Gyroscope with three axes

02555.00

Operating Instructions

Fig. 1. Overview of the equipment required for quantitative measurement for the physics of the gyroscope in accordance with the Equipment list (Section 5).

1 PURPOSE AND DESCRIPTION

The gyroscope with three axes is used to demonstrate gyroscopic phenomena such as directional stability, precession and notation. With the help of a few simple measuring devices (hand-held stopwatch and light barrier with counter for rotational speed measurements, cf. Fig. 1) the following quantitative laboratory experiments, among others, can be performed:

- Investigation of the linear correlation between the duration of a precessional revolution and the rotational frequency of the gyroscopic disk (Fig. 3)
- Investigation of the linear correlation between the precessional frequency and the tilting moment exerted on the gyroscopic axis for the same rotational frequencies in each case (also evident in Fig. 3).
- Investigation of the linear correlation between the rotational frequency of the gyroscopic disk and the nutational frequency (Fig. 4).
- Determination of the moment of inertia from the precessional duration, the rotational frequency, and the tilting moment exerted on the gyroscopic axis.
- Direct Measurement of the moment of inertia of the gyroscopic disk, e.g., from the angular acceleration for known torque.

A second identical gyroscopic disk with a compensation weight is available as an accessory (02556.00). It is primarily used to show that, when two disks rotate in opposite directions with the same rotational velocity, the gyroscopic phenomena described here disappear.

Gyroscope 02555.00 has a stable plate base: The main axis around which the ball-bearing-supported disk rotates can be turned around a horizontal and around a vertical axis. The counterweight is normally positioned on the gyroscopic axis in such a manner that it exactly compensates the torque that the gyroscopic disk exerts on the horizontal axis (force-free gyroscope). To generate defined tilting moments, a weight holder (10 g) and a slotted weight (50 g) are included in the delivery package. Using the second support rod and the bosshead which are part of the gyroscope package, the gyroscopic axis can be fixed (cage gyroscope). To do this, the rod is fixed in the second clamping location on the plate base.

There is a winding reel on the gyroscopic disk for winding up the gyroscope with the cotton cord included in the delivery package.

2 ASSEMBLY OF THE GYROSCOPE

For reasons of transport safety, the gyroscope is delivered in a dismounted condition. The correct arrangement of the parts is shown in Fig. 2. The gyroscopic disk is pushed onto the rod until it catches. Subsequently, the gyroscopic disk is secured with a locking screw in the appropriate groove. The reserve disk clicks into position in the second groove.

Fig. 5. shows the set-up with the additional gyro-disk (02556.00). In this case, both retaining washers are required and the additional gyro-disk is secured with another retaining washer.

3 OPERATION IN AN EXPERIMENT

The following gyroscopic phenomena can be demonstrated with the material contained in 02555.00 without additional accessories:

- Precession (effect of torque and rotational frequency)
- Nutation (effect of the rotational speed of the disk on the nutational frequency)

If one desires to investigate these relationships quantitatively, only the few optional measuring devices already illustrated in Fig. 1 are required. The precessional and nutational frequencies are so low that they can be determined

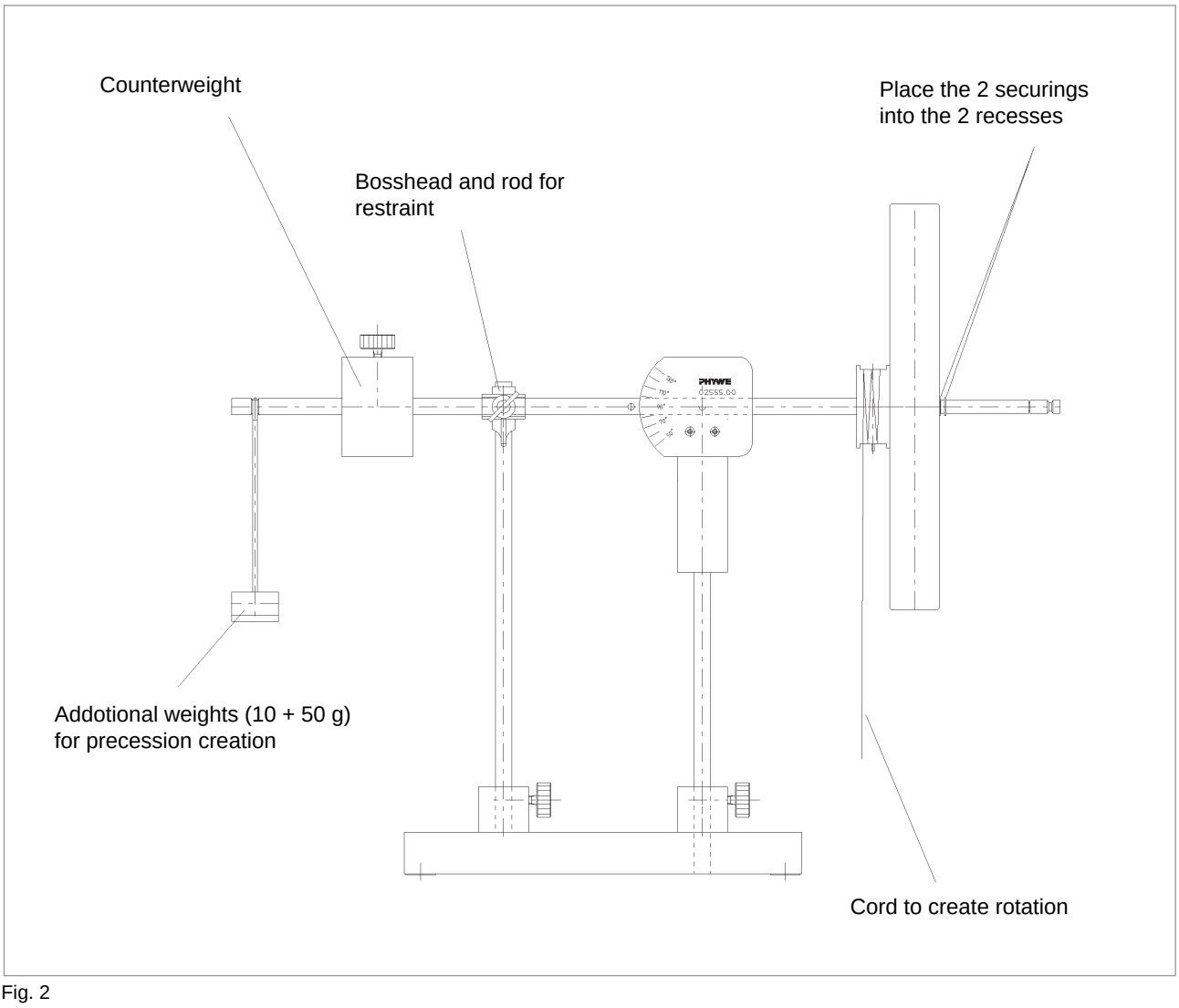


Fig. 2

with a hand-held stopwatch. The rotation time of the gyroscopic disk is determined with the light barrier with counter; to interrupt the light path, attach a narrow strip of paper (e.g. adhesive label) to the edge of the disk. Caution: only something made of a soft material maybe used in order to avoid injuries if someone touches the rotating gyroscope.

For all quantitative evaluations it is important to know the moment of inertia I of the gyroscopic disk. To measure I, a known torque D is exerted on the gyroscopic disk (weight on wound cord), and the resulting angular acceleration is measured.

$$\frac{d\omega}{dt} = \frac{D}{I}$$

Fig. 3. Rotational frequency *f* of the gyroscope as a function of the duration of a processional revolution

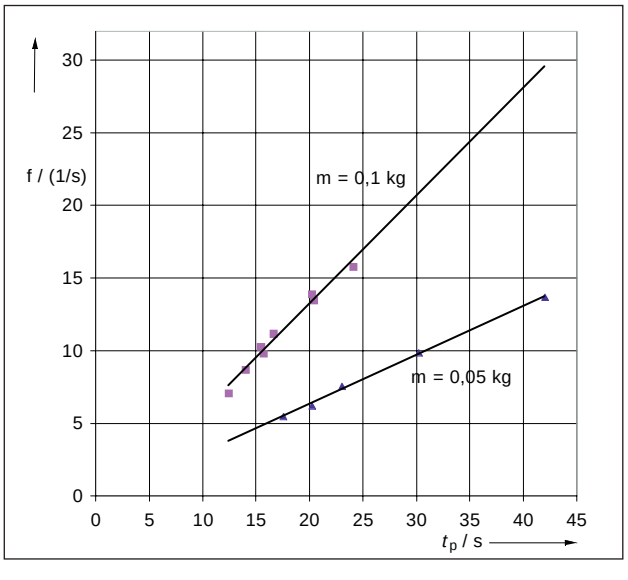
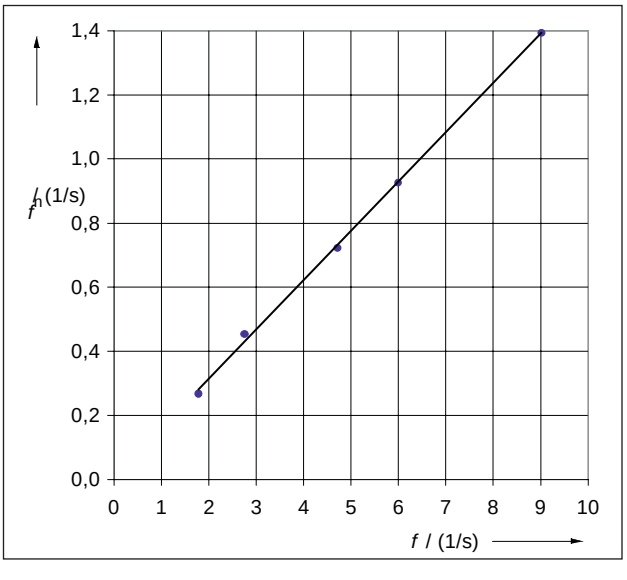


Fig. 4. Nutational frequency f_n as a function of the rotational frequency *f* of the gyroscopic disk



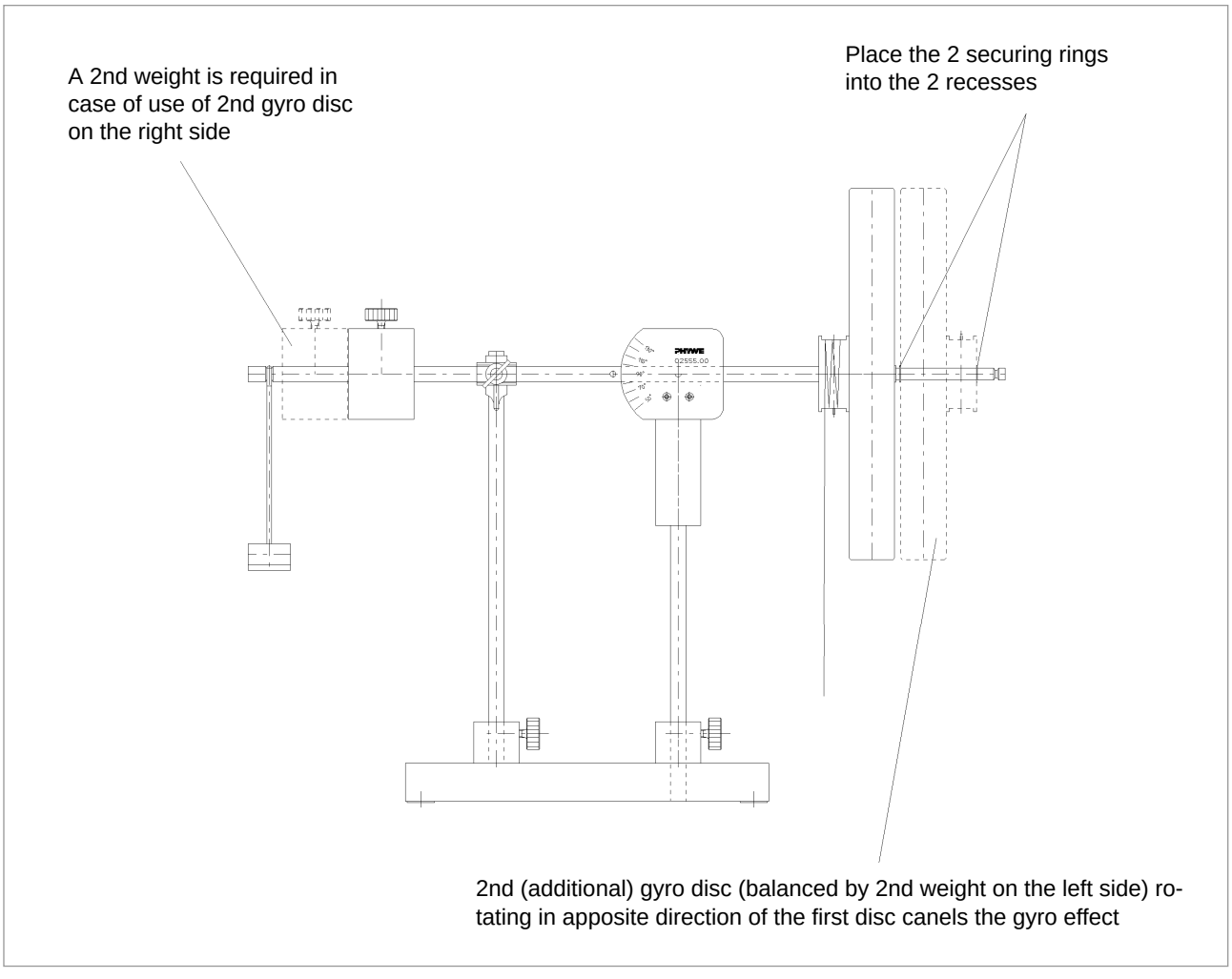


Fig. 5

The torque $D = m \cdot g \cdot r$ is known (m = mass of the accelerating weight, r = radius of the winding reel = 22.5 mm). The angular acceleration is determined by timing the duration of acceleration Δt from the time of disk release until the weight touches the floor and then immediately measuring the angular velocity ω_E . For practical reasons one measures the duration of one disk revolution. This measurement is performed in seconds by pressing the reset button on the light barrier and moving the latter toward the gyroscopic disk until the attached strip of paper (diaphragm) interrupts the light path. The light barrier's operation mode is set in such a manner that the first interruption of the light path starts the counter and the second one stops it. The angular acceleration is the calculated according to the following equation:

$$\frac{d\omega}{dt} = \frac{\omega_E}{\Delta t} \quad \text{i.e.} \quad I = \frac{D \cdot \Delta t}{\omega_E} \; .$$

For this device one obtains I = 9.3 g m^2.
The measured points of the two curves in Fig. 3 are recorded as follows:

- Wind up the force-free, balanced gyroscope (f > 10/s).
- Measure the rotational frequency f (duration of one revolution) as described above.
- Hang a mass of 50 g in the groove on the end of the gyroscopic axis opposite the disk. (The distance to the pivot point of the gyroscopic axis is 270 mm.)
- Measure the duration of half a precessional revolution (value must be multiplied by 2).
- Remove the mass so that the gyroscopic axis comes to rest, and immediately measure the rotational frequency again. Record the average of the two measurements in the diagram above the measured precessional duration (cf. Fig. 3).
- In the same manner record the remaining measured points for decreasing gyroscope rotational velocity.
- After completing the measurement series rewind the gyroscope and record a measurement series with a mass of 100 g in the same manner.

By comparing the two straight lines in Fig. 3, one can directly ascertain that, as a good approximation, a doubling of the moment of tilt results in a doubling of the precessional frequency.
From the slope a of the straight lines one can determine, e.g., the moment of inertia I independent of the method described above. It is as follows:

$$I = \frac{mgR}{4\pi^2 \cdot a} \; .$$

where R is the distance of the application point of the mass m from the pivot point on the gyroscopic axis (R = 27 cm). Thus, one obtains, e.g., the following value for the slope of the measured straight lines with m = 0.05 kg (analysis with Microsoft Excel®): a = 0.3631. Thus, a value of I = 9.24 g m^2 is obtained, which agrees well with the value determined above. The measured series presented in Fig. 4 was recorded on the force-free gyroscope. Nutation is generated by striking the gyroscopic axis lightly. In each case the duration of an appropriate number of nutational revolutions is timed; and, in the customary manner, the gyroscopic disk's rotational time is determined before and afterwards (take the average value).

If the additional gyro-disk with counterweight is also mounted in accordance with Fig. 5, one can show that characteristic gyroscopic phenomena do not occur when the two disks are rotated in opposite directions with approximately the same rotational speed. This condition is achieved by winding the two ends of the cotton cord in opposite directions on the two winding reels. The same length of cord should be wound onto each of the two reels. The two disks are set in motion by pulling strongly in the middle of the cord.

4 LITERATURE REFERENCE

University Laboratory Experiments, Physics; 1.2.08.2
“laws of gyroscopes / 3-axis gyroscope”

5 EQUIPMENT LIST

Parts included in the delivery package of 02555.00:

Support rod, l = 250 mm		02021.00
Weight holder for slotted weights		02204.00
Slotted weight, 50 g, black		02206.01
Right-angle clamp		37697.00

Additional equipment, illustrated in Fig. 1, which is required to perform the described quantitative experiments:

Light barrier with counter		11207.08
Barrel base		02006.55
Power supply, 5 V DC / 0.3 A		11076.93
Stopwatch, digital, 1/100 s		03071.01
Slotted weight, 10 g, black	(4 pcs.)	02205.01

Available supplementary accessory:

Additional gyro-disk with counterweight	02556.00