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BY

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ONLINE ABSORPTION CONTROL SYSTEM FOR WAVE GENERATION

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ABSTRACT

The paper deals with the development of an Online Absorption Control System for laboratory wave generation in a two-dimensional wave channel near to prototype scale. Specially for long-term tests the reflections of the test structure re-reflected by the wave paddle has to be absorbed. This must be done online superimposed with the wave generation process to get well defined wave conditions over the total test run.

The accurate consideration of all phase shifts and the combination of two independent control loops show best results in efficiency and stability of the absorption control system. Giving the wave train signal directly to the wave paddle allows variable amplifications to the absorption process without affecting the current wave generation. The system works with all kinds of regular and irregular wave trains and will not be influenced by the tested coastal structures. Long time tests with a constant energy level are practicable.

INTRODUCTION

The Large Wave Flume is a notable facility for basic research in coastal engineering phenomena of the Coastal Research Center (Forschungszentrum Küste) of the University of Hannover and of the Technical University of Braunschweig. Water waves up to 2 m height under quasi-prototype conditions can be simulated in the 300 m long, 7 m deep and 5 m wide flume. The installed power of the piston type wave generator is about 900 kW (Fig. 1). The gearwheel driven carrier gives a maximum stroke of 4 m to the wave paddle. The big cylinder

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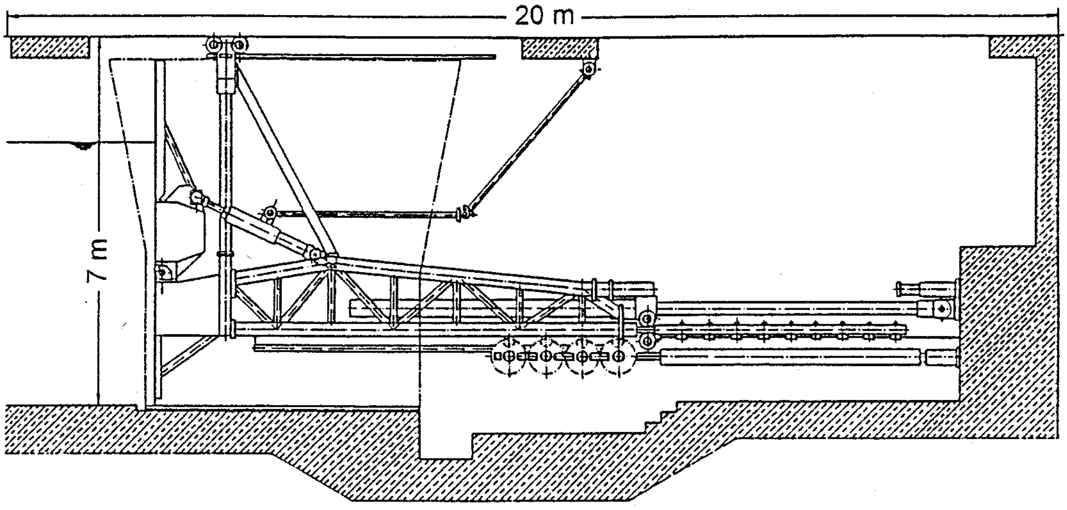


Figure 1.
Cross section of the piston-type wave generator of the Large Wave Flume

integrated in the carrier compensates the static water force (rear is free of water) from the still water level in front of the paddle in a passive manner. As a result of the preferred machine design with 8 oil pressure acting and servo-controlled drive rotators instead of one large cylinder the accuracy of the wave generator is extremely high.

Various structures for coastal protection measures, sandy sea-beds and beaches in shallow waters, vertical and rubble mount breakwaters, revetments, pile constructions and pipeline sections are investigated similar to prototype scale. Specially for wave-induced morphological alterations and scourings of a sandy seabed and for controlled destruction tests of coastal structures the test objects must be exposed to well defined wave spectra. The wave energy level has to be stabilized over the total test length. The quality and accuracy of the tests depends decisively upon the exact generation of waves in the channel and the consideration of interfering processes and disturbance variables. These disorders of the wave climate are primarily reflections of the investigated structure re-reflected at the wave paddle acting as a vertical wall.

In the past practical tests in a wave flume must be stopped when the re-reflection reaches the investigated structure. Today it was attempted to identify the reflection previously in front of the wave paddle and to eliminate it immediately with an active controlled movement of the wave generator. For this purpose in the end of the 80^{th} an analog control system bought by an external contractor was installed at the Large Wave Flume. The efficiency of this system obtains approximately 60% and besides it was strongly dependent by frequency. Consequently for long time tests this control system was not suitable. This situation passes to the conclusion to develop an own absorption control system for the wave generation.

OBJEKTIVES

The demands to the desired control loop are:

- Highest possible efficiency,
- operation within all wave conditions both with regular waves as well as with arbitrary spectra,
- no influence by the tested structure and its reflection characteristics,
- arbitrary test length.

Off-line based solutions operating with a pre-calculated answer from the tested structure and the corresponding re-action of the wave generator are not qualified to meet this requirements. Best suited is an online control system. According to this the actual wave height in front of the wave generator was measured and continuously compared with the desired water elevation η at the paddle. Each deviation to the rated value will be interpreted as an reflection interference coming back from the tested structure and corrected immediately by the corresponding active countermovement of the wave generator. Indeed such a process presupposes fast system components. Further the control algorithm must be calibrated exactly to each hardware element of the feedback loop.

TECHNIQUE USED

To be as flexible as possible in development the decision was made to a digital computer based absorption control system with appropriate A/D- and D/A-converters and analog filter systems. The handling of the discrete time control was managed by a real-time operating system of the computer. The first system completed in 1990 based on the RTE-A operating system by Hewlett-Packard. Actually it changed to the MS-DOS real-time extension RTKernel established by OnTime Informatic Limited (Hamburg, Germany).

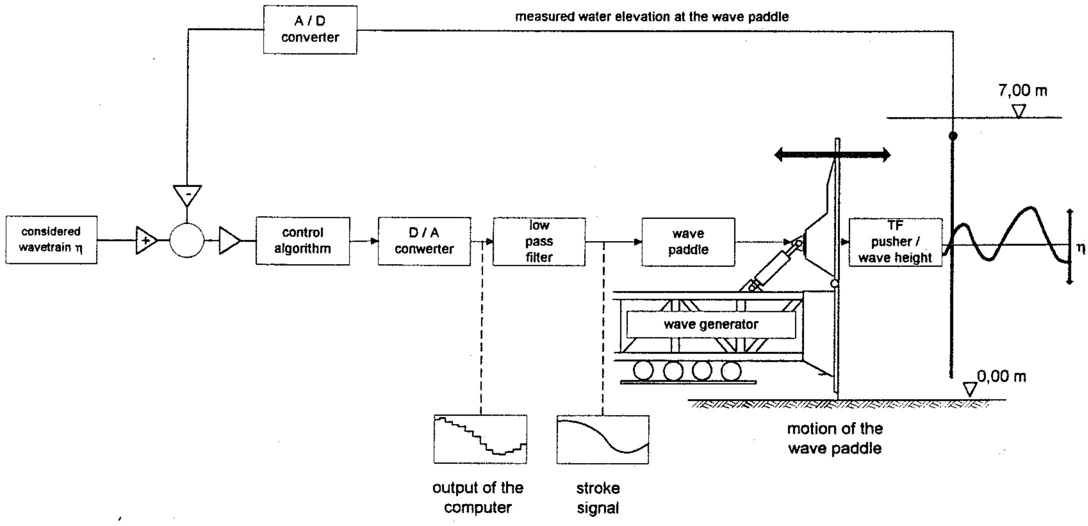
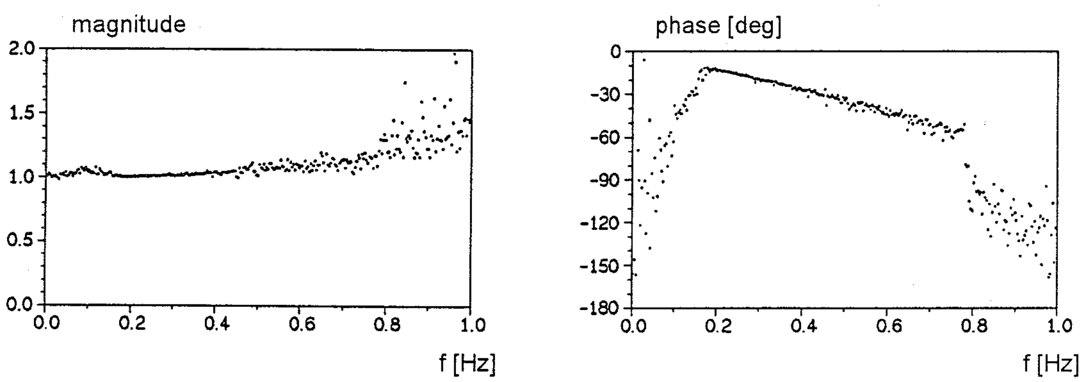


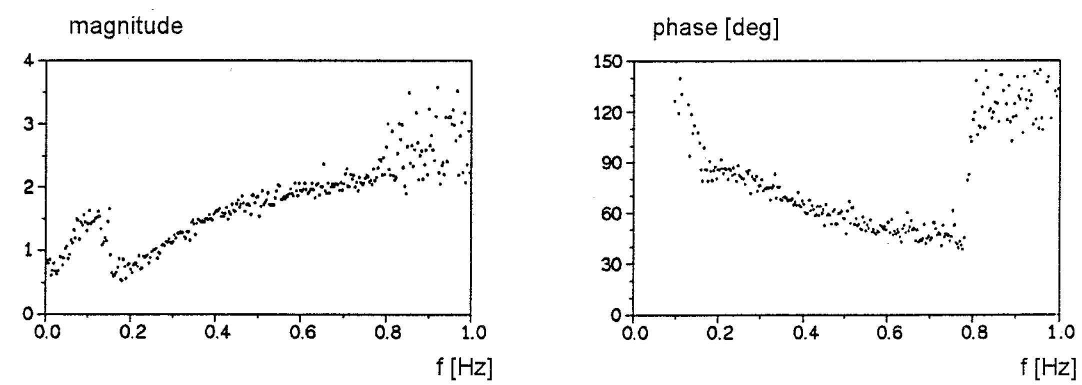
Figure 2. First design of the closed-loop control system

Fig. 2 shows the first design of the closed-loop control system for the wave generation in the Large Wave Flume. Input and reference value is only the water elevation η in front of the wave paddle.

For the election of a suitable control algorithm it is important to identify all available features of the system components very exactly. According to Fig. 2 this are particularly the transfer function of the wave generator and the so called hydraulic transfer function between wave paddle and wave height. Yet the phase shift of the low pass filter as well as the D/A-converter, and even the small distance between the wave paddle and the wave gauge has to be considered in detail. To do this a wide banded wave spectrum (white noise) was generated. The system response was measured and analyzed in the frequency domain. The magnitudes and phases of the transfer functions between the output of the computer and the movement of the wave generator and the water elevation in front of the wave paddle are shown in Fig. 3. The results within the low frequency sector are not significant since they are influenced by the first reflections from the end of the wave flume.



TF Control Signal - Pusher Position



TF Pusher Position - Water Elevation η

Figure 3. Transfer functions measured at the Large Wave Flume

The characteristic of the transfer function of the wave generator is described best as an all-pass system. The transition between pusher and water elevation fits to a derivative-timeshift reaction. As a general result the stroke calculation in frequency domain for pusher type wave generators are determined to

$$\text{amplitude stroke}_i = \text{amplitude}\ \eta_i \cdot \frac{\sinh(2\cdot k)+2.5\cdot k^{1.2}}{4.24\cdot \sinh(k)^2} \tag{1}$$

$$\text{phase stroke}_i = \text{phase}\ \eta_i + 90° \tag{2}$$

$$\text{where:}\quad k = \frac{2\cdot\pi\cdot d}{L_{1.\,ord.\,i}}$$

Practically the three sections D/A-converter, low pass and transition paddle to water elevation are handled together as only one system. Using the results of the system identification it is possible to calculate the adapted output signal of the computer. This can easily be done off-line before the beginning of the test from the desired wave-train. However within a discrete-time controlled system the interference's must be corrected immediately after their recognition at the wave paddle. It is too time consuming to calculate the answer of the control-circuit in frequency domain. For a time-discrete control system the transfer function must be converted into a difference equation. The type of equation depends on the selected controller type. Appropriate techniques are available in the faculty of control engineering. However the controller type must determined.

From the analysis of the behavior of the system parts the integral part included in the hydraulic transfer function is the most important factor of the designed control system. For this a controller type was selected which corresponds in main parts to that of a PID-controller (=proportional-integral-derivative-controller). It is described by the following z-transform (Doetsch, 1967):

$$F = \frac{1-z^{-1}}{q_0 + q_1\cdot z^{-1} + q_2\cdot z^{-2}} \tag{3}$$

$$\text{where:}\quad q_0 = k\cdot\left(1+\frac{T_D}{\Delta t}\right) \tag{4}$$

$$q_1 = -k\cdot\left(1+2\cdot\frac{T_D}{\Delta t}-\frac{\Delta t}{T_I}\right) \tag{5}$$

$$q_2 = k\cdot\frac{T_D}{\Delta t} \tag{6}$$

k = amplification factor
T_i = Time constants

The correspondent difference equation reads as follows:

$$x_{in}(n)\cdot q_0 + x_{in}(n-1)\cdot q_2 + x_{in}(n-2)\cdot q_3 = x_{out}(n) - x_{out}(n-1) \qquad (7)$$

If there is a derivative-timeshift element included in a control system it is known that with the integral part stability problems raises up. Therefore it is important to consider the stability limits of the controller. This was performed with the control engineering technique by Hurwitz (Parks, Hahn, 1981). Fig. 4 shows a closed stable aréa for the interesting area where the wave generation will operate. Indeed

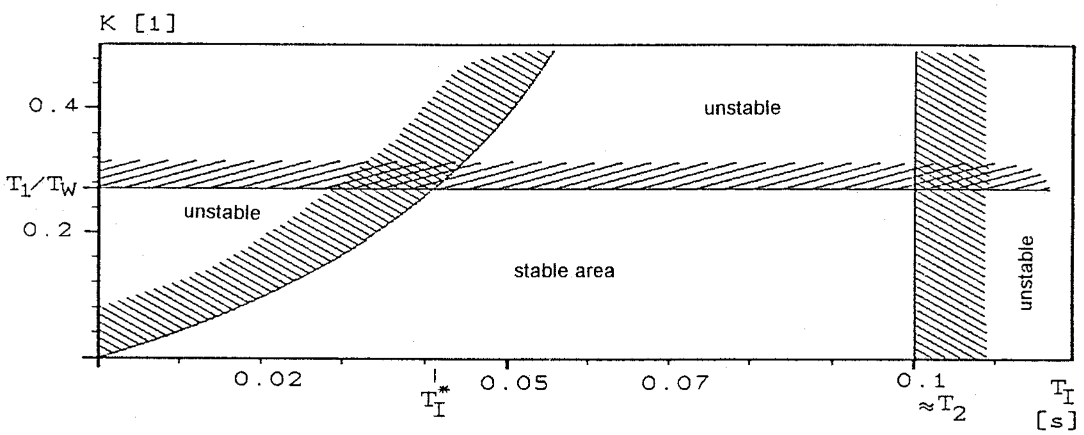


Figure 4. Stability areas of the control system

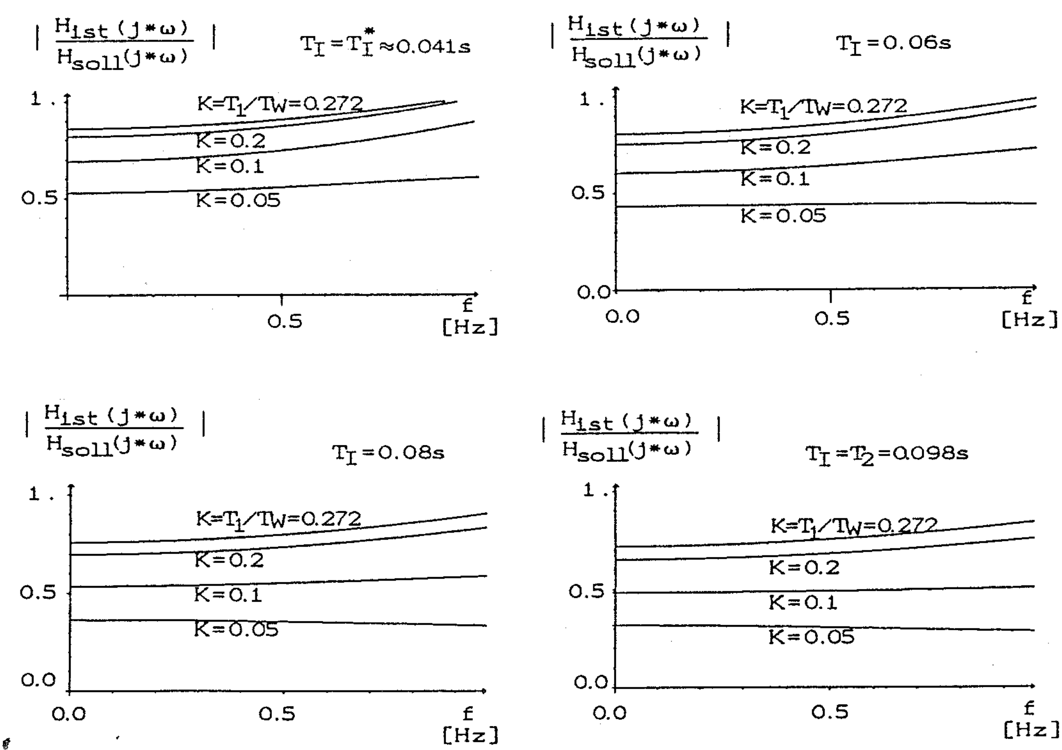


Figure 5. Amplitudes of the transfer function of the control system

a further examination of the total control loop shows that the magnitudes of the transfer functions never catches the 100 percent (Fig. 5). According to the individual parameter settings the wave generation as well as the wave absorption has an efficiency between 35 and 85 percent only. Generating the initial water elevation exclusively by the control system, this means the absence of an water elevation in the flume initiates a reaction of the controller, the desired wave height wouldn't be obtained.

Furthermore the integral part of the control algorithm introduces another obstacle. Due to small DC-errors in the measured water elevation the calculated output signal of the controller and coupled with this the wave paddle will run out of the middle position. This effect can not be prevented and must be treated through additional corrections. The controller output will be observed for a DC drift and if necessary corrected. This process however decreases the efficiency of the control loop particularly at low frequencies.

The solution of the two mentioned problems was a fundamental change the signal flow and the addition of a second stationary wave gauge in a slight distance in front of the wave paddle. Fig. 6 gives an overview of the new designed closed-loop control system. A substantial element facing the first draft is the direct connection of the before test begin off-line calculated stroke signal to the wave generator. By this the generated wave train is not affected by the control algorithm. Also the power of the controller will not be reduced by generating the desired wave. Exclusively the located deviations in the water elevation are treated by the control system and will be added to the guiding voltage.

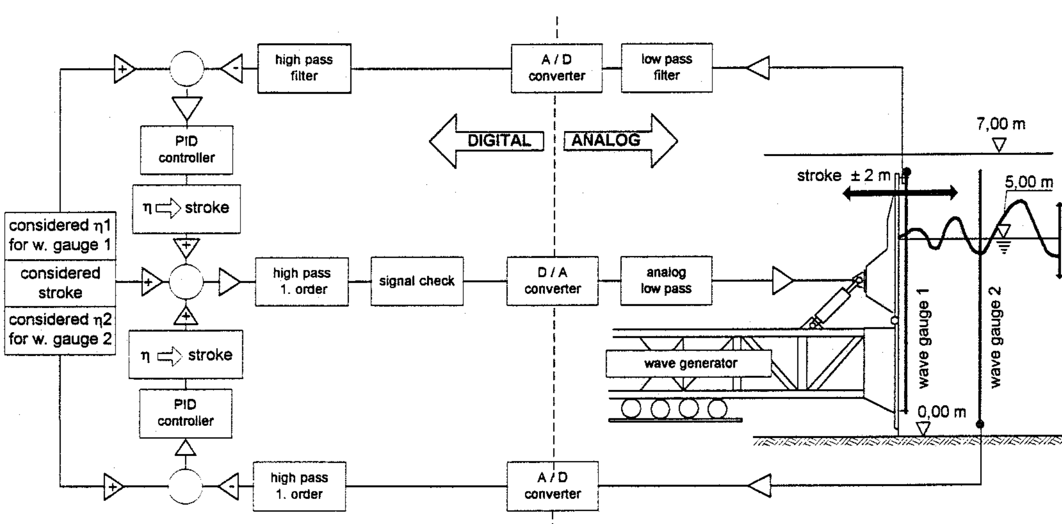


Figure 6. Double-loop online control system at the Large Wave Channel

The second loop is not absolutely necessary however further information about the differences of the water elevation increases the efficiency of the process. This is important particularly for the lower frequencies. As mentioned before the efficiency of the absorption system decreases due to the DC-drift correction. This effect will be compensated nearly completely by the second wave gauge. Specially the natural frequency of the wave flume itself with about 140 seconds period is located in the low frequency area. The compensation of these long waves requires large movements of the wave paddle and will reduce the power of the wave generator. That's why already smallest amplitudes must be recognized and removed immediately.

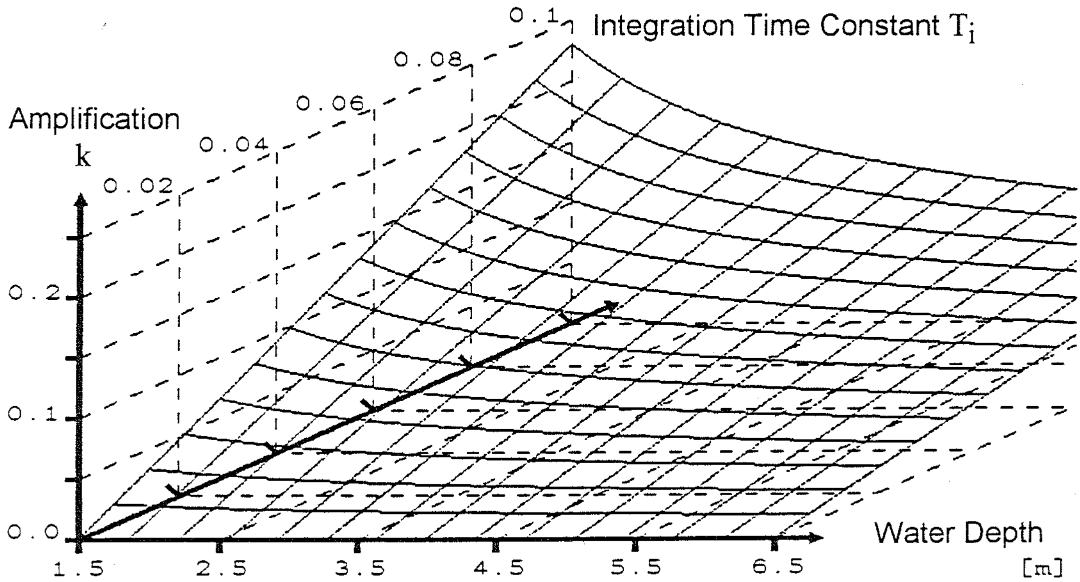


Figure 7. Stability limits of the second control loop

The design of the two control loops is basically identical. As a result of the distance between the second wave gauge and the wave paddle the wave train for the comparison at this position must be time shifted. In the reverse case the observed deviation must be delayed by the duration the error wave requires to reach the wave paddle. This is performed by a supplementary high pass filter in the second control loop. Also for the second control loop a stability check was performed. According to the different character of the loop the criterion after Nyquist was applied. Because of his complexity it is not treated here. Fig. 7 shows stability limits of the second control loop.

RESULTS

The equipment allows generating regular waves as well as natural motion of the sea over unlimited duration. The accurate consideration of all phase shifts and the combination of two independent control loops show best results in efficiency and stability of the absorption control system. Giving the wave train signal directly to the wave paddle allows variable amplifications to each control loop dependent to the desired efficiency. Even a gentle overestimation of the absorption process is possible before it becomes unstable. The system works with all kinds of regular and irregular wave trains and will not be influenced by the tested coastal structures.

Fig. 8 shows regular waves measured in the Large Wave Flume hitting a vertical wall. In front of the vertical wall a clapotis wave field will be formed covering the total flume by the time.

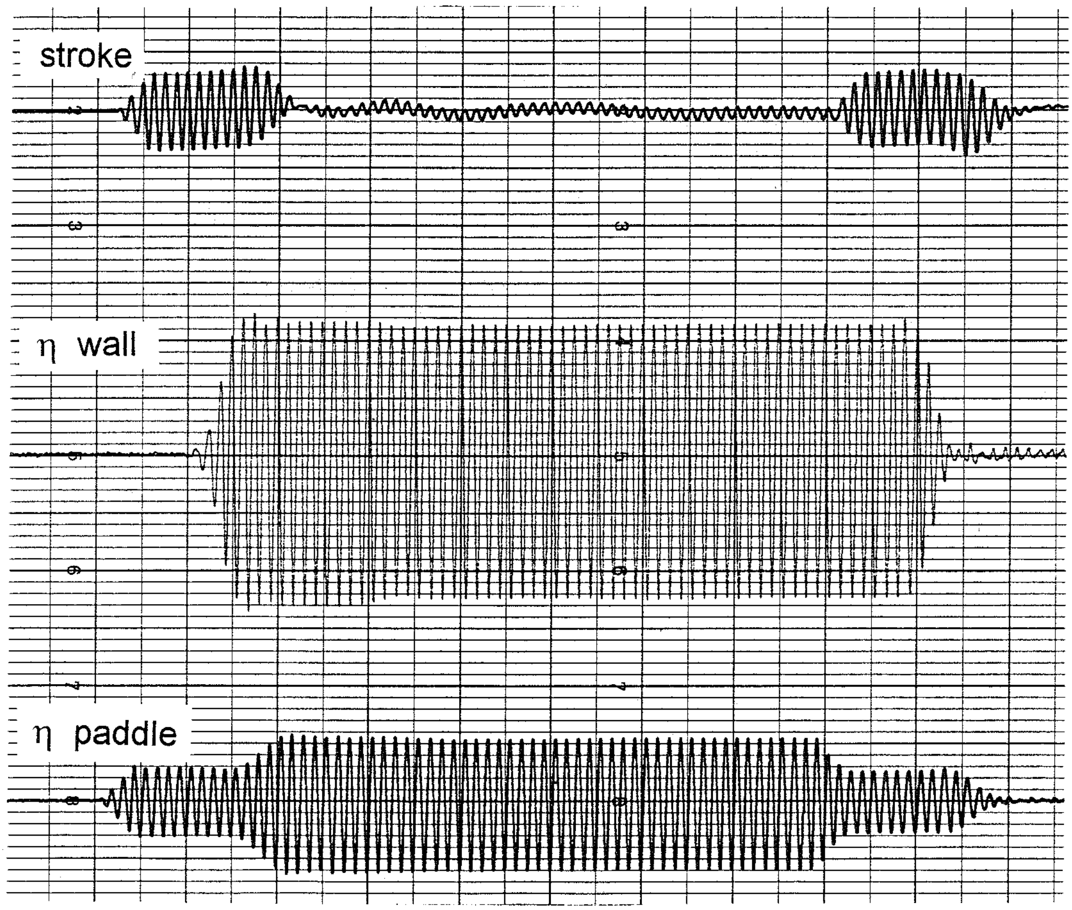


Figure 8a. Regular wave in front of a vertical wall

The first case (Fig. 8a) shows a situation with a selected wave length that the wave paddle is located exactly in the middle of wave crest and wave trough. In the beginning of the test-run the wave train will be established. The stroke of the wave generator corresponds to that to generate the desired wave height once. The middle part of the test shows the situation where the total-reflection reaches the wave generator with a phase shift of 180 degrees. Now the wave generator must eliminate the total-reflection and create the next waves in the wave-train. The required stroke doubles itself. In the end the test is faded out. The waves still located in the flume will be absorbed reaching the wave paddle. Nearly all wave energy will be eliminated in the first step.

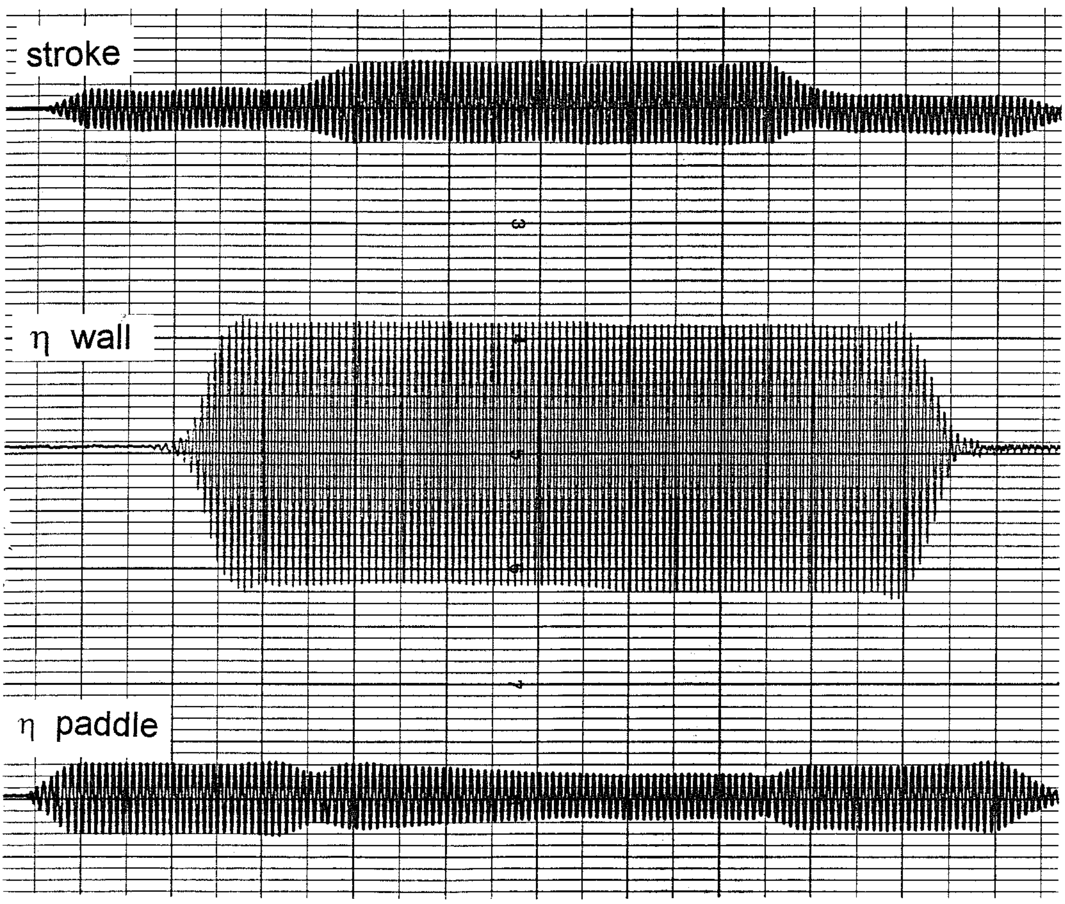


Figure 8b. Regular wave in front of a vertical wall

The second case (Fig. 8b) shows the situation with a selected wave length that the wave paddle is located exactly in the wave crest (and consequently as well in the wave trough). like before in the beginning of the test-run the wave train will be established. The stroke of the wave generator corresponds to that to generate the desired wave height once. The middle part of the test shows the situation where the total-reflection reaches the wave generator within phase. Similar to the situation at the end of the flume the wave paddle acts as a vertical wall too. The waves are reflecting totally at both ends of the wave flume. Nearly no energy must be added. There is minimum movement of the wave generator. In the end the test is faded out like seen before. The wave generator absorbs the remaining waves with the normal stroke.

A measured wave train from a long time test with a wave spectrum is shown in Fig. 9. The repetition time of the spektrum is 204.8 seconds. The different repetition cycles can be detected clearly. Long time tests with a constant energy level are checked by the three gauge analysis method too (Woltering, 1996).

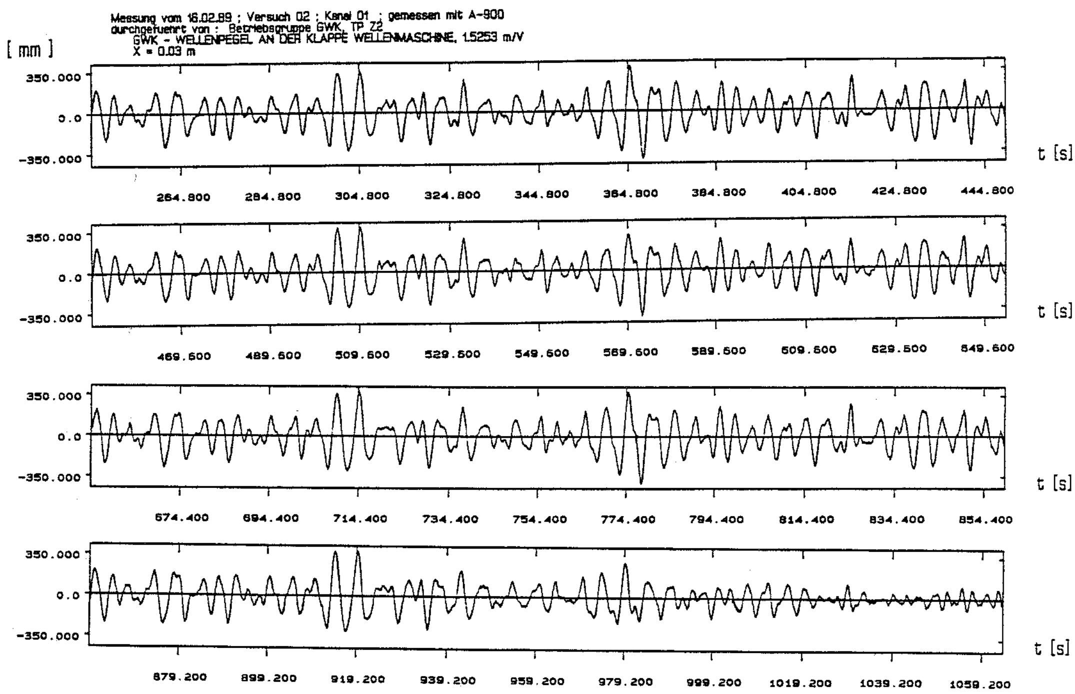


Figure 9. Measured wave train of a long-time test in the Large Wave Flume with a spectrum repetition time of 204.8 s

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