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Float converter model for wave power sources

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Abstract

In the article it is proposed to improve wave power plants by using a primary manipulator converter (PMC) with the structure of a parallel six-mobile manipulator for converting energy of waves into mechanical energy. There has been developed a physical model of a primary manipulator converter confirming its functionality. There have been obtained geometrical dimensions of a primary manipulator converter and a float taking into account wave parameters. For selecting and analyzing the primary manipulator converter of wave power plants there are proposed the dependences for calculating power. The use of the primary manipulator converter in underwater wave power plants will permit to increase their reliability and efficiency in operation.

Keywords: parallel manipulator, wave energy converter, wave power plant.

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1. Introduction

At present the transition from traditional sources of electric energy to renewables of waves is the established tendency in developing present day power engineering.

As numerous studies show, superficial waves of large water spaces (oceans, seas, large lakes) possess a huge stock of energy. For extracting and using this energy there are used various wave power sources (WPS). A complete review of the WPS designs and principles of action is provided in works [1-4].

However successful development of wave power and broad application of wave power sources are interfered by a number of problems the main of which are low productivity and predisposition to destructions from dynamics of waves.

In wave power sources the basic device in the functional relation is a primary converter intended for conversion of wave energy into "organized" mechanical energy.

In the article, for increasing the efficiency of extracting energy of the wave movement and eliminating the problems it is proposed to use in wave power plants (WPP) a primary manipulator converter based on the parallel manipulator.

2. Primary manipulator converter

The review of facilities used for extracting energy of waves in WPS [5] shows that the existing primary converters of energy of waves use a limited amount of energy of the water mass movement, for example, of the vertical movement of a float due to the difference of the wave height. However, according to the Stokes theory [6], the water particles movement in large reservoirs is made on the closed orbit. The orbit radius on the lower boundary of the water surface is $r_0 = H/2$ where H is the wave height. With the depth (h) the orbit radius of the water particles movement (r) decreases under the exponential law:

$$r = r_0 e^{-2\pi H/r}. \quad (1)$$

If to consider tridimentionality of waves, i.e. unevenness of the wave dimensions along the crest of waves, then it is possible to draw the conclusion that the water particles movement under the impact of superficial

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waves are spatial. Proceeding from it, WPS floats actually take energy of moving on the spatial closed trajectories particles of water and at the same time make spatial movements. In this regard for converting the floats spatial movement into mechanical energy it is proposed to use a manipulator converter with the design of the SHOLKOR parallel manipulator [7, 8]. It is well-known that in this manipulator a mobile platform can perform spatial movements with six degrees of freedom. If to connect the mobile platform with the WPS float, then there will be a system called in the article a primary manipulator converter (PMC).

In Figure 1 there is shown a model of a six-mobile PMC without a float. Here there is shown platform 2, mobile in the form of a hoop, and motionless platform 1 connected in such a way that each of six connecting kinematic chains (CKC) 3-8 consists of a ram and a guide forming a forward kinematic couple have sensors.

As a PMC works generally in the hostile water environment, there have been introduced changes into the SHOLKOR manipulator design.

If to assume that the resultant from the Archimedean and gravity forces operating on the float passes through the geometrical center of the platform, then with the float movement under the impact of the water weight the center of the top platform will move on the closed orbit, and the platform itself will make a spatial progress. With such a movement of the top platform 2 there will change the lengths of all six CKC (3-8).

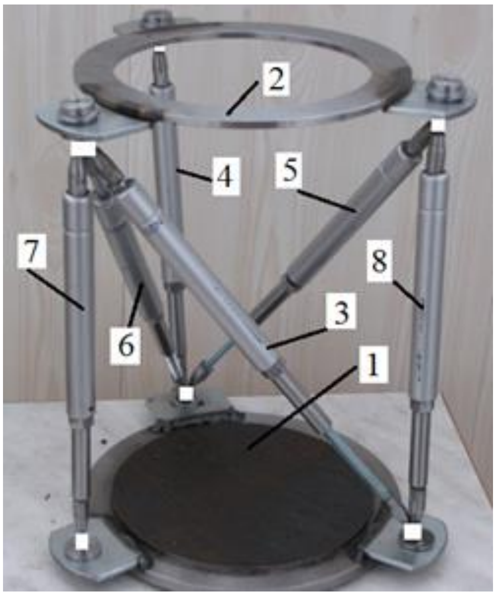

Figure 1. Primary manipulator converter

The results of solving the kinematic task for the parallel manipulator in MatLab by the algorithm proposed in work [7] and provided in Figure 2 show that with the mobile platform forward movement all six CKC obtain increments in movement.

Thus, the float movement under the impact of the moving water particles energy is converted into mechanical energy of six forward movements. It should be noted that in the majority of the existing WPS the float movement energy is converted into energy of only one forward or rotary motion. It demonstrates that a PMC, in comparison with the existing wave converters, permits to take and to convert more effectively wave energy into mechanical energy.

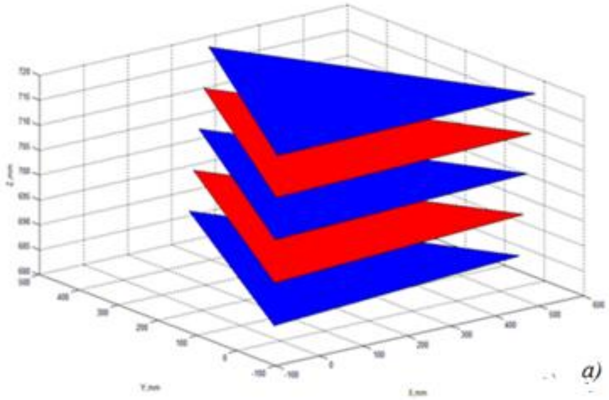

Figure 2. Diagram of the PMC top platform movement

3. Defining PMC geometrical characteristics

The maximum changes of the CKC lengths and the float diameter are referred to the PMC geometrical characteristics. We will define the PNC geometrical characteristics from the condition that the limit movements in CKC caused by the wave maximum height H_{Max} would be smaller than the extreme values of the CKC lengths.

With such a choice of the design dimensions the PMC won't make an obstacle to the float movement for any waves, i.e. it won't be subject to destructive actions from wave dynamics.

Proceeding from it the values of the maximum lengthening of the side CKC 4, 7, 8 are to be larger than the wave maximum height H_{Max}. In Figure 3 there are shown four positions of the PMC: initial: 0, the most remote: 1, with side shifts: 2, 3.Thus, the maximum movements of the side CKC 4, 8, 7 (Figure1) for the PMC of the overwater WPS are selected from the condition:

$$\Delta l_1 > l_0 + H_{max} \tag{2}$$

where l_0 is the length of the side CKC at the initial position depending on the reservoir depth in the place of the PMC mounting.

The maximum movements in the diagonal CKC 3, 5, 6 (Figure 1) are defined from the condition:

$$\Delta l_d = \sqrt{(\Delta l_l + l_t)^2 + a^2} - \sqrt{l_0^2 + a^2}, \tag{3}$$

where a is the distance between the hinges.

For underwater WPS PMC the maximum movements of the side CKC are selected from the condition:

$$\Delta l_1 > l_0 + 2r \qquad (4)$$

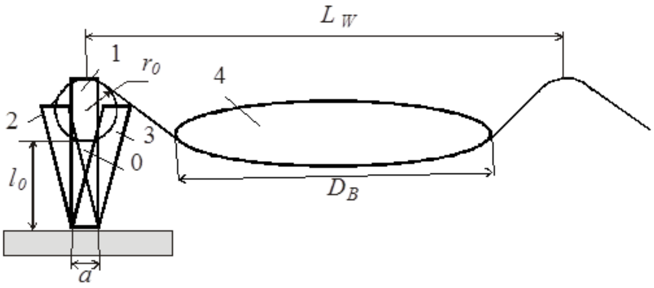

Figure 3. Selecting PMC dimensions

At this the orbit radius of the water particles movement under water (*r*) is selected in the place of the WPS mounting according dependence (1).

The maximum envelope diameter D_B of the float shall be selected so that it could be placed in a trough between waves as shown in Figure 3. In this case there is selected the minimum wavelength L_W.

It should be noted that the wave parameters are selected from the average data obtained for the place of the WPS mounting.

4. PMC kinematic design

In Figure 4 there is presented a simplified WPP diagram based on the PMC that consists of top platform 2 with a float, lower platform 1 fixed to the bottom, six CKC with forward couples, three of them with a changing length.

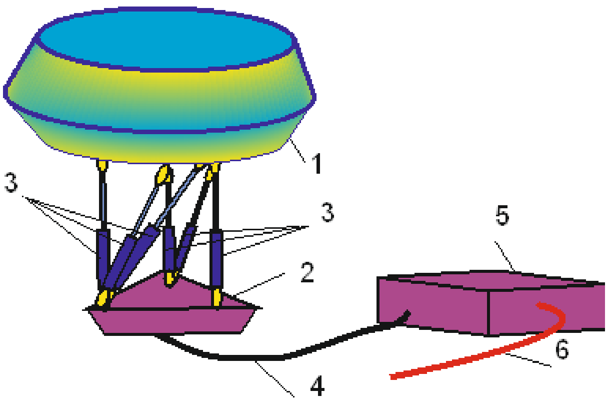

Figure 4. Simplified diagram of the wave power plant

The principle of the WPP action is based on that the moving particles of water affect float 2 connected with the PMCP mobile platform and cause changes of the CKC-3 length, i.e. back and forth movements of rather a motionless basis fixed to the bottom of the reservoir of lower platform 1. Back and forth movements of six CKC are converted into electric energy in known ways. The current generated by electric generators is transferred via cable 4 to power electronic block 5 and further to power cable 6 to the transformer located on the coast. Mechanical energy of back and forth movements can be also converted into electric energy in known ways: directly, via the linear generator; through the working liquid operating the electric generator shaft; via various mechanical converters of progress into rotary movement of the shaft of one or several electric generators.

Using PMC is most preferable in the underwater wave power plants located near the coast. In this case the risk of the destructive action of superficial waves and wind decreases, on the other hand, the operational expenses connected with servicing, transporting electric energy decrease.

For the WPP power assessment in designing or in the course of operation there are needed the data of efforts in CKC and the speed of the rod movement. For this purpose below there is given the calculation of efforts in CKC by the kinetostatic method.

We will apply the forces acting on top platform 2 with the float in case when the float moves down. Platform 2 (Figure 5) at three nodal points A_2, B_2, C_2 is affected by the Q_1, Q_2, Q_3 components from Archimedean forces, the float gravity with the platform and the main vector of forces of inertia of the platform with the float Q. On the other hand, the platform is affected by forces of reaction of six CKC (3-8) N_3, N_4, N_5, N_6, N_7, N_8 directed along the axes of the corresponding CKC. The kinetostatic equations in the selected system of the $C_1X_1Y_1Z_1$ coordinates have the following form:

$$\sum_{i=3}^{i=8} N_{ix} = 0;\ \sum_{i=3}^{i=8} N_{iy} = 0;\ \sum_{i=3}^{i=8} M_z(N_i) = 0;$$
$$\sum_{i=3}^{i=8} M_x(N_i) + y_{A2}Q_1 + y_{B2}Q_2 = 0;$$
$$\sum_{i=3}^{i=8} N_{iz} + Q_1 + Q_2 + Q_3 = 0;$$
$$\sum_{i=3}^{i=8} M_y(N_i) - x_{A2}Q_1 + x_{B2}Q_2 = 0. \qquad (5)$$

Here the CKC direction and coordinates (x_{A2},x_{B2},y_{A2},y_{B2}) of the A_2,B_2,C_2 nodal points of applying vectors of forces $\boldsymbol{N_i}$ (i=1-3) are defined from the kinematic calculation [7]. For example, in Figure 6 it is shown that the force of reaction N_6 is applied at the C_2, point, at this the N_6 force projections to the axes C_1Z_1 and C_1X_1 are defined respectively by equalities:

$$N_{6x} = N_6 Cos\alpha_6,\ N_{6z} = N_6 Cos\alpha_6\,. \qquad (6)$$

In these equalities angles α_6, α are defined according to geometrical calculations at any CKC relocations [7]. Thus, in six equations of kinetostatics the unknown variables are the values of six forces of CKC response: N_i $(i=3,\ldots,8)$.

Q_1, Q_2, Q_3 forces can be determined using tensometric sensors mounted at three nodal points A_2, B_2, C_2, and CKC movements speeds v_1 $(i=3,\ldots,8)$ can be measured using displacement sensors. In this case it is not difficult to determine the PMC mechanical energy power according to the dependence:

$$P = \sum_3^8 N_i \cdot v_i \,. \qquad (7)$$

Taking in the PMC initial static position that forces $Q_1 = Q_2 = Q_3 = Q/3$, we obtain approximated values of the efforts on CKC, namely:

$$N_7 = Q/3;\; N_3 = N_8 = Q/6;\; N_4 = N_5 = N_6 = Q/9. \qquad (8)$$

These data can be used in selecting drives for changing CKC lengths.

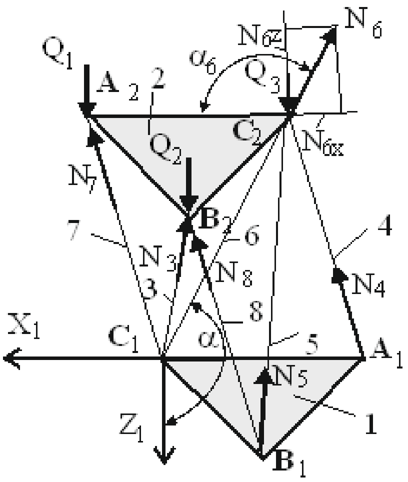

Figure 5. Design diagram

Conclusion

The analysis of the converters used in wave power sources shows that it is possible to avoid a lot of available problems if to select a new device like a converter of wave energy into mechanical energy, i.e. a manipulator converter with the parallel structure. In the article there is given a physical model of a primary manipulator converter; the principle of action of a wave power plant based on the PMC; the dependences for defining geometrical and power characteristics of the PMC.

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