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Ship Electrical Propulsion System

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ABSTRACT

Historically, ships have always played an important role in the transport of Commerce held and sea journeys. Hence always the study of ship propulsion systems was considered by investigators to obtain the most ideal operating conditions of the ship propulsion system requirements. Due to the growing advances in marine industries and science on the one hand and on the other hand discussion of replacing diesel engines with electric motors (due to higher efficiency, less maintenance, wider range of speed control, better dynamics and running out of fossil fuels) In all propulsion systems such ships, the goal of this paper is an investigate about the feasibility of using electric motors in of vessels propulsion systems. So in this article after introduction and compendious describe about electric ships different kind of ship propulsion systems will be discussed. After that to obtain an appropriate electrical propulsion system tree common types of propulsion electro motors is reviewed. In the next part proposed electrical ship propulsion system consist of propeller and induction motor is achieved. At part 4 a load character is added to the model. Then by simulation the obtain model the maneuverability and fast response of electromotor to speed reference is proven. At the end in conclusion consequence of paper is expressed.

KEYWORDS: ship propulsion system, electric motors, ship resistance, electromagnetic propulsion, HTS motors, and High-temperature superconductor.

1. INTRODUCTION

Since in any case, the first step is identifying the problem, so after the introduction and the discussing about the aim of the project, different components of model will be explained. The propulsion system of the vessel includes of power generation, transmission and propulsion tools are being paid. For each component the advantages and disadvantages of the various types will be discussed and at the end of third section, proposed electrical ship propulsion system is achieved.

Electric propulsion systems, regard to the method of applying force to the propulsion systems are generally divided to electric propulsion systems using electric motors and electric propulsion systems using electromagnetic propulsion. The first part of this article is paid to different kind of electric motors that can be used in vessel propulsion and their speed control systems (drives), and simulation of one type of these systems. Noble type of electric motors that is used in propulsion systems because of using superconductors in their structure is named high temperature superconducting motors (HTS motors),which has been mentioned in this article. Second part is based on description of electromagnetic propulsion systems.

Conventional propulsion systems to generate the required force are using diesel engines. And again scientific investigation about electrical propulsion systems, the shipping companies do not have any interest to order the electrical ships so the aim of this paper, by showing the advantage of electric propulsion systems, is encourage them to use electrical ships.

The scientific contribution of this paper are: 1) complete describe and design of a ship propulsion system. 2) Simulation of an electrical ship propulsion system with a load Characteristic of a real vessel.

Finally, in conclusion, reason of superiority of electrical systems on other types for use in ships propulsion systems has been expressed.

2. Principle of Ship Propulsion System

The propulsion system, even more generally any system, to move needs three different parts; force generation, force transmission and force conversion. In some systems these three parts of propulsion system may be designed individually. But basically, performance of this three parts is related together, for example a transmission system which designed for rotational motion, cannot be used for a motor with reciprocating movement. Furthermore, these three parts volume, weight, and moment of inertia should be fit together which the final system performance will be desirable. Vessels are not exempt from this rule and all of these three parts, (especially the force conversion part) should be selected and designed respect to the application. So these three parts will be described briefly in this paper.

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2.1. Force generation: any object to move needs the force. In the most cases the power supply placed inside the object body and those device or vehicle is named automotive. Since the invention of the steam engine by Thomas Newcomer and especially after its development in the 18th century by James Watt, use of this force generator to create driving force in various vehicles such as trains and steam ships begins[1].Then by development of knowledge, other types of force generators created.Can be said firmly; today the most force generator, because of its simple structure, is diesel engine.But should not forget that in valuable systems, such as ship; flexibility, performance and reliability are more important than simplify factor and for this goal other types of force creator like gas turbine, nuclear engine and electrical motorshave been studied. By this reasons the study for design an appropriate force generator for ship propulsion system will be continued.

2.2. Force transmission: any propulsion system, regardless of the variety of driving part and generation part, to move needs to a force transmission system which based on force generator and force conversion system it will be chosen. Generally, the force generator can be connected to force conversion part indirectly (with gearbox) or directly (without gearbox).

In the term of force transmission, the best engine with wide range of speed control is electrical motor, because with consider to recent advances in power electronics, the amplitude and frequency of supply voltage can be controlled which result to shaft speed control from zero up to above nominal speed andEvenby control the supply voltage, the rotation direction can be reversed and consequently the gearbox and clutch can be omitted and the efficiency of force transmission part can be increased up to the ideal.

2.3. Force conversion: After mechanical power transmitted from force transmission part, to create movement from mechanical power, force conversion part is needed. In fact force conversion part converts the mechanical power to thrust force. The main part of this mechanical power can be used to create torque in power vessels or to create speed in high speed vessels. Full description of different types of force conversion systems (including fixed pitch propellers, ducted propellers, podded and a zimuthing propulsions, contra rotating propellers, overlapping propellers, tandem propellers, controllable pitch propellers, water jet propulsion, cycloidal propellers, paddle wheels, magneto hydrodynamic propulsion and superconducting motors for marine propulsion [2, 3]), needs several papers. So in this article only the most used force conversion part (fixed pitch propellers) is used.

3. Ship Electric Propulsion Systems

Usually electric propulsion system consists of one or two electric motors that are connected directly (or by gear box) to the propeller of the ship. Required electric power of this motors are provided by the ship's diesel generators. Electric motors and their control systems used in ships are very varied that cannot be described in a paper and even though in several papers. So In this article those electric motors that are widely used in propulsion systems are briefly reviewed.

3.1. Electric motors that are widely used in propulsion systems

3.1.1.Direct Current Motors: Due to the high controllability in both states; speed increasing and braking, up to about 40 years ago this type of motors had been the only choice in all industrial application of electrical drives. Further of these motors high depreciation and maintenance costs, armature limited current, low torque and limited output power of these motors are disadvantages of them for using in ship electric propulsion systems.

3.1.2.Synchronous Motors: Synchronous electric motor is an AC motor, which rotations speed of the motor’s shaft is proportion to the applied stator frequency and the number of poles. Constant rotor speed with high power of motor is the advantages and reasons for using them in huge ships such as icebreaker ships. These engines also have high depreciation somewhat like direct current motors.

3.1.3.Induction Motors: Induction motors due to simple structure, high starting torque (along with the appropriate drive), long life and high reliability and other their benefits, always are a serious option in electrical drives. As long as can say, this generation of electric motors, for high maneuverability, is a serious choice for ship electric propulsion systems.

3.2. Proposed electrical ship propulsion system

Consider to The title of this article and the presented information. In this section selecting the various components of eligible propulsion system can be concluded such as:

3.2.1.Force generation: Due to the advantages of electric motors, which are described in its own section.in this part, the induction motor with vector control for control the speed of rotor form the force generation part of propulsion system.

3.2.2. Force transmission: As have been described, chose this three part of propulsion system are tied together. Due to stable and wide range of speed control (by vector control method), direct transmission (without gearbox) is selected for force transmission part.

3.2.3. Force conversion: regard to the studies in this paper, which aims to study on vessel propulsion systems, for force conversion part fixed pitch propellers is chosen.

Torque - speed, thrust - speed and power - speed curves regard to this relationships[4]:

$$Q = K_q \rho n^2 D_p^5 \qquad \text{Torque [N.m]}$$

$$T = K_t \rho n^2 D_p^4 \qquad \text{Thrust [N]}$$

$$P = Q\omega = K_q \rho \omega n^2 D_p^5 \qquad \text{Power [w]}$$

Are the order of 2, 2 and 3 generally, but for simulation only speed - torque curve is needed (n: propeller speed [rps], D: propeller diameter [m],ρ: water density [kg/m^3],ω:rotor speed [rpm], andK_q are K_tTorque and Thrust coefficient respectively).

4. Load Characteristic

One of the duties of the ship designers are design a body shape for ship which has the lowest resistance. Ship propulsion system and ship body shape must be properly designed that the required amount of energy, for moving the ship, be minimized. Usually the main force convertors are the propellers and force generators are diesel engines, electric motors and etc. In other words, all the elements of system should be set well that the required power to drive the vessel reached the least and ship simultaneously have high efficiency and good maneuverability and operation at sea[5].

Ship resistance consist of several parts (Figure 1), that some of them only can be estimated and exact calculate of them is impossible which in those parts estimation is enough. There are several ways (like: Method ITTC 1957, Method of Hughes Prohaska, Method of ITTC 1978 , Geosim method of Telfer, Propulsion test, ITTC 1978, and performance prediction method) to calculate the ship resistance and for each types of ships one of this method will be used. Since calculate the ship resistance and its complex formula is not the subject of this paper one of the calculated ship resistance typical will be used for load characteristic (Figure 2).

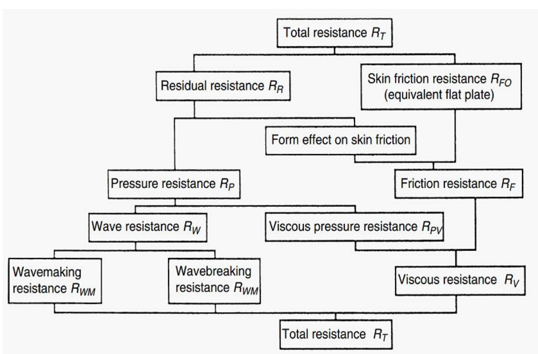

Figure 1: element of ship resistance

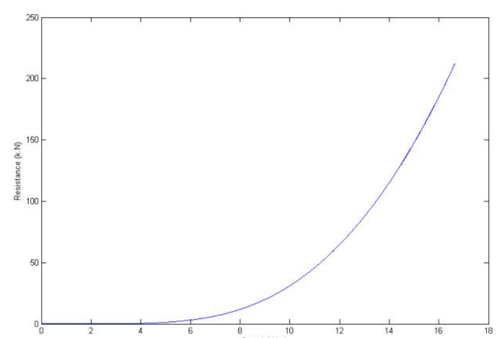

Figure 2: ship resistance-speed curve*

5. Simulation

Regard to torque, thrust, power relationships and assumed resistance – speed curve in figure 1 for supposed vessel propulsion system needs two induction motor which each of them have 2250 hp power and 380 $r.p.m$ shaft speed. For simulation assumed $\rho = 1000\ kg/m^3$therefore propeller diameter will be 1.8m. Because the equal condition for both propulsion electro motors simulation is done only for one motor with half of the ship resistance.

Simulation of Mentioned propulsion system leads to this result:

*This curve is half of ship resistance (because it proposed ship have two equal motor, so the portion of each motor is half of the total resistance) with 340 tons net weight and 780 tons gross weight

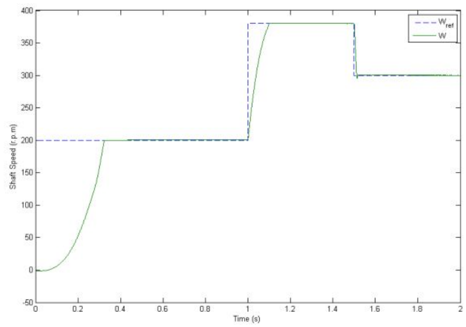

Figure 3: reference speed and speed curves

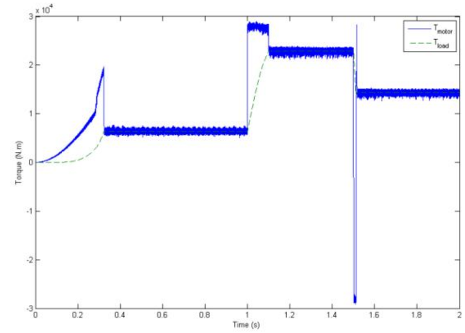

Figure 4: motor torque and load torque curves

The aim of this study was to provide an induction motor control system with a good dynamic speed that can follow the reference speed. For this propose a speed reference curve like green curve in figure 3 is intended which consist of speed change from zero up about half of nominal speed and then increasing and decreasing in value. With regard to figure 3 is obvious that in time aspect this goal is reached, because the speed of the motor shaft with a slight delay have followed the reference speed (at 0 to 1 sec, 200 rpmat 1 to 1.5 sec, 380 rpm;at 1.5 to 2 sec, 300 rpm).

With attention to figure 3 is apparent at t=0 to 0.3 sec when the motor is increasing the shaft speed up to reference speed (200 rpm) motor torque is higher than torque load and the rotor speed is increasing, then at t=0.3 to 1 sec when the reference speed have been reached motor torque and torque load is equal. There is a similar argument for next reference speed (380 rpm and 300 rpm).

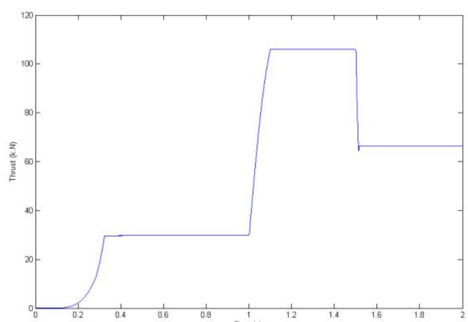

Figure 5: thrust-time curve

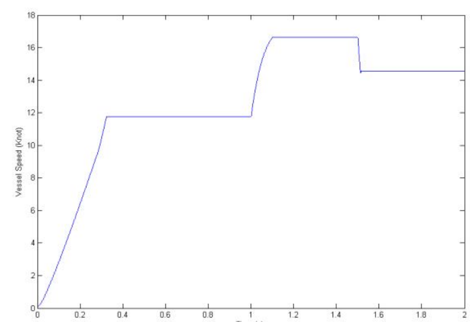

Figure 6: speed-time curve

Because the thrust force and the torque have a linear relationship together, these two waveforms (thrust and load torque) have similar curves (figure 5).

Calculated vessel move curve in ideal situation without consideration of cavitation (which is practically impossible to omit it) would be as Figure 6.Whereas Figure 6 is nothing more than a dream, but it show the good dynamic of induction motor because in a short time the motor provide the required load torque. For obtain practical speed-time curve mechanical and hydrodynamics effect most be considered which needs another paper.

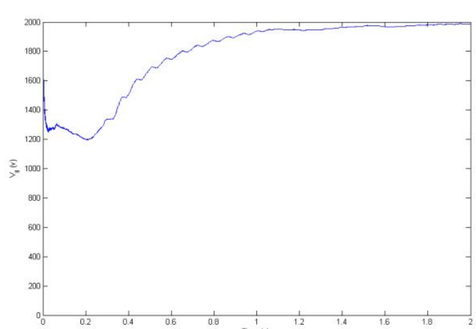

Figure 7: voltage$_{(rms)}$-time curve

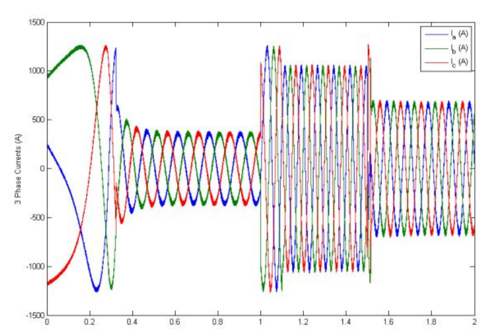

Figure 8: 3phase currents-time curve

Regard to figure 7, in steady state first harmonic of voltage have been stabled in 2000 v that by considering the inverter effect the effective value of stator voltage is 2400 v.

Regard to figure 8 in t=0 to 0.3sec that the rotor speed is increasing up to 200 rpm, motor current is about three times of the rated current. Then between t=0.3sec and t=1sec that the motor reached the reference speed and consequently the motor torque and load torque is equal, the stator effective current stabled in 300 A. after t=1sec reference speed increased to 380 rpm so for increasing the rotor speed the motor torque will be greater than the load torque and consequently the stator current will be amplified. By achieve the reference speed at t=1.09 sec the stator current will be stabled. Finally in third section in t=1.5 sec for decreasing the motor speed to 300 rpm Sequence of phases will be changed.

6.Future of electrical ship propulsion system

6.1. HTS ship propulsion motors

Study for using of superconductivity technology have been started from 1970thand in 1980th by Manufacturing some generator that they used low temperature superconductors (LTS) this project reached new borders. At first this technology Implement in DC machines, although those project never reached the industrial level but those was a good start point. Main problem of LTS technology is low operating temperature that needs complicated cooling system[6].With the advent of high-temperature superconductor (HTS) materials, hopes of commercialization of superconducting motors, because of high operating temperature of used material and consequently use of liquid nitrogen in cooling system,have been increased[7].Since the electric propulsion motors in terms of volume and power consumption have significant part, designers tend to increase compression and efficiency of electric propulsion motors, for these goals HTS motors are the best choice because besides those two advantages, the ability to control the speed of HTS motors are the same as conventional electric motors, and HTS propulsion motors can be used in any types of ships and vessels. Main advantages of HTS motors are[8, 9];

- ✓ The density of the HTS motor torque is three times more than conventional motors. It was far less weight and volume that makes transport, installation and positioning of them easier.
- ✓ HTS motors have high efficiency from low speed up to rated speed.
- ✓ Noise of HTS motors are less than conventional motors.

6.2. Electric propulsion systems with use of electromagnetic propulsion

Unlike other types of propulsion system, this system does not need any propeller or shovel to make the thrust force for propelling the vessel on sea. Principle of electromagnetic propulsion system performance based on interaction between two magnetic fields. First field is effect of fixed wires in back part of vessel and second magnetic field is because of electrical current created by two electrodes placed at the back of the vessel in sea water. Refer to relationship between electromagnetic force (F), electrical current (I) and electromagnetic flow density (B): $F = I\ (L \times B)$ where L is the vector in the direction of the current and “×”denotes the cross product. According to the right hand rule that is shown in Figure 9, based on the relative direction of the magnetic fields, vessel can move forward or backward, and the speed of vessel can be controlled by amplitude of electrical current in fixed wires[10, 11].

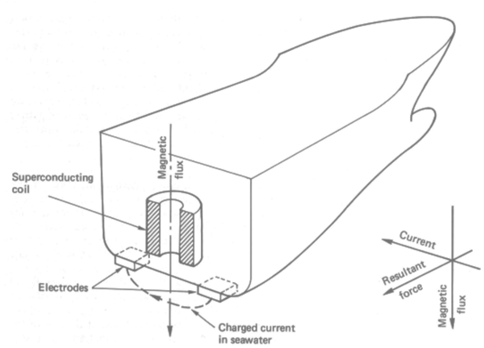

Figure 9: Principle of electromagnetic propulsion system performance

Figure 10: Yamato 1: Experimental electromagnetic propulsion

7. Conclusion

As mentioned in this article electrical ship propulsion system like other propulsion systems consist of three parts: force generation, force transmission and force conversion. According to reasons that described above electrical motor especially induction motors can be a good choice for force generation part in ship propulsion system. Because of limited speed change in ship propulsion applications force transmission section is direct and gearless. Hence the common type of force conversion part in ships is propellers, for that part propeller is selected.

Regard to obtained curves (figures 3–6)from the presented simulations in this paper, can be said induction motor beside vector control has an excellent performance and quick dynamic in following the speed reference in both increasing and decreasing the speed (figure 3). By this reasons, induction motor can be a serious option for propulsion system in all types of vessels, especially for high speed vessels which need high maneuverability (changing the speed like figure 6).The most important advantage of electro motors versus the common types of propulsion motors (diesel engines) are maneuverability. And can be hoped that the induction motor because of its maneuverability, high starting torque (figure 4), Wide range of speed control, great reliability and long life time can be used widely in marine industries. Regard to figure 6by using electrical propulsion system, the speed of vessel can be changed fast and the only limitations for it is hydrodynamic problems.

In the other hand Based on the successful experience gained from the application of HTS motors, can be said that by use of high temperature superconducting motors both transient and steady state response improved, dimensions and weight of propulsion system will be decreased.

To conclude about the future of the electromagnetic ship propulsion system is too early because the current systems are built on the low power levels and spend their research steps.

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