MESUREMENTS OF WAVE POWER IN WAVE ENERGY CONVERTERS EFFECTIVENES EVALUATION.

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This article is devoted to the water surface gravity wave oscillation alternative budget measuring equipment of the technical solution and the theoretical justfication of the calculated oscillation power. This solution combines technologies such as lasers, WEB-camera image digital processing, interpolation of defined function at irregular intervals, volatility of discrete Fourier transformation for calculating the spectrum.

Keywords- Wave energy converter, effectiveness, laser beam, image processing, wave height, function interpolation, discrete Fourier transformation, spectrum, wave power.

INTRODUCTION

In the project "Operation research of a twisting and rotating wave energy conversion plant" the objective was the need to assess the efficency ot the energy receiver and converters dynamic systems, in an environment such as waves. Resulting analysis showed that this can be achieved through specific measurement of time and space that fully characterizes the environment without destroying it, it is both complex and at the same time within the project budget. This project phase resulted in technical measuring equipment for which there are other applications, such as level sensors of converters for adequate management development, to ensure active wave energy capture systems. The draft of the proposed technical solution is based on the conservation of energy and the dynamic potential and kinetic energy balance of the surface wave in the gravitational field. Fixing the water surface elevation changes, characterized by the fluids potential energy during the time of change, it is possible to quantify the corresponding kinetic energy changes as well as the total energy of the system. It is a dynamic system so that the various measuring steps process necesitate automation.

LASER MESURE STRUCTURE

As a solution we used a laser height gauge, the web - camera (the camera) image we projected on the screen - float (at a certain angle) by the incident laser beam (beam) created light contrast "point" (Point) (Figure 1.). If the float is placed in the liquid, which is subject to wave type fluctuations, the vertical distance from the ray source will change and the image on camera will show the points horizontal offset. Fixing certain parameters in such a system, it is possible to solve the problem in an alternative way: measuring the Point shift, calculate the absolute distance of the surface or the relative deviation from the steady state.

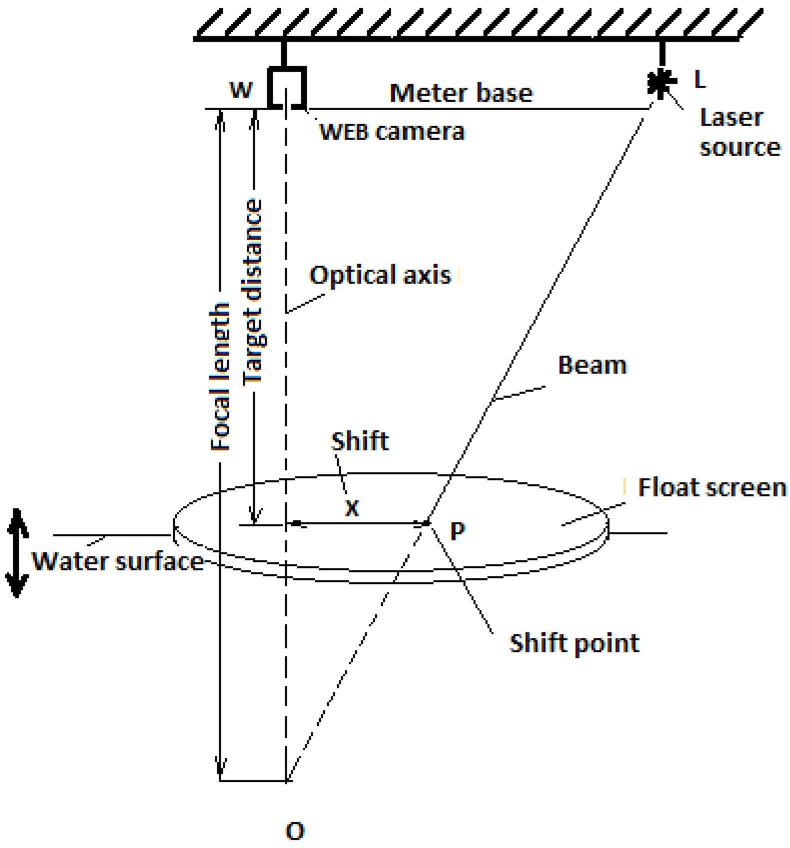


Fig. 1. Laser meter scheme

This solution is functional and simple. In laboratory conditions it promises to be sufficiently accurate.

OPTICAL SHEMATIC

Optical scheme (Fig. 2.) space has two measurement dimensions consisting of vertical-downward right-angled triangle whose hypotenuse LO is formed by laser beam. Shorter cathetus WL which a narrow angle near the apex located ray source L and W camera, whose lens center, in turn is, placed at the apex of the right angled triangle. The central optical axis (the "axis") WO. The straight edge of the camera center to beam WL = A - base distance from camera to the Laser source.

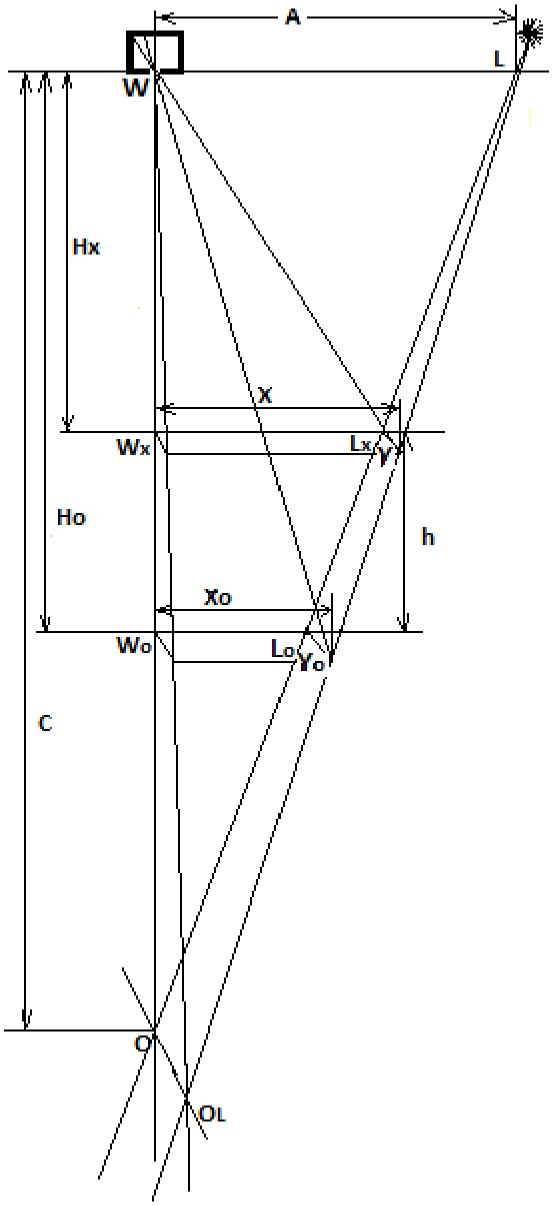


Fig. 2. Laser measure optical schematic.

The third dimension is used in beam LO shift OO_L from the measurement plane control and the vertical distance correction, if necessary. Thus the floats vertical distance between the triangle WLO apex O is expressed by two similar triangles W_0L_0O and WLO side ratios:

$$C/A=C- H_X/X, \qquad (1);$$

$$C- H_X=C/A \times X , \qquad (2);$$

The elevation measurement from zero water level :

$$H = C/A * X - (C-H_0), \qquad (3);$$

where H_0 - is the distance between the camera and the no waves water-level;

A - is the laser mesure system (meter) base distance;

C - is focal lengrth of the laser mesure system (meter).

PIXEL LINEAR SIZE PROBLEM

The picture in the camera consists of pixels (dots). In a simple camera there are 640x480 pixels. This is known as the standard VGA image resolution. Evaluation of the distance between two points in the camera image is not possible to detect in a different way than other than in these units. At the same time take into account that the pixel is an angular unit. Every distance from camera corresponds to a different pixels linear dimension. In household application, this is not critical, but in this case, it is neccessary to know the cameras pixel linear dimensions and to follow the changes in different distances from the camera lens (lens center). This means that, given that the camera axis coordinates of the images in the camera are x = 320; y = 240, connection (3) expressing straight shift edge X in its linear dimensions having observable shift point coordinates, we obtain:

$$X = (x-320) \text{ x } p_{X0} \text{ x } (1+ (x-x_0)/H_0), \qquad (4);$$

where

p_{X0} – is the pixels linear horizontal size at level H_0.

CALIBRATION

Different cameras and even one manufacturers camera model in practice constructive differences or the influence of shifts can vary the pixels corresponding linear dimensions. Also after production the based measurment of A (cut-off) sizes may vary as can the beam angle relative to the camera's optical axis. In this case we chose a solution where in the manufacture of the equipments mechanical parts of precision is not important. Numerical constants, which are necessary for processing the results of measurements, are obtained by calibrating equipment under laboratory conditions. Essentially the linear distance measured numerical values are fixed in laboratory conditions. Distance h and the shift X are calculated in (3) and (4). As our unknowns are A and $p_{X0.}$ To get determined solution, we need two independent equation system, what means to fix system parameters in 2 different distance measurements (H_0, H_x).

A technical solution peculiarity is that the beams and the optical axis angle as soon as focal length C are variable depending on measureing conditions and this measurement adjustment is made at the beginning of each mesurement session, recording the shift from X_0 at a distance of H_0 (zero water level).

The camera image has a fixed coordinates window which the shift point must "hit". This is done to reduce image processing time and reduce the glare of different noises in the system.

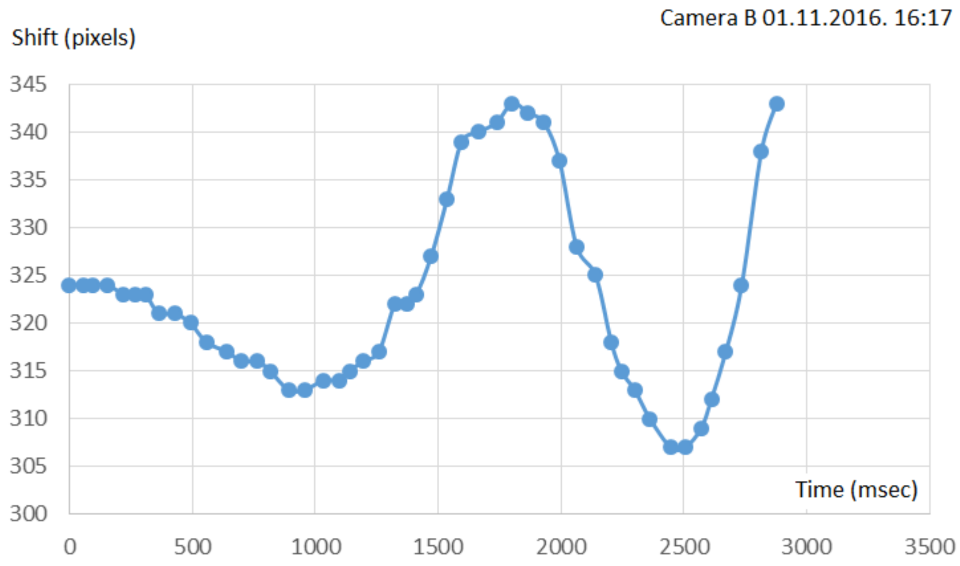


Fig.3. Graphical representation of B camera source data example.

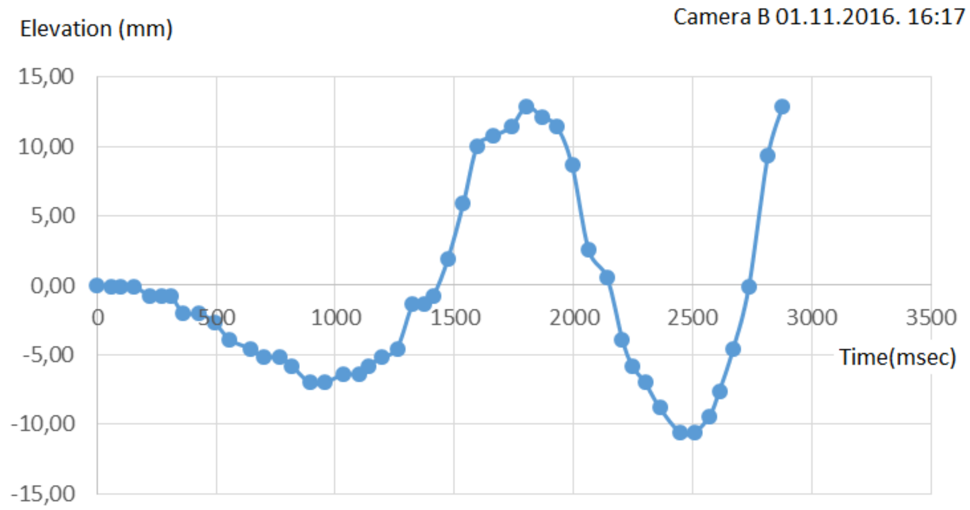


Fig. 4. Processed source data P_{X0} = 0.31mm A = 166,17mm.

MESUREMENT PROCESSING

In measurement processing we start with image processing: average shift point coordinate calculation, or of the center of the gravity coordinates and their fixation (in pixels) of the results file are syncronised with the time with the experimental sessions relative and absolute measurement (in microseconds). As a result we have got a source data. Graphically example of source data sequence looks like have shown at (Fig. 3.).

These type of data sequences, as we see, are sufficient to be able to draw conclusions about waveform levels or offsets, but not "convenient" for the use of different analysis tools, for further analysis of this volatility, including components of the energy evaluation. The problem is the fact that in the processing of the data, we have chosen a universal computer, which runs the OS MS Windows 7. This has a number of advantages: user interface, device driver (connection interfaces and management programs), a wide transmission spectrum of possibilities, data processing, storage and storage options. But at the same time the prior complex process breaks in this case does not guarantee equal intervals between measurements, which leads to the next processing step, based on intermittent time interval data replacement with as close as possible and smooth function f = z (t), which provides realistic function values at any point in time.

INTERPOLATION WINDOW

Variable interpolation problem solutions have been widely applied in the past. There are a whole range of mathematical tools to solve this problem. The problem, is the great number of variable defined points (several thousand): we introduced the "interpolation window" (Figure 5) "segment interpolation" concepts. The interpolation window has final number n in changing h_i, the evaluation time. The interpolation process is carried out in two stages. In the first phase, using regression analysis with EXEL LINEST array functions polynoma modification. In this window, using the least squares method, the statistical nth degree polynomial coefficient values K_i:K_{i+N+1} substitution function expression is calculated.

$$\{K_i:K_{i+N+1}=\text{LINEST}(h_i: h_{i+N}; t_i: t_{i+N}\ \hat{}(1,2,..,N))\}, \quad (5);$$

$$z(t)= K_i \times t^N + K_{i+1} \times t^{N-1} + \ldots + K_{i+N} \times t + K_{i+N+1}, \quad (6);$$

The interpolation window is shifted by one step (i + 1) and the polynomial coefficient calculations are repeated until all the interpolation segment is thus treated.

The next step is a regular iteration step Δt and their choice of their number m and the calculation of corresponding coefficient of an array of choice of features j-values z (tj). To determine the irregular time interval, which correspond to the current time iteration value t_j $z(t_j)$ - function terms a built-in selective filter, is used useing the tool "MATCH" (7) and an indirect addressing function "INDIRECT" (8) the vector K_i:K_{i+N+1} addressing the polynomial coefficients in the array, which is designed to process data sequentially shifting the interpolation window (Fig. 5).

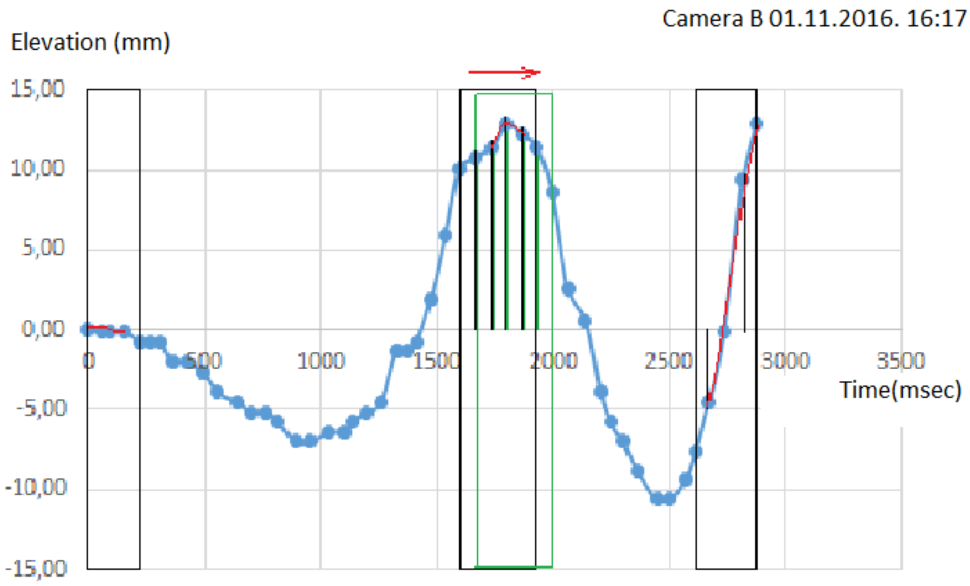


Fig. 5. Example of segment interpolated function with sliding interpolation window.

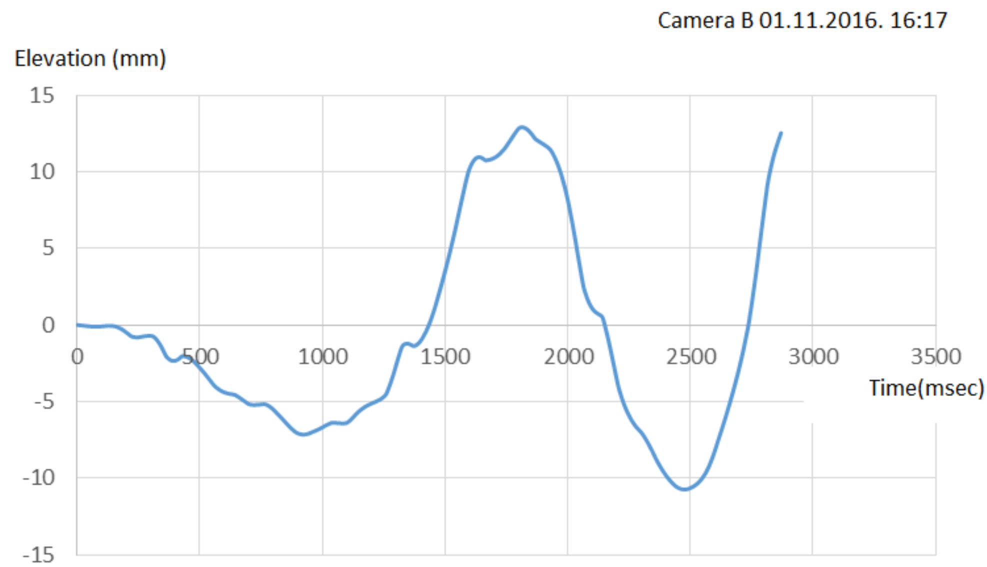


Fig. 6. Example of smooth segment interpolated function with a regular iteration step Δt =7ms.

$$K = MATCH(t_j\,;\, t_i\!:\, t_{i+N};1), \qquad (7);$$

$$K_i\!:\, K_{i+N+1} = INDIRECT\ (\{array\ of\ coeficients\ \}(i\!:\!i+N+1);\ k+D_k),\ (8);$$

where

k - specific interpolation window number,

D_k - interpolation window interval shift for prevention curve distortions on interval boaders.

DISCRETE FURIER TRANSFORMATION

The next step in our wave analysis is irregular and unlinear oscillation split into various frequences sine wave components (9), [1].
The transformation result is a complex variable function (9) providing information about the relative contribution to the wave by each discrete frequency m Δf, where Δf = 1/T, of m/2 number frequencies (regarding Naikvist criterion).

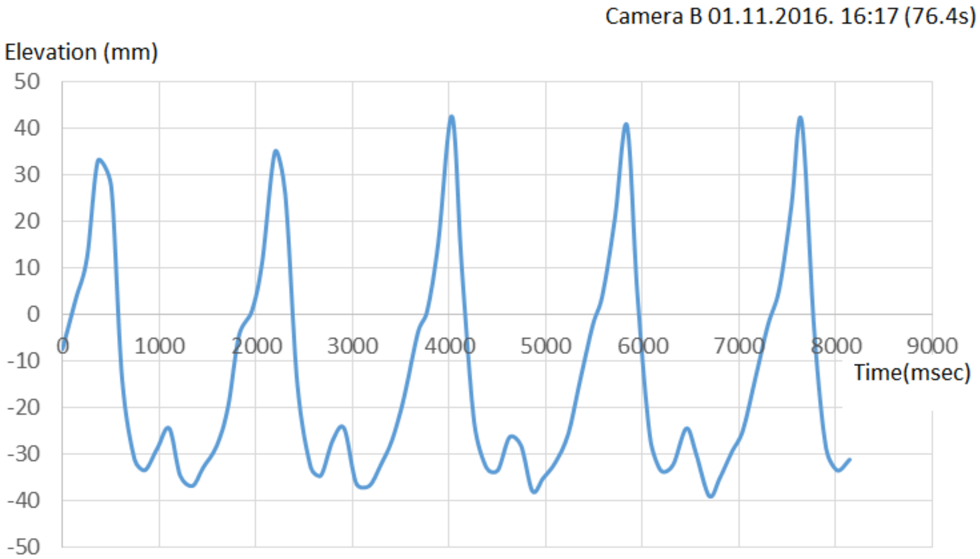
$$F(m * \Delta f) = \sum_0^{N-1} z(m * \Delta t) * e^{-i(2\pi m\Delta f)*n\Delta t}, \qquad (9);$$

where

m= 0, 1, 2, ...,N−1.

To get adequate results, we have to reduce unphysical error in the FFT, called leakage. It is subject to follow certain conditions, [1].

1. In principle, if an infinite number of discrete data points are taken, leakage would not be a problem. However, any real data acquisition system performing FFTs uses a finite number of discrete data points (in our case around 1000 points);
2. Time domain segment T for FFT application must be at least three oscillation periods (in practice will use at least 4 oscillation periods).



3.

Fig. 7. Example of water waves time domain segment at measurement session, Camera B 16:17 01.11.2016.

In order to obtain the spectrum of normalized amplitude of discrete frequency sine wave R (m), we use the expression (10). To perform FFT the analysing functions initial values number has to be power of 2 (two) (16, 64.128, 256, ...) to the argument, whose step must be constant (in practice will use initial values number 1024).

R(m)= (IMABS(supplied variable(m)))/512, (10);

where

f(m) = m x 1/T, (11);

The oscillation frequency component phase shift angle in degrees θ (m) is available from the expression:

θ(m) = ROUND (((IMARGUMENT({complex variable}(m)))/3,14*180); 0), (12);

Thus, a graphical representation (Fig. 8) surface wave displacement data strings 4 periods Sector (fig. 7) processing results we have a visible picture of the constituent components of the oscillation (the amplitude and frequency known).

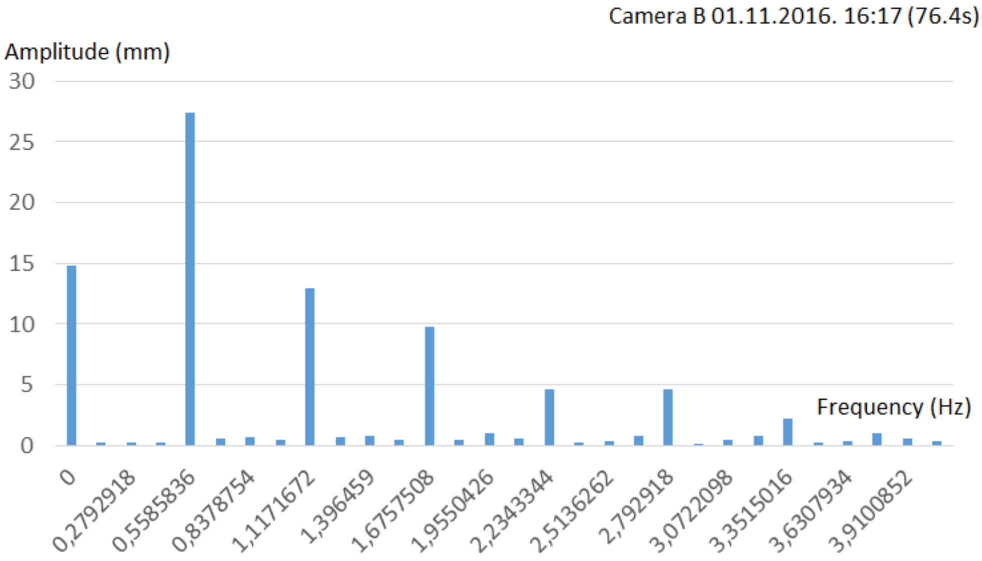


Fig. 8. Harmonic amplitude spectra after discrete Fourier transformation.

Next, using linear wave theory basic equation [4. p. 408] we can calculate the average power of each frequency component in this time segment:

$$N_k(m)= N_p(m)= \rho g^2 R(m)^2 /8\pi f(m), \quad (13);$$

This correlation is applicable when the wavelength λ_0 and the wave phase velocity C_0 determination can use the deep-water wave regularities (14,15), [2]:

$$\lambda_0 = \frac{g*T2}{2\pi}, \quad (14);$$

$$C_0 = \frac{\lambda 0}{T} = \frac{g*T}{2\pi}, \quad (15);$$

That is true, if the conditions are met $h \geq \frac{\lambda}{4}$, (16);

If the condition is not met and $h < \frac{\lambda}{4}$, (17);

where

h is the dynamic water depth,

Then assuming that the force of a deep-sea formula can not, because although the wave height changes can be measured, the wave phase velocity - C changes and must be calculated using equation (18) and for wave power calculation a correction must be applied for waveform at transition depth [2, page 4].

$C = \tanh(kh)$, (18);

where

k is wave number: $k = \frac{2\pi}{\lambda}$ (19);

In practice, for the adjustment we used graphics 2. 2, [3], which reflects the relative wave parameters as a function of depth and conditional deepwater wavelength relationship.

ENERGY SPECTRUM

Expression (13) allows you to get an idea of the aggregate wave power (20) energy diskret frequency distribution. (Fig. 9).

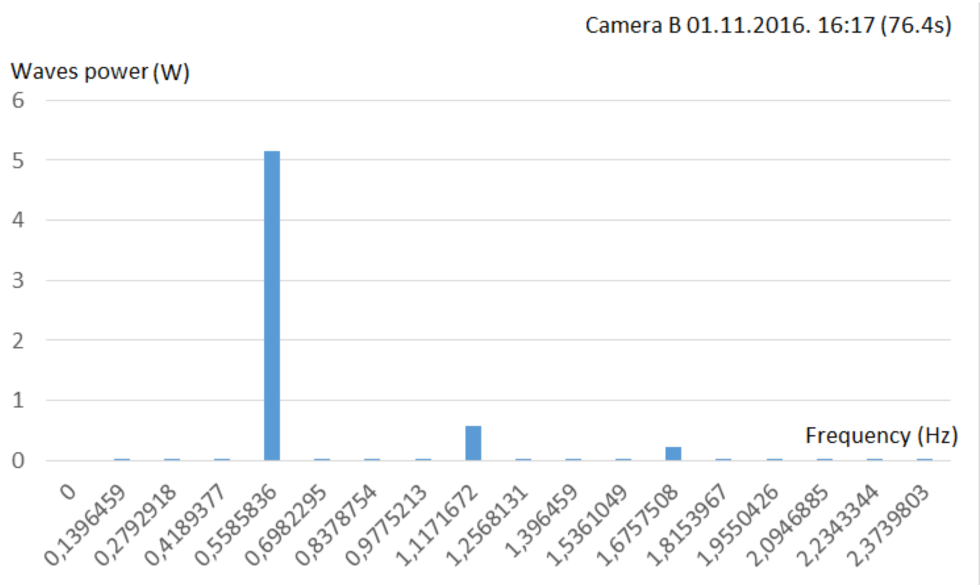


Fig. 9. Wave kinetic energy and average power frequncy spectrum.

The total capacity of the plane wave, which is fitted with a lazer measure is calculated as:

$$\text{Nsum} = \sum_{1}^{N-1} N(m), \qquad (20);$$

THE SENSOR LOCATION

Locating wave environment "lazer meter", which can carrying out the measurements and mesure the oscillation amplitude and power management must be based on a few considerations:

1. All of the aforementioned are partly based on the assumption that the wave propagation direction is known, because without additional conditions, the following point sensors practical wave propagation direction can not be determined. Conclusion – Lazers must be deployed in pairs. This theoretically makes it possible by experimental measurements to determine the direction of wave propagation, wave phase of the wave phase speed of movement, which is necessary for the calculation of wave power.

2. If foregn objects are inserted into the wave path dynamic system as a component, for example, with the object of wave energy absorption and conversion to another form of energy, in order to evaluate these devices require data on what part of the wave energy is consumed/ stifled. Conclusion - one detector must be placed in front of the equipment and the other - after it.

3. Any foreign body will reflect part of the wave energy. This process affects the transformed energy balance / ratio. If this process is going to control the open water area before the receiver should be installed at a distance of two meters. A single detector and a fixed control measurement session without a receiver would suffice in a wave bath.

TESTING

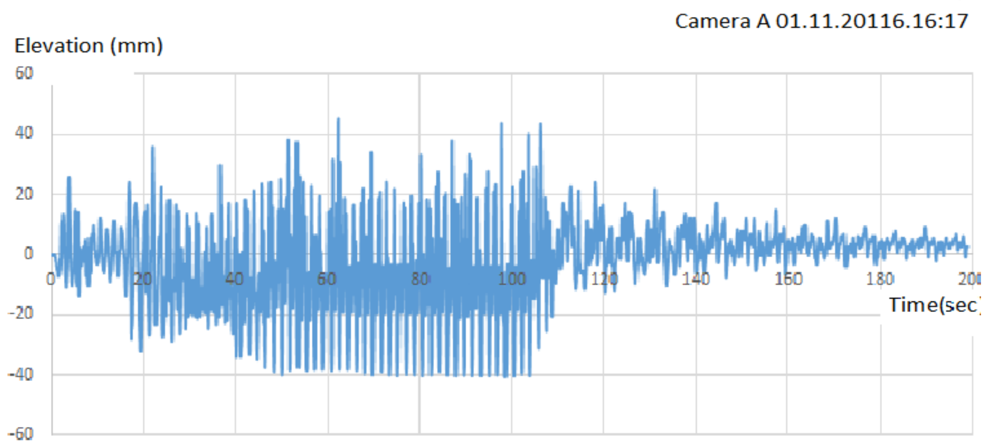


Fig. 10.Waves in an "no object" wave tank 1.95 m away from the wave generator.

On the basis of these considerations, in a wave bath, 3.00 m away from each other, on both sides of the potential waveconverter, 1 95 m away from the wave generator and 1.97 meters from the wave absorber, we installed two calibrated measuring detectors (A, B). To test the wave tank unit, as regards to converter measurement, a test session without a converter was initiated (in a wave tank containing no an alien object). The corresponding measurements are shown in Figures 10 and 11.

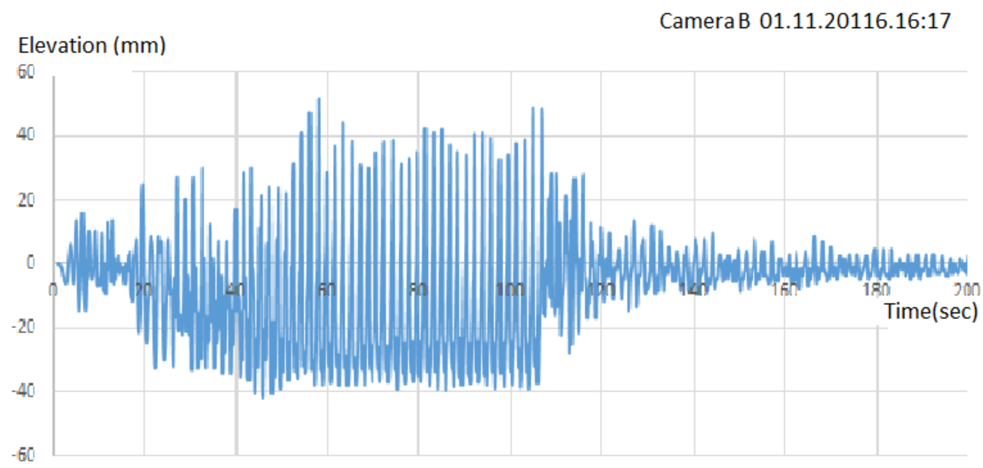


Fig. 11. Waves in an “no object” wave tank 3 meters from the A sensor and 1.98 m from the wave absorber.

CONCLUSIONS

The developed method enables automated and efficient recording of wave surface elevation time function characterizing data and saves them for further processing.

It allows us to keep records of wave energy, power and determination of the changes between certain mesure wave planes.

The chosen two laser measure configuration allows the receiver - wave tank system to detect wave phenomena, such as: resonance, standing waves; wave absorption, reflection, dispersion, refraction.

Addressing the fluid wave energy receiver absorption determination, the project "twisting and rotating wave energy converter operation research" within the framework of the solution chosen was practically implemented (equipment and software was developed for necessary measurements) and tested in a real experimental conditions.

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