Equipment for Engineering Education

Experiment Instructions

TM 400 Apparatus for Investigating Hooke's Law

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TM 400

Apparatus for Investigating
Hooke's Law

Laboratory Manual

Contents

Translated by Dr. Dennis Buckley

GUNT

Apparatus for Investigating Hooke's Law

1. List of Parts

To the apparatus belong:

10 weights, each 0.5 N
1 pointer
1 weight carrier
2 coil springs

2. Experiment Set-up

The proper set-up can be determined from the cover photo of this brochure.

3. Didactic Remarks

3.1 Teacher Demonstration or Student Experiment ?

Discovering Hooke's law experimentally is practically a 'classical' example of an effective student experiment:

- the experiment set-up is easily grasped
- carrying out the experiment presents no problems
- the measured quantities are practically free from error and are easy to interpret

Two or three students can work successfully with one apparatus.

Of course, the size of the apparatus permits teacher demonstrations, too.

3.2 Learning Objectives: Content

- To understand a coil spring's extension reaction to force
- To know that the extension is proportional to the force
- To understand the mathematical formulation of Hooke's law
- To know what a spring constant is
- To know how a system of two coupled coil springs behaves
- To know that Hooke's law is also applicable to the extension of massive metal test bars (see the stress-strain diagram, p. 12)
- To understand accompanying graphic representations
- To know that Hooke's law is only applicable to elastic change of shape

3.3 Learning Objectives: Procedure

The area of subject-procedural learning objectives - for example, insight into the methods of determining a law experimentally - can be given special attention here, because in this experiment the set-up, the measurement results and the evaluation are especially clear.

- To know that in an experiment there is a dependent and an independent variable
- To know that the way the experiment is conducted determines which variable is dependent or independent

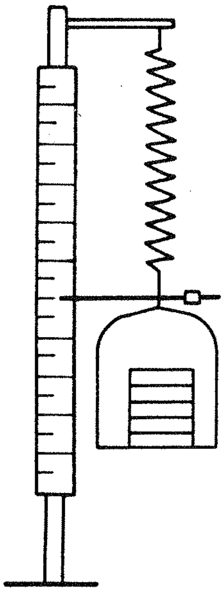
- To know how measurement results are tabulated
- To know how a mathematical equation can be gained from measured quantities
- To know which characteristics allow for the description of a relationship between variables to be a proportional one
- To be able to distinguish between deductive and inductive discovery of a law

4. Suggestion for a Work Sheet

Experiment set-up, measured quantities and evaluation can conveniently be summarized on a work sheet during instruction.

On the following page you will find a suggestion for such a work sheet.

Work Sheet: Extension of a Coil Spring



1. Experiment Set-up

Independent variable in the experiment is: ....

Dependent variable in the experiment is: ....

The .... is dependent upon the ..... .

. is a function of . :

Represented in the diagram:

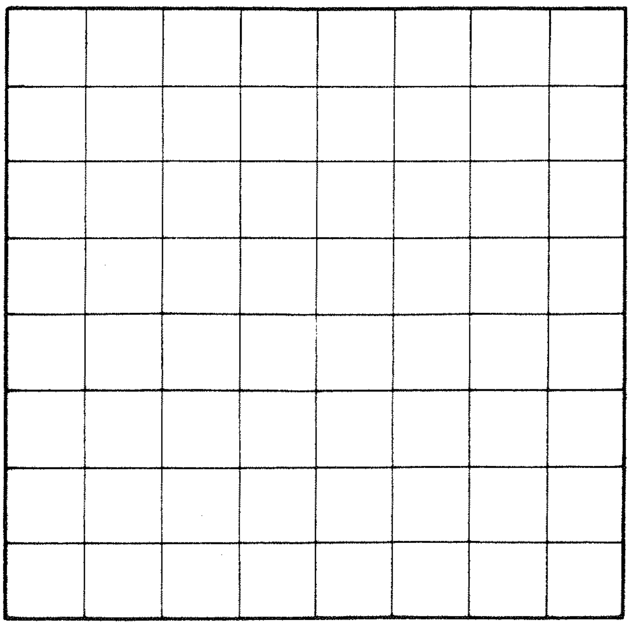
horizontal axis: ....

vertical axis: ....

2. Measured Quantities and Evaluation

F in N										
s in mm										

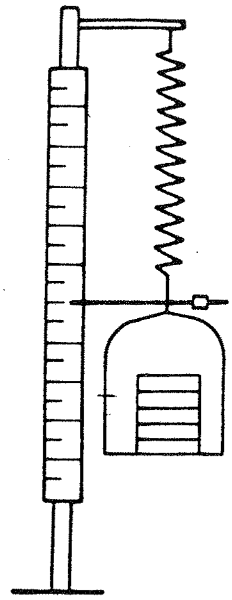
-
-
-
-



If there is a proportional relationship between two variables, the graph will show a ....
....

C:.............

....



1. Experiment Set-up

Independent variable in the experiment is: force F ....

Dependent variable in the experiment is: extension s ....

The extension s is dependent upon the force F

s is a function of F :   s = f·(F)

Represented in the diagram:

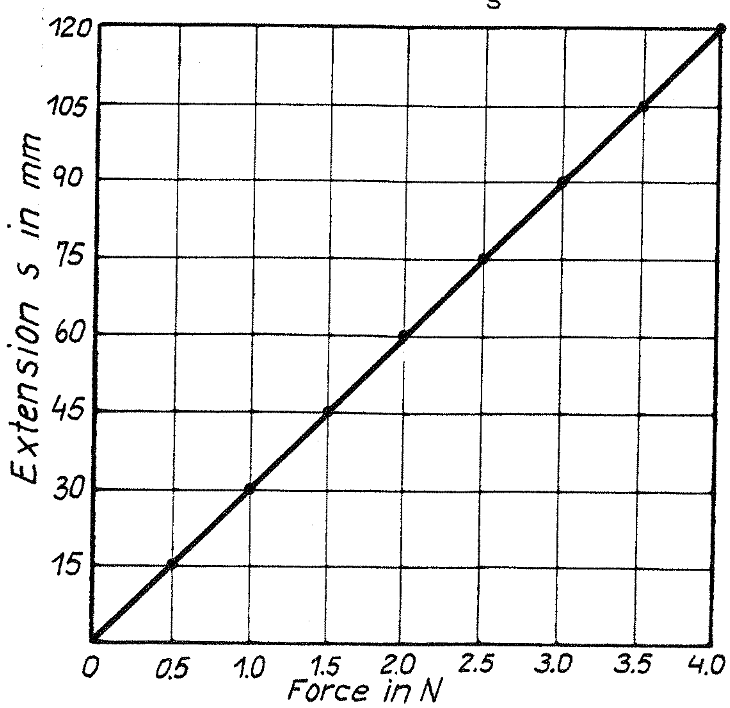
horizontal axis: independent variable

vertical axis: dependent variable

2. Measured Quantities and Evaluation

F in N	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
s in mm	0	15	30	45	60	75	90	105	120	135
F in N	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
s in mm	15	15	15	15	15	15	15	15	15	
$\frac{F}{s}$ in $\frac{N}{mm}$	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333

- The same change in force means the same change in length
- e.g., tripling the force means tripling the length
- The extension is proportional to the force $s \sim F$
- The relationship $\frac{F}{s}$ is constant



If there is a proportional relationship between two variables, the graph will show a a straight line originating at zero

$\frac{F}{s}$ = constant = C

C: spring constant

$F = C \cdot s$

Hooke's law

5. Experiment 1: Extension Spring No. 1

Extension spring No. 1: This is the spring whose coils do not lie on one another. (53 coils)

Performing the Experiment

Hang the pointer and weight carrier onto the spring.
Adjust the scale to zero.
Lay on the additional weights one after another and read off the amounts of extension.

Measured Quantities and Evaluation

F in N	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
s in mm	15	30	45	60	75	90	105	120	135	150
$\frac{F}{s}$ in $\frac{N}{mm}$	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333	0.0333

Comments

The quotient $\frac{F}{s}$ is incontestably constant.
It will be called the spring constant C. For the term spring constant one also finds in the literature the expression 'direction constant' with the symbol 'D'.

6. Experiment 2: Extension Spring No. 2

Extension spring No. 2: This is the spring whose coils lie close together. (106 coils)

Performing the Experiment

Hang the pointer and weight carrier on the spring.
Lay on three weights as pre-load.
(This is necessary in order that the coils separate from each other.)
Adjust the scale to zero.
Lay on the additional weights one after the other and read off the amounts of extension.

Measured Quantities and Evaluation

F in N	0.5	1.0	1.5	2.0	2.5	3.0	3.5
s in mm	31.5	62.5	94.0	125.0	155.5	186.5	218.0
$\frac{F}{s}$ in $\frac{N}{mm}$	0.0159	0.0160	0.0160	0.0160	0.0161	0.0161	0.0161

Comment

Here, too, the quotient $\frac{F}{s}$ is clearly constant.

7. Comparison Between Extension Spring 1 and Extension Spring 2

Extension spring 1 has approx. 53 coils.

Extension spring 2 has approx. 106 - 108 coils.

All other data, such as coil diameter, wire diameter and type of material are the same for both coils.

Comments

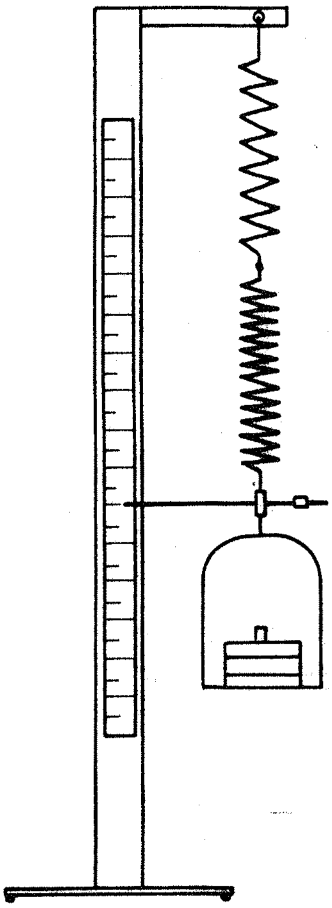
A greater number of coils means a 'softer' spring. The spring constant will be smaller.

In this case:
Doubling the number of coils leads to halving the spring constant.

8. Experiment 3: Connecting 2 Extension Springs in Series

Performing the Experiment

Experiment Set-up



Adjust the scale so that a whole number is indicated.

A setting at zero is not possible.

Lay on additional weights one after another and read off the amount of extension.

Measured Quantities and Evaluation

F in N	0.5	1.0	1.5	2.0	2.5
s in mm	46	91	137	183	229
$\frac{F}{s}$ in $\frac{N}{mm}$	0.0109	0.0110	0.0109	0.0109	0.0109

The scale does not extend far enough to allow for additional weights.

Comment

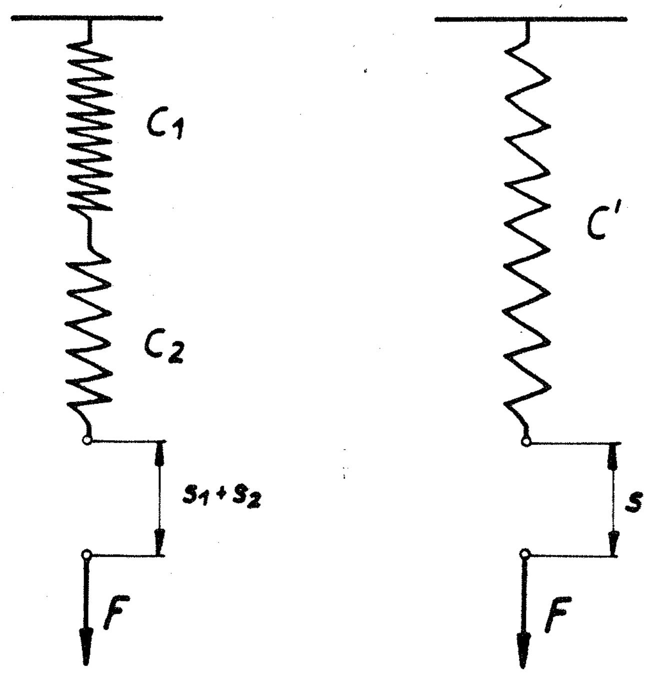
The combined spring constant for a system of two springs connected in series is less than the smaller of the two constants.

Didactic Hint

Here it is possible to make a formal analogy with problems from electrical engineering:

Parallel connection of resistors
Condensers connected in series

Mathematical Derivation of the Combined Spring Constant



$$s_1 + s_2 = s$$

$$\frac{F}{C_1} + \frac{F}{C_2} = \frac{F}{C'}$$

$$\frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{C'}$$

$$\boxed{C' = \frac{C_1 \cdot C_2}{C_1 + C_2}}$$

Our Experiments

$C_1 = 0.0333$ N/mm

$C_2 = 0.0159$ N/mm

$C' = 0.0109$ N/mm

Mathematically

$$C' = \frac{0{,}0333\ \frac{N}{mm} \cdot 0.0159\ \frac{N}{mm}}{0.0333\ \frac{N}{mm} + 0.0159\ \frac{N}{mm}}$$

$$C' = 0.0108\ \frac{N}{mm}$$

9. Suggestion for a Test Sheet

The following test sheet is a suggestion as to how you might quickly check what has been learned.

Apparatus for Investigating
Hooke's Law

Test Sheet

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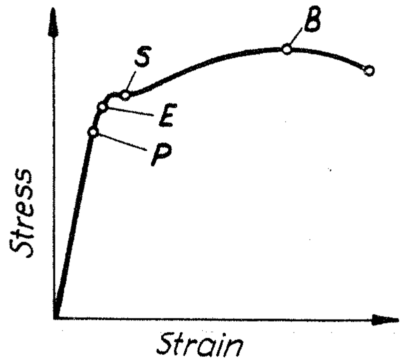
Hooke's law is valid for:

- elastic and plastic changes of shape ☐
- all elastic changes of shape ☐
- elastic changes of shape with proportional force-distance relationship ☐

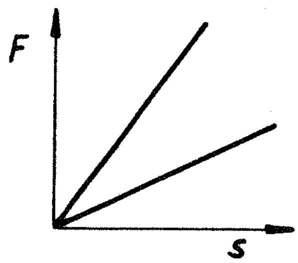


Stress-strain diagram for steel

P = Limit of proportionality
E = Limit of elasticity
S = Limit of stretch
B = Breaking limit

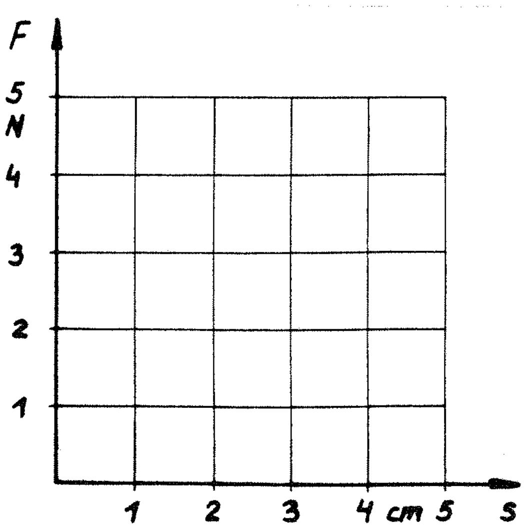
Colour the part of the curve which obeys Hooke's law.

Experiments ↓ Measured Quatities ↓ Physical Law A	Existing Physical Laws ↓ Theory ↓ New Physical Law B	Place the letter in the corresponding box deductive determination of law ☐ inductive determination of law ☐



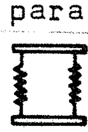
$C_1 > C_2$

Write the spring constants C_1 and C_2 on the characteristic rectilinear of the diagram.



A coil spring has a spring constant $C = 1\ \frac{N}{cm}$

- On the adjacent graph draw in the F-s relationship for the spring. (Label with a '1')
- Two springs of this type are connected parallel to each other.

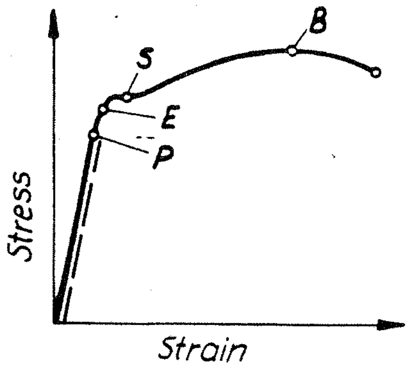


On the graph draw in the F-s relationship of this system. (Label with a '2')

- Two of these springs are connected in series. Draw in the F-s relationship of this system. (Label with a '3')

Hooke's law is valid for:

- elastic and plastic changes of shape ☐
- all elastic changes of shape ☐
- elastic changes of shape with proportional force-distance relationship ☒



Stress-strain diagram for steel

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Colour the part of the curve which obeys Hooke's law.

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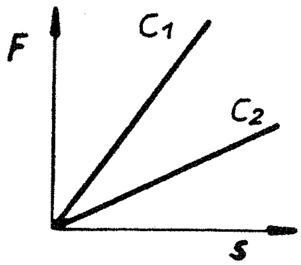
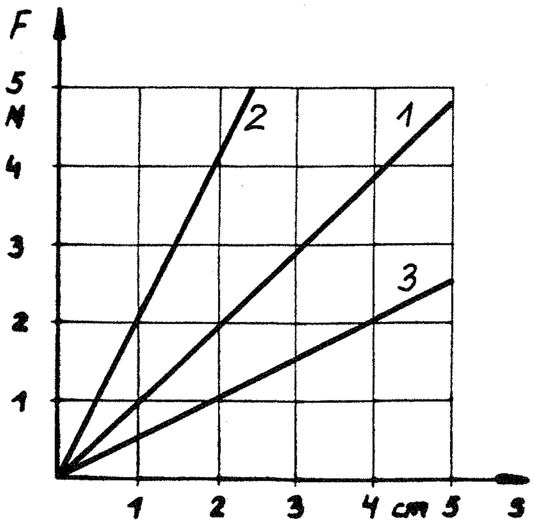


$C_1 > C_2$

Write the spring constants C_1 and C_2 on the characteristic rectilinear of the diagram.



A coil spring has a spring constant $C = 1\ \frac{N}{cm}$

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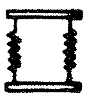


On the graph draw in the F-s relationship of this system. (Label with a '2')

- Two of these springs are connected in series. Draw in the F-s relationship of this system. (Label with a '3')

10. Experiments from Pendulum Theory

The TM 400 apparatus provides you with the opportunity for conducting a series of basic experiments from the field of oscillation theory.

10.1 Spring Oscillations

Experiment set-up the same as for Hooke's law.

First series of experiments

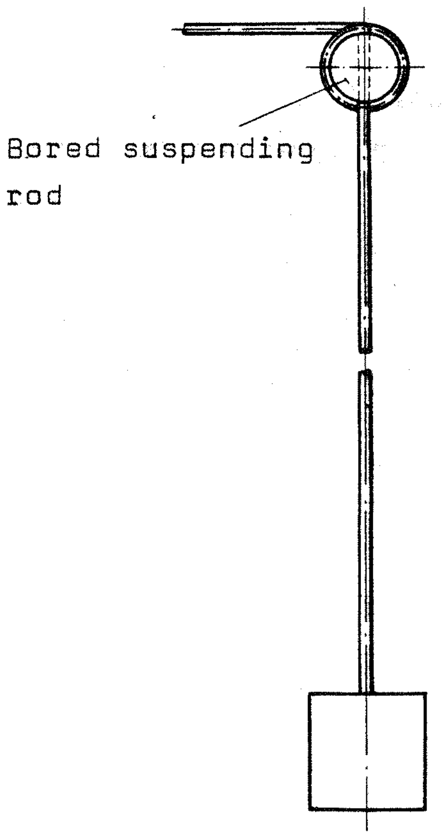
Oscillation period as a function of the spring constants.
Mass remains constant.
Three different spring constants are already available.

Second series of experiments

Oscillation period as s function of mass.
The spring constant is not changed.

It is advisable technically to clock the time of 5 or 10 complete oscillation periods with a stop-watch.

10.2. Pendulum Oscillations



String pendulum

You will need a small pendulum-bob on a string.

Pull the string through the bore of the suspending rod, beginning at the bottom, and secure it with several loops.

Experiments

Oscillation time 'T' as a function of the length of the string 'l'.

The string length is measured with a supplementary ruler (foot-ruler).

Timed with a stop-watch for 5 or 10 complete oscillation periods.