High Precision Torque Measurement Systems in Engine Test Benches

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1 Introduction

The demand for drive concepts to develop economical vehicles that meet environmental guidelines always involves increasing requirements on test equipment. Highly dynamic, high-resolution torque measurements in the shaft train are essential for designing and optimizing engine, transmission and chassis.

Reproducibility is very good with modern, strain gage-based torque transducers. The overall accuracy of the torque measuring system is basically determined by mechanical disturbance variables and by thermal and humidity effects that have not been compensated for. Carrier frequency amplifiers are used in rotating measurement flanges to minimize the effects of thermal voltages and low-frequency drifts in operational amplifiers. Digital signal processing enables torque transducers to be flexibly configured and adapted to meet the requirements of the test stand.

2 Applications

2.1 Torque measurement technology in power test stands

Test stands play an important role in the development of engines, powertrain components and brakes. Requirements on power test stands are continually on the increase and are becoming ever more complex. In particular, increasing mechanical performance, enhancing efficiency, protecting energy resources, reducing environmental pollution are becoming increasingly important. Modern test technology helps to reduce development times irrespective of ever more complex concepts and requirements. The more stringent these demands, the more important becomes adequate test equipment.

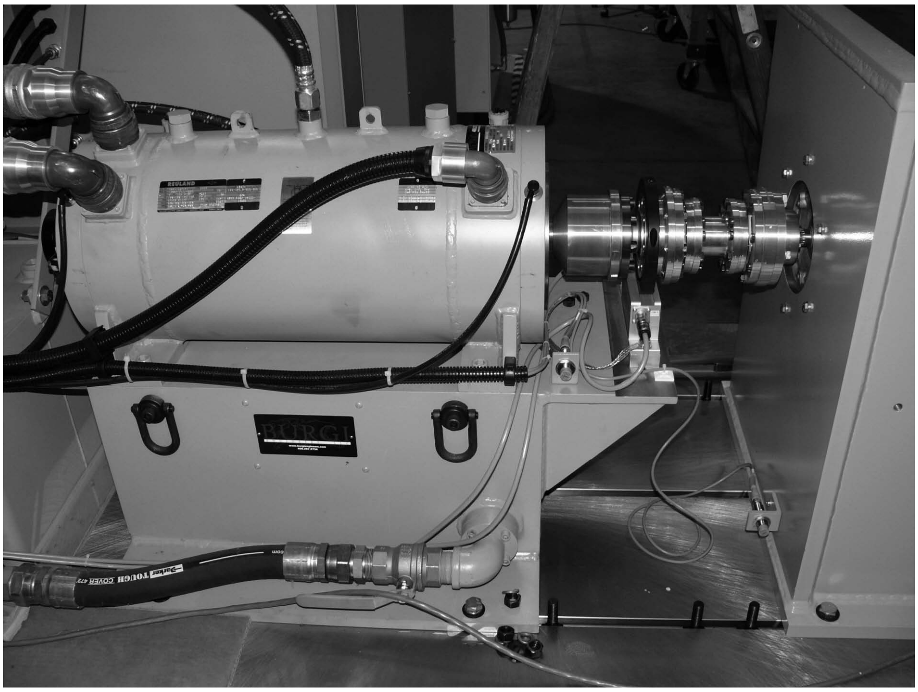

Fig. 1: Engine test stand with T40 torque transducer (Anderson)

Torque transducers in power test stands stand out because of the following features [1]:

- Precision
- EMC
- High dynamics
- High torsional stiffness
- Reliability
- Ruggedness
- Compact design.

2.2 Torque measurement technology in production monitoring

In production monitoring, test equipment is directly integrated into manufacturing systems or production processes. Typical applications include determination of viscosity by measurement of torque or monitoring of screwing processes by measurement of torque/angle of rotation. In addition, there are many special applications, for example the production of inhalers or torque control in steel rolling mills. Measurements when screwing together filled products are closely related. With medicine, for example, torque measurement ensures optimal sealing of the bottles thus preventing deterioration of the product. Ultimately, health risks are thus minimized.

In component and functional testing, test stands bring about cost savings through simulation under real conditions without the need for expensive practical tests. Using component and functionality test stands has thus become virtually indispensable in modern production. Specialized test stands are used, for example, at the end of production lines in the production of drive trains, transmissions, power dividers and shafts for testing correct assembly and the quality of components.

2.3 Torque technology for calibration tasks

Measurement technology for use with calibration tasks has to meet particularly high requirements with regard to accuracy and stability. This requires that the measuring chain into which the torque transducer is integrated has an accuracy class of 0.03 or better (according to the strict HBM definition). For this reason, special, non-rotating types with particularly high precision are often used in these cases [2].

In the torque calibration laboratory, they are either integrated as reference transducers in a calibration system or used as transfer standards for receiving the reference torque from a superior laboratory. They are used as reference transducers for on-site calibration and enable new calibration concepts to be implemented that no longer require using lever arms and weights. A particularly important field is the calibration of rotating torque transducers in test stands. In transmission test stands, the dynamometers of two opposite wheels can be coupled via a reference transducer and these two machines can be used to apply torque for calibration at rotational speed 'zero'.

The main characteristics of transducers for calibration tasks are:

- High accuracy class
- Excellent reproducibility
- very good stability

3 Torque transducer layout

In general, transducers with an accuracy class of 0.03 are used as transfer standards for calibration tasks. These are measuring bodies working according to the radial or axial shear principle that are mapping the torque as a change in resistance in a resistive strain gage measuring bridge. The strain gages are arranged in a bridge circuit such that the temperature effects on the zero signal and on the nominal (rated) signal are passively compensated for. The influences of parasitic loads such as bending moments or axial forces are compensated for as well. During reference measurements, the signal of these passive transducers is evaluated using a stationary carrier-frequency amplifier, with the signal bandwidth usually being restricted to less than 1 Hz.

Measurements in a rotating shaft train absolutely require contactless power and signal transmission. These active transducers have primary electronics integrated in the rotor for conditioning of the measurement signal of the strain gage bridge and transfer to the fixed part, the stator. Typically, DC amplifiers which are noted for their low power demand and small size are used in the rotor. The newly developed T12 torque flange enabled carrier frequency amplifiers to be used in rotating applications for the first time. The effects of thermal voltages and low-frequency noise on the measurement signal could thus be efficiently eliminated. Optimization of the temperature effect on the measurement signal by the high level of symmetry of the measuring bridge is complemented with digital compensation of remaining temperature effects. Digital signal conditioning and transmission enable the current high accuracy of non-rotational torque transducers to be achieved in a rotating shaft train as well. These transducers are designed as measurement systems acquiring torque and, in addition, angle of rotation, rotational speed and the temperature of the measurement shaft. Prior to signal filtering, this information is used for computing the mechanical power transmitted by the transducer. In addition, all measurement signals can be routed to analog and digital outputs as desired. However, using a carrier frequency amplifier in the rotor results in reduced signal bandwidth. For this reason, DC amplifiers are still being used for highly dynamic measurements.

Consistently minimizing the sources of interference enabled a product tailored to test stand applications such as the T40 torque flange to be developed. The concept involves distinction between the fully functional measurement flange for standalone operation and the digital signal processing unit providing high flexibility. The test stand operator can now use the external signal processing unit for filtering, scaling and integrating the measurement signal through analog outputs or bus interfaces into the measurement task as required, with the signal properties directly at the measurement flange not being affected and available for test stand control.

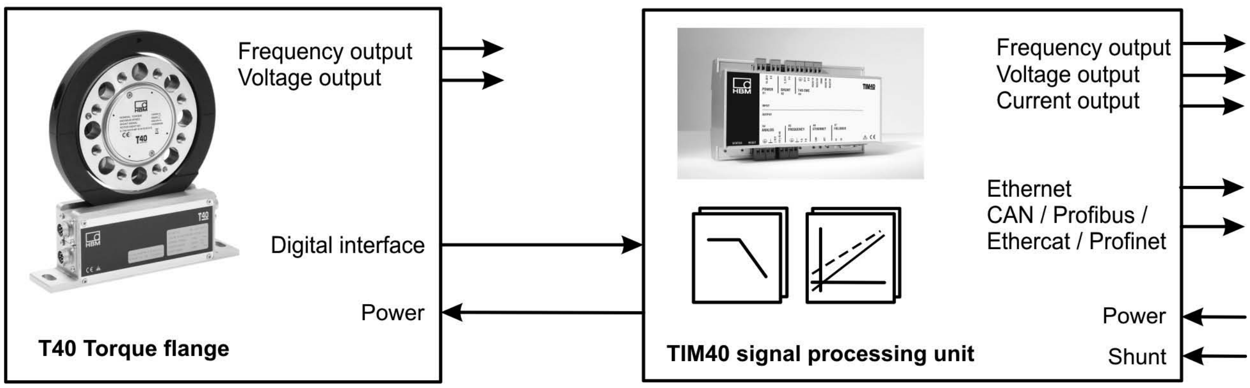

Fig. 2: T40 – TIM 40 System

The rugged rotor design involving a transmitter coil integrated in the flange together with the reduction of the wiring effort to a single pcb increases reliability and reduces down time. The permissible vibrational stress could be substantially increased so that during the tests acceleration of over 35 g in the frequency range of up to 2 kHz did not result in any failures.

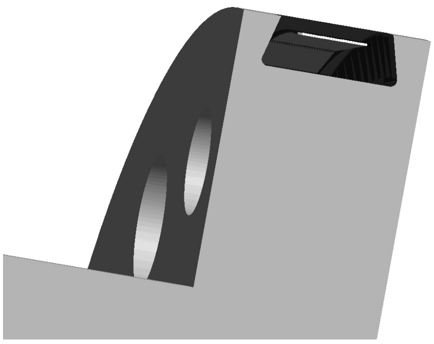

Fig. 3: Dovetail guide rotor design

The new T40 / TIM40 torque measurement system has been tested very successful by our beta test customers. At the moment we are in the product launch phase. For this reason the following application examples are related to the high accuracy torque flange T12.

4 Practical technological benefits

Maximum accuracy in combination with high permissible dynamics and diagnosis features ensures the user's competitive edge. The vast measurement frequency range enables highly-dynamic test stands and measurements to be implemented. The approach involves a resolution that goes up to the physical limits of strain gage technology, there is no need to switch measuring ranges. Internal aliasing is prevented by the high sampling rate. CAN parameterization in combination with the T12 Assistant that is available in addition (fig. 4 shows some options) ensures ease of service and use. Two TEDS (Transducer Electronic Data Sheet) including different templates are available to users who want to use other amplifier systems in addition to the fieldbus interfaces, for example because of the dynamics of torque measurement or RS422 signals requiring direct analysis. Integrated TEDS devices supply the measuring amplifier with all the important characteristic transducer data. The TEDS amplifier converts the characteristic transducer data and automatically makes the correct parameter settings [3].

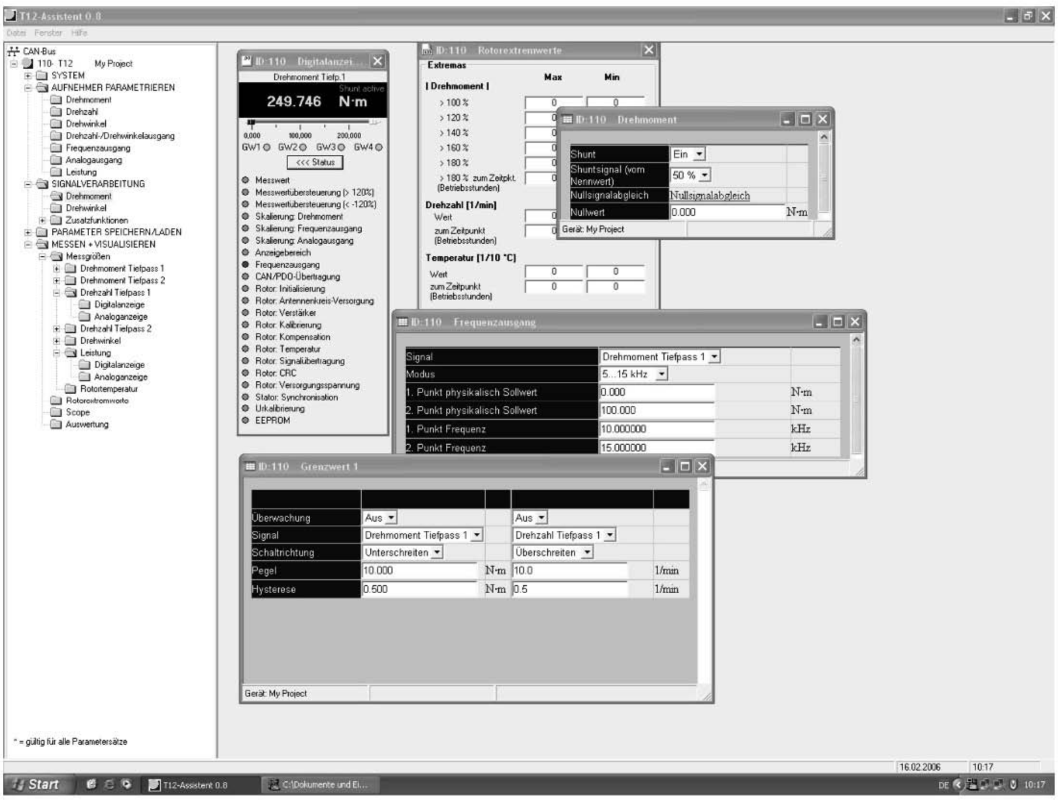

Fig. 4: Display options of T12 Assistant Software.

5 Selected example applications

Firstly, target applications include highly-dynamic measurements on performance, functionality and optimization test stands, for example for transmissions, and, secondly, a level of accuracy resulting from technology that has never been achieved before. The following characteristics apply, for example, to the torque signal on the fieldbuses:

- Linearity error including hysteresis < ±0.02 %, optional < ±0.01 %
- Rel. standard deviation of reproducibility < ±0.01 %

- Influence of temperature on sensitivity < ±0.03 % / 10 K
- Influence of temperature on zero < ±0.02 % / 10 K, optional < ±0.01 % / 10 K

Users expect their investment to be secure over the coming decades, especially where engine, transmission and roll test stands are concerned. This is where to use HBM's T12 digital torque transducer. It acquires both the important measurand of torque as well as rotational speed and computes the mechanical output power with high dynamics. It is also possible to measure angle of rotation and temperature. The complete measurement signal conditioning is integrated in the transducer. This greatly increases the quality of the signal and achieves the best uncertainty worldwide.

Its compact design saves space and thus costs in test stand construction. Because the rotor weighs less, the load on the bearings is reduced and the lower mass moments of inertia result in smaller dynamic moments during acceleration and braking. This can be seen, for example, in a four-wheel-drive transmission test stand made by Horiba (Figure 5).

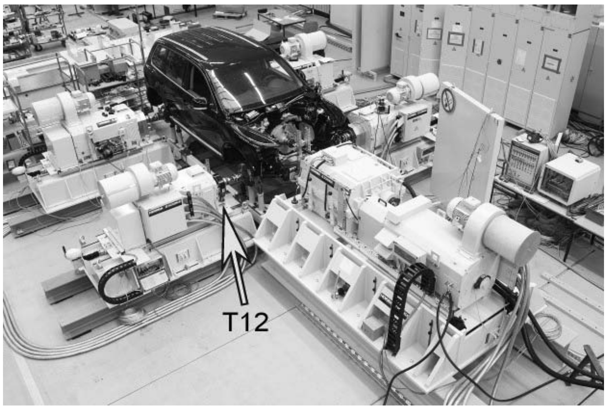

Fig. 5: 4WD driveline test stand (source: Horiba)

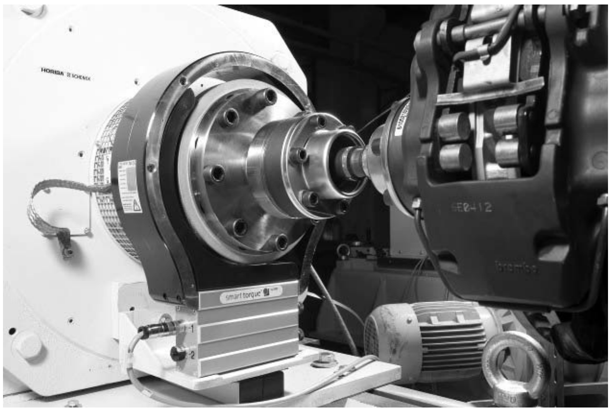

Fig. 6: T12 / 5 kN·m in 4WD driveline test stand (Horiba)

This test stand [4] is used in the development and testing of 4-wheel drives. The test stand has a base area of about 8 * 8 m and enables many different simulations, e.g. cornering ability to be made. A fueled combustion engine can be used, but more importantly, the engine can be simulated by an electrical machine with torque transducer. This achieves a considerable cost reduction, as supply logistics are not required and helps preserve the environment as there are no exhaust emissions. Figure 6 shows a detailed view.

Figure 7 shows the T12 digital torque transducer integrated in a brake for engine test stands. In this case, torque is used as both a pure measurement quantity and, even more important, as a control variable for many different operating modes.

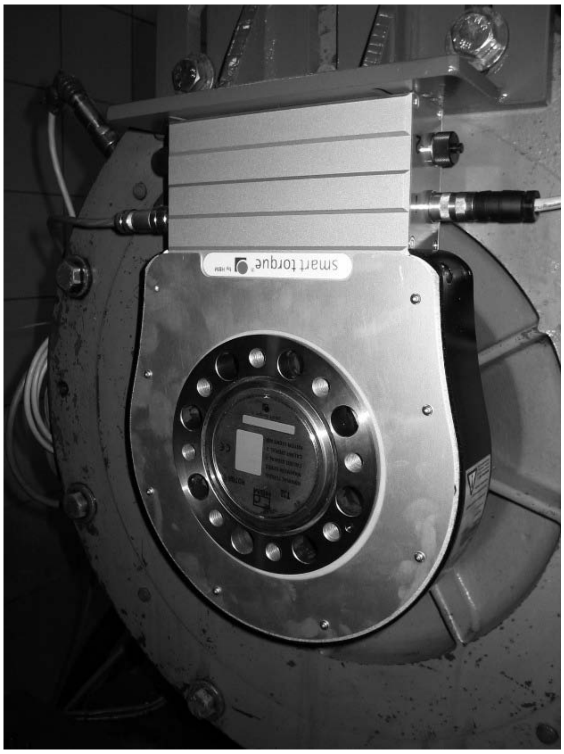

Fig. 7: T12 / 2 kN·m nominal (rated) torque with protection against contact on a brake for an engine test stand (source: APL Automobil-Prüftechnik Landau GmbH)

6 Conclusions

T12 and T40 digital torque transducers enabled the step from the transducer to the complete measurement system to be taken. This requires that all those involved rethink, because measurement quantities are now determined and output as physical values. T12 combines a measuring body that has been optimized for years and the advantages of carrier frequency technology and fast digital signal conversion and analysis. It has the following outstanding attributes: maximum accuracy, higher measurement frequency range with simultaneously high resolution, digital measurement signal conditioning and self-diagnosis. T40 has been developed from scratch and provides increased ruggedness at lower cost.

References

[1] Schicker, R.; Wegener G.: Drehmoment richtig messen (Measuring Torque Correctly", ISBN 3-00-009015-0 Herausgeber Hottinger Baldwin Messtechnik GmbH, Darmstadt, 2002.

[2] Rainer Schicker: Drehmoment-Messflansch nach dem Prinzip der Scherkraftmessung am Doppel-T-Profil; Sensoren, Aufnehmer und Systeme 2000 by b-Quadrat Verlag, 86916 Kaufering, 2000.

[3] Kuhn, S; Schicker, R.: Ein hochpräzises Drehmomentmesssystem durch Trägerfrequenz-Messverstärker und Digitaltechnik, tm-Technisches Messen 75 (2008) 2, S.91, Oldenbourg Wissenschaftsverlag, München 2008.

[4] HOTline 1/2007, Herausgeber HBM, www.hbm.com, Darmstadt, 2007