A system capable of dampening roll and producing electricity installed on the hull of a fishing vessel

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***Abstract*—The necessity to improve the security of fishing's crew during their work can create a favourable condition to produce electrical energy. This solution to problem can do with a system that balance the forces induct from the sea to the fishing vessel. This device in this action generates electrical energy.**

***Keywords*—linear generator, PTO, dampening roll, on-board electrical energy production**

I. INTRODUCTION

A working environment such as deep-sea fishing has been the focus of scientific research for some time now in order to solve some of the problems that arise during hours spent at sea [1], [2]. Essentially, the problems related to fishing are based on security during crew's work.

Many universities focused this area trying carried out solutions [3]. Crew fishing works for several hours in deep sea and in very dangerous condition because often very rough sea. The forces induct from the sea to the vessel generate essentially two reactions to the ship: pitching and rolling. The first is due to the parallel wave hurting the vessel and the second is due to perpendicular wave [4], [5].

This paper has the aim to show how a system, capable to balance rolling motion, can generates electrical energy to power on-board equipment. Some studies like this have the same aim, in fact in literature there are some technologies like active flap or a pitch roll stabilization that controls four active fins capable to estimate the forces induct and react against them [6]. Both the solutions use a controller installed on board that tracks the sea condition, measures the forces, and evaluate the optimal position of the fins to balance the sea forces. Another technology use a neural network controller based on an algorithm that is capable to control rudder that try to stabilize the ship [7], [8]. It is possible to use a non-controlled flap to contrast roll motion installed below the chine of the ship. Obviously, his form, dimension and attack angle have to optimised in order to minimise the forces that cause roll motion [9].

The Department of Engineering of University of Palermo has been working on coupling the system that can ensure safety on the fishing and also to produce electrical energy to exploit on board. This kind of ships have the necessity to powering the equipment related to the auxiliary service (depth sounder, GPS, radar) and a cold room where a large quantity of caught fish is stored several days. If this technology proves to be efficient and capable of generating enough energy to cover part of this electrical load, the use of generating sets could be reduced, with consequent savings in diesel consumed. In fact, the study is focused on the system capable to stabilise ship and generate electrical energy. This is the Power Take Off (PTO) [10], [11].

II. CASE STUDY

The system object of the study consists of at least two linear generators, one on each side of the hull, attached to buoys by means of a rigid rod and then connected to a controller that interfaces with both. As shown in Figure 1 the hull is stabilized because the oscillation induced by the sea to the vessel allows the system, connected to the generator, to extend and retract in motion opposite to that to which the vessel is subjected.

The generator is composed by a linear translator running in a stator anchored to the waterproof cap. This translator, connected to the buoy, is sensible to the hull oscillating, in fact it generates a opposite force that stabilize the ship but at the same time generate electrical energy. The Department of Engineering of University of Palermo has previously developed a prototype of this type that uses a linear generation system to produce electricity [12]–[14].

The controller, installed on board and it is composed by an accelerometer capable of measuring the oscillations due to rolling and then controlling the rods, balancing the hull when necessary [15].

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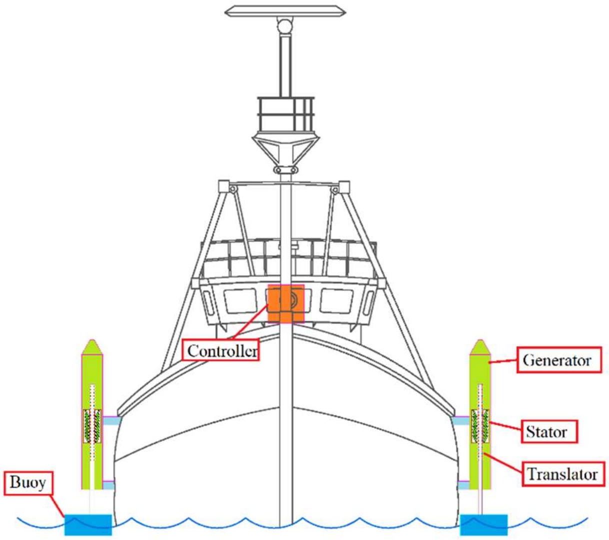

Fig. 1. Scheme of technology installed on fishing vessel

As already mentioned, the study focused on the PTO, but studies were also carried out on the components required for its installation. To this end, a watertight housing, capable of containing the stator-translator system, was prepared. Fig. 2 shows a light but strong cylinder with a suitable anchorage support for the hull.

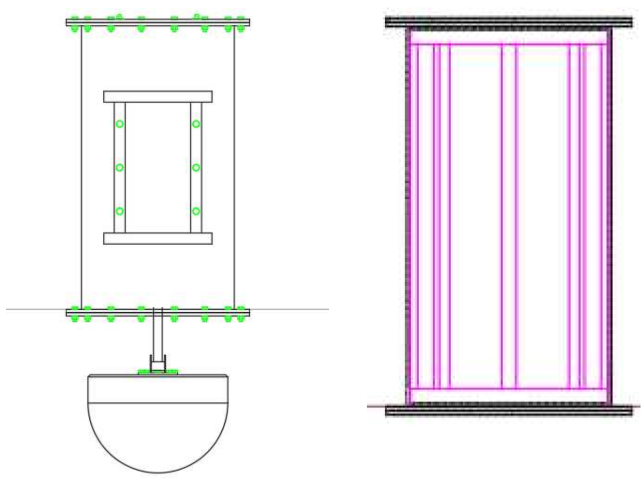

Fig. 2. Generator housing, front view (left) and section (right)

The front view figure shows:

- Two flanged and bolted ends capable of maintaining watertightness and allowing electrical connection to the hull from above and mechanical connection to the buoy from below.
- Solid anchorage to the hull capable of resisting stresses and strains due to rolling.
- Rod with integral connection to the buoy to transfer motion to the translator and thus produce energy by damping the vessel's oscillation.

The section view figure shows:

- The internal cage capable of supporting the PTO and all the accessory components necessary for the system to function properly, such as: electrical shunts, terminal blocks, etc.

A. Power Take Off (PTO)

In the past, there has been great development in the field of rotating machinery, as this type of motion lends itself to easy connection with the countless existing mechanical devices [16]–[18]. Just think of all the driving machines such as water turbines, wind turbines, steam turbines and internal combustion engines, as well as operating machines such as pumps and compressors. All these devices supply or absorb energy by means of a rotating shaft. In this way it is possible to connect the electrical machine directly or indirectly, if the rotation speed is not compatible with the two machines, with a revolution multiplier.

From this point of view, wave motion is a particular source [19], since it is difficult to exploit it to drive ordinary rotating generators, unless special mechanical converters are made to straighten and regulate the motion [20]. On the other hand, it is much simpler to exploit wave motion to produce a linear alternating motion and, therefore, to drive an electrical machine of this type [21]–[23].

In rotating machines, a distinction can be made between a fixed part called the stator and a moving part called the rotor. In perfect analogy, given the different motion, in linear machines the mobile part is called the translator, while the fixed part retains the name of stator. Given the different nature of motion, the driving or braking torque typical of rotating machines is replaced by the driving or braking force of linear machines [24].

Linear machines can take on various configurations, which differ in the way the magnetic field is created, and the angle formed between the magnetic field lines inside the stator and the direction of motion of the moving part [25], [26].

As regards the creation of the magnetic field, this can be achieved using permanent magnets, or it can be specially created with exciter coils. In the second case, one speaks of switched reluctance generators. This is generally only pursued in high-power machines, due to the greater constructional complexity involved.

About the angle formed between the magnetic field lines inside the stator and the direction of the translator's motion, a distinction is made between generators with longitudinal flux and those with transverse flux.

In the first type, the magnetic field lines inside the stator iron impact on the coils parallel to the movement of the side shifter. The coils are installed in such a way that their normal is parallel to the field of motion of the moving part.

In the case of a transverse flux generator, the magnetic field lines on the coils are perpendicular to the motion of the side shifter. In this configuration, the current in the coils travels some distance parallel to the translator's field of motion.

To describe the generator assumed to be installed in the vessel's roll control system, the PTO proposed here can be categorised as a crossflow permanent magnet linear generator. This prototypal PTO is shown in Figures 3 and 4.

Fig. 3. Detail of the PTO carried out by the Engineering Department of the University of Palermo

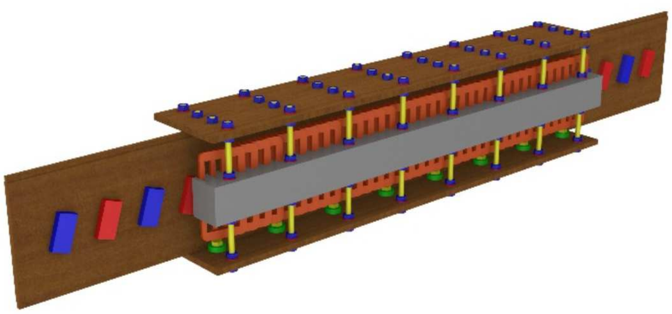

Fig. 4. 3D construction of the PTO carried out by the Engineering Department of the University of Palermo

As shown in studies currently underway at the Department of Engineering at the University of Palermo [12] the idea was to develop a linear generator with a stator made from steel sheets.

This classic configuration ensures a higher power density which, in the case study under consideration, is very important since the side shift stroke depends on the size of the boat's hull.

Despite this advantage, there is a cogging force due to the alternance of tooth and slot during the movement of magnets and therefore the magnetic flux encounter during the translating motion. Another source of disturbance is the so-called end effect, i.e. the moment when the magnet, after leaving the stator, re-enters and creates relative motion between the magnet and stator. Both of these phenomena generate vibrations that worsen the operation of the system [27], [28]. This cogging force friction can be dangerous in a stabilisation system such as the one proposed. A borderline situation could arise where both installed buoys, having to overcome these inertia forces, do not respond promptly to roll counteracting. A time delay in intervention can generate two problems: firstly, the stabilisation of the vessel fails, creating dangers for the fishermen working on board, and secondly, the amount of energy produced decreases.

A reduction of the effect due to tooth and slot alternation is made possible by: screwing the magnets into the shifter [29] and install them rotated by 17° respect to the axis orthogonal to the side shifter [12], [30], [31]. This second optimization is shown in Figure 5.

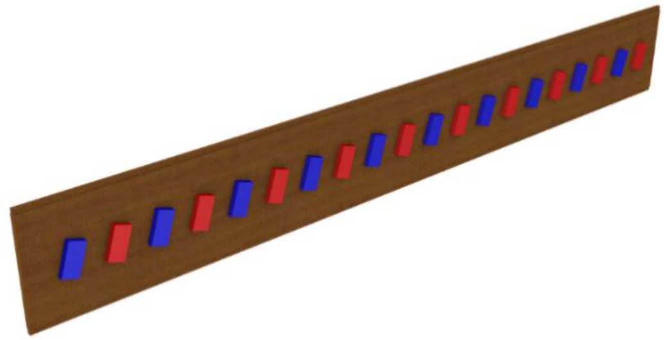

Fig. 5. Installation of th magnets rotate by 17° respect to the axis orthogonal to the side shifter

To reduce the entity of the second problem, end effect, it is necessary to exploit a translator where the magnets are constrained to move only within the stator. This option involves a reduction in specific extractable power, so it is necessary to study a new distribution of magnets which has not been studied at this stage.

At this time the research team focused a new kind of experimentation based on a generator composed by the same translator, just discussed, but a stator with the absence of iron. In fact, in the laboratory of marine technology, in Department of Engineering of Palermo University, was built a stator made of wood. With a no-iron stator there aren't interactions between magnet and iron, in fact the cogging is lost completely. In this alternative solution there is the same problem due to reduction of specific extractable power.

It is important to underline that the wood stator is bult in a small scale from the iron one, but the other technical characteristics are the same. To underline this aspect, is shown the electrical scheme of the three phase connection copper coils installed in both two generators. This is reported in Figure 6.

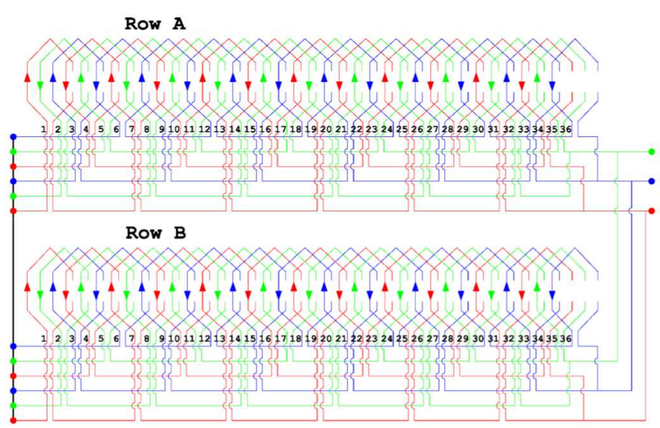

Fig. 6. Three phase connection in both generators

In this way the comparison can carried out only the difference in term of cogging force and specific power [12], [32].

In terms of cogging force are carried out two measures, one from iron stator and one from wood stator. As shown in Fig. 7 the difference is very important because, the iron generator produces 45 N while wood generator produces very small forces. In Figure 8 is shown the wood generator during cogging force measurements.

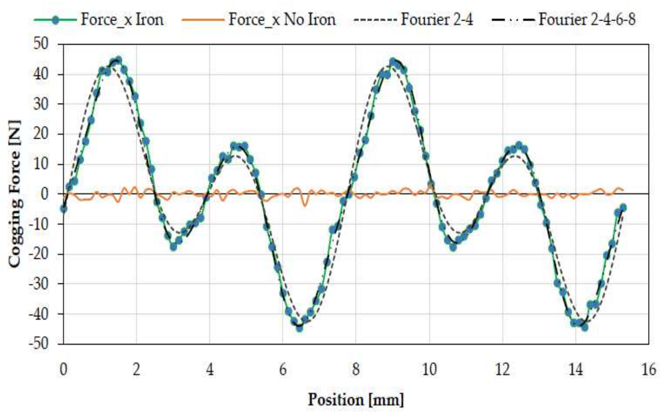

Fig. 7. Cogging force measured in iron generator and no-iron generator

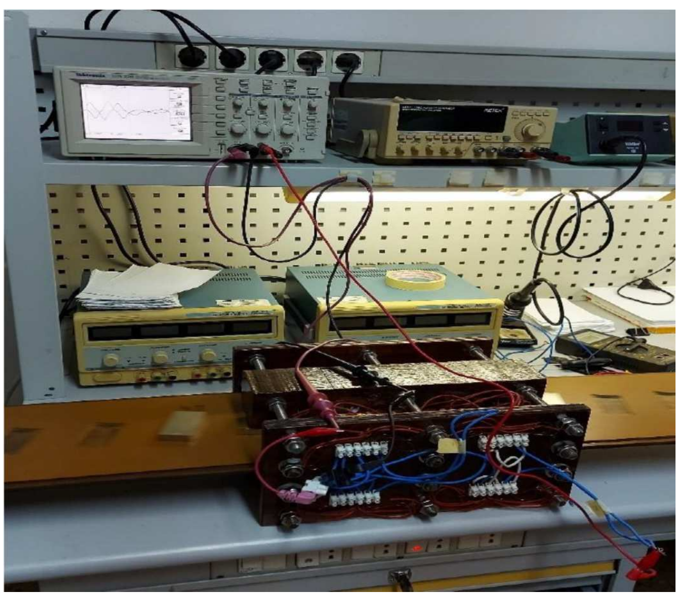

Fig. 8. Linear generator composed by wood stator during cogging force measurements

III. CONCLUSION

In this period the comparison between two kinds of generators, in terms of technical characteristics, is continuing on the basis of laboratory measurements.

The research team, in order to sizing the generator, is going to buy or rent a ship with the aim of measure the forces created from the roll motion. In this way the generators studied can be installed both separately on the hull. From the results of this on-board measurements the optimal size can be chose.

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