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Analysis of energy losses in a hydraulic load sensing proportional valve

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Abstract. The paper presents modeling and simulation of a hydraulic proportional valve PVG 32 by Danfoss widely used in agricultural machinery. A suitable mathematical model is created in LMS Amesim and SolidWorks Flow simulation software programs with the analysis of its energy performance. Their outcomes are validated with the experimental results to correctly describe the real valve characteristics. Since the spool valves are designed with over-running loads in mind, considerable throttling losses are observed in the discharge line when the machine is operating with a resistive load.Therefore; this paper suggests the possibility of implementing energy saving techniques in the valve by using independent metering and gives simulation model for further use.

1. Introduction

Nowadays energy saving is a topical issue due to increasing fuel costs and this aspect is amplified by more stringent emissions regulations that impact on agricultural machine development. A recent study conducted by the U.S. Department of Energy shows that about five percent of the U.S. energy consumption is transmitted by fluid power equipment. Nevertheless, this study also shows that the efficiency of fluid power is 21 percent on average. This offers a huge opportunity to improve the current state-of-the-art of fluid power machines, in particular to improve the energy consumption of current applications. These facts dictate a continuous strive toward improvements and more efficient solutions: to accomplish reduction of hydraulic losses and better control strategies of the hydraulic systems.

In fluid power, there exist many techniques to reduce/recover energy losses of the conventional layouts, e.g. load sensing, electrohydraulic flow matching, independent metering, etc. One of the most efficient ways to analyze these different layouts and identify the best hydraulic solution is done through virtual simulations instead of prototyping, since the latter involves higher investment costs to deliver the product into the market. However, to build a fluid power machine virtual model, some problems arise relative to different aspects, for instance: loads on actuators (both linear and rotational) are not constant and pumps are driven by a real engine whose speed depends on required torque [1, 2]. Furthermore, it is important to achieve higher level of detail to simulate each component in the circuit:

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the greater detail, the better the machine behavior is portrayed, but it obviously entails heavy impact on simulation time and computational resources. Therefore, there is a need to create mathematical model of components and systems with sufficient level of detail to easily acquire all those phenomena necessary to correctly evaluate machine performance and make modifications to the fluid power component design [3, 4].

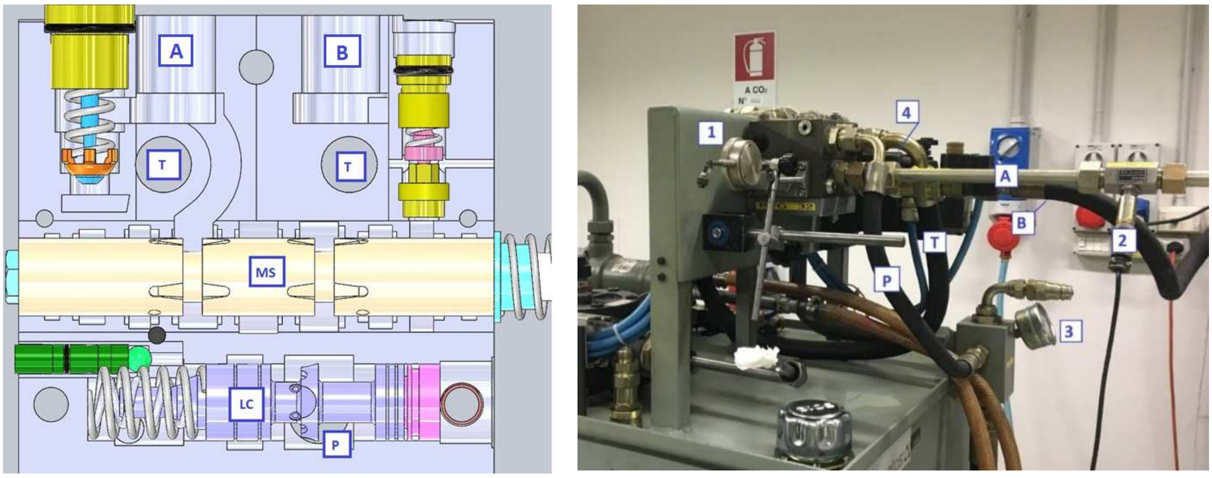
In this context, a hydraulic proportional valve PVG 32 by Danfoss is taken as an object of study, its performance is analyzed with suitable mathematical model and simulation is done to observe closeness of a model to the laboratory experiment results.

2. Materials and methods

Working fluid in the experiment is chosen MOBIL DTE25 and its temeperature is required to be 38°C during the experiment. Tank gauge pressure is set to 0.5 bar. Before conducting an experiment, pressure transducers are calibrated by using rotary dead weight tester. Experiment is repeated 50 times to avoid repeatability error. Venturi flow meter is used to measure the flow rate to the actuator and to the tank.

3. Modeling and simulation of the valve

The example of the load sensing pre-compensation technique is a block of PVG32 made by Danfoss. There are several PVB modules for each user with electro-hydraulic actuation and manual operation for safety reasons. The flow rate controlled by each PVB is exclusively a function of the available command signal, which displaces the main spool *MS* leftwards and rightwards.



a b

Figure 1.a - Cross section of the PVB module. Flow passing through the local compensator *LC* feeds port *A* or *B* depending on the main spool *MS*displacement; b - experimental test layout. Pump is connected to the inlet of PVB, the pressure transducer *3*monitors its pressure. Solenoid *4* acts to displace the main spool, the analog position sensor *1* measures displacement of the spool.Venturi flow meter *2* measures flow rate through line*A*. Two pressure transducers measure pressures at port *A* and *B*.

By acting on the spool with the solenoid *4* and moving the main spool to the rightwards, pressure port *P* is connected to port *A* and port *B* is connected to port *T* (tank). Pressures at ports *P, B* and *A* are measured and valve characteristics are shown in Figure 2.

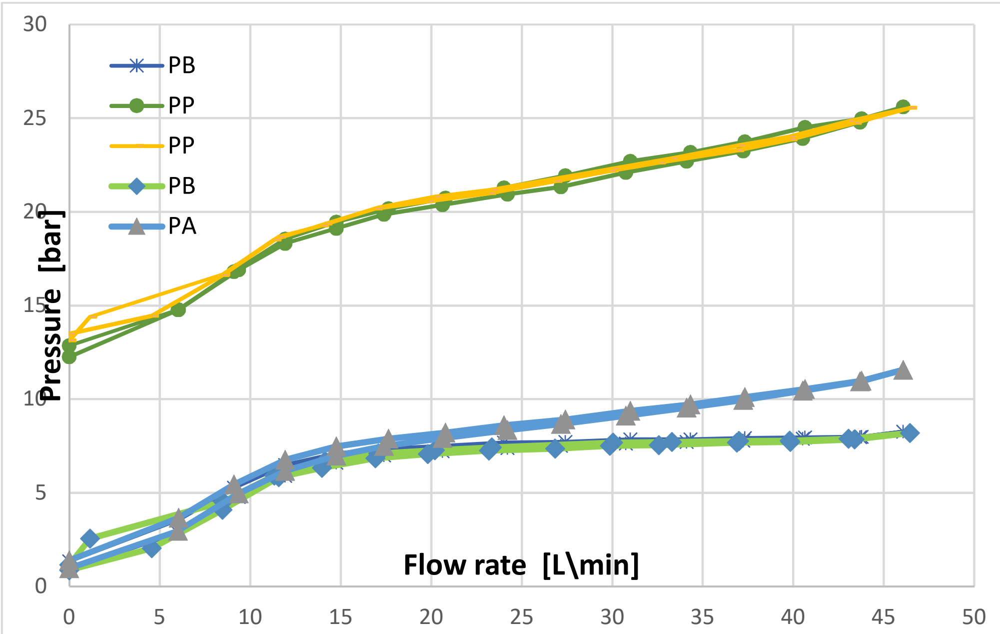


Figure 2. Experimental results of valve characteristics. Pressure losses of 7-9 bars between port *B* and the tank are observed when power port *P* is connected to port *A*.

As it is seen from Figure 2, as a result of designing with over-running loads in mind, pressure of port *B* is not equal to the tank pressure. Hence, there is a pressure loss of 7 to 9 bars between port *B* and port *T*. If it was possible to open the connection B-T fully while throttling connection P-A, losses in B-T would have been avoided and higher energy efficiency of the valve would be possible. This would imply decoupling of the meter-in and meter-out ports and application of independent metering technique [5].

Below is the simulation model of the PVB in LMS Amesim. It is composed of two components, namely, the local pressure compensator on the left and the main spool on the right. Ports *A* and *B* are interconnected via a restrictor. As input parameters, position of the spool and pressure is given. As an output, flow rate through the valve is computed.

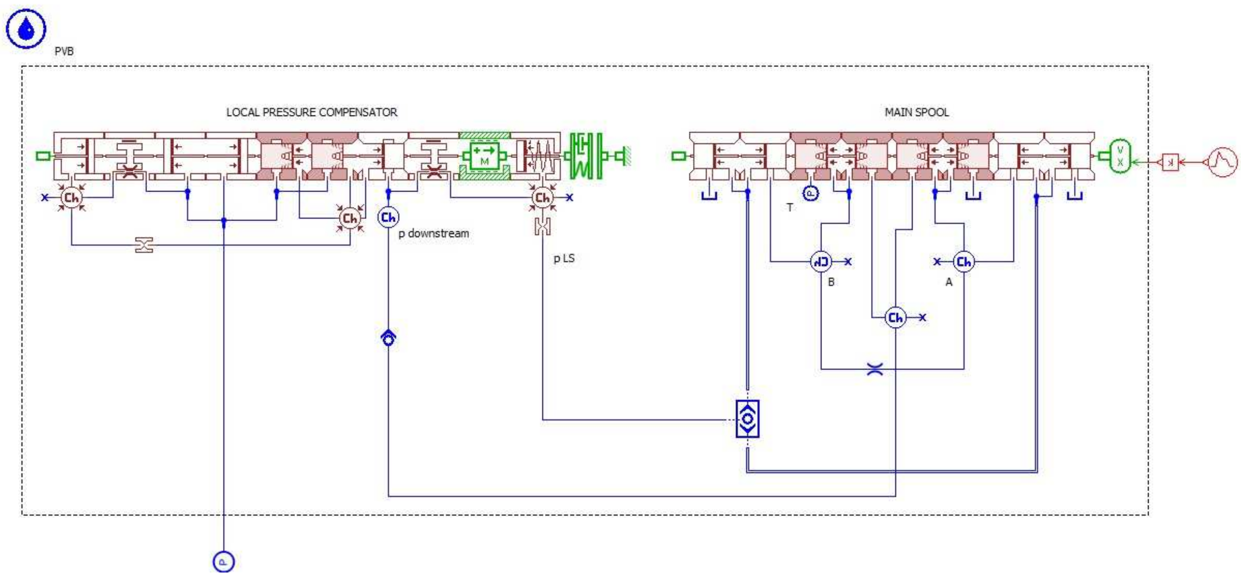


Figure 3. Amesim model of PVB valve.

The validation of the Amesim model of the valve is done and flow rate versus spool displacement characteristics are verified with experimental results (Figure 4).

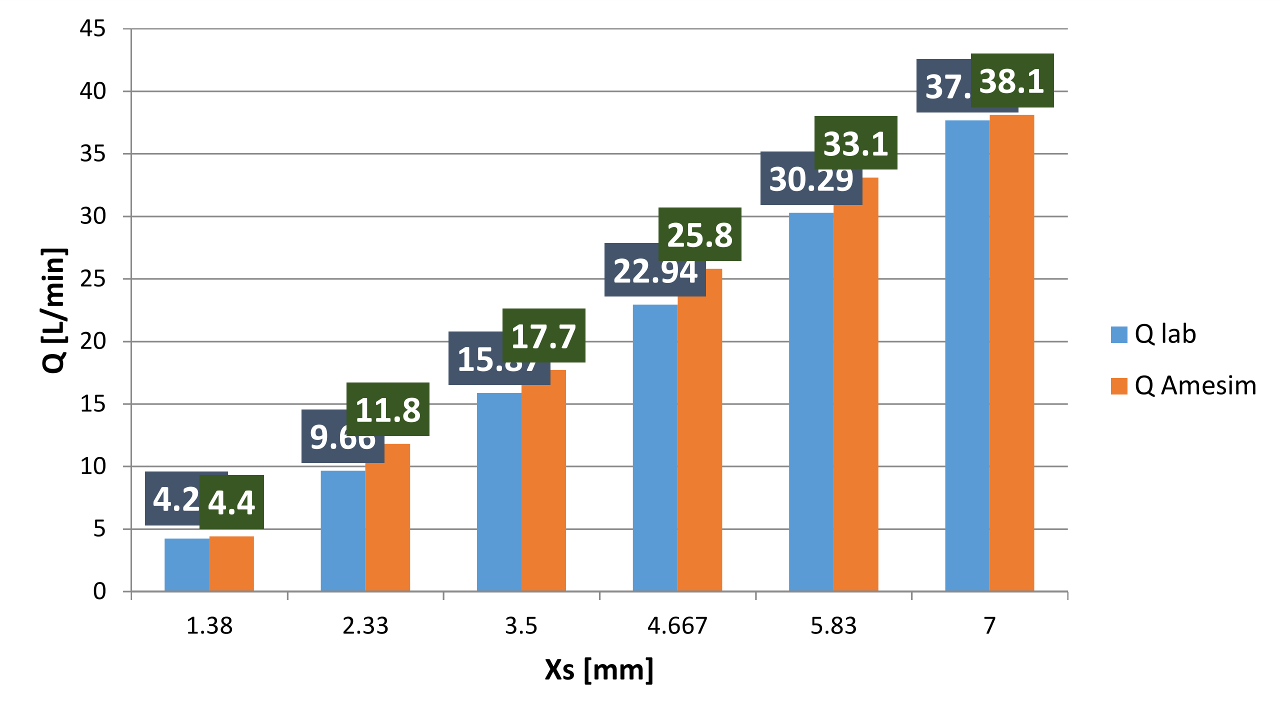


Figure 4. AAA Z Flow rate versus spool displacement data are compared in laboratory experiment and mathematical model.

Moreover, it is also useful to check the value of the discharge coefficient C_d of the metering edge which is used in the simulation model. The default value is equal to 0.7. As it is proved later in this article, this value is the good estimation of it.

Table 1. Discharge coefficient C_d of the metering edge connecting B and T ports

Main spool displacement Xs, mm	Flow rate Q, l/min	Experimental result of pressure at port B, bar	Amesim result of pressure at port B, bar	Amesim value of discharge coefficient C_d
2,45	14,13	7,69	7,83	0,7080
3,78	23,34	8,77	8,50	0,6720
5,6	37,01	8,7	8,00	0,6870
6,5	43,06	8,89	8,60	0,7440
7	46,45	9,19	9,10	0,7590
			Mean value:	**0,71**

Similar value of the discharge coefficient has been obtained for the metering edge connecting port P and port A. In summary, it is seen that discharge coefficients at the P-A and B-T connections can be set to be equal to 0.7 in an Amesim model of the valve.

4. Conclusion

The following useful conclusions are obtained after the simulation and experimental analysis of the hydraulic proportional load sensing valve PVB. The mathematical model made in Amesim of the PVB module of the PVG32 block correctly describes the real valve and has been validated to experimental results. Considerable throttling losses are observed at the connection between B and T when connection P and A is open. Since the spool valves are designed with over-running loads in mind, throttling losses are observed in the discharge line when the machine is operating with a resistive load.

Further research will concentrate on implementation of energy saving techniques in the valve by using independent metering, electronic flow matching, etc. Independent metering could be used by splitting the valve into two equal parts and operating them electronically. But further research should be done to study the valve controllability [6].

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Nomenclatures and Symbols

PVG 32 is the code name of the block of valves, PVB is the proportional direction control valve, Q is the flow rate, P is the pressure port, A and B are the user ports, C_d is the discharge coefficient.

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