INFLUENCE OF COUNTER ROTATING BEARINGS IN TORQUE CALIBRATION DEVICES

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ABSTRACT

This article is concerned with the use of counterrotating mechanical bearings in torque calibration systems. First a short overview on some general aspects of this bearing type will be given, which includes a general description of their construction as well as of their functionality. The main section deals with experimental examinations made on the performance of counterrotating bearings. These experiments were completed mainly using the horizontally arranged MIKES-RAUTE 2 kN·m torque standard calibration device. Additionally initial results gained with the new vertically arranged 20 kN·m torque reference device are included. Main points of interest were the particular elements of the uncertainty budget as stated in EA-10/14. They are opposed for counterrotating and standing bearings. Also some investigations about other error influences of the bearings are presented. Overall these results show that counterrotated bearings can provide a strong reduction of uncertainty but also need some further investigation especially in vertical devices.

1. INTRODUCTION

An intermediate bearing is used in torque calibration devices to support the shaft between the reference and calibration objects. Its main purpose is to absorb radial forces that occur in dead weight torque devices as well as during wrench calibrations. As it is situated directly within the measurement chain, its properties have a high influence on the measurement capability of the calibration device. Especially the friction – and with it a loss of torque between calibration object and reference - that occurs in the bearing has a significant effect on the accuracy of the measurement. Secondary to the higher deviation of the calibration values from their true value friction also increases the hysteresis span.

As part of the development of torque calibration devices in the last decade several types of intermediate bearing systems have been devised to reduce the influence of friction. Most of the solutions are based either on air bearings, counterrotating bearings or standing bearings. Air bearings are a widely accepted solution for highly accurate measurements as they offer the smallest friction within the bearing. But they also have some disadvantages, mainly the expensive price and an unfavourable ratio between installation size and maximum applicable load. On the other hand standing bearings are the cheapest way to support the measurement shaft. Although they have a fairly big influence on the calibration results, they may be used for devices with low uncertainty demands.

As a third possibility counterrotating bearings consisting of mechanical ball bearings can be used. Based on their special construction they reduce friction and so are a suitable solution for calibration devices with a required uncertainty in the range of a few 10^{-4}. Additionally the cost reduction as compared to air bearing is a crucial factor in the application of counterrotating bearings. This report will attempt to give an overview of the theoretical aspects of counterrotating bearings as well as the experiences with them in MIKES-RAUTE torque calibration devices that were gained over the last few years.

2. PRINCIPLE ASPECTS OF COUNTERROTATING BEARINGS

Counterrotating bearings can generally be used in all kinds of torque calibrating devices. Each of these devices has special demands on the construction of the intermediate bearing, although the general principle remains the same. At MIKES-RAUTE two torque calibration machines with counterrotating bearings are in use. These are the horizontally arranged 2 kN·m dead weight device and the vertically built 20 kN·m reference device. The different orientations lead to varying points of emphasis in the construction of the bearing system, which will be discussed later in this chapter.

Counterrotating bearings are generally built using mechanical ball bearings. Two of these bearings are fixed on the measurement shaft between the reference object (which can be a lever with weights or a reference transducer) and the calibration object. They build the inner bearings. The outer rings of the bearings are each mounted into a bush. To enable rotation the bushes are mounted into slightly bigger outer bearings, which are fixed in the frame of the calibration device. All bearings used are standard roller ball bearings of type 60. Furthermore a drive system of some sort has to be realized in order to rotate the bushes. This is accomplished in RAUTE-MIKES devices by a motor with a gearbox and tooth belts. A general overview of the set-up of the 2 kN·m dead weight device is shown in Figure 1. The bearings also are covered to reduce contamination by dirt and dust. This is simply done by plates fixed on the frame that do not touch the shaft.
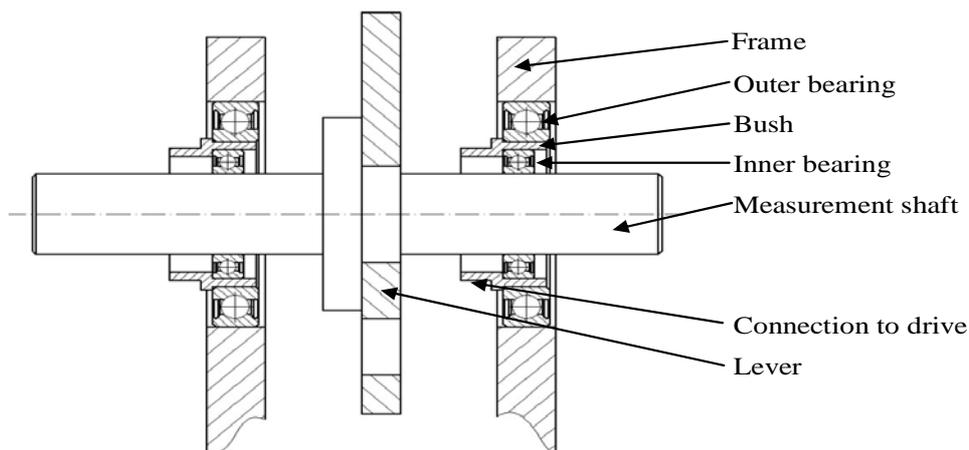

Figure 1: Cross-section through the counterrotating bearing in the MIKES-RAUTE 2 kN·m device (connecting parts such as screws not shown)

To reduce the influence of friction, the two bushes – and with them the outer rings of the inner bearings – are counterrotated. Because of the rotation only rolling friction occurs, which is already fairly small. According to the calculation method from SKF the maximum emerging friction in one bearing of the 2 kN·m device is less than 100 N·mm and is 500 N·mm in the 20 kN·m device. By counterrotating the two bearings the friction torque occurring acts in opposite directions, so that the total torque produced in the bearing system is theoretically 0 N·m. In practice there is of course an influence of the bearings on the calibration, as it will be shown in chapter 3. This is mainly caused by differing properties of the bearings used and unequal load distribution on both bearings.

The counterrotating bearing can be adapted to different applications in various ways. For dead weight calibration devices the two bearings can be separated and support the shaft on both sides of the lever, as shown in Figure 1. In the case of a reference device both bearings can be fitted together in one unit between reference transducer and calibration object. As already mentioned the vertical (especially for reference devices) and horizontal orientations of the machine need

different solutions for the bearings. Because usually only radial load on the bearings occurs in horizontal set-ups, normal ball roller bearings are a good solution for them. They also provide the smallest friction within standard bearings. In vertically arranged devices the bearings also have to carry the weight of the shaft, of the connected adaptors and flexible couplings and partly of the transducers as axial load. For this purpose ball roller bearings can be used also but are not the best choice, as the examinations on the new MIKES-RAUTE 20 kN·m device have shown. Also the axial load has to be distributed equally on both bearings, as the friction depends on that. If the axial load is different, the bearing with higher load will produce a higher friction, which leads to a resulting turning moment in its direction of rotation. Better performance is expected from the use of angular contact ball bearings that are braced one against the other. A closer look at this will be taken in future.

3. EXPERIMENTAL EXAMINATIONS AND RESULTS

The aim of the experimental examinations was to determine the influence of counterrotating bearings on measurement accuracy as compared to standing bearings. In particular the contribution of hysteresis, reversibility and reproducibility to the uncertainty budget (according to EA-10/14) was investigated for both versions. Also the influence of the rotational movement on the current measurement value is demonstrated. Most of these measurements were undertaken with the horizontally arranged MIKES-RAUTE 2 kN·m torque standard device. The corresponding results are presented in the first part of this chapter. Some results of initial measurements with the new vertically arranged 20 kN·m torque reference device will be presented after that. Also mentioned are some peculiarities of the vertical arrangement with regards to counterrotating bearings.

The measurements on the 2 kN·m device (accredited relative uncertainty $5 \cdot 10^4$) were undertaken in a clockwise direction both with counterrotating and standing bearings. A 500 N·m transducer of type TT1 was used as the calibration object. The calibration procedure was carried out according to EA-10/14 with 6 steps. The following graphs show the particular relative uncertainty contribution against the applied torque. Each diagram contains values for both counterrotating bearings and standing bearings.

As displayed in the left side of Figure 2 the counterrotating bearings of the 2 kN·m device reduce the reversibility up to 40% compared to standing bearings over the entire measure range. Also reproducibility is reduced under advantageous circumstances by two-thirds, which can be seen in Figure 2 on the right side. This works especially for lower values of the calibration range.
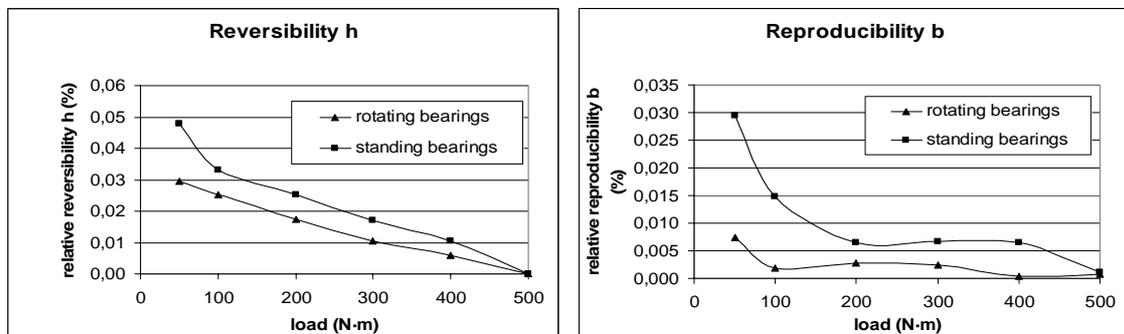

Figure 2: Reversibility and reproducibility in the 2 kN·m device with counterrotating and standing bearings

Repeatability can be improved by counterrotating bearings as well. Its influence could be reduced up to 50 percent for lower torque values (less than 30% of nominal torque). For some reason this improvement could not be investigated for higher torque values. Finally the calcula-

tion of expanded relative uncertainty shows that it can be improved from maximal 0.042% with standing bearings to a maximum value of 0.023%, both at smallest applied torque value of 10% of nominal load. This yields an improvement of relative uncertainty of about 40% with counter-rotating bearings. Details of expanded relative uncertainty are given in Figure 3.
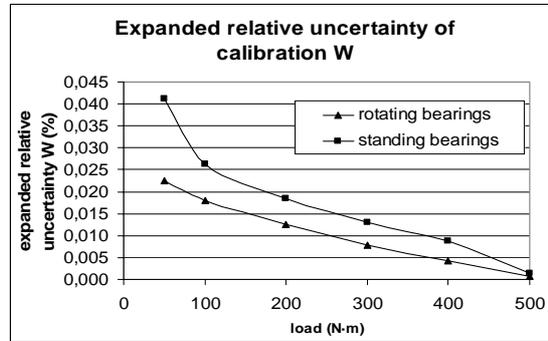

Figure 3: Expanded relative uncertainty in the 2 kN·m device with counterrotating and standing bearings

A look was also taken on the dynamic aspects of the movement of counterrotating bearings. An example of the fluctuation of the torque signal is given in Figure 4. For this experiment a 1000 N·m TT1 transducer was fully loaded clockwise in the 2 kN·m device. Only the fluctuation of the transducer signal around its mean value is displayed in the diagram. This experiment was undertaken without any filters. Also the transducer output signal was calculated in units of torque to get an idea of the actual size of the fluctuations. Oscillations with a frequency of 10 Hz and an amplitude of about 0.2 N·m can be observed. This is caused by the unequal shape of the rotating balls inside the bearings and also some dust and dirt on the tracks of the balls that cannot be avoided completely. But as the frequency is fairly higher than the measurement frequency these oscillations are filtered out by the amplifier. A 0.1 Hz oscillation that can also be seen is caused by a slight movement of the lever used. It can be avoided by carefully applying the mass pieces. The use of high precision bearings may bring some better results but as standard bearings achieve satisfactory results this has not yet been investigated.
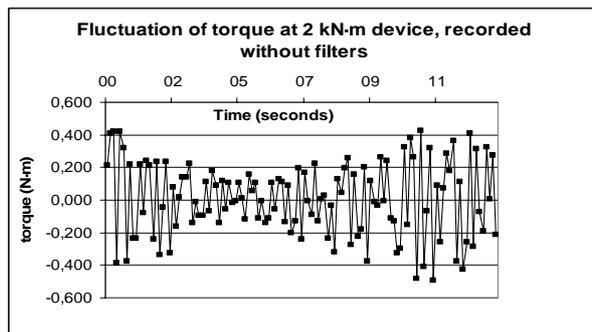

Figure 4: Fluctuation of torque during bearing rotation

Some information was also gained during these examinations about the effect of the transverse force that is applied in lever-based calibration devices. For this the bending force bridges of the transducer were read out during loading process. At a load of 1000 N·m, which corresponds to a force of 1000 N on the lever, the transducer measured a transverse force of 80 N. This means that the bearings are yielding outward approximately 10 µm.

Some measurements were also undertaken with the vertical 20 kN·m torque reference device. As it is a new device, only some initial results will be presented here, which will be the subject

of further investigations. Since the device is a vertical device, the performance of the intermediate bearing is of even more importance than in horizontal devices (as mentioned in chapter 1). The 20 kN·m device by RAUTE-MIKES currently uses standard roller ball bearings as counterrotating bearings. Although this is not the best solution some results already show the possibilities of counterrotating bearings. After a carefully prepared set-up of the machine the reversibility could be reduced from 0.03 % to 0.01% at the smallest calibration point, which means a reduction of two-thirds compared to standing bearings. For this experiment two 5 kN·m TT1 transducers were used as the reference and calibration objects. Details are given in Figure 5. Also the expanded relative uncertainty could be reduced in some cases of more than 50% to 0.02%.
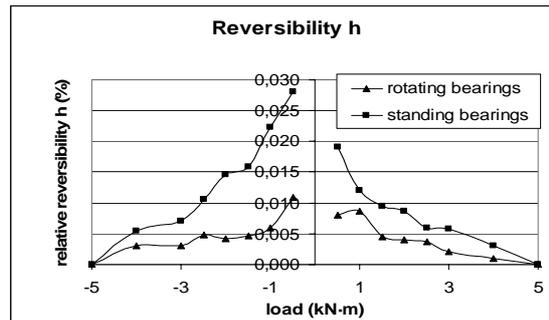

Figure 5: Reversibility in the 20 kN·m device with counterrotating and standing bearings

The performance of the intermediate bearing in connection with the heavier 20 kN·m transducers needs some improvements. Initial measurements showed just small advantages of counterrotating bearings. It could be seen that with increasing load the friction in the intermediate bearing increases only slightly in the range of less than 2 N·m. But with increasing axial load the uncertainty of the measurement values themselves increases a great deal. Reasons for this could be uneven load distribution on the bearings and also inaccuracies in production. Some investigations on that will be done.

4. SUMMARY

This report has shown that the use of counterrotating bearings in torque calibration devices is a good alternative to air bearings in the range of uncertainty down to some 10^{-4}. This kind of intermediate bearing can reduce the uncertainty of the calibration device up to 40 percent compared to standing bearings. In horizontally arranged torque devices counterrotating bearings perform adequately but some improvements are needed for the use of counterrotating bearings in vertically arranged machines. Here some research is necessary according to the type of bearings and their arrangement. But it could be shown that the principle of counterrotating bearings also works in upright devices and improves their uncertainty.

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