COMPARISON MEASUREMENTS OF MIKES-RAUTE 20 kN·m TORQUE REFERENCE DEVICE WITH THE PTB

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ABSTRACT

This article deals with the vertical 20 kN·m torque reference calibration device newly built by MIKES-RAUTE. It widens the possibilities of the MIKES-RAUTE Mass and Force Laboratory in the field of torque calibrations from 2 kN·m up to 20 kN·m. A brief overview about the construction and setup of the device is included in this report. Also some information about the applied calibration process is given. The main part of this article describes comparison measurements with the PTB, Germany, from summer 2004 and presents their results. They show that the device will attain an uncertainty level of $5 \cdot 10^{-4}$ or better over the entire measurement range.

1. INTRODUCTION

The need of torque calibrations with higher nominal loads in Finland has led to the development of the new vertically arranged 20 kN·m torque reference device. Its measurement range is designed for the calibration of torque transducers from above 1 kN·m up to 20 kN·m nominal load. As smallest possible expanded relative uncertainty a value of $5 \cdot 10^{-4}$ was acquired. The device was completed in winter 2003.

After a period of investigations first comparison measurements with PTB took place in July 2004. They were undertaken for two measurement ranges with a nominal torque value of 5 kN·m and 20 kN·m. As transfer standard transducers both from MIKES-RAUTE and from PTB were used such that the comparison was a double comparison. The measurements showed that the expected uncertainty of $5 \cdot 10^{-4}$ can be reached.

This report gives first an overview on the setup and the construction of the new MIKES-RAUTE 20 kN·m torque reference device. Thereafter some specifications on the calibration procedure, which is generally according to EA-10/14 at the moment, will be given. In the main section the comparison measurements with PTB are described. The main results of these investigations are given and also some other results will be briefly presented.

2. DESCRIPTION OF THE NEW RAUTE-MIKES 20 kN·m TORQUE REFERENCE DEVICE

Within the new MIKES-RAUTE 20 kN·m torque reference device the main parts are arranged vertically in line one above the other. An overview of the machine is given in Figure 1. The main components are the reference transducer, the intermediate bearing and the drive. They are supported by the main frame, which consists of two pillars. All mechanical connections of reference transducer and calibration object to the machine are made using ETP Hyloc respectively ETP Express hydraulic clamping bushes. To reduce the influences of axial, radial and angular misalignment flexible shaft couplings are used at both transducers. Depending on the calibration object a reference transducer of 5 kN·m, 10 kN·m and 20 kN·m nominal load can be used.

The reference transducer is installed into the machine in upper position. Its one end is fixed via the described parts to the top end of the machine. The measurement shaft is connected to a shaft

that is fixed in the intermediate bearing. For this intermediate bearing counter rotating groove ball bearings are currently used. The performance of that system is sufficient but is expected to be improved by the use of angular ball bearings. This change will be done in the beginning of 2005. Reference transducer and intermediate bearing are mounted together into a separate inner frame. It is vertically relocatable within the main frame, so that its position can be adapted to different calibration object dimensions.
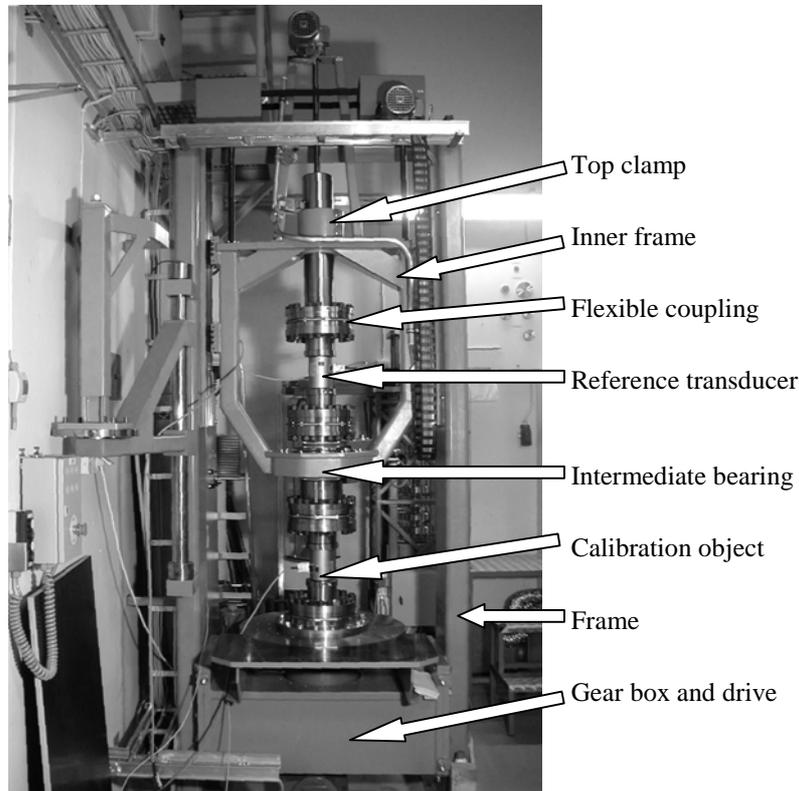

Figure 1: Overview of the vertical MIKES-RAUTE 20 kN·m torque reference device

The measurement shaft of the calibration object is connected via adaptors to the lower shaft end of the intermediate bearing. The other end is connected to a rotary table. To produce the torque the table is mounted onto a high ratio gearbox (1:3800) driven by a stepping motor. This motor works in micro step mode with a resolution of 4000 steps per revolution to provide the necessary sensitivity for the calibration process.

For operating the system a PC-based measuring program is used. It utilises a two channel DMP 40 and controls the stepping motor based on the measurement results of the reference transducer. The program records automatically the measurement results from the calibration object and the reference transducer and exports them to an Excel sheet after finishing the calibration process.

3. PARTICULARITIES OF CALIBRATION PROCESS

According to the nominal value of the calibration object reference transducers with a nominal value of 5 kN·m, 10 kN·m and 20 kN·m can be used. The calibration process currently used is based on EA-10/14 with 8 steps of 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 80 % and 100 % of nominal load of the calibration object. The calculation of uncertainty is also as described in EA-10/14.

As the device is a reference device it is not possible to achieve a still standing value indication within a reasonable time. This is caused by system creep, occurring mainly in the frame, the reference transducer and the calibration object. To get nevertheless a useable measurement value the following procedure is used. The control program includes the reference values of reference transducers as they are stated in their calibration certificates. They are used as an indication of the calibration point. Between two calibration points the stepping motor is going fast with a stepping frequency of 300 Hz. When the reference transducer indicates that a certain small distance to the next calibration point is reached, the stepping motor is switched to a slightly slower speed (3 to 5 Hz, depending on the transducers used). A few seconds after changing the speed but before the calibration point is reached, the PC starts to record measurement values both from reference transducer and calibration object with a frequency of 5 Hz. After passing over the calibration point the PC stops measurement recording and switches the stepping motor to fast drive again to continue to the next point. Figure 2 shows torque as a function of time for one calibration step. To calculate the final measurement values a linear interpolation is made to the reference point with the values gained for each calibration point. The occurring uncertainty is also calculated and added to the uncertainty budget. It normally lies in the range of $2 \cdot 10^{-5}$ or less. This uncertainty also can be used as indicator for the performance of the counter rotating bearings.
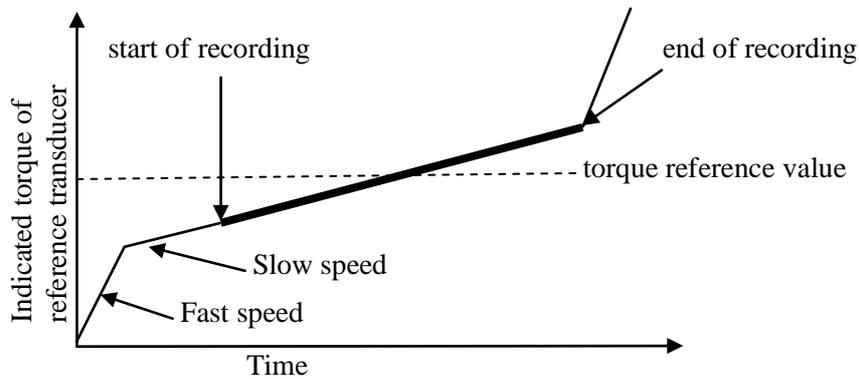

Figure 2: Recording of measurement values and drive speed in 20 kN·m device for one measurement point

At the beginning of a calibration a little torque is applied on the system, which is situated in the range of 0,2 % of the nominal load of the calibration object. This is necessary to get the play out of the gearbox. The indication value of reference transducer after this procedure is used as zero value. The influence of this on the accuracy of the calibration is considered to be negligible but will be investigated in future.

4. REALISATION OF COMPARISON MEASUREMENTS WITH THE PTB AND RESULTS

In order to make initial assessments about the measurement capability of the new MIKES-RAUTE 20 kN·m torque reference device comparison measurements with the PTB in Germany took place in July 2004. The comparison was carried out with transfer transducers from both MIKES-RAUTE and the PTB. Both institutes provided transducers with nominal loads of 5 kN·m and 20 kN·m. MIKES-RAUTE used two transducers of type TT1, while the PTB used a 5 kN·m TB2A and a 20 kN·m TT1. The two MIKES-RAUTE transducers were first calibrated using the new calibration device, then were shipped to the PTB for calibration and finally were recalibrated in Finland. The PTB first calibrated its transducers in its 20 kN·m torque standard device, shipped them thereafter to Finland for calibration and recalibrated them back in Germany. This means that the comparison was in fact doubled. Based on the gained calibration

results the uncertainty of the MIKES-RAUTE device was calculated. After a short overview about calculation of uncertainty this chapter presents the best results of the comparison for both used measurement ranges. The comparison measurements were conducted with manual control of the calibration machine in Finland. As the MIKES-RAUTE device was improved one month after the comparison with an automatic control, which led to better measurement performance, some results taken later are included here as well.

The calculation of relative expanded uncertainty of all calibration processes undertaken was done according to EA-10/14. For calculation of uncertainty of the comparison following contributions were used:

- w_{Ref} – relative uncertainty of reference transducer used in MIKES-RAUTE calibration device, as stated in its calibration certificate

- w_{Trans} – relative uncertainty of transfer transducer; for MIKES-RAUTE transducer taken from calibration at PTB, for PTB transducers maximum from first and second measurement at PTB

- w_{Cal} – relative uncertainty of calibration of transfer transducer in MIKES-RAUTE device; for MIKES-RAUTE transducer maximum from first and second measurement; also included is the uncertainty of interpolation of the calibration values as described in chapter 3

- w_{Dev} – relative uncertainty of deviation between first and second calibration at PTB respectively at MIKES-RAUTE

The whole expanded relative uncertainty ($k = 2$) is calculated by the following equation (1):

$$W = 2 \cdot \sqrt{w_{Ref}^2 + w_{Trans}^2 + w_{Cal}^2 + w_{Dev}^2} \tag{1}$$

All other uncertainty contributions such as the uncertainty of the indication device DMP 40 S2 and the uncertainty caused by temperature differences are neglected because of their small size. Additionally the influence of creeping is not considered yet, but will be determined in future after additional investigations. The deviations between calibration values at PTB and MIKES-RAUTE were not included into the uncertainty calculation. In the presented graphs they are displayed as actual deviation.

In the range up to 5 kN·m the best comparison results were achieved through the use of the MIKES-RAUTE transfer transducer of type TT1. The results are shown in Figure 3. There the deviation between the calibration of the reference transducer at the PTB and MIKES-RAUTE is displayed. It can be seen that the relative deviation is less than ±0,03 % through the entire measurement range. The uncertainty is displayed using error indicators. Except the first calibration step clockwise the sum out of relative deviation and uncertainty does not exceed the intended relative uncertainty limit of 0,05 %.
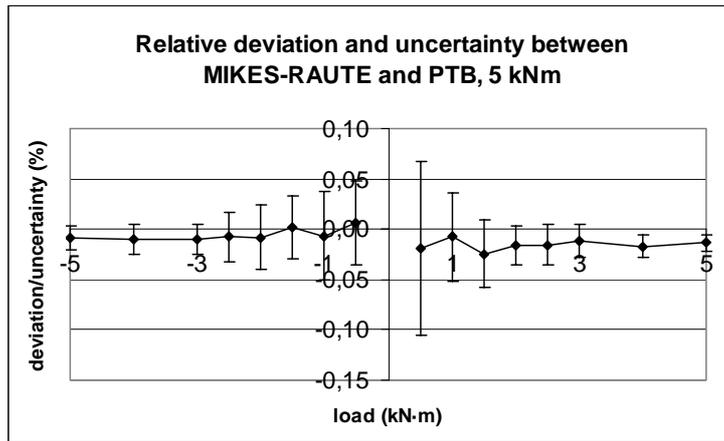
Figure 3: Relative deviation and uncertainty of MIKES-RAUTE 20 kN·m device compared with PTB, calibration with 5 kN·m transfer transducer during comparison measurements, manual control of MIKES-RAUTE device

Figure 4 shows the results of measurements taken after the comparison measurements. They were undertaken with the automatic control of the MIKES-RAUTE device. As base values the same results from PTB as above were used. It can be seen that there is a relative deviation of -0.02% over the entire measurement range. The reasons for that will be investigated in future. The expanded relative uncertainty with automatic control shows a much better performance compared to Figure 3. Based on these results it can be said that the new torque calibration device reaches the expected relative uncertainty level of $5 \cdot 10^{-4}$ in the range of 5 kN·m.
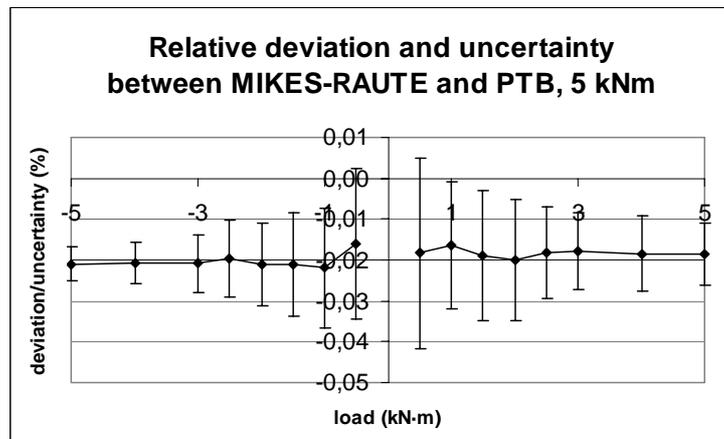

Figure 4: Relative deviation and uncertainty of MIKES-RAUTE 20 kN·m device compared with PTB, calibration with 5 kN·m transfer transducer, automatic control of MIKES-RAUTE device

In the range up to 20 kN·m the best results could be obtained by the use of the PTB transfer transducer of type TT1 during comparison measurements. According results are shown in Figure 5. The relative deviation between PTB and MIKES-RAUTE is usually in a range less than ± 0,01 %. Considering that and the occurring uncertainty it can be seen that also in this range the expected best relative uncertainty range of $5 \cdot 10^{-4}$ will be reached.
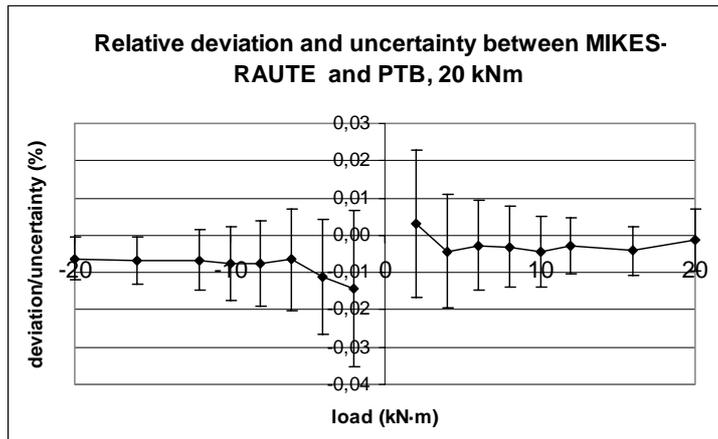
Figure 5: Relative deviation and uncertainty of MIKES-RAUTE 20 kN·m device from PTB calibration with 20 kN·m transfer transducer, manual control of MIKES-RAUTE device

5. SUMMARY

The new MIKES-RAUTE 20 kN·m torque reference device successfully proved its measurement capabilities during the comparison measurements with the PTB in July 2004. The expected measurement uncertainty of $5\cdot10^{-4}$ was reached in the range up to 5 kN·m as well as up to 20 kN·m. In general all components used showed a good performance. Although the counter rotating mechanical bearings worked in a satisfying way, they need some research and improvements to increase their reliability. Overall it can be said that the principle of vertically arranged torque calibration devices with intermediate bearing is applicable up to a nominal value of 20 kN·m.

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