

## ROUGHNESS EFFECT ON STABILITIES OF STANDARD WEIGHTS CLASS E

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**Abstract:** The stability of the mass of a weight is highly dependent on the surface structures of the weight. In this research, the data have been collected more than 10 years in order to study the trend in changing values of the conventional mass of the standard weight of 1 g to 1 kg class E1 and E2 by controlling the environment of the storage room for these standard weights. The resulting values are assessed to determine the relationship between the conventional mass when it is changing by time. The mean height of roughness profile (Ra) and maximum height of roughness profile (Rz) are determined at the begin and the end of this experiment. Which at the beginning of the experiment, the two values are within specification of OIML R 111-1. These two values are measured by applying a Mirau interferometer (MI) is composed of interference microscope with mirau objectives and light emitting diodes (LEDs) that provide white light over several  $\mu\text{m}$  and a vertical scanning interferometry (VSI). At the same time, the uncertainty values are reported. The drifting trend of the conventional mass value over time is quite constant when the values of Ra and Rz are within the specification of OIML R 111-1. Whereas, the drifting trend of conventional mass value is moving up or moving down when the roughness of the surface is out of specification.

**Keywords:** Mass standard, Roughness, Mirau interferometer (MI) and Vertical scanning interferometry (VSI)

### 1. INTRODUCTION

Surface roughness is one of many parameters that influences on mass stability of standard weight, commonly used as a transfer standard of mass SI unit [1]. A weight with a smooth surface is expected to be more stable than a weight with a rough surface. For surfaces with many scratches, It is more difficult. In dimension metrology, surface roughness is clearly distinguished from surface defects, such as scratches. However, scratches will collect dirt if the weight is exposed to it, so the amount of scratches should be assessed in parallel to the roughness of the non-scratched part of the surface.

Assessing the roughness of a weight is first performed by visual inspection. However for class E and F standard weights, the assessment should also be performed with a stylus instrument or by optical measurement [2]. The instrument used for the roughness measurement should be

validated for its use by roughness standards, i.e. specimens with certified roughness in the same range as the roughness of the weight. This method is more accurate and does not damage the surface. One non-invasive methods for determining surface roughness from a surface profile of material is a interference microscopy with a white light source.

In this paper, the samples are the standard weight of 1 g to 1 kg class E1 and E2 with the total of 52 pieces by controlling the environment of the storage room for these standard weights at the average temperature of  $\pm 0.5^\circ\text{C}$  per 12 hours and at the average relative humidity of  $\pm 5\%$  per 4 hours. The Ra and Rz reported from the measurements of standard weights comprised of 12 measurement points that are: top surface, base surface and rolled-out side surface. Each surface is measured in 4 positions and each position is measured for 10 times. Both values are considered with the drifting trend of the conventional mass value.

### 2. TECHNICAL DETAILS

The system of measurement, called Mirau interferometer (MI) compose of light emitting diodes (LEDs) white illumination is light source, a measurement objective, a scanner assembly and a CCD camera. The interference used to calculate the surface height by splitting the light into reference and sample beams. The reference beam is reflected off a super flat reference mirror inside the objective, while the sample beam is reflected off the sample. The reference mirror inside the objective is positioned so that it is in the same focal plane as the sample. In this configuration, the two light beams recombine and form an interference pattern of light and dark bands called fringes which is detected by CCD camera. The number of fringes and their spacing depends upon the sample shape and the relative tilt between the sample and the reference mirror. If the sample is very flat, the fringes are straight. As the relative tilt between the sample and the reference mirror is reduced, the number of fringes is also reduced until the sample and reference mirror are parallel.

The concept of a Vertical scanning interferometry (VSI) system uses a broadband light source [3]. It is effective for measuring samples with rough surfaces. In VSI, the internal translator moves the objective in z-direction while the camera periodically records frames. As each point on the surface comes into focus, the modulation on that point reaches a maximum, then tapers off as the objective passes

through focus. By recording the height of the translator at maximum modulation, the system can determine the height of each pixel. Fig.1 shows setup of MI system.

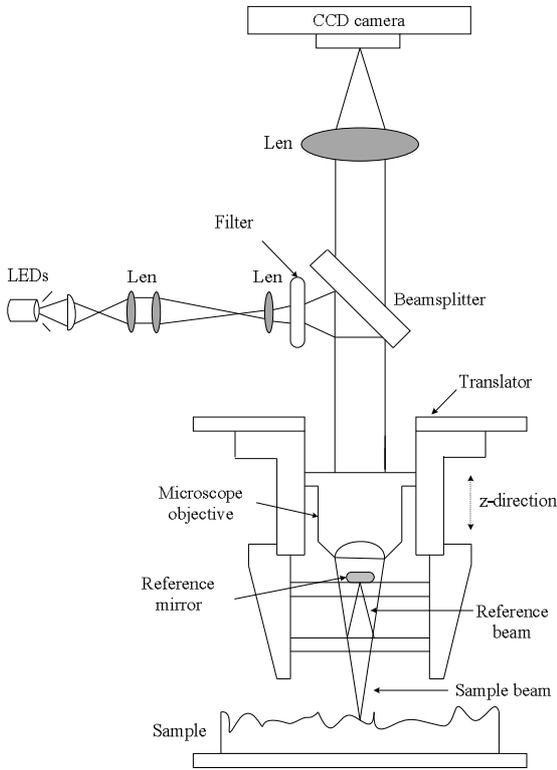


Fig.1 : Schematic of experimental setup

This system, the height of each pixel can be plotted as graph which has a relationship between intensity,  $I$  and scanning position,  $z$ . The Nyquist sampling of the sample data is to be reconstructed as the waveform then it is enveloped [3] as seen in Fig.2. The result for each pixel of the CCD camera as function of the scanning height is a correlogram. From this the height for each pixel can be evaluated and in result can get  $z$ . From each image one or more profile can be extracted. After subtraction of the form by using a form filter, which can evaluate the roughness parameters  $R_a$  and  $R_z$ .

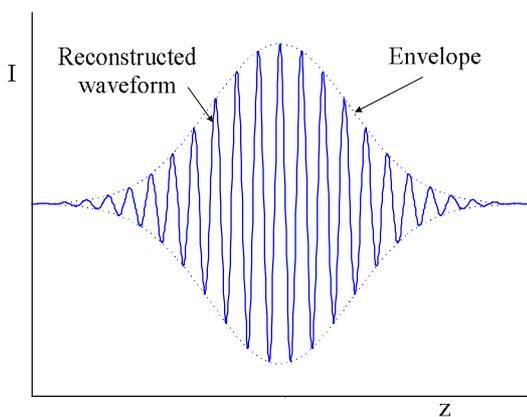


Fig.2 : The relationship between intensity and scanning position

For the mean height of roughness profile ( $R_a$ ) is defined relative to a mean line. It is the mean height departure of the profile from the mean line [4,5]. Fig.3 shows  $R_a$ .

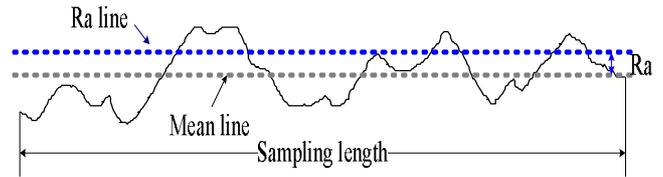


Fig.3 : Mean height of roughness profile,  $R_a$

Thus, if  $z = f(x)$  is the roughness profile measured from the mean line and  $l$  is the length of the profile being assessed (sampling length), then  $R_a$  is defined by

$$R_a = \frac{1}{l} \int_0^l |Z| dx \quad (1)$$

For the maximum height of roughness profile ( $R_z$ ), this parameter is simply the difference in level between the highest peak ( $Z_p$ ) and the lowest valley ( $Z_v$ ) in the sampling length [4,5]. Fig.4. shows  $R_z$ .

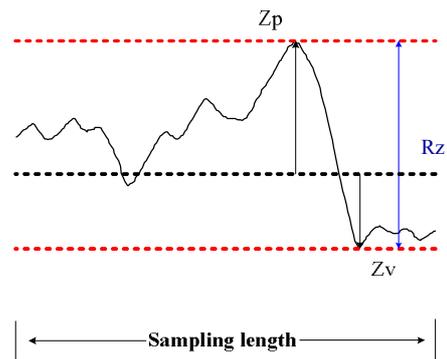


Fig.4 : Maximum height of roughness profile,  $R_z$

The formula of  $R_z$  is

$$R_z = Z_p + Z_v \quad (2)$$

### 3. MEASUREMENT

In this research, the Mirau interferometer and the LEDs are used to characterize the surface area of samples. The standard weight of 1 g to 1 kg class E1 and E2 with the total of 52 pieces are used as samples. The LEDs generate a light beam which is split into two beams; a reference beam and a sample beam. Each beam reflects off a super flat reference mirror and the sample respectively. After that two beams are together combined and are detected by a  $640 \times 480$  pixels Basler scA74-640fm CCD camera. In this paper, the magnification of objective 20X and 50X are used, the numerical aperture of 20X and 50X are 0.4 and 0.55 respectively, the field of view of 20X and 50X are 0.32 mm x 0.24 mm and 0.13 mm x 0.10 mm respectively and the

working distance of 20X and 50X are 4.7 mm and 3.4 mm respectively.

For recording the interferogram, the translator is gradually moved along the z-direction by computer controlled. The vertical measurement range is 0.1 nm to 10 mm. The VSI system with electronic data acquisition that provide a signal for each image pixel as a function of scanning position. The intensity pattern shown in Fig. 2 is the correlogram of a white light intensity, which show the signal itself and an overall modulation envelope with a peak position that at least conceptually provides a non-contact optical measurement of surface height. By combining the results calculate from every pixels of CCD camera, surface topography could be constructed as shown in Fig. 5.

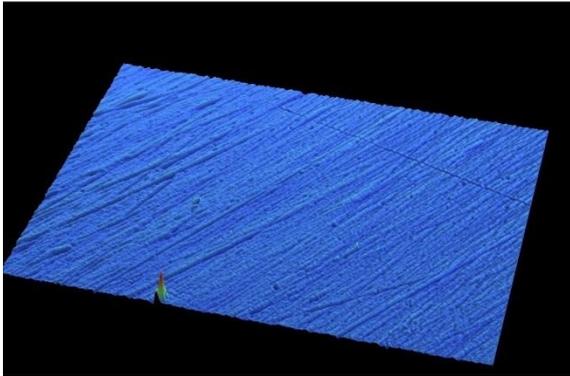


Fig.5 : Surface topography

The Ra and Rz reported from the measurements of standard weights comprised of 12 measurement points that are: top surface, base surface and rolled-out side surface. The measurement points are shown in Fig. 6. Each surface is measured in 4 positions and each position is measured for 10 times.

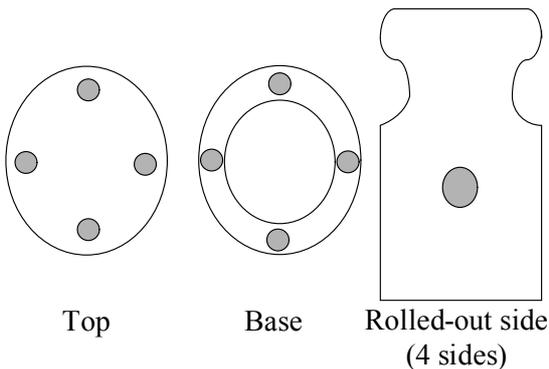


Fig.6 : The measurement points

#### 4. RESULTS AND DISCUSSIONS

In this research, the data have been collected more than 10 years in order to study the trend in changing values of the conventional mass of the standard weight of 1 g to 1 kg class E1 and E2 by controlling the environment of the storage room for these standard weights. The resulting

values are assessed to determine the relationship between the conventional mass when it is changing by time. Most of the conventional mass does not have any change or change a little. The drifting trend of the conventional mass value is quite constant. However, there are some weights with the change. The drifting trend of conventional mass value is moving up or moving down when the roughness of the surface is out of specification. Fig.7 shows the example of roughness profile of the standard weight.

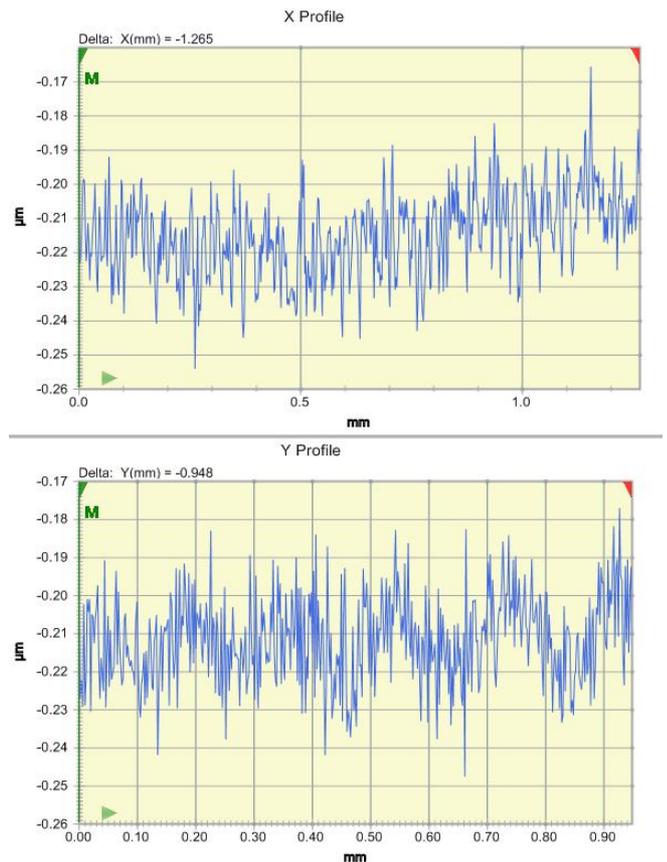


Fig.7 : The example of roughness profile of the standard weight

In this experiment, the drifting trend of conventional mass is separated into 2 groups. The first is the moving up and the second is the moving down. Both results are shown in Table 1 and 2 respectively.

Table 1 : The results of the drifting trend of conventional mass value is moving up (increase of conventional mass)

Nominal value	Drift per year	Ra	Rz
200 g (1)	0.00066 mg	0.02 $\mu\text{m}$	0.93 $\mu\text{m}$
200 g (2)	0.00051 mg	0.03 $\mu\text{m}$	0.83 $\mu\text{m}$
100 g	0.00049 mg	0.03 $\mu\text{m}$	0.80 $\mu\text{m}$
50 g	0.00043 mg	0.02 $\mu\text{m}$	0.70 $\mu\text{m}$
10 g	0.00020 mg	0.02 $\mu\text{m}$	0.55 $\mu\text{m}$

Table 2 : The results of the drifting trend of conventional mass value is moving down (decrease of conventional mass)

Nominal value	Drift per year	Ra	Rz
1 kg (1)	0.009 mg	0.03 $\mu\text{m}$	1.12 $\mu\text{m}$
1 kg (2)	0.005 mg	0.03 $\mu\text{m}$	0.97 $\mu\text{m}$
200 g (1)	0.002 mg	0.03 $\mu\text{m}$	0.90 $\mu\text{m}$
200 g (2)	0.00073 mg	0.02 $\mu\text{m}$	0.82 $\mu\text{m}$
2 g (1)	0.00049 mg	0.04 $\mu\text{m}$	0.78 $\mu\text{m}$
2 g (2)	0.00036 mg	0.07 $\mu\text{m}$	0.67 $\mu\text{m}$
1 g (1)	0.00031 mg	0.08 $\mu\text{m}$	0.64 $\mu\text{m}$
1 g (2)	0.00016 mg	0.05 $\mu\text{m}$	0.54 $\mu\text{m}$

From the result, the Ra separates two ranges :  $0.006 \mu\text{m} < \text{Ra} \leq 0.02 \mu\text{m}$  and  $0.02 \mu\text{m} < \text{Ra} \leq 0.1 \mu\text{m}$ . Refer to ISO 4288 [6]; for the first range, the roughness sampling length is 0.08 mm and the roughness evaluation length is 0.4 mm. For the second range, the roughness sampling length is 0.25 mm and the roughness evaluation length is 1.25 mm are shown in Fig. 7. The data analyzer uses remove linear tilt from surface measurement in a plane fit. Moreover, in this research also uses  $\lambda c$  is 0.08 and 0.25 mm. While  $\lambda s$  be used is 2.5  $\mu\text{m}$  [7].

The examples of the resulting values are assessed to determine the relationship between the conventional mass when it is changing by time are shown in Fig. 8.

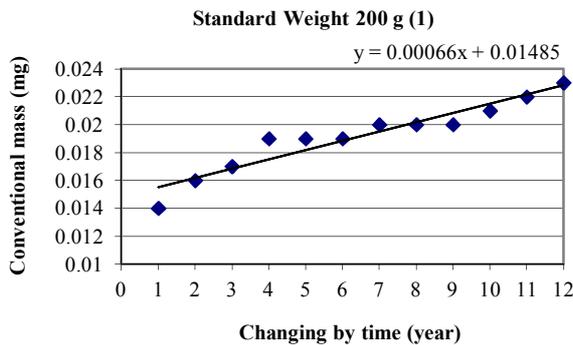


Fig.8a : The relationship between conventional mass and changing by time of the standard weight 200 g (1)

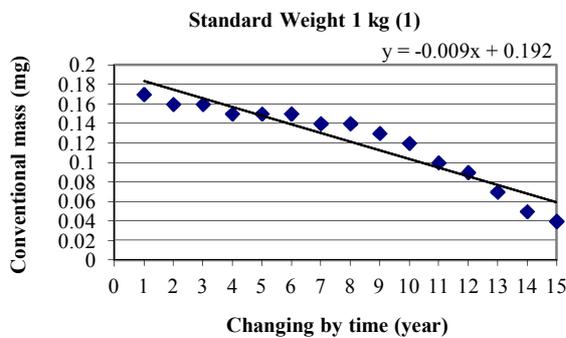


Fig.8b : The relationship between conventional mass and changing by time of the standard weight 1 kg (1)

According to the OIML R 111-1 specification specifies that the standard weight class E1, the Ra and Rz should be less than or equalled to 0.1 and 0.5  $\mu\text{m}$  respectively. In class E2, the Ra and Rz should be less than or equalled to 0.2 and 1  $\mu\text{m}$  respectively. Since 1998, the maintained conventional mass at NIMT is computed for Ra and Rz. These two values are within specification. Presently, the Ra and Rz shows in Table 1 and 2, the Ra measured between 0.02 and 0.08  $\mu\text{m}$  is within its specification. In contrary, the Rz measured results are between 0.54 and 1.12  $\mu\text{m}$ . All the weights are out off their specification according to class E1. Except for 1 kg weight is out off the specification according to class E2. Therefore, the factor that affects the conventional mass of the standard weight is the Rz. The diagrams of the change of conventional mass as function of Rz are shown in Fig. 9.

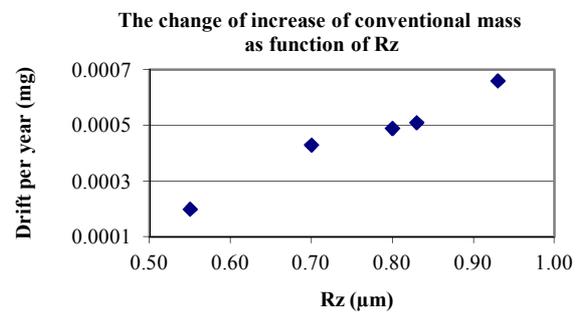


Fig.9a : The diagram of the change of increase of conventional mass as function of Rz

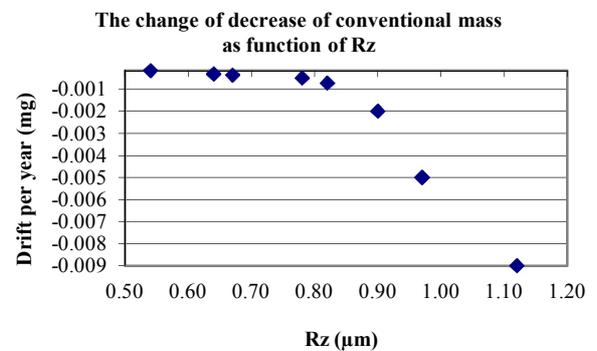


Fig.9b : The diagram of the change of decrease of conventional mass as function of Rz

The Rz with approximately the same amount, the drift rate per year of moving up value is less than the drift rate per year of moving down value (comparing the values in Table 1 and 2). The cause of this manner is because the weights had piled up dirt into itself. The conventional mass of weights are increased rather than decreased, where the drift rate has a small amount. If the standard weights are in the same range, the Rz of those standard weights with larger amount affect the value of the drifting rate at higher rates.

The mathematical model of the system is specified as:

$$Z_C = C \cdot Z_m - Z_{ref} \quad (3)$$

where  $Z_c$  is the corrected roughness profile,  $C$  is the calibration factor ( $d_c/d_m$ ),  $Z_m$  is the measured roughness profile and  $Z_{ref}$  is the correction due to reference mirror in Mirau objective lens.

The  $Z_m$  depends on influence factors in (4).

$$Z_m = Z_d + Z_w + Z_{homo} + Z_{homo-UUC} + Z_n + Z_{motor} \quad (4)$$

From (3) and (4) can be modified to (5).

$$Z_C = \left( \frac{d_c}{d_m} \right) (Z_d + Z_w + Z_{homo} + Z_{homo-UUC} + Z_n + Z_{motor}) - Z_{ref} \quad (5)$$

From (5), the uncertainties of this system comprise of: the uncertainty of standard used for calibration of system ( $d_c$ ), the uncertainty of the measure value of standard used for calibration of system ( $d_m$ ), the uncertainty of the digital resolution of system ( $Z_d$ ), the uncertainty of the repeatability of measurement ( $Z_w$ ), the uncertainty of the homogeneity of standard ( $Z_{homo}$ ), the uncertainty of the homogeneity of standard weight ( $Z_{homo-UUC}$ ), the uncertainty of the noise of system ( $Z_n$ ), the uncertainty of the linearity of stepping motor ( $Z_{motor}$ ) and the uncertainty of the correction due to reference mirror in interference objective lens ( $Z_{ref}$ ).

Thus, the uncertainties as explained above are sources of uncertainty of Ra and Rz. The uncertainty of Ra can be calculated from (1); which can be modified into simple form as follows.

$$Ra = \frac{1}{N} \sum_{i=1}^N |Z_i| \quad (6)$$

$$Ra = \frac{1}{N} [|Z_1| + |Z_2| + |Z_3| + \dots + |Z_N|] \quad (7)$$

Therefore, the combined standard uncertainty of Ra is:

$$u_c(Ra) = \sqrt{u_c^2(Z)} \quad (8)$$

The uncertainty of Rz can be calculated from (2) as follows.

$$u_c^2(Rz) = u_c^2(Zp) + u_c^2(Zv) \quad (9)$$

Therefore, the combined standard uncertainty of Rz is:

$$u_c(Rz) = \sqrt{2u_c^2(Z)} \quad (10)$$

From (7), (8), (9) and (10) using assumption that all points on the roughness profile has the same uncertainty.

In this experiment, the measurement uncertainty is calculated according to M3003 [8]. Examples of uncertainty budget computation are as shown in Table 3 and 4.

Table 3 : An example of uncertainty budget computation of Ra

Quantity	Standard uncertainty		$c_i$	Uncertainty contribution		Degree of freedom
	Absolute	Relative		Absolute	Relative	
$d_c$	-	6.000	0.002 $Z_m$	-	0.012 $Z_m$	$\infty$
$d_m$	-	0.940	0.002 $Z_m$	-	0.002 $Z_m$	$\infty$
$Z_d$	0.0003nm	-	1	0.000 nm	-	$\infty$
$Z_w$	0.0991nm	-	1	0.099 nm	-	9
$Z_{homo}$	2.3904nm	-	1	2.390 nm	-	$\infty$
$Z_{homo-UUC}$	2.8490nm	-	1	2.849 nm	-	$\infty$
$Z_n$	0.0918nm	-	1	0.092 nm	-	$\infty$
$Z_{motor}$	-	0.510	1 $Z_m$	-	0.510 $Z_m$	$\infty$
$Z_{ref}$	0.4196nm	-	1	0.420 nm	-	$\infty$
$u_c(Ra)$				3.745 nm	0.510 $Z_m$	
$U(Ra)$			Normal $k=2$	7.490 nm	1.021 $Z_m$	$\infty$
				$= \sqrt{(7.490)^2 + (1.021 \cdot Z_m)^2}$ nm		

Table 4 : An example of uncertainty budget computation of Rz

Quantity	Standard uncertainty		$c_i$	Uncertainty contribution		Degree of freedom
	Absolute	Relative		Absolute	Relative	
$d_c$	-	25.000	0.000 $Z_m$	-	0.011 $Z_m$	$\infty$
$d_m$	-	1.874	0.000 $Z_m$	-	0.000 $Z_m$	$\infty$
$Z_d$	0.0003nm	-	1	0.000 nm	-	$\infty$
$Z_w$	0.8486nm	-	1	0.849 nm	-	9
$Z_{homo}$	5.8450nm	-	1	5.845 nm	-	$\infty$
$Z_{homo-UUC}$	38.363nm	-	1	38.363 nm	-	$\infty$
$Z_n$	0.3112nm	-	1	0.311 nm	-	$\infty$
$Z_{motor}$	-	0.502	1 $Z_m$	-	0.502 $Z_m$	$\infty$
$Z_{ref}$	3.0002nm	-	1	3.000 nm	-	$\infty$
$u_c(Rz)$				55.058 nm	0.711 $Z_m$	
$U(Rz)$			Normal $k=2$	110.116 nm	1.422 $Z_m$	$\infty$
				$= \sqrt{(110.116)^2 + (1.422 \cdot Z_m)^2}$ nm		

The Ra and Rz shown in Table 1 and 2 are calculated uncertainties according to the mathematical model as explained in (5), (8) and (10). The computed uncertainties of Ra range between 0.022 and 0.082  $\mu\text{m}$ ; whereas, the uncertainties of Rz range between 0.776 and 1.596  $\mu\text{m}$ .

Sources of measured uncertainties can be separated into two categories; namely, uncertainty caused by measurement system and uncertainty caused by measured samples. The sources of uncertainty caused by measurement system are consistent; it only changes after the yearly calibration program. The uncertainty caused by measured sample is changed in every measurement depending on the sampling weights. The changing sources are the uncertainty due to the repeatability of measurements and the uncertainty due to the homogeneity of standard weights.

## 5. CONCLUSIONS

The drifting trend of the conventional mass value is moderately constant when the values of Ra and Rz are within their specification. On the contrary, the drifting trend of conventional mass value is moving up or moving down depending on the roughness of the surface especially when the Rz is larger than its specified specification. This research shows that when the Rz is larger than 0.5  $\mu\text{m}$ , it affects the moving value of the conventional mass by drifting down at the rate of 0.01 mg per year (this amount is largest of the round up values into two digits), while the moving up value is at the rate of 0.001 mg per year (this as well is largest amount of the round up values into three digits). The changing rates of weights are proportional to the standard weights.

## 6. REFERENCES

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