Measurement 91 (2016) 377–384

Contents lists available at ScienceDirect

Measurement

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

Ambient pressure compensation for hermetically sealed force transducers

Toshiyuki Hayashi *, Kazunaga Ueda

National Metrology Institute of Japan (NMIJ), AIST, Japan

ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form 2 May 2016
Accepted 19 May 2016
Available online 19 May 2016

Keywords:
Hermetically sealed force transducer
Strain-gauge-type transducer
Pressure compensation
Calibration uncertainty
Repeatability
Reversibility

ABSTRACT

Readings of hermetically sealed force transducers are affected by fluctuations in atmospheric pressure, and measured deflections vary when the ambient pressure changes quickly between two readings at zero force and at a certain force step. For some types of force transducers, readings at the zero point are quite sensitive to the ambient pressure change and this influence is not negligible. By periodically repeating measurements on two force transducers, it was verified that the repeatability of the measurements can be improved, and hence calibration uncertainty can be reduced to some extent, by compensating for deflections of the force transducers due to ambient pressure fluctuations by referring to the zero sensitivity.

1. Introduction

Strain-gauge-type force transducers and load cells have been widely used for force measurements and weighing for a long time. The sensing elements of most high-quality force transducers are hermetically sealed, because moisture and contaminating substances in ambient air affect the mechanical and chemical characteristics of the strain gauges and change their sensitivities. However, with variations in the ambient pressure, the sealed structures behave like balloons, causing variations in the readings of the force transducers. A Technical document OIML R60 requires load cells to be insensitive to barometric pressure; that is, only an output change within the minimum resolution is allowed for a pressure change of 1 kPa over the range from 95 kPa to 105 kPa [1]. Another document VDI/VDE/DKD 2638 defines the term of "Ambient pressure effect on zero signal per 1 kPa (pK_0)" as variation of the zero signal of the force transducer due to variation of the ambient pressure [2]. The output change of the force transducers due to air pressure variation results in a change in tare, but this can be cancelled out by performing a zero adjustment before applying the force or weighing. However, this assumption is valid only when the ambient pressure is stable enough during the force measurement or the weighing. When the pressure drastically varies between the zero adjustment and force measurements, the sensitivity of the force transducer also varies. Therefore, force measurements with small uncertainties are not possible under rapid pressure changes, e.g. during an approaching storm.

Many National Metrology Institutes (NMIs) claim Calibration and Measurement Capabilities (CMCs) of 2×10^{-5} relative [3]. More attention should be paid to ambient pressure changes when calibrating force transducers with such small uncertainties. Although there have been some studies that dealt with the influences of temperature and humidity on strain-gauge-based transducers, to the best of our knowledge, it has not yet been reported how ambient pressure quantitatively affects the characteristics of high-quality force transducers.

This paper describes the quantitative dependence of the sensitivity of force transducers on ambient pressure variations in a short period. It also introduces a measure to correct the force transducer readings for the influence of pressure variations.

2. Dependence on ambient pressure fluctuations

2.1. Tolerance to ambient pressure variations

In calibrations of force transducers, readings are recorded both at zero force and at a calibration force step, and the difference between these two readings to determine the deflection at that force step. As already mentioned, the change in ambient pressure between these two recordings is the source of the sensitivity change. Here, there are two points that should be considered: (a)

* Corresponding author.
E-mail address: t-hayashi@aist.go.jp (T. Hayashi).

http://dx.doi.org/10.1016/j.measurement.2016.05.067
0263-2241/

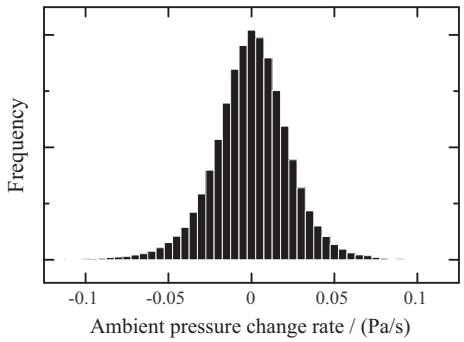

Fig. 1. Histogram of pressure change rates in ten-minute intervals, based on environmental recordings for 4 years at the force lab of NMIJ.

Fig. 2. Photograph of a force transducer in which the seal was accidentally broken.

tolerance for variations of force transducer readings associated with pressure fluctuations, and (b) the time interval between the two readings. The former could affect the CMCs at the level of NMIs. If the sensitivity fluctuation due to a change in ambient pressure exceeds 1×10^{-5} relative, it cannot be ignored in the calibrations performed at NMIs. Though the latter depends on the measurement conditions, a time interval of 10 min may be a typical value. This value is similar to the time required to increase the force from zero to the maximum force in a force standard machine with 8 or 10 calibration force steps. It is also close to the time interval from zero to the maximum of 12 min that is prescribed in the measurement protocols of the key comparisons conducted among NMIs in the past [4,5]. In this paper, a criteria is imposed on the ambient pressure variation; that is, an ambient pressure variation is not allowable if it causes the sensitivity of a force transducer to vary by more than 1×10^{-5} relative within a time interval of 10 min.

2.2. Actual pressure fluctuations in a laboratory

Actual ambient pressure fluctuations were evaluated by using records of the air pressure at the force laboratory of NMIJ. The air pressure was recorded every 10 min using a digital barometer (General Electric, type: DPI-142). Fig. 1 depicts a histogram of the pressure differences between two neighboring records in a ten-minute interval, taken between April 2011 and March 2015. The standard deviation of the distribution was 0.025 Pa/s. The maximum and minimum values were 0.45 and −0.49 Pa/s, respectively,

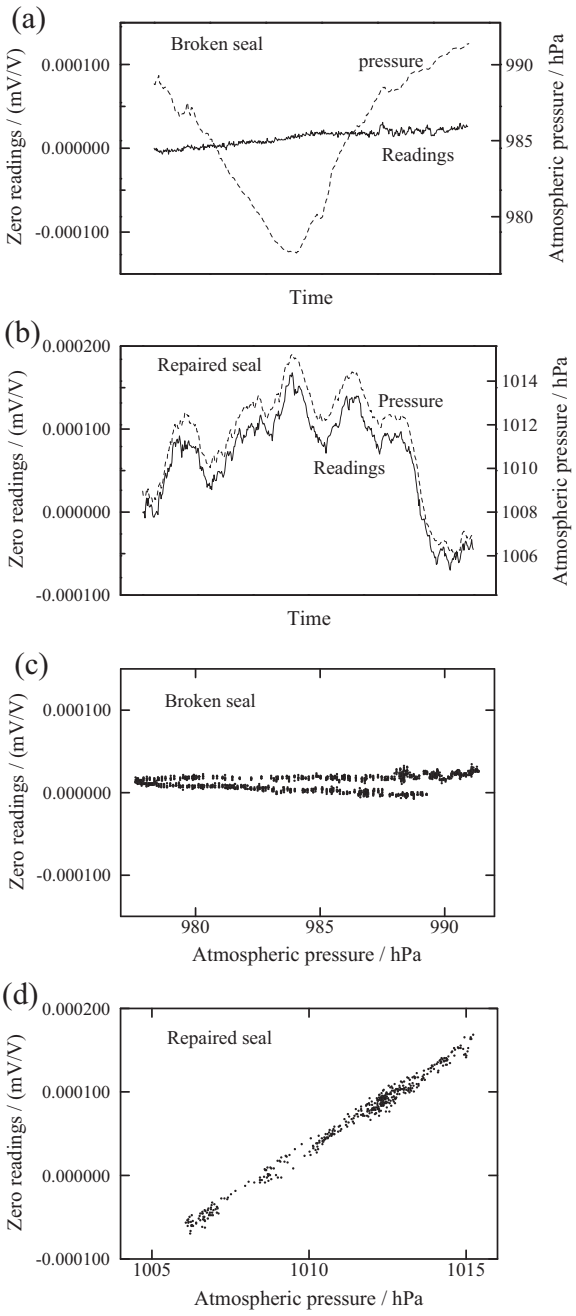

Fig. 3. Pressure dependence of the C4-type force transducer.

but such large values, caused by approaching storms, were excluded from the histogram. Fig. 1 shows that pressure fluctuations of 0.05 Pa/s, twice the standard deviation, are not so rare.

2.3. Sensitivity of force transducers to ambient pressure

When the ambient pressure varies, the output of a sealed force transducer without a load, i.e., the reading at the zero point, also varies due to expansion and contraction of a diaphragm, bellows and so forth. The sensitivity of the zero readings of the force transducer to the pressure fluctuation can be estimated by monitoring the output of the force transducer and the ambient pressure simultaneously.

When the seal of a force transducer (Hottinger Baldwin Messtechnik GmbH, type: C4, capacity: 100 kN) was broken by