ISSN 1454 - 8003
Proceedings of 2016 International Conference on Hydraulics and Pneumatics - HERVEX
November 9-11, Baile Govora, Romania

ELABORATION OF WAVE ENERGY CAPTURE SYSTEMS

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Abstract: *The largest energy reserves are stored in the oceans - a large area of water currents continuously moving and covering about 71% of the planet's surface. The Planet Ocean has a huge energy potential that can be employed to produce electricity. The main sources of the ocean energy considered, at least in the current technical level, refer to: tides, currents, waves, temperature differences of the seawater layers.* some technical solutions have been developed for wave energy capture devices at conceptual level. *These solutions are protected by six patents. Future development is expected based on these inventions, namely, laboratory samples and their testing in laboratory conditions.*

Keywords*: wave energy, conversion systems*

1. Introduction

If at the end of the nineteenth century the most widespread energy used – the electricity - had an auxiliary and insignificant role in the global energy balance, then in 1930 about 300 billion kWh of electricity were produced in the world, and in 2004 this figure reached 21000 billion kWh [1]. The material and the spiritual level of mankind are directly dependent on the amount of the available energy. The stringent laws of the nature state that useful energy can be obtained only by converting it from other forms. The World energy structure analysis shows that 4 out of 5 kW are obtained, in principle, using the same method by which the primitive man heated himself, that is by burning fuel, or by using its chemical energy converted into electricity at power plants. Of course, fuel combustion methods have become much more perfect.
But the largest energy reserves are stored in the oceans - a large area of water currents continuously moving and covering about 71% of the planet's surface. The Planet Ocean has a huge energy potential that can be employed to produce electricity. The main sources of the ocean energy considered, at least in the current technical level, refer to: tides, currents, waves, temperature differences of the seawater layers. The first mathematically documented explanation of the tidal forces was done in 1687 by Isaac Newton in his work *"Philosophiae Naturalis Principia Mathematica".* Tides occur regularly in certain coastal areas of the planet at amplitudes reaching sometimes 14-18 m, resulting in slow oscillations of the sea water level.
Among the clean and non-pollutant energy sources, the wave energy of sea and ocean is one of the most abundant to take advantage of. The wave energy potential is estimated at 219 giga-watts along the coast of the European Union, or more than 180 TW/h per year [1]. Over the years, various devices have been designed to extract the wave energy, exploiting the lifting force of the waves with floating bodies.
Although Moldova does not border a sea or an ocean, the topic is of interest primarily in terms of international cooperation. Taking into account the importance of the topic, research is conducted at the Centre for Renewable Energy Conversion Systems Design (CESCER), at the Technical University of Moldova. Research is at an early stage. In this respect, some technical solutions have been developed for wave energy capture devices at conceptual level. These solutions are protected by six patents. Future development is expected based on these inventions, namely, laboratory samples and their testing in laboratory conditions.

2. 2. Wave energy conversion plants

2.1. Fixed tower plants and floating bodies

Such devices are part of the coastal power plants based on the use of a fixed tower and some floating bodies that are linked to the tower via a swivel connection. Further on, two patented

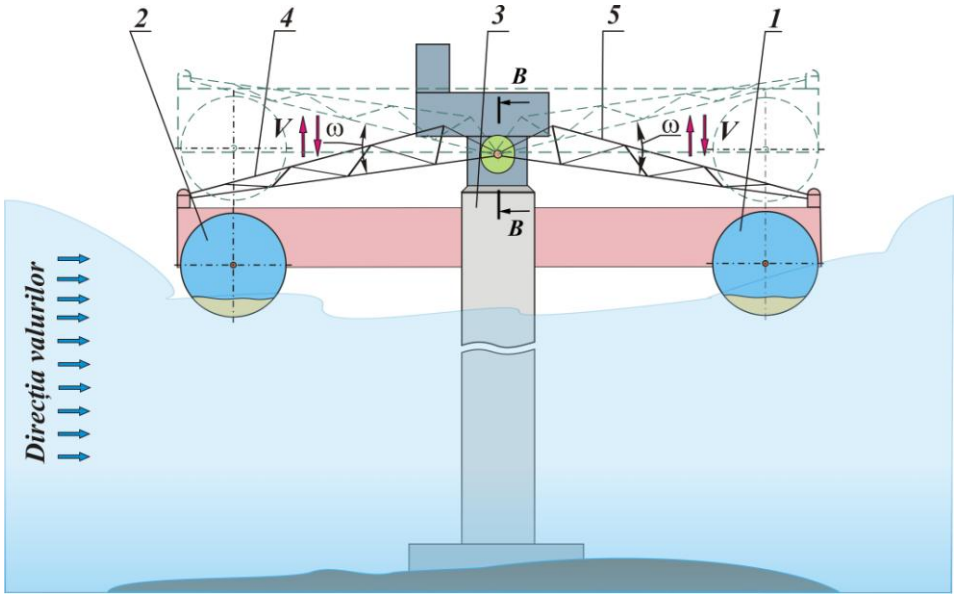

Fig. 1. Unit for wave energy conversion.

technical solutions will be considered. The installation (Fig. 1) [2] shows a plant, in which spherical or cylindrical floating bodies 1 and 2 are placed on both sides of the fixed tower 3 and are jointed to the tower by means of two arms 4 and 5. Since arms 4 and 5 are driven by the floating bodies 1 and 2 into alternate rotational motion with different directions, a motion adder, with bevel-gear wheels 6 and 7, was designed to sum up these motions; bevel-gear wheels are linked rigidly to the arms 4 and 5 (fig. 2).

At a certain wave period, the body will make a motion equal to the height of the wave (amplitude).

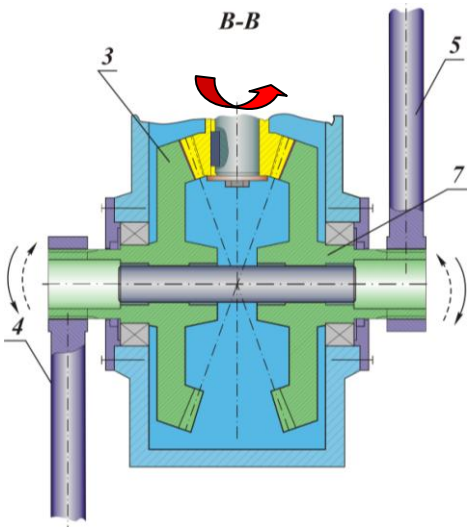

Fig. 2. Adder of alternate rotational motions and their conversion to one-way motion

The lifting force developed by the floating body at its vertical motion is determined by the Morison's equation:

$$dF = \pi\rho\frac{D}{4}C_M v^2 + \frac{\rho}{2}DC_D|v|v, \qquad (1)$$

where D is the diameter of the floating body,

ρ is the fluid density;

v is the upward velocity of the floating body;

C_M and C_D **–** are the coefficients that depend on the geometrical shape of the body, Reynolds number and Keulegan**–**Carpenter number (can be defined empirically, experimentally or by CFD computer simulation).

Next, the summary force $\boldsymbol{F_1}$, developed by the floating body *1*, will be transmitted to the gear segment *5* via arms $\boldsymbol{l_1}$ and $\boldsymbol{l_2}$:

$$F_5 = F_1\frac{l_1}{l_2}. \qquad (2)$$

The moment of torsion developed by this force will be transmitted to the electric generator 8 through the gearing 6 and the multiplier 7. Alternate rotational motion of the rods 7 and, respectively, the gear segment 5 is transformed and multiplied by gearing 6 and multiplier 7 into continuous rotational motion, which is transmitted to the electrical generator 8. The wave energy is pulsating in rather wide limits and its frequency is high - from 1-2 seconds to 10-20 seconds. In this case, the normal operation of the plant needs a flywheel. In general, the wave energy is constant for a long period of time (several hours). In order to reduce rotational non-uniformity of the electrical generator rotor 8 and to improve the quality of the produced power, the flywheel 10 is mounted on the multiplier 7 output shaft. The proposed solution is advantageous as its construction is simple, easy to maintain and very efficient. Due to the provision of an arm driving the wave lifting force, a multiplied moment is transmitted to the input shaft that ensures an increase of the transformed energy.

2.2. DUCK-type wave energy device

This is another floating wave energy device based on the use of several floating bodies linked by hinged joints. The operating principle of this wave energy device was described in p.7.4 of this chapter.

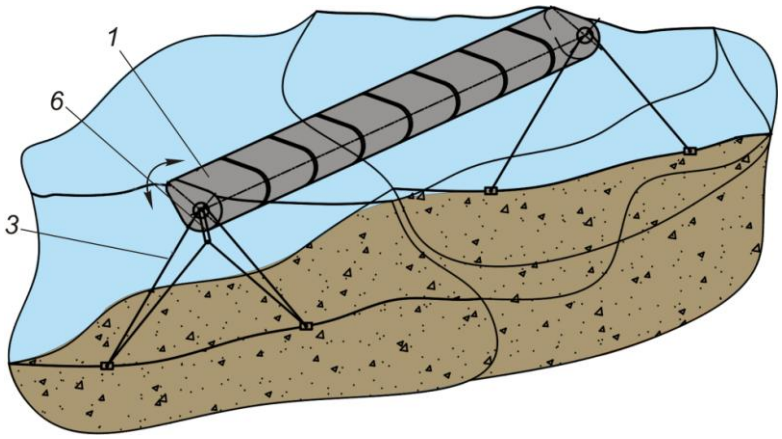

Fig. 3. Floating unit for wave energy conversion (DUCK-type).

The device shown in fig. 3 [3] is a version of the *DUCK* wave energy device; it includes the floating bodies 1, mounted on the fixed shaft 2 (fig. 2), which is anchored by anchoring cable 3. The floating body 1 includes an oval casing 4, made of plastic; its submerged part is bigger than the outside part. The casing 4 is located on a fixed shaft 2 with limited possibility of alternative rotation towards it. On the shaft end 2 a disk 5 and a bar with two holes executed at a certain distance are installed through which the anchor cable 3 is passed. The centre of buoyancy of the “DUCK” floating body is shifted to its bottom by filling it with solid material. A summary mechanism of alternative rotational motions, called adder, is placed in the casing 4.

The adder (fig. 4) includes a bevel wheel 6 geared with the bevel pinion 7; on the inner flange of the pinion the toroidal surface 8 is made. Disks 9 and 10 enter in contact with the toroidal surface; their axles are linked to the sleeve 11, fixed rigidly on the casing of the electrical generator 12. Disks 9 and 10 contact with their diametrically opposed sides with the toroidal surface of the friction wheel 13. The inertial mechanism 14, linked kinematically via a system of levers with the disk axles 9 and 10, is fixed on the wheel hub 13 linked rigidly to electrical generator rotor 12. This inert mechanism provides homogenisation of rotational speed of the friction wheel.

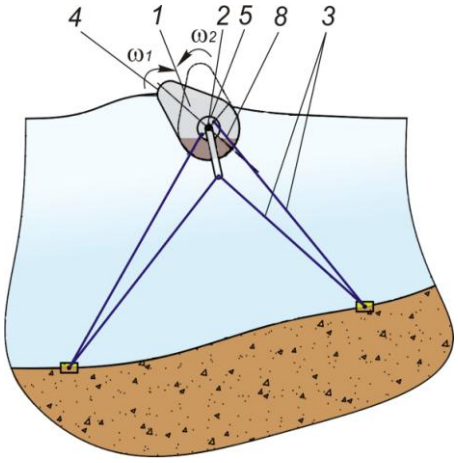

Fig. 4. DUCK type floating body (with counterweight to bring it back into initial position).

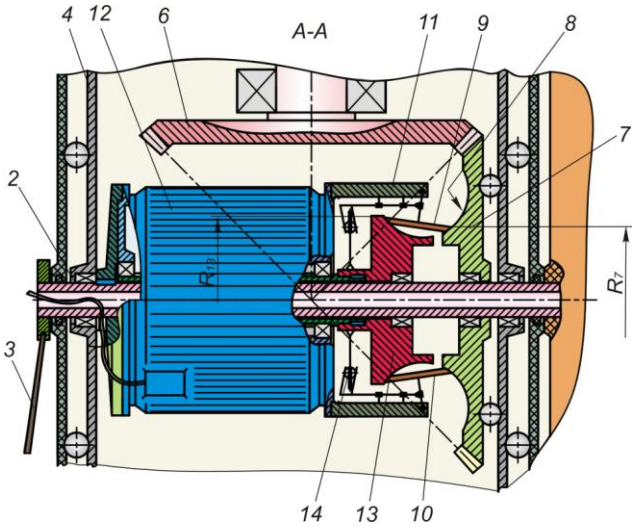

Fig. 5. Adder of alternative rotary motion, based on the use of bevel-gear transmission and friction toroidal speed variator

The wave linear theory shows that the motion of a point on the wave surface is sinusoidal. At wave travelling to a certain wave length **λ** in the indicated direction (fig.3,4), the floating body 1 performs alternate rotational motion around the fixed shaft axis 2. The wave period ***T*** that moves a point can be expressed by:

$$T = \sqrt{\frac{2\pi\lambda}{g}}, \qquad (3)$$

where ***λ*** is the wavelength (m).
The power contained in a wave can be expressed by the following expression depending on the wavelength (kW/m):

$$P = \frac{\rho g^2 a^2 T}{8\pi}, \qquad (4)$$

where *a* is the wave amplitude (m).
This potential energy of the waves can be converted into electricity by using floating bodies (Fig. 3). Rotational motion $\boldsymbol{\omega}_1$ of a floating body 1 generated by the wave and the rotational motion $\boldsymbol{\omega}_2$ at its coming back under the action of the counterweight is transmitted to the rotating casing 4 of the adder (Fig. 4), where these two alternate rotational motions are summed up in a one-way rotational motion.
In the adder shown in fig. 5, the rotational motion of the conical pinion 6 is transmitted via disks 9 and 10 to the friction wheel 13 and, further on, to the electrical generator rotor,12. Summary gear ratio is equal to:

$$i_{\Sigma} = i_{\Sigma 1} \cdot i_{2var}, \qquad (5)$$

where

$$i_{2var} = \frac{R_{13var}}{R_{7var}}, \qquad (6)$$

but $\boldsymbol{R_{13var}}$ and $\boldsymbol{R_{7var}}$ are contact radiuses of disks 9 and 10 with toroidal surfaces of the friction wheels 7 and 13.

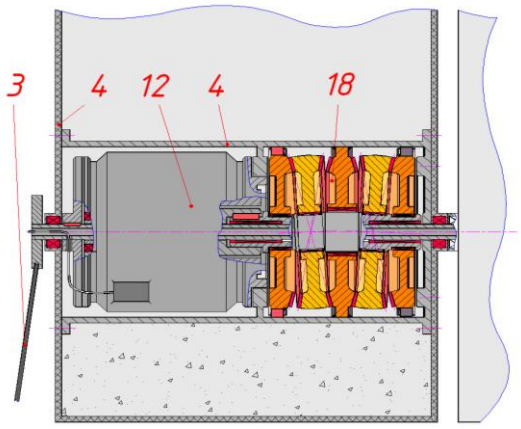

Fig. 6. Adder of alternative rotary motion based on the use of planetary precessional transmission.

In the result, the gear ratio will change and the electric generator rotor speed will become uniform. Adder kinematics allows partial equalization of summary angular velocity components values of the electrical generator rotor composed of $\boldsymbol{\omega}_1$ and $\boldsymbol{\omega}_2$ components, and thus improve the quality of generated electricity.
In the wave energy capture plant [4], unlike the previous facility, the returning of Duck bodies 1 to the original position is done through a system of curved elements 2 placed between the flange of the rotating disc 3 and the fixed part 4 (fig. 5).

A portion of energy stored in these curved elements at their decompression brings back the DUCK elements into the initial position (previous to the wave action). Summing up of alternative rotational motions is performed by an adder based on the use of coaxial planetary precessional transmission 18 in several steps and of a one-way clutch system (fig. 6). This system leads to partial equalization as value of the summary angular speed components of the crank shaft and to the improvement of the produced electrical current quality, as well.

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