

CHARACTERISATION OF REFERENCE TORQUE WRENCHES BY THE IMGC SIX-COMPONENT CALIBRATION SYSTEM

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Abstract

This paper describes the metrological characterisation of two Reference Torque Wrenches (RTW) of 100Nm and 500Nm capacity.

The characteristics of the torque sensors were evaluated by using the IMGC-CNR six-component calibration system (EUROMET agree facility, project 113). The repeatability of the absolute variation of the output signal of the two TTS under the application of the different spurious components, referred to the R.O., is in general of the order of $5 \cdot 10^{-5}$.

The sensitivity to spurious components are normally better than $2 \cdot 10^{-3}$ of the nominal torque.

Introduction

In recent years, the calibration and the metrological characterisation of multicomponents force sensor, torque meters and load cells by Multicomponents Calibration Systems (MCS) experienced considerable development. For such instruments has been required to determine their sensitivity to the main component (force or torque) and, in addition, the products of interaction between the different components of the force tensor.

This demand, for the calibration of sensors to be used in several fields, like robotics and wind tunnels, was first met by the development of a multicomponent calibration systems at the IMGC-CNR starting from 1973.

At the same time, the sector of multicomponent reference torque meters has been developed (PTB, RPO, HBM), with the design and construction of instrument measuring, besides the torque, also the other force-tensor components, on the analogy of what was done with six-component dynamometers (IMGC-CNR). On the other hand HBM has developed reference torque wrenches (RTW), highly insensitive to spurious components, to be used to check the metrological characteristics of torque calibration system or torque wrenches.

The metrological characterisation of the 100 Nm and 500 Nm HBM - RTW by using the IMGC six-component calibration system, was performed by using a sequential and a semi-factorial planes, in order to evidence any cross-correlation effects between the torque moment (F_N) and the other components: axial force (F_Z), side forces (F_X , F_Y) and bending moment (F_L , F_M).

A reduced factorial plane was applied, after the preliminary tests, in order to evaluate the 2nd order and the most significant of the 3rd order cross-correlation effects

In the paper the main metrological characteristics (repeatability, linearity, sensitivity for the different components) of the two RTWs are given, and the crossed sensitivities.

Instrumentation set-up and experimental method

Fig. 1 shows the schematic diagram of the 6-component calibration systems for testing the two TTS torque sensor, that was designed and constructed at the IMGC. Axial loads of 105 kN with uncertainty of $2 \cdot 10^{-5}$, transverse loads to 6 kN with uncertainty of $3 \cdot 10^{-4}$ and three

moments to 2 kNm with uncertainty of 5×10^{-4} can be applied individually or in combination [3].

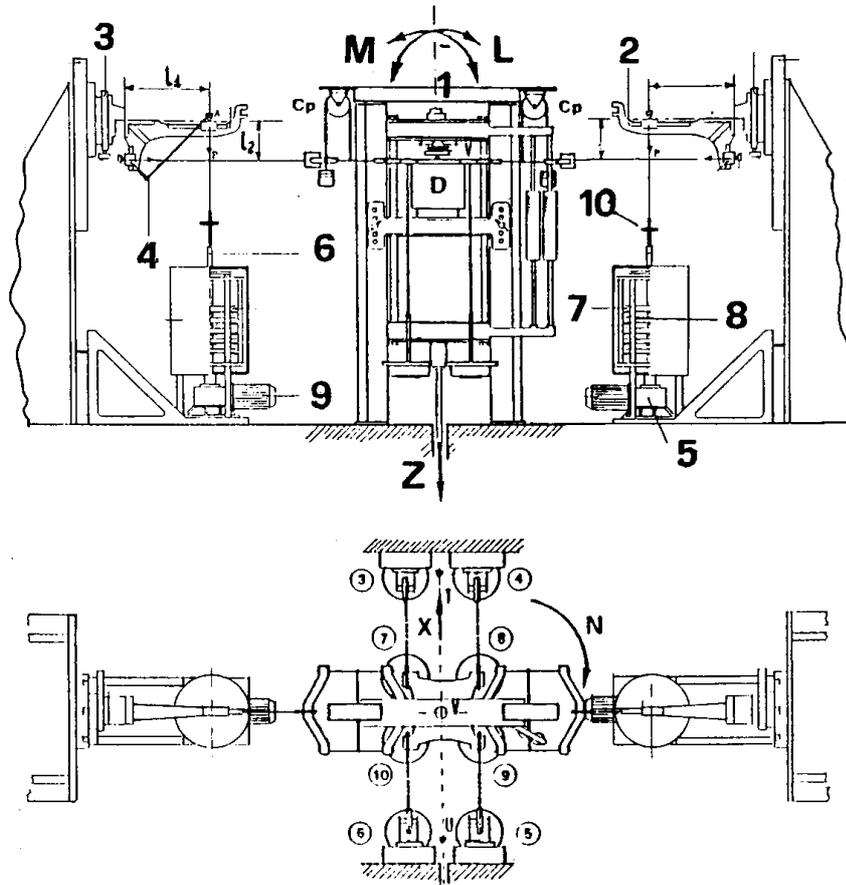


Fig. 1 - IMGC automatic multi-component calibration system with elastic hinge levers

Experimental methods

The output of a multi-component force sensor as a function of applied components X_i ($i = 1, 2, 3, \dots, 6$) can be adequately approximated by a second-order polynomial with 6 coefficients of the first order and 21 of the second order (6 quadratic and 15 products of interactions). The first order terms correspond to the linear effects of the 6 components. The second order terms correspond to double interactions and can be interpreted as a sensitivity variation for a component, caused by the deformation induced by the application of another component, and to individual quadratic effects. Only with a six-component calibration system can all the twenty-seven terms be determined. Fortunately, not all the linear and quadratic coefficients prove significant; they depend on transducer structure, machining tolerances, strain gauge positions, and so on.

The characterisation of the HBM-TTS 100Nm and 500Nm RTW by using the IMGC six-component calibration system with elastic hinge levers were performed by using a sequential and semi-factorial planes. Table I shows the sequential plane used to evaluate sensitivity, linearity, and inversion effect for the parasitic components

Table I – Sequential plane

Type of Components	Nominal Values of spurious components		Torque Level to Rated Load
	TTS 500	TTS 100	
Side Forces F_Y	1200 N	400 N	0; $\pm 30\%$ and/or $\pm 50\%$; $\pm 100\%$
Side Force F_X	1200 N	400 N	0; $\pm 30\%$ and/or $\pm 50\%$; $\pm 100\%$
Bending moment F_L	120 N·m	40 N m	0; $\pm 30\%$ and/or $\pm 50\%$; $\pm 100\%$
Bending moment F_M	120 N·m	40 N m	0; $\pm 30\%$ and/or $\pm 50\%$; $\pm 100\%$
Axial Force F_Z	1 kN	400 N	0; 50%; 100%

In order to evidence any cross-correlation effects between the torque moment and the other components, the tests were performed normally at five torque levels

A reduced factorial plane was applied after the previous tests in order to evaluate the 2nd order cross-correlation effects

Tab II is given as an example; it was performed only the tests with high significance level..

Table II – Example of reduced factorial plane for three components interaction

N = -100%; -50%; 0; 50%; 100% and Z = 0; 50%; 100%	M = -50%; 0; 50% or L = -50%; 0; 50% or X = -50%; 0; 50% or Y = -50%; 0; 50%
N = -100%; -50%; 0; 50%; 100% and X = -100%; -50%; 0; 50%; 100%	M = -50%; 0; 50% or L = -50%; 0; 50% or Y = -50%; 0; 50%
N = -100%; -50%; 0; 50%; 100% and Y = -100%; -50%; 0; 50%; 100%	M = -50%; 0; 50% or L = -50%; 0; 50%
N = -100%; -50%; 0; 50%; 100% L = -100%; -50%; 0; 50%; 100%	M = -50%; 0; 50%
N = -100%; -50%; 0; 50%; 100% M = -100%; -50%; 0; 50%; 100%	L = -50%; 0; 50%

When more components were applied simultaneously, the maximum values of the components applied during the tests were reduced, for safety evaluation, taking into account the values suggested by the HBM technical data.

The TTS 500 - RTW was tested at torsion moments F_N of 0 Nm, ± 160 Nm and ± 480 Nm, and the TTS100 - RTW at a torsion moments F_N of 0 Nm, ± 16 Nm, ± 48 Nm and ± 96 Nm.

A high precision indicator (HBM-DK38S6, sensitivity : $2\text{mV/V}=200.000$ digits) with uncertainty of $2,5 \times 10^{-5}$ was used to measure the outputs of the two TTS.

Experimental results and analysis

Fig.2 shows some examples of the absolute variation of the output signal of TTS100 under the application of different spurious components at different level of the torque moment F_N .

Figs.2a, b show the test results (two cycles) obtained by the application of F_Z with clockwise and un-clockwise torque moment; The ratio of the sensitivity for F_Z axial component to the nominal R.O. (Rated Output) for the F_N torque component is:

$$\text{Sensitivity for } F_{Z(R.O.)} / \text{Sensitivity for } F_{N(R.O.)} = 40 \text{ digit} / 180.000 \text{ digit} = 2,2 \cdot 10^{-4}.$$

Figs. 2c,d give the output variation for F_Y at two different level of torque moment ($F_N = 16 \text{ Nm}$; $F_N = 0 \text{ Nm}$)

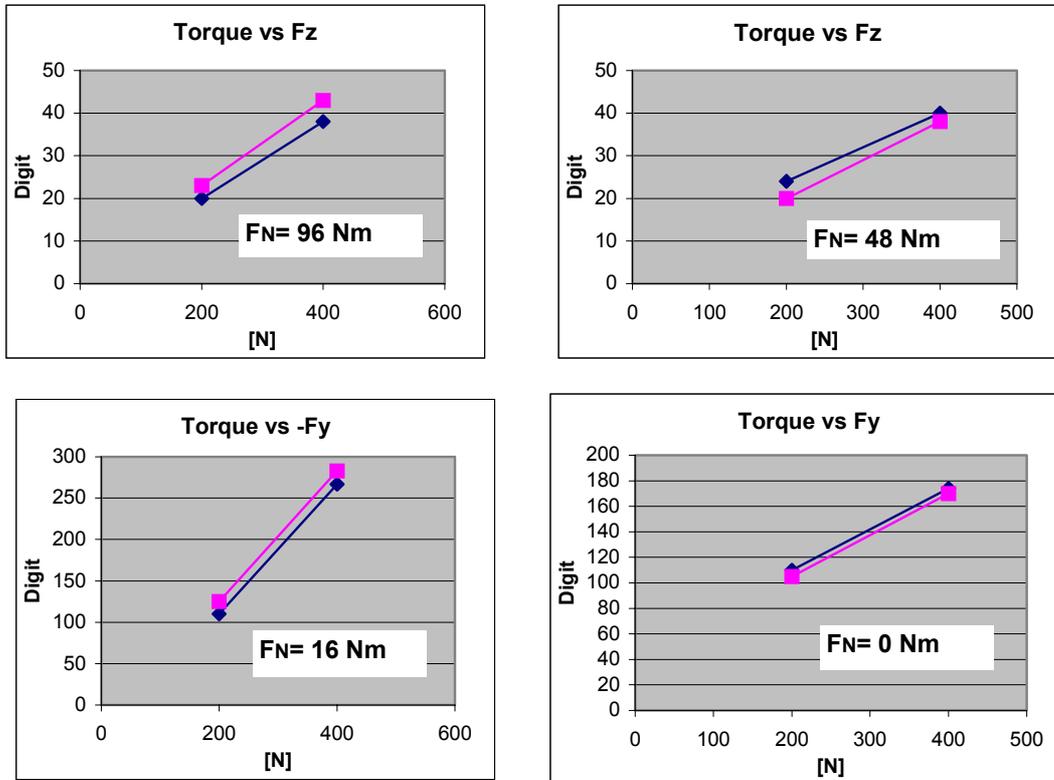


Fig. 2 a, b, c, d - Evaluation of sensitivity coefficients for TTS - 100

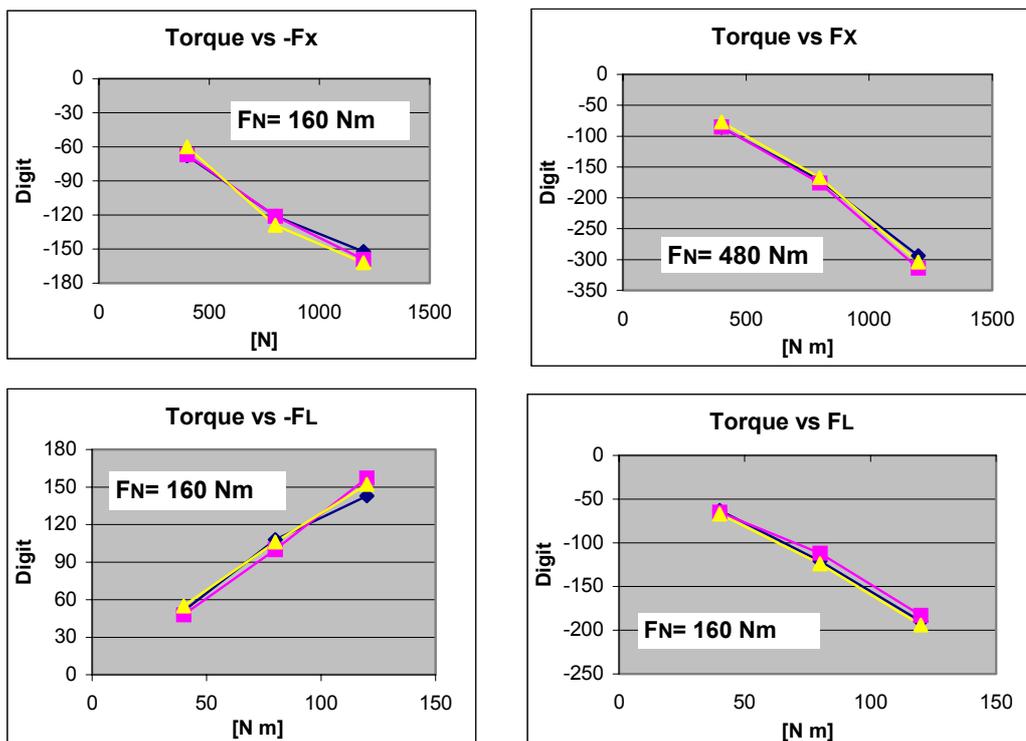


Fig. 3 a, b, c, d - Evaluation of sensitivity coefficients for TTS - 500

Fig.3 gives some examples of the absolute variation of the output signal of TTS500 under the application of the different spurious components and for different levels of the torque moment F_N .

Figs. 3a,b show the test results obtained by the application of the side component F_X at two

TAB. III - SENSITIVITY COEFFICIENTS AT RATED LOAD

Component applied	TTS - 100 Torque Moment F_N		TTS - 500 Torque Moment F_N	
	Clockwise	Un clockwise	Clockwise	Un clockwise
F_Z	$2,5 \cdot 10^{-4}$	$2,5 \cdot 10^{-4}$	$2,5 \cdot 10^{-4}$	$2,5 \cdot 10^{-4}$
F_X	$2,5 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$1 \cdot 10^{-3}$
F_Y	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
F_M	$1,5 \cdot 10^{-3}$	$1,5 \cdot 10^{-3}$	$2 \cdot 10^{-4}$	$2 \cdot 10^{-4}$
F_L	$2,5 \cdot 10^{-3}$	$2,5 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$1,5 \cdot 10^{-3}$

different levels of the torque moment ($F_N = 160 \text{ Nm}$ and $F_N = 480 \text{ Nm}$).

Figs 3c,d give the output signal variation caused by the application of the bending moment F_L up to 120 Nm for clockwise and un-clockwise torque moment ($F_N = 160 \text{ Nm}$).

Tab III gives a synthesis of the sensitivity ratio for the different spurious component to the RO of main component for the two TTS.

Several tests were carried out with three or four component applied simultaneity.

Tab. IV gives an example of the test results obtained on the TTS100 by applying four components all together ($F_N = 96 \text{ Nm}$; $F_Z = 400 \text{ N}$; $F_L = F_M = 20 \text{ Nm}$).

TAB. IV - Cross-sensitivity with four components applied

$F_N = 96 \text{ Nm (clockwise)}$ $F_Z = 400 \text{ N}$							Sensitivity Coefficient
F_L [Nm]	F_M [Nm]	1° cycle [div]	2° cycle [div]	Δ_1 [div]	Δ_2 [div]	Δ_m [div]	
0	0	-179290	-179292				$5 \cdot 10^{-4}$
20	20	-179372	-179367	-82	-75	-78,5	
0	0	-179292	-179290				

All the test results have shown a small cross-sensitivity between the different spurious and the main components.

The off-set at zero-load during the application of side forces could be given by a small preload that was applied, to avoid the possibility of rotation of the system around its axes under the action of the torsion moment.

The repeatability of the absolute variation of the output signal of the two TTS under the application of the different spurious components, referred to the R.O., is in general of the order of $5 \cdot 10^{-5}$.

Non-linearity and hysteresis are less than 0,01% R.O.

The average cross-sensitivity errors (interference error) are of the order of 0,1%; the biggest interference error is about 0,25% R.O. for the force side component F_x (TTS-100 and TTS-500), and about 0,25% for the bending moment F_L (TTS100).

These results are referred at two torque reference wrenches and can give only a typical hint. In fact, as it is well known, the influences of the parasitic components on one- or multi-component force and torque transducers depend on several factors, like: symmetry of hole construction, gauge positioning or milling symmetry and the last, but not the least, by the transducer-calibration system interaction /1,2,5/.

Conclusion

A complete metrological characterisation of the TTS100 and TTS500 HBM-RTW, with the IMGC six-component calibration system, were performed by using a sequential and semi-factorial planes. The repeatability of the different spurious components, referred to the R.O., is in general of the order of $5 \cdot 10^{-5}$. Non-linearity and hysteresis are less than 0,01% R.O.

The sensitivity to spurious components are normally better than $2 \cdot 10^{-3}$ of the nominal torque. The Multicomponents Calibration System of IMGC-CNR is available to the different European partners and to industrial sectors for possible feasibility studies and the characterisation of multicomponents prototypes (dynamometers or torque-meters), as previously was done for others national laboratories (NIN-China and KRISS-Korea).

Acknowledgement

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