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Effect of eddy current frequency on measuring properties of devices used in non- destructive measurements of non-ferromagnetic metal plates

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ABSTRACT

Purpose: To determine optimal frequency of the electromagnetic field that raises eddy currents during the search for surface defects in non-ferromagnetic materials or conductivity measurements by means of eddy currents methods. The frequency choice takes into consideration sensitivity of measuring device, depth of the eddy currents penetration and elimination of undesirable phenomena that affects result of the exploration.

Design/methodology/approach: During the design and scalling of the devices based on phenomenon of eddy currents implying changes of contact coil impedance components, significant influence of the electromagnetic field frequency on measurement results was observed. Additionally, some other phenomena can be observed which causes invalid interpretation of devices indications. Basing on a mathematical model of a contact coil located above a conductive non-ferromagnetic plate, the sensitivities to the measured parameters are determined. Furthermore, a novel definition of the eddy currents penetration depth is proposed.

Findings: Depending on specific applications, recommendations enabling proper choice of the electromagnetic field frequency are formulated.

Practical implications: Describred phenomena and calculations are useful for the designers of the devices utilising the phenomenon of eddy currents, and also for the users of flaw detectors and conductometers. Remarks included in this paper can be useful for proper interpretation of the observed results and phenomena.

Originality/value: A modified definition of the actual penetration depth of eddy currents proposed in the paper differs from the classical approach based on the 1/e level. This definition may be especially convenient and useful for operators utilising eddy current devices. Described sensitivity model facilitates setting up the devices for a specific task involved in a different technological process.

Keywords: Non-destructive testing; Eddy currents; Flaw detection; Conductometry

PROPERTIES

1. Introduction

The discussed issue concerns testing of non-ferromagnetic plates using eddy currents methods. A contact coil, used in the research was designed to be put close or to be applied to relatively flat surface of the tested element. The contact coil is fed with alternating current, and while put on the surface of a conductive plate the eddy currents are induced in the tested material. The magnetic field associated with the eddy currents acts on the exciting field and implies changes in the impedance components of the coil. The measurements of the changed components provide

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information about the plate conductivity and thickness, as well as on the distance from the tested surface. This phenomenon is used in conductometers, thickness gauges and flaw detectors operating on the base of the eddy currents phenomenon [1-3]. Defects of the tested material cause disturbances in the flow induced by the eddy currents. The measuring device detects this situation as an apparent decrease in the tested material conductivity and as an apparent increase in the distance between the coil and the material surface. Such a flaw detector may be scaled in the range of the assumed artificial defects.

Sensitivity of the measuring device, defined as the dependence of the changes in measuring coil impedance components on changes in the tested quantities, is strongly dependent on the eddy-currents frequency. During tests with devices operating on the base of the eddy currents effect on measuring coil impedance phenomenon it was observed that the result of the measurement depends on the properties of some near-surface strata of the tested material. The knowledge of the depth of actual penetration of material tested using the eddy currents methods is necessary to assess the conductivity measuring error caused by surface defects or error of determination of size of surface defects. The eddy currents penetration depth is to a large extent dependent on their frequency. For a designer of the eddy-current instruments such as: flaw detectors, conductometers or thickness gauges the ability to determine the depth of penetration of a given material is essential. It is also useful for the operator while searching for defects or conducting measurements. Modern devices using the eddy currents phenomenon are designed based on DSP processors (Digital Signal Processor). High accuracy of analog-to-digital converters and numerical capabilities of DSP are the reason for which measuring error of change in measuring coil impedance components is insignificant. It is also easy to change the frequency of the eddy-currents exciting field. The result, even of a complicated calculation is obtained in a short time, therefore it is possible to select the exciting field on-line while conducting the measurement. For the eddy-current tests, proper selection of exciting field frequency is essential to obtain optimal sensitivity [1-6].

Selection of the frequency is then of the special importance for: searching for surface defects, at various depths, measurement of conductivity, measurement of conductive material or thickness of non-conductive layer placed on conductive base. Calculation of intensity of field inside the material tested using the eddy currents methods can be conducted numerically by means of finite element method or Boundary Integral Method. These method make possible determination of field distribution in any shape of material [16]. The point is that in testing metal elements using the eddy currents method the actual depth of penetration is unimportant. However, in the case of searching for defects in a thick material, the maximum depth at which a defect can be found is important. When conductivity of a thin sheet or foil is measured it is important to know whether geometric dimensions or material defects affect the results of measurements or they are irrelevant. Thus selected frequency should first of all ensure proper accuracy of the measurement.

2. Mathematical model

The problem of determining the changes in the impedance of the contact coil evoked by a conductive element, for which the thickness *d* is smaller than the penetration depth of eddy currents will be solved by assuming that the dimensions of the measured element are greater than the dimensions of the contact coil.

The coil has *n* turns concentrated in a circle with the radius r_o, placed at the distance *h* from the tested element surface. The coil is fed with sinusoidal alternating current. The position of the coil in relation to the measured element is shown in Figure 1. [4-6].

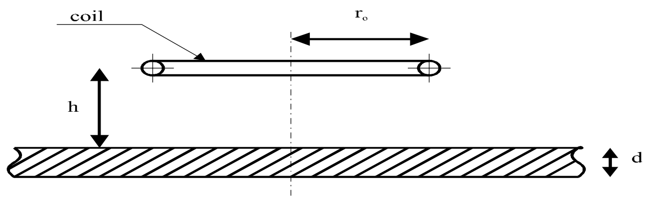

Fig. 1. The contact coil above the tested element

Let us calculate the change in the coil impedance evoked by the presence of the conductive material [4]. For this purpose, the following generalized parameters can be introduced:

$$\alpha = \frac{2h}{r_0} \tag{1}$$

$$\beta = r_0\sqrt{\omega\mu_0\sigma} \tag{2}$$

$$\rho = \frac{2d}{r_0} \tag{3}$$

where: σ - conductivity of the material, *h* - distance between the coil and the tested surface, *d*- plate thickness, r_o -coil radius, ω-current angular frequency in the coil, *n*- number of turns.

If ΔZ denotes the impedance change of the coil, then

$$\Delta Z = n^2\omega\pi\mu_0 r_0 Q(\alpha,\beta,\rho) \tag{4}$$

where:

$$Q(\alpha,\beta,\rho) = \int_0^\infty J_1^2\ (y)e^{-\alpha y}\frac{\beta^2\left(1-e^{-\rho\sqrt{y^2+j\beta^2}}\right)}{\left(\sqrt{y^2+j\beta^2}-y\right)^2 e^{-\rho\sqrt{y^2+j\beta^2}}-\left(\sqrt{y^2+j\beta^2}+y\right)^2}dy$$

By separating the real part of this equation and the imaginary one, it is possible to derive a relation that describes the change in the coil impedance components evoked by the presence of the conductive material:

$$r = R - R_0 = n^2\omega\pi\mu_0 r_0\varphi(\alpha,\beta,\rho) \tag{5}$$

$$\omega l = \omega\left(L - L_0\right) = -n^2\omega\pi\mu_0 r_0\chi(\alpha,\beta,\rho) \tag{6}$$

where:

$$\varphi(\alpha,\beta,\rho) = \mathrm{Re}Q(\alpha,\beta,\rho) \tag{7}$$

$$\chi(\alpha,\beta,\rho) = \mathrm{Im}Q(\alpha,\beta,\rho) \tag{8}$$

Here R_o and L_o are the parameters of the distance between the coil and the tested element.

Numerically calculated values φ and χ with respect to the parameter β for constant value ρ=0.2 and various values α=0.1 and α=0.4 are presented in Figure 2. Numerically calculated values φ and χ with respect to the parameter β for constant value α=0.4 and various values ρ=0.1 and ρ=0.5 are presented in Figure 3. Described passage coil model placed over infinitely large plate is a simple and very useful for theoretical analysis and for applications while a device is designed. For the current calculations performed with DSP during measurements using conductometers and flaw detectors, the Author used the above-described, simplified model of coil with all the turns located in one circle. The fact of replacing a real contact coil with an abstract one (with radius r_o placed at distance h above the tested surface) is compensated by the process of scaling the coil. The coil is put onto the element with known parameters, the impendence components are measured and, subsequently, parameters r_o and α calculated. Next, the following value is derived:

$$h_0 = \frac{\alpha \cdot r_0}{2}.$$

Accordingly, Equation (1) may be expressed as:

$$\alpha = \frac{2(h+h_0)}{r_0}$$

where: h- distance between the real coil and the tested surface, h_o- distance resulting from the process of scaling the coil.

In practice, h_o depends on the coil construction; for the coil with the diameter of 2 cm h_o is in then range from 0.05 to 1 mm. It was assumed for the calculations that h_o = 2 mm which corresponds to the generalized parameter α = 0.4. Issues connected with the design and construction of coils for testing using the eddy currents methods are out of the scope of this study.

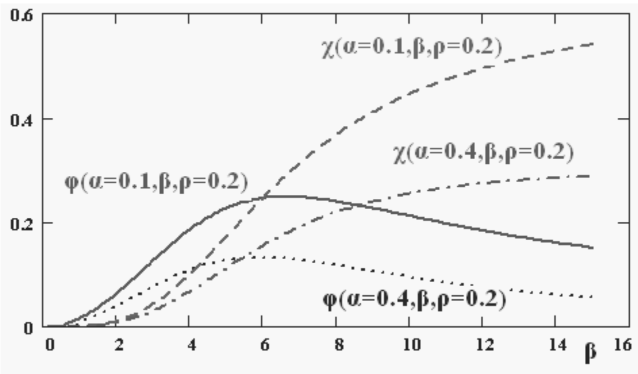

Fig. 2. Graphs of functions φ and χ depending on parameter β for constant value ρ and various α

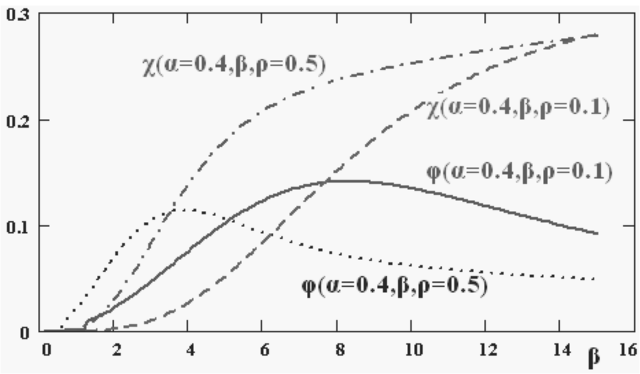

Fig. 3. Graphs of functions φ and χ depending on parameter β for constant value α and various ρ

3. Measuring device sensitivity

Using the described model [5] it is possible to calculate the sensitivities defined as the coefficients of the impact of conductivity σ, distance between the coil and the plate h on the coil impedance components: r and l.

$$\Delta rh = \frac{\Delta r}{\Delta h} = \frac{n^2\beta^2\pi}{\sigma r_0^2}\frac{\partial\varphi}{\partial\alpha} \tag{9}$$

$$\Delta r\sigma = \frac{\Delta r}{\Delta\sigma} = \frac{n^2\beta^3\pi}{4\sigma^2 r_0}\frac{\partial\varphi}{\partial\beta} \tag{10}$$

$$\Delta lh = \frac{\Delta l}{\Delta h} = -n^2\mu_0\pi\frac{\partial\chi}{\partial\alpha} \tag{11}$$

$$\Delta l\sigma = \frac{\Delta l}{\Delta\sigma} = -n^2\mu_0\pi r_0\frac{\beta}{4\sigma}\frac{\partial\chi}{\partial\beta} \tag{12}$$

In the next step, numerical calculations were made using Equations (9), (10), (11) and (12). To facilitate the comparison between the calculations results, it is convenient to express them in the form of relative sensitivity values:

$$\partial Rh = \frac{\Delta R}{R} : \frac{\Delta h}{h}, \quad \partial R\sigma = \frac{\Delta R}{R} : \frac{\Delta\sigma}{\sigma}, \quad \partial Lh = \frac{\Delta L}{L} : \frac{\Delta h}{h}, \quad \partial L\sigma = \frac{\Delta L}{L} : \frac{\Delta\sigma}{\sigma}.$$

In Figure 4 the results of the numerical calculations are shown in the form of graphs. The assumed coil diameter is 2 cm, n=300 turns, ρ=0.2 and α=0.4. Some characteristic values of the generalized parameter β are compiled in Figure 4. For instance for copper, each marked value of β represent a frequency given in the Table 1.

Table 1.

β_m	β_n	β_k	β_i
f = 1.2kHz	f = 4.3kHz	f = 8.2kHz	f = 18.5kHz

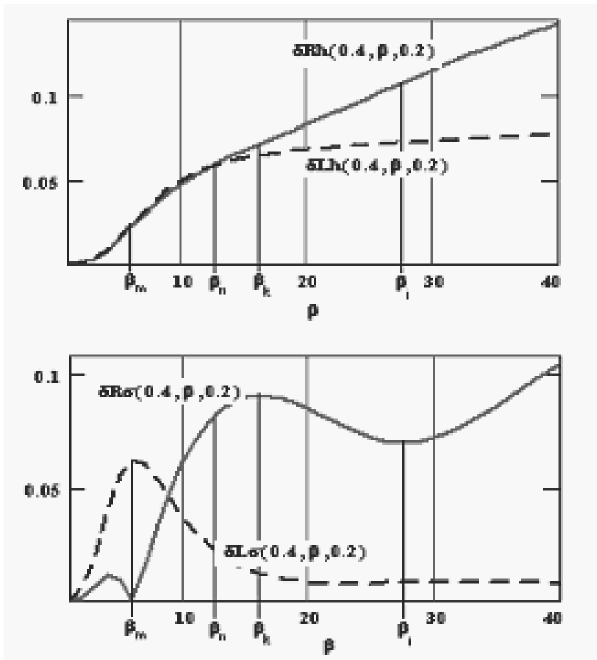

Fig. 4. The coefficient of the impact of coil conductivity and distance from the tested surface on the coil impedance components as a function of the generalized parameter β

For $\beta = \beta_m$ the function φ described by Equation (7) has its maximum due to an independent variable β.

For the frequency corresponding to β_m the impact of conductivity on the changes in the coil inductance is the greatest, whereas conductivity exerts no impact on resistance. Changes in distance *h* affect both impedance components. If the frequency goes over the value corresponding to β_m then the sensitivity of the two measured parameters to the coil resistance increases; at the same time, the impact of conductivity on the inductance decreases. The range from β_m to β_k is very interesting for many applications. A more detailed designation of the optimal frequency of the exciting field should be carried out in consideration of the problem of compensating the discontinuity of the tested structure.

4. Compensation of influence of surface unevenness on eddy currents testing results

One of the most important problems that should be solved in the design of the devices utilising the eddy currents principle is the choice of the method of compensating the influence of the unevenness of the tested structure and material defects on the measurements results. Such a surface emerges, for example, after the treatment described in [7]. Depending on the chosen compensation mechanism, a device may be a conductometer or a flaw detector. The compensation in a conductometer enables the measurement of the conductivity of coarse or cracked materials, even though the devices is scaled by means of polished standard samples. On the other hand, as far as the eddy currents flaw detectors are concerned, this mechanism should be inversed and should amplify the impact of small cracks on the readings. The oldest compensation method was discussed in [8]. Each probe intended for testing using the eddy currents method is a single coil or a set coils. Such a coil is connected into the measuring circuit ensuring that the change in coil impedance components influences parameters of electric circuit which are convenient to be measured. High sensitivity can be obtained when, for instance, the coil becomes a component of a resonant circuit, and frequency of the coil current is close to the resonant frequency. The diagram of two parallel resonant circuits supplied with the same alternating voltage source is presented in Figure 5. In the diagram, the coils have been replaced with the resistance and the inductance. Right resonant circuit includes the measuring coil. Resistance and inductance of this coil changes in the presence of conductive element being tested. The capacitance of capacitor C_m is constant, i.e. it does not change with time. The coil of the left circuit is a reference one, its impedance is constant and does not change during the measurement. The capacitance C_r is retuned.

It can be represented as the capacitance of a varicap diode. During measurement the device equipped with a feedback loop automatically changes its capacitance C_r, for instance through changing of voltage of a reversely polarized varicap diode, being a set of diodes in practical solution so as to obtain equality of voltages at both coils $|U_r| = |U_p|$. After the equality of voltage module at both coils is achieved, the capacitance C_r or voltage tuning the varicap diode become the measure of conductivity of material of which the tested element is made. It is sufficient to

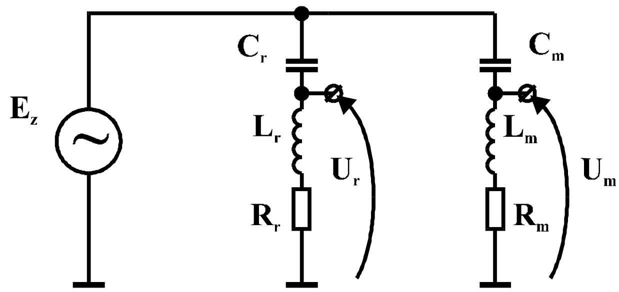

Fig. 5. Example of measuring bridge diagram

perform scaling process consisting of assigning specific conductivity value to each capacitance or tuning voltage value. By closing the measuring coil to the surface of the conductive tested element, the inductance of the measuring coil L_m is reduced. Thus, resonance frequency of circuit L_mC_m is shifted right, in the direction of higher frequencies. At the same time, the coil resistance R_m increases, and causes reduction of resonant circuit magnification factor, that is the "flattening" of characteristic $|U_m|(f)$ describing the relation between the voltage module at the measuring and the frequency. Graphs of voltage module U_m in the function of frequency of E_z supply voltage frequency are presented in Figure 6. The graphs are drawn for three cases: measuring coil closed to lead Pb - a relatively poorly conductive material, aluminium Al of average conductance and copper Cu - a well-conductive material. If the measurement is conducted at a frequency lower than the resonant frequency, which lies on the left slope of the resonant curve, then the change in module of the voltage U_m being measured is influenced in the same direction by changes in both resistance and inductance. Then, changes $\Delta|U_{Al-Cu}|$ and $\Delta|U_{Pb-Al}|$ are substantial, so substantial is also sensitivity of the measuring device. If the measurement frequency is selected higher than the resonance frequency, that is located at "right edge of characteristics" then the changes in the coil resistance cause such change in voltages being measured which decrease the change evoked by the drop of inductance. In such a case, changes in voltages $\Delta|U_{Al-Cu}|$ and $\Delta|U_{Pb-Al}|$ are much lower. Sensitivity of device tuned in this way is noticeably lower. Despite its lower sensitivity, the latter method of tuning a measuring device, "at right edge of characteristics" has an important advantage. By selecting proper frequency, parameters of the reference coil, and design of capacitor C_r it is possible to achieve compensation of the influence of surface defects, surface unevenness and the coil distance on the conductance measurement result. To design correct compensation mechanisms it is necessary to select the eddy currents frequency, that is the frequency of the coil supply voltage, so the change in conductance does not influence, or influence to a slight extent the change in measuring coil resistance. This frequency represents generalized parameter $\beta = \beta_m$. Denote this frequency with f_m. It is convenient to select this frequency for conductance equal half of the designed measuring range e.g. σ = 35 MS/m (self-conductance of aluminium). If the contact coil is put against a smooth surface of an element made of aluminium σ = 35 MS/m, the coil has certain inductance and resistance. Then, the coil is distanced from the tested element surface. Change in resistance and inductance is observed. This change was calculated numerically for a coil of radius r_o = 1 cm, including 300 turns. Results of calculations are presented in

Figures 7 and 8. Coil resistance decreases and its inductance increases as the distance of coil from the tested surface increases. Figure 9 presents the graph of amplitude of U_m voltage on measuring coil in the function of frequency, in case in which the coil is brought closer to the tested surface to the distance representing value of parameter α and $\alpha+\Delta\alpha$.

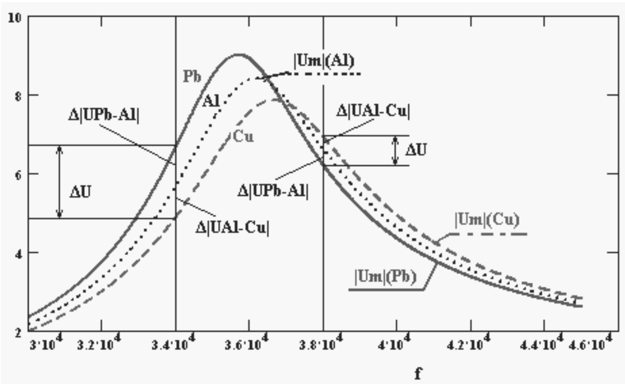

Fig. 6. Module of U_m voltage on measuring coil from the circuit as in Figure 5, brought closer to Aluminium and copper as the function of supply voltage change

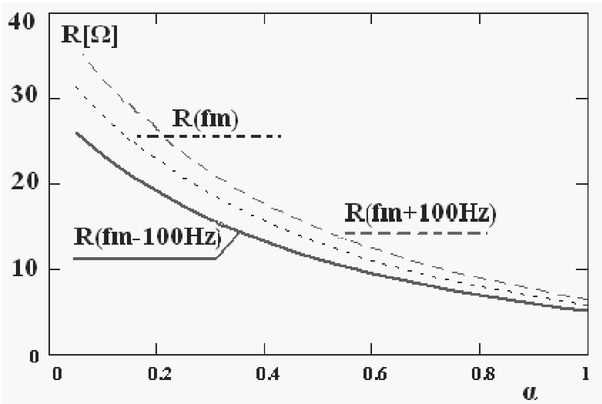

Fig. 7. Dependence of measuring coil resistance on the distance from the tested surface

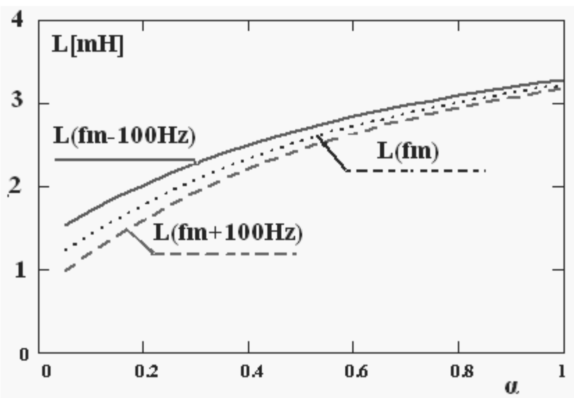

Fig. 8. Dependence of measuring coil inductance on the distance of measuring coil from the tested surface

It should be emphasised that after selection of the eddy currents frequency marked in the figure with a vertical line, the distance of the coil from the tested surface causes an increase in voltage amplitude on the measuring coil. From comparison of this figure with Figure 6 it follows that the increase in voltage amplitude on measuring coil represents increase of conductance. In other words, increase in conductance causes increase in voltage amplitude, likewise slight distance of coil from the tested surface. Finally, the measuring device was successfully tuned in the above-described way, so the increase in coil distance from the surface increases the result of conductance measurement as shown in Figure 10.

The above-described method for compensation of the effect caused by the distance of measuring coil from the surface of the work piece under test has to be applied to the conductmeter design. It should be emphasised, that any unevenness of surface, such as slight cracks, influence the measuring coil in the way as if the distance increased and the conductance diminished. Application of the method for compensation of the measuring coil's distance from the surface makes it possible to effectively measure the conductance with the device even if the surface exhibits slight cracks or traces of machining. If the device is tuned so as the measurement frequency is "at the left edge of resonance curve" then the above-described method acts in reverse direction and heightens the increase of indications of the device, which is a favourable situation for a flaw detector.

Such a flaw detector is very sensitive to any changes and discontinuities in the tested structure.

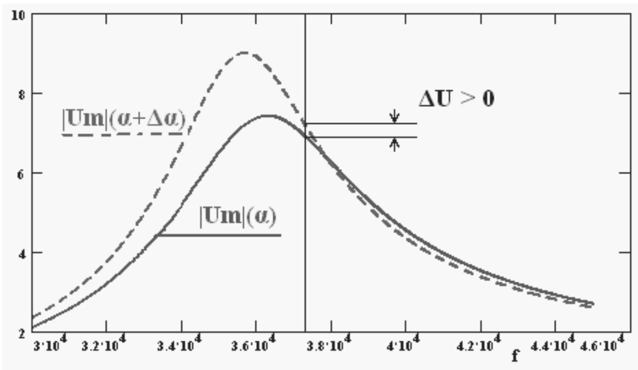

Fig. 9. Effect of distance of measuring coil from the tested surface

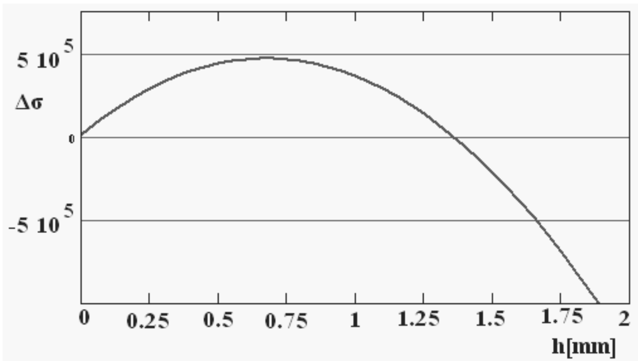

Fig. 10. Compensation of influence of coil distance from the tested surface

Nowadays, in view of considerable computational power (DSP), more sophisticated methods may be employed. However, in each case, the method must be adjusted to the frequency of the exciting field and to the coil impedance components. In some solutions, the compensation effectiveness is so important that it compels to apply a specific frequency of the exciting field.

In Figure 11 functions φ and χ described by Equations (7) and (8) are plotted with respect to the parameter β. If the measuring device is set up for direct measurements of the coil resistance and inductance, for example, in the case of the equivalence bridge, it is convenient to select the frequency corresponding to $\beta = \beta_m$. The measurements of resistance variations make it possible to determine increase of the apparent distance *h* and then the correction factor can be calculated which, in turn, is taken into account when conductivity has to be determined on the basis of inductance measurements.

Modern devices measure the impedance components by the technical method with a sufficiently small error; thus, two parameters that are functions of resistance and inductance are measured directly. In such a case it is recommended to select the frequency corresponding to the range of the generalized parameters from β_m to β_i. The compensation process is presented in a graphic way in Figure 11. If there are no defects in the material, and its surface is smooth, the observed changes in the impedance components would correspond to the values of functions φ and χ (for α=0.4) designated as "0". In such a case, the measured conductivity could be derived from Equation (2) based on $\beta = \beta_o$. In reality, in view of the non-ideal nature of the tested material, the measured impedance components correspond to the values of functions φ and χ designated as "1". Note that the curves relate to φ and χ (for α=0.48), so the parameter $\beta = \beta_1$ decreases. The compensation process assumes that the distance between the coil and the tested surface does not change; hence, the parameter α does not change either. Accordingly, the calculations should be continued with the applicable curves, designated as arrows in Figure 11. Finally, following certain assumptions, it is possible to achieve effective elimination of the impact of surface defects.

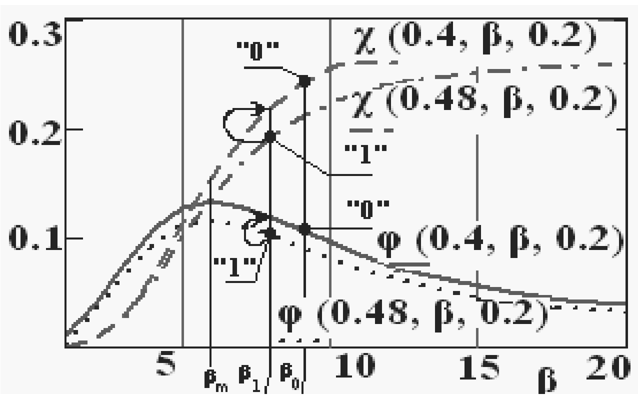

Fig. 11. Graphic interpretation of the compensation process for surface defects in the course of conductivity measurements

5. Impact of the frequency of the eddy currents on the penetration depth

During selection of the frequency of eddy currents, limited penetration depth of the tested element should be taken into account. The classical concept of the eddy currents penetration depth, e.g. as discussed in [9-11], may be calculated by the methods proposed in [12-15]. The penetration depth of the eddy currents may also be determined as a minimal conductive plate thickness *d* influencing, in consideration of the accuracy of measurements, the change in the impedance components to the same degree as any semi-space with identical conductivity. Due to placing the coil onto the conductive semi-space, its impedance components are changed by values *r* and *l*. The penetration depth of the eddy currents is regarded as equal to *d* designated in the following way: after placing an identical coil at the identical distance, not onto the semi-space, but, this time, onto the plate with thickness *d*, the coil impedance components changed by values *r* and *l* designated with the accuracy of the error in the measurement of the impedance components of a given measuring device. Denote the error in designating the resistance change as δr, and the coil inductance as δl. The changes in the coil impedance components are caused by the proximity of the conductive material. In such a case, for each pair of parameters α and β, each of the equations expressed below may be solved in view of the unknown ρ.

$$\frac{2 \cdot \delta r}{n^2 \omega \pi \mu_0 r_0} = \left| \varphi(\alpha,\beta,\rho) - \lim_{\rho \to \infty} \varphi(\alpha,\beta,\rho) \right| \quad \Rightarrow \rho_r \tag{13}$$

$$\frac{2 \cdot \delta l}{n^2 \pi \mu_0 r_0} = \left| \chi(\alpha,\beta,\rho) - \lim_{\rho \to \infty} \chi(\alpha,\beta,\rho) \right| \quad \Rightarrow \rho_l \tag{14}$$

Assume that the maximal value from all the calculated values of ρ_r and ρ_l will be generalized penetration depth of eddy currents:

$$\rho_p = MAX\left(\rho_r, \rho_l\right) \tag{15}$$

The real infiltration depth of eddy currents may be derived if the dimensions of the contact coil are known

$$d_p = (\rho_p \, r_0):2 \tag{16}$$

The knowledge of the real penetration depth of eddy currents, dependent on frequency, is very useful during the tests. It may also be calculated by means of a digital device during measurements. To explicate the observed nature of penetration depth, Equation (13) is transformed to the following form:

$$\delta r = a(\alpha,\beta,\rho) = \frac{n^2 \omega \pi \mu_0 r_0}{2} \cdot \left[\varphi(\alpha,\beta,\rho) - \lim_{\rho \to \infty} \varphi(\alpha,\beta,\rho) \right] \tag{17}$$

Similarly, from conversion of Equation (14) the following function is obtained:

$$b(\alpha,\beta,\rho) = \frac{n^2 \omega \pi \mu_0 r_o}{2} \cdot \left[\chi(\alpha,\beta,\rho) - \lim_{\rho \to \infty} \chi(\alpha,\beta,\rho) \right] \tag{18}$$

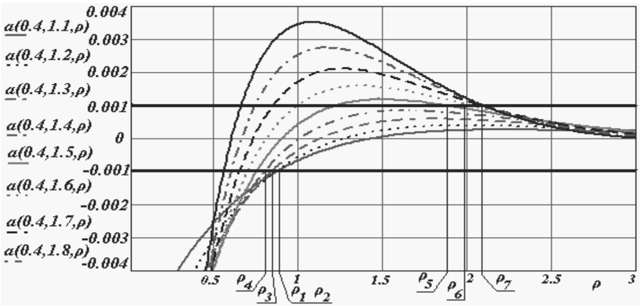

Fig. 12. Explication of the phenomenon of the abrupt change in the penetration depth of eddy currents

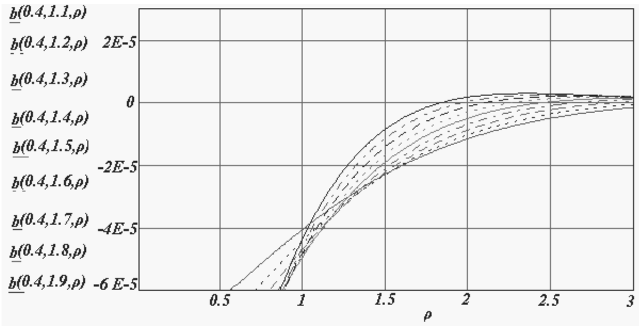

Fig. 13. Graph of function $b(\alpha,\beta,\rho)$ depending on parameter ρ for several selected values β

Figure 12 presents values $a(\alpha,\beta,\rho)$ calculated for the generalized parameter β = 1.1-1.8. As far as the copper tests are concerned, for the coil with replacement radius equal to 1 cm, the corresponding frequencies are on the level of dozens of Hz. However, a similar example may also be found for higher frequencies. Analysing Figure 4, with the indicated dead zone of the measuring device, it may be stated that for the generalized parameter β = 1.1 and β = 1.2 the values of the generalized penetration depth are close and equal to ρ_1 and ρ_2. If the frequency of the exciting field is increased to the value of the generalized parameter β = 1.3, the penetration depth of the eddy currents decreases to the value corresponding to ρ_3. Likewise, if the frequency of the exciting field is increased to the value of the generalized parameter β = 1.4, the penetration depth of the eddy currents decreases to the value corresponding to ρ_4. Another increase in frequency corresponding to the value of the generalized parameter β = 1.5 leads to improved sensitivity of the measuring method at higher depths and, accordingly, the penetration depth of the eddy currents is ρ_5 which is bigger than ρ_4. Every successive insignificant increase of frequency evokes a significant increase in the penetration depth of the eddy currents to the values of the generalized parameter ρ_6 and ρ_7, successively. Graph of function $b(\alpha,\beta,\rho)$ depending on parameter ρ is presented in Figure 13. For the data of the presented example, change in inductance is influenced only by external layers of material and the depth of the eddy currents penetration should be determined by solving the Equation (17). Numerically calculated eddy currents penetration depth expressed as the dependence on

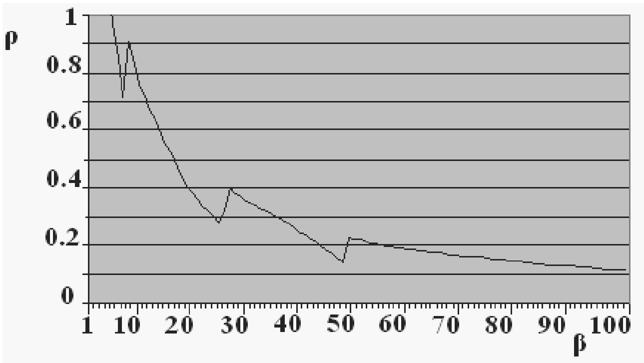

Fig. 14. Calculated generalized eddy currents penetration depth as function of parameter β

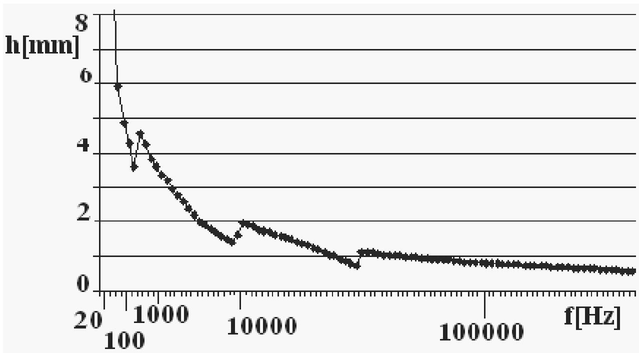

Fig. 15. Eddy currents penetration depth in copper for a coil with effective radius 1cm

generalized parameters, with the assumption that measuring device measures both components of the coil impedance with the same error equal 1%, is drawn in Figure 14. The eddy currents penetration depth during measurement of copper element with the coil of effective radius 1 cm is drawn in Figure 15.

6. Conclusions

The proposed mathematical model that reflects the impact of the eddy currents on the coil impedance facilitates the choice of the optimum frequency of the field generating eddy currents. Selection of proper frequency is essential for achieving high sensitivity of device. This frequency depends on the intended use of the device, measurement method of the coil impedance components and also on expected spatial dimensions. Remarks stated above can be helpful for the designers and users of apparatus operating on the principle of the eddy currents phenomenon. The observations concerning the penetration depth of the eddy currents are of special importance, as this parameter may be calculated by means of numerical methods based on the model: contact coil placed above semi-space. It turns out that the presence of a defect in the tested material, even if located below the designated boundary, is detected by the measuring device. Such a defect apparently increases the infiltration depth of the eddy currents. Thus, the measuring device has a penetration zone larger than the calculated infiltration depth. This situation is presented in Figure 16. The proposed definition of the infiltration depth of the eddy currents put forward in the paper is more convenient for flaw detectors: contact coil placed above a conductive non-magnetic plate. Standard definition of eddy currents infiltration depth is based on the principle of decrease of field intensity to the value 1/e is less useful.

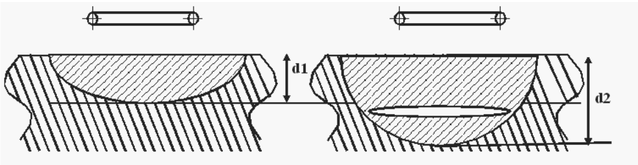

Fig. 16. Defect located below the limit of existence of electromagnetic field deteriorates properties of screening metal and infiltration limit increases to the value determined by the suggested definition

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