M104. Free fall and sliding on the ramp

Aims:

- *Observation of electromotive force induction in a coil by a magnet moving inside the coil.*
- *Observation of changes in the position and velocity of a body performing a free fall and sliding over a ramp.*
- *Measurement of the acceleration of a body sliding over a ramp as a function of the ramp inclination angle.*
- *Determination of the friction coefficient characterising the friction between the sliding body and ramp surface.*

1. Introduction

Galileo Galilei is regarded as one of the fathers of contemporary science in recognition of his studies in the area of astronomy and physics. One of his greatest achievements was performance of the accurate effect of the gravitational force on the free fall of bodies. Galileo assumed that upon free fall the velocity of the falling body should increase by the same value in the same time so at a constant rate. In his times the testing of this hypothesis was a great challenge. Galileo was not able to measure the motion of a free falling body in time as there was no technology allowing recording of so fast changes. To overcome this problem Galileo decided to decrease the velocity of the falling body by placing it on a ramp. This solution is justified by the fact that the free fall can be treated as sliding on a vertical ramp. Thus the body sliding over an inclined ramp should change its velocity in the same way as a freely falling body.

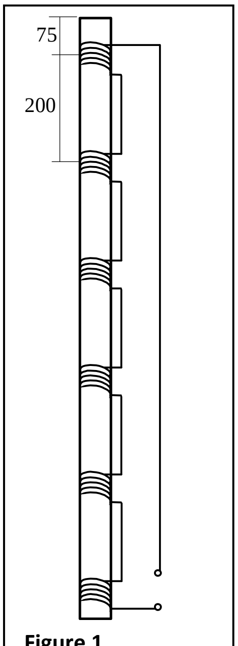


Figure 1. Experimental setup

2. Equipment

A plastic tube with a system of equidistant coils, permanent magnets.

3. Instruments

Changes in velocity of a given object when it is moving can be realised by measuring time changes in the object position, so measuring the path dependence on time. Determination of a moving object position needs a possibility of checking its position over a relatively long path. Such a possibility can be realised using a plastic tube of 1.15 m in length on which 6 equidistant and connected in series coils are wound up. The first coil is wound up at a distance of 7.5 cm from the upper end of the tube. The other coils are wound at every 20 cm. Each coil is about 1 cm long, has the internal diameter of 1.5 cm, while the external diameter of 1.6 cm. The coils are identical and are made of 17 loops of copper wire of 0.5 mm in diameter. The ends of the wire are connected to the sockets through which they are linked to the measuring interface. This construction permits the use of electromagnetic induction (IEM) to determine the moment of time at which a given object passes the coil, although the falling object has to be a magnet. In this experiment two permanent magnets differing in the type of surface, will be used. Their use will permit determination of the effect of a static friction (between the surface of the magnet and the surface of the ramp) on the movement of the object.

4. Theoretical introduction

Electromagnetic induction

Because it is related to the method for the measurement of position of a sliding body, let's refresh your knowledge on electromagnetic induction.

In short, the electromagnetic induction is the phenomenon of generation of an electromotive force E in an electric circuit upon time changes in the flux of magnetic inductionpassing through the circuit. The source of a magnetic field can be a permanent magnet. The electromotive force generated is proportional to the rate of changes in the magnetic flux Φ:

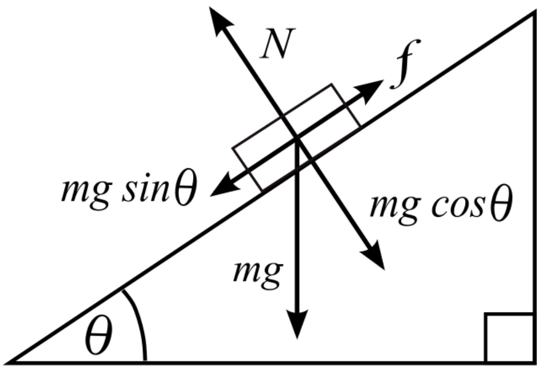
$$E = -\frac{d\Phi}{dt}. \qquad (1)$$

The minus sign means that the direction of the induced current is such that the effects of the current oppose the phenomenon (the change) generating it, the Lenz rule.When a permanent magnet passes through a cell of N wire loops, the total value of Ecan be approximated by the equation

$$E = -N\frac{d\Phi}{dt}. \qquad (2)$$

Measurement of Eas a function of time permits determination of certain parameters related to the magnetic field of the falling magnet.

A body on the ramp



The figure presents a body of mass *m*placed on a ramp inclined at the angle $\theta$to the flat surface and the forces acting on it. *N*is the force of pressure, *g* is the earth gravitational constant, *f* is the friction force, $f=\mu N$, where μis the coefficient describing the static friction between the surface of the body and the surface of the ramp. Analysis of the forces presented in the figure leads to the well-known equation describing the acceleration of the sliding body as a function of the ramp inclination angle,

$$a = g(\sin(\theta) - \mu\cos(\theta)) \,. \tag{3}$$

The acceleration calculated from this equation can be compared with that measured in the experiment in order to find out the static friction coefficient.

5. Realisation of the experiment

A. Observation of electromotive force induction

1. Start the program “Spadek.vi” [Fall.vi] and record the time course of voltage induced in the coil by the magnet moving inside it.
2. Note that the voltage induced in each subsequent coil changes linearly with the time of the magnet fall. What does this observation imply about the magnet velocity?

B. Free fall of a body

1. Start the program “Spadek.vi” [Fall.vi] and similarly as above record the time changes in the induced voltage. Press the button “Zakończpomiariprzejdźdo analizy” [Stop the measurement and go to analysis].
2. In the tab“Analiza” [Analysis] you will find the results of analysis of the measured time

changes in the voltage induced; moment of the start of motion, acceleration determined from the time dependence of the path for the minima and maxima. The tables also give the positions and values of the minima and maxima of the measured induced voltage.

3. Change the angle of the ramp inclination to get the maximum value of the measured acceleration, a. This value corresponds to the acceleration of the body sliding on the vertical ramp, $\theta=90^o$. Make the measurements for two magnets differing in the material on their surfaces. Why the accelerations measured for the two magnets are different although the tube is in the vertical position? Why the acceleration values measured differ from the expected value equal to the gravitational constant g?
4. Perform a few measurements and write the acceleration values measured for the two magnets.

C. Friction in sliding motion

1. Using the program "spadek.vi" [Fall.vi] measure the accelerations of the magnets a, as a function of the ramp inclination angle, θ. Reduce the ramp inclination by the step of 5^o starting from 90^o.
2. Continue the measurements until the body on the ramp will stop sliding.
3. Draw the values of a/g as a function of the ramp inclination angle θ (assume that $g=a$, $\theta=90^o$).
4. Compare the measured relation $a/g(\theta)$ with the relation given by eq. (3). Change the values of static friction coefficient, μ, as long as it takes to get the theoretical relation closest to the experimental data, (the quality of the fit evaluate subjectively).
5. Are you able to linearize equation (3) to be able to apply linear regression analysis for determination of μ?
6. Calculate the static friction coefficients, μ, for the two magnets. Calculate the critical angles.