MODELING AND SIMULATION OF AIR BRAKE HYDRAULIC SYSTEM OF FIGHTER AIRCRAFT USING AMESIM SOFTWARE

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Abstract: The air brake is a critical system of fighter aircraft which is operated by hydraulic system during landing to reduce the speed of aircraft. The model of air brake hydraulic system of fighter aircraft was built using AMESim software (advanced modeling environment for performing simulations of engineering systems). The different components of system such as swash plate axial piston pump, accumulator, bootstrap reservoir, and actuator are modeled and simulated individually and integrated in AMESim software. The model of air brake hydraulic system was simulated to analyze flow rates, pressure, and pressure drop and to determine actuation time of the air brake system. The theoretical calculations are also done for the same which gives the information about system pressure, flow rate and response time and compared with the results obtained from the simulation.

Index Terms: Air brake, Fighter aircraft, AMESim, Swash plate axial piston pump, Bootstrap reservoir

I. INTRODUCTION

Fighter aircraft hydraulic system is designed to generate the power required for operation of flight control surfaces for maneuvering of aircraft, aircraft brakes and landing gear and to control the aircraft during flight. The air brake is a flight control surface mounted on fuselage behind cockpit which is operated by hydraulic system during landing to reduce the speed of the fighter aircraft. Hydraulic system uses the pressurized fluid to transfer the energy from one place to another. The hydraulic system consists of different components such as hydraulic pump, accumulator, bootstrap reservoir, direction control valves, actuators and other accessories like filters, heat exchangers, NRVs, safety valves and pipelines and hose. The complexity of hydraulic system differs from small aircraft that requires that require fluid only for manual operation of the wheel brakes to large transport aircraft where the systems are large and complex. Hydraulic system has many advantages as power source such as light in weight, ease of installation, simplification of installation and minimum maintenance requirements. The efficiency of hydraulic operation is also almost 100% with negligible loss due to fluid friction.

For testing and analysis of hydraulic system traditional methods have been based on developing the prototype of system to confirm the system performance. But in case of aircrafts it requires lot of time and cost for prototype testing. With the wide applications of computers, the computer simulations can be used for testing and analysis of system performance which saves the time as well as cost. In this paper, the AMESim model of air brake hydraulic system is built to check the system performance.

II. MODELING OF HYDRAULIC SYSTEMCOMPONENTS

1. Modeling of hydraulic pump

The hydraulic pump used is variable displacement swash plate axial piston pump which is driven by the engine. The hydraulic pump consists of nine piston-cylinder, valve plate, swash plate, control valve, and control piston. These parts are separately modeled and integrated to build the axial piston pump. The discharge of pump is depends on the angle of swash plate. The swash plate controls the displacement of the piston inside cylinder. The control valve and control piston, controls the angle of swash plate according to discharge of pump. The valve plate which is connected to piston-cylinder consists of two kidney ports for suction and discharge of hydraulic fluid. The discharge flow rate of pump is calculated theoretically without considering the leakage. The equation used to calculate the discharge flow is,

$$Q = A_p \times r \times w \times \tan(\alpha) \times \sum_{n=1}^{n'} \mathrm{Sin}(\Theta_n) \quad (1)$$

For a VAPP with odd number of pistons,

$$n' = \frac{N+1}{2} \quad \text{for } 0 \le \Theta i \le \frac{\pi}{N}$$

$$n' = \frac{N-1}{2} \quad \text{for } \frac{\pi}{N} \le \Theta i \le \frac{2\pi}{N}$$

The hydraulic pump is rotate at a speed of 4200 rpm. The maximum swash plate angle is 150 degree. The theoretical flow rate pump obtained from calculations is 251.62 lit/min. The complete AMESim model of swash plate axial piston pump is shown in figure 1.

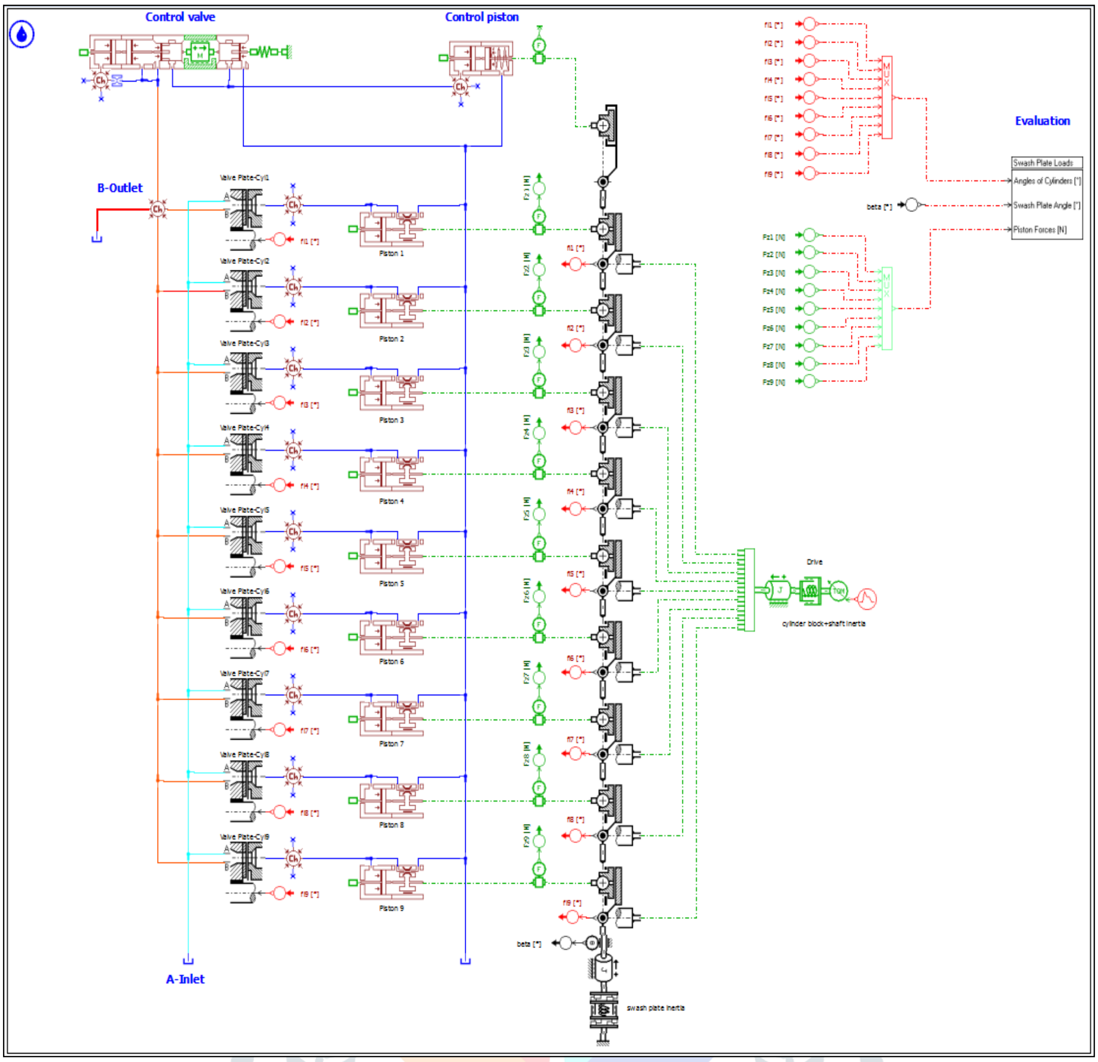

Figure 1. AMESim Model of Axial Piston Pump

2 Modeling of bootstrap reservoir

The reservoir used in fighter aircraft hydraulic system to store the hydraulic fluid is a bootstrap reservoir which is a self-pressurized reservoir. The bootstrap reservoir ensures positive suction pressure of hydraulic pump and avoid cavitation. The reservoir consists of two chambers high pressure and low pressure chamber which contains N_2 gas and hydraulic fluid respectively. The high pressure N_2 gas from accumulator is sent to high pressure chamber of bootstrap reservoir. The pressure of hydraulic fluid in low pressure chamber of reservoir will be constant by adjusting the ratio of areas of high pressure chamber and low pressure chamber.

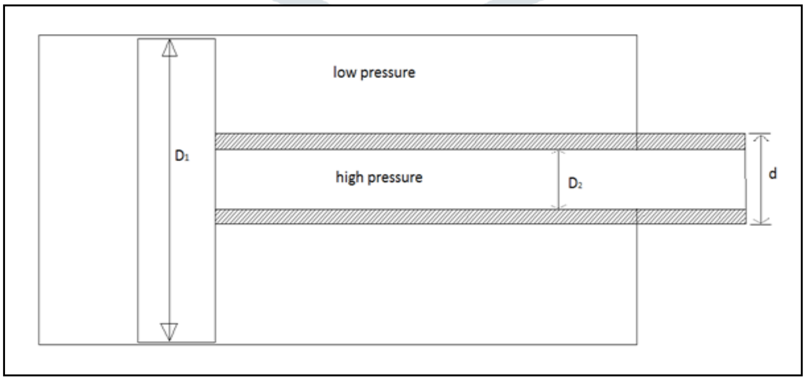

Figure 2. Bootstrap Reservoir

The equation of the hydraulic fluid in low pressure chamber is,

$$P_{low} = P_{high} \times \frac{A_2}{A_1} \quad (2)$$

The pressure of N_2 gas in high pressure chamber is 280 bar and ratio of area is 0.0168. From calculation the pressure of low pressure chamber obtained is 4.72 bar.

The AMESim model of bootstrap reservoir is shown in figure 3.

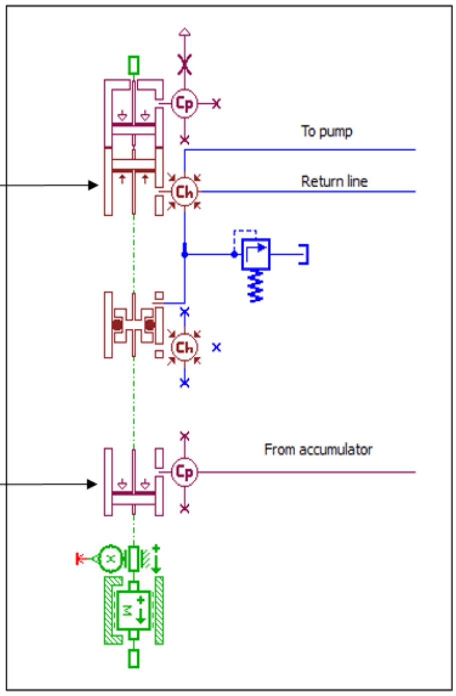

Figure 3. AMESim Model of Bootstrap Reservoir

3. Modeling of hydraulic accumulator

A hydraulic accumulator is a device that stores the potential energy of an incompressible fluid held under pressure by an external source against some dynamic force. It absorbs pulsations in pressure and supply hydraulic fluid when demand is high. The accumulator used in hydraulic system is piston type accumulator in which gas side is precharged with N_2 gas. Since the gas side of accumulator is connected to bootstrap chamber the conventional accumulator available in AMESim cannot be used. Therefore the AMESim model of accumulator is built in AMESim using hydraulic component design library.

The equation of pressure for hydraulic accumulator pressure is,

$$P_0 v_0{}^n = P_1 v_1{}^n \tag{3}$$

In this equation P_0 v_0 are pressure and volume of pre charged gas and P_1 v_1 are pressure and volume of gas when it is in use. n is the polytrophic index of gas, the value is 1 if isothermal process and 1.4 if adiabatic process. The value of n is 1 in the simulation. The precharge pressure of N_2 gas is 280 bar and is fully filled in cavity. The change in volume of N_2 gas obtained from calculations is 1.52 lit. The AMESim model of hydraulic accumulator is shown in figure 4.

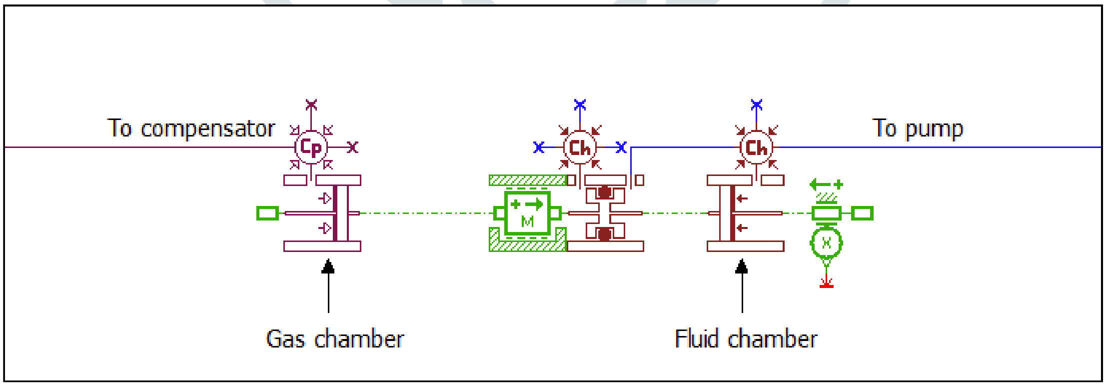

Figure 4. AMESim Model of Hydraulic Accumulator

4. Modeling of hydraulic actuator and DCV:

The direction control valve controls the direction and amount of flow of fluid from pump to the either side of the actuator. The direction control valve used is 3 position 4 ports hydraulic closed center valve. The equation for flow rate from DCV is,

$$Q = Cq \times A \times \sqrt{\frac{2}{\rho} \times \Delta p} \tag{4}$$

Where, Cq is the coefficient of discharge, ρ is the density of hydraulic fluid, Δp is the pressure drop across valve. The rated pressure drop is 12 bar, the value of Cq is 0.7 and value of ρ is 850 kg/m^3. The flow rate obtained from calculations is 53 lit/min.

The actuator is used to transform the pressure energy of fluid into mechanical energy i.e. force or motion. The actuator is connected to air brake control surface which extends and retracts by the hydraulic system. The actuator used is unbalanced double acting linear actuator. The actuator is modeled in AMESim by using hydraulic component design library. The submodel of mass with friction and end stops is used to define mass and displacement limits of piston. The equation to calculate the extension and retraction time is,

$$T_{ext} = \frac{A_1 \times x_{ext}}{Q} \quad (5)$$

$$T_{ret} = \frac{A_2 \times x_{ret}}{Q} \quad (6)$$

Where x is the displacement of piston, Q is the flow rate from DCV and A_1 and A_2 are the areas on piston and rod side respectively. The value of X is 0.68 m and value of Q is 53 lit/min. The extension and retraction time of actuator is 2.17 sec and 0.95 sec respectively. The AMESim model of actuator and DCV is shown in figure 5.

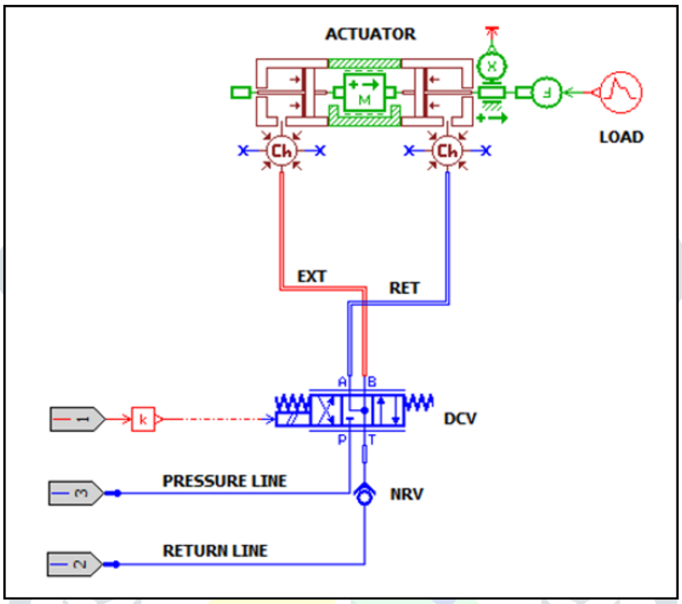

Figure 5. AMESim Model of Actuator and DCV

5. Modeling of filter and pipelines:

The filter is used to clean the hydraulic fluid from any dirt and abrasive particles. There are 3 filters are used in system for delivery, return, and circulation line. The hydraulic filter offers resistance to flow of hydraulic fluid which creates pressure drop across filter element. The standard filter model available in AMESim is used in hydraulic system model. The equation used for calculation of pressure drop across filter is,

$$\Delta P = \frac{Q \times \mu \times t}{A \times k \times \epsilon} \quad (7)$$

Where, Q is flow rate in mm^3/s, μ is viscosity of hydraulic fluid in Ns/mm^2, t is thickness of filter element in mm, A is filtering area in mm^2, k is permeability constant, and ∈ is porosity.

The pipelines and hoses are considered the same for the purpose of modeling. The material of pipes is steel. The pipelines model considers the losses in fluid flow. The equation for pressure drop in pipelines is,

$$\Delta P = \frac{\rho \times f \times l \times v^2}{2d} \quad (8)$$

Where, ρ is density of fluid, f is friction factor, l is length of pipe, v is velocity of fluid and d is diameter of pipe.

III. MODELING AND INTEGRATION OF AIR BRAKE HYDRAULIC SYSTEM IN AMESIM

AMESim model of air brake hydraulic system is modeled by integrating the individual models of swash plate axial piston pump, bootstrap reservoir, hydraulic accumulator, actuator, direction control valve and other components like filter, pressure relief valve, heat exchanger, and non-return valve. The components are connected with the pipelines according to the functional requirements. AMESim model of air brake hydraulic system is shown in figure 6.

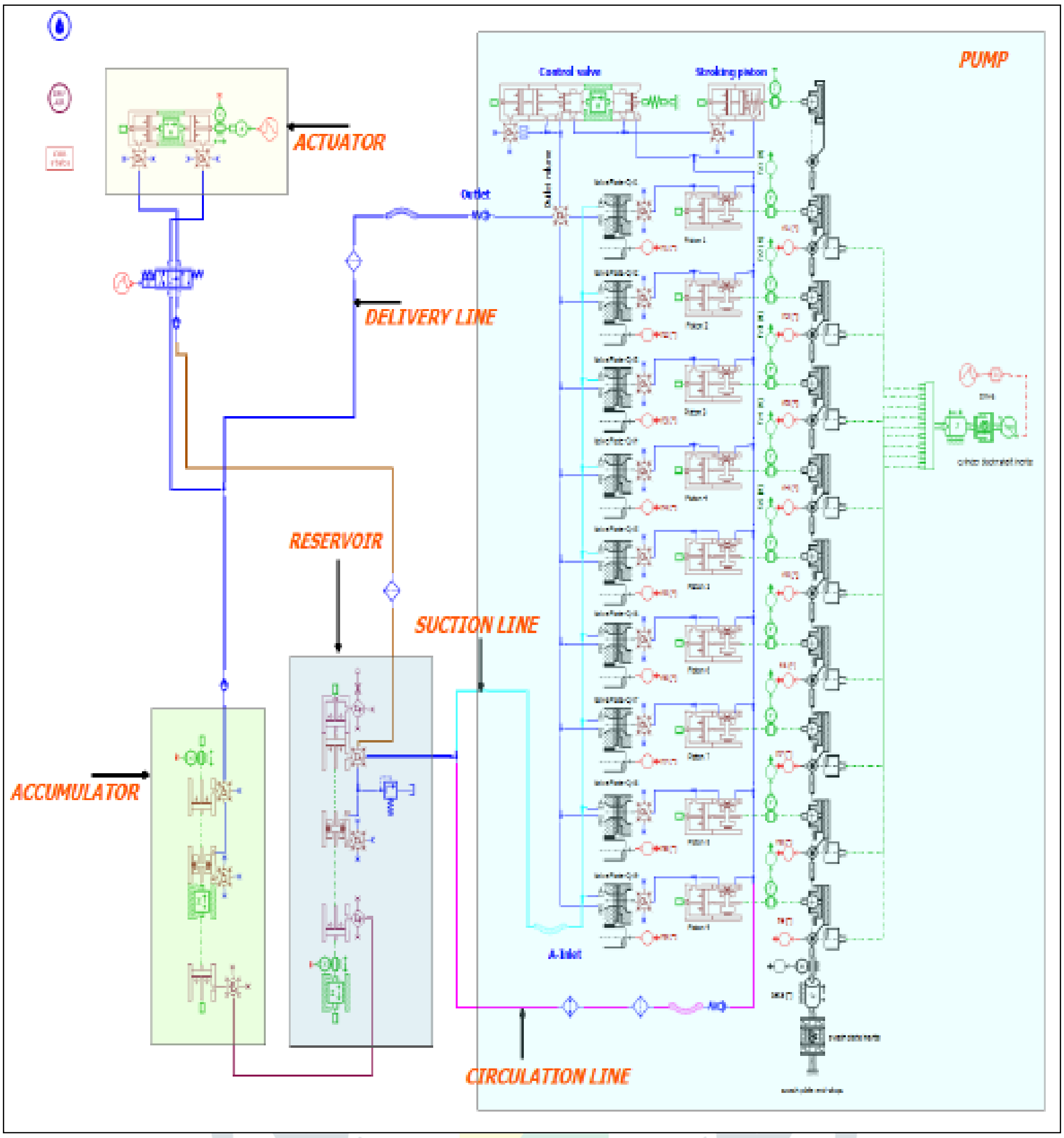

Figure 6. AMESim Model of Air Brake Hydraulic System

IV. SIMULATION OF AIR BRAKE HYDRAULIC SYSTEM

Simulation of the air brake hydraulic system is done using AMESim software. The major aim of the simulation is to determine the pressure, flow rate, pressure drop, and extension and retraction time of the system components. The inputs for simulation are rotating speed of pump in rpm, maximum swash plate pump, and input current signal to actuate the direction control valve.

The input signal for pump is given in 3 stages, for first stage pump speed is 0 rpm. In second stage pump speed increases from 0 rpm to 4200 rpm and third stage maximum pump speed of 4200 rpm is constant from 5.5 seconds to 15 seconds. The pump speed signal is shown in the figure 7.

The input signal for the direction control valve is 50 mA and -50 mA current for extension and retraction respectively, since the valve rated current in model is set as 50 mA. The input signal is given in 4 stages as shown in figure 8.

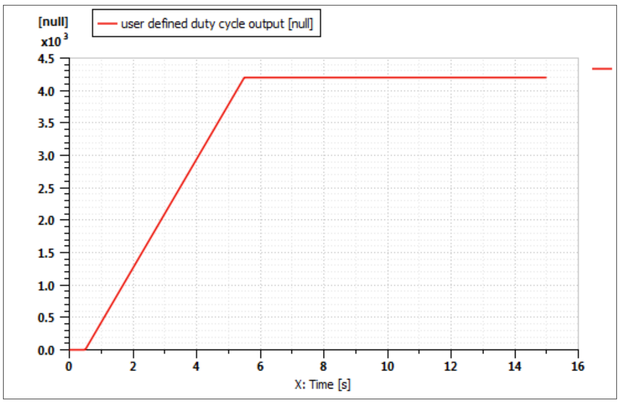

Figure 7. Input Signal to Pump

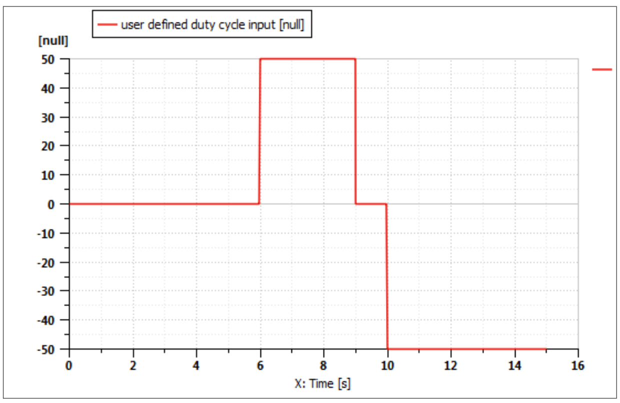

Figure 8. Input Signal to DCV

The table 1.shows the parameter set for simulation of air brake hydraulic system.

Table 4.1 Parameters of Simulation

Title	Value
Simulation time	15 sec
Print interval	0.001 sec
Pump speed	4200 rpm
Maximum swash plate angle	15 degree
Input valve rated current	50 mA

V. Results and discussion

The discharge pressure of pump with respect to time is shown in figure 9. The discharge pressure of pump remains constant at 280 bar and drops below 280 bar at the time of extension (i.e. opening of valve) and retraction (i.e. closing of valve). The variation of suction pressure of pump is shown in figure 10.

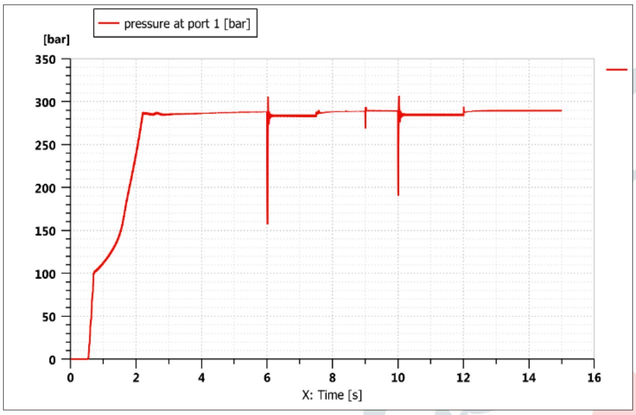

Figure 9. Discharge Pressure of Pump

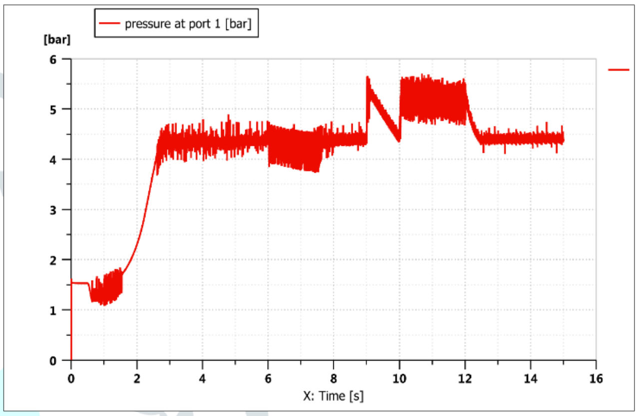

Figure 10. Suction Pressure of Pump

The discharge flow of pump is shown in figure 11. The pump flow increases initially from 0.5 seconds to 3 seconds, in this period hydraulic fluid fills the accumulator. Once the accumulator is filled with hydraulic fluid, the pump flow increases for extension and retraction of the air brake.

The variation of pressure of N_2 gas in accumulator is shown in figure 12. The initial pressure of N_2 gas is 100 bar which increases up to 280 bar as hydraulic fluid from pump fills the accumulator which is at pressure 280 bar.

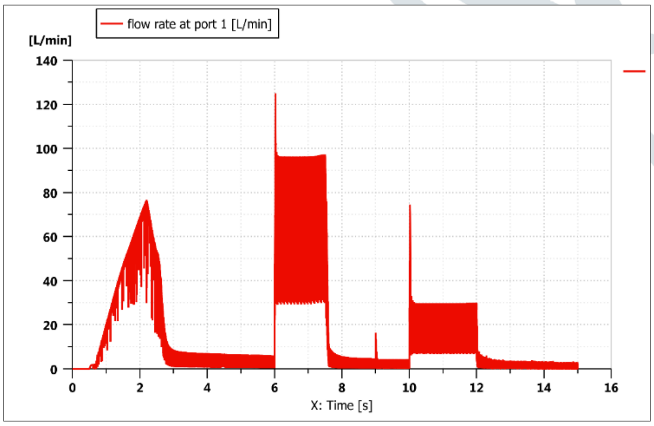

Figure 11. Discharge Flow Rate of Pump

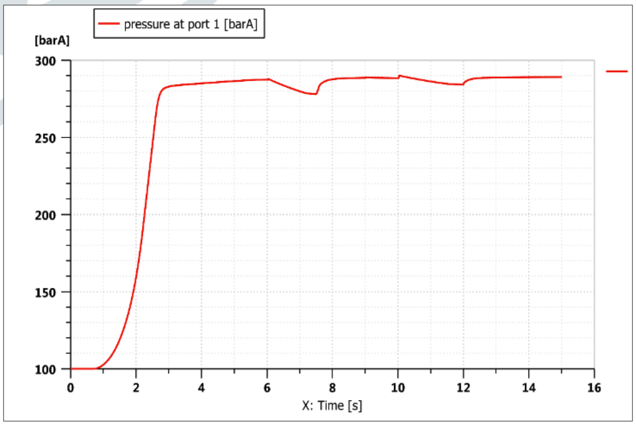

Figure 12. Pressure of N2 Gas in Accumulator

The input parameter given to filter is table of flow rate vs. pressure taken from manufacturer's catalogue. The result of simulation of pressure drop with respect to time is shown in figure 13. The maximum pressure drop is between 4 bars to 5 bars during extension of air brake when flow rate pump increases.

The extension and retraction of air brake actuator is shown in figure 14. The extension of air brake starts at 6 seconds. The total extension time for air brake is 1.6 seconds. Since the signal for retraction is starts at 10 seconds, air brake remains in extended position up to 10 seconds for 2.3 seconds. The total time for retraction is 1.6 seconds. The displacement of extension and retraction is 0.68 meter.

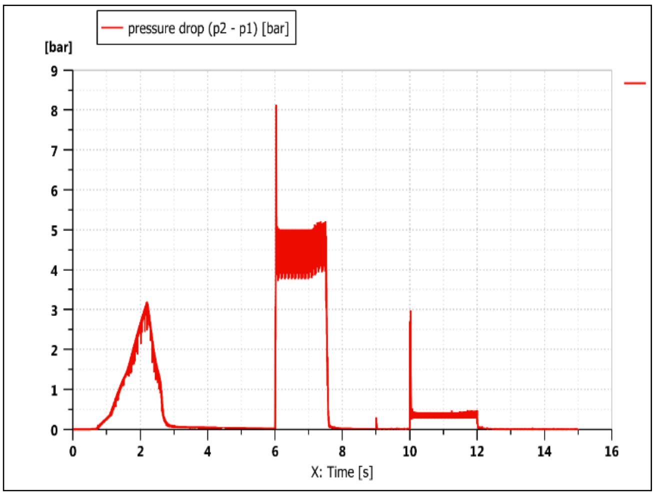

Figure 13. Pressure Drop in Filter

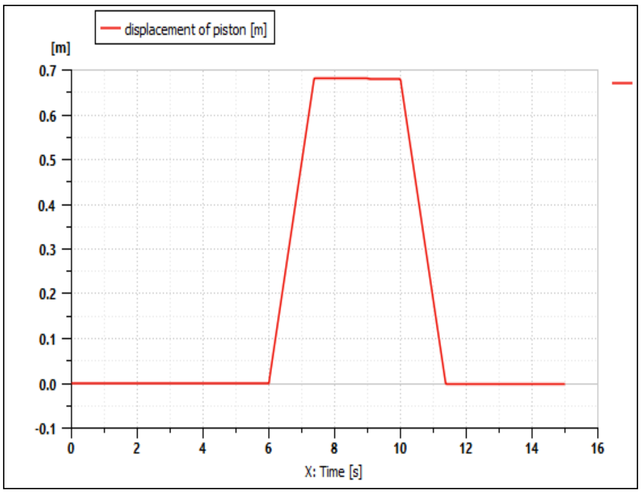

Figure 14. Displacement of Air Brake Actuator

VI. Conclusion

In this research each element of air brake hydraulic system is modeled and simulated individually and are successfully integrated to model complete air brake system using AMESim software. The integrated system is successfully simulated under normal conditions to analyze and determine pressure, flow rate, extension and retraction time of air brake. The mathematical calculations are done for the same and compared with simulation results. The AMESim model of hydraulic system can be further used for troubleshooting and fault diagnosis purpose.

VII. Acknowledgment

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