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Wave energy utilization with kinetic harvesters for ship propulsion

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Abstract

Ship emissions are a major contributor to global climate change which puts pressure on environment and humans. Maritime sector is really working hard to achieve zero or negligible pollutant emissions by 2030. Our aim is to make a diesel free propulsion system for the maritime sector. We plan to utilize wave energy onboard ships for electricity generation and further, for ship propulsion. We plan to use water floats which harvest the kinetic energy of the ocean waves with the help of hydraulic pistons. These pistons transmit this actuating motion to highly efficient electric generators accounting for the mechanical energy required by the generator to produce electricity. This electricity generated can be stored or used simultaneously to power the ship machinery and the propulsion motor of the vessel. For 'cold starting' of the ship and to ensure smooth sailing in calm seas, provision for auxiliary batteries and emergency batteries can be kept onboard .As waves in an ocean are This venture of ours has ensured to maximize the energy output of this system onboard and minimize all the limitations associated with it.

readily available we literally have an infinite pool of energy which can be harnessed without damaging the environment and reducing, if not eliminating the need of fossil fuels. If we could capture just 0.1% of the ocean's kinetic energy caused by surface waves we could satisfy the current global energy demand over 5 times. With electric devices onboard this energy can be harnessed with negligible losses and yield the best results. According to a study a wave with a height of 1.2 m and a time period of 10 seconds delivers a power of 35000hp (26000kw) per mile on the coast. The structural differences we are proposing also reduce the rolling phenomena, as the floats will act as stabilizers to the vessel and will also increase the overall beam of the ship. Furthermore, these floats can also be used to minimize the use of ballasting tanks, where the floats themselves act like one. Wave energy power plants usually range from 5- 10 MW. Even 40% of this is more than sufficient to propel large vessels along with other machineries onboard ships.

Keywords: **Water floats; Wave energy; actuating motion; Hydraulic pistons; electric generators; electric motors; power per unit length.**

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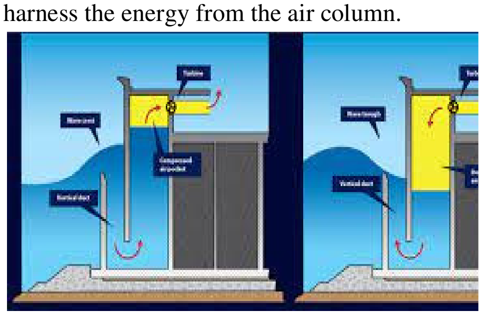
Introduction

70% of our planet is water. Out of this, around 97% part is what we call as seawater. The oceans cover an area of around 361.9 million km^2 and have a volume of about 1.335 billion km^3. It is this seawater's energy that we plan to harness. Fossil fuels are not reliable in the longer run as they are exhaustible resources and upset the very fabric of our ecosystem. Not only the maritime industry, but every sector is trying to find alternative fuels or energy sources from nature itself. Ocean wave energy is utilized in many ways some of them are:-

1.) Oscillating water columns- This method harness the actuating motion of the air column which is further actuated by the waves' oscillating nature. A wells turbine is used to harness the energy from the air column.



2.) Tapered channels (also known as TAPCHANS) - This method of wave energy conversion collects into a channel which tapers into a large reservoir. According to conservation of energy, as the wave width decreases, the amplitude increases, enabling the wave travel up a ramp and pour into the reservoir.

3.) Attenuators- they capture energy by being placed perpendicular to the length of the wave, this causes the attenuator to continuously flex where segments are connected. This connection is then connected to hydraulic pumps which convert the energy.

4.) Absorbers- They extract energy from the rise and fall of the waves with a buoy. Once the energy is extracted it is then converted to electrical energy with a linear or rotary generator.

5.) Kinetic harvesters or water floats- These stay on the water membrane and harness the kinetic energy of the wave for electricity generation. The actuating motion is delivered to generators via hydraulic pistons for electricity generation.

Since wave energy is still relatively new, there are fewer areas that currently have or are installing wave farms. Some main areas for wave farms are Portugal, the United Kingdom, Australia, and the United States.

Portugal has the very first wave farm, the Aguçadoura Wave Farm. It's about 3 miles offshore, north of Porto, and was designed to use 3 Pelamis wave energy converters. It has an installed capacity of 2.25 MW, and

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was officially opened in September, 2008. Due to the financial collapse from an economic crisis, however, it was shut down.

United Kingdom. In May, 2010, a wave farm (currently 66 machines) was launched in Scotland. It was announced in 2007 and cost over 4 million pounds, equivalent to $5.9 million dollars.

Off the north coast of Cornwall, England, the Wave hub facility acts as a giant extension cable. It allows 20 MW to be connected to it, but could go up to 40 MW. It also could end up powering up to 7,500 households and save around 300,000 tons of CO2 in the next 25 years.

Australia has wave farms that are currently under development off the West coast and near Portland, Victoria. Both of these projects are targeted to cost upward of $65 million. There is also a *green Wave* device off of Southern Australia.

United States The United States was to have a wave farm off of the West coast by Oregon. The Reedsport farm was supposed to be installed in 2013, but due to legal and technical problems, the project came to a halt.

Denmark has also come up with a wave energy utilization power plant known as wave star. It uses water floats for harnessing the actuating motion of waves. It has 20 floats, each float has a radius of 10m it operates on waves with a mean significant height of 0.1m and generates an output of around 6MW.

There are also possibilities in Russia and Italy for potential wave farms. Chile has an enormous potential for harnessing wave energy. The north Atlantic, north pacific and the southern ocean are some regions where wave energy potential is significant.

These wave farms are power plants fixed in the ocean, used for household or industrial use of energy generation. Our vision is to harness this energy onboard ship using kinetic harvesters or water floats.

Working

We aim to bring structural differences to our ships for harnessing wave energy. We introduce water floats on both sides of the ship. These water floats will be attached to the vessel by means of float arms. The float arms will be responsible for energy transmission. To maximize the harness, floats will be placed in such a way that they are just above the water membrane as waves lose their energy exponentially with depth. In addition to this the floats and the float arm will converge into the ship keeping in mind the frictional resistance experienced by the ship and the overall stability of the vessel.

Wave power- The power of a wave is expressed in the form of power per unit length, and is given by the formula:-

$$P= \rho g^2 H^2 T/ 64\pi$$

Where, P is the wave energy flux per unit per unit of wave crest length.

ρ is the density of seawater= 1025 kg/m^3

g is the acceleration due to gravity = 9.81 m/s^2

H is the significant height of the wave. Ocean waves reach a height of 2-3 m in normal weather.

T is the time period of wave. Surface waves usually have a period of around 20- 30 s.

Calculating the estimated power we get:-

$$P= 1025 \times 9.81 \times 9.81 \times 2.5 \times 2.5 \times 25 / 64 \times \pi$$

Which implies, P= 76.657 KW per meter = 76.657 x 1.341= 102.8 hp/ m

Now at an economic speed of 11 knots= 102.8 x 11 x 0.5144, thus

A total output of 581.71 hp can be obtained from one float

A ship with n number of floats can harness the above value multiplied by n considering some energy to dissipate. Our proposal for the number of floats is dependent on the L.O.A (length overall) of the ship. Naturally, only an even number of floats shall be used to keep the ship stable.

- For ships with length 0-120 m 6 floats of radius 3 m.
- For ships with length 120-250 m 8 floats of radius 3m.
- For ships with length 250m and above 10-12 floats of radius 3m.

Now for a ship with 12 floats power generated per unit time will be= 581.72 x 12x 0.8 ≈ 5500hp.

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The maximum output of this system in favourable conditions (H= 4m T= 30s) can reach up to 14000 hp, after loss reduction.

For perspective, the most powerful engine used in the shipping industry namely The RTA96C-14 turbocharged 14-cylinder, two-stroke diesel engine by Wartsila-Sulzer, produces around 10000 hp at its economical speed. The above calculated power output can be increased by steering the vessel into relatively rough waters. A factor of 0.8 was multiplied with the total result considering all the losses and approximations that were taken during the calculation.

(Note- The above calculations are averaged and approximated to some extent, the output may vary during practical trials. Nevertheless, the authors of this paper take full responsibility that the values deduced are mathematically correct and very accurate to the actual values.)

For electric generators, we plan to use convertors, and drives for a constant and smooth output (AC supply with a frequency of 50 -60 Hz as mentioned below) and install large scale electric generators of industrial grade maybe of the rating of 2MW. The number of such generators can be calculated according to the type of ship and the energy requirements of the vessel.

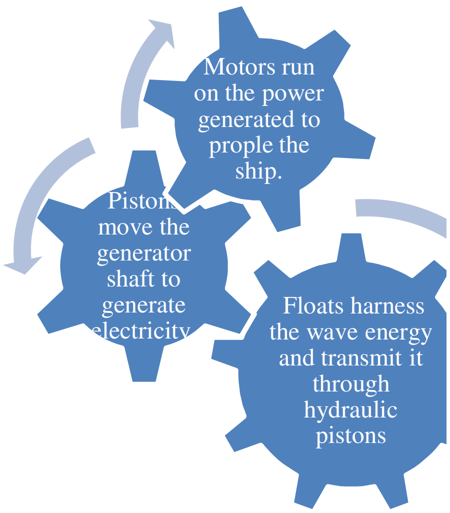
Our proposal not only involves float harvesters, but diesel free propulsion of the vessel as well, for this we have introduced induction type electric motors which will propel the ship. Induction motors have a high efficiency of 85 to 96% at full load, are self starting and economical. Contrary to this, electric motors don't work effectively in low loads. To resolve this problem we will use a motor with low power rating, an auxiliary motor for the 'cold starting' of the ship. On board ship, AC power is preferred, a 3phase, 3wire, 440 V with a frequency of 50 to 60 Hz. High voltage marine systems operate at 3.3, 6.8 or 11.3 kV and Low voltage marine systems operate at around 690 V.

Not all the energy we produce will be used simultaneously. On analysing, the induction motor and the associated machinery would require an output which is controllable for speed adjustments and smooth sailing. For this large scale electric batteries will be used. Det Norske Veritas and Germanischer Lloyd (DNV GL) which is the world's largest maritime class society, supports the safe introduction of large maritime battery systems with battery rules such as type approval services, industry guideline and advisory services. They further explain that a 2011 study by DNV GL demonstrated that energy storage technologies represent a substantial potential for improving both fuel economy and reducing emissions in the maritime industry.

• The batteries can provide the required electrical power and enable switching off numerous engines when they would be running inefficiently at the same load. The batteries can then be recharged when the engine is operating with lower SFC, CO_2 and NOx emissions. This setup can save fuel, reduce emissions, increase comfort because of reduced noise and temporarily enable sailing without emissions, noise and vibrations from the engines.

• Batteries can provide back-up power during a failure of the combustion power supplies (diesel generators and gas turbines); this in turn can potentially reduce the installed power on vessels with a requirement for high availability of propulsion as the need for running extra diesel engines is reduced.

• Batteries can enable peak shaving; the battery delivers power when high power is required and recharges when less power is required. This in turn allows the engines to run more efficiently and the installed power can be reduced.



Working conditions

Our proposals regarding the structural changes increase the beam of the ship by a total of 20-24 m. While this is advantageous as far as rolling is concerned, the increase in the beam won't allow the vessel to passage in canals and riverine ports. In addition to this the floats system proposed can only work in waves which have a significant height of 1-4 meters, rough weather might damage the floats and the ship's structural integrity might be compromised. To counter these problems we have come up with 3 solutions:-

- The floats can be lifted up, in case of canal passage and rough weather. The auxiliary batteries come into play here for propelling the vessel.
- The floats can also be folded along the hull of the ship; this will reduce the transverse length of the ship by 8-10m. This arrangement will reduce the beam and also render the floats operational.
- The floats can be withdrawn inside the hull of the ship and a similar approach for auxiliary batteries is taken; this will allow the stability to increase as the weight is drawn towards the centre of gravity of the ship. Furthermore the withdrawn floats can also contribute in ballasting of the ship by making use of their hollow nature, as water can be stored into them and they can replace ballasting tanks completely of partially. This idea however, is not profitable for the investors as the storing capacity of the ship will be reduced.

Accompanied by the increased pressure and bending moment on the float arms, again poses a challenge to keep the vessel stable and intact. Mass of water in one float = density of seawater multiplied by volume of the hemispherical float.

$M= 1025 \times (2 \div 3) \times \pi \times 3 \times 3 \times 3 = 57960$ kg

Thus, 58 tonnes of water approximately can be stored in one float of radius 3 m.

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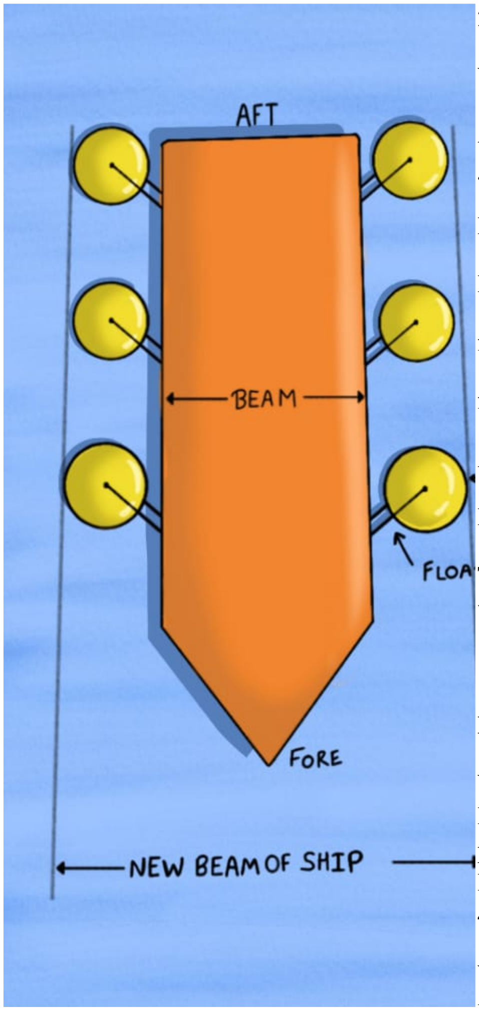

Frictional resistance of floats can be calculated by assuming:-

- They are smaller vessels/ boats.
- 12 to 15% of their surface area is submerged underwater.
- This submerged area becomes the wetted surface area of the small boat, and the perpendicular distance between the bottommost parts till the centreline is the draft of the float.

Now, surface area of hemisphere= 2 x π x r^2

2 x π x 3 x 3= 56.54 m^2

WSA of ship = 56.54 x 0.15 = 8.482 m^2

According to Froude's formula frictional resistance is given by = $fSV^{1.825}$

Radius of submerged hemisphere= r x r = 8.482/ 2 x π

$R_{new} =$ 1.161 m

f= 0.417 + 0.773/ (R_{new}+ 2.862)

f= 0.609

At 11 knots R_f= 0.609 x 1.161 x $11^{1.825}$

$R_f \approx$ 4 - 5 N for one float.

Thus, an increase in the ship's frictional resistance would be observed.

Materials used

We plan to use a material known as ABS (Acrylonitrile Butadiene Styrene). ABS is a common thermoplastic polymer. Its chemical formula is $(C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)_n$. It has a young's modulus= 2.28 GPa; tensile strength= 43MPa and Density= 1070 kg/m^3.

We have envisioned using this amorphous solid as the material of the float as Abs is highly durable; it has high impact strength; is electrically insulated; it is resistant to acids, salts and water. In addition to this, we have improvised a PVC coating which provides flexibility and softness and a latex paint applied to prevent it from UV radiations.

For the float arms we plan to use steel. Because of its high tensile strength and low cost, steel is used in buildings, infrastructure, tools, ships, trains, cars, ma chines, electrical appliances, and weapons. Its density varies from 7750- 8050 kg/m^3. We will use CRES type of steel which is a corrosion resistant steel alloy.

Mass of float = density of material x volume of material= 1070 x 2/3 x π x (3^3- 2.5^3)

Mass of float = 25,487.4 kg ≈ 25 tonnes.

For steel arm its dimensions are assumed to be 7m x 2m x 2m = $28m^3$

Mass of 1 steel arm = 7900 x 28 ≈ 221 tonnes

Mass of total setup = 221+ 25 ≈ 250 tonnes

The thickness of hollow sphere is taken as 0.5 m and hence we calculated the mass of float. For the steel arms we have assumed a mean density value which was specified above. This calculation is only to provide the reader's with some perspective .The mass of this setup can be changed according to the type of ship this is used in. The material, dimensions can be altered as per the investor's and ship builder's discretion.

Advantages

- Wave energy has a lot of potential. Oceans cover 71% of the Earth, so it's very accessible. It literally is an infinite pool of energy. Where, as we like to call it, we 'convert water into watts'.
- The energy is green. Harnessing wave energy doesn't emit any harmful gases, and it can easily replace energies that do, such as using fossil fuels. Additionally it has a negative impact on marine life.
- The energy is renewable and inexhaustible. Ultimately, the energy is caused by heat which is emitted from the Sun, and this energy will not be disappearing any time soon.
- There is an incredible potential in wave energy. For every meter of wave, the power density is between 55Hp to 210Hp. The Electric Power Research Institute (EPRI) analyzed the potential, and for the U.S. alone, there is a potential of about 2,640 TWh/y along the continental shelf edge.
- Wave energy is reliable. Solar always needs the Sun, and wind energy always needs the wind to work. Since waves are essentially always in motion and are never interrupted, it's a reliable source compared to others.
- The energy output estimation becomes extremely easy, as only 2 variables need to be calculated in the wave power equation i.e. the mean significant height of the waves and the time period associated with them. These two variables can be easily determined by forecasting the waters on which the vessel has to voyage.
- Increasing the beam of the ship reduces the rolling phenomena. The model we have proposed indirectly increases the transverse length of the vessel by 20-24 m, thereby reducing rolling.
- These floats, as mentioned earlier can also be used for ballasting purposes where they are withdrawn inside the vessel with filled with water. One float of radius 3 m can have up to 58 tonnes of water.

Disadvantages

- The proposed model involves high cost as far as installation, constructional differences and maintenance of the whole system is concerned.
- The frictional resistance of the ship is increased as shown above. This can be resolved to some extent by placing the floats in an arrow like formation so that a converging stream is created thereby decreasing the frictional resistance.
- This project involves more moving parts, more moving parts means the rate of failure is subjected to increase.
- With additional machinery the cargo space of the ship is also compromised to some extent.

Conclusion

Wave energy utilization is the next big thing the maritime industry can have for clean energy generation, of course it may seem a not-so- investor- friendly project. But if we come to think of it the time and money invested in these types of projects will eliminate the need for fossil fuels applications. In other words, we are simply eliminating engines which run on petroleum products and investing in ventures such as this where the environmental fabric of our planet is not disturbed and the same amount of power, if not more is generated. When we say that the float mechanism and the accompanying machinery compromises the space onboard a vessel we also are, indirectly implying that present day big and bulky engines along with their cooling apparatus are no longer needed. Eventually, this compensates the cost and the space factor to some extent. Explicitly, the rate of failure is also compensated as a large amount of machinery will be taken out from the ship, keeping the moving parts almost the same on board ship.

Coming onto the advantages, a lot of ideas were proposed and discussed regarding the additional advantages of the floats, rather than just energy generation. Ballast tanks replacement and advantageous moderate heaving are some topics that are still debatable and require more data for research in this project. Overall, wave power has some disadvantages as of now, but the potential is enormous, not only for maritime industry, but for the whole world.

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