A Novel Stator and Rotor Dual Permanent Magnet Vernier Motor with Space Vector Pulse Width Modulation

Shuangxia Niu, S. L. Ho and W. N. Fu
Department of Electrical Engineering,
The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
eesxniu@polyu.edu.hk

***Abstract*—In this paper, electric machines with dual permanent magnet (PM) structures on the stator and rotor are studied and evaluated as one special case of flux modulating machines. The low-speed high-torque feature of the machine is mainly attributed to its gear effect, which is explained in the full paper. The main feature of this proposed machine is that PMs are buried both in stator and rotor ingeniously so as to produce a large torque at very low speed. This machine is compared with Vernier machines with a single side PM structure. The torque improvement with the proposed design is verified numerically. The motor is controlled by using vector control method with space vector pulse width modulation (SVPWM). Time-stepping finite-element-method (TS-FEM) is used to analyze the transient performance of the machine and its controller**

***Index Terms*—Electric machine, electric vehicle, finite element method.**

I. Introduction

Due to their high power density and high efficiency, permanent magnet (PM) machines are widely used in numerous industrial systems. In many applications, direct-drive PM motors are introduced to operate at low speed and high torque requirements. Direct-drive machines are generally featured with outstanding merits of having reduced noise, enhanced efficiency with fast and precise responses [1-2]. However, since the pole number of these machines is large, most direct drive PM machines suffer from having bulky size and heavy weight.

A new category of machine, namely the Vernier PM machine, have been proposed to successfully overcome the afore-mentioned problems [3]. It uses a flux modulating principle to produce the gear effect by modulating the magnetic field in the airgap [4-6]. The stator pole-pair number is generally designed to be much less than the rotor pole-pair number. Consequently, the space within the stator may be fully utilized. One method to realize the flux modulation is to exploit the stationary ferrite poles and multi surface mounted PMs on the rotor to produce the output torque.

In this paper, a novel Vernier dual PM machine is presented. The main feature of this proposed machine is that the PMs are buried in both the stator and rotor to to produce a large torque at very low speed. The motor is controlled using space vector pulse width modulation (SVPWM). A time-stepping finite-element-method (TS-FEM) is used to analyze the transient performance of the machine and its controller [7].

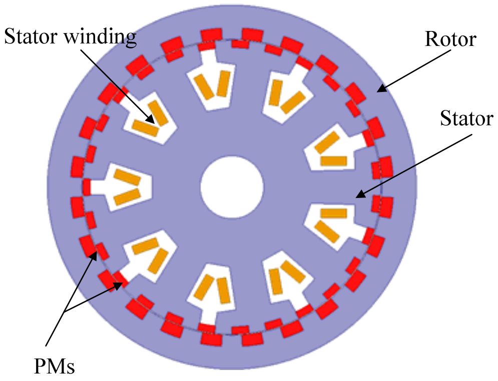
II. Machine Design and Control

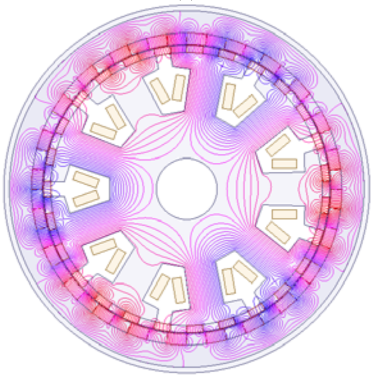
The basic structure of machine is shown in Fig. 1. There are Ns teeth in the stator and Nr teeth in the rotor. PMs are buried in the teeth and magnetized with the same polarity. The pole-pair number of the stator armature winding is p. The relationship p=Zs-Zr governs the synchronous speed of the Vernier machine. The stator slot number ps is designed to be relatively small and concentrated stator winding is used in this machine.

This machine design has many salient advantages: 1) Both stator and rotor have PMs, hence the torque density of the motor is increased significantly. 2) The structure is compact and thanks to the Vernier structure and concentrated winding distribution, the stator slot space is fully utilized. 3) Multipole structure in the rotor allows the synchronous speed of the machine to be low and the output torque of the motor is produced at a relative low speed. 4) Both synchronous effect and magnetic reluctance effect are involved in torque production which means the output torque can be further improved when compared to conventional machines which produce torque due to either synchronous effect of reluctance effect. 5) SVPWM is applied to this machine to minimize the switching loss in the inverter and the eddy current loss in the PMs inside the machine. 6) As SVPWM operates at a constant switching frequency, it is relatively simple to filter off the undesirable harmonics in the power supply to further improve the efficiency of the system and 7) TS-FEM is developed to precisely simulate the transient performance of the machine.

III. Results

In this proposed Vernier dual PM machine, there are 27 PM poles in the stator and 24 in the rotor. The stator slot number is 9 and stator pole number is 3. The flux distribution under no load is given in Fig. 1(b). With SVPWM based vector control, the three phase current waveform during starting is shown in Fig.2(a) and the d-axis and q-axis currents are shown in Fig. 2(b). The transient speed waveform is shown in Fig. 3 and the sector transition during starting is shown in Fig. 4. More comparison results which showcase the torque improvement of the proposed machine will be given in the full paper.





(b)

Fig. 1. Dual PM Vernier machine. (a) Structure. (b) Flux distribution.

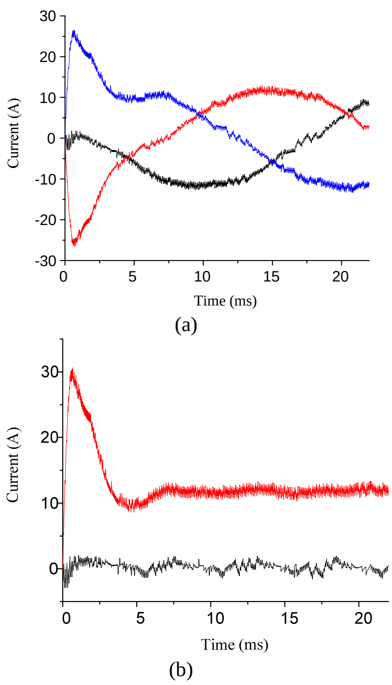


Fig. 2. The starting current waveforms. (a) Three phase current waveforms. (b) Id and Iq waveforms.

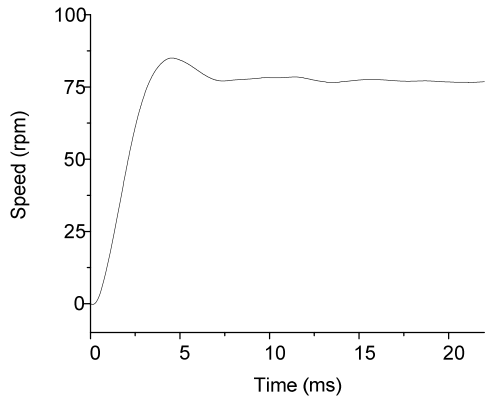


Fig. 3. The speed waveforms during starting.

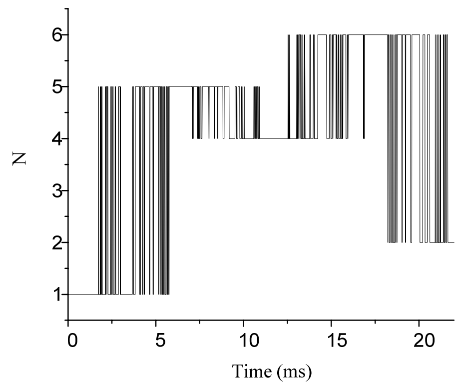


Fig. 4. The sector transition for SVPWM during starting.

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