DYNAMIC CONTROL OF PNEUMATIC ACTUATOR SYSTEM

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Abstract: *Pneumatic actuators are among the most used non-electric drive systems. The cost, simplicity of control and mechanical structure are some of the advantages they impose. The main disadvantage of this type of drives consists in unable control of intermediate positioning and dynamic movement. The paper also presents a hybrid drive system, with the actuator pneumatic piston and magnetorheological element for control. This drive system allows complete control of piston displacement and movement dynamics. We also present the experimental results obtained in order to determine the parameters of magnetorheological element for different operating modes.*

Keywords: *unconventional drives, pneumatic, magnetorheological, dynamics*

1. INTRODUCTION

A. Pneumatic actuator

A pneumatic actuator mainly consists of a piston, a cylinder, and valves or ports. The piston is covered by a diaphragm, or seal, which keeps the air in the upper portion of the cylinder, allowing air pressure to force the diaphragm downward, moving the piston underneath, which in turn moves the valve stem, which is linked to the internal parts of the actuator. Pneumatic actuators utilize compressed air to generate the operating energy. These actuators are quick to respond, but are not ideal for environments under high pressures, as gas is compressible. Because of the compressibility of the working environment, pneumatic pistons allow displacements only between extreme positions (zero displacement or maximum displacement), so we cannot achieve partial displacements. Also, the dynamic movement is heavily dependent on the pressure and flow rate of the working and load.

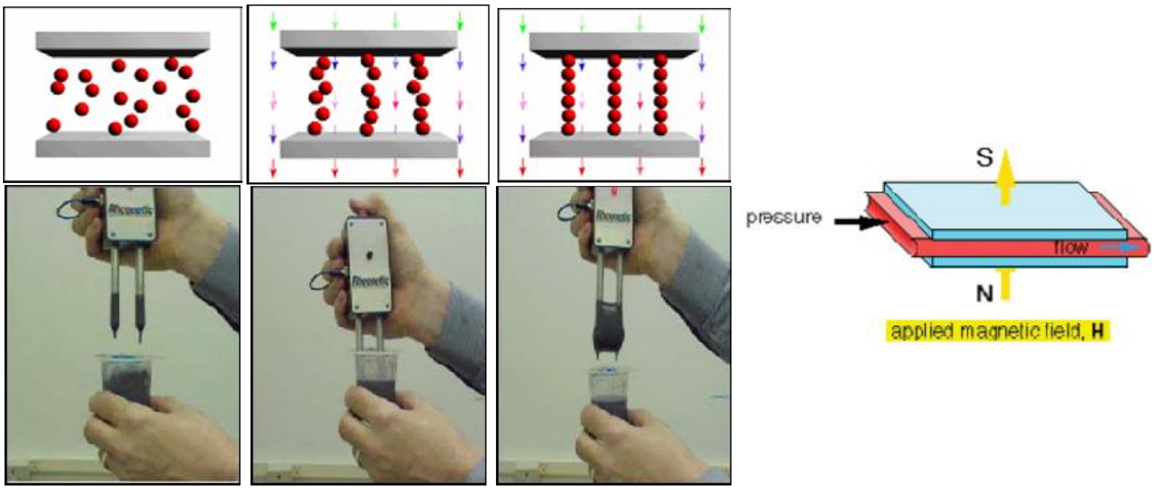
B. Magnetorheological fluid

Magneto-rheological (MR) fluids, generally consisting of small magnetic particles dispersed in a liquid, are material systems whose rheological properties are controllable through the application of an external magnetic field (Fig.1 (a)). Under a high magnetic field, the magnetic particles have been observed to aggregate into elongated clusters aligned along the magnetic field direction. This macro-structure is responsible for the solid like rheological characteristics and is hereby denoted the ground state of the MR fluids at the high field limit. One of the main applications is the stop-valve (Fig.1 (b)).

C. Stop-valve

Since the phenomena occurring during flow of viscous rheological fluids are very complex and difficult, for mathematical modeling is necessary to determine the experimental parameters, global descriptive rheological stop-valve.

Mathematical models proposed for fluids, applied to rheological systems go from ideal operating premises and therefore cannot fully describe a real system.



(a) (b)

FIG. 1. Magnetorheological fluid in a magnetic field (a) Magnetorheological stop-valve

Therefore part of the system parameters must be approximated on the basis of preliminary experiments.

Thus for a system with valve-stop depending on the type and size of valve, the constructive rheological parameters are determined experimentally. The mathematical model that describes the behavior in electrical and magnetic field will be based on them.

2. HYBRID DRIVE

A. General description

The paper presents a hydraulic cylinder which is divided in four rooms interconnected with the pressure generator and the MR valve.

For the assurance and the control of the pressure from the cylinder rooms, a generator of controlled pressure built around of a MR stop-valve is used (Fig. 2)[7].

The pressure P (maximum admitted by system) is transmitted in a controlled manner to system through a MR stop-valve. The system consists of the tank with gas under pressure 9, the lines of pressure between tank and cylinder 7 and 8, the double piston 4 and the stop-valve with MR 3. The cylinder 4 is divided transversal in 4 identical rooms by the piston 6. Each among these is divided in two parts by a piston which can displace across cylinder. MR fluid can be found in both central rooms that communicate with the MR valves through pipelines 5. In the rooms from the ends of cylinder gas can also be found and trough the valves; these communicate with the tank with gas under pressure 9 by the pipelines 7 and 8, or they can free the gas in outside cylinder trough other valves.

We suppose the movement is accomplished on the left. Therefore pressure is released in pipeline 7 from the tank of pressure 9. Consequently the piston 6 is displaced on the down. Due to this movement the volume of the MR liquid from internal cylinder is modified and it appears as a circulation of the liquid between cylinder and valve MR 3. This depends on the applied magnetic field which controls the movement piston; it may or may not modify the fluid volume in the room. The movement in opposite direction is analogously made after the release of the pressure of the gas from the rooms by cylinder.

B. Description of MR valve

The magneto-rheological liquids are intelligent smart fluids which modify their physical and chemical properties under the magnetic field action. We modify the fluid viscosity under the influence of the magnetic field. One of the main applications of this effect is the structure of stop-valve.

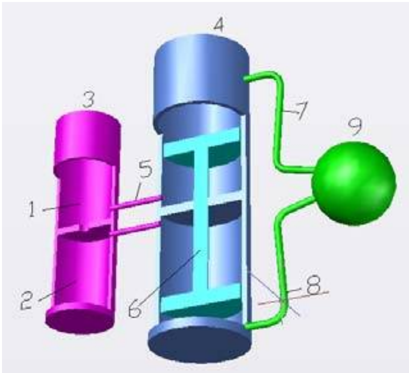


FIG. 2. The hybrid drive – schematic

A stop-valve consists in two lateral walls in which the sources of magnetic field can be found. If the liquid which flows among electrodes is a MR type, then the pressure decreases longitudinally and thus, the difference of pressure on the admission valve or the flow can be controlled through the intensity variation of the applied magnetic field.

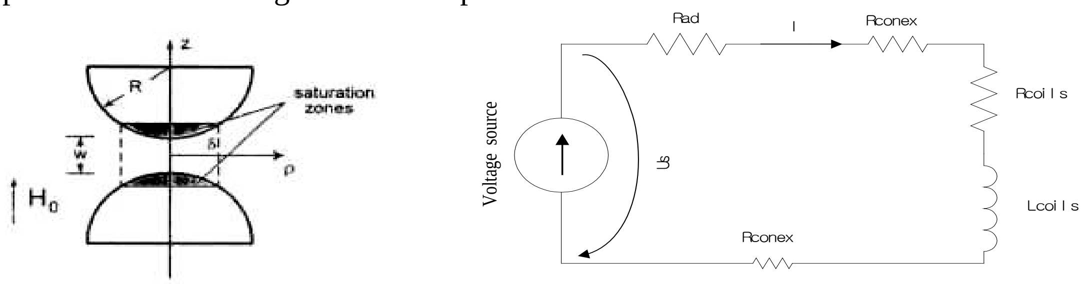
The net advantage of this type of admission valve consists in a gradient type control of the resulted pressure. Because the dynamic model must describe the fluid viscid flow (which presents non-Newtonian flow) and because it differs substantially from one geometric valve’s model to another, as well as depending on the type of fluid, the difference of pressure on valve according with the intensity of the magnetic field is experimentally determined establishing a tabular correspondence.

3. PROBLEM SOLUTION

A mathematic model for applications and a physical platform for determining stop-valve parameters have been created [1] [2] [3] [4].

Considering that the fluid is an one-dimensional type and that the strength of body and convection effects are negligible, when applying conservation we obtain a differential first degree differential equation between viscosity gradient and axial pressure gradient.

The solution of this equation leads to a linear distribution of viscosity, independent of the type of material existing between the poles.



(a) (b)

FIG. 3. Stop-valve MR parameter (a), Simple control circuit (b)

When the material has a characteristic viscosity gradient, such as MR fluid, it will flow until the resulting pressure gradient will increase to a level that it becomes greater than the dynamic viscosity opposition. In this case, the critical pressure gradient, amplitude, for fluid flow is:

$$\left|\left(\frac{dp}{dx}\right)_c\right| = \frac{2\tau_y}{h} \quad (1)$$

If the pressure gradient is equal to or greater than this critical value, and the fluid in the immediate vicinity of the stimulant poles, where the apparent viscosity maximum, we will have all conditions for the fluid to flow. Near the center, where the apparent viscosity is identical to zero, there will be an area with non-active material, characterized by an uniform axial velocity similar to that of free flow. Its modifications in pressure tubes (based on the formula of d'Arcy for circular tube) are

$$\Delta P_{short\_pipes} = f\frac{l}{d}\frac{\rho}{2A^2}Q^2 = \frac{64}{\mathrm{Re}}\frac{l}{d}\frac{\rho}{2A^2}Q^2 = \frac{K}{K_1}Q^2 \approx K_{\Delta P}Q^2 \quad (2)$$

l - length of tube [m] d - inside diameter of tube [m] - fluid density [kg/m^3], A - area of the tube section [m^2]; Q - flow rate [m^3/sec] f - friction factor ; Re - Reynolds number or the most frequently used form (meaning the change of nozzle or valve):

$$Q = \pi d\Delta x\sqrt{\frac{2}{\rho}}\sqrt{\Delta P} \quad (3)$$

After calculations we obtain:

$$\frac{d}{dt}\left(\frac{\Delta Q}{Q_0}\right) + a_1\frac{\Delta Q}{Q_0} = a_2\frac{\Delta H}{H_0} \quad (4)$$

where

$$a_1 = \frac{12\eta}{g^3 w\rho} - \frac{Q_0}{A^2 wgL} \quad a_2 = \frac{\alpha cm}{g\rho Q_0}H_0^m \quad (5)$$

Using relationship between the magnetic field intensity and the number of spiral coil we obtain

$$\frac{d}{dt}\left(\frac{\Delta Q}{Q_0}\right) + a_1\frac{\Delta Q}{Q_0} = a_2\frac{\Delta I}{I_0} \quad (6)$$

The structure of the most simple control circuit includes a source of current / voltage with additional resistors and coils:

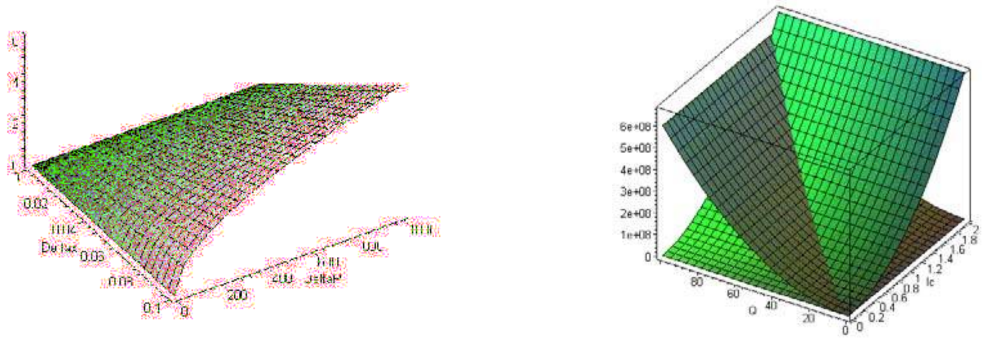
$$\left(R_{ad} + R_{conex} + R_{coils}\right)I + L_{coils}\frac{d}{dt}I = U_s \quad (7)$$

To simplify the electrical circuit, resistance winding with the auxiliary connections can be neglected in comparison with Rad. Using the same technique, with the equivalent circuit that has a dynamic system of order we have:

$$\frac{d}{dt}\left(\frac{\Delta I}{I_0}\right) + a_3\frac{\Delta I}{I_0} = a_4\frac{\Delta U_s}{U_{S0}} \quad (8)$$

where

$$a_4 = \frac{U_{S0}}{I_0 L_{coils}} \quad a_3 = \frac{R_{ad} + R_{conex} + R_{coils}}{L_{coils}} \approx \frac{R_{ad}}{L_{coils}} \tag{9}$$

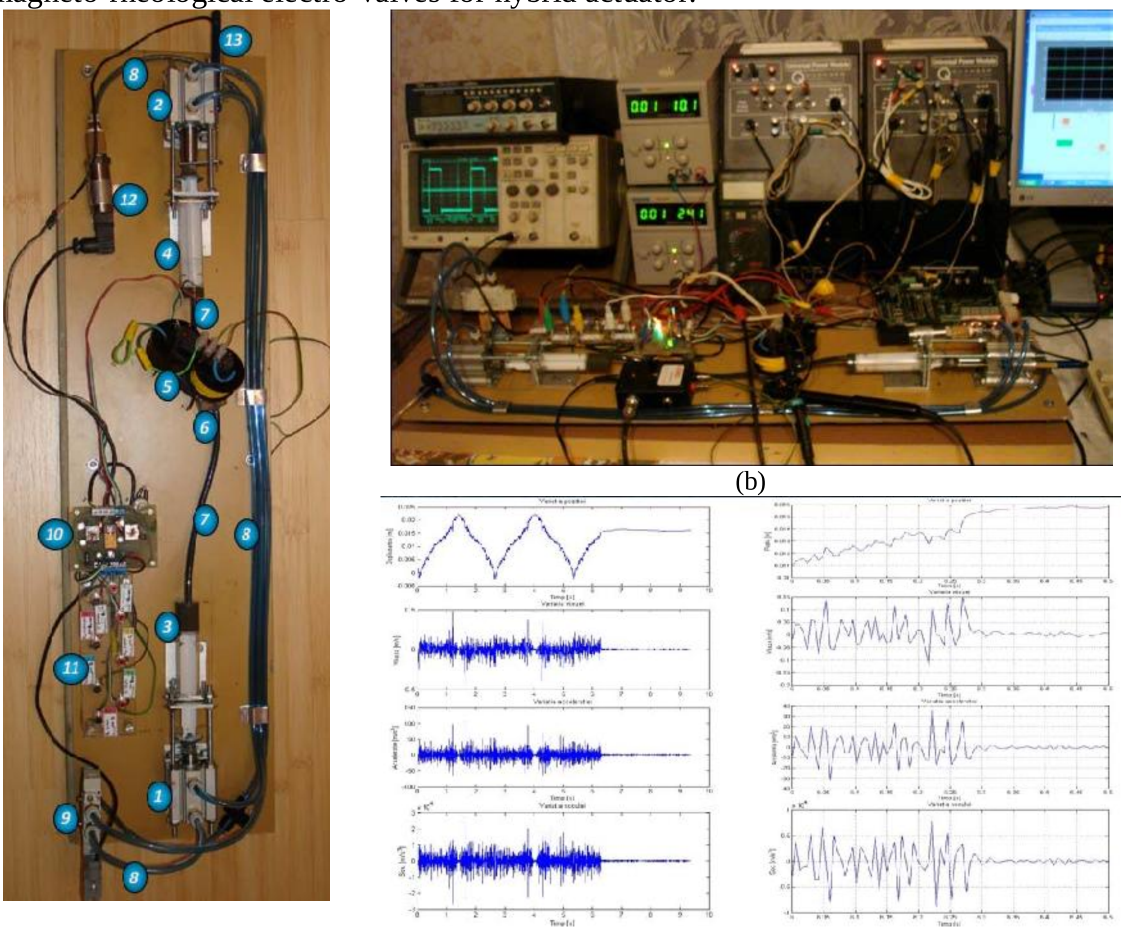


(a) (b)

FIG. 4. Changes in pressure tubes (a), Dependent flow of intensity magnetic field (b)

4. EXPERIMENTAL STAND

The presented platform is designed to determine the experimental parameters of magneto-rheological electro-valves for hybrid actuator.



(b)

(a) (c)

FIG. 5. Experimental stand (a) (b), Experimental results - stop-valve parameters for step signal (from up to down: the displacement, the speed, the acceleration, the shock; evolution and detail from left to right)(c)

As a concept, the platform is composed of a block which moves rheological fluid, the block which generate the excitation field and the MR electro-valve [5][6]. The experimental stand is shown in figure 5 (a)(b).

Block 1 is composed of two pistons, both with the same shaft, a pneumatic piston and a hydraulic piston. The pneumatic plunger has the role of motion generator, while the other piston trains the magneto-rheological liquid. The second block has a similar construction and operates the same way. I have to mention that the movement is generated only in one of the blocks 1 or 2 at a time. Therefore a block has the role of motor, the other having the role of a generator. These are in series to the block 3 - the magneto-rheological stop-valve. Electro-valve energy may be influenced by the utilization of an electromagnetic element composed of a framework for ferrite winder - block 4. The command is given for the both pistons in a positive or negative direction of the axis. By applying magnetic field to the electro-valve MR we control the speed of MR fluid. The final result depends on ~~of~~ the speed of movement of the rheological fluid, which ~~is~~ also depends on the power energy which generates the magnetic field.

The order of displaced pistons from blocks 1 and 2 is done by the electro-valve with pneumatic drawer - block 5. Depending on its supply voltage (0V and 24V) a movement is generated for pistons from block 1 and block 2).

By using PC with a Simulink algorithm command and by interfacing the computer with the platform, the acquisition board from Quanser system is used. The order stand is made by Quanser acquisition system using a PC. Control laws are implemented through a custom Simulink Quanser model. This model allows modeling of the voltage generator excitation control according to a law implemented and the process repeated a sufficient number of times to obtain average values of the parameters real valve.

CONCLUSIONS

The presented actuator has a simple construction having all the features of a pneumatic drive. The motion control is precise by using the stop-valve MR. Only a little volume of MR fluid is used in the circuit controller of pressure.

Although mathematic modeling can be difficult and although it depends on the actuator model and on the used material, it can easily establish a tabular correspondence for sizes that we concern, using experimental methods.

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