THEORETICAL SETTINGS WITH PRACTICAL APPLICATION

We are going to deal with rules and phenomena connected to electromagnetic induction. If magnetic flux Φ runs through a surface limited by a contour, and if it is variable through time, the electromotive force is inducted in that contour,so

$$e = \oint \mathbf{E}_{ind}\, d\mathbf{l} = -\frac{d\Phi}{dt} \tag{1}$$

where:$\mathbf{E}_{ind}$ presents the vector of the electric field voltage;$d\mathbf{l}$ the vector of the contour;$d\Phi$ presents the change of the magnetic flux. The change of flux in the contour is inducted by the electromotive force

$$e_L = -L\frac{di}{dt} \tag{2}$$

where:L is a self-inductance coefficient and depends on the geometry contour and on the number of the turns. The vector of the strength of the magnetic field is

$$\oint \mathbf{H} d\mathbf{l} = \sum \mathbf{I} \tag{3}$$

As generally known, as well as per [2-4], the Eqs.(1), (2) and (3) can be represented by Maxwell's equations having the form of

$$rot\mathbf{H} = \delta + \frac{\partial \mathbf{D}}{\partial t} \tag{4}$$

$$rot\mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \tag{5}$$

where:δ is currency the current density;$\mathbf{D} = \varepsilon_0 \varepsilon_r \mathbf{E}$ electric induction; and $\mathbf{B} = \mu_0 \mu_r \mathbf{H}$.

We are going to deal with the surface effect on the example of variable current running as per the profile of the rectangle cross section. If the dimensions are huge, then the metal body can have a flat surface on which electromagnetic waves rest. Based on [1-5] for the solution of Maxwell's equations, under the condition of H and E being of the sinusoidal character, we can have:

$$H_m = H_{me}\, e^{-\frac{x}{\Delta}} \sin\left(\omega t + \theta_H - \frac{x}{\Delta}\right) \tag{6}$$

$$E_m = \sqrt{2}\left(\frac{\rho}{\Delta}\right) H_{me}\, e^{-\frac{x}{\Delta}} \sin\left(\omega t + \theta_H - \frac{x}{\Delta} + \frac{\pi}{4}\right) \tag{7}$$

$$\delta_m = \sqrt{2}\left(\frac{H_{me}}{\Delta}\right) e^{-\frac{x}{\Delta}} \sin\left(\omega t + \theta_H - \frac{x}{\Delta} + \frac{\pi}{4}\right) \tag{8}$$

where:H_{me} is a complex amplitude of the strength of the magnetic field on the surface;θ_H- the initial phase;x- distance of the point from the surface of the conductor;δ_m- surface current;Δ- depth of penetration;$\omega = 2\pi f$- angular frequency;γ- specific electrical conductance. The pattern for penetration depth is known:

$$\Delta = \sqrt{\frac{2}{\omega \mu_0 \mu_r \gamma}} \tag{9}$$

Analysing the analytical values in Eqs.(6), (7) and (8) we can see that these values are decreasing as we go from the surface of the conductor, in this case steel tube stripe, towards the inner part as per the exponential form. Boundary conditions of the magnetic and electric field strengths on the surface are

$$x = 0, H_m = H_{me}, \quad E_m = 1.41 \frac{\rho}{\Delta} \tag{10}$$

and at distance $x = \Delta$

$$\frac{H_m}{H_{me}} = \frac{E_m}{E_{me}} = \frac{\delta_m}{\delta_{me}} = \frac{1}{e} = 0.37 \tag{11}$$

thus,we can conclude that at depth $x = \Delta$ approximately 86% of heating power and welding is lost.

As per [8-10] and L.R. Neiman and A.G. Sluhocky's papers, it has been shown that for half-indefinite areas (μ- variable, ρ- constant), the active power has the value of

$$P_a = 0.685 \cdot H_{me}^2 \frac{\rho}{\Delta_e} \tag{12}$$

where: Δ_e- represents the depth of field entrance, and H_{me} represents the strength of magnetic field against the surface. Reactive power is given by

$$P_r = 0.486 \cdot H_{me}^2 \frac{\rho}{\Delta_e} \tag{13}$$

Dealing with active power Eq.(12) and reactive power Eq.(13) we get $\cos\varphi = 0.83$. High frequency currents in the material surface release heat and temperature increases. A larger amountof energy is released in the layer of metal closer to the surface and the temperature at this point increases faster. This is how a difference in temperature is made so that the energy is transferred from the surface- to inner layers. The temperature of the surface layer decreases as the temperature in the inner layers increases.

2.2 Designing the product heat treatment

Example: Design and calculate the parameters of HF welding of the steel pipe 21.3 mm in diameter and 2.65 mm wall thickness in such a way that the production rate is 60 m/min. The inner diameter of the inductor is 85 mm, generator frequency is 440 kHz, welding temperature is 1500 °C, mean distance of the inductor from the joint point of the sheet rim is 45 mm, and 0.56 mm thick conduction pellet at the pitch of 385 mm. The gap between ferrite and interior rim of steel sheet is b_1 =3 mm, and the inductor length is a_i =30 mm. Heating characteristics are adopted in the usual way as in [1] to [10].For welding to take place, the power P_{tr} = 68.32 kW released at the rims of the steel sheet is necessary, thus the current through the sheet is I_{tr} =1188 A and voltage on the steel sheet nose is U_{tr} =111 V.The power efficiency is η_i =0.809 and the electric efficiency is η =0.993, and with this the necessary power for the inductor is calculated

$$P_i = \frac{P_{tr}}{\eta_i \cdot \eta} = 85 \text{ kW} \tag{14}$$

By elementary calculation we get the inductor current

$$I_i = 1406.8 \text{ A} \tag{15}$$

and voltage on the inductor

$$U_i = 114 \text{ V} \tag{16}$$

It has been considered that impedance Z_m, as a function of the inner pipe diameter and the characteristic of ferrite as the concentration field, has an infinite value. The depth of heat penetration in the steel sheet is $\Delta_k = 0.824 \cdot 10^{-3}$ m.

Having in mind the approximate losses in the oscillator and other generator appliances as well as the performed calculation, it is proven that a quality welding of this steel pipe with the selected welding speed is possible.