Study in determining of junction point value for shifting measurement method on line scale calibration in SNSU BSN

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Abstract. Calibration of line scale in the National Standards Measurement-National Standardization Agency in Indonesia (SNSU-BSN) is carried out by using one dimensional measuring machine (SIP machine) which traceable to the laser interferometer or laser interferometer itself. Although line scale calibrated using laser interferometer, the system needs SIP machine as linear movable carriage and SIP table as the base on line scale. Length measurement of the SIP machine covers only up to 400 mm and for line scale above 400 mm, measurement can be extended to 1000 mm using shifting methods. When the scale is shifted, the position of the last point of previous measurement might not be on the same position, even though it has been well alignment for the second measurement. There is an error due to a junction between position scale on the first measurement to the second measurement. This error is added to the uncertainty budget as a junction point error because of the shifting. This paper described how to determine an appropriate value that should be attached on the uncertainty budget. It was found the error value of junction point due to shifting method in line scale calibration is 0.42 µm and the expanded uncertainty of line scale calibration for 1000 mm is 2.5 µm.

1. Introduction

The product quality can be defined by some parameters such as conformance to the specification, design quality, long term stability, and conformance durability. These items are typically related to the design engineering and manufacturing [1, 2]. The manufacture has to consider their products meet the conformance to specification to fulfil the competitiveness of products in the market [3]. To ensure the product meets the specification, the validity of measurement must be guaranteed and the calibration of instruments or tools is required.

One of important instruments for industry and scientific measurement is line scale. It is widely used to measure the size of products or to calibrate the instruments depending the accuracy and variety of line scale. High accuracy line scale is usually made from glass scale with narrow and sharp chromium graduation [4] while the low accuracy line scale is known as steel ruler. Both of glass scale and steel ruler are required calibration to achieve the traceability in order to ensure the validity of measurement results. They are many methods to calibrate line scale such as by measuring using microscope machine, interferometer, or using scanning optical microscopy [4, 5, 6, 7]. Line scales cannot be measured efficiency by static method considering has multiplicity of interval [4, 8]. The best way to measured line scale are by dynamic measurement, fringe counting, or interferometry [9, 10, 11, 12].
Calibration of line scale in SNSU BSN is traceable through System International (SI) units by two kind of methods. One is traceable to a measuring microscope machine named by SIP machine, and another is traceable to the laser interferometer. The differences in using these methods are required for accuracy of line scale that want to achieve, usually laser is used high accuracy or reference standard scale. Since the calibration of line scale is typically a dynamic measurement, it needs a carriage displacement, correspond to the scale interval length or graduation line of line scale. This carriage is perform by SIP machine during the calibration process. In interferometry method, laser interferometer is used along with SIP machine [13].

Capability of the SIP machine covers only up to 400 mm, while some of the industrial instruments have scales above this size. To compensate this limitation, the artifact has to be able to shift gradually during the measurement process. Since there has to be more than one shifting action for each artifact, then several values of uncertainties are calculated depending on the number of the shifting.

Previously, line scale calibration in SNSU BSN was conducted without considering the error that may occur because the shifting. There are also several supporting points methods in length calibration, such as Bessel points, Airy points, Flat support, and other supports points [14, 15, 16, 17]. However, several publications explained that supporting points for short scale are not needed, because the method of supporting a scale only influences the long ones [15]. Sawyer et al. also explained that error without supporting point in very short scales is negligible, however ignoring this error in long artifact above 700 mm may give a slight bend or some combination of these geometric errors [18].

To improve the knowledge about the junction point influence to the result of calibration due to the shifting measurement, examinations is carried out by taking some calibrations using several parameters into account. This paper describes an appropriate value should be added on the uncertainty budget because if the junction point error due to the scale shifting.

2. Method

The standard measurement device used to this research is a microscope measuring machine (SIP Machine 414M) calibrated by laser interferometer and traceable to SI. The unit under test is a standard glass scale of 500 mm in range. The line scale is placed on the glass table of the SIP machine illuminated from below by light source as shown in Figure 1. The resolution of the SIP machine is 0.0005 mm. The graduation lines are detected by eyepiece of 45 times objective magnification microscope with a central cross wire [13]. Measurement process is conducted in an environment as follows; (20 ± 0.5) °C for temperature and (55 ± 10) % for relative humidity. The carriage of SIP machine is moved by hand wheel manually [13, 19]. Sliding table will travel smoothly by rotating the gears system from 0 – 400 mm.

![Figure 1. Microscope measuring machine (SIP machine)](image)

The length between two graduation lines is determined as the difference between the means of indicated position when the cross wire is appointing at the left and right edge of the graduation line
This method is called edge to edge measurement method. The measured scale is average between the left and the right edge after offsetting to zero. This method conforms with the work instruction of line scale measurement in SNSU BSN. Another method called center to center method; can also be used if the line thickness is too thin and difficult to see the line scale edge. By using the center and center method, the length between two graduation length is determined as difference between center of thickness line to the center of thickness of the next line [13]. The uncertainty of line scale calibration by using the edge to edge method is smaller than center to center method due to small error of targeting graduation line of scale.

The measurement is carried out three times for each points after one series of measurement is completed, using bi-directional taking data method. Measurement data process and analysis were done using statistical software.

Due to the limitation of SIP machine length, the line scale measurement in SNSU BSN is conducted with several connections points for shifting process for artifact which have range above 400 mm. They are 350 mm and 700 mm. When range of 500 mm line scale is measured, then first measurement is 0-350 mm, and the second measurement is 350 mm – 500 mm. The position of line scale measurement setting is shown as Figure 2.

![Figure 2. Line scale measurement setting 0-500 mm.](image)

After taking data for first measurement from 0 – 350 mm as Figure 2(1), at the left edge or at the right edge of line of 350 mm, the value is recorded as the last position of the scale. After that, the scale is shifted to cover the line scale measurement of 350 mm to 500 mm as Figure 2(2). However, the line scale is aligned on the 300 mm to 500 mm for the second measurement as perfect as first measurement. The difference value may occur between the same line on the first measurement and second measurement because there is not guarantee the line still at the same position due to the shifting even though the alignment is perfect. The second measurement was started from the 250 mm gradually increasingly up to 500 mm. The overlap length of 250 mm - 350 mm is considered as an overlap difference. The difference between maximum and minimum overlap difference is attached on uncertainty budget as overlap or junction error.

3. Result and Discussion
The result of measurement is reported as deviation of line scale. It is a difference between nominal length of line scale and the measured length that shown by SIP machine after adding correction value from machine calibration. The difference values between data before shifting and after shifting is shown on the Table 1.
Table 1. The deviation of measurement of 500 mm line scale before shifting and after shifting.

| Nominal scale (mm) | Line scale deviation 0-500 mm (mm) |
|--------------------|-----------------------------------|
|                    | Before Shifting | After Shifting |
| 0                  | 0.0000          | -              |
| 100                | -0.0002         | -              |
| 200                | -0.0002         | -              |
| 250                | 0.0008          | 0.0008         |
| 275                | 0.0011          | 0.0007         |
| 300                | 0.0003          | 0.0008         |
| 325                | 0.0008          | 0.0006         |
| 350                | 0.0008          | 0.0004         |
| 375                | -               | 0.0011         |
| 400                | -               | -0.0001        |
| 500                | -               | -0.0002        |

The difference between result before shifting and after shifting then is calculated as overlap value for each points. The difference between maximum and minimum overlap value calculated as junction point value and then is taken in uncertainty budget. The junction point or overlap value can be determined by using another glass scale with different scale length. Figure 3 shown the overlap value with scale length of 500 mm and 600 mm from nominal length 250 mm up to 350 mm.

Figure 3. Overlap value of line scale because of shifting

As seen in the Figure 3, in several point the overlap lap for line scale 500 mm and 600 mm has 0.3 µm different but they are still in the same agreement. The difference may occur due to quality of mark of graduation line of scale or some imperfect alignment. Since the data has taken by eye-piece detection, it is also influenced by the objectivity of technician observation. However, to ensure the measurement conducted precisely, the consistency of data repeatability of technician is important. The final of junction point is obtained from the maximum and minimum difference of overlap value. The junction point value from this research results is 0.42 µm.

Because of line scale of 0 to 500 mm is measured by using two step processes, then the uncertainty budget for line scale is also determined by two steps, first is uncertainty budget for 0 to 350 mm, then uncertainty budget for 350 mm to 500 mm which consist of constant uncertainty components and
length-dependent uncertainty components. Those budgets then are combined as square root of sum to be a final uncertainty of measurement [20]. It is also similar to the line scale 1000 mm. Because the line scale is measured by three times of shifting, then measurements are conducted by 0 to 350 mm, 350 mm to 700 mm, and 700 mm to 1000 mm. The uncertainty budget for each measurement is counted per process, then they are combined by squared root of sum. The total uncertainty in process two is given by square root of sum of uncertainty in first process and second process. The total uncertainty in process three given by square root of sum uncertainty in the third process and the total uncertainty in process two.

Table 2. Uncertainty budget for line scale of 350-350 mm

| Uncert. source | Unit | Distr. | Semi-range or exp. Uncert. or std. Dev. | Std. Uncert./ ui | Sens. Coeff./ ci | c_i.u_i |
|----------------|------|--------|----------------------------------------|------------------|-----------------|--------|
| Repeatability  | µm   | Type A | 0.37                                    | 0.1167           | 1               | 0.117  |
| Overlap        | µm   | Rect   | 0.42                                    | 0.2406           | 1               | 0.241  |
| Display resolution | µm  | Rect   | 0.25                                    | 0.1443           | 1               | 0.144  |
| Certificate of standard | µm  | Normal | 0.60                                    | 0.3000           | 1               | 0.300  |
| Abbe error     | µm   | Rect   | 0.33                                    | 0.1889           | 1               | 0.189  |
| Targeting error | µm  | Rect   | 0.50                                    | 0.2887           | 2               | 0.577  |

Combined uncertainty, u(c) for constant uncertainty components (µm) 0.7425

| Uncert. source/ | Unit | Distr. | Semi-range or exp. Uncert. or std. Dev. | Std. Uncert./ ui | Sens. Coeff./ ci | c_i.u_i |
|-----------------|------|--------|----------------------------------------|------------------|-----------------|--------|
| Difference of UUT's temperature from 20 °C | °C   | Rect.  | 0.05                                    | 2.89E-02         | 3.50E-06 L      | 1.0E-7L |
| Temperature difference UUT and scale reference | °C   | Rect.  | 0.05                                    | 2.89E-02         | 8.0E-06 L       | 2.31E-07 L |
| Thermal expansion coefficient of UUT | °C   | Rect.  | 1.0E-06                                 | 5.77E-07         | 0.05 L          | 2.89E-08 L |
| Geometrical (cosine error) | µm  | Rect.  | 1.523E-04 L                            | 8.8E-05 L        | 1               | 8.79E-05 L |
| Thermal expansion difference of UUT and scale reference | °C   | Triang. | 1.0E-06                                 | 5.77E-07         | 0.5 L           | 2.89E-07 L |

Combined uncertainty, u(c) for length-dependent uncertainty components 8.8E-05 L

Total combined uncertainty (constant and length-dependent, u(c), L in mm) Q[0.743, 0.00009 L]

Expanded uncertainty at k = 2 (L in mm) U = Q[1.5, 0.00018 L]
Budget uncertainty of 0 mm – 350 mm is typically similar to budget uncertainty 350-500 mm. However, some differences are the repeatability value and overlap junction value that is not used for line scale 0-350 mm. Final uncertainty and the difference using overlap value are shown on table 3.

### Table 3. Budget uncertainty and overlap

| Nominal Length (mm) | Uncertainty (µm) | Without overlap | With Overlap value |
|---------------------|------------------|-----------------|-------------------|
| 0-350               | 1.4              | -               |                   |
| 0-500               | 2.0              | 2.1             |                   |
| 0-600               | 2.0              | 2.1             |                   |
| 0-1000              | 2.4              | 2.5             |                   |

The uncertainty budget in 500 mm and 600 mm are similar. It is 0.001 µm different and since the uncertainty is reported by two significant digits, then it is not seen due to rounding error. The uncertainty components from constants uncertainty component is dominant than length-dependent components since the component values of targeting error and machine calibration are gave high contribution to the budget. This is because the limit of resolution of SIP machine which has 0.0005 µm.

### 4. Conclusion

The line scale which has nominal length longer than measurement range of the SIP machine; can be measured by extending the range of measurement with shifting method with added uncertainty component of the junction point value due to effect of shifting. The junction point value as results on this research is 0.42 µm, and the expanded uncertainty for line scale 500 mm is 2.1 µm, and foe line scale 1000 mm is 2.5 µm. However, this research is still conducted to get smaller junction value in order to make accuracy of measurement higher. It is considered to use laser interferometer and without eyepiece detection manually.

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