The acceptable range of roughness instrument calibration factor

A Rahman¹, N Alfiyati¹, O Novyanto¹, N L Kartika² and R Z Amdani²

¹National Standardization Agency, South Tangerang, Banten, Indonesia
²Indonesian Institute of Sciences, Jakarta, Indonesia

E-mail: ardi.rahman@bsn.go.id

Abstract. There were no studies that show an acceptable range of calibration factor value on precision surface roughness instruments. It is generally known that the calibration factor plays an essential role in precision surface roughness instruments. This study demonstrates the acceptability range for the calibration factor using the Shewhart control chart method. Calibration factor data were obtained by comparing the calibration certificate of a type A artifact with the measurement results obtained from a surface roughness instrument. During the last five years, the calibration factor data from the Talysurf i120 surface roughness machine were analysed using the Shewhart control chart to determine the lower (LCL) and upper control limits (UCL) the range of acceptability. The results showed that the acceptance range was between 0.849 and 1.041, with a doubt level of 1%. These results are expected to be useful for metrologists, industries, and surface roughness practitioners in general to analyse the reliability of their surface roughness instruments/profiliometer.

1. Introduction
The finger is one of the senses useful for assessing an object's surface's roughness or softness. The disadvantage is that the fingers cannot measure surface roughness quantitatively. Currently, there are many surface roughness machines on the market, from linear variable displacement transformer (LVDT) based up to laser-based, both with contact and non-contact sensors [1, 2, 3]. Several roughness measurements were also published, such as LVDT, machine vision, and laser [4, 5, 6].

Surface roughness is one of the quality control parameters of the object's surface by providing an overview of the quality of the rough or soft level of a test object. The surface roughness of the fuselage directly plays a role in its aerodynamic system [7]. The beverage can industry makes the cans' surface roughness one of the parameters determining its consumers' comfort level. The surface roughness of the engine block also determines in engine rating systems [8]. Moreover, surface roughness also plays a role in surface finish checking, detecting wears and defects in the automotive and manufacturing world [9, 10, 11], medical implant polishing quality [12, 13], rock and semiconductor analysis [14, 15], up to quality control in additive manufacturing technology [16, 17, 18].

A National metrology institute (NMI) tasks in assuring the quality of measurements in a country, including measuring surface roughness. Based on data from the international measurement bureau (BIPM), there are 77 out of 106, or more than 70% of its member countries that have measurement and calibration capability (CMC) in the field of surface roughness [19]. It indicates that the surface
roughness is an essential parameter to maintain so that, in the end, it minimizes technical trading barriers among the countries [20, 21].

In the world of surface roughness metrology, the calibration factor is commonly known for correcting surface roughness machine readings in the calibration process. Inaccuracy in determining the calibration factor has a direct impact on the calibration results. No article describes the acceptability range of calibration factors on surface roughness machines. The paper provides an overview of determining the acceptability range of a surface roughness machine in the SNSU-BSN laboratory, NMI of Indonesia. Calibration factor data for the past five years were analyzed in advance to determine the acceptability ranges. Hopefully, it is useful for metrology practitioners at NMI, calibration laboratories, and industries to determine their surface roughness machines' quality limits.

2. Method
A surface contour is quantified digitally via an analog to digital converter. This work is initiated by a stylus tracing the contoured surface. The stylus must have a small enough radius (usually less than 5 µm) to fit into the surface's crevices. A transducer converts the stylus's signal into an electric signal, then sent to the analog to digital (A/D) converter. Finally, the computer does further analysis of the digitally quantified surface contour signal. Figure 1 shows the process of surface roughness measurement, as described before. The computer analysed the surface traced profile into various parameters such as average roughness ($R_a$), maximum profile height ($R_t$), depth ($d$), and many more parameters as described on [22].

Electronic systems are certainly not free from errors. Moreover, the transducer on a surface roughness machine converts the stylus shift (due to tracing a surface's profile) into an electronic signal. The transducer works based on the LVDT principle, an iron core that moves in the coil. The mechanical energy of the shift is converted into electrical energy by a transducer. Ideally, the movement of the iron core is proportional to the output voltage generated by the transducer. In many cases, it never met the ideal conditions, which is why a calibration factor (CF), or 'gain' in some terms, needs to be applied as a corrector to the surface roughness machine readings. The calibration factor of the roughness measuring machine ($f$) is attained from the comparison of the certificate value of depth(s) ($d_{\text{cert}}$) and the measured values of depth(s) by using a roughness machine ($d_{\text{meas}}$) [24, 25], as mentioned in equation 1.

$$f = \frac{d_{\text{cert}}}{d_{\text{meas}}}$$

According to [26], there are five types of surface roughness standard artifacts, namely Type A, B, C, D, and E. Type B application is to check the shape and condition of the stylus, while types C, D, and E applications are to determine overall system performance. Type A is useful for measuring the sensor's linearity by analyzing several grooves' depth in the profile. Based on the bottom shape, type A divided into two types, namely A1 for the flat bottom and A2 for the round bottom. Figure 2 shows the three artifacts used in this study. *Halle* A1 has 6 valleys namely (in µm) 0.239, 0.748, 2.403, 7.501,
23.992, and 75.277; Halle A2 with 6 grooves namely (in µm) 0.229, 0.537, 1.179, 2.683, 5.570, and 9.079; Taylor Hobson (TH) A1 with 2 valleys namely 0.418 µm and 2.315 µm. Type A artifacts were measured in five different sections using a surface roughness machine to obtain the depth values. Each part is measured five times repeatedly and then averaged.

Checking the CF using three alternating artifacts reduces the risk of wear on artifacts and allows for cross-checking. The guarantee of the trueness of the three artifacts' value is illustrated in the measurement traceability chain diagram to the international system of a unit (SI) of the three standards (see Figure 3). Halle A1 was calibrated to another NMI, which had direct traceability to SI, while the other two artifacts, Halle A2 and TH A1, were traced to SI via Halle A1. Hand-carry instrument and roughness specimen from calibration laboratories or industries calibrated using Halle A2 or TH A1.

The research began with analyzing the CF of the Talysurf i120 roughness machine made by Taylor Hobson. It is equipped with a 2 µm stylus radius and 90° arm angle. It also embedded ultra software v.5.14.8.29.2006 for data acquisition and analysis. For the last five years, the CF data distribution was analyzed using a control chart to determine the acceptable range of the CF values.

\[
UCL = \bar{x} + (k \cdot \sigma) \\
LCL = \bar{x} - (k \cdot \sigma)
\]

Equations 2 and 3 expressed the calculation of UCL and LCL, respectively [32, 33]. Where the average and standard deviation of five years CFs are denoted by \( \bar{x} \) and \( \sigma \), respectively. \( k \) is the...
coverage factor. The estimation of \( k=2 \) will produce about 5% of the CF out of control, while \( k=3 \) is of approximately 1%. CFs are plotted on the chart versus a timeline. CFs that are outside the limits considered to be out of control limit.

3. Result and Discussion

The CFs have been analysed by equation 1 using three types A artifacts over the past five years. Table 1 shows typical of it in different time ranges. The results show that the CF values of 0.9421, 0.9173, and 0.9945 for the Halle A1, Halle A2, and TH A1 artifacts. It shows how varied the CF value of surface roughness machines was (about 9%) over the last five years. If this variation is uncontrolled, it undoubtedly results in more inaccuracy in measuring surface roughness in the measurement traceability chain (see Figure 3). The critical point is, regardless of the CF values, as long as it is applied as a correction value of surface roughness machine reading, the measurement results are valid. However, as quality control and preventive action in surface roughness systems, the determination of the CF's acceptability range is a must.

**Table 1. Typical calibration factor measurements at SNSU-BSN**

| Halle A1 (10-Jan-2020) | Halle A2 (26-Mar-2018) | TH A1 (9-Jun-2016) |
|------------------------|------------------------|---------------------|
| \( d_{\text{cert}} \) (µm) | \( d_{\text{meas}} \) (µm) | Cal. factor | \( d_{\text{cert}} \) (µm) | \( d_{\text{meas}} \) (µm) | Cal. factor | \( d_{\text{cert}} \) (µm) | \( d_{\text{meas}} \) (µm) | Cal. factor |
| 0.239 | 0.277 | 0.229 | 0.310 | 0.9421 | 0.418 | 0.424 | 0.9945 |
| 0.748 | 0.841 | 0.537 | 0.572 | 2.403 | 2.617 | 1.179 | 1.253 | 0.9173 |
| 7.501 | 8.043 | 2.683 | 1.456 | 23.992 | 25.543 | 5.570 | 5.879 | 2.315 | 2.332 |
| 75.277 | 79.953 | 9.079 | 9.597 | 75.277 | 79.953 | 9.079 | 9.597 |

**Figure 4. Calibration factor control chart**
Figure 4 shows a graph of the CF's distribution concerning time, from 26 May 2015 to 12 August 2020. The most considerable CF value occurred in May 2015 at 1.0012, and the lowest was 0.9125 in October 2017. Average of CF ($\bar{\chi}$) was 0.9454 with a standard deviation ($\sigma$) of 0.0961. Using equations 2 and 3 for $k=2$, the acceptable range for CF was achieved between LCL=0.881 and UCL=1.009. Using the same equations, for $k=3$, the LCL and UCL were acquired between 0.849 and 1.041. It also obtained that none of the CF was out from the limitations for both values of $k$.

The three most recent CF values were taken in a short time difference (less than 3 hours, in September 2020) using three types of A artifacts (see Figure 2) to convince the artifacts' stability and validity. The CF data were 0.9422, 0.9484, and 0.9441 for Halle A1, Halle A2, and TH A1 artifacts. As a result, the CF values obtained were very close to the average of CF ($\bar{\chi}$) and it still in the CF acceptance range, as previously described.

4. Conclusion
The process of determining the acceptance range of calibration factor value using the Shewhart control chart on an electronic-based transducer surface roughness machine was described. In the last five years, data shows that the Calibration factor's acceptable value was between 0.849 and 1.041, with a doubt level assumption of 1%. The surface roughness machine users need to evaluate their machines if the Calibration factor value deviates from it. Moreover, it is necessary to investigate the variation of optical-based transducer surface roughness machines' calibration factor value in the future.

References
[1] Nasreen S, Rokunuzzaman M and Biswas S 2017 Assessment of Surface Roughness Using LVDT: A Convenient and Inexpensive Way of Measuring Surface Irregularities Int. Conf. Mech. Ind. Mater. Eng. 6
[2] Xu D, Yang Q, Dong F and Krishnaswamy S 2018 Evaluation of surface roughness of a machined metal surface based on laser speckle pattern J. Eng. 773–8
[3] Valiček J, Držík M, Hryniewicz T, Harničárová M, Rokosz K, Kušnerová M, Barčová K and Bražina D 2012 Non-contact method for surface roughness measurement after machining Meas. Sci. Rev. 12 184–8
[4] Santhosh K V and Roy B K 2017 Online implementation of an adaptive calibration technique for displacement measurement using LVDT Appl. Soft Comput. J. 53 19–26
[5] Ghodrati S, Kandi S G and Mohseni M 2018 Nondestructive, fast, and cost-effective image processing method for roughness measurement of randomly rough metallic surfaces J. Opt. Soc. Am. A 35 998
[6] Riegler-Nurscher P, Moitzi G, Prankl J, Huber J, Karner J, Wagentristl H and Vincze M 2020 Machine vision for soil roughness measurement and control of tillage machines during seedbed preparation Soil Tillage Res. 196 104351
[7] Büche D, Klostermann S, Rogé G and Loyatho X 2019 Uncertainties in compressor and aircraft design Notes Numer. Fluid Mech. Multidiscip. Des. 140 35–51
[8] Tootooni M S, Liu C, Roberson D, Donovan R, Rao P K, Kong Z (James) and Bukkapatnam S T S 2016 Online non-contact surface finish measurement and control of tillage machines during seedbed preparation Soil Tillage Res. 196 104351
[9] Leo Kumar S P 2019 Measurement and uncertainty analysis of surface roughness and material removal rate in micro turning operation and process parameters optimization Meas. J. Int. Meas. Confed. 140 538–47
[10] Zhao T, Zhou J M, Bushlya V and Ståhl J E 2017 Effect of cutting edge radius on surface roughness and tool wear in hard turning of AISI 52100 steel Int. J. Adv. Manuf. Technol. 91 3611–8
[11] D'Amato R, Calvo R, Ruggiero A and Gómez E 2017 Measurement capabilities for ball bearing wear assessment Procedia Manuf. 13 647–54
[12] Li J, Hu J, Zhu Y, Yu X, Yu M and Yang H 2020 Surface roughness control of root analogue
dental implants fabricated using selective laser melting *Addit. Manuf.* **34** 101283

[13] Singh J, Chatha S S and Singh H 2020 Characterization and corrosion behavior of plasma sprayed calcium silicate reinforced hydroxyapatite composite coatings for medical implant applications *Ceram. Int* **23** 1–28

[14] Azinfar M J, Ghazvinian A H and Nejati H R 2019 Assessment of scale effect on 3D roughness parameters of fracture surfaces *Eur. J. Environ. Civ. Eng.* **23** 1–28

[15] Rahman A, Novyanto O, Alfiyati N, Sidik A, Idris I and Nugraha A R 2019 Design and Characterization of Spin Coater To Support National Semiconductor Industry *J. Stand.* **21** 4411–22

[16] Gockel J, Sheridan L, Koerper B and Whip B 2019 The influence of additive manufacturing processing parameters on surface roughness and fatigue life *Int. J. Fatigue* **124** 380–8

[17] Whip B, Sheridan L and Gockel J 2019 The effect of primary processing parameters on surface roughness in laser powder bed additive manufacturing *Int. J. Adv. Manuf. Technol.* **103** 4411–22

[18] Cabanettes F, Joubert A, Chardon G, Dumas V, Rech J, Grosjean C and Dimkovski Z 2018 Topography of as built surfaces generated in metal additive manufacturing: A multi scale analysis from form to roughness *Precis. Eng.* **52** 249–65

[19] BIPM 2017 *CMC statistics Bipm* **07** 1–25

[20] Milton M and Donnellan A 2020 Measurements for Global Trade (WMD 2020 Message from the BIPM and BIML Directors) *Meas. Tech.* **63** 333

[21] Redgrave F and Howarth P 2008 *Metrology – In Short 3rd Edition*

[22] International Organization for Standardization 1997 *ISO 4287:1997(en), Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters*

[23] Vorburger T V., Renegar T B, Zheng A X, Song J F, Soons J A and Silver R M 2008 NIST Surface Roughness and Step Height Calibrations: Measurement Conditions and Sources of Uncertainty 1–7

[24] Koenders L, Andreasen J L, De Chiffre L, Jung L and Krüger-Sehm R 2004 EUROMET Project 600 - comparison on surface roughness standards *Metrologia* **41** 4001

[25] Rahman A, Alfiyati N and Amdani R Z 2019 Investigation of RCM-LIPI Surface Roughness Comparison Results on APMP-L-K8 *Instrumentasi* **42** 85

[26] International Organization for Standardization 2000 *ISO 5436-1:2000(en), Geometrical Product Specifications (GPS) — Surface texture: Profile method; Measurement standards — Part 1: Material measures*

[27] He Y, Liu F, Cui J, Han X, Zhao Y, Chen Z, Zhou D and Zhang A 2019 Reliability-oriented design of integrated model of preventive maintenance and quality control policy with time-between-events control chart *Comput. Ind. Eng.* **129** 228–38

[28] Abbas N 2018 Homogeneously weighted moving average control chart with an application in substrate manufacturing process *Comput. Ind. Eng.* **120** 460–70

[29] Čampulová M, Veselik P and Michálek J 2017 Control chart and Six sigma based algorithms for identification of outliers in experimental data, with an application to particulate matter *PM10 Atmos. Pollut. Res.* **8** 700–8

[30] Khatun M, Khoo M B C, Saha S and Castagliola P 2020 A new distribution-free adaptive sample size control chart for a finite production horizon and its application in monitoring fill volume of soft drink beverage bottles *Appl. Stoch. Model. Bus. Ind.* **1** 1–14

[31] Shaub A R N, Al-Bedoor B O and Ezokoye I 2003 Economic design of x-bar control chart under hybrid maintenance policy *J. Qual. Maint. Eng.* **9** 100–1

[32] NIST 2013 Example of Shewhart control chart for mass calibrations

[33] Murdoch J 1979 *Control Charts* (London: The Macmillan Press Ltd.)