

PRECISE RADIAL SYMMETRIC SHEAR BEAM FORCE TRANSFERE TRANSDUCERS FOR COMPRESSION FORCE

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Abstract – Force sensors based on the principle of symmetric radial shear beams are known from their advantages in the fields of material testing, experimental mechanics and industrial process control. In the last years those kinds of sensors became more and more important in the field of calibration. Newest developments do now show that the class 00 according the ISO 376 standard is visible for radial symmetric shear types for compression forces.

Keywords: Radial symmetric shear beams, Reference force transducers, Force calibration, compression load cell

1. INTRODUCTION

Strain gauge based force sensors are commonly used in the field of calibration as they can be produced with relatively low production costs and they do reach a very good accuracy.

The fundamental principle is shown in figure 1. Strain gauges are installed on a spring body. If a force is applied to the spring body a mechanical stress appears. According the Hook's law a strain occurs as a consequence of the mechanical stress.

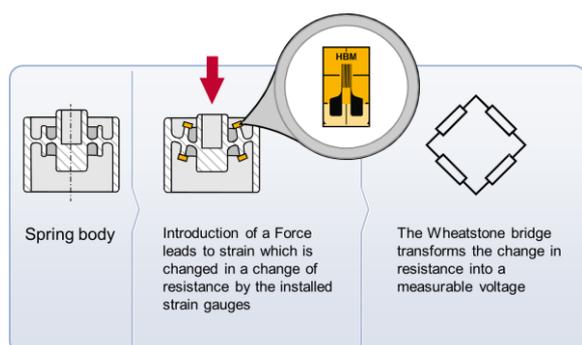


Fig. 1. Principle of strain gauge based force sensors shown with the example of a C18 reference force sensor.

Strain gauges turn the strain into a change of resistance according the fundamental equation:

$$\frac{\Delta R}{R} = k \cdot \varepsilon \quad (1)$$

In which is

ΔR	Change in resistance
R	Resistance of the strain gauge
k	Gauge factor (sensitivity of the strain gauge)
ε	Strain in the area of the strain gauge

If four or multiple of four strain gauges are connected to a Wheatstone bridge and the circuit is supplied with a voltage (usually 1 V up to 5 V) the measurable output voltage can be easily calculated by

$$\frac{V_o}{V_i} = \frac{k}{4} \cdot (\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4) \quad (2)$$

As the relation between strain and mechanical stress as well as the relation between mechanical stress and force show a linear dependency to each other the relation between introduced forces a measurable output voltage is also given as a nearly perfect linear relation.

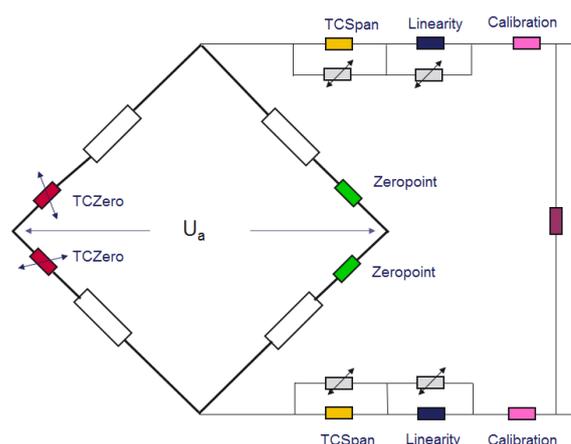


Fig. 2. Internal wiring of a radially symmetric bending beam (Z4A from HBM)

It is an advantage of the strain gauge technology that electrical compensation is possible for many effects such as linearity, bending, temperature effects etc. This gives the possibility to design the load cell optimized for its application. Low accurate load cells for industrial use are coming along with the just four strain gauges, a spring body

and a cable while reference sensors are designed to compensate most of the effect that reduce the accuracy of the load cell.

The technology of electrical compensation for load cells is shown in figure 2. [3]

The compensation of bending moments is very important for reference force transducer as this allows reaching optimized results for the repeatability under different mounting conditions also under difficult conditions. [2]

2.1. Properties of radial symmetric shear beams and strain gauge aspects

In [1] was shown that radial symmetric shear beams do have outstanding mechanical robustness, which is given for three fundamental reasons.

The mechanical design of those load cells is done in such a way so that the strain field in the area of the strain gauges is given without any peaks or strain gradients and there is no area with a higher stress than in the strain gauge installation area on any place at the force sensor. See figures 2 and 3.

This is of high importance as the fatigue life of strain a gauge is very much related on the strain level. The change in resistance of the strain gauge is related to the mean value of strain in the area of the measurement grid, but the fatigue life is given by maximum strain in this area.

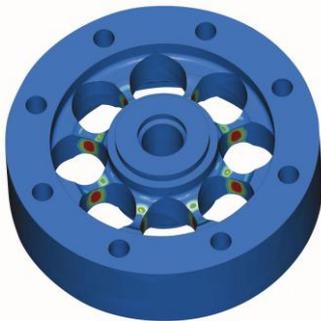


Fig. 3. Spring body of a radial symmetric shear beam. The shear stresses on the bars are used for strain gauge installation. The strain field is free of any gradients. Strain gauges are installed under 45 degrees so that shear strains are measured [1]

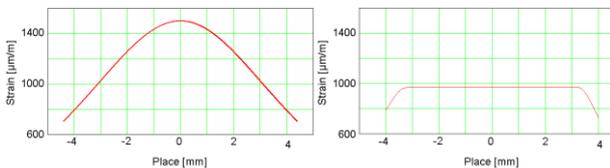


Fig. 4: Strain filed of a so called “S-type” load cell (left) with the strain filed of a radial shear type (right). It can be seen the no gradients occur with the radial shear types, maximum strain is lower. [1]

Figure 5 shows the fatigue behaviour of strain gauges – in a range up to 1500 µm/m strain gauges do not reach their endurance limit.

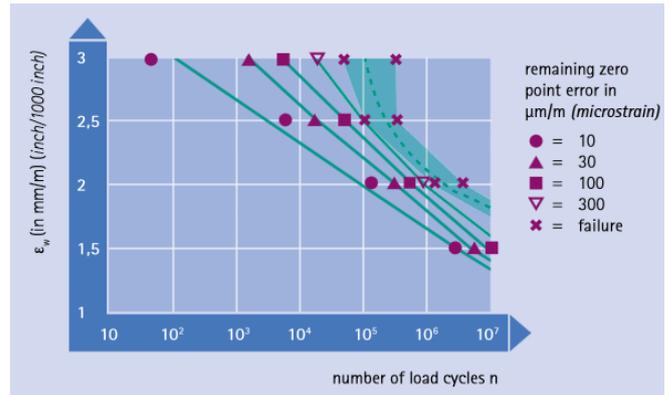


Fig. 5: Fatigue behaviour of metallic strain gauges. Up to 1500 µm/m strain gages do not reach their endurance limit.

The use of Chrome Nickel Strain gauges is of advantage as those strain gauges have a higher gauge factor which leads to a higher output signal at the same strain level if the situation is compared with constantan strain gauges. The common gauge factor for Constantan is around 2, Chrome - Nickel gauges reach 2.3. This can be used to lower the strain levels and therefore the mechanical load in the most critical area of a force transducer without lowering the output signal.

In [1] a further advantage of the Chrome Nickel strain gauge technology was shown: As the dependency of the gauge factor is in the opposite way of constantan. Constantan is widely used for its low production costs, but Chrome – Nickel can compensate the temperature behaviour of the spring body material. The spring body material (aluminium or steel) shows a decreasing Young’s over the time which leads to a higher strain level if the same force is applied at higher temperature. As a result the output signal increases also with higher temperatures if no action is taken to avoid this. Chrome Nickel Strain gauges compensate this as the gauge factor is decreasing with higher temperatures. [4] While producing the Chrome- Nickel strain gauges it is possible to adapt their temperature behaviour to a certain kind of steel

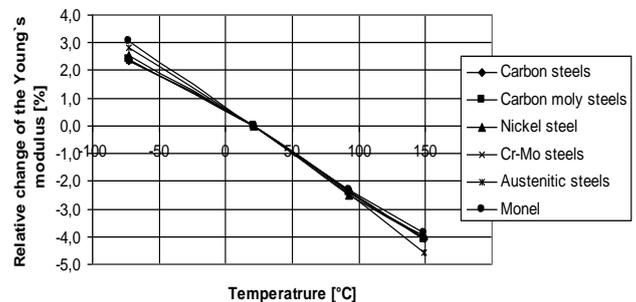


Fig. 6. Typical relative change of the Young’s modulus for spring body materials [1]

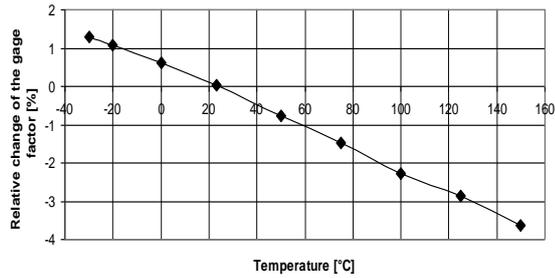


Fig. 7. Typical temperature dependent change in sensitivity of chrome – nickel strain gauges [1]

In case of using constantan strain gauges additional so called “Mod gauges” are required. Those nickel elements are introduced in the voltage supply line of load cells and made from special Nickel alloys. The nickel resistors are installed in such a way so that they have the same temperature conditions. If the temperature increases, the resistance of the nickel element increases as a consequence. Therefore the voltage drop at the nickel resistance increases—less voltage occurs at the Wheatstone bridge. This leads to less output voltage. The nickel elements can compensate the temperature behavior of the steel of the spring body as well as the constantan strain gauges.

The disadvantage of this technology is that the nickel elements lower the output signal at any temperature- values of 35 up to 70 Ohms for a precise constantan based load cells are usual - depending on the steel used and the optimization of strain gauge measurement foil.

Radial symmetric shear type load cells in combination with high end Chrome Nickel Strain gauges combine all three effects: Low mechanical load without strain gradients or peaks as a result of the design, higher gauge factor of the Chrome - Nickel strain gauges and the lack of so called “Mod-gauges”. This technology can be used in two ways: Optimizing the force sensor for use in experimental field or optimizing it for the use as a reference load cell.

2. USE OF RADIAL SYMMETRIC FORCE SENSORS

As shown before the radial symmetric load cell can be used in the field of experimental mechanics as the low mechanical load of the components (strain gauges and spring body).

The nominal output of strain gauges based sensor is in many cases 2mV/V. If the equation (1) is used and a strain gauge factor 2.3 is applied (which is very common for Chrome – Nickel strain gauges) the strain level is app. 850 $\mu\text{m}/\text{m}$ - if a Young’s modulus of 210000 N/mm^2 assumed for the spring body material the mechanical stress is just 178.5 N/mm^2 . The possibility of overload capability (Up to 300% of nominal force) and excellent fatigue behaviour is used widely.



Fig. 8. Radial symmetric shear load cell in use for experimental mechanics. Measurement of forces introduced in on board kitchens of aircrafts.

Well-designed shear beams can also be used for reference load cells. The design allows an electrical bending moment adjustment and a high output of > 4mV/V as a consequence of the conservative mechanical design.

The higher output reduces the mechanical overload capability and the fatigue performance, but in case of use as a reference load cell, the extreme high output signal is of higher importance than the mechanical robustness. The stress level of app. 350 N/mm^2 as a consequence of the doubled load is acceptable for use in the field of reference technology; the strain gauges do still work in their endurance range so that the load cell can be used for dynamic and static applications.

The higher output has two effects: Firstly the influence of all measurement errors relating to the full scale of the sensor are becoming just 50% of value compared with the 2 mV/V load cells. This is especially of importance for the temperature dependency of the zero point. This value can be calculated according:

$$TC_{zero} = \frac{\left(\frac{S_{Zero}(T_1) - S_{Zero}(T_2)}{T_1 - T_2} \right)}{S_{FS}}$$

Where

TC_{Zero}	Temperature dependency of the zero point
$S_{zero}(T_x)$	Output of the Sensor at Temperature T_x
T_x	Temperature x
S_{FS}	Output of the sensor under nominal force

In many cases it is more important that the requirements to the amplifier system is also reduced by a factor of two. The noise /signal ratio as well as the resolution benefit from the higher output of the load cell.



Figure 9: U15 radial symmetric shear force transducer for reference purposes. The bolt is mounted in the internal thread from the shelf as this guarantees best performance

3. SOME LIMITATIONS OF RADIAL SYMMETRIC SHEAR BEAMS

Radial symmetric shear beams are produced as so called flange sensors so that they have a low height. In case of using them for experimental tasks this is of advantage. In the field of reference purposes it is necessary to mount a so called load base.

The use of a load base allows a calibration of the mounted sensor which is a fundamental condition to reach the required performance in repeatability and reproducibility for the accuracy classes 0.5 and 00 according ISO376.



Figure 10: Radial symmetric shear beam force transducer as a flange (right) and with a loadbase (left)

The creeps between the load base and the force flange need to be installed very carefully. Under tensile forces any kind of movement of the flange relatively to the load base will lead to hysteresis errors. In case of compressive forces a complete unloading of the creeps has to be avoided also to achieve low hysteresis.

Further more the internal thread requires a mounting under a preload which is in any case higher than the force to be measured when using the sensor later on. A force transducer with a capacity of 1 MN requires a preload of the

bolt mounted in the central thread of 1.2 MN. In practice this can only be achieved at producers side or very well equipped customer workshops.

For reference radial symmetric shear beams the bolt is mounted at the load cell from the shelf and the transducer can be calibrated with bolt and load base.

The mounting under pre - load is especially of importance for measurement of compression forces as this load reduces the stress between the bolt and the internal thread. If the preload is going to be zero the interpolation error as well as hysteresis are increasing very much. Normally those reference sensors reach class 0.5 according the ISO376 standard in many cases better. Not correctly installed bolts do decrease accuracy dramatically.

4. RADIAL SYMMETRIC SHEAR BEAMS FOR COMPRESSION LOAD

To overcome the problem regarding highest required preload a new load cell was designed that takes the advantages of the radial symmetric shear system for compression use only.



Figure 11: Radial symmetric shear beam force transducer for compression forces

The load cell leaves away the internal thread and substitutes it for an load introduction.

As the technology is similar to the tension / compression load cells also the compression load cell offers an output of $>4\text{mV/V}$. As no tension occurs it is possible to optimize the strain gauge positions for compression, better performance is the result in all important properties. The test of the pre serial production was very successful as the class 00 according the ISO376 standard was found for all capacities in the range between 2.5 kN and 1 MN.

4. CONCLUSIONS

The radial symmetric shear beam load cells were optimized in the last years and did reach the level of the accuracy class 0.5. With the new technology for compression load class 00 was reached. The advantages (independence of bending moments, low influence of temperature effect, high output signal) are especially of highest interest if a measurement chain for calibration purposes with a limited budget is required. Radial symmetric shear types can be produced economical and reduce the requirement to the performance of the amplifier systems.

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