

MEASUREMENT SYSTEM ANALYSIS OF OUTSIDE MICROMETER FOR NON-STANDARD TEMPERATURE CONDITIONS

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Abstract— Standard atmospheric conditions for precise measurements have always been priority in metrology. Industrial lengths defined as the size since 1931 have been measured at standard reference temperature of 20°C. As it is practically difficult to maintain this temperature all around the manufacturing or measurement facility at all the time, any change in temperature has to be studied and the resulting change in measurement process has to be accounted. To solve the challenges arising due to this condition, Measurement system analysis (MSA) is used to locate and measure the spread of the variation in measurement system. This paper presents the study conducted on outside micrometer screw gauge at varying room temperature in uncontrolled measuring facility. Bias and Linearity study is performed on the recorded dimensional measurement and temperature data. To study the recorded data, Statistical process control analysis (SPC) is also performed. The study shows the effect of the non-standard temperature over the recorded dimensional measurement data in terms of control charts and bias and linearity values. The paper also discusses real time temperature measurement SCADA system application for the temperature data collection.

Key words—Measurement system analysis (MSA), outside micrometer, Statistical process control (SPC), Bias and Linearity.

I. INTRODUCTION

As the measurement is the assignment and comparison of a number to a characteristic of event or an object with other events and objects. To define the length of an object human has always used standard units since his evolution. Comparison has always been done with conditions required for the measurement to yield the precise results and maintain it for specific period. As in length measurement practiced in metrology many metrologists have suggested different conditions like atmospheric, equipment standards and appraiser for long time. Temperature being very considerable factor during defining the length of an object it is studied and controlled all around the world. Since 1931 standard reference temperature of 20°C have been accepted worldwide after the long discussions. Since then all practitioners have used this temperature for measurement of length wherever high accuracy and precision has to be achieved in measurement process.

A. Origin of Standard Reference Temperature

All materials experience change in their physical state under temperature change or temperature drift which cause their size to increase or decrease. This phenomenon is known as thermal expansion, especially all metals show different thermal expansion when brought under temperature change. Normally metals expand under high temperature and contract under low temperature. This expansion is measured by coefficient of thermal expansion. The coefficient of thermal expansion measures the fractional change in size per degree change in temperature at a constant pressure and is given by following equation [1].

$$\alpha_L \Delta T = \Delta L/L \quad (1)$$

Rearranging for ΔT gives:

$$\alpha_L = \Delta L/\Delta TL \quad (2)$$

Where α_L the coefficient of thermal expansion ($\mu\text{m. m}^{-1} \cdot \text{K}^{-1}$), ΔT is the change in temperature (K), ΔL is the change in length (μm) and L is original length (m).

As earlier manufacturing and assembly of the metal parts was done at different temperature the problem in their fitting was seen and observed which needed to be solved. As one part measured at lower temperature was not given allowance for the expansion when it was supposed to be assembled or fitted with the another part at higher temperature. This caused incorrect fit between parts. After long discussion and with the efforts of one of the famous metrologists of that time C. E. Johnson, the International Committee for Weights and Measures (CIPM) adopted 20°C as the standard reference temperature on April 15, 1931 [2]. Since then all sub assembly or individuals' parts are measured at controlled facilities having temperature of 20°C.

B. Measurement System Analysis (MSA) [4]

As the standard conditions required to maintain the measurement process efficiency to the maximum, the cause of variation, its effect and corrective measures have to be studied and depending upon this data the location of the variation and the width of the variation has to be known. Many factors affecting the measurement process like ambient conditions, equipment, operator, procedure and type of measured has to be studied. To achieve this Measurement system analysis (MSA) is performed. Measurement system analysis is an experimental and mathematical method of determining the how much variation within the measurement process contributes to overall process variability.

A general measurement system is characterized into following ways:

1. Location (Average measurement values vs. Actual values)
2. Variation (Spread of Measurement values - precision)

This paper presents the study done to find the location of the variation and includes Bias and Linearity.

a. Bias

Bias is the difference between the true value also called as reference value and the observed average of measurements on the same characteristics on the same part. Bias gives the measure of systematic error of the measurement system.

b. Linearity

Linearity is the consistency of the accuracy or bias over the range of the measurement. Linearity shows how the measurement variations are located for large no. parts or objects.

II. METHODOLOGY

The measurement system analysis is done on the experimental data collected for temperature and dimensional data. The experimental work conducted in achieving the objective of the study is divided into following steps [3]:

1. Material selection
2. Experimental work
3. Statistical analysis

A. Material Selection

The material required for the study is selected as measurement system and measured. Measurement system is required to measure two conditions, room temperature and dimensional data for the measured. Outside micrometer screw gauge with the range of 0-25mm is used and real time temperature measuring SCADA system is used for room temperature monitoring and recording. The measured used for the study is calibration plate used as the working standard for CMM calibration. The measured material is chosen depending upon the hardness and the stability towards the room temperature change.

a. Measured

Figure 3 CMM Calibration plate (measured)

CMM Calibration plate used as a measured is made of two components, base plate and spherical balls. For study spherical balls were selected which were glued to the base plate. The base plate is made of High carbon high chromium (HCHCr) steel and the balls are made of Chrome steel. The specifications of the measured are given as follow:

Table 1. Measured Specifications

Sr. No.	Part	Specifications	
		Material	Dimension (mm)
1	Base plate	High carbon high chromium (HCHCr) steel	450×450×19
2	Spheres	Hard chrome steel	25.4

b. Dimensional Measurement System

The dimensional measurement system used is outside micrometer screw gauge and the specifications are as follow:

Table 2. Micrometer Screw Gauge Specifications

Sr. No.	Specifications							
	Type	Make	Range (mm)	Least count (mm)	Accuracy (mm)	Length (mm)	Breadth (mm)	Weight (kg)
1	Outside micrometer screw gauge	Mitutoyo	0 - 25	0.001	± 2	157	58	0.275

c. Temperature Measurement System

Real time temperature measuring SCADA system is used to monitor and record the room temperature data. The system uses hardware and software based system to monitor the room temperature. Allen Bradley Micro 820 PLC and RTD temperature sensor are the major part of hardware of the system.

B. Experimental Work

The dimensional data on outside micrometer screw gauge is recorded for every 0.1°C change in room temperature. For more accurate results specially designed micrometer fixture is used to hold the micrometer screw gauge. This paper includes observation of one sphere for the temperature range of $22.0 - 30.0^{\circ}\text{C}$. Five trials are taken on the fixed and marked surface of the measured for every 0.1°C room temperature change by single appraiser. The experimental setup is shown in figure 4.



Figure 4. Experimental Setup

a. Experimental Data

The experimental data is collected by one operator for the temperature range of $22.0 - 30.0^{\circ}\text{C}$ with five trials for every 0.1°C . The experimental data is shown in table

Table 3. Experimental data

Sr.No.	Dimension (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1	25.394	25.395	25.394	25.393	25.394
2	25.394	25.394	25.394	25.394	25.394
3	25.394	25.395	25.394	25.394	25.394
4	25.394	25.395	25.394	25.394	25.394
5	25.393	25.395	25.394	25.394	25.394
6	25.394	25.394	25.395	25.393	25.394
7	25.394	25.394	25.395	25.393	25.391
8	25.394	25.394	25.395	25.392	25.394
9	25.393	25.394	25.395	25.393	25.394
10	25.393	25.494	25.395	25.393	25.394
11	25.393	25.395	25.395	25.393	25.393
12	25.393	25.395	25.394	25.393	25.393
13	25.393	25.395	25.394	25.394	25.394
14	25.393	25.395	25.394	25.394	25.394
15	25.393	25.395	25.394	25.393	25.394
16	25.394	25.395	25.394	25.393	25.394
17	25.394	25.395	25.394	25.393	25.394
18	25.393	25.393	25.395	25.393	25.394
19	25.393	25.395	25.394	25.393	25.393
20	25.394	25.395	25.394	25.393	25.393
21	25.394	25.395	25.393	25.394	25.393
22	25.394	25.395	25.394	25.394	25.393
23	25.394	25.395	25.394	25.392	25.392
24	25.394	25.395	25.393	25.393	25.393
25	25.394	25.394	25.394	25.393	25.393
26	25.394	25.394	25.394	25.393	25.394
27	25.394	25.394	25.394	25.393	25.394
28	25.394	25.395	25.394	25.393	25.394
29	25.394	25.395	25.394	25.393	25.393
30	25.393	25.395	25.395	25.393	25.393
31	25.392	25.395	25.395	25.392	25.393
32	25.394	25.394	25.395	25.393	25.393
33	25.394	25.395	25.395	25.391	25.393

34	25.394	25.395	25.394	25.393	25.393
35	25.394	25.394	25.395	25.393	25.393
36	25.395	25.395	25.395	25.393	25.394
37	25.394	25.395	25.394	25.393	25.394
38	25.394	25.395	25.394	25.393	25.394
39	25.394	25.395	25.394	25.393	25.394
40	25.394	25.395	25.395	25.393	25.394
41	25.394	25.395	25.394	25.393	25.394
42	25.394	25.394	25.394	25.393	25.394
43	25.394	25.394	25.394	25.393	25.394
44	25.394	25.394	25.394	25.393	25.394
45	25.394	25.395	25.394	25.394	25.394
46	25.393	25.395	25.393	25.393	25.393
47	25.393	25.394	25.394	25.393	25.394
48	25.393	25.394	25.394	25.393	25.394
49	25.393	25.395	25.394	25.393	25.395
50	25.393	25.395	25.395	25.393	25.394
51	25.393	25.395	25.395	25.393	25.394
52	25.394	25.395	25.395	25.393	25.394
53	25.394	25.395	25.396	25.393	25.394
54	25.394	25.395	25.395	25.392	25.394
55	25.394	25.394	25.395	25.393	25.394
56	25.395	25.395	25.395	25.393	25.394
57	25.395	25.395	25.395	25.394	25.394
58	25.395	25.395	25.395	25.393	25.394
59	25.395	25.395	25.395	25.393	25.394
60	25.395	25.395	25.395	25.394	25.394
61	25.395	25.395	25.394	25.394	25.394
62	25.394	25.396	25.394	25.394	25.394
63	25.394	25.395	25.395	25.394	25.393
64	25.394	25.395	25.395	25.394	25.393
65	25.395	25.396	25.395	25.393	25.395
66	25.395	25.396	25.395	25.394	25.394
67	25.395	25.396	25.396	25.394	25.394
68	25.394	25.396	25.394	25.394	25.394
69	25.394	25.396	25.396	25.395	25.394
70	25.394	25.395	25.395	25.395	25.393
71	25.394	25.395	25.395	25.394	25.394
72	25.394	25.396	25.395	25.394	25.394
73	25.394	25.396	25.395	25.393	25.394
74	25.395	25.396	25.396	25.393	25.395
75	25.395	25.396	25.396	25.393	25.395
76	25.394	25.397	25.396	25.396	25.395
77	25.395	25.397	25.396	25.393	25.395
78	25.395	25.397	25.395	25.393	25.394
79	25.395	25.396	25.395	25.396	25.396
80	25.395	25.396	25.395	25.393	25.396
81	25.395	25.396	25.396	25.393	25.396

C. Statistical analysis

Statistical analysis performed over the collected data is divided into two parts for the close observation over the data and variation in the measurement process. Control charts are plotted to study whether the process is in control or not. Control chart also show the out of control points within sub groups. For observing the process control eight test are performed and the data falling under fulfillment of these test is used to find the process control. Based on the results and standard deviation from the control charts, Bias and linearity study is conducted.

III. RESULTS & DISCUSSION

Based on the statistical process control analysis and measurement system analysis following results are seen:

A. Statistical Process Control (SPC) Analysis [5].

Eight tests are used to monitor the data points marked on the control chart which are beyond control limits are given as:

- 1) One point more than 3σ from the centre line.
- 2) Nine points in a row on the same side of the centre line.
- 3) Six points in a row on the same side of the centre line.
- 4) Fourteen points in a row, altering up and down.
- 5) Two out of three points more than 2σ from the centre line (same side).
- 6) Four out of five points more than 1σ from the centre line (same side).

- 7) Fifteen points in a row within 1σ of the centre line (either side).
- 8) Eight points in a row more than 1σ from the centre line (either side).

a. X bar Chart

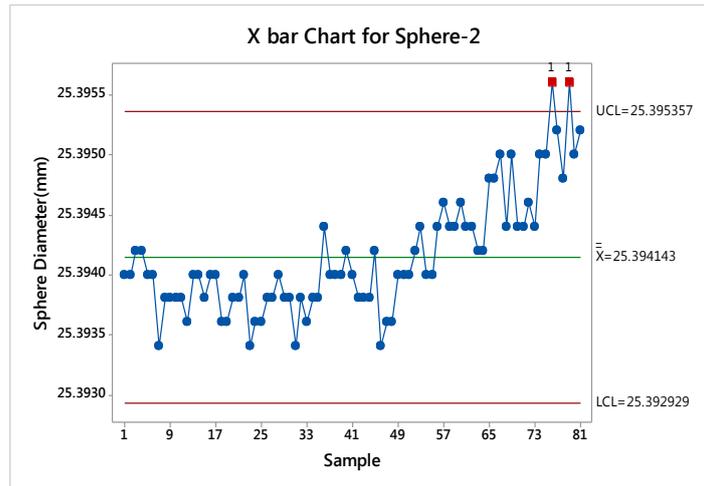


Figure 5. X bar Chart

From the figure 5 it is seen that the lower and upper control limits are 25.392 and 25.395, respectively. Therefore, the subgroup averages are expected to fall between 25.321 and 25.395. The center line (estimate of process average) is 25.394. Two points are located above upper control limit which indicates that the data fail in test 1 and also indicates process out of control, but as only two points fail the test out of 405 measurement and show very little variation which may be caused due to special cause of variation such as uncontrolled room temperature.

b. R-Chart

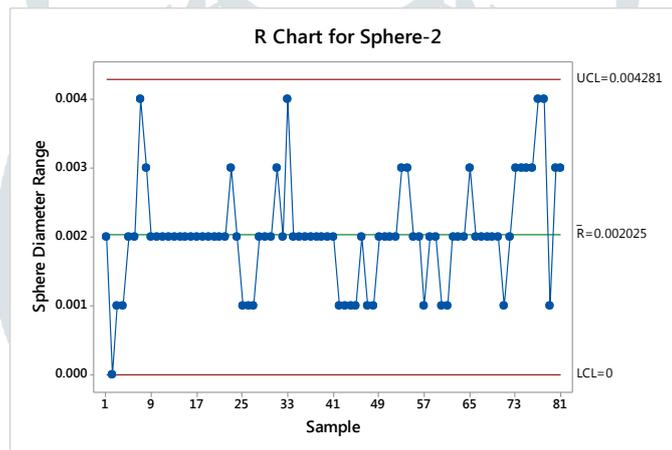


Figure 6. R-Chart

From the figure 6 it is seen that The lower and upper control limits are 0 and 0.0042, respectively. Therefore, the subgroup ranges are expected to fall between 0 and 0.0042. The center line (estimate of process variation) is 0.002025. Since no point is out of control limits the process variation is in control.

c. S Chart

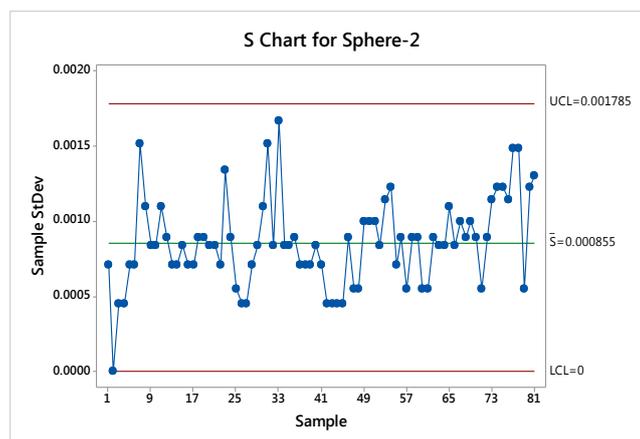


Figure 7. S Chart

From the figure 7 it is seen that the lower and upper control limits are 0 and 0.001785, respectively. Therefore, the subgroup ranges are expected to fall between 0 and 0.001785. The center line (estimate of process variation) is 0.000855. Since no point is out of control limits the process variation is in control.

From the control charts, measurement data is seen in control and the spread of the variation with in control limits. The variation seen may be because of special causes of variation like ambient conditions, equipment, operator and procedure. Since all three conditions are tried to maintain stable in following study ambient conditions can be considered for the cause of variation.

B. Measurement System Analysis (MSA)

From the standard deviation and the sub group data from the statistical process control, bias and linearity study is done to show the location of the variation caused in the measurement process under non-standard temperature conditions.

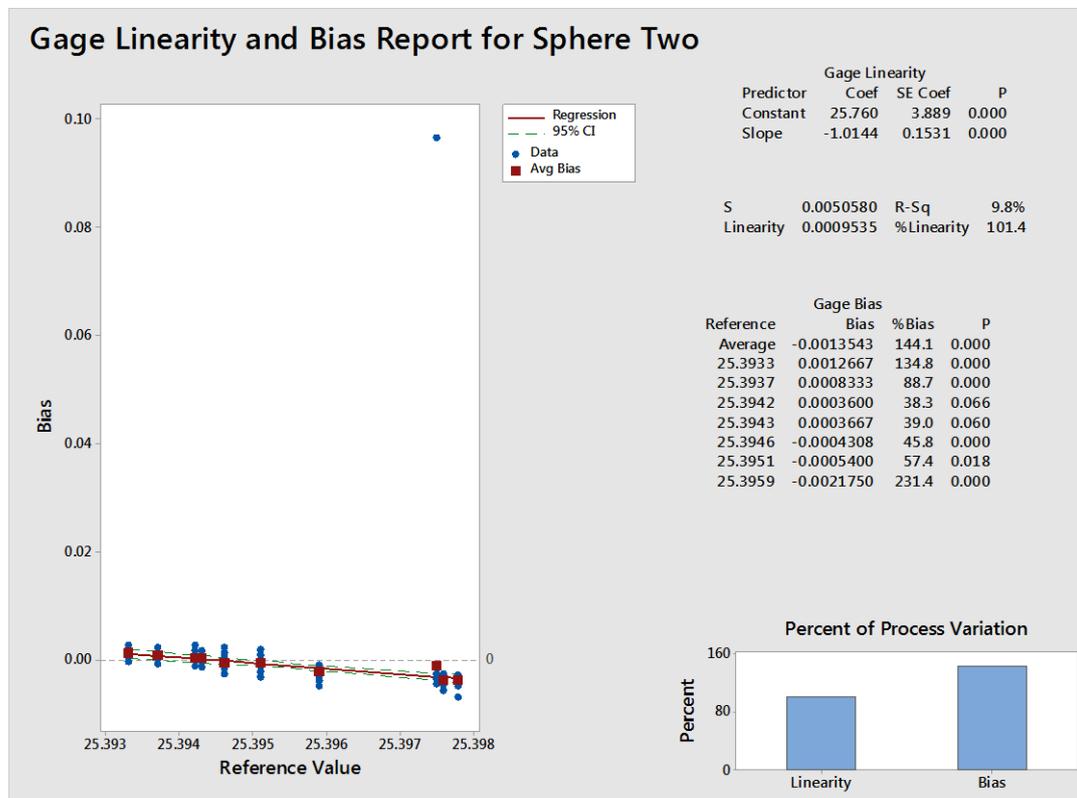


Figure 8. Gage linearity and bias

From figure 8 it is seen that for the parts data, the %linearity is relatively large (101.4%), which indicates a problem. Smaller parts tend to measure too high, while larger parts tend to measure too low. Because the R value is not to high (9.8%), you can assume that the relationship between the master part measurement and bias is close to linear. It is reasonable to assess linearity for the parts data. For the parts data, the average bias (-0.0013543) indicate that there is some variability due to bias. The p-value is 0.000. Because the p-value is less than the chosen level of significance (α -level), typically set at 0.05, you can reject the null hypothesis that bias equals 0.

IV. CONCLUSION

The research performed over the dimensional and temperature data for the outside micrometer screw gauge performance at non-standard temperature shows that the process is in control with few measurements beyond the control limits, as only few measurements are out of 405 measurements fail in first test. This concludes that the process is acceptable and the special cause of variation is present in the system and corrective measures should be taken to minimize it. The research also shows that the gauge underestimates as the negative bias is seen over the room temperature drift and the some variability is seen in the measurement process due to presence of bias with 101.4 % linearity.

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