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The mechanical design of a strain-gage based load cell

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In this article we will cover the basic calculations and the mechanical design of a strain-gage based load cell.
To convert a rectangular bar into a load cell, four strain gages are mounted on the central region of the bar with two opposite gages in the axial direction and two opposite gages in the transverse direction, as shown in Fig. 1.
When a axial load P is applied to the bar, the axial and transverse strains produced are

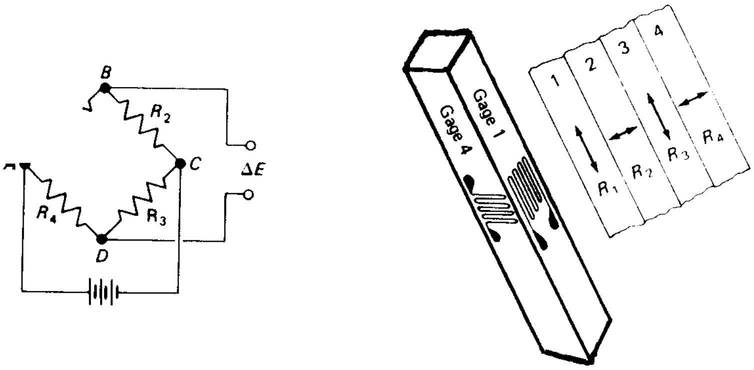
$$\epsilon_a = \frac{P}{AE} \quad ; \quad \epsilon_t = -\frac{\nu P}{AE}$$

where A = cross-sectional area of the rectangular bar,
E = modulus of elasticity of the material, and
ν = Poissons ratio of the material.

If the four gages are positioned in the Wheatstone bridge as shown in Fig. 1, the ratio of output voltage to supply voltage $\Delta E/V$ is given by

$$\frac{\Delta E}{V} = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right)$$

Actually we have placed eight strain-gages in the bridge to increase the output voltage to supply voltage ratio.



Developed surface showing gage orientations.

Figure 1. Strain-gages mounted on the bar to produce a load cell.

The changes in resistance of the four gages on the rectangular bar are

$$\frac{\Delta R_1}{R_1} = \frac{\Delta R_3}{R_3} = S_g \epsilon_a \quad ; \quad \frac{\Delta R_2}{R_2} = \frac{\Delta R_4}{R_4} = S_g \epsilon_t$$

When substituting the two above equations it gives

$$\frac{\Delta E}{V} = \frac{S_g P}{2AE} (1 + \nu)$$

The gage factor S_g is for a metallic strain gage equal to 2. It is evident that the ratio $\Delta E/V$ is linearly related to the load P. The magnitude of $\Delta E/V$ will depend upon the design of the rectangular bar, i.e., its cross-sectional area A and the material constants E and ν. In most commercial load cells $\Delta E/V$ varies between 0.001 and 0.003. Steel with E = 207GPa and ν = 0.30 is usually used to fabricate the bar. The range of the load cell P_R is then

$$P_R = A \frac{\Delta E}{V} \frac{E}{1+\nu}$$

The upper limit on the output signal $\Delta E/V$ is determined by the strength of the rectangular bar and the fatigue limit of the strain gages. The maximum stress in the bar is

$$\sigma = \frac{P}{A} = \frac{\Delta E}{V} \frac{E}{1+\nu}$$

Placement of the strain gages on the four sides of the bar, as shown in Fig. 1, provides a load cell which is essential independent of either bending or torsional loads. Temperature compensation is also achieved with the four active strain gages in the bridge.

It is subjected to great calibration errors if you determine the voltage-strain relationship from the equations.

A more precise and direct procedure is to apply different loads to the load cell and read the output voltage from the amplifier.

For the load cell we use a bar of the material DIN St.35.7 and a side length of 0.02 m. The yield stress and cross-sectional area can then be found to

$$\sigma_{0.2} = 0.7 \cdot 35\,kp/mm^2 = 240\ MPa$$
$$A = (0.02\,m)^2 = 4 \cdot 10^{-4}\,m^2$$

Further the modulus of elasticity E is 210 GPa and Poisson's ratio ν is 0.3 for the rectangular bar. Now the safety factor can be obtain

$$S_f = \frac{\sigma_{0.2}}{\sigma} = \frac{\sigma_{0.2}}{\Delta E/V} \frac{1+\nu}{E} = 1.49$$

which is acceptable. Here we use the lower limit for the $\Delta E/V$ ratio. The maximum range of the load cell is

$$P_r = A \frac{\Delta E}{V} \frac{E}{1+\nu} = 65000\,N \simeq 6.5\ tons$$

The strain gages must have a fatigue limit there is at least twice the applied strain which is

$$\epsilon_a = \frac{P_r}{AE} = 770\,\mu s \quad ; \quad \epsilon_t = -\frac{\nu P_r}{AE} = -230\,\mu s$$

Normally the fatigue limit is approx. 2000 μs for the most common strain gages. Further the strain gage must be of the same material as the rectangular bar. On the next page there is a drawing of the load cell.

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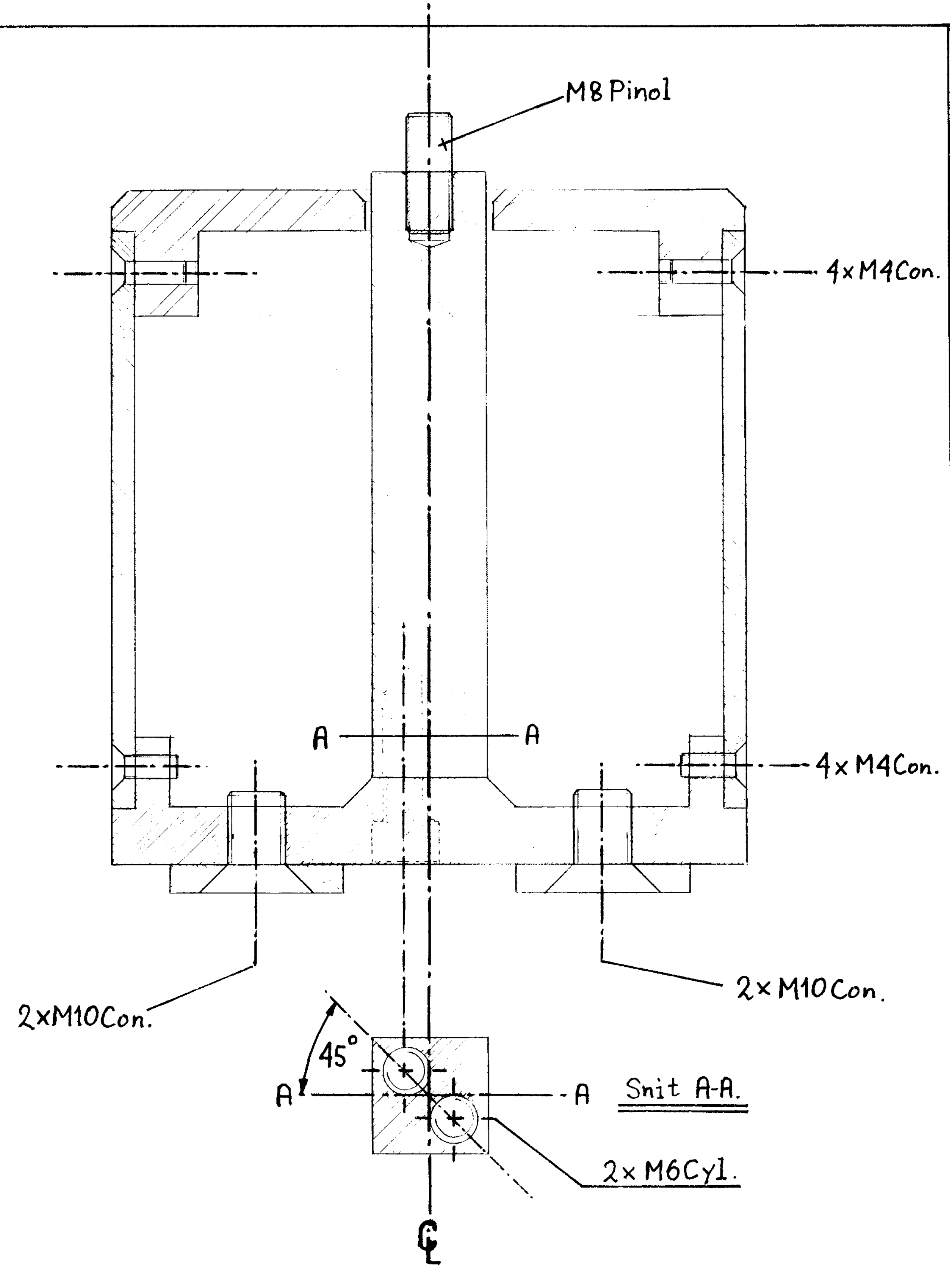

Strain gauge-baseret
Loadcell - Indtil 5ton.
Samlingstegning.
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