AN APPROACH FOR SEA WAVES ENERGY UTILIZATION

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ПОДХОД ЗА ОПОЛЗОТВОРЯВАНЕ НА ЕНЕРГИЯТА ОТ МОРСКИТЕ ВЪЛНИ

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Резюме: *Пътят към екологична индустрия и намаляване на нивото на въглеродни емисии в атмосферата се разкрива посредством положителното влияние на енергията от възобновяеми източници. Тя също така оказва влияние и от икономическа гледна точка в дългосрочен план, тъй като е получена от природата. Настоящата статия предлага подход, позволяващ използването на морската енергия, която ще окаже най-голямо влияние върху морския транспорт, крайбрежните области и пристанища. Също така се полага и добра основа за повишаване на количеството на произвежданата екологична енергия.*

Abstract: *The positive impact of green energy over the carbon emissions in the atmosphere reveals the path towards clean industry. It has also a financial impact over the industry in long term as it is provided by the nature. The present paper suggests an approach that allows the sea energy to be exploited which will make an impact over the sea transport, coastal areas and seaports. This is a good basis for improvement of the amount of the green energy produced.*

Introduction: At the current state of the science, the green energy is gathered mainly as a product of the elements – light, wind and water. The force of the water as a source of energy is well known and applied for the past century. In the past decade due to improvement in technology, major increase in the application of solar and wind energy is observed [1]. Solar systems today find not only industrial application, but also power self-sustaining households, sea vessels and vehicles [2]. The improvement of the power conservation technology – increase of the lithium batteries capacity and charge cycles and improvements in hydrogen cells [3] provides the required energy even when the energy source is absent during the dark hours of the day, cloudy and rainy days. The wind turbines similar to the solar cells are dependent on the presence of air flowing through the propellers and thus it does not have the capabilities to provide seamless flow of electricity.

There is a vast amount of energy conserved in the sea which is not yet fully deployed. For example, the hydrogen sulfide on the sea bottom [4] is extremely volatile and it can provide a substantial amount of energy when gathered. Some methods for applying the ocean currents and waves are presented in [5], ocean waves energy harvesting devices start to emerge on the ocean bottom, floating waves harvesting devices are also present. The aim of the present scope is to propose a suitable approach in order to devise an equipment suitable for sea water and specifically for the waters of the black sea. An important moment in the research work must be also the underwater currents providing water movement and thus a viable source of energy even at the point where no sea waves are present on the water surface.

Sea waves envelope model

The sea waves are a product of waves under the sea level, waves on the surface level and seabed waves. The underwater waves are caused as a result of temperature gradient of the water in different regions and thus producing underwater drafts, the seabed waves are usually caused by tectonic movements. The surface waves are formed by the sea wind as well as the gravity by the moon differential force on earth materials. The resulted waves are characterized by spatial movement in all three dimensions – x, y and z in the cartesian coordinate system xyz that specify the wave plane. Thus, the sea waves energy can be presented as the modulus of the magnitude of the particular waves in xoy and yoz planes as shown in fig. 1.

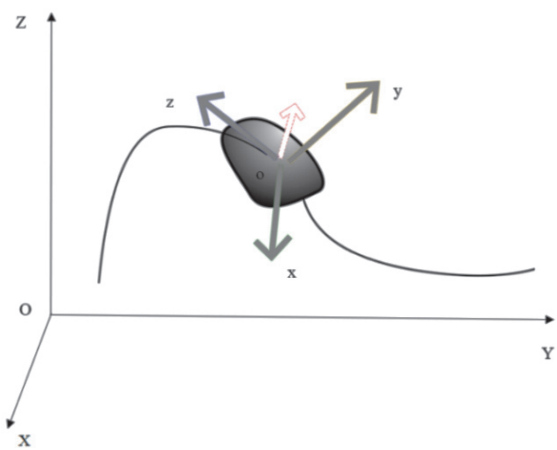

Figure 1. Spatial movement of the sea wave

Fig. 1 poses the first of several problems concerning the process of waves energy utilization – the coordinate system of the wave plane is literally floating in the cartesian coordinate system of observation or solid ground, resulting a change in the angle of incidence on a stationary point where the energy collection apparatus will be situated.

To represent the power of a sea wave [7, 8, 9] in terms of mechanical work, that can be obtained by equation (1):

$$P(t) = \frac{W(t)}{t} \tag{1}$$

where W(t) is the amount of work, t is the time period at which the work is done.

The amount of work depends on the force of the wave – F(t) expressed by (2)

$$W(t) = \int_0^t F(t)dt \tag{2}$$

The force of the wave is a product of the wave acceleration and its mass (3)

$$F(t) = m.a \tag{3}$$

Where m stands for the mass of the wave and a is the wave acceleration at the current time sample

The acceleration can be represented as the magnitude of velocity V at the certain time sample t (4)

$$a = \frac{dV}{dt} \tag{4}$$

The wave velocity can be specified by the rate of change of the spatial position of the water parcel in time (5)

$$V = \frac{dWp}{dt} \tag{5}$$

where Wp(x,y,z,t) is the position of the water parcel in the current time sample.

The wave magnitude is a product of all the possible wave components of sea [8] mentioned above. The modulation of the amplitudes of the wave components with different direction and speed results the sea wave as illustrated in fig. 2.

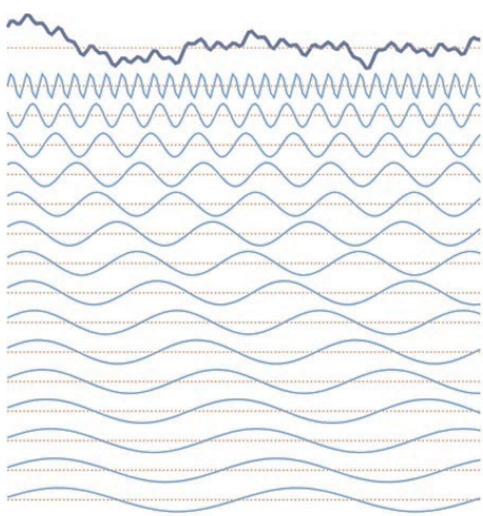

Figure 2. Structure of the wave

It is well known that the sea waves are not constant in presence neither in magnitude especially in black sea gulf of Burgas, which presents the second problem. Another problem is that the waves are impacting the harvesting system both in azimuth (XOY) and elevation (XOZ/YOZ) planes which further increases the complexity to transfer and transform the energy from the wave to the electric grid. Furthermore, in normal circumstances the energy generated depends proportionally on the wave magnitude. However, in case of severe winds and even a storm the waves have a destructive power that leads to disasters and thus it can lead to mechanical malfunctions in the harvesting system.
The knowledge of the sea wave parameters and behavior is fundamental for the system design approach. It will help to consider a suitable transformation of the kinematic movement of the wave and thus designing optimal mechanics of the system. This will provide the required clarity to specify the electrical end of the system with the lowest degree of losses.

Mechanics consideration

The basic kinematics of the wave presented in the previous chapter aid the process help to propose a mechanical design suitable to transfer the energy. As pointed in paragraph 1 – the magnitude of the sea waves depends on the acceleration of certain water volume at a specific moment of time. The acceleration on another hand is a factor of the wind force, tectonic forces etc., providing the water movement – with the increase of the wind speed over certain space of the sea surface the magnitude and thus the energy of the waves become larger. The wind energy is accumulated in the water volume, and it is carried to the shallow parts of the sea – a convenient point of placement and service. Basically, there are two main directions of movement of the waves – azimuth direction (left and right) in the horizontal plane and elevation (up and down) in the vertical plane due to the sine nature of the waves. The direction of movement mentioned above suggests transferring the reciprocating motion of the waves to a rotational movement to the appropriate converter is about to be attached – fig. 3.

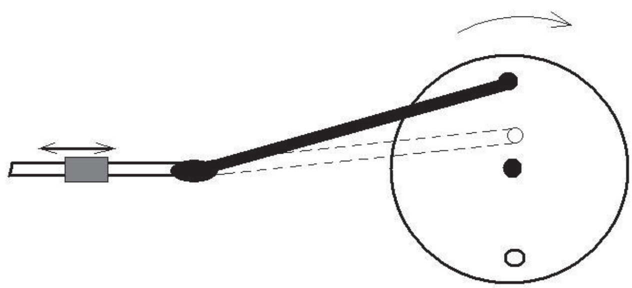

Figure 3. Transformation of reciprocation to circular motion

An alternative is to retain the reciprocating movement and transfer it directly to the axis where the mechanoelectrical converter will be attached – fig. 4.

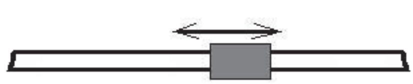

Figure 4. Transfer of linear movement

It must be noted that the mechanics proposed in fig. 3 and fig. 4 are only applied to one direction of movement – corresponding to either the horizontal or the vertical axis of the coordinate system. However, the sea surface wave does have as horizontal as well as vertical and tangential movements which must be considered when designing the mechanics. At this point choosing an appropriate mechanics to transfer the wave movement suffices. The reason that two types of mechanical converters are proposed is due to the specifics of the mechanoelectrical converters which will be clarified in the next paragraph.

Design considerations

This section of the article presents the design propositions for sea waves energy utilization as well as consideration of the type of electrical and mechanical parts used. Paragraphs 2 and 3 presented the amount of energy in a wave as well as the way it is transferred to be appropriately applied to an mechanoelectrical converter. According to the kinematical movements illustrated in figs. 3 and 4 an appropriate converter will be specified as it is strongly dependent. This will impact the overall efficiency of the system as the different types of converters are not equal.

Design of a system with bidirectional linear movement

As shown in fig. 4 there is almost no need of specific mechanics to convert the movement of the wave in horizontal or vertical direction [10]. This type of systems is applicable when using converters that is dependent on the constant change in the movement direction which is closer to the principle of the electromagnetic induction of current through a conductor moving in magnetic field. This design is illustrated in fig. 5.

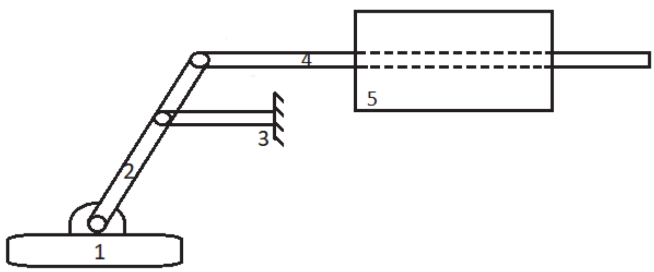

Figure 5. Energy harvesting system using an inductor and a magnet.

As can be seen in fig. 5 the wave movement is related to the magnet – 4 inducing voltage in the inductor – 5 by a lever – 2 that pivots on a point connected to the ground. When the magnet is moved throughout the inductor it creates a voltage U on its terminals according to equation 6.

$$U = B.L.v \tag{6}$$

where $B = \mu H$ is the induction, μ is the magnetic permeability, H is the magnetic intensity, L is the inductance and v - the velocity of movement.

For the system to generate more electricity it must have bigger inductance L which will increase the length of the device greater induction B – using larger magnet or increase the speed of movement of the magnet – v which depends on the wave speed.

An alternative solution is the usage of the piezo effect. The design of such type of system [6, 10] is illustrated in fig. 6.

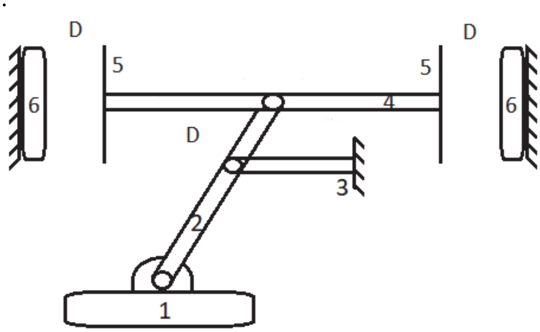

Figure 6. Energy harvesting system using piezo effect.

As can be seen in fig. 6 a piezoelectric plate – 6 is statically attached to the shore. The electricity is generated when bidirectionally moving piston – 5 presses the plates – 6. The piston is attached to an arm – 2 which is pivoting on a foundation which is also stationary attached to the shore – 3. The arm – 2 translates the wave motion from the float – 1 to the rod – 4 which connects the pistons – 5.

The voltage on the piezo element terminals can be represented by (7).

$$U = g\frac{F_N t_m}{Am^2}, g = \frac{d}{\varepsilon_0 \varepsilon_r}$$

Where g, F, t, and A are piezoelectric voltage constant, applied force, thickness, and area of the piezo material, respectively, ε_0 *and* ε_r are the permeability of vacuum and of the piezo material.

The amount of generated electricity depends on the impact area as well as the impact force over the crystal surface and it can be reaching a level of several thousands of volts but on the price of reduced current.

Design of a system with rotational movement

Figure 7 depicts the design of a system that transforms the reciprocating movement of the waves to rotation movement [7 2] suitable for implementation of electric generators.

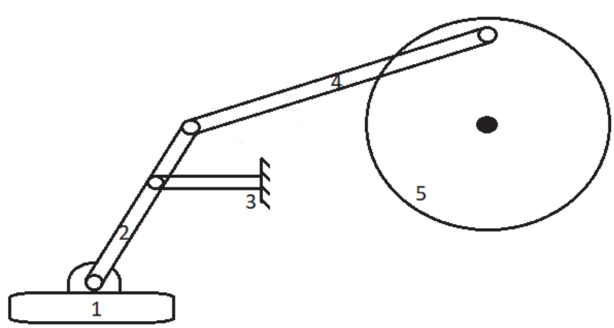

Figure 7. Energy harvesting system using an electric generator.

The generator – attached to a flywheel – 5 is attached to a rod – 4. The rod is attached off the center of the flywheel to apply a force which will turn the flywheel clockwise or counterclockwise according to the direction of the wave. The rod 4 is connected to an arm – 2 with a rotating joint to transfer the movement from the float – 1 to the flywheel – 5. The arm – 2 is pivoting on a support – 3, attached solid to the ground.

As the generator can be rotated in both directions, it is wise to use an AC generator rather than DC generator due to the greater efficiency as well as the minimization of voltage polarity problem. This type of system allows to increase the voltage by increasing the rotation speed using a mechanical transfer box.

The voltage is generated according to expression (6). The difference between this system and the system from paragraph 3.1 is that in this case the inductors are moving through the magnetic field of a stationary situated magnets.

Conclusion

The approach of sea energy utilization posed in this work is of a great interest. The proposed design of energy harvesting systems is up to date and it is fully feasible for implementation. According to the system efficiency – the designs from paragraphs 3.1 and 3.2 are not efficient enough due to the limiting factors of the speed of move and the system size for the first system, and the impact force along with the requirement of larger elements. This also makes both systems not cost efficient and in terms of reliability the less reliable is the system from paragraph 3.2 due to the excessive wear of the piezo material during impact.

The system design proposed in paragraph 3.2 has the greatest efficiency of the three in terms of amount of generated energy, reliability and implementation. It is also the most cost efficient.

It must be noted that the mechanical design proposed in this paper can be applied to the wave movement only in one plane. In order to use the full energy of the waves the second plane of movement has to be used as well, that problem will be addressed in a future work.

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Reference:

1. Zhang, R., Xu, X., Zhai, P., Liu, K., Kong, L., Wang, W., „Agile and integrated workflow proposal for optimising energy use, solar and wind energy potential, and structural stability of high-rise buildings in early design decisions", Journal of Energy and Buildings Volume 300, Elsevier, 1 December 2023, ISSN: 0378-7788
2. Kumar R., a, Chaitanya K., Natarajan, S., „Solar thermal energy technologies and its applications for process heating and power generation – A review", Journal of Cleaner Production Elsevier, Volume 282, 1 February 2021, ISSN: 0959-6526
3. Christopher Depcik C., Cassady T., Collicott B., Burugupally S., Li X., Alam S., Arandia J., Hobeck J., „Comparison of lithium ion Batteries, hydrogen fueled combustion Engines, and a hydrogen fuel cell in powering a small Unmanned Aerial Vehicle", Journal of Energy Conversion and Management Volume 207, 1 March 2020, ISSN: 0196-8904
4. Millero F., „The thermodynamics and kinetics of the hydrogen sulfide system in natural waters", Journal of Marine Chemistry, Volume 18, Issues 2–4, March 1986, Pages 121-147, ISSN: 0304-4203
5. Aderinto, T., Li, H., „Ocean Wave Energy Converters: Status and Challenges", Journal of Wave Energy Potential, Behavior and Extraction, 14 May 2018, MDPI, ISSN 1996-1073
6. Uchito, K., „Piezoelectric energy harvesting systems with metal oxides" Metal oxides in energy technologies, Elsevier 2019 ISBN 978-0-12-811167-3
7. Maor, E., „An Example of a Non-Harmonic Oscillator: Crankshaft Motion", A Repetoire of S.H.M., The Physics Teacher 10, ISBN 377-382 (1972)
8. Akylas, R., Li, G., Mei, C., Rosales, C., 1.138J / 2.062J / 18.376J Wave Propagation, Fall 2004 http://dspace.mit.edu/handle/1721.1/41865
9. IOC, SCOR and IAPSO, 2010: The international thermodynamic equation of seawater – 2010: Calculation and use of thermodynamic properties. Intergovernmental Oceanographic Commission, Manuals and Guides No. 56, UNESCO (English), 196 pp.
10. Mankame, N., Ananthasuresh G., „A Novel Compliant Mechanism for Converting Reciprocating Translation Into Enclosing Curved Paths", Journal of Mechanical Design, Volume 126, Issue 4 July 2004, ISSN 1050-0472