Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Evolution and Future of Torque Measurement Technology

Dr. W. Krimmel
Lorenz Measurement Technology GmbH
Obere Schlossstr. 131
73553 Alfdorf, Germany
Tel.: +49-7172-93730-0, e-mail: info@lorenz-sensors.com

Received: 2 March 2006 Accepted: 22 March 2006 Published: 27 March 2006

Abstract

The journey to the past of torque measurement technology begins in the 17th century. It takes us from the first incipiencies of torque measurement to the problem of the transfer of the measurement signal from a rotating shaft, which existed for several decades. This task was solved by the integration of high-precise digital measuring amplifiers in the torque sensors, which is expressed by broad application fields, today. The future will appertain to highly dynamic measuring sensors as well as to intelligent torque sensors, which are able to transmit their sensor-specific characteristics to evaluation devices.

Keywords: torque sensors, torque transducers, torque measurement technology, torque cells

---

1. Strain Gauge (SG) Measurement Technology

The historical evolution of torque measurement technology began in the year 1678. In this year, Robert Hooke described the proportionality between the material extension and the associated material tension in the well-known Hooke's law.

$$\sigma = E \cdot \varepsilon = E \cdot \frac{\Delta l}{l} \tag{1}$$

with E is the elasticity modulus.

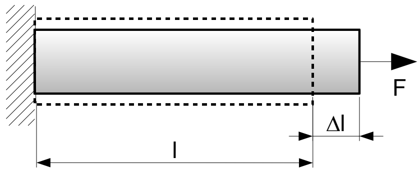

Fig. 1. Tension rod stressed with force F.

For further evolution, only year 1833 has a relevancy again.

The bridge circuit was then described by Hunter-Christie, by which smallest voltage changes can be measured. Nevertheless the switching received the name of the second inventor Wheatstone later, the actual fame belongs to Hunter Christie.

$$\frac{U_M}{U_0} \sim \frac{\Delta R}{R} \tag{2}$$

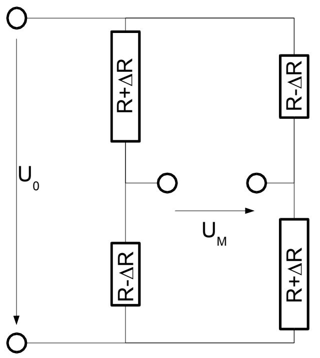

Fig. 2.

In 1856, Thomson, who later was called Lord Kelvin (the temperature scale was named after him), discovered the coherency between mechanical strain ε of a resistance wire and its resistance change.

$$\varepsilon = \frac{\Delta l}{l} \sim \frac{\Delta R}{R} \tag{3}$$

Δl is the longitudinal change of the resistance wire; ΔR is the resistance change of the wire.

Thereafter, experiments with resistance wires were consistently carried out; e.g. in 1917 Nernst experimented with them in order to measure pressure on combustion engines. However, the first model of an easy to apply SG was not available until year 1938. Then, the first SG was developed by Prof. A.C. Ruge. Already three years later, the first industrially produced wire-SG was available on the market and spread very fast. In 1952, the new foil-SG guaranteed the acceptance of industrially manufactured SG-sensors. It was etched by foils, coated with resistance material. Today, SG's are manufactured in the same way. The first foil-SG's for torque measurement were offered in the same year. Therewith, stationary SG-torque sensors were manufactured. These sensors helped to solve many problems in development and experiments by means of reaction momentum measurement. However, measurements in the rotating shaft line are the most important and the most frequent applications for torque sensors. Here, the evolution still lasted some more years in order to be able to offer serviceable SG-torque sensors on the market.

2. First Rotating Torque Sensors

If a shaft is loaded below an axial torque, it twists to an angle, proportional to the torque. This angle can be measured with an angle measuring system. According to this principle, the first rotating torque sensors with inductive measuring systems were already produced and offered on the market in 1945. Carrier frequencies of hundreds of kHz were used to supply the sensors. Therewith, the necessary coil systems were small. The amplitude of the AC voltage- measurement signal was proportional to the rotation angle of the measuring system and had the same frequency as the supply voltage.

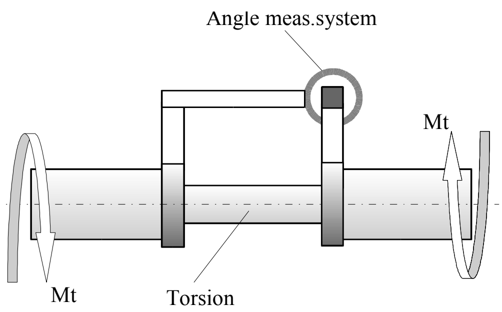

Fig. 3. Principle for an angle-measuring torque sensor.

For the supply of the measuring system arranged on the rotating shaft and for the transfer of the amplitude-modulated measurement signal, rotating transformers were used which were set-up according to the principle of a transformer. A coil of the transformer is attached in the stator, the second coil is ordered concentrically to the first coil on the rotor. If amplitude modulated measurement signals are transmitted via this type of rotating transformer, its coupling factor enters into the result of the measurement directly.

By axial or radial displacements, noncircular courses, changes of the magnetic material characteristics and by magnetic shunts, measurement errors can occur.

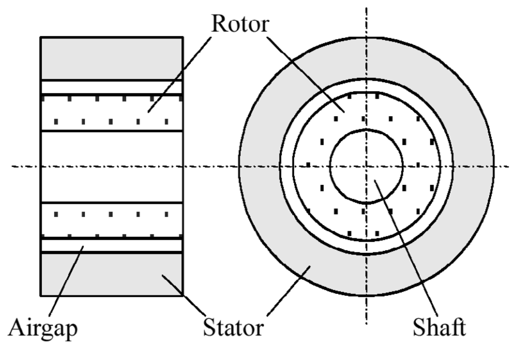

Fig. 4. Principle sketch of a rotating transformer.

The first transfer of the measurement signals of a SG-bridge, which was applied on a rotating shaft was carried out with slip rings in 1952.

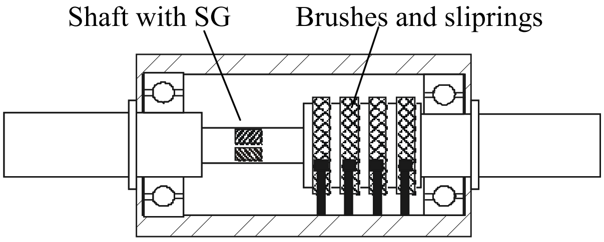

Fig. 5. Sectional view through a slipring sensor.

The transfer of the supply voltage and output voltage through slip rings requires certain wariness. The slip rings must be isolated from the shaft and from each other, even smallest insulation faults can cause considerable measurement errors. The surface pressure of the sliding contacts must be chosen in such a way, that on the one hand a preferably small transition resistance, sufficient safety against lift-off due to vibrations and out-of-roundness of the slip rings is available, but on the other hand that too strong heating and too strong abrasion does not occur. Next to the material selection, thorough processing of the surfaces is arbitrative.

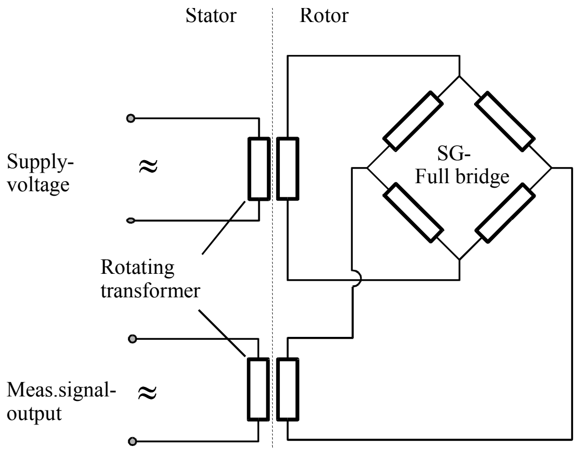

Fig. 6. Block circuit diagram for rotating sensors with AC-supply.

Difficulties are to be expected in particular at high circumferential velocities. Some sensors are equipped with lift-off fixtures for the brushes, which are attached for the measurement only. Disadvantage of this technique: the slip rings and coal brushes wear out and hence need to be renewed.

In order to retain a sensor with stable and maintenance-free signal transmission, a torque sensor was developed which enables slipring-free transfer of the measurement signals of a SG-bridge. Through AC supply of the bridge, an amplitude modulated AC voltage, proportional to the torque is obtained at the output of the bridge. , The AC voltage necessary for supply, the SG bridge and the measurement signal can be transmitted via a rotating transformer.

Therewith the triumphal procession of the rotating torque sensors on SG basis could not be stopped anymore.

In 1971, by electronics becoming invariably smaller, it was possible to integrate an amplifier onto the rotating shaft, which was used for the supply of the SG-bridge and for the processing of the measurement signal. A rotating transformer was used for the supply of the sensor; the second one for the frequency-modulated transfer of the measurement signal.

In the meantime, SG-technology was advanced as well. Today, the sensors are produced temperature-compensated and creep-compensated. The great advantage of SG-technology consists of the fact that the compensation of the disturbance signals can be carried out at the point of measurement directly. The temperature dependence of the elasticity modulus of the used materials e.g. steel is approx. 3% per 100K temperature change. Since this disturbance signal enters into the characteristics of the sensor directly, it must be compensated accordingly.

At angle-measuring sensors a compensation, if at all, is only carried out the in the amplifier, thus a thermal behaviour of the characteristics is always reckoned. Furthermore, angle-measuring sensors have to fight the problem that they require relatively large angles of twist for the measurement of torque, which leads to torsion-supple arrangements, which only allow slow measurement procedures.

By the electronics becoming continuously smaller and hence improved transmission possibilities of the measurement signals, the market has changed to that effect that today many torque sensors are provided with integrated measuring amplifiers.

3. Modern Rotating Torque Sensors

The first torque sensors normally had analog signal outputs. At these interfaces, disturbances by adjacent power modules and drives are possible, especially in case of long feed lines and high dynamics For this reason in the past, the signal level of the sensor was increased; signal levels of ±5V and/or ±10V are usual. However, for many applications the interference immunity is not sufficient. The solution is digital sensor electronics. Its principle mechanical assembly is shown in the following sectional picture.

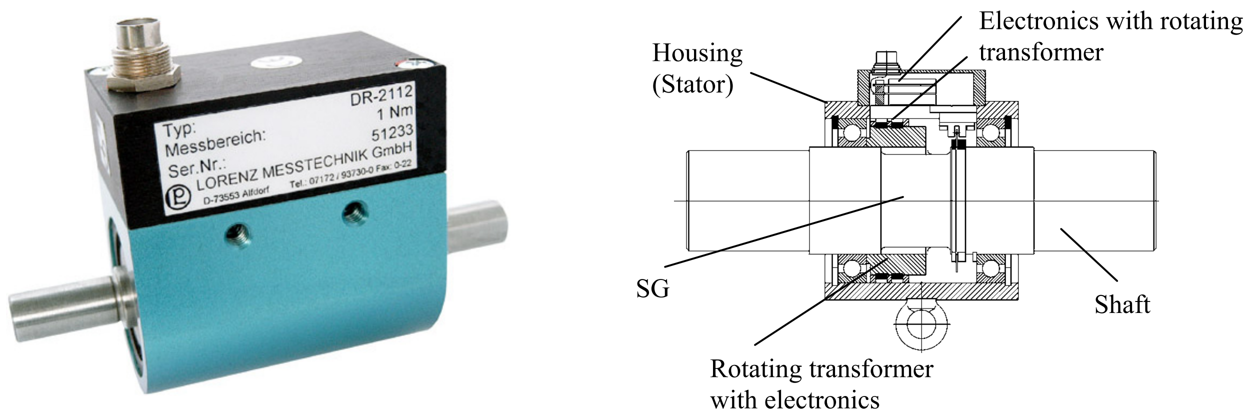

Fig. 7. Modern Torque Sensor with Integrated Electronics.

Located on the shaft is an area, reduced at the diameter, to which the SG-bridge is applied. The rotating part of the rotating transformer and the rotating electronics is attached on the shaft as well. The fixed part of the rotating transformer and additional electronics are located in the housing. For the connection of the sensor, a connector plug is implemented in the housing.

The integrated electronics has a µC, both in the stator and in the rotor with an appropriate memory. The measured value consumption occurs on the rotor by means of SG, the signal is immediately amplified and digitalized there. This digital signal then proceeds into a µC, which prepares it for the transfer to the stator in the form of a serial word with checksum. The data signal gets conditioned in the stator and then converted for a serial RS 485 interface in a µC.

By the use of µC's, data such as serial number, calibration values, measuring range, calibration dates etc. can be stored and read out on demand from the shaft as well as from the stator.

The supply of the sensor takes place by a power supply unit, monitored by the µC, which can switch to a calibration control for the check-up of the sensor as well. A very high reliability of the measuring device is achieved by storing and read-out of the sensor data and the direct digitalization of the measurement signal at the point of origin.

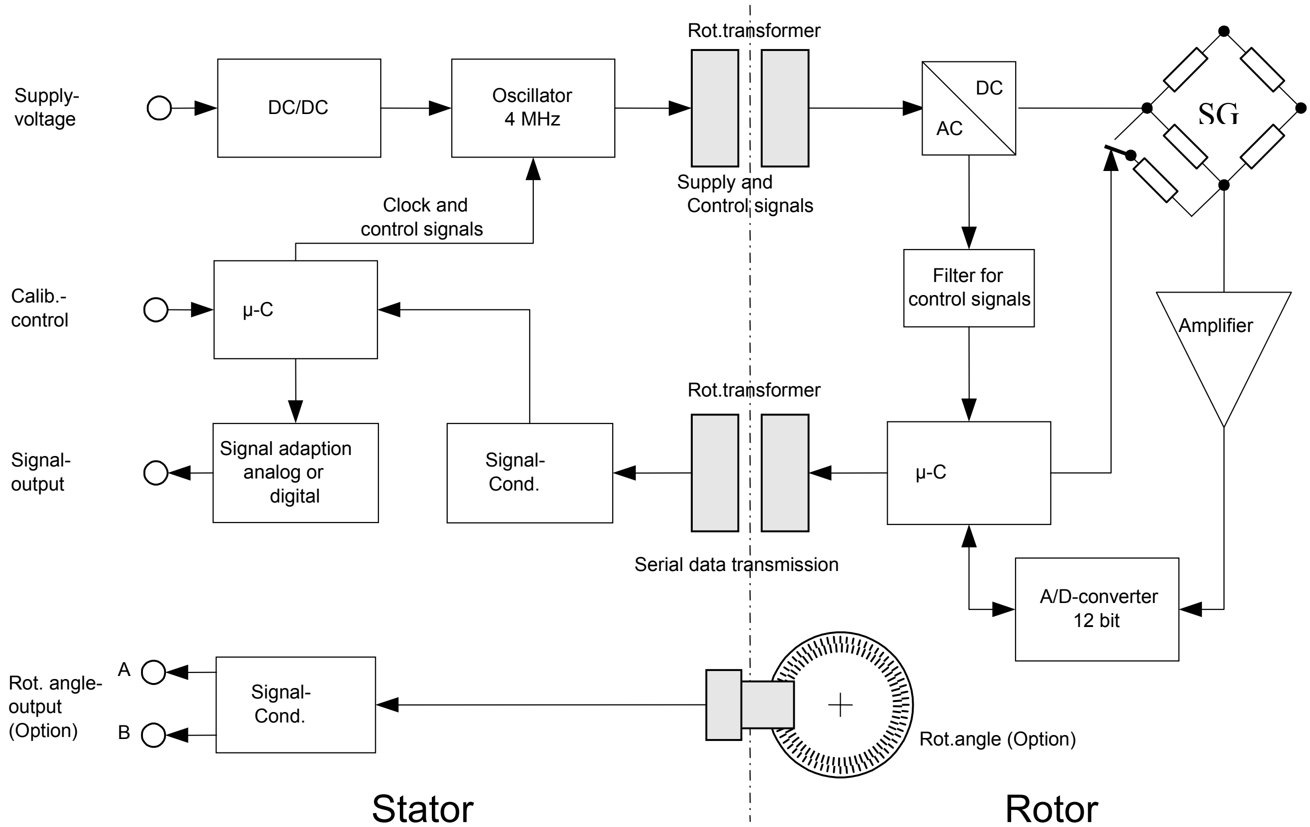

Fig. 8. Block diagram for a digital measurement signal transfer with integrated µC's.

4. Areas of Applications for Torque Sensors

Today we cannot imagine to proceed without torque sensors in many areas. Here is a small extract of areas of applications (fig.9).

As you can see, torque sensors are used in all fields, from training to product design, from production, quality assurance to product monitoring. Even in farming, torque sensors can be found in the machinery. For the traceability verification of measurements, reference torque sensors are used more and more in order to check the production equipment on site, directly.

Application Areas for Torque Sensors - Extract -

Training	Development Testing	Production Quality Assurance Product monitoring	Other Applications
Electric Motor Characteristics Performance Torque **Combustion Engine** Characteristics Performance Torque	**Test Stands** Roller test stand Electric motors Combustion engines Transmissions Generators Fans Pumps **Measuring Systems** Torque sensors in sundry measuring configurations Sliding roof Window lifter **Rheology** Rheometer **Torque sensors integrated in automobiles**	**Control, Regulation** Tightening torque of screw caps **Calibration** Bearing preload Spring preload Axial displacement **Screw Technique** Tightening torque Unscrewing torque **Performance Test** Crank torque Generator Pump Compressor Fan Conveyor belt Electric motors Combustion engines Bearing friction Shrink fit Sealings (friction) **Rheology** Rheometer **Test Stands for Endurance Tests** Hand tools Household appliances Automobile Combustion engines	**Wind Power Plants** Performance Torque **Derrick** Torque in bore rods **Actuators** Locking characteristics of valves **Farming** Torque controlled machines **Ships** Ship shafts

Fig. 9. Areas of Applications for Torque Sensors.

4.1 Case of Application Motor Test Stand

For engines and driven hand tool applications, a torque sensor and a load unit are required. The average performance data in the continuous operation is acquired there. These data provide information about the correct function of the components, e.g. homogeneity of the magnetic rotor fields in the electric motor. However, information about controlling characteristics of the drive can also be determined by dynamic load.

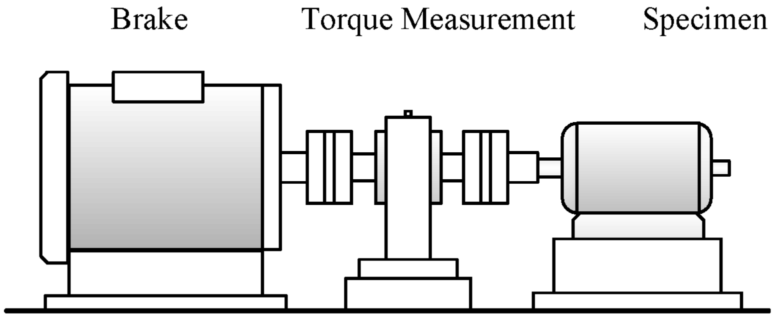

Fig. 10. Basic Set-Up for a Motor Test Stand.

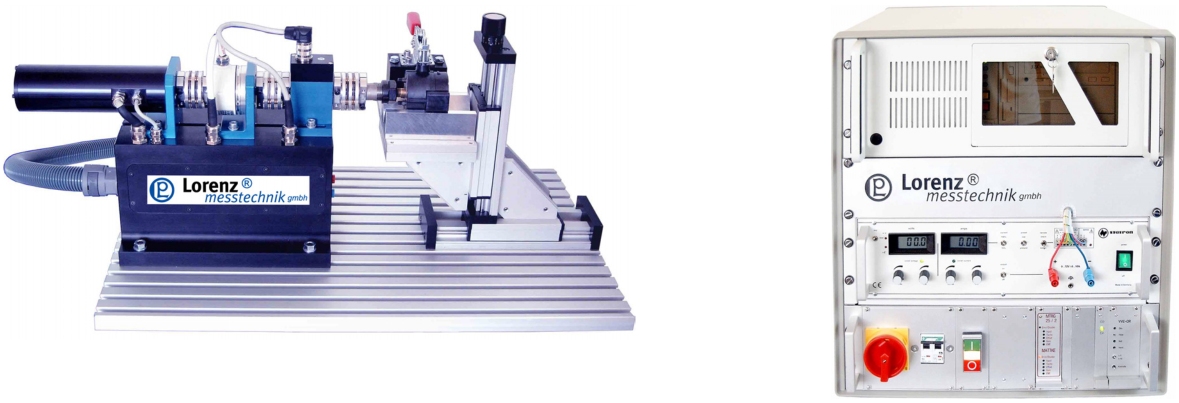

Fig. 11. Test Stand for Electric Motors.

4.2 Case of Application for Test Stand Combustion Engine

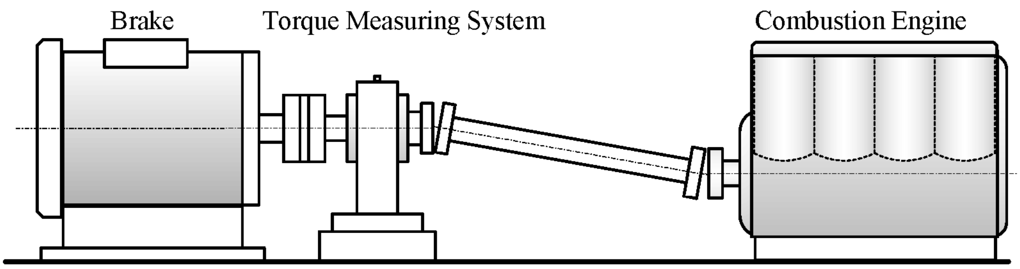

Fig. 12. Case of Application for Test Stand Combustion Engine.

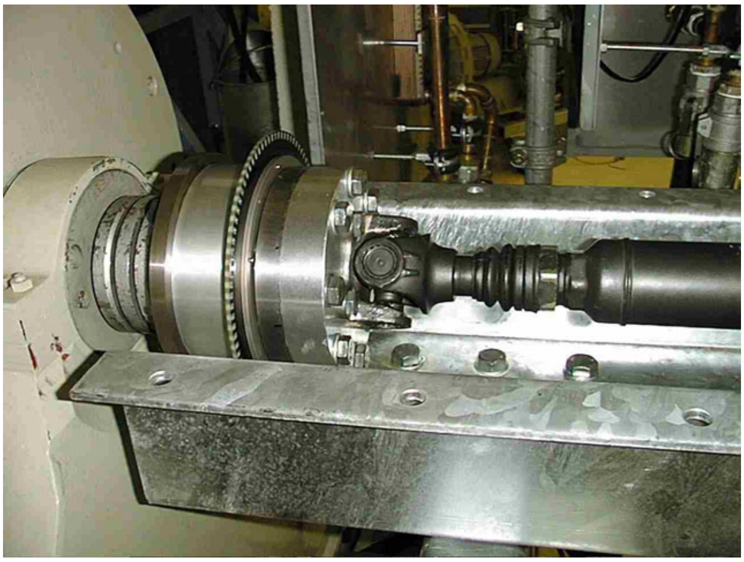

Fig. 13. Torque Sensor with Coupled Joint Shaft.

Here the sensor is coupled to the brake directly. The coupling of the combustion engine occurs via a joint shaft. By this, the alignment of the specimen is considerably simplified. Furthermore, the oscillations of the engine are not transmitted onto the sensor as strong. As you can see, there is a burst protection and a protection against contact positioned around the sensor and the joint shaft in order to assure sufficient protection from contingently detaching parts.

5. Future of Torque Sensors

The SG technique will be the primary solution for torque sensors in the future. By the electronics becoming smaller and electrically more stable, the sensors can be designed for higher spring rates, which leads to improved dynamics of the measurement. The continuous progress in the amplifier technique allows to boost smallest measurement signals exactly and nearly error-free.

The improved measurement signal conditioning can be used for a higher accuracy of the testing equipment layout as well.

The future also belongs to intelligent sensors with stored metrological data, whereby the measurements become increasingly reliable and the data for quality assurance can be recalled from the sensor directly.

References

[1] Rohrbach Ch., Handbuch für elektrisches Messen mechanischer Größen. VDI-Verlag GmbH, Düsseldorf, 1967.
[2] Hoffmann, Karl, Eine Einführung in die Technik des Messens mit Dehnungsmessstreifen, HBM, 1987.
[3] Fischer R., Messtechnik an Antrieben, Vortrag von W. Krimmel: Technik und Einsatz von Drehmomentmesswellen, TAE-Esslingen, 1993.
[4] Keil S., Beanspruchungsermittlung mit Dehnungsmessstreifen; Cuneus Verlag, Lippstadt, 1995.