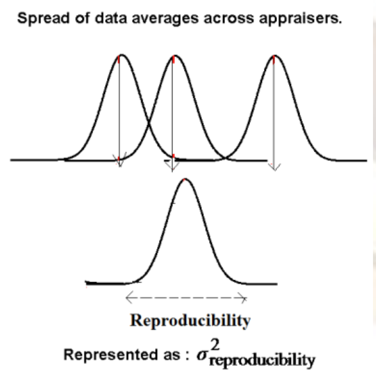

Fig. 3. Schematic of reproducibility

The purpose of Gauge R&R study as stated by Burdick.R, Borror.C and Montgomery.D [3] is to determine the amount of variability in the collected data that is due to the measurement system, isolate the sources of variability in the measurement system, assess whether the measurement system is suitable for broader application, and quantify the variability in the measurement process attributed by the operators, parts and operators-part interaction. Raffaldi and Kappele (2004) mentioned that, if the measurement variations can be reduced along with improved repeatability and reproducibility ratios, it is easier to differentiate the parts between in and out of specification with increased level of confidence for acceptance or rejection of the part [4].

Hence, the Gauge R&R can be use as a monitoring tool which provides feedback to improve measuring systems and methods. In the view point of mathematical statistics, the repeatability and reproducibility(R&R) is an important quality index which can reflect measurement capability and precision, namely the discreteness caused by statistical random effect. The discreteness must be controlled within a certain range to ensure that measurement results are reliable. Relation between R&R can be shown by fig.4 given below;

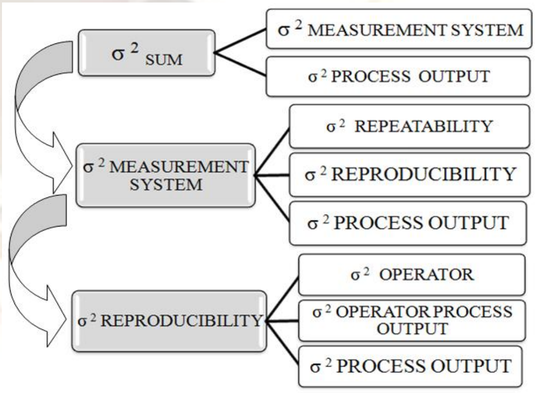

Fig. 4. Correlation between R&R [6]

III. R&R ANALYSIS METHODS

Generally in the Gauge R&R studies, repeatability and reproducibility observations illustrate how much of the production process variations belong to the measurement system dispersion. Various methods could calculate an instrument's R&R index and persisting some of them are evaluated.

1) Range Method**:** It is used to determine a quick approximation in measurement system variation. But this method could not divide these variations to the two interprets like repeatability and reproducibility.
2) Average and Range Method: This is a computational way for representing a system repeatability and reproducibility approximation. Evaluating the range method this method divides variation to these interprets.
3) Average and Standard Deviation: This method has the same features as the earlier method.
4) Analysis of Variance (ANOVA) Method: This method could separate the repeatability and reproducibility interprets. These separations are between variations related to operators and tools.

Since all these methods, the Average Range and ANOVA methods are the most common and important. Although all of them contain information on variation reasons but ANOVA method has a more extensive usage. This function leads to its comparison with Average and Range method. This can also be thought of as between operator variation. In addition, it enables the use of statistical hypothesis testing on the results to identify statistically significant effects. In order to determine the considerable effects in our gage study, we make a use of the examination of the difference (ANOVA) technique.

IV. ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) is a statistical technique estimates the amount of variability induced in measurements by the measurement system itself, and compares it to the total variability observed in order to determine the viability of the measurement system. The ANOVA method tests the hypotheses of mean biases of the experiment and also provides estimates of the variance components attributed to gage and operator. The assumptions of ANOVA method involved in this analysis as stated by Tsai [5] are as follows:

1. The operator, part interaction and gage (error) effects are additive.
2. The operator, part and gage effects are normally distributed with zero mean and variances.
3. The gage errors must be independent of the operator, part and interaction effects of each other .

The total variation is partitioned into operator, part, interaction between operator and part as shown in the table 1 below.

Table 1. ANOVA Calculations

Source of variability	Degree of Freedom (df)	Sum of Squa(ss)	Mean squares (MS)	F
Operator	k - 1	SS_O	$MS_O=\frac{SS_O}{(k-1)}$	$\frac{MS_O}{MS_{O*P}}$
Part	n- 1	SS_P	$MS_P=\frac{SS_P}{(n-1)}$	$\frac{MS_P}{MS_{O*P}}$
Operator by Part	(k-1)(n-1)	SS_{O*P}	$MS_{O*P}=\frac{SS_{O*P}}{(k-1)(n-1)}$	$\frac{MS_{O*P}}{MS_E}$
Equipment	nk(r-1)	SS_E	$MS_E=\frac{SS_E}{nk(r-1)}$	
Total	nkr-1	SS_T		

Regarding to the ANOVA table, the below definitions could be presented:

A. Sum of squares (SS): The sum of squares is calculated by squaring the deviations of each category and adding them together. Sum of squares represents how much the data varies in the samples.

B. Degree of Freedom (DF): This is the factor that considers number of groups and adjusts how large the groups could be.

C. Mean square (MS): which is the product of the sum of squares divided by the degrees of freedom. The mean square value represents how much a category varies between its sum of squares and degrees of freedom. One important mean square value is the error mean square, which shows the variance within the groups.

D. F-statistic. The F-statistic displays the distribution of values regarding the data and the null hypothesis. A large F-value generally lends to rejecting the null hypothesis and a small F-value generally leads to failing to reject the null hypothesis.

E. P-value (not shown in table): Finally the most important part in the ANOVA table is the P-Value amount which iss shown by P. Its related factor would be more important and significant when this value is lower.For example, if it is use a 5 percent test and the P-value is less than 5 percent, it can reject the null hypothesis.

ANOVA Methods divides in to two categories:

A. One-Way ANOVA: It has been termed as one-way as there is only one category whose effect has been studied and balanced. Thus the basic idea is to test whether the samples are all alike or not.

B. Two-Way ANOVA: It allow for experiments where populations are classified in two categorical factors. This method remove some of the random variability and allow the experimenter to look at the interactions between factors. It also allow experiments with a smaller total sample size, as two things are being studied at once.

In a two-way ANOVA with interaction, three hypotheses are tested which are:

1. H_o: All parts are similar Vs. H_1: All parts are not similar
2. H_o: All operators are equally good Vs. H_1: All operators are not equally good
3. H_o: Interactions between parts and operators are negligible Vs. H_1: Interactions between parts and operators are not negligible

The data collected for ANOVA at random and graphical analysis could perform on the data, resulting in the output in terms of the Main Effect plot and the Interaction Effect plot. The experimentation including the following keys or steps ;

1 Identify factors of interest and a response variable.
2 Determine appropriate levels for each explanatory variable.
3 Determine a design structure.
4 Randomize the order in which each set of conditions is run and collect the data.
5 Organize the results in order to draw appropriate conclusions.

Main Effects Plots are a quick and efficient way to visualize effect size. The grand mean is plotted as a horizontal line. The average result is represented by dots for each factor level on the Minitab software.

V. COMPUTATION OF R&R INDEX

To do the R&R index calculations by ANOVA technique several softwares are available but the most relevant is Minitab. In order to do the ANOVA calculations in Minitab, two ways are offered: Crossed Gauge R&R and Nested Gauge R&R. Gauge R&R study (Crossed) is to be selected when all operators measure parts from each batch and Gauge R&R study (Nested) is preferred whenever operators measure unique parts.

Minitab provides two methods for assessing repeatability and reproducibility. X-bar and R, and ANOVA. The X-bar and R method breaks down the overall variation in to three categories: part-to-part, repeatability and reproducibility. The ANOVA method goes one step further and breaks down reproducibility in to its operator, and operator-by-part, components. The ANOVA method is more accurate than the X-bar and R method, because it allows the variability of the interaction between the operator and the parts to be determined. In the Table No.2 ANOVA calculations in Minitab are shown as an example.

Table 2. ANOVA Computations [7]

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	8	46.1489	5.76861	769.148	0.00000
Oper	1	0.0400	0.04000	5.333	0.04974
Oper* Part	8	0.0600	0.00750	0.675	0.70735
Repeatability	18	0.2000	0.01111		
Total	35	46.4489			

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Part	8	46.1489	5.76861	576.861	0.00000
Oper	1	0.0400	0.04000	4.000	0.05605
Repeatability	26	0.2600	0.01000		
Total	35	46.4489			

The above table shows ANOVA output with full model and with reduced model made of the Gauge R&R Study (Crossed) since each operator measures each part. With the ANOVA output corresponding to the full model, It is unable to reject the null hypothesis that the operator by part interaction effect is equal to zero, even at the α = 0.1 level. It is also find that with the reduced model, the part component is statistically significant, as one would desire, and it is unable to reject the null hypothesis that the operator effect is equal to zero at 5% level. The variance component computations is shown below in the table no.3 which indicates that less than 1% of the total variation is due to Gauge R&R.

Table 3: Gauge R&R

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.01167	0.80
Repeatability	0.01000	0.69
Reproducibility	0.00167	0.11
Operator	0.00167	0.11
Part-To-Part	1.43965	99.20
Total Variation	1.45132	100.00

Process tolerance = 8

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.10801	0.64807	8.97	8.10
Repeatability	0.10000	0.60000	8.30	7.50
Reproducibility	0.04082	0.24495	3.39	3.06
Operator	0.04082	0.24495	3.39	3.06
Part-To-Part	1.19986	7.19913	99.60	89.99
Total Variation	1.20471	7.22824	100.00	90.35

Number of Distinct Categories = 15

VI. SELECTION CRITERIA

The percentage of the *R & R* in the total variation is an important index that can be used to evaluate whether a measurement system should be accepted or not. The measurement capability of the system is considered enough and acceptable if *R & R%* is less than 10% and is not enough and should be improved if *R & R%* is greater than 30% .Iff *R&R%* falls within 10% to 30% , in this case, whether the system is acceptable or not depends on the practical application.

VII. CONCLUSION

This study is described the measurements of the Gauge repeatability and reproducibility database by using the ANOVA analysis in the MINITAB Software. The main purpose of this paper is to study to determine the measurement system could produce precise and accurate data for better result. Further we are going to study in details using experimental and practical section with a particular product with interpreting the system with ANOVA on Minitab software.

REFERENCES

[1] Afrooz Moatari Kazerouni, "*Design and Analysis of Gauge R&R Studies: Making Decisions Based on ANOVA Method", World Academy of Science, Engineering and Technology 52 (2009)*

[2] AIAG:Automotive Industry Action Group(2002), *"Measurement Systems Analysis, Reference Manual"; third ed. ,Detroit,MI*

[3] Burdick, R. K., Borror, C. M., and Montgomery, D. C. (2005), *Design and Analysis of Gauge R&R Studies: Making Decisions with Confidence Intervals in*

Random and Mixed ANOVA Models, SIAM, Philadelphia, PA

[4] Smith R.R., McCrary S.W., Callahan R.N., *"Gauge repeatability and reproducibility studies and measurement system analysis: A Multi method exploration of the state of practice", Journal of Quality Technology, 23, 1, 1-11, (2007)*

[5] Tsai.P (1988-89). *"Variable Gauge Repeatability and Reproducibility Study Using the Analysis of variance Method", Quality Engineering, 1(1), 107-115*

[6] Lin R., *"Strategic Application of Measurement System Analysis", Ford Lio-Ho Motor Company, (2004)*

[7] Keith M. Bower, Michelle E.Touchton *"Evaluating The Usefulness of Data By Gauge Repeatability and Reproducibility", Minitab Inc. (2009)*