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Proficiency Testing for Surface Roughness Standard and Groove Depth Standard

ARIF SANJID M.*, K P. CHUADHARY and R.P. SINGHAL
National Physical Laboratory
Dr. K.S. Krishnan Road, New Delhi-110 012
**e-mail : sanjid@mail.nplindia.ernet.in*

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Abstract

Surface finish of products indicates the quality of machining process in manufacturing industry. Surface texture measurements provide index of quality of manufacturing stability. National Physical Laboratory, New Delhi, India (NPLI) maintains reference surface roughness standards and measuring equipment and established traceability in surface roughness measurement rendering the surface roughness calibration services. National accreditation board for testing, calibration laboratories (NABL) conducted proficiency testing (PT) program among NABL accredited laboratories for the measurement of surface roughness standard and groove depth. NPLI has coordinated the PT Program and acting as reference laboratory among ten accredited laboratories. A technical protocol is designed in line with internationally adopted method. In this paper, the results are analyzed statistically by arithmetic mean methods. The performance of the laboratories is described using the calculated normalized error (E_n) value as an index.

1. Introduction

Surface metrology research and practice is focused on the classical approach of surface wavelength content-based analysis. Quantitative measurements of surface features have received enormous attention from science and industry following the rapid development of precision technologies. Different kinds of methods are being developed for measuring surface textures. Among them, stylus profilometry, optical and scanning probe techniques are three main categories of widely used methods. Stylus profilometry is a traditional method with a history of more than 70 years. It usually uses a diamond tip; which is scanned across sample surfaces. The topographic information on the surface is then derived from the vertical motion of the stylus measured by means of an optical, capacitive or inductive sensor.

Globally, considerable efforts are being made in building the confidence that the measurements made in one location in the world are equivalent/ compatible to those made elsewhere on the same or related products. One way of achieving this is interlaboratory comparison of measurement results. This is also a requirement under Mutual Recognition Arrangement of Asia Pacific Laboratory Accreditation Cooperation (APLAC) to participate in the PT and establish the technical competence.

NPLI under MoU with National Accreditation Board for Testing & Calibration Laboratories (NABL) conducted proficiency testing amongst the NABL accredited calibration laboratories in India [1].

This report summarizes the results of measurements of seven roughness parameters on two surface roughness standard artifacts submitted by participant laboratories. Ten NABL accredited laboratories participated in this program. This is the first interlaboratory comparison within the country in the area of length measurement using surface roughness standards as artifacts. The circulation of artifacts commenced in November 2005 and completed in January 2007.

2. Design of the Program

The accreditation body ,the NABL is required to organize proficiency testing programs similar to international inter-comparisons following document NABL-162(2001)[2] to build and maintain the technical competence of all its accredited laboratories. Interlaboratory comparison is a powerful tool in assessing laboratory's capability and provides objective evidence that laboratory is competent and that it can achieve the level of uncertainty for which it is accredited. Such exercise gives an opportunity to accredited calibration laboratories to have traceability to National Metrology Institute i.e. NPLI. Two artifacts (a) Surface Roughness Standard (Type D) with

Table 1
Time Schedule of completion by participant

Sl No	Participant Laboratory	Planned Duration	Actual Duration
Ref	National Physical Laboratory New Delhi –110012 **(Reference Laboratory)**	—	02.10.2005 15.10.2005
1	Fluid Control Research Institute, Palghat	02.11.2005 (22.11.2005)	02.11.2005 (13.12.2005)
2	Khosaca calibration Lab (P)Ltd. Chennai-600053	28.11.2005 (18.12.2005)	16.12.2005 (25.01.2006)
3	Metrology Laboratory CMTI,Bangalore-560022	25.12.2005 (15.01.2006)	30.01.2006 (10.04.2006)
4	Metrology Lab Tata Engineering, Pimpri Pune-411018	22.01.2006 (12.03.2006)	12.04.2006 (31.04.2006)
5	TMC Measuring Instruments, Pune	15.01.2006 (05.02.2006)	03.05.2006 (19.05.2006)
6	Baker Gauge India Ltd., Pune-411 014	07.02.2006 (28.02.2006)	22.05.2006 (15.06.2006)
7	Regional Testing Center (NR), New Delhi -110020	05.03.2006 (26.03.2006)	15.06.2006 (27.07.2006)
8	Maruti Udyog Limited, Gurgaon-122015	29.03.2006 (20.04.2006)	27.07.2006 (26.08.2006)
9	Institute of Machine Tools Technology Batala-143505	27.04.2006 (18.05.2006)	30.08.2006 (20.09.2006)
10	Cummins India ltd., Pune	25.06.2006 (16.06.2006)	20.09.2006 (10.10.2006)
Ref	National Physical Laboratory New Delhi –110012 **(Reference Laboratory)**	—	15.11.2006 (25.01.2007)

The dates shown in parenthsis are the dates of completion of measurements.

nominal value of Ra = 0.6 µm and serial number 555(0791555) and (b) Groove Depth Standard (Type A1) with a nominal value of groove depth D = 9.1µm and serial number 1430(PEN-10-1) have been circulated to participant laboratories following the agreed schedule as given in Table 1. The laboratories were selected knowing the facility available in their laboratory with their letter of willingness to participate in the program. This PT program is coded as NABL-M-Length-005. These artifact standards are packed in a wooden box and transported through courier service.

As per ISO 4287:1997, definitions of the parameters measured are as follows:

Ra : Arithmetic mean deviation of the assessed profile : arithmetic mean of the absolute ordinate values Z(x) from the mean line within a sampling length.

Rz : Maximum height of profile : average height of the largest profile peak height Zp and the largest profile valley depth Zv over a sampling length.

Note : Number of evaluation lengths must be five in this context.

Rmax : Maximum height of profile : largest profile peak height Rz within a sampling length.

Pt : Total height of profile : sum of the height of the largest profile peak height Zp and the largest profile valley depth Zv within the evaluation length.

D (Depth) : As per the definition given in ISO 5436-1-2000 **Type A1 :** the height from the maximum valley to top flat surface.

The participants were advised to measure the surface roughness parameter "Ra; Rz; Rmax" on surface roughness artifact and groove depth parameters "D (Left); D (Right) and Pt (Left); Pt (Right)"on groove depth standard.

3. Methodology

NPLI uses diamond tip stylus to measure the

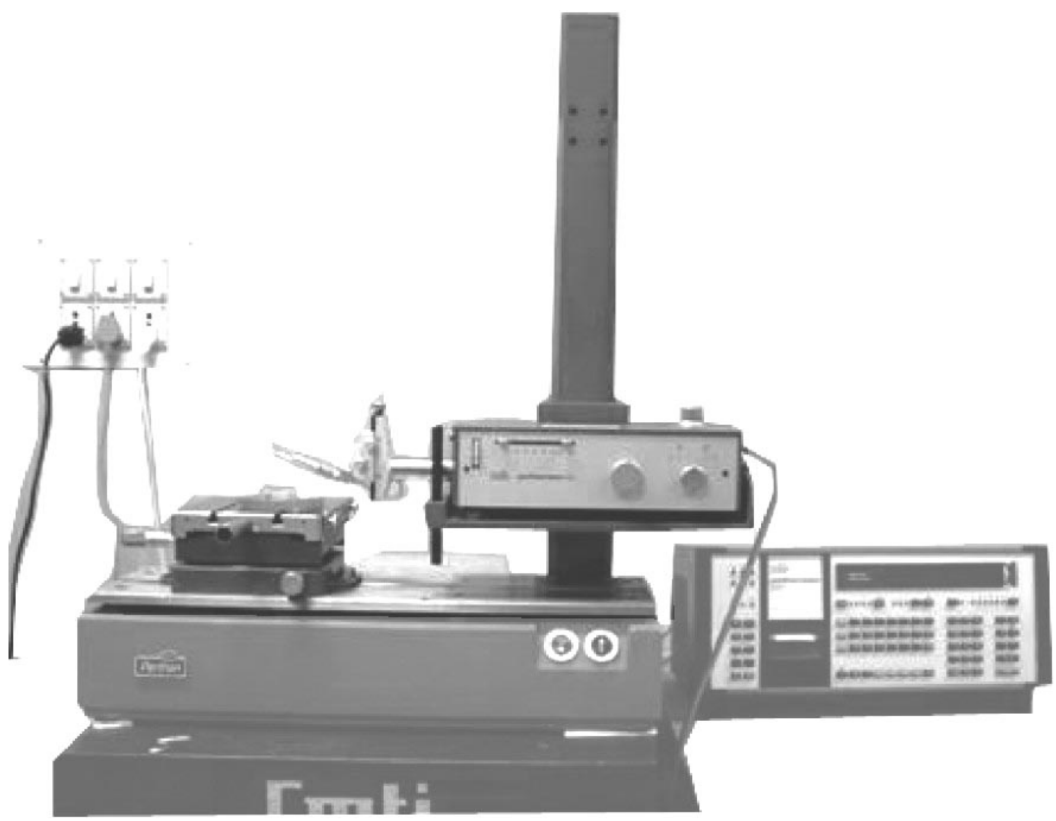

Fig. 1. Surface roughness measuring instrument arranged at NPLI

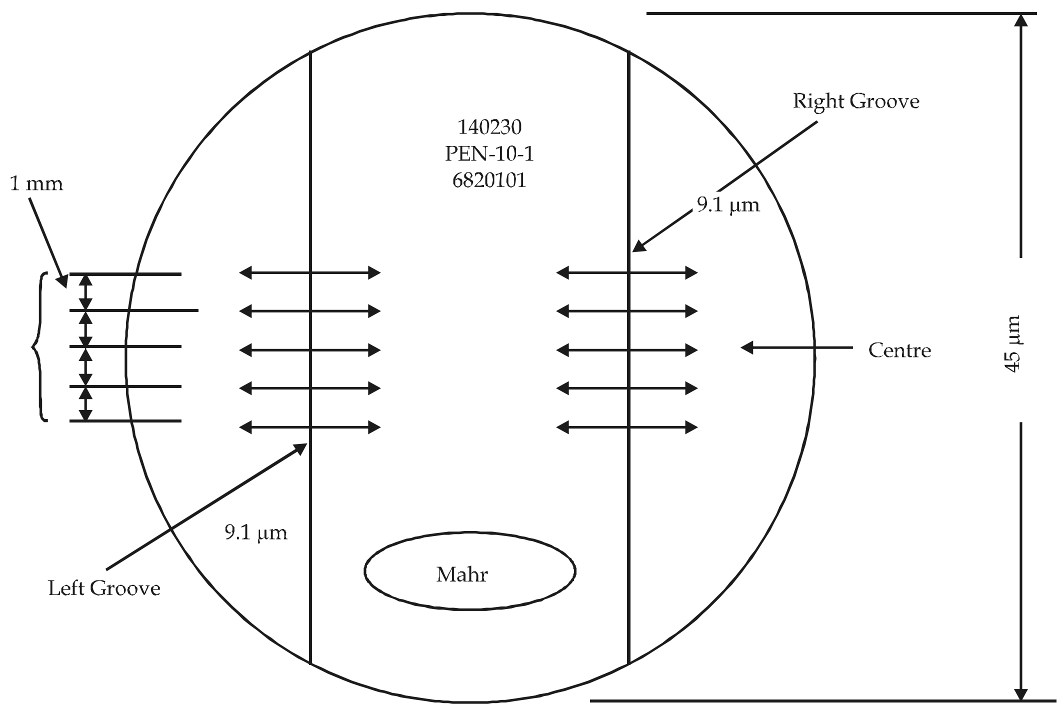

Fig. 2 a. Tracing scheme for Groove depth standard (Type A) artifact circulated among the participant laboratories

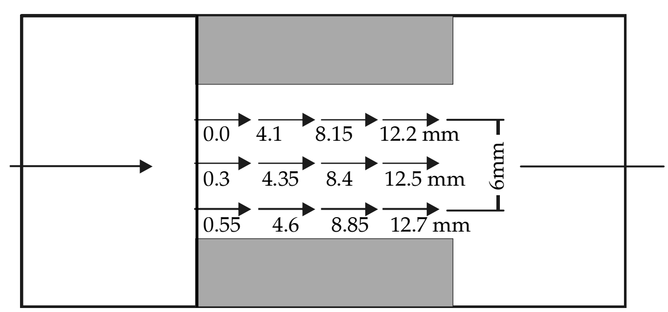

Fig. 2 b. Tracing scheme for Surface roughness standard artifact circulated among the participant laboratories

surface profile of the sample. The tip size is of 4 µm and an angle of 45°. The profile is traced for the specified evaluation length according ISO 4288 suitable to measure the texture of surface. The instantaneous vertical displacements of diamond are coupled though cantilever to LVDT sensor electronics. This electronic sensor produces the signal according to the trace of the stylus tip [3-5]. The lateral movement is controlled to the set values by the controller of the instrument. RC filters are employed to produce the roughness profile, waviness profile from the raw profile (primary profile). Fig. 1 depicts the surface roughness measurement set-up at NPLI. The tracing scheme for Groove depth standard (Type A) and Roughness Standard (Type D) is as shown in the Fig. 2 (a, b) [6].

3.1 *Groove Depth Standard*

- Make five trace on left and right groove separated by 1 mm both forward and backward direction (unlike roughness measurement, in this case the specimen may be traced bidirectional).

- Opt for Pt and Depth of the Groove.
- The waviness and tilt observed between the grooves will contribute to the symmetry of the specimen (the form).

3.2 Surface Roughness Standard

- Align the specimen on the platform of instrument so as to match the tracing trajectory in line with the Arrow Mark direction indicated on the specimen.
- A minimum five readings must be taken for three trace in the Centre, Right side (shift the specimen by 2.5 mm to right side) and Left side (by shifting the specimen by 2.5mm away from centre to left side).
- Take the readings in forward direction i.e. only as indicated by the arrow mark.
- Opt for the Ra, Rz and Rmax values.

4. Results

The results submitted by the participant laboratories are summarized and given in Tables 2 & 3. Participant laboratories were asked to express their results in a format provided to them and also to certify these measurements in the format of their practice to customers. An example measurement uncertainty was given in the Technical Protocol for guidance. Laboratories were also asked to mention

Table 2

Summary of participant laboratory results (in μm)

Code	Ra	Rz	Rmax	Pt(Left)	Pt(Right)	D(Left)	D(Right)
1	0.5998	NA	NA	NA	NA	NA	NA
2	0.5860	NA	NA	NA	NA	NA	NA
3	0.6000	3.32	4.28	NA	NA	NA	NA
4	0.6230	3.766	3.7	NA	NA	9.1	9.0
5	0.6100	NA	NA	NA	NA	NA	NA
6	0.6013	3.491	4.425	9.29	9.336	NA	NA
7	0.5880	3.335	4.31	9.333	9.33	NA	NA
8	0.5850	3.2734	4.04	9.22	9.21	9.14	9.15
9	0.6330	3.341	4.114	9.263	9.25	9.127	9.134
10	0.6000	3.4	1.4	14.4	14.5	10.1	10.1

Table 3

Uncertainty of participant laboratory results (in μm)

Code	Ra	Rz	Rmax	Pt(Left)	Pt(Right)	D(Left)	D(Right)
1	0.042	NA	NA	NA	NA	NA	NA
2	0.0486	NA	NA	NA	NA	NA	NA
3	0.0504	0.276	0.345	NA	NA	NA	NA
4	0.0561	0.323	0.316	NA	NA	0.735	0.735
5	0.034	NA	NA	NA	NA	NA	NA
6	0.062	0.216	0.264	0.541	0.541	NA	NA
7	0.059	0.334	0.431	0.933	0.933	NA	NA
8	0.032	0.180	0.222	0.58	0.507	0.503	0.503
9	0.042	0.224	0.276	0.93	0.988	0.913	0.932
10	0.080	0.080	0.182	1.872	1.885	1.313	1.313

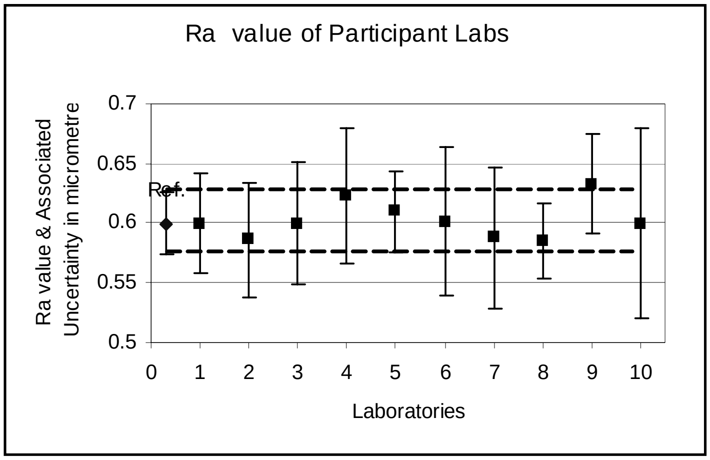

Fig. 3 a. Graphical representation of participant laboratory results for parameter Ra

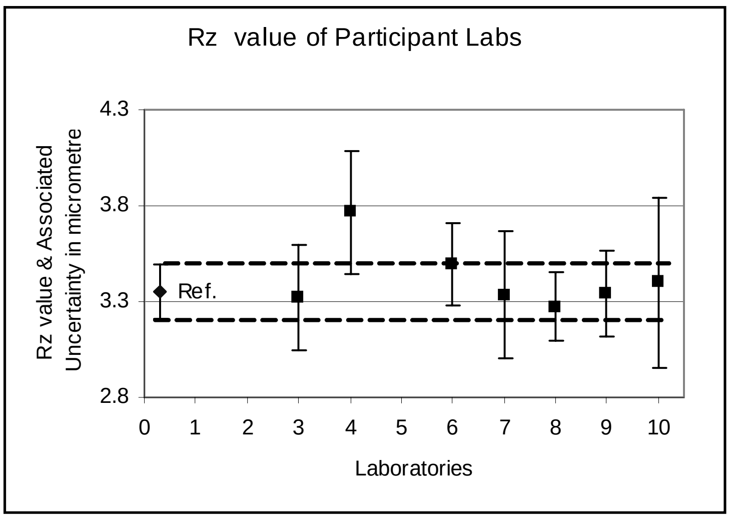

Fig. 3 b. Graphical representation of participant laboratory results for parameter Rz

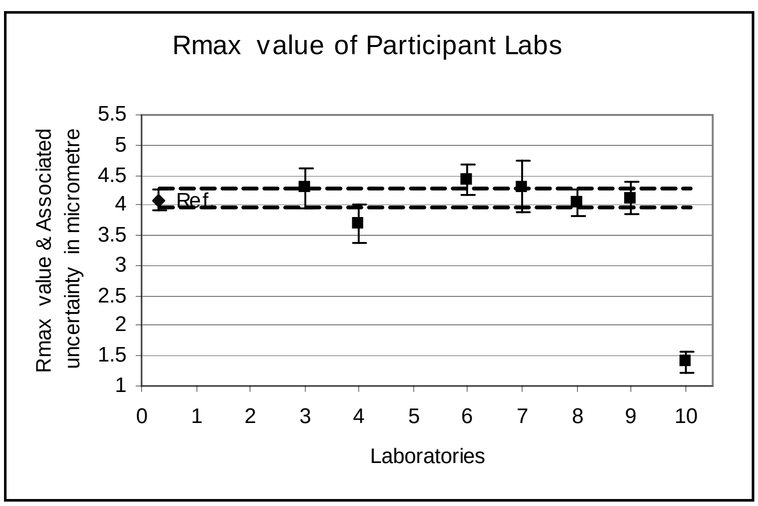

Fig. 3 c. Graphical representation of participant laboratory results for parameter Rmax

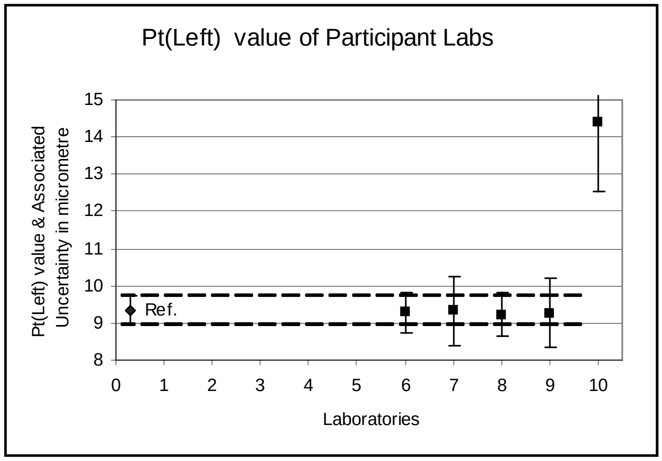

Fig. 3 d. Graphical representation of participant laboratory results for parameter Pt (Left)

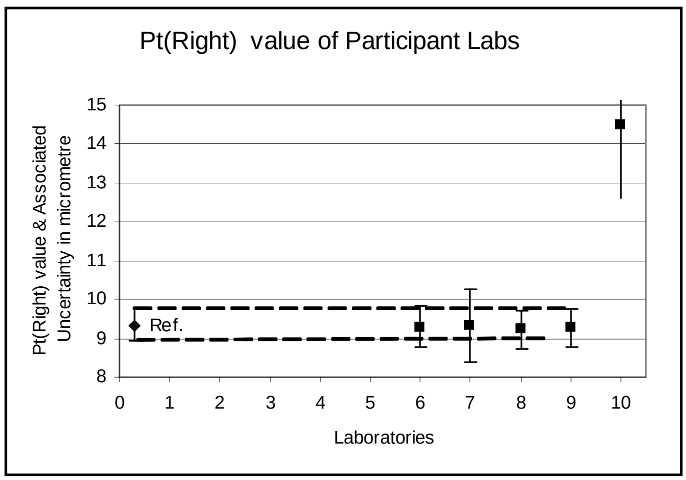

Fig. 3 e. Graphical representation of participant laboratory results for parameter Pt (Right)

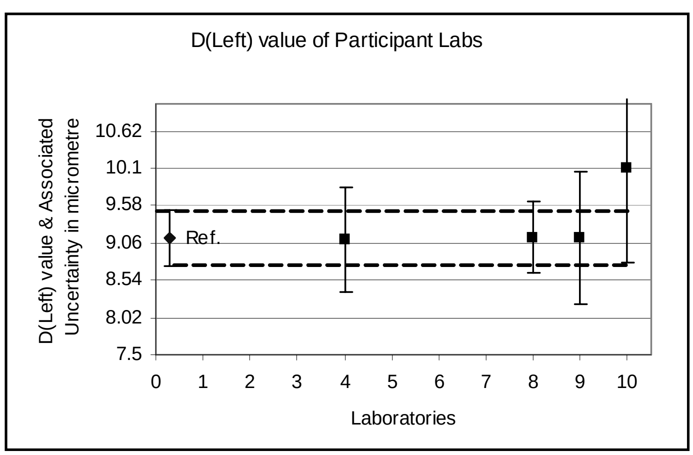

Fig. 3 f. Graphical representation of participant laboratory results for parameter D(Left)

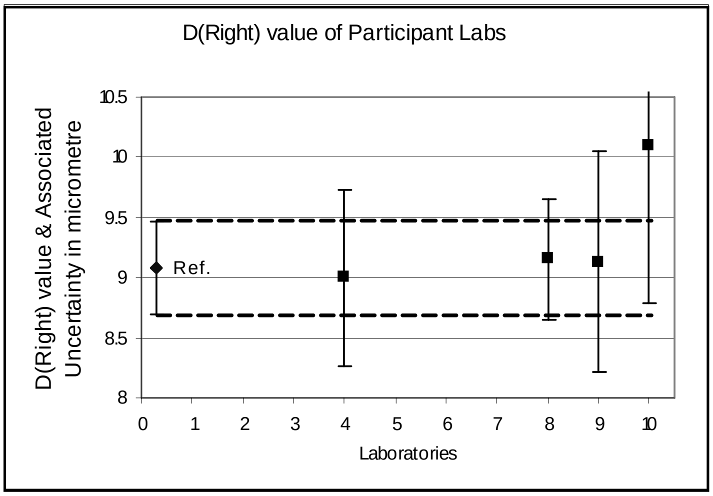

Fig. 3 g. Graphical representation of participant laboratory results for parameter D (Right)

Table 4
Results obtained by the Reference Laboratory

Parameters	Before circulation (µm)	After circulation (µm)	Reference value (µm)	Uncertainty (µm)
Ra	0.599	0.60	0.600	0.026
Rz	3.42	3.29	3.355	0.142
Rmax	4.19	3.98	4.085	0.173
Pt (Left)	9.39	9.27	9.330	0.396
Pt (Right)	9.37	9.27	9.320	0.395
D (Left)	9.11	9.13	9.120	0.387
D (Right)	9.09	9.06	9.075	0.385

traceability evidence i.e. calibration certificates of the reference instrument used in measurements, calculation sheet for determining the uncertainty of measurements and calibration certificate of the surface roughness in the format normally issued to a customer. The graphical representation of participant laboratory results along with associated uncertainties is given as Figs. 3 (a-g).

5. Analysis of Results

A reference value is calculated by arithmetic mean and its associated uncertainty is calculated for each parameter from results (y_i) obtained at reference laboratory before and after circulation [7]. The reference value (y_{ref}), associated uncertainty ($u_c(y_{ref})$) are calculated using the following equations. The calculated reference value and its associated uncertainty are given in Table 4. Here N is equal to two.

$$y_{ref} = \sum_{i=1}^{N} y_i / N \tag{1}$$

$$u_i(y_{ref}) = \sqrt{\sum_{i=1}^{N} u^2(y_i)/N^2} \tag{2}$$

In accordance with international practice, measurement performance has been assessed on the basis of normalized error (E_n) number of each measurement. The E_n number is calculated using a standard statistical formula given below.

$$E_n = \frac{\text{Lab. Value} - \text{Ref. Value}}{\sqrt{(U_{lab})^2 + (U_{ref})^2}} \tag{3}$$

Table 5
E_n value of participant laboratories for each parameter

Code	Ra	Rz	Rmax	Pt(Left)	Pt(Right)	D(Left)	D(Right)
1	0.00	NA	NA	NA	NA	NA	NA
2	-0.25	NA	NA	NA	NA	NA	NA
3	0.00	-0.11	0.50	NA	NA	NA	NA
4	0.37	1.17	-1.07	NA	NA	-0.02	0.03
5	0.24	NA	NA	NA	NA	NA	NA
6	0.02	0.53	1.08	-0.07	0.02	NA	NA
7	-0.19	- 0.06	0.48	0.00	0.01	NA	NA
8	-0.36	-0.36	-0.16	-0.21	-0.17	0.03	0.12
9	0.66	0.05	0.09	-0.07	0.17	0.01	0.06
10	0.00	0.10	-10.69	2.70	2.69	0.72	0.75

NA : Not attempted to measure these parameters by the participant laboratory due to non availability of facility or lack of competence of measurement.

In this U is reported expanded uncertainty with a coverage factor, k=2 at a confidence level of approximately 95%. For the results to be internationally acceptable, values of E_n between-1 and +1 must be achieved. An E_n number between-1 and +1 indicates an acceptable degree of compatibility between the laboratory's results and the reference value when the quoted uncertainties are taken into account. E_n number outside the -1 and +1 range is unacceptable and requires immediate investigation and corrective action by the laboratory concerned. E_n values for each parameter of the participant laboratories are summarized in Table 5.

6. Discussion

In general, an E_n number with an absolute value greater than unity indicates that there is a significant deviation in the laboratory's result from the reference value and the its quoted uncertainty associated with the laboratory results does not adequately accommodating the deviation. The deviation may be due to *(i) improper calibration of the instrument against the calibrated surface roughness standard used for its setting (ii) not taking sufficient care to align artifacts and measuring stylus movement (iii) not considering some of the uncertainty components while preparing uncertainty of measurements.*

- All the participants reported surface roughness parameter "Ra" along with its associated uncertainty.
- E_n value for Lab code no. 4 and 6 is marginally high 1.07 and 1.08 respectively. The E_n value of Lab Code no.10 is 10.69 for surface roughness parameter Rmax.
- Lab code No. 10 wrongly calculated the uncertainty for Rz, Rmax, Pt (Left), Pt (Right) and D (Left), D(Right). Their uncertainty is taken as same as that calculated for surface roughness parameter Ra i.e. 13%. They need to calculate the uncertainty again.
- The measured values of D (Left), D (Right) of lab code no. 10 are falling away from the reference laboratory value.
- The Pt (Left), Pt (Right) measurements of lab code no.10 are away from reference value and hence large E_n value is resulted.
- Lab code no. 8 reported depth parameters mean of "Pt (Left), Pt (Right) and D (Left), D (Right)" in the certificates. As the measurement is carried out on left and right groove separately, their results need to be reported separately. Reference laboratory have taken these results submitted by the lab in the format as given in the Technical Protocol for calculations.

The following corrective actions suggested

i. Lab code no. 8 needs to consider the effect of stylus radius during calculating uncertainty of measurement. Lab code no. 8 is using stylus of diameter 2 μm which is smaller than the stylus diameter used by reference laboratory and remaining participant i.e. 5 μm.

ii. The surface roughness instrument setup is of industrial type at Lab code no. 5 and 10. The accuracy of these instruments is low compared to that of laboratory type of instrument used by reference laboratory and remaining participant.

iii. Lab code no. 5 reported lower uncertainty as it is not considering some uncertainty contribution components viz. alignment errors, surface texture homogeneity, instrument calibration errors.

iv. Lab code no. 5 and 10 attempted to follow the uncertainty evaluation of surface roughness as given for guidance in the technical protocol. Unfortunately they have not substituted their own instruments details viz. resolution, nonlinearity etc and their instrument calibration setting standard wherever required.

v. Lab code no 3 did some conceptual mistakes in evaluation of uncertainty.

vi. Lab code no. 8 and 9 reported the variation of parameters as maximum value to minimum value and also mean value. This leads to confusion to predict the surface texture. The parameters must be measured homogeneously as given in the protocol to estimate mean, uncertainty contribution as Type - A.

vii. Lab code no 1, 2 and 5 are advised to establish facility to measure parameters Pt and D; which are important for the calibration of surface roughness instrument.

viii. All the participant laboratories have followed different methods of uncertainty calculation as no unique method is readily available. Further training is required regarding uncertainty of measurement calculations

7. Conclusion

The proficiency testing confirms that the results reported by the accredited laboratories were generally in good agreement. Out of the 42 measurement results, 36 (87%) were in agreement with the reference laboratory.

References

[1] ISO/IEC 43-1 Proficiency Testing by Inter Laboratory Comparison Part-1 Development and Operation of Proficiency Testing Schemes.

Part 2 Selection and use of Proficiency Testing Schemes by Laboratory Accreditation Bodies.

[2] Guidelines for Proficiency Testing Program for Testing & Calibration Laboratories. NABL 162 (2001).

[3] Calibration of Stylus Instruments for Measuring Surface roughness, EAL-G20, Edition **1**, August 1996.

[4] W.L. Wang and D.J. Whitehouse, Method for Setting Fidelity Criteria for Surface -Measuring Instruments, Precision Engineering, **17** (1995) 274-280.

[5] H. Haitjema, International Comparison of Depth-Setting Standards, Metrologia, **34** (1997)161-167.

[6] Euromet Supplementary Comparison "Surface Texture" Technical report, May 2004.

[7] Guidelines for Estimation and Expression of Uncertainty inmeasurement. NABL -141 (2000).

[8] R.P. Singhal, N.K. Aggarwal, A.K. Sexena and S.U.M. Rao. Interlaboratory Proficiency Testing; Gauge Block Intercomparison-2001/02, MĀPAN-JMSI, **17** (2002) 91.