Modeling for assessing the dynamic performance of pneumatic valve  
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ABSTRACT – The fundamental control system for an electro-pneumatic valve is explained where this work discusses of the mathematical model and MATLAB program used in controlling system of pneumatic valve. This paper presents an approach to assessment of the dynamics performance of pneumatic valves.

1. INTRODUCTION

Pneumatic is one of preferred power source in industries due to it is simple, cheap, easy to handle and maintenance and has a high degree of controllability. Within the pneumatic system, valve plays a significant role in controlling fluid flow into different paths from one or more sources. In getting a good results in pneumatic system operation, users need to monitor and control the valve operating condition. Therefore, this requires the development of suitable control techniques in order to deal with nonlinearities that are common in valve[1].

2. BACKGROUND

Pneumatic valve commonly consists of a body with ports that are connected to internal flow passages by spools inside a cylinder. It is can be controlled either mechanically or electrically controlled. The movement of the spool restricts the flow of fluid. Thus the valve controls the fluid flow. Another typical application of this valve is to control the rate of air flow under a given set of pressure condition[2]. The pneumatic valve works when it is actuated either by actuator, followed by movement of spool or end with emission of gaseous.

3. BASIC CONTROL SYSTEM

The basic mathematical model and control block diagrams will be utilized in modeling control system of pneumatic valve.

3.1 Mathematical Models

Mathematical models relating the various physical parameters may predict and improve the performance of the valve. This paper focuses on electro-pneumatic valve and the mathematical model involved can be separated into three major distinct parts, which are magnetic circuit, mechanical subsystem and air flow path (see Figure 2).

![Basic mathematical model](Image)

Figure 2 Basic mathematical model

3.1.1 Magnetic Circuit

In general, the mathematical model of the magnetic circuit can be concentrated to the electromagnetic force, magnetic flux and air gap[3]. Below are the mathematical model for the magnetic circuit.

a) Electromagnetic force on the armature

\[ FM = \frac{\partial^2 A_0}{\partial I} \]  

where

- \( B \) = the magnetic flux density
- \( A_0 \) = the cross-sectional area of the air gap
- \( \mu_A \) = the magnetic permeability of air

b) Magnetic flux

\[ B = \frac{\Phi}{A_0}; \quad \Phi = \frac{\mu_A A_0 I n_c}{L_M} \]  

where

- \( \Phi \) = magnetic flux
- \( A_0 \) = the cross-sectional area in the air gap
- \( \mu_A \) = the magnetic permeability of air
- \( I \) = the current of the control signal
- \( n_c \) = the number of turns in the solenoid coil
- \( L_M \) = the magnetic circuit length

c) Current control signal

\[ FM = \frac{\partial F}{\partial I} (I - I_1) + \frac{\partial F}{\partial y} y \]  

where

- \( \partial F/\partial I \) = the electromagnetic stiffness by a control signal current
- \( \partial F/\partial y \) = the electromagnetic stiffness by an armature movement
- \( I \) = the current of the control signal
- \( I_1 \) = the value of the control signal current when the valve armature begins to move
- \( y \) = the stroke of the armature

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3.1.2 Mechanical Subsystem

The mathematical model of mechanical subsystem can be concentrated on the motion of the valve plug together with solenoid armature.

Figure 3 Spool valve schematic diagram (source: [3])

a) Motion of the valve plug together with solenoid armature[3]

\[ m_V \ddot{y} + b_{VV} \dot{y} + k_{SV} (y_0 + y) + F_{VF} = (P_1 - P_2) A_{VE} + F_M \] (4)

where

- \( A_{VE} \) = valve effective area
- \((P_1 - P_2)\) = differential pressure across the plug
- \(m_V\) = the armature and plug assembly mass
- \(b_{VV}\) = the viscous friction coefficient
- \(k_{SV}\) = the valve spring constant
- \(y_0\) = the valve spring compression in the valve closed position
- \(y\) = the valve plug displacement
- \(F_{VF}\) = the coulomb friction force
- \(A_{VE}\) = the valve plug effective area
- \(F_M\) = the solenoid electromagnetic force

3.1.3 Valve Flow Ability

The most important parameters of control valves are their flow ability and control valve effective area[3].

a) Mass flow rate (flow capacity)

\[ G = A_V \beta P_{in} \sqrt{2 \alpha \frac{k R T_{in} (k-1)}{k-1} \phi(\sigma)} \] (5)

where

- \( A_V \) = valve area
- \( \beta \) = the degree to which the control valve is open
- \( T_{in} \) = Test medium air temperature
- \( k \) = constant
- \( \sigma \) = critical value
- \( P_{in} \) = the upstream pressure

b) Control valve effective area

\[ A_V = \frac{G}{\beta P_{in} \phi(\sigma)} \sqrt{\frac{2 \alpha R T_{in} (k-1)}{k-1}} \] (6)

where

- \( G \) = mass flow rate
- \( \beta \) = the degree to which the control valve is open
- \( \beta_{in} \) = the density of air under standard conditions
- \( T_{in} \) = Test medium air temperature
- \( k \) = constant

3.2 Control System Block Diagrams

The control diagram below represents free body diagram and block diagram of pneumatic valve.

Figure 4 Control diagram of electro-pneumatic valve

4. METHODS

Figure 5 depicts the process flow for identifying result in this project. Begin with identification of the DCV basics. Next, modeling the control system of DCV. Lastly, evaluate response of DCV control system.

Dynamic performances of electro-pneumatic valve are illustrated below. Graph A represents mechanical part and graph B represents electrical part while graph C represents the air flow rate part.

Figure 6 Dynamic performance of electro-pneumatic valve

5. SUMMARY

Mathematical model control system of pneumatic control valve has been identified. To account the control system, we have to analyze the underlying mathematical model with respect to the selected valve. Examining the control system through the mathematical models is the most efficient method whereby this work suggests it is possible to analyze and evaluate the dynamic performance of an electro-pneumatic valve.

6. REFERENCES