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A continuously variable hydraulic pressure converter based on high-speed on–off valves

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ABSTRACT

A continuously variable hydraulic pressure converter utilizing high-speed on–off valves is studied in this paper. The hydraulic pressure converter is analogous to a switchmode buck converter in power electronics. Substituting the electronic components in the buck converter with their hydraulic counterparts, a hydraulic pressure converter is built. The steady state and fluctuation characteristics of the hydraulic pressure converter are studied in both the theoretical analysis and the simulation. The hydraulic pressure converter was built and tested. Experimental results show that the system output pressure can be continuously adjusted by changing the duty ratio of the PWM signal supplied to the high-speed on–off valve. Although there is fluctuation on the output pressure, the system output pressure has a quasi-linear relationship with the PWM signal duty ratio. Results also show that the output pressure fluctuation is greatly influenced by the PWM signal frequency and the flywheel inertia. The hydraulic pressure converter based on high-speed on–off valves brings a new way to transform system pressure continuously.

1. Introduction

Digital hydraulic systems are considered as a competitive alternative to traditional control with servo or proportional valves. Important benefits of digital hydraulic systems are low throttling losses, good repeatability, low sensitivity to contamination and low cost. It also enables more intelligent control since various system configurations can be made through different valve arrangements, such as parallel or series connected on–off valves [1]. Digital hydraulic systems are classified into three types. The first type is the traditional on–off technology in which the system output has only two discrete values, such as pump/motor rotating or stopped, cylinder moving or stopped. Traditional on–off technology has not been studied too much nowadays. However, it is still the best solution for cases in which the control characteristics can be tolerated, and the approach is very popular in pneumatic systems.

The second type is the digital hydraulic system consisting of parallel-connected on/off valves. The system is truly digital as the system output has only discrete values. The on–off valve development and the control technique have resulted in extensive research of this technology since 2000 [2]. The system is fault tolerant and the failure of single valve does not prevent the use of the actuator [3]. However, a rather complicated controller is required for the synchronous valve switching [4]. Moreover, large numbers of valves are needed to achieve high flow rate resolution.

The third type is the switching hydraulic technique which imitates the principle of the switchmode power electronics. The switching technique relies on fast valve switching and the main benefits of this technique are continuous output and simple hardware [5]. The purpose is typically to produce a smooth analog output by using high-speed on–off valves. Applications of the switching technique include ABS and fuel injection in modern vehicles and agriculture machinery [6,7]. It has also found application in the fan drive system of the mobile machinery [8].

Research have been conducted on the switching hydraulic systems for decades. Scheidl proposed two concepts of hydraulic switching converters: a wave converter and a resonance converter [9,10]. The wave converter consists of a switching valve and two pipelines. The second pipeline connects at the midpoint of the first pipeline and has half the length of the first pipeline. The output pressure of the second pipeline is almost constant, with the magnitude being the product of system pressure and switching valve duty cycle. The output pressure is largely independent of the flow rate. The system is a nearly ideal pressure control system [11,12]. The resonance converter consists of a switching valve, a spring-loaded cylinder and an accumulator [13]. The cylinder chamber is alternately connected to the pressure, tank and consumer line. The resonance converter

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