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Review

A review of progress and applications of ship shaft-less rim-driven thrusters

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ABSTRACT

The shaft-less rim-driven thruster (RDT) has become an attractive ship propulsion device in the marine industry in recent years, as it can provide many advantages over traditional ship propulsion plants including reduced vibration and noise, enhanced onboard comfort and propulsion efficiency, flexible installation locations arrangement, light weight and compact size. This paper reviews the latest research focuses, progress and applications of RDT. Theoretical and experimental research on the design, performance analysis and control of the RDT are discussed, including electric motor, bearings structure, hydrodynamic optimization, and coupling design between RDTs and ship hull. Typical application cases of RDTs are introduced, and a statistic for the worldwide commercial RDT companies and the key parameters of their typical products is given. High-power RDT technology remains generally unsophisticated; the performance and reliability of the RDTs need to be further improved, especially in regards to the development of high-power and low-speed electric motors, electromagnetic-thermal-fluid-solid coupling research, high power RDT cooperative design method, vibration and noise control, the improvement of anti-fouling and anti-damage capability, multiple RDTs cooperative control method. The advantages of RDT make it a potentially highly effective and economical choice for a wider range of ships than other propulsion alternatives in the future.

1. Introduction

The conventional propulsion plant (Fig. 1(a)) used in marine applications is a propeller driven by a prime mover such as a diesel or gas turbine engine. The propeller is connected to a shaft that protrudes from the rear of the vessel to the prime mover which is situated within the hull. Stern bearings and intermediate bearings support the shaft and constrain its radial motion. For vessels equipped with high- or medium-speed main propulsion power plants, a reduction gearbox is typically utilized to convert the high speed but low torque of the prime mover into the low speed and high torque that are required to rotate the propeller. The shaft, bearings, and reduction gearbox, however, not only cause substantial friction power loss, but also occupy a large amount of engine room space and increase the ship construction cost, and even produce high-level noise and vibration when they work.

The podded drive propulsion plant (Fig. 1(b)) has been of interest to researchers since the 1990s (Shamsi et al., 2014) and are currently popular in the marine industry. This plant offers many advantages over conventional propulsion systems, such as more uniform flow, improved maneuverability, enhanced sea keeping performance characteristics, lower noise and vibration, less fuel consumption, space savings in ship architecture and arrangement, and rudder and shaft elimination. The main components of the podded drive plant include the strut, the pod, and the propeller. Its disadvantage is that an electric driven motor is installed in the pod, resulting in the pod very long and large in diameter, which further impacts propulsion efficiency (Van Blarcom et al., 2002).

The shaft-less rim-driven thruster (RDT) (Fig. 1(c)) is a novel integrated motor propulsor (IMP), also called shaft-less rim-driven propulsor (RDP). It is a marine propeller which does not require a shaft or a gearbox for transmission of the driving torque (Tan et al., 2015). In this new technology, a marine propeller is structurally integrated in an electric motor; the stator of the motor is mounted in the duct while the rotor forms a ring around the propeller rim (Fig. 2). The rotor and stator are coated with epoxy material or sealed by metallic can respectively for water proof. The whole unit operates submerged and only electric cables pass through the ship hull. As a new type of ship electric propulsion system, the RDT integrated propeller and electric motor is a revolutionary innovation. Similar to an azipod, the RDT can be designed as fixed, retractable, and/or azimuthing. It has several advantages compared to conventional shaft driven thruster (Cao et al., 2012) and pod:

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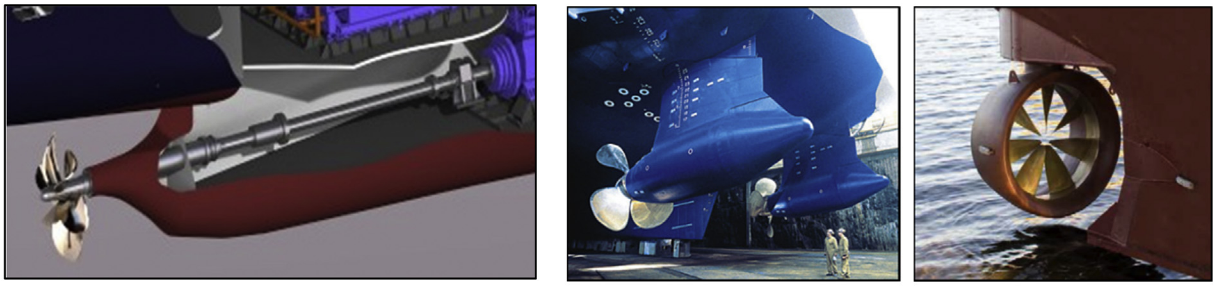
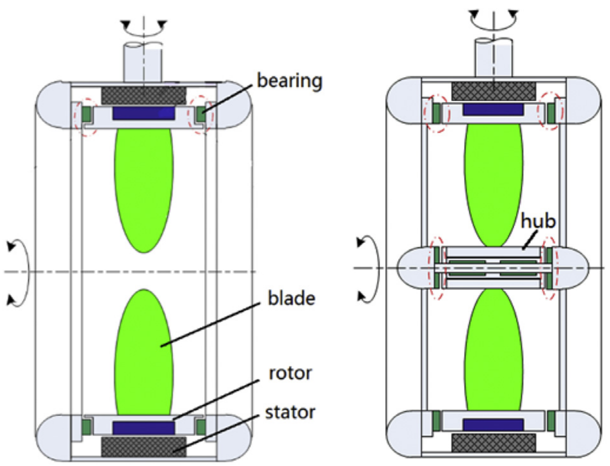


(a) Conventional form of propulsion system; (b) podded drive propulsion plant; (c) shaft-less RDT.

Fig. 1. Different marine propulsion systems.



(a) Hub-less RDT and (b) hub type RDT

Fig. 2. RDTs.

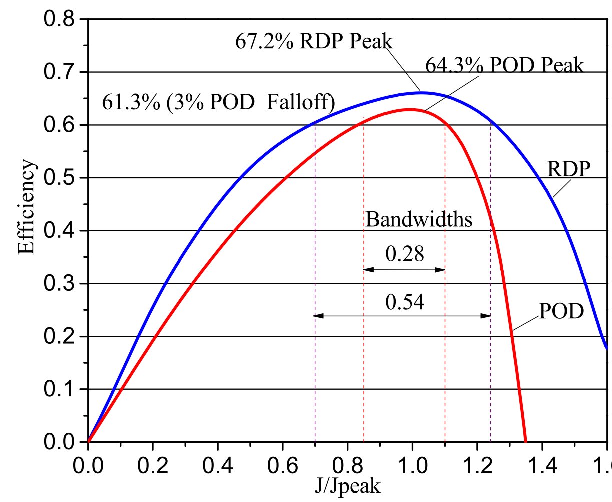


Fig. 3. Open water efficiency at model scale of a RDT developed for a Panamax Cruise Ship vs. a Representative, Good Hub-Drive Pod.

1) Compact design, which saves cabin space and allows for flexible installation and arrangement.
2) Higher motor efficiency (Van Blarcom et al., 2002), larger speed range, and more flexible adjustment. RDT is powered by a permanent magnet (PM) radial field motor, and power does not have to be applied to the field and field power losses are thus eliminated. This makes it more efficient than the Wound field synchronous (WFS) motors which power most current hub-drive pods. Moreover, rotor of the PM motor is mounted on the rim that around the propeller, which allows the motor to produce a higher torque, thus enabling it operating at a low RPM. The low RPM results in low relative velocity over the blades, which contributes to good efficiency and cavitation performance.
3) Higher hydrodynamic efficiency (Lea et al., 2002). As shown in Fig. 3 (Lea et al., 2002), at model scale, the maximum open water efficiency of the RDT and the comparative hub-drive pod is 67.2% and 64.3% respectively. The RDT is more efficient than the POD at all operating conditions. At off peak advance coefficients the hydrodynamic efficiency of RDT is much less sensitive than that of the comparative hub-drive pod. If the off design operation is limited to a 3% drop in efficiency from the POD peak (to about 61.3%), the off design operation range of the RDT is almost twice than that of the hub-drive pod range ($0.54/0.28 = 1.93$). This insensitivity of the RDT to off design operation can enable lower ship operating costs and higher operating speeds in heavier sea states with the RDT.
4) Reduced demand for secondary systems such as motor cooling system, bearing lubrication system. The RDT does not require a dedicated motor cooling system, and therefore the energy to run such a system is saved. It uses seawater lubricated bearings instead of oil lubricated bearings. The ship's lubrication systems energy consumption is thus also reduced.

Shaft-less RDTs can be roughly split into two categories: Hub-less and hub type, as shown in Fig. 2. In the hub-less type RDT, the support bearing and thrust bearing are installed in the duct. In the hub type RDT, bearings can be installed in the duct or in the hub. Each type has its own advantages. The hub-less RDT is beneficial in reducing damage caused by fishing nets or ropes entering the system and has higher hydrodynamic efficiency. The hub type RDT, however, has a stronger impeller because the blade tips are all connected with the hub, so it can be built larger in size and output higher thrust force.

This paper reviews the research progress of RDTs in terms of both theoretical and experimental studies on driven motor performance, motor control systems, hydrodynamic performance, and optimization. Several application cases are enumerated and future research directions are also proposed accordingly.

2. Progress and development

The earliest principle model of RDT was proposed in a German patent in 1940 by Kort (1940), with the rotor on a ring around the propeller and the stator coils housed within the duct of the thruster (Fig. 4). Following this patent, several RDT patents were established (Pierro, 1973; Ono and Yamamoto, 1976; Edwards, 1988; Taylor et al., 1989; Veronesi et al., 1993; Veronesi and Drake, 1993), but focused solely on the description of the general concept of the device, while none addressed the design of the machine itself or its performance. The actual practical realization of an efficient compact RDT had become possible just within the past two