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

Part II: Constructive-Electromagnetic Dimension and Verification of the Electromagnet Operation

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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. We present the constructive - electromagnetic dimensioning and the verification of the electromagnet operation.

Keywords: *electromagnet, direct current, magnetic circuit, dimensioning, verification.*

1. Establishment of the initial data for the design calculus

In Part I of the paper we established the following initial data for the design of the electromagnet:

δ = 16 [mm] - electromagnetic working air gap;

$\theta_{ad} = 75^o C$. – admissible heating;

T_{ad} = 100°C - maximum temperature;

$\rho = 0{,}0225\left[\Omega \cdot mm^2 / m\right]$ - resistivity of the wire material;

$h = 13 \cdot 10^{-4}\left[\frac{W}{grad \cdot cm^2}\right]$ - heat dissipation coefficient on the coil exterior surface;

$h_{in} = 35{,}1 \cdot 10^{-4} \left[W \big/ grad \cdot cm^2 \right]$ - Coefficient of heat exchange on the coil inner surface;
δ = 16 [mm] = 1.6[cm] - electromagnetic working air gap;
d_i = 22 [mm] = 2.2[cm] – magnetic core of the inner diameter;
$d_e = 3{,}84[cm]$ - exterior diameter of the magnetic core;
$s_m = 0{,}82[cm]$ - thickness of the magnetic core
$A_b = 1{,}2[cm]$ - coil width A_b;
$H' = 10[cm]$ - winding height H';
S_{Cu} = 0.12 [cm^2] - winding section:
$N = 45[spire]$- approximate number of spires;

We choose constructively Δ_2 from the coil to the magnetic circuit yoke.

2. Winding calculation

The dimensions of the cylindrical coil are [1], [2]:
- coil height H_b:

$$H_b = H' + 2\Delta_2 = 10{,}2[cm]; \tag{1}$$

- coil width A_b:

$$A_b = 1{,}2[cm]. \tag{2}$$

The coil diameters are determined as follows:
- the coil interior diameter D_i (is approximately equal with the exterior diameter of the iron core):

$$D_i = d_e + 2 \cdot \Delta_2 = 4[cm] \tag{3}$$

- the coil exterior diameter, D_e:

$$D_e = D_i + 2 \cdot s_b = 6{,}4[cm] \tag{4}$$

- the copper thickness will be:

$$s_b = n \cdot s_m = 0{,}8 \cdot 0{,}82 = 0{,}65[cm] \tag{5}$$

The relation is satisfied if the copper winding will be realised in 5 layers.

3. Establishment of the magnetic core dimensions

The magnetic core is made of steel 0.5 mm thick [1], [2].
The dimensions of the magnetic core are:

- the magnetic core width:

$$A_m = s_m + 2 \cdot \Delta_2 = 0{,}82 + 2 \cdot 0{,}1 \cong 1[cm] \tag{6}$$

- the magnetic core height: H_m = 9[cm];

4. Establishment of the dimensions of the magnetic circuit yoke

The dimensions of the cylindrical magnetic circuit are [1], [2]:

- the section of the magnetic circuit yoke, S_j, in order to avoid saturation, should not be less than the section of the core S_m:

$$S_j \geq S_m = 7[cm^2]; \tag{7}$$

- the thickness of the magnetic circuit yoke a is determined as follows:

The interior diameter of the yoke D_{ij} is: $D_{ij} = D_i$ = 6.4[cm];

The exterior diameter of yoke D_{ej} is determined as follows:

$$\frac{\pi}{4} \cdot D_{ej}^2 - \frac{\pi}{4} \cdot D_{ij}^2 = S_j \tag{8}$$

$$D_{ej} = \sqrt{\left(S_j + \frac{\pi}{4} \cdot D_{ij}^2\right) \cdot \frac{4}{\pi}} = \sqrt{49{,}87} \cong 7[cm] \tag{9}$$

It results that: $$a = \frac{D_{ej} - D_{ij}}{2} = \frac{7 - 6{,}4}{3} = 0{,}3[cm] \tag{10}$$

- the width of the magnetic circuit yoke, A_j, will be:

$$A_j = a + 2 \cdot \Delta_2 = 0{,}3 + 2 \cdot 0{,}1 = 0{,}5[cm] \tag{11}$$

- the height of the magnetic circuit yoke, H_j, will be:

$$H_j = H_m + \delta = 9 + 1{,}6 = 10{,}6[cm] \tag{12}$$

5. Establishment of the polar parts dimensions

They are located at both ends of the magnetisation coil and are presented in figure 1 [1], [2].

The dimensions of the two steel polar parts are:

- the polar part diameter:

$$d_p = \tau \cdot d_e = 1{,}6 \cdot 4 = 6{,}4[cm] \tag{13}$$

One chooses: $d_p = D_{ej}$ + 0.5 = 7 + 0.5 = 7.5[cm].

- the thickness of the polar part, e, is usually chosen with variable thickness, resulting: e_1 = 0.8[cm] and e_2 = 0.5[cm].

The other dimensions are: d = 1[cm] and l_p = 1.5[cm].

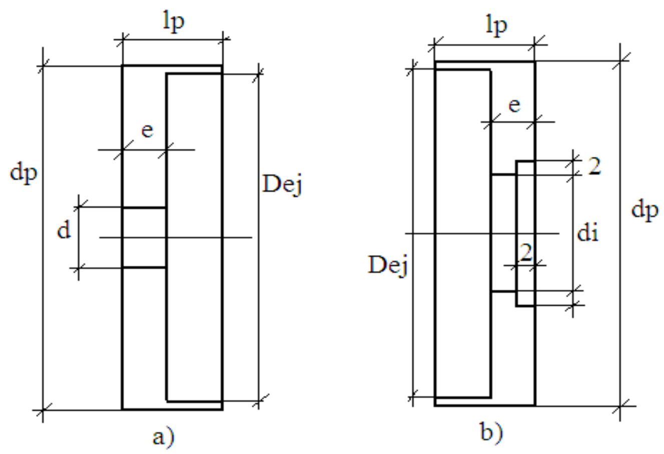

Figure 1. Polar parts diagram: a – polar part 1; b – polar part 2

6. The calculus of the magnetic circuit parameters

The magnetic circuit is plotted in figure 2, being a sum of cylindrical and annular surfaces.

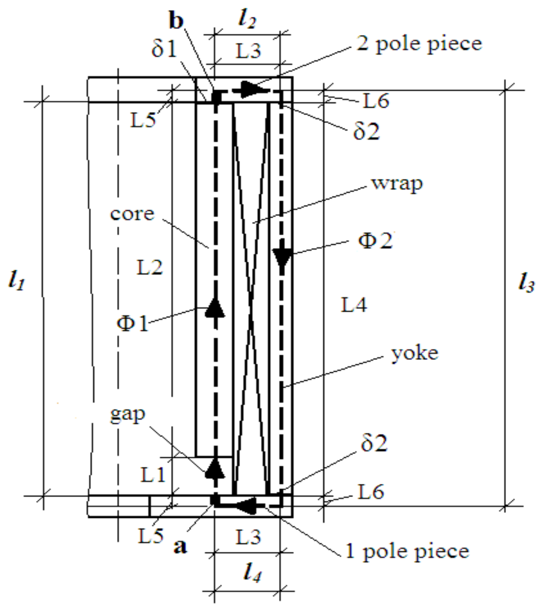

Figure 2. Diagram of the magnetic yoke

The dimensions of the magnetic circuit are:

L1 = δ = 1.6[cm];

δ1 = δ2 = 0.5[mm] = 0.05[cm] – auxiliary air gaps (of leakages) due to the imperfection of the mechanical contact between core (and yoke respectively) and polar parts;

L2 = H_m = 9[cm];

L3 = A_m/2 + A_b + A_j/2 = 0.5 +1.2 + 0.25 = 1.95[cm];

L4 = H_j = 10.7[cm];

L5 = e_1/2 = 0.4[cm];

L6 = e_2/2 = 0.25[cm];

We also know: I = 100[A]; N = 40[spires]; μ_r = 1000;

$\mu_0 = 4 \cdot \pi \cdot 10^{-7}$[H/m].

The magnetic reluctances of the circuit sides are:

- magnetic reluctance of main air gap δ:

$$R_{m\delta} = \frac{1}{\mu_0} \cdot \frac{L1}{\varepsilon' \cdot \frac{d_e + d_i}{2} \cdot s_m} = 43{,}15 \cdot 10^6 \left[{}^{Asp}\!/\!{}_{Wb} \right] \tag{14}$$

where: ε' = flow swelling factor:

$$\varepsilon' = \sqrt{1 + \frac{2{,}08}{\chi}} = 1{,}2, \tag{15}$$

$$\text{where: } \chi = \frac{d_e + d_i}{2 \cdot \delta} = \frac{3{,}8 + 2{,}2}{2 \cdot 1{,}6} = 4{,}8. \tag{16}$$

- magnetic reluctance of auxiliary air gap δ1:

$$R_{m\delta 1} = \frac{1}{\mu_0} \cdot \frac{\delta_1}{\varepsilon' \cdot \frac{d_e + d_i}{2} \cdot s_m} = 1{,}34 \cdot 10^6 \left[{}^{Asp}\!/\!{}_{Wb} \right] \tag{17}$$

- magnetic reluctance of auxiliary air gaps δ2:

$$2 \cdot R_{m\delta 2} = 2 \cdot \frac{1}{\mu_0} \cdot \frac{\delta_2}{\varepsilon' \cdot \frac{D_{ej} + D_{ij}}{2} \cdot s_j} = 3{,}3 \cdot 10^6 \left[{}^{Asp}\!/\!{}_{Wb} \right] \tag{18}$$

where: s_j = 0.3[cm] = $0.3 \cdot 10^{-2}$[m] – yoke thickness.

- magnetic reluctance of iron in side l_1:

$$R_{mFel1} = \frac{1}{\mu_0 \cdot \mu_r} \cdot \frac{l_1 - L1 - \delta 1}{\varepsilon' \cdot \frac{d_e + d_i}{2} \cdot s_m} = 0{,}264 \left[{}^{Asp}\!/\!{}_{Wb} \right] \tag{19}$$

where: *l_1 – L1 – δ1 = 0.8 + 9 = 9.8[cm] = $9.8 \cdot 10^{-2}$[m].* (20)

- magnetic reluctance of iron in side l_2:

$$R_{mFel2}=\frac{1}{\mu_0\cdot\mu_r}\cdot\frac{l_2}{\varepsilon'\cdot\frac{D_{ej}+d_{im}}{2}\cdot s'_p} \quad (21)$$

where: *l_2 = L3 = 1,95[cm] = 1.95·10^{-2}[m];*

$(D_{ej}+d_{im})/2$ = (7 + 2,2)/2 = 4.6[cm] = 4.6·10^{-2}[m]; (22)

s'_p =(e_1 + e_2)/2 = (0.82 +0.3)/2 = 0.56[cm] =0.56·10^{-2}[m]. (23)

It results: $R_{mFel2}=\frac{1}{1000\cdot 4\cdot\pi\cdot 10^{-7}}\cdot\frac{1{,}95\cdot 10^{-2}}{1{,}2\cdot 4{,}6\cdot 0{,}56\cdot 10^{-4}}=0{,}05\cdot 10^{6}\left[{Asp}/{Wb}\right]$.

- magnetic reluctance of iron in side l_3:

$$R_{mFel3}=\frac{1}{\mu_0\cdot\mu_r}\cdot\frac{l_3}{\varepsilon'\cdot\frac{D_{ej}+D_{ij}}{2}\cdot s_j} \quad (24)$$

where: *l_3 = L4 +0.3 =10.7 + 0.3 = 11[cm] = 11·10^{-2}[m];*

$(D_{ej}+D_{ij})/2$ = (7 +6,4)/2 = 6,7[cm] =6,7·10^{-2}[m]. (25)

It results that :

$R_{mFel3}=\frac{1}{1000\cdot 4\cdot\pi\cdot 10^{-7}}\cdot\frac{11\cdot 10^{-2}}{1{,}2\cdot 6{,}7\cdot 0{,}3\cdot 10^{-4}}=0{,}363\cdot 10^{6}\left[{Asp}/{Wb}\right]$.

The magnetic reluctance of iron on side l_4 is equal with the magnetic reluctance of iron on side l_2: $R_{mFel4}=R_{mFel2}=0{,}05\cdot 10^{6}\left[{Asp}/{Wb}\right]$.

With the senses proposed on figure 2 for the flows in the 4 sides, by the application of the Kirckkoff theorems in the knot *a* of the current loop, we obtain the following relations [1]:

$$\begin{aligned}&(a)\Phi_1-\Phi_2=0;\\&(II)\Phi_1\cdot(R_{m\delta}+R_{mFel1}+R_{m\delta 1})+\Phi_2(2\cdot R_{Fel2}+R_{mFel3}+2\cdot R_{m\delta 2})=N\cdot I.\end{aligned} \quad (26)$$

where: N = 45[spires]; I = 100[A].

With the above data, the solutions of the system are:

$$\Phi_1=\Phi_2=\frac{N\cdot I}{2\cdot(R_{m\delta}+R_{mFel1}+R_{m\delta 1})}=\frac{45\cdot 100}{2\cdot(43{,}15+1{,}34+0{,}264)\cdot 10^{6}}=0{,}05\cdot 10^{-3}[Wb] \quad (27)$$

The calculus of induction in the elements of the magnetic circuit is made depending on the flow in the air gap Φ_δ, and the flow of leakages Φ_s, through the dispersion coefficient σ, which , for the air gap δ is determined with the relation:

$$\sigma=\frac{\Phi_\delta+\Phi_s}{\Phi_\delta}=1+\frac{\Phi_s}{\Phi_a}=1+\frac{G_s}{G'_{e\delta i}} \quad (28)$$

where:

G_s - permeance to the leakage flow from the end of the core and yoke;

$$G_s = \frac{g \cdot H'_m}{2} \quad (29)$$

$G_{e\delta i}$ - equivalent permeance of the portions with air gaps δ_a, δ_1 and δ_2.

$$G_{e\delta i} = \frac{G_\delta \cdot G_{\delta 1} \cdot G_{\delta 2}}{G_\delta \cdot G_{\delta 1} + G_{\delta 1} \cdot G_{\delta 2} + G_\delta \cdot G_{\delta 2}} \quad (30)$$

The magnetic permeances are:

- specific permeance at leakages, g:

$$g = \frac{2 \cdot \pi \cdot \mu_0}{\ln \dfrac{l + \sqrt{l^2 - (\frac{s_m + s_j}{2})^2}}{\frac{s_m + s_j}{2}}} = 5{,}31 \cdot 10^{-8} \left[{Wb}/{Asp} \right], \quad (31)$$

where: $l = L3 - s_b = 1{,}95 - 0{,}65 = 1{,}3[cm]$; (32)

- permeance related to the leakage flow at the end of core:

$$G_{sm} = \frac{g \cdot H_m}{2} = 23{,}85 \cdot 10^{-8} \left[{Wb}/{Asp} \right]; \quad (33)$$

- permeance related to the leakage flow , at the end of yoke:

$$G_{sj} = \frac{g \cdot H_j}{2} = 28{,}09 \cdot 10^{-8} \left[{Wb}/{Asp} \right]; \quad (34)$$

- total permeance related to the leakage flow G_s is:

$$G_s = G_{sm} + G_{sj} = 51{,}94 \cdot 10^{-8} \left[{Wb}/{Asp} \right]; \quad (35)$$

- permeance related to the leakage flow in the working air gap:

$$G_\delta = \frac{2 \cdot \mu_0 \cdot s_m \cdot \pi d'_m}{\delta} = 12{,}06 \cdot 10^{-8} \left[{Wb}/{Asp} \right] \quad (36)$$

where: $d'_m = \frac{d_e + d_i}{2} = \frac{3{,}8 + 2{,}2}{2} = 3[cm]$; (37)

- permeance of the parasite air gap δ_1:

$$G_{\delta 1} = \frac{\mu_0 \cdot s_m \cdot \pi d'_m}{\delta_1} = 193{,}11 \cdot 10^{-8} \left[{Wb}/{Asp} \right]; \quad (38)$$

- permeance of the parasite air gap δ_2:

$$G_{\delta 2} = 2 \cdot \frac{\mu_0 \cdot s_j \cdot \pi d'_j}{\delta_2} = 315{,}57 \cdot 10^{-8} \left[{Wb}/{Asp} \right], \quad (39)$$

where: $d'_j = \frac{D_{ej} + D_{ij}}{2} = \frac{7 + 6{,}4}{2} = 6{,}7[cm]$; (40)

The equivalent permeance of the portions with air gaps δ, δ_1, δ_2 will be:

$$G_{e\delta i} = \frac{G_\delta \cdot G_{\delta 1} \cdot G_{\delta 2}}{G_\delta \cdot G_{\delta 1} + G_{\delta 1} \cdot G_{\delta 2} + G_\delta \cdot G_{\delta 2}} = 10{,}96 \cong 11\left[{Wb}/{A}\right], \quad (41)$$

Coefficient of dispersion σ

$$\sigma = 1 + \frac{G_s}{G_{e\delta i}} = 1 + \frac{51.94 \cdot 10^{-8}}{11 \cdot 10^{-8}} = 5{,}72. \quad (42)$$

The corrected flow Φ_1 is:

$$\Phi'_1 = \sigma \cdot \Phi_1 = 5{,}72 \cdot 0{,}05 \cdot 10^{-3} = 0{,}29 \cdot 10^{-3}[Wb] \quad (43)$$

The value of induction in the magnetic circuit elements, with the corrected magnetic flow, will be:

$$B_\delta = \frac{|\Phi'_1|}{1{,}2 \cdot S_\delta} = \frac{0{,}29 \cdot 10^{-3}}{1{,}2 \cdot 0{,}82 \cdot \pi \cdot 3 \cdot 10^{-4}} = 0{,}31[T] \quad (44)$$

$$B_m = \frac{|\Phi'_1|}{S_m} = \frac{0{,}29 \cdot 10^{-3}}{0{,}82 \cdot \pi \cdot 3 \cdot 10^{-4}} = 0{,}375[T] \quad (45)$$

$$B_{\delta 1} = \frac{|\Phi'_1|}{1{,}2 \cdot S_{Fe1}} = \frac{0{,}29 \cdot 10^{-3}}{1{,}2 \cdot 0{,}82 \cdot \pi \cdot 3 \cdot 10^{-4}} = 0{,}31[T] \quad (46)$$

$$B_{p1} = \frac{|\Phi'_1|}{\pi \cdot \frac{D_{ej} + d_{im}}{2} \cdot s'_p} = \frac{0{,}29 \cdot 10^{-3}}{\pi \cdot 4{,}6 \cdot 0{,}56 \cdot 10^{-4}} = 0{,}36[T] \quad (47)$$

$$B_j = \cdot \frac{|\Phi'_1|}{\pi \cdot \frac{D_{ej} + D_{ij}}{2} \cdot s_j} = \frac{0{,}29 \cdot 10^{-3}}{\pi \cdot 6{,}7 \cdot 0{,}3 \cdot 10^{-4}} = 0{,}46[T] \quad (48)$$

$$B_{p2} = \frac{|\Phi'_1|}{\pi \cdot \frac{D_{ej} + d}{2} \cdot s'_p} = \frac{0{,}29 \cdot 10^{-3}}{\pi \cdot 4 \cdot 0{,}56 \cdot 10^{-4}} = 0{,}41[T] \quad (49)$$

$$2 \cdot B_{\delta 2} = 2 \cdot \frac{|\Phi'_1|}{\varepsilon' \cdot \pi \cdot \frac{D_{ej} + D_{ij}}{2} \cdot s_j} = 2 \cdot \frac{0{,}29 \cdot 10^{-3}}{1{,}2 \cdot \pi \cdot 6{,}7 \cdot 0{,}3 \cdot 10^{-4}} = 0{,}76[T] \quad (50)$$

The magneto-motor tensions necessary for the magnetisation of the elements of the magnetic circuit analysed are:

$$[N \cdot I]_{\delta} = \frac{\delta}{2} \cdot \frac{B_{\delta}}{\mu_0} = 0{,}8 \cdot 10^{-2} \frac{0{,}31}{12{,}5 \cdot 10^{-7}} = 2969{,}6 = 1984[Asp] \tag{51}$$

$$[N \cdot I]_m = H_m \cdot \frac{B_m}{\mu_r \cdot \mu_0} = 9 \cdot 10^{-2} \frac{0{,}375}{12{,}5 \cdot 10^{-4}} = 27[Asp] \tag{52}$$

$$[N \cdot I]_{\delta 1} = \delta_1 \cdot \frac{B_{\delta 1}}{\mu_0} = 0{,}5 \cdot 10^{-3} \frac{0{,}31}{12{,}5 \cdot 10^{-7}} = 4{,}6 = 124[Asp] \tag{53}$$

$$[N \cdot I]_{p1} = \delta_{p1} \cdot \frac{B_{p1}}{\mu_r \cdot \mu_0} = 4{,}6 \cdot 10^{-2} \frac{0{,}36}{1000 \cdot 12{,}5 \cdot 10^{-7}} = 14[Asp] \tag{54}$$

$$[N \cdot I]_j = H_j \cdot \frac{B_j}{\mu_r \cdot \mu_0} = 10{,}7 \cdot 10^{-2} \frac{0{,}46}{1000 \cdot 12{,}5 \cdot 10^{-7}} \cong 40[Asp] \tag{55}$$

$$2 \cdot [N \cdot I]_{\delta 1} = \delta_2 \cdot \frac{2 \cdot B_{\delta 2}}{\mu_0} = 0{,}5 \cdot 10^{-3} \frac{1{,}52}{12{,}5 \cdot 10^{-7}} = 608\,[Asp] \tag{56}$$

The total magneto-motor tension is:

$N \cdot I = 2797[Asp]$.

The intensity of current through the 45 spires is:

$I = \frac{2797}{45} = 63[A]$.

In order to realise the coil winding of the electromagnet one uses a rectangular wire of CuE with the dimensions s·l = 1,2·10[mm], according to SR EN 60317-0-4:2003/A1:2003, wound with lacquer-impregnated glass fibre.

7. Determination of the window filling factor and of coil electric resistance

The wires are placed in 5 rows with 9 rectangular spires joined in sequence and with insulation between the layers [1], [3].

The window filling factor is determined with the relation:

$$f = \frac{S_{Cu}}{S_b} = \frac{6}{12} = 0{,}5, \tag{57}$$

where:

S_{Cu} = 6[mm] – width of winding (copper) without insulation;

S_b = 12[mm] – width of winding with insulation.

The real filling factor takes into account the non-uniformity of the placement of wires and is:

$$f_u = K_a \cdot f = 0{,}85 \cdot 0{,}5 = 0{,}425 \qquad (58)$$

where: K_a = 0,85.

The precision of the number of spires in the coil is determined with the relation:

$$N = \frac{f_u \cdot S_b \cdot H_b}{s_{Cu} \cdot l_{Cu}} = \frac{0{,}425 \cdot 1{,}2 \cdot 10{,}6}{0{,}12 \cdot 1} = 45{,}05 = 45[spire]. \qquad (59)$$

The coil electric resistance is:

$$R_0 = 10^{-3} \cdot \rho_0 \cdot \frac{\pi \cdot D_{med}}{S_{Cu}} \cdot N = 0{,}00992[\Omega] \qquad (60)$$

where: D_{med} = 5.2[cm] = 52[mm];

s_{Cu} = s·l = 12[mm^2] (61)

The very low electrical resistance of the coil is due to the large section and small length of the copper wire.

8. Verification of the electromagnetic operation

The volume of the coil winding is [1], [2=3]:

$$V = \pi \cdot D_{med} \cdot A_b \cdot H_b = \pi \cdot 5{,}2 \cdot 1{,}2 \cdot 10{,}7 = 40{,}3[cm^3]. \qquad (62)$$

The power consumed by the coil at the room temperature is:

$$P_0 = R_0 \cdot I^2 = 0{,}0099 \cdot 10000 = 99[W]. \qquad (63)$$

The specific losses in the coil at the room temperature are:

$$q_0 = \frac{P_0}{V} = \frac{99}{40{,}3} = 2{,}463\left[W/cm^3\right]. \qquad (64)$$

The equivalent thermal conductibility of the winding is determined as follows:

- the double of the wire insulation thickness is:

2δ = 0.85·A_b/n - s_{Cu} = 0.85·12/5 – 1.2 = 0.84 [mm]) 0.084 [cm]; (65)

- the ratio of the non-insulated and insulated wire thicknesses:

$$c = \frac{s_{Cu}}{s_{Cu} + 2\delta} = \frac{1{,}2}{1{,}2 + 0{,}84} = 0{,}588; \qquad (66)$$

- equivalent thinks of the air-filled portions:

$$2i = 0{,}15 \cdot \frac{A_b}{5} = \frac{0{,}15 \cdot 1{,}2}{5} = 0{,}036[cm]; \qquad (67)$$

- the equivalent thermal conductivity of the winding:

$$\lambda_i = \frac{2\delta + 2i}{\frac{2\delta}{2 \cdot (\lambda_1 + \lambda_2)} \cdot \frac{2i}{\lambda_3}} = 0{,}177 \cdot 10^{-3}\left[W/cm \cdot grad\right], \qquad (68)$$

where: δ – where insulation thickness;

λ_{Cu}, λ_1, λ_2, λ_3 – thermal conductibility or the wire and air insulation: $\lambda_1 = 7 \cdot 10^{-3} W / cm \cdot grad$; $\lambda_2 = 1{,}6 \cdot 10^{-3} W / cm \cdot grad$;

$\lambda_3 = 0{,}26 \cdot 10^{-3} W / cm \cdot grad$;

λ_{Cu} = 3.99[W/cm·grad]; $\lambda_{0ţel}$ =0.43[W/cm·grad].

The equivalent thermal conductibility of the magnetisation coil will be:

$$\lambda_{eb} = \frac{(2\delta + 2i) + s_{Cu} + s_m + s_j}{\frac{2\delta + 2i}{\lambda_i} \cdot \frac{s_{Cu}}{\lambda_{Cu}} \cdot \frac{s_m + s_j}{\lambda_{otte}}} = 68 \left[W \middle/ cm \cdot grad \right]. \qquad (69)$$

The temperature by which one shall heat the electromagnet winding is:

$$\Delta T = \frac{P_0}{A_b \cdot \lambda_{eb}} = \frac{99}{0{,}6 \cdot 68} = 2{,}42 \cong 2{,}5 [°C] \qquad (70)$$

where: $A_b = 0{,}6 [cm]$

Thus during operation, the electromagnetic coil will have the temperatures of the operation environment plus 2 ÷ 3 [˚C].

9. Conclusions

The paper represents the second part of a case study regarding the design of a direct current electromagnet for the MIG welding of metal materials.

The constructive and electromagnetic dimension thereof led to a magnetisation system with the following dimensions and performances:

- dimensions of the rectangular copper winding wire: s·l = 1.2·10[mm];
- number of spires of the copper winding: N = 45[spires];
- magnetic induction in the rotation air gap of electric arches: B = 0.05[T];
- increase of the temperature of the magnetisation system during operation: ΔT = [˚C];
- size dimensions of the magnetisation system: D·L = ø75·130[mm].

By using the SolidWorks Educational software we elaborated the execution drawing of non-standardised elements and the overall drawing of the MIG-MAG winding pistol with the adapted magnetisation system, presented in figure 3.

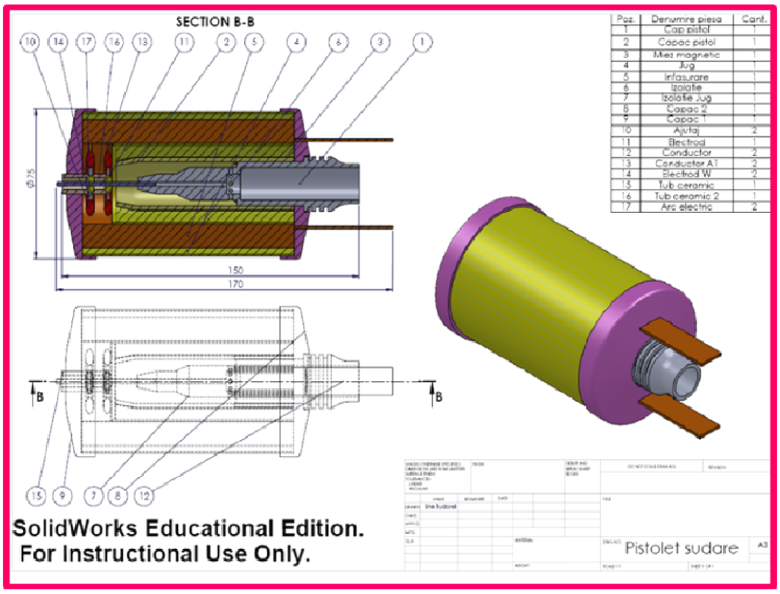

Figure 3. Overall drawing of the MIG-MAG welding pistol with the adapted magnetisation system [4]

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