Improving uncertainty of strain gauge bridge standards

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Abstract. The article proposes a procedure for calibration of strain gauge bridge standards with improved relative calibration uncertainty. In contrast to a typical calibration with voltage ratio standards or comparison calibration with other bridge standards, the proposed procedure uses a calibrated reference bridge amplifier, additionally evaluated using combinatorial calibration technique to improve its calibration uncertainty. The resulting uncertainty of ratio steps referenced to zero ratio step is lower than the traditional uncertainty achieved through direct independent traceability to mVV^{-1} ratio values. The proposed procedure enables direct application of the calibrated bridge standard values with low relative uncertainty for calibration of bridge amplifiers, without the need for additional combinatorial evaluation of each individual bridge amplifier.

1. Introduction

In the field of measurement of mechanical quantities such as force, torque, and pressure, strain gauge base transducer are commonly used. These transducers work in combination with bridge amplifiers which supply the voltage for the strain gauge bridge excitation and detect and evaluate the change in the bridge output when the transducer is loaded. Bridge amplifiers indicate the measured quantity as ratio of bridge output voltage versus supply voltage, typically expressed in mVV^{-1}. For a typical force transducer the voltage ratio range is usually 2 mVV^{-1}. A part of assuring traceability of mechanical quantities is thus linked to voltage ratio traceability. The link of the bridge amplifier to the voltage ratio standard is usually accomplished by a calibrated bridge standard traceable either directly to a voltage ratio standard or via higher level bridge standards. The best available expanded calibration uncertainties U for bridge standards offered by national metrology institutes are 10 nVV^{-1} [1] and 20 nVV^{-2} at next lower level calibration laboratories. Such calibration uncertainties lead in the best case to about 20 nVV^{-1} expanded uncertainty for a calibrated bridge amplifier and can contribute significantly to the final measurement uncertainty of measured mechanical quantity as the relative uncertainty increases exponentially for lower ratio values.

In previous publications we proposed a method that can be used to improve the uncertainty of calibrated bridge amplifiers by making additional measurements using combinatorial resistive circuit [2-4]. The calibration of the bridge amplifier using the bridge standard at higher voltage ratio can be improved by determining the linearity of the bridge amplifier with combinatorial technique down to the lower ratio range, resulting in lower relative uncertainty for the critical range. In this paper, we describe a procedure where the calibrated bridge amplifier is used to transfer its lower calibration uncertainty to a bridge standard.

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2. Bridge standard calibration uncertainty

Bridge standards which simulate the operation of a strain gauge transducer are usually built either as resistive voltage dividers applicable to DC or AC excitation voltage such as HBM K3608 or inductive voltage dividers applicable to AC excitation voltage only such as HBM BN100A. Both types offer a limited number of ratio step values that can be selected. Each step is calibrated individually and as such represents absolute reference value, independent from other steps. However, when bridge amplifiers are calibrated, the final results are typically expressed relative to zero step value, as during use the measurement results are referenced to the no load condition.

When a bridge standard is calibrated on the highest level it is compared with a reference voltage divider. This procedure enables calibration uncertainties of about 10 nVV^{-1}, limited by precision of the reference divider calibration system [1,5]. On the next lower level, the calibrated values can be transferred to another bridge standard via comparison of the two bridge standards using a bridge amplifier. In this case a high precision bridge amplifier is used as a comparator. The uncertainty during this procedure usually doubles the uncertainty to about 20 nVV^{-1}. An example of calibration result of a bridge standard type HBM K3608 is shown in figure 1 with expanded uncertainty for the ratio range -2 mVV^{-1} to +2 mVV^{-1} of 20 nVV^{-1}.While the relative calibration uncertainty of the bridge standard is sufficiently low for 2 mVV^{-1} ratio values it becomes too large for lower values, figure 2. The best available bridge standard of type HBM BN100A would have a calibration uncertainty of 10 nVV^{-1}, but the relative uncertainty at the lowest ratios is still too high.

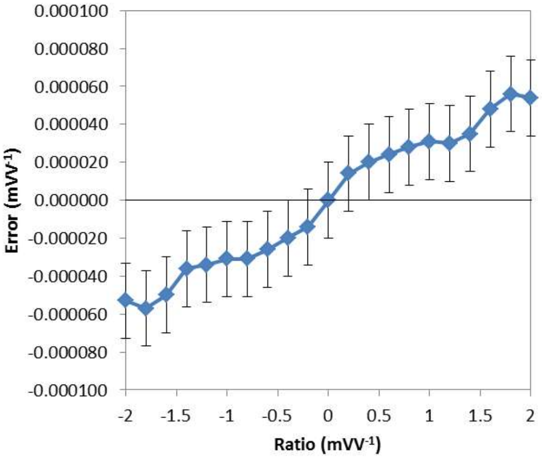

Figure 1. K3608 calibration result - error and standard uncertainty U=20 nVV^{-1}.

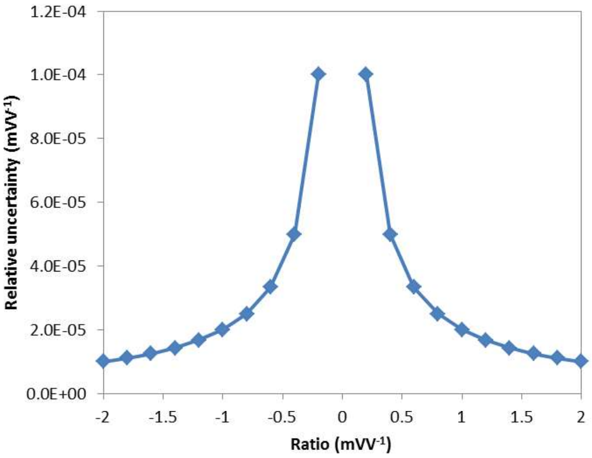

Figure 2. Relative standard uncertainty of the bridge standard for U=20 nVV^{-1}.

3. Measuring equipment and procedure

When a bridge amplifier is calibrated with a bridge standard and additional evaluation of the linearity is performed with the combinatorial method, the combined uncertainty can be reduced for the lower part of the range as shown in figure 3. Furthermore, the combinatorial calibration results in a polynomial approximation for the range of the bridge amplifier [6], with estimated uncertainty for the whole range. The amplifier calibration results are more suitable for the typical calibration needs than the results of a traditional calibration with a bridge standard, therefore it would be of benefit if the bridge amplifier results could be transferred to the bridge standard, as the combinatorial resistance network can not be directly applied to the bridge standard. Also, the combinatorial calibration of the amplifier takes more time than a calibration with a bridge standard and it must be done for each amplifier additional to the traditional calibration with the bridge standard. With improved uncertainty, the bridge standard could then be used directly to calibrate the bridge amplifier, as usual, but with calibration results referenced to the zero step.

The procedure for the calibration of the bridge standard is similar to the procedure for calibration of the amplifier. The reference bridge amplifier is connected to the bridge standard, the zero step selected on the bridge standard, amplifier indication set to zero (or zero value later subtracted) to compensate for the zero offset and the indication of the amplifier is recorded for each bridge standard ratio step within the amplifier range. Several measurement series are typically made and the average value and standard deviation is calculated for each step and any corrections taken into account. The calculated ratio values can then be assigned to each ratio step of the bridge standard.

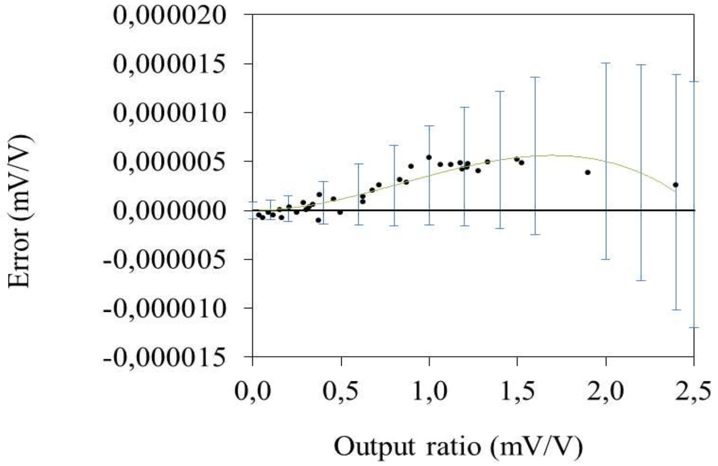

Figure 3. Example of amplifier HBM DMP41 calibrated with HBM BN100A bridge standard and additional combinatorial linearity assessment. Amplifier error and its standard uncertainty (u) are shown.

The traceability chain for proposed procedure is shown in figure 4 and is as follows:

- first a bridge amplifier is calibrated with a voltage ratio standard,
- the bridge standard is then used as a reference to calibrate a bridge amplifier,
- the linearity of bridge amplifier is additionally evaluated using the combinatorial technique to reduce the uncertainty in the lower ratio range,
- the bridge amplifier is then used as a reference to calibrate the bridge standard.

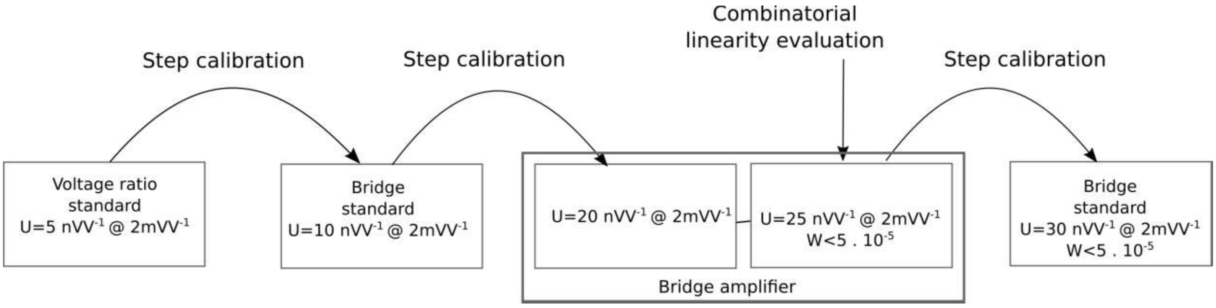

Figure 4. Traceability link for proposed procedure from voltage ratio standard to bridge standard

4. Results

Figure 5 shows the result of a calibration of an HBM K3608 bridge standard from figure 1 using a reference bridge amplifier DMP41. The amplifier is a 225 Hz carrier frequency type with selected 5 V excitation voltage and 2.5 mVV^{-1} range. It was calibrated with a HBM BN100A and with HBM K3608 bridge standard for +2 mVV^{-1} and -2 mVV^{-1} ratios with 10 nVV^{-1} calibration standard uncertainty and the linearity of the amplifier was determined with combinatorial technique with 1 nVV^{-1} standard uncertainty. The expanded uncertainty U of the calibrated amplifier at ±2 mVV^{-1} was 25 mVV^{-1}. The expanded uncertainty of the bridge standard at ±2 mVV^{-1} has been increased from 10 nVV^{-1} to about 30 nVV^{-1} but improved towards the zero step, to 3 nVV^{-1} or below 2x10^{-5} relative expanded uncertainty at 0.2 mVV^{-1} opposed to 5x10^{-5} achievable with best available traditional calibration, and with even larger potential for lower values.

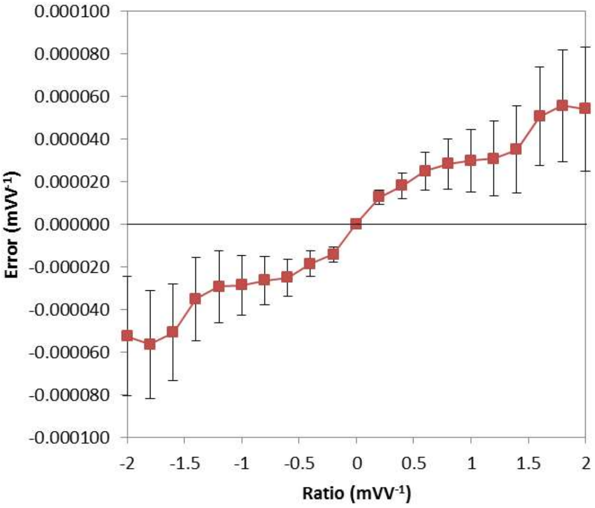

Figure 5. Calibration of a bridge amplifier using a calibrated bridge amplifier (including combinatorial technique) - error and expanded uncertainty (U).

5. Conclusion

In the paper we proposed a calibration procedure for bridge standard calibration using a calibrated bridge amplifier improved with combinatorial technique. With lower calibration uncertainty in the lower ratio range, the bridge standard can be applied as usual for calibration of other bridge amplifiers, now fulfilling the requirements for precise measurement of mechanical quantities which can not be achieved by traditional bridge amplifier calibration.

References

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