

## **Continuous calibration of force transducers**

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### **Abstract**

A technique for calibrating force transducers under dynamic input conditions is reported and evaluated. The output of a test transducer is determined at a number of points on an applied input force ramp by comparison with a calibrated reference transducer connected in series, enabling the output sensitivity of the test transducer to be determined. Experimental results show that transducer output values obtained using this dynamic calibration technique are in agreement with those obtained using a static calibration procedure to within 0.05 %. This continuous calibration technique provides an alternative to calibrating the transducer statically, greatly reducing the time required for transducer calibration. Investigation of the creep characteristics of a range of test transducers demonstrates that creep performance is a major contribution to agreement between transducers in continuous calibrations, leading to possible techniques for the correction and subsequent improvement of calibration results.

*Keywords:* dynamic, continuous, calibration, force, transducer, creep

### **1. Introduction**

Currently, most transducers used to measure quantities such as force and torque are calibrated in a static manner; a constant input is applied to the transducer under test, a specified settling time is allowed to elapse, and then the transducer output is recorded. This process is repeated for a number of different input values, generally in an incremental pattern, with the entire process repeated possibly two or three times. Transducer calibration can therefore be a laborious, time-consuming, and expensive exercise. This paper outlines a dynamic calibration technique that can be used to calibrate transducers by measuring their output during the application of an input force ramp – this is termed a “continuous calibration”. Experimental results indicate that the technique produces transducer output values in good agreement with those obtained using a static calibration technique, while greatly reducing the time taken for transducer calibration.

### **2. Principle of the calibration technique**

The calibration process uses a comparison technique in which the known output of a reference transducer is related to the unknown output of the transducer under test. The transducers are connected in series and are then subjected to an applied force ramp. The two transducers are connected to a data acquisition system and the two output signals are synchronously captured throughout the ramp application period. The output data therefore consists of

two temporally-correlated transducer output curves. Since the output sensitivity of the reference transducer is known (from a static calibration), its output can be used to determine the force applied to the transducer pair at any point during the force ramp and, because the transducer output signals are recorded synchronously, the output signal from the transducer under test can also be determined at this known applied force. By repeating this process at a number of further points over the force ramp, a calibration look-up table can be produced for the transducer under test and the output sensitivity of this device determined.

### 3. Experimental procedure

The experimental set-up used to evaluate the calibration technique is shown in Figure 1. The reference transducer and the transducer under test were connected in series using a precision threaded bush to provide secure mechanical connection and to ensure the transducers were axially aligned. The transducers were then positioned between the seating table and the moving crosshead of an Instron 5567 load frame. This load frame is operated under software control and can apply test loads of up to 30 kN.

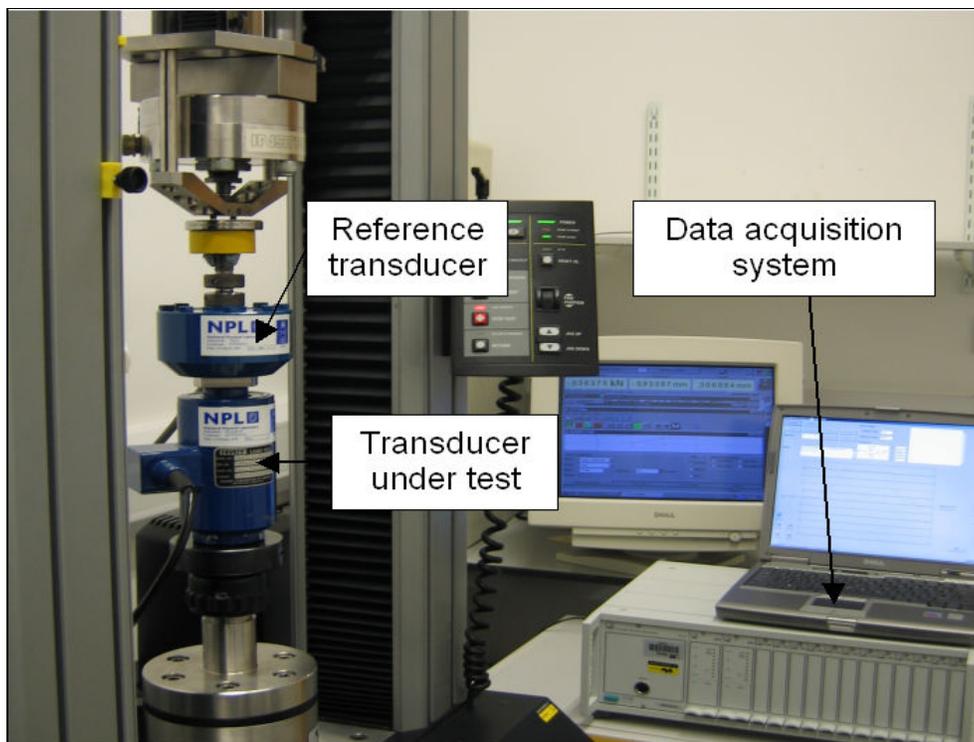


Figure 1: Experimental set-up

The outputs of both transducers were connected to a two channel HBM MGCplus data acquisition system operated under computer control. Each input channel was fitted with a high accuracy amplifier module compatible with strain gauge full bridge transducers and having a maximum data acquisition rate of 75 Hz.

Three test transducers were used in the evaluation of this technique: a Revere Model USP1 Super Precision load cell with a capacity of 22 kN (transducer 1), an Interface Model 1600 calibration grade load cell with a capacity of 22 kN (transducer 2), and an HBM Model C3H2 load cell with a capacity of 20 kN (transducer 3). The transducer used as the reference was an Interface Model 1600 calibration grade load cell with a capacity of 22 kN. All transducers were initially calibrated statically in NPL's 20 kN deadweight force standard machine in accordance with BS EN ISO 376:2004 [1] over the input range 0 kN - 20 kN prior to commencement of the "continuous calibration" measurements.

The calibration technique was evaluated over a range of compression force application rates from  $0.5 \text{ kN}\cdot\text{s}^{-1}$  to  $20 \text{ kN}\cdot\text{s}^{-1}$  up to a maximum applied force of 20 kN. The output data from the two transducers were saved to a datafile for post-experimental analysis. The experimental procedure was then repeated for transducers 2 and 3.

#### **4. Experimental results**

The measurement results presented here were produced by post-processing the captured measurement data. The outputs of both transducers were zeroed before a known force ramp was applied to the transducer pair. The output of the transducer under test was determined at a regular series of points over the ramp at input force values derived from the reference transducer output. In order to assess the validity of the technique, the output signal of the test transducer under force ramp conditions was compared with the same transducer's output signal under static loading conditions for a given input force, with the difference in output signal expressed in percentage terms.

Figure 2 is a plot of the initial experimental results obtained for transducer 1, with force application rate plotted as the independent variable (x-axis) and transducer output difference plotted as the dependent variable (y-axis). The multiple plots show the influence of force application rate on the output difference at specific input force values. The plots indicate that the transducer output signal is very similar whether the input load is applied statically or dynamically, with the magnitude of the largest observed difference less than 0.08 %. A comparison of the observed outputs shows reasonably good agreement over the entire transducer operating range, even at dynamic force application rates of up to  $20 \text{ kN}\cdot\text{s}^{-1}$ .

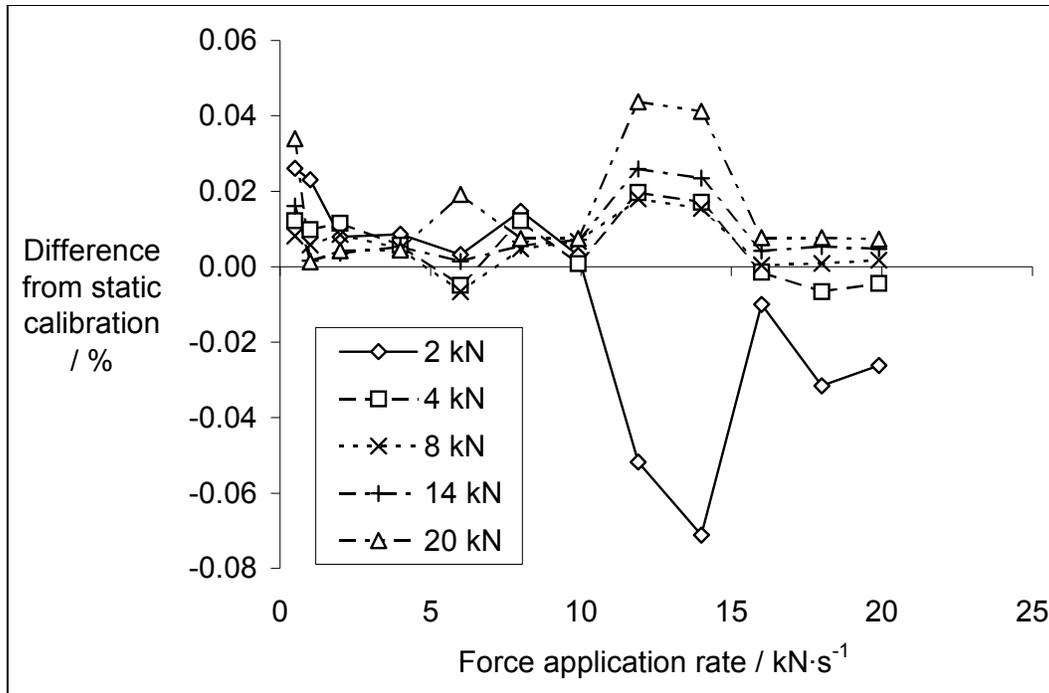


Figure 2: Transducer 1 – Initial experimental results

The plots do show some discontinuities, particularly at force application rates in the  $10 \text{ kN}\cdot\text{s}^{-1}$  to  $15 \text{ kN}\cdot\text{s}^{-1}$  range. Further analysis of the experimental data indicated that the discontinuities were caused by inaccuracies in the determination of the force application rates. Limitations in the control system driving the load frame meant that, at some nominal application rates, the actual force application rate could be as much as 50 % in error of the nominal value indicated by the operating software, due to undershoot and overshoot. A corrected force application rate can be determined from the reference transducer output, and this was used to estimate correction factors which could then be applied to the test transducer nominal force application rates to determine the actual force application rates.

Tests showing large overshoots were repeated, and the data from tests with smaller overshoots were corrected to reflect the actual applied force rates – the results of this work are given in Figure 3. The majority of the discontinuities have now been smoothed out and the measured transducer output values are now in extremely good agreement between statically and dynamically applied input forces over the range of application rates investigated, with the magnitude of the maximum difference approximately 0.03 %.

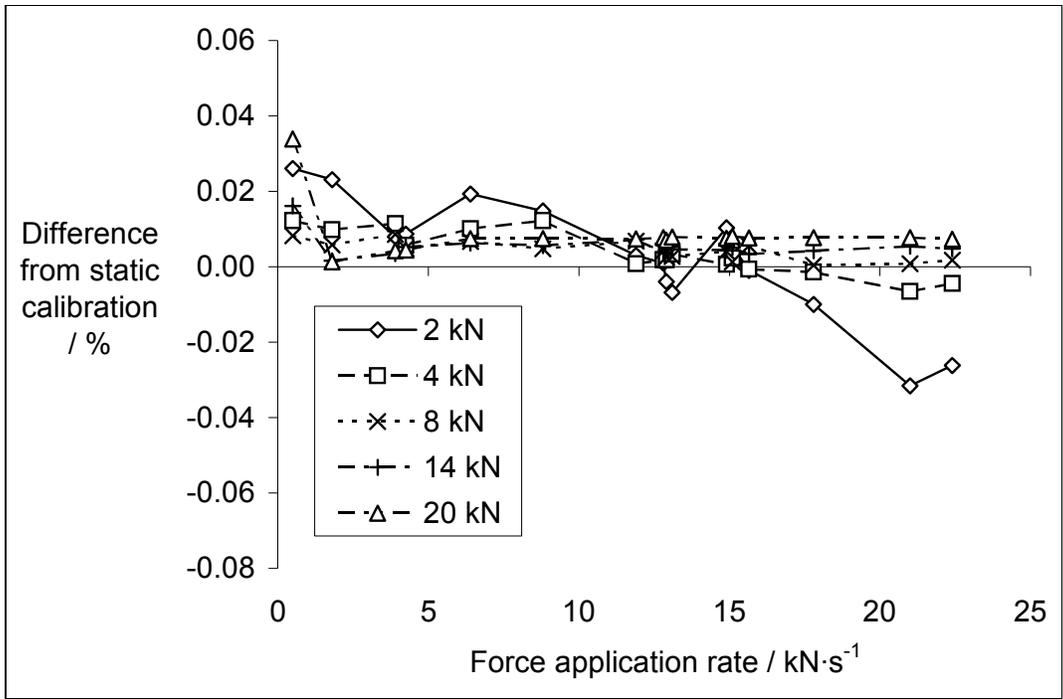


Figure 3: Transducer 1 – Corrected experimental results

Figure 4 is a comparison plot showing the output differences for all three transducers investigated. The force application rates have again been corrected to reflect the actual applied values. For clarity only the test transducer output values for a 10 kN input force are shown. The figure shows that, while the outputs of transducers 1 and 3 are in good agreement between statically and dynamically applied input forces, the output of transducer 2 shows an increasing divergence from the static case as the application rate is increased.

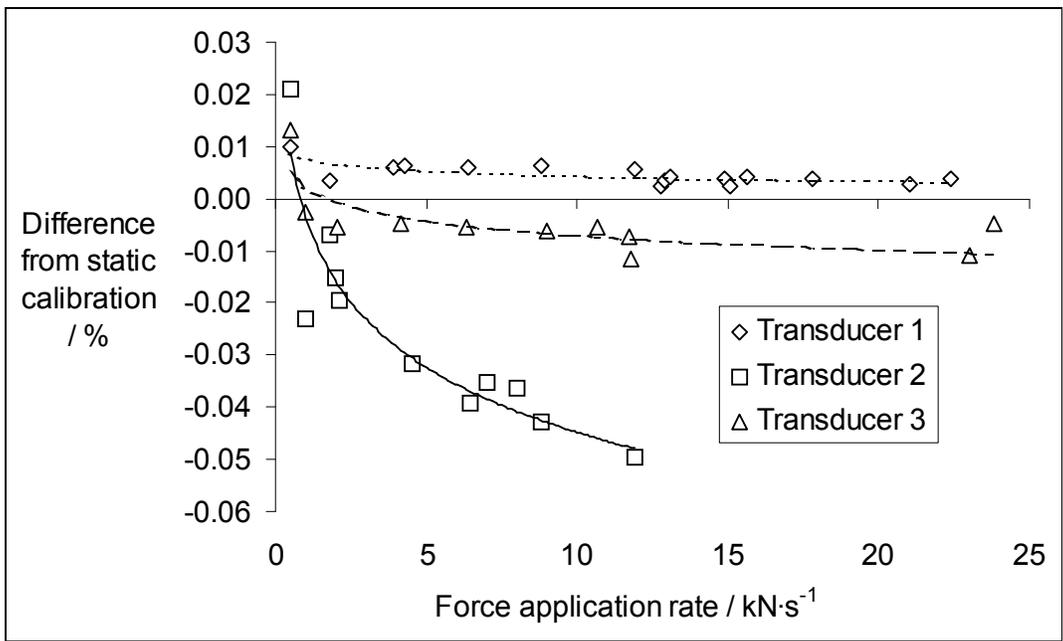


Figure 4: Comparison of the three test transducers at 10 kN

After all tests had been completed, the static calibrations of all four transducers were repeated in the 20 kN machine to determine whether their sensitivities had drifted – all changes were less than 0.01 %, so the assumption was made that the initial calibration values were valid throughout the exercise.

The dynamic calibration technique described here will only be applicable for use with transducers having an appropriate dynamic response. One of the major influences on the dynamic response of the type of force transducer investigated here will be its creep characteristics [2]. To investigate whether the effects of creep would significantly affect the test transducer output profiles under dynamic force input conditions, a creep test was performed on each of the transducers used in the above experiments and the resulting output data compared. The tests indicated that, while the creep characteristics of the reference transducer, transducer 1, and transducer 3 were similar, the creep characteristics of transducer 2 were significantly different – see Figure 5. The magnitude of observed drift in output signal of transducer 2 over a 150 s period at a force of 20 kN was significantly greater than that of the other three transducers. This is a possible explanation for the results observed in Figure 4, with the creep characteristics of transducer 2 leading to the discrepancy in measured output signal values between static and dynamic input force conditions. This analysis suggests that it may be possible to apply a correction factor, determined from the measured creep characteristics of the transducer, to the test transducer's output calibration data, to adjust for the effects of creep.

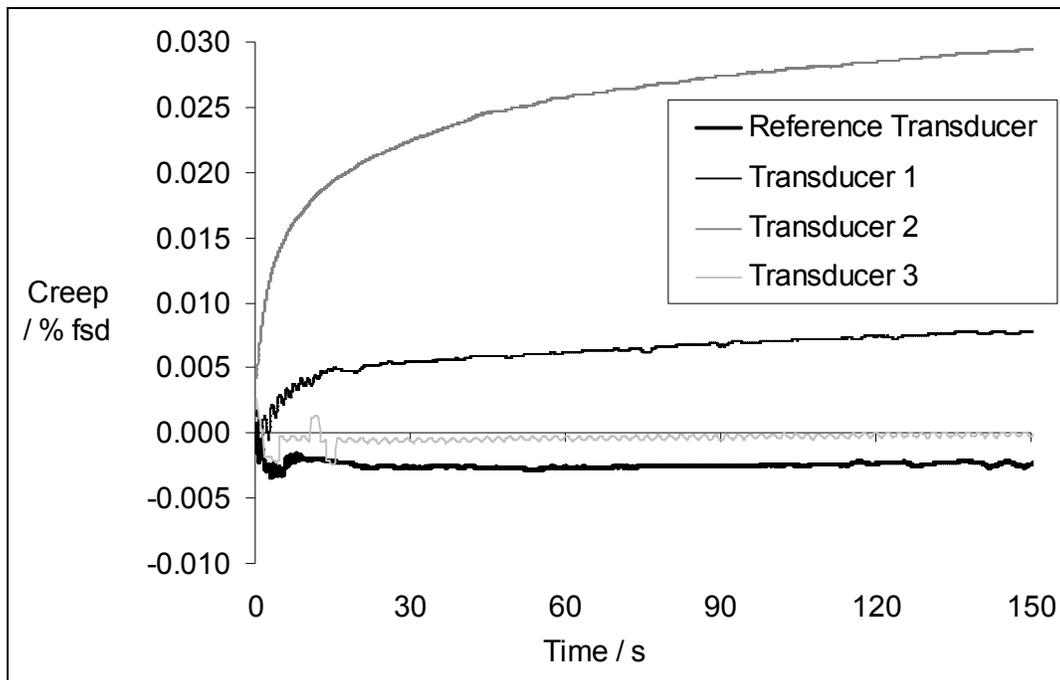


Figure 5: Creep characteristics of the four transducers

## **5. Conclusions**

A technique for calibrating force transducers under dynamic force input conditions has been described and experimentally evaluated. Transducer calibration output data produced using the technique has been shown to be in good agreement with equivalent output data generated using a static calibration procedure. The technique was evaluated over a range of input force application rates up to  $20 \text{ kN}\cdot\text{s}^{-1}$ , and a comparison of transducer output data obtained using both static and dynamic calibration approaches indicated a difference of less than 0.05 % in the measured output signal. The effects of transducer creep on the soundness of the calibration technique have also been investigated. Although the calibration technique may not be applicable when the lowest transducer measurement uncertainties are required, the experimental results presented here indicate that it would be adequate in applications where a slightly higher measurement uncertainty is acceptable. The technique is also potentially applicable to other transducer types normally calibrated in a static manner. The calibration technique offers a means of greatly reducing transducer calibration times, consequently reducing the calibration costs incurred.

## **6. References**

- [1] BS EN ISO 376, Metallic materials – Calibration of force-proving instruments used for the verification of uniaxial testing machines, November 2004.
- [2] A. Crawshaw, A. Robinson, The calibration of force transducers "on-the-fly", NPL Report CMAM 86, September 2002.

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