Centrifugal force on an orbiting body

Measuring with the central force apparatus

**Objects of the experiments**
- Measuring the centrifugal force $F$ on an orbiting body as a function of the angular speed $\omega$.
- Measuring the centrifugal force $F$ as a function of the path radius $r$.
- Measuring the centrifugal force $F$ as a function of the mass $m$.

**Principles**

The centrifugal force acting on an orbiting body is

$$F = m \cdot \omega^2 \cdot r$$

where $m$ is the mass of the body, $\omega$ its angular speed and $r$ the radius of the orbit. In the central force apparatus, the centrifugal force on a test body is transmitted via an angled lever and a toe bearing to a leaf spring with strain gauge. The transmission ratio of the lever system is chosen so that changes in the path radius $r$ of the orbiting body are negligible. The force acting on the strain gauge is measured by means of a newtonmeter. The analogue output signal of the newtonmeter is connected to the Y input of an XY recorder. A tachymeter connected to the central force apparatus measures the angular speed and supplies an analogue signal, which is fed to the X input of the recorder.

At a constant path radius $r$ and a constant mass $m$, the parabolic shape of the curve recorded confirms the proportionality

$$F \propto \omega^2$$

Measurements at different path radii $r$ and with different masses $m$ confirm the proportionalities

$$F \propto r$$

and

$$F \propto m$$
Setup

The newtonmeter must warm up for at least 15 minutes before the experiment starts:
Swich on the newtonmeter with the central force apparatus connected.

The experimental setup is illustrated in Fig. 1.
- Fix the central force unit in the bench clamp, and connect it to the newtonmeter via the multicore cable; connect the analogue output of the newtonmeter to the Y input of the recorder (y-axis: 1 V/cm), and switch the newtonmeter on.
- Connect the drive motor (a) to the low-voltage power supply paying attention to the polarity.
- Screw the holding clamp of the tachymeter (b) into the tapped hole of the central force apparatus.
- Mount the motion sensor (c), and see to it that the contact between its running wheel and the O-ring of the central force unit is perfect.
- Connect the measuring unit (d), and feed its output to the X input of the recorder (x-axis: 0.1 V/cm).

The central force apparatus is driven by the O-ring at the radius $r = 10$ cm. The transmission ratio between the rotational speeds of the tachymeter and the central force unit is 4:1. Therefore, the angular speed $\omega$ of the central force apparatus is 25 s$^{-1}$ when the tachymeter displays the orbital velocity $v = 1$ m s$^{-1}$.

Carrying out the experiment

a) The centrifugal force $F$ as a function of the angular speed $\omega$:
- Make the zero compensation by setting the pushbutton COMPENSATION of the newtonmeter to SET.
- Fix the mass $m = 100$ g at the distance $r = 25$ cm from the axis of rotation.
- Switch the recorder on, and lower the recording stylus.
- Set the output voltage of the low voltage power supply to zero, and switch the low voltage power supply on.
- Slowly increasing the output voltage, record the measurement curve.
- Lift the recording stylus, and set the output voltage back to zero.
- Vary the radius $r$, for example, and record other measurement curves. Afterwards switch the recorder off.
b) The centrifugal force $F$ as a function of the radius $r$:
- Repeat the zero compensation of the newtonmeter.
- Fix the mass $m = 50$ g at the distance $r = 25$ cm from the axis of rotation.
- Increase the output voltage until the tachymeter displays $v = 0.6$ m s$^{-1}$ (that is $\omega = 15$ s$^{-1}$).
- Measure the force $F$, and take it down.
- Decrease the distance $r$ in steps 5 cm down to 5 cm. Each time adjust the same angular speed, and repeat the measurement.

c) The centrifugal force $F$ as a function of the mass $m$:
- Repeat the zero compensation of the newtonmeter.
- Fix the mass $m = 50$ g at the distance $r = 15$ cm from the axis of rotation.
- Increase the output voltage until the tachymeter displays $v = 0.6$ m s$^{-1}$ (that is $\omega = 15$ s$^{-1}$).
- Measure the force $F$, and take it down.
- Mount the masses 75 g and 100 g, adjust the same angular speed in each case and repeat the measurement.

Measuring example and evaluation

a) The centrifugal force $F$ as a function of the angular speed $\omega$:
Fig. 2 shows the measurement curves recorded with the recorder. The parabolic shape of the curves confirms the proportionality $F \propto \omega^2$. 

<table>
<thead>
<tr>
<th>$r$ (cm)</th>
<th>$F$ (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td>10</td>
<td>1.4</td>
</tr>
<tr>
<td>15</td>
<td>2.2</td>
</tr>
<tr>
<td>20</td>
<td>2.9</td>
</tr>
<tr>
<td>25</td>
<td>3.7</td>
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Fig. 3 is a plot of the measuring values from Table 1. Within the accuracy of measurement, they agree with the straight line drawn through the origin, that is, $F \propto r$.

c) The centrifugal force $F$ as a function of the mass $m$:

Table 2: The centrifugal force as a function of the mass $m$
($r = 15\, \text{cm}, \omega = 15\, \text{s}^{-1}$)

<table>
<thead>
<tr>
<th>$m$ [g]</th>
<th>$F$ [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>2.2</td>
</tr>
<tr>
<td>75</td>
<td>3.2</td>
</tr>
<tr>
<td>100</td>
<td>4.4</td>
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</tbody>
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Fig. 3 is a plot of the measuring values from Table 2. The agreement with the straight line drawn through the origin confirms the proportionality $F \propto m$.

Fig. 4 The centrifugal force $F$ as a function of the mass $m$
($r = 15\, \text{cm}, \omega = 15\, \text{s}^{-1}$)