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Advances in magnetic materials and their impact on electric machine design

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Abstract

The paper presents machine design considerations introduced by exploiting new magnetic material characteristics. The materials considered are amorphous alloy ribbons as well as Neodymium alloy permanent magnets involving very low eddy current losses. Such materials enable electric machine operation at higher frequencies compared with the standard iron laminations used in the traditional magnetic circuit construction and provide better efficiency.

Keywords: Magnetic materials; Permanent magnets; Iron losses

1. Introduction

Permanent magnets (PM) have been extensively used to replace the excitation winding in synchronous machines with the well-known advantages of simple rotor design without field windings, slip-rings and exciter generator, avoiding heat dissipation in the rotor and providing higher overall efficiency [1]. Various machine configurations and control strategies are used and implemented in different applications such as wind generators. The rotor design can be distinguished in three main types according to the magnet position, namely the "interior", the "peripheral" and the "claw pole" type.

At the stator side, the material considered are amorphous alloy ribbons involving very low eddy current losses [2]. Such materials enable electric machine operation at higher frequencies compared with the standard iron laminations.

The paper investigates two main selected topics of the PM drive technology: the converters in use and the dynamic behavior of the PM motors. More precisely, the following aspects are commented.

The basic dynamic behavior of the various PM motor types (starting, run-up synchronization, response to sudden load changes, etc.) including the effects of saturation is analyzed [3,4]. Ways of achieving steady-state fault tolerance requirements for the converter-motor arrangements are discussed. Moreover, PM demagnetization risks due to short circuits after faults in the windings or in the converter supply are examined.

2. New material characteristics

Standard silicon iron laminations which have dominated magnetic circuits at low frequency applications (50 Hz) cannot be used in high frequencies enabled by power electronic converter developments (a few kHz) due to the high iron losses associated. Such losses are mainly due to eddy currents as the lamination width is no more compatible with the respective skin effect depth.

In this range of frequencies ferrites and amorphous alloy ribbons seem to provide important advantages due to their low eddy current losses. Technological developments enabled production of such materials with high saturation induction approaching 1 T and very reduced coercive force providing the possibility of conception of high speed actuators with very attractive performance.

Moreover technological advances in permanent magnet materials enabled production of Neodymium alloy magnets with magnetization attaining 1.25 T and coercive force of 10^5 A/m [5]. Combination of such materials, that is high magnetization permanent magnets in the rotor parts and amorphous alloy ribbons in the stator parts, is expected to enable new machine designs, with light structure, high rotor speed and increased effi-

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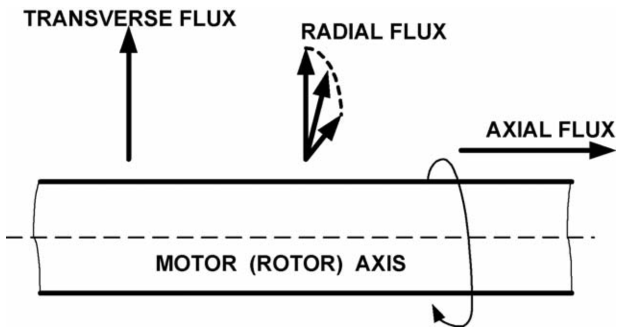

Fig. 1. PM motors' classification according to flux direction w.r.t. rotor axis.

ciency. Such machines will be supplied by convenient power electronic converters, enabling high frequency current generation. Moreover, sinusoidal waveforms are no more needed, and design procedure will tend to simplify the construction of the machine.

3. Permanent magnet motors for ship propulsion

3.1. General

PMM's are essentially synchronous motors (where) the field excitation comes from a permanent magnet rotor instead of dc carrying winding on the rotor. Although PMM's have been used for many years, the construction of a PM motor to propel a frigate-size ship is a real challenge. The PM motors can be classified in three main categories according to the rotor–stator configuration and effectively according to the direction of excitation flux in the motor's air gap (Fig. 1).

The three PMM's categories are the radial flux PMM (RFPMM), the axial flux PMM (AFPMM) and the transverse flux PMM (TFPMM).

The PM motors' main advantages over the conventional motors are:

- There is no requirement for excitation power and the respective devices (slip-rings).
- In general, it is claimed to be lighter and smaller.

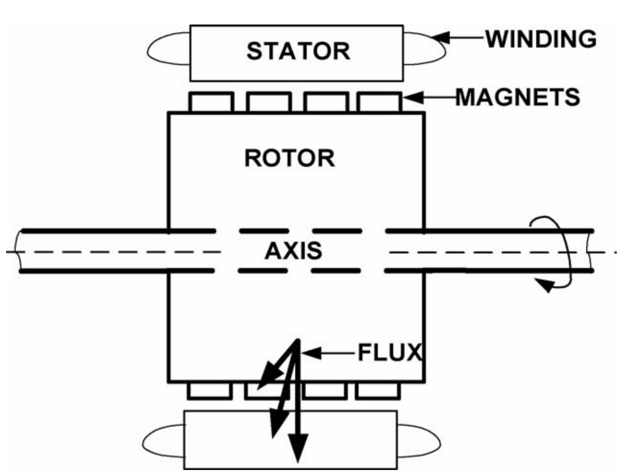

Fig. 2. Radial flux permanent magnet motor.

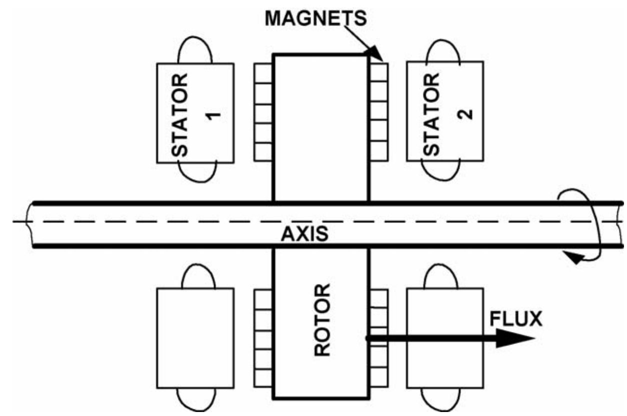

Fig. 3. Axial flux permanent magnet motor.

- Since the losses at the rotor windings do not exist the requirements for cooling are less and their efficiency improves.

The difficulties/considerations associated with PMM's development are:

- The high cost of the rare-earth magnets and the special manufacturing procedures necessary to assemble the motors (due to large magnetic forces).
- The cooling requirements, a problem common to all types of motors. Although most of the electrical losses occur in the stator where several (water-cooling) techniques are used for heat dissipation, measures have also to be taken for cooling of the rotor where significant stray losses (eddy currents) can occur from armature-induced harmonic fluxes.
- The behavior of PMM's under fault conditions and the higher operation frequencies. Since PMM's remain permanently excited, fault (short circuit) currents will continue to flow even after the motor has been disconnected from its main supply. PMM's are more power dense by using higher pole numbers; consequently, the operating frequencies of the motor are higher and special care is needed to avoid relevant losses.

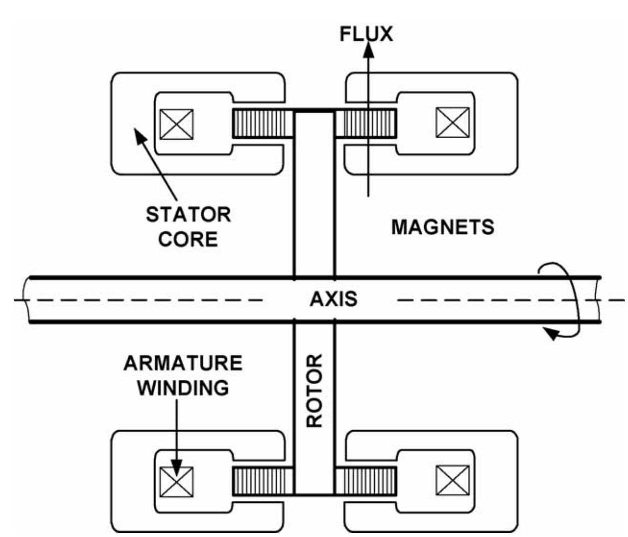

Fig. 4. Transverse flux permanent magnet motor.