One spring element for all cases

High-precision torque sensor for flexible measuring

Torque measurements in automotive applications often present a special challenge. In some applications there is a preference for covering multiple measuring ranges with only one torque sensor. There are several approaches for a solution to this challenge. The measuring range of the sensor can be extended electrically or mechanically, for example. In the first case, however, accuracy suffers because factors contributing to measurement uncertainty such as hysteresis, signal noise and the temperature response of the zero point are reinforced with the spread of the measuring range. In the other case the mechanical properties deteriorate due to the highly complex structure of the measuring body. HBM has therefore followed a different approach, developing the 12HP digital torque flange with FlexRange. This sensor covers the entire measurement range with only one spring element, with an enormously high level of accuracy.

Requirements for motors and automotive components – greater energy efficiency, lower consumption and longer ranges – are steadily rising. This also means higher requirements for accuracy in development and research – and thus for testing equipment as well. Torque measurements are a crucial factor for many testing applications in the automotive industry. This is especially demanding if measuring ranges of different sizes have to be covered during a measuring process, as for example in engine tests. Then a torque sensor has to acquire both high and low torques, depending on the test – with uniform accuracy over the entire measuring range. The main challenge is to achieve a balance between measurement accuracy and error tolerance.

In many applications, for example brake tests, the peak torques that occur are very high in comparison to the average measured torques. The nominal (rated) measuring range of the sensor is dimensioned appropriately to ensure the sensor is not overloaded, damaged or even destroyed by peak torques. Peak torques represent the maximum torque in the application. If a sensor is adjusted to the maximum torque, however, it may possibly be over dimensioned for measuring the other torques that occur during the test. Over-dimensioned sensors have a disadvantage: important data sheet information, which must be used to evaluate errors, refers to the nominal (rated) measuring range, not to the average measured torque.

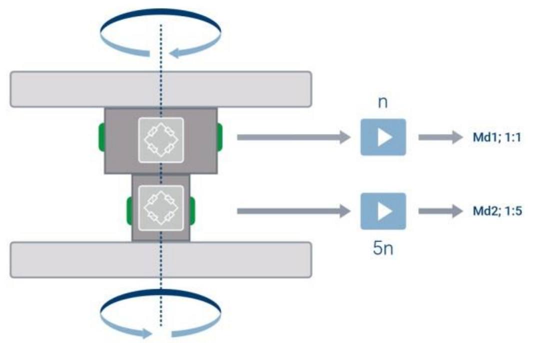

Figure 1: Dual-range sensor with two different measuring bodies in which the small measuring body must also receive the nominal (rated) torque of the larger measuring range.

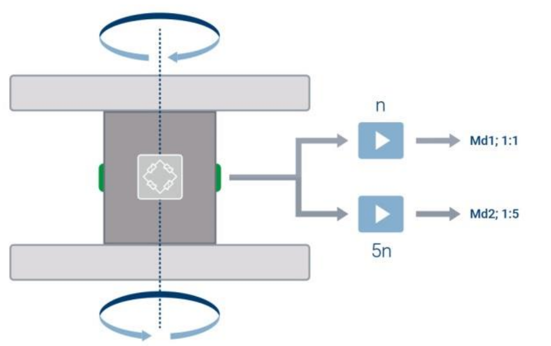

Figure 2: Electrical dual-range sensors have one spring element and simulate a second smaller measuring range electrically.

The relevant error evaluation may therefore produce an unfavorable result because important parameters named in the data sheet such as the temperature response TC_0, non-linearity and the hysteresis as well as effects due to parasitic loads generally refer to the nominal (rated) measuring range of the sensor.

Two approaches for dual-range sensors

The ideal solution for recording multiple measuring ranges during a single test process would be ongoing adaptation of the sensor measuring range to the respective maximum torque. Since this is not practical for technical reasons, however, a number of different variants of dual-range sensors have been developed that are able to cover both a large and a small measuring range. Two different principles serve as the basis for dual-range sensor: sensors with two spring elements and electrical dual-range sensors with only one continuous spring element and two separate measurement channels.

Multiple spring elements allow for multiple measuring ranges

Dual-range torque sensors measure in two torque ranges that differ in size. To do this they have two spring elements or measuring bodies which differ in size and have different nominal (rated) measuring ranges and are connected in series or parallel. Each of these measuring bodies carries a specially coordinated strain gauge bridge connected to a data acquisition system. This makes it possible to determine the material strain of the measuring body, from which the torque can then be derived. Torque transducers of this type are referred to as "true" dual-range transducers. The disadvantage of the variant with the spring elements connected in series is that it is only suitable for static or quasi-static torque measurements.

In dynamic applications the overload protection of the smaller spring element would lead to signal overlapping. Since the smaller spring element also records the high torques of the larger spring element, it is equipped with mechanical overload protection that removes the connection when torques are too high, transferring the torque to the larger sensor. Without this overload protection there is a danger that the smaller element will be damaged. If the overload protection does engage, however, the result is an unclear signal.

That can lead to inaccurate interpretations later when the measurement results are evaluated. The second, small measuring range often also has a very "soft" design in this arrangement, to be able to generate a sufficiently high characteristic value at low torques. Because of this, the small measuring range responds very sensitively to parasitic loads such as axial forces, which result in crosstalk against the torque and may even damage or destroy the sensor in extreme cases.

In another variant of "true" dual-range sensors, the spring elements of different sizes are connected in parallel. This type makes do without overload protection, thereby also avoiding the interference inherent in signal overlapping. But in this case as well the smaller spring elements must also record large torques. There is thus a danger that the smaller spring element will be overloaded, leading to plastic deformation. To prevent this, the smaller spring element is designed so that together with the larger measuring body it is able to support the maximum torque. However, this results in too low a characteristic value for the second strain gauge bridge. The result: Insufficient resolution together with a high level of inaccuracy, including realization of the temperature response.

Figure 3: T12HP Digital Torque Sensor

Electrical dual-range sensor simulates small measuring range

The T12HP torque sensor also differs from "non-true" dual-range sensors that have only one spring element or measuring body and simulate a second spring element electrically.

It contains an additional measuring amplifier connected to the sensor which is set to the smaller measuring range. This second measuring amplifier amplifies the output signal, usually by a factor of 5 or 10. Thus a second useful signal is available which also represents smaller torque loads. The disadvantage of this principle: The second measuring range only appears to increase accuracy. The crucial parameters for measurement uncertainty refer to the nominal (rated) measuring range and thus not to the amplified useful signal. Since the second signal in a "non-true" dual-range sensor simply spreads the signal electrically, these influencing factors are also amplified if no additional values are explicitly specified in the data sheet for the second range, which increases the measurement uncertainty.

Important factors are:

1. Signal noise
2. Temperature response of the zero point TC_0
3. Hysteresis (relative reversibility error)
4. Parasitic loads

1. Signal noise

Every electronic signal includes background noise that is also represented in the measurement. The signal for the smaller measuring range in a dual-range sensor is lower in quality by its very nature, because this signal noise also increases with the amplification. A comparison of the zero signal noise in the large measuring range (1:1) and in the small one (for example 1:5) shows that the electrical amplification also increases the noise by a factor of about 5. Thus tolerances in the measurement signal are also amplified, for example those due to temperature effects. The signal noise is low with the T12HP torque sensor because the second, smaller measuring range is not generated by electronic amplification. The high basic accuracy paired with the high resolution of the sensor – FlexRange functionality – covers the entire measuring range. Therefore the signal noise remains low even when the signal strength is low in the lower range.

2. Temperature response of the zero point TC0

The temperature affects the measurement accuracy of a sensor. If the measurement signal is amplified for an electrical dual-range sensor, the temperature response of the zero point TC_0 also increases. The SG measuring bridge is adjusted to the nominal meas-uring range with the signal intensity factor 1:1. A signal spread with the factor 1:5 also increases the accuracy by a factor of 5 if nothing to the contrary is indicated in the data sheet. If the temperature response of the larger measuring range is specified as 0.1 %/10K, a subrange full scale value of 0.5 %/10K is accordingly obtained for the second, smaller measuring range. Note also in this case whether a separate value is specified in the data sheet for the temperature response of the second range. If not, the spread in the measurement signal will not result in any corresponding improvement in accuracy. Thanks to HBM's FlexRange technology, the T12HP is able to cover the entire measuring range with only one amplification. With an extremely low value of only 0.005 %/10K, very high accuracy is achieved even in the subrange.

3. Hysteresis (relative reversibility error)

If the characteristic curve of the measurement signal is recorded first with continuously increasing torque and then with identical continuously decreasing torque, the output signals will not match exactly. They will each deviate from the characteristic curve. The maximum deviation between the falling and rising load is referred to as the hysteresis or the relative reversibility error. It depends on the elastic properties of the spring element material and the design of the measuring body.

The quantity of the hysteresis depends on the stress and the strain resulting from it in the measuring body, thus on the maximum torque. If there is a change to the smaller measuring range during a torque measurement, for example a brake test with the brake open and closed, the hysteresis remains "saved" in the spring element due to the high initial load or the strain in the spring element. When the measuring range changes, however, so does the deviation from the characteristic curve – from the large distance to the small one.

Because of this there is a gap in the recordded measurement signal curve where the change occurs called the point of discontinuity or the zero point offset. This error is amplified similarly to the gain factor of the measurement signal. For example, if the relative reversibility error for an electrical dual-range sensor is 0.05 percent of the nominal torque in the large measuring range (1:1), after switching directly to the small measuring range (1:5), an offset error of 0.25 percent of the nominal torque may occur. The T12HP torque transducer covers the entire measuring range – and there is no change of measuring range. The FlexRange technology thus allows for one continuous measurement signal and eliminates the point of discontinuity in the application and in the accuracy evaluation.

A point of discontinuity always occurs if for example there are different accuracy levels in a dual-range sensor which always depend in their application or interpretation on preloading and thus on the hysteresis.

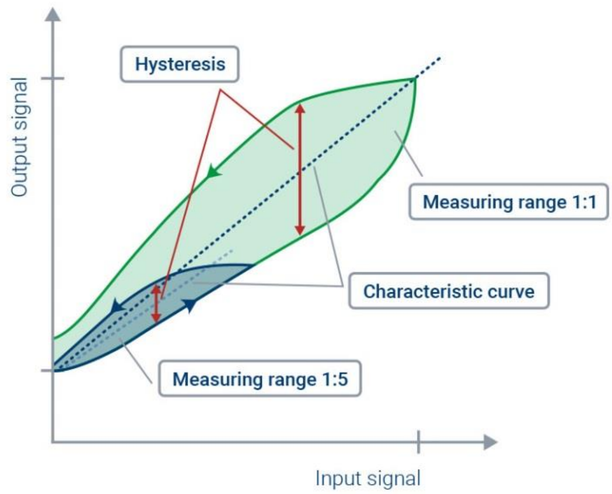

Figure 4: When changing from the larger to the smaller measuring range during a torque measurement, the characteristic curve changes due to the hysteresis

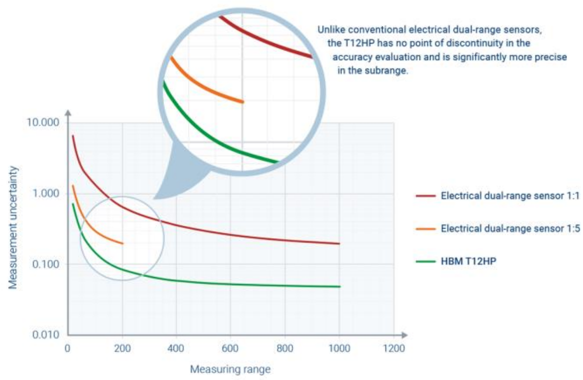

Figure 5: General realization of the point of discontinuity in the accuracy evaluation when changing measuring ranges of electrical dual-range sensors

4. Parasitic loads

Axial offsets occur in practically all drivetrain applications depending on design and assembly. This is due partly to tolerances in the dimensional accuracy of the components that are used and alignment problems and partly to other influences such as temperature. The remaining offset can be practically compensated for by the use of compensating couplings. However, the crosstalk resulting from parasitic loads cannot be compensated for without additional elaborate measurement technology measures. This effect is reduced to a minimum in the T12HP due to the sophisticated geometry of the measuring body and thanks to the very high accuracy and quality of the strain gauge application. The parasitic loads are zero point-relative and spreading the measurement signal in an electrical dual-range sensor multiplies the effect of the loads by the gain factor. These sensors produce large measurement errors in the small measuring range. With a single-range torque sensor like the T12HP, the parasitic loads are manageable.

FlexRange functionality

HBM reached the physical limits of strain gauge technology in the development of the T12HP. In addition, use of the HBM carrier frequency technology guarantees optimum signal quality. The result is a torque measuring system with extremely high basic accuracy and stability as well as high effective resolution of the measured value. This unique combination makes it possible to consider selected measuring ranges with a "magnifying glass", with sufficiently high accuracy and resolution.

It is this philosophy that makes FlexRange functionality possible: excellent accuracy, stability and resolution for every measured value with only one measuring body and one signal path. As a result, no second measuring range is needed to meet the requirement for sufficient accuracy and resolution, even in the subrange.

Figure 6: Thanks to high-quality strain gauge and carrier frequency technology, the FlexRange functionality of the T12HP torque sensor from HBM offers the highest resolution with maximum accuracy.

Conclusion

There are various possibilities in torque measurements for measuring torques of different quantities in two measuring ranges. There are losses in accuracy in most variants due to the design, especially in the smaller measuring range. True dual-range sensors with multiple measuring bodies are not really suitable for dynamic applications because of the overload stop which is required. Since the second range is frequently designed to be sensitive so that it will generate a large useful signal, the permitted limit loads are correspondingly low and lead to more crosstalk against the torque signal with a relatively large error fraction.

In electrical dual-range sensors with only one measuring body, spreading the measurement signal amplifies interfering properties such as signal noise, hysteresis, temperature response of the zero point TC_0 and parasitic loads. Unless otherwise indicated in the data sheets, this does not increase the measurement accuracy of the second range. The temperature response of the zero point TC_0 as well as the signal noise are magnified and at the change from the large measuring range to the small one a point of discontinuity may occur. The principle of the electrical dual-range sensor also amplifies parasitic loads depending on the application.

These interfering influences are minimized in the T12HP torque sensor with FlexRange functionality. The transducer combines the filtering and scaling flexibility of digital signal editing with very high basic accuracy and resolution, thus offering the advantages that would be expected from a dual-range sensor – but without any of the disadvantages of that solution.

Thanks to the patented measuring body with a very high basic accuracy and resolution, combined with carrier frequency technology, guaranteed error limits of only 0.007 % or 0.005 %/10K can be achieved for technical data such as linearity and hysteresis, temperature effect on zero signal $TC_0$and more. The T12HP with its FlexRange functionality is thus clearly superior to the dual-range sensor in many aspects. The philosophy of the T12HP, to use the full potential of strain gauge technology up to its physical limits, thereby significantly increasing the basic accuracy of the sensor, greatly simplifies the technology for users.

Thus HBM's T12HP measurement flange does not need a second amplifier in the subrange. With its excellent mechanical properties it offers very high accuracy over the entire measurement range. This makes the T12HP torque transducer suitable for high-precision efficiency measurements and also for highly dynamic torque measurements with different measurement ranges, for example in running or towed engine tests, brake tests with active and released brakes or transmission and tire tests.

	T12HP with FlexRange (carrier frequency)
Accuracy HBM accuracy class	0.02
Linearity including hysteresis for maximum torque in the range: between 0% and 20% of Mnom > 20% and 60% of Mnom > 60% and 100% of Mnom	 ≤± 0.003 % ≤± 0.005 % ≤± 0.007 %
Temperature coefficient of zero signal – $TC0_0$	≤± 0.005 %/10K
Temperature coefficient of the output signal – TC_c	≤± 0.02 %/10K
Repeatability Relative standard deviation of repeatability (DIN 1319)	≤± 0.005 %

Figure 7: The T12HP digital torque flange with FlexRange technology and only one spring element offers significant advantages compared to conventional dual-range sensors.

Learn more on T12HP at
www.hbm.com/T12HP

About HBM Test and Measurement

Founded in 1950, HBM Test and Measurement is today the technology and market leader in the field of test and measurement. HBM's product range comprises solutions for the entire measurement chain, from virtual to physical testing. The company has production facilities in Germany, USA, China and Portugal and is represented in over 80 countries worldwide.