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MODELLING OF SERVO-DRIVE SYSTEM WITH HYDRAULIC "MULTI-PISTON" MOTOR

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ABSTRACT

The great progress in computer hardware and software technique and technology changed the way of new product designing. It concern not only new designing tools like CAD/CAM programs but also a new approach to creation process. Additional stage of work appeared - the computer modelling. It helps us to find out mistakes at the very beginning. The computer modelling helps to understand real physical process in machinery and verify the construction.
The complexity of computer models depends on destination and programs possibility. It is possible to base model on physical equation and law, which are written in classical form of differential equation. Nevertheless, it is not easy to find model of hydraulic motor which presents the conversion of oil pressure to torque.
In paper authors present their experience in modelling of servo-drive system with hydraulic piston motor with MATLAB/SIMULING software use. The result of simulation and real tests are compared and discussed.

KEYWORDS

Computer modelling, hydraulic system, hydraulic piston motor

1. INTRODUCTION

The great progress in computer hardware and software technique changed a way of new product designing. It concerns not only new designing tools like CAD/CAM programs but also a new approach to creation process. Additional stage of work appeared – the computer modelling. Before real scaled model could be prepared for investigation the computer model should be built and tested. Preparing such model, we have to systematize and verify our knowledge on system and understanding it [1]. It helps us to find out mistakes at very beginning and therefore save a lot of time and money. The computer modelling helps us to understand real physical processes in machinery and to verify used equation and relations. This can be used in designing control systems, especially automatic ones. The modelling is particularly important for designing heavy machineries, which are rather expensive. There are many special devices which are designed only for one application. The special sensors net and feedback controlled subsystems and systems are needed for them. The computer model allows us to simulate and investigate the future machinery behaviour under various work, load and surrounding conditions. For this reason the computer simulation is the most efficient way to gain some experience.

The complexity of computer models depends purpose and programs capability.

Many computer programmes not only calculate values of equations but they can solve differential equations. It is possible to use the equation and law of classical physics, which are written in differential form in time domain.

There are many computer models of hydraulic plants with actuators description in various literature. They allow to analyse oil pressure and flow. However it is not so easy to find model of hydraulic motor which concentrate on conversion of oil pressure to torque. Most of models are too simplified with omitting some important phenomena like for instance the friction problem or motor movement instability.

In the next parts of this paper the model of hydraulic system with piston motor will be presented. This model was built with the use of MATLAB/SIMULING. This software is very common and it is often used for students teaching and training. In this paper the special attention is paid to the basic relation between torque, pressure and liquid flow especially in the hydraulic piston motor and servo-valve. The phenomenon of friction in valve and piston are taken under consideration and its influence on simulated system behaviour is presented. The result of simulation and real tests are compared and discussed.

2. HYDRAULIC CIRCUIT MODEL

The well known and quite common hydraulic circuit what can be found in many basic books is presented in Fig. 1.

It consists of tank with oil, pump, valve and motor which are connected with pipe. For technical-hydraulic description of running process we use values like pressure and flow in special points (especially on the input /inlet/ and output /outlet/ of these elements) [1–3].

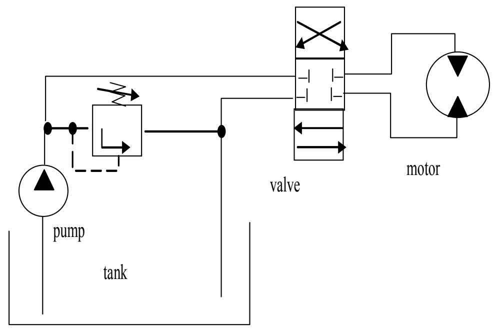

Figure 1. Typical hydraulic circuit

When we start to build computer model we would like to have a such model which mirror the shape and connection of physical object. But in real object we have one pipe and at least two important values inside, which are pressure and flow for our first approach. For some others purpose we can add temperature, density etc.

In modelling we can treat those values as a signals which pass through elements and parts of circuit.

Some methods of modelling enable us to show the transformation of signals. An example of such model is presented in Fig. 2. We have three blocks and three signals. Two signals: F (force from Load) and p (oil pressure form pressure supplier) enter into the Actuator and they are transformed into signal "v" speed of piston movement.

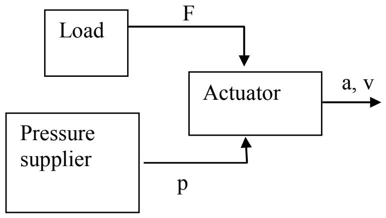

Figure 2. Simplified model of hydraulic system with signal transformation

It is a very simple model, but the mathematical description for real system can not be so simple. The "v" (speed) is the result of "a" (acceleration) integration. This acceleration depends on F (load) and p (oil pressure) on the actuator input (inlet). But this pressure in turn, depends on pressure losses in the pipes. These losses are connected with oil flow, which is proportional (roughly) to piston movement speed – "v".

Therefore, if want to find the speed we have to use quite complicated implicit function like [4]:

$$u = f(a,c,u) \tag{1}$$

Its means that value of *u* depends on itself

This problem can be solved by the usage of more sophisticated model (presented in Fig. 3) with some kind of feedback signal [4].

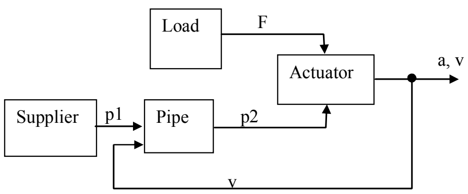

Figure 3. Model with back-loop structure

Additionally in computer simulation the calculation is made in discrete time domain. It allows to use the just calculated values (in the previous cycle) as the (semi-actual) input value. For short time interval the difference between values in the following cycles should be small, so the mistake coming from this method is negligible, and the equitation is much easier to be solved. So the eq.1. can be replaced with:

$$u_n = f(a_n,c_n,u_{n-1}) \tag{2}$$

The usage of such method allows replacing complicated relation with quite simple one. It is possible to build a model of full hydraulic drive basing on simple physic laws and equations.

In the Fig. 3 we can see that the pipe is represented by block, which has two inputs and one output. However if we need the value of flow in the pipe, we will need another output from this block.

So, the (natural) 'one input – one output' block which represents the pipe (in Fig. 1), should be replaced with 'two input – two output' block: one pair: input/output for pressure and another pair for flow.

The example of the inner of such block is presented in Fig. 4.

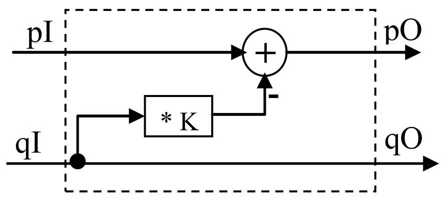

Figure 4. Exemplary inner of pipe modeling block

In the similar manner we can model each hydraulic block with adding some inputs and outputs for other kind of values (signals) like: mechanical – speed and torque (for motor), electrical – current (for electrically controlled valves).

This approach to each element of the system gives us following advantages:

- makes the modelling much more simple,
- results with homogenous model of system,
- makes available all required values in their pure forms,
- enables usage of basic laws and rules for model building.

There are many programs which can help us to design and model systems. Some of engineers prefer to write simulating program themselves using such common use software as C (Builder), Pascal (Delphi).

3. SUBJECT OF MODELLING

3.1. Modelling matter

Described model is a shortened version of hydraulic drive of mini-excavator. This excavator was prepared for special use and very low stable speed rotary was needed [5]. The idea was to use typical driving system with slow rate radial piston motor which was supplied with oil though electronically controlled servo-valve. The encoder – (the senor of rotation angle) was the only sensor that could be used as a feedback signal source [6].

As it was said at the beginning the analysis of system behaviour was required for better understanding and modelling. Model was used for control system design and algorithm analyses. This methodology was much more effective and cheaper than starting with real tests.

3.2. Task Analyses

The aim of this modelling was to build regulator which increase speed rate (rate the maximum to minimum stable speed) and makes this drive system more accurate. It was assumed that this widening of stable speed range would be achieved by lowering lowest stable speed given by producer. The lower stable speed should affect higher positioning accuracy. For this reason, a model which includes all necessary elements (such as: regulators, supplier, pipes, motors and load, which shows motor running at slow movement speed) was needed.

There are few important problems to be solved before modelling begins. The first one is to choose parameters which would be treated as the primary and parameters which would be treated as derivate. In real device all parameters influence each anthers. And changes stop when the device reaches the state of balance. It means that all load forces and torque are balanced with forces produced by oil pressure. The flow of oil affects on pressure drop. The pressure which appears on hydraulic supplier output depends on oil flow resistance. When this resistance decreases, the flow rises but it is limited by pump's features. The kinetic parameters like position speed and acceleration, are related to dynamic parameters (forces and torques). Of course some simplifying assumptions can be done, for instance:

- constant output power of hydraulic supplier,
- linear relation between pressure drop and oil flow through the hydraulic pipes (for expected flow rate).

3.3. Model of System

In this paper the model built in Matlab environment is presented. It is quite common software which is very often used by students and engineers. The MATLAB environment with SIMULINK graphic interface is a quite efficient tool for such challenge [7–9].

The general scheme of proposed model is shown in Fig. 5.

There are following blocks which represent main functional elements of hydraulic drive system: position and speed regulators, hydraulic supplier, hydraulic drive, gear (coupler), load, position sensors for motor and load. The structure of this model can be changed with switches' set-up. All this blocks can be developed deeper – to a more detailed structure, right down to the simple mathematic function, like relation between pressure drop and flow, piston position in relation to motor shaft angle, etc. This structure enables modification of model in details of particular blocks, without any needs of changes in other parts. All dynamic relations are modelled (described) with use of the differential equations in time domain. This way was chosen because it is most natural for average engineers and it is also easier to analyse and to make direct comparison with results of real experiment.

It is one more of advantages of this software. If good methodology is taken you can develop elements separately replacing them with more sophisticated version.

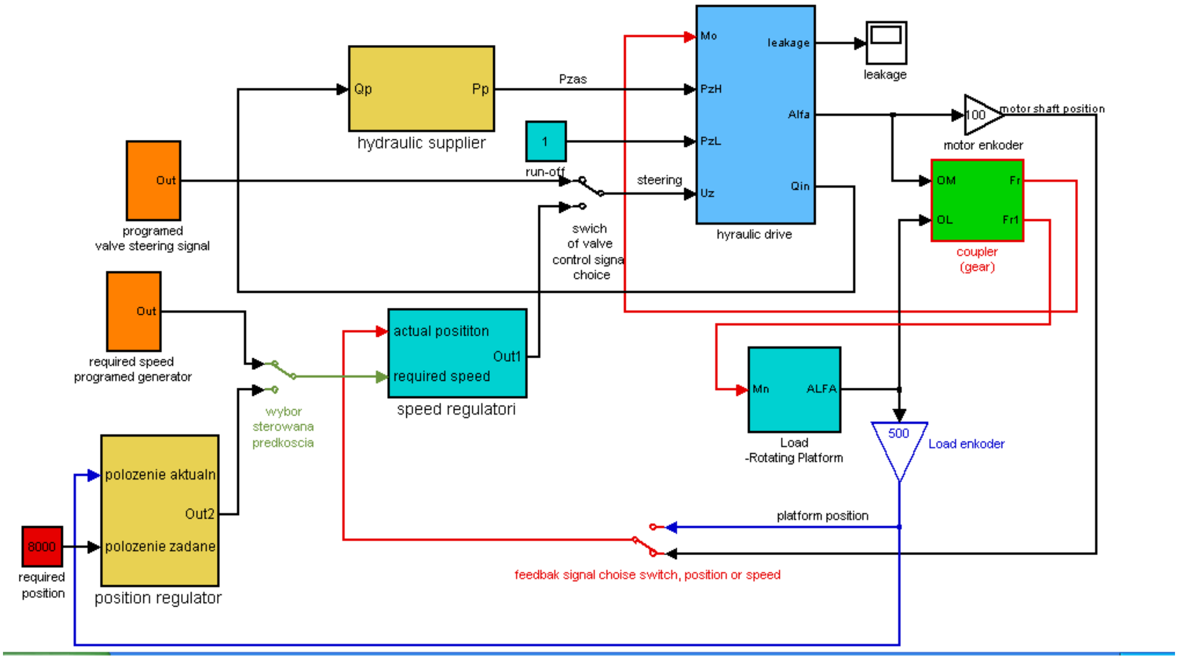

Figure 5. Hydraulic driver system

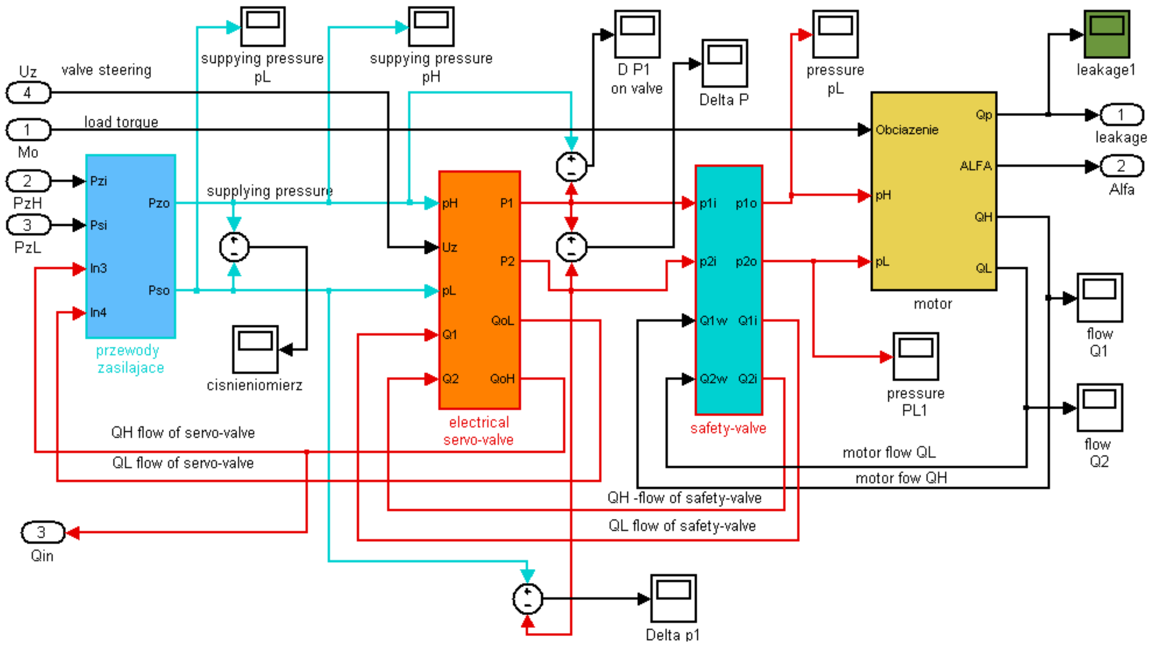

Figure 6. Drive block “inside”

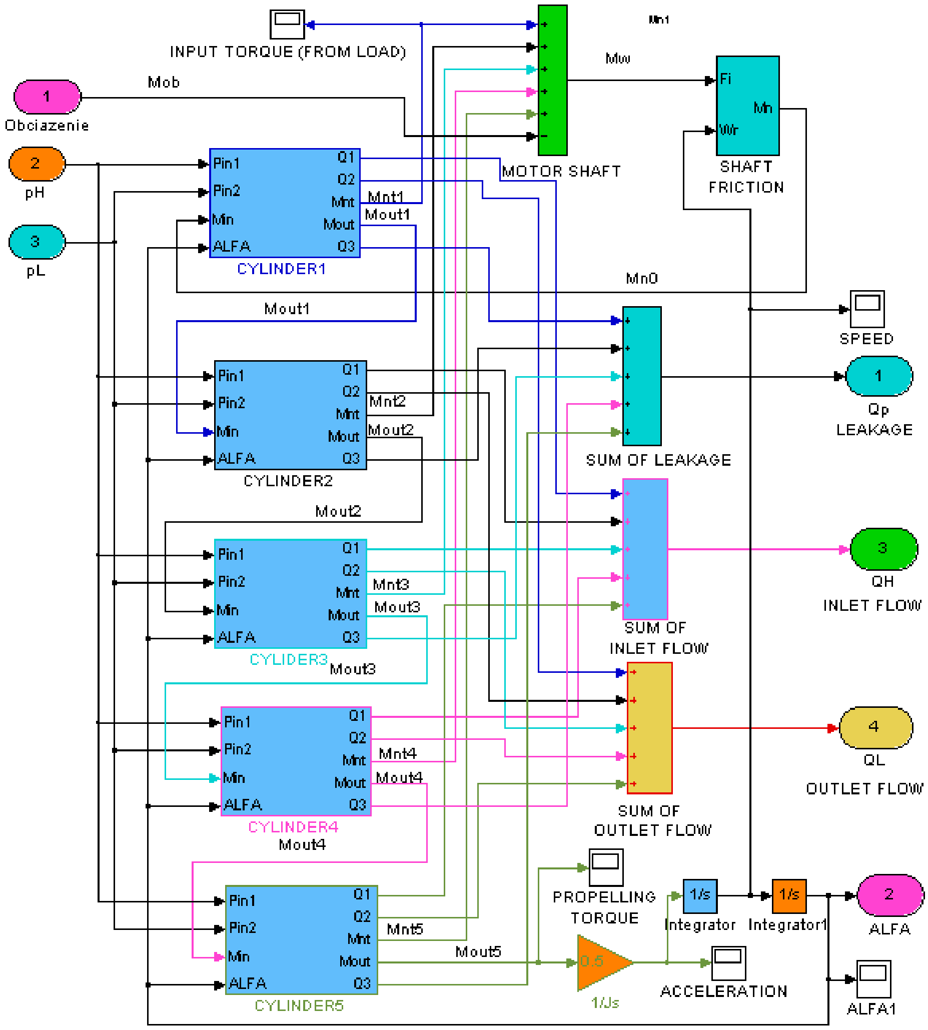

Figure 7. Model of radial piston rotary hydraulic motor

The most important part of this model is hydraulic drive. The revealed driver block is shown in Fig. 6.

The inlet and outlet pressure, and load torque are the inputs signal, and the position (angular) of motor's shaft and flows of inlet and leakage are the output signals. The motor rotation angle is given to gear block, from where it gets input signal of motor load. In simplification the difference between motor load and propelling piston forces (and torques) cause acceleration of pistons and shaft. Their speeds changes, and changes motor flows.

3.4. Model of piston motor

The main element of hydraulic drive is a hydraulic motor. The main problem in piston motor modelling is a coexistence and co-operation of linear and rotation movement. The linear movement is converted to rotation and vice versa.

For instance the force created by pressure in one cylinder, affects on movement all pistons and the shaft of this motor. So it has to overcome friction forces which appear there. Of course motor rotation can be also caused by external torque.

Another problem is lack of multiple valued function which defines shaft position in relation to piston displacement. There are two shaft angular positions for almost all piston positions. But a such relation exists in opposite direction. It is very easy to calculate piston position basing on shaft rotation angle.

The model of motor which considers these inter-actions is presented in Fig. 7.

This model consists of identical blocks of motor's cylinders. Inputs of these blocks are: shaft angle, supplying pressure, propelling torque. Outputs are: flows, torque generated in this cylinder and propelling torque. All torques created in cylinders are summed with external load, and result the torque which propels all piston and shaft. So this torque is given to the input of first cylinder. It is passing through this cylinder but it is decreased by value of piston movement resistance and inertia forces. Result of this is passed to next cylinder input and so on to the last cylinder and farther to the shaft. The remaining torque affects shaft acceleration. Integration of it gives speed and again shaft angle.

The shaft position is one of motor output signals. It is given to gear block where the position of load is given as well. The outputs of this block are: load torque (which is given to motor input) and propelling torque (passed to load input). This model considers backlash between cogs. When difference of motor and load position exceeds backlash the cogs are strained and reaction forces appear. The created torques is proportional to radius of cog-wheels. Motor's and load's torques are in relation which corresponds to gear rate.

4. SIMULATION RESULTS VERSUS REAL TESTS

The proposed way of modelling appears very effective. The results of simulation are in high accordance with real test findings. An example of simulation and real test for changes of servo-valve coil current for both directions is shown in Fig. 8. The result of simulation and real test for constant servo-valve current is shown in Fig. 9. We can see that the characters of both registrations are similar.

The difference between simulation and real tests arise from different time interval-simulation time was much shorten than real tests, so, we can notice the stroke movement instability.

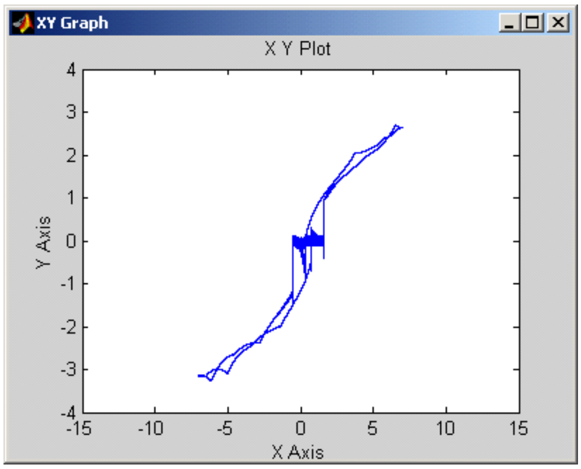

Figure 8. Simulation result for control current linear changes from 0mA up to 10mA, next down to –10mA and back to 0mA

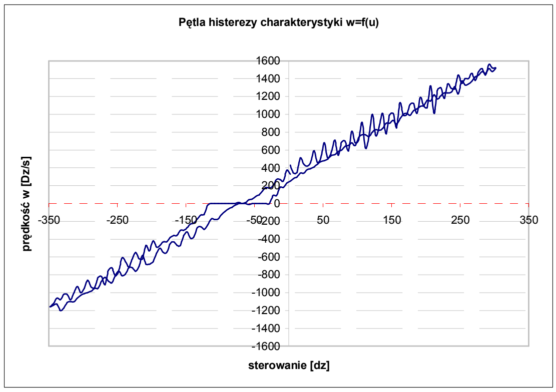

Figure 9. Real tests result for control current linear changes from 0mA up to 10mA, next down to –10mA and back to 0mA

The next picture (Fig. 10, 11) shows result of simulation and real tests for stable movement with constant valve control current.

We can observe high similarity between them. The difference is connected with gear fault (non centric) which was simulated in the next step.

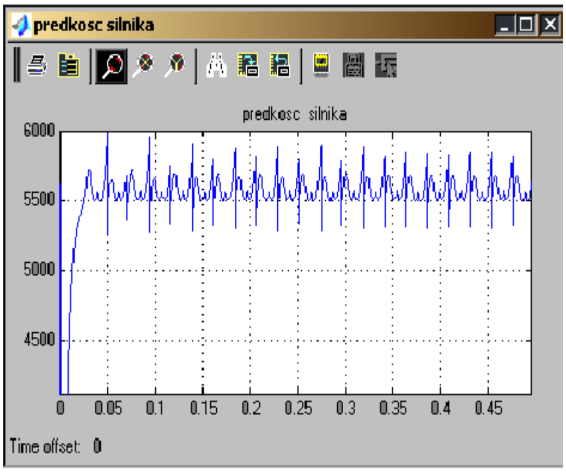

Figure 10. results of simulation for constant value of valve's coil current

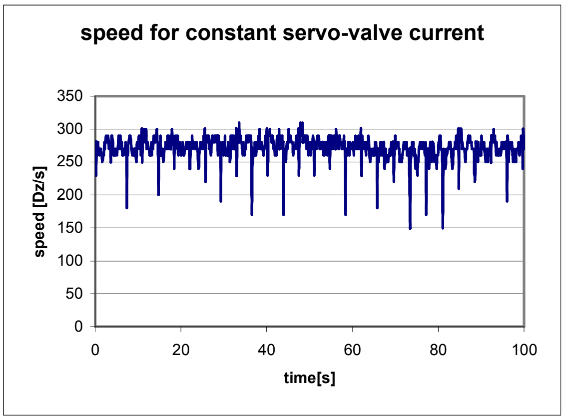

Figure 11. Results of real tests for constant value of valve current

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