CONCRETION, DESIGN AND REALIZATION OF AN ELECTROMAGNET USED TO ACTION THE SLIDING VALVES OF A VACUUM DISTRIBUTOR

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The paper presents the practical realization way of a plunger type electromagnet, design and realized by the author. Such an electromagnet is used to action the sliding valves of a vacuum distributor (pulsator).

In a first stage were determine some parameters necessary for designing of this type of electromagnet, by using a suitable concretion breviary. It was made a preliminary calculation, followed by a dimensional one for coil and a calculation for the size of magnetic circuit.

The second stage is represented by the constructive realization of electromagnet on the basis of done calculations. Are presented aspects connected with the used materials and also the applied constructive solutions.

In the final part of the paper are presented some dates regarding the test, in laboratory conditions, of this plunger type electromagnet.

***Key words**: design and execution element; electromagnet, plunger*

Electrical action elements could be of electromagnets type or electrical engines ones (by a.c or d.c), usually named electrical servo-engines.

Action with electromagnets (plunger type) assures a non-continuous movement, bi-positional, obtaining at the exit two stationary positions (close - open; right – left). The pass from a level to another is realised in a short time.

Choosing of the action electromagnet is not a simple operation and must be done in according with some calculation standards for an optimal designing.

In this way, the paper presents the designing, realization and test of an electromagnet used to action the sliding valves of a vacuum and air distributor at atmospheric pressure.

MATERIAL AND METHOD

In the designing stage of the electromagnet were establish some certain parameters, by using an adequate calculation standard [2; 4]. For sizing the coil and magnetic circuit were also made concretions, which are presented below.

Preliminary dates for designing are: tension voltage, U_n = 12 V; action force, F_a = 2 N; run (maximum inner-iron), $\delta = 5 \cdot 10^{-3}$ m; connection time, D_c = 0.5 s; electromagnet type – with check.

Concretion of electromagnet constant (**C_e**), is realising with the formula:

$$C_e = (\sqrt{F_a})/\delta_{max} \quad [N^{1/2}/m] = 282.84\ [N^{1/2}/m] \qquad (1.1)$$

where: F_a = - action force, F_a = 2 N; δ_{max} =5·10^{-3} m - maximum inner-iron

Magnetic induction in inner-iron (B_o), according with [2], is:

$$B_0 = 0.44 \ [T]$$

Concretion of plunger radius (r_1) is made starting from the expression of action force, at electromagnet type with plunger with cone-shaped head [2]:

$$r_1 = \sqrt{\frac{2\pi_0 \cdot F_a}{B_0^2 \cdot \pi} - \frac{\delta_{max}^2 \cdot \sin^2 2\beta}{8}} \ [m] \Rightarrow r_1 = 2.27 \cdot 10^{-3}\ m \qquad (1.2)$$

in which: F_a = action force, F_a = 2 [N]; U_m = magnetic voltage; $\mu_0=\pi\cdot 4\cdot 10^{7}$[H/m] - magnetic permeability of vacuum; B_0 = 0.44 [T] - magnetically induction; δ_{max} = 5·10^{-3} [m] - maximum inner-iron, β = 45^o – angle between cone generatrix and base

Will be choose the value r_1 = 4·10^{-3} [m]**.**

Concretion of solenoid (Θ). Accepting that magnetic voltage in iron represent 15…35% from magnetic-engine voltage, then solenoid (Θ) could be appreciating with the formula:

$$\Theta = \frac{B_0}{\mu_0 \cdot (1-k_1)} \cdot \delta_{max} \cdot \cos\beta \ = 1456.4\ [A] \qquad (1.3)$$

in which: B_0 = 0.44 [T] - magnetically induction; μ_0 = $\pi\cdot 4\cdot 10^{-7}$[H/m] - magnetic permeability of vacuum; k_1 = 0.15 - coefficient between 0.15 and 0.35; δ_{max} = 5·10^{-3} [m] - maximum inner-iron; β = 45^o - angle between cone generatrix and base.

Coil sizing

For coil sizing the following concretions must be done:

- *Average admissible heating (θ)* could be determine with the formula [2]:

$$\theta = \frac{\theta_m}{1.05^2} - \Delta\theta \ = 58.02\ [^oC] \qquad (1.4)$$

where: θ_m = 75 [^{o}C]. - average admissible heating [2]; $\Delta\theta$ =10 [^{o}C] – temperature increase inside coil; $\Delta\theta$ = 5…10 [^{o}C].

Estimating **θ = 58 [^{o}C].**

- *Coil resistively (ρ_θ)* is according with the following formula:

$$\rho_\theta = \rho_{20} \cdot (1 - \alpha_p \cdot \Delta\theta) = 2.135 \cdot 10^{-8}\ [\Omega m] \qquad (1.5)$$

in which: ρ_{20} = 1.75·10^{-8} [Ωm] – resistively of the wrapping up material at 20^o C; α_p = 4·10^{-3} [W/m^{2o}C] - coefficient of heat giving up, for wrapping up material [2]; $\Delta\theta$ = 55 [^{0}C] – temperature variation.

- *Ratio between length and thickness of coil* **(k_b).** Is chosen from constructive point of view.

$$k_b = \frac{h_b}{g_b} = 2.5 \qquad (1.6)$$

in which: h_b = wrapping up length; g_b = coils' thickness.

- *Wrapping up length (h_b)***.** Using as filling factor (**f_a**) equal with 0.68, could be concrete the wrapping up length with the following formula:

$$h_b = \sqrt[3]{\frac{D_c \cdot \rho \cdot k_b \cdot \Theta^2}{2\alpha \cdot \theta}} = 0.038 \text{ [m]} \tag{1.7}$$

in which: D_c = 0.5 [s] – action time; ρ = 2.135·10^{-8} [Ωm] – coils' conductor resistively; k_b = 2.5 – ratio between length and thickness of coil; Θ = 1456.4 [A] - solenoid; α = 12.5 [W/m^{2o}C] - coefficient of heat giving up [2];

- *Coils' thickness* **(g_b)** could be determine with the following formula:

$$g_b = \frac{h_b}{k_b} = 0.015 \text{ [m]} \tag{1.8}$$

in which: h_b =0.038 [m] – wrapping up length; k_b = 2.5 - ratio between length and thickness of coil;

- *Conductors' diameter* **(d).** Starting from plunger thickness and taking in consideration the thickness of guiding pipe, and also the thickness of coils' frame, could de concrete the minimal radius of wrapping up (**r_{b1}**) and maximal radius of wrapping up (**r_{b2}**).

$$r_{b1} = r_1 + g_{tg} + j = 7.2 \cdot 10^{-3} \text{ [m]} \tag{1.9}$$

in which: r_1 = 0.004 m – plunger radius; g_{tg} = 0.003 [m] – thickness of guiding pipe; j = 0.0002 [m] – stroke between plunger and guiding pipe.

$$r_{b2} = r_{b1} + g_b = 0.022 \text{ [m]} \tag{1.10}$$

in which: r_{b1} = 7.2·10^{-3} [m] - minimal radius of wrapping up; g_b =0.015 [m] - thickness of coil.

The diameter of conductors' wrapping up will be concreted with the formula:

$$d = 2\sqrt{\frac{\rho \cdot (r_{b1} + r_{b2}) \cdot \Theta}{U}} = 5.5 \cdot 10^{-4} \text{[m]} \tag{1.11}$$

Will choose d = 0.6·10^{-4} [m].

in which: ρ = 2.135·10^{-8} [Ωm] – resistively of coils' conductor; r_{b1} = 7.2·10^{-3}[m] - minimal radius of wrapping up; r_{b2} = 0.022 [m] - maximal radius of wrapping up; Θ = 1456.4 [A] - solenoid; U = 12 [V] – tension voltage.

- *Ratio of wrapping up filling* **(f_u)** is equal with:

$$f_u = k_u \cdot f_{ui} = 0.63 \tag{1.12}$$

in which: k_u = 0.75 – correction coefficient; k_u = 0.7…0.9; f_{ui} = $\pi d^2/\pi d_1^2$ = 0.84 – ideal filling coefficient (d = 5.5·10^{-4} [m] - conductors' diameter; d_1 = 0.6·10^{-3} [m] – diameter of isolated wire).

- *Concrete number of helix* **(N)**

$$N = 4f_u \cdot \frac{h_b \cdot g_b}{\pi \cdot d^2} = 1287 \text{ helix} \tag{1.13}$$

in which: f_u = 0.63 – coefficient of wrapping up filling; h_b = 0.038 [m] – length of wrapping up; g_b = 0.015 [m] – coils' thickness; d = 5.5·10^{-4} [m] – diameter of conductor.

- *Coils' resistance* **(R_b)** will be calculate with the formula:

$$R_b = 4 \cdot \rho \cdot \frac{(r_{b1} + r_{b2}) \cdot N}{d^2} = 10.67 \text{ [Ω]} \tag{1.14}$$

in which: ρ = 2.135·10^{-8} [Ωm] – coils' conductor resistively; r_{b1} = 7.2·10^{-3}[m] – minimum radius of wrapping up; r_{b2} = 0.022 [m] – maximum radius of wrapping up;
N = 1287 helix – number of helix; d = 5.5·10^{-4} [m] – conductors' diameter.

The current in coil (I) will be:

$$I = \frac{U}{R_b} = 1.13 \text{ [A]} \quad (1.15)$$

in which: U = 12 [V] – tension voltage; R_b = 1.6 [Ω] – coils' resistance.

Verification of solenation will be made with the following formula:

$$\Theta = N \cdot I = 1454.3 \text{ [A]} \quad (1.16)$$

in which: N = 1287 helix - number of helix; I = 1.13 [A] - current intensity;

The difference between the solenation resulted from the size concretion and the one resulted from verification concretion is 2.09 [A], an insignificant value.

Sizing of magnetic circuit

For sizing the magnetic circuit will be calculate the following:

- *Height of check* **(v)** could be between 15 and 20% from coils' length. Will choose v = 15% from coils' length.

$$v = 0.15 \cdot h_b = 5.7 \cdot 10^{-3} \text{ [m]} \quad (1.17)$$

in which: $h_b = 38 \cdot 10^{-3}$[m] - coils' length.

- *Initial penetration of the mobile core* **(u).** Is calculated with the formula:

$$u = h_b - v - \delta = 0.0272 \text{ [m]} \quad (1.18)$$

in which: $h_b = 38 \cdot 10^{-3}$ [m] - coils' length; $v = 5.7 \cdot 10^{-3}$ [m] - height of check; $\delta = 5 \cdot 10^{-3}$ [m] - maximum inner-iron;

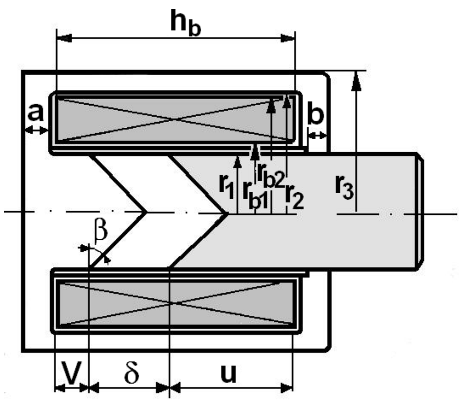

Figure 1 **Electromagnet type with plunger with cone shaped head**
β = angle between cone generatrix and base; h_b = length of wrapping up; r_1 = plunger radius; r_{b2} = maximum radius of wrapping up; r_{b1} = minimum radius of wrapping up; r_2 = internal radius of the frame; r_3 = external radius of the frame; a = frames' thickness at the check side; v = height of check; δ = inner-iron; u = initial penetration of the mobile core; b = thickness of the front plate at check point

- *Internal diameter of the frame* **(d_2)**. Is concrete with the formula:

$$d_2 = 2r_{b2} + D_1 = 0.047 \text{ [m]} \quad (1.19)$$

in which: $r_{b2} = 22 \cdot 10^{-3}$ [m] - maximum radius of coils' wrapping up; $D_1 = 3 \cdot 10^{-3}$ [m] - distance between coil and frame ($D_1 = 3 \ldots 5 \cdot 10^{-3}$ [m]).

- *External diameter of the frame* **(d_3)**. Is concrete with the formula:

$$d_3 = \sqrt{\frac{d_1^2}{0,8} + d_2^2} = 0.0487 \text{ [m]} \quad (1.20)$$

in which: $d_1 = 8 \cdot 10^{-3}$ [m] - plunger diameter; $d_2 = 0.047$ [m] - internal diameter of the frame.

- *Frame thickness at check side* **(a).** Is calculate with the formula:

$$a = \frac{r_1}{2} = 2 \cdot 10^{-3} \text{ [m]} \quad (1.21)$$

in which: $r_1 = 4 \cdot 10^{-3}$ [m] - plunger radius.

In figure 1, are presented the concrete elements of the magnetic circuit.

RESULTS AND DISCUSSIONS

Having in view that the supply circuit of the impulse generator, for action the designed electromagnet, were made at 12 volts, we choose the same tension for supplying the wrapping up of the electric coil.

Also we focused in the dimensional calculation that the working temperature of the wrapping to be as close as possible to the one of the environment, and the adsorbed current by these ones to could be support by the common electronic parts that we used.

The constructive elements of the designed electromagnet are presented in figure 2.

Figure 2 **Action electromagnet**
1- plunger; 2- check of plunger; 3- cylindric support of wrapping; 4- side supports of wrapping; 5- electric wrapping; 6- cylindric frame; 7- plate with check; 8- front plate.

Plunger (1), with an 8 mm diameter, was realized from soft steel (OL 37), and the check (2) of it, from a non-magnetic material (bronze), which will have a good behaviour also at friction. Plunger has at the upper part, cone disengagement, with the angle at pointed end of 45^o, to could follow the check profile. We decide to use a cone type check, to increase the initial attraction [1]. At the front part, plunger is provided with a thread hole, for giving the possibility of mounting the guiding pipe of the sliding valve. For avoiding the large friction surfaces, plunger has two support sectors, with a 2.5 mm width. Also is provided with a limiter (5), which not allows them to bump into the check.

To realize the wrapping up of the electric coil, we choose a conductor with a 0.5 mm diameter, face to the value of 0.55 mm which was resulted from concretion. After tests, we see that at this value of the wrapping up wires' thickness, electromagnets' coil did not heat over 40 ^{o}C, at a 10 minutes usage, and realized the desire action force, at a 5 mm inner-iron (*table 1*).

Table 1

Checking up the temperature of the electromagnet for a 10 minutes alimentation time of the coil

Test number	Temperature [^{o}C]	Force [N]
1	38	2.4
2	38	2.4
3	38	2.4

The wrapping up of the wire was done on support composed by three parts. A cylindrical support, realized from a plastic material pipe (with the internal diameter of 11 mm and the external one of 13 mm), and two side supports, also from plastic material, with 1 mm thickness, *figure 2.*

Electric coil has 1300 helix. After wrapping up the wire, we obtained a coils' thickness of 13 mm, with 2 mm smaller that the calculated one. Constructive, the distance between coil and frame was chosen of 1 mm, of 3 mm value proposed by the calculation standard. External diameter of the frame has a value of 44 mm, face the value of 47 mm resulted from sizing calculation.

Metallic frame of the coil was made from soft steel (OL 37) and it is realized by three parts (*figure 2*) as follow: a cylindrical frame (6); a plate (7), with check, and a front plate (8).

The union of the frontal plate and the one with check with the cylindrical frame was made through some welding points.

CONCLUSIONS

After testing the designed electromagnet, realized after the date from the concretion standard, we observe that this one is suitable from the point of thermal working regime and the desired action force.

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