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INVESTIGATION OF THE INFLUENCE OF CARRIER FREQUENCY OR DIRECT CURRENT VOLTAGE IN FORCE CALIBRATIONS

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Abstract − This paper describes analysis and evaluation of calibration of several force transducer types, each transducer first calibrated by a precision amplifier at 5 V 225 HZ carrier frequency excitation voltage and second by a precision amplifier at 5 V direct current excitation voltage. Some calibrations were made according to ISO 376 in order to determine the uncertainty; much more calibrations were performed in two series with changing amplifier in order to detect the influence of the excitation voltage. There were two goals of the investigation: The first goal was to achieve confidence of the different calibration equipment for carrier frequency and direct current voltage by statistical data, the second goal was to experience the interchangeability of two different amplifier types on different transducer types.

Keywords: carrier frequency (CF), direct current (DC), force transducer

1. INTRODUCTION

Force transducers used as transfer standards for calibration of Force Machines or Material Testing Machines are calibrated in secondary calibration laboratories like DKD-laboratories in Germany. A large amount of transducers are not calibrated together with the amplifier which is used in field, but with calibration laboratories' equipment. Therefore laboratories use CF-amplifiers like HBM DK 38, DMP 40 or MGC with ML 38. This type of amplifier technology is well established for years. Due to its' precision and measuring method the replacement of an amplifier is assumed to be done without considerably increasing the uncertainty.

It's a matter of common knowledge that replaceability is given for the same excitation voltage only, e.g. replacing 5 V to 5 V and replacing 10 V to 10 V.

The main advantage of CF-amplifiers is their insensitivity to the influence of thermoelectric voltage and other additive error signals, leading to a very small device uncertainty [1].

The development of modern electronic and digital devices improved the performance of the DC-amplifiers in the last years. Today more and more DC-amplifiers are used in industrial applications and for calibration purposes. Even from a physical point of view the small uncertainty of CF-amplifiers is not reachable with DC-amplifiers.

This paper deals with the following questions:

a). What size is the influence by usage of DC- instead of CF-amplifiers regarding the uncertainty of ISO 376 calibrations?

b). Which points have to be taken into consideration, when a replacement of amplifiers with different excitation types shall be done?

c). Do two different metrological chains in the traceability of voltage ratio, namely the CF-chain and the DC-chain, come to the same results in force calibration?

2. MEASUREMENT EQUIPMENT

The investigation point was a comparison of 5 V 225 Hz carrier frequency and the 5 V direct current voltage. The investigation has been carried out at GTM's DKD-laboratory in the period from January 2008 to May 2009.

2.1. Voltage ratio standards

Two voltage ratio standards were used to calibrate the different type amplifiers, a HBM BN100 A for the CF-amplifiers [2] and a HBM K148 for the DC-amplifier. Both voltage ratio standards were calibrated in the range of 0,1 mV/V to 2,5 mV/V at PTB. As expected the uncertainty of the HBM K148 is worse than the uncertainty of the HBM BN 100 A, mainly caused by thermoelectric voltage.

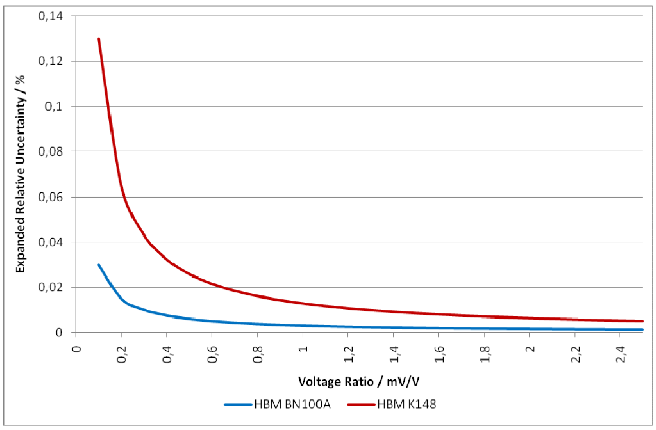

Fig. 1. Expanded Relative Uncertainty (*k*=2) of the voltage ratio standards.

2.2. Amplifiers

The used CF-amplifiers were a HBM DK 38 and a HBM DMP 40. Both amplifiers are very well known over years and show an excellent reproducibility. The measurement values of these amplifiers were automatically read while investigation via RS 232 by the PC of the used Force Calibration Machines. In case of DK 38 the "Filter 3" was used, in case of DMP 40 filter setting was 0,1 Hz Bessel.

The DC-amplifier was of type GTM LT Digitizer. The amplifier uses an USB 2.0 interface and configurable PC-software including a module for digital communication. The device parameters were an integration time of 500 ms and a mean value filter of 2 s.

Fig. 2 to Fig. 4 show the calibration results depending on the used amplifier with the deviation of indication as a curve and the expanded uncertainty (k = 2) as error bars in the range from 0,1 mV/V up to 2,5 mV/V.

The calibrations were performed with the voltage ratio standards mentioned in the previous chapter. The uncertainty of calibration is calculated by the uncertainty contribution of the voltage ratio standard, the indication deviation of the amplifier and in case of DC-calibration an estimated amount of thermoelectric voltage. For that reason the uncertainty of the calibrated DC-amplifier is about three times the uncertainty of CF-amplifiers.

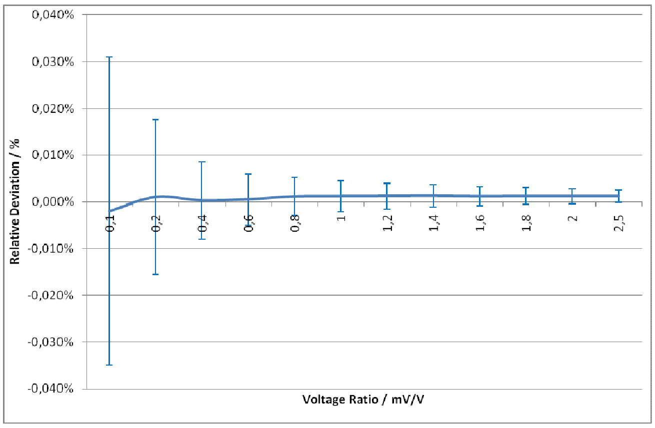

Fig. 2. Relative Deviation and Relative Uncertainty of DMP 40.

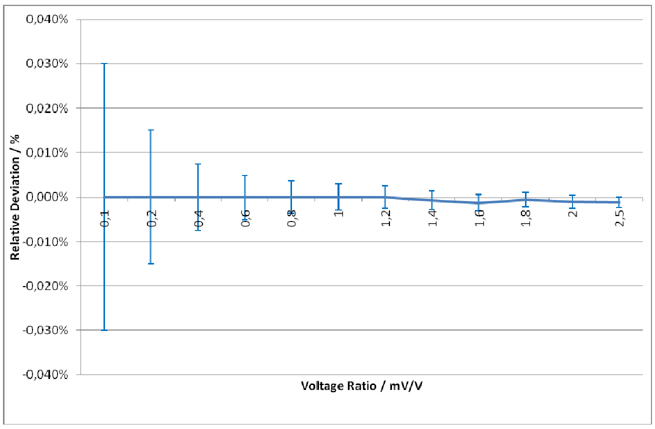

Fig. 3. Relative Deviation and Relative Uncertainty of DK 38.

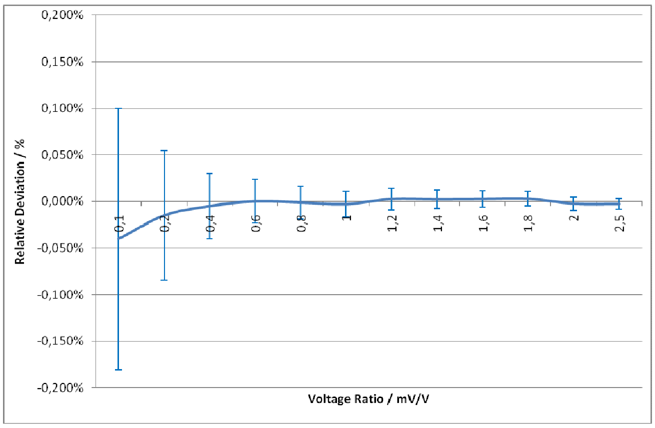

Fig. 4. Relative Deviation and Relative Uncertainty of LT-Digitizer.

2.3. Force transducers

The investigation is based on an amount of 94 transducers with nominal loads from 2,5 kN up to 250 kN.

The transducers were of following types:

Table 1. Types and number of force transducers

Transducer type	Number
HBM / C4	2
HBM / C3	3
HBM / Z4	25
GTM / KTN-P	30
HBM / Z3	34

The HBM / Z3 series transducer consist of type Z3, Z3H2 and Z3H3.

The structural shapes of the used transducers are very different. The HBM transducers e.g. use small strain gauges with a resistance of 350 Ω. The GTM transducers use spiral strain gauges with a resistance of 1000 Ω. The covered surface of the spiral strain gauges is comparatively high, so the thermal dissipation loss related to the surface is much lower.

Because of the different assembly the frequency of the excitation voltage can contribute different amounts to the transducers' signal by inductive or capacitive effects within the electronic circuits.

But it is shown later, that these properties didn't affect the points of this investigation in any way. Based on the knowledge that the used transducer types differ extremely in their shape, it could be concluded that the results of the investigation can also be transferred to other industrial transducer types.

2.4. Force Calibration Machines

All force calibrations were performed on the Calibration Machines of the GTM laboratory and all used machines are within the scope of the accreditation of the German Accreditation Association DKD.

Table 2. Types and expanded relative uncertainty of force standard machines

Force Calibration Machine	Expanded Relative Uncertainty
Deadweight up to 5 kN	0,01 %
Jockey weight up to 25 kN	0,02 %
Lever amplification up to 100 kN	0,01 %
Hydraulic Reference up to 1200 kN	0,02 %

3. CALIBRATION PROCEDURES AND RESULTS

3.1. Calibrations according ISO 376

Nine transducers were calibrated according to ISO 376 first with a CF-amplifier and second with a DC-amplifier.

ISO 376 is used for the calibration of force transducers by introducing known forces and taking readings from the amplifier. The calibration is performed in one direction only (compression or tension force) or in both directions. The procedure insists of four series in three rotational positions of 0°, 120° and 240°. Series one and two are increasing series without changing the transducers' rotation angle (position 0°), series three (position 120°) and four (position 240°) contain increasing and decreasing series.

For investigation only compression force calibrations were taken into account.

Fig. 5 shows the average of the uncertainty of the ISO 376 calibrations with maximum and minimum uncertainties as error bars. The results of using a DC-amplifier are in accordance with the results using a CF-amplifier within only 0,01%. The kind of excitation voltage doesn't affect the calibration result and classification.

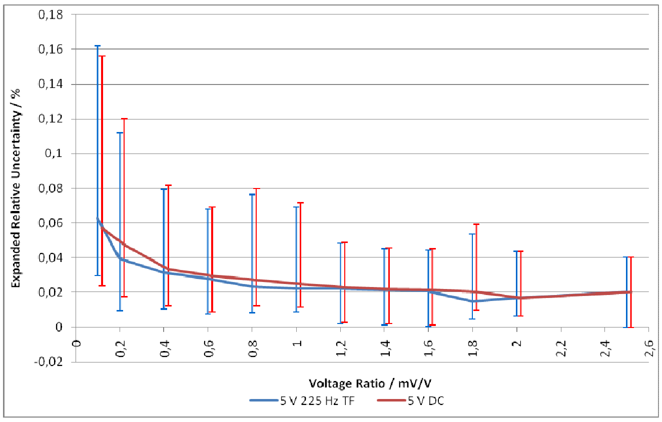

Fig. 5: Average of the expanded relative uncertainties achieved with CF- and DC-amplifier

3.2. Comparison of two series

85 transducers were calibrated by performing two series of increasing and decreasing forces, using first the CF-amplifier and second the DC-amplifier. The series were applied back-to-back, the position of the transducer remains unchanged.

For evaluation the readings of the first series (*A*) are compared with the readings of the second series (*B*). Therefore each series is tared by its zero reading and the readings of the load step *i* are compared by calculating the relative deviation (ΔS):

$$\Delta S = ((B_i - A_i) / A_i) \quad (1)$$

All investigated transducer types had the same behaviour regarding the influence of CF- or DC-excitation voltage, there was no appreciable difference. Therefore it is advisable to evaluate all transducers as one group.

Fig. 6 shows the average of the relative deviation of all transducers calculated by equation 1 for each transducer. With the measurement of the force transducers it is shown, that the two different metrological chains (CF-chain and DC-chain), run to the same result within the uncertainty of the CF-voltage ratio standard only.

But a comparison of the relative deviations at 0,1 mV/V of Fig. 4 with 0,04 % and Fig. 6 with 0,006 % shows that the assumed uncertainty of 0,13 % in DC-calibration seems to be adequate. In spite of the high amount of uncertainty in DC-calibration the results achieved with the force transducers are much better.

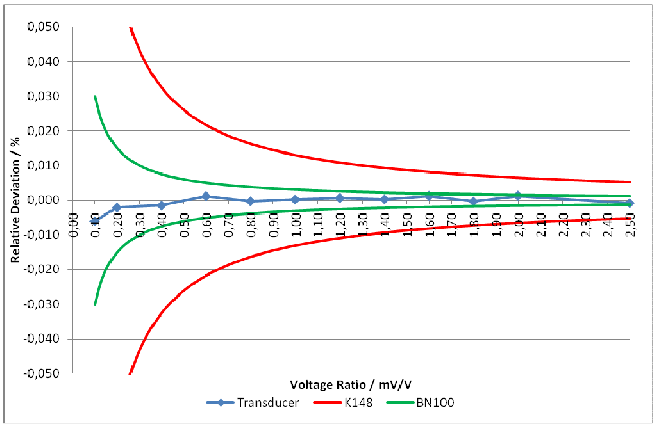

Fig. 6. Relative deviation 5 V DC to 5 V 225 Hz, all transducers

Fig. 7 shows the frequency of the relative deviation calculated by equation 1 for four exemplary voltage ratios (0,1 mV/V, 0,2 mV/V, 1 mV/V and 2 mV/V) with the limits of the reproducibility (*b'*) according ISO 376 for class 00 and class 0,5 transducers.

It must be considered, that these are the deviations of two measurement series only and that the single repeatability contributions of the transducers are not negligible. Some of the transducer types are specified as class 0,5 transducers. Anyway, the investigated range started at 5 % (0,1 mV/V) of the nominal load.

It can be concluded that the interchangeability of CF-amplifiers and DC-amplifiers is given for class 1 (*b'* = 0,1 %) and class 2 (*b'* = 0,2 %) transducers without any risk, in particular as the investigated transducers are very different in construction as described in chapter 2.3.

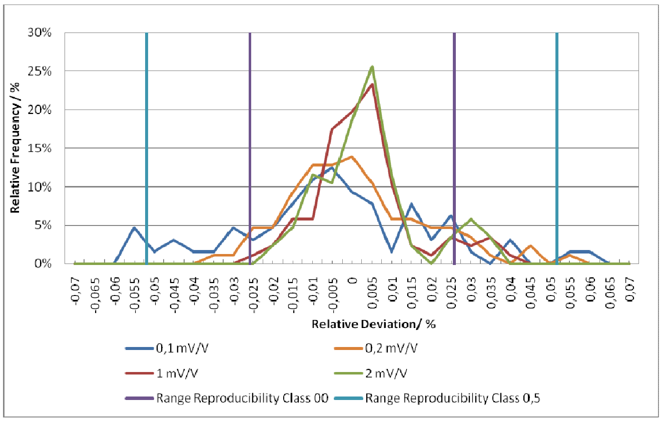

Fig. 7. Density graph of relative deviation for exemplary ratios

Table 3 shows the relative frequency of the repeatability considering the requirements for class 00 and class 0,5 transducers of ISO 376.

Table 3. Relative Frequency fulfilling the repeatability requirements of ISO 376

Voltage Ratio	Class 00 *b'* = 0,025 %	Class 0,5 *b'* = 0,05 %
0,1 mV/V	72 %	91 %
0,2 mV/V	85 %	99 %
1 mV/V	92 %	100 %
2 mV/V	92 %	100 %

Taken into account, that the contributions of the calibration machines and of the force transducers itself are not negligible as mentioned before, and that the calibration results as described in chapter 3.1 were identical, a replacement in the range starting at 5 % seems to be admissible for class 0,5 transducers on condition that the influence of the excitation voltage is investigated for this type of transducer.

In case of class 00 transducers a further investigation with the respective transducer is advisable to decide on the interchangeability and its range. The achieved relative frequencies given in Table 3 with 72 % to 92 % for class 00 transducers are too low for a general recommendation. It must be kept in mind, that not all of the calibration machines and transducers used in this investigation fulfil the requirements of class 00.

4. CONCLUSIONS

Using 5 V 225 Hz- amplifiers and 5 V DC-amplifiers in force measurement runs to the same sensitivity of common used force transducers.

The different traceability chains CF- and DC-voltage ratios as well provide same sensitivity, much better than expected because of the worse uncertainty of DC-calibration capability. An improvement of the DC-standard facilities would be desirable for the future.

The achieved uncertainties and classifications according ISO 376 with precision CF- and DC-amplifiers are identical.

CF-amplifiers and DC-amplifiers are interchangeable if used with class 0,5 transducers of investigated types. In case of class 00 transducers an exchange could be done after checking in detail the respective transducer.

ACKNOWLEDGMENTS

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