СЕКЦІЯ 1. НОВІТНІ ДОСЯГНЕННЯ У БІОМЕДИЦИНІ ЯК НАСЛІДОК РОЗВИТКУ ПРИРОДНИЧИХ НАУК

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INVESTIGATION OF THE INTERACTION OF EDDY CURRENTS IN ALUMINIUM DISCS USING DIFFERENT SOLENOIDS

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Abstract. The physical processes occurring at the resonance of different solenoids with an aluminium disc of different diameters or two discs with varying distances between them are considered. The optimal inductances and resonant frequencies for experimental studies are selected. The frequency dependencies of the quality factor Q(f), active resistance R(f), and insertion loss d(f) for two solenoids with one aluminium disc of fixed radius in the middle are considered. The dependence of the insertion loss d of the solenoid on the distance r between two identical discs located in the middle of the solenoid is also considered.

Key words: resonance, solenoid, oscillating circuit, aluminium disc, eddy current, quality factor, skin effect

The study of eddy currents in aluminium discs at different frequencies is of both applied and scientific importance in terms of the effects of skin effect and proximity effects in various electronic systems, especially when they are miniaturized. Electrode-free electrical conductivity measurements are often associated with eddy currents that occur in the objects under study [1-2]. Therefore, the objects under study are often chosen in the form of a disc, cylinder, or capillary, in which the behaviour of eddy currents can be relatively easily understood and calculated theoretically [3-5].

For the study, aluminium discs with a thickness of 78 μm were chosen. To study the frequency dependence of the Q-factor of solenoids, a disc with an area of 350 mm^2 was chosen. All solenoids had the same internal diameter. The introduced attenuation d for eight different solenoids is shown in Fig. 1. According to Fig. 1, two solenoids were selected for further research. The first solenoid was studied at a frequency of 160 kHz, and the second at a frequency of 12 MHz.

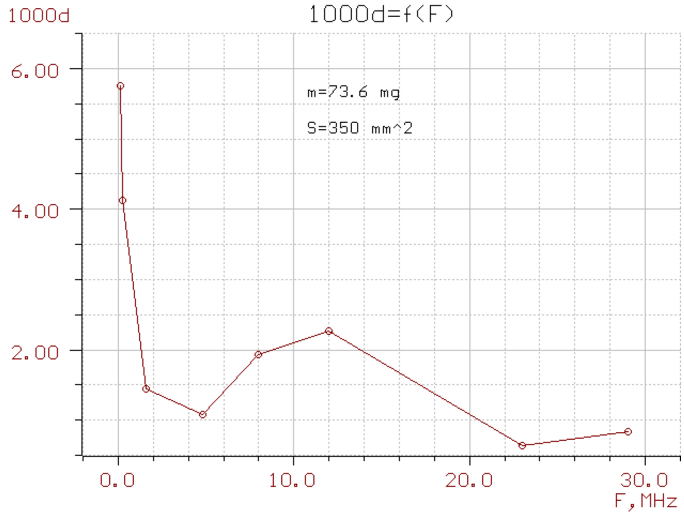

Fig. 1. The introduced attenuation d of eight solenoids at the corresponding resonant frequencies caused by the presence of an aluminium disc placed in the region of maximum magnetic field homogeneity

To determine the inductance L and parasitic capacitance Cp, the frequency dependences of Q and capacitance C of the exemplary oscillating capacitor were studied. The plots of the dependence of the Q factor Q(f), the active resistance R(f), and the insertion d(f) for a number of resonant frequencies f are shown in Figs. 2-4 for one solenoid (3-12 MHz) and Figs. 5-7 for the other solenoid (50-160 kHz), respectively.

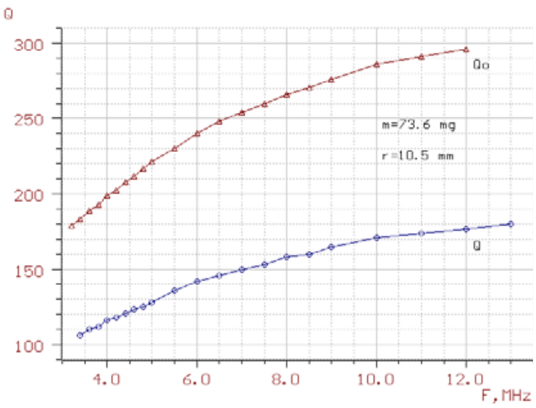

Fig. 2. Dependences of the quality factor Q of the oscillating solenoid circuit on the resonant frequency f in the presence (Q) and absence (Q0) of an aluminium disc

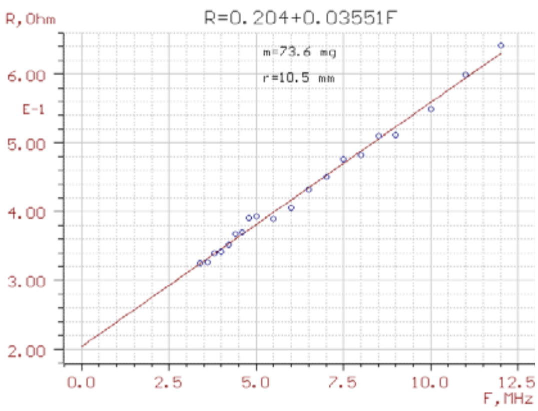

Fig. 3. Dependence of the active resistance R of the oscillating solenoid circuit on the resonant frequency f in the presence of an aluminium disc

The active resistance R of the oscillating solenoid circuit in the frequency range of 3-12 MHz is linearly dependent on the frequency according to the formula:

$$R=0.204+0.03551\cdot f. \quad (1)$$

The introduced attenuation d of the oscillating circuit is linearly dependent on the inverse frequency according to the formula:

$$1000d=1.56+0.279/f, \tag{2}$$

From formulas (1-2) it follows that the active resistance to eddy current is much higher than the reactive resistance and the skin effect is significant [4].

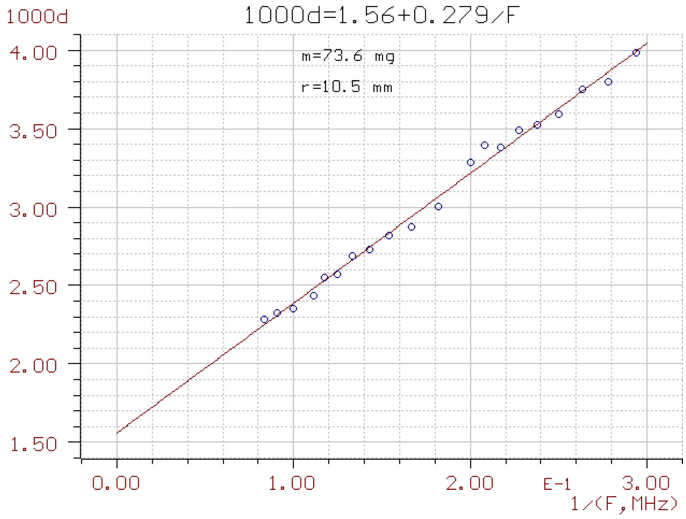

Fig. 4. Dependence of the introduced attenuation d of the solenoid oscillating circuit on the inverse frequency f in the presence of an aluminium disc

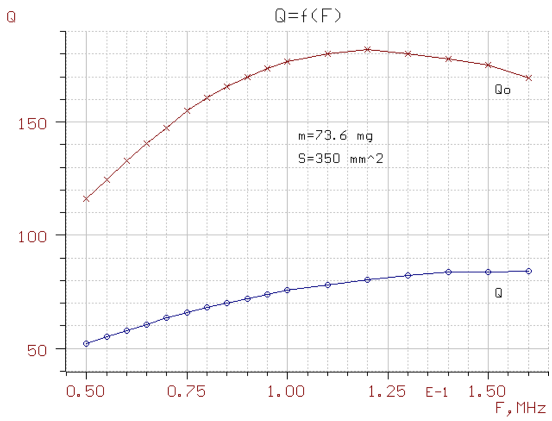

Fig. 5. Dependences of the quality factor Q of the oscillating solenoid circuit on the resonant frequency f in the presence (Q) and absence (Q_0) of an aluminium disc

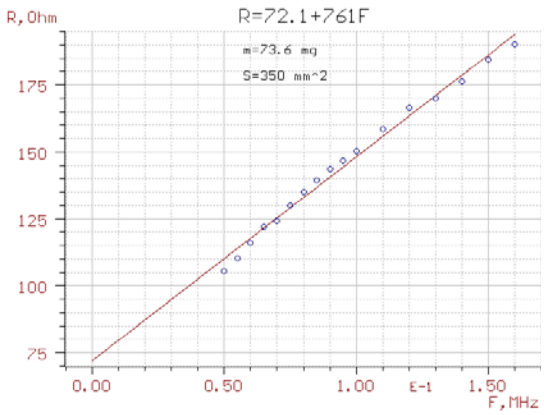

Fig. 6. Dependence of the active resistance R of the oscillating solenoid circuit on the resonant frequency f in the presence of an aluminium disc

The active resistance R of the oscillating solenoid circuit in the frequency range of 50-160 kHz is linearly dependent on the frequency according to the formula:

$$R=72.1+761\cdot f\,. \tag{3}$$

The product of the d-f insertion loss of an oscillating circuit is linearly dependent on the frequency according to the formula:

$$1000d{\cdot}f=0.36+3.85{\cdot}f. \quad (4)$$

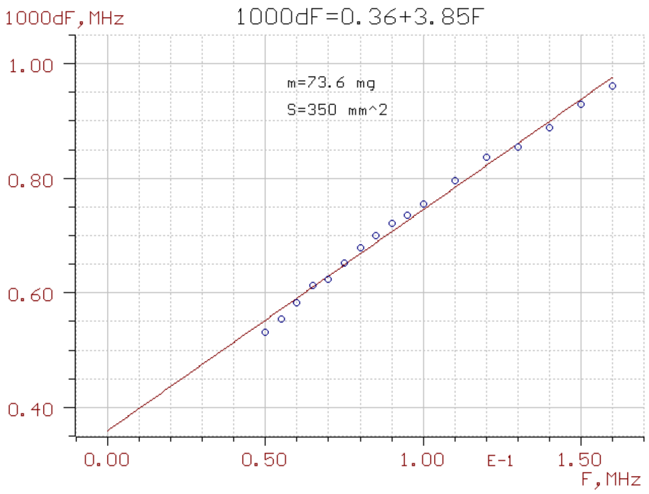

Fig. 7. Dependence of the introduced attenuation d of the solenoid oscillating circuit on the resonant frequency f in the presence of an aluminium disc

The above studies have shown that it is best to study the interaction of eddy currents in aluminium discs at different distances between two discs in a solenoid with a resonant frequency of 160 kHz. Special equipment was created for this purpose. The results are shown in Figs. 8-9, which show that with an increase in the distance r between the discs, the insertion d of the solenoid increases due to the weakening of the interaction between the eddy currents. Reducing the interaction between the currents leads to their growth, which increases the insertion loss d.

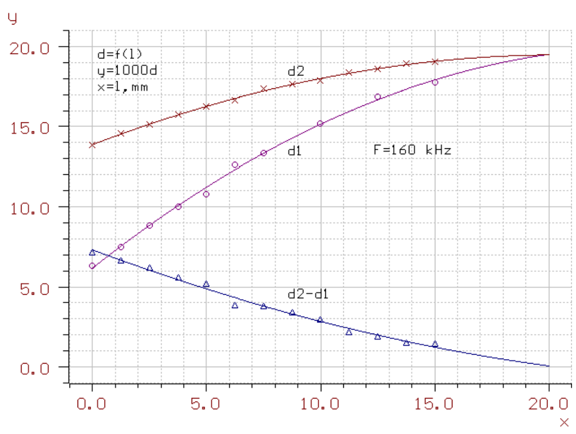

Fig. 8. Dependence of the introduced attenuation d1 of two identical discs on the distance r=l between them

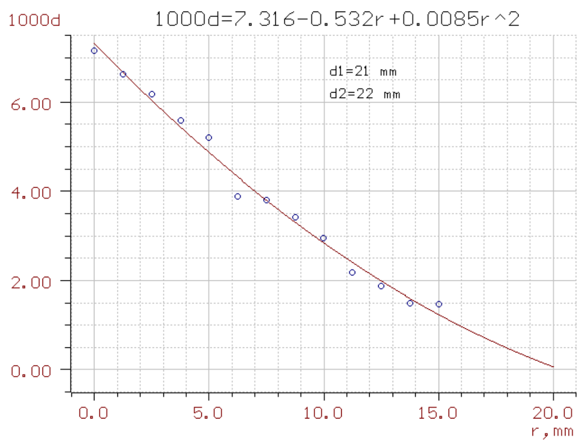

Fig. 9. Differential attenuation d caused by the interaction of eddy currents of two discs separated by a distance r between them

The sum of two separate insertion densities d_2, which is composed for one disc at the point r=0 and the second disc at the point r=l. The difference d_2-d_1 characterizes the interaction of the currents of the two discs, as a result of which the currents partially cancel each other out.

The results of the studies indicate a significant influence of the proximity effects at disc spacing of less than 20 mm. At larger distances, the effects of proximity can be neglected. Now the form of the d(f) dependence shown in Fig. 1 becomes clear. The initial decrease in the introduced attenuation d with increasing frequency f is explained by the decrease in the cross-sectional area of the bulk eddy current and its reduction due to the growing influence of the skin effect. When the minimum d(f) is reached, the thickness of the skin layer becomes equal to half the thickness of the disc. With a further increase in the frequency f, two surface currents are formed instead of the volumetric eddy current, the distance between which begins to increase. Initially, the surface vortex currents increase due to a decrease in their interaction, which results in an increase in the insertion d of the solenoid. The decrease in the cross-section of the surface eddy currents with increasing frequency leads to a further decrease in the insertion loss d of the solenoid, which is clearly observed after the maximum of d(f).

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