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# RADIAL SHEAR BEAMS USED AS HIGH PRECISION TRANSFERE TRANSDUCERS

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**Abstract** – Radial shear type transducers are frequently used in the field of experimental mechanics and test rigs as their spring body design allows a high dynamic bandwidth as well as best overload capability. But the design of the spring bodies as well as the used strain gauges allows the use of these transducers as reference transducers in the field of calibration.

**Keywords:** Reference force transducer, Radial shear beams, Force calibration

## 1. INTRODUCTION

All Force transducers with strain gauges are based on the same physical laws in every case.

The force to be measured is introduced into a spring body. This causes mechanical stresses inside the material. According to the Hooke's law the stresses are converted into strain. Strain gauges are installed in suitable areas, which convert the strains into a change of resistance. Next step is the use of the Wheatstone bridge circuit which turns these strains into a measurable output voltage.

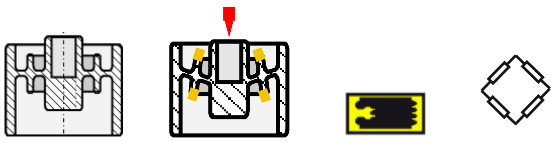

Fig. 1. From left to right: A spring body is affected by an external load. The deformation is measured by strain gauges which are connected to a Wheatstone bridge. A voltage to be measured is the final output.

In most of all cases the nominal strain in the area of strain gauge installation is 1000 µm/m. If the strain applied to all strain gauges is that value, we will find:

$$\frac{V_o}{V_i} = \frac{k}{4} \cdot (\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4) \quad (1)$$

$$\frac{V_o}{V_i} = 2mV/V \quad (2)$$

In (1) k is the gauge factor. The value of the gauge factor indicates the sensitivity of the strain gauge and is around two in case of constantan strain gauges. $V_o/V_i$ is the relative output of the transducer.

Many force transducers have an output 2 mV/V as this leads to a nominal strain of 1000 µm/m which is very suitable for most metals. The stress in case of steel as a spring body material is around 200Mpa in average. At this load a very linear relationship between stress and strain can be found, therefore it is possible to reach best measurement properties such as low linearity error and good hysteresis.

## 2. THE CONCEPT OF RADIAL SYSMMETRIC SHEAR BEAMS

### *2.1. The mechanical concept*

The used spring body has a big influence on the performance of the force transducer. Fig 2. shows a double bending beam. This transducer design is frequently used for load cells and force transducers as the production is cheap and linearity as well as hysteresis is very low. Strain gauges are installed in the area of lowest thickness of material.

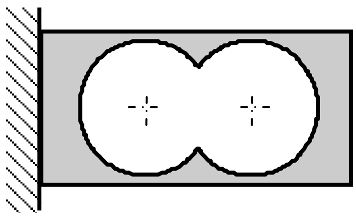

Fig. 2. A double bending beam: If force is applied to this spring body an s-shaped deformation can be obtained. Strain gauges are mounted in the area of lowest thickness.

Fig. 3 shows the strain field of such a kind of transducer. The mean value of strain is 1000 µm/m, but in the area of lowest thickness of the spring body strain values of 1500 µm/m can be obtained. Beside of this peak the strain level is lower and at the end of the measurement grids only 700 µm/m can be found

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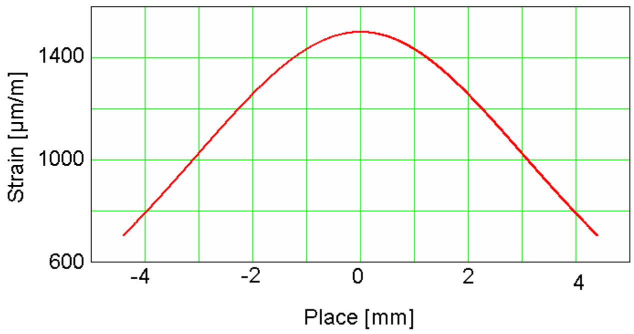



Fig. 3. Strain field of the double bending beam. Zero mm is the middle of the measuring grid of the strain gauges

As strain gauges always measure the mean value of the strain in the area of the measurement grid, the output signal of the load cell is still 2mV/V.

Also the stress shows a peak at the point of highest strain. Double bending beams reach a stress of typically 350 MPa in this area. This stress peak is the limitation for the overload capacity as well as for the dynamic bandwidth.

The spring body of a radial shear beam is shown in the Fig. 4 .

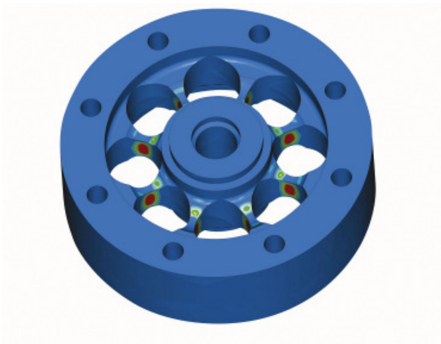
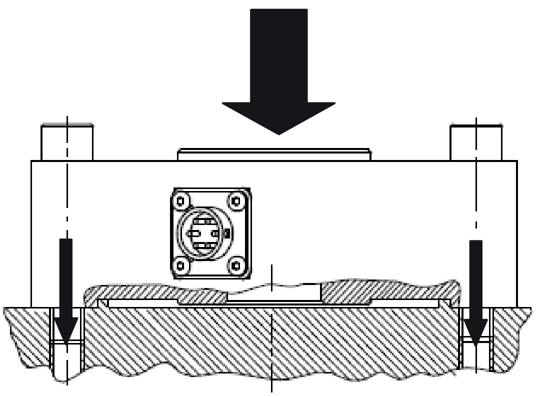


Fig. 4. Spring body of a radial symmetric shear beam. The shear stresses on the bars are used for strain gauge installation. The strain field is free of any gradients. Strain gauges are installed under 45 degrees so that shear strains are measured

Fig. 5 shows a radial bending beam from the side. The force is introduced in the centre of the upper side on the outer ring of the button side of the transducer as marked with arrows in Fig. 5



g. 5. Spring body of a radial symmetric shear beam looking from

A side view of a radial shear beam. The arrows show the force introduction.

The force introduced in such a kind of transducer leads to a shear stress in the area of the bars, which are used for strain gauge installation. The strain gauges are installed under 45 degrees relative to the centre line. Two strain gauges are installed on every bar one gauge on each side. One of the gauges measures a positive strain, the other a negative strain. Therefore every bar is temperature compensated. Eight gauges are used to be connected in a Wheatstone bridge circuit.

The strain field affected by the force is constant without any strain peaks. A calculation of the strain field of such a spring body under nominal load is shown in Fig. 6.

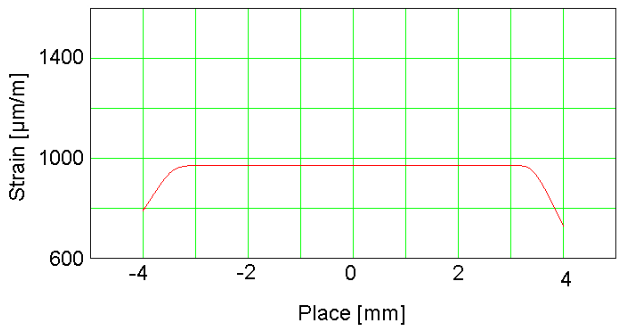



Fig. 6. Strain field of a radial symmetric shear beam: No strain peaks occur in the area of strain gauge installation. The stresses and strains are lower in all other areas of the spring body.

This concept leads to the lowest thinkable stress and strain values without any peaks. Therefore radial shear types show a very good mechanical performance such as a dynamic bandwidth of 200 % and an overload protection of more than 300% and due to the low stresses best linearity. An output signal of 2mV/V is reachable with maximum stresses bellow 200 MPa for steel load cells.

### *2.2. Strain gauge aspects*

Constantan is widely used as a strain gauge measuring grid material in the field of force transducer production. This material is easy to handle and shows very good properties such as linearity and hysteresis or temperature dependence of the zero point. As mentioned before gauge factor is around two and the dependence of the gauge factor relative to the temperature is positive. This means that the strain gauges get more sensitive with higher temperatures.

In addition to that the thermal change in sensitivity of the force transducer is also a result from the temperature dependency of the Young's modulus of the material used for the spring body. This causes higher strains for the same stress (load) level at a higher temperature.

Fig. 7 shows the Young's modulus of different possible transducer materials. It could be clearly seen that the modulus decreasing with increasing temperature.

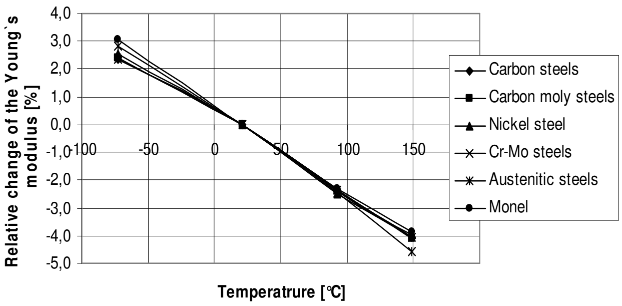



Fig. 7. Typical relative change of the Young's modulus for spring body materials

The result of both effects, the temperature dependency of the gauge factor as well as the temperature dependency of the young's modulus, is a strong temperature dependence of the sensitivity of the transducer. To compensate this so called "Span temperature compensation resistors" are installed in the voltage supply of the Wheatstone bridge.

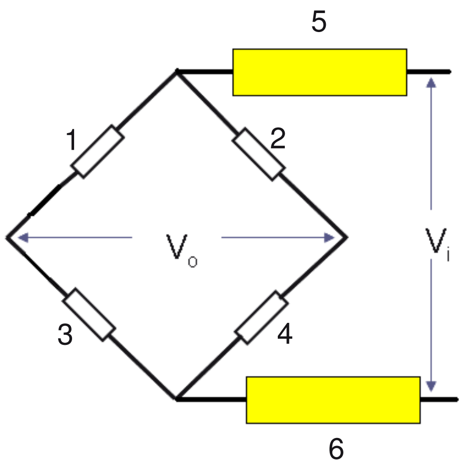



Fig. 8. Circuit of a Wheatstone bridge circuit with strain gauges (resistors 1-4) and span temperature compensation resistors (5 and 6)

Span temperature compensation resistors are made from nickel and show a very high temperature dependency of the resistance, which is around 5000ppm/K.

If the temperature increases, the span temperature compensation resistors will show a higher electrical resistance. This will result in a lower voltage at the Wheatstone bridge circuit as the span temperature compensation resistors and the Wheatstone bridge build a potential divider. This leads to a lower output of the Wheatstone bridge circuit. The reason therefore is that the output signal is in linear dependency to the input voltage of the bridge. As a result the change of the resistance of the span temperature compensation resistors with temperature compensates the temperature effects of Young's modulus of the spring body material as well as the temperature dependency of the gauge factor. The sensitivity of the transducer is constant over a wide temperature range.

On the other hand this concept leads to a voltage drop at the span temperature compensation resistors at every temperature. To reach the same output as a force transducer without span temperature compensation resistors higher mechanical strain is required.

As an alternative to constantan strain gauges in combination with span temperature compensation gauges it is possible to use chrome-nickel strain gauges for the production of force transducers. Comparing chrome-nickel as a measuring grid material with constantan, these strain gauges show a decreasing gauge factor with increasing temperatures.

Fig 9 shows the temperature effect of such a kind of strain gauges.

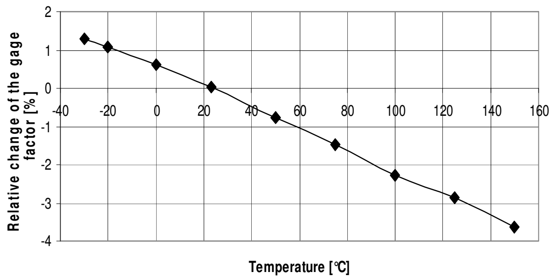



Fig. 9. Typical temperature dependent change in sensitivity of chrome – nickel strain gages

The relative change in resistance of a strain gauge in a stress field can be described as :

$$\left(\frac{\Delta R}{R}\right)_{mech} = \sigma \frac{k}{E} \qquad (3)$$

ΔR = change in resistance
R = basic resistance
σ = material stress
k = gage factor
E = Young's modulus

Equation (3) shows the principle of the compensation of the temperature dependence of the young's modulus of the spring body using chrome-nickel strain gauges. As mentioned before the sensitivity of a transducer as a function of temperature is primarily related to the change in the Young's modulus of the transducer material and the change in gage factor of the strain gage. If the relative change with the temperature of k is the same as for E, the ratio k/E remains the same. The influence of temperature effect of the sensitivity is substantially reduced. The temperature dependence of gauge factor and Young's modulus are compensating each other so that no span temperature compensation resistors are needed to be used any more.

In addition to that chrome-nickel strain gauges have a gauge factor which is 10% higher compared with constantan strain gauges.

Under use of chrome-nickel gauge gives the possibility to drop down the mechanical strain of the spring body as the higher gauge factor and the compensation effects of the temperature dependence of the Young's modulus lead to lower strain requirements in the area of strain gauge installation.

The consequence of higher gauge factor, no need for span temperature compensation resistors and mechanical design is the high dynamic bandwidth of 200% and a very high overload capability. Furthermore it is possible to produce radial shear beam transducers with an output of 4mV/V instead of the normal used 2mV/V using the lower strain and lower material stresses.

### *2.4. Using radial shear types as reference transducers*

Looking at the measurement uncertainty of force transducers, the single effects can be classified into two groups.

Some effects like creep or temperature dependence of sensitivity are related to the current measurement value, others like the temperature dependence of the zero point are related to the full scale output of the transducer.

All errors which are related to the nominal output of the transducer have a lower impact with the higher output of radial shear types.

### *2.5. Temperature coefficient of zero point*

As the output is doubled, the relative influence of this error is just the half.

This is of importance as temperature coefficient of the zero point is one of the widest impacts on the error calculation of calibration measurement. This error is dropped down by the factor of two compared with a 2mV/V transducer.

Therefore a use of radial shear beams for mobile calibration tasks where constant temperature conditions can not be guaranteed is very suitable, as temperature influence also gradients have a very low impact.

Furthermore the strain gauge arrangement with two gauges on every bar compensates temperature gradients.

### *2.6. Signal noise ratio and resolution*

With the doubled output the signal noise ratio becomes two times better with radial shear beams. The resolution of the measurement system will be better as the full input of the amplifier systems can be used.

Therefore a simpler amplifier system with lower resolution can be used in many cases.

### *2.7. Hysteresis and Linearity*

Hysteresis and linearity of radial shear beam transducers are in the suitable to guarantee a classification "05" according the ISO376.

There is a potential for further improvement if the mounting situation of the transducer relative to its adapters can be optimized in the future.

### *2.8. Further aspects*

The other technical characteristics of radial shear beam transducers do not show better characteristics by using a higher output signal, as these errors are related to the current load. Creep, thermal dependence on the sensitivity as well as repeatability can not be decreased by a higher output. On the other hand all these characters do not show any values worse compared with transducer using the 2mV/V technology.

Radial symmetric shear beams show a linear function between force and strain in the area of strain gauge installation so that no linearization is required. This linearization is normally realized by using semiconductor strain gauges, which causes another voltage drop in the supply line of transducers

The dimensions of radial shear beams and their weight is low with respect to the capacity. Especially the height of these transducers shows very compact masses.

## 3. CONCLUSIONS

In this article the construction of radial shear beams was presented.

It was shown that the combination of modern strain gauge technology and design of the spring body lead to a wide dynamic bandwidth of 200 % or a high output signal of 4mV/V. This is the root for best temperature behaviour as the relative error of the temperature effect of the zero point can be dropped down by the factor two. The strain gauge arrangement guaranties also a low impact of temperature gradients.

For this reason radial shear beams are the best choice for calibration tasks under industrial environment where highest accuracy is not as important as resistance against influences of the environment and light weight construction.

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