

E103. Study of the Faraday's law of induction

1. Introduction

Electromagnetic induction was a landmark event in the science of electricity and magnetism at the beginning of the nineteenth century. After the discovery of an electricity (Galvani, Volta) and the well-known properties of permanent magnets, the observations showed the link between electricity with magnetism on the example of the electromagnet (Ampere). The challenge was to observe a reverse effect - the electric field source obtained with a permanent magnet. It was took up by the most talented experimenter of that time, Michael Faraday.

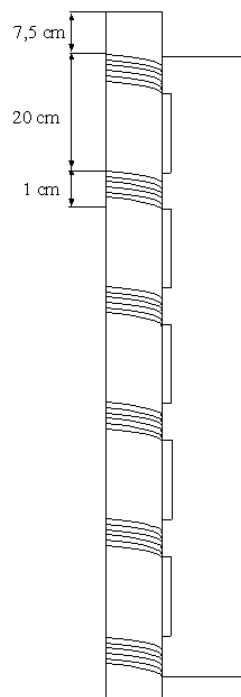


Figure 1. Scheme of the measurements.

Faraday induction is based on the electromotive force (E , called the induction electromotive force) that occurs in the electrical circuit placed in the alternating magnetic field:

$$E = -\frac{d\phi}{dt}, \quad (1)$$

where ϕ is the flux of the magnetic field. The sign "-" expresses Lenz's law fixing the

direction of the induced current, so that its effects is opposed to the cause of its creation.

In this laboratory we use the combined set of coils (connected in series, see Figure 1), wound on the plastic tube, through which we throw a magnet. The magnet passing through the coils induces electromotive force therein. When the lower magnet pole penetrates the coil then the magnetic field increases, so that it increases the value of E induced in the coil. The magnet poles are spaced, therefore the slipping of lower pole of the coil is accompanied by a decrease of E . But then the top (opposite) pole starts to penetrate, and the magnet induces E but with the opposite sign. At the end, when the magnet leaves completely given coil, electromotive force induced in it disappears completely. The magnet falls down further approaching the next coil.

The whole process is repeated. The maxima of E are higher for faster velocity of the magnet since the changes of the same magnetic field flux are more rapid (eq. 2). As a result, one obtains the characteristic dependence of the electromotive force, E , on time, $E(t)$, with maxima and minima peaks, presented in Figure 2.

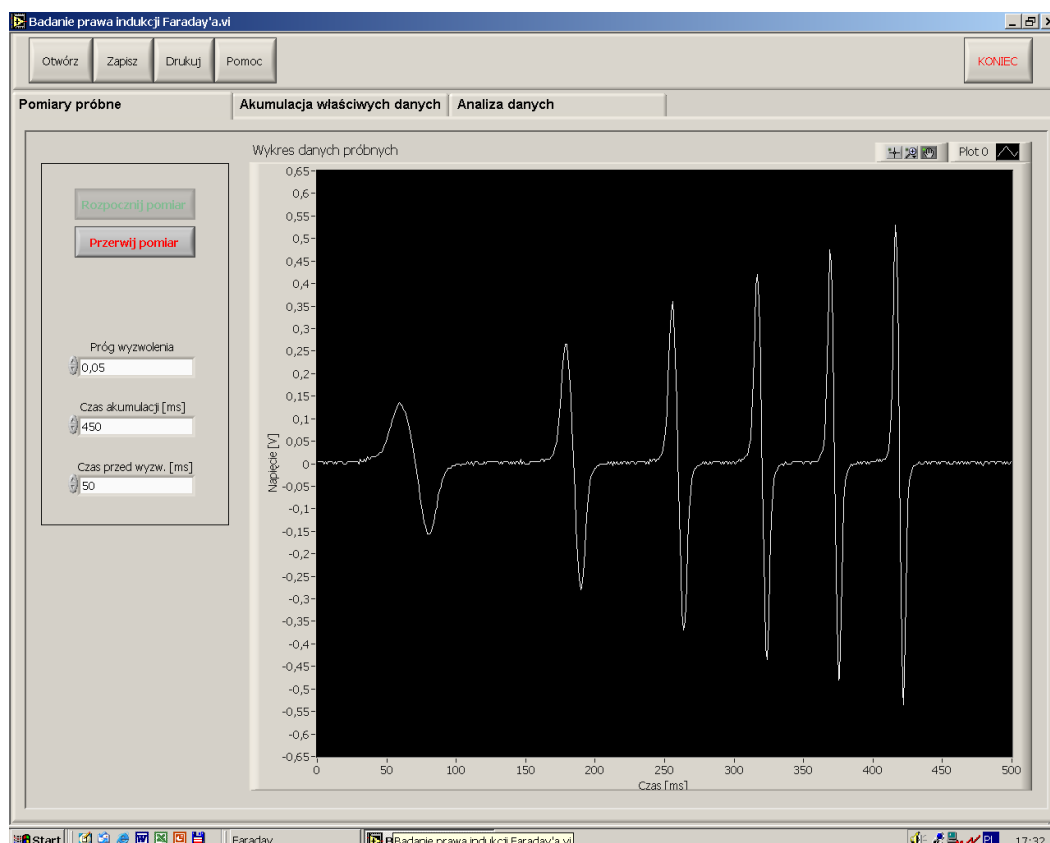


Figure 2. Screenshot of the application with the measured signal.

2. Apparatus and measurements

At the beginning the user has to establish the parameters of the measurements to properly collect the data of the electromagnetic induction. This is done in the first fold of the application (*Pomiary próbne*), and the necessary parameters are: the trigger level, in volts (*Próg wyzwolenia*), time of accumulation after trigger, in ms (*Czas akumulacji*) and time of accumulation before trigger, in ms (*Czas przed wyzw.*). To test the choice of parameters, the green button (*Rozpocznij pomiar*) starts the signal acquisition, while the red button (*Przerwij pomiar*) stops the measurements.

The appropriate measurements are collected using the second fold of the application (*Akumulacja właściwych danych*). The parameters are the same as previously established. A user can add more than one signal curve (*Dodaj kolejne przebiegi*), see Figure 3.

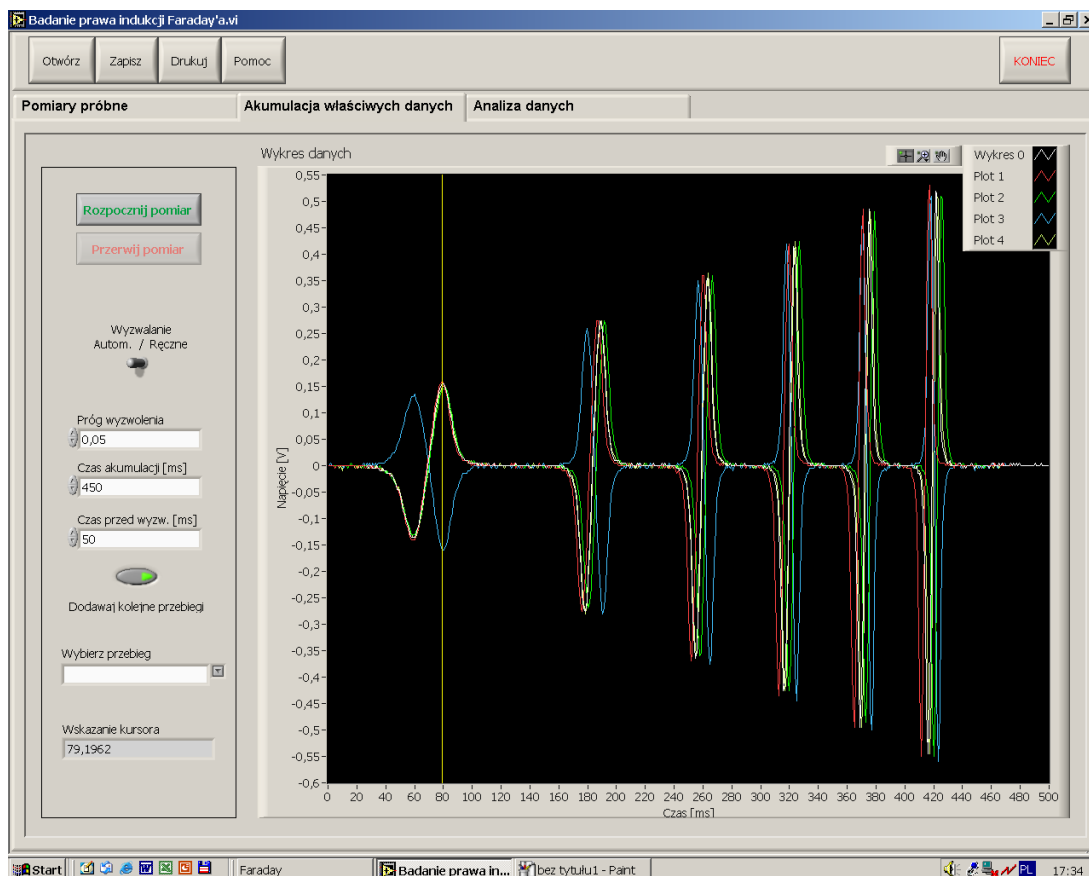


Figure 3. Collecting several signals.

The last fold of the application (*Analiza danych*) is used to analyze the data. A user has to choose which set of data (*Przebieg*) will be analyzed (Figure 4). It is also possible to save the data to the text file (button *Zapisz*) and open them from the text file (button *Otwórz*).

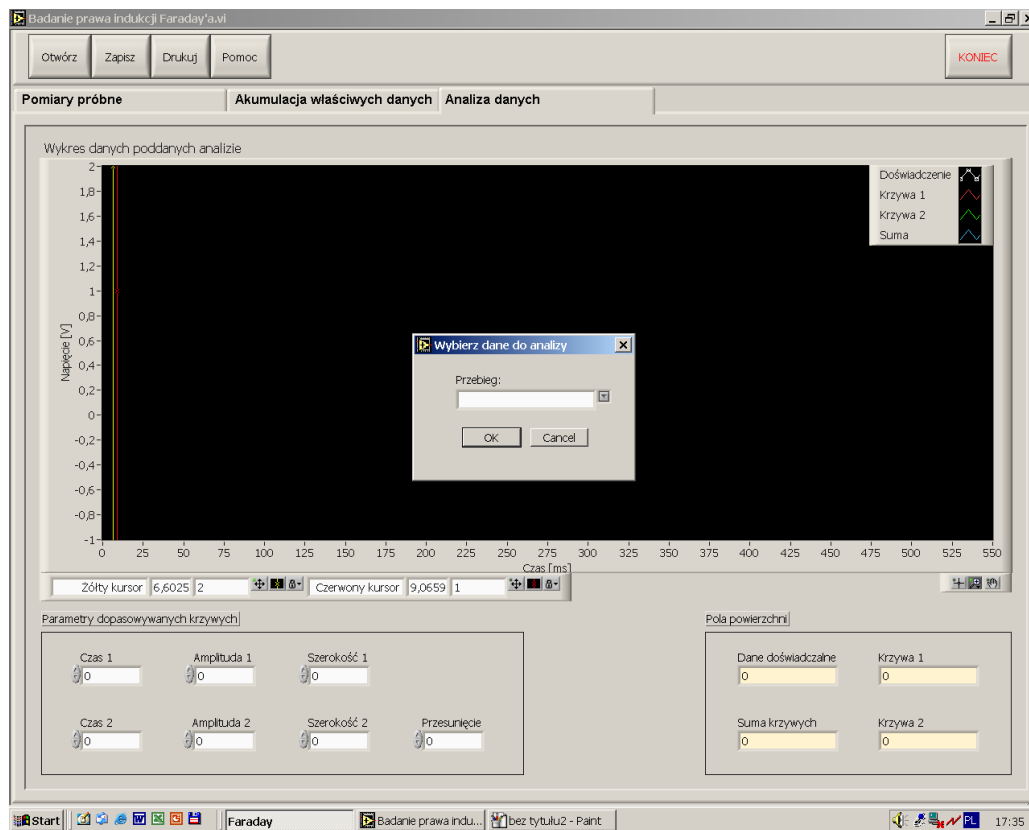


Figure 4. Choosing which signal will be analyzed.

When the chosen data appear on the screen, each of the pair of peaks has to be analyzed. The most convenient way is to zoom the plot to a certain pair of maximum and minimum of $E(t)$, see Figure 5. For each maximum and minimum the values of electromotive force E_{max} and E_{min} , as well as the corresponding times at which they occur, t_{max} and t_{min} , need to be found. It can be done in two ways. First, the positions of the red and the yellow cursors can be read below the plot. Alternatively, one can fit two Gaussian functions to the data (lower-left frame in Figure 5). The user has to find the best values of the time zero of the Gaussian function, in ms (*Czas*), its amplitude, in volts (*Amplituda*) and width, in ms (*Szerokość*). Indexes 1 and 2 refer to the first and to the second Gaussians function, and if the offset parameter, in volts (*Przesunięcie*) is used to shift the functions vertically. The results of finding E_{max} (t_{max}) and E_{min} (t_{min}) by these two methods (manual and by fitting the theoretical function) should be compared and discussed.

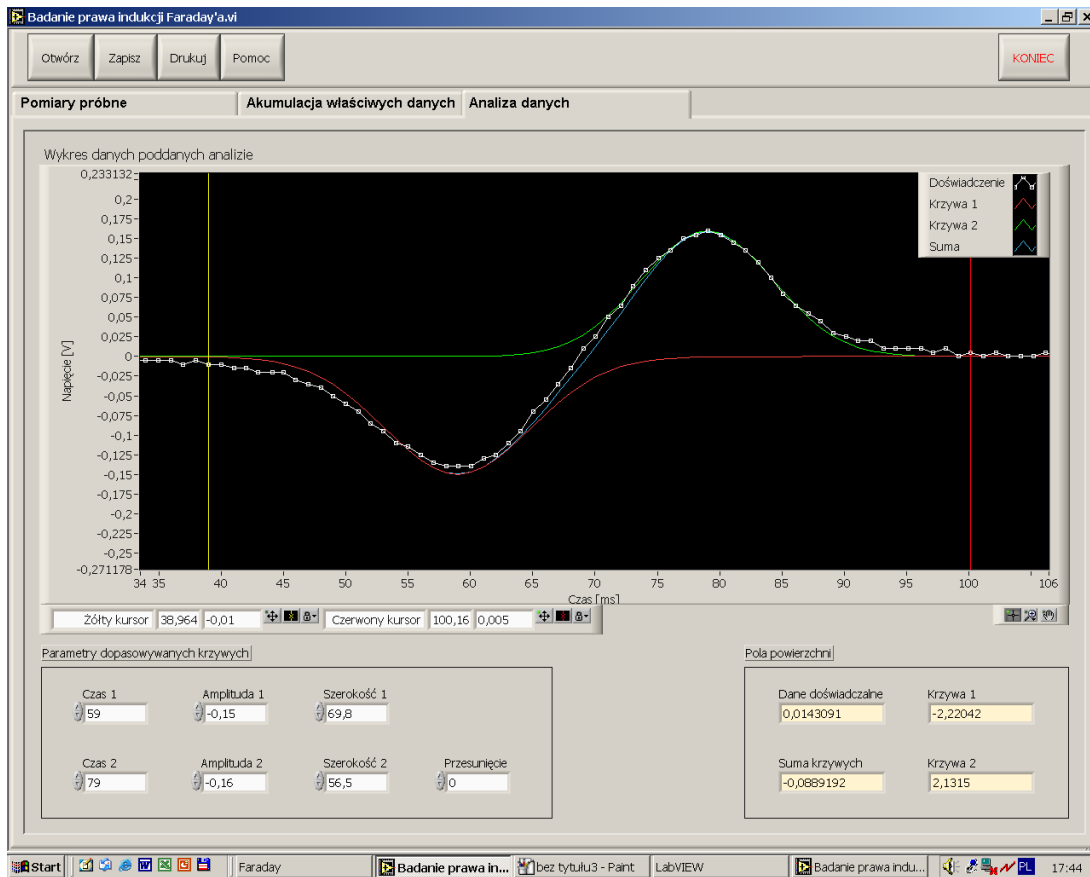


Figure 5. Analyzing the data.

Then, the linear proportionality of the dependences of the maxima and minima of the induced electric on time should be checked by collecting the (E_{max}, t_{max}) and (E_{min}, t_{min}) values for all coils and making linear regression. It can be shown that the electric field given by eq (1) is linearly proportional to the velocity v of the magnet passing through the coil, which in the case of gravitational free-fall (uniformly accelerated motion) is also linearly proportional to the time.

Next, assuming the same velocity of both poles of the magnet in certain coil, the distance d between poles can be calculated as:

$$d = v (t_{max} - t_{min}). \quad (2)$$

The velocity of the magnet can be calculated, for example, from the well-known formula for the gravitational free-fall:

$$v = \sqrt{2 \cdot g \cdot z}, \quad (3)$$

where g is gravitational acceleration and z is the distance from the top of the tube where the

fall of the magnet started. The values of distance d calculated from the signals of all coils can be compared.

Finally, the total flux of the magnetic field can be calculated of each of the coils. It is equal to the surface area under the curves, calculated by the application and shown in the lower-right frame (Figure 5). The program shows the area under the experimental data between two cursors (*Dane doświadczalne*) as well as the area under the first (*Krzywa 1*), the second (*Krzywa 2*) fitted Gaussian functions and the sum of these two areas (*Suma krzywych*). It can be observed whether the flux from the top pole of the magnet and that from the bottom pole cancel each other or not.

The reasons for the deviations (if any) of all the results from the predictions (approximations) could be discussed.