# STATIC DIMESIONING OF COMPONENT PARTS OF TWO-STAGE SERVO VALVES

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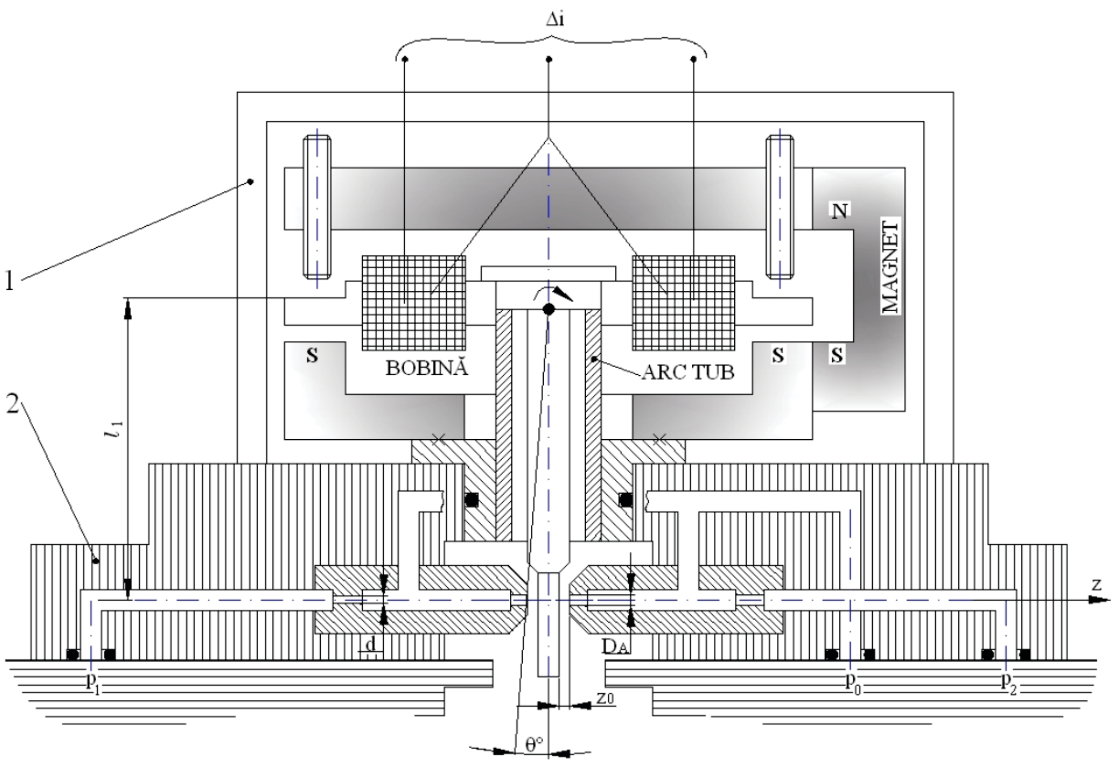
1. Knowing of constructive and functional relations between component parts of servo valves' stages can be important beyond merely information as a basis for initiation of research on changes in functional adjustment dedicated to a particular application for which in initial condition is inappropriate, as well as for some routine operations relating to design and functional rehabilitation of used samples which are below the catalogue parameters.

Complex structure of servo valves involves elements from the field of electro technique, low pressure fluidics, machine parts and applicative fluid mechanics.

The main structural elements are the **torque motor** electromechanical assembly design to adjust the gap nozzle-flap, driven by a proportional variation current, **pre-amplifying stage** which receives the displacement induced by the mobile fitting and by varying the distance nozzle-flap varies the control pressure; and the **amplifying stage** which actually operates on hydraulic parameters of the system where the servo valve is embedded.




## 2. Torque motor

Structurally, it consists of a **fixed fitting** (set of permanent magnets) and an iron **oscillating fitting** without remanence, mounted on a tube spring embedded by means of a sealing and attachment system on the preamplifier body.

According to classical theory configuration of the torque motor can be schematically shown as in Fig.2.

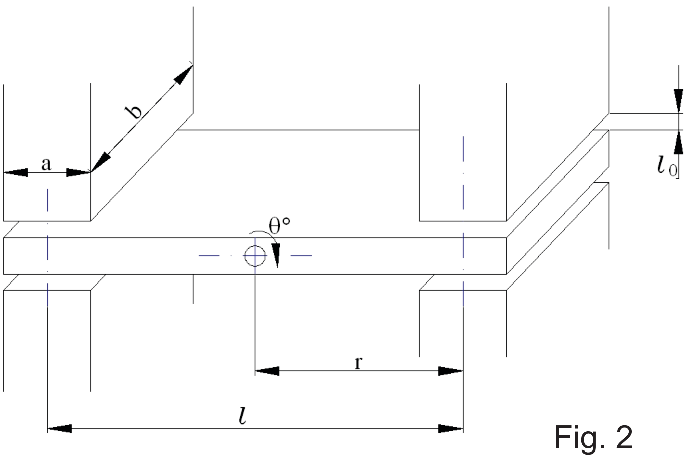



Fig. 2

Notations represent:
- a, b: sizes of magnetic pole;
- r: rotation radius;
- l: distance between poles;
- θ: rotation angle;
- $\theta_0$: maximum rotation angle;
- $l_0$: between iron and permanent magnets;
- η :magnetic permeability;
- N: number of coil whirls;
- B: magnetic induction;
- i : current

**a) Active torque** developed by the motor depending on intencities and rotation angle has the expression:

$$M_a(i,\theta)=\frac{4ba}{\left(1-\frac{\theta^2}{\theta_0^2}\right)^2}\cdot\left(\frac{B\cdot N}{\theta_0}i+\frac{B^2r}{\mu\theta_0}\theta+\frac{\mu N^2}{r\theta_0^2}i^2+\frac{BN}{\theta_0^3}i\theta^2\right) \quad (1)$$

If $\theta << \theta_0$ then $\frac{\theta^K}{\theta^{K+1}} \to 0 \quad \forall K \in N$

and terms 3 and 4 can be neglected, and by noting magnetoelastic constants

$$K_1=\frac{4abNB}{\theta_0} \text{ and } K_2=\frac{4abrB^2}{\mu\theta_0} \quad (2)$$

it results: $M_a = K_1 i + K_2\theta$ (3)

**b) Geometric parameters**
Relation angle-displacement is given by $Z \cong \lambda_1\theta$
where $\lambda_1$ length of the blade

- **Elastic constant** of tube spring according to classic theory and Fig. 3 has the expression:

$$K_E=\frac{\pi E\left(D_T^2-d_T^2\right)}{64 l_T} \quad (4)$$

where E is the longitudinal modulus of elasticity.

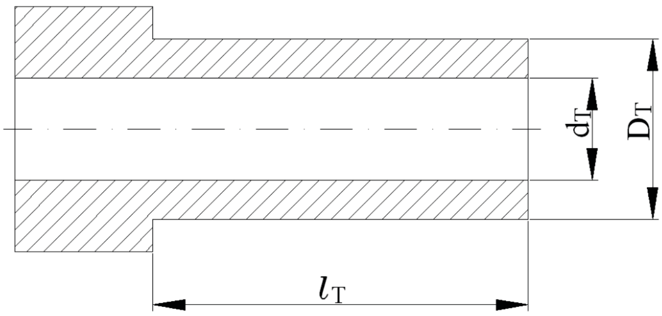



Fig. 3

**3. Static dimensioning of the system nozzle-blade**

a) Evaluation of parameters is performed according to Fig. 1 where are expressed:

- Area of the nozzle $A_{aj}=\frac{\pi D_A^2}{4}$

$D_A$ diameter of the nozzle

- Connection: $Z \to \theta$ $\quad Z=\lambda_1\theta$

- Other necessary information:
d : diameter of control nozzles;
$C_D$: coefficient of flow through control nozzles $(C_D \cong 0.61)$
ρ : density of fluid
$C_{DA}$: coefficient of flow through nipples

In stationary regime flows $Q_1$ and $Q_2$ through nozzles and nipples are:

$$Q_1=\pi C_{DA}\cdot D_A(Z_0-Z)\sqrt{\frac{2p_1}{\rho}}=C_D\frac{\pi d^2}{4}\sqrt{\frac{2(p_0-p_1)}{\rho}} \quad (5)$$

$$Q_2=\pi C_{DA}\cdot D_A(Z_0+Z)\sqrt{\frac{2p_2}{\rho}}=C_D\frac{\pi d^2}{4}\sqrt{\frac{2(p_0-p_1)}{\rho}} \quad (6)$$

$$p_1=\frac{p_0}{1+\left(\frac{C_{DA}}{C_D}\cdot\frac{4D_A}{d^2}\right)^2(Z_0-Z)^2};$$
$$p_2=\frac{p_0}{1+\left(\frac{C_{DA}}{C_D}\cdot\frac{4D_A}{d^2}\right)(Z_0+Z)^2} \quad (7)$$

Diference between pressures gives the **control pressure**

$$\Delta p_C = p_1 - p_2 = p_0\left[\frac{1}{1+K(Z_0-Z)^2} - \frac{1}{1+K(Z_0+Z)^2}\right] \quad (8)$$

$$K = \left(\frac{C_{DA}}{C_D}\cdot\frac{4D_A}{d^2}\right)^2 \quad (9)$$

From condition of continuity of flowing sections in order to avoid saturation of holes is necessary that:

$$\frac{C_{DA}}{C_D}\cdot\frac{4D_A}{d^2} Z_0 = 1 \quad \text{it results:} \quad Z_0\sqrt{K} = 1 \quad (10)$$

Egality between geometric sections of flowing nozzle-flap and nozzle

$$\pi D_A Z_0 \le \frac{1}{2}\cdot\frac{\pi D_A^2}{4} \quad \text{it results:} \quad Z_0 \le \frac{D_A}{8} \quad (11)$$

- Linearized equation of **control flow** of the preamplifier

$$Q_C = K_Q^1 Z - K_C^1 \Delta p_C \qquad \text{where:}$$

$$\begin{cases} K_Q^1 = \pi C_{DA}\, D_A\sqrt{\dfrac{2p_0}{\rho}} \\ K_Q^1 = 2\pi C_{DA}\, D_A\,\dfrac{Z_0}{\sqrt{2\rho p_0}} \end{cases} \quad (12)$$

## 4. Evaluation of dynamic parameters

- natural pulsation

$$\omega_N = \sqrt{\frac{K_a - K_{e2}}{J}} \begin{cases} K_a : \text{constant of the tube spring} \\ K_{e2} : \text{constant of the spring of amplifier} \\ J : \text{reduced inertial torque of the fitting} \end{cases} \quad (13)$$

- frequency $f_n = \dfrac{\omega_N}{2\pi} \quad \left[\dfrac{1}{S}\right]$ (14)

- damping factor

$$\xi = \frac{(T_3 - T_A)\omega_N}{2} \text{ where} \begin{cases} T_3 = \dfrac{K_E L + K_V R}{R K_E} \text{ where} \begin{cases} L \text{ inductance of the coil} \\ R \text{ resistance of the coil} \\ K_V = \eta\,\dfrac{D_A l_1}{Z_0} \text{ coefficient of dynamic viscosity} \end{cases} \\ T_A = \dfrac{L}{R} \end{cases} \quad (15)$$

Replacing at the end

$$\xi = \frac{1}{2}\cdot\frac{K_V}{K_E}\sqrt{\frac{K_a - K_{e2}}{J}} \quad [0] \quad (16)$$

- Pulsation of the system:

$$\omega_p = \omega_N\sqrt{1-\xi^2} \quad \left[\frac{1}{S}\right] \quad (17)$$

- Overadjustment

$$-\xi\frac{\pi}{\sqrt{1-\xi^2}} \qquad \sigma = l \quad (18)$$

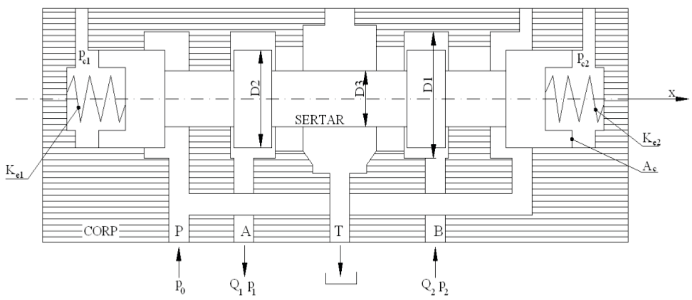
## 5. Evaluation of the sizes of the amplifying stage of servo valves

5.1. **Initial data** before structural dimensioning $p_0$ supply pressure of servo valve; $Q_n$ supply flow; $\Delta p_n$ pressure drop in servo valve; type of $(a^-; a^+)$ coverage $p_i$ threshold of insensibility

5.2. Possible **numerical values**

$$p_0 \cong 3...15 MPa;\ Q_n \cong 25...125\ l/\min;$$
$$\Delta p_n = 7 MPa;\ a^-, a^+ \approx 3...6\ \mu m;\ p_i \cong 1\%$$

5.3. Diagram of calculus is shown in Fig. 4




a) Diameter of the slide valve

$$D_2 = \frac{Q_n}{\pi C_D C_{max}}\sqrt{\frac{\rho}{2\Delta p_n}} \begin{cases} C_D = 0{,}61 & \text{flowing coefficient} \\ C_{max} \approx 10^{-4}\, m & \text{maximum stroke} \end{cases} \quad (19)$$

$$A_C = \frac{\pi D_2^2}{4} \quad (20)$$

**a) Deviation** from the rated size of coverages

It is considered that the deviation which brings about negative coverage $a^{(-)}$ causes a lost flow of 1% from $Q_n$ and deviation is taken into consideration only for edges P – A and P – B.

- Expression of negative deviation is:

$$a^{(-)} = \frac{Q_p}{\pi C_D D_2 \sqrt{\frac{2\Delta_p}{\rho}}}$$ where:

$$\begin{cases} Q_p \cong 0{,}01\, Q_n \\ \Delta p \cong 2\Delta p_n \end{cases} \qquad a^{(-)} \approx 10^{-6} m \tag{21}$$

- Positive deviation is related to the threshold of insensibility

$$a^{(+)} = p_i \cdot C_{\max} \approx 10^{-2} \cdot 10^{-4} \approx 10^{-6} (m) \tag{22}$$

c) Radial clearance

$$J_R = \sqrt[3]{\frac{12\eta Q a^{(+)}}{\pi D_2 \Delta_p}} \tag{23}$$

d) Diameter of the ring slot

$$D_1 = \sqrt{\frac{4}{\pi} \cdot \frac{Q_n}{C_D} \sqrt{\frac{\rho}{2\Delta p}} + D_2^2} \tag{24}$$

e) Diameter of the rod of slide valve

$$D_3 = \sqrt{D_2^2 - \frac{4}{\pi} \cdot \frac{Q_n}{C_D} \sqrt{\frac{\rho}{2\Delta p}}} \tag{25}$$

Methods that can be developed based on the above data may represent a basis for structural and functional development, taking into consideration the characteristics of an appliance in order to know certain information:

- Rated flow which determies rated span
- Supply voltage
- Tipe of coverage which determies sensibility

Group of information about mechanical parameters of the actuated machine part

- Stroke and respectively rotation angle
- Speed and respectively rotational speed
- Force and respectively torque

Group of information about electronic control:

- Adjustment technique
- Type of regulator
- Measurement technique.

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