Wave Energy Recovery System Based on the Hydrostatic Principle

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Abstract: *Due to the certainly fact that the energy needs are constantly increasing at the present time, the handy production methods and also constituting environmentally friendly methods must be considered. Thus, processes and devices for energy production based on our planet renewable sources, constituted in water flows, solar energy, wind power and not at least the waves and tides force, have been continuously invented and developed. A solution for wave energy capture operating on the hydrostatic principle is presented in this paper. The solution particularity is represented by the operating principle of a constructive variant of wave energy recovery plant that has to be located directly on the seafront in order to have direct access at the waves continuously motion which drive the installation's floats. A set of large volume floats are located directly on the water surface, which by the cyclical movement in vertical direction drives the hydraulic cylinders of the plant producing hydraulic energy in the form of volumetric flow rate and fluid pressure. This energy flow stream has the possibility to drive hydrostatic motors that provide axis rotational motion and rotation torque necessary for the operation of the electricity generators.*

Keywords: *Wave energy recovery, hydrostatic actuation, circuit model*

1. Introduction

The production of energy from renewable sources represents the optimal option to be applied for an environment not irreparably affected. Whether we are talking about applications using solar energy, wind energy, wave or tidal power, it should be emphasized that the contribution of all these methods for obtaining green energy has gained increasing importance in the total energy produced today in the world, thus replacing the traditional energy production methods that bring inevitable changes in the environment.

Of the procedures for obtaining energy from renewable sources, the waves force is of particular importance because by wave continuous movement a significant amount of mechanical energy can be recovered that can be transformed into electricity.

There are multiple applications that have been developed over time regarding the wave energy recovery. It represents a method of use the large amount of energy provided by the wave motion worldwide over seas and oceans coastal regions. This existent potential based on cyclic motion described by wave motion must be used at the real value in order to recovery and convert the energy amounts in electrical energy for human communities needs. The power plant concept uses this potential motion to achieve a continuous hydraulic fluid power stream within a closed circuit necessary for a rotary engine motion that provide angular velocity and torque at the shaft necessary for a generator to convert the mechanical energy into electric energy.

The constructive solution for a generative power plant based on the waves force is presented, which can be located on the shore, having direct access to the sea. This concept uses a set of large floats positioned at the water level near the shore, having the possibility to make repeated cyclical movements in the vertical direction dictated by the waves force. These floats have the connections with hydrostatic systems anchored on the shore and which receive the mechanical energy required to move the piston due to the continuous floats cyclic movement. Through this process the working fluid existing inside the hydrostatic systems is entrained within the circuit having the possibility to transmit the energy flow to a hydrostatic motor that transforms the taken energy in the form of volumetric flow rate and pressure into mechanical energy of rotation at the motor shaft.

There are presented aspects related to the possibilities of realization and location of such a power plant in the sea immediate vicinity. The plant facility must be located so that it has an adequate depth of water (steep bank) and at a very small distance from the water so that the floats are located not too far from the central unit. The mechanical connections between the floats and the hydrostatic systems must be made in such a way as to ensure the floats moving possibility, pushing the hydrostatic systems rods, with a very low coefficient of friction between the components in contact so as not to affect the installation efficiency.0

2. Wave energy concept

Marine waves are formed at the contact surface between water and atmospheric air. Due to the atmospheric air forced movement as a result of the uneven atmosphere heating levels in different areas, the winds are occur acting on the large water surfaces and causing the water movement.
The combined frictional and pressure forces action on the water surface have results in the mechanical energy transfer from the air movement to water. Thus, the waves are formed with a significant amount of energy stored dependent of wind velocity, time and acting surface.
Depending on the sinusoidal functions, the behavior of the deep-sea waves can be modeled. The approximate shape of the deep-sea waves is shown as a sinusoidal curve, and the wave-specific parameters are shown in Figure 1. 00

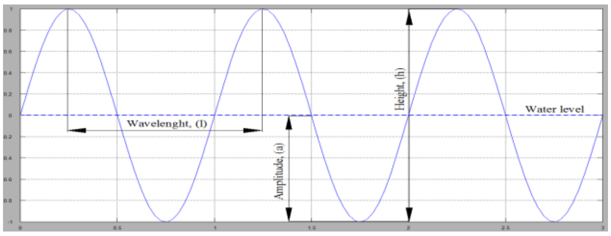

Fig. 1. Sine wave approximation curve

Starting from the concept of fluid mechanics that considers the displacement of a single fluid particle on a given trajectory (Lagrange) the velocity field can be shaped at a certain time (Euler).
Using the Lagrange method, the fluid particle motion reported to an OXYZ reference axis system can be studied, where the position of the particle depends on the time t and the initial position given by its coordinates (x_0, y_0, z_0) at time (t_0).
The trajectory equations are as follows: 0

$$x = x(x_0, y_0, z_0, t);\ y = y(x_0, y_0, z_0, t);\ z = z(x_0, y_0, z_0, t) \tag{1}$$

Velocities and accelerations are expressed as: 0

$$\begin{aligned} &u = \frac{\partial x}{\partial t};\ v = \frac{\partial y}{\partial t};\ w = \frac{\partial z}{\partial t} \\ &a_x = \frac{\partial u}{\partial t} = \frac{\partial^2 x}{\partial t^2};\ a_y = \frac{\partial v}{\partial t} = \frac{\partial^2 y}{\partial t^2};\ a_z = \frac{\partial w}{\partial t} = \frac{\partial^2 z}{\partial t^2} \end{aligned} \tag{2}$$

The Euler method determines the motion elements of all fluid particles passing through a point in space reported by its coordinates to a fixed trihedral in time. Thus, the field velocity values are obtained at the points of the space occupied by the fluid movement as well as the velocities variation at these points as a time function.
The velocity field and accelerations are given by the following relations: 0

$$u = u(x, y, z, t);\ v = v(x, y, z, t);\ w = w(x, y, z, t) \tag{3}$$

Where x, y, z represent the space points coordinates and not of the fluid particle.

$$du = \frac{\partial u}{\partial t}dt + \frac{\partial u}{\partial x}dx + \frac{\partial u}{\partial y}dy + \frac{\partial u}{\partial z}dz \quad (4)$$

$$\begin{aligned} a_x &= \frac{du}{dt} = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} \\ a_y &= \frac{dv}{dt} = \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} \\ a_z &= \frac{dw}{dt} = \frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} \end{aligned} \quad (5)$$

Details of the fluid particle motion using the Lagrange and Euler methods are shown in the figure 2.

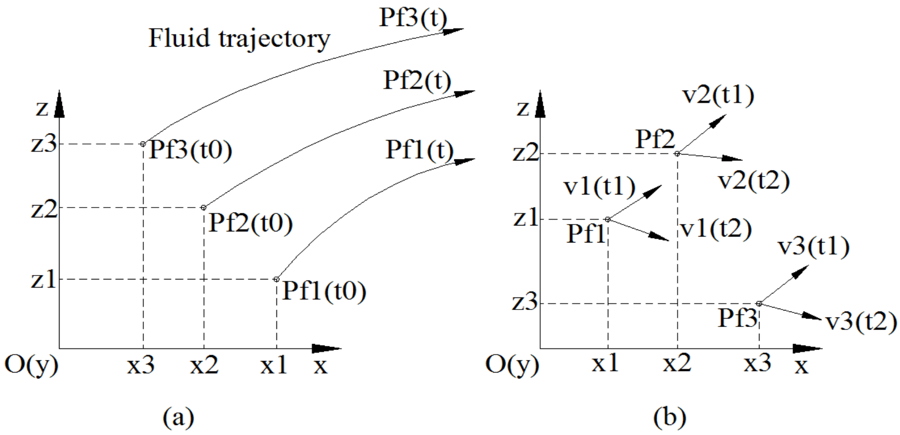

Fig. 2. Description of fluid motion: Lagrange method (a) and Euler method (b)

For the case of the fluid considered incompressible having $(\rho = 0)$ and $\left(\frac{\partial \rho}{\partial t} = 0\right)$ the continuity equation is written: 00

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (6)$$

If fluid motion is considered as irrotational, the velocity forms may be expressed in terms of velocity potential (ϕ):

$$u = \frac{\partial \phi}{\partial x};\ v = \frac{\partial \phi}{\partial y};\ w = \frac{\partial \phi}{\partial z} \quad (7)$$

By making the substitutions in the continuity equation is obtained:

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0 \quad (8)$$

The obtained equation is known as the Laplace equation, which describes the wave motion of the deep water regions.

3. Model of hydrostatic circuit used for energy recovery

For the wave energy recovery plant basic unit, a constructive solution is presented which allow the take over of wave energy and its conversion into hydraulic energy of the working fluid used in a closed circuit. For this purpose, a hydraulic circuit is designed in order to use linear motors that acquire cyclic motion from the sea wave providing a continuous fluid stream to a rotary hydraulic motor of the system, ensuring rotational movement at the motor axis, necessary for driving the electric current generator. 0
The installation composition shown in figure 3, based on the specific symbols of industrial hydraulics, is being made up of drive floats, linear motors for working fluid transport, hydraulic accumulators for fluid pressure accumulation, distribution and directional fluid flow apparatus inside circuit, a rotary hydraulic motor with variable displacement that operates based on the fluid flow rate received as a result of the forced displacement of the floats corresponding to the wave motion. 0

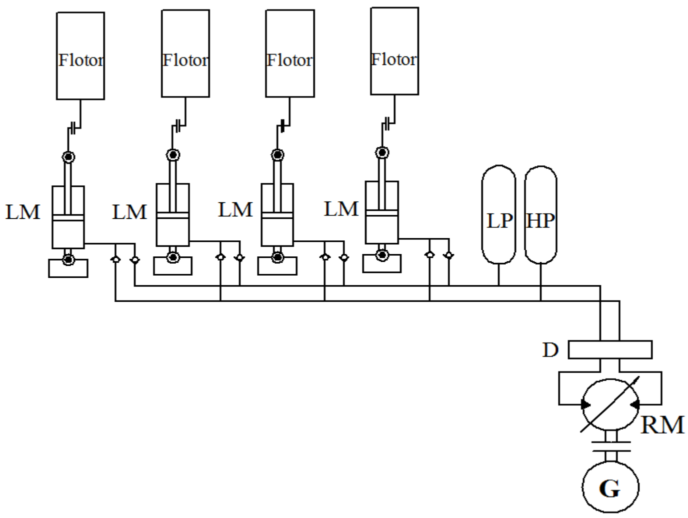

Fig. 3. Schematically representation of wave energy recovery power plant (WERP).

Depending on the waves amplitude is possible to obtain optimal results regarding the energy recovered using the hydrostatic method proposed.
The operating principle based on the hydraulic drive implies high operation efficiency due to the reliability of the installation components.
The system performs two types of energy conversion functions corresponding to changing the waves mechanical energy into hydraulic energy of the moving fluid being converted again into mechanical energy as motor shaft rotation.

4. Hydrostatic wave energy conversion method

A hydrostatic method of wave energy recovery is presented that involves phenomena of energy transfer between the component elements of the installation recovery unit. Theoretical aspects of calculation that underlie these phenomena dictate the operating principle of the wave energy recovery plant.
The primary energy conversion function ensures the retrieval of the mechanical energy from the power source represented by linear motors and the energy amount transfer to the installation rotary motor through the working fluid. The basic fluid parameters inside the hydrostatic drive are represented by volumetric flow rate and hydrostatic pressure.
The primary conversion function type (PCF) made with linear motors is required for this type of recovery circuit and the working phases characteristic of the operation describe the working cycle of the linear pumps.
The principle diagram of the drive system with linear motors is shown in Figure 4. 0

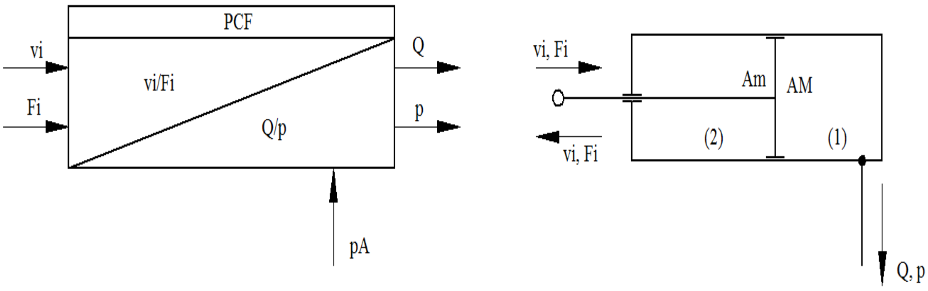

Fig. 4. Primary conversion function (PCF)

The linear motors constructive characteristics involving the piston working areas, the characteristic piston stroke, the fluid flow conveyed at the maximum piston stroke ensure the hydraulic power values obtained through the use of the linear motor.
The multi-polar model of the primary conversion function (PCF) performed with the linear motor comprises the characteristic equations for the input and output parameters represented by the input force and velocity, as well as the fluid flow rate and pressure at the output. 0

$$Q = 6\eta_v A_M v_i \quad (9)$$

$$F_i = \frac{1}{\eta_{mh}}\left(A_M p - A_m p_A\right) \quad (10)$$

By applying the principle of fluid flow continuity and the association with the differential equation of motion of the active components involved in energy transmission, the dynamic model of the primary conversion function (PCF) is obtained.0

$$\begin{aligned} Q &= A_M \frac{dx}{dt} - a_M\left(p - p_A\right) - \frac{V_{0M}}{E}\frac{dp}{dt} \\ F_i &= m_r \frac{d^2x}{dt^2} - b_M \frac{dx}{dt} - C_f \frac{\dot{x}}{|x|}\left(A_M p - A_m p_A\right) \end{aligned} \quad (11)$$

Based on the cyclical and continuous action of the linear motors dictated by the waves movement, the working fluid flow inside the circuit is provided, which ensures an energy flux necessary to drive the hydrostatic motor. This motor takes the energy from the working fluid in the form of energy components flow rate (Q) and pressure (p), further converting it into mechanical energy, through the components moment (torque) and angular velocity at the axis, necessary to drive the electric current generator.
This energy conversion is considered as the secondary conversion function (SCF) presented schematically in figure 5. 0

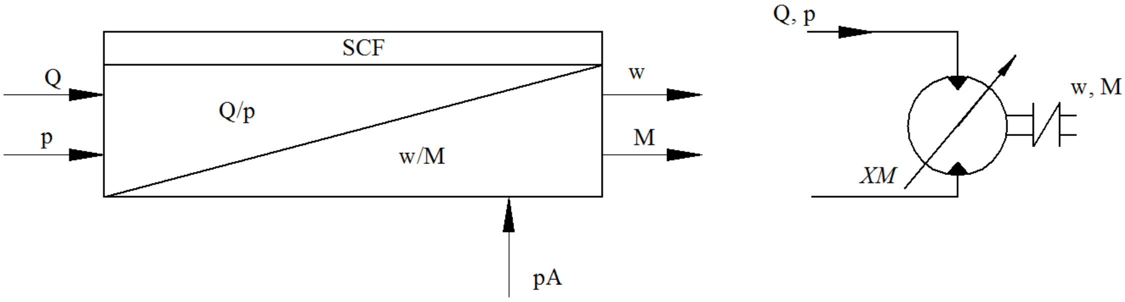

Fig. 5. Second conversion function (SCF)

The theoretical flow rate value received by the hydraulic motor taking into account the XM command and its momentary and maximum cylinder rates is of the form: 0

$$Q = V_m \frac{w}{2\pi} = XM \frac{1}{2\pi} V_0 w \tag{12}$$

The real flow rate taking into account the engine volumetric efficiency will be of the form: 0

$$Q = XM \frac{1}{2\pi\eta_v} V_0 w \tag{13}$$

The relations for mechanical and hydraulic power are: 0

$$P_m = M \frac{w}{2\pi};\ P_h = Q\left(p - p_A\right) \tag{14}$$

where:

$$P_m = \eta_t P_h \tag{15}$$

$$M \frac{w}{2\pi} = \eta_v \eta_{mh} XM \frac{1}{2\pi\eta_v} V_0 w\left(p - p_A\right) \tag{16}$$

$$M = \eta_{mh} XMV_0 \left(p - p_A\right) \tag{17}$$

From the obtained equation can be determined the pressure necessary value for achieving the mechanical torque (M) at the motor shaft: 0

$$p = p_A + \frac{M}{\eta_{mh} XMV_0} \tag{18}$$

For angular velocity the relation is: 0

$$w = \frac{2\pi\eta_v Q}{XMV_0} \tag{19}$$

The multi-polar model of the secondary conversion function (SCF) is thus obtained: 0

$$n = \eta_v \frac{1000Q}{XMV_0}\ \left[rot/\min\right];\ \ p = p_A + \frac{10M}{\eta_{mh} XMV_0}\ \left[bar\right] \tag{20}$$

The presented model provides information on the modality to convert the input parameters $\left(Q, p\right)$ into output parameters $\left(M, w\right)$ depending on the hydraulic motor cylinder control mode $\left(XM\right)$.

5. Conclusion

Current methods of obtaining energy from alternative sources have been developed and improved in order to be able to provide higher amounts of green energy, thus reducing the energy consumption that comes from the sources that have a direct effect on the environment.

Of all used methods, the sea and ocean waves energy must be highlighted as a viable energy source to be recovered and converted into electrical energy.
A constructive variant for a wave energy recovery plant was presented in this paper. It is a concept of using a hydrostatic drive system powered by the cyclical movement of a set of floats positioned directly on the water surface.
Due to the waves continuous movement the floats press directly on the pistons of the hydrostatic systems through the rods, forcing the fluid to circulate in the circuit. This results in a volumetric flow rate and pressure that constitutes the flow energy necessary for a hydrostatic motor that performs axial rotational movement with a certain velocity value.
It represents a working principle that can be used in the construction of such generative energy units based on the waves motion.

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