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A METHOD TO INCREASE THE ACCURACY OF THE MATHEMATICAL MODEL USED TO HYDRAULICALLY ACTUATED MECHANICAL SYSTEMS

Assoc.Prof.Dr. Eng. Niculai HAUK
Interdisciplinary Regional Research Centre in Vibro-Acoustic Pollution and Environmental Quality
„Dunarea de Jos" University of Galati

ABSTRACT

In order to achieve mathematical models describing hydraulically driven mechanical systems are taken into account both consumer behavior and characteristics of power sources and hydraulic circuits. The variable resistance of hydraulic circuits is very difficult to describe in mathematical terms. On the one hand intervenes the complexity of geometry of hydraulic devices and on the other hand some parts change their geometry over time. This paper presents a method for evaluating the hydraulic resistance as time-varying functions, starting from the geometry changes in fluid bodies.

KEYWORDS: hydraulic resistance, hydraulic distributor, numerical integration

1. INTRODUCTION

For driving various types of machinery are used speciale hydraulic schemes They must ensure both the functional aspects and the technical and economic. Figure 1 shows a partial hydraulic diagram of a Hydraulic Excavator.

The scheme includes:

- A variable flow hydraulic pump;
- A pump control system;
- The consumer - the hydraulic cylinder;
- A protection system to limit maximum work pressure;
- Three-way hydraulic directional valves with open center;
- Pipes and hydraulic hoses conected by special fasteners.

All these hydraulic elements are opposed to product flow of the hydraulic pump. The hydraulic resistances cause pressure drops which means energy loss and decreases efficiency.

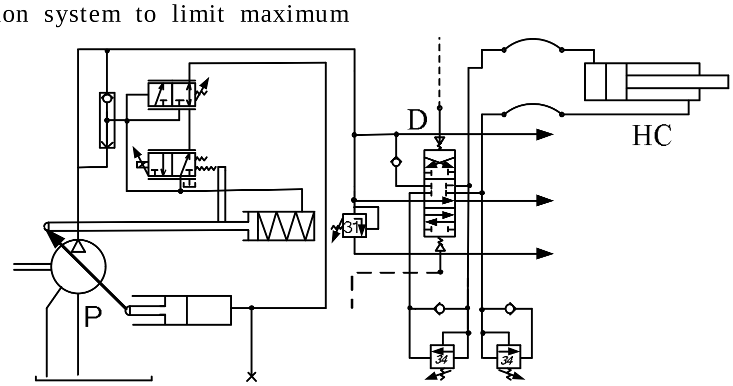

Fig. 1. Partial hydraulic diagram of a hydraulic excavator

Modeling hydraulic behavior requires knowledge of the behavior of each component.

A special problem is the behavior of hydraulic directional valves. Models currently used consider that hydraulic directional valves open suddenly. That means that directional valves do not modify the flow produced by the hydraulic pump. In reality, the directional valves are open in a time interval imposed by the system-control unit. Consequently, the directional valves produce variable pressure drop that depend on the geometry of components at a certain time and the flow received from the pump. Modeling this aspect is difficult, given the complexity of the geometry and distributor components that it connects.

This paper presents a solution that can be used right from the design stage of the hydraulic system.

2. SOME CHARACTERISTICS OF DIRECTIONAL VALVES

Figure 2 shows a section through a common hydraulic directional valves [5].

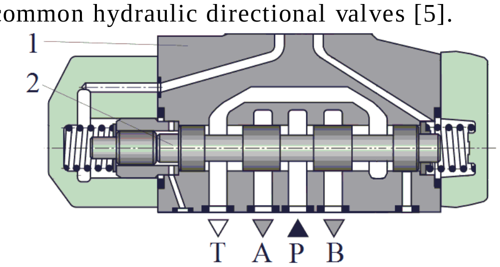

Fig. 2 Section through a hydraulic directional valve

Also, the manufacturers indicate in graphic form, the behavior of hydraulic a directional valve. In Figure 3 illustrates such an example. The curves indicate flow pressure drops depending on flow on different ways of connecting.

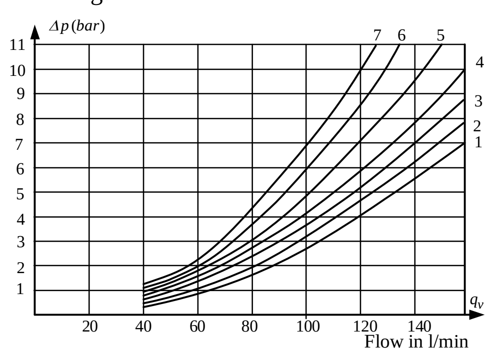

Fig. 3. Pressure drops on different connecting routes (2 - P / A, 4 - A / T, ...) depending on the flow of hydraulic fluid.

The information provided by these diagrams is insufficient for a rigorous simulation because:

- Curves are drawn for a maximum possible opening without indicating what happens at partial openings;
- There is little information on the flow at the beginning of the operation;
- The hydraulic oils used differ significantly;
- The operating temperature of the hydraulic oils influences the viscosity.

Therefore getting consistent information on the behavior of the hydraulic equipment is important.

3. NUMERICAL SIMULATION

In order to determin the performance characteristics of mechanical and hydraulic system first must be established the components characteristics. For the hydraulic systems were chosen for analysis the numerical simulations. After determining the characteristics of components are analyzed the characteristics of the ensemble.

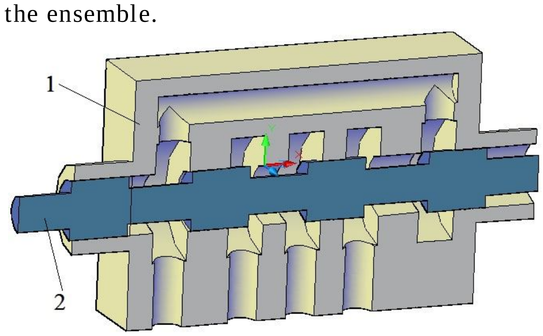

Fig 3. Directional valves DN20. 1- hausing; 2 – spool.

One of the components of the hydraulic system is the directional valve. In Figure 3 is shown, in section, such a device madein a 3D graphic design.

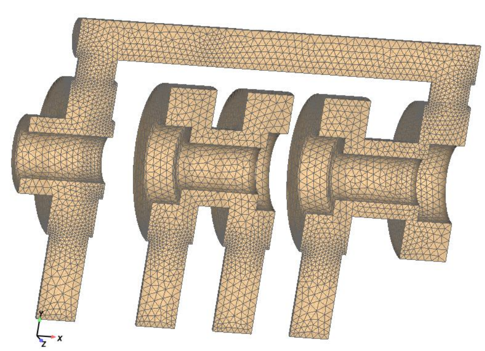

Fig. 5. The bodies of fluid

Starting from the 3D assembly in Figure 3 were made, using FloWizard, fluid bodies for different positions of the spool. In Figure 4 there is an example of such a body of fluid with multiple flow paths.

Numerical simulation can be done on multiple body fluid or on a single component. In Figure 5 is shown one of the graphic results of the numerical simulation.

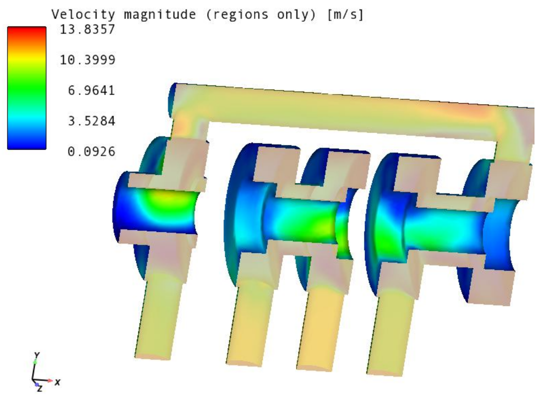

Fig. 5. The graphic result of the simulation flow for a directional valve.

The forms of fluid bodies change depending on spool position.

4. SIMULATION RESULTS AND RESULTS INTERPRETATION

For numerical simulations it is considered as working fluid H46 hydraulic oil. Under production rules kinematic viscosity, υ, is between 44.4 cSt and 49 cSt at 40 ^{o}C. For a certain temperature, kinematic viscosity is calculated using Equation (1). The kinematic viscosity was considered at temperature of 50 °C and it is 0.000043 m^2 /s.

$$\upsilon_{(t)} = 0{,}018125 \cdot t^2 - 2{,}725 \cdot t + 120{,}93 \ \text{[cSt]} \quad (1)$$

For the hydraulic oil, the density is 900 kg/m3, resulting a dynamic viscosity of 0.0387 kg / ms.

$$\eta_{din} = \upsilon \cdot \rho \quad (2)$$

We have considered the space (F) between the body and the spool from 0.1 mm to 12 mm.

To present the principle of the method are presented results for body fluid connecting outlet A with hydraulic inlet P. In Figure 6 there is an example of numerical and graphical results obtained for the considered body fluid.

In Table 1 are summarized results of simulations showing the pressure drop between the inlet and the outlet .

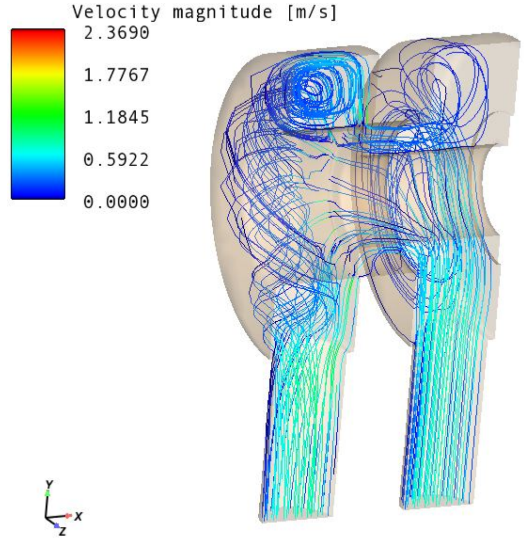

Fig. 6. Lines of flow in the body fluid.

Vertically it is shown the speed on the inlet and horizontally the space F.

Table 1

Speed [m/s] v	space F [mm]					
	0.1	0.5	1	2	6	12
	$\Delta p \quad P-A$					
0.1	34114	646	235	95	63	60
0.2	98121	1588	601	237	159	152
0.5	180965	6624	2470	909	588	559
1	619036	22373	7919	2776	18775	1588
2	2257111	81005	27311	9140	5242	4841
5	13281655	474415	154143	49421	26747	24146
10	53029013	1884542	603544	191147	99570	89254
20	207180180	7484261	2399085	745123	388291	345818

We have further used these results to calculate the Reynolds number (relation 3) and flow coefficients (relation 4).

$$Re = \frac{v \cdot D_n}{\upsilon_{(t)}} \quad (3)$$

$$Cv = v \cdot \sqrt{\frac{\rho}{2 \cdot \Delta p}} \quad (4)$$

Based on these relations and from data obtained from numerical simulations Table 2 was created. It indicates how the variation of the flow coefficient depends on F space and flow rate of hydraulic oil.

Table 2

Speed [m/s] *v*	space F [mm]						*Re*
	0.1	0.5	1	2	6	12	
	Flow coefficient *Cv*						
0.1	0.0115	0.0835	0.1384	0.2176	0.2673	0.2739	46.51
0.2	0.0135	0.1065	0.1731	0.2756	0.3365	0.3441	93.02
0.5	0.0249	0.1303	0.2134	0.3518	0.4374	0.4486	232.56
1	0.0270	0.1418	0.2384	0.4026	0.1548	0.5323	465.12
2	0.0282	0.1491	0.2567	0.4438	0.5860	0.6098	930.23
5	0.0291	0.1540	0.2702	0.4771	0.6485	0.6826	2325.58
10	0.0291	0.1545	0.2731	0.4852	0.6723	0.7101	4651.16
20	0.0295	0.1551	0.2739	0.4915	0.6809	0.7215	9302.33

Figure 7 shows the variation of flow coefficient for an opening F 1 mm.

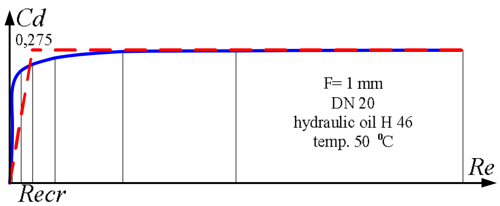

Fig. 7. Graph of the function $Cd(Re)$

Approximation of the function thus obtained (drawn with a continuous line) can be produced by any of the known processes. A simple way is that it is considered a critical Reynolds number and the two intervals are linearized.

5. CONCLUSIONS

The presented method can obtain mathematical functions that describe the future operation of components before being physically done.

The information thus obtained can be used in mathematical models describing the operation of complex machinery.

Since it is difficult to specify the flow regime for each component of the hydraulic system it can be analyzed the hydraulic behavior of the assembly of components.

The necessary working time for obtaining the flow characteristics is high, but the simulation of machine operation becomes faster and it is more accurate.

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