International Journal for Quality research
UDK- 378.014.3(497.11)
Original Scientific Paper (1.01)

GAUGE R&R FOR AN OPTICAL MICROMETER INDUSTRIAL TYPE MACHINE

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Abstract: *The measurement of the uncertainty of a metric system, as 'Gauge R&R' and the collation of results between the Xbar & R and the ANOVA method, are extended in this essay. In an academic school laboratory we accomplished a sequence of measurements with the use of an Optical Micrometer Industrial Type Machine (MUL 300).*
This paper analyzes the measurement system that used in the laboratory and checks the reasons of the variability's provocation that observed in the machine, between the theoretical calculations and measurements. In order to find out this problem, we will use the 'Gage Repeatability and Reproducibility' technique of Measurement System Analysis (M.S.A.). This technique uses analysis of variance.
In addition, will use Minitab program in order to find out the factors that we have in the whole experiment as enlarge the problem of measurements. In this paper, a statistical method using the correlation between Gage R&R and process capability indices is proposed for evaluating the adequacy of the acceptance criteria of P/T ratio.
Finally, a comparative analysis has also been performed for evaluating the accuracy of Gage R&R between two methods (ANOVA and R- Xbar method). Hopefully, the results of this research can provide a useful reference for quality practitioners in various industries.
Keywords: *Gauge repeatability and reproducibility, criteria of (P/T) ratio, classical Gage R&R method, Analysis of Variance (ANOVA), Measurement System Analysis (MSA)*

1. INTRODUCTION

Aiming at shortening the production time cycle in today's manufacturing environment, researchers continuously investigate the areas where the production can be accelerated. Continuous improvement of manufacturing process can effectively be achieved by the systematic approach with the appropriate application of different methods and tools [7]. Works have been focused on optimizing and automating the quality of production that are manipulated by the use of quality programs, such as Statistical Process Control (SPC) and Six Sigma. Manufacturers and suppliers use quality measures calculated from dimensional data to make informed decisions regarding measurement systems and product quality. When a good measurement system is in place, the measurements of quality characteristics are precise, and therefore characteristic may be controlled and the variation may be reduced.[10]

The main thrust of the project is to review methods for conducting and analyzing measurement systems capability studies, focusing on the analysis of variance approach. A successful gauge capability study is one that provides reliable estimates of the components of variation in the measurement process and identifies the factors that are most influential. This one, and with the combination of the potential effectiveness of the gauge as a measurement tool, means that the design of a well-described experiment is important for the investigation of the precision of the measurement system at the domain of industry. The variability is often divided into two components: the first caused by observers (or operators) and the other by the measurement device (the 'gauge') itself. Since these components are called '*Reproducibility*' and '*Repeatability*', respectively the experiment is also known as an *R & R* study.[10] The study should also provide and demonstrate information about statistical design and statistical computations, including the number of parts to be used in the study, the number of measurements per part, how the parts are selected, and ensuring that the true replicates are actually obtained as opposed to repeat measurements by several different operators.

What is more, the work tries to link the results between the two factors of Reproducibility and Repeatability for measurements to assure coherence with the different outputs that a quality program generates. Firstly, the report illustrates briefly the research methods, the strategies, the application tools and the sources from where the basic principles will be adopted so as to develop the project.

To fulfill the aim of the project and meet the expected requirements, programming sequences are developed by using Statistical Process Control (SPC) and MINITAB software[21]. An alternative measure for the gauge R & R is proposed for this study, and it is shown that this may improve the perception of the quality of the measurement system markedly, especially with only a few observers.

2. LITERATURE REVIEW

The literature review part of the thesis contains topics concerning Statistical Process Control (SPC), ongoing evolution and categories, state-of-the-art Statistical Methods approaches, definitions (Accuracy, Quality Control, Reliability, Reproducibility, etc.) / operations-calibration of the machine device for the experiment / measurement conditions, feature priorities / precedence constraints and basic principles of gage R&R all inspired from the domain of manufacturing industry.

The functions of the complex experiment are about to be presented in the same sequence as a standard number of observers examines an optical micrometer of industrial type. In the following sections will be reviewed the standard gage R&R experiment, will be provided an extended number of measurements in tables, and cite additional references for more complex design. Furthermore, some aspects of measurements systems, such as calibration and assessing linearity, are beyond the scope of the project.

Testing laboratories shall have and shall apple procedures for estimating of measurement. In certain cases the nature of the test method may preclude rigorous, metrologically and satistically valid, calculation of the repeatability and reproducibility of measurements. [8]

3. RESEARCH METHODOLOGY

The following figures present an optic accurate micrometer to be studied of *0,01 μm* or *0,0001mm* (MUL 300, SWITCZHERLAND), see Figure 1. Five operators participate to the machine calibration. While pieces to be measured are shown in Figures 2 ,3 & 4.

Fig.1 Industrial Optic Accuracy Micrometer 0,01 μm

Fig.2 Exterior diameter measuremen of the above piece to be studied.

Fig.3 Prototype controller (on the left & controlled) to be examined (on the right) for internal diameter.

Fig.4 Axis for the external diameters measurement for mechanical equipment.

For this study purposes we will follow the following stages:

a) Metrological qualities (length reading, eye-piece scale control, scale adjustment)
b) Conformity study (We will use gages blocks in the order to 10mm zero quality's (0).
c) Sensitivity identification
d) Study of Correctness
e) Calibration Curve, corrections to 0,1 μm
f) Specify the Accuracy
g) Measurement of pieces with parallel sides
h) Measurement results that will include the following for each operator separately: the observation values on a table per measurement, the mean value of the above, the correction of the calibration, the corrected value, the maximum possible error and values width of the actual value.
i) Study of the temperature effect that will include a table per operator with the observed initial value and the observed value after heating of the piece. These values difference will give us results required for the permissible temperature shift for a plate of 10mm.

j) Measurement of external diameter of a round piece (Fig. 2)
k) Measurement of the ellipsoid of the axis (Fig. 4)
l) Measurement of the internal diameter (Fig. 3)
m) Statistical control of measurements – Measurement analysis for all 5 operators, that is:

1. We will make χ measurement for the pieces to be studied with great care. Continuously, we will draw up a separate measurements table for each observer and will take mean measurements value for value Xï from the observers measurements.

In conclusion, it is worth underscoring that the objective proposed in this study to enhance the quality of EEIs by identifying the student needs was appropriately met.

PART / 1ST OPERATOR	**1**	**2**	**3**	**MEAN**
1st Measure				
2nd Measure				
3rd Measure				
4th Measure				
(AVG) $\bar{x}_p$				$\bar{x}_i =$
(RNG) $\bar{R}$				$\bar{R}_i =$

2. After the four first measurements have been made for all five operators, then we change codification for the same pieces and all five operators repeat measurements for the same pieces.

3. Then we will calculate mean value $\bar{x}_p$ from all five operators for each piece separately, as well as mean width value $\bar{R}_p$ from five operators for each piece.

	1	**2**	**3**	**4**
(AVG) $\bar{x}_p$				
(RNG) $\bar{R}$				

4. Then we calculate formula:

$$\frac{\bar{x}_{i(\max)} - \bar{X}_{i(\min)}}{2}$$ [9,11]

5. From mean value $\bar{x}_i$ for each operator, we will calculate $\bar{X}_{DIFF} = \bar{X}_{ii(\max)} - \bar{x}_{i(\min)}$

6. From mean value $\bar{R}_i$ for each operator, we will calculate $\bar{\bar{R}} = \bar{R}_{i(\max)} - \bar{R}_{i(\min)}$

7. Repeatability – Equipment Variation (EV) : EV = $\bar{R}$ x Kf , where constant Kf is obtained by tables depending on the repetitions number for each piece.

REPETITIONS	**K*F***
2	4,56
3	3,05

8. Reproducibility-Appraiser Variation (AV)

$$AV = \sqrt{\left[\left(\bar{x}_{DIFF} \times k_z\right)^2 - \left(\frac{EV^2}{n \times r}\right)\right]}$$

Where, n : number of pieces
r : number of repetitions [9,11]

OPERATORS	**2**	**3**
Kz	3,65	2,70

10. We calculate the total measurement of system's instability (Repeatability & Reproducibility (R & R) based on the formulae:

$$R \& R = \sqrt{\left(EV^2 + AV^2\right)}$$ [9,11]

11. We then calculate dissemination (Part Variation (PV) :

PV = Rp x K3 [9,11]

Where K3 we obtain by table with respect to Measurement System Analysis.

NUMBER OF PIECES	**K3**
2	3,65
3	2,70
4	2,80
5	2,08
6	1,93
7	1,82
8	1,74
9	1,67
10	1,62

12. We calculate the total dissemination of the measurements (Total Variation (TV) :

$$TV = \sqrt{\left(R \& R\right)^2 + PV^2}$$ [9,11]

13. In the last step we calculate percentage % *R&R* from formula:

$$\%R\&R = \left(\frac{R\,\&\,R}{TV}\right)\cdot\% \quad [9,11]$$

n) Conclusions – Results

4. THE MEASUREMENT SYSTEM ANALYSIS (M.S.A.)

Determining the capability of a measurement system is an important aspect of most process and quality improvement efforts. Indeed, in any activity involving measurements, some of the observed variability will arise from the units that are measured and some variability will be due to the measuring instrument or gauge.

The purposes of most measurement systems capability studies are to:

i. determine how much of the total observed variability is due to the gauge;

ii. isolate the sources of variability in the system; and

iii. assess whether the gauge is capable (that is, determine if it is suitable for use in the broader project or application).

In many measurement systems capability studies, the gauge is used to obtain replicate measurements on units by several different operators, for different set-ups, or for different time periods. In these types of studies, two components of measurement systems variability are frequently generated: repeatability and reproducibility.

Repeatability represents the variability from the gauge or measurement instrument when it is used to measure the same unit (with the same operator or set-up or in the same time period).

Reproducibility reflects the variability arising from different operators, set-ups, or time periods. These studies are often referred to as gauge repeatability and reproducibility (GR&R) studies.

Two methods commonly used in the analysis of a Gauge R&R study are:

1) Xbar & R method,an analysis of variance approach followed by estimation of the appropriate variance components; and
2) ANOVA method that relies on the range method to estimate the standard deviations of the components of gauge variability.

We focus on the analysis of variance approach because the method is easy and widely available to practitioners, it can be adapted to deal with very complex experiments, and it admits confidence interval estimates of the important components of gauge variability. Furthermore, the properties of these confidence intervals are reasonably well understood.[4]

In this phase we will use the Measurement System Analysis in order to check the reasons that cause the differences between the theoretical calculations and the measurements. It is because of the measurement organs that we use in the laboratory or because of the different operators that use it.

5. DESIGNING A GAUGE R&R EXPERIMENT

A successful gauge capability study is one that provides reliable estimates of the components of variation in the measurement process and identifies the factors that are most influential. The study should also provide information about the potential effectiveness of the gauge as a measurement tool. Consequently, the design of the experiment is very important. Poor statistical design of the experiment can lead to a situation where the true variation in the measurement process is underestimated, and these results in an overly optimistic conclusion regarding gauge capability. Some important statistical design issues include the number of parts to be used in the study, the number of measurements per part, how the parts are selected, and ensuring that true replicates are actually obtained as opposed to repeat measurements [4].

A good general practice is to use many parts in the experiment with relatively few measurements each, as opposed to few parts with many measurements per part. There are several reasons for this recommendation. First, parts are typically selected from actual production and are representative of the material that the measurement system will encounter during routine operation. The gauge may exhibit less variability on a production unit that is near the centre of the manufacturing specifications than on product at the extremes of this specification. An extreme example of this is non-linearity of the gauge, which results in unstable or unreliable results beyond a certain operating region. Using a relatively large number of parts in the study increases the likelihood of detecting this problem. If we want to use “golden” or “standard” parts in a measurement systems capability study as opposed to production parts we must be very careful because that means that standard units may not share important product responses with the typical production units, and they might produce unexpected measurement errors. Alternatively, standard units typically exhibit less variability than production units with respect to key quality responses [4].Secondly, it is not unusual to find that the variance of the measurements is not constant, and often depends on the mean level of the product characteristic. This is unlikely to be detected if only a narrow range of good production parts or standard parts are used in the study. Sometimes visual inspection of the data can reveal this problem, but a better approach is to carefully analyze the residuals from a gauge capability experiment, using the same residual plots typically employed in any designed experiment. In particular, the plots of residuals versus the predicted response, residuals versus parts, residuals versus operators, and residuals versus time order all convey very specific diagnostic information. For example, an outward-opening funnel pattern on the plot of residuals versus time order suggests that variability in the measurement process is increasing with time, perhaps due to operator fatigue, an instrument that does not hold calibration or environmental factors such as temperature that may change over time and affect the performance of the gauge [4].Finally, when many measurements are to be made on the same part, our experience has been that operating personnel are less likely to perform complete replications of the measurement process or to completely randomize the order of the trials. Sometimes all measurements on a part will be taken successively without any change in measurement system setup. Some analysts refer to the repeatability component obtained in this manner as “static repeatability” while if complete replicates are performed the repeatability component is called “dynamic repeatability.” We feel that it is important to use complete replicates and to conduct the trials in random order. Without complete replicates and randomization, we omit important sources of variability due to such factors as fixturing and positioning of the part, measurement tool alignment, batches of reagent in a chemical assay, or sources of variability that are associated with time.

Consequently, the “static” estimate of the repeatability component of measurement variability is overly optimistic. Using a relatively large number of parts and making few measurements on each part encourages true or complete replication as opposed to simply making repeat measurements [4].The number of parts and the number of operators to choose is an important consideration. A useful approach to these decisions is to consider the length of the confidence interval estimates of the relevant parameters that will result. A two-factor random design with only five operators provides very wide intervals. Unfortunately, there are no closed-form solutions for sample sizes that will tell us how many parts and how many operators to use to produce confidence intervals of a specified length at a stated confidence. However, a trial-and-error approach using preliminary estimates of the quantities in these equations and simulated data can be used to obtain reasonably good estimates of the required sample sizes [4].

6. THE EXPERIMENT FOR THE GAUGE R&R

<u>PART A</u>: *The Experiment*

A study was conducted to investigate the precision of measuring the length of three parallel plates, the internal diameter of three controllers and the external diameter of three constructed axis using a certain optical micrometer industrial type machine with the accuracy at the range of 0,001μm or 0,0001mm. Five operators were randomly selected for the study.

Three constructed parts for each piece are randomly selected. Each operator measured each piece four times. So, the same characteristic will be measured four times with the same measurement organ from the same operator. The results of our measurements are listed in tables. The data is presented in the following section

I. Measurement of pieces with parallel sides

We used the quality 0,0 of the Block-gauges.
(See Figure 5).

Fig. 5 Block Gauges qualities 0,0.

We choose the gauge block type 10 nominal dimension.(See figure 6).

Fig.6 The Gauge block type 10 nominal dimension.

Then each operator adjust the force for each experiment. (See Figure 7).

Fig. 7 The adjustment of the force.

Then the operators made the adjustment of the measuring instrument of zero to the 10 nominal dimensions. (See Figure 8 & 9).

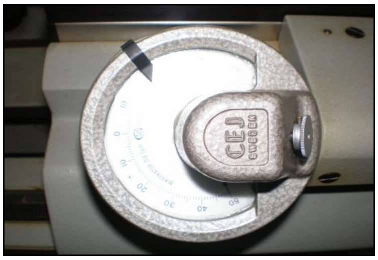

Fig.8 *The adjustment of the force of the measuring instrument.*

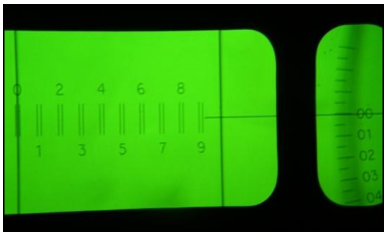

Fig. 9 *The zero adjustment (the calibration) of the measuring instrument, view from the optical micrometer eyepiece.*

Finally we re-adjusted the force and dismissed the air between the fixed and the movable contactor. (calibration).

II. External diameter of the cylinder

The five operators must control the perpendicular (vertical) of the standard plate gauge. (See Figure 10).

Fig.10 The vertical control of the plate gauge.

The operators to achieve the perpendicular must taken the less indication in the unit of μm, the unit which have also the diameter. (See Figure 11)

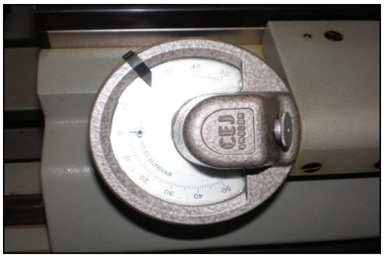

Fig.11 The indicator for perpendicular of piece.

1. Diameter measurement

Fig.12 Axis measurement.

2. Internal diameter

The operators measured the internal diameter. Firstly, they calibrate the machine with an internal limit gauge 40mm, 20ºC (See Figure 13).

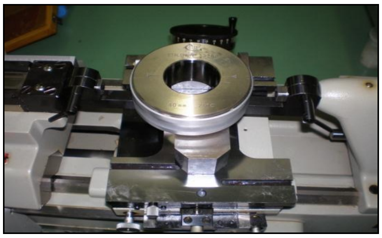

Fig.13 The adjustment of the internal limit gauge.

Then operators adjusted the counter force for the internal diameter measurement.(See Figure 14).

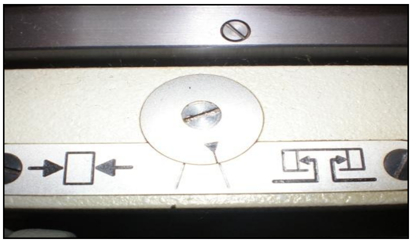

Fig.14 The adjustment of the counter force of the machine.

In continuity, the operators rotated left and right the table (test desk) and received the index which had the greater diameter than all the other values. (See Figure 15).

Fig.15 The indicator for the comparison of diameters

The next tribune for the operators was to adjusted the position of the measurement piece in according to the x, y and z axis. (See Figure 19 in page 11).

Then the operators measured the internal diameter of a construction piece (See Figure 16).

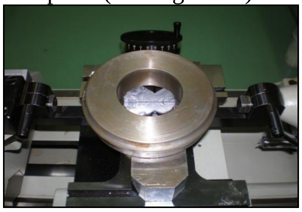

Fig.16 The piece for the internal diameter measurement.

In order to probe which of the factors is playing role to our experiment, except the operators, the measurements and the machine, we will, also , examine the factor of the temperature in the laboratory. So, the five operators will measure one piece, concretely one of the parallel plate, two times each of them in two different temperatures.

These raise in the temperatures of 21,6ºC and 22,7 ºC in our laboratory. The measurements of those responses will become with the same optical micrometer machine, in order to discover the quality and the accuracy of them.

↓	C1	C2	C3
	Part	Operator	Measurement
1	1	1	10,0000
2	1	1	10,0004
3	1	1	10,0003
4	1	1	10,0002
5	1	2	10,0000
6	1	2	10,0004
7	1	2	10,0003
8	1	2	10,0003
9	1	3	10,0000
10	1	3	10,0004
11	1	3	10,0006
12	1	3	10,0005
13	1	4	10,0000
14	1	4	10,0004
15	1	4	10,0004
16	1	4	10,0008
17	1	5	10,0000
18	1	5	10,0002
19	1	5	10,0006
20	1	5	10,0005
21	2	1	10,0001
22	2	1	10,0003
23	2	1	10,0004
24	2	1	10,0003
25	3	1	10,0000
26	3	1	10,0004
27	3	1	10,0001
28	3	1	10,0002
29	2	2	10,0003
30	2	2	10,0005
31	2	2	10,0002
32	2	2	10,0001
33	3	2	10,0000
34	3	2	10,0004
35	3	2	10,0003
36	3	2	10,0001
37	2	3	10,0001
38	2	3	10,0003
39	2	3	10,0004
40	2	3	10,0005
41	3	3	10,0004
42	3	3	10,0001
43	3	3	10,0002
44	3	3	10,0000
45	2	4	10,0001
46	2	4	10,0001
47	2	4	10,0000
48	2	4	10,0002
49	3	4	10,0003
50	3	4	10,0004
51	3	4	10,0005
52	3	4	10,0001
53	2	5	10,0003
54	2	5	10,0003
55	2	5	10,0000
56	2	5	10,0002
57	3	5	10,0003
58	3	5	10,0001
59	3	5	10,0001
60	3	5	10,0004

Table I Parallel Plate Measurement in Minitab Programme

So, we will check which of those factors influences more the reliability and the reproducibility of this system we examine and we will presented all the results of the experiment with the use of Graphs and Reports of a statistic program for the domain of Quality, such as Minitab.[21]

In the table that follows (Table I) we have the measurements that made the five operators for the first 10 parallel plates with four measurement for each part every operator, with the use of Minitab programme.[21] In the following table (Table II) we presented the measurement of a parallel plate with different temperature in the laboratory. Each operator measure two times the same part with the same temperature.

↓	C1	C2	C3	C4
	Operator	Temperature	Measurement	RESI1
1	1	21,6	10,0008	0,0000500
2	1	21,6	10,0007	-0,0000500
3	1	22,7	10,0002	-0,0000500
4	1	22,7	10,0003	0,0000500
5	2	21,6	10,0002	-0,0002000
6	2	21,6	10,0006	0,0002000
7	2	22,7	10,0005	0,0000500
8	2	22,7	10,0004	-0,0000500
9	3	21,6	10,0009	0,0000000
10	3	21,6	10,0009	0,0000000
11	3	22,7	10,0003	0,0001000
12	3	22,7	10,0001	-0,0001000
13	4	21,6	10,0004	-0,0001000
14	4	21,6	10,0006	0,0001000
15	4	22,7	10,0001	-0,0001000
16	4	22,7	10,0003	0,0001000
17	5	21,6	10,0005	-0,0001500
18	5	21,6	10,0008	0,0001500
19	5	22,7	10,0002	-0,0002000
20	5	22,7	10,0006	0,0002000
21				

Table II.Temperature Measurement for a parallel plate in Minitab Programme

Each of the five operators made four different measurements of the internal diameter of the 3 constructed controllers, with the same measurement organ. So, we have the tables for each of the five operators with the use of the Minitab programme.[21]

Table II Internal Diameter Measurements in Minitab Programme

↓	C1	C2	C3	↓	C1	C2	C3
	Part	Operator	Measurement		Part	Operator	Measurement
1	1	1	48,8040	29	2	3	48,8066
2	1	1	48,8062	30	2	3	48,7417
3	1	1	48,8044	31	2	3	48,8056
4	1	1	48,8044	32	2	3	48,8062
5	1	2	48,8049	33	2	4	48,8069
6	1	2	48,7421	34	2	4	48,8057
7	1	2	48,7408	35	2	4	48,8059
8	1	2	48,8049	36	2	4	48,8065
9	1	3	48,7420	37	2	5	48,8061
10	1	3	48,7410	38	2	5	48,8065
11	1	3	48,8062	39	2	5	48,8065
12	1	3	48,8054	40	2	5	48,8058
13	1	4	48,8055	41	3	1	48,8040
14	1	4	48,8054	42	3	1	48,8062
15	1	4	48,8067	43	3	1	48,8044
16	1	4	48,8055	44	3	1	48,8044
17	1	5	48,8058	45	3	2	48,8049
18	1	5	48,8059	46	3	2	48,7421
19	1	5	48,8053	47	3	2	48,7408
20	1	5	48,8065	48	3	2	48,8049
21	2	1	48,8049	49	3	3	48,7420
22	2	1	48,8053	50	3	3	48,7410
23	2	1	48,8043	51	3	3	48,8062
24	2	1	48,8051	52	3	3	48,8054
25	2	2	48,7414	53	3	4	48,8055
26	2	2	48,8047	54	3	4	48,8054
27	2	2	48,7407	55	3	4	48,8067
28	2	2	48,8055	56	3	4	48,8055

Below, we can see the measurements of the external diameter of the 3 constructed axis that made the five operators with four measurement for each part every operator with the use of Minitab programme.[21]

Table III External Diameter Measurements in Minitab Programme

↓	C1 Part	C2 Measurement	C3 Operator
1	1	25,9954	1
2	1	25,9952	1
3	1	25,9956	1
4	1	25,9958	1
5	1	25,9953	2
6	1	25,9955	2
7	1	25,9957	2
8	1	25,9955	2
9	1	25,9956	3
10	1	25,9956	3
11	1	25,9949	3
12	1	25,9995	3
13	1	25,9945	4
14	1	25,9950	4
15	1	25,9962	4
16	1	25,9948	4
17	1	25,9940	5
18	1	25,9948	5
19	1	25,9941	5
20	1	25,9950	5
21	2	25,9942	1
22	2	25,9948	1
23	2	25,9941	1
24	2	25,9958	1
25	2	25,9944	2
26	2	25,9949	2
27	2	25,9959	2
28	2	25,9955	2
29	2	25,9947	3
30	2	25,9942	3
31	2	25,9999	3
32	2	25,9953	3
33	2	25,9941	4
34	2	25,9953	4
35	2	25,9946	4
36	2	25,9944	4
37	2	25,9949	5
38	2	25,9943	5
39	2	25,9954	5
40	2	25,9961	5
41	3	25,9941	1
42	3	25,9952	1
43	3	25,9946	1
44	3	25,9943	1
45	3	25,9959	2
46	3	25,9952	2
47	3	25,9947	2
48	3	25,9950	2
49	3	25,9944	3
50	3	25,9954	3
51	3	25,9961	3
52	3	25,9949	3
53	3	25,9941	4
54	3	25,9948	4
55	3	25,9953	4
56	3	25,9946	4

In the chapter 'Conclusions', we will give all the results and the conclusions that occurred from the measurements that we made for the MSA method and concern the measurement system of the laboratory.

PART B: *The Theory of the Experiment*

1. *MEASUREMENT DEVICE*

I. Scope of experiment

- Study of a device permitting length measurements in great accuracy.
- Study of metrological qualities of the device
- Study of some special measuring techniques.

II. Technological study of the device

1. Principles

- The item to be measured is placed between a firm and a load-supported mobile tip aided by a bolt system.

A millimetric scale connected to the load is dislocated towards a microscope equipped with a micrometric eyepiece permitting measurements 1/10 of micro.

2. Device description

- Careful reading of the manufacturer's instructions and identification of various components of the device.
- Please particularly note:
  - Arrangement of the original value and the role of microscope
  - The system posing a stable pressure on the measured to be item
  - Micrometric measurements system
  - Study the location of the system between the points and the "UNIVERSAL" bank.

3. Recommendations

- The device should be considered as a valuable item worth to receive gentle care and ought to be treated very carefully.
- Load dislodgement has to be done slowly to avoid impacts.
- Placement of the system between the points and the "UNIVERSAL" bank on the sliders has to be performed with great caution. A minimum impact would deform the sliders and cause great damage to the device's quality.
- Always use the items to be measured, especially prototype plates, in clean hands without touching, if possible, those surfaces where the measurements are going to be made.

2. *METROLOGICAL QUALITIES*

2.1. Length reading

We put on the load allowing a distance of a few centimeters between the edges. We read the indication

in centimeters on the external scale of the load. Using the rotary button at the right of the eyepiece we put the double notch located nearer at both sides' millimetric notches.We send decimal millimeter digit up or down from the double incision and then the next two digits/centimeter and millimeter of mm on the cyclic vernier and with an interference 1/10 of micro. Retain the load at this location and perform 10 consecutive adjustments. We compare the 10 readings.
Conclusions are concerning certainty measurements.

2.2. Control of the eyepiece's scale

As previously, we allow a distance of some centimeters between the edges. Using the button at the right of the eyepiece we put vernier indication at 00. Again using the same button for the slow shift of the load we put a milimetric incision between 2 verticals of a class indication or decimals.

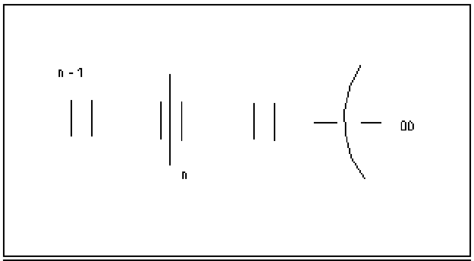

Fig.17 The scale of the eyepiece of the optical-micrometer designed by a mechanical program Autocad Mechanical 2006[22]

We turn the button at the right of the eyepiece to shift the micrometric scale and to put n-1 indication on the millimetric incision.

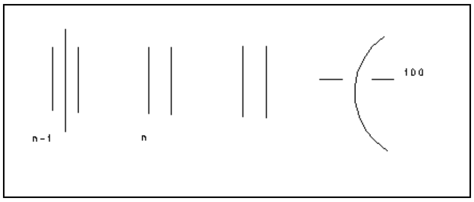

Fig.18 The scale of the eyepiece of the optical-micrometer designed by a mechanical program Autocad Mechanical 2006[22]

Having immobilized the load we restart aforementioned procedures and note all possible deviations and 10 consecutive operations. Mean deviation should not exceed some 1/10 of micro.

2.3. Scale adjustment

Due to the ample surface of the contacts at the device's edges, it is not possible to adjust on zero with precision at 1/10 of micro. In fact, linkage of both contacts cannot be perfect due to inability in the removal of the thin layer of air that is not a negligible one. In contrast, precise measurement is fisible when using a prototype tile placed between the two contacts after a good cleaning of both contacts and tiles. We use a tile of 10mm.

Lightly moving the tile placed between contacts we could remove air layer till perfect contact of surfaces is achieved. At this point reading could be 10.000 mm. If the reading is different we put vernier on 0,00 using the button at the right of the eyepiece and then using the button at the left (having raised the lid) we put the two incisions

 on each side of the millimetric scale.

Device is then ready for measurements.
It is recommended to check the adjustment during its usage.

2.4. Conformity study

We use a tile width of 10mm, we carefully place it between the contacts and check for conformity. We wait for a few minutes to have heat balance restored. Conformity faults originate mainly from the usage of the micrometric eyepiece. Without touching the tile any more we are going to slightly move, before each measurement, the right button in order not to have it affected by the previous location of the vernier. Each user will perform that measurement for a 10-fold period and will study measurements disperse.

2.5. Sensitivity

Sensitivity will be defined by ratio:

$$\sigma = \frac{\text{Increase of the noted variable}}{\text{Corresponding increase to the size measured}}$$

It is content to calculate indication length (indication's variation length) corresponding to the measurement of 1 micro.

We estimate the approximate vernier's variable phenomenal length corresponding to 1 micro.
Sensitivity that we here can name transmission or magnification ratio is

$$\boxed{\sigma = \frac{\eta \cdot 1000\mu m}{1\mu m} = 1000 \cdot \eta}$$

where mm corresponds to the phenomenal length of variation tally to 1 μm.

2.6. Correctness, Verification curve

A device having been verified by the manufacturer providing a table of the corrections made. Interestingly, we can design the verification curve 1 to 20 mm, recording lengths on x axis and corrections on y axis (1/10 of micro). These correction values should be added algebraically to the measurements results.

2.7. Accuracy

Accuracy is the total quality of the device we can conclude to after that study of metrological quality.
What is the total error?
We can ascertain that a measurement can be made with 0.1μm to 0.2μm.
IV. Items measurements with parallel surfaces
1. Scale adjustment with the use of a 10mm tile.

3. INNER DIAMETER

Measurement of inner diameter is made with the use of the bank used as a support of both the item to be measured and a couple of contacts we fix on the device's edges.

3.1. The bank

The bank is cautiously placed on the sliders having previously been dislocated at a sufficient distance from the fixed edge.

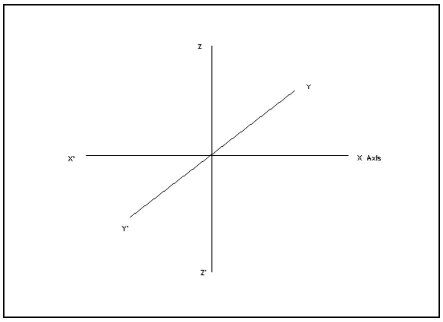

Fig.19 The axis of the Orthogonal-Cartesian System designed by a mechanical program Autocad Mechanical 2006 [22]

- The graduated wheel located behind the bank permits a vertical dislocation (along ZZ´ axis).
- The button located in front of the bank dilocates per yy´ axis
- The button located on the left of the bank allows rotation per yy´ axis
- The button located in front on the right of the bank allows rotation per ZZ´ axis

Generally, on the bank we put metallic blocks with shims permitting us to access the central part of the measured items.

3.2. Internal contacts

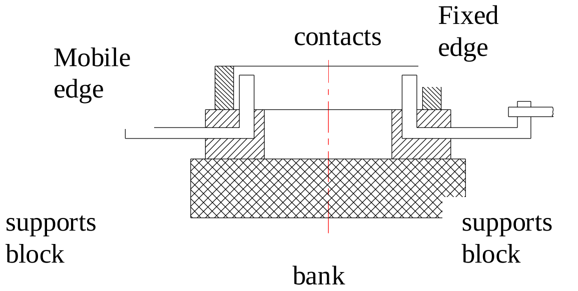

Fig.20 *The parts of the bank which compose the optical-micrometer, designed by a mechanical program Autocad Mechanical 2006 [22]*

These contacts consist of two pieces fixed on the device's edges that allow our access with the interior surface of the cylinder.

Thin-edged contacts are designed for diameters 10-20 mm and the others with thick edges are designed for diameters 20-200 mm.

3.3. Item placement

We are about to place the item in a way that contacts edges are precisely in contact with the edges of a diameter.

In fact, if we do not take all necessary precautions we may have errors, as shown in the figures below.

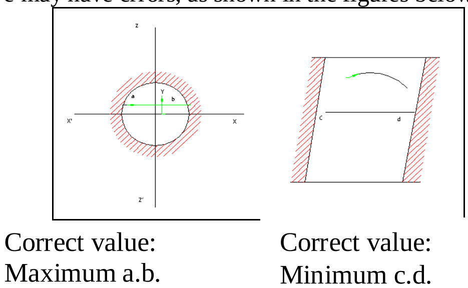

Fig.21 The corrected value of measurements in graphics depiction of the Orthogonal-Cartesian System designed by a mechanical program Autocad Mechanical 2006 [22]

After having carefully cleaned item and contacts we put the item on the supports. We bring contacts in contact with the interior surface. We bring side contact in contact with micrometer. We adjust pointer around zero. Using the central anterior button of the bank we move the bank per yy´ axis till we have a maximum indication on the micrometer. Then, using the button located on the left of the bank we close the bank so that indicator reaches to its minimum. Adjustments are made both for axis controllers and the items to be measured.

3.4. Diameter measurement

It is about an internal differential measurement where reference length is a prototype axis controller.

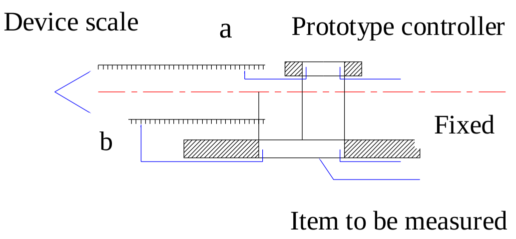

Fig.22 The process of internal diameter measurement of the Optical-micrometer industrial type machine, designed by a mechanical program Autocad Mechanical 2006[22]

Diameter OB about to be measured is:
OB = OA + AB
but, AB = b-α
where b and α are the values taken at the device, where:
OB = e + b – α
where e = OA (prototype diameter)

We have to make verification corrections on b and α. We will try to identify precision of that measurement considering device's precision.

6. CONCLUDING REMARKS

The estimated variance components are obtained from the Gage R&R study. One basic criterion for the acceptability of the measurement system is that

$$\hat{\sigma} / \hat{\sigma}_T \quad or \quad \sqrt{\hat{\rho}_M} \langle 0{,}1$$

commonly referred to as the Total gage R&R %Study Var, should be suitably small. (It should be noted that the title '%Study Var' as provided in statistical packages, refers to the per cent study variation which involves ratios of standard deviations and not ratios of variances as the name % Study Var may lead the reader to believe).[14] Values between 0.1 and 0.3 may be acceptable depending on factors such as the importance of the application, the cost of the measurement device, and the cost of repair. Values over 30% are generally considered unacceptable and it is recommended that every effort should be made to improve the measurement system.[14]

According to the Measurement System Analysis (M.S.A.) and the Gauge R&R technique, which focused in the above section, we can estimate that:

1. If we have R&R%<10% then, the measurement system that we use is excellent.
2. If we have R&R%<30% then, the measurement system that we use is moderate.
3. If we have R&R%>30% then, the measurement system that we use is worthless.

If we observe the figures with the calculations in the chapter 'Conclusions for the Gauge R&R Technique' of the thesis, we will see that the measurement system that we are using in the laboratory is excellent for some measurements, moderate for more and worthless for some of them.

In addition, if we notice the tables that there are in the thesis, we will see that the operators do not have any significant role in the measurement system. The difference in the measurements between the five operators is very small and in the most measurements, there isn't any difference at all. The operators didn't know the results from the theoretical calculations. Moreover, each of the five operators made the measurements without any other influence and separate from the other operator.

Results for Parallel Plates :

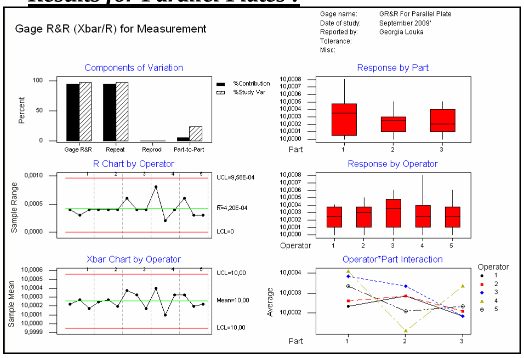

*Fig.6.1 The Gage R&R Charts with the method Xbar/R,, for the parallel plate pieces. These depicts the following charts: Components of Variation, R Chart by Operator, Xbar Chart by Operator, Response by Part, Response by Operator & Operator*Part Interaction, with the use of Minitab program,Version13 [21]*

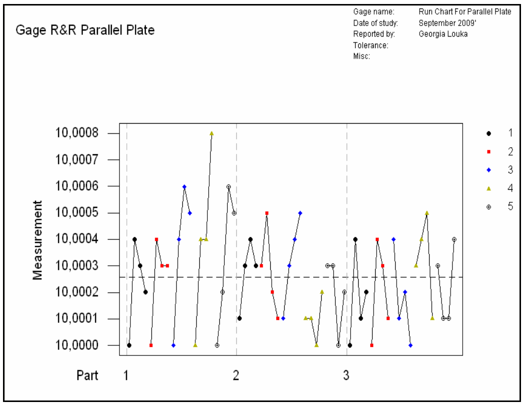

Fig.6.2 The Run Chart of measurements for parallel plates in graphics depiction with the use of Minitab program,Version13 [21]

Results for Internal Diameter Pieces:

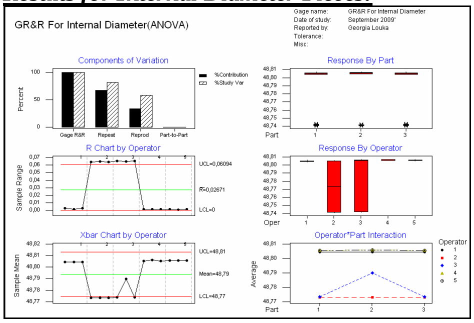

*Fig.6.3 The Gage R&R Charts with the method ANOVA,, for the internal diameter pieces. These depicts the following charts: Components of Variation, R Chart by Operator, Xbar Chart by Operator, Response by Part, Response by Operator & Operator*Part Interaction with the use of Minitab program,Version13 [21]*

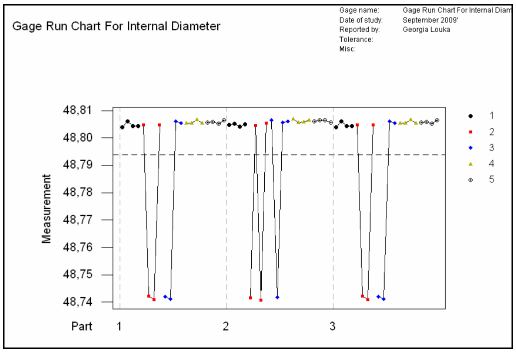

Fig.6.4 The Run Chart of measurements for internal diameter pieces in graphics depiction with the use of Minitab program,Version13 [21]

Results for External Diameter Pieces:

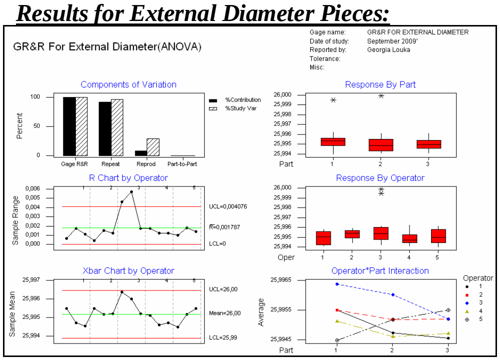

*Fig.6.5 The Gage R&R Charts with the method ANOVA,, for the external diameter pieces. These depicts the following charts: Components of Variation, R Chart by Operator, Xbar Chart by Operator, Response by Part, Response by Operator & Operator*Part Interaction, with the use of Minitab program,Version13[21]*

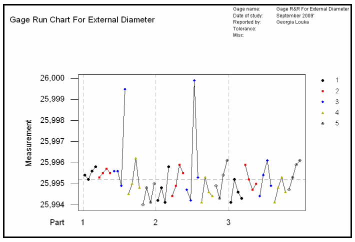

Fig.6.6 The Run Chart of measurements for external diameter pieces in graphics depiction with the use of Minitab program ,Version 13[21]

Results for the Temperature factor with ANOVA Method :

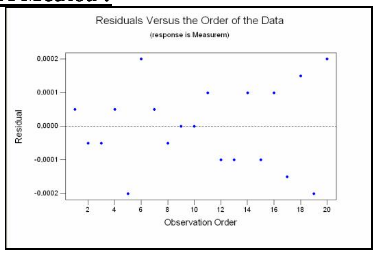

Fig.6.7 *Residuals Versus the Order of the Data, which the response is the Measurement, with the use of Minitab program,Version13 [21]*

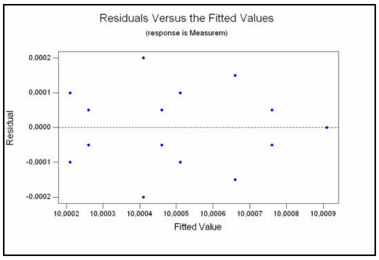

Fig.6.8 Residuals Versus the Fitted Value, which the response is the Measurement, with the use of Minitab program, Version 13[21]

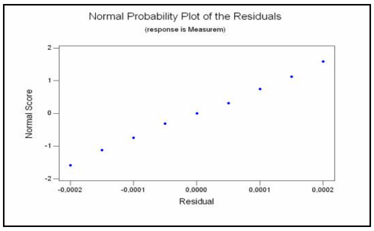

Fig.6.9 Normal Probability Plot of the Residuals, which the response is the Measurement, with the use of Minitab program, Version 13[21]

Summarized all the above calculations we can assay that the measurement of the experiment has remarkable deviations, consequently in the repeatability of the metric system. In the piece of the measure the internal diameter the operator has significant

effectiveness. In contrast, in the experiment of the measure of the external diameter axis significant deviations presents the pieces, that is to say the measurements of each operator.If %GCR Repeatability > 10% or 1, a red sign is flagged, and an immediate attention is needed for instrument adjustment or calibration. So, in the experiment we estimate that :
GCR(Parallel Plate) = 0,57 < 1 , Acceptable
GCR (Internal Diameter Piece) = 78,328 > 1, UnacceptableGCR (External Diameter Piece) = 3,167 > 1, UnacceptableThe system we used presented the above results and we can demonstrate that there is an explanation about that situation. During the experiment we made the proper calibration firstly for the parallel plates which is the first part we measure. Then the machine keep measure the other pieces without calibration again. That is, the measuring system we used to calculate our data -the Gauge R&R- is reliable for examine the reliability and reproducibility of the machine. In conclusion, we can say that our measurement system has a lot of variability itself and we can characterize it as uncertain. It is necessary for us to improve it, in order to measure with reliability.Therefore, the measurements from the five operators are very reliable and the difference that we observe between the measurements and the theoretical calculations it is because of the measurement system or because of the calibration of the machine in the laboratory.

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Received: 30.09.2010 Accepted: 30.11.2010 Open for discussion: 1 Year