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Case Study Regarding the Design of a Direct Current Electromagnet for the MIG Welding of Metallic Materials

Part I: Description of the Welding Methods and Preliminary Calculus of the Electromagnet

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The paper refers to the design of a direct current electromagnet, located on the head of a swan neck welding gun of a MIG welding equipment and used for magnetising the rotation space of two additional electric arches, in order to preheat the electrode wire and of the protective gas, partially turned into plasma jet. One describes the MIG welding method in which the electromagnet is used as well as its preliminary calculus.

Keywords: *MIG welding, electromagnet, direct current, preliminary calculus*

1. Description of the welding method

The welding method using the electromagnet is presented in principle in figure 1 and consists in the completion of the following stages:

- initial preheating of the free end of the electrode wire (1), which travels at the advance speed v_e, by the advance system (3) of the MIG welding installation, before the ignition of the MIG welding arch (13); the preheating is realised by the additional electric arch (10), ignited on wire and rotating in the B induction magnetic field, created by the direct current electromagnet of the magnetisation system (8), located on the head of the swan neck welding gun from the endowment of the MIG-MAG welding equipment;
- preheating before and during the welding of the surface of the basic metal in the welding area, by the protective gas (argon) partially transformed into plasma jet at its passage through the rotating electric arch and pushed to the surface of the basic metal through a ceramic tube;

- the actual welding realised by the priming and maintaining of the MIG welding arch (13) during the travel at the v_s welding speed of the welding gun, simultaneously with the preheating of the wire by the rotating arch, welding arch and protective gas.

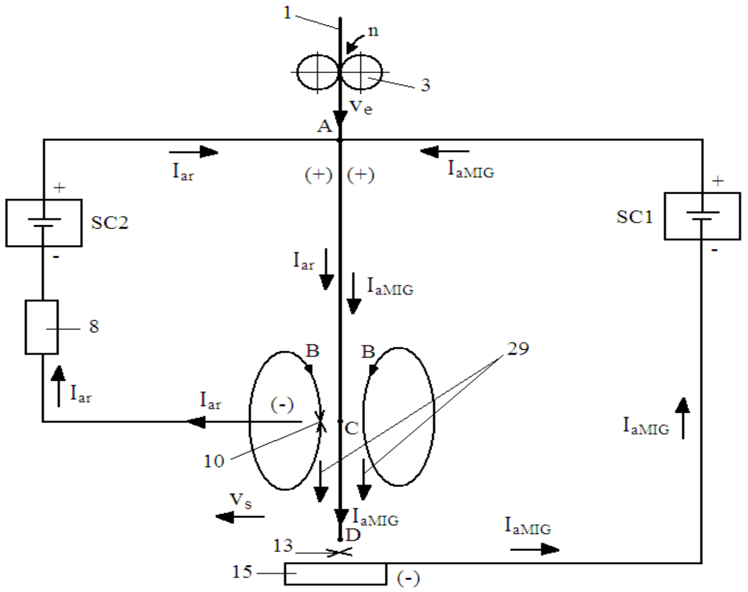

Figure 1. Schematic diagram of the method of welding

The welding installation is a classic MIG welding installation endowed with direct current source (SC1) and with a system of electrode wire advance with the advance speed of the wire depending on the length of the arch, electrically connected with the positive pole (+) to the electrode wire and the negative pole (-) to the basic metal (15), being used for the ignition and maintaining of the welding arch (13), of the intensity I_{aMIG}.

The welding installations also contains a MIG welding gun, cooled with liquid, an additional source of inert gas (argon), an additional source of welding (SC2), of direct current (ex. a welding inverter), with falling external characteristics, a magnetisation system mounted on the head of the welding gun, a plasma generator, located inside the magnetisation system and mounted in series with it in the secondary circuit of the source SC2, which closes through the rotating electric arch 10, of intensity I_{ar}, ignited and maintained between the cathode of the plasma generator and the electrode wire (1).

2. Establishment of the initial data

In the electromagnet design calculus from the structure of the magnetisation system one adopted the constructive variant presented in figure 2.

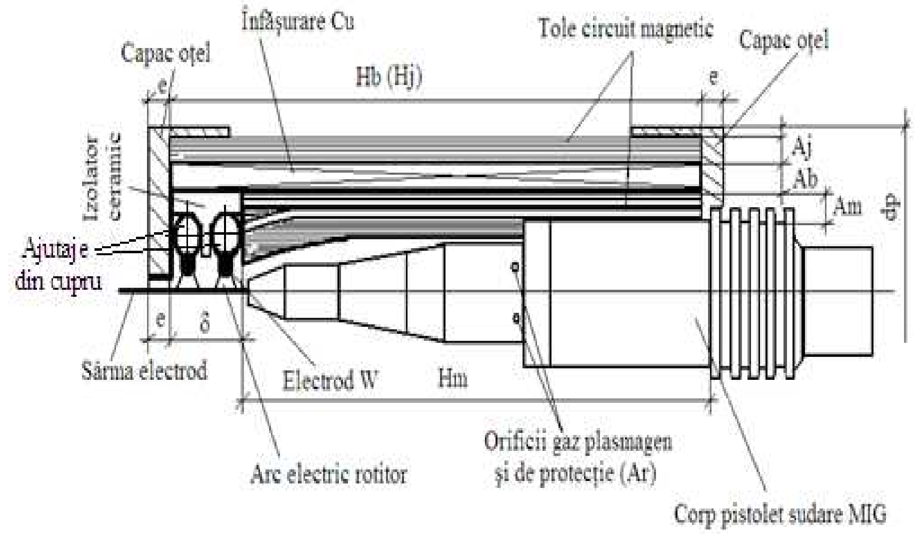

Figure 2. Drawing of the welding gun head

The notations in the figure have the following meanings:
s_b – coil thickness;
A_b – coil width;
H_b – coil height;
s_m – thickness of magnetic core;
A_m – width of magnetic core;
H_m – core height;
a – thickness of the magnetic circuit yoke;
H_j – height of the magnetic circuit yoke;
A_j – width of the magnetic circuit yoke;
e – polar part thickness;
d_p – diameter of the polar part;
δ – air gap;
The other dimensions are chosen in constructive manner.
The initial data are:

- $\delta = 16$ [mm] - the electromagnet working air gap;
- $B = 0{,}05$[T] – maximum magnetic induction in the air gap;
- $I_m = I_s = 100$[A] – maximum magnetisation current;

- $r_0 \approx 8 \cdot 10^{-3}$[m] – distance for the symmetry axis of the copper nozzles cooled with water to the symmetry axis of the electrode wire;
- $r \approx 2 \cdot 10^{-3}$[m] – length of the rotating arch in magnetic field;
- dimensions of the rectangular wire of the copper winding:
$s \cdot l = 1{,}2 \cdot 10$[mm].

The maximum magnetic induction in the air gap was established from the condition of equilibrium between the electromagnetic force and the aerodynamic resistance force which act on the arch as follows:

$$\begin{cases} F_e = B \cdot I \cdot l \\ F_r = \dfrac{c}{2} \cdot \rho_g \cdot D_g \cdot v_{rot} \end{cases} \tag{1}$$

where:
B = magnetic induction [T];
I = current intensity [A]:
$I_{max} = 100$[A];
l = distance between the electrodes (arch length) [m]:
$l = 2 \cdot 10^{-3}$[m];
c = aerodynamic constant (1 for cylindrical bodies);
ρ_g = density of the environment where the arch shifts takes place [Kg/m^3]:
$\rho_g = 1.784$ [Kg/m^3] for argon (used as plasmagenous gas)
D_g = debit of plasmagenous gas [Kg/m^3]:

$$D_g = 12\left[\frac{litres}{\min}\right] = \frac{12}{60 \cdot 1000}\left[\frac{m^3}{s}\right] = 0{,}2 \cdot 10^{-3}\left[\frac{m^3}{s}\right]$$

v_{rot} = rotation speed of the rotating arch [m/s].

From the experimenting of rotating arch welding in magnetic field, the stable rotating speed thereof in argon environment is n ≈ 350 [rot/s].

It results, for the analysed case (d_{rot} = 5 mm):

$$v_{rot} = \frac{\pi \cdot d_{rot} \cdot n}{1000} = \frac{\pi \cdot 5 \cdot 350}{1000} = 5{,}5\left[\frac{m}{s}\right], \tag{2}$$

The aerodynamic resistance force will be:

$$F_r = \frac{1}{2} \cdot 1{,}784 \cdot 0{,}2 \cdot 10^{-3} \cdot 5{,}5 = 0{,}9812 \cdot 10^{-3}[daN] = 9{,}812 \cdot 10^{-3}[N]$$

The magnetic induction in the air gap (necessary to the rotation of the centric arch) is:

$$B_i = \frac{F_r}{I \cdot l} = \frac{9{,}812 \cdot 10^{-3}}{100 \cdot 2 \cdot 10^{-3}} = 0{,}049[T]);$$

3. Choice of coefficients for the preliminary calculus

The heat dissipation coefficient on the exterior surface of the coil (h) [4], [6] is determined with the relation:

$$h = 9{,}3 \cdot 10^{-4}(1 + 0{,}059 \cdot \theta_{ad}) = 13 \cdot 10^{-4}\left[\frac{W}{\deg \cdot cm^2}\right]. \tag{3}$$

where: $\theta_{ad} = 100^o C - 25^o C = 75^o C$. – admissible heating [2, 4].

The resistivity of the wire material (ρ) [4,6] is:

$$\rho = \rho_0(1 + \alpha_0 \cdot T_{ad}) = 0{,}0225\left[\Omega \cdot mm^2 / m\right] \tag{4}$$

where : T_{ad} = maximum temperature equal with 100°C;

$\rho_0 = 0{,}0162$ [Ω·mm²/m]; $\alpha_0 = 0{,}00393$ [1/°C].

The heat exchange coefficient on the coil inner surface (h_{in}) [4], [6] is determined with the relation:

$$h_{in} = \alpha \cdot h = 35{,}1 \cdot 10^{-4}\left[W / grad \cdot cm^2\right], \tag{5}$$

where: α = 2,7 – for the coil wound on the core.

The dimensional coefficients adapted for the preliminary calculus are:
n = 0.8; β = 5; m = 3; τ = 1.6; f_u = 0.5; χ = 0.85; γ = 0.7.

4. Preliminary calculus

4.1. Constant C

It is determined [4], [6] with the relation:

$$C = \frac{2 \cdot 10^3 \cdot \rho(1+n)}{\gamma^2 \cdot \chi^2 \cdot f_u \cdot \tau^2 \cdot m^2 \cdot n(1 + 2n + \alpha) \cdot h \cdot \theta_{ad}} = 38{,}4 \tag{6}$$

4.2. The induction in the working air gap

It is determined depending on constant C and attraction force realised at the middle of the air gap:

$$B_i = \frac{4{,}8 \cdot 10^{-3}}{\tau \sqrt[5]{C}} \cdot \sqrt[10]{\frac{F_a^3}{\left(\delta / 2\right)^4}} = 4{,}73 \cdot 10^{-2}[T]. \tag{7}$$

4.3. Determination of the magnetic core dimensions

One determines the coefficient ε, which takes into account the flow swelling in the air gap [1], [3]:

$$\varepsilon^2 = 1 + \frac{2{,}08}{\tau \cdot \chi} = 2{,}5 \text{ ,[4,6], } \varepsilon = \sqrt{2{,}5} = 1{,}58 \qquad (8)$$

One determines the equivalent diameter of the iron core with the curve:

$$\frac{F}{\delta_a^3} = \frac{\varepsilon^2}{C_1} \chi^5 , \qquad (9)$$

$$\text{where: } \chi = \frac{d_{me}}{\delta} . \qquad (10)$$

By using the values of ε and C one plots the curve $\frac{F}{\delta^3} = f(\chi)$ and with the help of the graphic-analytical methods one determines the value of χ corresponding to point $\frac{F}{\delta^3} = 5$, which is: $\chi = 4$.

It results that: $d_{me} = \chi \cdot \delta_a = 4 \cdot 0{,}75 = 3$[cm]. (11)

The dimensions of the tubular magnetic core are:

- section of the magnetic core:

$$S_m = \frac{\pi}{4} \cdot d_{me}^2 = \frac{\pi}{4} \cdot 3^2 = 7\left[cm^2\right]; \qquad (12)$$

- the inner diameter of the tubular magnetic core:

d_i = 22 [mm] = 2.2[cm];

- the external diameter of the tubular magnetic core, d_e, is determined by using the relation:

$$\frac{\pi}{4} \cdot d_e^2 - \frac{\pi}{4} \cdot d_i^2 = S_m \qquad (13)$$

It results that: $d_e = \sqrt{\left(7 + \frac{\pi}{4} \cdot 2{,}2^2\right) \cdot \frac{4}{\pi}} = \sqrt{13{,}75} = 3{,}84[cm]$

- the thickness of the magnetic core will be:

$$s_m = \frac{d_e - d_i}{2} = \frac{3{,}84 - 2{,}2}{2} = 0{,}82[cm] \qquad (14)$$

4.4. Determination of the dimensions of the electromagnet winding

One determines the following, depending on the core equivalent diameter (d_{me}) [1], [3]:

- coil width A_b:

$$A_b = n \cdot \frac{d_{me}}{2} = 0{,}8 \cdot \frac{3}{2} = 1{,}2[cm] \qquad (15)$$

- winding height H':

$$H' = m \cdot d_{me} + \delta = 3 \cdot 3 + 1 = 10\left[cm\right]; \tag{16}$$

- the necessary magneto motor tension [4,6]:

$$I \cdot N = \frac{4{,}5 \cdot 10^{3}}{\chi \cdot \gamma \cdot \tau} \cdot d_{me} \cdot \sqrt{\frac{d_{me}}{C_1}} = 3965\left[Asp\right] \tag{17}$$

- the section of the winding: s = 1.2[mm]; b = 10[mm];

$$S_{Cu} = s \cdot b = 1.2 \cdot 10 = 12\ [mm^2] = 0.12\ [cm^2]. \tag{18}$$

- the approximate number of spires in the space established for the winding:

$$N = \frac{f_u \cdot A' \cdot H'}{S_{Cu}} = 45\left[spire\right] \tag{19}$$

where: $f_u = 0.45$; $A^{/} = 1.2[cm]$; $H^{/} = 10[cm]$; $S_{Cu} = 0.12[cm^2]$.

5. Conclusions

The paper represents the first part of a case study related to the design of a direct current electromagnet which is a component of the magnetisation system located on the head of the welding gun of classic MIG winding installations in order to improve its welding performances.

From paragraph 1 we may conclude that the electromagnet, connected in series in the welding circuit with an additional welding source with falling external characteristic and with the plasma generator located in the magnetisation system, produces magnetisation with the induction B of the rotation space of an additional electric arch, ignited and maintained between the cathode(s) of the plasma generator and electrode wire.

The rotation of the additional arch around the electrode wire is realised by the electromagnetic force resulted from the interaction of the magnetic field with the arch current, and this improves the thermal conditions of the welding process and the productiveness of the procedure.

Paragraph 2 sets the initial data for the electromagnet design, the value of the magnetic induction B in the rotation space being determined by equalling the electromagnetic force with the aerodynamic resistance force of the protective gas.

In paragraph 3 we determined the heat dissipation coefficient on the exterior surface and the interior surface of the coil, the electrical resistivity of the wire material and we adopted the dimensional coefficients for the preliminary calculation.

In paragraph 4 we performed the preliminary calculus of the electromagnetic, using the coefficients fro paragraph 3.

We determined the approximate mathematic induction and dimensioned the magnetic core and the electromagnetic winding, the results being 45 spires.

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