Interactive virtualisation in Java Script of electromagnetism when changing the dynamic, static parameters of ferromagnetics

Adambek Tatenov
Department of Physics, Kazakh National Women's Teacher Training University, Almaty, Republic of Kazakhstan,
tatenov7541-1@ubogazici.in

Nauan Shambulov
Department of Physics, Kazakh National Women's Teacher Training University, Almaty, Republic of Kazakhstan

Umirbek Baitukayev
Department of Engineering, Eurasian Technological University, Almaty

Aidana Ospanova
Department of Physics, Kazakh National Women's Teacher Training University, Almaty

Nurgul Shinykulova
Department of Physics, Kazakh National Women's Teacher Training University, Almaty

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Abstract

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RESEARCH PAPER

Interactive Virtualisation in Java Script of Electromagnetism Upon Changing the Dynamic, Static Parameters of Ferromagnetics

Adambek Tatenov [a],*, Nauan Shambulov [a], Umirbek Baitukayev [b],
Aidana Ospanova [a], Nurgul Shinykulova [a]

[a] Department of Physics, Kazakh National Women's Teacher Training University, Almaty, Kazakhstan
[b] Department of Engineering, Eurasian Technological University, Almaty, Kazakhstan

Abstract

Laboratory-based work is necessary for developing the skills of measuring physical quantities, performing physics experiments, and drawing correct conclusions from their observations. Training programs that simulate physics processes and phenomena that cannot always be shown "live", can significantly help students. The authors developed and implemented the processes of the phenomenon of the physics course "Electromagnetism" − "Study of dynamic hysteresis of ferromagnets" and interactively virtualised using the Java Script computer software environment. The originality of this approach is that it provides a convenient tool for creating a simulation environment for any physics problem. This interactive virtual laboratory development will be introduced into the educational process of the Kazakh National Women's Pedagogical University.

Keywords: Hysteresis, Induction, Oscilloscope, Current strength, Electrical circuit

1. Introduction

Physics is an experimental science. Therefore, the training program involves not only the theoretical studies but also laboratory research. Laboratory-based work is necessary for developing the skills of measuring physical quantities, performing physics experiments, and the ability to draw correct conclusions from their observations. Modern computer technologies allow complementing this conventional training scheme. Training programs, which simulate physics processes and phenomena that cannot always be shown "live" in classroom conditions, can considerably aid students [1−7]. The importance of such programs, however, should not be exaggerated. It is necessary to remember that nothing can replace a real physics experiment in which a part of a natural phenomenon "speaks" to the researcher, and not a copy of virtual reality modeled by a person. The Virtual Interactive Laboratory (VIL) software for the study of dynamic and static parameters of ferromagnets in alternating and constant magnetic fields, a phenomenon of the physics course "Electromagnetism" is remarkably effective and can be used in the learning process in diverse ways [8−11].

The effectiveness of the use of virtual and digital physics laboratories in the educational process has been proven by many studies. J.D. González et al. [12,13] conducted an experiment on the study of electromagnetism using ordinary practical experiments and virtual manipulation tools. As a result, virtual laboratories obtain greater acceptance. G.M. Oghlu Sharifov's [14] experiment also confirmed the positive impact of the virtual laboratory on students' attainment of more in-depth scientific knowledge in electromagnetism. The authors developed a Virtual Electromagnetism Laboratory as a didactic strategy for engineering students. The article describes the successful implementation of technology in the educational process [15]. No less successful were the studies [16] in this field.

Firstly, it can be used for demonstrations to explain new material. Such demonstrations are visual, improve perception, and arouse interest in the subject. The advantage of such demonstrations, in comparison with ordinary videos, is also that the teacher can quickly answer students' questions by changing the parameters in the program: "What happens if … ?". The answer is: "Let us do it and see". Secondly, the program can be used as a "laboratory" workshop. These classes are best conducted in a computer classroom. In this case, each student will be able to perform their laboratory work independently. For such a lesson, preliminary preparation is usually necessary – when the theory of the phenomenon is already mastered, then meaningful work with experimental installations can be useful for a deeper understanding of the subject. The proposed set of laboratory works and demonstrations does not exhaust all the possibilities of the program, and the teacher can always supplement this list with their personal developments [17–21].

Thirdly, research activities and projects can be carried out within the program. Its capabilities allow conducting research on complex magnetic processes and phenomena, the theory of which goes beyond the scope of the educational program. Below are examples of laboratory works and demonstrations that can be used in the program. Notably, the calculations performed by the program for the model of real electrical circuits are quantitative and qualitative in nature. The list of laboratory works proposed for performing on a computer in the physics course "Electromagnetism": laboratory work No. 1 "Study of dynamic hysteresis of ferromagnets"; laboratory work No. 2 "Measurement of the magnetisation curve and the hysteresis loop in a constant magnetic field" [22–25].

2. Theoretical overview

Among the substances that can be magnetised in a magnetic field, a special class is formed by substances that are characterised by a magnetically ordered state in the absence of an external magnetic field. Substances that have spontaneous magnetisation in a certain temperature range in the absence of an external magnetic field are called ferromagnets. Ferromagnetic materials include iron (Fe), cobalt (Co), nickel (Ni), rare earth materials: gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), and many alloys and compounds of these metals among themselves and with other non-ferromagnetic elements. The magnetic properties of ferromagnets are remarkably diverse and depend on many factors: the external field, temperature, external mechanical stresses, the nature of the magnetisation process. The magnetic susceptibility x of ferromagnets is positive [26] ($\chi > 0$) and reaches values of 104–105; their magnetisation J and magnetic induction B grow with increasing magnetic field strength H non-linearly and in sufficiently strong fields reach the limit value Js (magnetic saturation).

Due to the nonlinear dependence of B(H), it is impossible to introduce the magnetic permeability µ as a certain constant value that characterises the magnetic properties of each given ferromagnet. It is a function of H (Fig. 1). The value of J depends on the magnetic background of the sample, this makes the dependence of J on H ambiguous – magnetic hysteresis is observed. When magnetising ferromagnets, their size and shape change. The opposite effect is also characteristic – the magnetisation curves and hysteresis loops depend on external mechanical stresses. Magnetic anisotropy is observed in ferromagnetic crystals – the difference in magnetic properties in different crystallographic areas.

The temperature course of the magnetic susceptibility of ferromagnets has a pronounced maximum near the Curie point Tc, and the saturation magnetisation Js weakly decreases at low temperatures and is characterised by a sharp decline to zero near the Curie point (Fig. 2). When ferromagnets are heated, the increasing thermal motion of the atoms "shakes" the existing magnetic order and at a temperature T = Tc in a ferromagnet, the spin magnetic moments of atoms are "disordered", i.e., a phase transformation occurs, as a result of which the magnetisation disappears, and the ferromagnet turns into a paramagnet, the change in the susceptibility of which follows the Curie–Weiss law

$$\chi = C/T - Tc, \tag{1}$$

where the Curie temperature Tc is included as an added constant, C is the Curie–Weiss constant.

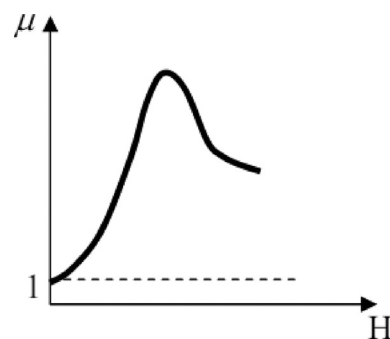The physical nature of ferromagnetism was understood only through quantum mechanics. Under
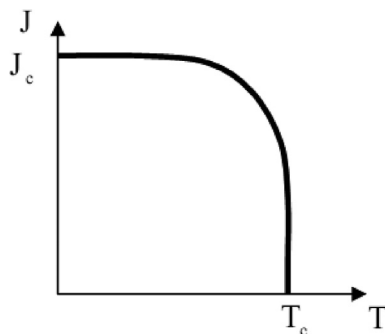

Fig. 1. Function H.

Fig. 2. Saturation magnetisation Js.

certain conditions, so-called exchange forces can occur in crystals, which cause the magnetic moments of the electrons to be installed in parallel to each other. As a result, there are regions (with a size of ~10−6 m) of spontaneous magnetisation − these regions are called domains. Within each domain, the ferromagnet is magnetised to saturation and has a certain magnetic moment. The directions of these moments vary for different domains, and therefore, in the absence of an external field, the total moment of the sample is zero and the sample as a whole appears macroscopically unmagnetised. In case of weak external fields, the course of the magnetisation curve is linear. In this region, mainly reversible processes of elastic displacement of domain boundaries occur. Domains whose vectors J make up the smallest angle with the direction of the magnetic field strength H, at the same time increase due to neighbouring domains with an energetically less favourable orientation J relative to the external field H. At the same time, the domains can change their shape, size, and their energy.

In stronger fields, the domain structure is rearranged due to both reversible and irreversible boundary shifts. When all the domains with the most favourable orientation J completely absorb the energetically less favourable domains, the growth of magnetisation continues due to the processes of rotation of magnetic moments until their complete orientation towards H. These processes are irreversible. Irreversible processes are the cause of hysteresis. Upon reaching the state of magnetic saturation, an increase in the magnetic field strength does not lead to a change in the magnetisation of the ferromagnetic sample, and the magnetic induction B continues to grow with an increase in H according to a linear law. In the state of magnetic saturation, the domain structure of a ferromagnetic sample is a single domain in which the spin magnetic moments of all atoms are oriented towards the external magnetic field H. The key characteristic property of ferromagnets is magnetic hysteresis, i.e., the delay of changes in magnetic states from measurements of the strength of the external magnetic field (Fig. 3).
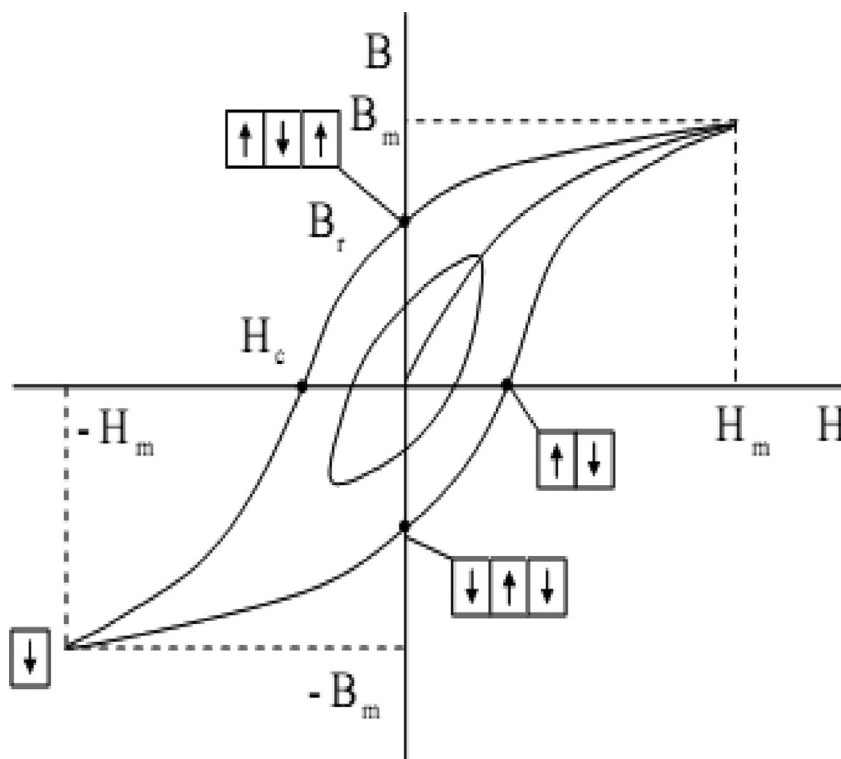

Fig. 3. Magnetic hysteresis.

Magnetic hysteresis is observed even before the ferromagnet reaches the state of magnetic saturation and is the reason for the ambiguous dependence of magnetisation and magnetic induction on the magnetic field strength. If, after reaching saturation at H=Hm, the value of the external magnetic field strength H begins to decrease, then the reverse curve will go higher than the main one, mainly due to the appearance and growth of domains with a magnetic moment directed against the field (Fig. 3). When H is reduced to zero, the sample keeps the residual induction Br. The sample is completely demagnetised only in a sufficiently strong field of the opposite direction, called the coercive field (coercive force) Hc. With a further increase in the magnetic field of the reverse direction, the sample is again magnetised along the field until saturation: − Bm. The subsequent change in the intensity from −H to + H corresponds to a change in the magnetic induction along the curve passing below the main one. The resulting curve (Fig. 3) is called the limit hysteresis loop. It is used to find the residual induction Br and the coercive force Hc of the ferromagnet under study. If H is not adjusted to the value of Hm, then smaller hysteresis loops (partial loops) will be obtained, the vertices of which will lie on the main magnetisation curve.

The area of the magnetic hysteresis loop is proportional to the energy lost in the sample during one cycle of changing the external magnetic field. This energy is ultimately used to heat the sample. The amount of heat released during remagnetisation is proportional to the "area" of the hysteresis loop. The values of Br and Hc for various ferromagnets vary widely. According to the magnitude of the coercive force, ferromagnets are divided into magnetically soft and magnetically rigid ones. The former ones have a small Hc and a significant magnetic permeability μ. The latter ones − large values of Hc and residual magnetisation Jr. Ferromagnets play an enormous role in various fields of modern technology: soft magnetic materials are used in electrical engineering (transformers, electric motors, generators, etc.), in low-current communication technology and radio engineering; magnetic-rigid materials are used for the manufacture of permanent magnets. Entire sections of technology are based on the use of the magnetic properties of substances, such as magnetic sound and image recording, magnetic flaw detection, and magnetic exploration of minerals.

3. Materials and methods

In this paper, the magnetic characteristics of ferromagnetic material are found by investigating the hysteresis loops in a magnetising field with a frequency of 50 Hz using an electron beam oscilloscope. The computers to be used in the educational process must have a 2.40 GHz processor, 8.00 GB RAM, Windows 7 operating system or newer. The sample from the ferromagnet under study in the form of a toroid (T) with an average radius rcp was equipped with magnetising (primary) and measuring (secondary) windings, the number of turns of which was n_1 and n_2, respectively (Fig. 4).

The voltage applied from R1 to the input X of the oscilloscope was proportional to the current I_1 in the magnetising winding
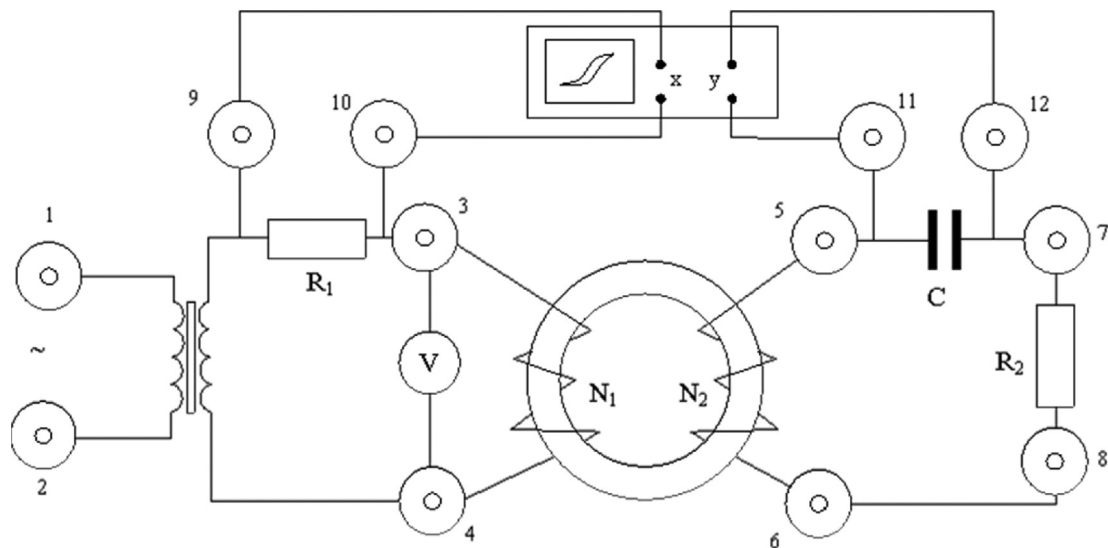

Fig. 4. A sample from the investigated ferromagnet in the form of a toroid.

$$U_R = I_1 R_1. \tag{2}$$

According to the circulation theorem, the strength H of the magnetic field created by the current I_1 was found as follows:

$$H = \frac{n_1}{2\pi r_{cp}} I_1 = \frac{n_1}{2\pi r_{cp}} \frac{U_R}{R_1} \tag{3}$$

In this case, an electromotive force (EMF) of induction occurs in the measuring winding:

$$\varepsilon_1 = -\frac{d\Phi}{dt} = -n_2 S \frac{dB}{dt} \tag{4}$$

through the surface covered by all the turns of the secondary winding, S − cross-sectional area of the toroid. According to Ohm's law for the secondary circuit:

$$\varepsilon_i = I_2 R_2 + \varepsilon_S + U_C \tag{5}$$

where I_2 is the value of the current in the measuring winding circuit, ϵ_s is the self-induction EMF that occurs in the secondary winding.

By selecting the resistance R2 and the electrical capacity C, $\epsilon_S + U_C << I_2 R_2$. The current strength in the secondary winding was obtained as follows:

$$I_2 = \frac{\varepsilon_i}{R_2} = -\frac{n_2 S}{R_2} \frac{dB}{dt} \tag{6}$$

Since the voltage on the capacitor:

$$U_C = \frac{1}{C} \int_0^t I_2 dt = -\frac{n_2 S}{CR_2} \int_0^B dB = -\frac{n_2 SB}{CR_2}, \tag{7}$$

then magnetic induction:

$$B = \frac{CR_2}{n_2 S} U_C. \tag{8}$$

Thus, the deviation of the oscilloscope beam along the X axis is proportional to the magnetic field strength H, and along the Y axis − the magnetic induction B in a toroidal sample. During one period of the sinusoidal current change, the electron beam on the oscilloscope screen will describe the complete hysteresis loop, and for each subsequent period it will repeat it exactly. As a result, a stable hysteresis loop will be visible on the screen. The main magnetisation curve obtained for the ferromagnet under study can be used to find the value of its differential magnetic permeability

$$\mu = 1\mu 0 dBdH \tag{9}$$

and build a dependency graph

$$\mu = \mu(H), \tag{10}$$

and also, using the ratio for magnetisation

$$J = \frac{B}{\mu_0} - H, \tag{11}$$

also build a graph

$$J = J(H). \tag{12}$$

Since

$$U_R = x\delta_x, U_C = y\delta_y, \tag{13}$$

where x and y are the coordinates of the hysteresis loop taken from the oscillograms, and δx and δy are the oscilloscope sensitivity along the X and Y axes, determined by the oscilloscope panel, then to simplify the calculations, the calibration constants h and b, determined by the equations, are used in the future:

$$h = \frac{n_1}{2\pi r_{cp} R_1} \delta_x \tag{14}$$

$$b = \frac{CR_2}{n_2 S} \delta_y \tag{15}$$

Considering the calibration constants, equations (3) and (8) take the following form:

$$H = hx \tag{16}$$

$$B = by \tag{17}$$

The values of J, μ are calculated using the formulas:

$$J = B/\mu_0 - H \tag{18}$$

$$\mu = \frac{1}{\mu_0} \frac{\Delta B}{\Delta H} \tag{19}$$

where:

$$\Delta B = B_i - B_{i-1}; \Delta H = H_i - H_{i-1}. \tag{20}$$

4. Results and discussion

The present requirement of time, visualisation, and interactivity, including animated images in the movements of physics phenomena and working with them requires a convenient software tool for implementation. The modern visual programming system Java Script provides a convenient tool for creating a simulation environment for any physics problem. To simulate the virtual interactive laboratory work No. 1 "Study of dynamic hysteresis of ferromagnets", all the necessary devices were modeled: an amperemeter, a voltmeter, an oscilloscope, a webermeter, a rheostat, a capacitor, a resistor, a toroidal coil, and a power source − an alternator, as shown in Fig. 5. The Java Script
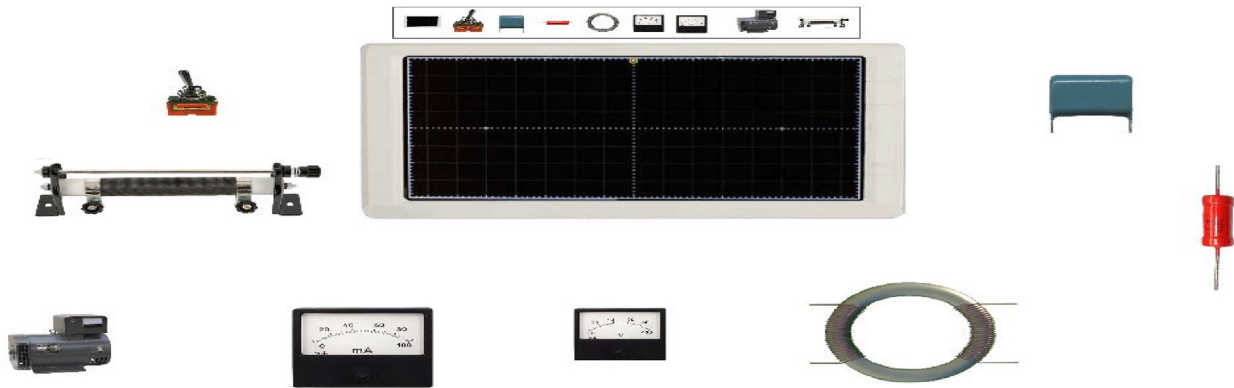
Fig. 5. Necessary devices and parts modelled for laboratory work.

computer program for modeling devices looked as follows:

aparature = "0"; //Assemble a set of laboratory tools for conducting research ....

Oscilograft_Drop._visible = false; vkluchatel_drop._visible = false; Condencator_drop._visible = false; Resistor_drop._visible = false; toroid_drop._visible = false; Voltmetr_drop._visible = false; ampermetr_drop._visible = false; Generator_drop._visible = false; Reostat_drop._visible = false; oscilograft_Drag.onPress = function(){startDrag(this); }; oscilograft_Drag.onRelease = function() {stopDrag(); aparatura++; Oscilograft_Drop._visible = true; osolograft_Drag._visible = false; };vkluchatel_Drag.onPress = function(){startDrag(this); }; vkluchatel_Drag.onRelease = function() { stopDrag(); aparatura++; vkluchatel_drop._visible = true; vkluchatel_Drag._visible = false; }; Condencator_Drag.onPress = function() {startDrag(this); };Condencator_Drag.onRelease = function(){stopDrag(); aparatura++; Condencator_drop._visible = true; Condencator_Drag._visible = false; };Resistor_Drag.onPress = function(){startDrag(this); }; Resistor_Drag.onRelease = function() {stopDrag(); aparatura++; Resistor_drop._visible = true; Resistor_Drag._visible = false; };toroid_Drag.onPress = function(){startDrag(this); }; toroid_Drag.onRelease = function(){stopDrag(); aparatura++; toroid_drop._visible = true; toroid_Drag._visible = false; }; Voltmetr_Drag.onPress = function(){startDrag(this); }; Voltmetr_Drag.onRelease = function(){stopDrag(); aparatura++; Voltmetr_drop._visible = true; Voltmetr_Drag._visible = false; };ampermetr_Drag.onPress = function(){startDrag(this); };ampermetr_Drag.onRelease = function(){stopDrag(); aparatura++; ampermetr_drop._visible = true; ampermetr_Drag._visible = false; };Generator_Drag.onPress = function() {startDrag(this); }; Generator_Drag.onRelease = function(){stopDrag(); aparatura++; Generator_drop._visible = true; Generator_Drag._visible = false; };Reostat_Drag.onPress = function(){startDrag(this); }; Reostat_Drag.onRelease = function() {stopDrag(); aparatura++; Reostat_drop._visible = true; Reostat_Drag._visible = false; };

Next was the installation of the electrical circuit with connecting wires, as in Fig. 6. The Java Script computer program for modeling the connection of devices was executed according to the following algorithm:

//Connection of devices according to the specified scheme:

stop();

loadMovie("file/shema.swf",1);

Oscilograft_Drop._visible = true; vkluchatel_drop._visible = true; Condencator_drop._visible = true; Resistor_drop._visible = true; toroid_drop._visible = true; Voltmetr_drop._visible = true; ampermetr_drop._visible = true; Generator_drop._visible = true; Reostat_drop._visible = true;

Based on the installed electrical circuit, measurements were performed to obtain a picture of the magnetic hysteresis family as a dependence of magnetic induction $-B$, on the magnetic field strength $-H$, as in Figs. 7 and 8. The algorithm of the Java Script program for modeling measuring points in the coordinate system to obtain a graph of the hysteresis loop in a step-by-step analogy of repeating points is given below://The graph of the hysteresis loop and the comparison of coordinate points.f1.onRollOver = function(){coord._x = 495.65; coord._y = −5.65; coord.h.text = "6.9974"; coord.b.text = "0.1079"} f2.onRollOver = function() {coord._x = 440.15; coord._y = −19.65; coord.h.text = "6.0950"; coord.b.text = "0.1070"}

To measure the magnetisation curve, it is necessary to demagnetise the sample, and then, gradually increasing the magnetic field, bring the ferromagnet into a saturation state, while measuring the
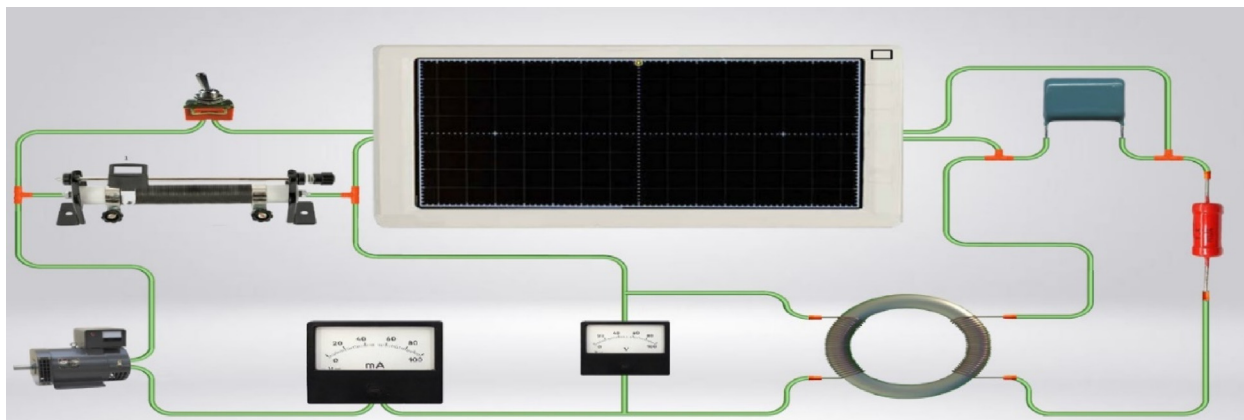
Fig. 6. Wiring diagram mounted with connecting wires.

magnitude of the magnetic field and induction at each point. To create an external magnetic field, a winding of n_1 turns is wound on a sample made in the form of a toroid (Fig. 5), which is called the primary winding. When a current is passed through this winding, a magnetic field is created in it, directed tangentially to the circle of the toroid. This field magnetises the sample. The field value is calculated using the equation (21). To measure the induction, a measuring winding with the number of turns n_2 is wound on the sample, which is also called a secondary winding. If a direct current i is passed through the primary winding, then the sample is magnetised under the influence of an external field and induction is created in it. In this study, the authors used direct current, since a change in the direction of movement and magnitude can lead to a large error in the results of the experiment. To avoid this, the study allowed "artificial condition" as a limitation. To measure the induction, a microwebermeter F5050 was used, the input of which was fed directly from the secondary winding of the sample. The study wrote the Faraday's law in the following form:

$$\int_{0\Phi}^{t} \varepsilon_{ind}\, dt = -n_2 \int_{l}^{\Phi_2} d\Phi = \Delta\Phi n_2. \tag{21}$$

If the sample is in a constant field, the voltage at the ends of the secondary winding is zero. If the magnetic field and the associated magnetic flux in the sample are abruptly changed from F1 to F2, then an EMF of induction occurs in the secondary winding, which depends on time, as shown in Fig. 9. The area of the pulse is equal to the change in the flow of ΔF. It is measured by the microwebmeter F5050. Thus, it is not the flow itself that is measured, but the change in the magnetic flux

$$\Delta F = F1 - F2. \tag{22}$$

To find the flow value, it was necessary that either the initial or final value was known. For example, if F1 = 0, then F2 = −ΔF. If the flow was
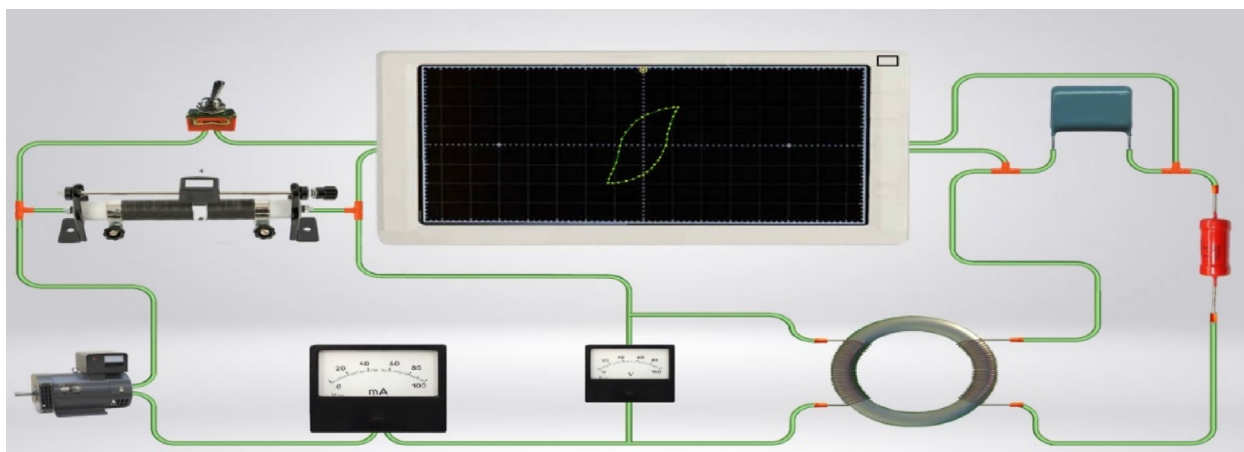

Fig. 7. The picture of a small magnetic hysteresis, as one of the family of hysteresis curves on the oscilloscope screen, when the values −H, do not reach the saturation state.
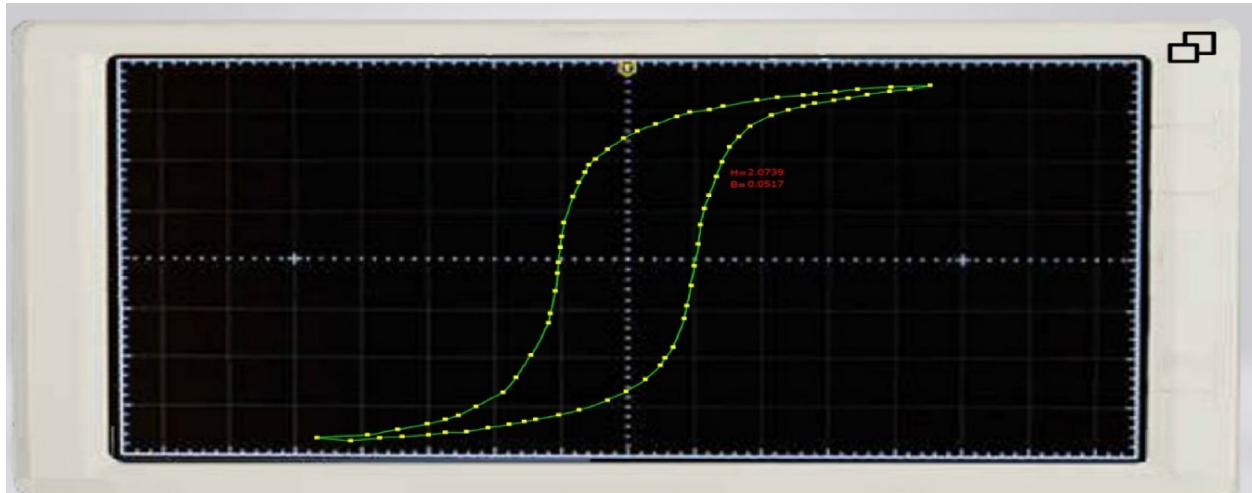
Fig. 8. The picture of the magnetic hysteresis loop on the oscilloscope screen, each point corresponds to the value of B and H with the saturation of the value of −H.

changed from −F to + F, then the change in the flow $\Delta F = -2F$.

Disregarding the heterogeneity of the sample magnetisation, it can be assumed that $F = BS$, where S is the cross-sectional area of the sample. Fig. 10 shows the electrical diagram of the installation for measuring the magnetisation curve and the hysteresis loop in a constant magnetic field. It is necessary to add the work of the webmeter and its software implementation.

Measurement of the hysteresis loop. The sample was brought to the state of magnetic saturation. In this case, the toggle switch P1 must be closed, and the resistance bank R set to 0. In this case, the sample was in state 0 (Fig. 11).

20–28 points were measured on the hysteresis loop, making 5–7 measurement cycles, respectively. This number of points was chosen arbitrarily, considering the limits of the experiment and the capabilities of the equipment. Notably, the hysteresis loop was measured to find the coercive force, and therefore, the reduction of the current (field) must be brought to values less than the coercive force. It is quite easy to

find this from the readings of a microwebermeter, since in the region of the coercive force at switching 1–0' and 3–0, ΔF should be approximately $\frac{1}{2}\Phi_{max}$, and this number is known from measurements of the magnetisation curve. Purpose and general features of the program. The product is intended to aid students (and teachers) of the secondary and specialised secondary educational establishments to study sections of the physics course "Electromagnetism". It naturally complements the conventional training scheme, which consists of mastering theoretical material and developing practical skills for laboratory experiments. The program is an electronic constructor that allows simulating the assembly processes of electrical circuits on the monitor screen, studying the features of their operation, measuring electrical quantities as it is done in a real physics experiment. The constructor can also be used within its capabilities for other tasks in the independent creative work of students. One of the primary features of the complex is the maximum possible imitation of a real physics process. For this purpose, the following was provided:

– the images of the parts of the designer and measuring devices were not shown schematically, but "as is";
– when the rated power of the electric current flowing through the resistance was exceeded, the latter "burned out" and took the form of a blackened part;
– if the operating voltage on the capacitor was exceeded, the latter also "broke";
– if the rated operating current was exceeded through the fuse, it "blew out";
– most operations and their results were accompanied by sound effects.
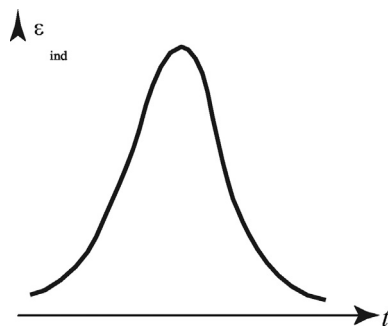

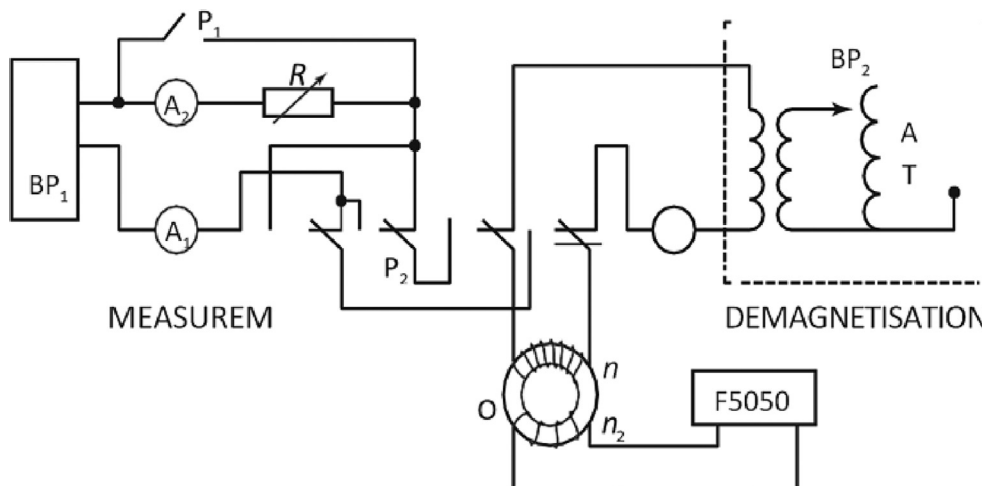*Fig. 9. The EMF pulse supplied to the input of the microwebermeter.*

Fig. 10. Electrical diagram of the installation.

This is done so that the students can clearly see the consequences of their mistakes, learn to understand the reasons for a particular unsuccessful experiment and develop the necessary skills for preliminary analysis of the scheme. To use the program, the initial skills of working in the Windows operating system are sufficient. The content of the working window and the basic principles of working with the complex. When starting the program, the following are displayed on the computer monitor screen:

- a mounting table with contact pads on which the student can assemble and analyse the operation of electrical circuits;
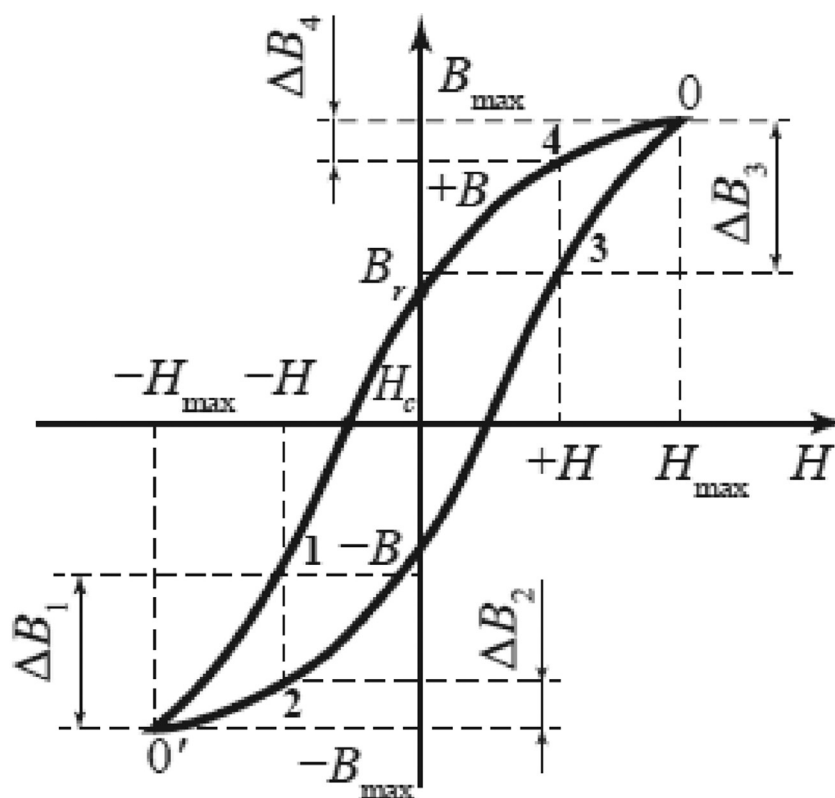- a panel of parts containing a set of electrical elements;

Fig. 11. Measurement of the hysteresis loop.

Table 1. Template for recording results and calculations.

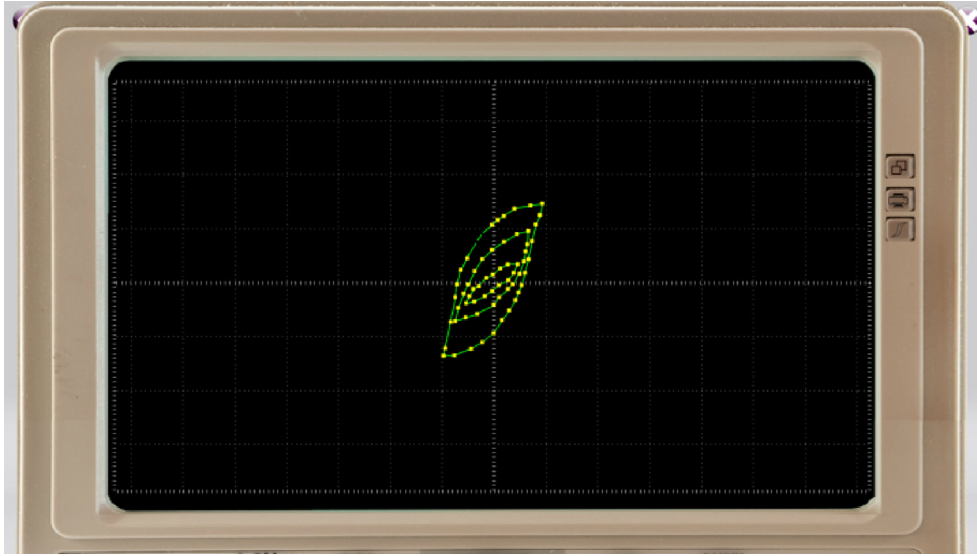| No.	x = L_x/2, points	δ_x	y = L_y/2, points	δ_y	H, A/m	B, weber/sq.m	J, A/m	μ
1								
2								
…								

Fig. 12. Family of hysteresis curves.

— the "trash can", where burned-out and unnecessary parts are thrown out (it is located in the lower left corner of the screen);
— program control panel with buttons for auxiliary tools;
— comments panel.

The residual induction V_r and the coercive force N_c of the studied ferromagnet are found from the picture of the magnetic hysteresis loop. Using the constructor, laboratory work and calculations can be performed according to the task as shown below:

1. Find the geometric dimensions of the resulting sample, the number of turns in the windings, the thickness of the wire.
2. Connect the devices to the test stand according to the scheme. Fix the resulting sample on the test bench.
3. Get the limit hysteresis loop on the oscilloscope screen and set it symmetrically relative to the origin. Using the resulting curve, find Hm and Bm.
4. Find the coercive force Hc and the residual induction Br of the investigated ferromagnetic material. To do this, measure the coordinates of the intersection points of the hysteresis loop with the horizontal X and vertical Y axes of the oscilloscope coordinate grid. Calculate the values of Hc and Br according to expressions (16) and (17). R1 = 2 Ω, C = 2 μF.

5. Gradually reducing the current in the magnetising winding, measure the x and y coordinates of the vertices of the hysteresis loops. Take measurements until the loop turns into a point. The measurements will be carried out with greater accuracy if the projection lengths of the hysteresis loop on the X-Lx and Y-Ly axes are found using the oscilloscope screen.
6. Calculate the value of the values H, B, J, and μ according to the equations 16–19. The results of measurements and calculations should be entered in Table 1.
7. Plot the dependence of the magnetic induction, magnetisation, and magnetic permeability of a ferromagnetic sample on the magnetic field strength B = B(H), J = J(H), μ = μ(H) (Fig. 12).

5. Conclusions

As part of information technology, a new branch is developing — virtual interactivity and visualisation of sophisticated topics of physics, chemistry, biology, and other subjects. The creation of virtual interactive laboratories with controlled measuring devices for these subjects is exceedingly rare. Therefore, the technology given in this paper for

creating a virtual interactive laboratory in the physics course "Electromagnetism" will be truly relevant to the creators of similar VILs – at a higher level in other subjects of knowledge. Such VILs on a computer help master a certain course of knowledge and develop independent research skills and awaken the creative search for research methods. This Virtual Interactive Laboratory for the physics course "Electromagnetism", due to the visual and interactive intervention in changing the conditions of the experiment, develops research skills in students. The considered software environment of the physics course "Electromagnetism" will be introduced into the educational process of the Kazakh National Women's Teacher Training University, at the Department of Physics for the laboratory study of electromagnetism. In further improvements of the course, the authors suggest shifting the emphasis to the dependence of the shape of the loop on the material.

Conflict of interest statement

The authors declare no conflict of interest.

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