MR haptic joystick in control of virtual servo drive

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MR haptic joystick in control of virtual servo drive

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Abstract. In the paper the one-axis haptic joystick is proposed and described. This joystick utilizes a magnethoreological (MR) brake in order to obtain operator movement opposite force which creates feedback force. The MR brake investigations results are shown. The designed and built joystick was then connected to the computer, and used to control of prepared in Matlab/Simulink software, virtual model of electrohydraulic drive. The main equations describing this drive were shortly described. Finally the investigations stand and some results are presented.

1. Introduction
The development of computer systems enabled the creation of so called Virtual Reality (VR) environment. In this modern technology new devices used for human-computer interaction have to be applied. Applications of such technology encompass computer games, training and rehabilitation devices, minimally invasive surgery devices, teleoperation, steer by wire devices and many others. In most of these applications visual and sound signals are used by the operator as a feedback. However, it would be advantageous, to have additional feedback like feeling of the force, produced by the controlled device [1, 2, 4]. Thanks to it, the operator will have the illusion of being in direct contact with this device. The answer is a haptic device which can act as a coupling between the human sense and the controlled object. One of the most commonly used haptic devices, are joysticks. They are present on the market since more then 10 years [2, 4]. Such joysticks can be successfully applied also in communication with virtual environment giving human operator filling of the force generated by virtual drives.

In the paper the joystick with force feedback used to control of virtual electro-hydraulic servo drive is proposed. In this joystick, a brake able to produce electrically controllable movement opposite torque is applied. Unique properties of magnetorheological (MR) fluids enable to design such brakes. The paper presents the construction of joystick in which such a brake is applied. The virtual model of the electro-hydraulic drive and its connection to the joystick is described. Some aspects of control of electrohydraulic servo drive with joystick which uses MR fluid, are also shortly considered.

2. Joysticks with MR brakes
In the investigations we designed and build a joystick with MR brake (figure 1). This brake utilizes the shear mode. Its housing is movable and the rotor has to be fixed. The coil is placed in the middle of the rotor and its connection wires are placed in the middle of the rotor shaft. The torque M_o generated by an operator is in balance to the opposite torque produced by the joystick, exactly by the MR brake. The Laplace’a transfer of its output torque can be described as follows:

$$M_d(s) = c_{d0} \cdot [s \cdot \Phi(s)] + \frac{c_{d1}}{R_d(T_d s + 1)} U_d(s) \tag{1}$$

where: M_d – joystick brake torque, Φ – angular rotor position, c_{d0} – viscosity damping coefficient (by absence of magnetic field) [N·s], c_{dl} – gain coefficient of the MR effect damping moment [N·m/A], U_d – supply voltage, R_d – brake coil resistance, T_d – total brake time constant.

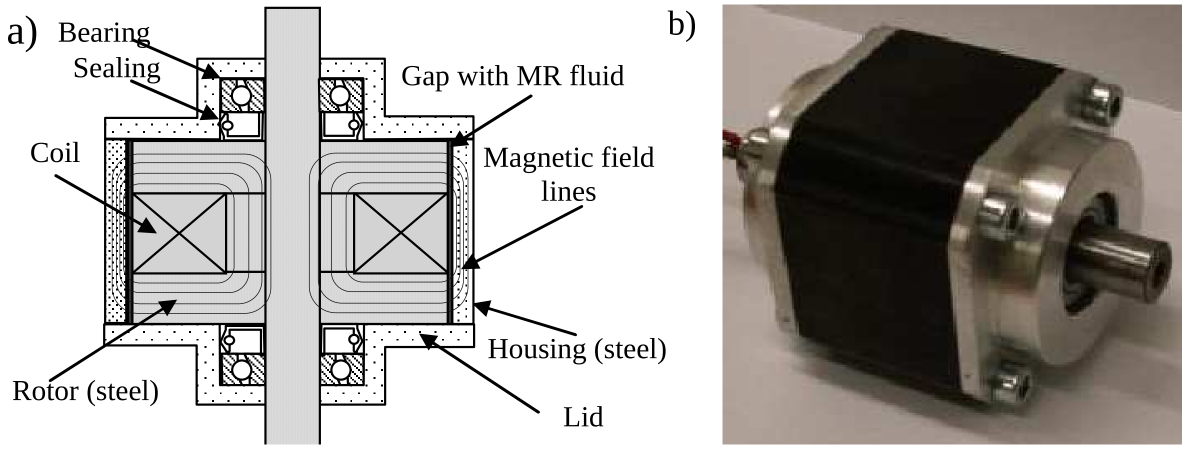

Figure 1. Design of MR brake and its photo.

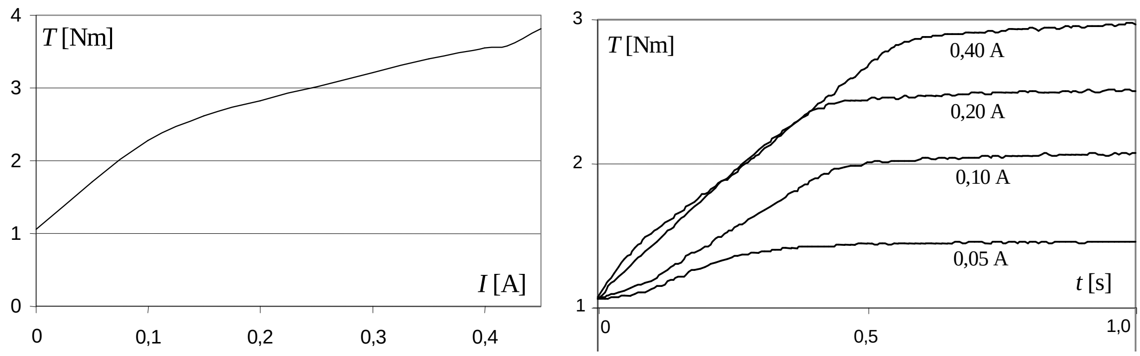

Figure 2. MR brake static and dynamic investigation results.

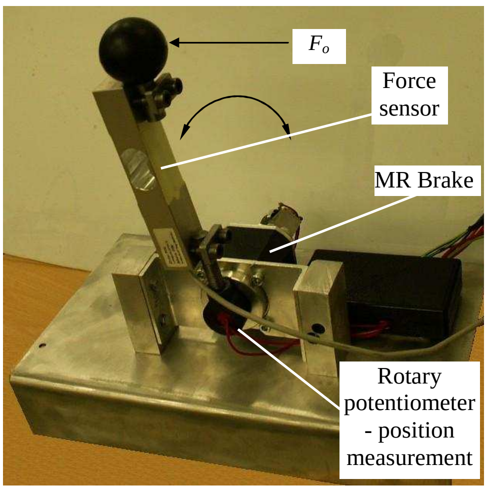

Figure 3. Joystick with MR brake.

In this equation the first component describes the non-magnetic behavior of the brake. Torque produced in this mode is proportional to the angular velocity. The second component is controlled by external signal (voltage U_d) and characterizes the brake output torque as a result of MR fluid properties changes in magnetic field.

In figure 2 investigation results of built by us MR brake are shown. The static torque reaches about 3.5 Nm when the coil is supplied by current equal to 0.4 A. However, the obtained by switching on a supply voltage, brake time constant is rather long and can be estimated at about 0.5 s.

The one axis joystick prepared for investigations is shown in figure 3. The position of its rotary arm is measured by rotary potentiometer. The joystick arm is created by tensometer transducer what enable the measurement of the force produced by an operator.

3. Virtual model of the hydraulic drive and its connection to the joystick

Electrohydraulic servo drives are widely used in many technological machines and devices [3]. Electrohydraulic drive consists of servo or proportional valve, hydraulic cylinder, position measure unit and a controller. The valve is usually regarded as a second order system. We assumed that in the drive proportional valve is used, which is described by following transfer function [3]

$$G(s) = \frac{x(s)}{U(s)} = \frac{200}{s^2 + 230s + 10000}, \tag{2}$$

where valve damping coefficient ζ_z = 1.15, natural frequency ω_z = 100 Hz and gain coefficient k_z = 0.02 (x – valve spool displacement, U – valve coil supply voltage) were specified basing on data taken from hydraulic proportional valve producer catalogue. The circuit: hydraulic amplifier-hydraulic cylinder was described as third order system (oscillatory element placed serial to an integrator). This system was described by transfer function taken as follows [3]

$$G(s) = \frac{y(s)}{x(s)} = \frac{15936437}{s^3 + 80s^2 + 159822s}, \tag{3}$$

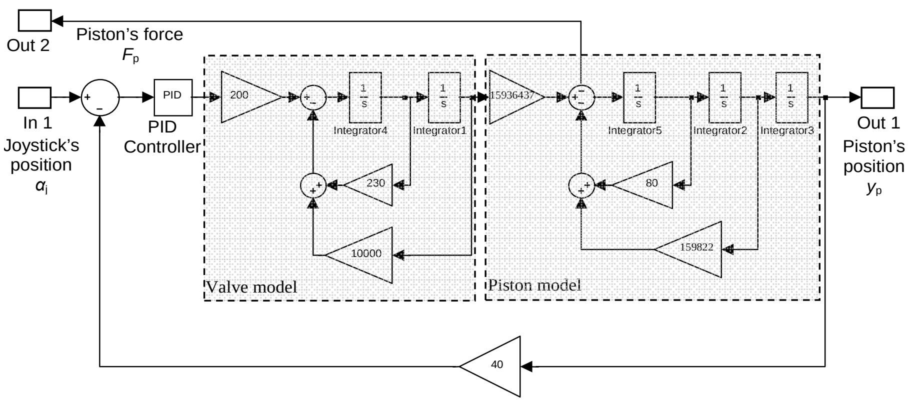

Figure 4. Hydraulic servo drive simulation model.

where y is the piston rod displacement. The parameters in this equation were calculated for following data: cylinder piston area 0.01 m^2, amplifier flow coefficient 1.0 m^2/s, dynamic friction coefficient 40 000 Ns/m, movable mass 500 kg and oil bulk modulus 10^9 Pa.

Basing on equations (2) and (3) the model was prepared in Matlab/Simulink software (figure 4). The drive model can communicate with the real word (here: joystick) by input and output: In 1 and Out 1 and 2, which are assigned to input/output card ports.

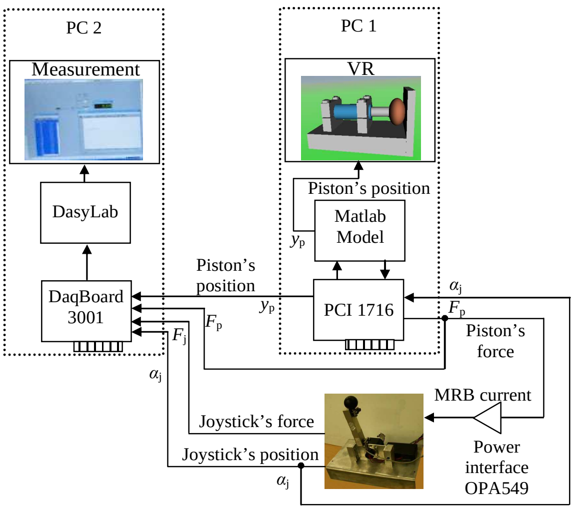

Figure 5. Measurement and investigation system's block diagram.

We used Virtual Reality Toolbox (VRLT) in Matlab software to present the movement of the cylinder piston rod and additionally to connect the joystick position measure element (In 1) and MR brake coil amplifier to the computer and to the virtual model (Out 2). In system described in this article we used as an output a servo-cylinder piston displacement signal. Available in VRLT VR Sink includes 3D library of different objects and graphic interface of the user combining simulation with virtual reality. However there are no hydraulic elements in a library and authors had to draw the hydraulic cylinder by themselves. The electrohydraulic servo drive was controlled by PID type regulator.

To the presented in figure 4 simulation model an artificial load (spring) was added. In our investigations we used two functions to describe this spring: linear $F_l = k_l \cdot y$ and non-linear $F_l = k_l \cdot y^2$. We also implemented a simulation of contact to a stiff wall, meeting and then shifting of a mass.

In figure 5 the block scheme diagram of investigation stand is shown. During the investigations we used two computers. The first of them (PC1) was used as VR system on which basing on Matlab/Simulink and VRLT, virtual reality environment is implemented. In this computer input/output card type PCI-1716 was installed and used to connect the VR model to haptic joystick output (potentiometer) and to its input (MR brake coil amplifier). The second computer (PC2) was used to collect data. In this computer the input/output card type DaqBoard 3001 was installed which was used to connect the signals taken from the joystick and the computer.

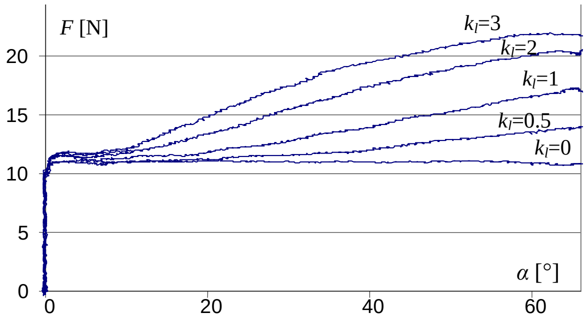

Figure 6. Results of simulation: joystick force in function of joystick angle for linear spring load.

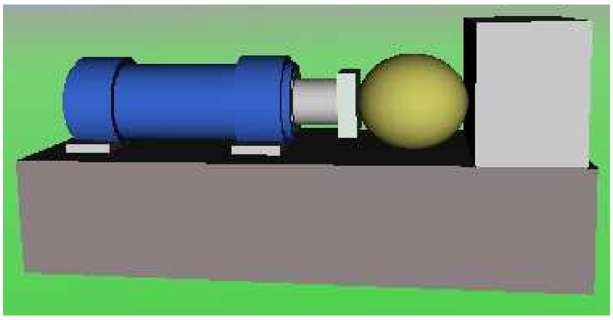

Figure 7. View of the VR screen.

In figure 6 the recorded, during virtual sphere squeezing, joystick force signal is shown. Figure 7 presents the screen of virtual reality system. The operator can watch the movement of the piston and the deformation of the virtual sphere. The force signal from the model was used to control the brake coil, thus the operator was able to feel this force on a joystick arm. As one can see, the force increases in function of joystick arm angle, what confirms the force feedback in a joystick.

4. Conclusion

The paper proposed one-axis joystick with MR brake which enable force feedback to communicate and interact with a virtual model of servo drive. The joystick was connected to the prepared virtual model of a drive. During the movement, the piston squeezed an artificial sphere. By the usage of MR brake in joystick, the impression of being in physical contact to the virtual drive and its environment was given to the human operator. Thanks to this, the operator-model interaction is more realistic.

Acknowledgments

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