Validation of Internal Gauge Plane Measurement System Using Gauge Repeatability and Reproducibility

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Abstract - *The submitted article focuses on the validation of internal gauge plane measurement system with the help of Gauge Repeatability and Reproducibility method. In this case the internal gauge plane measurement system was used for detecting the gauge plane of inside taper ring. The average and range method of GRR was used to check the validity of measurement system.*

Key Words: ***Measurement system, GRR, Average and Range Method, MSA***

1 INTRODUCTION

The Gauge repeatability and reproducibility method is normally used in measurement system analysis (MSA) process to validate the measurement system. The measurement system described here is used for detecting the internal gauge plane of inside taper ring.

Gauge plane is an ISO taper pipe thread term equivalent to U.S. term and that is 'Plane of hand tight engagement'. Its location from the reference plane at small end of thread is called gauge length; and the major diameter at this plane is called gauge diameter in U.S.

The basic universal formula to calculate internal taper angle is:

$$\tan \alpha = \frac{D2 - D1}{2L}$$

<u>General method of internal taper measurement:</u>

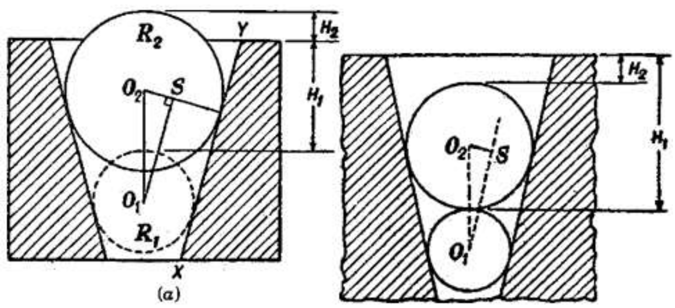

Fig 1: General method of internal taper measurement

In this method we required two balls of different diameter, depth gauge or height gauge etc. This method is generally used for checking taper ring gauges. First a small ball with radius r1 is inserted in the hole in lower position and depth H1 from upper surface of tapered hole to the top of ball is measured. Small ball must be such a size as to be seated somewhere in between hole then bigger ball of radius R2 is placed in the hole and distance H2 that is between the top of ball and tapered hole is measured with height gauge refer 'fig 1'. We can measure the angle of taper ring by using formula given below.

$$\sin\frac{A}{2} = \frac{R2\text{-}R1}{H1 + H2 + R1 - R2}$$

2 INTERNAL GAUGE PLANE MEASUREMENT SYSTEM:

Internal gauge plane measurement system works on combine basic metrology and electronic principle. This system uses taper plug gauge for measurement of internal taper and LVDT probes are used to measure the deflection of gauge plane from actual or required results. This system is used for production line where it checks each and every ring which manufactures such as 100 percent inspection.

This customized measurement system is developed to detect the gauge plane of inside taper ring. This is semi automatic system where the loading of ring to the measurement station is manual and rest all procedure is automatic. The working cycle of this measurement system is divided into three stages these are such as: loading component or ring at measurement station – Measurement – Unloading of ring from measurement station and loading at 'OK' and 'NOT OK' station as per results.

The measurement station has specially designed plug for given ring specifications. This plug is provided with spring around its handle. Plug handle with spring is fitted in bore of circular table where the head of plug is free above the circular table is shown in 'fig 2'. Due to the spring plug can move in upward and downward direction. The measurement unit is cluster of three LVDT probes and three springs; 'fig 3' shows measurement unit. The springs are provided for the purpose of clamping the ring after placing it over the plug against the top surface of measurement table; refer 'fig 4'.

The LVDT probes are provided to measure the difference between plug position after clamping the ring and plug position after clamping master ring. Master ring is master of inside taper ring used for mastering or for referencing at a time of measurement. The measurement unit slides in upward – downward direction above the measurement unit with the help of LM guides and pneumatic cylinder.

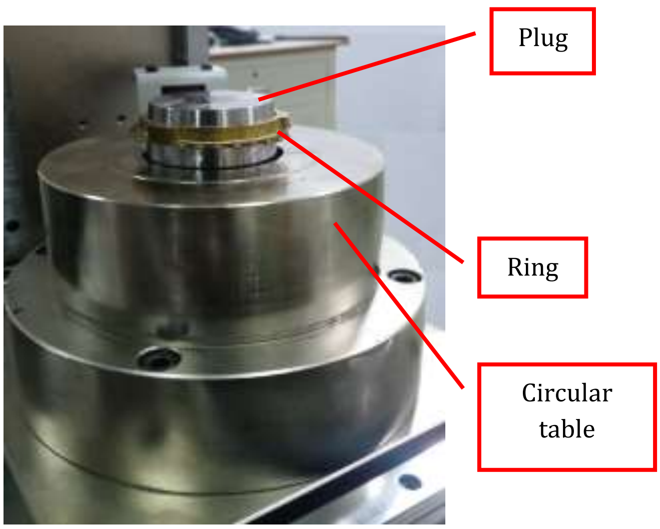

Fig 2: Measurement Table

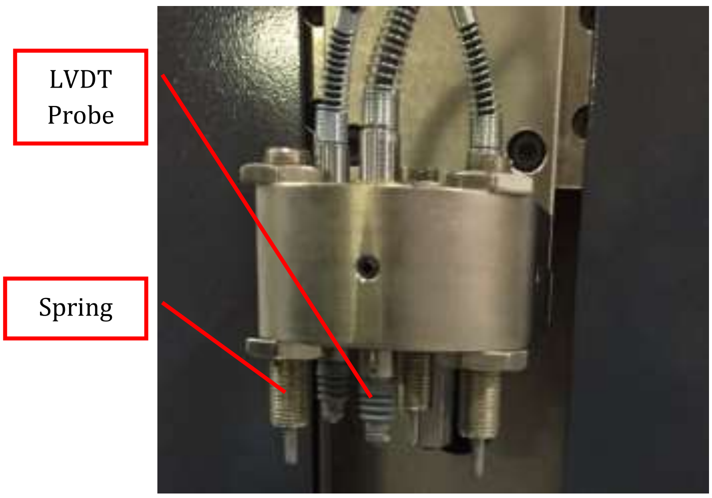

Fig 3: Measurement unit

- At the time of measurement first mastering operation is done. In mastering operation master ring is placed over the plug head then the measurement unit slides in downward direction and the spring starts presses the ring against the top surface of measurement table. The stopper is provided with the measurement unit when stopper touches the top surface of measurement table; sliding of measurement unit in downward direction stops. Due to the spring force exerted on ring, clamping operation done which provides accurate results; also it provides tight engagement of ring in plug which is important for calculation of gauge plane diameter of ring. At this time LVDT probes touches the top surface of plug and there are three probes hence the result is average of the readings of these three probes. The results obtained from mastering are reference results.
- After measurement cycle, component is placed over the plug and the obtained results are in the form of deflection from reference results.

3 VARIABILITY IN MEASUREMENT SYSTEM:

Measurement system is combination five main groups such as: people, material, instrument, environment, method and there are number of subgroups in these main groups; refer 'fig 5'.

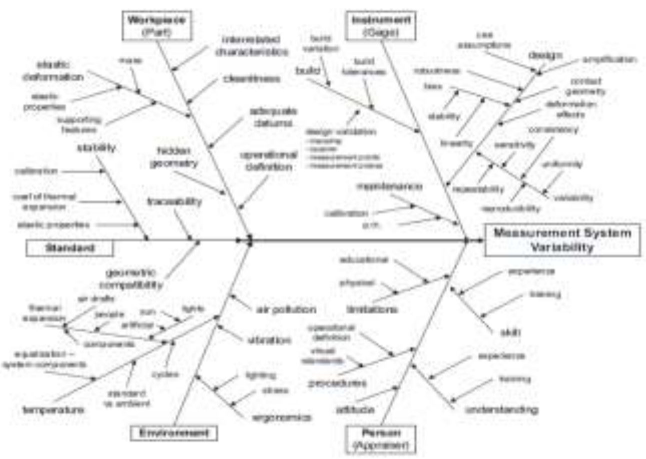

Fig 5: Fishbone Diagram of measurement system

Similar to all process, the measurement system is impact of both random and systematic sources of variation. These sources of variation are due to common and special causes. In order to control the measurement system variations [5]:

1. Identify the potential source of variation.
2. Eliminate or monitor these sources of variation.

4 MEASUREMENT SYSTEM ANALYSIS:

Measurement system analysis (MSA) is a study which quantifies the sources of variation that influence the measurement system [1]. MSA is also defined as an experimental and mathematical method of determining the how much the variation within measurement process contributes to overall process variability [2]. Although the principles are same, there are two main types of Measurement System Analysis (MAS). It depends on type of data being collected using the measurement system [3].

- Continuous data: this type of data comes from measurement on continuous scale eg., Temperature, time, distance, dimensions. **Gauge Repeatability & Reproducibility** (GRR) is measurement system analysis method used to analyse measurement system which collect continuous data [3].
- Attribute data: is based on how many units fall into discrete distinctions such as: pass – fail or percentage defective. **Attribute Agreement Analysis** is the measurement system analysis method used to analyse measurement system for attribute data [3].

In this case the internal gauge plane measurement system collects continuous data hence to analyse this system 'Gauge Repeatability & Reproducibility' method was used here.

4.1 Gauge Repeatability & Reproducibility:

Gauge repeatability and reproducibility is statistical tool use to analyse the variations in measurement system. A gage R&R study usually is performed using 2 to 3 appraisers and 5 to 10 parts. Each appraiser measures the parts multiple times. Two components are being examined: gage variation (repeatability) and appraiser variation (reproducibility).

Repeatability is the "within appraiser" variation. It measures the variation one appraiser has when measuring the same part (and the same characteristic) using the same gage more than one time. This variation is usually referred to as Equipment Variation (EV) in the gage R&R study. This is also called the "within system" variation.

Reproducibility is the "between appraisers" variation. It is the variation in the average of the measurements made by the different appraisers when measuring the same characteristic on the same part. This is also called the "between systems" variation.

The part was inside taper ring and its raw material is brass. According to drawing documentation the thickness of ring is 6mm, outer diameter of ring 56mm, inner diameter is 44.25mm and inside taper angle is 7˚ 15". Parts for measurement were collects randomly. It is important that chosen parts cover the full manufacturing tolerances before conducting GRR study [3]. Therefore during of collection of part for study; one part from each production shift was chosen. Total 10 parts were collected and numbered on its bottom surface from 1 to 10. There were total three operators selected to perform this activity who were familiar with the measurement process. As per the procedure first operator has measured all parts, then the second operator and at last the third operator. The measurements of each part were conducted by hiding the part number. It means that the operator did not know which part number there where measuring, but the person who recorded the results knows the part number this measured data noted down in excel spreadsheet. 'Table no.1' shows the overview of measure data.

Table No.1: Measurement data of internal gauge plane measurement system

APPRAISER	TRIALS	1	2	3	4	5	6	7	8	9	10
A	1	0.049	0.041	0.023	0.115	-0.010	-0.125	-0.040	-0.023	0.028	-0.007
	2	0.044	0.045	0.022	0.111	0.001	-0.118	-0.044	-0.021	0.036	-0.002
	3	0.055	0.035	0.031	0.112	-0.002	-0.120	-0.040	-0.026	0.036	-0.004
B	1	0.034	0.037	0.021	0.112	0.002	-0.114	-0.022	-0.017	0.005	-0.017
	2	0.047	0.026	0.034	0.111	-0.011	-0.110	-0.043	-0.015	0.036	0.008
	3	0.051	0.036	0.034	0.116	0.012	-0.113	-0.031	-0.019	0.021	0.003
C	1	0.066	0.046	0.023	0.116	0.008	-0.114	-0.037	-0.016	0.032	-0.009
	2	0.080	0.038	0.034	0.111	0.000	-0.114	-0.036	-0.008	0.035	-0.003
	3	0.079	0.041	0.038	0.122	0.007	-0.116	-0.023	-0.011	0.038	0.005

4.2 Average and Range Method:

The average and range method ($\overline{X}, \overline{R}$) is a method for measurement system evaluation of continues scale. The results of method have to be interpreted based on graphical and numerical results as it is highlighted by klaput [4]. After the statistical process stability is confirmed, the measurement system evaluation is continued by numerical step by step evaluation.

- First, the measurement repeatability EV calculated according to (1)

$$EV=K_1\overline{\overline{R}} \qquad (1)$$

Where,

$\overline{\overline{R}}$ =average variation range of all operators repeated measurements for all parts, $\overline{\overline{R}}$ estimated according to (2)

$$\overline{\overline{R}}=\frac{\overline{R}_A+\overline{R}_B+\overline{R}_C}{3} \qquad (2)$$

K_1= Constant; it depends upon the number of trials used in the gauge study and is equal to the inverse of d_2. where, d_2 is depends on the number of trials (m) and the number of parts (see appendix C in MSA, AIAG guideline) [5].

- Second step, Measurement reproducibility calculated according to (3)

$$AV=\sqrt{(\overline{X}_{DIFF}\ \times K_2)^2-\frac{(EV)^2}{nr}} \qquad (3)$$

Where,

$\overline{X}_{DIFF}$ = Maximum average appraiser difference.

K_2= Constant, depends on the no of appraisers used in the gauge study, and is inverse of d_2. d_2 is dependent upon on of appraisers (m), and g=1. (see appendix C in MSA, AIAG guideline) [5] .

n = Number of parts.

r = Number of trials.

- Next step, Gauge repeatability and reproducibility calculated according to formula (4)

$$GRR=\sqrt{EV^2+AV^2} \quad (4)$$

- The calculated GRR value does not have any ability. The measurement system suitability is possible to evaluate just after the comparison of repeatability and reproducibility with the total variability [6].

- Total variability calculated according to (5).

$$TV=\sqrt{GRR^2+PV^2} \quad (5)$$

Where,

PV= Part variation calculated according to (6).

$$PV= R_p \times K_3 \quad (6)$$

Where,

R_p= the variation range from the measurement of arithmetic mean of the individual repeats for the individual subgroups of the parts.

K_3= Constant, it depends upon the number of parts and is the inverse of d_2 d_2 is dependent on the number parts (m) and (g), in this case g=1 science there is only one range calculation

- The measurement system suitability indicator %GRR – gauge repeatability, %AV – reproducibility, %PV - product variability were calculated. The %GRR value calculated according to (7)

$$\%GRR=100\times \frac{GRR}{TV} \quad (7)$$

- %EV - %Equipment variation calculated according to (8); EV represents variation due to equipment or instrument.

$$\%EV=100\times \frac{EV}{TV} \quad (8)$$

- %AV - %Appraiser variation calculated according to (9); AV represents variation due to appraiser or operator.

$$\%AV=100\times \frac{AV}{TV} \quad (9)$$

- %PV - %Part variation calculated according to (10); PV represents variation due to parts or components.

$$\%PV=100\times \frac{PV}{TV} \quad (10)$$

Last step, number of district categories that is ndc parameter calculated according to (11). ndc calculation defines the number of distinct categories that can be distinguished by measurement system. This number indicates the number of categories into which the measurement process can be divided. This value should be greater than or equal to 5 [5]

$$ndc = 1.41\times \frac{PV}{GRR} \quad (11)$$

Trials / Samples	Part										Average
	1	2	3	4	5	6	7	8	9	10	
A 1	0.049	0.041	0.023	0.115	-0.010	-0.125	-0.040	-0.023	0.028	-0.007	0.005
2	0.044	0.045	0.022	0.111	0.001	-0.118	-0.044	-0.021	0.036	-0.002	0.007
3	0.055	0.035	0.031	0.112	-0.002	-0.120	-0.040	-0.026	0.036	-0.004	0.008
Average	0.049	0.040	0.025	0.113	-0.004	-0.121	-0.041	-0.023	0.033	-0.004	$\bar{X}_A$=0.007
Range	0.011	0.010	0.009	0.004	0.011	0.007	0.004	0.005	0.008	0.005	$\bar{R}_A$=0.007
B 1	0.034	0.037	0.021	0.112	0.002	-0.114	-0.022	-0.017	0.005	0.034	0.004
2	0.047	0.026	0.034	0.111	-0.011	-0.110	-0.043	-0.015	0.036	0.047	0.008
3	0.051	0.036	0.034	0.116	0.012	-0.113	-0.031	-0.019	0.021	0.051	0.011
Average	0.044	0.033	0.030	0.113	0.001	-0.112	-0.032	-0.017	0.021	-0.002	$\bar{X}_B$=0.008
Range	0.017	0.011	0.013	0.005	0.023	0.004	0.021	0.004	0.031	0.025	$\bar{R}_B$=0.015
C 1	0.066	0.046	0.023	0.116	0.008	-0.114	-0.037	-0.016	0.032	-0.009	0.012
2	0.080	0.038	0.034	0.111	0.000	-0.114	-0.036	-0.008	0.035	-0.003	0.014
3	0.079	0.041	0.038	0.122	0.007	-0.116	-0.023	-0.011	0.038	0.005	0.018
Average	0.075	0.042	0.032	0.116	0.005	-0.115	-0.032	-0.012	0.035	-0.002	$\bar{X}_C$=0.014
Range	0.014	0.008	0.015	0.011	0.008	0.002	0.014	0.008	0.006	0.014	$\bar{R}_C$=0.010
Part Range	0.056	0.038	0.029	0.114	0.001	-0.116	-0.035	-0.017	0.030	-0.003	R_p=0.230
$(\bar{X}_A+\bar{X}_B+\bar{X}_C)$/No of Appriaser											$\bar{\bar{X}}$=0.010
$(\bar{R}_A+\bar{R}_B+\bar{R}_C)$/No of Appriaser											$\bar{\bar{R}}$=0.011
Max$\bar{X}$ – Min$\bar{X}$											$\bar{X}_{DIFF}$=0.008

Table 3: GRR calculations for internal gauge plane measurement system

Measurement System Analysis	% Variation
Repeatability–Equipment Variation (EV) EV=$K_1 \times \bar{\bar{R}}$ =3.545 ×0.011 =0.039	$\%EV = 100\times \frac{EV}{TV}$ $= 100\times \frac{0.039}{0.436}$ = 8.94%
Reproducibility – Appraiser Variation (AV)	$\%AV = 100\times \frac{AV}{TV}$

$AV=\sqrt{(\bar{X}_{DIFF} \times K_2)^2 - \frac{(EV)^2}{nr}}$ $=\sqrt{(0.008 \times 1.6974)^2 - \frac{(0.039)^2}{10 \times 3}}$ = 0.023	$= 100\times \frac{0.023}{0.436}$ = 5.269%
Gauge Repeatability & Reproducibility (GRR) $GRR=\sqrt{EV^2 + AV^2}$ $=\sqrt{0.039^2 + 0.023^2}$ = 0.045	$\%GRR = 100\times \frac{GRR}{TV}$ $= 100\times \frac{0.045}{0.436}$ = 10.32%
Part Variation (PV) $PV=R_p \times K_3$ $=0.23 \times 1.887$ =0.434	$\%PV = 100\times \frac{PV}{TV}$ $= 100\times \frac{0.434}{0.436}$ = 99.54%
Total Variation (TV) $TV=\sqrt{GRR^2 + PV^2}$ $=\sqrt{0.045^2 + 0.434^2}$ = 0.436	Number of Distinct Categories (ndc) $ndc = 1.41\times \frac{PV}{GRR}$ $= 1.41\times \frac{0.434}{0.045}$ = 13.59

In average and range method final step is making a decision whether the measurement system is acceptable or not acceptable or conditionally acceptable based on the decision making matrix [4]. First criterion is based on %GRR, refer table no 4 and the second criterion is based on ndc parameter, refer table 5.

Table 4: GRR criteria for Acceptance of Measurement System [5]

GRR	Decision
GRR ≤ 10%	Considered to be acceptable measurement system. This measurement system provides reliable and accurate measurements.
10% < GRR <30%	May be acceptable for some applications. This measurement system acceptable with some conditions hence it also called as conditionally acceptable.
GRR >30%	This measurement system considered to be not acceptable. This system does not provide reliable measurements or information about process change.

Table 5: ndc criteria for Acceptance of Measurement System [6]

ndc ≥ 5	Measurement system accepted. This measurement system provides reliable information about change in process.

5 CONCLUSION:

In this paper study of internal gauge plane measurement system were done. Validation of gauge plane measurement system was done by Average and Range method of GRR. %GRR of the system was 10.32% according to table no 3. Hence according to the GRR criterion for acceptance of measurement system according to table no 4; the measurement system provides reliable and accurate results and hence it was accepted. It is useful for sorting and classification of parts or when tighten process control is required [5]. Calculated ndc was 13.59 hence according to table no 5 which indicates ndc criteria for measurement system acceptance measurement system was accepted. This study validates the internal gauge plane measurement system.

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