Measurement uncertainty analysis and challenges associated with the instrumentation of rotating electrical machine test benches for electric vehicle powertrain applications

EVS35 OSL2022

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Summary

Rotating electric machine test benches used for testing electric drive systems in the automotive industry consist of different kinds of sensors and instruments for measuring and analyzing the performance of different components in electric mobility systems. Even if rigorous, tests performed on the test bench may deliver useless results if the measurement instruments are not configured properly. Efficiency measurements of the electric drive system in the test bench with various speed and torque values are a critical part of analyzing the performance and quality accuracy of the power train units of electrical vehicles (EVs). In this paper, different kinds of experiments are performed on the test bench to calculate its efficiency, with a focus on the measurement uncertainty (MU) values at various *n* and *M*.

Motivation, Background and Overview

- Why MU analysis associated with the instrumentation of rotating electrical machine in EV?

- Precise electrical and mechanical quantities measurement on the test bench → power loss and efficiency determination
  - torque and speed transducers→ Error caused by torque *M* under rotation speed *n*
- *Settings of the measurement instruments* + a new technique for varying *M* and *n* → the performance, quality and accuracy of powertrain units

Methodology and Testing Protocol

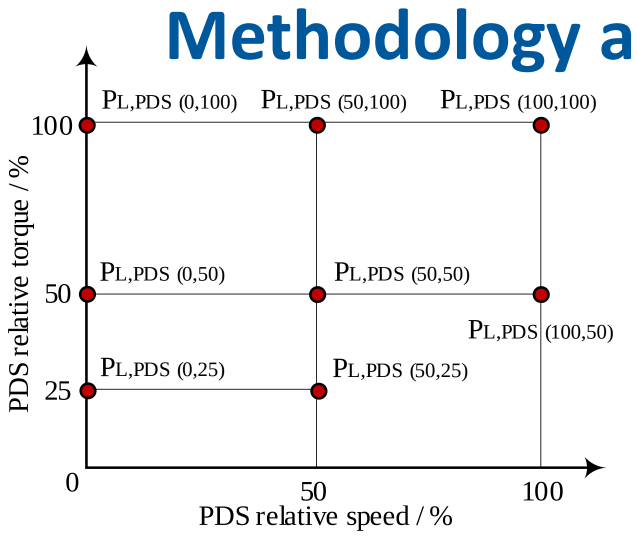

Fig. 1. Proposed efficiency measurement as described in IEC 60034-2-3 [1] and IEC 61800-9-2 [2]

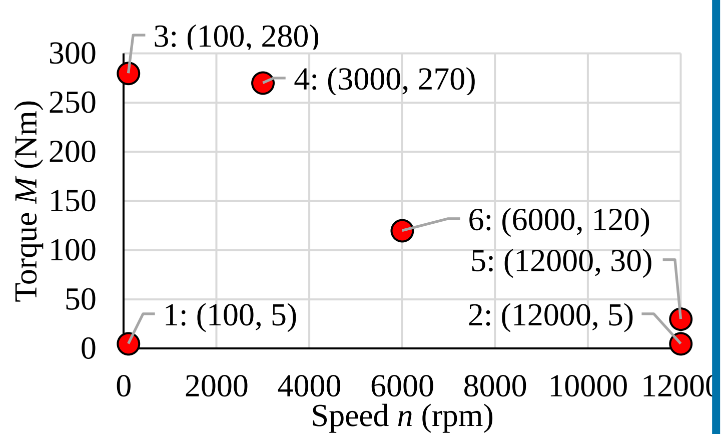

Fig. 2. Six measurement points (① to ⑥) for dynamic testing of the rotating inverter-fed electrical machine on the test bench.

Procedure 1 / Procedure 2

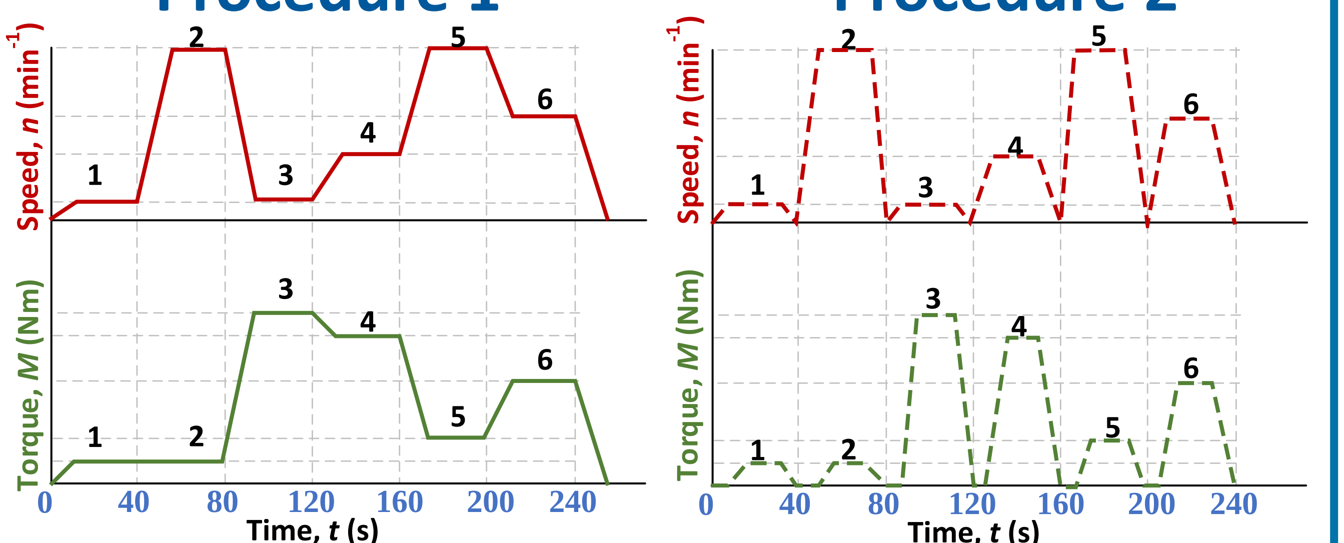

Fig. 3. Experimental procedures to apply speed and torque to the inverter-fed rotating electrical machine on the test bench.

Procedures	Description of operating conditions of torque and speed during the experiment
1	During the test, the torque is applied in parallel with the rotational speed.
2	After the speed has been applied, the torque is applied and maintained. After the measurement, the torque is set to 0 Nm and the speed is lowered to 0 rpm.

Measurement test setup

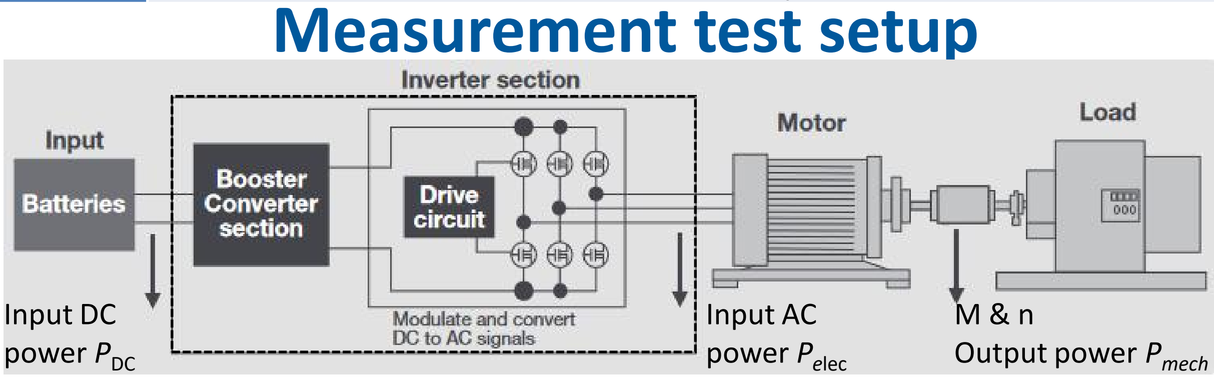

Fig. 4. Graphical representation of total system input/output power dissipation for efficiency measurement of the inverter-fed electrical machine in the test bench based on [3].

Power Loss Measurement with MU

Models for MU evaluation

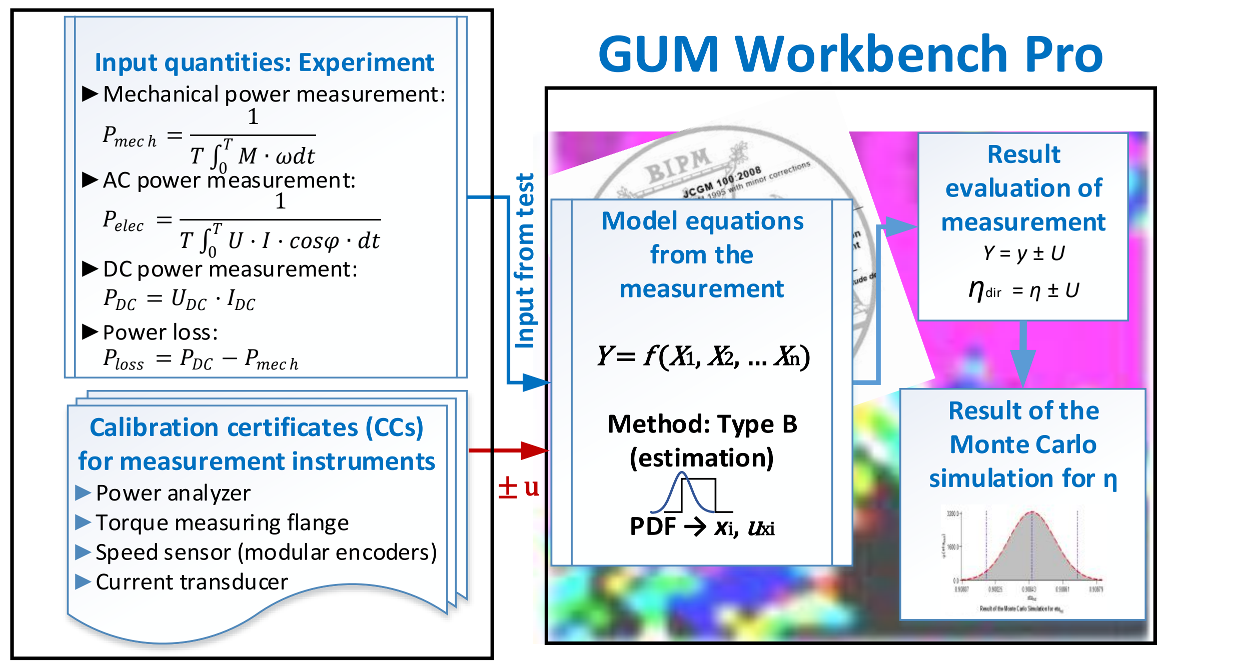

Fig. 5. : Block diagram of the GUM [4] measurement model based on the CCs for measurement instruments for MU for power loss measurements

Setting	Description
I	Old measurement with fixed range (1kV/1kA) and line filter (1 kHz) / HBM T12 (10 Hz)
II	Old auto range setting instead of fixed range in power analyzer WT 1800 with reduced HBM resolution error
III	New measurement fixed range HBM 1kV and 1kA
IV	New measurement auto WT 1800 and HBM T12

Measurement points (speed *n* / Torque *M*)	Power losses (W) in experimental procedure 1: Setting III (1)	Power losses (W) in experimental procedure 1: Setting IV (2)	Power losses (W) in experimental procedure 2: Setting III (3)	Power losses (W) in experimental procedure 2: Setting IV (4)
MP 1 (*n* =100/*M* =5)	100.5 ± 3.2	100.5 ± 0.2	137.8 ± 3.2	137.8 ± 0.19
MP 2 (*n* =12000/*M* =5)	437.3 ± 5.6	437.3 ± 4.5	427.4 ± 5.6	427.4 ± 4.5
MP 3 (*n* =100/*M* =280)	3113.3 ± 8.5	3113.3 ± 6.9	6101.3 ± 7.3	6101.3 ± 5.9
MP 4 (*n* =3000/*M* =270)	3253 ± 38	3253 ± 35	3233 ± 42	3233 ± 40
MP 5 (*n* =6000/M=120)	1200 ± 27	1200 ± 24	1181 ± 27	1181 ± 25
MP 6 (*n* =12000/*M* =30)	579 ± 13	579 ± 11	576 ± 13	576 ± 11

Measurement points (speed *n* / Torque *M*)	Power losses (W) in experimental procedure 1				Power losses (W) in experimental procedure 2			
	Setting I (5)	Setting II (6)	Setting III (7)	Setting IV (8)	Setting I (9)	Setting II (10)	Setting III (11)	Setting IV (12)
MP 1 (*n* =100/*M* =5)	3.4 ± 3.2	3.44 ± 0.19	100.5 ± 3.2	100.5 ± 0.2	8.3 ± 3.2	8.26 ± 0.19	137.8 ± 3.2	137.8 ± 0.19
MP 2 (*n* =12000/*M* =5)	119.5 ± 5.7	119.5 ± 4.6	437.3 ± 5.6	437.3 ± 4.5	214.1 ± 5.6	214.1 ± 4.5	427.4 ± 5.6	427.4 ± 4.5
MP 3 (*n* =100/*M* =280)	2439 ± 8.6	2438.7 ± 7	3113.3 ± 8.5	3113.3 ± 6.9	2542 ± 8.6	2542.5 ± 7	6101.3 ± 7.3	6101.3 ± 5.9
MP 4 (*n* =3000/*M* =270)	3285 ± 38	3285 ± 36	3253 ± 38	3253 ± 35	2990 ± 37	2990 ± 35	3233 ± 42	3233 ± 40
MP 5 (*n* =6000/M=120)	634 ± 27	634 ± 25	1200 ± 27	1200 ± 24	614 ± 26	614 ± 24	1181 ± 27	1181 ± 25
MP 6 (*n* =12000/*M* =30)	277 ± 13	277 ± 11	579 ± 13	579 ± 11	116 ± 13	116 ± 11	576 ± 13	576 ± 11

Summary, conclusion and future work

- Due to a new measurement setting wherein the power factor is no longer rounded to two decimal places, the rounding error no longer affects the MU.
- The new measurement procedure yields only very small changes in the MU values. As before, the setting of the auto range for the MP 1/2/3 yields a better measurement uncertainty than a setting using fixed ranges for current and voltage. This is because the small amount of current (IDC) is measured with the MP 1/MP 2/MP 3 in the high fixed range.
- The new measurement setting brings a significant change in the power loss. Here, the losses are usually much greater than with the previous procedure.
- The power factor listed in the CCS has a constant expanded MU of 0.0001 (values are not in the scope of accreditation). Compared to the old measurement procedure, the MU of the new procedure is thus significantly higher for MP 1/2/3 and lower for MP 5 (similar MU for MP 4 and MP 6). Thus, this contributes significantly to a high MU for the first three measurements and to a lower MU for MP 5.

References

[1] IEC TS 60034-2-3, Rotating electrical machines - Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC induction motors, 1st ed. 2013.

[2] IEC 61800-9-2, "Adjustable speed electrical power drive systems - Part 9-2: Ecodesign for power drive systems, motor starters, power electronics, and their driven applications - Energy efficiency indicators for power drive systems and motor starters."

[3] Bulletin WT1800E-01EN, "WT1800E Series High performance Power Analyzers Flexible & reliable." [Online]. Available: https://cdn.tmi.yokogawa.com/BUWT1800E-01EN.pdf. [Accessed: 28-Oct-2021].

[4] BIPM et. al., "Evaluation of measurement data — Supplement 1 to the 'Guide to the expression of uncertainty in measurement' — Propagation of distributions using a Monte Carlo method," Evaluation, vol. JCGM 101:2, p. 90, 2008.

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