Final Report of APMP.AUV.V-S2: Supplementary comparison on calibration of laser tachometers using mechanical generators or optical simulators

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1. Introduction

This report presents the results of the second Asia Pacific Metrology Programme (APMP) supplementary comparison in the area of rotational speed, which in this case means calibration of laser tachometers.

The participants have reached consensus and considered the weighted mean as the most appropriate method for this particular comparison to compute the supplementary comparison reference values (SCRVs) and the degrees of equivalence (DoEs). Detailed analysis and application of the method for use of the weighted mean in comparisons in the field of vibration, is documented in the CCAUV.V-K1 report [1]. The calculation of the SCRVs is also in accordance with the Guidelines for CIPM key comparisons [2].

The Technical Protocol, published in 2022 [3], specifies in detail the aim, the task of the comparison, the conditions for the measurements, the transfer standard used, measurement instructions, time schedule and other items. A brief survey of the Technical Protocol is given in the following sections. Refer to Annex A for details of the TP.

It should be noticed that for this comparison, mechanical generators or optical simulators are applied as rotational speed standard devices with the comparison range from 30 rpm to 99 996 rpm. The previous comparison of APMP.AUV.V-S1 allows only mechanical generators as rotational speed standard devices with the comparison range from 10 rpm to 99 999 rpm [4]. The results of these two comparisons can support each other as direct or circumstantial evidence.

2. Participants

Table 2.1: List of participants and schedule of APMP.AUV.V-S2

No.	Participant Laboratory	Acronym	Country	RMO	Calibration period (week/year)
1	National Institute of Metrology	NIM	China	APMP	41/2022 to 42/2022
2	National Metrology Centre, Agency for Science, Technology and Research	NMC	Singapore	APMP	45/2022 to 46/2022
3	National Metrology Laboratory	NML	Philippines	APMP	49/2022 to 50/2022
4	National Institute of Metrology	NIMT	Thailand	APMP	01/2023 to 02/2023
5	Kenya Bureau of Standards	KEBS	Kenya	AFRIMETS	05/2023 to 06/2023
6	National Institute of Standards	NIS	Egypt	AFRIMETS	09/2023 to 10/2023

Six metrology institutes (NMIs) from two RMOs participated in the comparison. They are listed in chronological order of measurement in Table 2.1.

3. Task and purpose of the comparison

According to the rules set up by the CIPM MRA [5], the consultative committees of the CIPM have the responsibility to establish Degrees of Equivalence (DoEs) between the different measurement standards operated by the NMIs. This is done by conducting key comparisons (KCs) on different levels of the international metrological infrastructure.

However, in the sub-field of rotational speed, there is no formal comparison either at Consultative Committee (CC) level or Regional Metrology Organization Technical Committee (RMO TC) level. Therefore, during the meeting of APMP TCAUV in 2021, the decision was taken to make preparations for a supplementary comparison targeted at rotational speed (constant acceleration).

This regional supplementary comparison is organized in order to compare primary measurements of rotational speed in the range from 30 rpm to 99 996 rpm. It is the task of the comparison to calibrate two laser digital tachometers at different rotational speed values as specified in section 3 of [3]. The results of this APMP supplementary comparison may serve as supporting evidence for the registration of ‘calibration and measurement capabilities’ (CMCs) in the framework of the CIPM MRA. [5].

The measured value of rotational speed is calculated as the average of ten successive measurement results at its reflective mark of a rotational speed standard device or upon the optical flash of an optical simulator type. The measured value shall be given in revolution per minute (r/min or rpm) for different measurement conditions specified in section 3 of [3]. To avoid rounding error of the optical simulators, the measured values for the comparison are exactly divisible by 60.

For the calibration of the laser tachometer, rotational speed standard device of mechanical generator type or optical simulator type has to be applied. Specifically, NIM, NMC and NIS use standard device of mechanical generator type. NML, NIMT and KEBS use standard device of optical simulator type.

The reported measured values and associated uncertainties will be used for the calculation of mean values of the supplementary comparison results and their associated uncertainties, as well as the deviations to the mean values with associated uncertainties.

4. Transfer standard as artefacts

For the purpose of the comparison the pilot laboratory selected two laser tachometers of which monitoring data for six months were available and not included in any published international cooperation work.

- Two laser tachometers, EMT260C, SN: NLYZ-02 and NLYZ-03.

The investigation of the long-term stability was continued after the circulation period. The results of the NIM stability measurements and other individual data of the transfer standards are given in Section 6. Note that NLYZ-03 was deliberately customized with a deviation of -0.1% from the nominal value.

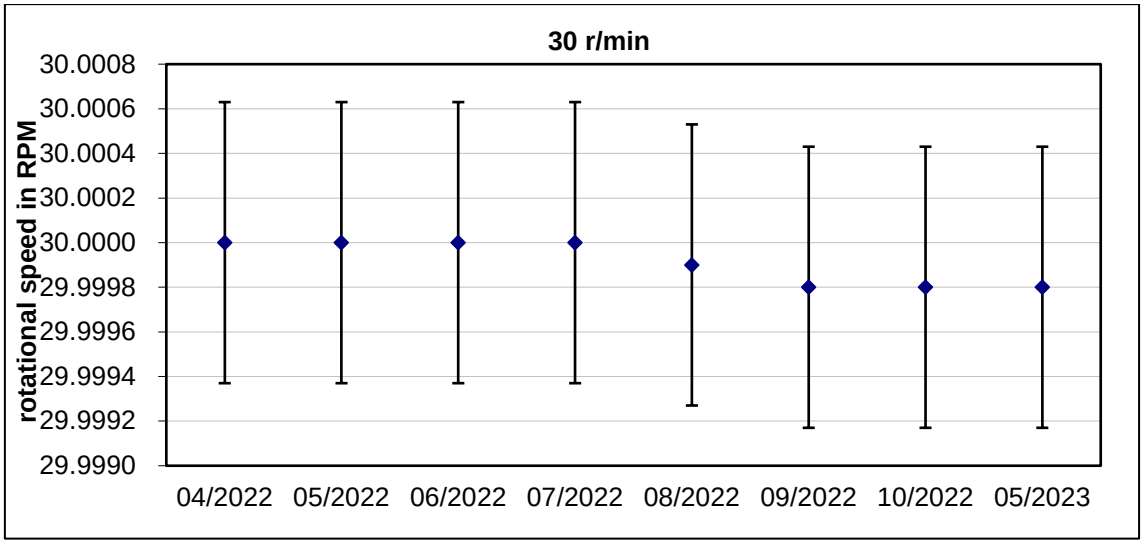
5. Circulation of the artefacts

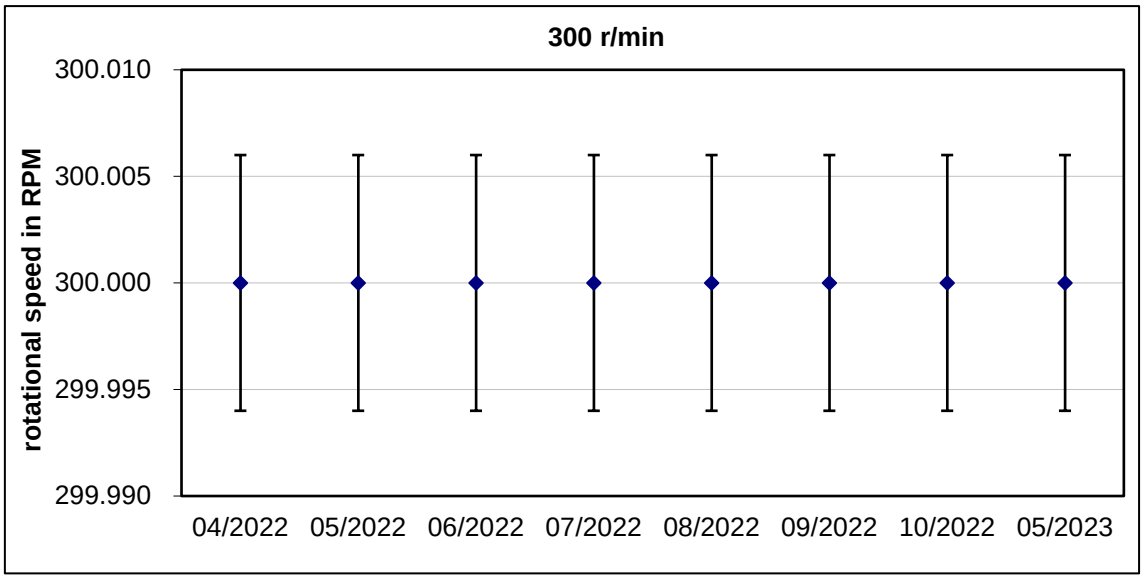
The artefacts were circulated in a star type with a measurement period of two weeks provided for each participating laboratory. At the beginning and the end of the circulation, the artefacts were measured by the pilot laboratory in order to monitor the stability of the transfer standard.

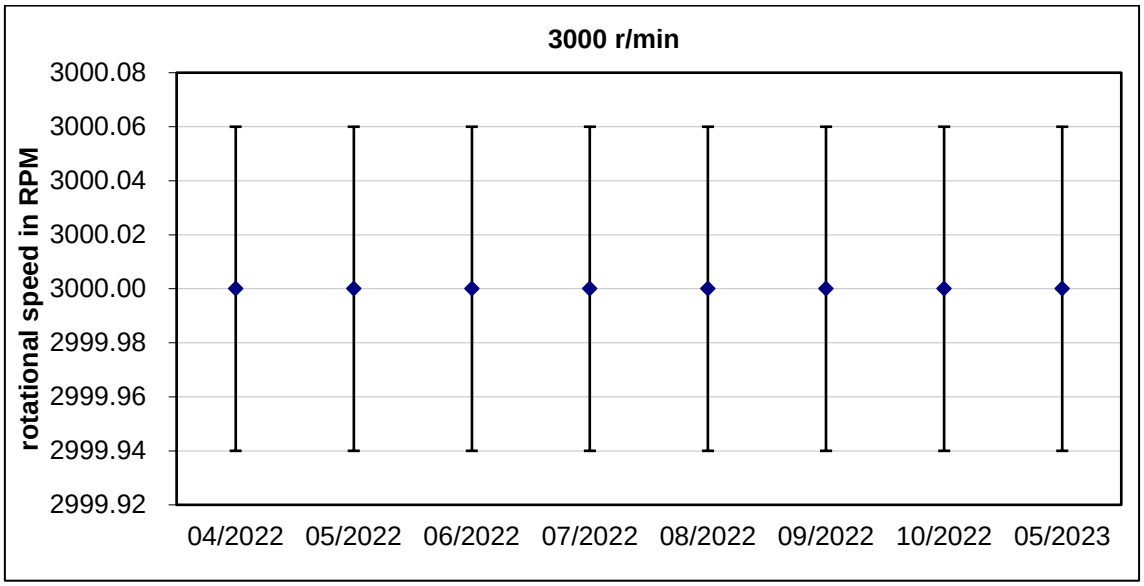
6. Results of the monitoring measurements

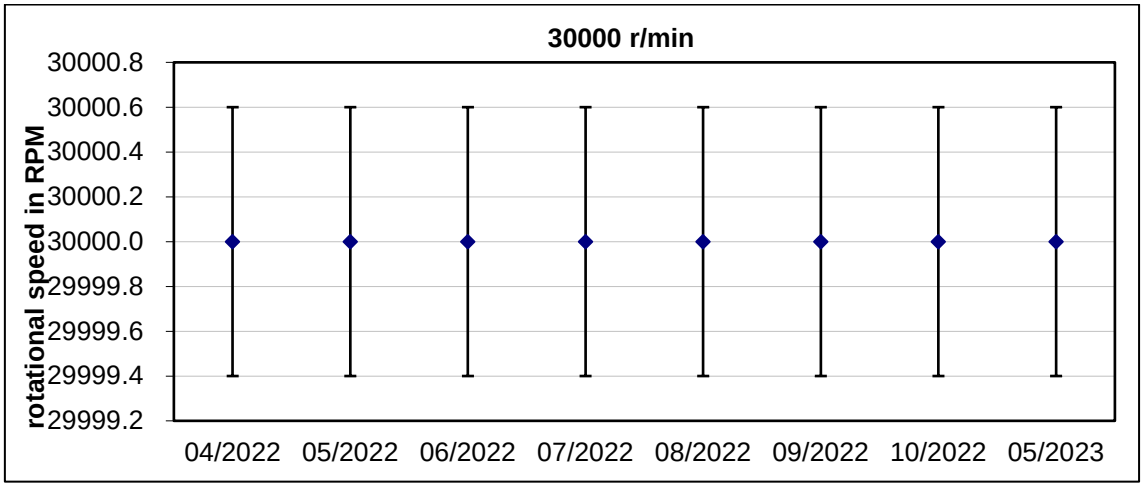
Starting with calibration data in April 2022, the artefacts were monitored during the preparation period and at the end of the comparison when they were back at the pilot laboratory. The measurements at five rotational speed values are presented in Figure 6.1 and Figure 6.2. These figures depict the stability of the artefacts over time for the duration of the comparison.

Figure 6.1 Monitoring of the rotational speed of NLYZ-02 over the comparison period






3000 r/min
rotational speed in RPM
3000.08
3000.06
3000.04
3000.02
3000.00
2999.98
2999.96
2999.94
2999.92
04/2022
05/2022
06/2022
07/2022
08/2022
09/2022
10/2022
05/2023


30000 r/min
rotational speed in RPM
30000.8
30000.6
30000.4
30000.2
30000.0
29999.8
29999.6
29999.4
29999.2
04/2022
05/2022
06/2022
07/2022
08/2022
09/2022
10/2022
05/2023

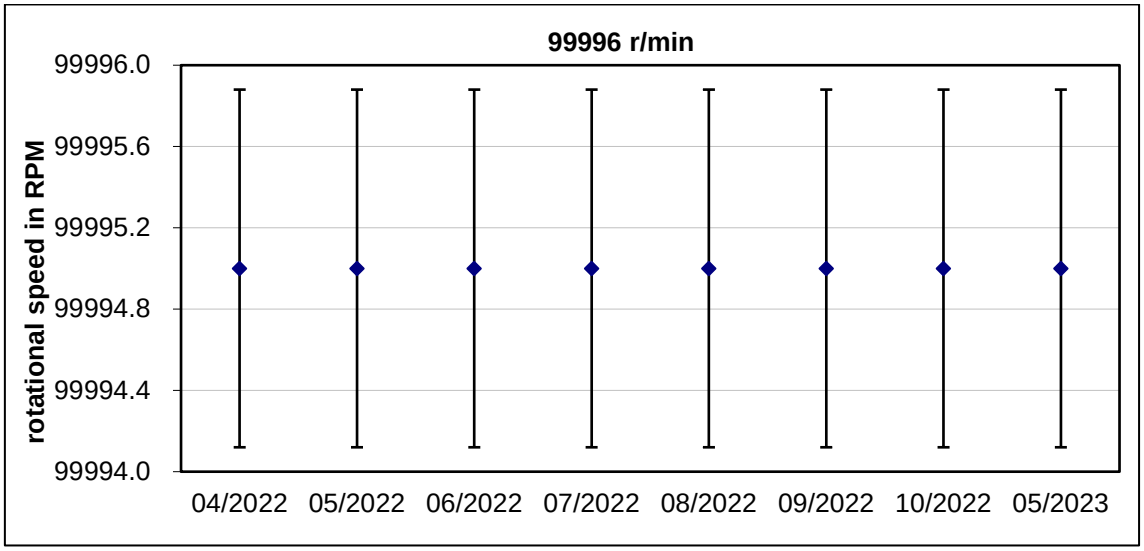
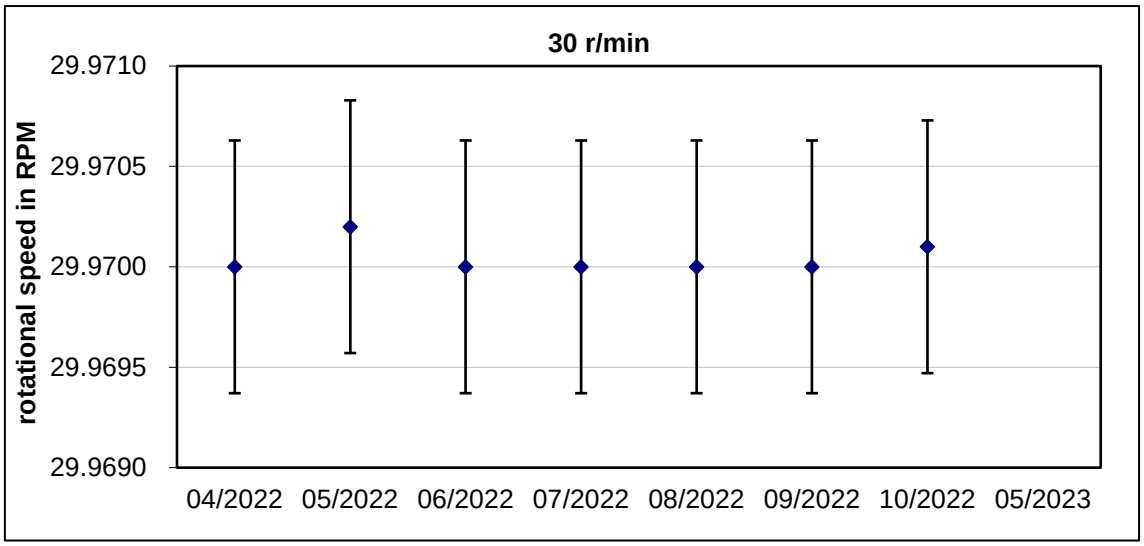
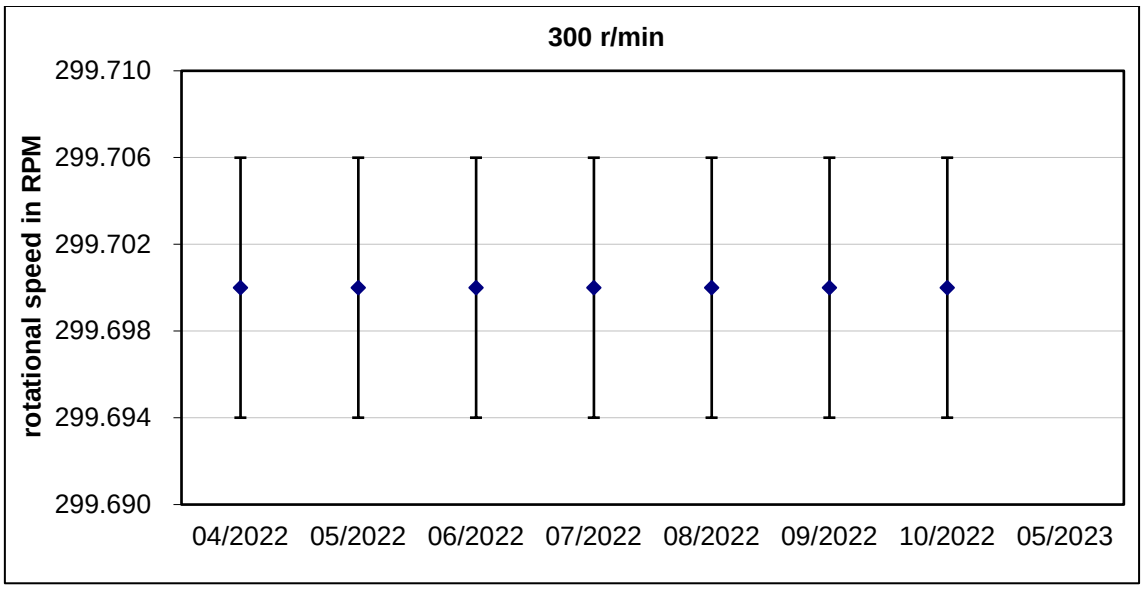
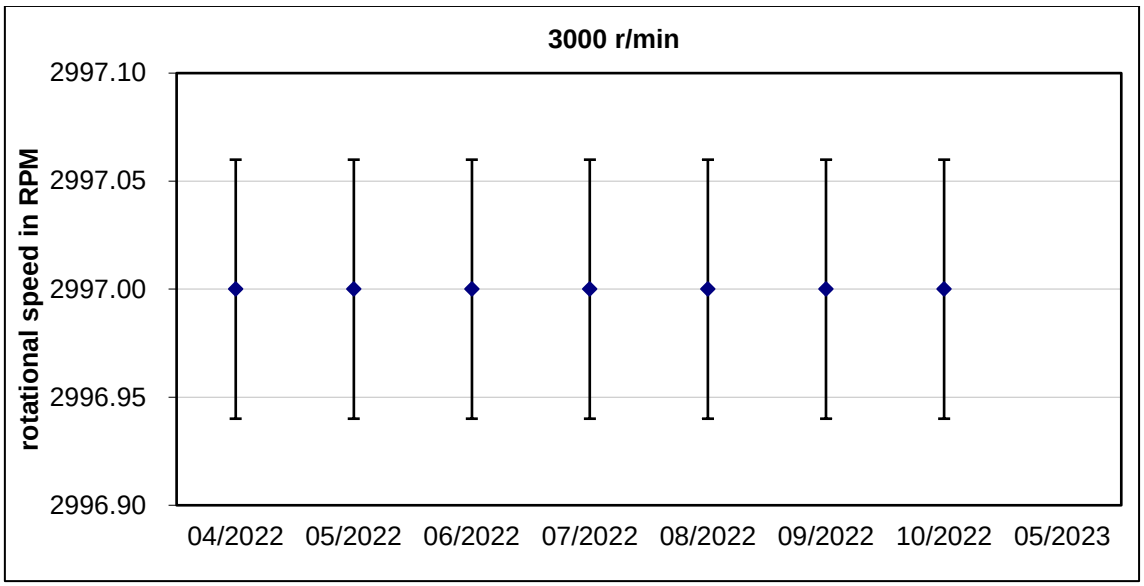
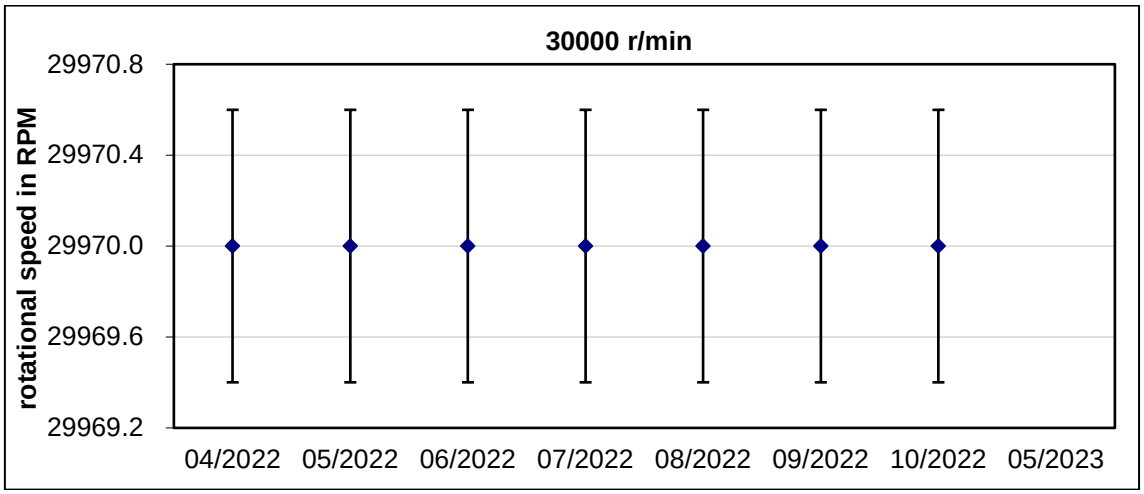

99996 r/min
rotational speed in RPM
99996.0
99995.6
99995.2
99994.8
99994.4
99994.0
04/2022
05/2022
06/2022
07/2022
08/2022
09/2022
10/2022
05/2023

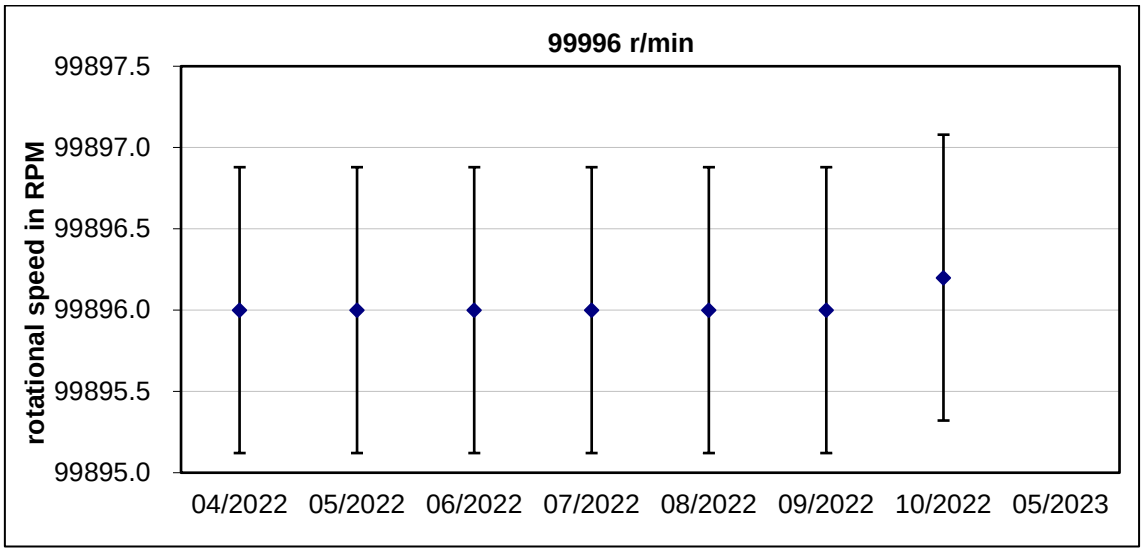
Figure 6.2 Monitoring of the rotational speed of NLYZ-03 over the comparison period











A visual inspection of the above results indicates that the artefacts were sufficiently stable during the whole period of the comparison. Note that NLYZ-03 was unfortunately opened and its laser source fixed by NIS (Egypt), the last laboratory in measurement sequence. Therefore, the monitoring data of NLYZ-03 after that was invalid even after it was delivered back to the pilot laboratory and checked in May, 2023.

7. Results of the participants

The following tables report the results submitted by the participants for the comparison to the pilot laboratory using the mandatory report spreadsheet. The pilot laboratory submitted its set of results as official data to the executive secretary of CCAUV in advance to the delivery of the artefact to the participating laboratory. The results presented are in r/min for the measurement results.

Table 7.1 Participants' results for NLYZ-02 with relative expanded uncertainties (k = 2)

	NIM		NMC		NML	
rotational speed	measurement result	rel. exp. Unc.	measurement result	rel. exp. Unc.	measurement result	rel. exp. Unc.
in r/min	in r/min	%	in r/min	%	in r/min	%
30	29.9998	0.0021	29.9996	0.13	30.0000	0.0020
300	300.000	0.0020	300.004	0.12	300.000	0.0019
3000	3000.00	0.0020	3000.06	0.12	3000.00	0.0019
30000	30000.0	0.0020	30000.2	0.12	30000.0	0.0019
99996	99995.0	0.00088	99997.0	0.12	99995.0	0.00058

	NIMT		KEBS		NIS	
rotational speed	measurement result	rel. exp. Unc.	measurement result	rel. exp. Unc.	measurement result	rel. exp. Unc.
in r/min	in r/min	%	in r/min	%	in r/min	%
30	30.0001	0.02	29.9990	0.0117	29.9992	0.19
300	300.000	0.01	299.990	0.0117	299.998	0.020
3000	3000.00	0.01	2999.90	0.0117	2999.96	0.0035
30000	30000.0	0.01	29999.0	0.0117	29999.3	0.0035
99996	99995.0	0.01	99996.0	0.0116	99994.6	0.0011

Table 7.2 Participants' results for NLYZ-03 with relative expanded uncertainties (k = 2)

	NIM		NMC		NML	
rotational speed	measurement result	rel. exp. Unc.	measurement result	rel. exp. Unc.	measurement result	rel. exp. Unc.
in r/min	in r/min	%	in r/min	%	in r/min	%
30	29.9701	0.0021	29.9862	0.13	29.9700	0.0020
300	299.700	0.0020	299.921	0.12	299.700	0.0019
3000	2997.00	0.0020	2998.01	0.12	2997.00	0.0019
30000	29970.0	0.0020	29971.0	0.12	29970.0	0.0019
99996	99896.2	0.00092	99898.8	0.12	99896.0	0.00058

	NIMT		KEBS		NIS	
rotational speed	measurement result	rel. exp. Unc.	measurement result	rel. exp. Unc.	measurement result	rel. exp. Unc.
in r/min	in r/min	%	in r/min	%	in r/min	%
30	29.9702	0.02	29.9700	0.0117		
300	299.702	0.01	299.700	0.0117		
3000	2997.00	0.01	2997.00	0.0117		
30000	29970.0	0.01	29969.5	0.0117		
99996	99896.0	0.01	99896.0	0.0116		

8. Degrees of equivalence with respect to the weighted mean

The evaluation of the results was performed using a weighted mean computed with the following equations:

$$x_{WM}(n) = \sum \frac{X_i(n)}{{u_i}^2(n)} \cdot \left(\sum \frac{1}{{u_i}^2(n)} \right)^{-1} \quad (1)$$

$$u_{WM}(n) = \left(\sum \frac{1}{{u_i}^2(n)} \right)^{-1/2} \quad (2)$$

where the WM was calculated using the results of the participants according to [1]. In the equations above the following symbols were used:

$x_i(n)$	result of participant *i* at rotational speed *n*
$u_i(n)$	absolute standard uncertainty of participant *i* at rotational speed *n*
$x_{WM}(n)$	best estimate of the weighted mean (WM) at rotational speed *n*
$u_{WM}(n)$	estimated absolute standard uncertainty for the weighted mean (WM) at rotational speed *n*

Consistency checks were performed for the measurement results of NLYZ-02 and NLYZ-03. The test defined by Cox in [6, 7] was applied in order to determine the participants that are members of the largest consistent subset (LCS).

The supplementary comparison reference values (SCRVs) were finally determined by the WM using the participants that are members of the largest consistent subset (MoCS):

$x_{SCRV}(n)$	best estimate of the SCRV at rotational speed *n*
$u_{SCRV}(n)$	estimated absolute standard uncertainty of the SCRV at rotational speed *n*

Table 8.1and 8.2 present the results of the consistency test for the NLYZ-02 and NLYZ-03 results.

Table 8.1: Results of the consistency test applied to all the results reported by the participants for NLYZ-02

rotational speed in r/min	number of participants	number of degrees of freedom	X²obs	X²(nu) with P < 0.05
30	6	5	0.48	11.07
300	6	5	0.32	11.07
3000	6	5	0.79	11.07
30000	6	5	1.81	11.07
99996	6	5	0.48	11.07

Table 8.2: Results of the consistency test applied to all the results reported by the participants for NLYZ-03

rotational speed in r/min	number of participants	number of degrees of freedom	X^2obs	X^2(nu) with P < 0.05
30	5	4	0.70	9.49
300	5	4	1.54	9.49
3000	5	4	0.33	9.49
30000	5	4	0.08	9.49
99996	5	4	0.14	9.49

For the further evaluation of the comparison, the unilateral degrees of equivalence with respect to the SCRVs were calculated according to:

$$d_{i,SCRV}(n) = x_i(n) - x_{SCRV}(n) \tag{3}$$

$$u^2{}_{i,SCRV}(n) = \begin{cases} u^2{}_i(n) - u^2{}_{SCRV}(n) & \text{for results within the LCS} \\ u^2{}_i(n) + u^2{}_{SCRV}(n) & \text{for results not within the LCS} \end{cases} \tag{4}$$

These formulas were applied for both NLYZ-02 and NLYZ-03 results. In the subsequent tables 8.3 and 8.4, $U_i = 2u_i$ and the results are marked using a light brown background where $|d_{i,SCRV}(n)| > 2 \cdot u_{i,SCRV}(n)$.

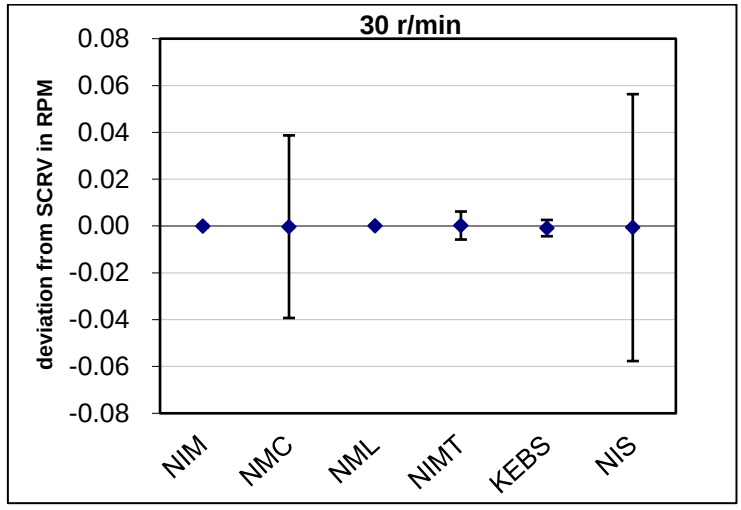
8.1 Results for NLYZ-02

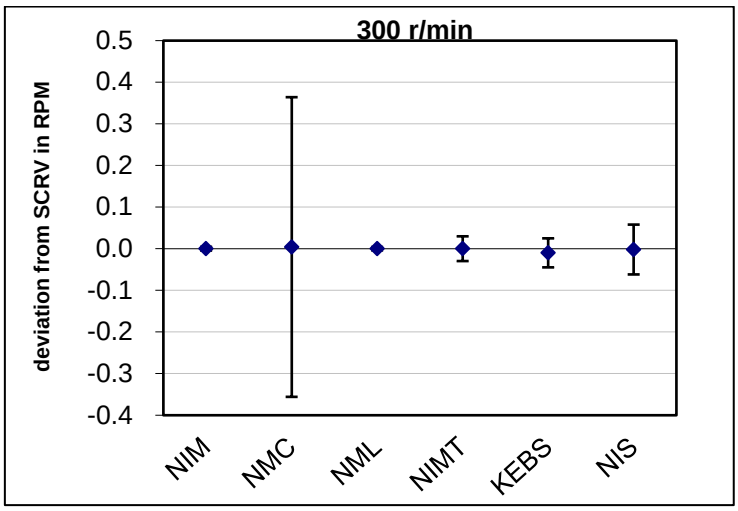
Table 8.3: Unilateral degrees of equivalence for NLYZ-02 with absolute expanded uncertainties ($k = 2$)

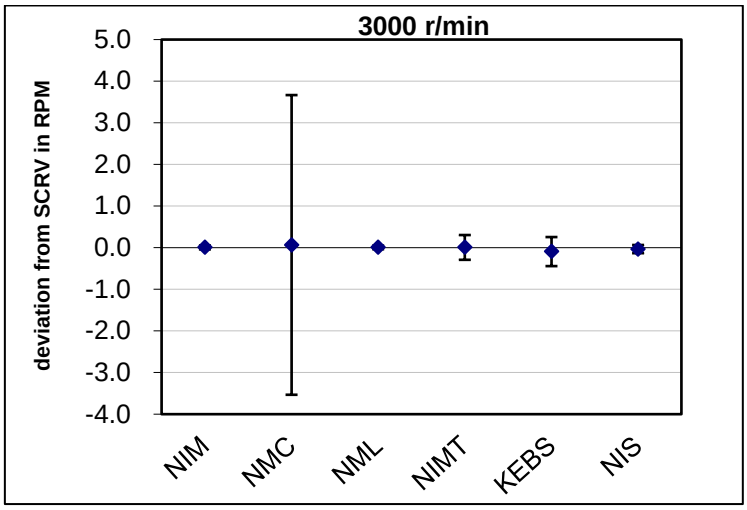
	SCRV		NIM		NMC		NML	
rotational speed	X_{SCRV}	U_{SCRV}	$d_{I,SCRV}$	$U_{I,SCRV}$	$d_{I,SCRV}$	$U_{I,SCRV}$	$d_{I,SCRV}$	$U_{I,SCRV}$
in r/min	r/min		r/min		r/min		r/min	
30	29.99989	0.00043	-0.00009	0.00046	-0.00029	0.03900	0.00011	0.00042
300	299.9999	0.00406	0.00014	0.00442	0.00414	0.35998	0.00014	0.00400
3000	2999.994	0.03792	0.00638	0.04650	0.06638	3.59987	0.00638	0.04256
30000	29999.90	0.37916	0.10293	0.46501	0.30293	35.99824	0.10293	0.42560
99996	99994.94	0.44244	0.06324	0.76064	2.06324	119.99558	0.06324	0.37498

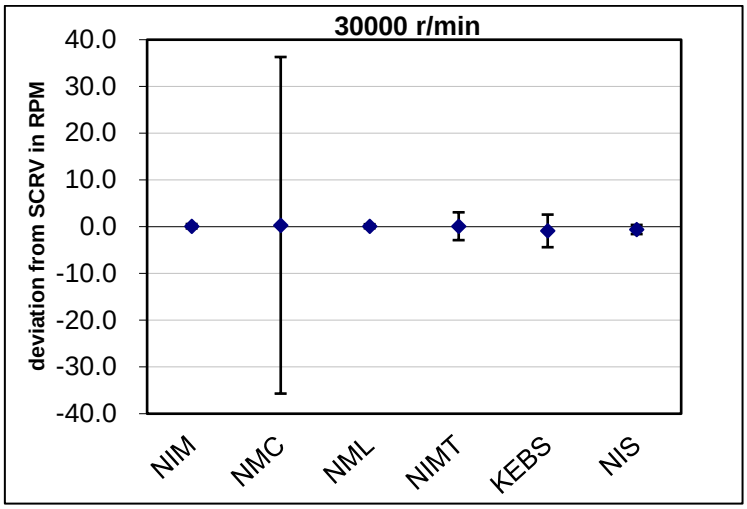
	SCRV		NIMT		KEBS		NIS	
rotational speed	X_{SCRV}	U_{SCRV}	$d_{I,SCRV}$	$U_{I,SCRV}$	$d_{I,SCRV}$	$U_{I,SCRV}$	$d_{I,SCRV}$	$U_{I,SCRV}$
in r/min	r/min		r/min		r/min		r/min	
30	29.99989	0.00043	0.00020	0.00598	-0.00089	0.00348	-0.00069	0.05700
300	299.9999	0.00406	0.00014	0.02972	-0.00986	0.03486	-0.00186	0.05986
3000	2999.994	0.03792	0.00638	0.29759	-0.09362	0.34893	-0.03362	0.09791
30000	29999.90	0.37916	0.10293	2.97594	-0.89707	3.48934	-0.59707	0.97912
99996	99994.94	0.44244	0.06324	9.98971	1.06324	11.59109	-0.33676	1.00703

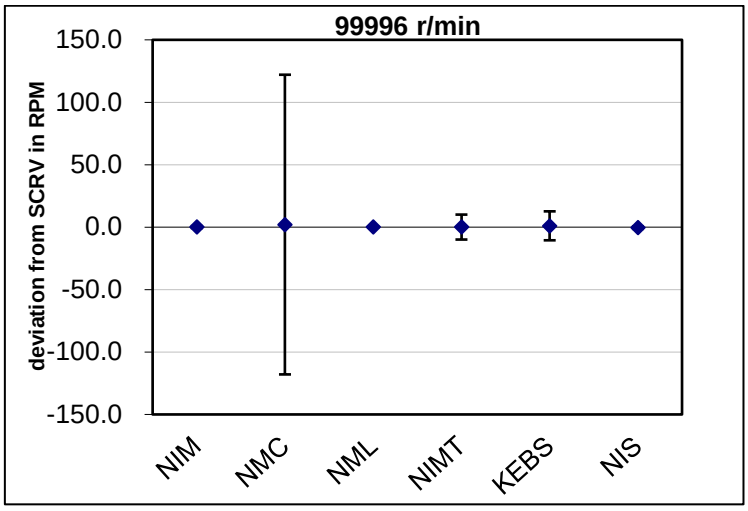
Figure 8.1 : Deviation of NLYZ-02 results from the SCRV for all rotational speeds of the comparison with expanded uncertainties $U_{i,SCRV}$ (k = 2)











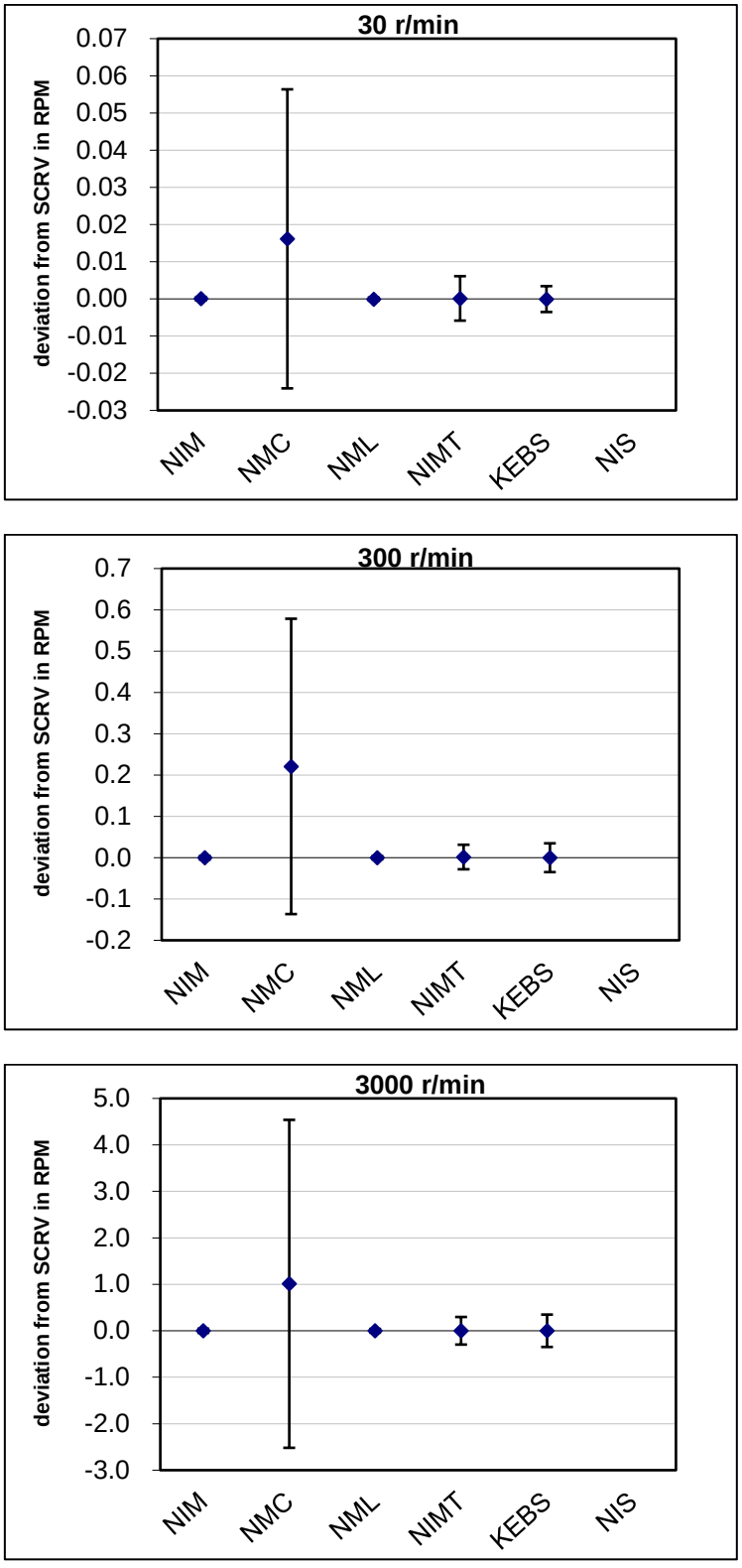
8.2 Results for NLYZ-03

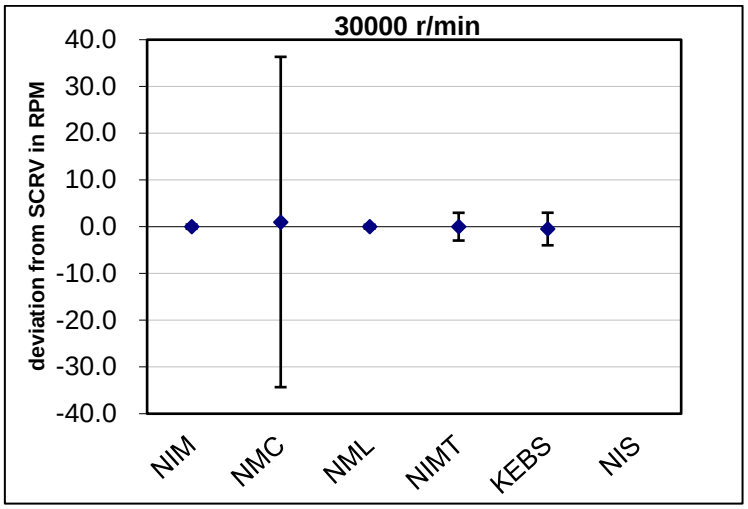
Table 8.4: Unilateral degrees of equivalence for NLYZ-03 with absolute expanded uncertainties (k = 2)

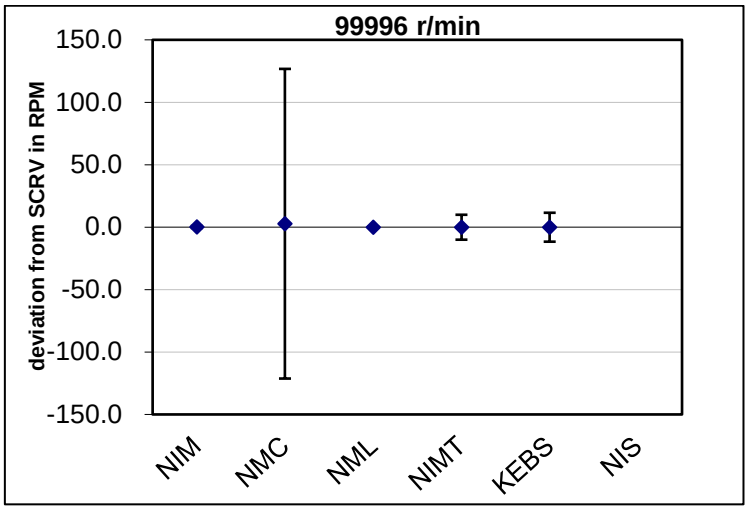
	SCRV		NIM		NMC		NML	
rotational speed	X_{SCRV}	U_{SCRV}	$d_{I,SCRV}$	$U_{I,SCRV}$	$d_{I,SCRV}$	$U_{I,SCRV}$	$d_{I,SCRV}$	$U_{I,SCRV}$
in r/min	r/min		r/min		r/min		r/min	
30	29.97005	0.00043	0.00005	0.00046	0.01615	0.04022	-0.00005	0.00042
300	299.7001	0.00406	-0.00006	0.00441	0.22094	0.35750	-0.00006	0.00399
3000	2997.000	0.04062	-0.00013	0.04408	1.00987	3.52860	-0.00013	0.03991
30000	29969.99	0.40619	0.00658	0.44078	1.00658	35.32589	0.00658	0.39907
99996	99896.06	0.48910	0.14331	0.77809	2.74331	123.98951	-0.05669	0.31062

	SCRV		NIMT		KEBS		NIS	
rotational speed	X_{SCRV}	U_{SCRV}	$d_{I,SCRV}$	$U_{I,SCRV}$	$d_{I,SCRV}$	$U_{I,SCRV}$	$d_{I,SCRV}$	$U_{I,SCRV}$
in r/min	r/min		r/min		r/min		r/min	
30	29.97005	0.00043	0.00013	0.00598	-0.00005	0.00348		
300	299.7001	0.00406	0.00164	0.02969	-0.00006	0.03483		
3000	2997.000	0.04062	-0.00013	0.29693	-0.00013	0.34829		
30000	29969.99	0.40619	0.00658	2.96935	-0.49342	3.48282		
99996	99896.06	0.48910	-0.05669	9.97762	-0.05669	11.57761		

Figure 8.2 : Deviation of NLYZ-03 results from the SCRV for all rotational speeds of the comparison with expanded uncertainties $U_{i,SCRV}$ (k = 2)







9. Conclusion

The rotational speed APMP supplementary comparison APMP.AUV.V-S2 revealed the current calibration capabilities of the 6 participants from 2 RMOs, APMP and AFRIMETS.

All the participating laboratories provided their calibration results, which were all consistent within their declared expanded uncertainties for the measurement results. Each participant contributed to the SCRVs calculated for five rotational speed comparison values of two laser tachometers, NLYZ-02 and 03, except that NIS's measurement results of NLYZ-03 is invalid.

NIM, NMC and NIS used mechanical generator for calibration, with expanded uncertainties in the order from 10^{-3} to 10^{-5}. NML, NIMT and KEBS used optical simulator for calibration, with expanded uncertainties in the order from 10^{-4} to 10^{-5}.

Smaller measurement uncertainties than the order of 10^{-5} for the calibration of laser tachometers are difficult to achieve for either mechanical generators or optical simulators with the current technology of rotational speed standard devices and laser tachometers.

10. Acknowledgment

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Bibliography

[1] von Martens, H.-J. et al., Final report on key comparison CCAUV.V-K1, 2003, Metrologia, 40, Tech. Suppl. 09001.

[2] Guidelines for CIPM key comparisons (Appendix F to the “Mutual recognition of national measurements standards and of measurement certificates issued by national metrology institutes” (MRA)). March 1, 1999.

[3] Technical Protocol of the APMP Supplementary comparison APMP.AUV.V-S2. NIM, Qiao Sun, 2022.

[4] Technical Protocol of the APMP Supplementary comparison APMP.AUV.V-S1. NIM, Qiao Sun, 2022.

[5] Guide to the implementation of the CIPM MRA CIPM-MRA-G-01 VERSION 1.2. June, 2013.

[6] M.G. Cox, The evaluation of key comparison data, Metrologia, 2002, volume 39, p 589-595.

[7] M.G. Cox, The evaluation of key comparison data: determining a largest consistent subset, Metrologia, 2007, 44, 187-200.

Annex A - Technical protocol

Technical Protocol of the APMP Supplementary comparison APMP.AUV.V-S2

1 Task and Purpose of the Comparison

According to the rules set up by the CIPM MRA the consultative committees of the CIPM have the responsibility to establish ‘degrees of equivalence’ (DoE) between the different measurement standards operated by the national NMIs. This is done by conducting key comparisons (KC) at different levels of the international metrological infrastructure.

However, in the sub-field of rotational speed, there is no formal comparison completed so far either at Consultative Committee (CC) level or Regional Metrology Organization Technical Committee (RMO TC) level. Therefore, during the meeting of APMP TCAUV in 2021, the decision was taken to make preparations for a supplementary comparison targeted at rotational speed (constant acceleration).

This regional supplementary comparison is organized in order to compare primary measurements of rotational speed in the range from 30 rpm to 99 996 rpm. It is the task of the comparison to calibrate two laser digital tachometers at different rotational speed values as specified in section 3. The results of this APMP supplementary comparison may serve as supporting evidence for the registration of ‘calibration and measurement capabilities’ (CMCs) in the framework of the CIPM MRA.

The measured value of rotational speed is calculated as the average of ten successive measurement results at its reflective mark or upon the optical flash. The measured value shall be given in revolutions per minute (rpm) for different measurement conditions specified in section 3.

For the calibration of the laser tachometer, rotational speed standard device of mechanical generator type or optical simulator type has to be applied.

The reported measured values and associated uncertainties will be used for the calculation of mean values of the supplementary comparison results and their associated uncertainties, as well as the deviations to the mean values with associated uncertainties.

2 Pilot Laboratory

Pilot laboratory for this regional supplementary comparison is

Vibration and Kinematics Parameters Laboratory
Mechanics and Acoustics Metrology Division
National Institute of Metrology, P.R. China

Contact Persons are

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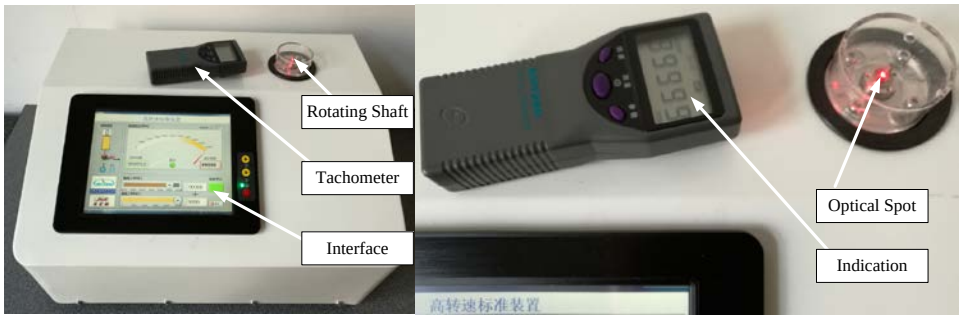
3 Device under Test and Measurement Conditions

For the calibration task of this comparison two laser tachometers will be circulated between the participating laboratories. The laser tachometers are two EMT260C (SN: NLYZ-02 and NLYZ-03).



The measurement value of the laser tachometers is to be calibrated according to those procedures and conditions implemented by the laboratory. The measurement values reported shall be the average of ten successive measurement results at its reflective mark of a rotational speed standard device or upon the optical flash of an optical simulator type.

The rotational speed range of the measurements was agreed to be from 30 rpm to 99 996 rpm. Specifically, the laboratories are supposed to measure at the following rotational speeds (all values in rpm).

30, 300, 3 000, 30 000, 99 996.

The measurement conditions should be kept according to the laboratory's standard conditions for calibration of customers' laser tachometers for claiming their best measurement capability.

Specific conditions for the measurements of this comparison are:

- Measurement distance is within 0.1 to 1 m.
- Ambient temperature during the calibration: (23 ± 3) ºC.
- Relative humidity: max. 75 % RH.
- No flash of background light affects the measurement.

4 Circulation Type, Schedule and Transportation

The artefacts are circulated in a star type fashion with a measurement period of two weeks provided for the participating laboratory. At the beginning and the end of the circulation, the laser tachometers are measured at the pilot laboratory in order to monitor the stability.

The schedule is planned as follows:

Participant	Measurement (calendar week)	Transportation to next Participant (calendar week)
NIM	41-42/2022	43-44/2022
NMC	45-46/2022	47-48/2022
NIML	49-50/2022	51-52/2022
NIMT	01-02/2023	03-04/2023
KEBS	05-06/2023	07-08/2023
NIS	09-10/2023	11-12/2023
NIM	13-14/2023	

The cost of transportation to the next laboratory shall be covered by the participating laboratory. The laser tachometers should be delivered by an international logistic service with on-line tracking system. The transportation has to include an insurance covering a value of USD 500 in case the artefacts get damaged or lost during transportation. Hand-carry can be used as an option.

5 Measurement and Analysis Instructions

The participating laboratories have to observe the following instructions:

- The motion of the rotational output disc of mechanical generator should be measured at the reflective mark surface in perpendicular direction.
- The optical flash of the optical simulator should be measured in line with the tachometer.
- A tripod is recommended for installation of the laser tachometer.
- It is advised that the measurement results should be compiled from complete measurement series carried out at different days under nominally the same conditions, except that the laser tachometer is remounted. The standard deviation of the subsequent measurements should be included in the report.

6 Communication of the Results to Pilot Laboratory

The participating laboratory will submit one printed and signed calibration report (a scanned copy sent by email to the pilot laboratory) for each laser tachometer including the following:

- a description of the calibration system used for the comparison with a photo of the system, preferably when the laser tachometer is installed,
- a description of the calibration method used and the mounting techniques for the laser tachometer,
- documented records of the ambient conditions during measurements,

- calibration results, including the relative expanded measurement uncertainty, and the applied coverage factor for each value,
- a detailed uncertainty budget for the system covering all components of measurement uncertainty (calculated according to GUM [1,2]). Including, among others, information on the type of uncertainty (A or B), assumed distribution function and repeatability component.

In addition, the use of the electronic spreadsheets for reporting is mandatory. The consistency between the results in electronic form and the printed and signed calibration report is the responsibility of the participating laboratories. The data submitted in the electronic spreadsheet shall be deemed as official results submitted for the comparison.

The results have to be submitted to the pilot laboratory within four weeks after the measurements have been completed.

References

[1] ISO/IEC Guide 98-3:2008 ‘Uncertainty of measurement -- Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

[2] ISO/IEC Guide 98-3:2008/Suppl 1:2008 ‘Propagation of distributions using a Monte Carlo method’

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Results sheet for APMP.AUV.V-S2

'Spreadsheet' for EMT260C (NLYZ-02 and NLYZ-03)

Results sheet forAPMP.AUV.V-S2

NMI		☐ I confirm that the data reported here has been checked against the data reported in the NMI certificate issued for the tachometer
Contact Person		
email		

rotational speed	measurement result	rel. expanded Uncertainty
in rpm	in rpm	in %
30		
300		
3000		
30000		
99996		

Note 1: measurement results should be in 6 effective digitals.
Note 2: relative expanded uncertainty should be in 2 effective digitals.

Annex B : Measurement uncertainty Budget (MUB)

1 – NIM

NLYZ-02

i	Uncertainty Components	Probability Distribution	30 r/min	300 r/min	3000 r/min
1	Repeatability of tachometer	Normal	1.3×10^{-4}	0.0×10^{-3}	0.0×10^{-3}
2	Resolution of tachometer	Rectangular	2.9×10^{-4}	2.9×10^{-3}	2.9×10^{-2}
3	Uncertainty of Standard	Normal	5.0×10^{-5}	5.0×10^{-4}	5.0×10^{-3}
Combined measurement uncertainty			3.2×10^{-4}	2.9×10^{-3}	2.9×10^{-2}
Coverage factor			2	2	2
Expanded measurement uncertainty			6.4×10^{-4}	5.9×10^{-3}	5.9×10^{-2}
Expanded relative uncertainty			2.1×10^{-5}	2.0×10^{-5}	2.0×10^{-5}

i	Uncertainty Components	Probability Distribution	30000 r/min	99996 r/min
1	Repeatability of tachometer	Normal	0.0×10^{-2}	0.0×10^{-1}
2	Resolution of tachometer	Rectangular	2.9×10^{-2}	2.9×10^{-1}
3	Uncertainty of Standard	Normal	1.0×10^{-1}	3.3×10^{-1}
Combined measurement uncertainty			3.0×10^{-1}	4.4×10^{-1}
Coverage factor			2	2
Expanded measurement uncertainty			6.1×10^{-1}	8.8×10^{-1}
Expanded relative uncertainty			2.0×10^{-5}	8.8×10^{-6}

NLYZ-03

i	Uncertainty Components	Probability Distribution	30 r/min	300 r/min	3000 r/min
1	Repeatability of tachometer	Normal	1.0×10^{-4}	0.0×10^{-3}	0.0×10^{-3}
2	Resolution of tachometer	Rectangular	2.9×10^{-4}	2.9×10^{-3}	2.9×10^{-2}
3	Uncertainty of Standard	Normal	5.0×10^{-5}	5.0×10^{-4}	5.0×10^{-3}
Combined measurement uncertainty			3.1×10^{-4}	2.9×10^{-3}	2.9×10^{-2}
Coverage factor			2	2	2
Expanded measurement uncertainty			6.2×10^{-4}	5.9×10^{-3}	5.9×10^{-2}
Expanded relative uncertainty			2.1×10^{-5}	2.0×10^{-5}	2.0×10^{-5}

i	Uncertainty Components	Probability Distribution	30000 r/min	99996 r/min
1	Repeatability of tachometer	Normal	0.0×10^{-2}	1.3×10^{-1}
2	Resolution of tachometer	Rectangular	2.9×10^{-2}	2.9×10^{-1}
3	Uncertainty of Standard	Normal	1.0×10^{-1}	3.3×10^{-1}
Combined measurement uncertainty			3.0×10^{-1}	4.6×10^{-1}
Coverage factor			2	2
Expanded measurement uncertainty			6.1×10^{-1}	9.2×10^{-1}
Expanded relative uncertainty			2.0×10^{-5}	9.2×10^{-6}

2 –NMC

NLYZ-02

NMC- Uncertainty Budget for RPM Measurement for APMP.AUV.V-P2 (NLYZ-02)							
Calculation of Rotational Speed - Dependent MU Contribution							
i	Unceratinty Components	Probability Distribution	30 RPM (%)	300 RPM (%)	3000 RPM (%)	30000 RPM (%)	99996 RPM (%)
1	Repeatbility of reference standard	normal	3.39E-03	3.31E-04	9.39E-05	6.67E-06	4.81E-05
2	Repeatbility of UUT (NLYZ-02)	normal	1.07E-02	2.18E-03	5.44E-04	1.09E-03	4.94E-04
3	Resolution of reference standard	retangular	9.62E-05	9.62E-05	9.62E-05	9.62E-05	2.89E-05
4	Resolution of UUT (NLYZ-02)	retangular	9.62E-04	9.62E-04	9.62E-04	9.62E-04	2.89E-04
5	Accuracy of reference standard (Keysight 53230A)	retangular	5.77E-11	5.77E-11	5.77E-11	5.77E-11	5.77E-11
6	Stability of Tachometer Calibrator RPM (TIS)	normal	6.57E-02	5.89E-02	5.85E-02	5.89E-02	6.21E-02
Combined relative measurement unceratinty			0.067	0.059	0.058	0.059	0.062
Effective degree of freedom			13365	4831676	1197813273	77331098	2233618754
Coverage factor			2	2	2	2	2
Expanded unceratinty (%)			0.13	0.12	0.12	0.12	0.12

NLYZ-03

NMC- Uncertainty Budget for RPM Measurement for APMP.AUV.V-P2 (NLYZ-03)							
Calculation of Rotational Speed -Dependent MU Contribution							
i	Uncertainty Components	Probability Distribution	30 RPM (%)	300 RPM (%)	3000 RPM (%)	30000 RPM (%)	99996 RPM (%)
1	Repeatability of reference standard	normal	2.44E-03	3.58E-04	4.81E-05	5.85E-06	5.55E-05
2	Repeatability of UUT (NLYZ-03)	normal	1.34E-02	9.10E-03	6.66E-03	8.61E-04	3.59E-04
3	Resolution of reference standard	retangular	9.62E-05	9.62E-05	9.62E-05	9.62E-05	2.89E-05
4	Resolution of UUT (NLYZ-03)	retangular	9.63E-04	9.63E-04	9.63E-04	9.63E-04	2.89E-04
5	Accuracy of reference standard (Keysight 53230A)	retangular	5.77E-11	5.77E-11	5.77E-11	5.77E-11	5.77E-11
6	Stability of Tachometer Calibrator RPM (TIS)	normal	6.57E-02	5.89E-02	5.85E-02	5.89E-02	6.21E-02
Combined relative measurement unceratinty			0.067	0.060	0.059	0.059	0.062
Effective degree of freedom			5699	16539	54851	197147903	7998313509
Coverage factor			2	2	2	2	2
Expanded unceratinty (%)			0.13	0.12	0.12	0.12	0.12

3 –NML

NLYZ-02

Test point 30 r/min 0.5 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	5.00E-13	Hz	60	(r/min)/Hz	1.732	1.73E-11	r/min
Short term tachometer reading variations; ± 3 digits	0.000075	r/min	1		1	0.000075	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 0.001 r/min	0.0005	r/min	1		1.732	0.000289	r/min
					Combined Uncertainty, convolved	0.000298	r/min
					Expanded Uncertainty, convolved, k = 1.73	0.00052	r/min

Test point 300 r/min 5 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	5.00E-12	Hz	60	(r/min)/Hz	1.732	1.73E-10	r/min
Short term tachometer reading variations; ± 1 digit	0.00035	r/min	1		1	0.00035	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 0.01 r/min	0.005	r/min	1		1.732	0.002887	r/min
					Combined Uncertainty, convolved	0.002908	r/min
					Expanded Uncertainty, convolved, k = 1.67	0.0049	r/min

Test point 3000 r/min 50 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	5.00E-11	Hz	60	(r/min)/Hz	1.732	1.73E-09	r/min
Short term tachometer reading variations; ± 1 digit	0.0035	r/min	1		1	0.0035	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 0.1 r/min	0.05	r/min	1		1.732	0.028868	r/min
					Combined Uncertainty, convolved	0.029079	r/min
					Expanded Uncertainty, convolved, k = 1.67	0.049	r/min

Test point 30000 r/min 500 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	5.00E-10	Hz	60	(r/min)/Hz	1.732	1.73E-08	r/min
Short term tachometer reading variations; ± 1 digit	0.035	r/min	1		1	0.035	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 1 r/min	0.5	r/min	1		1.732	0.288675	r/min
					Combined Uncertainty, convolved	0.290789	r/min
					Expanded Uncertainty, convolved, k = 1.67	0.49	r/min

Test point 99996 r/min 1666.6 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	1.67E-09	Hz	60	(r/min)/Hz	1.732	5.77E-08	r/min
Short term tachometer reading variations; ± 1 digit	0.035	r/min	1		1	0.0350	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 1 r/min	0.5	r/min	1		1.732	0.288675	r/min
					Combined Uncertainty, convolved	0.290789	r/min
					Expanded Uncertainty, convolved, k = 1.67	0.49	r/min

NLYZ-03

Test point 30 r/min 0.5 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	5.00E-13	Hz	60	(r/min)/Hz	1.732	1.73E-11	r/min
Short term tachometer reading variations; ± 3 digits	0.000075	r/min	1		1	0.000075	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 0.001 r/min	0.0005	r/min	1		1.732	0.000289	r/min
					Combined Uncertainty, convolved	0.000298	r/min
					Expanded Uncertainty, convolved, k = 1.73	0.00052	r/min

Test point 300 r/min 5 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	5.00E-12	Hz	60	(r/min)/Hz	1.732	1.73E-10	r/min
Short term tachometer reading variations; ± 1 digit	0.00035	r/min	1		1	0.00035	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 0.01 r/min	0.005	r/min	1		1.732	0.002887	r/min
					Combined Uncertainty, convolved	0.002908	r/min
					Expanded Uncertainty, convolved, k = 1.67	0.0049	r/min

Test point 3000 r/min 50 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	5.00E-11	Hz	60	(r/min)/Hz	1.732	1.73E-09	r/min
Short term tachometer reading variations; ± 1 digit	0.0035	r/min	1		1	0.0035	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 0.1 r/min	0.05	r/min	1		1.732	0.028868	r/min
					Combined Uncertainty, convolved	0.029079	r/min
					Expanded Uncertainty, convolved, k = 1.67	0.049	r/min

Test point 30000 r/min 500 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	5.00E-10	Hz	60	(r/min)/Hz	1.732	1.73E-08	r/min
Short term tachometer reading variations; ± 1 digit	0.035	r/min	1		1	0.035	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 1 r/min	0.5	r/min	1		1.732	0.288675	r/min
					Combined Uncertainty, convolved	0.290789	r/min
					Expanded Uncertainty, convolved, k = 1.67	0.49	r/min

Test point 99996 r/min 1666.6 Hz

Source of Uncertainty	Uncertainty Value		Sensitivity Coeeficient		Distribution Factor	Standard Uncertainty	
Pulsed light frequency (from Cesium Primary Frequency Standard); 1 part in 10^{12} accuracy	1.67E-09	Hz	60	(r/min)/Hz	1.732	5.77E-08	r/min
Short term tachometer reading variations; ± 1 digit	0.035	r/min	1		1	0.0350	r/min
Day to day tachometer reading variations	0	r/min	1		1	0.000000	r/min
Effect of distance of tachometer to pulsed light source	0	r/min	1		1	0.000000	r/min
Stray light	nil*	r/min	1		1	0.000000	r/min
Tachometer resolution; 1 r/min	0.5	r/min	1		1.732	0.288675	r/min
					Combined Uncertainty, convolved	0.290789	r/min
					Expanded Uncertainty, convolved, k = 1.67	0.49	r/min

4 –NIMT

NLYZ-02

Table 1 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-02) at the frequency setting 0.5 Hz in the nominal RPM at 30 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.00018	1	0.00018	9
U_2	B	Resolution of tachometer	0.00096	1	0.00096	∞
U_3	B	Accuracy of frequency of Multi Calibrator	0.00866	1	0.00866	∞
U_c	-	Combined uncertainty			0.0087	
U(k=2)	-	Expanded uncertainty			0.0174	
		Uncertainty report			0.02	

Table 2 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-02) at the frequency setting 5 Hz in the nominal RPM at 300 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.0000	1	0.0000	9
U_2	B	Resolution of tachometer	0.00096	1	0.00096	∞
U_3	B	Accuracy of frequency of Multi Calibrator	0.00087	1	0.00087	∞
U_c	-	Combined uncertainty			0.0013	
U(k=2)	-	Expanded uncertainty			0.0026	
	-	Uncertainty report			0.01	

Table 3 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-02) at the frequency setting 50 Hz in the nominal RPM at 3000 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.00000	1	0.00000	9
U_2	B	Resolution of tachometer	0.000962	1	0.000962	∞
U_3	B	Accuracy of frequency of Multi Calibrator	0.000087	1	0.000087	∞
U_c	-	Combined uncertainty			0.0010	
U(k=2)	-	Expanded uncertainty			0.0019	
	-	Uncertainty report			0.01	

Table 4 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-02) at the frequency setting 500 Hz in the nominal RPM at 30000 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.00000	1	0.00000	9
U_2	B	Resolution of tachometer	0.00096	1	0.00096	∞
U_3	B	Accuracy of frequency of Multi Calibrator	0.0000087	1	0.0000087	∞
U_c	-	Combined uncertainty			0.0010	
U(k=2)	-	Expanded uncertainty			0.0019	
	-	Uncertainty report			0.01	

Table 5 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-02) at the frequency setting 1666.6 Hz in the nominal RPM at 99996 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.00000	1	0.00000	9
U_2	B	Resolution of tachometer	0.003176	1	0.003176	∞
U_3	B	Accuracy of frequency of Multi Calibrator	7.10E-05	1	7.10E-05	∞
U_c	-	Combined uncertainty			0.0032	
U(k=2)	-	Expanded uncertainty			0.0064	
	-	Uncertainty report			0.01	

NLYZ-03

Table 6 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-03) at the frequency setting 0.5 Hz in the nominal RPM at 30 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.00020	1	0.00020	9
U_2	B	Resolution of tachometer	0.00096	1	0.00096	∞
U_3	B	Accuracy of frequency of Multi Calibrator	0.00866	1	0.00866	∞
U_c	-	Combined uncertainty			0.0087	
U(k=2)	-	Expanded uncertainty			0.0174	
	-	Uncertainty report			0.02	

Table 7 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-03) at the frequency setting 5 Hz in the nominal RPM at 300 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.00032	1	0.00032	9
U_2	B	Resolution of tachometer	0.00096	1	0.00096	∞
U_3	B	Accuracy of frequency of Multi Calibrator	0.00087	1	0.00087	∞
U_c	-	Combined uncertainty			0.0013	∞
U(k=2)	-	Expanded uncertainty			0.0027	
	-	Uncertainty report			0.01	

Table 8 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-03) at the frequency setting 50 Hz in the nominal RPM at 3000 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.00000	1	0.00000	9
U_2	B	Resolution of tachometer	0.00096	1	0.00096	∞
U_3	B	Accuracy of frequency of Multi Calibrator	0.000087	1	0.000087	∞
U_c	-	Combined uncertainty			0.0009	∞
U(k=2)	-	Expanded uncertainty			0.0019	
	-	Uncertainty report			0.01	

Table 9 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-03) at the frequency setting 500 Hz in the nominal RPM at 30000 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.00000	1	0.00000	9
U_2	B	Resolution of tachometer	0.00096	1	0.00096	∞
U_3	B	Accuracy of frequency of Multi Calibrator	0.0000087	1	0.0000087	∞
U_c	-	Combined uncertainty			0.0009	∞
U(k=2)	-	Expanded uncertainty			0.0019	
	-	Uncertainty report			0.01	

Table 10 The example of uncertainty budget for comparison of tachometer (Model: EMT260 s/n: NLYZ-03) at the frequency setting 1666.6 Hz in the nominal RPM at 99996 r/min.

Symbol	Type	Sources of Uncertainty	Standard Uncertainty (%)	Sensitivity Coefficient C_i	Relative Uncertainty Contribution (%)	V_{eff}
U_1	A	Repeatability of measurement	0.00000	1	0.00000	9
U_2	B	Resolution of tachometer	0.003179	1	0.003179	∞
U_3	B	Accuracy of frequency of Multi Calibrator	7.10E-05	1	7.10E-05	∞
U_c	-	Combined uncertainty			0.0032	∞
U(k=2)	-	Expanded uncertainty			0.0064	
	-	Uncertainty report			0.01	

5 –KEBS

NLYZ-02

30 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom v_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{v_i}$
Std	Uncertainty of Standard	From calibration certificate	1.43E-05	B	Normal 2s	2	0.0000	rpm	1	rpm	0.0000	100%	Infinite	0.00%	5.09796E-11	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.0005	B	Rectangular	1.7321	0.0003	rpm	1	rpm	0.0003	100%	Infinite	2.70%	8.33333E-08	6.94444E-15	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	0.003	B	Rectangular	1.7321	0.0017	rpm	1	rpm	0.0017	80%	12.5	97.30%	0.000003	9E-12	7.E-13
Rep	Repeatability	Statistical analysis	1.18424E-15	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	1.40242E-30	1.96678E-60	1.E-60

	$u_c(y)$	0.001755957		3.08338E-06 9.00694E-12 7.E-13
	v_{eff}	13.20452614		
	Level of Confidence	95.45%		
	Coverage factor	2		
	Expanded uncertainty U	**0.003511914**	rpm	
	Relative Uncertainty	**0.01171%**	%	

300 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom v_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{v_i}$
Std	Uncertainty of Standard	From calibration certificate	6.96E-05	B	Normal 2s	2	0.0000	rpm	1	rpm	0.0000	100%	Infinite	0.00%	1.21104E-09	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.005	B	Rectangular	1.7321	0.0029	rpm	1	rpm	0.0029	100%	Infinite	2.70%	8.33333E-06	6.94444E-11	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	0.03	B	Rectangular	1.7321	0.0173	rpm	1	rpm	0.0173	100%	Infinite	97.30%	0.0003	0.00000009	0.E+00
Rep	Repeatability	Statistical analysis	1.89478E-14	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	3.59019E-28	1.28895E-55	6.E-56

	$u_c(y)$	0.017559457		0.000308335 9.00694E-08 6.E-56
	v_{eff}	1.47516E+48		
	Level of Confidence	95.45%		
	Coverage factor	2		
	Expanded uncertainty U	**0.035118915**	rpm	
	Relative Uncertainty	**0.01171%**	%	

3000 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom v_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{v_i}$
Std	Uncertainty of Standard	From calibration certificate	6.96E-05	B	Normal 2s	2	0.0000	rpm	1	rpm	0.0000	100%	Infinite	0.00%	1.21104E-09	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.05	B	Rectangular	1.7321	0.0289	rpm	1	rpm	0.0289	100%	Infinite	2.70%	0.000833333	6.94444E-07	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	0.3	B	Rectangular	1.7321	0.1732	rpm	1	rpm	0.1732	100%	Infinite	97.30%	0.03	0.0009	0.E+00
Rep	Repeatability	Statistical analysis	1.51582E-13	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	2.29772E-26	5.27954E-52	3.E-52

	$u_c(y)$	0.175594233		0.030833335 0.000900694 3.E-52
	v_{eff}	3.60143E+48		
	Level of Confidence	95.45%		
	Coverage factor	2		
	Expanded uncertainty U	**0.351188465**	rpm	
	Relative Uncertainty	**0.01171%**	%	

30000 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom v_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{v_i}$
Std	Uncertainty of Standard	From calibration certificate	6.96E-04	B	Normal 2s	2	0.0003	rpm	1	rpm	0.0003	100%	Infinite	0.00%	1.21104E-07	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.5	B	Rectangular	1.7321	0.2887	rpm	1	rpm	0.2887	100%	Infinite	2.70%	0.083333333	0.006944444	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	3	B	Rectangular	1.7321	1.7321	rpm	1	rpm	1.7321	100%	Infinite	97.30%	3	9	0.E+00
Rep	Repeatability	Statistical analysis	1.18424E-15	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	1.40242E-30	1.96678E-60	1.E-60

	$u_c(y)$	1.755942327		3.083333454 9.006944444 1.E-60
	v_{eff}	9.66752E+60		
	Level of Confidence	95.45%		
	Coverage factor	2		
	Expanded uncertainty U	**3.511884653**	rpm	
	Relative Uncertainty	**0.01171%**	%	

99996 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom v_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{v_i}$
Std	Uncertainty of Standard	From calibration certificate	6.96E-05	B	Normal 2s	2	0.0000	rpm	1	rpm	0.0000	100%	infinite	0.00%	1.21104E-09	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.5	B	Rectangular	1.7321	0.2887	rpm	1	rpm	0.2887	100%	infinite	0.25%	0.083333333	0.006944444	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	9.9996	B	Rectangular	1.7321	5.7733	rpm	1	rpm	5.7733	100%	infinite	99.75%	33.33066672	1110.933344	0.E+00
Rep	Repeatability	Statistical analysis	1.18424E-15	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	1.40242E-30	1.96678E-60	1.E-60
															33.41400005	1110.940288	1.E-60

$u_c(y)$	5.780484413	
v_{eff}	1.13535E+63	
Level of Confidence	95.45%	
Coverage factor	2	
Expanded uncertainty U	**11.56096883**	rpm
Relative Uncertainty	**0.01156%**	%

NLYZ-03

30 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom ν_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{\nu_i}$
Std	Uncertainty of Standard	From calibration certificate	1.43E-05	B	Normal 2s	2	0.0000	rpm	1	rpm	0.0000	100%	Infinite	0.00%	5.09796E-11	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.0005	B	Rectangular	1.7321	0.0003	rpm	1	rpm	0.0003	100%	Infinite	2.70%	8.33333E-08	6.94444E-15	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	0.003	B	Rectangular	1.7321	0.0017	rpm	1	rpm	0.0017	60%	12.5	97.30%	0.000003	9E-12	7.E-13
Rep	Repeatability	Statistical analysis	1.18424E-15	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	1.40242E-30	1.96678E-60	1.E-60
															3.08333E-06	9.00694E-12	7.E-13

$u_c(y)$	0.001755957	
ν_{eff}	13.20452614	
Level of Confidence	95.45%	
Coverage factor	2	
Expanded uncertainty U	**0.003511914**	rpm
Relative Uncertainty	**0.01172%**	%

300 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom ν_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{\nu_i}$
Std	Uncertainty of Standard	From calibration certificate	6.96E-05	B	Normal 2s	2	0.0000	rpm	1	rpm	0.0000	100%	Infinite	0.00%	1.21104E-09	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.005	B	Rectangular	1.7321	0.0029	rpm	1	rpm	0.0029	100%	Infinite	2.70%	8.33333E-06	6.94444E-11	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	0.03	B	Rectangular	1.7321	0.0173	rpm	1	rpm	0.0173	100%	Infinite	97.30%	0.0003	0.00000009	0.E+00
Rep	Repeatability	Statistical analysis	1.89478E-14	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	3.59019E-28	1.28895E-55	6.E-56
															0.000308335	9.00694E-08	6.E-56

$u_c(y)$	0.017559457	
ν_{eff}	1.47516E+48	
Level of Confidence	95.45%	
Coverage factor	2	
Expanded uncertainty U	**0.035118915**	rpm
Relative Uncertainty	**0.01172%**	%

3000 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom ν_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{\nu_i}$
Std	Uncertainty of Standard	From calibration certificate	6.96E-05	B	Normal 2s	2	0.0000	rpm	1	rpm	0.0000	100%	Infinite	0.00%	1.21104E-09	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.05	B	Rectangular	1.7321	0.0289	rpm	1	rpm	0.0289	100%	Infinite	2.70%	0.000833333	6.94444E-07	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	0.3	B	Rectangular	1.7321	0.1732	rpm	1	rpm	0.1732	100%	Infinite	97.30%	0.03	0.0009	0.E+00
Rep	Repeatability	Statistical analysis	1.51582E-13	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	2.29772E-26	5.27954E-52	3.E-52
															0.030833335	0.000900694	3.E-52

$u_c(y)$	0.175594233	
ν_{eff}	3.60143E+48	
Level of Confidence	95.45%	
Coverage factor	2	
Expanded uncertainty U	**0.351188465**	rpm
Relative Uncertainty	**0.01172%**	%

30000 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom ν_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{\nu_i}$
Std	Uncertainty of Standard	From calibration certificate	6.96E-04	B	Normal 2s	2	0.0003	rpm	1	rpm	0.0003	100%	Infinite	0.00%	1.21104E-07	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.5	B	Rectangular	1.7321	0.2887	rpm	1	rpm	0.2887	100%	Infinite	2.70%	0.083333333	0.006944444	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	3	B	Rectangular	1.7321	1.7321	rpm	1	rpm	1.7321	100%	Infinite	97.30%	3	9	0.E+00
Rep	Repeatability	Statistical analysis	1.18424E-15	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	1.40242E-30	1.96678E-60	1.E-60
															3.083333454	9.006944444	1.E-60

$u_c(y)$	1.755942327	
ν_{eff}	9.66752E+60	
Level of Confidence	95.45%	
Coverage factor	2	
Expanded uncertainty U	**3.511884653**	rpm
Relative Uncertainty	**0.01172%**	%

99996 r/min

Symbol	Description	Uncertainty Source	Uncertainty Estimate (±)	Type	Probability Distribution N,R,T	Divisor	Standard Uncertainty $u(x_i)$	units	Sensitivity coefficient c_i	units	Uncertainty contributor $u(y_i)$	Reliability %	Degrees of Freedom ν_i	Significance	$u(y_i)^2$	$u(y_i)^4$	$\frac{u(y_i)^4}{\nu_i}$
Std	Uncertainty of Standard	From calibration certificate	6.96E-05	B	Normal 2s	2	0.0000	rpm	1	rpm	0.0000	100%	Infinite	0.00%	1.21104E-09	0.0000	0.E+00
Res	Resolution of UUT	From manufacturers specifications. Semi-range used	0.5	B	Rectangular	1.7321	0.2887	rpm	1	rpm	0.2887	100%	Infinite	0.25%	0.083333333	0.006944444	0.E+00
Acc	Accuracy of Tacho-adaptor	From manufacturers specifications (0.01% of value). Semi-range used	9.9996	B	Rectangular	1.7321	5.7733	rpm	1	rpm	5.7733	100%	Infinite	99.75%	33.33066672	1110.933344	0.E+00
Rep	Repeatability	Statistical analysis	1.18424E-15	A	Normal 1s	1	0.0000	rpm	1	rpm	0.0000	-	2	0.00%	1.40242E-30	1.96678E-60	1.E-60
															33.41400005	1110.940288	1.E-60

$u_c(y)$	5.780484413	
ν_{eff}	1.13535E+63	
Level of Confidence	95.45%	
Coverage factor	2	
Expanded uncertainty U	**11.56096883**	**rpm**
Relative Uncertainty	**0.01157%**	**%**

6 –NIS

NLYZ-02

reading 1	30.000	299.99	3000.0	29999	99994
reading 2	30.003	300.01	3000.0	30000	99995
reading 3	29.997	299.99	3000.0	30000	99995
reading 4	30.003	299.99	3000.0	29999	99994
reading 5	30.001	300.00	2999.9	29999	99994
reading 6	29.996	300.00	3000.0	30000	99995
reading 7	30.003	300.00	2999.9	29999	99995
reading 8	29.998	300.01	2999.9	29999	99995
reading 9	29.996	299.99	2999.9	29999	99995
reading 10	29.995	300.00	3000.0	29999	99994
N	10	10	10	10	10
stdv	0.003190263	0.007888106	0.051639778	0.48304589	0.516397779
UA	0.00100885	0.002494438	0.016329932	0.15275252	0.163299316
UresTACHO	0.000288675	0.002886751	0.028867513	0.28867513	0.288675135
Uexp REF TIS Calibrator (in rpm)	5.8E-02	5.9E-02	8.3E-02	8.4E-01	8.4E-01
Ustd REF TIS Calibrator (in rpm)	2.9E-02	0.0295	0.0415	0.42	0.42
Avgerage measured value (rpm)	30.00	300.0	3000.0	29999	99995
Standard Uncertainty (rpm)	2.9E-02	3.0E-02	5.3E-02	5.3E-01	5.4E-01
Uexp (in rpm) (k=2)	5.8E-02	5.9E-02	1.1E-01	1.1	1.1
Uexp (in %) (k=2)	**1.9E-01**	**2.0E-02**	**3.5E-03**	**3.5E-03**	**1.1E-03**
REF TIS calibrator actual value (in rpm)	**30.0**	**300.0**	**3000.0**	**30000.0**	**99996.0**
REF TIS calibrator error (in rpm)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
REF TIS calibrator correction (in rpm)	**0**	**0**	**0**	**0**	**0**
TACHO actual measured value (in rpm)	**29.9992**	**299.998**	**2999.96**	**29999.3**	**99994.6**

NLYZ-03

Not available.