Exercise 7
Harmonic oscillator: the spring

Aim

Determination of the elasticity coefficient of the spring and the shear modulus (rigidity) of the material, experimental verification of the Hooke's law and the theory describing the pendulum spring.

Required theoretical knowledge

The theory of simple harmonic motion. Derivation of the formula for the period of the pendulum mass including the spring mass. Elastic properties of solids, in particular Hooke's law, modulus of elasticity, Young's modulus, rigidity modulus. Derivation of the formula for rigidity modulus of the spring material based on its geometric parameters and the elasticity modulus.

Equipment

Set are springs, tripod with integrated scale allowing to determine the static extension of springs (due to suspended weights), mechanical weight, slide caliper, micrometer screw and a stopwatch.

Problems for discussion:

Introduction of the Hooke's law in the form of a graph of force and interpretation of the slope. Dependence of the elasticity coefficient. What is the Young's modulus and stiffness modulus, and what are their units in the SI system?

Measurement plan:

1. Determination of the elasticity modulus using the static method.

a) Weigh different weights (ask teaching assistant which ones)
b) Determine the static extension of given spring x for different loads F.
c) Draw a graph of $F(x)$ and the fit to the experimental points by a simple **one-parameter** linear regression.
d) On the basis of the slope of the fitted line determine modulus and its uncertainty.

Problems for discussion:

What determines the period of oscillation of the pendulum spring? Sketch the graph of the square of the period of the mass of the weight and interpret the slope of the line and the point of intersection with the x axis.

2. Determination of the elasticity modulus using the dynamic method.

a) Measure the duration time of the oscillation twenty oscillation periods for each mass M.
b) Draw a graph of $T^2(M)$ and the fit to the experimental points using simple linear regression with **two parameter**.
c) Interpret the parameters of the fitted line and determine the elasticity modulus and its uncertainty.

3. Determination of rigidity modulus *G*.

a) Compare the uncertainty of elasticity modulus measured using method 1 and 2. For the determination of the rigidity modulus select a value with less uncertainty.
b) Count the number of turns of the spring *n*, measure the diameter of the wire, and the diameter of the spring coils in several places, calculate the average of the wire radius *r* and the average radius of the spring *R* and their uncertainties.
c) Determine the rigidity modulus G and its uncertainty.

Problems for discussion:

Transform pattern on the modulus of elasticity: $k = \frac{Gr^4}{4nR^3}$ *, so that the stiffness modulus can be calculated How to estimate the uncertainty values, which are based on other values with given uncertainties (name the method and present example).*

4. Conclusions

Compare the determined rigidity modulus with table values for different materials presented below and try to deduce, taking into account the uncertainty defined value, what is the spring made of. What may be the most important sources of uncertainty modulus?

Material	Typical rigidity modulus in [GPa] at room temperature	Material	Typical rigidity modulus in [GPa] at room temperature
Diamond	478	Gold	27
Silicon- manganese steel	85	Glass	26.2
Coal steel	77 ... 81	Aluminum	25.5
Copper	45	Concrete	2.2
Titanium	41	Lead	0.60
Brass	35	Polyethylene	0.117
		Rubber	0.0006

Sources:
http://www.wolframalpha.com
http://en.wikipedia.org/wiki/Shear_modulus

Literature

1. *Halliday, Resnick "Fundamentals of Physics - 8th edition", John Wiley 2007,*
2. *Pracownia Fizyczna Wydziału Fizyki i Techniki Jądrowej AGH, Część I. Wydanie drugie, pod redakcją Andrzeja Zięby, Kraków 1999. Skrypty uczelniane SU 1608, str. 87.*