

COMPARISON OF TWO 1 kN FORCE TRANSDUCERS AT CONTINUOUS CALIBRATION

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Abstract:

This paper describes a comparison of simultaneous continuous force introduction to two strain-gauge force transducer in a force calibration machine. The continuous force was generated by a single loading/unloading step of the full load of the 1 kN deadweight force calibration machine. Loading rates from 0.3 kN/s to 3.8 kN/s were applied. The results are presented for different loading speeds and for different amplifier types (225 Hz and 4.8 kHz carrier frequency).

Keywords: calibration; continuous; force; error

1. INTRODUCTION

Standardised calibration procedures for force transducer calibration are typically defined under static loading conditions only, e.g. ISO 376 procedure [1]. When these transducers are used for measuring continuous forces [2], additional effects affecting the indicated force need to be evaluated [3]. As traditional static force calibration machines do not provide a metrologically traceable continuous force, one way of investigating the possible effect is a comparison of the response of two different transducer types to loading and unloading with different loading rates additional to the static calibration. In these scenarios, not only the transducer type but also the measuring amplifier type and its settings can have an effect on the result.

2. PROCEDURE AND EQUIPMENT

To investigate the effect of continuous loading on strain gauge force transducers' characteristics, two strain gauge force transducers were exposed to the same continuous force under various loading conditions. The selected force transducers were a 1 kN HBM U1 type and a 1 kN HBM U2B type. Both force transducers can measure compressive and tensile forces but, for this investigation, they were loaded by tensile forces only.

The force was generated by a 1 kN deadweight force calibration machine. The two transducers were mounted in series as shown in Figure 1. To generate the continuous force, the full load of 1 kN was applied in a single step to the transducers with

various loading frame approach speeds. The time taken for the step change from unloaded to fully loaded transducers was in the range from about 0.26 s to 3.3 s, leading to loading rates from about 0.3 kN/s to 3.8 kN/s.

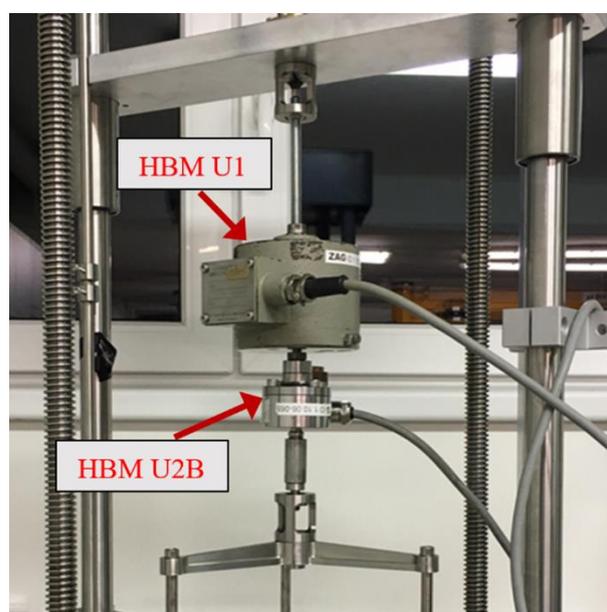


Figure 1: Force introduction in the force calibration machine: tension loading in series for 1 kN HBM U1 (top) and 1 kN HBM U2B (bottom) force transducers

Both force transducers were connected to an HBM MGCplus system with two ML38B amplifier modules (225 Hz carrier frequency) with the same settings: 5 V bridge excitation voltage and 10 Hz Butterworth low pass filter. The sampling rate was set to 75 Hz for continuous loading. Both transducers have the same nominal sensitivity of 2 mV/V.

The measurements were repeated also with the transducers connected to two HBM ML55B amplifiers modules (4.8 kHz carrier frequency) within the MGCplus system, again with 5 V bridge excitation voltage and 10 Hz Butterworth low pass filter amplifier settings and 75 Hz sampling frequency.

The loading profile consisted of loading the transducer with a specified frame approach speed, waiting about 5 s to 10 s under full load and unloading with the same loading frame speed. A

loading profile example for 1.6 kN/s load rate setting is shown in Figure 2.

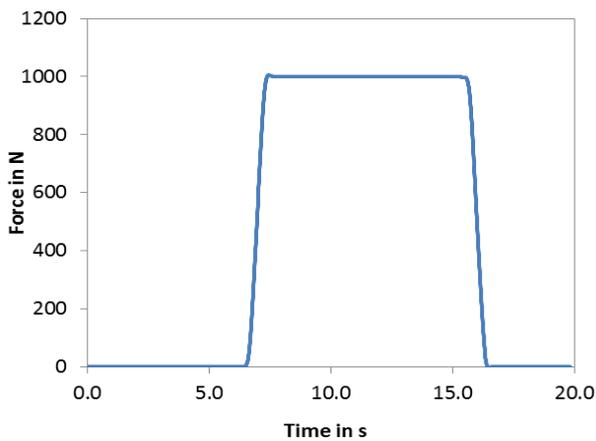


Figure 2: Example loading profile for 1.6 kN/s loading speed

Loading rates depended on the loading frame approach speed settings which were selected to cover the operating range of the machine. The actual measured loading rates based on selected loading frame speeds are shown in Figure 3 for increasing and decreasing load.

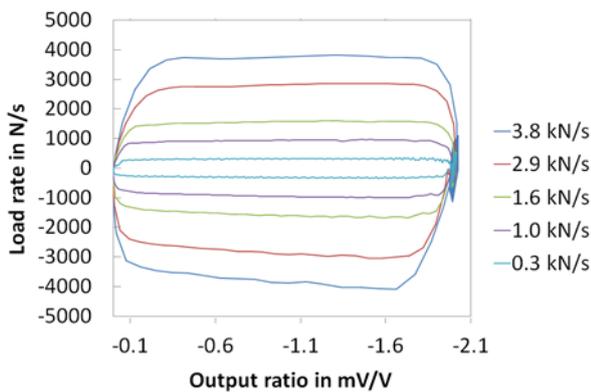


Figure 3: Measured increasing/decreasing loading rates for selected load rate settings

Additional to the single continuous full-load loading step, the transducers were also loaded and unloaded stepwise through all available force steps of the machine (17 steps from 10 N to 1000 N) and the indicated force was recorded continuously. With this procedure the interval between steps was about 5 s for the fastest machine speed and 30 s for an ISO 376 compliant static calibration procedure. These measurements serve as a reference and provide the link for force traceability.

To analyse the effect of amplifier influence, measurements were repeated also with a 1.5 Hz Bessel filter at selected loading speed in addition to the 10 Hz Butterworth setting. Furthermore, some measurements were repeated with swapping the amplifier connections from transducer one to amplifier two and transducer two to amplifier one to investigate any differences between the amplifiers.

3. RESULTS

Figure 4 shows the results for measurements with ML38B amplifiers with various loading rates from 0.3 kN/s to 3.8 kN/s for increasing and decreasing loading. The “static calibration” curves with 5 s and 30 s holding force steps are included for comparison. It can be seen that the increasing loading rate influences the measured deviation results between transducers for increasing and decreasing force (hysteresis envelope). While the average increasing/decreasing deviation agrees with the reference static calibration deviation to within 0.1 %, the hysteresis envelope exceeds this value and increases to $\pm 1\%$ and more for low forces (0.1 mV/V and below).

The 5 s step and 30 s step “static calibration” curves agree well, and both also agree well with the continuous 0.3 kN/s loading rate curve. Higher loading rates introduce significant deviations from the “static calibration” curves.

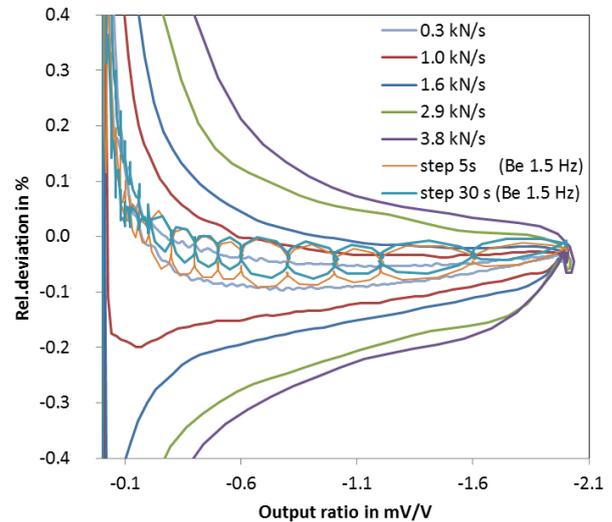


Figure 4: Comparison of transducer difference U1-U2B for various loading rates acquired with ML38B amplifier modules

Figure 5 shows the effect of setting the filter settings on the ML38B amplifiers to a 1.5 Hz low pass Bessel filter in comparison to a 10 Hz low pass Butterworth filter setting for 1.6 kN/s loading rate from Figure 4. The results show good agreement for most of the range to within less than 0.03 % except for the lower quarter of the range where the difference increases toward 1 % and more (for 0.1 mV/V and below).

In order to investigate any amplifier module differences, the transducer-amplifier connection was swapped. The connection of the transducer and amplifier was switched, so that the first transducer was connected to the second amplifier module and the second transducer was connected to first amplifier module. Any amplifier-related effects

such as amplifier sensitivity and data acquisition synchronisation should cause different output deviations for different amplifier-transducer combinations.

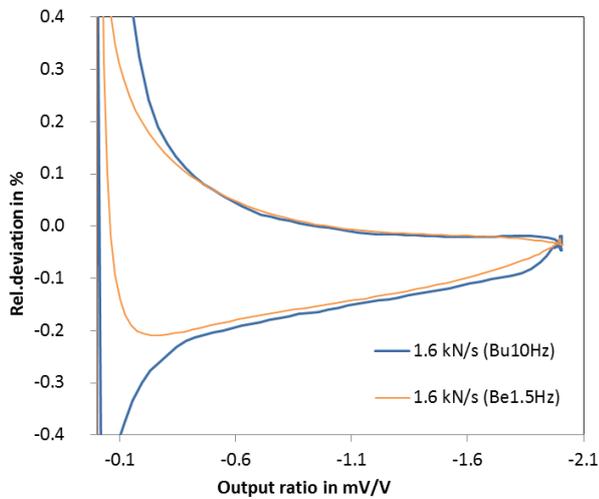


Figure 5: Comparison of transducer output difference between U1-U2B for different low pass filter settings on ML38B amplifier modules

Figure 6 shows results of swapping the amplifier channels in the case of ML38B amplifier modules. In this case the setup was changed by switching the amplifier modules between the transducers from original to swapped two times to verify the reproducibility of the swapping procedure. The loading rate was kept the same for all tests.

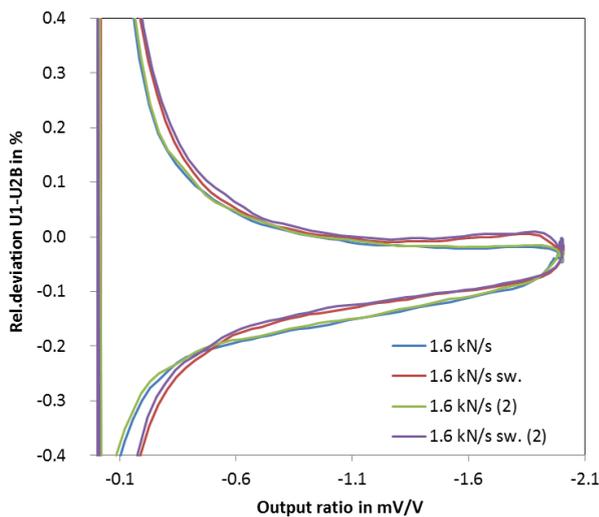


Figure 6: Comparison of transducer difference between U1-U2B for switching of the channel connections with ML38B amplifier modules

It can be seen from the results that swapping the amplifiers has an influence on the shape of the curves and the measured deviations between the two transducers. While the sensitivity of both amplifiers agrees to within 0.01 % at -2 mV/V, the difference between the resulting curves increases from 0.03 % for the most of the range to 0.5 % for values below

0.1 mV/V for switched configuration, implying additional effects affecting the comparison results. At the same time, the curves for the repeated transducer-amplifier combinations agree very well and confirm the good reproducibility of the same transducer-amplifier combinations and of the comparator system.

Measurements from Figure 4 were repeated for connection of the transducers to HBM ML55B amplifiers instead of HBM ML38B amplifiers. The results for loading rates from 0.3 kN/s to 3.8 kN/s are shown in Figure 7. It can be seen that in this case the increasing loading rate has a much smaller influence on the measured difference between the transducers than with the ML38B amplifiers. The measured deviation for increasing force is within 0.03 % and at the same time the hysteresis envelope is much tighter with much less effect from the force rate. The hysteresis envelope is mostly within 0.05 % and within ± 0.1 % from 0.2 mV/V upwards.

The “static calibration” curve with a 5 s force step loading is shown for comparison and traceability. The curves for continuous loading agree well with the “static calibration” curve to within 0.05 % for the most part of the range.

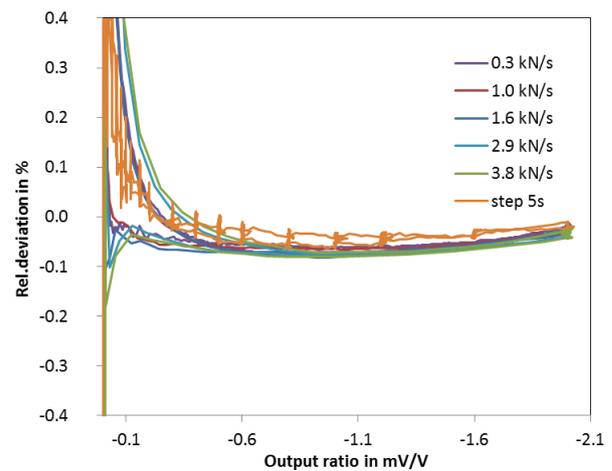


Figure 7: Comparison of transducer difference between U1-U2B for various loading rates acquired with ML55B amplifier modules

Similarly to ML38B amplifier switching procedure, the same procedure was applied to the transducer-amplifier combinations with ML55B amplifier modules, with the same loading rate. The results are shown in Figure 8 for original and switched combinations (one curve for each only). In case of ML55B amplifier modules the deviation between original and switched combinations is very low, below 0.01 %.

In all presented cases, the results are produced directly from synchronously acquired raw data values from the amplifier modules within the same MGCplus chassis, without any additional filtering

corrections or post-processing. Amplifier readings were zeroed before each measurement.

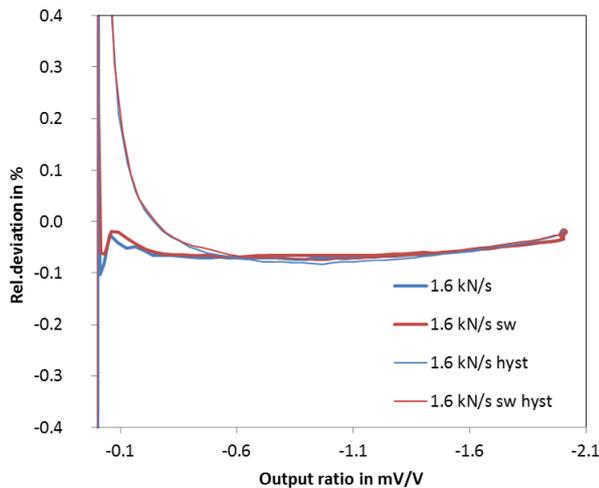


Figure 8: Comparison of transducer difference between U1-U2B for switching of the channel connections with ML55B amplifier modules. Increasing force is shown with thick line and decreasing force with thin line

4. DISCUSSION

The measurement results for comparison of 1 kN force transducers during continuous loading with ML38B amplifier modules showed significant deviation from static calibration values as well for increasing as for decreasing force application. The deviation envelope was somewhat symmetrical to the static values throughout the range. The resulting hysteresis deviation envelope results increased with loading rate what is in contradiction with the expected hysteresis and creep behaviour of strain-gauge force transducers. The analysed loading rates were in the range of 30 % FS/s (full scale per second) for 0.3 kN/s loading rate to 380 % FS/s for 3.8 kN/s loading rate.

Repeating the measurements with ML55B amplifier modules showed that the actual deviation between the two 1 kN force transducers is much smaller than implied by ML38B amplifier results. The hysteresis deviation results are in this case almost independent of the evaluated loading rates. At the same time, the hysteresis deviation envelopes are compressed by a factor of ten.

These results lead to the conclusion that the evaluated 1 kN force transducers produce very similar sensitivity curves for continuous loading rates at least up to 380 % FS/s and the deviation between the two transducers agrees well with their static calibration curves. This suggests that both transducers would provide comparable results when used in static and continuous loading applications.

However, there was a significant effect observed from the employed amplifier modules. The ML38B amplifier with its lower bandwidth and 225 Hz carrier frequency introduced significant load rate dependent deviations. The ML55B with 4.8 kHz carrier frequency on the other hand produced much better results for continuous force measurements albeit its lower precision. It has to be noted though, that when using 4.8 kHz carrier frequency amplifiers with transducers originally calibrated with 225 Hz carrier frequency amplifiers, the significantly increased calibration uncertainty of the former needs to be taken into account.

The final results favour the ML55B amplifiers as the more appropriate amplifiers for continuous force measurement in the evaluated range of loading rates and highlight some issues to be further investigated when using ML38B amplifiers under such conditions.

5. SUMMARY

A response of two transducers was measured for loading rates from 30 % FS/s (full scale per second) to 380 % FS/s and compared to static calibration. Different amplifier filter settings and different amplifier types were used and results show that HBM ML55B amplifiers are less susceptible to loading rate effect than ML38B amplifiers and are to be preferred for loading rates above 100 % FS/s. The results show a consistent deviation between the two transducers, comparable to their static deviation to within less than 0.1 %, for a wide range of loading rates.

6. ACKNOWLEDGMENT

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7. REFERENCES

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