Performance Investigation of a Hydro-pneumatic type Accumulator used in a Hydrostatic Drive System of Off-road Vehicles

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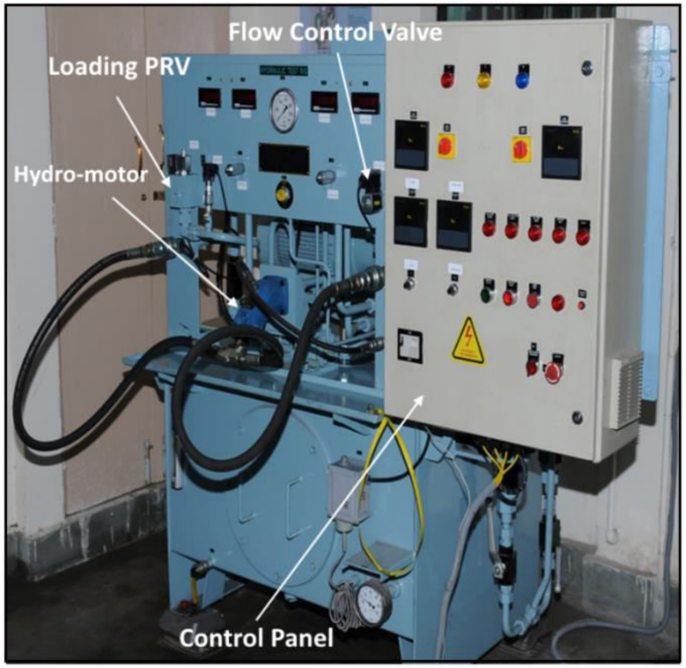

Presentation Outline

Objective

- In this article, the performance characteristics of a hydro-pneumatic type accumulator on the responses of the hydrostatic drive system are studied.
- This paper deals with the issue of understanding the dynamic phenomena in bladder- type accumulators by controlling its various performance parameters.
- The physical system considered for the analysis consists of fixed displacement pump, hydro-motor coupled with a loading unit and an accumulator.
- By varying the capacity and precharge pressure of the hydraulic accumulator and load torque on the hydro-motor, the performance behaviour of the accumulator is determined.
- In MATLAB/Simulink® environment, the simulation studies are made. By comparing the simulation results with the test data, the model is validated.
- Using the validated model, the parametric studies are also made to rationalize the system design.

Introduction

- Efficient performance and energy saving in construction and mining machinery has become a preeminent issue due to the increase in fuel price and increasing demand of production. Hydraulic systems are predominantly used in several industrial applications and are indispensable for mobile equipment used in mining operations.
- Commonly, in a typical working cycle of mining equipment the potential energy and the kinetic energy are dissipated in form of heat. So it is required to make maximum use of regenerative energy for further improvement of fuel consumption and also to ensure higher system control performance. One of the possible solutions is the incorporation of hydraulic accumulators in a hydraulic main.
- The hydraulic accumulator is one of the hydraulic elements of the system that will be used to reduce pressure and speed pulsation inside it; thus, the selection and workflow modelling have a significant influence on the stability of the entire system. For proper selection of accumulators, the understanding of its dynamic phenomena is essential.
- Significant number of research works made in this area in recent past are discussed in the article.
- This paper deals with the issue of understanding the dynamic phenomena in bladder-type accumulators by controlling its various performance parameters. The analysis has been done using two different sizes of accumulators.
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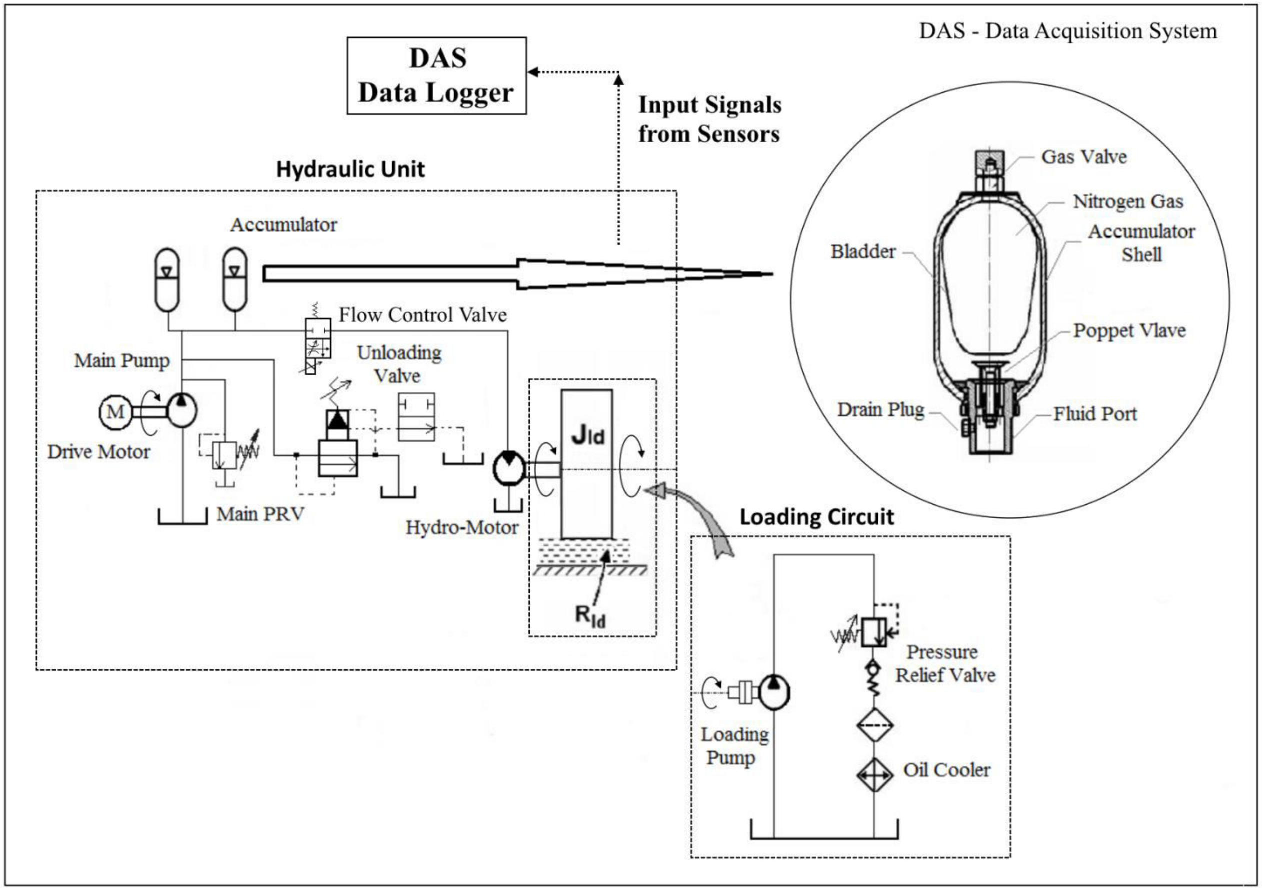
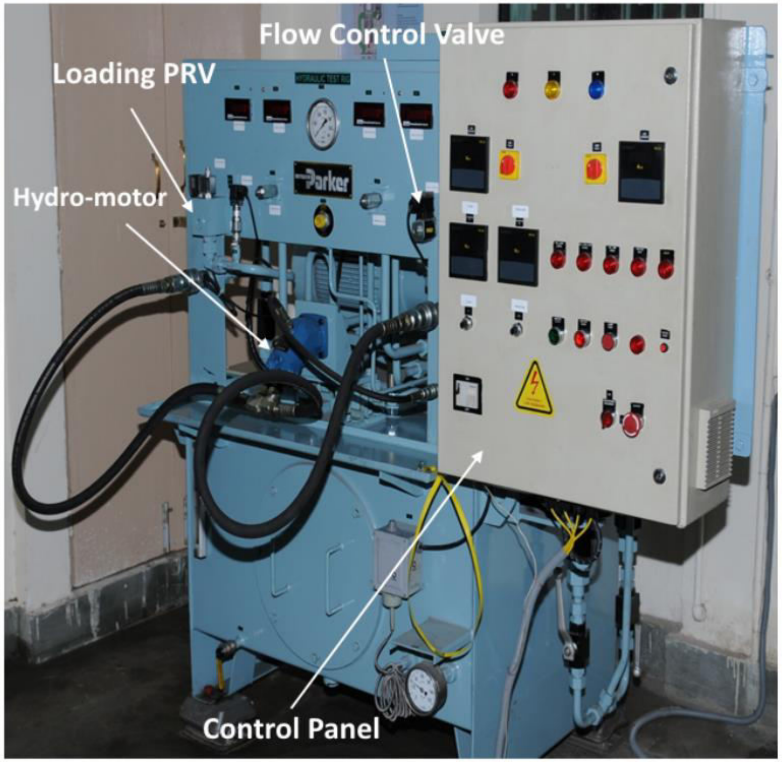
The Physical System

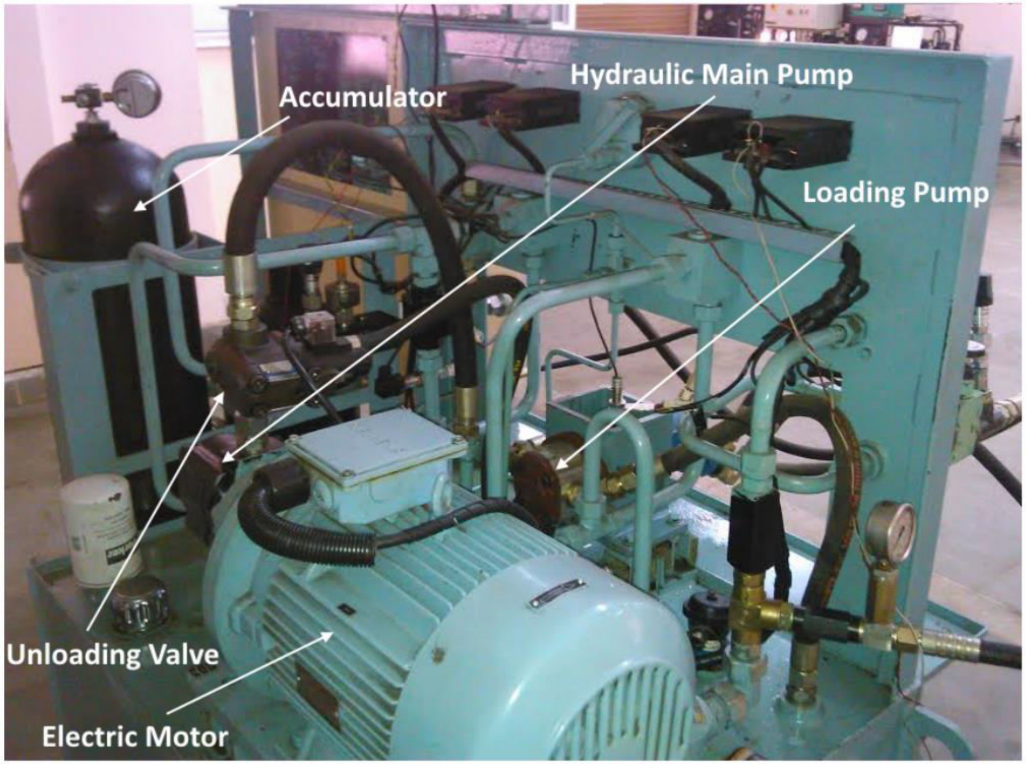


A Schematic representation of the physical system incorporating hydro-pneumatic type accumulator

Experimental Test Set-up



(a) Front View



(b) Rear View

Mathematical Model

- In order to perform a dynamic simulation of the system, the mathematical model of the system is developed defining the behaviour of the critical components.

- **Fixed-Displacement Pump.** The pump flow rate is given by

$$q_P = D_P\,\omega_P - k_{leak}\,\Delta P_P$$

where $k_{leak} = \frac{K_{HP}}{\nu\,\rho}$

- **Accumulator.** Hydro-pneumatic type accumulators of capacities 20 litres and 10 litres are used in the physical system for analysis. The rate of change of accumulator absolute pressure is given by

$$\dot{P}_a = \frac{\beta}{\rho}\left[\frac{\rho\,q_{acc}/V_F}{1+\frac{\beta}{\rho}\frac{\rho\,V_a}{\gamma\,P_a\,V_F}}\right]$$

The accumulator is considered to be working in an adiabatic process. The oil flow rate discharged by the accumulator is expressed as;

$$q_{acc} = \frac{dV_a}{dt} = -\frac{V_a\,\frac{dP_a}{dt}}{1.72\,P_a}$$

Mathematical Model

- **Hydro-motor and Loading system.** Fixed displacement bent axis hydro-motor is used in the proposed system. The describing equations of the hydro-motor considered for the analysis are expressed below.

The inlet flow to the hydro-motor is expressed as;

$$q_M = D_M \frac{d\theta_M}{dt} + C_{lm}\,\Delta P_L + \frac{V_M}{\beta}\frac{d\Delta P_L}{dt}$$

The torque load on the hydro-motor is given by;

$$T_{th} = J_M\,\alpha_M + B_M\,\omega_M + T_L$$

where load torque T_L is given by;

$$T_L = D_{PL}\,\Delta P_{PL}$$

The value of is determined by investigating the steady state characteristics of the hydro-motor as studied by N. Kumar et al.

Mathematical Model

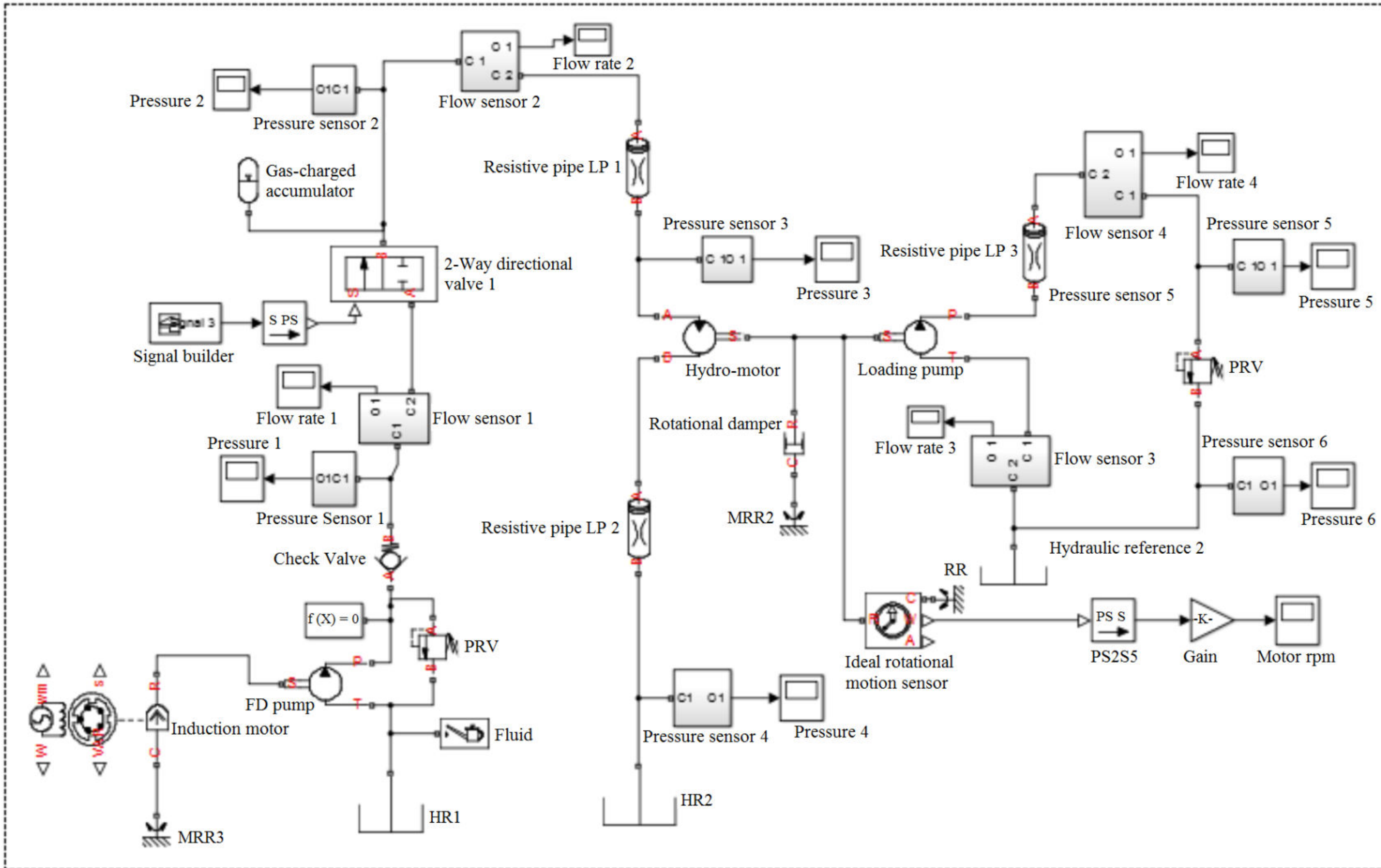
- **Control Valves.** With the movement of the valve spool due to the pressure acting on it, the valve port starts opening at its cracking/set pressure and at the full open pressure, the movement of the valve spool is arrested. The model of the control valves considers for both the laminar and turbulent flow states by analysing the Reynolds number (Re) and correlating its value with the critical Reynolds number (Re_{cr}). The flow rate q_{CV} across the control valves is determined by the following equations.

$$q_{CV} = \begin{cases} C_D\, A(\Delta P_{CV}) \sqrt{\frac{2}{\rho}\, |\Delta P_{CV}|}\, sign\,(\Delta P_{CV}) & for\ \ Re \geq Re_{cr} \\ 2\, C_{DLam}\, A(\Delta P_{CV})\, \frac{D_{orifice}}{\nu\, \rho}\, \Delta P_{CV} & else \end{cases}$$

(8)

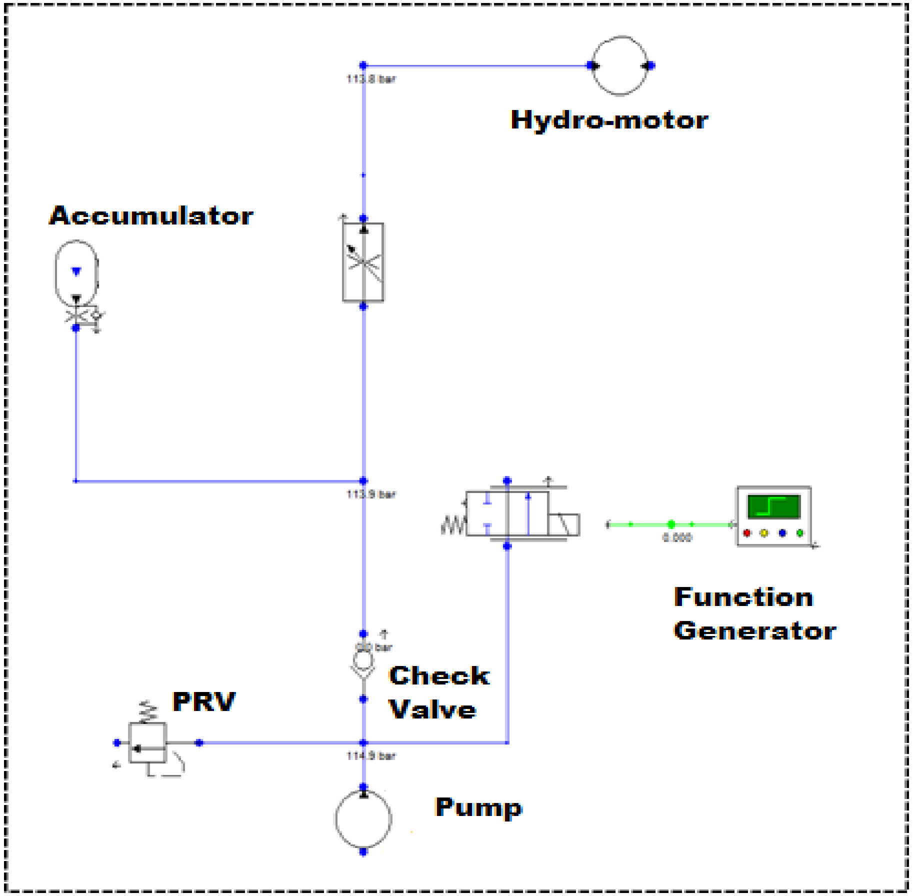
where $C_{DLam} = \left(\frac{C_D}{\sqrt{Re_{cr}}}\right)^2$

Simulation Model



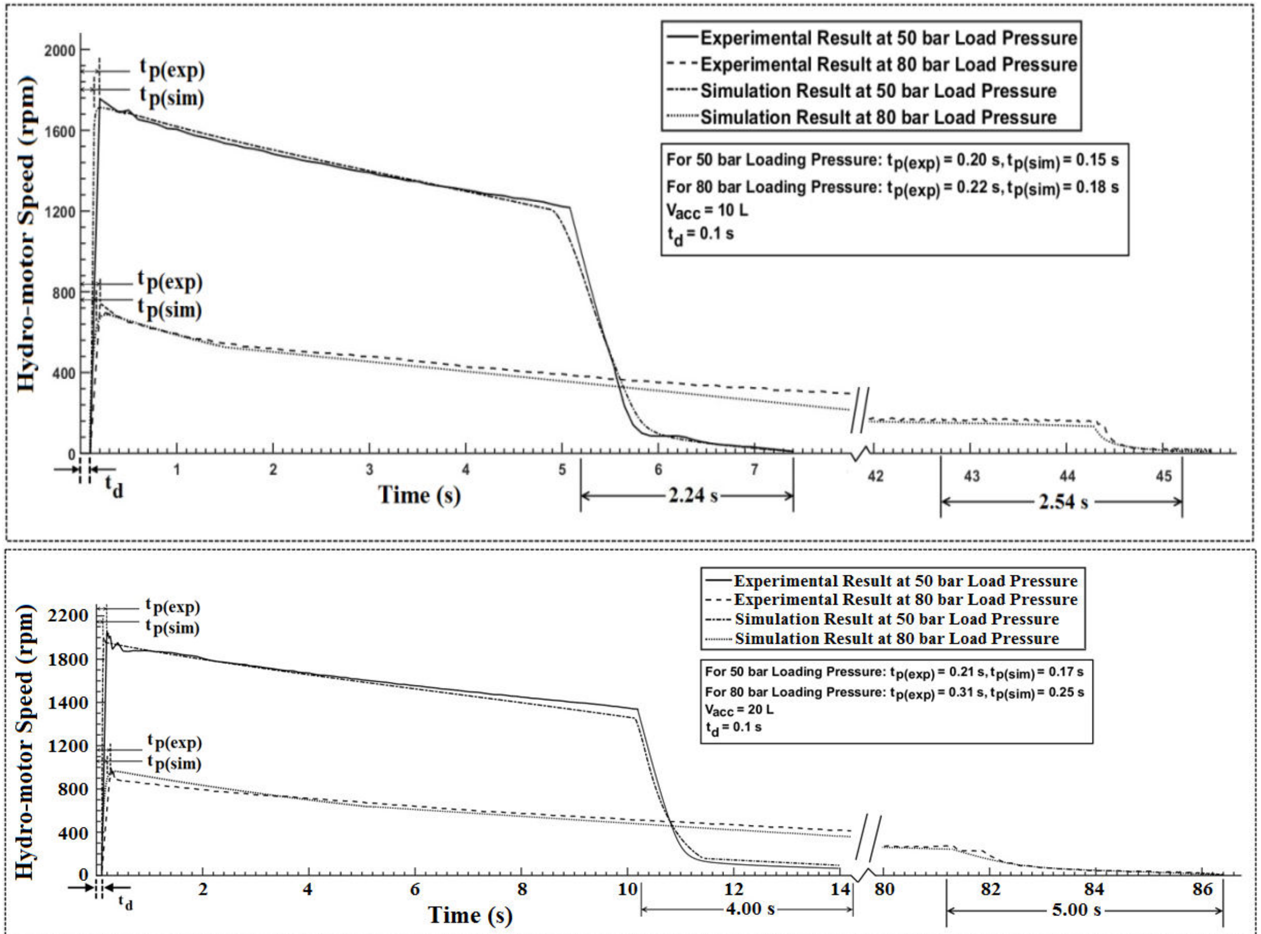
MATLAB/Simhydraulics model of the physical system

Simulation Model



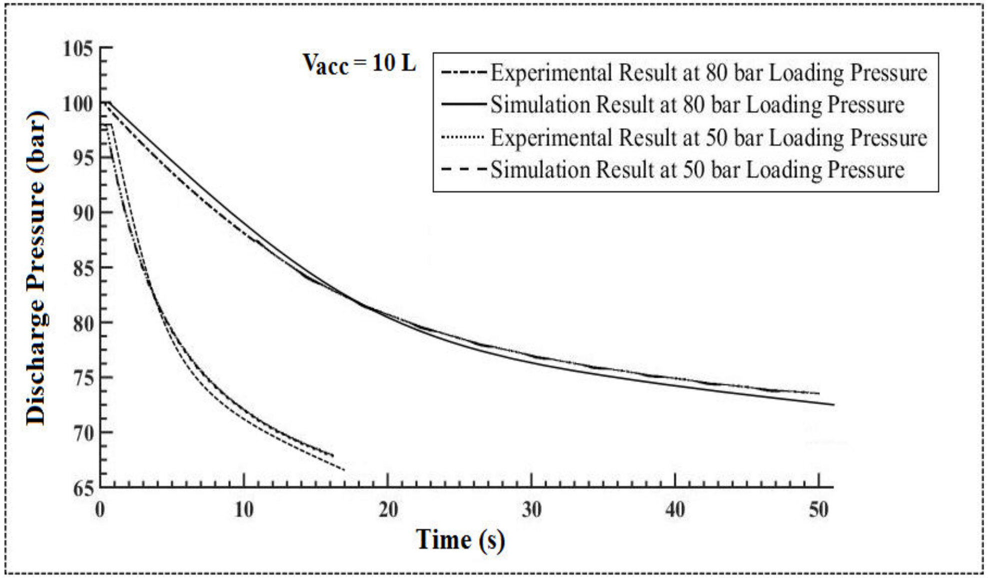
Simulation graphics of the hydraulic test rig created using DSH software.

Results & Discussions

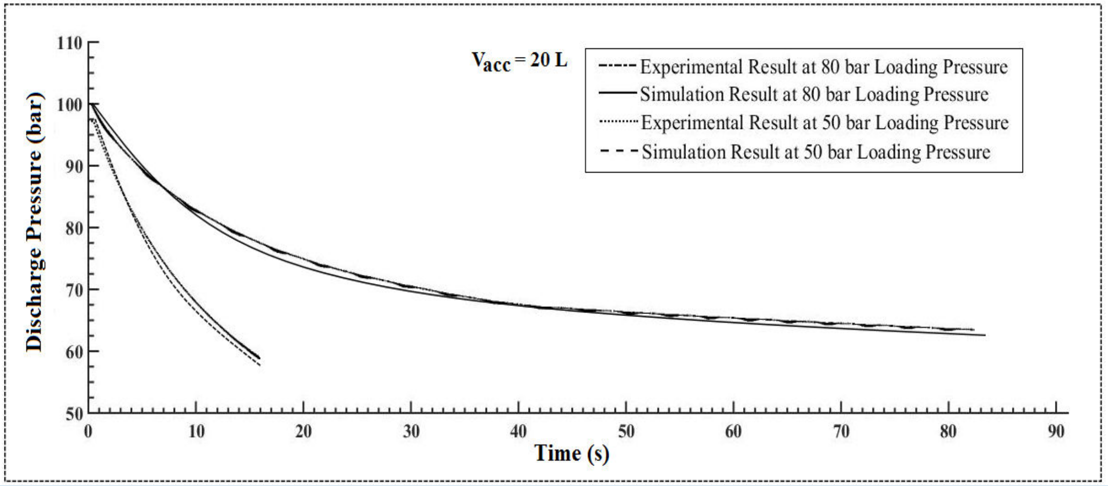


Comparison of the simulation and the experimental results of the hydro-motor speed for 10 and 20L capacities of accumulator.

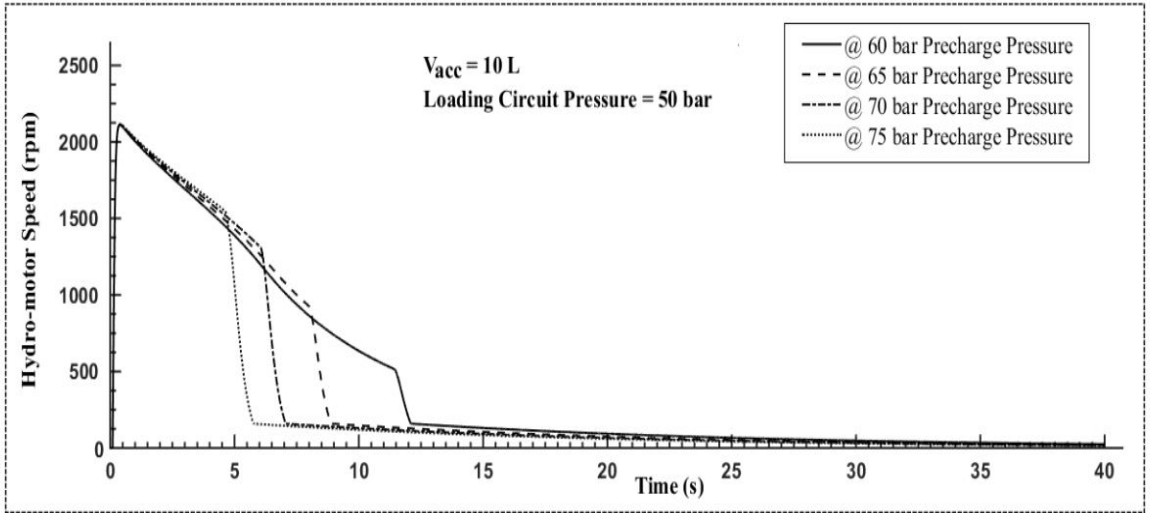
Results & Discussions



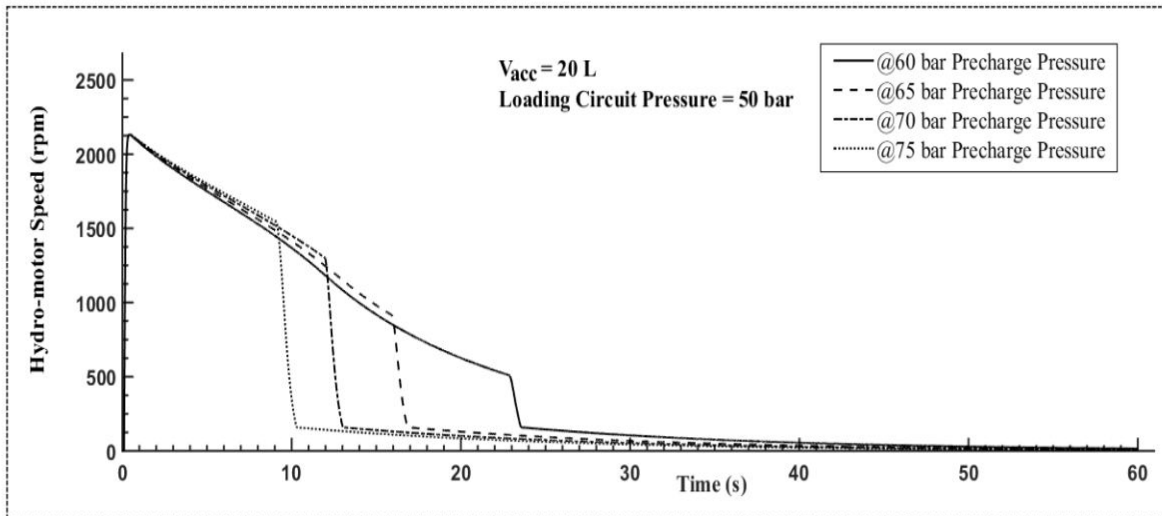
Variation of discharge pressure for 10 and 20L capacities of accumulator at different resistive loads.



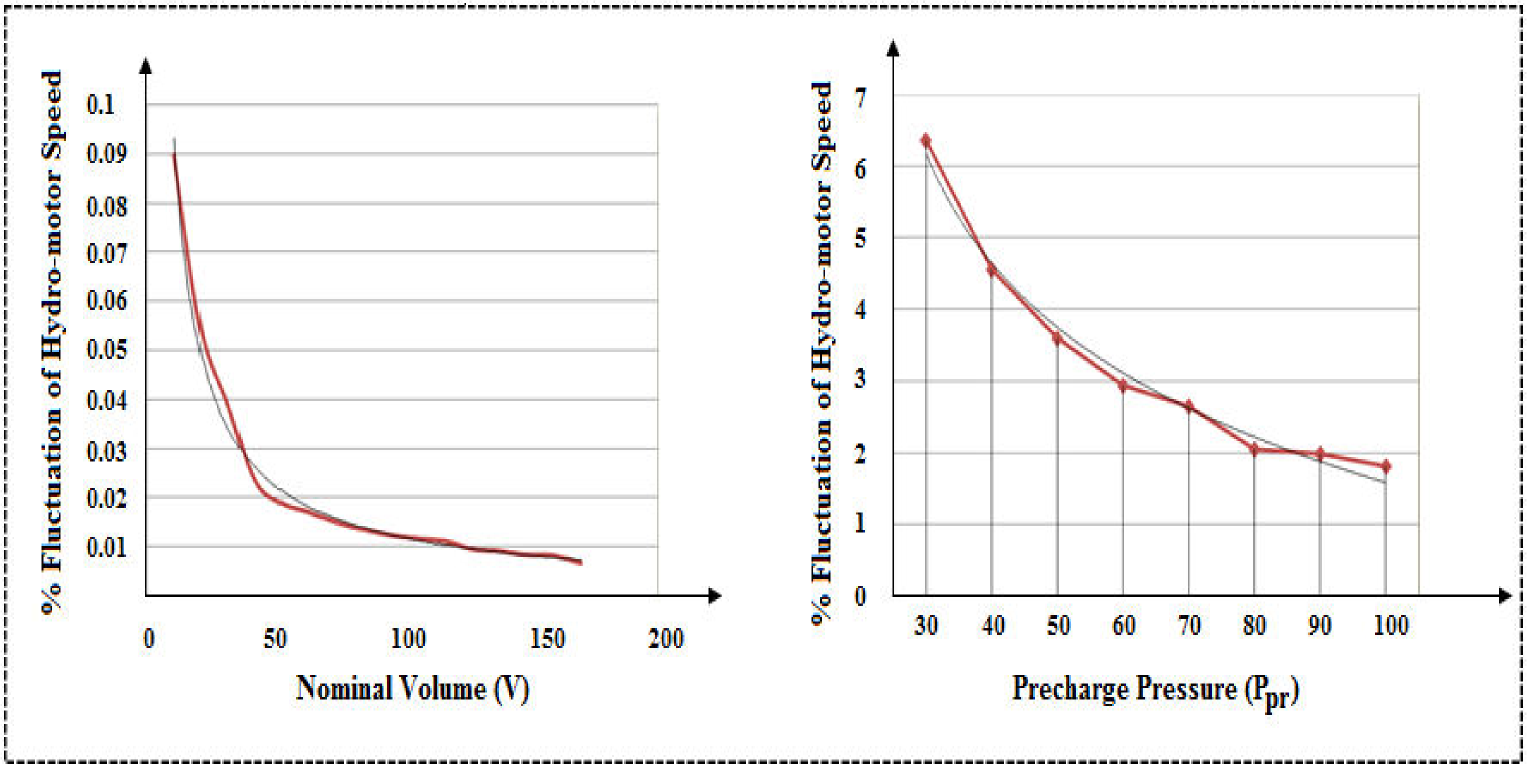
Results & Discussions



Characteristics of the hydro-motor speed at different precharge pressures of 10 and 20L capacities of accumulator.



Results & Discussions



Effect of nominal volume and precharge pressure of accumulator on percentage fluctuation of hydro-motor speed.

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Conclusions

- This paper analyses the characteristics of a hydro-pneumatic type accumulator on the responses of a hydraulic drive system typically used in off-road vehicles.
- In this respect, the simulation model of the physical system has been made using MATLAB/Simulink® environment.
- The model has been validated through experiments at different characteristics of the system. The analysis has been performed for two different sizes of accumulators at different loads as well as at different precharge pressures of the accumulator.
- Comparing the simulation results with the test data, it is observed that the variation is within ± 2% to 3% and therefore it is ascertained that the model fairly depicts the characteristics of the accumulator used in the hydrostatic drive.

➢ The following conclusions are drawn with respect to the observations made in the analysis

- For a particular capacity of accumulator, at the same precharge pressure, the pressurized fluid stored in it drives the hydro-motor at a higher speed for a shorter period of time for the smaller load. With the increase in the capacity of the accumulator, the hydro-motor rotates for a longer period of time.
- With the increase in the precharge pressure of the accumulator, less energy is stored in it which results in the decrease in decay time of the hydro-motor speed.

Conclusions

- The small size accumulator shows the quicker response in minimizing the pressure surge as compared to the large size accumulators. However, the energy stored and the discharge characteristic of large size accumulator is much better as compared to the smaller accumulator.
- Discharging of accumulator is poly-tropic process, for proposed setup it follows the equation $P\,V^n = Constant$.
- Drive efficiency decreases when differential pressure across the flow control valve increases. System efficiency increases with the accumulator in the hydraulic system.

➢ The future scope of this work will be to analyse the energy stored in the accumulator owing to pressure surge which needs both simulation and experimentation work, to be carried out. The authors believe that the studies made in this article may be useful for selecting a proper size of accumulator for a given application.

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Thank you for your attention!

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