A gearbox test-bed with HeavyDuty rotary encoders for high-precision dynamic speed control

Hard at work

Robust rotary encoders in action on gearbox test-beds

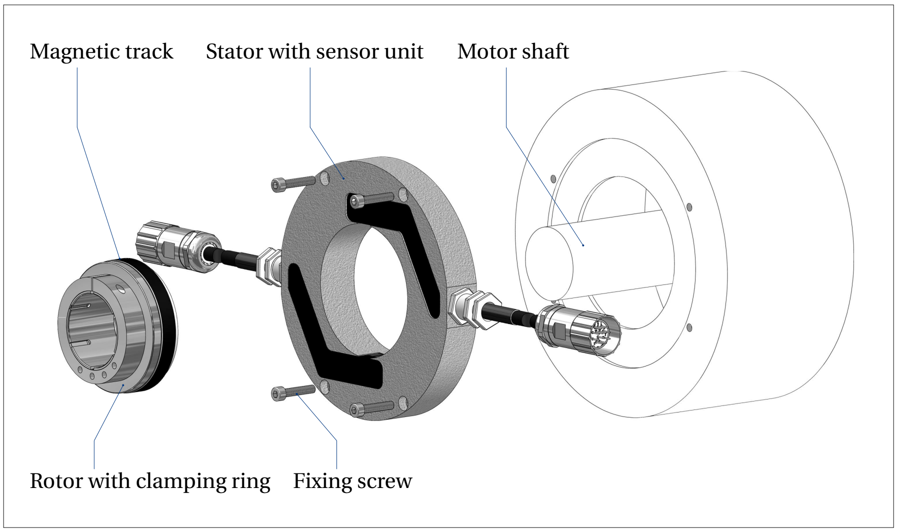
Ralf Schenk, Bernhard Hiller

Vehicle components are subjected to rigorous durability tests before they are approved for series production. If they are components which are involved in the drive train, then the tests are especially hard. The test-beds which are specially designed for this purpose have to be appropriately dimensioned and fitted with sensors that are both tough and precise. The following describes the advantages which are offered for users by a new type of magnetic encoder that is, for instance, being used on gearbox test-beds.

In the early days of test engineering it was usual to test the durability of individual vehicle components by applying a purely synthetic generated load profile. Synthetic, in this connection, means that the object under test was subjected to a load profile that was generated purely in the testing laboratory, whereby one knew that the profile only provided a rough approximation to the loading experienced in real operation, but could at least obtain an approximate value for the expected operating life of the components. And design weaknesses could also be revealed at an early stage. Continual progress in the field of control and measurement technology have now made it possible to subject vehicle components to load profiles that create an almost exact simulation of forces and accelerations previously measured at the points where they occur. So today's test profiles for the application of force and torque are no longer synthetically generated, but rather a test-bed application of loads that have been established on the road through adaptive control techniques. Putting it another way: the real-life stresses produced on the road can now be just about perfectly simulated in the test laboratory.

In order to achieve this, the measurement data undergo a wear & tear analysis before they are used as setpoint values for the test-bed controller, and are edited in such a way that the wear & tear effects are compressed and the various loading stress situations are fairly represented. For testing a shock-absorber, for instance, this could mean that the extreme stresses measured for the comparatively rare event of driving over a pothole on the road would be repeated every 10 meters in the simulation on the test-bed. In this way, an appropriately composed long-term test in the testing laboratory can make an exact simulation under precisely reproducible

The authors:
Ralf Schenk is Director of Marketing, Bernhard Hiller is Director of Research & Development at the Baumer Hübner GmbH, Berlin, Germany



1: The magnetic encoder consists of a stator and a rotor that uses a clamping ring for a fixed mounting on the drive shaft

conditions, and in a much shorter time, of the condition that the shock-absorber would have reached after, for example, 200,000 kilometers on the road. For testing a gearbox, this means that the highly varied load situations affecting the drive chain must all be equally simulated: forwards drive with the maximum permitted speed, full braking with an extreme deceleration, driving in reverse at a low speed, but with a high torque - a very great stress on the gearbox, such as would be caused by driving over a roadside kerb while parking backwards.

Wide and adjustable range of measurement

Standard incremental encoders reach their limits when it is necessary to provide reliable measurement over such a wide speed range. On the one hand, the incremental encoder must have an extremely high resolution, in order to generate enough increments per time unit to be able to acquire the speed/velocity information at very low speeds. On the other hand, the output signal from such a high-resolution incremental encoder would become unusable at high speeds. The output signal would have such a high frequency that it could no longer be transmitted reliably over the cables as a square-wave signal and evaluated. And we have not yet taken into account that in typical HeavyDuty applications it is unavoidable that signal and measurement cables have to be routed through an environment full of EMC problems – for instance, close to cables that are carrying large pulsed motor currents. This places further restrictions on the tolerance limits for the maximum square-wave frequency that can be transmitted without errors. Quite apart from the problem of signal transmission, normal types of inverter are restricted in the frequency range of the input signals that they can handle.

But Baumer Hübner is going down a new path with its robust magnetic encoders. Here, sin/cos signals are generated by a magnetic sensing method and then treated by complex programmable signal processing and evaluation electronics so that they can be optimally adapted to the requirements of the measurement task. For the speed control of the gearbox test-bed, this means that the very lowest speeds (such as for the "parking" sequence) are measured just as reliably and precise as during the "motorway journey" sequence, where the synchronous or asynchronous motors simulating the vehicle drive rotate at up to 10,000 rpm. The new encoders have a rotor with a hollow shaft that is mounted directly on the drive shaft, and has a track on the outside that is fitted with a magnetic scale. The rotor is fixed to the drive shaft by a clamping ring (**Fig. 1**). Two sensing heads, which are completely embedded in the stator, detect the magnetic field of the rotor and generate the sin/cos signals. Since the two sensing heads are arranged at 180° to one another, they not only provide redundancy for the signal detection, but also make it possible to detect and compensate for measurement errors that are caused by roundness deviations. Although the basic sin/cos signal principle has a lower achievable resolution than that obtainable from comparable optical encoders, the sin/cos signals have the decisive advantage of excellent harmonic quality. This is the feature that makes it possible to achieve very high number of counts by turn by applying a subsequent interpolation.

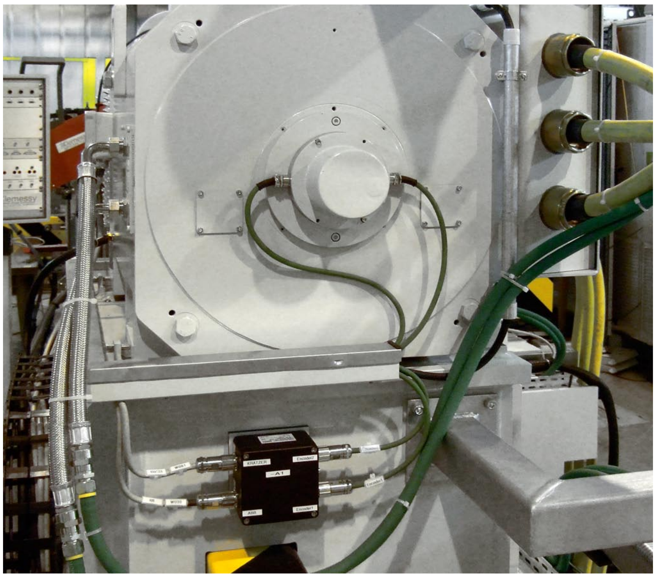
Extremely high vibration and shock resistance

In the case of the gearbox test-bed, the sensing heads are passive, i.e. the magneto-resistive (MR) sensors are supplied from a close (but separate) box that contains the signal processing electronics (**Fig. 2**). Depending on the application, however, it would also be conceivable to integrate the electronics into the sensing head. Each one of the three components – rotor, stator and the signal processing box (detached or otherwise) – has a high level of enclosure protection and stands up to very high levels of shock and vibration. Please bear in mind that the highly dynamic synchronous or asynchronous motors which are built into the gearbox test-bed accelerate the drive chain at a rate of over 50,000 rpm per second. At such acceleration rates, a speed measurement is anyway only possible with a completely torsion-free mounting of the encoder, as implemented here, and conventional coupled rotors or stators would be unsuitable.

Complex signal processing electronics

The signal processing electronics senses the sin/cos signals at up to 30 MHz, digitizes the signals, and then applies a preliminary digital filtering to them. The use

2: Redundant magnetic sensing in the encoder, signal conditioning via an external signal processing box



3: Rotary encoder with protective cladding (against bodily contact), on the drive motor of the test-bed

of offset and amplitude control methods, as well as a following oversampling filter, means that high signal quality can be achieved at the output, even when the input signals are noisy or have interference peaks. The resulting signal is available as a TTL, HTL, or regenerated sin/cos signal, depending on the application requirements. So it is possible to make a multiple evaluation of the actual speed signal, whereby the interpolation factors can be selected independently for each output. These factors may be chosen as division or multiplication factors, i.e. the pulse period of the output signal can be correspondingly lengthened or shortened in comparison with the period of the input signals. Non-binary intermediate values can also be achieved. All this allows just about any adaptation of the measurement signal to the following control and evaluation electronics.

Frequency-modulated output signal

The signal processing electronics that is used in the gearbox test-bed, for instance, goes even a step further. While the inverter which controls the motor that is used to achieve a specific output torque value uses an HTL signal, the speed control is not made through the usual TTL signal, but by a frequency-modulated signal. The signal for the extremely wide speed range of 10,000 rpm is converted into a high-frequency signal in the range from 25 kHz to 175 kHz. Very low speeds in particular are thus precisely detectable as clearly defined frequencies, including zero speed as a frequency of 100 kHz, which occurs when the system changes direction. The speed information is available not only as a very precise value, but also with practically no delay – something which could not be achieved using the classic square-wave pulse evaluation. To achieve this, the signal processing electronics includes not only the features already described, but also additional frequency synthesis algorithms that allow a time quantization of 7 nanoseconds!

Various state variables can be acquired

Not only the speed has to be measured as a state variable, but frequently also the angular position and acceleration, especially for highly dynamic test-beds. This is possible with the signal processing electronics from Baumer Hübner as well. The measured variables can furthermore be transmitted digitally, either via an easily implemented SSI interface, or via an Ethernet-based real-time interface, such as EtherCAT. Profibus and CANopen connections are also available if required and, in addition, status and error messages can be transmitted as required via the interfaces or specially assigned outputs. Summarizing, one can see that the combination of magnetic sensing and complex signal evaluation makes it possible for the new magnetic encoders to simultaneously fulfill several requirements that, up to now, technically contradicted one another, and, furthermore, the encoders can easily be adapted to the requirements of the specific measurement task.

Features of the magnetic absolute encoders at a glance:

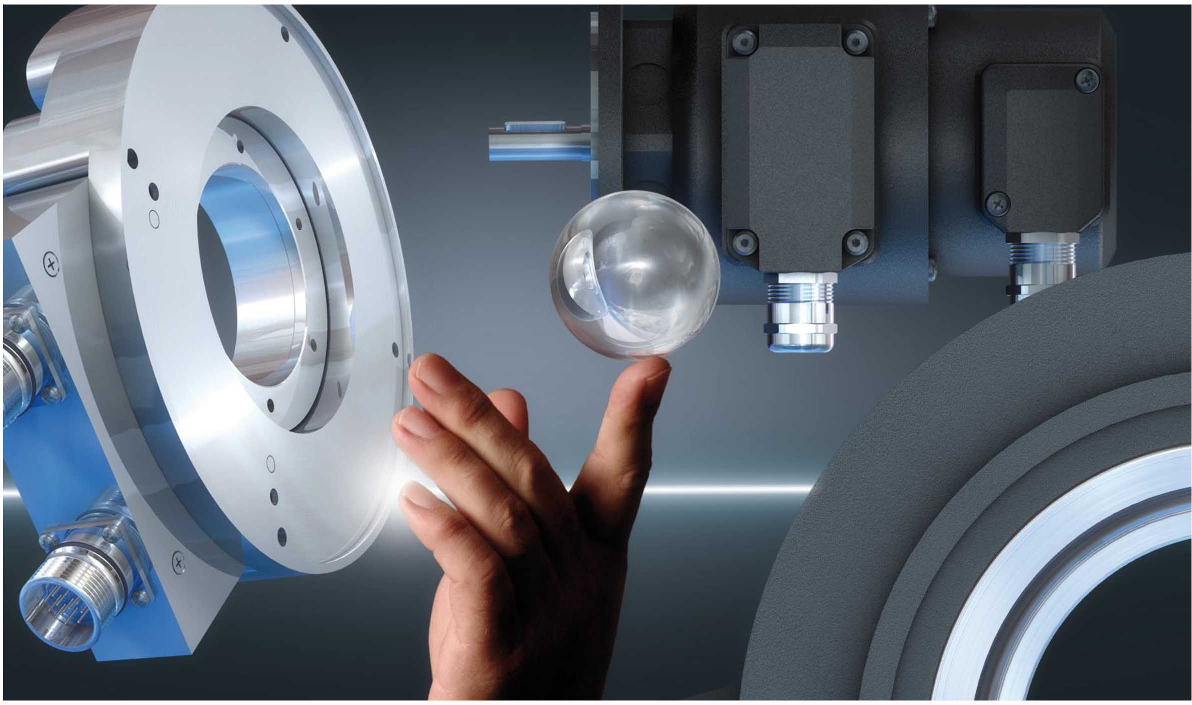
- very robust and free from wear, as they have no bearings and the electronics is completely embedded in the sensor head
- extremely high vibration and shock resistance
- wide operating temperature range
- insensitive to dirt, and with a high level of enclosure protection
- very compact dimensions, very short axial fitting length
- large permissible axial displacement
- suitable for very large shaft diameters
- simple, fast installation, easy adaptation to existing fittings
- signal processing can be individually adapted to the measurement task, multiple evaluation is possible
- precise, high-resolution acquisition of speed over a very wide and adjustable range of measurement

Expanded reprint from
antriebstechnik 9/2007

Baumer Hübner GmbH
Postfach 61 02 71 · D-10924 Berlin
Planufer 92 b · D-10967 Berlin
Germany

HeavyDuty Sensors for Drive Technology

Motion Control



Baumer Hübner's domain is where movement is controlled. Sensors which are intrinsically designed for extreme industrial applications show their benefits particulary in rugged operation, such as extreme ambient conditions. Baumer Hübner Components for drive technology have contributed greatly to the quality and reliability of machines and heavy equipment – worldwide and over many decades. Let's talk about *your* drive task.

2006 Absolute Encoders without gearbox and without battery, Programmable Digital Speed Switches

2005 Analyzer for Encoders

2004 Precision Interpolators

2002 Magnetic Encoders with hollow shaft up to Ø 690 mm

2001 Absolute Encoders in HeavyDuty Technology

1998 Ferraris Acceleration Sensors: linear/rotary in patented technology

1995 Sine Encoders: Sine signals with an especially low harmonic content – the standard for precision

1989 Explosion Proof Devices: Labelled »II 2 G EEx de IIC T6 resp. T5« (ATEX 95)

1982 Combinations: Incremental Encoders, Tachogenerators and/or Speed Switches in one single housing with common shaft

1978 Incremental Encoders in HeavyDuty Technology: rugged electrical and mechanical construction

1970 Speed Switches: mechanical (centrifugal) or electronic with internal or external power supply

1955 Tachogenerators: Their rugged construction provides the foundation for HeavyDuty Technology

1934 Foundation of the company in Berlin

BaumerHübner

Baumer Hübner GmbH · Planufer 92 b, D-10967 Berlin, Germany · P.O. Box 61 02 71, D-10924 Berlin
Phone +49 (0)30/69003-0 · Fax +49 (0)30/69003-104 · info@baumerhuebner.com · www.baumerhuebner.com