FACULTY OF MECHANICAL ENGINEERING institute of solid mechanics, mechatronics and biomechanics

Experimental mechanics (REM)

Name:	Václav Valíček	
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Assigment name:	**K factor**	
Supervisor	Ing. Petr Krejčí, Ph.D.	Evaluation:

Assignment

Identify the magnitude of gage factor of strain gauge attached tobeam loaded with 4-point bend. Process results using uncertainty measurement methodology.

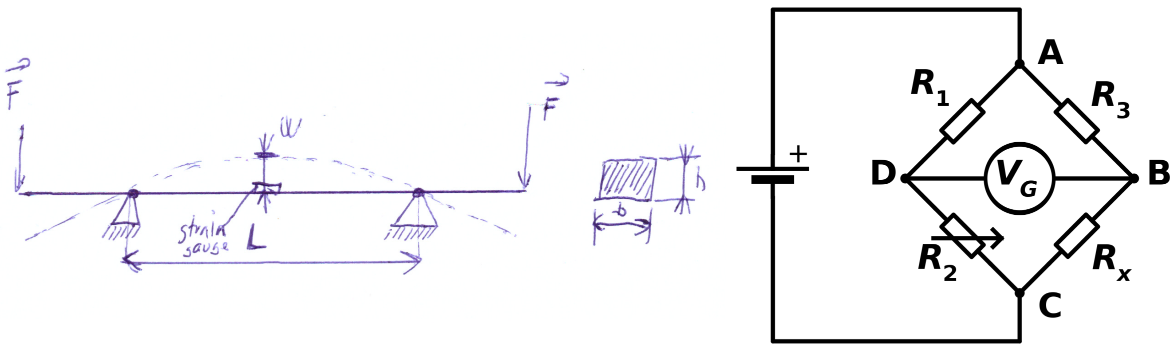
Experiment

Overview

Gage factor plays part in formula for relative change in resistance of strain gauge:

$$\frac{\Delta R}{R} = k * \epsilon \quad (1)$$

Where k stands for gage factor (dimensionlesss). It's usual value is around 2.



(a) Apparatus scheme

(b) Compensator wiring

Figure 1: Experiment basics

Where w is rod deflection, h is rod height, L displacement between supports, R_* resistance of resistor belonging to compensator. R_x is strain gauge, R_2 variable resistor used to balance Wheatstone bridge, V_G is galvanometer.

Measurement

Knowing resistance of strain gauge (equation 1), gage factor (k-factor) can be expressed in few steps. At first it's needed to determine deformation sensitivity compared to resistance of strain gauge:

$$k = \frac{\frac{\Delta R}{R}}{\epsilon_s} \tag{2}$$

Where $\frac{\Delta R}{R}$ is resistance change of strain gauge and ϵ_s is actual deformation of test sample in area of strain gauge. Resistance change can be expanded with knowledge of basic Wheatstone bridge:

$$\frac{U_v}{U_n} = \frac{\Delta R}{4R} = \frac{1}{4} * k_z * \epsilon_i \tag{3}$$

Where k_z is k-factor set on measuring amplifier (usually $k_z = 2$) and ϵ_i is deformation indicated on measuring amplifier. From the above it follows:

$$\frac{1}{4} * k_z * \epsilon_i = \frac{1}{4} * k * \epsilon_s \tag{4}$$

$$k = 2 * \frac{\epsilon_i}{\epsilon_s} \tag{5}$$

$$k = 2 * \frac{\epsilon_i}{w * \frac{4*h}{L^2}} \tag{6}$$

$$k = 2 * \frac{\epsilon_i * L^2}{2 * h * w} \tag{7}$$

Where ϵ_s is function of L, w and r (radius of sag line), which can be expressed as:

$$\frac{1}{r} = \frac{M_b}{E * J} = \frac{W_b * \sigma}{E * J} \tag{8}$$

$$\frac{1}{r} = \frac{W_b * E * \epsilon_s}{E * J} = \frac{2 * \epsilon_s}{h} \tag{9}$$

$$\frac{1}{r} = \frac{8 * w}{L^2} \tag{10}$$

To determine combined uncertainty of k-factor we had to obtain three measurement sets with different sag of beam. Measuring started with checking of height and displecement of beam support. Since 17 students attended, we got 17 values in table **??**

h [mm]	9.5	9.1	9	9.2	9.12	9.02	9.11	9.1	9.01
L [mm]	300	300	301	301	301.5	301	301	301	301
h [mm]	9.2	9.02	9.12	9.12	9.21	9.1	9.1	9.2	-
L [mm]	301	300.5	300	300	301	301	301	300.5	-

Table 1: Measure of rod dimensions

As it was mentione earlier, we had to make 3 sets of measures. Using bolt and mechanism, beam was loaded and bent in multiple steps containing adjusting force, balancing Wheatstone bridge with compensator and measuring compensator value. For each measuring set, there was value A (initial state) and bunch of values B (changing every step). From those, we could calculate $\epsilon_i = B - A[\mu/m]$. Unit of w is mm.

w	A	B	ϵ_i
0.0		25800	0
0.2		25883	83
0.4		25974	174
0.6		26059	259
0.8		26144	344
1.0	25800	26230	430
0.8		26146	346
0.6		26062	262
0.4		25978.5	178.5
0.2		25891	91
0.0		25815	15

w	A	B	ϵ_i
0.0		25815	0
0.2		25900	85
0.4		25986.5	171.5
0.6		26071	256
0.8		26155	340
1.0	25815	26239	424
0.8		26153	338
0.6		26070	255
0.4		25984	169
0.2		25899	84
0.0		25816.5	1.5

w	A	B	ϵ_i
0.0		25817	0
0.2		25904	87
0.4		25989	172
0.6		26074	257
0.8		26161	344
1.0	25817	26246	429
0.8		26157.5	340.5
0.6		26073	256
0.4		25991	174
0.2		25905	88
0.0		25818.5	1.5

Table 2: Three measures

Calculation

To obtain combined uncertainty of measurement (u_k) there needs to be defined uncertainty u_A and u_B.

At first, there were computed arithmetic means of essential values according to equation 11.

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i \tag{11}$$

Obtained values are:

$$\bar{h} = 9.13\ mm$$
$$\bar{L} = 300.7\ mm$$
$$\bar{w} = 0.45\ mm$$
$$\bar{\epsilon_i} = 195.62\ \mu m/m$$

Uncertainty of type A

Calculation of individual standard uncertainties by method A is done by equation 12.

$$u_{Ax} = \sqrt{\frac{1}{N*(N-1)} * \sum_{i=1}^{N} (x_i - \bar{x})^2} \tag{12}$$

Obtained values are:

$$u_{Ah} = 0.033\ mm$$
$$u_{AL} = 0.105\ mm$$
$$u_{Aw} = 0.057\ mm$$
$$u_{A\epsilon_i} = 24.052\ \mu m/m$$

Transmission (sensitivity) coefficients needs to be calculated (see eq. 13).

$$A_x = \frac{\delta k}{\delta x} \tag{13}$$

Obtained values are:

$$A_h = -0.236\ mm^{-1}$$
$$A_L = 0.014\ mm^{-1}$$
$$A_w = -4.784\ mm^{-1}$$
$$A_{\epsilon_i} = 11004.1$$

Finally uncertainty of type A can be calculated (see eq. 14).

$$u_A = \sqrt{u_{Ah}^2 * A_h^2 + u_{AL}^2 * A_L^2 + u_{Aw}^2 * A_w^2 + u_{A\epsilon_i}^2 * A_{\epsilon_i}^2} = 0.38 \tag{14}$$

Uncertainty of type B

Uncertainty of type B is determined from maximum possible deviations of z_{max} for individual measurement instruments. Those are:

- caliper - $z_{max} = \pm 0.01\ mm$
- ruler - $z_{max} = \pm 0.25\ mm$
- dial gauge - $z_{max} = \pm 0.5\ \mu m$
- manual balancer - $z_{max} = \pm 2\ \mu m/m$

Calculation of individual standard uncertainties by method B is done by equation 15 where $\chi = \sqrt{3}$ as normal division is assumed.

$$u_{Bx} = \frac{z_{max}}{\chi} \tag{15}$$

Hence obtained values are:

$$u_{Bh} = 0.012\ mm$$
$$u_{BL} = 0.144\ mm$$
$$u_{Bw} = 0.289\ \mu m$$
$$u_{B\epsilon_i} = 1.155\ \mu m/m$$

Uncertainty of type B is calculated by equation 16:

$$u_B = \sqrt{u_{Bh}^2 * A_h^2 + u_{BL}^2 * A_L^2 + u_{Bw}^2 * A_w^2 + u_{B\epsilon_i}^2 * A_{\epsilon_i}^2} = 0.013 \tag{16}$$

Combined uncertainty and k-factor

Combined uncertainty and k-factor are calculated. For combined uncertainty is given equation 17 and for k-factor already computed equation 7.

$$u_k = \sqrt{u_A^2 + u_B^2} = 0.381 \tag{17}$$

$$k = \frac{\epsilon_i * L^2}{2 * h * w} = 2.15 \tag{18}$$

K-factor of strain gauge is: $\underline{k = 2.15 \pm 0.381}$

Conclusion

Large set of data was measured and evaluated during experiment resulting in gage factor (k-factor) of value 2.15 with uncertainty ±0.381. Value of k-factor (2.15) could be right, as it's close to 2. Uncertainty is aroun 18% which is bit more then it should be, but after remembering how measuring was done even this number makes sense.