The 10th JFPS International Symposium on Fluid Power FUKUOKA 2017 Oct. 24-27, 2017 The Japan Fluid Power System Society

ATTRACTION FORCE CHARACTERISTICS OF PROPORTIONAL SOLENOID ACTUATOR FOR AN INDEPENDENT METERING VALVE

So-Nam Yun*, Young-Bog Ham*, Jung-Ho Park* , Tae-Soo Park**, Seong-Cheol Jang** and Yoshito TANAKA***

*Energy Systems Research Division, Korea Institute of Machinery & Materials
156 Gajeongbuk-ro, Yuseong-gu, Daejeon, 34103 Republic of Korea
(E-mail: ysn688@kimm.re.kr)
**Dept. of Aviation Mechatronics, Korea Polytrchnic
**Dept. of Machine System, Chungju Campus of Korea Polytechnic Ⅳ
*** Korea Brain Pool Researcher, Korea Institute of Machinery & Materials
156 Gajeongbuk-ro, Yuseong-gu, Daejeon, 34103 Republic of Korea

Abstract. The latest construction vehicles are gradually shifting towards Independent Metering Valve(hereinafter IMV) type instead of the shapes of 4/3 way or 4/2 way spool type valve because of the pressure loss and fuel consumption efficiency. There are two types for IMV. One is a two-stage type and the other is a three-stage one. In case of a two stage type, a great magnetic attraction force is needed for controlling the spool or poppet of the second stage because of the higher operating pressure and flowrate. In case of a three stage type, very tiny magnetic attraction force is needed because this solenoid actuator is only used for pilot control. In this study, attraction force characteristics of a proportional solenoid actuator for IMV of the construction vehicle are discussed. And in order to confirm the performance of the fabricated proportional solenoid actuator, the important performance parameters such as response time, hysteresis and repeatability are experimented and analyzed.

Keywords: Attraction Force, Construction Vehicle, Independent Metering Valve, Proportional Solenoid Actuator, Pulse Width Modulation

INTRODUCTION

Generally, solenoid actuators are classified by force control method with a plunger movement. One is an on-off solenoid actuator and the other is a proportional one. An on-off solenoid actuator has an attraction force characteristics that is proportional to the negative square of plunger displacement($1/x^2$, where x: plunger displacement) or square of magneto motive force(NI^2, where N: coil turns, I: input current). On other hand, an attraction force of a proportional solenoid actuator is only proportional to the input current. So, a proportional solenoid actuator has a special stationery core for a magnetic flux leakage and magnetic flux saturation.
The latest construction vehicles are gradually shifting towards Independent Metering Valve type instead of the shapes of 4/3 way or 4/2 way spool type valve because of the pressure loss and fuel consumption efficiency. There are many kinds of IMVs are currently being studied for the next generation excavator which has basically four-valves for one actuator such as an arm, an boom, an bucket cylinder actuation and a rotating hydraulic motor actuation. And all IMVs use proportional solenoid actuator and the proportional solenoid actuator has some special characteristics such as higher endurance and reliability performance for the life of an excavator. In this study, attraction force characteristics of a proportional solenoid actuator for IMV of the construction vehicle are discussed. And in order to confirm the performance of the fabricated proportional solenoid actuator, the important performance parameters such as response time, hysteresis and repeatability are experimented and analyzed.

THEORETICAL ANALYSIS

IMV Circuit Introduction

Figure 1 shows an example of a power extension mode of the construction vehicle as an excavator which has some IMVs. In this case, cylinder operating direction is right side but external load direction is opposite(left)

side. Then valve K_{sb} and K_{at} is closed, and valve K_{sa} and K_{bt} is controlled by electric control unit. So, the efficiency control with no-pressure drop contrary to spool type valve of 4/3 or 4/2 method is capable.

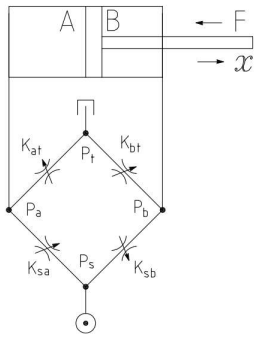
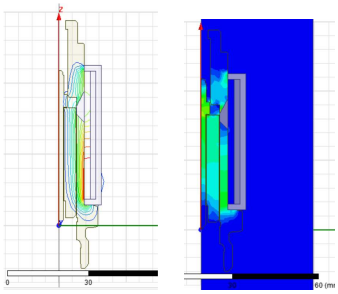


FIGURE 1. Excavator circuit with IMVs

Magnetic Fields Analysis

Figure 2 is the results of flux line and flux density distribution of a designed proportional solenoid actuator with a special control cone. The input parameters for magnetic field analysis such as coil turn, resistance and current are 1445[turns], 22.8[Ω] and 0.3[A] to 1.2[A], respectably. From the Figure 2, we can know that the magnetic flux distribution is controlled by control cone of the stationery core.



a) Flux line b) Flux density

FIGURE 2. Magnetic fields analysis results

EXPERIMENTAL SETUP AND RESULTS

Figure 3 shows an experimental setup with PWM signal generator for static and dynamic measurement of the fabricated proportional solenoid actuator. For the important performance parameters measurement such as response time, hysteresis and repeatability, a laser displacement sensor and a force sensor were equipped and data acquisition system was also installed.

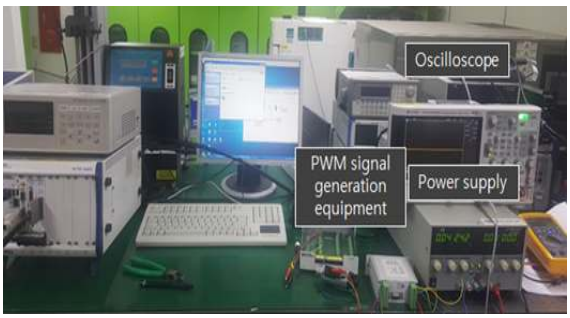


FIGURE 3. Experimental setup for solenoid actuator

Figure 4 is the results of the duty ratio variation by input voltage and is the final signal for the controlling the fabricated proportional solenoid actuator which is generated by the fabricated PWM controller. Duty ratio is generated by PWM controller which has capable of operating frequency of 20[kHz] and duty ratio of 0[%] to 100[%]. From the Figure 4, we can know that the duty ratio is proportional to the input voltage.

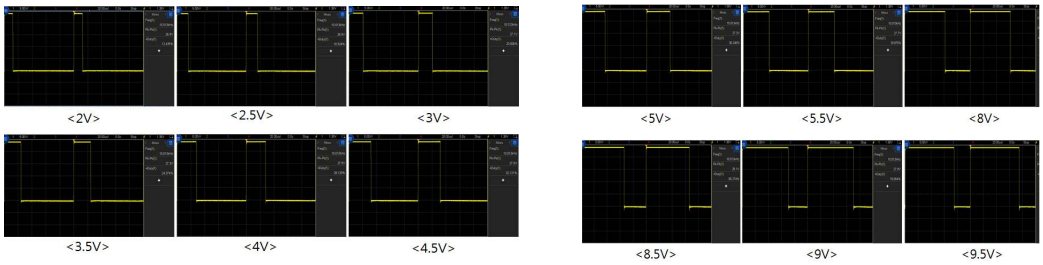


FIGURE 4 Duty ratio variations by input voltage

Figure 5 is the response characteristics by input pulse frequency variation in the fabricated proportional solenoid actuator and all data were measured from the experimental setup for solenoid actuator performance verification of Figure 3. For the experimental conditions, frequency variation range is 40[Hz] to 12[kHz] and duty ratio range is 20[%] to 80[%]. The response characteristics are changed by input frequency and the duty ratio variation but almost constant values are gotten at the 100[Hz] point regardless of duty ratio variation. From the Figure 5, difference response values were measured under the conditions of duty ratio variation and we can know that the response time also changed by PWM frequency variation. From the Figure 5, finally it is confirmed that the optimal operating frequency range of the fabricated proportional solenoid actuator is 100[Hz] and the response time is also 31[ms].

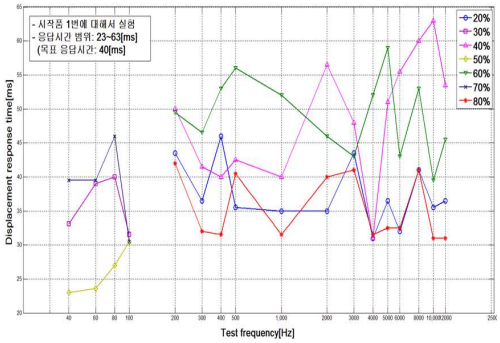


FIGURE 5 Response results by frequency variation

CONCLUSIONS

In this study, an electro-hydraulic proportional solenoid actuator for the IMV of a new construction vehicle was studied. Firstly, Conceptual design and magnetic fields analysis were conducted and in order to confirm the performance characteristics of the fabricated proportional solenoid actuator, design parameters such as response time, hysteresis and repeatability were analyzed through the experimental setup.
From this study, we got the results that the optimal operating frequency range of the fabricated proportional solenoid actuator is 100[Hz] and the response time is also 31[ms].

ACKNOWLEDGMENTS

This research was financially supported by the Korea Evaluation Institute of Industrial Technology(KEIT, No.: 10063469).

REFERENCES

1. S. A. Nahian, et al. Introduction of Independent Metering Valve for Energy Saving Excavator System, Journal of Drive and Control 12(1), 2015, pp. 45-52.
2. Thomas J. Ulery, Proportional cartridge valves-economical alternative to large valves, Agricultural Engineering 71, No.4, 1990,P.11.
3. Ruth Book and Carroll E. Goering, "Programmable Electrohydraulic Valve", International off-highway and powerplant co ngress and exposition, 1999-01-2852, 1999, pp. 1-7.
4. Qinghui Yuan, Perry Y. Li, "Robust Optimal Design of Unstable Valves", IEEE Transactions on control system technolog y, Vol. 15, No. 6, 2007, pp. 1065-1074.
5. Munson, et al. “Fundamentals of Fluid Mechanics”, 2009, pp. 201.

