

Software for wave generator control

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Abstract - For the purpose of Split harbor model analysis, a wave generator was developed with ability of producing various waveforms. The generator itself is composed of three fundamental parts: the actuator (paddles powered by electrical motors), control modules and user application. Real time display and analysis of twenty measured probe signals is provided. Application communicates with programmable automation controller (PAC) which contains the FPGA layer. The user interface and the parts of application control algorithms which are running on a separate computer using Windows operating system are elaborated in this paper. Implementation of applied Ethernet communication is also explained.

I. INTRODUCTION

The city harbor of Split is scheduled for a large reconstruction in a few years. Before starting the field construction work, a series of calculations and experimental tests has to be performed. One of the most important starting parameters in harbor construction design is the influence of the waves to the piers, docks and water currents. The special wave generator described in this paper is designed and implemented for experiments needed for the harbor design.

The wave generator can generate different kinds of waves. It has six paddles (Fig. 1), driven by six electric asynchronous motors. To enable simultaneous and independent work of all paddles, this system is controlled by very fast programmable controllers with FPGA modules (Fig. 2.) using complex software application. Getting feedback information about generated waves and their influence is enabled through 20 measurement probes.



Fig. 1. Actuators – movable paddles of wave generator

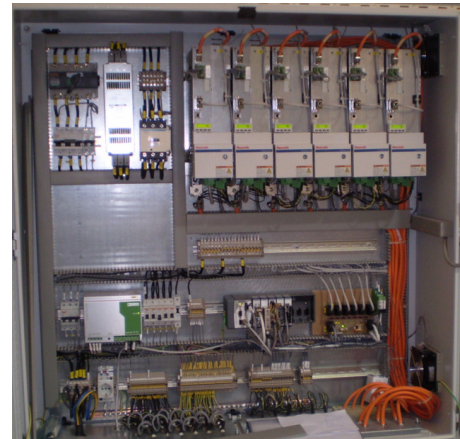


Fig. 2. Motor drivers and controllers

Measurement signals, based on water level difference, are also processed and monitored by the application.

II. APPLICATION PROGRAMME STRUCTURE

The application is designed in a graphic programming language. This was a good choice because of fast implementation from idea to realization, possibility of simple modifications and comprehensible object structure. Disadvantages like large amount of needed memory are avoided using powerful PC. The PAC is running in the same language and has the same problem with memory. In this case the hardware possibilities are much more limited than with the PC, but it has to handle important acquisition data. The limitation is solved using continuous data sharing which means the paddle position data are not given at once, but, part by part, every 20 seconds.

The paddle position data are arrays of references for paddle motion. After defining the appropriate wave and experiment configuration at the user interface, all information needed for position data calculation is obtained.

III. USER INTERFACE

Having in mind reducing human errors during wave configurations, a lot of care is invested in ergonomics and intuition of the user interface. (Fig. 3.) There are always two or three graphs on the panel showing references or measured

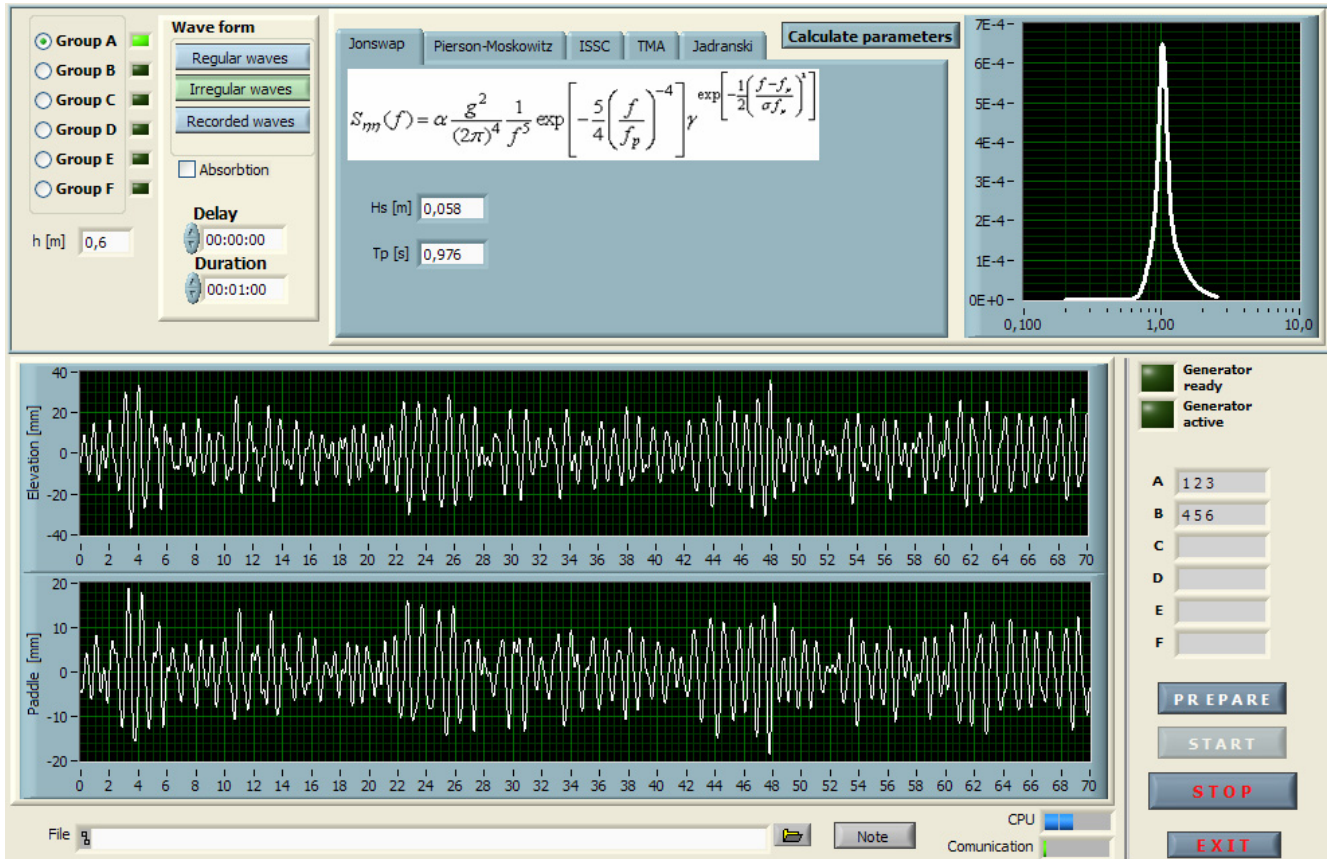


Fig. 3. Main user interface panel

signals. The main panel provides information about the target wave field and spectrum.

The buttons are conditional, only active wave type and its parameters are shown, others are hidden. The configuration or calibration windows have to be selected from menu tab on the top of the main panel. The enabled panels are:

- Paddle calibration – calibrate paddle position
- Probe calibration – calibrate the probe
- Paddle position – join each paddle to some group
- Probe position – choose probe for absorption feedback

Some information important for safety of the system, like paddle position, are always shown.

When the configuration is completed, the generator is activated by pushing the start button, and the new window is opened. Now, the wave measurement result and wave spectrum are shown online. The spectrum is being calculated from 5 second periods of measurement data.

When the desired generation time has elapsed, the generation automatically stops.

IV. PARAMETAR CALCULATION ALGORITHM

Different calculation algorithm is used for each of the three kinds of wave forms.

1) *Regular waves* are modified sinusoid signals: *Stokes*, *Cnoidal* and *Solitary* waves. The transformation to paddle position is based on Biesel function [1].

Using Biesel functions, paddle control signal can be calculated from the wave spectrum:

$$S_{\eta}(f) = ie_0 S_x(f) \quad (1)$$

and, same as with equation (2):

$$x(k) = \sum_{f=f_1}^{f_M} \sqrt{2S_x(f)\Delta f} \sin(2\pi f \Delta t k) \quad (2)$$

where S_x is the wave spectrum, f is the frequency, Δf is the frequency interval, Δt is the time period, f_1 is the starting frequency, f_M is the maximum frequency, and e_0 is the wave transfer function, dependent on the type of the paddle. Surface elevation and paddle movement signals are shifted by 90 degrees.

For piston-based paddles transfer function e_0 is

$$e_0 = \frac{4 \sinh^2(k_0 h)}{2k_0 h + \sinh(2k_0 h)}, \quad (3)$$

where k_0 is the wave number, and h is the water depth.

While it has no large demand on process time, every parameter change triggers new calculation.

2) *Irregular waves* – imitation of original environmental waves. (Fig. 4.)

The random phase method is a deterministic method simulating random waves in the frequency domain by assigning random phases to each frequency component [2]. Subsequent use of the Fast Fourier Transform (FFT) – Algorithm provides the time domain representation of the wave train.

Wave spectral density is usually defined by two parameters: significant wave height H and time period T [3]. It is starting point in getting paddle reference signal. As shown in fig. 5., elevation spectral density of the generated waves matches the reference very well, with less than 5 percent error.

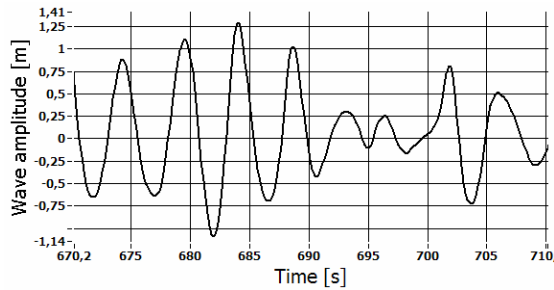


Fig. 4. Surface elevation for irregular waves

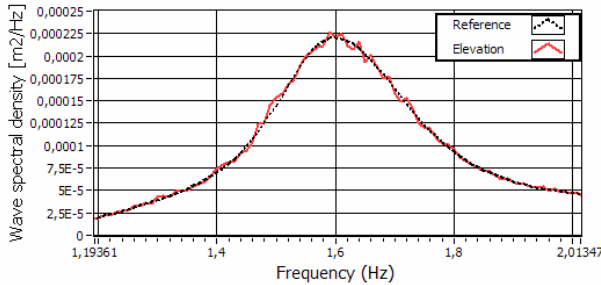


Fig. 5. Wave spectral density

The implemented spectrums are:

◇ JONSWAP

$$S_{\eta}^{JONSWAP}(f) = \frac{\alpha g^2}{(2\pi)^4 f^5} \exp\left(-\frac{5}{4}\left(\frac{f_p}{f}\right)^4\right) \cdot \exp\left(\ln(\gamma) \exp\left(-\frac{(f-f_p)^2}{2\sigma^2 f_p^2}\right)\right) \quad (4)$$

$$\gamma = 3.3$$

$$\sigma = 0.07 \quad \text{for } f \leq f_p$$

$$\sigma = 0.09 \quad \text{for } f > f_p$$

where α is the scaling parameter, γ is the peak enhancement factor, f_p is the peak frequency and σ is the spectral shape parameter.

◇ Pierson – Moskowitz, for fully developed wind-generated waves

$$S_{\eta}^{PM}(f) = \frac{\alpha g^2}{(2\pi)^4 f^5} \exp\left(-\frac{5}{4}\left(\frac{f_p}{f}\right)^4\right), \quad (5)$$

◇ ISSC - International Ship Structures Congress

$$S_{\eta\eta}^{ISSC}(f) = \frac{5}{16} H_s^2 \frac{f_p^4}{f^5} \exp\left[-\frac{5}{4}\left(\frac{f}{f_p}\right)^4\right] \quad (6)$$

◇ TMA spectrum may be considered as an extension of the JONSWAP spectrum with an additional function Φ depending on the water depth h .

$$S_{\eta\eta}^{TMA}(f) = \phi(\omega_h) S_{\eta\eta}^{JONSWAP}(f) \quad (7)$$

$$\phi(\omega_h) = \begin{cases} 0.5\omega_h^2 & \text{for } \omega_h \leq 1 \\ 1 - 0.5(2 - \omega_h)^2 & \text{for } 1 \leq \omega_h \leq 2 \\ 1 & \text{for } \omega_h > 2 \end{cases} ; \quad \omega_h = 2\pi f \sqrt{\frac{h}{g}}$$

◇ Spectral density of the Adriatic sea waves

$$S_{\eta\eta}^{Adriatic}(f) = \alpha \frac{0.0116g^2}{(2\pi)^5 f^5} \cdot \exp\left[-\frac{5.186}{(2\pi)^4 f^4 H_{1/3}^2}\right] \cdot z^p \quad (8)$$

$$p = \exp\left[-\frac{(f-f_m)^2}{2\sigma^2 f_m^2}\right]; z = 1.63$$

$$\sigma = \begin{cases} 0.08 & \text{for } f < f_m \\ 0.10 & \text{for } f \geq f_m \end{cases}$$

$$f_m = \frac{1}{2\pi} \left(0.32 + \frac{1.80}{H_{1/3} + 0.6}\right)$$

3) *Saved waves*

All the waves are repeatable if we save paddle position data or surface elevation. Also some recorded natural waves can be reproduced with this application. If the saved surface elevation is loaded, than this procedure has to be done:

- Calculation of wave spectral density
- transformation from time to frequency domain – FFT
- calculating paddle position data – inverse Biesel function
- frequency to time domain transformation.

V. COMUNICATION

Data transfer between PC and PAC is realized via LAN network using TCP-IP protocol. Short commands like start, stop etc. are directly linked with shared variables, so the program environment does all the networking. But large data packages like paddle data would cause Ethernet meltdown. That's the reason why this important online data transfer is made on lower level using TCP-IP function blocks. Consider the fact that some antivirus programs slow the connection while trying to monitor data. If network connection fails anyway, the smooth stopping is enabled.

VI. DEVIATIONS

The main reason for deviations is reflection. The tested model construction is placed in shallower water. After harbor piers starts the deep water, so wave reflection are very intensive [4]. Additional undesired consequence of reflection caused by the angle of the reflecting barrier is generation of sideways waves which disables simple absorption [5]. On the other hand, if the wave is generated from some other direction (southwest - SW), where are no direct piers reflections, the influence is minimal because the wave is breaking at the shelf and freely enters the harbor.

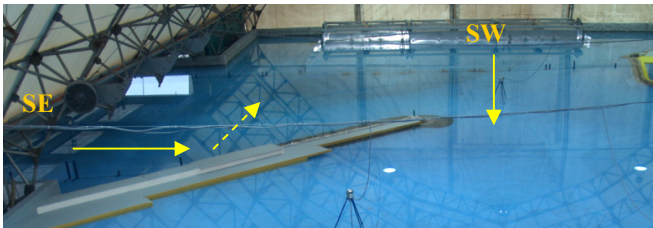


Fig. 6. Wave reflection from pier

While testing the accuracy of the generated irregular waves in southeast (SE) direction, significant amplitude attenuation is spotted as shown in fig. 7. The source of this problem is the reflection effect [6]. The attenuation coefficient depends on wave direction and its frequency.

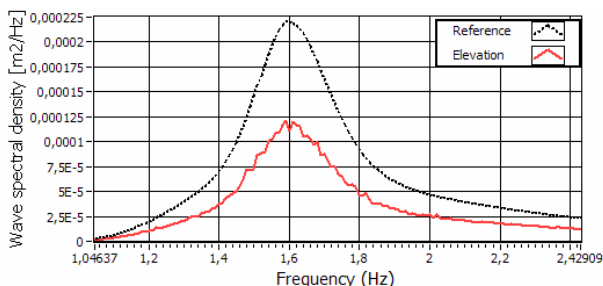


Fig. 7. Response error of wave spectral density

Adding a gain coefficient to the reference parameter H is not the best solution, but is surely the most practical and effective. Other, better alternative is active absorption realized with the feedback loop [7].

Besides complex reflections, active absorption struggles with delay times, especially when testing irregular waves. After 5 second time, while spectral density is calculated and compared, the phase is changed and now is hard to match the phases. The results are good only for regular waves.

The readings from sensors on the same short distance from the generator paddles are not the same because of a router near the generator [8]. During the movement of the paddles, router is warping under pressure and makes its own waves. The most significant difference is at high wave frequencies.

With irregular waves, if wave generation duration is very long, the signal would have repeatable segments [9].

VII. CONCLUSION

The results of the measurement experiment have shown a very satisfying accuracy without reflection incident. The absorption of reflections for 2D waves is planned to be implemented, but it will not give much better results because of reflection in different directions. The irregular reflection is caused by harbor model structure, so the final results are undesired sideways waves. This anomaly effects regular waveforms much more than the others.

The designed software is capable to monitor and control all necessary information for wave generation. Providing stability and fast response, the application fulfills all demands for safe and good testing work.

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