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HIGH CAPACITY REFERENCE TRANSDUCER FOR TENSILE FORCES

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Abstract: It is visible on the market for reference transducers that there is a growing demand for higher forces. In the last years several new sensors came up, such as the C18/5MN which offer a low measurement uncertainty combined with measurement ranges in the Mega newton ranges. This article presents a strain gauge based transducer for tensile forces of up to 6.5 MN features four galvanic insulated Wheatstone bridges.

Keywords: Reference Transducer, Tensile forces, High Capacity force transducers

1. INTRODUCTION

In the past the force measurement technology was mainly driven by the automotive industry. In this field of application load cells with capacities up to 500 kN were in use for experimental tasks. Following this demand the mostly required forces for calibration tasks were also in this range.[1]

In the last period there is a clear trend to higher capacities, driven by new opportunities, as shown in the following examples

- The wind energy industry needs to test gear boxes and bearing elements of larger wind mills- the forces are growing to 2.5 MN and even higher values in those test rig applications.
- The railway industry develops larger locomotives with more power. The consequence is the same as with the requirement in the wind industry: Higher .forces need to be measured and calibration facilities for these sensors are required
- The larger aircrafts which are now available were tested and qualified in new tests rigs with suitable for high forces

The consequence of higher capacity load cells is the demand of calibration in those higher force ranges and therefore the need for high capacity force transducers for reference tasks.

2. CURRENT STATE OF FORCE TRANSDUCERS FOR EXPERIMENTAL TAKS

The requirement on load cells for test rigs and experimental tasks, especially dealing with those high forces is very often not the highest accuracy, but a higher degree of protection, low influence of lateral forces and bending moments as well as double and triple bridges for safety reasons.

The so called “pan cake style” has taken place in this field of application.

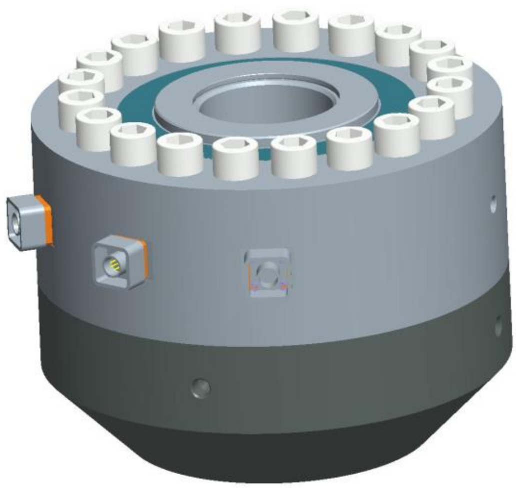

Figure 2.1: Pancake with Load base for nominal forces up to 1.5MN (dynamic) and 3MN (static). Triple bridge version.

Those radial shear type sensors have been proofed for those applications also for lower capacities from 1.25 kN on.

It can be shown that radial symmetric shear beams such as a U10M are also a very reasonable alternative for references tasks, especially for calibration on side [1]. Looking at higher forces it hast to be taken in account, that the spring bodies are becoming quite heavy and the screws that connect the load base with the spring body show a critical behaviour in case of tensile forces in the range of Mega - Newton.

Figure 2.2: Pancake without load base. (Flange) The holes on the outer ring are designed for a suitable connection between flange and load base

A pancake consists of two parts in general: The load base and the flange load cell itself. The mechanical connection is realized with screws of high strength grade. The quality of the sensor is depending on the perfect connection between load base and flange, in means of a suitable pressing per unit of area between the two parts. It is visible that this condition is easy to fulfil for compression forces, in case of tensile loading the things are becoming more difficult. The screws have to withstand the force to be measured as well as the mechanical stress required to ensure the pressing.

In any case a lower pressing will be the result. Depending on the force introduced the pressing is especially reduced in case of high tensile forces. Under this condition very little movements between flange and load base cannot be avoided- this leads to a different stress state at the point where the strain gauges are installed.

The consequences are:

- Limitations in zero point return
- Hysteresis will increase

Capacity	2.5 kN...10 kN	25 kN...50 kN	100 kN...500 kN	1.000 kN
Hysteresis rel. to measurement value (data sheet)	750 ppm	1.000 ppm	1.250 ppm	1.500 ppm
Hysteresis rel. to measurement value (typical)	400 ppm	500 ppm	750 ppm	1.250 ppm
Zero point return (data sheet)	100 ppm	100 ppm	100 ppm	200 ppm
Zero point return (typical)	50 ppm	60 ppm	80 ppm	150 ppm

Table 2.1: U15 Pancake: With increasing capacity increasing values for hysteresis and zero pint return.

Capacity	2.5 kN...10 kN	25 kN...50 kN	100 kN...200 kN	500 kn
Hysteresis rel. to measurement value (data sheet)	300 ppm	300 ppm	300 ppm	700 ppm
Hysteresis rel. to measurement value (typical)	200 ppm	250 ppm	250 ppm	500 ppm
Zero point return (data sheet)	40 ppm	40 ppm	40 ppm	40 ppm
Zero point return (typical)	15 ppm	15 ppm	25 ppm	30 ppm

Table 2.1: Top-Transfer Transducer with monolithic design: The hysteresis and zero point return show a much better performance.

The tables above show the advantages of the performance of a reference transducer constructed in a monolithic design (TOP – Transfer). Zero point return and hysteresis can be approved by a factor of two as a minimum; all over the monolithic sensors fulfil the requirements of the class 00 according the ISO376 for all for four cases, (Cases A, B, C and D, means suitable for calibration tasks for in- and decreasing forces) while a pancake can only fulfil those requirements if used for increasing forces only.

In the use for in- and decreasing forces the hysteresis limits according the current status of technology the accuracy to the class 0.5 according the ISO 376 Standard for pancake style sensors.

In [3] the progress of the performance of radial symmetric bending beam force transducers was shown if they are constructed in a completely monolithic way. Currently those sensors are available on the world market in capacities up to 500 kN. 1 MN is visible, but higher capacities show an enormous weight.

Figure 2.3: Force transducer Top – Z4a/500KN. Completely monolithic structure of the spring body.

Capacity	1,25 MN	2,5 MN	5 MN
Weigth	160 kg	380 kg	700 kg
Thread	M120x4	M150x4	M200x4
Diameter	390 mm	520 mm	660 mm

Table 2.3: Radial symmetric shear beams: Weight and dimensions of large capacity spring bodies

The Table 2.3 shows the dimension and weight of radial symmetric bending beams of higher capacities. The values can be taken for pancakes as well.

3. CONCEPT OF A TENSION BAR WITH FOUR WHEATSTONE - BRIDGES

Looking at the thoughts above a suitable reference force transducer for capacities in the Meganewton range and acceptable performance in tension has to be made in a monolithic design. Furthermore the dimensions have to be suitable as well as the weight as the sensors need to be trasnported in many cases.

Tension bars are a very easy to realise mechanical concept for force measurement. [2]

The force is applied on the bar and under ideal conditions a single axis stress state can be obtained on the surface. ($\sigma_2 = 0$). The strain level can be calculated by

$$\varepsilon = \frac{F}{A \cdot E} \qquad (1)$$

Meanings are as follows:

ε: Strain
F: Force applied on the sensor
E: Young´s modulus of the spring body material
A: Cross section of the tensile bar

To turn the strain gauge signal into a measurable voltage the Wheatstone bridge configuration is a so called Poisson bridge. Within this circuit two strain gauges are working in the direction of principle stress, while the two others are using the Poisson effect. There for the strain gauges are installed in a direction of 90 degrees to the principle stress The occurring strain in this direction is negative and can be calculated by using the Poisson ratio.

The output is

$$\frac{U}{U_0} = k \cdot (1+\nu) \cdot \varepsilon \qquad (2)$$

Meanings are as follows:

U/U_0: Relative output voltage of the Wheatstone bridge
k: Gauge factor of the used strain gauges
υ: Poisson ratio

Tension bars are not perfect linear sensors as the cross section is depending on the load. A bar under tensile load shows due to the Poisson effect a change in cross section area:

$$A = \frac{F}{E \cdot \varepsilon} - \nu \cdot \varepsilon \qquad (3)$$

Meanings are as follows:

υ: Poisson ratio
ε: Strain
F: Force applied on the sensor
E: Young´s modulus of the spring body material
A: Cross section of the tensile bar without load

In case of industrial sensors a correction of the linearity error is applied in most cases. This is realized by high sensitive strain gauge connected in the voltage supply of the Wheatstone bridge. As every resistance in the voltage supply line means a lower output on the other side, the consequence is a lower accuracy in many properties, such as TCZero or resolution, this technology is not realized for reference transducers. The linearity is also no aspect with reference force technology as the high precision instruments like HBM´s DMP41 feature a mathematical compensation anyhow.

It is important to note that no output can be measured in case of bending load as this is compensated by the Wheatstone bridge. Furthermore an electrical bending moment adjustment took place [2]. This is achieved by installing four measurement points distributed around the sensor. By an electrical adjustment all bridges for tension have the same sensitivity. In case of bending the measuring points positioned on opposite sites compensate each other.

The following picture shows the principle. The gauges 2/3, 4/5, 6/7 and 8/1 are installed in one measurement point, the resistances are connected for adjustment of the sensitivity. This method is always requiring information about the bending moment sensitivity of the bridges installed for tension measurement. In addition to that eight strain gauges are the minimum and the configuration explained before is required for this technology.

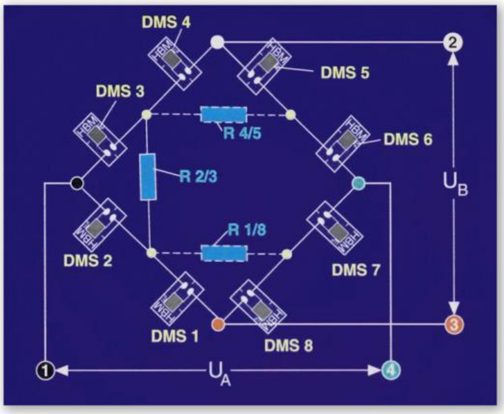

Figure 3.1: Electrical bending moment adjustment.

In reference purposes it is very often of importance to have information about the bending moment that is applied to the sensor. This can be achieved by the concept of the so called strain cylinders, which feature four independent Wheatstone bridges working sensitive to tension and compression. According the international standard *EN 12390-4* [4] the bending influence can be analysed.

Another method is to use a strain gauge configuration that is sensitive to bending only as an additional Wheatstone measuring bridge. This can be achieved installing two measurement points featuring two gauges each on the opposite side of the force transducer. In this configuration all measuring grid are installed in the direction of the bar.

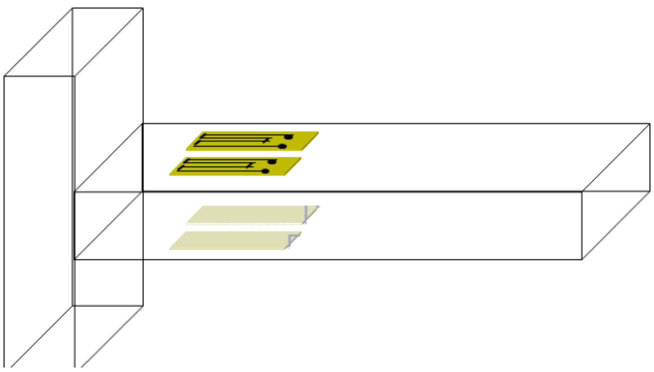

Figure 3.2: Strain gauge arrangement for bending sensitive measurement. Upper gauges are connected as gauge 1 and 3- positive strain lead to positive output, lower gauges are connected as gauges 2 and 4 – negative strain lead to positive out put

The strain gauge configuration is insensitive against pure tension or compression. For strain gauges are required as a minimum, two under tension in case of bending two under tension, mounted exactly on the opposite side.

The output of the transducer at a certain bending moment is given by

$$\frac{U}{U_0} = k \cdot \frac{M_b}{E \cdot \pi} \cdot \frac{32}{d^3} \qquad (4)$$

Meanings are as follows:

M_b: Bending moment
d: diameter of the spring body in the area of strain measurement

The formula above describes transducer with round cross sections. Due to the manufacturing process this design is mostly used.

If two bridges are used in that way so that the direction of measurement is 90 degrees to each other, bending moments in two directions can be measured. Figure 3.3. shows the installed strain gauges in the two of the four positions. Two bridges are used for the measurement of the tensile forces. (Four measurement points distributed around the sensor) another two bridges are in place for the measurement of bending in X- and Y-direction. (Two measurement points 180 degrees two each other for each bending sensitive Wheatstone bridge)

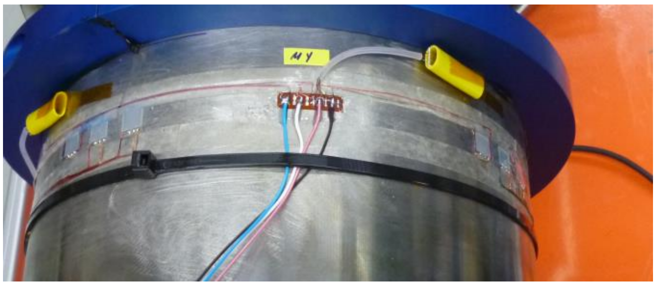

Figure 3.1: Strain gauge installation on a 6.5MN tension bar. Two Wheatstone bridges for tension and two bridges for bending are installed

For lower capacity force transducer a bending moment can be introduced into the sensors by using the machine shown in the picture bellow. Applying a bending moment in this way there is also the possibility to have a calibration for bending moments.

Figure 3.2: Machine for the introduction of bending moments. The sensor is mounted on the plate (left) the weights (right, button) are applied over a lever arm. The sensor turns while measurement so that a constant bending can be applied all directions.

The calibration of bending moments is currently not related to any standard.

4. REALISATION OF A 6.5 MN TRANSDUCER FOR TENSILE FORCES

The following picture shows an example of a sensor working according this principle. The design is a tensile bar and two Wheatstone bridges for tension and two bridges for bending are installed as described above.

The nominal output is 1mV/V in order obtain highest reliability and mechanical robustness. The hysteresis error could be limited to 150 ppm relative to full scale- at 20% of the nominal load 0,08 % to the actual value was achieved for both tensile bridges.

Figure 4.1: 6.5MN Tension bar in the 5MN calibration machine of HBM.

5. REFERENCES

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