Permanent Magnet Online Magnetization Characteristic Analysis of a Flux Mnemonic Double Salient Motor Using a Piecewise-linear Hysteresis Model

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Abstract —In this paper, a new type of memory motors, namely stator-PM flux mnemonic doubly salient motor, is proposed and implemented. The concept of flux memory is due to the nature that the magnetization level of the permanent magnets of AlNiCo in the motor can be online regulated by a temporary magnetization current pulse and memorized automatically. To accurately analyze the variation characteristics of flux density and field intensity of permanent magnets in the proposed memory motor under different magnetization current, a piecewise-linear hysteresis model is employed in the time-stepping finite element method. Both simulations and experimental results of the motor are given to verify the validity of the new method.

I. INTRODUCTION

With ever increasing concerns on environment protection and energy conservation, EVs have been identified as the most viable zero-emission vehicles. Among different EV motors, the stator-permanent-magnet (stator-PM) motor drive is more feasible, since it inherently offers high efficiency, high power density, and free maintenance[1]. Also, it takes the definite advantage that the PMs are located in the stator so that the thermal influence on the PMs becomes insignificant while the rotor becomes mechanically robust. However, because of uncontrollable PM flux, the stator-PM motor cannot offer high-speed constant-power operation and maintain high efficiency over wide-speed operation which are essential for EVs. By incorporating both PMs and DC field windings in to the stator-PM motor, the hybrid excitation motor can retain the desired air-gap flux control while improve the power density and efficiency[2]. Nevertheless, the use of DC field current still causes continuous and unnecessary power loss in the flux weakening or flux strengthening region.

Recently, a new class of memory motors has been proposed, which employs the property of low coercivity of the aluminum-nickel-cobalt (AlNiCo) PMs in the rotor-PM motors [3]-[4]. By vector control techniques, the magnetization of AlNiCo-PMs can be tuned by applying temporary negative *d*-axis current pulses, hence controlling the air-gap flux efficiently. The purpose of this paper is to incorporate the concept of online tunable flux-mnemonic PMs into the stator-PM motor in such a way that the resulting stator-PM flux-mnemonic doubly salient (FMDS) motor can offer effective and efficient air-gap flux control.

II. MOTOR TOPOLOGY

Fig 1 shows the topology of the proposed stator-PM FMDS motor. The motor adopts a three-phase 12/8-pole doubly-layer-stator outer-rotor topology. In the stator, the armature windings are located in the outer layer, while both the PMs of AlNiCo and the magnetizing windings are located in the inner layer, hence achieving a compact structure. Moreover, since the armature windings and PMs are located in different layers of the stator, the PMs can be immune from accidental demagnetization by armature reaction, which is a major problem in current rotor-PM memory motors [5]. Also, since the outer-rotor is simply composed of salient poles with neither PMs nor windings, it is very robust and suitable for vehicular operation.

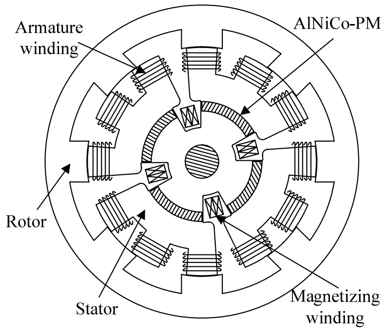
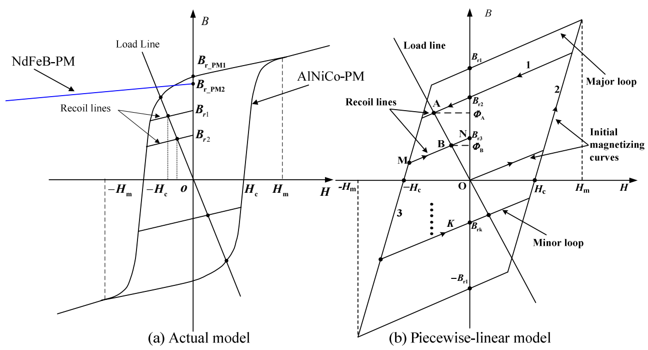


Fig. 1 Structure of stator-PM FMDS motor.

III. PIECEWISE-LINEAR HYSTERESIS MODEL

The AlNiCo-PMs adopted in the proposed memory motor exhibit nonlinear demagnetization characteristics. Fig. 2(a) shows the actual hysteresis model. A relatively low coercive force H_c of the PMs enable bipolar online magnetization. Fig. 2(b) shows the piecewise-linear hysteresis model.



(a) Actual model (b) Piecewise-linear model

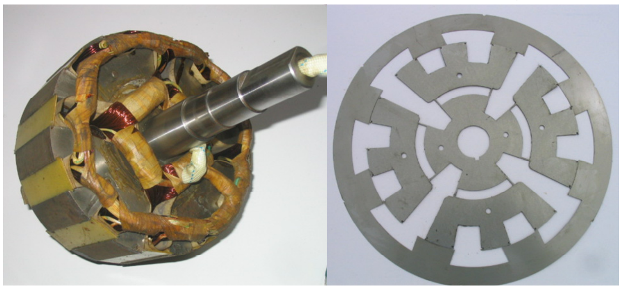
Fig. 2 Hysteresis curves of AlNiCo-PM.

Since the hysteresis curves of AlNiCo-PM is far different from those of the NdFeB-PM, the traditional finite element method (FEM) that was developed for NdFeB-PM motors is unable to provide an accurate analysis for the memory motors [6]. So, in this paper a time-stepping FEM coupled with a piecewise-linear hysteresis model is proposed for the analysis of the PM online magnetization phenomena of the motor under different magnetizing or demagnetizing current in details.

IV. Performance Analysis and Experimental Results

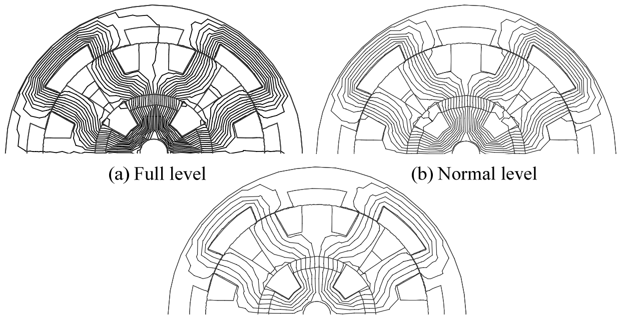
In order to testify the validity of the proposed model, the proposed motor is newly designed and prototyped, which is shown in Fig.3.

Firstly, by temporarily tuning the magnetizing current, the PM magnetization level can be flexibly adjusted at different levels. The corresponding magnetic field distributions at no load are shown in Fig. 4. For experimental verification, the back EMF wave forms at 700 rpm under same conditions are simulated and measured, which are shown in Fig.5. As expected, the amplitude of EMF can be effectively controlled.



(a) Stator (b) Stator and rotor laminations

Fig. 3. The Prototype.

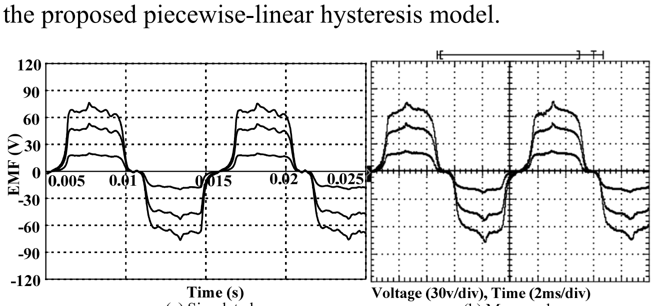


(a) Full level (b) Normal level

(c) Weak level

Fig.4 .The magnetic field distributions.

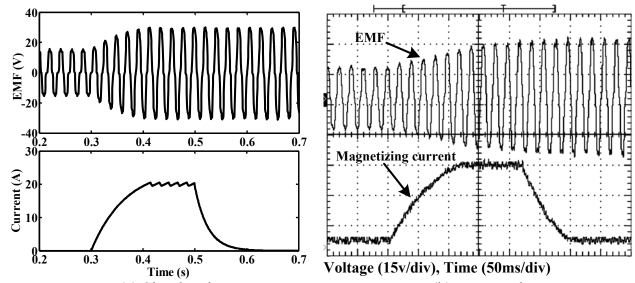
Then, the transient responses of the back EMF at the speed of 300 rpm subjected to a temporary magnetizing current pulse are simulated and measured as shown in Fig. 6. Namely, by applying a magnetizing current of about 20 A with a duration of about 0.3s, the back EMF can be swiftly increased. Compared with the FEM-simulated waveforms shown in Fig. 6(a), the measured waveforms shown in Fig.6(b) exhibit a good agreement, hence verifying the accuracy and validity of the proposed piecewise-linear hysteresis model.



(a) Simulated (b) Measured

Fig. 5. The back EMF waveforms under different PM magnetization levels.

Finally, by using a negative current with a magnitude of 12 A, the PMs can be completely demagnetized and even can be re-magnetized reversely, thus, the pole of the PMs can be reversed efficiently. The corresponding effects are shown in Fig. 7.



(a) Simulated (b) Measured

Fig. 6. The transient responses of the back EMF waveforms.

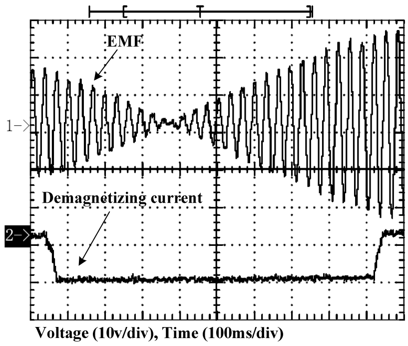


Fig. 7. The transient responses of the back EMF waveforms subjected to demagnetizing current.

V. Conclusion

In this paper, a new stator-PM FMDS motor drive has been proposed for EVs. By employing a piecewise-linear hysteresis model in the time-stepping FEM, the online magnetization characteristic of the motor are successfully obtained. Both the theoretical analysis and measured results not only verify the validity of the new method, but also show that the proposed motor can retain the advantages of effective flux control, high efficiency and high power density, which makes the motor an interesting candidate for electric vehicles.

VI. References

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