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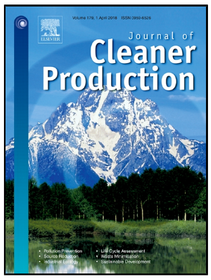

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ABSTRACT

As one of the most widely used power sources in the engineering field, compressed air is especially common in industrial applications. In a traditional pneumatic circuit, a three-position five-way valve is used to control the air inlet and exhaust with a single pressure, which has low efficiency. This paper proposed a novel bridge-type circuit with variable pressure control using four on-off valves to improve the energy efficiency of compressed air for pneumatic actuators. The key idea of the method was to use air expansion energy to do work. Reducing the volume of consumed air was the goal, and a numerical method was presented to calculate the optimal on-off time sequence of the four valves using nonlinear dynamic optimization. The sequence was obtained based on the combination of a finite element polynomial configuration method and a reduced space sequential quadratic programming algorithm. Then, experimental validation was conducted to illustrate the energy efficiency, including pneumatic cylinder motion test under different conditions. Compared with the traditional circuit, the experimental results show that the bridge-type circuit put forward by this paper can significantly improve the energy efficiency of pneumatic driving systems by 50-70%. Additionally, the bridge-type circuit allows the piston to move smoothly to the end of the stroke, which can take the place of the function of cushion component and speed control valve of the traditional circuit.

Keywords: pneumatic actuator system; energy efficiency; bridge-type circuit; variable pressure control; nonlinear dynamic optimization

1 Introduction

Compared with other actuators, pneumatic actuators have the advantages of low cost, large output force/weight ratio, rapid response, strong adaptability to various circumstances, and long life. They are also very adaptive for linear motion load and have been widely used in industrial production (Bunse, K., 2011). However, during pneumatic conversion and transmission, compressed air loses a large amount of energy (Yang, A., 2009). Nearly 60–90% of input work is wasted as heat, so the pneumatic actuator system has low energy efficiency (Yusop, M. M., 2006). Energy consumption in the pneumatic system has two main components: the first is the utilization of compressed air power, and the second is the use of air consumption in the pneumatic circuit (Saidur, R., 2010; Shaw, D., 2013). This paper focuses on a strategy to improve the utilization rate of compressed air in the pneumatic actuator system.

The pneumatic cylinder is the most widely used actuator in pneumatic systems. Many manufacturers of pneumatic components attempt to provide energy savings by changing the structure of the cylinder, but the effect is not significant, so savings are limited. Traditional pneumatic drive systems are controlled by a single pressure with a three-position five-way reversing valve. The pneumatic actuator maintains the inlet chamber's air pressure supply throughout the trip time, and the exhaust chamber remains connected with the atmosphere, whereas the return process involves the opposite conditions; this will inevitably lead to a relatively low utilization rate of air energy. In recent years, many scholars have achieved the aim of saving compressed air by changing the combination of pneumatic valve and cylinder (Jihong, W., 2000).

Beater (P. Beater., 2007) proposed that a pressure relief valve could be added in the rod chamber to control the inlet pressure of the rod cavity under the greatest pressure set by the relief valve. Results showed that the air pressure when the cylinder piston returned was below the pressure when the piston stretched out, and this system could reduce energy usage by 25%. The same method was used in a vertical test bench in which the piston moved upward with high-pressure air to lift the load and moved