Design and Development of Pneumatic Actuator System with Directional Control Valves and Controllers

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Abstract: Pneumatic actuator system plays a major role in various automation processes. In this research a pneumatic controller is modeled using MATLAB/SIMULINK simulation software. System Identification method is used to estimate the mathematical model of a pneumatic actuator system to develop a controller. The experiment approach was used to acquire data on the system's input and output signals. In order to assess the effectiveness of the planned controllers in a real-time system, various external loads are added.

Keywords: Controllers, Directional control valve, Pneumatic Actuator, Pneumatic controller, actuating cylinder,

1. INTRODUCTION

Pneumatic actuators are also called as artificial muscles which are used in various automation industries and also in machine manufacturing processes. The pneumatic actuators have the following parameters. It has a good force to weight ratio and available at a cheaper cost. The actuators show higher accuracy, excellent positioning control and effective force control. The applications of these systems can be extended to the design of medical instruments and industrial process control. The actuator also shows eco friendly, worker safety and is more reliable than hydraulic controllers. The designs of pneumatic systems are much more difficult than other systems due to air compression, non linear dynamics and parasitic frictional effects.

The performance of pneumatic servos is better than hydraulic servos in terms of production expenses and resistance to contamination. Actuators posses higher potential stress limits, so that can be utilized even in nuclear reactors. Pneumatic actuator systems also have no effects with change in ambient temperatures. Exhaust gases need not be collected from actuators so there is no fluid pipelines are required. The pneumatic systems are virtually dry, so there is no need of any long term storages. The necessasity of pneumatic systems are in demand due to their higher flexibility and high weight to torque ratio.

Markov et al, 2009, developed a standard PID controller for non linear applications that require higher actuator rigidity and accurate precision for positioning. In order to increase the system response a linear neural model based predictive controller (LNMBPC) has been developed by combining artificial neural network (ANN) and model based predictive control (MBPC).

A new precise position control technique for servo pneumatic actuator systems have been established by Jihong et al. (1999). A modified PID controller has been employed to manage a pushing mechanism in sugar candy packing process. The aforesaid technique posses higher rate of positioning control and accuracy for the production industries.

Nagarajan et al. (1985) proposed a decision controller that delivers the decisions in a loop that can modify the process of pneumatic servo drives with a closed loop control action. This proposed work results in improvement with the response time, improved system accuracy and with accurate positioning control.

(SyNajib et al) established a study on non linear gain with modified PID controller. The automatic changes in non linear gain can reduce the system errors. The proposed non linear gain system exhibits higher robustness with non linear changes in load variations. Amin et al, 2011 developed a control strategy called LQR control that can provide a better performance in the control operations using non linear PID controllers in non linear system a[applications.

The size of the state feedback controller can be reduced by employing a LQR controller. A feedback gain matrix has been constructed in order to minimize the objective function of the problem in order achieve the goal of balance between controller magnitude and speed of response of the system. Also this system can increase the system stability in a promisable limit.

Jian-Bo, He et al, 1998 developed a controller that can process a single input single output system (SISO) with a phase margin limit of 60 degree to infinity. Jian- Bo, He et al, 1998 made an experiment in LQR solutions that are suitable for time delayed systems with effective tuning systems.

2. METHODOLOGY

Figure 1 shows the basic block diagram of a pneumatic actuator. The system consists of a compressor, directional control valves, a pressure relief valve, filters, a silencer, control valves, and a pneumatic actuator. Pneumatic actuators, also known as pneumatic cylinders, are extremely dependable and safe motion control devices that convert energy into rotary or linear motion.

Control valves are widely used in process control industries. The frequent opening and closing of valves need an automatic pneumatic control for their effective operations. In some industries it is not possible to operate the control values due to their higher hazard levels. In this situation control valves with pneumatic actuators is good choice for control operations.

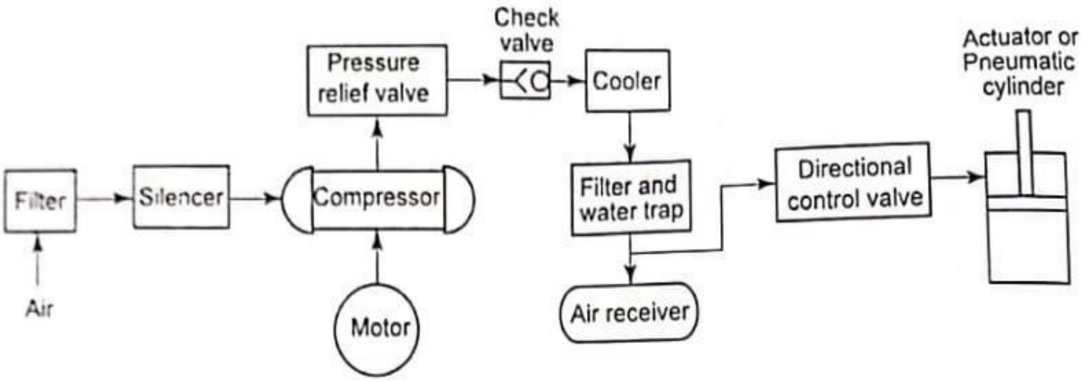

Figure 1.Basic block diagram of a pneumatic controller

In some pneumatic actuators position movements and diaphragm are available. The operational energy can be increased by the effective usage of compressed air in the actuators. The movement of piston is due to the air compression force and pressure. Mechanical movements can be adjusted by using control valves with air circulation. Two important factors that can influence s the actuator system they are absorption properties and high compression of air. This will increases the system safety when compared to other gases. The kinetic energy can be controlled effectively buy using pneumatic actuators in the industrial manufacturing environment.

MATLAB/SIMULINK Model For Pneumatic Actuator System

The graphical user interface (GUI) in the MATLAB/SIMULINK can be used for the estimation and analysis of linear and non linear control system models. The mathematical models and user defined dynamic system models can be developed using this software. Both the time domain and frequency domain analysis can be made easy. The state space models also made easy by using this software for multiple input and multiple output (MIMO) systems. The system identification tool box in MATLAB includes maximum likelihood, prediction-error minimization (PEM), subspace system identification, and other identification techniques. The software also be used for system forecasting applications.

When compared to single acting actuator the double acting actuator system is made up of Translational Mechanical Converter blocks that provide an interaction between the translational mechanical system and a gas network. When the valve spool moves to its maximum position during simulation in the positive displacement then the actuator reaches its maximum stroke. When the spool is at center position when load increases. The valve spool moves towards negative maximum direction, the actuator reacts to its shortest stroke. The circuit can dissipate the pressure when the thermal convection increases between pipes and the environment.

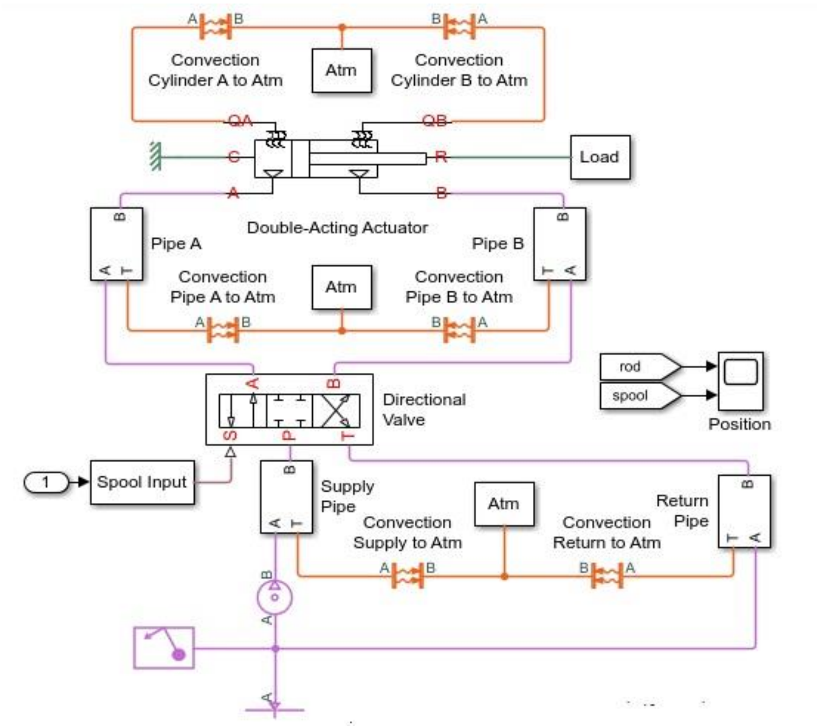

Figure 2. MATLAB / SIMULINK model for Pneumatic actuator system

Figure 2 depicts how the components can be combined to create a controlled pneumatic actuator model. When the directional control valve operates then the actuator system can open and close the system path way. The valve is operated by a subsystem which is made up of Variable Local Restriction blocks.

Double activating controller sub system

The valve position control can be achieved by double action control valves (sides open and close). Most commonly used valves in most industrial process are ball valve, control valve, choke valve, spring return actuators and double acting actuators. Figure 3 depicts the MATLAB/SIMULINK subsystem configuration for a double actuating controller.

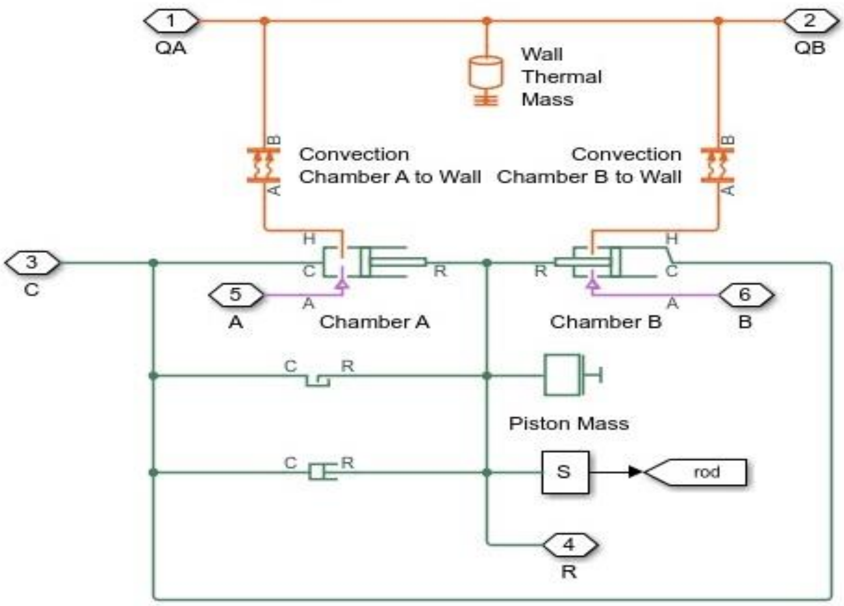

Figure 3. Sub system illustration of a double actuating controller

The spring return actuator is a valve position control device that seals or opens the valve using spring force. We only need to pressurize one side of the valve to make it work. The valve is operated solely by the double acting actuator via a piston. We must alternately pressurize both sides of the actuator to open the valve.

Directional valve subsystem

Valve ports, which provide a pathway for flow to or from other components/sources, allow fluids or gases to flow into diverse paths from directional control valves. They are an essential component of hydraulic and pneumatic systems. A manually or electrically controlled spool inside a cylinder makes up a directional control valve. The location of the spool enables or restricts fluid flow within the channel; this happens quickly, causing fluid to accelerate and decelerate quickly.

Figure 4 depicts the subsystem layout of a directional valve using MATLAB/SIMULINK. Directional Hydraulic Control In the agricultural, industrial, and mobile industries, valves are used to provide smooth operation, low pressure drop, and quick reaction for accurate fluid control in a lightweight valve. These valves have a 2000 psi pressure rating and a flow rate of 10 GPM. They are in high demand due to their versatility, and they are used in a wide range of applications.

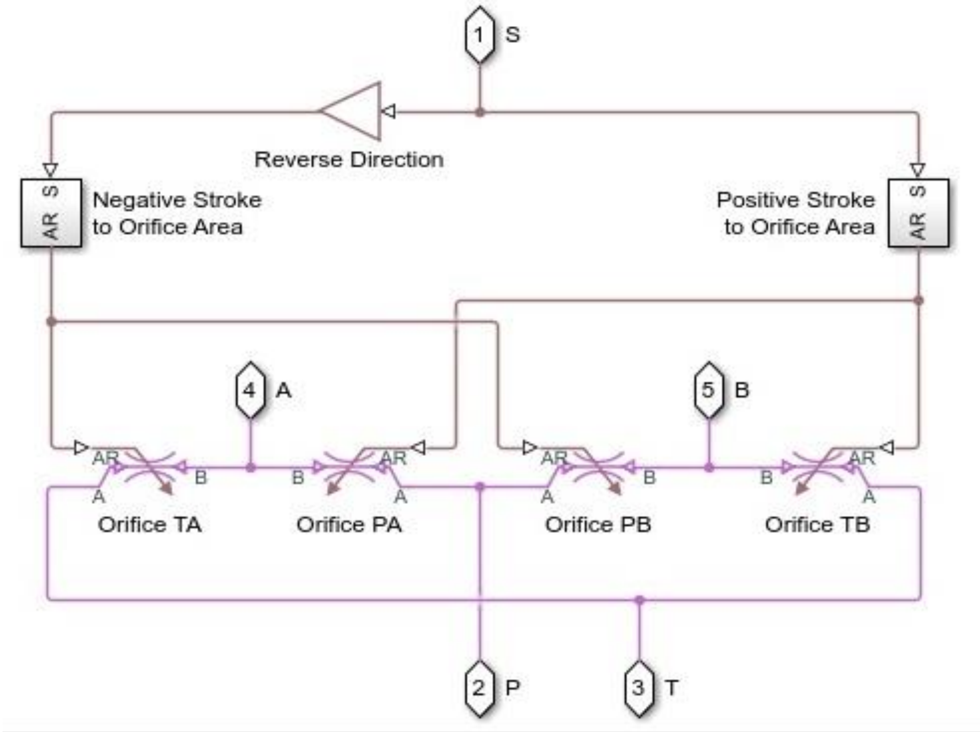

Figure 4. subsystem model for directional valve

A movable spool inside a cylinder with lands and grooves is typical of a directional control valve. The spool is normally manually or electrically driven, and its position controls the fluid channel by restricting or allowing flow. The grooves on the spool, for example, allow oil or gas to flow around the spool and through the valve body, whereas the lands on the spool prevent oil passage through the valve body.

Supply pipe sub system

In pneumatic systems, for the compressed air transport hoses or tubes can be used. Compressor oil condensation and dust particles are the major pollution by products of compressed air. These pollution products severely affect the environment. The hoses are tubes should withstand higher amount of stress and temperature

Tubes are generally made up of single layer materials also called monolayer substances. The tubes are chemically inert materials and also they are water proof for hoses, several layers of materials will be used. As a result, while the inner hose material should be resistant to compressor oils and condensate, the outer shell should be made of a different material to protect it from the elements. Figure 5 depicts a supply pipe subsystem topology created in MATLAB/SIMULINK.

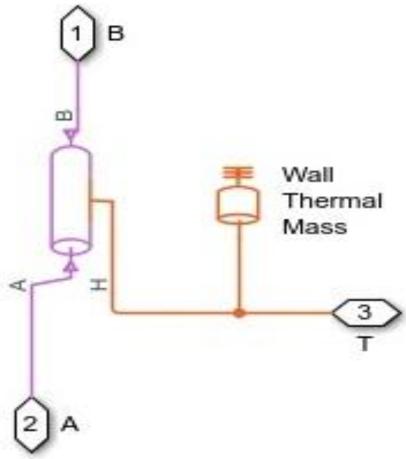

Figure 5 supply pipe system for pneumatics

Flexible tubing or hoses are used to link pneumatic components like valves, cylinders, and pressure regulators to the main air supply line. They can, however, be strengthened, such as a metal-plastic pipe, which provides for toughness while remaining light and flexible. Flexibility is vital since the components may vibrate or move, therefore a flexible hose will take this into account. They're also near the conclusion of the pneumatic cycle, thus they can have the lowest diameter required. They use fittings to connect to the main air supply line and individual components.

3. SIMULATION RESULTS AND DISCUSSION

For multiple trial runs, the intended pneumatic system has been simulated. When employed in linear motion control applications, pneumatic actuators can produce great force and fast movement rates. This is because of the device's use of air pressure and flow.

From figure 6 through figure 8, the simulation output from the pneumatic systems is shown. The simulation output of the suggested pneumatic actuator system is shown in Figure 6. The spool position of the control valve is shown in millimeters, whereas the actuator rod positions are shown in metres. At a 2.5-second interval, while the spool position is at 5 mm, the corresponding rod position is at 0.2 m. From 3.5 to 6.1 seconds, the actuator rod reaches its greatest value of 0.2 m. The valve spool position has the lowest value of -5 mm and the largest movement of 5 mm.

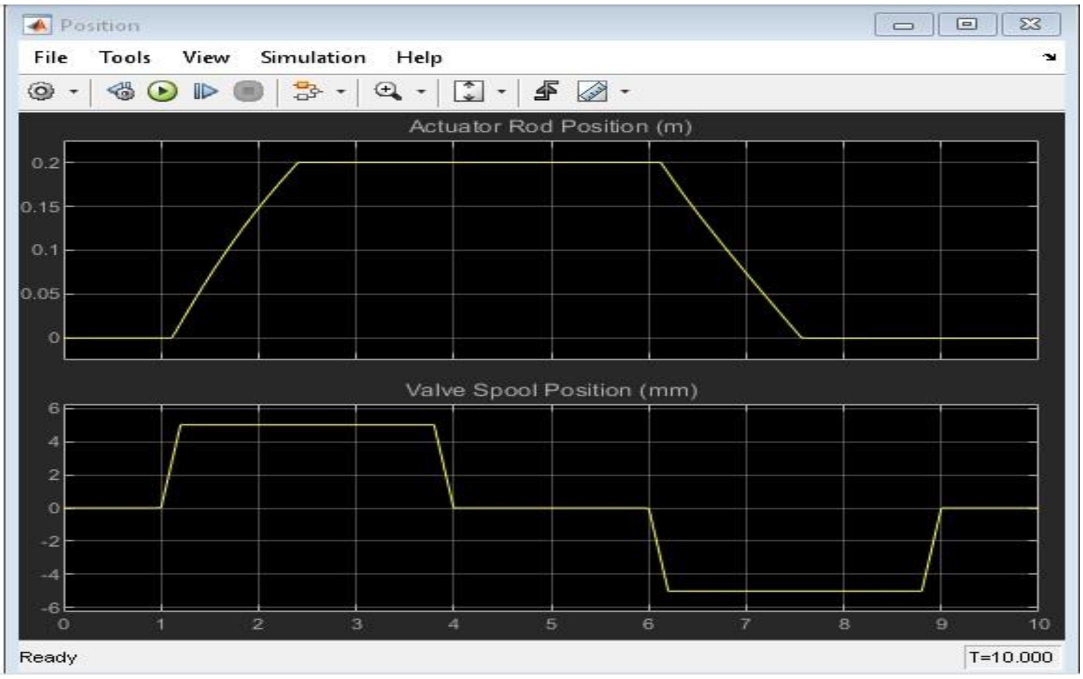

Figure 6 Pneumatic actuator system response with valve spool position movement

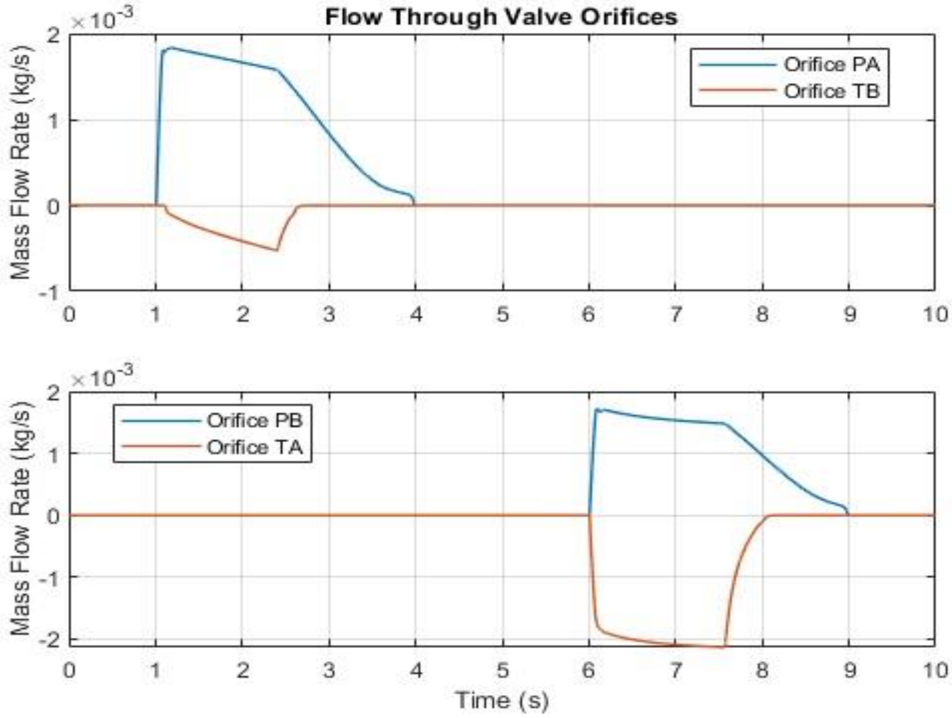

Figure 7 simulation output for flow through valve orifaces

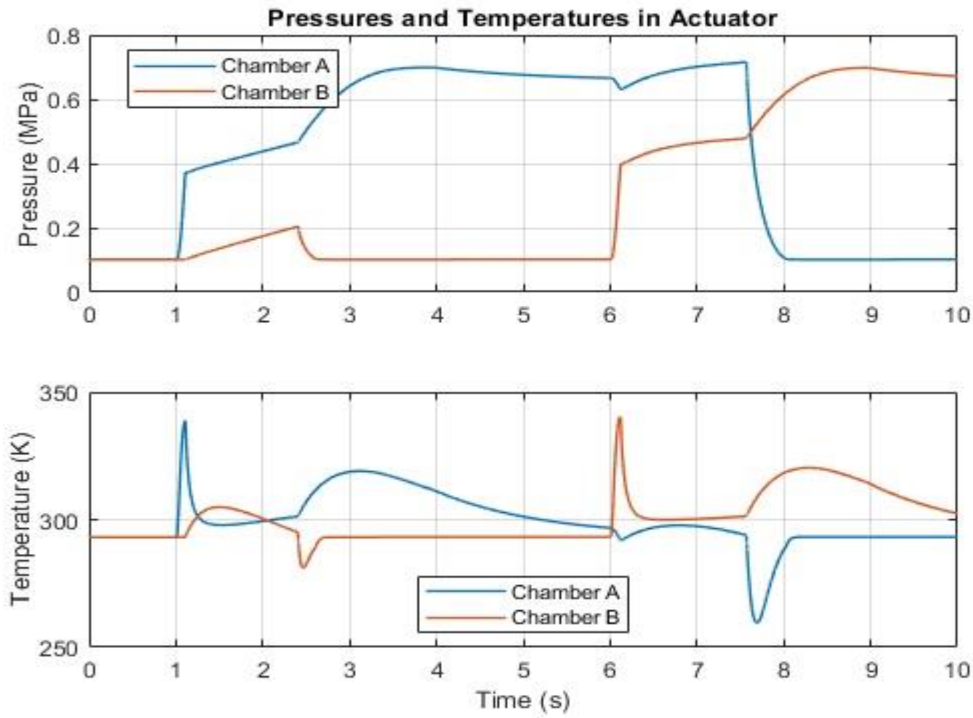

Figure 8 simulation output for pressure and temperature in actuator

The orifice output of the PA and PB is shown in blue, while the orifice output of the TA and TB is shown in red. The graph depicts the mass flow rate in kilogram's per second. 1.9 x 10-3 kg/s is the largest mass flow rate achieved. The pressures and temperatures inside the actuator chambers A and B are depicted in Figure 8. Chamber A has a maximum pressure of 0.75 MPa, while chamber B has a maximum pressure of 0.73 MPa. The maximum temperature reached in both chambers A and B is 340 K, indicating that the pressures and temperatures in both chambers are safe. Orifice PA and Orifice TB open when the valve spool position is positive, allowing gas to flow from port P to port A and port B to port T. Orifice PB and Orifice TA open when the valve spool position is negative, allowing fluid to flow from port P to port B and from port A to port T.

4. CONCLUSION

Using linear controllers, the suggested pneumatic actuator system provides a simple way to control a nonlinear system. It has been used to successfully construct the optimal linear discrete model for a pneumatic actuator system. The control valves were successful in controlling the actuator rod locations. Inside the chambers, the pressure and temperature are both acceptable. Nonlinear systems can be effectively controlled with the proposed actuator system.

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