EVALUATION OF THE DEFECT LEVEL OF ELECTRICAL MACHINES BY HIGH-FREQUENCY METHODS

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Introduction. When designing an electric machine, its performance, optimum operating conditions, thermal state, and many other factors are calculated using the nominal values of the steel, winding, and in general all materials used in the machine. However, these materials do not always have the stated characteristics and quality. For example, when manufacturing and stamping sheets of electrical steel, it is subjected to a significant level of influence, which in some way affects its characteristics. Moreover, even if we assume that during the production process, all stages of material production have come to a flawless state, and as a consequence, the parameters of materials and EM generally change during operation as a result of emergencies or even simple aging and wear.

Therefore, in view of these facts, it becomes clear that during planned or unplanned repair work it makes sense to check the condition of materials, insulation, since their condition depends on the permissible loads, temperature regime, etc. In particular, the state of the magnetic circuit largely determines the temperature around the conductors in the slots and as a result determines how much the windings will actually serve, as opposed to the specified lifetime and the rated power at which this EM should be used.

Analysis of recent research. An analysis of foreign literature has shown that most scientific publications that have been found under the study of magnetic steel lines refer to the study of steel not yet assembled in the stator package.

The most common method is the loss measurement presented in [1, 2], which is called hysteresis loop measurement. In this method, the core is wound as a transformer with two windings: the primary winding is used for excitation and the secondary for the measurement of the induced voltage. The core losses can be calculated by integrating the product of the measured voltage and the current passing through the primary winding [3].

Formulating the goals of the article. Determination of loss distribution in hysteresis magnetic circuit and eddy currents for mixed general purpose EM magnetic cores at industrial and high frequencies.

Main part. *Magnetic induction distribution in a magnetic circuit*. In the COMSOL Multiphysics mathematical package, on the basis of a ready-made computational model, the distribution of magnetic induction in one investigated magnetic line was calculated during the study by the wattmeter method. Figure 1 presents the distribution of magnetic induction in the magnetic circuit of the AD series 4АА63В4У3 0.37 kW. The peak value of the induction corresponds to the position of the excitation winding.

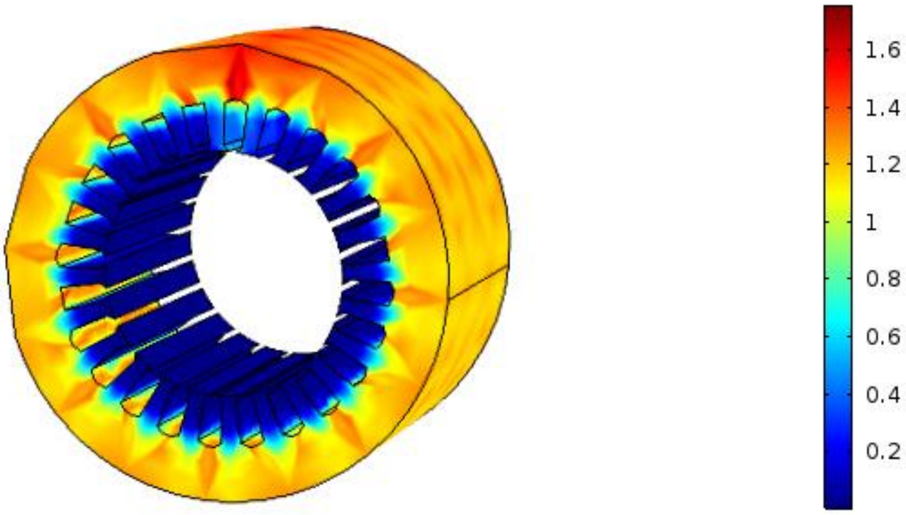

Figure 1 – Distibution of magnetic induction in magnetic core of AC machine series 4AA63B4У3 0,37 kW

This calculation visually reflects the magnetic flux paths and confirms the formulas used in the calculations, namely that the magnetic flux does not enter the tooth. Thus the fact that only the height of the stator back was used to calculate the area of the active steel and that only the back mass is calculated in the calculation of the active steel mass is theoretically and mathematically justified.

Also, based on the finished mathematical model, the induction distribution of the sheet thickness at different frequencies was calculated. That is, it presents a picture of the effect of a surface effect. Figure 2 shows the distribution of magnetic induction in the magnetic circuit sheet at different frequency values.

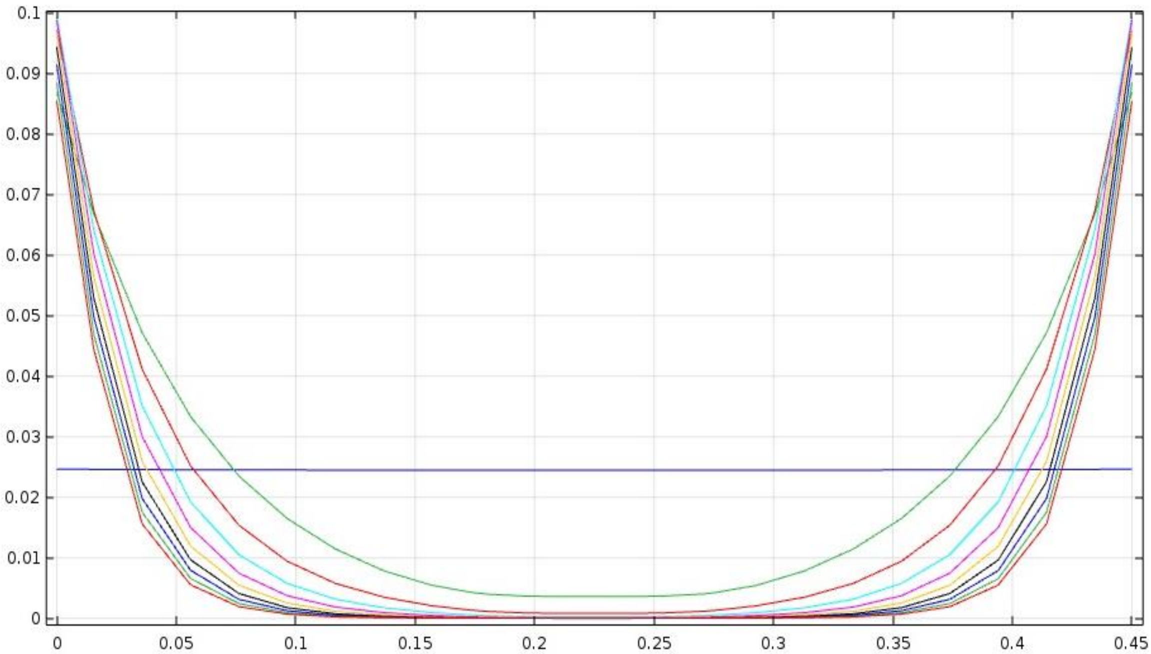

Figure 2 – The distribution of magnetic induction by the thikness of the sheet in the magnetic core of AC machine series 4AA63B4У3 0,37 kW in different frequency values

Thus, at a frequency of 50 Hz to which the purple line corresponds, it can be seen that the induction is distributed evenly over the width of the sheet, that is, it completely penetrates it. And with increasing frequency, it can be seen that in the center of the sheet, the induction value decreases and is almost zero, indicating that the magnetic flux penetrates the sheet only on the surface and does not penetrate.

Division of measured losses into components. For this, the Jordan method was chosen, the formula of which is:

$$p_{\text{Ст}} = p_{\text{г}} + p_{\text{в}} = C_{\text{г}} f \hat{B}^2 + C_{\text{в}} f^2 \hat{B}^2. \qquad (1)$$

Therefore, to calculate the component losses, it is necessary to obtain the values of the coefficients C_d and C_v. These coefficients are empirical. To determine them, experiments were conducted [4] to determine the losses in the magnetic circuit at different values of frequency and induction according to the scheme in Figure 3.

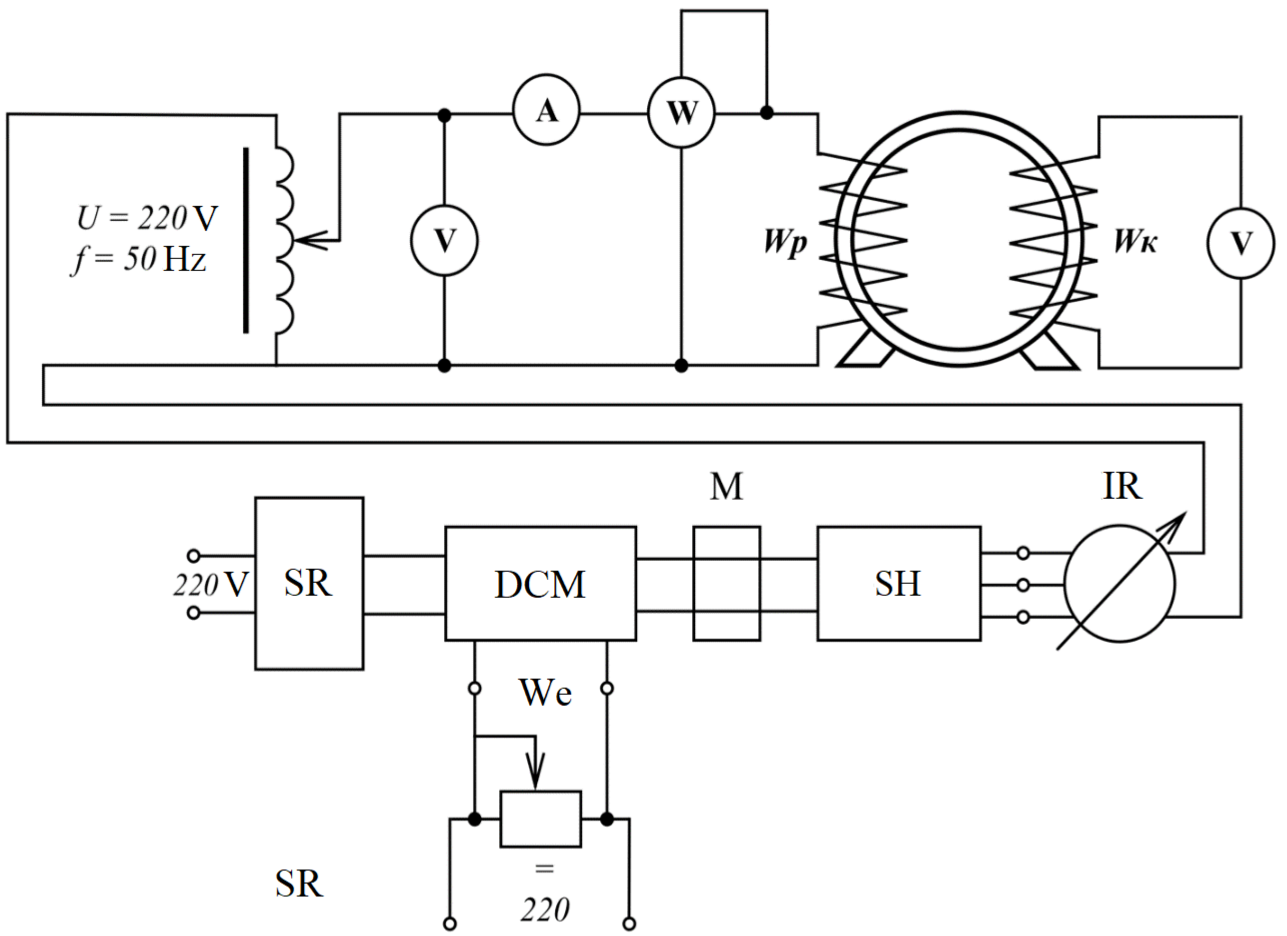

Figure 3 – Scheme of the wattmeter method for working on frequency other than 50 Hz

Based on the results of the loss distribution, a plot of the dependence of each type of loss on the total loss value for the case without (Figure 4) and with defect in interlayer isolation (Figure 5) was constructed.

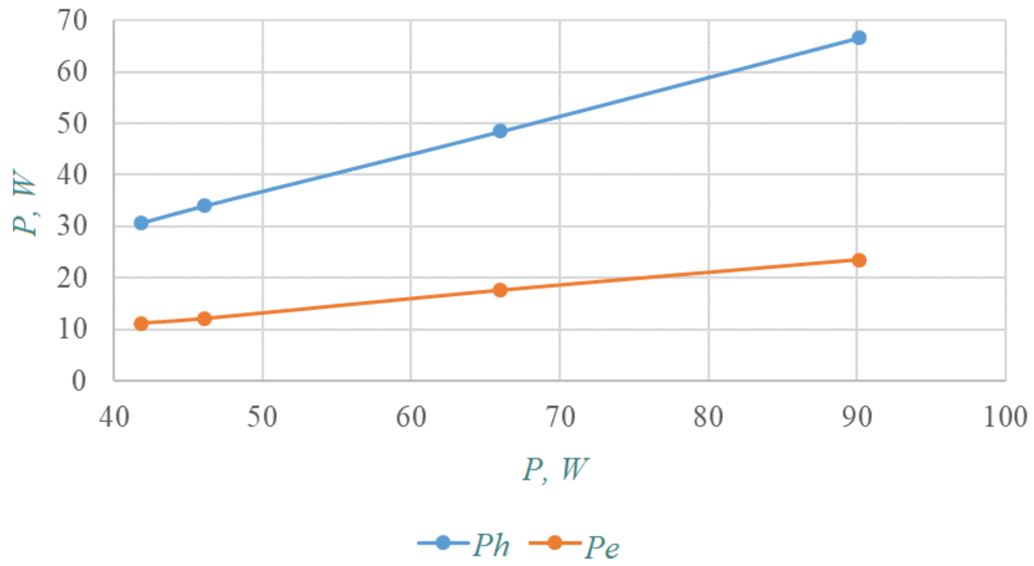

Figure 4 – Graph of the dependence of both components of the loss in steel on the total loss in steel

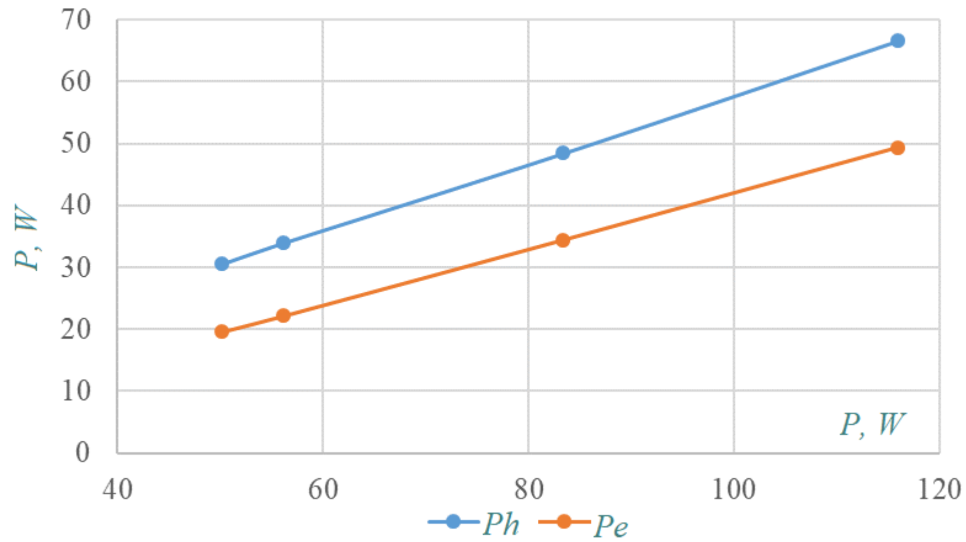

Figure 5 – Graph of the dependence of both components of the steel loss on the total steel loss for the case of artificial defect

When comparing the two graphs, it can be seen that with the appearance of the defect, the direct losses on eddy currents became steeper, which indicates an increase in this component of losses, while the nature of the direct losses on hysteresis did not change [5, 6].

The proposed method of research. As mentioned above, with the deterioration of the magnetic circuit, the component of losses on eddy currents increases, so it is worth using this feature in the developed method. A characteristic difference of eddy currents is that they depend on the square of the frequency as opposed to the eddy current losses, this fact can also be used. With these two facts in mind, it is proposed to use a technique based on the influence of eddy currents and surface effect at frequencies above the industrial one.

The idea behind the method is: each eddy current, when flowing, creates its own magnetic flux, the eddy currents interact with the main magnetic flux, and since these fluxes are directed counter-relative to the main one, the resulting magnetic flux is attenuated. Thus, because the problem of the magnetic circuit losses on the eddy currents are increased, it can be observed in a stronger attenuation of the magnetic flux.

In order to obtain clearer and clearer results, measurements at frequencies above 50 Hz are suggested. As at a frequency above the network frequency the surface effect begins to manifest and the losses will increase according to the quadratic law. With increasing frequency there are two countervailing tendencies, the first - with increasing frequency losses in steel increase, namely losses on hysteresis increase linearly, and losses on eddy currents increase quadratically, and the second tendency - a surface effect is manifested, which leads to a decrease in the active cross section of the magnetic sheet as a result the flow decreases and the losses also decrease [7]. Therefore, it is not enough to simply set high frequency values, but to determine the most suitable frequency values at which the demagnetizing effect of the eddy currents is most apparent.

And the method based on this method will be as follows - it is necessary to wind several turns of the working winding on the magnetic circuit, which will be supplied with power from the frequency generator and one turn of the measuring winding.

Experimental verification of the method. To test whether the proposed method really has the results expected based on physical dependencies, a series of experiments were conducted on magnetic lines of different sizes and interstitial isolation. For this purpose, the scheme described above was collected and the value of the voltage on the secondary winding was taken at the frequency range from 50 Hz to 20 kHz. The results of the experiments for each of the magnetic cores under study will be summarized below.

Results of experiments. The graph of frequency dependence for the magnetic circuit of the 4AA63B4U3 series 0,37 kW is shown in Figure 6.

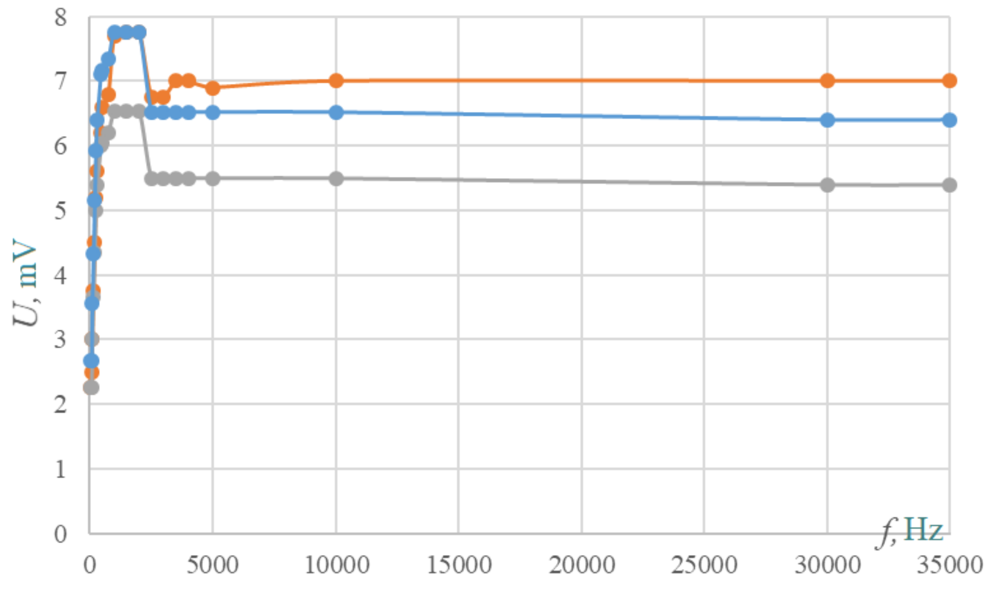

Figure 6 – Graph of the frequency dependence of the measuring winding on the frequency for the magnetic circuit of the AC machine series 4AA63B4У3 0,37 kW

The results are given was performed as follows, each point of the curve for the case of a turn was multiplied by a factor representing the ratio between the values at the point of the maximum value of the voltage. In this case, this is the 750 Hz point and the coefficient definition is given in equation (2).

$$k = \frac{U_{maxwithout\ wind}}{U_{max.with\ wind}} = \frac{7,75}{6,54} = 1,1 \quad (2)$$

Thus, the maximum value of the graph for the case of no-turn and the given curve will coincide and the difference between the defective and defective magnetic conductor will be very clearly seen. Similar steps were performed for magnetic circuits, where the points of the voltage value at a frequency of 1 kHz do not coincide.

The curve for the magnetic core without defect corresponds to the specific loss $3,92\ \frac{W}{kg}$, with defect - $5,85\ \frac{W}{kg}$.

Graph of frequency dependence of voltage for a magnetic core of AC machine series 4A71B4У3 0,75 kW shows on figure 7.

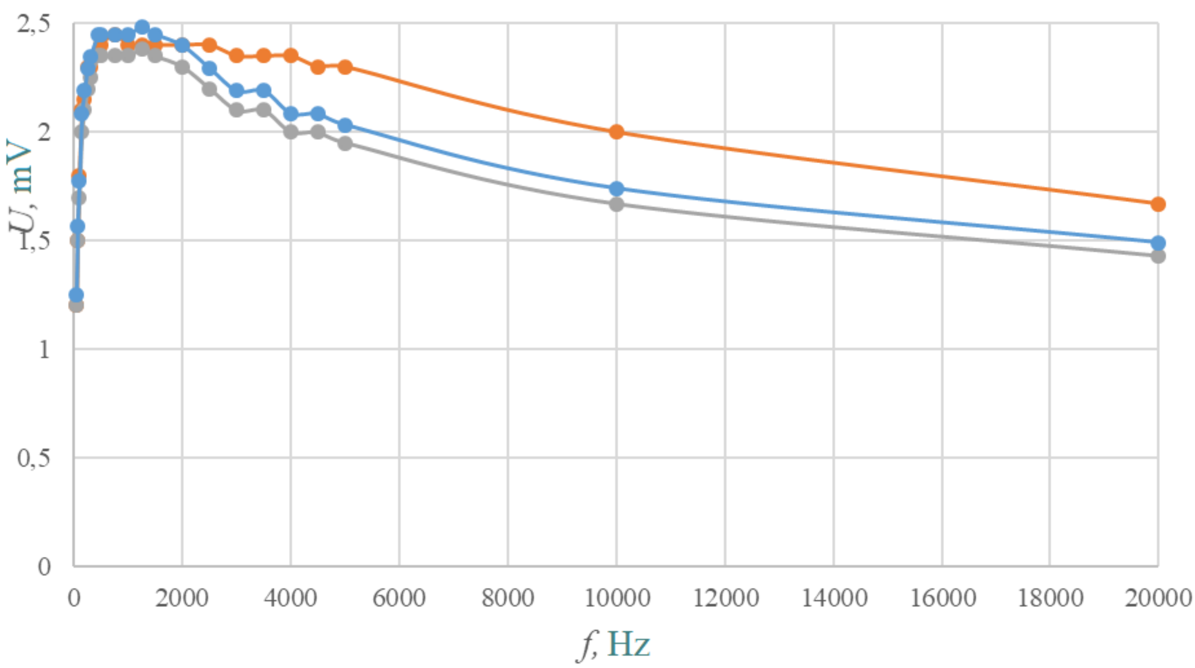

Figure 7 – Graph of frequency dependence of voltage for a magnetic core of AC machine series 4A71B4У3 0,75 kW

The curve for the magnetic core without defect corresponds to the specific loss $5,03\ \frac{W}{kg}$, with defect – $6,7\ \frac{W}{kg}$.

The graph of frequency dependence for the part of the magnetic core of the 4A90L2U3 3 kW series AD is shown in Figure 8. In this case, it was not necessary to make the adjustment, since the maximum voltage value is the same for both cases.

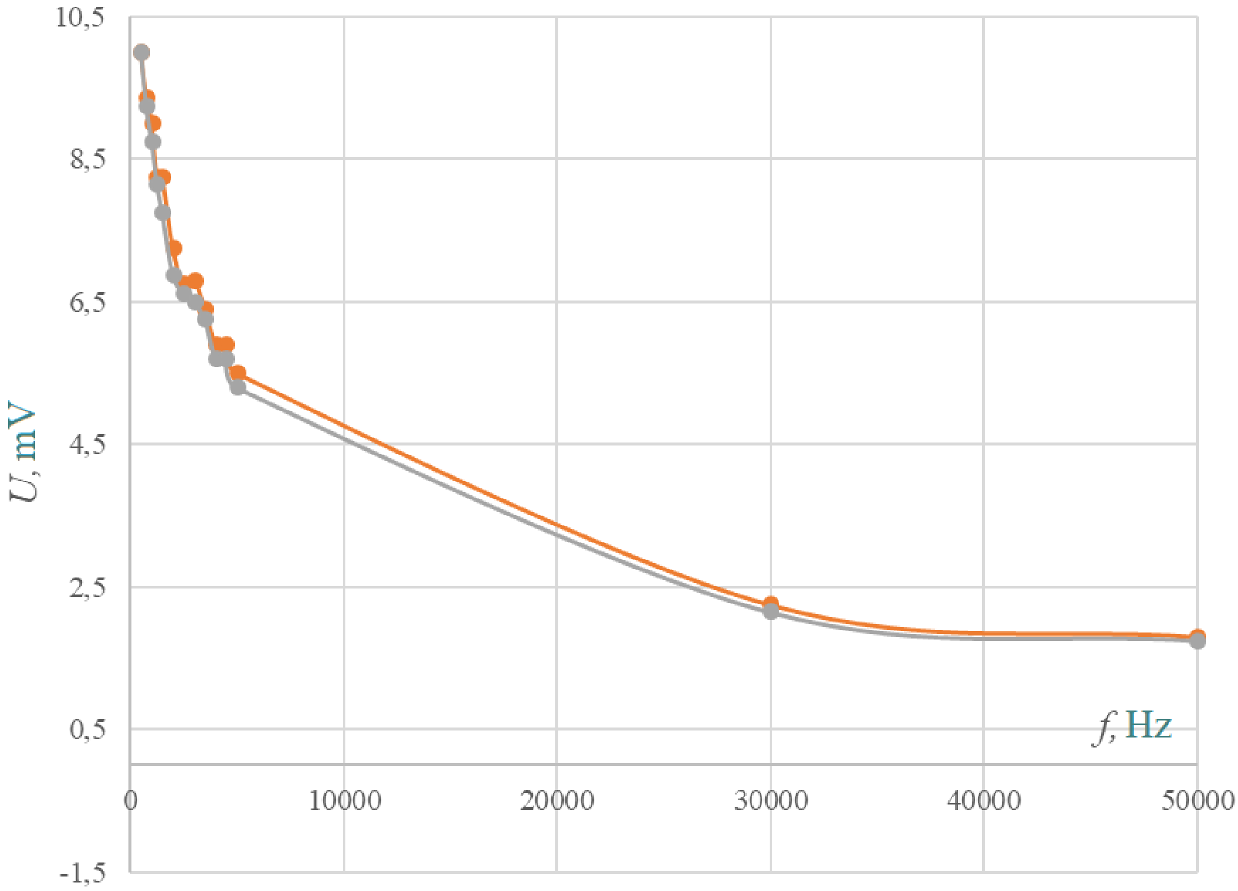

Figure 8 – Graph of frequency dependence of the measuring winding for the part of the magnetic core of AC machine series 4A90L2U3 3 kW

Analysis of results. As can be seen from the results of the experiments, the technique is confirmed with respect to the fact that magnetic conduits with larger specific losses have a smaller value of the voltage on the measuring coil [8, 9]. For the 4A90L2U3 3W series magnetic core, the difference between the case without a coil and with it is not quite evident, although the results of the third magnetic core study confirm the general trend. Since this magnetic circuit has a high loss value even without a spin, its further deterioration does not affect the results much less than other magnetic circuits.

Results. As a result of theoretical and experimental analysis, specific losses in the charge lines of electric machines of general-purpose machines of various degrees of defect were determined.

Using the field mathematical model, the distribution of the magnetic field in the magnetic circuit was calculated during the study by a wattmeter method, which visually showed the ways of closure of the power lines and allowed to determine the average induction and the average cross section of the magnetic circuit. Also, on the basis of the finished model, the distribution of induction over the width of the sheet at different frequencies is calculated, which clearly reflects the effect of the surface effect.

The mathematical method is used to separate the losses obtained during the implementation of the wattmeter method into components, assuming that the hysteresis losses do not change with the deterioration of the magnetic circuit. The analysis of the loss distribution showed that with the deterioration of the interlayer isolation of the magnetic circuit, it is precisely the losses on eddy currents.

In the experimental study of the non-operating stroke of the engine of the 4A100L6U3 series engine, it is proved that there is a direct correlation between the specific losses of a single magnetic conductor and the losses in the steel of the collected EM, and, as a result, an increase in its specific intensity, steel.

A high-frequency method of estimating the quality of interlayer insulation by estimating the intensity of eddy currents in a magnetic circuit at different frequencies is proposed.

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