EXPERIMENTAL RIG FOR SIMULATION OF HYDROMECHANICAL SYSTEM WITH ENERGY REGENERATION

Milan Klapka*, Josef Nevrlý*, Tomáš Panáček*

The article deals with design of the experimental rig with hydromechanical system and energy regeneration. Suggested rig is also scaled model of the heavy vehicle hydrostatic drive. The energy regeneration circuit is connected in the series with the hydraulic circuit of the drive. The test rig enables verification of mathematical model of the heavy vehicle drive and optimization of the operational parameters of the drive to achieve high efficiency of regeneration. Such procedures will be extremely difficult to perform directly on the vehicle.

Keywords: *hydrostatic drive, energy regeneration, heavy vehicles*

1. Introduction

A lot of effort is paid to reducing fuel consumption of vehicles. It is a result of global energy costs rising and demands of low vehicle operational costs by its owners. Driving energy regeneration is one of possible discussed solutions. Usually, it means saving of vehicle braking energy and its utilization for acceleration. Common drivelines with energy regeneration consist of combustion engine connected together with hydraulic or electric drive. The concept of drives with regeneration of energy for heavy vehicles such as construction vehicles is recently discussed by Baseley [1] and Filipi [2].

2. Problem definition

A regenerative hydraulic drive is developed at the Brno University of Technology currently. It is mentioned to be used on heavy vehicles. Selected vehicles are usually equipped with a hydrostatic drive, which ensures the required smooth speed change. Therefore, the regenerative circuit could be connected in series with hydrostatic drive. Such solution is easier to design and has lower economical demands than parallel connection for hybrid drives. However, achieving of high efficiency of the drive is crucial for any future practical application, according to Sun [3]. A detailed mathematical model of the drive needs to be created. It will be used to optimize the operating parameters of the hydraulic system. Therefore, it will be necessary to obtain considerable number of real input parameters. Also, the simulated results should be compared with experimental data. Conduction of required experiments would be very challenging directly on the vehicle in terms of needed design adjustments and economical resources. Suggested experimental rig enables implementation

* Ing. M. Klapka*, Ph.D., prof. Ing. J. Nevrlý*, Ing. T. Panáček, Institute of Machine and Industrial Design, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2, 616 69 Brno, Czech Republic

of necessary modes of operation, enables measurements of desired operating parameters and also match the real vehicle driveline most closely.

3. Hydraulic circuit of the experimental rig

First draft of the hydraulic circuit was based on experimental rig described by Pourmovahed [4, 5]. The design concept of the hydraulic circuit was adjusted according the drives commonly used in heavy construction vehicles (Fig. 1). Hydrostatic drive consists of a hydraulic pump (HG) and hydromotor (HM) that drives the attached flywheel. The hydraulic pump/generator block main part is a controlled axial piston pump with operational parameters according Table 1.

operational param. (HG)	value	dim.	operational param. (HM)	value	dim.
variable displacement, Vg	28	cm^3	variable displacement, Vg	28	cm^3
maximum flow, Q	40	l/min	maximum flow, Q	40	l/min
max. static pressure, p	30	MPa	max. static pressure, p	30	MPa
nominal power, P	18.5	kW	nominal torque, M	179	Nm
nominal speed, n	1450	min^{-1}	nominal speed, n	3600	min^{-1}

Tab. 1: Technical parameters of pump (HG) and hydromotor (HM)

The pump is driven by an electric motor of 22 kW peak power with a nominal speed of 1450 RPM. The electric motor replaces the combustion engine used in vehicles. Controlled axial piston hydromotor drives connected dynamometer flywheel which simulates the inertial mass of the vehicle. The inertial mass of the dynamometer can be adjusted by additional weights and additional braking torque could if required. Operational parameters of the hydromotor are shown in Table 1 as well.

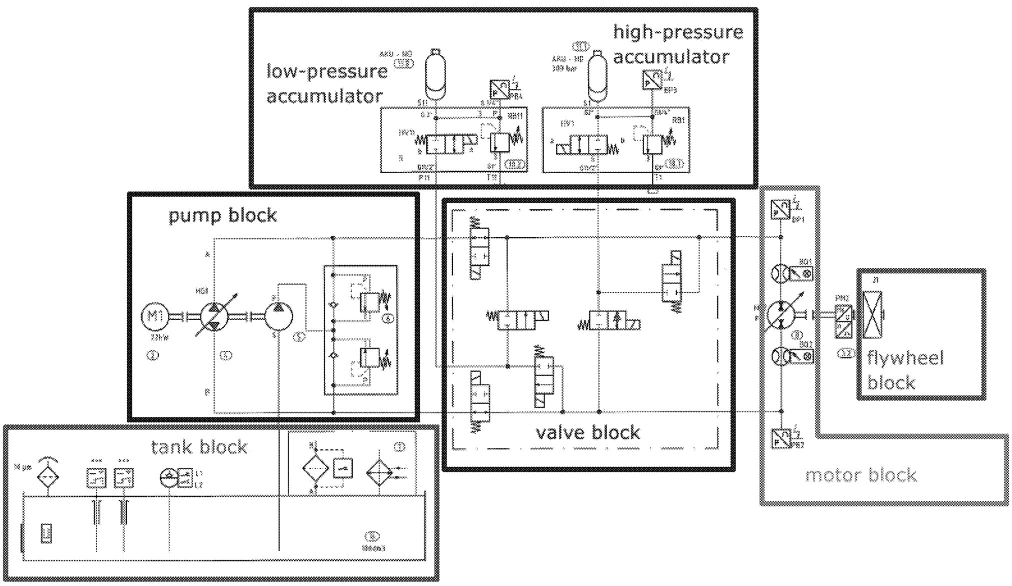

Fig.1: Hydraulic circuit of the experimental rig

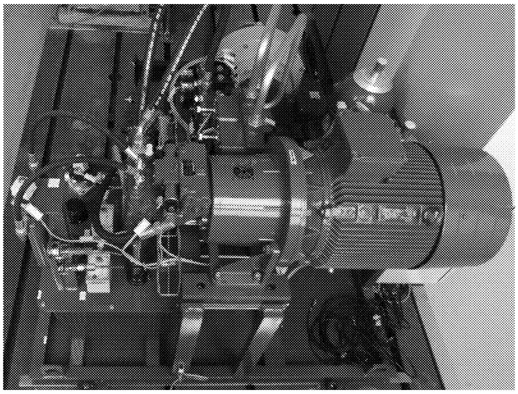

Fig.2: Experimental rig for hydraulic energy regeneration testing and optimization

A valve manifold and two bladder pressure accumulators are connected into the hydraulic circuit of the hydrostatic drive. The valve manifold is connected to the circuit in series and it is equipped with six electronically controlled solenoid valves. Valves control the flow of the hydraulic fluid according to the selected mode of operation. Bladder pressure accumulators have a volume of 10 liters, different operational hydraulic fluid pressure and different nitrogen gas pressure. At first it is necessary to pressurize one of the accumulators to 3 MPa (pressure of the hydraulic fluid) to ensure the proper function of the regenerative circuit; this accumulator is called low-pressure (ND). The supply of hydraulic fluid is closed during braking cycle and hydraulic fluid is flowing from the low pressure accumulator through hydromotor to the high-pressure accumulator (HD). Amount of pressure in the high-pressure accumulator depends on the speed before braking and duration of braking cycle. Energy charged in high-pressure accumulator is discharge during acceleration cycle. In this mode, the hydraulic fluid is pumped from the high-pressure accumulator to a low-pressure one through pump. The load of electric motor is therefore reduced as it must cover only the difference between demanded pressure and pressure delivered from regeneration circuit supplied to the pump. Thus it provides reduction of energy consumption compared to a simple hydrostatic drive. The entire experimental rig arrangement is shown in Figure 2. The rig is designed as a scale model of the real driveline due to energy supply limitations.

4. Measurement chain

Measuring chain is shown in Figure 3. According to the required number of signals it would be very difficult to conduct such detailed measurements directly on the vehicle. However, usually it is not a problem to extend or modify the measurement as needed in case of experimental rig.

5. Controlling system

The control system for the test rig is developed in collaboration with the supplier of the control unit which is used in heavy vehicles. It is a modification of a standard solution upgraded with valve manifold control system. The operation of the test rig is controlled by the user who selects the available modes on the dedicated remote control. It is also possible to use automatic mode where selected operational modes are repeated with the given number of cycles automatically.

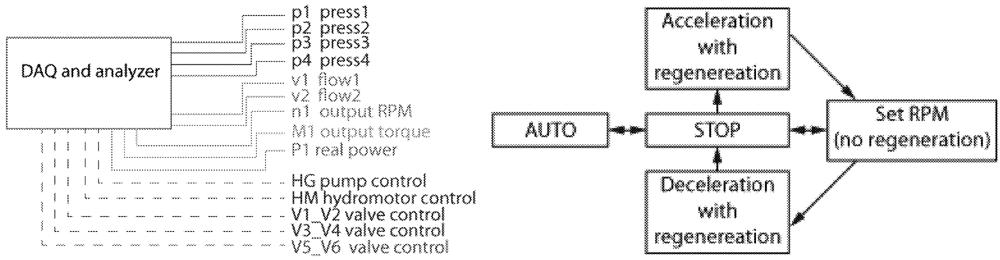

Fig.3: Measurement chain and diagram of control system with transitions among operational modes

The output speed is the user-controlled parameter and it is indirectly adjusted by software pedal. The control unit ensures setting of desired operating parameters and setting of valve manifold according to the selected operational mode. The control unit checks the safety features of the test rig. Simplified scheme of control algorithm is in Figure 3.

6. Results

Figure 4 shows the comparison of time responses of selected variables obtained experimentally and by simulations. Comprehensive numerical model of the hydraulic system is used for simulations implemented in Matlab/Simulink. Good agreement of experiment and simulation was achieved in hydrostatic drive mode (without energy regeneration). Discussed test cycle is composed of the acceleration to the desired speed and braking to stop. Obtained results provided validation of the proposed mathematical model of the hydrostatic circuit and also confirm the potential of the system for energy regeneration.

If results of the simulation and experiments with energy recovery are compared, sufficient agreement has not yet been reached. This is due to significantly non-linear behavior of the system with regeneration. Thus there is necessary to obtain a more accurate description of the control system, especially information about setting the valve manifold (reaction times of valves etc.). It is also necessary to refine the measuring of the control process of the actuators, i.e. pump and hydromotor and use them in simulations.

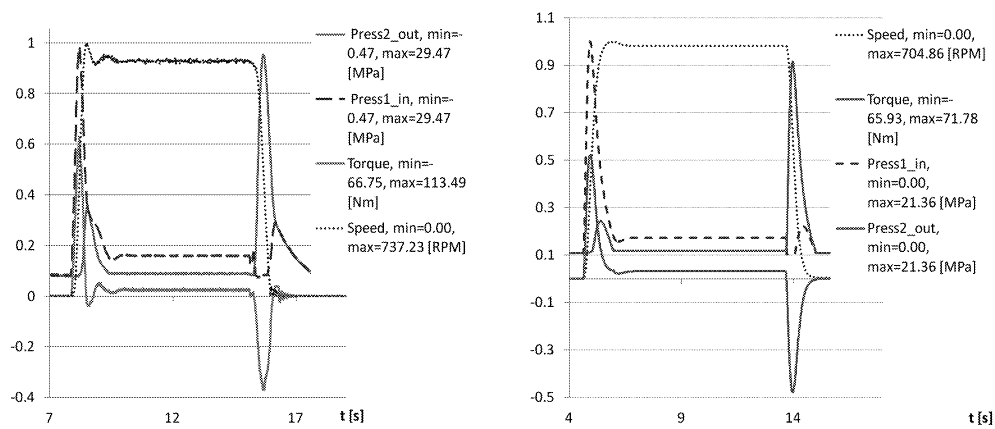

Fig.4: Time responses obtained by measurement and simulation, SetRPM mode

7. Conclusions

The proposed experimental rig is scaled simulator of a heavy vehicle hydrostatic driveline. It enables identification of the operational characteristics of the system and verification of the potential for energy regeneration. Simultaneously, the test rig enables measuring of input parameters for mathematical modeling, which would be difficult to measure on real vehicle. The main purpose of the device is verification of the hydraulic system mathematical model and subsequent testing of optimized sets of operational parameters in order to achieve the highest efficiency of energy regeneration. Currently, the hydrostatic circuit numerical model was successfully verified experimentally. Verification of the numerical model of the system with connected energy regeneration still continues. Operational parameter optimization of the system will follow after successful validation of the model with the regeneration. Optimized parameters will be experimentally verified on the test rig. Finally the optimized system will be tested on selected heavy vehicle sample.

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