ANALYSIS OF ELECTRO-RHEOLOGICAL FLUID IN HYDRAULIC SYSTEM

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Abstract Use of intelligent materials has been a more widespread technology in the last ten years in the area of research and development of mechatronic equipments. It's main reason is that some problems of the utilization needed such a solution, which couldn't be solved only with new materials produced by material texture modification.
A claim has come up in the research of the mechatronical systems to develop materials that can get and understand an information from a computer and change their attribution accordingly. The connection, what we can establish between the computer and material, sets a limit to the quality characteristics that can be operated by the computer. This transposal can be ensured by effects that's induction and abolition rate can be compared or the control is bigger just as the velocity of the change of a material characteristic. From a control technology viewpoint using electric or magnetic field is the most obvious.
One group of these materials is electro-reologic (ER) liquids that change their shear strength according to the electric field. The flow qualities of the ER liquids can be continually changed inside certain borders, with orders of magnitude shorter interval from the previous hydraulic solutions. Making an opportunity by to create faster controlling and regulating systems from the present ones.
The main aim of this work is the modification of basic properties of this kind of liquids and specification of its utilization possibilities in mechatronic systems such as hydraulic control equipments. Mathematical model as well as its numerical solution of a flow control valve (ER valve) as an appropriate element of hydraulic systems has been prepared during this work. Function tests of this unit have been carried out by computer aided simulation of the above mentioned mathematical model.

Keywords *Electro-rheological, Flow control, Hydraulics, modeling*

1. INTRODUCTION

The ER phenomenon as a material model is described by the Bingham model related to ER liquids, which is based on the mathematical model describing the non-newton liquids [3]. The Bingham model is a complex viscoplastic rheological model [1]. As a material model it can be divided into an ideally ductile an ideally viscous member [7]. (Fig. 1)

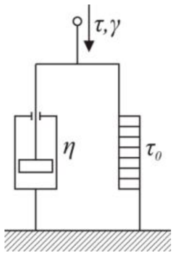

Fig. 1. The Bingham model

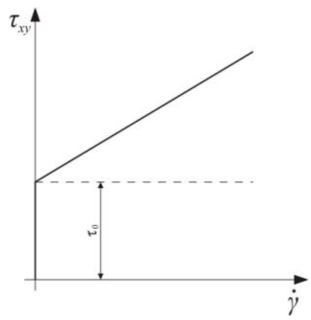

Fig. 2. The shearing tension in the function of shearing gradient

1.1 Research objectives

The aim of testing of the flow properties of the ER liquids is to establish a model, which can be generally applied of testing the behaviours of ER liquids made of different materials considering the phisycal data of the applied materials. By computer simulation the parameters of this mathematical model can be determined, which can be generated by minimum search. As the first step of the model identification the approximate search of the minimum of the established target fuction is accomplished by genetic algorithm, then the refinement of the result with the known numerical methods.

2. THE APPLICATION OF THE FLOW REGULATOR

During the further material and application tests it is practical to use a device which has application possibilities too. In this consideration for further investigations we need the design of a hydraulic ER valve, which can be operated built in hydraulic circuits.

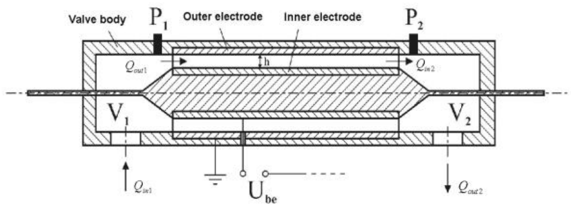

Fig. 3.: The ER valve

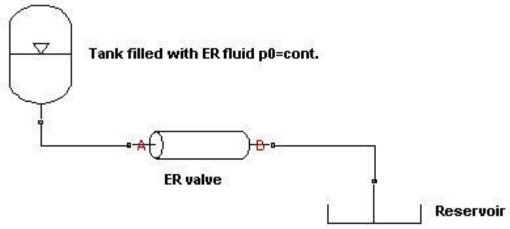

Fig. 4. The conceptual diagram of simulation

1.2 Applied Mathematical Model

The flow rates which go in and out the valve can be determined by the following equations:

$$Q_{in1} = \mu \cdot A_1 \cdot \sqrt{\frac{2 \cdot (p_0 - p_1)}{\rho_f}} \quad (1) \qquad Q_{out2} = \mu \cdot A_2 \cdot \sqrt{\frac{2 \cdot (p_2 - p_3)}{\rho_f}} \quad (2)$$

Where μ is the coefficient of flow loss, p is the pressure and ρf is the density of the liquid. On the basis of the incoming and leaving flow rates the balance (differential) equations are the followings:

$$Q_{in1} = \frac{V_1}{E_f} \cdot \frac{dp_1}{dt} + Q_{out1} \quad (3) \qquad Q_{in2} = \frac{V_2}{E_f} \cdot \frac{dp_2}{dt} + Q_{out2} \quad (4)$$

In equations (3) and (4) the Ef is the bulk modulus of the liquid. The flow rate between the electrodes is:

$$Q_{out1} = Q_{in2} = \frac{L \cdot \Delta p_N}{12 \cdot \eta \cdot b \cdot h^3} \quad (5)$$

In equation (5) L means the length of the electrodes, η is the ER liquid's dynamic viscosity, b is the inside circumference of the electrode, h is the size of the gap between the electrodes. The pressure drop of the liquid flowing through the ER valve is composed of two parts: the first part is resulted by the liquid's ideal viscid behavior (Δp_N); the second part comes from the electric field (Δp_{ER}). Hence by the right of Bingham-model the pressure drop is [5] [6]:

$$\Delta p_{12} = \frac{12 \cdot \eta \cdot L \cdot Q_{out1}}{b \cdot h^3} + \frac{2 \cdot L \cdot \tau_{ER}}{h} \quad (6)$$

The size of τER depends on the ER liquid's physical parameters and the electric field:

$$\tau_{ER}(t) = \alpha \cdot E^{\beta} \cdot \left(1 - e^{-\frac{t}{T}}\right) \quad (7)$$

In the equation (6) the α and the β are parameters, the T is the time constant. The value of the time constant depends on the applied electric field too. With the above equations the behavior of the ER valve can be described .

1.3 The Numerical Solution of the Applied Mathematical Model

The solution of the mathemetical model of the ER valve was accomplished by MATLAB with block–oriented method, using Kelvin-Thompson return-circuit principle [2] .

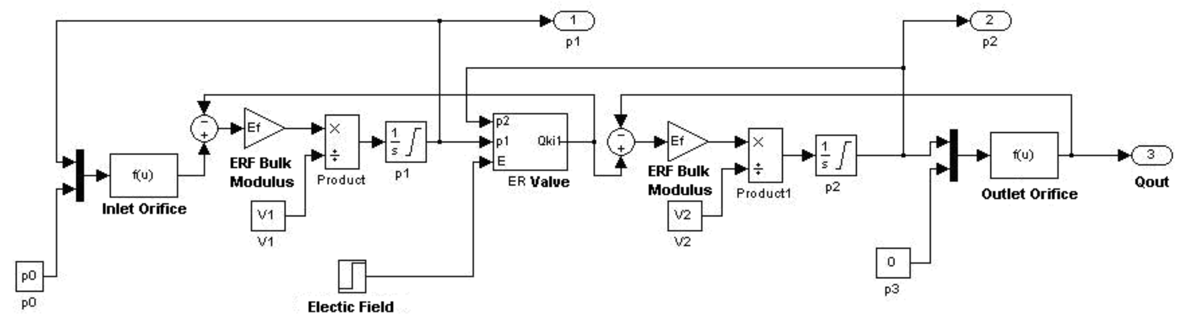

Fig. 5. The block diagram of simulation

With this method the volume, which was evolved by the constant pressure difference, put on the ER valve can be measured. In this layout the the liquid volume can be controlled by electric field strength. With this we can create a hydraulic valve, which without moving parts, can be controlled by the application of eletric field. It can be seen from the measurement data of the professional literature [4], that for the evolvation of the effect it is enough (2-10) ms, which is a much smaller value, that the indication time of the proportional valves applied nowadays.

3. THE RESULTS OF OPERATION OF THE MODEL

In Chart 6 at making the simulation results we applied 6 bar inlet pressure.

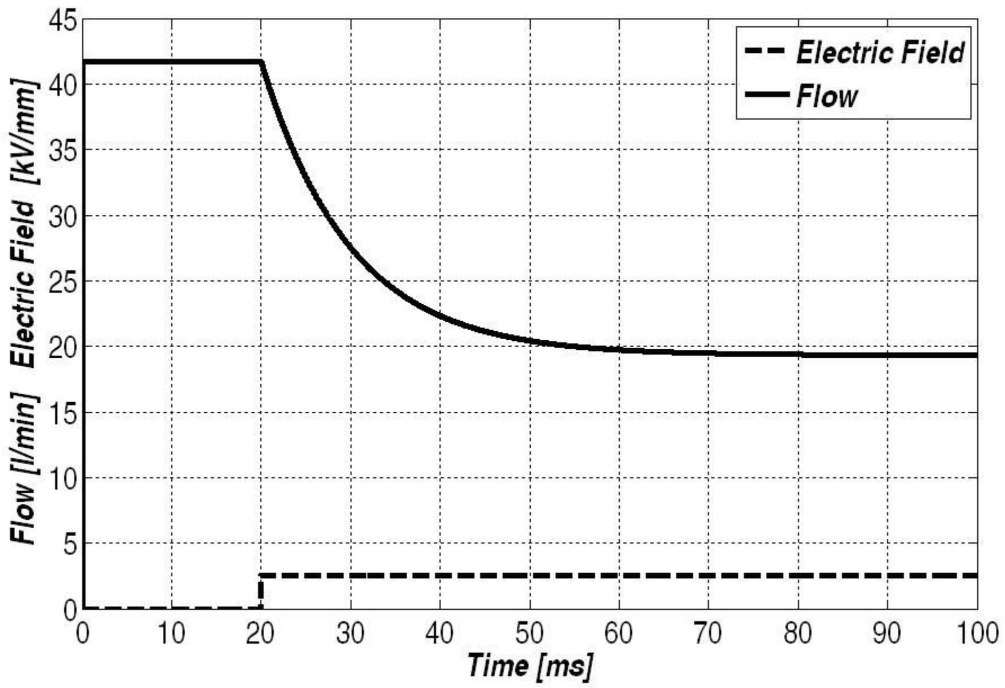

Fig. 6.

As it seems on the figure 6. the flow is 42 l/min up to 20 ms, then by switching 2 kV/mm electric field the streaming flow decreases to 18 l/min in 40 ms.

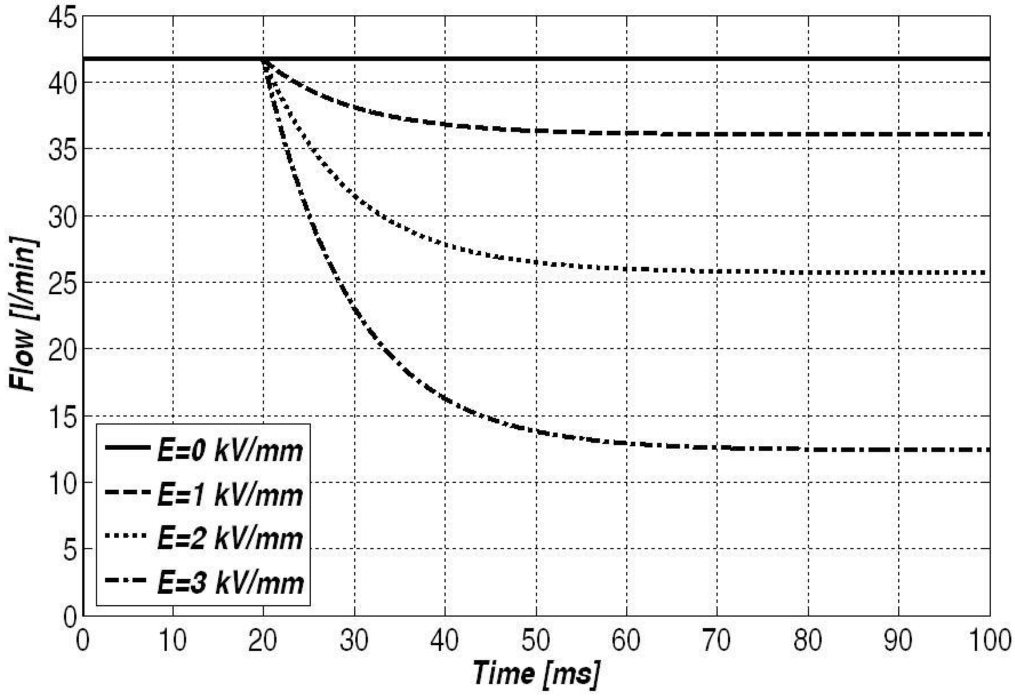

Fig. 7.

At the simulation in the figure 7. constant 6 bar inlet pressure (p0) was used. It is shown that how the flow changes at various size electric field.

4. EXPERIMENTAL SYSTEM AND RESULTS

The system consists of three main parts, like: the hydraulic power unit, ER circuit, data acquisition and control system. The hydraulic unit ensures the flow of ER fluid by a driving servo cylinder. The ER valve with flow meter and the pressure difference meter are fitted into the ER circuit.

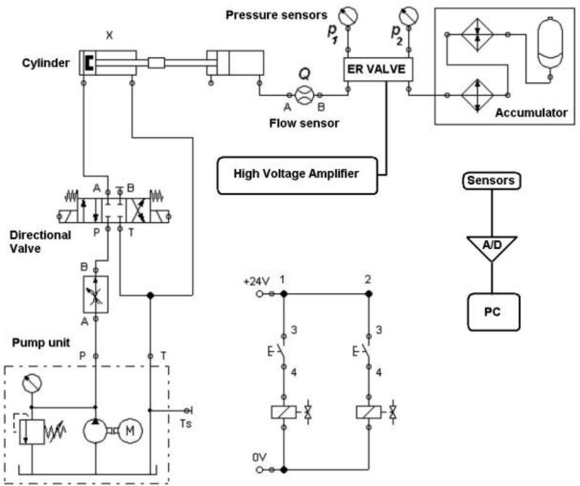

Fig. 8. Experimental setup

Fig. 9. Experimental setup (picture)

1.4 Results

The pressure difference required by the ER fluid to flow was ensured by a bladder-type accumulator had been pre-charged up to 6 bar before the experiment. The change of shearing stress of the fluid was determined by the equation of 6 from the pressure difference and the fluid flow rate after the electric field was switched on.

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The Fig 10 shows the change of shearing stress of the ER fluid (line) influenced by the change of electric field of 8.2 kV/mm. The measure of orifice of applied ER valve is h = 0.5 mm, the length is l = 200 mm, the potential is U = 4.1 kV. The broken line shows the result of simulation made by the mathematic model introduced before.

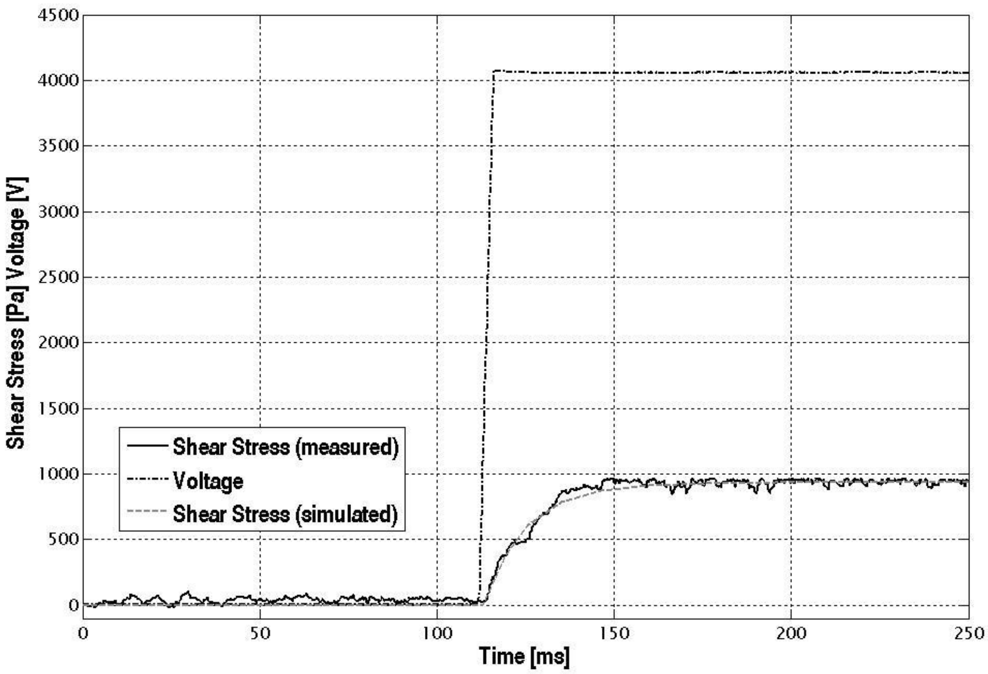

Fig. 10. The results of simulation and measurement

5. CONCLUSIONS

On the basis of simulation experiments we can assume that the above introduced ER valve can be applied in hydraulic systems. Certainly this concept has to be further tested in term of application technique, such as the wear-effect of the particles of the used ER fluid and the temperature dependency of the ER effect. Since the developed flow control valve doesn't containg moving parts and it can be controlled by external electrical field, thus, in theory, the probability of mechanical failures can also be decreased.

REFERENCES

1. Csizmadia B. – Nándori E. (szerk.): Modellalkotás, Nemzeti Tankönyvkiadó, Budapest, 2003.
2. Dr. Farkas I.: Számítógépes szimuláció. Gödöllő, 1999.
3. H.-G. Lee – S.-B. Choi: Dynamic properties of an ER fluid shear and flow modes, In: Materials and Design, 2002., XXIII. évf.
4. Valasek I. – Auer J. (szerk.): Kenőanyagok és vizsgálataik, Tribotechnik Kft., Budapest, 2003
5. Seung-Bok Choi, Dong-Won Park, Myoung-Soo Cho : Position control of a parallel link manipulator using electro-rheological valve actuators. Mechatronics, Volume 11, Issue 2, 1 March 2001, Pages 157-181

6. S. B. Choi, Y. T. Choi, E. G. Chang, S. J. Han, C. S. Kim: Control characteristics of a continuously variable ER damper. Mechatronics, Volume 8, Issue 2, March 1998, Pages 143-161
7. Zrínyi M.: Intelligens anyagok, Magyar Tudomány, 1999., 6. sz., 682.

