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ALTERNATIVE CALIBRATION PROCEDURE FOR STRAIN GAUGE AMPLIFIERS

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Abstract – The article presents a method for calibration of strain gauge amplifiers with improved uncertainty in low voltage ratio range. The method is based on linearity check of amplifier using resistance circuit and combinatorial calibration method in combination with traditional strain gauge bridge simulators.

Keywords: calibration, strain gauge, simulator, amplifier, uncertainty

1. INTRODUCTION

Strain gauge bridge transducers need an instrument for excitation of the strain gauge bridge and indication of the bridge output signal, which depends on the load applied to the transducer. Strain gauge bridge amplifiers usually perform these tasks, where they indicate the result as the ratio of the bridge supply voltage and the bridge output voltage, Fig. 1. As an important part of the measurement chain, the performance of amplifiers should be verified regularly. Amplifiers are generally calibrated with strain gauge bridge simulators, by simulating defined voltage ratio values as reference values.

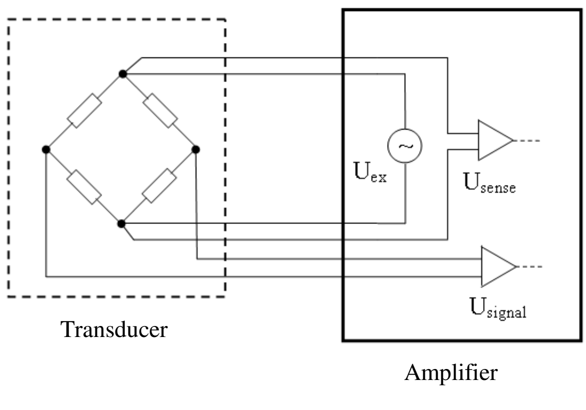

Fig. 1. Strain gauge bridge transducer with 6-lead connection to the amplifier.

Such simulators need to be calibrated for each reference value they output. For high precision simulators and amplifiers (e.g. 225 Hz carrier frequency), a typical expanded uncertainty of calibration of reference values of 2 mV/V is about 0,00001 mV/V at NMI level [1] to 0,00002 mV/V at calibration laboratory level for further dissemination. For low ratio values, such calibration uncertainties consecutively lead to large relative uncertainty of strain gauge amplifier measurement [2].

Traditional calibration of the amplifiers can be performed with calibrator units (such as HBM K3608 or HBM BN100A) at 2 mV/V with 0,00002 mV/V expanded calibration uncertainty, resulting in $5x10^{-6}$ relative standard uncertainty at nominal value and rising to $5x10^{-5}$ relative standard uncertainty at ratio value of 0,2 mV/V, and $2,5x10^{-4}$ at 0,04 mV/V (typical low range limit of 2 % nominal value for force transducers), Fig.2. Relative standard uncertainty of calibration at NMI level is also shown, where the relative standard uncertainty reaches $1,25x10^{-4}$ at 0,04 mV/V ratio.

Calibrating the amplifier together with the strain gauge transducer as a measurement chain is one solution to overcome this limitation, but it limits the transducer to be always used with the same amplifier, and the transducer calibration can be void in the case of amplifier replacement. If the transducer is calibrated with other amplifier than the one employed during normal use, both amplifiers should be calibrated, to assure comparability of results, and both amplifier calibration uncertainties considered. If both amplifiers are not checked with the same simulator, the calibration uncertainty of the simulator can become the major uncertainty contribution.

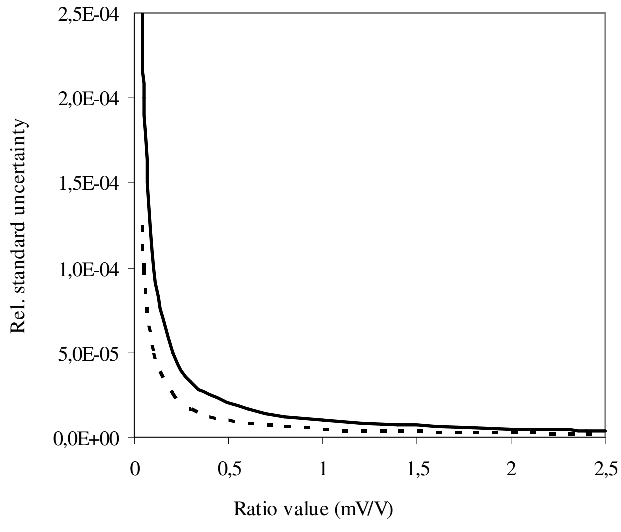

Fig. 2. Relative standard uncertainty of typical calibrated high performance strain gauge simulator or amplifier (solid line) and best available standard uncertainty at NMI level (dotted line).

Another solution is to try to calibrate the strain gauge amplifier with lower uncertainty. This can be achieved by calibrating the amplifier with a calibrated simulator at higher ratio values, where relative uncertainty is adequate, and use an alternative linearity check with lower uncertainty to verify the rest of the range.

2. MEASUREMENT EQUIPMENT AND PROCEDURE

The linearity check can be performed with the resistance network described in [3]. The circuit is suitable for application of combinatorial calibration method [4] to voltage ratio indicating instruments. The method has been successfully applied in other fields (e.g. thermometry bridge calibration [5]).

A general schematics of the circuit employed for linearity check is shown in Fig. 3. The circuit is based on a voltage divider with additional resistor networks connected to the output leads of the divider to reduce the variation of the output resistance of the circuit. The output ratio is varied by tapping the output over a single base resistor or a combination of consecutive base resistors. Fig. 3 shows a circuit layout with four base resistors over which the output can be tapped. The output ratios of the divider, as well as input and output resistance of the circuit, can be adapted to meet the requirements.

The combinatorial calibration method is based on measuring a set of artefacts: each individual artefact separately and also all possible combinations of these artefacts. From the difference of measured values of possible combinations and calculated results from the same combinations, the non-linearity of the system can be estimated.

In the case of the circuit in Fig. 3, the set of artefacts is defined by the base resistors, which form a part of the voltage divider network. Output ratio of the circuit can be measured either for selection of each individual base resistor or for combinations of consecutive resistors.

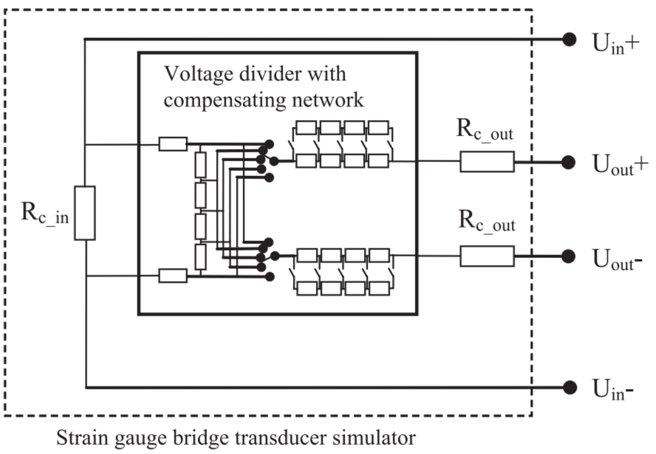

Fig. 3. Circuit for amplifier linearity check.

The actual circuit built to check the linearity of the amplifier was designed for 350 Ohm input and output resistance and 2,5 mV/V nominal output ratio. Using eight base resistors, it can cover the range from about 0,04 mV/V to 2,5 mV/V. When the circuit is applied in combination with the combinatorial calibration method, the resulting uncertainty of the linearity check depends mainly on the quality of the measuring instrument. If it is aplied to high precision amplifiers [6], it is possible to reach standard uncertainty of the linearity check 0,000002 mV/V.

The circuit based on eight base resistors allows a total of 36 non-zero output combinations. It is connected to the amplifier and the indication on the amplifier is recorded for each available output combination. When ratio values for all combinations have been measured, deviation of the measured sum of selected resistors and the calculated sum of selected resistors is determined. The errors for base resistor readings are fitted, based on error distribution from all measurements. A linear fit is calculated from the resulting deviation values, and residuals of the fit serve as standard uncertainty estimation.

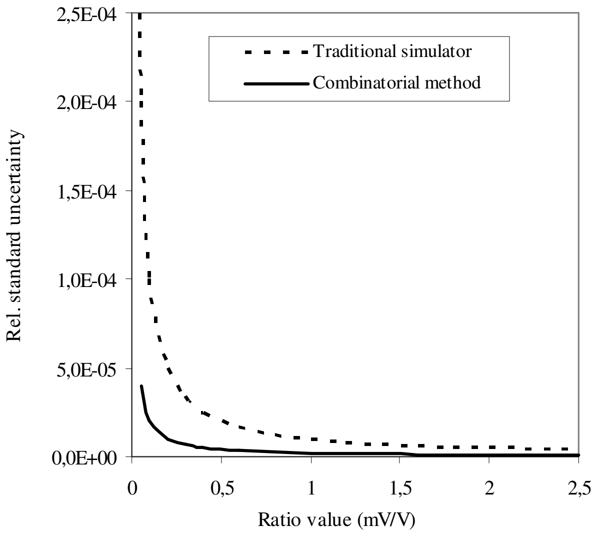

Fig. 4. Comparison of simulator relative standard uncertainty and relative standard uncertainty of linearity check with combinatorial method.

Fig. 4 shows the comparison between relative standard uncertainty of linearity measurement achieved by using traditional simulator, and by employing resistive circuit with combinatorial calibration method.

The result of the linearity check alone is not enough to characterise the performance of the amplifier. Additional calibration must be made at least at one non-zero ratio value to establish the absolute error of the amplifier indication. For this purpose, traditional simulators can be employed, as, depending on the selected range, the simulator relative calibration uncertainty can be adequate for the required task.

Fig. 5 shows the effect of the selection of absolute calibration point on the scaling of its uncertainty contribution. For values lower than the calibrated point, the uncertainty contribution is proportionally smaller and for values higher than calibrated point proportionally larger. It is beneficial to choose the largest possible absolute calibration point, as it will provide the lowest uncertainty contribution in the rest of the range. It is also possible to extend the calibration range above the calibrated point, at the expense of increased uncertainty contribution due to the uncertainty of calibrated point.

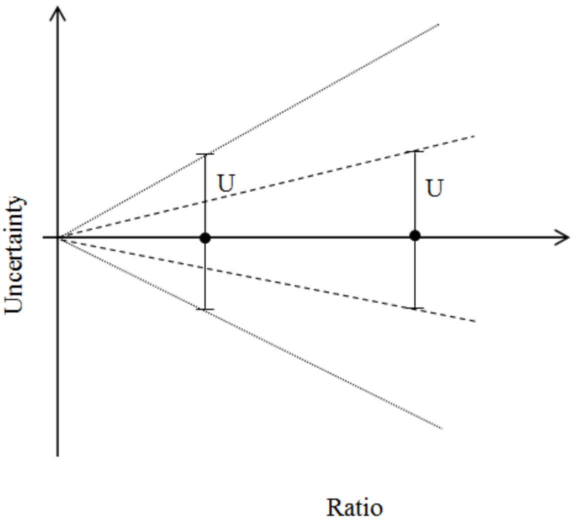

Fig. 5. The uncertainty contribution of absolute calibration with respect to the selected calibration point.

The linearity check was performed on an HBM DMP41 high-precision amplifier. The selected range was 2,5 mV/V and excitation voltage 5V. A calibrated strain gauge simulator HBM K3608 was used to check the amplifier at 2 mV/V, which was the highest calibrated ratio value of the simulator. The expanded calibration uncertainty of the simulator for 225 Hz and 5V excitation voltage was 0,00002 mV/V, or $1x10^{-5}$ relative uncertainty. This uncertainty limits the final achievable uncertainty, but allows, in combination with linearity check, the calibration of the amplifier in the whole range from 0,04 mV/V to 2,5 mV/V.

In this paper only calibration uncertainty of simulator and the uncertainty of the linearity check are considered. Other contributions, such as resolution of the instrument, drift of the simulator ratio value and other possible contributions are not taken into account.

3. RESULTS

Fig. 6 shows the result of the linearity check with combinatorial calibration method. The figure shows the resulting deviation of measurement of 36 possible resistor combinations from the linear fit. The calculated standard deviation of the residual errors is about 0,000002 mV/V. It can be seen, that there is some non-linearity in the results. This non-linearity could be corrected if a correction function was calculated from the deviation results, reducing the uncertainty of the residuals. However, in this example, no correction is applied.

Fig. 7 shows the results from Fig. 6 if they are expressed as relative deviations. The standard deviation of the residual errors in this case is $3,3x10^{-6}$.

These results are sufficient to characterise the nonlinearity, but they do not provide enough information for the calibration of the amplifier, since the linear error is not known. Additional measurement at one ratio value is required to fully calibrate the instrument. If the absolute calibration in one point is made with a simulator with 0,00002 mV/V expanded uncertainty, it will define the base uncertainty in that point. Together with the linearity check uncertainty, the total calibration uncertainty of the instrument can be calculated.

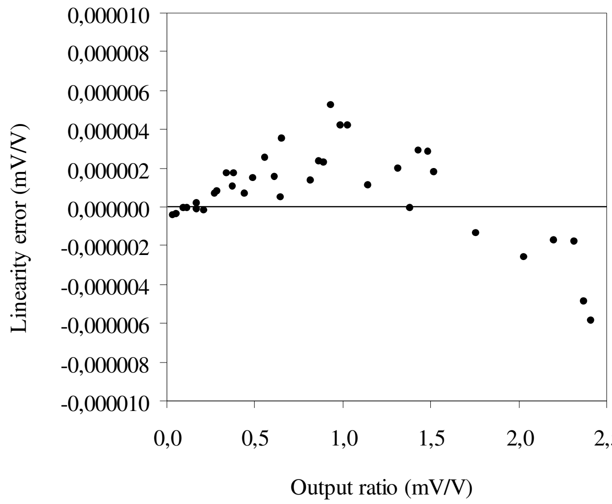

Fig. 6. Linearity error for linearity check with combinatorial method.

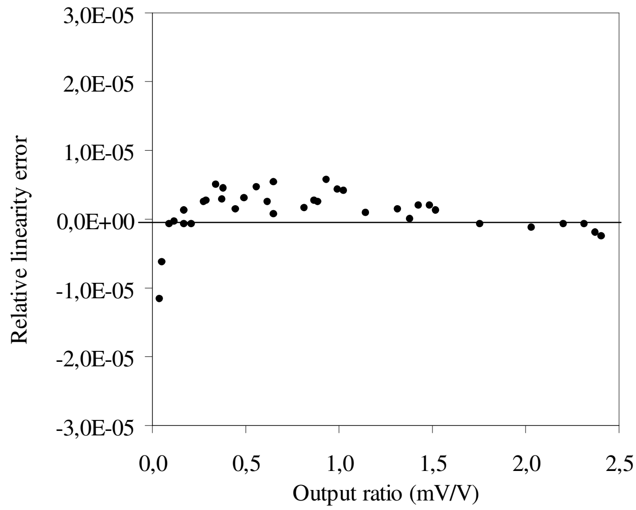

Fig. 7. Linearity error for linearity check with combinatorial method - expressed as relative error.

Fig. 8 shows the standard uncertainty contributions for the combination of absolute calibration of the amplifier at 2 mV/V and linearity check based on data from Fig. 6 and expressed in units of mV/V. The dashed line represents the simulator calibration uncertainty of 0,00001 mV/V. For linear instruments, this value can be scaled proportionally with the ratio value (dotted line), which is the contribution due to simulator uncertainty. The second contribution is the standard uncertainty of the linearity check (thin solid line) performed with the resistor circuit and combinatorial method. The final combined standard uncertainty is shown as thick solid line. It can be seen, that the dominant uncertainty contribution is the simulator calibration uncertainty for most of the range. Compared to calibration employing only the simulator, the uncertainty has been reduced significantly in the lower range of ratio values, and slightly increased for ratio values above absolute calibration point.

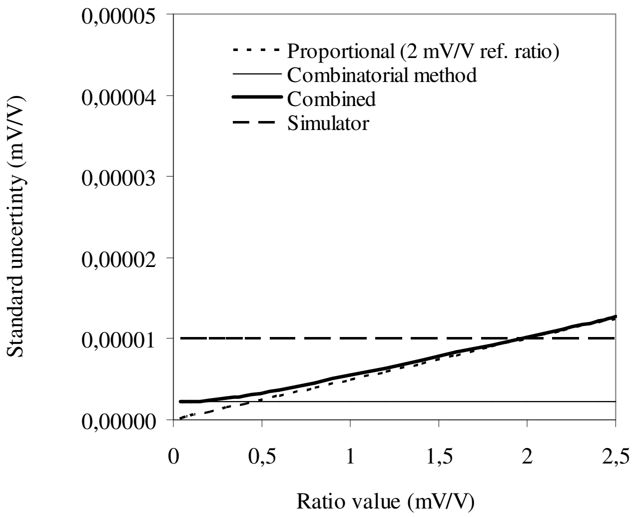

Fig. 8. Combined standard uncertainty of absolute calibration at 2 mV/V and linearity check for the whole range.

In Fig 9, the same measurement example is shown, but the standard uncertainty contributions are expressed as relative standard uncertainties based on Fig. 7. We can see that the simulator calibration uncertainty increases exponentially for lower ratio values (dashed line). The proportional part of the absolute calibration uncertainty at 2 mV/V, when expressed as relative uncertainty, is the same for the whole calibration range (dotted line). The contribution of the linearity check is shown as thin solid line. The combined relative standard uncertainty is about $6x10^{-6}$ for the whole range of the instrument. If additional uncertainty component due to limited resolution is taken into account, it increases slightly the total uncertainty at lowest ratio values (below 0,1 mV/V), but the relative standard uncertainty is still below $1x10^{-5}$. Again, the reduced uncertainty compared to employing only the simulator is evident at low ratio values. Above 1,5 mV/V, the uncertainty has been slightly increased.

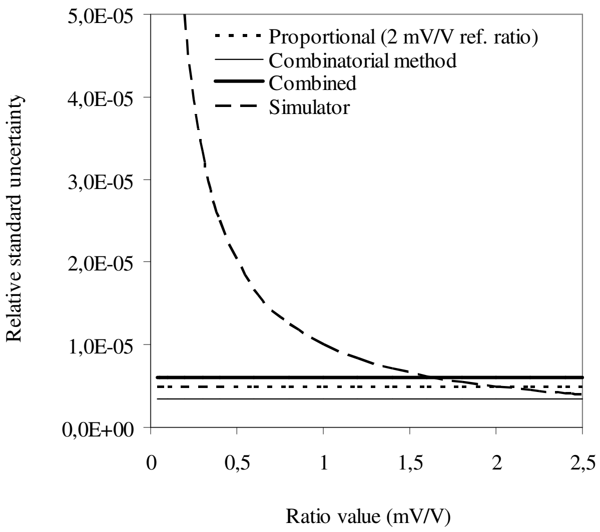

Fig. 9. Combined standard uncertainty of absolute calibration at 2 mV/V and linearity check for the whole range.

4. CONCLUSIONS

The results of the evaluation of the amplifier show improvement in measurement uncertainty in comparison to traditional strain gauge simulators calibration only, for the range below the absolute reference value. Combining the absolute calibration with traditional simulator and linearity check with the resistive network, improved absolute calibration in the lower part of the range can be achieved. With the presented method, the relative standard uncertainty at 0,05 mV/V can be reduced from typical values of $2x10^{-4}$ to values below $2x10^{-5}$.

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