

# Electromagnetic Design of a Novel Hybrid Flux SMCs PMSM

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**Abstract**—The hybrid flux PMSM includes both axial flux and radial flux, so its design method is different from the traditional cylindrical permanent magnet synchronous motor. In this paper, based on the analysis of the structure and operation principle of the hybrid flux motor, the design principle of the motor is given. The authors study the effects of slotting, permanent magnet thickness, and pole-slot match on the motor and determine the important parameters of the motor. Finally, the finite element method is used to verify the electromagnetic performance of the motor, and the correctness of the proposed design principle is verified.

**Keywords**—Soft magnetic composites; Hybrid flux; Electromagnetic design; Finite element analysis

## I. INTRODUCTION

Soft magnetic composites (SMCs) are a new type of soft magnetic material developed in the 1990s. It is the international name of the metal powder parts that have been pressed and heat treated with three-dimensional magnetic properties<sup>[1-3]</sup>. SMCs consist of surface-insulated high-purity iron particles. These particles are compressed and an isotropic part with a complex profile can be formed in one step. SMCs use powder metallurgy technology to mold high purity iron powder and organic material, and the surface of iron powder particles is covered with insulating layer and organic material which is bonded. Compared with silicon steel, SMCs has many advantages: magnetic properties of isotropic; to allow complex shapes; eddy current loss is small; good heat transfer; low cost and so on. These advantages provide the possibility to manufacture permanent magnet motors with complex magnetic circuits.

The idea of applying SMCs to electric motor dates back to the 19th century, but it was not until the 1980s that the idea was taken seriously. In 1990, Kordecki and Weglinski introduced several soft magnetic powder composites and suggested some of their application problems<sup>[4]</sup>. Jansson reported the processing and characteristics of SMCs applied to AC magnetic circuits in 1992<sup>[5]</sup>. Since then, the development of SMCs and its application to the motor has become a hot spot. They study a variety of different structures and uses of SMCs motor, and made a lot of research results<sup>[6-9]</sup>.

M.Sc. Tobias Kellner et al. Developed the axial flux switched reluctance motor using the characteristics of SMCs<sup>[10]</sup>. They solved the problem that the axial magnetic field reluctance motor was difficult to use the traditional stamping laminar mass production and the motor structure complex, and

tested the static and dynamic performance of the motor. In [11], it is proposed to apply SMCs in a double stator single rotor axial field motor. That is, using SMCs as the stator teeth, and then combined with the formation of the stator core of the stator core yoke, effectively solve the slotted axial motor stator core manufacturing problems. Not only improve the motor slot full rate, but also make the winding production more convenient. Fabrizio Marignetti et al. compared the differences between the two axial flux permanent magnet synchronous motors (AFPMSM) using solid steel and SMCs, respectively<sup>[12]</sup>. The results show that the rotor with SMCs can reduce the motor loss, improve the motor power density and efficiency, the motor no-load loss reduced by 19%, the motor efficiency increased by 12%. Jan Doering et al. developed a transverse flux reluctance motor (TFRM) with SMCs and a rotor disc<sup>[13]</sup>. This motor does not require permanent magnets; the rotor is not excited, with high torque density, high power density and compact structure. However, the fundamental frequency of the motor is high and the torque fluctuation is large, making it difficult to control the motor. In [14], a new low-cost claw pole permanent magnet motor is proposed. The output power of the motor is 675W and the output torque is 1.8Nm, but the total cost of the motor is only 9.8 USD. The purpose of this motor is to replace the traditional permanent magnet motor in air conditioning compressor through the use of SMCs and ferrite to significantly reduce costs. In this motor, the rotor spoke structure can make the ferrite produce a very high airgap flux density. Sweden G. Nord and others use the characteristics of SMCs to develop two vertical motor prototypes<sup>[15]</sup>. The first prototype did not meet the requirements. The number of airgaps in the second prototype increased from 1 to 2, achieving several improvements. Inductance, motor size, and current are reduced, while efficiency is improved. The second motor basically reaches the design target. Although the torque of the vertical motor is larger than that of the conventional motor, the airgap is larger than the traditional motor and the motor core is longer. Therefore, the power density and mass density of the motor are relatively small.

In this paper, a novel permanent magnet synchronous motor using SMCs combined with axial flux and radial flux is proposed. We analyze the structure and operation principle of this motor, and study the design principles and steps of the motor.

## II. NEW HYBRID FLUX PMSM BASED ON SMCs

### A. The structure of Hybrid Flux PMSM

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