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ScienceDirect

Procedia Engineering 177 (2017) 331 – 338

Procedia Engineering

www.elsevier.com/locate/procedia

XXI International Slovak–Polish Conference "Machine Modeling and Simulations 2016"

Concept of improving positioning of pneumatic drive as drive of manipulator

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Abstract

The paper presents a mathematical model of pneumatic actuator based on a piston rod air double acting cylinder. The model was solved using MATLAB Simulink. The results of model simulations were compared with experimental results and the drive control system was proposed. The article also includes the concept of the control system of pneumatic drive equipped with electromagnetic brake. The application of the brake is to increase the accuracy of the positioning of the actuator piston, which in turn will enable the use of this drive in the structure of parallel kinematic manipulator. Presented research provides preliminary data for assessment of the improvement of air cylinder control.

Peer-review under responsibility of the organizing committee of MMS 2016

Keywords: pneumatic drive; control system; controller; mathematical model; simulation;

1. Introduction

Owing to a wide range of operating force pneumatic drives are widely used in robotics and automation systems [1-4]. They are easy to maintain in clean condition and feature a high reliability with a relatively low investment cost to buy the pneumatic system components [5-7]. The typical cylinders have both the cylinder and the cylinder rod sealed with elastomer packing rings resulting in non-linear frictional resistance and stick-slip effect. The result is irregular linear motion of the piston at low speeds [8, 9]. This affects the positioning accuracy of the cylinder piston. As a result the range of application of conventional air cylinders as active kinematic pairs in manipulator's kinematic structures is considerably reduced.

A number of currently undertaken research projects are devoted to find methods limiting the unwelcome effect of friction. In one of such methods nano-meter sized particles are added to the packing lubricant [10].

The paper presents preliminary results of the mathematical model of double acting pneumatic cylinder, which are crucial for assessment of positioning performance. Simulation studies are used to develop methods to improve the accuracy of positioning of the actuator [11, 12]. The results of simulation experiments of classic pneumatic drive as presented below, are intended to be used for development of a mathematical model of a pneumatic drive system equipped with external electromagnetic brake. The premise for the application of the brake is to increase positioning

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1877-7058
Peer-review under responsibility of the organizing committee of MMS 2016
doi:10.1016/j.proeng.2017.02.234

accuracy, maintain a constant setpoint position of the piston and to shorten positioning time. This will allow to use such a drive in parallel manipulator [13, 14] and build its prototype to enable carrying out experimental tests.

Nomenclature

p_1, p_2	pressure in chambers No. 1 and No. 2 respectively [Pa]
p_a, p_M	atmospheric pressure and the air pressure in the main line [Pa]
γ_M	specific gravity of air supplied from the main line [N/m^3]
κ	adiabatic exponent
x_0	initial volume co-ordinate [m]
x, $\dot{x}$	piston travel distance [m] and speed [m/sec.]
s, u	stroke [m], spool position
$\dot{m}_1$, $\dot{m}_2$	mass flow rate to chamber No. 1 from chamber No. 2 [kg/sec.]
R	gas constant of air [J/kg K]
A_1,A_2	piston area [m^2]
$V_1(t)$, $V_2(t)$	volumes of cylinder chambers (No. 1 and No. 2) [m^3]
g	acceleration due to gravity [m/sec.^{2}]
f_e	effective inlet/outlet port area
c, F_t	viscous friction coefficient, mechanical friction force [N]
T_1, T_2	temperature in chambers No. 1 and No. 2 respectively [K]

2. Mathematical modelling of the motion of a double acting cylinder piston

A complete dynamic analysis of a typical air cylinder covers the extend and retract (return) stroke times, which can be divided into:

- piston start-up time – time between the control command and the moment at which piston starts to move,
- piston travel time – time of piston travel to the end of stroke,
- dwell time at the end of stroke – pressure build up time.

This paper focuses on time of piston travel to determine the change of position over time and the pneumatic actuator positioning capability. Changes of pressure and temperature over time when the piston is a at a standstill during the start-up and dwell times were not considered. However, a detailed analytical model should consider the thermodynamic processes involved, heat exchange and leakages – both internal (transfer of air from a chamber with higher pressure to a chamber with lower pressure) and external (leakage of air to the atmosphere) [15]. Figure 1 presents the computational diagram of the analysed double acting air cylinder and the schematic of the accompanying manifold [16].

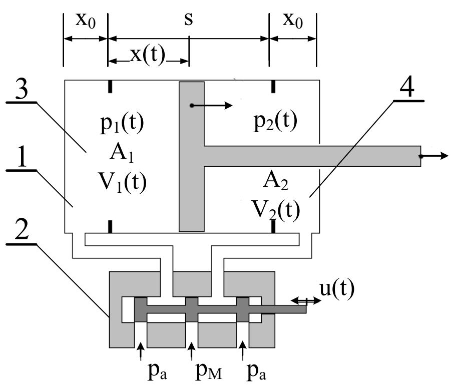

Fig. 1. Air cylinder and manifold: 1 – cylinder, 2 – manifold, 3,4 – cylinder chambers.