Measurement 78 (2016) 202–206

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Metrological characterization of an hexapod-shaped Multicomponent Force Transducer

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ARTICLE INFO

Article history:
Received 24 March 2015
Accepted 29 September 2015
Available online 22 October 2015

Keywords:
Multicomponent Force Transducer
Hexapod-design
Calibration procedure
Uncertainty evaluation

ABSTRACT

A Multicomponent Force Transducer (MFT) was devised by INRiM for a specific request in railway industry, entailing measurement of two force components (transversal and axial force). Measurement of other components, while not strictly required, was deemed helpful for practical use. INRiM, basing on its experience, developed and calibrated a full six-component hexapod-design prototype of MFT. Best Subset Regression was applied to identify parsimonious models linking applied components to MFT outputs. Finally, the uncertainty associated to the values of transversal and axial force was evaluated.

1. Introduction

The present work was originated by a specific industrial request, concerning performances of coil springs in railway carriage suspension. Spring deflection under axial load entails also, as a rule, a side component, originating a transversal force and/or displacement, see (Fig. 1). Such a displacement (orthogonality error under load) is currently denoted by the French term "Chasse" [1].

These coil springs are usually checked on large capacity dedicated testing machines, relying upon hydraulic or mechanical devices for force generation. Machine platens usually do not allow side displacement; therefore "Chasse" may not be measured directly. Furthermore it is worth remarking that what really matters is preventing carriage's side displacement due to spring deflection. Therefore in railways engineering practice coil springs are assembled, and oriented, in carriage suspension aiming at offsetting side displacement, by producing under deflection side forces opposing each other. In order to achieve such result, knowledge of side force under axial load, and its orientation, is a prerequisite.

However technical specifications [1] mandate formal evaluation of the displacement "Chasse". A measurement strategy was adopted, based upon identifying side force direction under load, and rotate the spring under test around its vertical axis in order to align the direction of "Chasse" with that of a sliding table, set upon testing machine platen. The sliding table is then moved as required to produce zero side force, the corresponding displacement being taken as a measure of "Chasse".

A device is therefore required, capable of measuring modulus and direction of both axial and side force, the former corresponding with spring axis. While a three-component Multicomponent Force Transducer (MFT) – capable of measuring F_x, F_y and F_z – would fit the bill, knowledge also of moments (M_x, M_y, M_z) offers substantial advantages, in terms of better identification of calibration equations.

Substantial experience accumulated at INRiM on development of multicomponent force measurement devices and related calibration rigs [2] suggested design and development of an *ad hoc* MFT. Capacity of MFTs previously

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http://dx.doi.org/10.1016/j.measurement.2015.09.054
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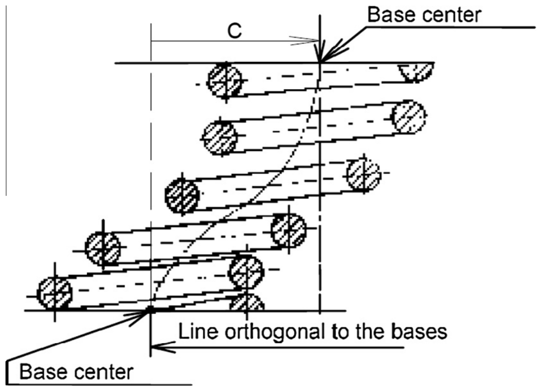

Fig. 1. "Chasse" C defined as side displacement due to axial load.

developed at INRiM ranges from few newtons to hundreds of kilonewtons, with different configurations, e.g. integral or built-up. Typical applications covered control of parasitic components in force standard calibration machines, verification of material testing machines, robotics, and cutting force evaluation in machining research [3].

A large capacity six component MFT, hexapod shaped, was developed for the task at hand by INRiM for a firm operating in the field of mechanical testing. Such a structure, typical of six degrees of freedom displacement devices (Stewart platforms), was previously exploited by INRiM in low capacity MFTs, particularly in robotics [4,5].

Mandated uncertainties for the case at hand are 1% on side force measurement, and class 1 of ISO 7500-1:2004 [6] on axial force measurement.

2. Description of the MFT

The MFT has an axial force capacity of 200 kN and of 30 kN for transversal force. Its built-up design is made up by six Uniaxial Force Transducers (UFTs) individually calibrated on a deadweight force standard machine. Their calibration equations are taken into account to get, in terms of the six UFT outputs O_i, the corresponding measures $F_{m,i}$ of the forces F_i acting on each arm ($i = 1,\ldots,6$).

Every UFT installed into the hexapod structure is decoupled by integral elastic hinges at both ends (Fig. 2), substantially eliminating spurious components, which might otherwise affect measurements [7]. Such a structure (Fig. 3) enables measuring three force components (transversal, F_x and F_y, and axial, F_z), and three moment components, (tilting, M_x and M_y, and torsion, M_z). Theoretical values of the three force and three moment components may be calculated in terms of nominal MFT geometry, and the relevant uncertainties estimated a priori by assuming a set of deviations from the geometry thereof.

Since this work covers mainly experimental evaluation of metrological characteristics of MFT, where actual geometry is directly taken into account, only uncertainty contributions due to reproducibility are considered.

3. Calibration of the MFT

Transducer design caters for both comprehensive initial calibration and a simpler procedure for maintenance over time. Within the specified range of combinations of applied forces and moments, all the UFTs are loaded in tension only.

The first calibration is useful to determine both the effects of the geometry of the structure and the sensitivities of the UFTs. Since the MFT, installed in a spring testing machine (Fig. 4), is not moved over time, the geometry is not subject to significant changes. Thus, the subsequent calibrations are restricted only to the evaluation of the variation over time of sensitivities of the UFTs by applying known values of vertical components F_z.

INRiM was tasked with the first calibration of the MFT in order to have traceable measurements with a proper uncertainty evaluation [8]. A well-established metrological approach [3] asserts that forces must be applied both independently and in combination to assess cross sensitivity among output channels (if any). Testing procedure strictly requires only calibration for F_x and F_z.

Calibration for F_z was performed on the primary INRiM deadweights standard machine with a capacity of 1 MN, following the international calibration procedure; results

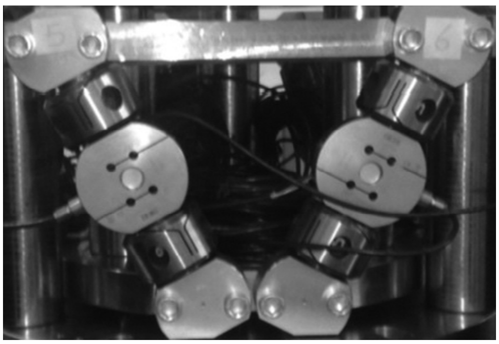

Fig. 2. Two of the six Uniaxial Force Transducers (UFTs) decoupled by integral elastic hinges at both ends.

Fig. 3. Layout of the hexapod-shaped Multicomponent Force Transducer (MFT).