Harmonic oscillations of spiral springs with CobraSMARTsense

Physics | Acoustics | Wave Motion

Difficulty level	Group size	Preparation time	Execution time
-	-	-	-

General information

Application

Fig. 1a: Setup parallel springs

Fig. 1b: Setup for springs im series

Harmonic oscillations are an integral to the study of vibrations and fluctuations. As such they are widely used in fields such as solid state physics, particle physics and thermodynamics.

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Other information

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Prior knowledge

The prior knowledge for this experiment is found in the Theory section.

Main principle

The spring constant k for different springs and connections of springs is determined. For different experimental set-ups and suspended mass the oscillation period is measured.

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Equipment

Position	Material	Item No.	Quantity
1	USB charger for Cobra SMARTsense and Cobra4	07938-99	1
2	Weight holder, 10 g	02204-00	1
3	Slotted weight, black, 10 g	02205-01	4
4	Slotted weight, black, 50 g	02206-01	7
5	Tripod base PHYWE	02002-55	1
6	Support rod, stainless steel, 1000 mm	02034-00	1
7	Right angle clamp expert	02054-00	1
8	Helical spring, 3 N/m	02220-00	2
9	Helical spring, 20 N/m	02222-00	1
10	measureLAB, multi-user license	14580-61	1
11	Cobra SMARTsense - Force and Acceleration, ± 50N / ± 16g (Bluetooth + USB)	12943-00	1

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Setup and Procedure

Setup (1/2)

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This experiment needs the software measureLAB. You can downlaod the measureLAB-Software at the PHYWE website or using following QR-Codes to download the software.

measureLAB

for Windows

measureLAB

for macOS

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Setup (2/2)

- In accordance with Fig. 1 the spring constants of the springs are measured. In total three springs are used: spring 1 and spring 2 with a spring constant of k = 3 N/m and spring 3 with k = 20 N/m
- Three measurement series are to be performed. At first, set each of the springs (spring 1 or spring 2 and spring 3) oscillating with varying suspended masses, determine the oscillation period and calculate the spring constant. Then connect two springs in parallel and in series and determine the spring constant again.
- The combinations of springs and suspended mass that are to be measured are listed in tables 1–3.

Procedure (1/2)

- Start the PC and Windows.
- Connect the Sensor with the PC
- Start the measure software package on the PC.
- Switch on the Sensor. The sensor is now automatically recognized.
- On being switched on, the force sensor is tared, i.e. at the start it shows a weight of 0 N.

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Procedure (2/2)

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- Load experiment (Experiment > Open experiment). All necessary settings for the recording of measured values will now be started.
- Start measured value recording in measure .
- Record the oscillation of the spring pendulum for approx. 1 minute, then end the measurement . Choose "send all data to measure". Repeat the measurement for all combinations of springs and suspended mass.

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Evaluation

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Evaluation (1/6)

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A typical measurement result is shown in Fig. 2. The spring force is at a minimum at the upper inversion point (no extension by the weight) and at a maximum at the lower inversion point (maximum expansion by the weight). The oscillation period T can be determined from the recorded measurement either from the distance apart of the oscillation maxima, or by means of Fourier analysis. Both methods will be described in the following.

To determine the oscillation period T from the distance between oscillation maxima of force, use the "Survey" function ( ) as follows. Position the cursor lines so that they lie on the oscillation maxima for the distance that is to be measured. The individual measurement points can be shown with "Display options", "Symbols". It is recommended that you determine the distance between several measurement points (a total of ten here) and then take the average for better accuracy.
The survey gives for k = 20 N/m, m = 250 g (Fig. 2):

$$T_{10} = 7.21\,\mathrm{s} \Rightarrow T = 0.721\,\mathrm{s} \Rightarrow f = 1.39\,\mathrm{Hz}$$

Evaluation (2/6)

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The oscillation period of the spring can be alternatively obtained using the "Fourier analysis" function ( )
(Fig. 3). The additional use of the "Peak analysis" function ( ) enables it to be clearly seen that the frequency of the characteristic oscillation lies at 1.39 Hz. The oscillation period is again found to be 0.717 s.

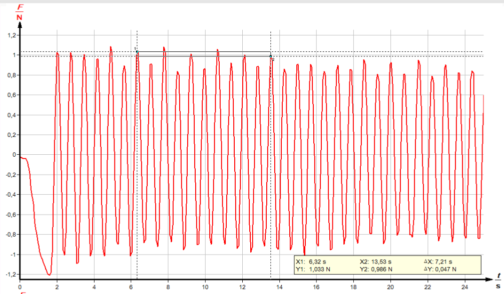

Fig. 2: Typical measurement result, use of survey function

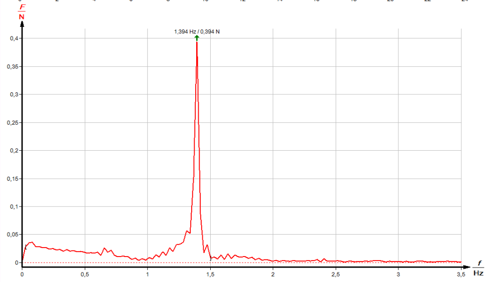

Fig. 3: Use of Fourier analysis and peak analysis function to determine the oscillation frequency

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Evaluation (3/6)

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According to Hooke's law, which describes the connection between the restoring force F and the displacement X with a spring constant k,the following is valid for an ideal spring under slight displacement:

$F = -k \cdot X$

Solving the equation of motion, the following is obtained for the oscillation period of a spring pendulum of mass m:

$T = 2\pi\sqrt{\frac{m}{k}}$

and from this

$k = m \cdot \left(\frac{2\pi}{T}\right)^2.$

Evaluation (4/6)

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Table 1 and table 2 confirm this relationship. For different masses the spring constant has a constant value within the scope of the measuring accuracy. The weaker spring is loaded with the smaller masses to avoid overstretching. Nevertheless, it can be seen that the value of the spring constant k slightly increases with increasing mass. The reason is that Hooke's law is only applicable for small deflections, otherwise the linear correlation becomes invalid. In an extreme case the spring can be even completely overstretched so that it does not return to its original form subsequent to unloading. The deviation also results because the mass and inner friction of the spring are not taken into account in the mathematical expressions.

m [g]	T [s]	k [N/m]
60	0.917	2.8
80	1.038	2.9
100	1.149	3.0
150	1.306	3.0

Table 1: Spring 1

m [g]	T [s]	k [N/m]
250	0.721	19.0
300	0.789	19.0
350	0.848	19.2
400	0.903	19.4

Table 2: Spring 3

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Evaluation (5/6)

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If springs, even of the same kind, are linked in parallel or in series, the total spring constant changes in a characteristic manner. When two springs are linked in parallel, each spring will be displaced by the same stretch and accordingly exert a restoring force on the weight. The individual forces add together (Fig. 4) Assuming this, we obtain arithmetically:

$$F = F_1 + F_2 = -(k_1 + k_2) \cdot X \;\Rightarrow\; k = k_1 + k_2$$

In the serial linkage, the individual displacements of the springs add together to a total displacement, so that the displacing force and the restoring force are identical for the two springs (Fig. 5). The following is valid which is shown in Table 3:

$$F = -k_1 \cdot X_1 \;\Leftrightarrow\; X_1 = -\frac{F}{k_1} \text{ and } F = -k_2 \cdot X_2 \;\Leftrightarrow\; X_2 = -\frac{F}{k_2}$$

$$X = X_1 + X_2 = -\left(\frac{1}{k_1} + \frac{1}{k_2}\right) \cdot F \;\Leftrightarrow\; F = -\frac{1}{\frac{1}{k_1} + \frac{1}{k_2}} \cdot X \;\Rightarrow\; \frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$$

Evaluation (6/6)

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Spring, coupling	m [g]	T [s]	k_{meas} [N/m]	k_{calc} [N/m]
Spring 1	60	0.917	2.8	---
Spring 2	60	0.883	3.0	---
Spring 3	350	0.903	19.2	---
Springs 1, 2 series	60	1.330	1.3	1.5
Springs 1, 3 series	60	1.010	2.3	2.5
Springs 1, 2 parallel	110	0.860	5.9	5.9
Springs 1, 3 parallel	310	0.743	22.2	22.0

Table 3: Connected springs

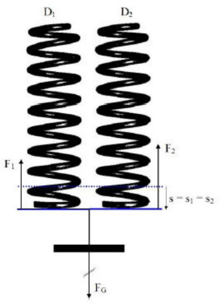

Fig. 4: Parallel connection of helical springs

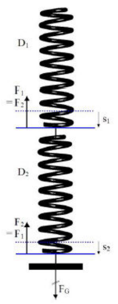

Fig. 5: Series connection of helical springs

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