

Related topics

Centripetal force, rotary motion, angular velocity, apparent force.

Principle and task

A body with variable mass moves on a circular path with adjustable radius and variable angular velocity. The centrifugal force of the body will be measured as a function of these parameters.

Equipment

| | | |
|-----------------------------|----------|---|
| Centrifugal force apparatus | 11008.00 | 1 |
| Car | 11060.00 | 1 |
| Holding pin | 03949.00 | 1 |
| Laboratory motor, 220 V AC | 11030.93 | 1 |
| Gearing 30/1, for 11030.93 | 11029.00 | 1 |
| Bearing unit | 02845.00 | 1 |
| Driving belt | 03981.00 | 1 |
| Support rod w. hole, 100 mm | 02036.00 | 1 |
| Barrel base | 02006.10 | 1 |

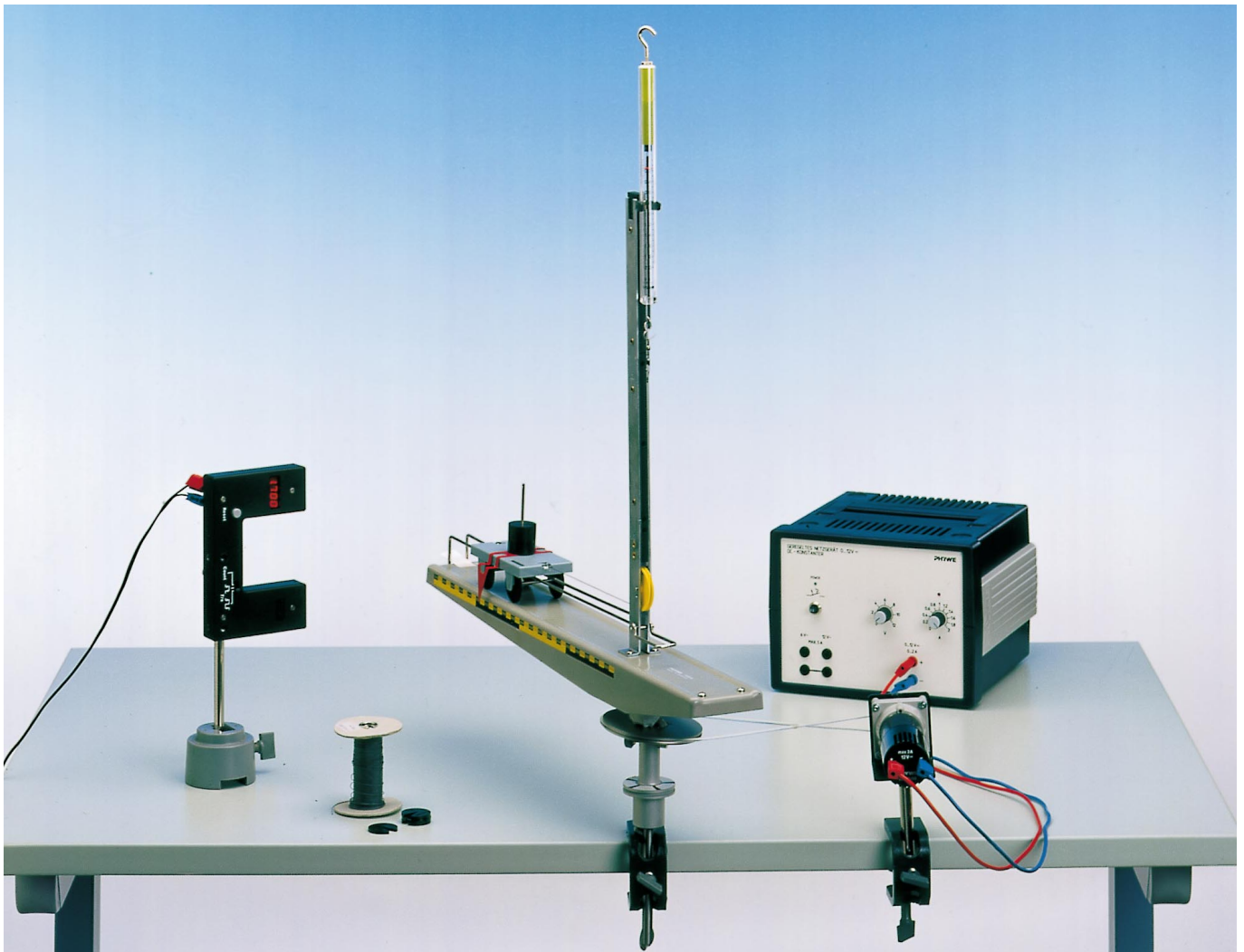
| | | |
|--------------------------------------|----------|---|
| Spring balance holder | 03065.20 | 1 |
| Support rod -PASS-, square, l 250 mm | 02025.55 | 1 |
| Bosshead | 02043.00 | 2 |
| Bench clamp, -PASS- | 02010.00 | 2 |
| Fish line, l 100m | 02090.00 | 1 |
| Spring balance, transparent, 2 N | 03065.03 | 1 |
| Slotted weight, 10 g, black | 02205.01 | 4 |
| Slotted weight, 50 g, black | 02206.01 | 2 |
| Light barrier with Counter | 11207.08 | 1 |
| Power supply 5 V DC/0, 3 A | 11076.93 | 1 |
| Connecting cord, 750 mm, red | 07362.01 | 1 |
| Connecting cord, 750 mm, blue | 07362.04 | 1 |

Problems

Determination of the centrifugal force as a function

1. of the mass,
2. of the angular velocity,
3. of the distance from the axis of rotation to the centre of gravity of the car.

Fig. 1: Experimental set-up for the measurement of centrifugal force.



Set-up and procedure

The experimental set-up is arranged as shown in Fig. 1. The red pointer supplied should be fitted on the central rod of the car. It indicates the distance (axis of rotation to centre of gravity of car). At the outermost end of the centrifugal apparatus, a mask is glued between the guide rods and serves for the start-stop triggering of the light barrier. When measuring the duration of a complete cycle switch to “ $\uparrow \downarrow$ ”-mode.

Ensure that the car does not touch the light barrier at maximum radius.

With increasing angular velocity, the radius increases, since the force measurement involves movement. This should be compensated by moving the spring balance up and downwards.

Determination of the centrifugal force as the function of mass.

The experimental car is gradually loaded with the additional weights. The centrifugal force apparatus with a constant angular velocity is rotated with each given mass m . The force occurring F_z is determined with the help of a spring balance. The car is connected below the pulley to a spring balance by a thread (approx 26 cm in length) and a decoupling hook. The spring balance is pushed down to the maximum possible position. Now a constant angular velocity is set to the motor, which remains constant during the entire course of the experiment. The force F_z experienced by the measuring car without any additional weight is read. The position r of the red pointer is marked by a piece of adhesive tape. For this purpose, the motor is stopped by switching off the power supply. The additional weights are placed on the measuring car and the spring balance is pushed up till the car stands a little before the pulley. The power supply is switched on. By fixing the spring balance in the upper range, it is possible to move it down (at intervals of approx. 1 cm). By this, the indicator on the measuring car approaches the marked position ‘ r ’. When its position is reached, the respective force F_z is read.

Note

If the measuring car moves beyond the marked position from the inside to the outside, the motor is to be stopped. The spring balance is to be pulled high again and the motor is to be re-started.

Determination of the centrifugal force as a function of angular velocity.

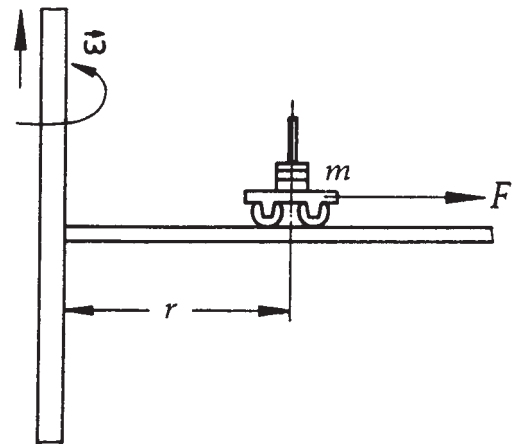
The mass of the experimental car stays constant in this part of the experiment. A predetermined radius (e.g. $r = 20$ cm) is marked with a piece of adhesive tape. At different angular velocities by means of displacement of the spring balance as in part 1, the measuring car is brought to position r . Push the car from inside to the outside. The respective forces F_z are read. The angular velocity $|\omega|$ is calculated from the time of rotation T .

$$\omega = 2\pi/T$$

Determination of the centrifugal force as the function of distance of the axis of the rotational centre and the mass of the measuring car.

The mass of experimental car remains constant. A fixed angular velocity is set to the motor. The radius of the orbit r of the measuring car is increased by means of displacement of the spring balance and the respective centrifugal force F_z and the radius r are measured.

Fig. 2: Mass m , at rest in the rotating reference system.



Theory and evaluation

In the reference system which rotates with the angular velocity $\vec{\omega}$, the equation of motion of a mass point (mass m , position vector \vec{r}) reads:

$$m \frac{d\vec{v}}{dt} = -\nabla U + m\vec{r} \times \frac{d\vec{\omega}}{dt} + 2m\vec{v} \times \vec{\omega} + m\vec{\omega} \times (\vec{r} \times \vec{\omega}) - \vec{F} \quad (1)$$

The external force field U (gravitational field) is compensated by the track, the angular velocity ω is constant, and the car is at rest in the rotating reference system ($U = 0$; $\vec{v} = \text{const.} = 0$; $\vec{\omega} = \text{const.}$).

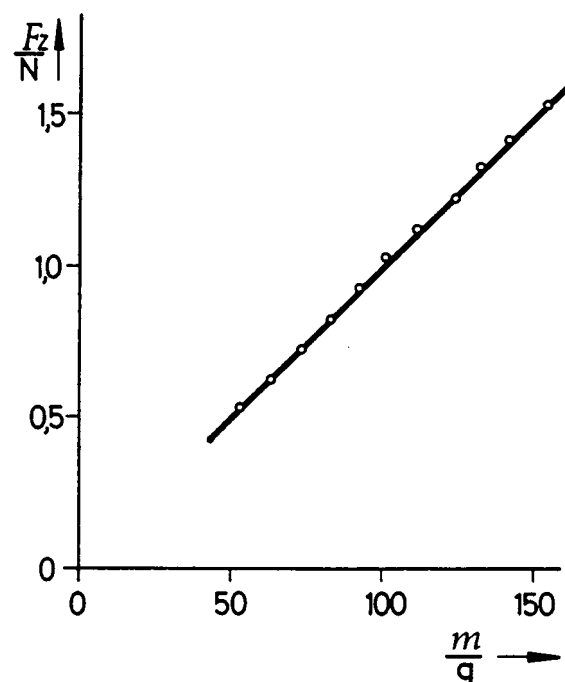
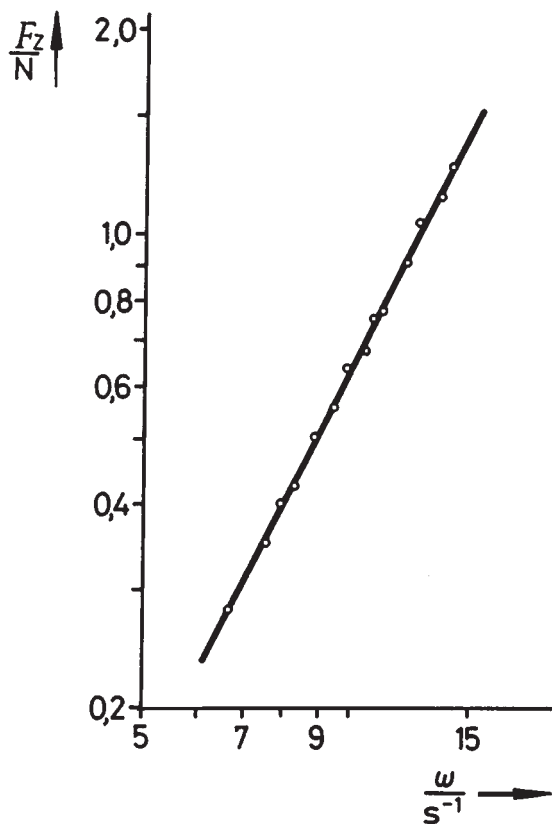


Fig. 3: Centrifugal force as a function of the mass m .

Fig .4: Centrifugal force as a function of the angular velocity ω .



Note

The spring balance used to measure the centrifugal force follows Hooke's law:

$$F_D = -k \cdot r,$$

where k is the spring constant.

Since the centrifugal force is also linear with respect to r :

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

a distinction must be made between three cases:

1. Stable condition for $k > m\omega^2$
2. Neutral condition for $k = m\omega^2$
3. Unstable condition for $k < m\omega^2$.

For safety reasons, the unstable condition should be avoided in the experiment.

Also, the range

$$k \approx m\omega^2$$

is unsuitable for the measurement because of the inaccuracies which occur.

From (1), there only remain the centrifugal force and the compensating force \vec{F} , which is read on a spring balance:

$$\vec{F} = m\vec{\omega} \times (\vec{r} \times \vec{\omega}).$$

Since $\vec{r} \perp \vec{\omega}$, it follows that

$$|\vec{F}| = m\omega^2 \cdot r.$$

From the regression line to the measured values of Fig. 4, with the exponential statement

$$Y = A \cdot X^B + Y_0$$

the exponent is obtained

$$B = 2.053. \quad \text{(see (2))}$$

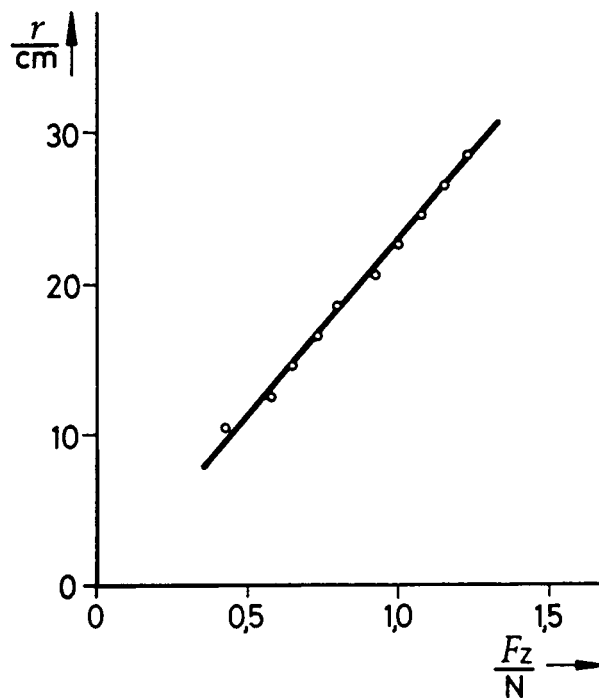


Fig .5: Centrifugal force as a function of the radius.