A Novel Direct Instantaneous Pressure Control of Hydraulic Pump System with SR Drive

Jianing-Liang, Tae-Hyoung Kim, Dong-Hee Lee, Jin-Woo Ahn

Kyungsung University
110-1, Daeyeon-Dong, Nam-Gu, Busan, 608-736 , KOREA

Abstract

Abstract- This paper proposes a novel direct instantaneous pressure control(DIPC) of hydraulic pump system with SR drive. And it has very simple control structure, because it doesn't use any speed and torque control for adjusting pump pressure. The hysteresis band of pressure and proper switching rules can make the actual pump pressure to be constant with fast dynamic response. Therefore, the proposed DIPC method can control of hydraulic pump pressure steadily with fast dynamic response.

1. Introduction

In a conventional hydraulic pump system, induction motor is much used in variable displacement pump system due to the cost and simplicity of the motor driving. But additional power loss and mechanical value for keeping the constant pressure are main problem of conventional hydraulic pump system. Nowadays, market demands for high efficiency in various applications are increasing from the viewpoint of economy of energy.

Switched reluctance motor is low cost. It has low inertia and rigid construction and high torque at low speed, which has high speed response and widely speed range[1]-[2]. So SR motor is most suitable for variable speed motor drive in fixed displacement pump system, which can retain required pressure at minimum speed to save power consumption. In order to improve performance of hydraulic oil pump system, this paper proposes DIPC of hydraulic pump system with SR drive. And it has very simple control structure, because it doesn't use any speed and torque control for adjusting pump pressure. The hysteresis band of pressure and proper switching rules can make the actual pump pressure to be constant with fast dynamic response. Therefore, the proposed DIPC method can control of hydraulic pump pressure steadily with fast dynamic response.

2. Conventional Hydraulic Pump System with SR Drive

For hydraulic pump system with SRM drive, the maximum torque and rated speed are obtained from the mechanical specifications of hydraulic pump. The maximum flux of hydraulic pump is determined by volume efficiency and pump speed as follows.

$$Q_{\max} = n_m \cdot v_p \tag{1}$$

Where, Q_{max} : maximum output flux
n_m : pump speed [rpm]
V_P : pump capacity [cm^3/min]

And the pressure of oil is determined with the assumption of constant output flux and no loss of hydraulic pump as follows:

$$p_p = T_m / v_p \tag{2}$$

Where, P_p : oil-pressure [Mpa]
T_m : pump torque [Nm]

Fig. 1 explains the conventional control block diagram of hydraulic pump system with SR drive. The pressure error is processed through a proportional plus integral(PI) to get the speed command, ω_m^*. From the speed command, the torque command T^* is obtained using speed PI controller. From the torque command, the current command is obtained using the torque constant, K_t. This torque constant is for the linearized inductance with rotor position characteristics for a particular value of current. The current command i^* injects into current control block to generate i_{max} and i_{min}. The feedback current is controlled within the hysteresis window to generate switching signal to adjust pressure of hydraulic pump system. The rotor position controls turn-on and turn-off angle of each phase.

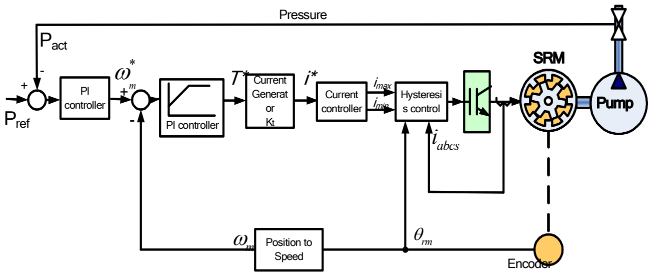


Fig. 1 Block diagram of hydraulic pump system with SR drive

3. Proposed DIPC Hydraulic Pump System

3.1 Proposed DIPC method

The proposed DIPC uses the switching states of asymmetric converter according to rotor position and pressure error of hydraulic pump. A novel hysteresis loop is used in this proposed DIPC method, which can directly control of pump system from feedback pressure signal.

Fig. 2 shows the conventional asymmetric converter of SRM. The conventional asymmetric converter can provide independent control of each phase even in phase overlap.

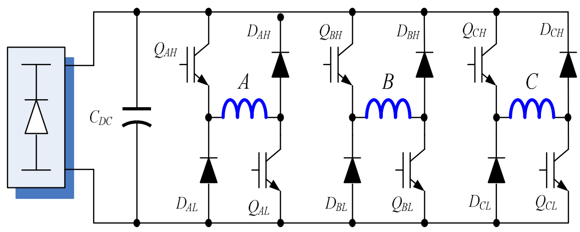
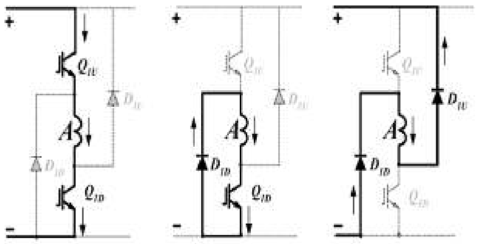


Fig. 2 The structure of asymmetric converter

The phase overlap is essential for communication control of DIPC operation. The possible switching modes are excitation mode, freewheeling mode and demagnetization mode, which are shown in Fig. 3. According difference voltage of three modes, the state of each mode can be defined as 1, 0 and -1, respectively.

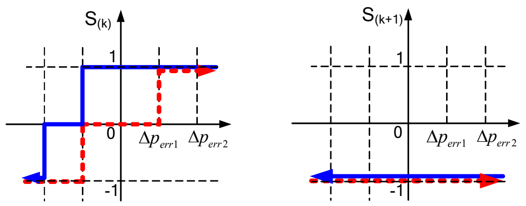


(a) Excitation (b) Freewheeling (c) Demagnetization

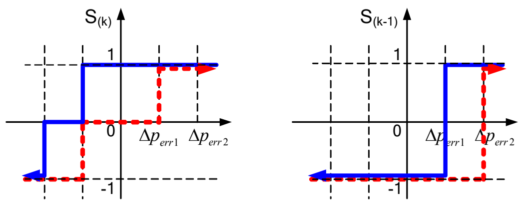
Fig. 3 Switching modes of conventional asymmetric converter

Fig. 4 shows control scheme of the proposed DIPC method. In this method, SR motor operates under two control schemes: single phase control scheme and communication control scheme. The control rules of hysteresis loop are shown as arrow line in Fig. 4. The dashed line indicates upper rule, and the solid line indicates down rule. x axis denotes state of one phase, and y axis denotes pressure error. Δp_{err1} and Δp_{err2} are threshold in the x axis so 5 hysteresis boundaries can be found. 2 hysteresis windows have been applied in y axis. Phase S(k) is prime activation phase in current rotor position, the phase S(k-1) is outgoing and the phase S(k+1) denotes incoming phase according to phase sequence.

Single phase control scheme is shown in Fig. 4(a), phase S(k) is prime phase which control the output pressure, and variable state follows the 2 hysteresis windows. Phase S(k+1) maintains the turn-off state during zero and negative inductance slope region, so it always is -1 state.



(a) Single phase control scheme



(b) Communication control scheme

Fig. 4 control scheme of DIPC of asymmetric converter

Communication control scheme is shown in Fig. 4(b). If pressure error is less than Δp_{err2}, prime activation phase S(k) can supply output torque to generate given pressure by itself. When torque error is more than Δp_{err2}, it means that phase S(k) can't satisfy oil-pressure requirement due to the small torque generation at the start point of inductance rising. So phase S(k-1) and phase S(k) take charge the output oil-pressure together.

3.2 DIPC hydraulic pump system

Fig. 5 denotes the characteristic curve of flux and oil-pressure in hydraulic oil pump system. Under preset oil-pressure, the flux of pump is limited maximum flux Q_{max}. Over the preset oil-pressure, flux is controlled by power saving mode as shown in Fig. 5. In a high oil-pressure, temperature of oil is fast increased with a friction of high flux. For this reason, the maximum flux is limited in high oil-pressure range.[3]

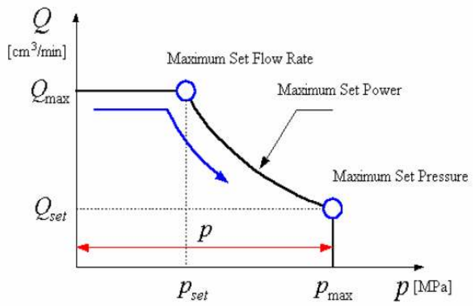


Fig. 5 The characteristic curve of flux and oil-pressure

Fig. 6 shows the proposed DIPC Block diagram of hydraulic pump system with SR drive. Reference pressure is obtained from the relationship of flux and command pressure. The pressure error which is difference value between reference pressure and action pressure is processed into digital hysteresis controller. The digital pressure hysteresis controller carries out DIPC scheme and generates the control signals for all activated machine phases according to rotor position and pressure error. And simple current protect can produce an over current signal to forbid output control. At last, suitable voltage of converter are supplied to SR motor, which provide enough output torque to drive hydraulic pump.

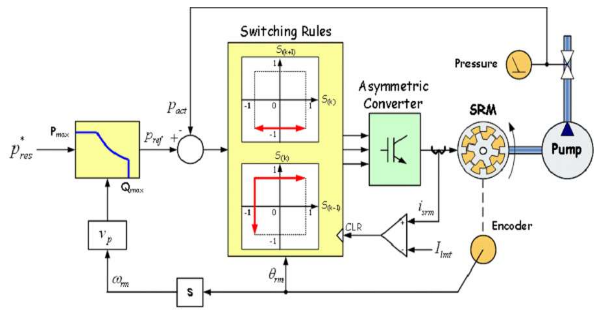


Fig. 6 block diagram of DIPC hydraulic pump system with SR drive

4. Simulation results

In order to verify the proposed DIPC method, some simulations are executed. The inductance and static torque characteristic of prototype SRM are analyzed from some experiments and Finite-Element-Method (FEM). The specification of prototype SRM is shown in table 1.

In the simulation of SRM drive system, the inductance data is needed for calculation of phase current and phase torque. The inductance profile of prototype SRM is shown in Fig. 7. 3-D torque table is described in Fig. 8.

Table 1. The specification of the prototype SRM

Stator pole	12	Number of phase	3
Rotor pole number	8	Stack-length	95[mm]
Dia. Of Stator	135[mm]	Air-gap length	0.25[mm]
Dia. Of Rotor	70[mm]	Stator pole arc	15[Deg]
Rotor pole arc	16[Deg]	Rated Speed	3000[rpm]
Number of turn	52		

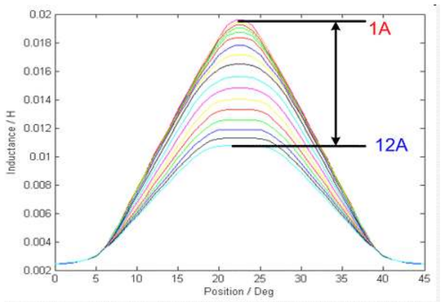


Fig. 7 Inductance profile of prototype SRM

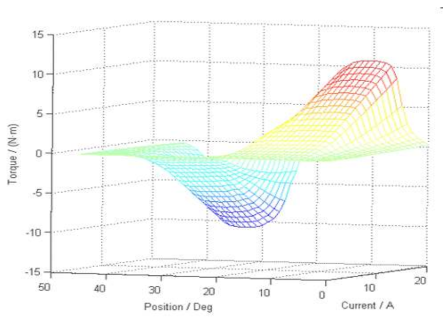


Fig.8. Torque profile of prototype SRM

The simulation results of DIPC hydraulic pump system with SR drive is shown in Fig. 9. Simulation results show proposed control method can output smoothing torque and pressure.

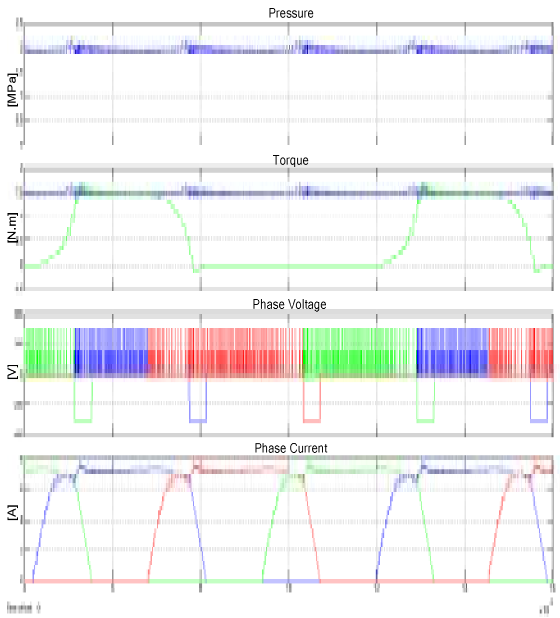


Fig. 9 Simulation of DIPC pump system at 2[MPa]

Pressure response of DIPC hydraulic pump system is shown in Fig. 10. The proposed hydraulic pump system has very fast dynamic response.

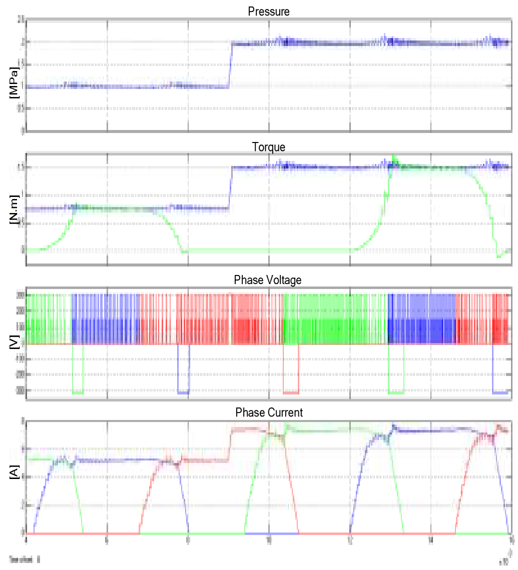


Fig. 10 pressure response of DIPC pump system

6. Conclusion

A novel DIPC of hydraulic pump system with SR Drive is proposed, which can simplify controller structure, save energy consumption and obtain fast dynamic response. A novel control schemes and hysteresis controller make pump system obtain stable pressure and fast dynamic response. Some simulations have been done in this paper.

감사의 글

이 논문은 산업자원부 지원에 의하여 기초전력연구원 (과제번호 R2005-B-109)주관으로 수행된 과제임

Reference

[1] B.C. Kim, D.H. Lee, J.W. Ahn, "Performance of SR drive for hydraulic pump" Proceedings of ICEMS 2005, Vol. 1, pp.659 - 663, 27-29 Sept. 2005.

[2] C. S. Kim, M. G. Kim, H. G. Lee and J. W. Ahn, "Development of SRM and Drive System for Small Pallet Truck" Annual Proc. of KIEE, pp.732-734, 2000.

[3] Igor J. Karassik, "Pump handbook", Third Edition, McGRAW-HILL, 2000

[4] C. S. Kim, S. G. Oh, J. W. Ahn and Y. M. Hwang, "The Design and the Characteristics of SRM Drive for Low Speed Vehicle" Annual Proc. of KIEE, pp. 871-873, 2001.

[5] Jame L. Johnson et al, "Introduction to Fluid Power", Science & Technology, 2004.

[6] P. J. Lawrenson, J.M. Stephenson and P. T. Blenkinsop et al, "Variable-speed Switched Reluctance Motors", IEE Proc. B, vol.127, no.4, 1980, pp.253-265.

[7] H. Chen and G. Xie, "A Switched Reluctance Motor Drive System for Storage Battery Electric Vehicle in Coal Mine", in Proceedings of the 5th IFAC Symposium on Low Cost Automation, 1998, pp.90-95.

[8] D.E. Cameron, J.H. Lang and S.D. Umans, "The Origin and Reduction of Acoustic Noise in Doubly Salient Variable-Reluctance Motors", IEEE Trans. Industry Applications, vol. IA-28, no.6, Dec. 1992, pp.1250-1255.