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MAIN MENU
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Development of a Nonlinear Dynamic Model for a Servo Pneumatic Positioning System

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Abstract **– A parametric dynamic model of a pneumatic servo system is useful for its computer simulation, mechatronic design and control algorithm design. Pneumatic servo positioning systems have advantages that include: inexpensive, clean, safe and high ratio of power to weight. However, they are difficult to accurately model. In this paper a methodology for deriving a nonlinear dynamic model for a pneumatic servo system is presented. The model includes cylinder dynamics, payload motion, friction and valve characteristics. Methods for estimating the model parameters from simple experiments are also described. It is shown that the standard mass flow rate valve model is not well suited to an open-center proportional valve. A new valve model is developed that more accurately fits the measured data. The proposed modeling methodology does not require special measurement equipment or disassembly of the system hardware. This is an advantage for a pneumatic servo system that is in continuous use. Experimental results demonstrating the ability of the model to predict the measured piston position and cylinder chamber pressures are included.**

I. INTRODUCTION

A parametric dynamic model of a pneumatic servo system is useful for computer simulation, mechatronic design and control algorithm design. The earliest study on the modeling of a pneumatic servo system was published by Shearer in 1956 [1]. His system consisted of a double rod cylinder driving a payload mass and controlled by an open-center servo valve. He derived a set of nonlinear differential equations representing the system dynamics based on five laws of physics. Specifically, these were: first law of thermodynamics, flow continuity equation, ideal gas equation, mass flow through a smooth orifice, and Newton's second law of motion. A similar model was presented in 1980 in [2]. These two important references have formed the basis for most of the modeling research published to date. Derivations of similar nonlinear models have been presented in many recent publications, for example [3-7]. The only other nonlinear modeling approaches have involved using neural networks or fuzzy logic. For example, a Takagi-Sugeno fuzzy model was used to model a pneumatic servo in [8].

In the literature the "standard model" based on [1,2] is often assumed without experimentally testing its applicability to the hardware being modeled. There is also very little information in the literature on how to obtain accurate values for the model parameters. The goal of this paper is to address these deficiencies. In our previous paper [9], we presented the final equations for the system model without providing any information on how they were derived, since the focus was on closed-loop control. In this paper we describe our system hardware in section II. The derivations of models for the cylinder, payload motion and friction are presented in section III. The valve model is modeled in section IV. In section V the algorithm for computer simulation of the model is given. The model validation is described in section VI and conclusions are drawn in section VII.

II. SYSTEM STRUCTURE

A schematic diagram of the pneumatic system is shown in Figure 1. The chamber on one side of the piston is denoted chamber *A* and the other side is denoted chamber *B*. The absolute pressure inside chamber *A* is termed p_a and the absolute pressure in *B* is termed p_b. Atmospheric pressure is denoted p_0. The hardware has been designed to allow the payload mass, type of linear slide and type of cylinder (*e.g.* single rod or rodless) to be changed easily. The orientation can also be altered to be vertical or horizontal to change the gravity loading. This flexibility allows testing to be performed over a wide range of conditions. The piston position is measured by a linear incremental encoder with a 0.01 mm resolution. The proportional valve is an open-center type (Festo model MPYE-5-1/8). Two pressure sensors are connected to the two chambers of the cylinder. The valve,

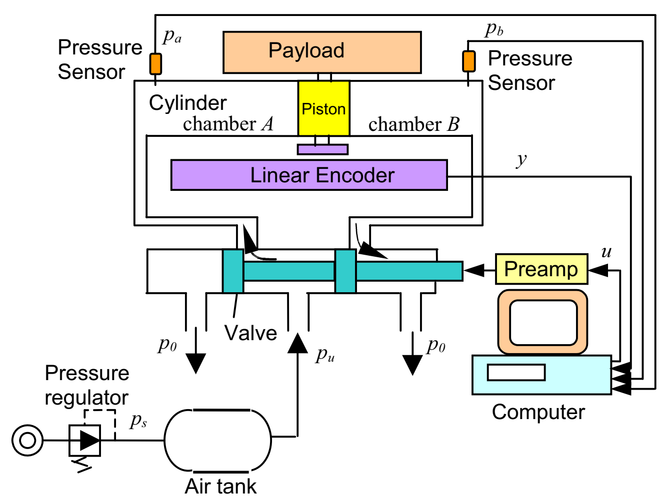

Figure 1. Pneumatic servo positioning system hardware