

# Realization, maintenance and dissemination of the measurand “AC voltage ratio in mV/V” for strain gauge measurements

Reinhold Vollmert and Günther Ramm

Physikalisch-Technische Bundesanstalt  
Braunschweig, Germany

## Abstract

Strain gauges allow the measurands force, pressure, torque or strain to be converted into voltage ratios and to be indicated by measuring amplifiers. Precision measurements are preferably carried out at 225 Hz and at voltage ratios of up to 2 mV/V. Bridge standards, which have to be traced back to national standards, are used for the electrical calibration of these measuring amplifiers. More than 15 years ago, in PTB the first measuring arrangement for this purpose has been developed and installed. The present contribution explains the traceability principle of bridge standards, shows the long-term stability of selected bridge standards on the basis of measurement results and brings first investigations into the interchangeability of measuring amplifiers up for discussion.

## Traceability of bridge standards

Strain gauge transducer and measuring amplifier form a measuring chain. For the calibration of the measuring amplifiers, the transducer is replaced by a so-called bridge standard which allows defined voltage ratios to be realized with high precision and to be applied as calibration signals to the measuring amplifier. Bridge standards contain resistance dividers (suitable for DC and AC applications) or inductive components and/or transformers (for AC applications only). They may be mounted as purely passive components or contain electronic circuits. At input voltages of approximately 5 V and at a measuring frequency of 225 Hz, the voltage ratio 0,002 or 2 mV/V is the calibration signal most frequently used for precision measurements. This ratio will be examined in detail.

At PTB, the voltage ratio 2 mV/V of AC bridge standards is traced back to national standards by means of inductive voltage dividers [1, 2, 3]. The calibration principle is represented in Fig. 1. The voltage ratio realized by the bridge standard DUT (device under test) is defined as  $D_x = U_a / U_e$ . For calibration, the cascaded inductive standard voltage dividers  $T_{N1}$  (type KT 14, PTB development, fixed divider ratio  $D_1 = 0,04$ ) and  $T_{N2}$  (type KT 02, commercial product, divider ratio  $D_2$  adjustable between 0 and 1 with a resolution of  $1 \cdot 10^{-8}$ ) are connected in parallel with the bridge standard. Balanced-to-ground, both are fed by

generator G via the auxiliary divider  $T_{H1}$ . With the aid of switch S and a lock-in amplifier (LIV) used as null indicator in the difference branch, the voltage ratios  $D_A$  and  $D_D$  are determined at the outputs A and D of the bridge standard in two successive measurements. The difference between the two voltage ratios provides the required voltage ratio  $D_x$  of the bridge standard in V/V [1, 2, 3]. In the calibration certificate, the correction  $K$  of this voltage ratio is usually given in mV/V.  $K$  is the difference between the measured voltage ratio  $D_x$  (measured value) and the rated voltage ratio  $D_n$  (nominal value) adjusted on the bridge standard:

$$\text{correction} = \text{measured value} - \text{nominal value}$$

For the rated voltage ratio  $D_n = 2 \text{ mV/V}$ , a standard measurement uncertainty ( $k = 1$ ) of  $5 \cdot 10^{-6} \text{ mV/V}$  (or  $2,5 \cdot 10^{-6}$  relative to the nominal value) is obtained.

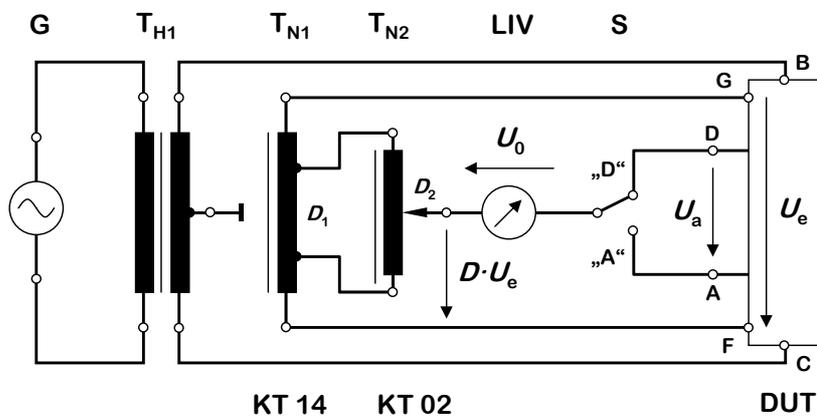


Fig. 1: Principle of calibration for AC bridge standards using inductive voltage dividers.

### Long-term stability of bridge standards

Since 1986, a large number of bridge standards have been calibrated. The history of the three selected and highly stable standards shown in Fig. 2 stands for all of them. Bridge standards 1 and 2 are of type BN 100 (commercial product, adjustable by switches in steps of 0,1 mV/V in the range from 0 mV/V to  $\pm 100 \text{ mV/V}$ , mounted with inductive components and using electronic circuits), bridge standard 3 bears the designation KT 11 (PTB development, adjustable by switches to 0 mV/V,  $\pm 2 \text{ mV/V}$ ,  $\pm 4 \text{ mV/V}$ ,  $\pm 8 \text{ mV/V}$  and  $\pm 10 \text{ mV/V}$ , purely inductive mounting without electronic components).

Corrections for the rated voltage ratio  $D_n = +2 \text{ mV/V}$  are shown. All values are tared, i.e. the influence of potential corrections for the zero point or the rated voltage ratio  $D_n = 0 \text{ mV/V}$  has been computationally eliminated. All measurements were carried out at an input voltage of 5 V and a frequency of 225 Hz.

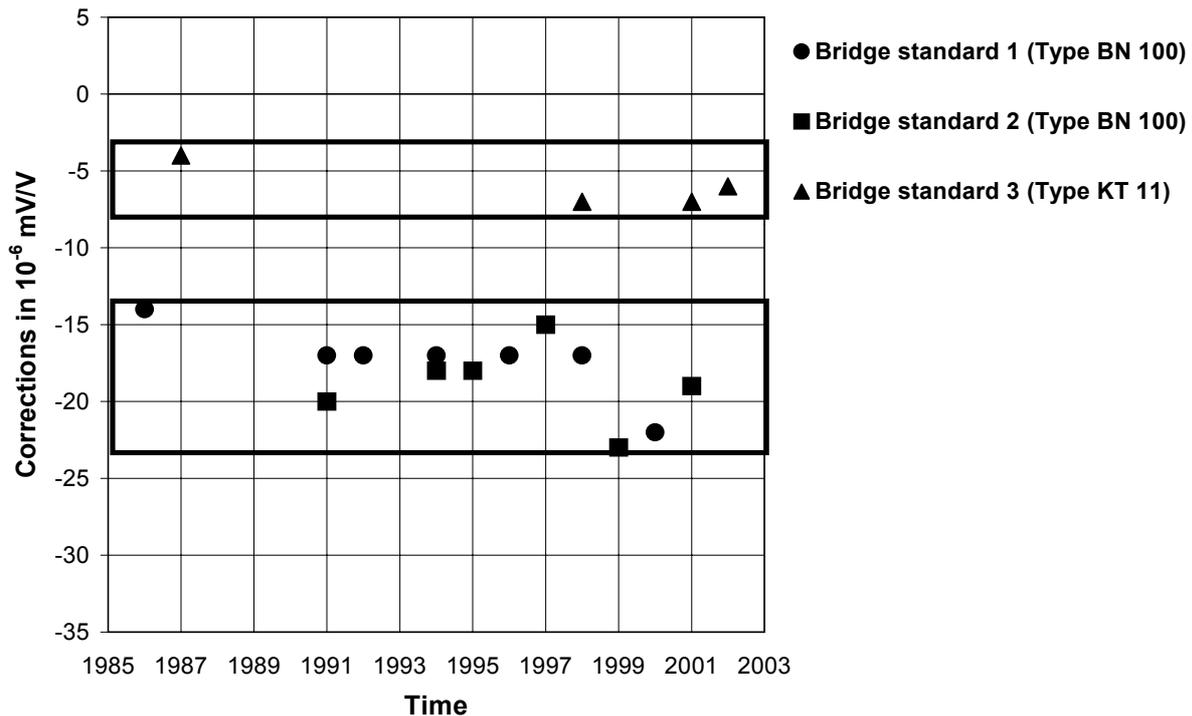


Fig. 2: Long-term stability of the corrections of three selected, highly stable bridge standards (determined at rated voltage ratio  $D_n = 2 \text{ mV/V}$  with input voltage of 5 V at 225 Hz over a period of more than 15 years).

The mean value of the corrections of bridge standards 1 and 2 is  $-18 \cdot 10^{-6} \text{ mV/V}$ , that of bridge standard 3 lies around  $-6 \cdot 10^{-6} \text{ mV/V}$ . A clearly defined drift with time cannot be seen. In the whole period covering more than 15 years, the individual measurement values for standards 1 and 2 lay within a bandwidth of  $\pm 5 \cdot 10^{-6} \text{ mV/V}$  or  $2,5 \cdot 10^{-6}$ , respectively (relative, as related to the nominal value 2 mV/V) and thus within the standard measurement uncertainty. Scattering of the measured values for bridge standard 3 is even lower by the factor two. These statements are also valid for the rated voltage ratio -2 mV/V not shown here. The results of these long-term observations impressively document the high stability of both, the bridge standards and the PTB standard measuring device.

### Interchangeability of measuring amplifiers

In strain gauge measurement technique, the calibration of measuring amplifiers is based on bridge standards which are stable over a long time. Whenever the measuring chain of transducer and measuring amplifier is separated, use of uniformly calibrated measuring

amplifiers is absolutely necessary. This is, for example, the case in intercomparisons in which only the (e.g. force) transducer is circulated (without a measuring amplifier inseparably connected to it) and the participants have to calibrate it with their own (different) measuring amplifiers.

To simulate this situation, seven precision measuring amplifiers available at PTB (all of type DMP 40) were calibrated using the three bridge standards described above. The measuring amplifiers (Nos. 1 to 7) were connected one after another to all three bridge standards (Fig. 3). In this way, three different values were determined for the measurement deviation of each measuring amplifier.

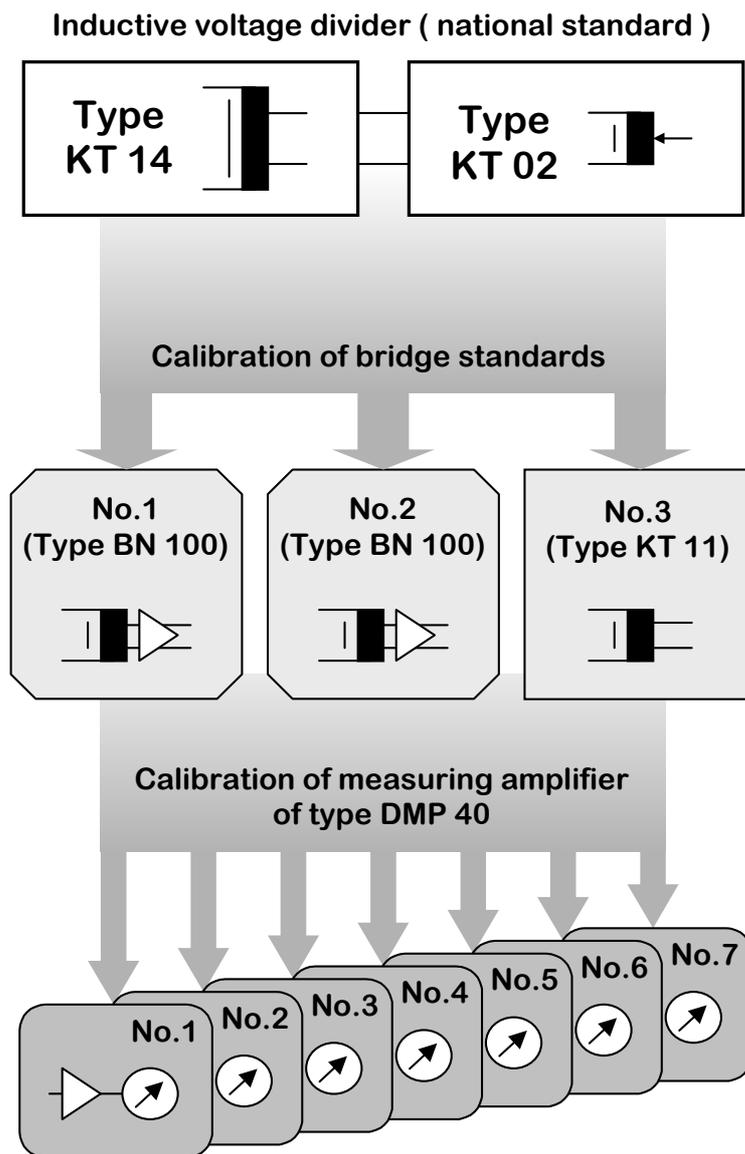


Fig. 3: Set of devices for traceable electrical calibration of AC bridge standards and measuring amplifiers for strain gauge measurements.

The results are compiled in Fig. 4. The plotted deviations are the differences between the values indicated (measured values) and the “true values”:

$$\text{measurement deviation} = \text{measured value} - \text{“true value”}$$

The “true values” are materialized by the bridge standards and consist of the nominal values and the associated corrections and their uncertainties:

$$\text{“true value”} = \text{nominal value} + \text{correction} \pm \text{uncertainty}$$

Before application of the calibration signals, the measuring amplifiers were always tared. The measurement deviations plotted in Fig. 4 are mean values obtained from several measurements, the associated standard deviations were typically smaller than  $5 \cdot 10^{-6}$  mV/V.

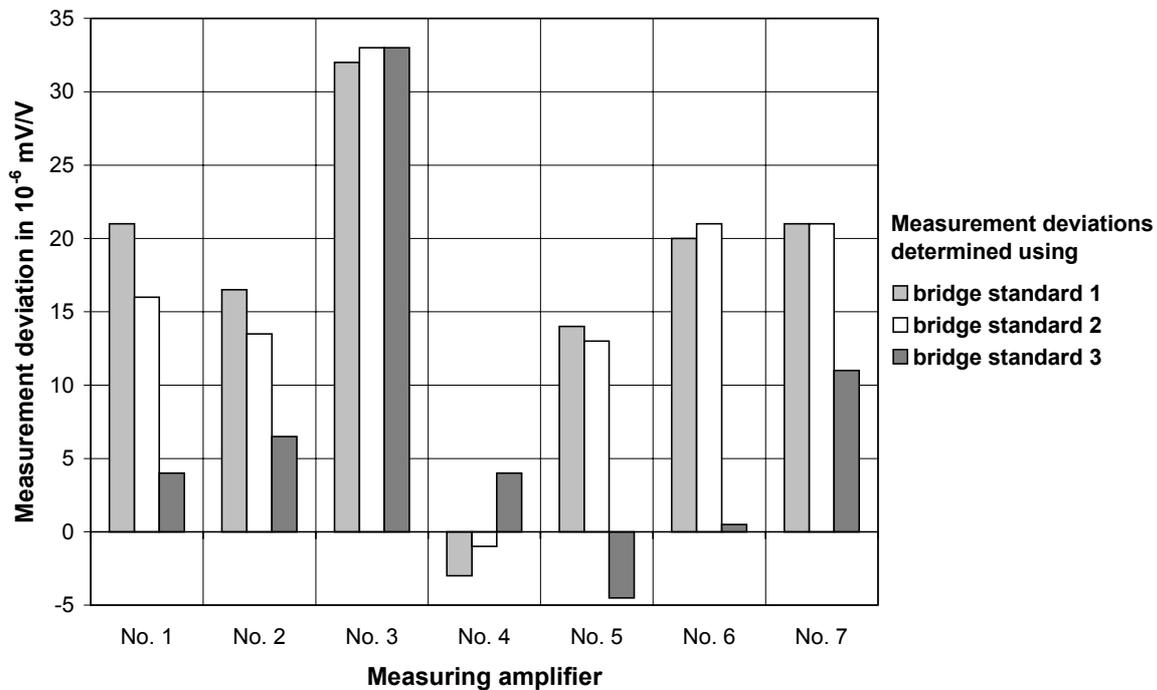


Fig. 4: Measurement deviations of the seven measuring amplifiers of type DMP 40 investigated (determined at rated voltage ratio  $D_n = 2$  mV/V for 5 V and 225 Hz) using three different bridge standards.

The mean value of the measurement deviations of all measuring amplifiers determined in different ways (Fig. 4) amounts to  $15 \cdot 10^{-6}$  mV/V. The individual values scatter within a band

of  $\pm 20 \cdot 10^{-6}$  mV/V. In relative terms, related to the nominal value 2 mV/V, this corresponds to a bandwidth of  $\pm 1 \cdot 10^{-5}$ . It is worth noting that each individual measuring amplifier responds differently to the three bridge standards. Up to now, no plausible explanation has been found for this behaviour. These measurements were carried out over a period of a few weeks; they give no information about the long-term stability. It has to be noted that for the voltage ratio 2 mV/V and under the measurement conditions stated, the measured values may deviate from one another by approximately  $40 \cdot 10^{-6}$  mV/V.

## Summary

The measurement results presented show that at input voltages of 5 V and a frequency of 225 Hz, bridge standards of different design are in a position to maintain the voltage ratio of 2 mV/V with a stability of  $\pm 5 \cdot 10^{-6}$  mV/V over a period of more than 15 years. It was, however, also found out that even the measured values determined by measuring amplifiers of identical design under identical measurement conditions may deviate from one another by  $\pm 20 \cdot 10^{-6}$  mV/V or in relative terms by  $\pm 1 \cdot 10^{-5}$  (relative to the nominal value 2 mV/V). In international comparisons, in which only the transducer is circulated and therefore different measuring amplifiers are used, this leads to a contribution to the uncertainty budget which may not be neglected. This contribution can be reduced if together with the (e.g. force) transducer a stable bridge standard is available for calibration of the measuring amplifiers.

## References

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## Contact point:

Physikalisch-Technische Bundesanstalt  
Bundesallee 100, D-38116 Braunschweig, Germany  
Tel.: +49 531-592-2316 (-2190)  
E-mail: reinhold.vollmert@ptb.de  
guenther.ramm@ptb.de