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Measurement and Calibration Using Reference and Transfer Torque Fanges

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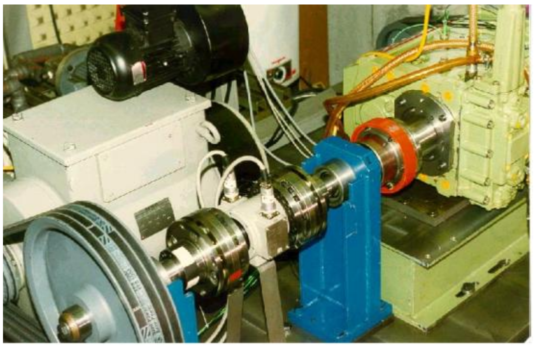
Abstract

Due to their extremely compact and short design and extremely high torsional stiffness, the so-called torque flanges based on strain gage technology are the most up-to-date devices used for in-line torque measurement in power test stands. The optimum transfer of the measurand torque into the shaft line is an important factor for a correct measurement of torque. Due to the compact and stiff design of the torque flanges some basic points must be taken into account. This paper describes specific factors affecting the measurement uncertainty and their reasons. It includes recommendations on how to avoid or minimize these effects in order to achieve optimum comparabilities, especially with respect to the sensitivity and the measuring characteristics. In addition, a new design principle is introduced which is less sensitive to the described effects.

1. Introduction

Often, torque transducers such as torque shafts or torque flanges based on strain gage technology are used for determining torque in power test stands (see figure 1A). New space-saving and simple power test stand designs require extremely compact and short torque transducers (figure 1B).



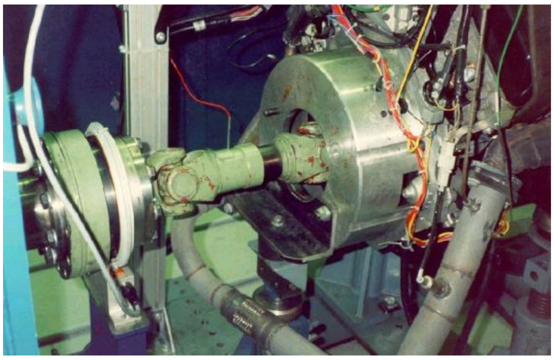


Figure 1 A. Conventional test stand with torque shaft, shaft line with bearing support point **Figure 1 B.** Short-design test stand with torque flange, shaft line without bearing support point

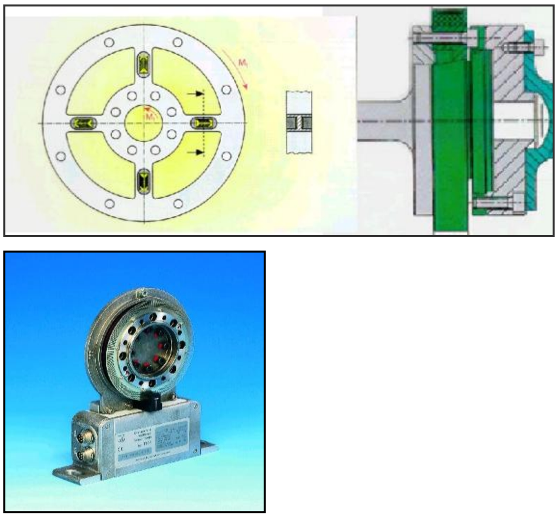


Figure 2. Shear-spoke sensor principle

Today, the so-called torque flanges are used for the majority of those applications (figure 2). They in particular enable the number of bearing support points to be minimized and high radial components to be absorbed. Normally, shaft lines with traditional torque transducers require considerably more space.

Due to the fact that industrial customers ever more often demand reduced measurement uncertainties, the optimum transfer of the measurand torque into the shaft line is an increasingly significant factor.

The subject of the present paper are fundamental considerations on the transfer of the measurand torque in test stand applications.

Due to the compact and stiff construction of the torque flanges, some basic points must be taken into account. Therefore, some specific factors affecting the measurement uncertainty and their reasons will be described. Furthermore recommendations will be included, on how to avoid or minimize these effects in order to achieve optimum comparability, especially with respect to the absolute measured values.

2. Transfer of the Measurand Torque into Test Stands

The simplest case is that the measurand torque is transferred directly via the torque transducer in the shaft line (figure 3A).

For this purpose, the torque transducers have already been adjusted and calibrated by the manufacturer or in calibration laboratories. However, it has to be noted that a production test by the manufacturer during which the torque transducer is calibrated in one mounting position does not permit a safe assessment of the torque transducer’s measurement uncertainty. The assessment of the measurement uncertainty can be enhanced by a calibration within the national calibration services, e.g. the DKD (Deutscher Kalibrierdienst – German calibration organization) according to DIN 51309 [1] or EA guidelines 10-14 [2]. The torque transducer is tested according to a specific procedure in different mounting positions and several partial load steps. Also, the additional measurement uncertainties resulting from the electrical test equipment and the torque reference standard testing machine approved for use within the DKD are taken into consideration.

If this torque transducer is later on used for its intended test stand application, the prevailing boundary conditions might considerably affect the measurement uncertainty of a torque measurement in the test stand and result in further deviations. The test stand components such as frame, couplings, component alignment, elastic material behavior of the adaptations or bolted joints, for example, might affect the deformation behavior in the shaft line and thus the torque transducer. This might considarably affect the torque transducer’s measuring characteristics (especially zero, sensitivity and comparability). Besides the above-described method there are further possibilities for transferring the absolute torque into the shaft line using transfer methods. Most beneficial are those methods enabling the effects of the test stand and its environment on the measurement results to be minimized and assessed.

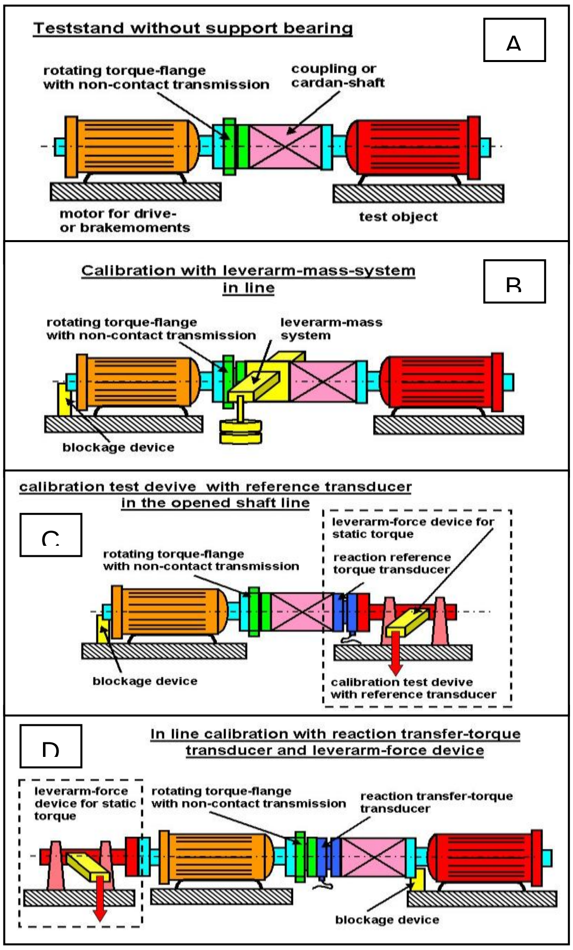


Figure3. Transfer of the measurand torque in test stands

The below 3 further methods are used today:

B. Lever arm-mass systems (fig. 3B), on the opened or closed test stand
C. Calibration device based on reaction torque transducers (fig. 3C), on the opened or closed test stand
D. Transfer torque transducer (fig. 3D) that can be integrated into the shaft line

Mass-mass systems have the disadvantage that, especially with bigger torques, calibrating the measurand is not easily manageable due to the fact that the masses and lever arms required are relatively big. The additional radial forces resulting from the masses’ and lever arms’ weight forces also affect the calibration (figure 3B). Often, bearings are required for supporting the radial weight forces. With shaft lines without bearing supports, the driving motor can also be used for this purpose. In this case potential losses due to bearing friction and magnetic residual moments in the motor that has been turned off must be taken into consideration.

Thus, high-precision reaction torque transducers are increasingly used for the calibration procedure. They are either adapted directly into the shaft line (figure 3D) or they are used in simple calibration machines (figure 3C). After the test stand shaft line has been opened, these calibration machines either can be directly coupled to the power test stand’s torque transducer, which is to be calibrated, or to the open end of the closed test stand’s input or output.

Simple, force-deflectable lever arms are used for torque introduction into the shaft line, if the motors cannot produce a nearly static calibration torque. The static reaction moment is introduced through blockage devices or brakes.

3. Transfer vs. Reference Torque Transducers

In this paper the terms “transfer transducer” and “reference transducer” are used for expressing which role the transducer takes during the transfer of the measurand into the application. This means in particular that the transducer integrated into the application can assume this function.

A transfer transducer transfers its calibrated sensitivity to another measuring device or application.

In general, transfer torque transducers are used for guaranteeing the traceability or transfer of the measurand torque from the national standard (e.g. PTB in Germany) through a reference standard (e.g. DKD in Germany) and factory standards (e.g. calibration machines) to the test systems or power test stands. For this purpose the transfer transducer can either remain integrated in the test stand being used for measurements, or it can transfer to another transducer or reference transducer that has been integrated into the test stand. To permit assessing of the additional components of the measurement uncertainty, the effects of the power test stand or the calibration machine on the transfer transducer must be known.

A reference transducer receives its reference torque y means of a calibration within ist intended application and mounting position. Applying an appropriate transfer method. A reference transducer must offer optimum repeatability as to this reference torque. An example for this task is the reaction torque transducer in the calibration machine represented in figure 3C.

Also in the case of a transducer that has been integrated into the test stand, the effect of all test stand components can be included in the calibration by means of a transfer transducer or calibration device. In the broader sense, this transducer takes on the function of a reference transducer.

In many cases, the whole test stand must be certified for the intended application to allow an assessment of the measuring results. For this purpose, transfer torque transducers, adaptable lever arm-mass systems or calibration machines with reference transducers can be used. The certification procedure includes the determination of measurement uncertainties resulting from the intended application and environmental conditions. Unfortunately, no standard or recommendation similar to the one for uniaxial compressive-tensile machines (EN ISO 7500-1) is available.

Today, the assessment process is often limited to assessing the possible match of transfer transducer and reference transducer or one of the transfer transducer's mounting positions. The assumed measurement uncertainty then is the maximum deviation of the reference transducer from the transfer transducer. In general, this is insufficient.

Certification calibrations with high accuracy requirements, e.g. 0.1%, are especially critical if they are performed using transfer transducers for which only so-called test protocols or working calibration certificates have been provided. In general, these certificates include only one series of measurements in one mounting position and therefore cannot take into account potential measurement uncertainties of the manufacturer's calibration for determining the measurand torque in an absolute way. This means that these simple calibration certificates are generally not sufficient for guaranteeing a qualified assessment of the measurement uncertainty even for the transducer alone.

4. Effects on the Measurement Uncertainty

As already mentioned above, boundary conditions prevailing in the test stands can affect the measurement uncertainty of torque measurement in the test stand.

Potential reasons e.g. of mechanical origin are:

- Parasitic loads such as bending moments, axial or radial forces
- Torque transducer adaptation
- Asymmetrical torque flow

Further factors are, of course, ambient conditions such as temperature, humidity and soiling effects, EMC effects or the usage of wiring or amplifiers other than used for the DKD calibration with differing signal phase delays. Therefore, calibrations should be made under conditions that are similar to those documented in the transfer transducer's calibration certificate.

The below section describes potential reasons for the mechanical effects and tips on how to avoid or reduce these effects in general and especially with torque flanges mainly used in static or quasi-static applications.

4.1. Parasitic Loads

Parasitic loads such as radial and axial forces and bending moments have an additional effect on the torque flange's zero signals. If they occur during torque introduction, they appear as a change in sensitivity.

Reason: Weight loads and stresses result in additional mechanical loads in the torque transducers. These loads affect the torque transducers as axial and radial forces and bending moments. The parasitic loads generate additional strains in the transducer's strain gage area, which are superimposed on the strains resulting from the torque.

Normally the strain gage arrangement and their connection in the form of a Wheatestone bridge have been chosen such that the effects of these parasitic loads ideally compensate each other.

In practical applications, however, a small so-called crossing over to the torque signals may occur. In some cases this crossing over on the zero signal does not depend on loading and rotation. Then taring is sufficient and it has no significance for the measurement uncertainty. In many cases, however, this crossing over changes as a result of torque introduction or rotation, sometimes even depending on the speed of rotation (e.g. unbalance).

Potential measures to be taken for avoiding or reducing these effects:

- Align the shaft line optimally and, if necessary, use torsionally stiff but laterally flexible shaft sections for decoupling from the transducer/flange
- If the required accuracy for alignment cannot be achieved, couplings have to be used that have no effects with respect to the parasitic forces
- Keep the weight of the shaft sections acting on the torque flange as small as possible
- Balance the test stand optimally

4. 2. Torque Transducer Adaptation

If the conditions of high stiffness in the shaft line around the torque transducers' force introduction and output deviate from the conditions prevailing during the calibration in the reference standard testing machine this might result in irregular torque introduction producing changes in the torque transducer's sensitivity. This is especially important for transfer transducers.

Reason:

- If the material used is too flexible this might result in plastic deformations on the flanges' supporting surfaces, or the thread is extracted from the flange surface with high wrench torques for bolts. Often this results in a deterioration of the flange surface's evenness.
- Adaptation flanges to the torque transducer in the test stand with a geometry deviating from the one of the adaptation flanges used for the calibration in the standard testing machine result in changed deformation behaviour of the torque transducer's strain gage area.
- Soiled flange surfaces, e.g. due to oil, grease, glue or paint.

Potential measures to be taken for avoiding or reducing these effects:

- Use high-strength or hardened adaptation components; especially near the torque flanges torque introduction and outputs.
- Observe the wrench torques for bolts.
- Use adaptation geometries that are similar to those used in the torque reference standard testing machine
- Use clean flange surfaces

4.3. Asymmetrical Torque Flow

Asymmetrical (unevenly distributed on the circumference) torque distributions in the shaft line might result in deformations in the shaft line, which in turn lead to the above mentioned parasitic loads. In addition, they cause asymmetrical torque introduction into the torque flange affecting the sensitivity.

Potential reasons:

- One-sided blocking devices or brakes near the torque transducer
- Individual bolts of the flanges have been tightened at different torques or not at all
- Flange surfaces have been soiled on one side, e.g. due to oil, grease, adhesive or paint
- The flange connections are uneven (roughness and evenness)
- Asymmetrically designed adaptation flanges

The materials used are too flexible and suffer an asymmetrical plastic deformation from loads. If wrench torques for bolts are too small this will result in gliding in the bolt connection and thus in an asymmetrical contact of the through holes with the boltshafts. If the through holes are too narrow, the bolt shafts have inside contact, which results in asymmetrical stress and locking

Potential measures to be taken for avoiding or reducing these effects:

- Avoid asymmetrical torque introduction or output, e.g. of blocking devices by means of toothed rim or feather key near the torque flange. The distance from the torque flange should be greater than half the flange diameter.
- Observe the required wrench torques.
- Use all bolt connections provided for fastening the torque flange/transducer
- Use even, if possible ground and clean flange surfaces

5. Practical Tips for the Use of Torque Flanges

Below, some torque flanges will be described with their sensitivity deviations that are typical for some mechanical influence factors (TB1A Reference torque measuring disc as a reaction torque transducer and T10F Torque flange for rotating applications). This information is to support the user in assessing the torque flanges' measurement uncertainty for the specific mounting conditions.

Furthermore, there are some tips and recommendations on how to achieve optimum mounting conditions for the described torque transducer types.

5. 1. Parasitic Loads

In the technical data for HBM torque transducers permissible parasitic loads (such as limit bending moments, limit radial force, and limit axial force) are specified and their potential crossing over to the torque signal is defined:

Any irregular stress (bending moment, radial or axial force, exceeding of the nominal torque) is permissible up to the specified individual limit provided that there is no other such stress occurring. Otherwise, the limit values must be reduced. For example, if 30% of the limit bending moment and the limit radial force occur at the same time, only 40% of the limit axial force are permissible and the *nominal torque must not be exceeded. The permissible bending moments, axial or radial forces can affect the measurement result by approx. 1% of the nominal torque.*

If the measures specified in section 4.1 are taken, only a fraction of the torque flanges‘ high limit values is utilised. For example, the typical weight of the special couplings recommended by HBM for TB1A and T10F amounts to less than 1% of a torque flange‘s permissible radial force. Taking into account the radial alignment accuracies of < 0.2 mm, the reaction bending moments typically occurring also amount to less than 1% of the permissible limit bending moments. In theory, this results in maximum additional measurement uncertainties of < 0.01%.

5.2. Deviating Adaptation and Asymmetrical Torque Introduction

The TB1A’s and T10F’s compact and short design which offers considerable benefits with respect to the space required and the stiffness, on the other hand means that the strain gages’ areas of strain are located at small distances from the bolted flange connections. Therefore, the torque flow between the bolted flange connection and the area of strain is relatively short, especially towards the areas of strain on the measuring body side. With the TB1A, the measuring body side carries the cable output (figure 4A). With the T10F the sensitive measuring body side carries the transmitter ring (figure 4B).

To assess the measurement uncertainties for direct transfer due to deviating mounting and adaptation conditions, different mechanical effects on the measuring ranges of 1 kNm to 5 kNm have been analyzed. If on this measuring body side unhardened materials are used for adaptation parts or the wrench torques for bolts are reduced to 50%, there will only be a relatively small effect of < 0.05%.

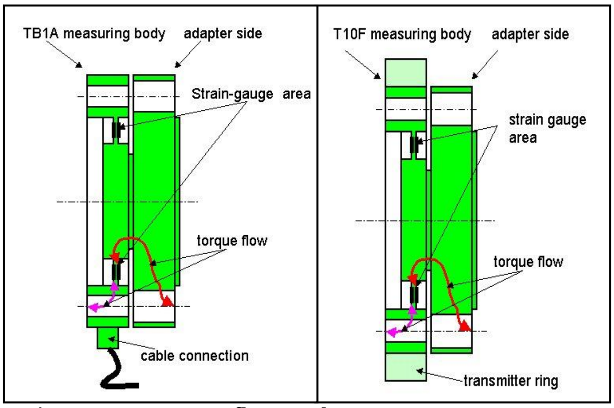


Figure 4A. Torque flow with TB1A
Figure 4B. Torque flow with T10F

More significant changes in sensitivity will result from a modified torque flow. If due to the adaptation of large flanges the torque flow is directed to the outside (figure 5A), it differs significantly from the conditions during the transducer’s adjustment and calibration at the factory, when the torque flow was directed to the inside (figure 5B). Tests with specimens with an extreme occurrence of such a flange design have resulted in sensitivity deviations of up to + 0.3%. Adaptation flanges with a markedly reduced stiffness due to additional bore holes can show similar sensitivity deviations.

Omitting 4 adaptation bolts on one side of the measuring body side results in an asymmetrical torque introduction (only half the measuring body flange is used for torque introduction). The sensitivity change amounted to max. –0.5%. On the T10F's and TB1A's adapter side these extremely deviating conditions resulted in considerably smaller sensitivity changes, as already expected, since the torque introduction and output are located at a markedly greater distance from the area of strain.

In all cases, the repeatability of the change in sensitivity was excellent. Thus, including the adaptation flanges into the calibration is a suitable measure for taking into account modified torque introduction conditions. As a consequence, there are no restrictions at all for usage as reference transducers.

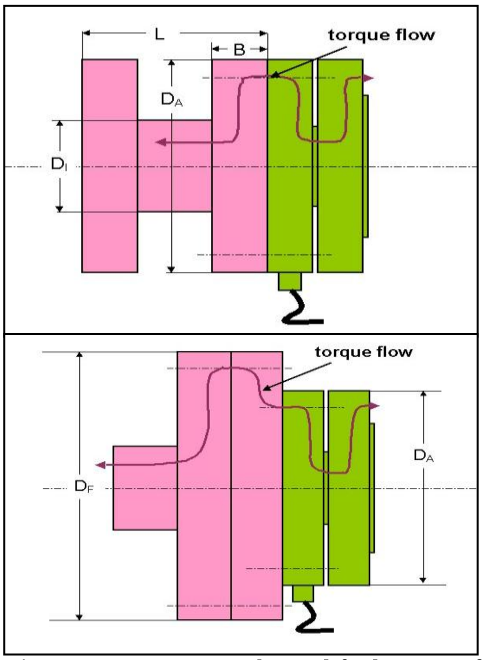


Figure 5A. TB1A with modified torque flow by adaptation to big flange

Figure 5B. TB1A with standard calibration adaptation on the measuring body side

Furthermore, usage as high precision transfer transducer is possible based on the information provided in section 4 and on the below recommendations for test stand adaptation:

- Use of high-strength or hardened components (minimum material strength > 900 N/mm2).
- Use of clean, even and ground adaptation surfaces (evenness < 0.01, roughness Rt < 0.8)
- Observe the wrench torques for bolts (Specifications see Mounting Instructions)
- outside into the torque flange Torque flow from inside (diameter DI) to
- (diameter DA), with the ratio DI/DA < 0.6
- Width of customer adaptation flange (B) approx. factor 1.5 to 2 of flange bolt diameter
- Asymmetrical torque input and output with a minimum distance L of half the diameter DA of the torque introduction point from the torque flange's measuring body side.

5.3. New Measuring Body Principle

The new measuring body principle of the T10FS torque flange for rotating applications and of the TB2 reaction torque transducer provides further advantages over the T10F and TB1A with respect to the transfer characteristics. Due to its design the T10FS and TB2 measuring body is symmetrical as to its torque introduction and output flanges (fig. 6). In addition, the strain gages' areas of strain have greater distances from the adapter sides' flange surfaces. This has a very positive impact on various mounting situations and conditions. Even the extremely critical one-sided asymmetrical bolted connection with half the number of bolts results in sensitivity changes of less than 0.03%. The T10FS/TB2

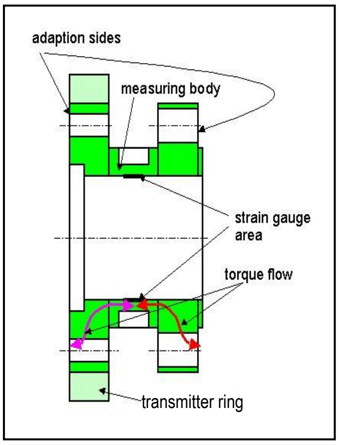


Figure 6. Torque flow in the T10FS/TB2 measuring body

measuring body design proved very insensitive to the above mentioned adaptation effects and suits torque transfer measurements very well. However, to optimally minimize measurement uncertainties we recommend to take into consideration the adaptation requirements for TB1A and T10F specified in sections 5.1 and 5.2 also for this new type.

6. Conclusion

This paper describes up-to-date procedures for transferring the measurand torque into power test stand applications with torque transducers.

A number of influence factors and their reasons have been considered which affect the assessment of measurement uncertainties when torque transducers are used. Especially for the use of torque flanges, results have been presented in order to support the user in assessing measurement uncertainties.

Recommendations on how to avoid or minimize these influences have been provided to enhance comparability, especially with respect to the sensitivity and the measuring characteristics. In addition, a new design principle has been introduced which offers reduced sensitivity to the described influences.

At present, there is no national or international standard or guideline for the transfer of the measurand torque including the determination of the measurement uncertainty in power test stands.

Firstly, this standard or guideline should describe static, quasi-static and continuous calibration methods for the non-rotating state in the power test stand and, in addition, permit a universal consideration of the measurement uncertainty. Secondly and in the long run, the transfer and the determination of the measurement uncertainty should also be standardized for the rotating dynamic case which is more common in practical applications.

7. References

[1]. DIN 51309, *Calibration of static torque measuring devices*, Deutsches Institut für Normung e.V. 1998.

[2]. EA guidelines 10-14; *EA guidelines on the calibration of static torque measuring devices*, European co-operation for accreditation, July 2000 – rev.00

[3]. *EN ISO 7500-1 , Verification of static uniaxial testing machines – part 1 testing/compression testing machines,* Deutsches Institut für Normung e.V., 1998

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