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Measurement uncertainty of a pressure sensor submitted to a step input

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ABSTRACT

In this paper we analyses the time response of a pressure sensor submitted to dynamic pressure step signals produced in a shock tube. The sensor is modeled as a linear second-order system and the mathematical modeling of the input signal is supplied by shock tube theory. The description of the sensor parameters is given and the experimental data are compared to the expected sensor response. The law of propagation of uncertainty and a Monte Carlo method are employed to estimate the uncertainty of the step input signal and uncertainties associated with the sensor parameters. Two approaches for estimate the damping were analyzed, one considering the first peak and other using the values of two consecutive peaks of the signal. The time response obtained by using the second approach showed a better agreement to the experimental output signal of the sensor and therefore seems to be more appropriate for the sensor characterization.

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1. Introduction

Applications which demand dynamic calibration are those whose sensors work under abrupt and significant changes of the signal over time. Sensors which act under these conditions are found in segments such as medicine, ballistics, automotive industries and aerospace engineering [1].

Pressure sensors are extensively employed in tests and launch campaigns of aerospace vehicles developed by the Institute of Aeronautics and Space, Brazil. Dynamic measurements are present in these applications, which require dynamic calibration of the sensors to be carried out prior to their use.

The document "A Guide for the Dynamic Calibration of Pressure Transducers" [2] is one of the most important documents on dynamic calibration of pressure sensors. This document describes the properties of sensors and the main calibration methods in the time and frequency domains, but it doesn't address the methodology for estimating uncertainty. Despite the efforts of the international metrological community composed of institutions such as the National Physical Laboratory, NPL (England), the Physikalisch-Technischen Bundesanstalt, PTB (Germany), the Laboratory of Dynamic Metrology, University of Brasilia, UNB (Brazil) and the Laboratoire Nationale de Métrologie et d'Essais, LNE (France), there is still a lack of standardization in dynamic calibration procedures, as can be seen in Refs. [3–5].

The procedures for calibration in static conditions are well established by metrological organizations. Ref. [6] supplies the standardization for the metrological terminology and methods for uncertainty evaluation are proposed by the Joint Committee for Guides in Measurement, JCGM, through the Guide to the Expression of Uncertainty in Measurement, GUM [7] and supplements [8]. Sometimes this standardization may not be present when considering dynamic calibration.

Different systems have been used to supply typical signals which can be used in the dynamic characterization of sensors. The shock tube is considered as an adequate signal generator when it is necessary to produce step inputs with great variations of amplitude and high frequency components [5]. In this situation, the output signal of the sensor is compared to the step input signal supplied by the shock tube.

The concept of traceability in dynamic pressure measurement is not well developed when employing shock tubes, mainly due to the lack of a standard input signal to be applied to the sensor under calibration. As there is no traceable standard for comparison, the analysis aims to characterize the pressure sensor by measuring the sensor response to a reference input signal. The response signal of the sensor is then compared to a theoretical input [5].

This paper addresses the characterization of pressure sensors submitted to input step signals generated in a shock tube. The experimental data were obtained in the tests carried out at the shock tube facility of the Institute for Advanced Studies, IEAv, Brazil. The maximum pressures found in the experiments were around 1 MPa and the higher frequency components were of the order of 60 kHz.

The parameters related to the characterization of the sensor and associated uncertainties are evaluated, as well as the uncertainty associated with the pressure step input signal imposed on the sensor. Two approaches were employed to estimate the uncertainty: the law of propagation of uncertainty [7] and a Monte Carlo method [8].

The values found for the time response of the sensor, predicted by the adopted second order model and the experimental response obtained in the shock tube tests, are shown.

2. The T3 Shock Tube/Tunnel facility

Experimental data originating from the T3 Shock Tube/Tunnel were used for the characterization of the pressure sensor. Fig. 1 depicts the T3 facility, composed of a shock tube, wind tunnel test section and exhaust tank. The facility is located at the Aerothermodynamics and Hypersonic Laboratory Prof. Henry T. Nagamatsu of the Institute for Advanced Studies, IEAv, Brazil. The total length of the system is 24 m. The shock tube section is divided in two parts: the driver, 4 m long, and the driven, 10 m long [9]. The test section and the exhaust tank of the wind tunnel were not activated during the tests carried out for this study.

For the pressure range covered in the tests, diaphragms made of 1020 steel with diameter of 0.2895 m and thickness of 0.0046 m were employed (Fig. 2) [9]. In order to reduce the disturbances caused by imperfect burst of the diaphragm, the central area presents cross grooves of 0.00125 m deep.

The distance of the sensor under test from the diaphragm is greater than 12 times the diameter of the diaphragm. This distance reduces the effects of the non-ideal diaphragm opening during the experiment [10].

Two manometers were used to measure the pressures P_4 in the driver tube and P_1 in the driven tube, and one thermometer to measure the temperature T_1 in the driven tube.

Two piezoelectric pressure sensors Kistler 701A were placed in positions P2 and P2[1] to measure the front wave speed. The second sensor is positioned 0.4 m downstream of the first. The sensor under test is the second sensor P2[1] also used to estimate the front wave velocity. The position of the sensors used in the tests is shown in Fig. 3.

The acquisition system is composed of a PCB Piezotonics Sensor Signal Conditioner Model Series 481 amplifier