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A Review of Flettner Rotor Sails

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Abstract: **This paper describes the approach taken to create a new assisted propulsion technology for commercial shipping, giving preliminary indications of the benefits achievable. The wind power technology described is the Rotor sails which are essentially the improved version of the Flettner rotors, with full automation. Although the basic principle of Flettner-rotors has been known for a long time, this is the first time that a rotor has been retrofitted on to a ship and made commercially available. This unique type of powered sail has attracted more recent interest for its potential to reduce fuel consumption on ships. Wind is a renewable energy source that is freely available on the world's oceans. As shipping faces the challenge of reducing its dependence on fossil fuels and cutting its carbon emissions this technology explores the potential for harnessing wind power for shipping. Consideration has been given to some of the practical limitations of retrofitting Flettner rotors to a ship, and some of the negative side effects that have been incorporated into the study. An attempt is also made to give a balanced and conservative assessment of the potential benefits.**

Keywords: **Flettner rotors, Magnus Effect, Aspect ratio, Yaw forces, "invisibility".**

Nomenclature:

EEDI: The Energy Efficiency Design Index

SEEMP: Ship Energy Efficiency Management Plan

MARPOL: Marine Pollution

FR: Flettner Rotors

1. INTRODUCTION

Gradual development of regional and international environmental policies are driving stricter requirements for vessel efficiency and environmental performance

To achieve the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) targets as per the amendments made to MARPOL (Marine Pollution) Annex VI [1], the shipping industry is doing its best to comply with environmental pollution issues as specified in MARPOL. Since the maritime industry is global, ship owners and operators bound to meet the requirements of the International Maritime Organization (IMO) as well as local shipping ports, coastal authorities, flag administrations, and other regional governing bodies to reduce emission of CO_2 by cutting down on the fuel consumption and thus meet the prescribed MARPOL targets.

Nowadays, with high fuel prices and a general growing awareness about green and environmental protection policies, the FRs are being seriously reconsidered as viable green ship propulsion devices.

'Magnus effect' Fig: 1, a phenomenon is used in Flettner rotors (FRs) for propulsion of ship using wind energy. This effect can be explained by a spinning body in a fluid flow incident upon it. A curving flight path of a ball in football game is caused due to this factor.

MAGNUS EFFECT:

A force acts on rapidly spinning cylinder or sphere moving through air or another fluid in a direction at angle to the axis of spin. A high pressure on one side of the rotating cylinder or sphere is developed as wind blows past the rotating cylinder, with a corresponding low pressure area on the opposite side. A lift force is generated due to this pressure difference which is perpendicular to the wind's direction and it is used to propel the ship forward.

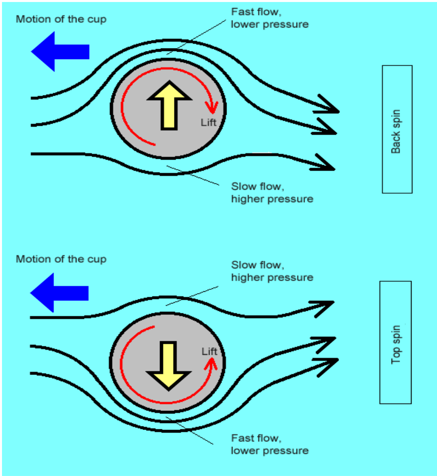

Fig 1: The Magnus Effect

Flettner Rotor was invented by Anton Flettner during 1920s as an effective method of reducing fuel cost while enhancing ship stability and passage times for merchant shipping. The effect of the Flettner rotor exerts as much force as a sail having 10-15 times as large a frontal area. The advantage of rotors over conventional wind-driven propulsion, being only one quarter of the weight of the masts, sails and rigging they replaced and hence it permits the vessel to make more rapid progress over a wide range of wind speeds and directions than conventional sails. The Flettener rotor would not have to be moved while a sail would have to be moved to accommodate for the wind angle.

2. BASIC THEORY AND ROTOR DESIGN:

When a rotating object is placed in a flow of water or air, Magnus effect occurs. Fig. 2 shows the vectors of the force which is divided into lift and drag. The direction of lift depends on the rotation direction and it is perpendicular to the direction of the flow. Drag is smaller and parallel to the flow. Like the swirl of a spinning ball, the superposition of these vectors is the force, or thrust that moves the object sideways in regard of the flow. The ship feels the thrust forward as the rotor is fixed to the ship and not moving freely, the ship gets the thrust forward. The pressure difference that the rotation creates on the opposite sides of the object is the reason for this effect similarly to the wing of an aeroplane. The possible applications in aviation have indeed been considered, but thus far the maritime applications are the only one realized in large scale. Rotors are basically fast spinning vertical cylinders. In comparison to the traditional sails or even to the modern kites the rotors are efficient as they work on wider wind angles, optimum being apparent side wind in 90◦ angle to the bearing. Rotors do not perform optimally with direct back wind unlike with sails, but by minimizing the lift and maximizing the drag it is possible to obtain some power to the right direction. This is not entirely practical, since lift always has larger effect than drag.

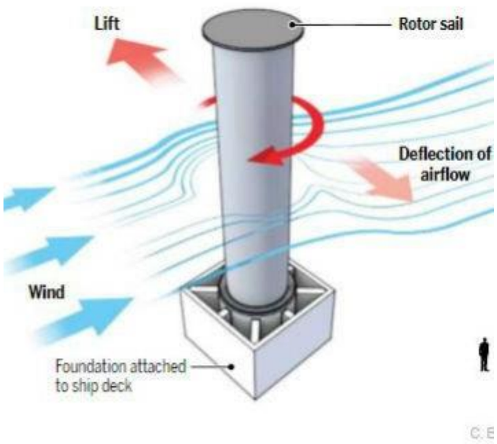

Fig 2: FR Features

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Also direct head wind can be troublesome. But, a 10 to 15◦ deviation from the middle line is sufficient to make the rotor produce appreciable amount of thrust. Performance as a function of true wind is shown in Fig 2. It is to be remembered that the rotor experiences the apparent wind which is the superposition of true wind and the ships speed, the maximal thrust is obtained when the apparent wind is in nearly 90˚ angle to the rotor. Therefore the maxima in Fig. 2 occur on values less than 90˚.

The material of the rotor has altered due to research through the years. The intention is to get the rotor as light weighted as possible, but still strong enough to be seaworthy. Researchers considered wood and fibre glass also. Major areas of concern were the ship movements, pitching and rolling, vibrations associated with engine revolutions along with outside conditions including rough sea, weather, temperatures, humidity.

Known Ships Performance [2]

Ship(year)	**Buckau (1924)**	**Barbara (1926)**	**Estraden (2014)**
Type	Retrofit	Newbuild	Retrofit
Height [m]	15.6	17	18
Width [m	2.8	4	3
Material	Zinc coated steel	Aluminium	Composite
Max. rpm	135	150	250

The rotor contains a empty hollow space with all the necessary equipments and sensors installed inside the cylinder and so they are kept safe from harsh atmosphere. The cylinder is the only rotating part in the FR, the inner parts are static. The base structure has the entry hatch door. But, the ship's crew need not enter the rotor. An emergency stop is provided on the hatch to ensure that whenever someone is inside, the rotor is not turned on.

Norsepower installed 2014, the first Norsepower Rotor Sail on Finnish shipping company Bore's RoRo vessel M/V Estraden [3], and in the end of 2015 Norsepower installed a second similar unit on the same ship.

The first rotor installed on Estraden is a 18 m and 3 m wide cylinder having smooth surface, and an end plate, with 5 m diameter. An external force is applied to rotate the rotor cylinder and together with the apparent wind and rotation create the thrust. The external power for the Norse power rotor is supplied by an electric motor which is placed inside the rotor. The motor is powered by the ship's power grid. It is very advantageous to use of electric motor since the variation of the rotation speed or direction to correspond the wind and weather conditions is very basic.

Aspect ratio:

The rotor should be long and narrow to develop sufficient thrust. Aspect ratio A, is the ratio between the height - h, and width – w. This ratio plays an important part for considering the effectiveness of a rotor. Cylinders with aspect ratio 5 or 6 are structurally strong against the bending forces and loads towards the material. In Norse power rotor the aspect ratio is 6.

FR cylinder has a plate fitted at the end. The end plate, called Thom disc, is critical. The effects of unfavourable aspect ratio can be fixed with adjustment of the end plate size.

3. SYSTEM FAMILIARISATION

POTENTIAL SAVINGS:

For propulsion systems with wind assistance, following points can be advantageous to marine vessel operators.

➢ SAVINGS IN FUEL CONSUMPTION: With wind assistance, Flettner rotor sails could save amount of fuel consumed upto 5-18%. Each rotor can save on an average 8% on fuel [4].

➢ POLLUTION FREE ENVIRONMENT: Harmful emission are controled, such as reduction on soot-causing carbon by thousands of tons per trip and Sox and Nox reductions are also attanined.

➢ REMOTE OPERATION FROM WHEEL HOUSE: Using sensors and controllers, a PLC program automatically controls the whole operation just by pushing buttons.

➢ DUEL POWER AT SEA: The automated rotor sail senses whenever the wind is strong enough to deliver fuel savings and at that point the rotor start automatically. The system will shut down in response to any disadvantageous changes in the direction or force of the wind. The power to drive the rotors is availed from alternators while the main engine power is reduced to account for the added thrust from FRs and hence it is reliable and the ship will continue to sail in case of rotor failure.

➢ NO ADDITIONAL HANDS REQUIRED: With the ease of control from sheltered navigation stations and the lack of furling requirements in heavy weather ensures no extra manpower is necessary.

➢ NO INTERFERENCE TO THE SHIP'S NORMAL OPERATION: Since a control panel gives the crew the full control of the operation and performance of the Rotor Sails, normal operations are not hindered. Wind & GPS sensors, which provide the automation system with real-time wind speed and direction information as well as ship speed and course data, the automation systemoptimizes the performance of the Rotor Sails

NEGATIVE EFFECTS:

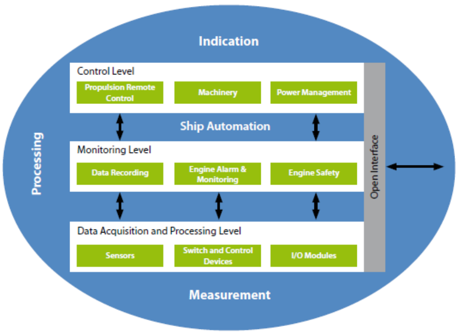
There are some factors that affect the overall performance of a FR fitted ship, and the ship type and layout are very important. Factors to be considered are:

 Side forces increasing the heeling moment; Increased yaw creating extra rudder drag; Forced vibrations (Resonance) [5].

When the apparent wind angle is nearly dead ahead or astern, the sideways (sway) forces can become very large. A large heeling moment on the ship will be created when the large sideways force combine with the vertical lever arm of a FR and will thus increase the angle of static heel, just as with a sailing ship. Care should be taken not to increase the static heel angle and safe levels must be ensured for safe sailing.

PLC-based alarm, monitoring and control system:

The alarm, monitoring and control system is used to monitor and control rotor operation including safeties. One emergency stop button and a lever for manual adjustment of rotation speed will also be provided. With three operation modes namely on, off and invisible mode, in invisible mode the rotor rotation is reduced to reduce the drag to be smaller than it would be in the case of full stop rotor thus making the rotor "invisible". When the rotor is turned on, the program calculates the optimal rotation speed and direction from the real time wind speed and direction. These values will be shown on the screen. The rotor power consumption and the power yield as well as the various instrument data from the engines will be shown.



The system provides features like data logging, trend monitoring, alarm and event history and user right management. The system can be easily extended with remote access for automatic and secure data transfer and storage to onshore data services for analysing purposes.

The safety system monitors the primary operating parameters of an rotor. It is the central unit for triggering an emergency shut-down of the rotor to avoid damage. Signal processing is purely digital. Together with fast and quartz-precise speed acquisition it ensures maximum safety and system reliability.

Relating to the measuring point, the channel statuses are indicated by three colour status indications with labelled text field highlighted in colour, Green colour for normal condition, yellow colour notifies a change which requires no further actions. Red colour is used for critical warnings, which will cause the rotor either to shut down or just slow the rotation speed automatically. Rotor component related warnings are the speed, temperatures, acceleration (vibration) of the bearings, wheels, data connections and warnings from outside operating conditions such as high wind speed, humidity, icing and heavy rolling.

INSTALLATION REQUIREMENTS:

- Design principles
- Strengthening of Hull and Pedestal
- Structures supporting Rotors
- Electrical power supply
- Automation system

FR is mainly designed for tankers, bulk carriers, ro-ro vessels and ferries, where:

The rotors should not prevent the required air-space for loading and unloading. For container ships, rotor may be designed with elevated/retractable rotors placed above the loaded containers level. Height limitations will apply according to ship stability and route restrictions [6].

The ship operating pattern, wind/weather and its variability are of great significance to reduce fuel consumption to produce power

While designing, aspects of geometry and size, no of rotors and the place to be installed should be the prime aspects for basic structures and measures of the rotor. Using the conditions for operating the ship, the controlling methods to be used and the calculations of the loads caused by the rotor structures on ship stability, the effects should to be clearly calculated.

4. CONCLUSION

The shipping industry faces a major challenge in how it can economically ship the increasing amounts of goods and energy the world demands, whilst lowering its environmental impact. Significant advantages in embracing, testing and driving innovative technologies like harnessing wind energy for propulsion show a real promise in helping the shipping industry meet this challenge. Since the FR is a separate machinery with independent operation, any failure on the operation of rotor will not cause propulsion failure.

Thanks to latest development in software, research in material science and control engineering, the latest FRs are light in weight, user friendly and not heavy in weight.

In the case of retrofit of old vessels, the machinery installation procedure is simple and fast.

It is expected that the environmental regulations will tighten in the future and the bunker costs will remain the main operating cost. The use of Flettner -rotors is a worthy option for reducing the emissions and gain savings.

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