MODELING OF THE FLOW IN SLIDING CONTROL VALVES

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The functional qualities of hydraulic distribution and control devices included in automatic control and operate hydraulic systems are depended on the qualities and internal flow conditions. The purpose of this paper is the comparative studies of different geometry generated thorugh the modification of the fundamental one.

The definition of the optimal geometrical structure for the spool - housing ensamble is followed by the non - dimensional fundamental equations which descriebes the fluid flow. The equation of continuity, the equations of motion and equation of energy for the defined structure are obtained appealing a COSMOS 386 program to get the numerical solution of flow through the valve. Further on the numerical solution are post processed and numerical valves for a given flow structure results.

The results obtained using specific programs written in TP6 based on the finite element method are described , the values of pressure and field in any point of the flow field also given.

In the second part of the paper on the basis of characteristics curves of the pressure and velocity distribution in the distribution sections, is made o comparision between theoretical and experimental results obtained usinga proportional directional control valve DN10. Considering the Reynolds similitude criteria relevant the results of the comparative study shouws a good concordance of pressure repartition and liquid jet, anticipate by numerical calculationsKeywords: words which are representative for the paper (up to 4 keywords).

Keywords: control valves, mathematical modeling, finit element method, hydrodinamic field

1. Introduction

The qualities of proportional control valves with spools are of greatest importance for the work performance of the whole drive system, both in continuos and transition operation. The rigorous definition of flow characteristics in the cross-section passage depends on the mathematical modeling of the liquid flux. For this purpose the Finite Element Method (FEM) is generally used . The analysis of the numerical results with specific computing programs allows the generalization of results and the possibility to obtain a set of numerical functions to describe the operation for a whole family of similarly control valves.

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differential equations which describe the flow near the spool valve presume the knowledge of some theoretical and practical aspects of the method.

2. The stages of mathematical modeling of the flow

Because it operates with differential equations describing a certain class of physical problems, the stages of mathematical modeling is specific for every investigation domain. It is assumed that for the problem under examination both the analytic model and the FEM model is known, eventually a computing code is also available. The phases of the computing process are the following:

- the selection of the finite elements and adequate interpolation functions;
- meshing with finite elements the analyzed domain;
- the evaluation of elemental matrices;
- the assemblage of matrices and formation of the equations system;
- solving the system of equations and obtaining the numerical solutions;
- numerical or graphic presentation of results.

The selection of finite elements type, respective of the interpolation functions must be performed taking into account the variation of the analyzed parameters (for instance linear, parabolic, etc.), the geometry of the investigated domain and the active memory of the computer used.

The meshing of the analyzed domain means the generation of both the finite elements array and the matrix of connections. The computer implementing of an analogous model with finite elements leads to the formation of some matrices which reflects dynamic properties of the elements. Thereafter follows the assembling of the finite elements upon the investigated domain. This process is done with the connection matrix, using either the elements or the nodes.

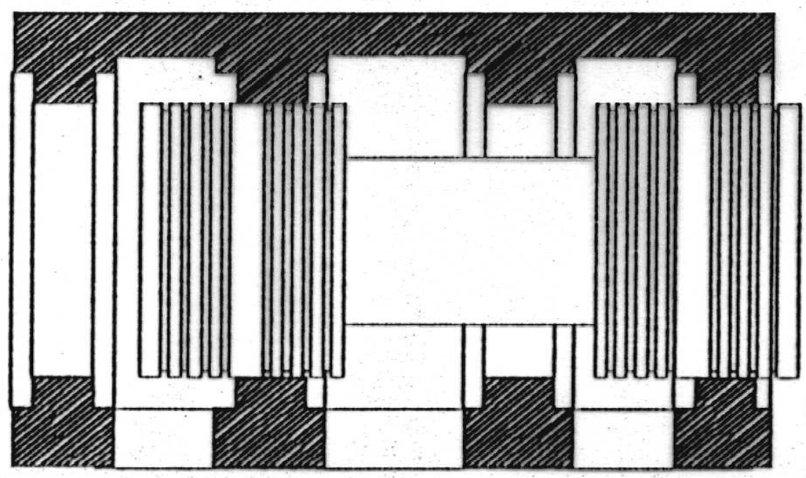


Fig.1 The analyzed control valve. The dimensions of the spool valve

The numerical procedures for solving the systems of equations with finite elements are generally divided into linear and nonlinear ones. The strategy of solving the equations for non-stationary flow are the same as in the case of finite differences.

The hypothesis of potential flow through the de control valve substantially simplify the partial differential equations. Using FEM it was determined the structure of the velocity field (stream lines and velocity distribution along this lines) for an incompressible, non-viscous fluid. The geometry of the valve is presented in figure 1. The flow domain through the control valve is considered axisymmetric. With this hypothesis it is sufficient to study the flow in the domain ABCD of the meridian cross-section yOr, presented in figure 2.

3. Motion equation for ideal fluid in axisymmetric flow

In order to study the axial-symmetric movement of the fluid, a cylindrical coordinates system is used, having the Oz as symmetry axis. The unit vectors of the Frenet trihedral are k, i_r and i_θ, (fig. 3).

The fluid movement is called axisymmetric if the following condition are satisfied:

a). $\text{rot}\,\overline{v} = 0$

b). the movement parameters do not depend of q, so

$$\frac{\partial(\ldots)}{\partial\theta} = 0$$

Consequently it is sufficient to study the movement in the meridian plan q =const.

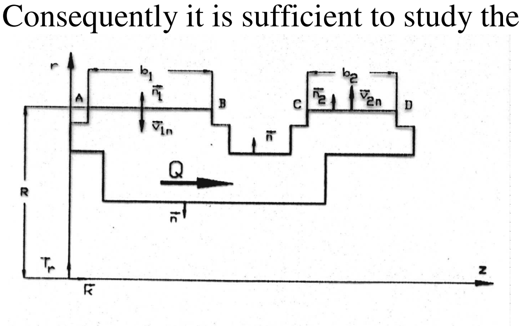


Fig.2. Flow domain

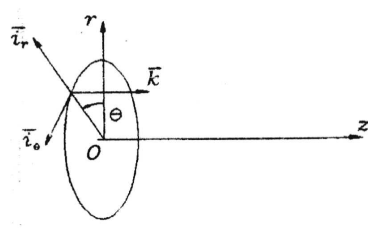


Fig.3.

In accordance with those hypothesis , the continuity equation is :

$$\frac{\partial}{\partial r}(r.v)+\frac{\partial}{\partial z}(r.v_z)=0 \qquad (1)$$

The differential equation of streamlines (L_c) in plane zOr is:

(2)

$$\frac{dz}{v_s} = \frac{dr}{v_r}$$

$$\text{or}: v_r dz - v_s dr = 0 \qquad (2, 3)$$

$$v_{i/i} = v_{r/r} + v_{z/z} = -r.v_{r/r} + r.v_{r/z} = 0$$

Introducing the stream function ψ:

$$\psi = \int \varepsilon_{ij}.v_i.dx_j \qquad (4)$$

in which the following necessary and sufficient condition is satisfied:

$$d\psi = \frac{\partial\psi}{\partial z}dz + \frac{\partial\psi}{\partial r}dr = r.v_{r/r} + r.v_{z/z} = 0 \qquad (5)$$

where:

$$v_z = \frac{1}{r}\frac{\partial\psi}{\partial r}; \quad v_r = -\frac{1}{r}\frac{\partial\psi}{\partial z} \qquad (6)$$

the velocity fields is:

$$v_j = \varepsilon_{ij}.\psi / j \qquad (7)$$

Because the movement is potential ($\text{rot}\bar{v} = 0$), there is a function φ called the velocity potential. The velocity components can be obtained as follows:

$$v_r = \frac{\partial\varphi}{\partial r}; \qquad v_z = \frac{\partial\varphi}{\partial z} \qquad (8)$$

$$v_j = \varepsilon_{ij}.\varphi_j$$

(9)

which verify the identity:

$$\varepsilon_{ij} = v_{j/i} \qquad (10a)$$

The link between φ and ψ is given by the relationship

$$\varphi / i = \varepsilon_{ij}.\varphi_j \qquad (10b)$$

Taking into account the previous relations it can be established the Laplace equation for the stream function:

$$\varepsilon_{ij} v_{j/i} = \varepsilon_{ij}.\varepsilon_{jk}.\psi_{/ki} = -\delta_{ik}\psi_{/ki} = -\psi_{/ii} \qquad (11)$$

and the velocity potential:

$$\varphi_{/ii} = 0 \qquad (11a)$$

From the relation ( ) it can be observed that y = const. are stream lines and the difference $y_a - y_b$ is the liquid flow capacity between two stream lines.

The curves j = const. are orthogonal upon the curves y = const, so that the relationship implies:

$$\varphi_{/i}\psi_{/i} = \varphi_{/r}\psi_{/r} + \varphi_{/z}\psi_{/z} = \varepsilon_{rz}\psi_{/z}\varphi_{/r} + \varepsilon_{zr}\psi_{/r}\varphi_{z} = 0 \qquad (12)$$

The assemblage of the curves family y =const. and j = const. form **the hydrodynamic field of the axisymmetric movement**. Consequently, in order to obtain the velocity is necessary to solve the Laplace equation for j, corresponding to the axisymmetric movement:

$$\frac{\partial^2\varphi}{\partial z^2} + \frac{\partial^2\varphi}{\partial r^2} + \frac{1}{r}\frac{\partial\varphi}{\partial r} = 0 \qquad (13)$$

With the mentioned expressions of the velocity components it can be obtained the Helmholtz equation for the stream function:

$$\frac{\partial^2\psi}{\partial z^2} + \frac{\partial^2\psi}{\partial r^2} - \frac{1}{r}\frac{\partial\psi}{\partial r} = 0 \qquad (14)$$

In the potential axisymmetric movement the stream function y is not harmonic . The complex function having as real part j and as imaginary part y is useless because it is not olomorph.

4. Domain analysis and limiting-conditions

The domain on which the Laplace equation is solved by using FEM is the working chamber of the control valve, defined by the boundaries of two elements in relative movement, namely the control valve body and the cylindrical spool. This elements assure the flow capacity control by modifying cross section passage (the flow capacity is one of the most easy controllable parameter). The motion element is called control element and in our particular situations is the spool. The spool displacement is noted with y, the algebraically sign being conventionally defined. In order to have a referential position for measuring the spool displacement y, it is used a value y_0 named **reference opening**.

In order to specify the limiting-conditions in fig. 2 there has been noted the inlet (the fragment AB of the boundary G), the outlet (the fragment CD of the boundary G), AD and BC being the solid boundaries.

The velocity component perpendicular upon the solid boundaries being zero, the solid boundaries are stream lines. At the inlet cross-section AB and at the outlet cross-section CD the velocity upon normal direction being constant, we have:

a) for j

$$\frac{\partial\varphi}{\partial n} = 0 \text{ ori AB and CD} \qquad (15)$$

b) for y $\qquad\qquad\qquad$ $\psi = 0$, on AB

where:

- Q - the volume flow;

- R - the boundary radii at inlet and outlet;
- b_1, b_2 - the length of inlet and outlet zones.

5. Obtained results

Departing from the identification-interpolation module of the point values it is possible to study local peculiarity in the interesting zones of the flow domain. The plotting of stream lines is now possible, in any interesting zone, specifying interactive the chosen point by digitization. Figure 4 present the obtained streamlines in various interest zones for the analysis of flowing phenomena.

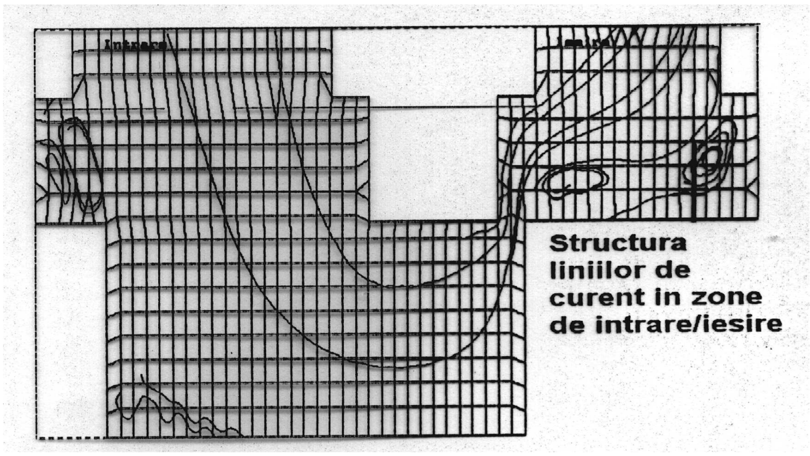


Fig. 4 The obtained streamlines
Intrare-inlet; Iesire- outlet;

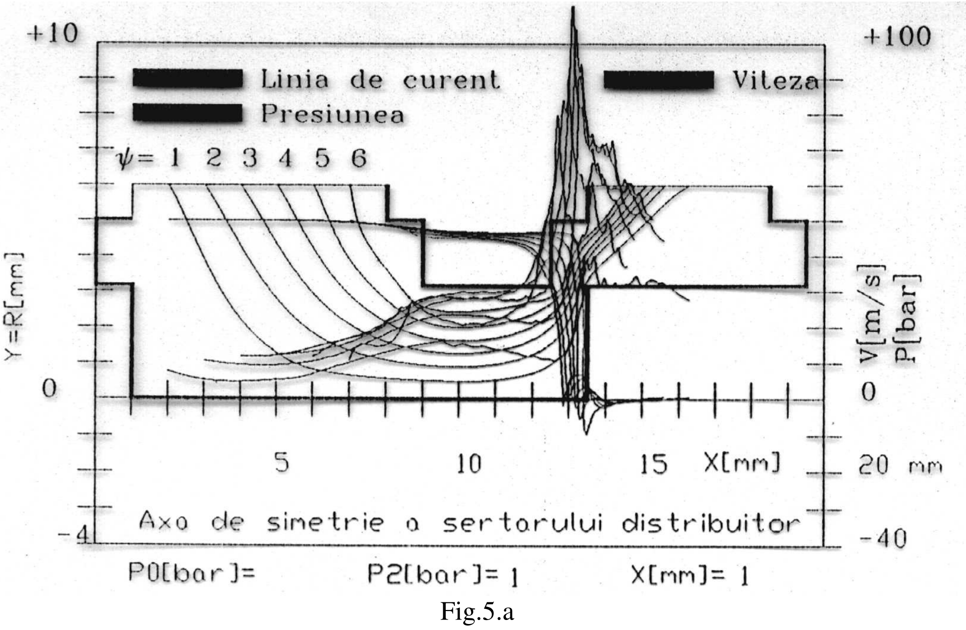
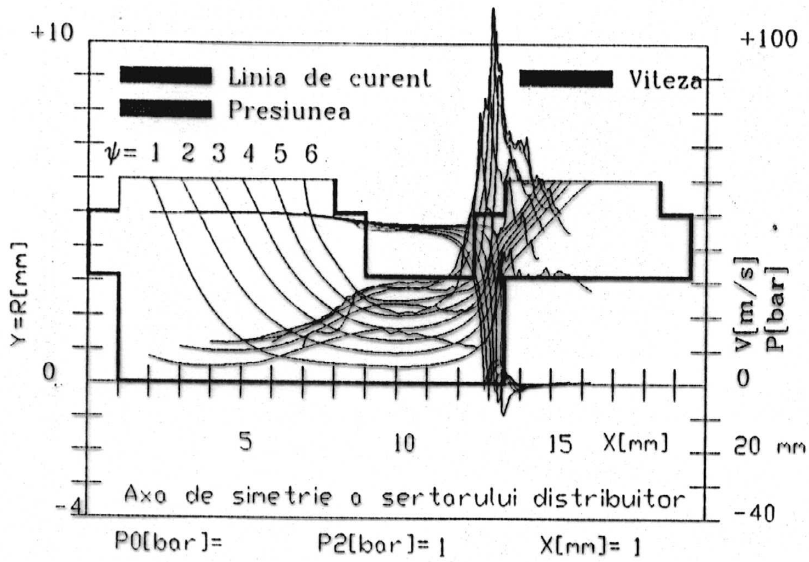


Fig.5.a

The streamlines are individually drawn indicating the first point of the line. Figure 5 gives the pressure and velocities along the streamline. The velocity variation can be also drawn along the streamline in curvilinear coordinates. The future developments foresee especially the increase of the available filters in order to allow comparisons between the results obtained with different programs but also the increasing the interaction precision screen-digitization-operator by describing some working methods in windows and by this way to increase the selection precision (in correlation with the computing power).



Streamline: pressure, velocity; Spool symmetry axis

Fig.5. b

6.Conclusions

6.1. The problem of greatest importance for a good design is the knowledge of the hydrodynamic field inside de working domain of the control valve. This field depends on the liquid physical characteristics (viscosity and density), the running conditions (flow capacity, pressure difference between inlet and outlet cross-sections, temperature), the control valve geometry and the value of the opening determined by the spool position.

6.2. In order to obtain the hydrodynamic field there have been determined approximate numerical solutions for the partial differential equations describing the flow, using computer programs and the finite element method.

6.3. A TURBO PASCAL program was built in order to obtain post-processing results with high quality and great precision. From the numerous obtained data have been retained the numerical values of significance for the hydrodynamic and cavitation phenomena in control valves.

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