IMEKO 2010 TC3, TC5 and TC22 Conferences
Metrology in Modern Context
November 22–25, 2010, Pattaya, Chonburi, Thailand

EXAMPLES AND PROPOSED SOLUTIONS REGARDING THE GROWING IMPORTANCE OF CALIBRATION OF HIGH NOMINAL FORCES

A. Schäfer

Hottinger Baldwin Messtechnik GmbH (HBM), Darmstadt, Germany

Abstract – With the further advance in industrial applications the task of measuring high forces gets more and more into the focus. While civil engineering is a rather traditional field of measuring high forces, also several other fields of application require forces up to 5MN or higher. For this reason HBM offers force transducers in standard range up to 5MN and as customised versions up to 20 MN, while customer requirements in terms of accuracy as well as long term stability are getting always higher.

Keywords: Reference force transducers, extrapolation, built-up system

1. MEASUREMENT OF HIGH FORCES BY FOIL TYPE STRAIN GAUGES

Foil type strain gauges are very usual in force measurement. The vast majority of force transducers as well as the load cells are based on foil type strain gauges. They are available in any kind of load cell designs. Measurement of both, tension and compression force, can be realised without additional effort and even shear forces can be measured.

One can summarise that a wide range of load cell designs such as column type, ring torsional design, S-shape type or simply a bending beam are possible. From the design point of view there is no reason, why force transducers based on foil type strain gauges could not be built with higher nominal loads and there is no other pick up principle needed [1]. Higher nominal forces do not inevitable mean large geometries [2]. So for instance the design based on the measurement of shear forces can be quite compact, especially in vertical direction.

2. ARISING NECESSITY FOR HIGHER FORCES IN INDUSTRY

2.1. Overview on application examples from various industries

In many fields of application, a clear trend towards increasing forces has become obvious over the past years.

As figure 1 shows aerospace industry is one of the examples. At the latest since projects such as Airbus A380 or A300M were started, it has become evident that significantly larger airplanes are built meanwhile.

Various components, for example the wings, the mounting parts of the turbine engines, and the cabin are subjected to considerably higher forces during operation than with their smaller predecessors.

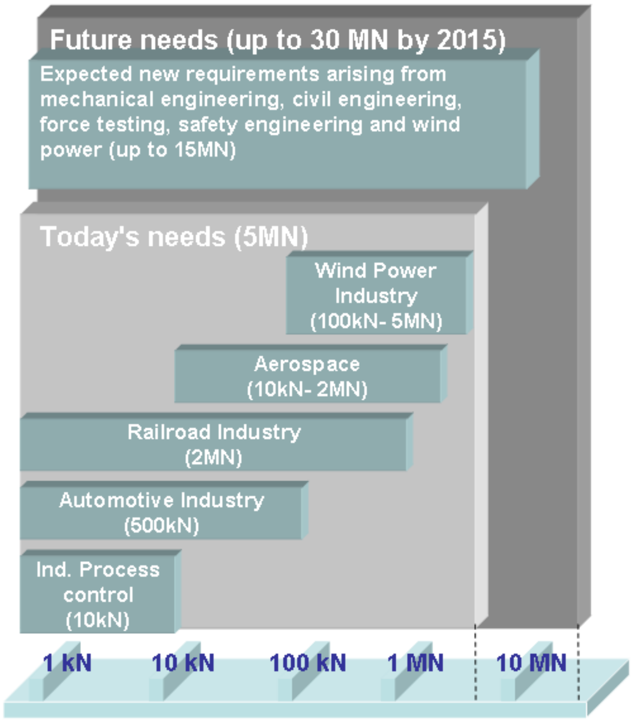

Fig. 1. Extension of force ranges necessary to be calibrated (several examples from industry)

Therefore it has become necessary to implement these high forces in test stands on the ground and, of course, to control and measure them. As a result, force transducers with nominal forces well in the mega Newton range are required.

Another example comes from railroad industry. For railroad vehicles where traction motors get more and more powerful new force measurement tasks of up to 2MN arise. But also for the large field of mechanical engineering the trend to higher forces is immense. Other demands come from building industry, safety engineering and testing of force.

As a summary from the above mentioned application fields one has to be prepared to measure higher nominal values with forces up to approximately 15 MN.

Traceable calibrations of suitable transfer standards should improve the measurement of force in industrial applications. This trend will continue and it is expected that by 2015 even larger nominal values may be required. So it is estimated that there is a need of forces up to 30 MN.

2.2. Wind power industry as an example for the increasing need of higher forces

Testing of wind power system is a good example to intension and extent of the change toward higher forces. In building up wind turbines beside of gearboxes bearings are vitally for the lifetime of the unit. Very high bending moments, similar to those occurring in actual operation, are applied to these bearings for testing and development. Such bearings are tested on test stands, which require force transducers with a range of 5 Mega Newton, and up to 15MN in the medium to long term. The market of wind energy generation is one of the most dynamic. The world market grows by 29% annually.

Fig. 2. Wind turbines going off-shore

These wind turbines are considerably bigger and higher than in the past, especially the wind turbines for off-shore use. There is a clear trend of going offshore. It is expected that the relation off-shore/on-shore projects will change rapidly toward off-shore. This trend is described by the BWE e.V., Association of Wind Energy makers in Germany [3]. It estimates that by the year 2020 the off-shore portion will be grown from now 10% to 16% and will further grow to 30% by 2030. There is a similarity in the development of all countries in wind power sites. In the beginning stage countries start to develop Wind energy mainly on-shore; during the next stage the share of off-shore installations steadily grows. As far as it considers Germany by 2020 the country plans to generate roughly 48% of all energy by renewable sources. This is a steep increase from just 16% today. More than half of the power of renewable sources will come from Wind energy and make it the major element in the progress in energy generation. Thus it is not possible to ignore this development. Industry has to meet the requirements of these trends.

3. CALIBRATION NEEDS AND SOLUTIONS

As a result, force transducers with such high capacities will have to be calibrated at regular intervals on several fronts - of course with high precision and at low cost. This requires reference transducers providing sufficiently high capacities. Should, however, calibration in a partial load range only be possible for cost reasons, it is absolutely necessary to assess the accuracy that can be attained at full load. Reliable models for extrapolation have to be developed. Moreover, the special requirements for calibrating these transducers need to be identified (e.g. longer delay before installation in the testing machine because of higher thermal capacity). In addition, the principal question to be answered is what transducer principles may be suitable for reference transducers with high nominal capacities.

3.1. Evaluation of the method of extrapolation

A so called partial load calibration may be seen as a possible escape, but in having to calibrate high forces with equipment for lower forces an inevitable problem arises. So the acceptance as well as the “certainty” of a calibration of only a partial load range is quite low. Procedure is like that: The higher range is predicted by the measurement data from the lower range. So based on the calibration data in the lower available range, data are extrapolated to higher values. By the customer it is considered a risk, which can not be quantified because there is no knowledge of the device in the higher range. Sometimes for cost reasons calibration in a partial load range may be the only possibility. However it is absolutely necessary to determine the accuracy that can be attained at full load, so finally there is no way without transfer transducers for the full nominal range.

3.2. Built-up system as an effective way to reach higher nominal forces

In the high force range build-up systems such as BU 18 are getting more and more popular as it is an effective method to increase the nominal range.

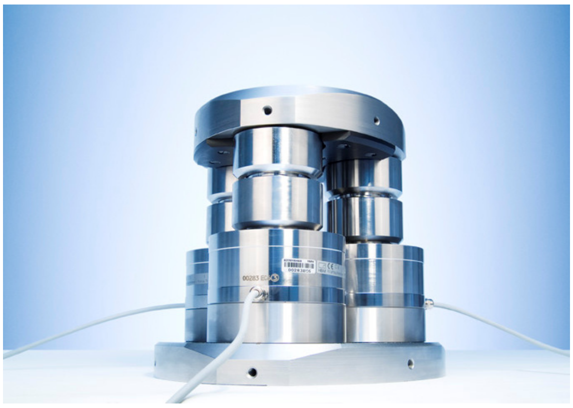

Fig. 3. View of built-up system BU18

Normally direct loading calibration machines are used for calibrating force transducers in national institutes and industrial calibration laboratories. With very large forces in the range of MN these machines are extremely large and also expensive. Furthermore build-up systems like shown in Fig. 3. and 4. are also a method which can be applied to industrial applications. In the latter use economics are even more important. Such systems are compact in height, weight and space−saving. In addition the systems allow the evaluation of parasitic components.

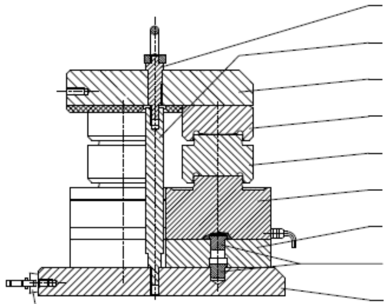

Fig. 4. Principle scheme of build-up system BU18

The BU18 build-up system, made by HBM, was developed to measure or calibrate large compressive forces as a smaller and less expensive alternative to existing direct loading machines. The system comprises three precision force transducers mounted in parallel onto which the force is distributed. The BU18 build-up system is based on HBM's type C18 compressive force transducer. This transducer provides compact dimensions and high accuracy. So C18 can attain an accuracy of Class 00 per ISO 376**.** In combination with DKD calibration certificate the whole built-up unit can obtain Class 00 to ISO 376.

With the BU18, based on 3 force transducers with a nominal force of 1 MN each, it can measure compression forces with a nominal (rated) force of 3 MN. The single transducers can be used for subsequent measurements on calibration machines with lower nominal (rated) forces. Electrically a junction box switches the output signals of the three transducers in parallel.

3.3. Transfer transducers for high nominal forces

An alternative way to direct loading machines is calibration by comparison using reference force transducers. Compared to the above mentioned solutions (see 2.1. and 2.2.) this is the best. However, the reference transducers also need to be calibrated and direct loading machines of adequate size for this task are often not available. To cover this range transfer standards have to be developed in order to reduce the uncertainty of measurement in industrial applications. Furthermore it has to be taken into account that forces may act nonaxial and that only the main component is calibrated by the calibration machine, but because of nonaxial loading the other components can significantly influence the uncertainty of measurement in applications. So also this aspect has to be considered.

Fig. 5. Force transducer KDB (5MN)

An example for a force transducer with a comparable high nominal force designed for the dedicated needs of a specific industry is the KDB transducer For the use in civil engineering he meets DIN 51302-2 or EN 12390-4, appendix A, and is therefore suitable for verifying compression testing machines for building materials. The four strain gage full bridges that have been attached at the circumference of the transducer spring body and offset by 90° each enable the transducer to be used for the tests required by the standard including the centric transmission of the testing force and the free movement or locking of the upper compression plate. Each of the four strain gage full bridges is equipped with a separate output who can be connected to 4 independent amplifier channels and thus can be used for bending moment measurement.

4. HBM'S NEW CALIBRATION MACHINE FOR FORCES UP TO 5 MN

As a result, force transducers with such high capacities will have to be calibrated at regular intervals on several fronts - of course with high precision and at low cost. [4] This requires reference transducers providing sufficiently high capacities. Generally the HBM calibration laboratory at its headquarters in Darmstadt (Germany) is quite well known for the force measurement and is accredited from 2.5 N to 1 MN. The machine uncertainties certified by the German Calibration Service (DKD) range from a mere 0.02 % to 0.005 % of the actual value. However for the above mentioned reasons more and more applications required 5 MN. So HBM decided on investing in a new calibration machine for forces up to 5 MN. The machine uses a hydraulic unit to generate the high forces. Calibration is performed by comparing the signal generated by the test specimen with those of the force reference transducer integrated in the machine. Under DKD-accreditation, the degree of uncertainty is verified under supervision of the German National Metrology Institute (PTB). Subsequently the uncertainty of only 0.02 % of the particular force has been stated. The combination of great force, high accuracy and the opportunity to calibrate not only compressive force, but also tensile force transducers, make the machine unique.

Fig. 6. HBM´s new calibration machine for forces up to 5MN

5. CONCLUSION

There are two major trends to get more efficient in production, energy generation or logistics. The first one is getting faster. The second one, described in this article, is using bigger units. The latter trend can be seen e.g. by the recent design larger airplanes, larger ships and larger wind power units. Further development will require even higher forces, but also other quantities, such as torque and pressure, will have to meet these demands [5], [6]. From the engineers point of view there is no reason why force transducers based on foil type strain gauges would not be the ideal way for also fulfilling this future needs as well. For all these needs HBM provides a complete measurement chain including products and services for force measurements. The company offers integrated solutions ranging from force transducers through a comprehensive range of amplifiers and software.

REFERENCES

[1] A. Schäfer, "Analogy observation of force transducers compared to strain and pressure transducers based on foil type strain gauges and the piezoelectric principle", *Proceedings of Asia-Pacific Symposium on Measurement of Mass, Force and Torque*, Tokyo, Japan, 2009

[2] A. Schäfer, "Force, strain and pressure transducers based on Foil Type strain gauges as well as the piezoelectric principle for the use in industrial applications" *Proceedings of "Eurosensors 2008"*, Dresden, Germany, 2008

[3] H. Albers, Plenary paper „Markets, trends and visions for Wind energy", *VDI conference „Vibrations in Wind energy units"*, VDI report No. 2088, VDI Publishing house, Düsseldorf, 2010

[4] Hu Gang, Zhang Zhimin and Zhang Yue „Internal Large Force Comparison in China", Mechanics and Acoustics Division, National Institute of Metrology, Beijing, P. R. China, Proceedings of Asia-Pacific Symposium on Measurement of Mass, Force and Torque, Tokyo, Japan, 2009

[5] A. Schäfer, et al. "A new type of transducer for accurate and dynamic pressure measurement up to 15000 bar using foil type strain gauges", *XVII IMEKO World Congress 2003*, Metrology in the 3rd Millennium, Dubrovnik, Croatia

[6] P.D. Hohmann and A. Schäfer, "Combined Calibration of Torque and Force in a 3in 1 Calibration unit", "APMF 2000", *Proceedings of Asia-Pacific Symposium on Measurement of Mass, Force and Torque*, pp. 204, Tsukuba, Japan, 2000