Bridge Amplifier Linearity Investigation with a Cascaded Inductive Voltage Divider Setup

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Abstract. We present the linearity investigation of high precision bridge amplifiers as used in static force and torque measurements. The setup with cascaded inductive voltage dividers allows a much more detailed bridge amplifier linearity analysis than it is possible with the BN100 bridge standard or a recently proposed resistor-based strain gauge bridge transducer simulator. The bridge amplifier linearity deviation can be determined with an expanded (k=2) uncertainty of 2 nV/V and only with the presented setup it is possible to potentially reduce the relative uncertainty for nominal ratios below 1 mV/V.

1. Introduction
Traceable measurements of static force and torque at highest level require most advanced bridge amplifier and transducer calibrations. The high precision bridge amplifiers used in such measurements operate with 225 Hz carrier frequency and can be calibrated with the HBM BN100 bridge standard [1].
At PTB we recently developed a calibration setup for bridge standard calibration which allows to reduce the (k=2) uncertainty of each nominal BN100 calibration point to 5 nV/V [2]. A calibrated bridge standard of this kind can be used to calibrate high precision bridge amplifiers as e.g. the DMP40 [3] or DMP41 [4]. However, the 0.1 mV/V step resolution of the BN100 limits the bridge amplifier calibration to these discrete calibration points. The nature of the BN100 calibration with absolute calibration values causes a constant calibration uncertainty in the range ±2.5 mV/V. Consequently, this results in higher relative uncertainties for nominal values below 1 mV/V (e.g. 0.1 mV/V).
In order to overcome these limitations, we developed a linearity investigation setup which is able to characterise the bridge amplifier linearity between ±5 mV/V in more than 10^7 steps. This is much more detailed than the 100 steps of a BN100 or the recently proposed resistor network for bridge amplifier linearity checks [5]. The following detailed linearity investigation of two bridge amplifiers types will show the case of an unexpected linearity deviation fine structure.

2. Bridge Standard and Bridge Amplifier Calibration
The calibration result in Fig.1 proves the excellent linearity of the BN100A bridge standard used for this investigation. The obtained (k=2) uncertainty of each nominal ratio calibration point is 5 nV/V. The offset between positive and negative nominal ratios (about 2 nV/V for our
device) make it necessary to fit two separate linear curves, as seen in Fig. 1. The deviation from these linear fits (residuals) can be seen in Fig. 2 and are all below ±1 nV/V. This is a sufficient starting point for the linearity check of bridge amplifiers.

The result of the bridge amplifier calibration with our BN100A is shown in Fig. 3. The DMP40 shows higher deviations from the linear fit curve than the new DMP41, as can be also seen from the residuals in Fig. 4. The residuals are below ±2 nV/V for the DMP41 and above ±5 nV/V for the DMP40. The expanded (k=2) uncertainty for the calibrated nominal ratios of the BN100A is for both bridge amplifiers 6 nV/V and is dominated by the BN100A uncertainty. The major question for the shown bridge amplifier calibrations is, if it is possible to do a linear interpolation with similar uncertainty between the calibrated points, or even to reduce the relative uncertainty below 1 mV/V.

3. Bridge Amplifier Linearity Investigation Setup
The new setup for bridge amplifier linearity investigation can be schematically seen in Fig. 5. It is based on a two-stage 1/200 inductive voltage divider (IVD) $T_N$ with a 350 Ω input resistor.
(R_f) and separate supply windings to source the magnetization windings of the two cascaded IVDs (T_{N21} and T_{N22}) in order to vary the output voltage ratio in small steps. The cascaded IVDs can be either two Sullivan F9200 eight-decade IVDs or two relay switched 24-bit binary divided IVDs for automated measurements as shown in Fig. 6. The 1/200 ratio of T_{N1} realizes a nominal ratio range ±5 mV/V which can be divided in more than 10^7 steps for the 24-bit binary IVDs. Since the ratio of T_{N1} is not calibrated we only characterise the linearity of the connected bridge amplifier. The determined linearity deviation (k=2) uncertainty is about 2 nV/V.

4. Linearity Investigation Results and Discussion
The result of the DMP40 and DMP41 linearity investigation is shown in Fig. 7 to Fig. 10. When the DMP40 linearity is investigated in the 100 µV/V step size (big blue points in Fig. 7) as used by the BN100, we obtain a very similar characteristic as in Fig. 4. However, when the step size is changed to 80 µV/V or 70 µV/V (orange and green curves in Fig. 7) quite different characteristics are obtained. Additionally, a shift of the 100 µV/V step size curve can be observed when the measurement is repeated after a 40h with Autocal switched.

![Figure 5](image1.png)

Figure 5. Schematic setup for bridge amplifier linearity investigation. The 1/200 IVD T_{N1} is connected in series with two similar IVDs (T_{N21} and T_{N22}).

![Figure 6](image2.png)

Figure 6. Automated version of the bridge amplifier linearity investigation setup with two relay switched 24-bit binary IVDs for T_{N21} and T_{N22}.

![Figure 7](image3.png)

Figure 7. DMP40 linearity deviations for different D_n steps and after 40h waiting time.

![Figure 8](image4.png)

Figure 8. DMP40 linearity deviations for different D_n steps down to 100 nV/V (insets).
A more detailed measurement with a 10 $\mu$V/V step size in Fig. 8 shows a wide spread of the measurement points. The range of this spread covers the measurement curve with 100 $\mu$V/V step size. The spread of the measurement points can be explained with a micro structure of the DMP40 characteristic as seen in the insets of Fig. 8 which detail several measurements with 100 nV/V step size. It can be seen that the DMP40 has a specific saw tooth characteristic with a 3 $\mu$V/V period and a peak-to-peak amplitude of 10 nV/V which is valid for the whole investigated range.

The DMP41 result with two 100 $\mu$V/V step size measurements carried out with a 20h time difference in Fig. 9, show a more ideal characteristic. Also the reduction of the step size to 10 $\mu$V/V in Fig. 10 or 100 nV/V in the insets show a linear behaviour and linearity deviations smaller than 2.5 nV/V.

**Figure 9.** DMP41 linearity deviations for different $D_n$ steps and after 20h waiting time.

**Figure 10.** DMP41 linearity deviations for different $D_n$ steps down to 100 nV/V (insets).

5. Conclusions

The presented linearity investigation setup is able to determine the linearity deviation of high precision 225 Hz carrier frequency bridge amplifier with sub-nV/V step size and 2 nV/V expanded (k=2) uncertainty. Only with this resolution the real linearity characteristic of two different bridge amplifier types could be revealed. This kind of result is not possible with a BN100 bridge standard or a recently proposed resistor-based strain gauge bridge transducer simulator.

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