Journal of the Korean Institute of Illuminating and Electrical Installation Engineers Vol. 22, No.7, pp. 22~27 July 2008 (22-7-4)

# 2-Stage Commutated SRM with Auxiliary Winding for Reduction of Acoustic Noise

Tae-Uk Jung*


## Abstract

A new excitation strategy for a Switched Reluctance Motor with Auxiliary Winding(SRMAW) is described and tested. The proposed scheme has auxiliary winding with one diode which is wound over all 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 resulting in vibration and noise. The acoustic noise is reduced remarkably through the 2-stage commutation.

The operational principle and a characteristic comparison of the conventional SRM show that this scheme has some advantages including noise reduction as well as high drive efficiency.


Key Words : Switched Reluctance Motor, Auxiliary Winding, Commutation, Acoustic Noise

## 1. Introduction

The inherent torque ripple and noise is derived from the torque production mechanism of SRM. During commutation of a phase, torque ripple and radial deformation of stator core due to magnetic attraction and rebounding is dominant factor to vibration and acoustic noise [1]. Some suggestions have been introduced to reduce vibration and noise. A multi level switching technique has been used to address the reduction of radial attraction [2-3].

The design optimization of magnetic structure is also used to reduce resonant vibration in the motor operation range [4]. Winding topology and phase excitation methods were also considered [5-6]. However, the full-pitched winding, which was used to utilize mutual torque, is disadvantageous for drive efficiency [5]. A symmetrical excitation technique in a conventional winding is also not desirable to the high drive efficiency [6].

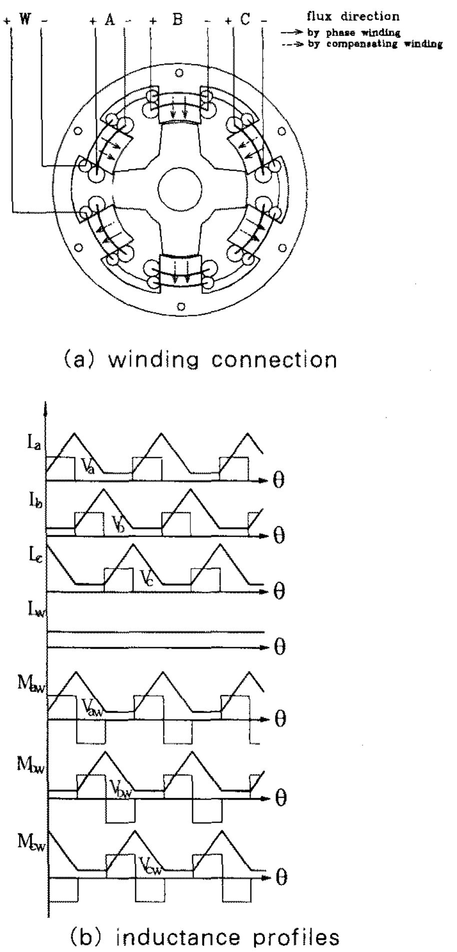
This paper addresses a new means to reduce the radial magnetic attractions and rebounding of stator core during magnetizing and demagnetizing. The abrupt change of mmf is caused by the excitation mechanism of SRM. In SRM phases are excited one after another. This means that full magnetization and demagnetization is needed to develop torque for each phase, which introduces attraction and rebounding of the magnetic circuits. This mode of operation also needs high VA and reactive power to drive a motor, eventually increasing the torque ripple. The 2-stage

* Main author : Kyungnam University as a professor
Tel : +82-55-249-2628, Fax : +82-55-249-2839
E-mail : tujung@kyungnam.ac.kr
Date of submit : 2008. 5. 26
First assessment : 2008. 5. 30
Completion of assessment : 2008. 6. 16

excitation using auxiliary commutation winding could be one of the possible considerations to reduce vibration and noise during excitation.

## 2. 2-stage Commutation with Auxiliary Winding

In the proposed magnetic structure of SRM with the auxiliary winding, the phase windings are same as in the conventional SRM. Besides, auxiliary windings is wound over all poles and each one is connected in series.




(a) winding connection

(b) inductance profiles

**Fig. 1. Configuration of SRM with auxiliary winding**

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 produced by 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.

### 2.1 2-step demagnetization with SRMAW

The inductance profile of a phase winding is identical to conventional SRM. The mutual inductance of the auxiliary winding has the same variation characteristics of phase inductance in accordance with rotor position angle. The self-inductance of auxiliary winding has to be constant to restrain negative torque generation. This is accomplished by that the overlapping angle between stator and rotor is always constant even though rotor position angle is changed.

In order to reduce the vibration, caused by an abrupt change of radial mmf, 2-stage demagnetization is introduced during phase commutation. Fig. 2 shows the operation modes of an 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 demagnetization.

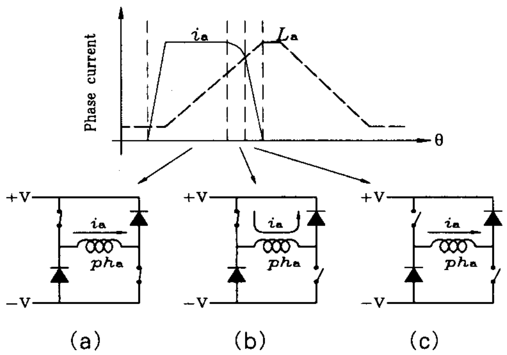



**Fig. 2. 2-step demagnetization control**
**(a) current build-up and torque developing period**
**(b) zero-voltage period**
**(c) demagnetizing period**

## 2.2 Analysis of operation Modes

Voltage and torque equations when phase A is excited are written as follows :

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

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

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

where, V, R and i are voltage, resistance and current of phase winding respectively, and Vw, Rw and iw are voltage, resistance and current of the auxiliary winding respectively, La is self inductance of phase, M is mutual inductance between phase winding and auxiliary winding.

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

In order to minimize vibration, 2-stage commutation technique having zero voltage period is very useful [2]. The excitation modes are shown in Fig. 3.

The voltage equation during current build-up is governed by (4), (5), where resistance of phase winding R and auxiliary winding Rw are neglected.

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

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

During torque developing period, voltage equations are presented below

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

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

Besides, during zero voltage period, the voltage equation is

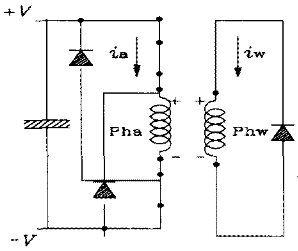
$$0 = L_a \frac{di_a}{dt} + i_a \frac{dL_a}{dt} \quad (8)$$

The voltage equation during demagnetizing period is

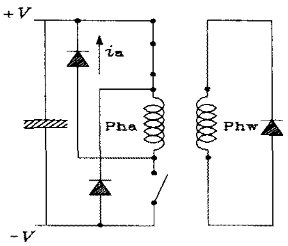
$$-(V_a + M \frac{di_w}{dt} + i_w \frac{dM}{dt}) = L_a \frac{di_a}{dt} + i_a \frac{dL_a}{dt} \quad (9)$$

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

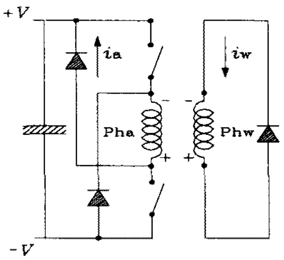
The demagnetizing voltage in (9) is $M \frac{di_w}{dt} + i_w \frac{dM}{dt}$ which is higher compare to conventional method. This high demagnetizing voltage can shorten demagnetizing time.




(a) current build-up and torque developing period




(b) zero voltage period




(c) demagnetizing period.

**Fig. 3. Operating modes in 2-stage commutation in SRMAW**

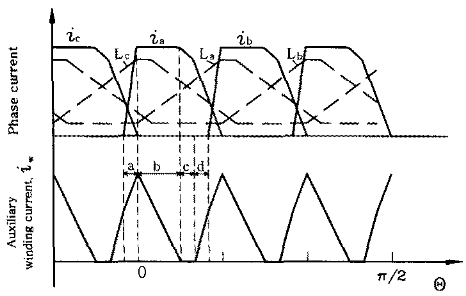



**Fig. 4. Current of phase winding and auxiliary winding**

Fig. 4 shows the phase currents and auxiliary winding current. 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. Experiment and Result

Fig. 5 shows SRM drive system with auxiliary winding which has a 6/4 SRM, classic-type inverter, encoder and controller. Fig. 6 shows the current waveform of phase winding and auxiliary winding. The rising rate of the auxiliary winding current 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.

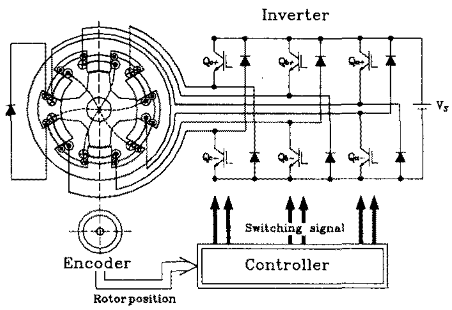



**Fig. 5. SRM drive system with auxiliary winding**

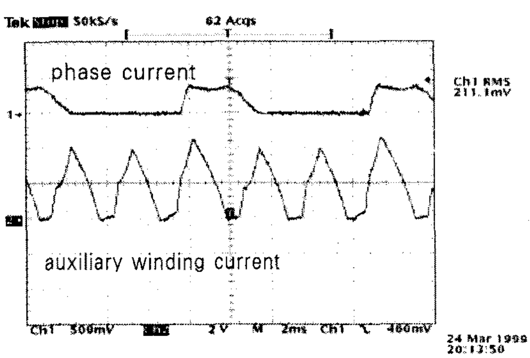



**Fig. 6. Current waveform of phase winding and auxiliary winding**

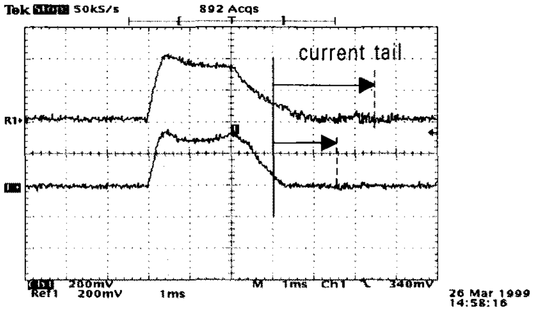



**Fig. 7. Comparison of phase current waveform (upper : conventional SRM, lower : proposed 2-stage commutation with SRMAW)**

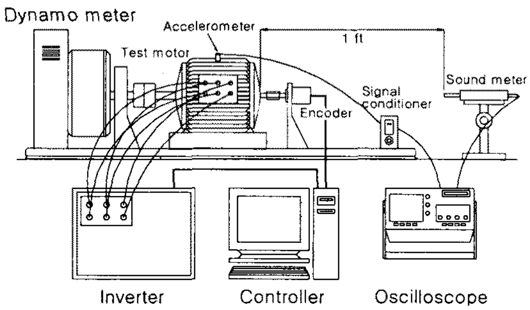
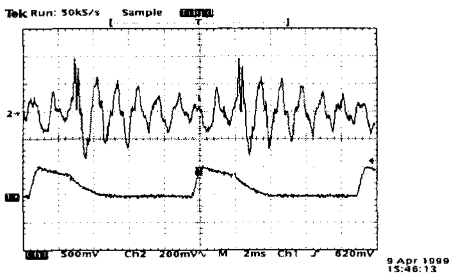


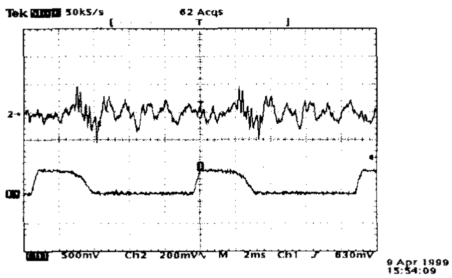

**Fig. 8. Test set-up for vibration and noise measurement**

The current of auxiliary winding contributes to the rotation torque during torque developing period of phase winding which increases output power, and to the demagnetizing voltage during switch-off which speeds up demagnetization.

Fig. 7 shows the phase current comparison of conventional and proposed schemes. The phase current in the proposed scheme is decaying quickly because the auxiliary winding absorbs residual magnetic energy during demagnetization. Vibration and noise tests are executed and compared with that of conventional SRM. Vibration is detected using accelerometer, 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] within 5~10[kHz]. The sound meter is 1[ft] apart from the motor axis.

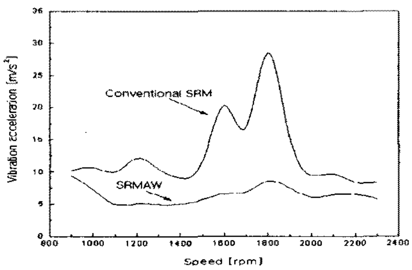



(a) conventional SRM

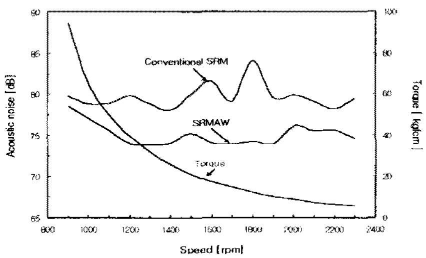



(b) 2-stage commutation with SRMAW

**Fig. 9. Vibration and phase current**




(a) vibration




(b) noise

**Fig. 10. Vibration and noise comparison**

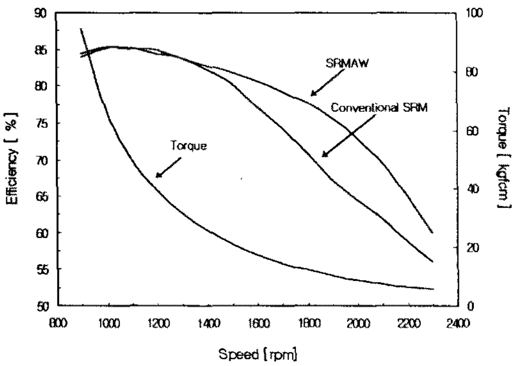


**Fig. 11. Efficiency comparison**

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

Fig. 10 shows substantial reduction of the vibration and noise at 1,600 and 1,800[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.

## 5. Conclusion

A new excitation strategy for a Switched Reluctance Motor with Auxiliary Winding (SRMAW) is introduced and tested. Described scheme has auxiliary winding with one diode which is wound in series over all poles 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 consequently resulting in vibration and noise.

The operational principle and a characteristic comparison of the conventional SRM demonstrate advantages of this scheme comprising of noise reduction and high drive efficiency. Especially, resonant vibration and noise are reduced remarkably. This is attributed to the auxiliary winding and 2-stage commutation reducing radial attractions and rebounding of stator core during commutation.

**Acknowledgement**

This work was supported by Kyungnam University Foundation Grant, 2008.

## References

[1] D.E.Cameron J.H.Lang, S.D.Umans, "The Origin and Reduction of Acoustic Noise in Doubly Salient Variable Reluctance Motors", IEEE Trans, on IA, Vol. 28, No.6, pp.1250-1255, 1992.

[2] C.Pollock, C.Y.Wu, "Analysis and Reduction of Acoustic Noise in the Switched Reluctance Drive", IEEE Trans, on IA, Vol.31, No.1, pp. 91-98, 1995.

[3] P.C. Kjaer, J.J. Gribble and T.J.E. Miller, "High-Grade Control of Switched Reluctance Machine," Proc. of IAS Annual Meeting '96. vol.1 pp. 92-100, Oct. 6-10 1996.

[4] I.Husain and M. Ehsani, "Torque Ripple Minimization in Switched Reluctance Motor Drives by PWM Current Control," IEEE Trans. on PE, Vol.11, No.1, pp. 83-88, Jan. 1996.

[5] T.Li, J.D.Lioyd, G.E.Horst, "Switched Reluctance Motor with DC Assisted Excitation", IEEE, conf. pp. 801-807, 1996.

[6] C. Hao, L. Diji, "Symmetry of Switched Reluctance Motor Drive", Proc. of IPEMC, pp606-610, 1996.

## Biography

### Tae-Uk Jung

He received the B.S., M.S. and Ph.D. degrees in electrical engineering from Busan National University, Korea, in 1993, 1995 and 1999, respectively. From 1996 to 2005, he was a Chief Research Engineer with Laboratory of LG Electronics, Korea. From 2006 to 2007, he was a Senior Researcher of Korean Institute of Industrial Technology, Korea. Since 2007, he has been with Kyungnam University as a professor. He is a member of the KIIEE and KIEE.