Structurally Integrated Slotless PM Brushless Motor with Spiral Wound Laminations for Marine Thrusters

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Keywords: slotless brushless PM motor, helical stator laminations, rim-driven thrusters, integrated thrusters.

Abstract

Rim driven thrusters with structurally integrated brushless PM motors are now an established technology with an increasing range of applications. In these thrusters, the stator of the motor is housed within the thruster duct, and the rotor forms a ring around the tips of the propeller. Such high pole number motors tend to be very thin radialy, have very small length to diameter ratios, and have relatively large airgaps to accommodate corrosion protection layers on the surfaces of the rotor and stator. The relatively large diameter stator laminations of such machines tend therefore to have very thin back of core and narrow teeth, which make them expensive and difficult to manufacture. This paper proposes an alternative potentially lower cost motor topology featuring a slotless stator whose laminations are manufactured from a single strip of steel that is edge wound into a spiral (like a "slinky" and then fitted over the windings that are preformed on the outside surface of a non-conducting former. The former is also part of the sealed housing that protects the stator from corrosion in seawater. The paper discusses the design optimisation of such a motor using analytical and finite element analysis (FEA), describes a demonstrator motor and reports experimental and FEA results.

1 Introduction

Marine thrusters with structurally integrated electric motors such as those shown in Figs. 1 and 2 have been the subject of significant research and development in recent years for a wide range of applications. Small thrusters (up to 300 mm prop dia, 15 kW) primarily for remotely operated and autonomous underwater vehicles were developed by the Authors and are now commercially available [1, 2, 3]. Podded rim driven thrusters with MW ratings are also under development by General Dynamics Electric Boat for large manned submarines and ship propulsion [9, 10]. Recently, Rolls-Royce announced the development of a tunnel rim driven thruster for offshore support vessels and other types of marine propulsor [8, 13]. In these ducted propeller thrusters, the stator of the motor is integrated within the structure of the duct, while the rotor forms a ring around the propeller rim (hence sometimes known as rim or tip driven thrusters), thus resulting in a compact unit, compared to ducted thrusters with hub electric motors, with comparable efficiency. Such a configuration is also suitable for other applications such as marine turbine generators [4], fans and pumps.

Although the concept of such a thruster was proposed early in the 20th century [7], actual practical realisation of an efficient compact device has become possible only relatively recently, when high-energy permanent magnet materials became available. Early demonstrators of such a concept used induction motor (IM) [5] and switched reluctance motors (SRM) with part stators [11]. But these demonstrators suffered from having relatively thick rotors and stators, and hence relatively thick ducts with high drag losses, which impair hydrodynamic efficiency at high vessel advance speeds. The performance of IM and SRM also tends to be inferior due to the large airgap needed to incorporate corrosion protection layers on the surfaces of the rotor and stator. A permanent magnet machine is however more tolerant of large gaps, and can be designed to have a large number of poles, thus resulting in relatively very thin rotors and stators, yet maintaining good machine efficiency [1].

Fig. 1: Photograph of a commercial rim-driven thruster designed by the Authors