

FURTHER IMPROVEMENTS ON HIGH-ACCURACY RADIALLY SYMMETRIC BENDING BEAMS

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Abstract: Radially symmetric bending beams are widely used in the field of reference force transducers. The performance that can be achieved with the transducers currently available is the result of a long development process. This article shows how new machining tools and modern strain gauge technology helps to achieve a new, even lower measurement uncertainty when radially symmetric bending beams are used.

Keywords: Reference force transducer, transfer standards, radially symmetric bending beams

1. MECHANICAL CONCEPT

Fig. 1 shows a sectional view of a radially symmetric bending beam using the Z4A force transducer from Hottinger Baldwin Messtechnik as an example.

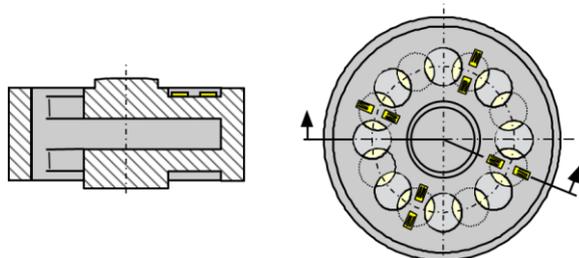


Fig. 1. Force is introduced into the center of the force transducer and led, via 8 bending beams, to the outer housing which is mechanically connected to the bottom so that, via a similar construction, force is transferred, again via 8 bending beams, to the center of the force transducer's bottom.

Force is introduced into the center of the transducer. Eight bending beams connect the center of the transducer with the outer housing, and a minimum of eight strain gauges are installed on those bending beams, as shown in the right hand sketch of Fig. 1. In case of compression, an S-formed bending occurs on each bending beam, i.e. negative strain on the strain gauges on the inner circle and positive strain on the strain gauges on the outer circle. The spring body has been designed in a way so that 200 MPa uniaxial stress occurs at each point of strain gauge installation, which results in a strain of 1000 $\mu\text{m}/\text{m}$, as steel with Young's modulus of 200 MPa is used.

Force is led to the centre of the bottom of the force transducer in a similar way as on the upper side; again eight bending beams are used.

It is a fundamental advantage that the whole spring body is produced as a monolithic element; there are no screws or bolts connecting parts which might cause hysteresis resulting from little movement between each other. The only exception is the inner bore hole and thread on the bottom of the transducer (refer to Fig. 2, left hand side). It is a cartridge that provides a suitable mechanical connection. Furthermore the machining process is easier having a larger hole at this place.



Fig. 2. A look into a Z4A. From left to right: Bottom side with the cartridge (inner hole); upper side with load introduction bolt. The bolt and a spring body are made from one piece.

The fundamental equation of the Wheatstone bridge can be used here [1], however, it is essential to take into account that every bridge leg contains two strain gauges. In this case, the mean value of the strain values under the strain gauges connected in one bridge leg can be seen as one strain gauge.

$$\frac{V_o}{V_i} = \frac{k}{4} \cdot \left(\frac{\varepsilon_1 + \varepsilon_2}{2} - \frac{\varepsilon_3 + \varepsilon_4}{2} + \frac{\varepsilon_5 + \varepsilon_6}{2} - \frac{\varepsilon_7 + \varepsilon_8}{2} \right) \quad (1)$$

In this equation, k is the gauge factor of the strain gauge. Constantan gauges are often used with radially symmetric bending beams. They have a gauge factor of about two and a rated output of 2mV/V is achieved with this concept

The symmetric design of the transducer ensures a minimum influence of bending moments that may occur if force is not introduced exactly into the center of the load cell. This is achieved by a special electrical adjustment, as shown in Fig 3.

The transducer is wired in a way so that strain gauges 8 and 1, 2 and 3, 4 and 5 and 6 and 7 are installed on one bending beam. Resistor $R_{1/8}$ shunts the pair of strain gauges 1 and 8 which enables the sensitivity of this single beam to be adjusted. Doing the same on three of the four bending

beams which are installed in a symmetric way (see Fig.1., right hand side sketch), all four measurement points can be adjusted to exactly the same sensitivity.

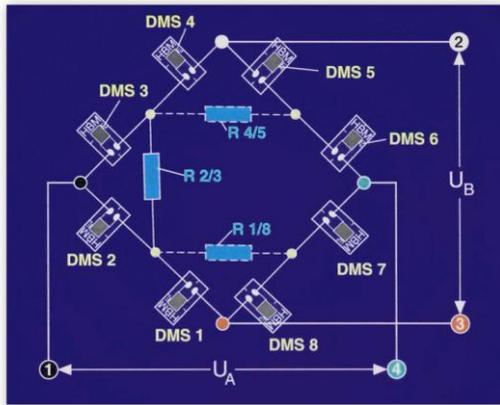


Fig. 3. Internal wiring of a radially symmetric bending beam (Z4A from HBM)

As bending moments influence opposite sides of the transducer in opposite directions, they do not show any output signal.

The complete circuit of the transducer is shown in Fig. 4.

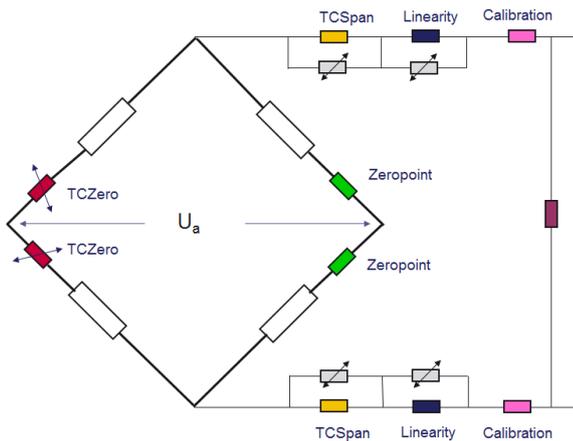


Fig. 4. Internal wiring of a radially symmetric bending beam (Z4A from HBM)

Linearity adjustment is implemented using a semiconductor strain gauge that adjusts the input voltage at the Wheatstone bridge at different load conditions and therefore the sensitivity at different load conditions.

The important technical data of the temperature variation of the zero point (0.015%/10 K) and the sensitivity (0.01%/10 K) has not changed over the years, as it was very low from the start. Considering the use of reference transducers like the Z4, most of the applications are running under stable temperature conditions so that further improvement would only lead to higher costs, but not to better performance in the labs.

2. PERFORMANCE OF RADIAL SHEAR BEAMS

The machining effort required with this kind of transducers is high, as the material between the higher and

the lower bending beams must be removed completely. But from the start of production over 35 years ago, the performance of the transducers has been impressive.

From the very beginning, the transducers offered repeatability in different mounting positions of 0.03% relative to the actual measurement value, and maximum creep was 0.04%. As an adjustment for linearity was used, 200 ppm deviation was achieved in those days.

Further development of the transducers has shown that the linearity as well as the hysteresis behaviour of the load cell is very closely connected to the position of the strain gauges on the bending beam. Advantages in strain gauge positioning and modern etching technology as well as more precise strain gauge installation technologies led to higher accuracy; repeatability remained the same on the data sheet, however, in practice, better results were achieved. Hysteresis could be reduced from 0.1% to 0.06% (capacities up to 200 kN) and from 0.2 to 0.15% for the version with 500 kN respectively.

Over the next years, a new way of developing load cells was introduced in mechanical engineering departments and using modern FEM calculation, further progress was achieved. By calculating the strain gauge position more precisely and increasing the effort involved in the wiring as well as in the installation process, the repeatability in different mounting positions was improved to 0.008% (compression) and 0.016% (tension). Creep is limited to 0.01% which corresponds to 100 ppm. Hysteresis is specified with a maximum of 0.03%. All values are relative to the value measured for all forces which are equal or higher than 20% of the transducer's nominal load, as described in the ISO376 standard.

As mentioned before, this progress was achieved through more precise positioning of the strain gauges. Secondly, this has been the result of very small, however very many improvements in the machining and hardening process.

Fig. 5 shows the development.

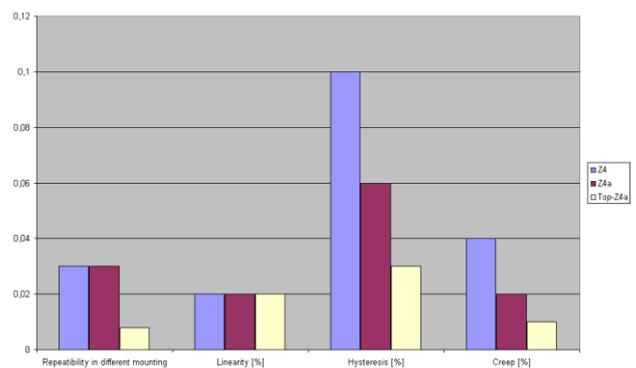


Fig. 5. Development of the measurement uncertainty of the radial bending beam transducer Z4 from HBM. All capacities except for the 500 kN version.

Load cells with higher capacities are more challenging, as the hysteresis shows higher tolerances with those transducers. [2] The reasons are higher mechanical stresses in threads and mounting accessories. Therefore the hysteresis value that can be achieved today is just 0.07% (relative to the measurement value). This is 140 ppm

relative to full scale and therefore a low uncertainty. However, more and more applications require measurements at just 5 or 10% of the nominal force, and in these cases a higher accuracy is often needed.

3. NEW DEVELOPMENTS AND FIRST RESULTS

As mentioned before, the spring bodies of modern radial shear beams are nearly monolithic, except for the cartridge that provides the mechanical connection.

The design is limited by the possibilities offered by the machining process. The material between the upper and lower bending beams needs to be removed completely. Therefore a hole with a suitable diameter is required as well as a cartridge to provide a suitable thread size. Tests showed that the influence of the cartridge mainly on hysteresis but also on the repeatability of the reference transducer is high; a reduction by 50% can be achieved.

The easiest option seems to be to omit the cartridge and have a bigger thread at the bottom. Considering the requirements for compatibility, this option cannot be used. The machining tools also have made significant progress over the past years and machining tests have shown that a Z4 can also be produced without a cartridge, however, using the same thread size as now.



Fig. 6. A look into the new Z4. From left to right: Bottom side without cartridge (inner hole); upper side with load introduction bolt. The complete bolt and spring body are made from one piece.

Therefore a complete monolithic spring body was designed. First tests have shown a hysteresis of just 0.03% relative to the actual measurement value for all forces to be measured which are higher than 20% of the nominal load. This corresponds to a maximum error of 80 ppm relative to full scale.

Repeatability has been reduced to 0.006%. Similar improvements in linearity and zero point return could be achieved.

5. FURTHER POTENTIAL FOR IMPROVEMENT

Modern strain gauges will be adapted to the radial bending beam concept in the future to achieve a better long term stability of the rated output and zero point. Although this is not required by international standards, it will make measurements more reliable.

State-of-the-art machining tools will be used for the machining process and will guarantee an even better hysteresis and repeatability due to better geometrical precision and make production safer.

The main disadvantage, the sensitivity to temperature gradients, cannot be improved using this design, as the position of the strain gauges for positive strain is always on another diameter as the position of the strain gauges for negative strain. For applications under those conditions, the reference transducers available are designed as radial shear beams.

6. CONCLUSIONS

This article has shown that the relatively old concept of radial shear beams has been improved over a time of more than 35 years. Modern tooling leads to a completely monolithic concept which significantly improves the measurement uncertainty of those types of reference force transducers

5. REFERENCES

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