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POSITION TRACKING CONTROL OF MINIATURE LOW PRESSURE WATER HYDRAULIC CYLINDERS

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ABSTRACT

Over the past 20 years research in the field of miniature actuators has increased substantially thanks to advances in smart material fabrication, semi-conductor chip technology and computer processing capability. Hydraulic cylinders offer many potential benefits as miniature actuators including: high power-to-weight ratio, mechanical stiffness, smooth motion and the potential for high positional accuracy. Despite their benefits the control of hydraulic cylinders with bore diameters under 10 mm has not been previously studied. The most significant obstacle to implementing the use of miniature cylinders is the unavailability of off-the-shelf proportional valves that are compatible with hydraulic fluid and precise enough for the position control task. In this paper two non-linear control strategies are presented for the position control of two 4 mm bore diameter cylinders. Four off-the-shelf, low cost, 2/2 on-off miniature solenoid valves were used to control the flow of water to and from the cylinder chambers. A novel valve modeling technique is also presented, which allowed the on-off valves to approximate the behaviour of proportional solenoid valves, increasing their control capability. The tracking performance of each controller was experimentally tested and both controllers were found to achieve steady state positioning accuracies within ± 0.07 mm. The robustness of the controllers to changes in payload mass and vertical orientation were also tested. Results from several experiments are presented and compared.

INTRODUCTION

Over the past 20 years research in the field of miniature actuators has increased substantially thanks to advances in smart material fabrication, semi-conductor chip technology and computer processing capability. The practical application of miniature actuators has expanded into areas including robotics, micromachining, micro valves, vibrators for cellular phones and computer hard drives. Hydraulic cylinders offer many potential benefits for use as miniature actuators, especially in the field of miniature robotics. As an example, a pair of cylinders could be combined with a rack and pinion mechanism to power a small rotary joint. Advantages of hydraulic cylinders include their high power-to-weight ratio, mechanical stiffness, smooth motion and their potential for high positional accuracy.

Despite their numerous advantages previous work with cylinders of 10 mm bore diameter or less is lacking. Prior to this paper the lone contribution was made in 1999 by Peirs, Reynaerts and Van Brussel [1], who developed their own miniature hydraulic cylinders with bore diameters of 3 mm. However, their work concentrated on the mechanical design of the cylinders and only open-loop testing was reported. One potential reason for the hesitancy towards miniature cylinders is the increased impact of the cylinder friction. As reported in [1], the increased significance of friction inside the cylinder results in stick-slip effects making accurate position control difficult. Intuitively, the relationship between increasing significance of friction and decreasing cylinder bore diameter makes sense if one remembers that the force acting on the face of the piston is proportional to the area (i.e. to D^2) while the friction force is proportional to the circumference of the piston (i.e. to D).

Another difficulty faced in the application of miniature cylinders is the absence of affordable miniature proportional valves capable of delivering the small precise flow rates required for accurate position control at the operating pressure. Since they are primarily intended for pneumatics applications, typical maximum pressure ratings for cylinders under 10 mm bore diameter are in the range of 100 psi. The required flow rates are on the order of 1 mL/min.

The goal of this paper is to further the research in the area of miniature hydraulic cylinder control by introducing a novel valve model and two control strategies for the position control of an antagonistic pair of 4 mm bore diameter hydraulic cylinders using low cost 2/2 on/off solenoid valves. Previous works have demonstrated the capability of accurately positioning hydraulic and/or pneumatic cylinders with on/off solenoid valves. Several techniques have been employed including: pulse-width-modulation (PWM) [2,3,4], pulse-