Drive Characteristics of 2-Stage Commutated SRM with Auxiliary Winding

Dong-Hee Lee, Seok-Gyu Oh, Sung-Jun Park and Jin-Woo Ahn

Abstract - The switched reluctance drive exhibits higher levels of vibration and acoustic noise than that of most competing drives. The main source of vibration in the switched reluctance drive is generated by rapid change of radial force when phase current is extinguished by commutation action. A new excitation strategy for a Switched Reluctance Motor with Auxiliary Winding (SRMAW) is described and tested. This scheme has auxiliary winding with one diode which is wound to all the poles in one winding. In this scheme, auxiliary winding is used to reduce magnetic stress during commutations. The abrupt change of a phase excitation produces mechanical stresses and it results in vibration and noise. The acoustic noise is reduced remarkably through 2-stage commutation. The operational principle and a characteristic comparison to that of the conventional SRM show that this scheme has some advantages including noise reduction as well as high efficiency drive.
Keywords - SRM, Auxiliary winding, 2-stage commutation, vibration, acoustic noise

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 variable speed applications. The simple magnetic circuit results in a high efficiency, low temperature rise. And this system provides a good operating characteristics. But the SRM exhibits higher levels of vibration and acoustic noise. The inherent torque ripple and noise derives from the torque production mechanism. During commutation of phases, torque ripple is occurred by the radial magnetic attraction and harmonic currents[1]. Some suggestions have been introduced to reduce torque ripple. A multilevel switching technique has been used to address the reduction of radial attraction [2,3]. Design optimization of magnetic structure is also used to reduce resonance in the motor operation range [4]. Winding topology and phase excitation methods were also considered[5,6]. The full- pitched winding, which was used to utilize mutual torque, however, is disadvantageous to drive efficiency [5]. The symmetrical excitation technique in a conventional winding is also disadvantageous to the developed torque [6].

This paper addresses a new strategy to reduce the radial magnetic attractions and reboundings during magnetizing and demagnetizing. The abrupt change of mmf is caused by the excitation mechanism of SRM. To develop reluctance torque of an SRM, the phases are excited one after another. This means that full magnetization and demagnetization is needed to develop torque for each phase, which introduces attractions and reboundings of the magnetic circuits. This mode of operation also needs high VA and reactive power to drive a motor, and increases torque ripples. A 2-stage excitation using auxiliary commutation winding could be one of the possible considerations to reduce vibration and noise during excitation.

This work was supported by a Grant No. R01-2001-00300 from Korea Science and Engineering Foundation.

Manuscript received: Feb. 20, 2001 accepted: Oct. 15, 2001.

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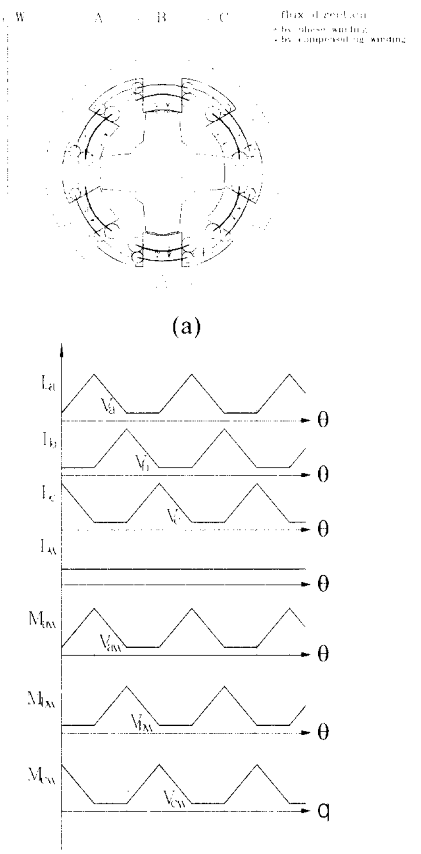
2. 2-Stage Commutation with Auxiliary Winding

The phase windings are same as the conventional type except the auxiliary winding. It is connected in series to all the poles in one winding and has one diode. Fig. 1 shows the winding connection and ideal inductance profiles of a Switched Reluctance Motor with Auxiliary Winding (SRMAW). The flux direction produced by auxiliary winding is the same as that of phase windings. The magnetic energy of the demagnetizing phase during phase commutation is absorbed by the auxiliary winding, and is utilized to excite the next phase. The absorption of the magnetic energy speeds-up phase commutation as well as smoothing the commutation.

The inductance profile of a phase is same as that of a conventional connection. Mutual inductance of auxiliary winding is same as that of phase inductance. Self- inductance of auxiliary winding is to be constant not to develop negative torque. This is accomplished by equaling the overlapping angle between stator and rotor.

2.1 2-step demagnetization with SRMAW

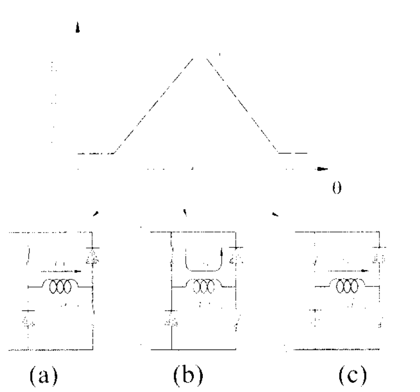
To reduce the vibration by an abrupt change of radial mmf, 2-atage demagnetization is introduced during phase commutation. Fig. 2 shows the operation modes of an



(b)

Fig. 1 Configuration of SRM with auxiliary winding. (a) winding connection (b) ideal inductance profiles

inverter during commutation. It has zero voltage period before applying negative voltage, which differs from the conventional method. The conventional method applies a negative value of magnetization voltage during demagnetizing in classic-type inverter. This zero voltage period may reduce abrupt changes of radial mmf during demagnetizing.



(a) (b) (c)

Fig. 2 2-step demagnetization control. (a)current build-up and torque developing period, (b) zero-voltage period (c) demagnetizing period

2.2 Analysis of operation modes

Voltage and torque equation when phase A excited are

$$V = R_a i_a + \frac{d\lambda_a}{dt} = R_a i_a + L_a \frac{di_a}{dt} + i_a \frac{dL_a}{dt} + M\frac{di_w}{dt} + i_w \frac{dM}{dt} \quad (1)$$

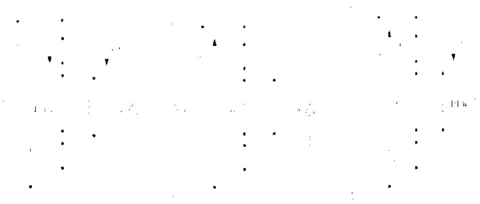
$$V_w = R_w i_w + \frac{d\lambda_w}{dt} = R_w i_w + L_w \frac{di_w}{dt} + i_w \frac{dL_w}{dt} + M\frac{di_a}{dt} + i_a \frac{dM}{dt} \quad (2)$$

$$T = \frac{1}{2} i_a^2 \frac{dL_a}{dt} + i_a i_w \frac{dM}{d\theta} \quad (3)$$

where, R_w and i_w are resistance and current of auxiliary winding respectively.

The last term of (3) is a torque developed by auxiliary winding, and that is developed by mutual action between auxiliary winding and phase winding.

A 2-stage commutation technique is to have a zero voltage period to minimize vibration[2]. The excitation modes are shown in Fig. 3.



(a) (b) (c)

Fig. 3 Operating modes in 2-stage commutation in SRMAW (a) current build-up and torque developing period (b)zero voltage period. (c) demagnetizing period.

The voltage equation during current build-up is as (4), (5), where resistance of phase winding R, auxiliary winding R_w are ignored.

$$V - M\frac{di_w}{dt} = L\frac{di_a}{dt} \quad (4)$$

$$-M\frac{di_a}{dt} = L_w \frac{di_w}{dt} \quad (5)$$

During torque developed period, voltage equations are as (6), (7)

$$V = L_a \frac{di_a}{dt} + i_a \frac{dL_a}{dt} + M\frac{di_w}{dt} + i_w \frac{dM}{dt} \quad (6)$$

$$-(M\frac{di_a}{dt} + i_a \frac{dM}{dt}) = L_w \frac{di_w}{dt} \quad (7)$$

And during zero voltage period, the voltage equation is

$$0 = L_a \frac{di_a}{dt} + i_a \frac{dL_a}{dt} \quad (8)$$

The voltage equation during demagnetizing period is

$$-(V_a + M\frac{di_w}{dt} + i_w\frac{dM}{dt}) = L_a\frac{di_a}{dt} + i_a\frac{dL_a}{dt} \quad (9)$$

$$M\frac{di_a}{dt} + i_a\frac{dM}{dt} = -L_w\frac{di_w}{dt} \quad (10)$$

The demagnetizing voltage in (9) is $M\frac{di_w}{dt} + i_w\frac{dM}{dt}$ which is higher than that of conventional method. This speeds-up demagnetizing time.

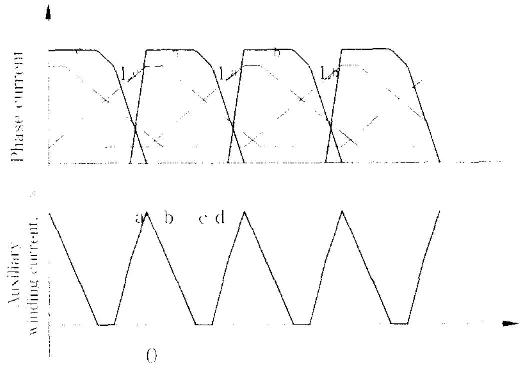


Fig. 4 Currents of phases and the auxiliary winding.

Fig. 4 shows the currents of phase and auxiliary windings. Interval a is the current build-up period. Interval b is the torque developing period. Interval c is the zero voltage period. Interval d is the demagnetizing period where auxiliary winding absorbs residual magnetic energy.

3. Experiments and Results

Fig. 5 shows an SRM drive system with auxiliary winding which has a 6/4 SRM, classic-type inverter, encoder and controller. Fig. 6 shows the currents of phase and auxiliary windings. The rising rate of the current of auxiliary winding is lowered after the current build-up period. The current of auxiliary winding is reduced to zero after the torque developing period because the changing rate of the phase current is reduced. The current of auxiliary winding contributes to the motoring torque during torque developing period which increases output power, and to the demagnetizing voltage during switch-off which speeds up demagnetizing.

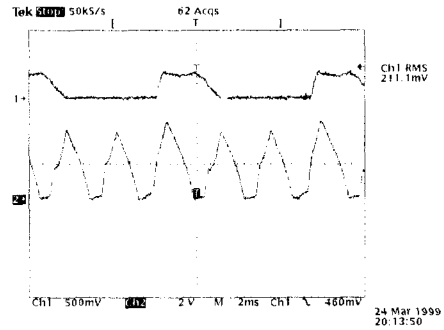


Fig. 6 Current of a phase and auxiliary winding

Fig. 7 shows the phase current comparison of conventional and proposed schemes. The phase current in the proposed scheme is decayed quickly because the auxiliary winding absorbs residual magnetic energy during demagnetizing. Vibration and noise tests are executed and com pared with that of conventional SRM. Vibration is using accelerometer and noise is detected using sound meter as shown in Fig. 8. The accelerometer is attached to the stator. The output of accelerometer is 99.5[mV/g] at 5kHz ~ 10kHz. The sound meter is 1 [ft] apart radially from the motor.

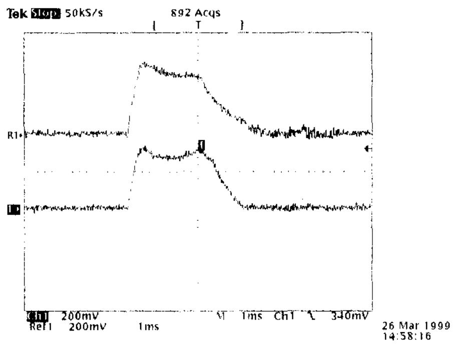


Fig. 7 Current of a phase ; in conventional drive(upper), with auxiliary winding drive (lower)

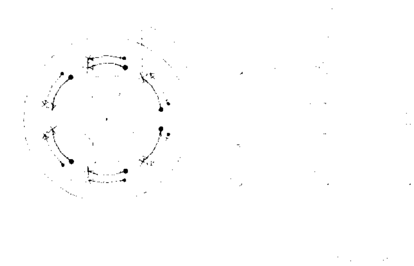


Fig. 5 SRM drive system with auxiliary winding

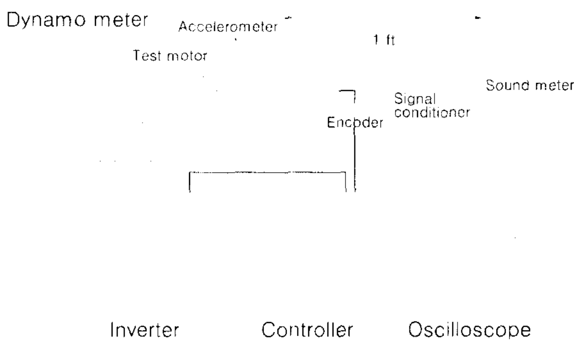
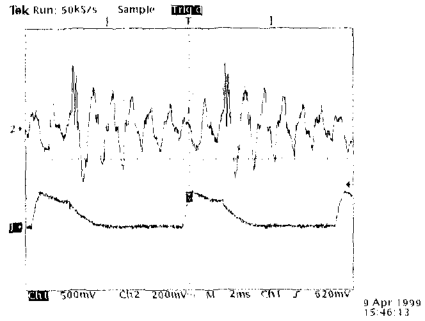
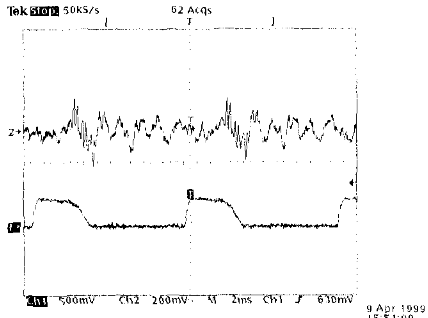


Fig. 8 Test set-up for vibration and noise measurement



(a)

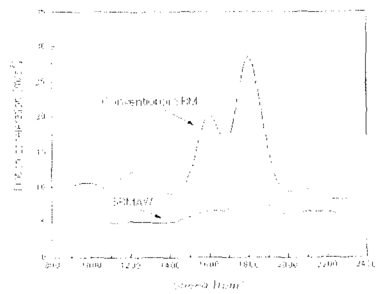


(b)

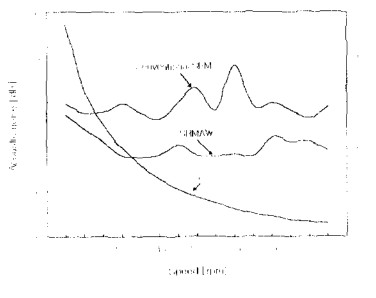
Fig. 9 Vibration and phase current (a) conventional SRM (b) 2-stage commutation with SRMAW detected

Fig. 9 shows that the vibration and phase current. The vibration of proposed drive is reduced than that of conventional drive especially at the switch-off instant.

The vibration and noise comparisons are shown in Fig. 10. These are reduced remarkably at 1600 and 1800[rpm], which are resonant frequencies of the motor. Drive efficiency which is shown in Fig. 11 is higher than that of the conventional drive at high speed range.



(a)



(b)

Fig. 10 Vibration and noise comparison (a) vibration, (b) noise

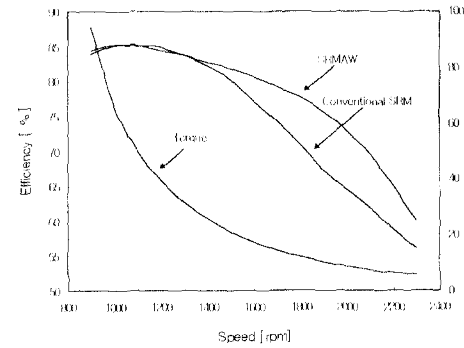


Fig. 11 Efficiency comparison

5. Conclusion

A new excitation strategy for a Switched Reluctance Motor with Auxiliary Winding(SRMAW) is described and tested. This scheme has auxiliary winding with one diode which is wound in series to the all poles all in one winding. Auxiliary winding is used to reduce magnetic stress during commutations with 2-stage commutation. The abrupt change of a phase excitation produces mechanical stresses and it results in vibration and noise. The operational principle and characteristics comparisons to that of the conventional one show that this scheme has some advantages including noise reduction as well as high efficiency drive. This is because that the scheme reduces radial attraction and vibration during commutation.

Acknowledgments

This work was supported by a Grant No. R01-2001-00300 from Korea Science and Engineering Foundation.

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