DSP 기반 고효율 정밀 속도제어 SRM

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High Efficiency and Precise Speed Controlled SRM of DSP based

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ABSTRACT

The switched reluctance drive is known to provide good adjustable speed characteristics with high efficiency. However, higher torque ripple and lack of the precise speed control are drawbacks. In the paper, a PLL(Phase Locked Loop) technique is adopted to regulate the dwell angle instantaneously. A PLL control technique in conjunction with dynamic dwell angle control scheme has good speed regulation characteristics. The F240 DSP based control system is used to realize this drive system. Test results show that the system has the ability to achieve good dynamic and precise speed control.

1. Introduction

The intrinsic simplicity, ruggedness, and simple power electronic drive requirement of a switched reluctance motor(SRM) make it possible to use in many commercial adjustable speed applications. However, the disadvantages to be overcome are the higher torque ripple and speed variation compared with that of a conventional ac drive. To minimize torque ripple and speed variation, it is known that the mmf current is to be controlled appropriately during torque developing period. As the SR drive is operated in a high level of flux density, the magnetic circuit is saturated severely. This saturation distorts the current waveforms.

In this paper, a high efficiency drive with a precise speed control scheme is proposed. The operating conditions for high efficiency are researched though theoretical and experimental tests, and a PLL technique in conjunction with a dynamic dwell angle control is adopted for precise speed control.[1-3] It is used widely to the motor speed control system for higher speed accuracy. The function of the phase detector in PLL is similar to that of dynamic dwell angle controller. PLL technique in SR drive regulates applied voltage by loop filter, and dwell angle by phase detector.

2. Precise speed control with high efficiency

The torque developed in SRM is proportional to the square of switching mmf current and the gradient of phase inductance according to rotor angular position as shown in (1).

$$\tau(\theta)=\frac{1}{2}i(\theta)^2\frac{dL(\theta)}{d\theta} \tag{1}$$

where L(θ) is inductance profile of the motor.

The SRM can be controlled by input voltage, switch-on and switch-off angle. Switch-on and switch-off angle of the SRM regulate the magnitude and shape of the current waveform. Also it result in affecting the magnitude and shape of the torque developed. Therefore, this angle is controlled precisely to get optimal driving characteristics.

The current level depends on the applied voltage, initial current, back speed e.m.f. and impedance voltage drop. The voltage equation for the SRM is (2).

$$V(\theta)=R\cdot i(\theta)+L(\theta)\frac{di(\theta)}{d\theta}+i(\theta)\frac{dL(\theta)}{d\theta} \tag{2}$$

2.1 High efficiency drive

The control parameters of SR drive are advance angle(switching-on angle), switching-off angle and applied voltage. In this study, it is calculated not to develop negative torque by the current tail during demagnetization of a phase. The approximated switch-off angle, θ_{off} is calculated from (3).[3]

$$\theta_{off} = \frac{L_{max}}{k} \tag{3}$$

where, $k = dL/d\theta$ and resistance of stator winding is neglected.

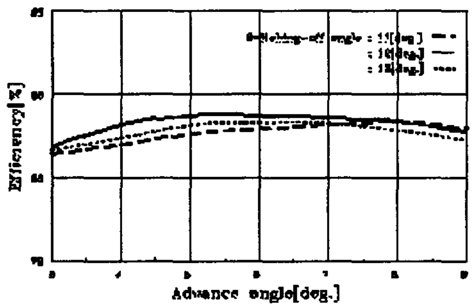


Fig. 1. Drive efficiency according to advance angle

Real drive efficiency is found through efficiency tests. Fig. 1 shows the test results at the rated output. It shows that switch-off angle of 12[deg.] is the best angle for high efficiency drive with this SRM. This switch-off angle approaches the calculated value.

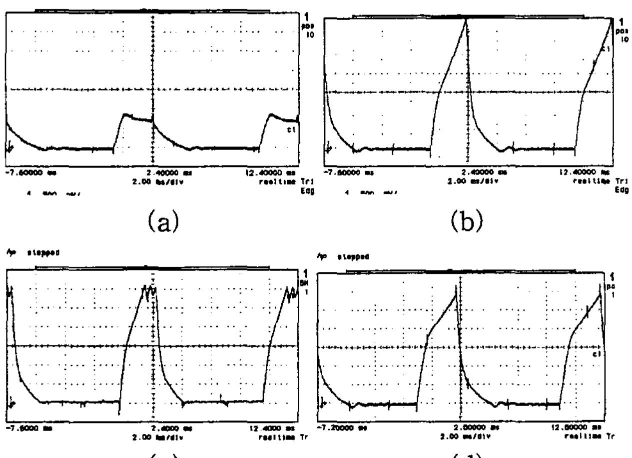


Fig. 2. Current shape at constant speed (a) before torque increased, 20[Kg-cm], (b) torque increased to 120[Kg-cm] with same condition as (a), (c) torque increased to 120[Kg-cm] with current limit, (d) torque increased to 120[Kg-cm] with advance angle control

Fig. 2 shows the current waveforms at constant speed. Load torque is 20[kg-cm] and 120[kg-cm], respectively.

The current shape is also influence to the efficiency. Fig. 3 is the test results of current shape. A current limit technique is easy and popular to control current and/or torque. But, dwell angle regulation is better for efficiency than that of current limit technique.

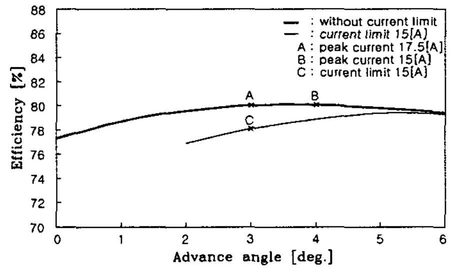


Fig. 3. Efficiency with current limit and advance angle control

2.2 Dynamic dwell angle control

The dwell angle control scheme proposed is similar to power angle control in synchronous machine [2].

When an SRM is driven in a steady-state condition, traces such as shown in Fig. 4(a) are produced.

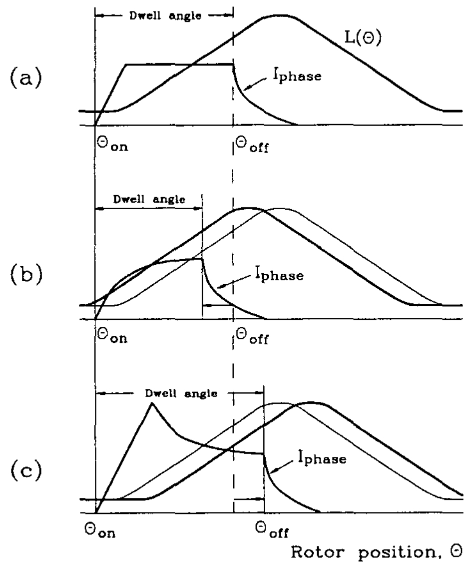


Fig. 4. Regulation of dwell angle according to load variation. (a) steady-state. (b) load decreased. (c) load increased.

The switch-off instant is fixed at a preset rotor position. This may readily be done by a shaft mounted encoder. If the load is decreased, the motor is accelerated almost instantaneously. The pulse signal from a rotor encoder is advanced by this acceleration. This effect will reduce switch-off interval until the load torque and the developed torque balances. Fig. 4(b) shows this action. On the contrary, if load is increased, the rotor will be decelerated and the switch-off instant will be delayed. The effect results in increasing the developed torque. Fig. 4(c) shows the regulating process of the dwell angle at this moment.

The principle of dynamic dwell angle is adopted in this paper to PLL technique. The function of the PLL in this control is to adjust the dwell angle for precise speed control. The phase detector in the PLL loop detects load variation and regulates the dwell angle.

2.3 PLL technique

Fig. 5 shows the basic PLL system. It has a phase comparator, loop filter, and voltage controlled oscillator (VCO). This control loop is very similar to an SR drive which is controlled by pulse-type power.

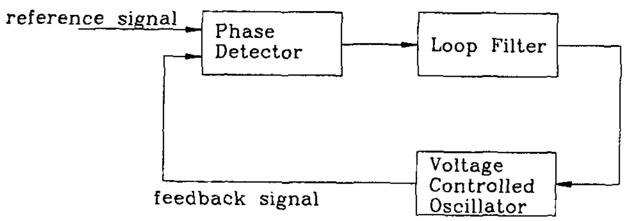


Fig.5. Basic PLL technique

3. PLL control scheme

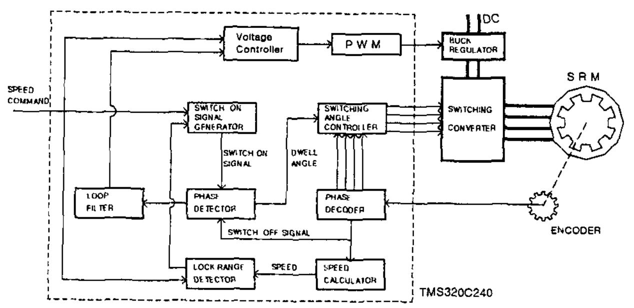


Fig. 6. Block diagram of suggested control system.

The drive system is set-up with a 2HP, 8/6 SRM using a DSP TMS320F240. The TMS320F240 has the architectural features necessary for high-speed signal processing and digital control functions, and it has the peripherals needed to provide a single-chip solution for motor control applications. The classic inverter with a buck type voltage regulator is used. The block diagram of suggested control scheme is shown in Fig. 6.

3.1 Phase detector and loop filter

The output of phase detector is made by phase difference between reference signal and the signal of rotor encoder. The dwell angle is similar to phase difference in a phase detector. To apply PLL control in an SR drive system, a reference frequency signals are used to switch-on, and the rotor encoder signal is used to switch-off similar to the function of a phase detector. The switch-off angle is fixed by the position of the rotor encoder. Therefore, the rotor encoder signal is delayed as load torque increased. This results in an increase of advance angle and initial phase current.

3.2 Switching angle control

The switch-on angle is regulated to remain within the maximum value. It is selected not to develop negative torque.

If it exceeds the maximum value by an abrupt increase of load or overload, then the frequency of the reference speed signal will be lowered. On the contrary, when the difference between the reference and feedback signal is very small, which may occur during an abrupt decrease of load, the reference signal will be advanced and be moved to the dynamic dwell angle mode. This is to prevent the feedback signal from advancing the reference signal

3.4. Control of drive system

The control system block diagram and control flow chart are shown in Fig. 6 and 7 respectively.

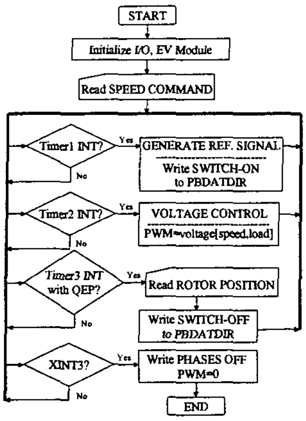
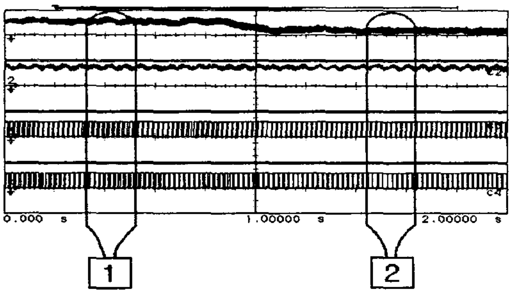


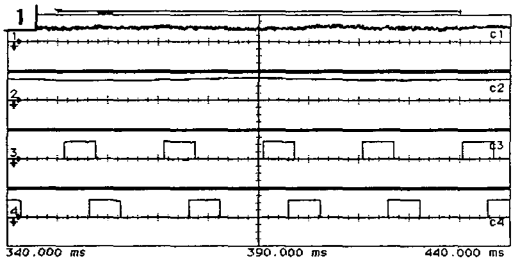
Fig. 7. Control flow chart

4. Experiments and Results

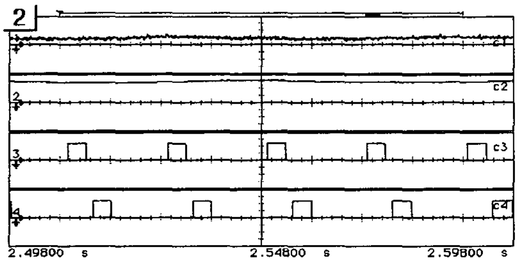
Fig. 8 shows the variations of the dynamic dwell angle when load increase. The phase current at 2000 [rpm] is shown in Fig. 9.



(a)



(b)



(c)

Fig. 8. Variation of dynamic dwell angle when load increase ; (b) and (c) are expanded of 1,2 in (a) ; CH1) load torque; CH2) speed; CH3) control signal of phase 1; CH4) control signal of phase 2

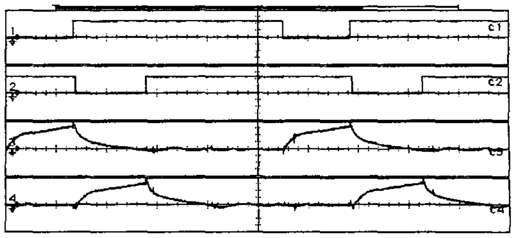
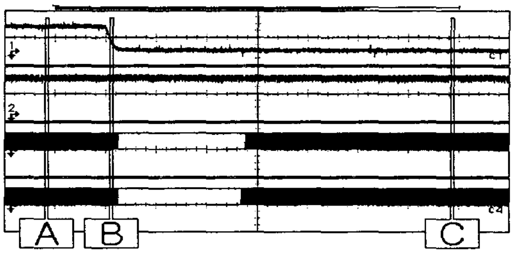
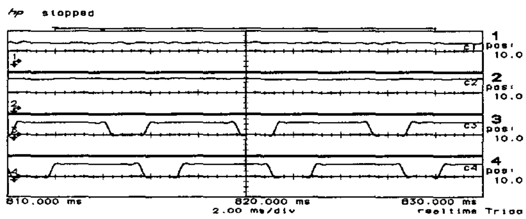


Fig. 9. Dwell angle and phase current ; CH1) dwell angle of phase 1 ; CH2) dwell angle of phase 2 ; CH3) phase current of phase 1 ; CH4) phase current of phase 1

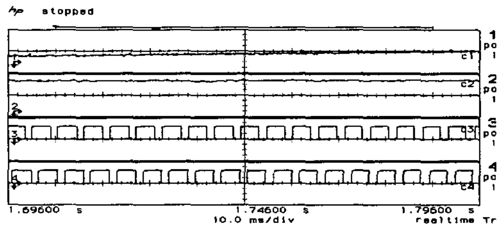
The regulation of the dynamic dwell angle when load increase and decrease are tested. Fig. 10 shows regulation capability when load increase.



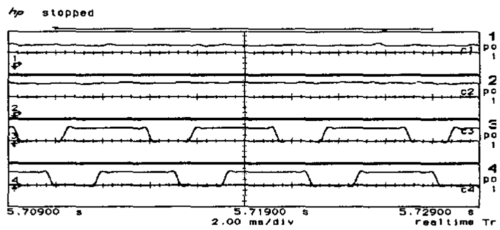
(a)



(b)



(c)



(d)

Fig 10. Regulation of dynamic dwell angle when load increase; (b),(c) and (d) are expanding of A,B,C in (a);
CH1) load torque; CH2) speed; CH3) control signal of phase 1; CH4) control signal of phase 2

5. Conclusion

A high efficiency drive with precise speed control scheme is suggested and tested. The switching angle condition for high efficiency is calculated and tested. And also a PLL technique is adopted for precise speed control. A custom PLL IC is difficult to overlap phases, which is very important to reduce torque ripple and maximize torque developed. A TMS320F240 type digital signal processor is used to reduce hardwares and have flexibility in controlling the motor.

This system has an excellent dynamic torque control characteristics. The dynamic dwell angle control is achieved via the PLL technique. Test results show that this system has both dynamic and precise speed control capability with high efficiency drive.

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