New design for a precise, radially symmetric shear-beam reference sensors for compressive force

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Abstract. Radially symmetric shear-type transducers for force measurement have been established in the field of mechanical testing for many years, as the design of those sensors combines a high overload capability and a very high dynamic bandwidth with a good precision. Radially symmetric shear types have been increasingly used in the field of calibration over the past years. A newly developed radially symmetric shear-beam force transducer offers even higher precision than these existing types.

1. Introduction

Strain gauges are the established basic technology for reference force sensors. In any case, the strain gauges are installed on a so-called spring body. The application of a force results in stress occurring in the structure of the sensor so that strain can be measured on the surface. Strain gauges convert the strain into a change of resistance. By using the Whetstone Bridge circuit this change in resistance is converted to a measurable voltage. The fundamental principle did not change in the past but many different types of spring bodies have been developed [1], [2] over the years. The different fundamental designs vary in terms of robustness and precision and are suitable for different capacities.

So-called “S-Type sensors” are very suitable for low forces up to 50 kN. In the field of high capacities, tension/compression bars are mostly used while in the field of high-end transfer standards for mid-range forces from 20 kN up to 500 kN, radially symmetric double bending beams are a very good option. (Fig. 1). Radial shear types are available in a range from 2.5 kN up to 2.5 MN.

Fig 1: Different sensor types and their force ranges. Radial shear types are suitable for a wide range from 2.5 kN to 2.5 MN.

[3] shows that radially symmetric shear types offer some advantages compared to other principles for use as reference load cells:

- Radially symmetric shear beams have a high output signal of more than 4 mV/V at full-scale loading. This reduces the requirements for the amplifier systems and improves the signal-to-noise ratio
Radially symmetric shear beams are quite insensitive to temperature gradients. The reason for this is the symmetric arrangement of the strain gauges (see Fig. 2) which guarantees the best possible self-compensation of temperature influences on the zero point.

The high stiffness of the radially symmetric shear beams allows using those sensors for dynamic measurements.

The design provides a high bending moment capability as well as a high resistance to lateral forces.

Fig. 2: A spring body of a radially symmetric shear-force transducer. The strain gauges are glued on the bars in a way that there is always one strain gauge picking up the negative strain and another one picking up the positive strain. The Wheatstone bridge circuit compensates the temperature influence on every single bar [3] so that the sensor has an excellent behavior under temperature gradients.

Radial shear type sensors always consist of a spring body (see fig 2) and a load base. Those components are connected by screws (see fig. 3.)

The accuracy of radial shear load cells is limited by the hysteresis. Table one show a comparison between a U15 type reference load cell (which is a radially symmetric shear type) and a Z4A load cell (which is a monolithic, radially symmetric double bending beam). The hysteresis of the Z4A type force sensors is approximately two times lower than the U15 values.

| Radial Shear type U15 | Monolithic Sensor Z4a |
|-----------------------|-----------------------|
| Capacity (2.5 kN, 10 kN) | Capacity (2.5 kN, 10 kN) |
| Hysteresis rel. to measurement value (data sheet) | Hysteresis rel. to measurement value (data sheet) |
| 750 ppm | 300 ppm |
| 1,000 ppm | 300 ppm |
| 1,250 ppm | 300 ppm |
| 1,500 ppm | 300 ppm |
| Hysteresis rel. to measurement value (typical) | Hysteresis rel. to measurement value (typical) |
| 400 ppm | 200 ppm |
| 500 ppm | 200 ppm |
| 750 ppm | 250 ppm |
| 1,500 ppm | 500 ppm |
| Zero point return (data sheet) | Zero point return (data sheet) |
| 100 ppm | 40 ppm |
| 200 ppm | 40 ppm |
| 100 ppm | 40 ppm |
| 200 ppm | 40 ppm |
| Zero point return (typical) | Zero point return (typical) |
| 50 ppm | 15 ppm |
| 50 ppm | 15 ppm |
| 100 ppm | 25 ppm |
| 100 ppm | 25 ppm |
| 1,500 ppm | 30 ppm |
| 1,500 ppm | 30 ppm |

Table 1: Comparison of the precision of a Z4A monolithic load cell (right) and a radial shear type with a screwed load base (left)

This is due to the fact that the load base required for all radial shear type sensors is fixed by crews. Very small movements at this joining point cause the hysteresis effect. [3]

Many optimizations over the last years have led to an improved performance and wider measurement ranges so that radial shear types do now comply with Class 0.0 according to the ISO376 standard in the force range between 20 % and 100 %. For lower forces, Class 0.5 can be offered between 10 % and 100 % with modern models.

2. New design for compressive force

Radial shear type load cells are mostly used for tension/compression load cells but an increasing number of models for compressive force are available on the market. Those force transducers also offer the advantages of the tension/compression models, such as high output signal and high natural frequency. The difference is quite simple, as the internal thread of the tension/compression transducers was exchanged by a load introduction sphere (see Fig. 3)
Again, these force transducer types were the first to have been established in the field of mechanical testing in many applications. The step to the more precise reference application required some redesigning and optimization concerning the mounting of the flanges on their load base.

2.1. Hysteresis effects

As tensile forces are not applicable to those sensors, a higher torque is applied to the screws connecting the spring body to the load base (Fig. 3). As a consequence, the contact of both parts is better than with tension/compression force transducers with a similar design. The results of the measurements taken show low hysteresis values (Table 2).

![Fig. 3: Radial shear type mounted on its load base. Screws are used to fix the sensor to its load base. It is important that no movement between the sensor and the load base is possible.](image)

| Tension / compression force transducer U15 Capacity: 1 MN | Compression force transducer C15 Capacity: 1 MN |
|---------------------------------------------------------|-----------------------------------------------|
| Hysteresis at 10% of capacity (datasheet), relative to measurement value | Hysteresis at 10% of capacity (typical), relative to measurement value |
| 0.15% | 0.13% |

Table 2: Comparison of the hysteresis values of radial shear type sensors for tension / compression (U15, right) and radial shear type sensors for compression only (C15, left)

2.2. Repeatability

Radial shear beams for compressive forces designed to be used in experimental mechanics have a massive load base to ensure robustness and easy mounting. The results of first calibrations showed that sensors with the load base designed for experimental tasks are not suitable to be used as reference force transducers. While the values for creep, reversibility, interpolation error, and zero return were very good with the first samples, the values measured for the reproducibility were not good enough to reach Class 1 according to the ISO 376 standard.

![Fig. 4: Comparison of the same sensor on different calibration machines. The results for the repeatability b depend on the bending moments and the quality of the application of force in the calibration rig](image)
It was investigated that the extremely stiff load base in combination with the spring body’s the low deflection under load causes uncertainties in repeatability of more than 0.1%. The reasons for this are bending moments and imperfect (uneven, non-parallel) load introduction. Looking at the results of the calibration processes performed, the results for the repeatability b according to the ISO standard depend on the quality of the calibration machine (Fig. 4).

A new load base had to be designed, which had to show a much lower bending stiffness so that bending moment from the calibration machine did have no influence on the force measurement. On the other hand, it was important to maintain the known high stiffness in the direction of the force to be measured to ensure the sensor’s known good dynamic characteristic with the optimized load base. The solution is shown in Fig 5.

![Fig. 5: Load base for experimental tasks (left) and for reference tasks (right). The stiffness in the direction of the force to be measured is nearly the same, but the sensor on the right-hand side shows a much better repeatability – also under critical circumstances.](image)

An example of the 1 MN load cell is shown in Fig 6. The numbers for the repeatability meet the requirements of the ISO376 Class 00 in a force range from 10 % to 100 % of the nominal force if the new load base is used.

![Fig. 6: Comparison of the same sensor but with different load bases. The new load base shows by far best results.](image)

3. Conclusion

The newly designed radially symmetric shear beam allows precise measurement also under critical mechanical circumstances. It combines the advantages of the known design such as high output signal and suitable characteristics for dynamic calibration with the requirement to provide higher precision. Future research will answer the question of whether this performance can also be transferred to tension/compression load cells.

References

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