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Using a reed switch to measure the angular speed of a fidget spinner

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Abstract

We have designed an Arduino-based setup to study the angular speed of a fidget spinner. The apparatus uses a reed switch to detect the magnetic field of a magnet placed in one of the spinner blades. The time interval between consecutive passages is determined from the switch state, and used to compute the angular speed of the spinner as a function of time. We measure the angular speed of the spinner after giving it an initial speed, and found that dry and viscous dissipative forces have to be considered to accurately fit the experimental data.

1. Introduction

Fidget spinners are popular toys, usually consisting of two or three plastic blades mounted around a ball bearing, designed to spin with little effort. For this reason, fidget spinners have been used in recent years to teach physical concepts related to rotational motion such as torque, angular momentum and moment of inertia [1–3]. When studying the rotational motion of the spinner an important parameter to be determined is its angular velocity. In previous works, this task has been performed by analysing the frequency of the sound emitted by the spinner [4], using stroboscopic lights, video analysis or commercial photogates [5]. In the present work, we use an alternative method to perform this task using a reed switch connected to an Arduino board. The main advantages of solutions based on the Arduino board are the low-cost of the components, the simplicity of operation, and the precision obtained [6–8]. We measure the angular speed of the spinner as a function of time after giving it an initial speed, and compare the experimental results with a theoretical model.

2. Experimental apparatus

Figure 1 shows the experimental setup used for the acquisition of data. The central bearing of the spinner is fixed to a vertical axle and a small magnet is placed in one of the spinner blades. A reed switch (Soway RS-02) is placed just below the spinner in order to be operated by the magnetic field of the magnet. The reed switch is connected the GND pin of the Arduino board (ground connection) and to the digital pin 12. When the magnet passes near the switch, the switch is closed and the digital pin from the Arduino board go to LOW. If the time of this event is recorded, then the angular speed of the spinner (averaged over a revolution) can be determined from the time interval between adjacent passages of the magnet.

The Arduino code used to determine the angular speed of the spinner is listed in figure 2. The variables myTime1, myTime2 and myTime3 are used to record the time of the 1st, nth and $(n+1)$ th passages, respectively. The interval between consecutive passages is calculated from myTime2 and myTime3, and used to compute the average

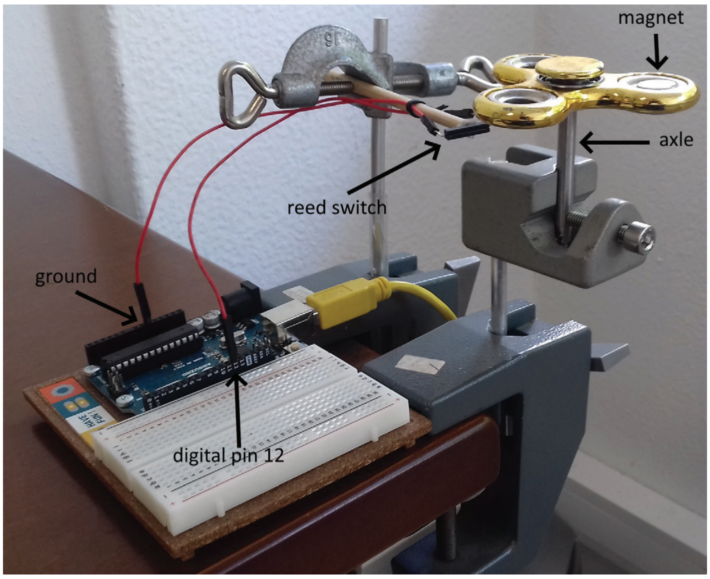

Figure 1. The experimental setup.

angular speed over a revolution. In order to ensure that time is recorded only once in every passage of the magnet, a boolean variable called myFlag is used. When the switch first closes due to the proximity of the magnet, time is recorded and myFlag set to HIGH, preventing any other time measurement. When the switch re-opens, myFlag is set to LOW allowing new measurements.

At this point, it is interesting to compare the use of the reed switch to measure time intervals with the use of a Hall effect sensor [8]. Although both sensors may be used with success, the reed switch readings are independent of the magnetic field intensity. For that reason, a simple programming code can be used to calculate the time intervals automatically with this sensor. On the other hand, a Hall effect sensor measures the magnetic field intensity, and, therefore, is better suited for applications where small amplitude movements must be detected.

3. Results and discussion

Figure 3 shows typical experimental data acquired with the reed switch. As expected, the angular speed of the spinner decreases with time due to the presence of frictional forces. At first glance, the decay of the angular speed seems to be essentially exponential. However, a semi-logarithmic plot of the angular speed versus time (inset of figure 3) shows that the relation between $\ln(\omega)$ and time is linear only for intermediate and large angular speed. In contrast, for very low speeds a downward curve is observed, indicating a non-exponential decay.

As previously discussed by Mungan [9], the frictional torque τ_f of objects spinning at moderate velocities is well described by a dry frictional term independent of the speed and a fluid drag term varying linearly with speed:

$$\tau_f = a + b\omega, \tag{1}$$

where a and b are constant coefficients and ω is the angular speed. On the other hand, from elementary rotational dynamics, we can write

$$\tau_f = -I\frac{\mathrm{d}\omega}{\mathrm{d}t}, \tag{2}$$

where I is the moment of inertia. Setting the right-hand sides of equations (1) and (2) equal to each other and separating variables, gives

$$-\int \frac{\mathrm{d}\omega}{a/I + (b/I)\omega} = \int \mathrm{d}t. \tag{3}$$

After integration, we obtain

$$\omega = I/b[C\exp(-bt/I) - a/I], \tag{4}$$

where C is a constant of integration. Setting $\omega(t=0) = \omega_0$ finally yields:

```
float angularSpeed, timeInterval;
float myTime1, myTime2, myTime3;
int n=1; // number of passages
boolean pinValue, myFlag;

void setup() {
  pinMode (12, INPUT_PULLUP);  // set digital pin 12 as Input
  Serial . begin (9600);
  myFlag = LOW;
}

void loop() {
  pinValue = digitalRead (12);      // read pin 12
  if (pinValue == LOW and myFlag == LOW)
  // time is recorded only if pinValue and myFlag are both LOW
  {
    myFlag = HIGH;    // when the switch closes, myFlag is set to HIGH.
    if (n == 1)
    {
      myTime1 = micros();   // time of the first passage
      myTime2 = myTime1;  // time of passage  n
      Serial.println ("starting....");
    }
    if(n > 1)
    {
      myTime3 = micros();   // time of passage n+1
      timeInterval = (myTime3 − myTime2);
      //  time between consecutive passages
      angularSpeed = (2 * 3.14159) / (timeInterval / 1000000);
      //  angular speed in rad/s
      Serial.print ((myTime3 − myTime1) / 1000000);
      //  time in s since the first passage
      Serial.print ("  ");
      Serial.println (angularSpeed);
      myTime2 = myTime3;
    }
    n++;
  }
  if (pinValue == HIGH and myFlag == HIGH)
  {
    myFlag = LOW;  // when the switch re−opens, myFlag is set to LOW.
  }
}
```

Figure 2. The Arduino code.

$$\omega = (\omega_0 + a/b)\exp(-bt/I) - a/b. \tag{5}$$

The solid line in figure 3 reproduces the best fitting to equation (5). The parameter values used were $\omega_0 = 138$ rad s^{-1}, $b/I = 0.087$ s^{-1} and $a/b = 8.66$ rad. As can be observed, the model reproduces accurately the experimental data in the entire range of angular speeds. As a result, dry and

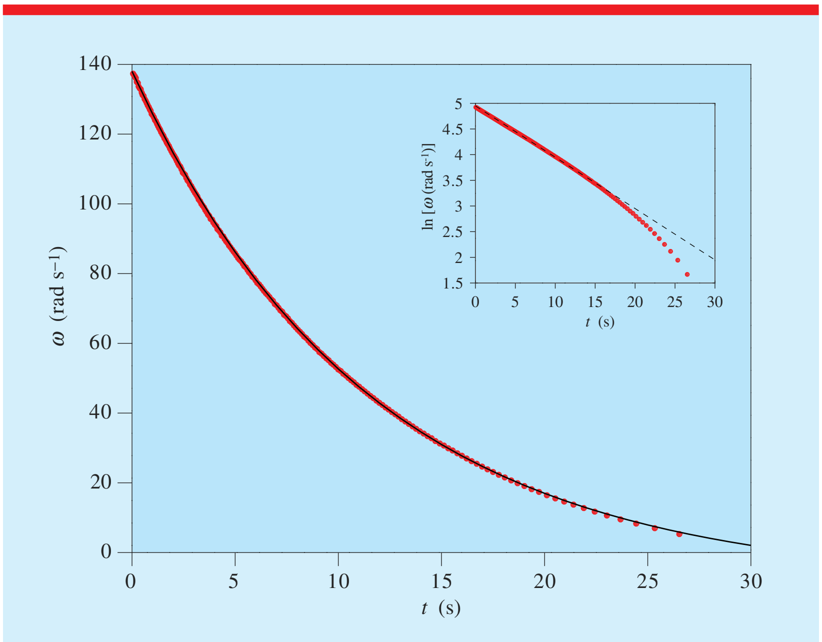

Figure 3. The angular speed of the spinner as a function of time. The red dots are experimental points. The solid curve reproduces the fit to equation (5) using $\omega_0 = 138.0$ rad s^{-1}, $b/I = 0.087$ s^{-1} and $a/b = 8.66$ rad. The inset shows a semi-logarithmic plot of the angular speed as a function of time. The dashed line is a linear fit to some of the data.

viscous dissipative forces have to be considered to accurately describe the movement of the spinner.

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Vitor Oliveira has been a teacher of physics at the Instituto Superior de Engenharia de Lisboa (ISEL) since 2008. He obtained his PhD in Materials Science and Engineering at the Instituto Superior Técnico (IST) in 2002. His research background is in pulsed laser materials processing but is also interested in the field of physics and science education.