HIGH ACCURACY HYDROACOUSTIC SYSTEM TO STUDY CODEND MODEL PARAMETERS

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An important task of fishing gear designers is to develop effective selective fishing gears by optimizing its geometry. The high accuracy hydroacoustic system for codend geometry measurements was designed for developing the construction of cod codend for the Baltic fishery. The system consists of 10 pairs of hydrophones, measuring microprocessor device and notebook computer. The high frequency short pulse excitation combined with the matched digital filtering make it possible to obtain high resolution of measure data. Additionally the thermistors mounted in the hydrophones are used to calculate the local sound velocity and enable precision calibration of obtained measuring data. The construction solutions, the measuring procedure and examples of obtained data are presented below.

INTRODUCTION

Due to rapid development of fishing gear over the recent decades, fishing is becoming increasingly more effective. Sadly, the growing efficiency of fishing gear has badly affected many fish species and caused serious environmental threats [1, 2]. The Baltic's dwindling cod stocks are an example. To curb any further cod stock decreases the European Union has imposed very strict fishing quotas on the member states. An important task of Fishery Research Institutes is to develop effective selective, environmental and stock friendly fishing gears, especially trawls' codends to ensure that only the right size fish are caught leaving young specimen unharmed.

The Department of Fishing Technique from University of Agriculture in Szczecin has been developing fishing gear for many years [3]. Models of new fishing gear are tested and verified at the Model Research Station on Ińsko Lake [4].

To obtain reliable codend geometry the Department of Fishing Technique from University of Agriculture in Szczecin contracted the Department of Marine Electronic

Systems from Gdańsk University of Technology to develop a new high accuracy device for measurements of codends geometry while towing.

The objective of the development work is to develop the design of a selective trawl for cod fishing in the Baltic, including the necessary measurement apparatus. The work is funded by the European Union under the Sectoral Operational Programme Fisheries and Fish Processing - Community Support Framework 2004-2006.

1. THE BLOCK DIAGARAM OF THE SYSTEM

The objective of the system is to measure the geometry of the cod codend as it is being towed by the measuring catamaran. The measurements should be able to identify 10 distances between pairs of hydrophones on the model. The system measures the distance by measuring the time of acoustic signal propagation from the sending hydrophone to the receiving hydrophone. The subsequent measurements occur in a series. The distance ranges were identified from 0.1 m to 10 m. The accuracy of the measurements should not be less than 1 cm, with resolution equal to 1 mm. The design of measuring apparatus is described below.

The block diagram of the system is presented on Fig. 1. The system consists of three segments:

– sensor segment,
– electronic circuits segment responsible for sending, receiving and signal processing,
– control and data storage segment in the notebook computer.

The measuring sensors segment has 10 pairs of small size hydrophones for measuring distances. This segment will soon be extended to include tensometric transducers for measuring the forces in the models' structural elements and a precision impeller log for measuring towing speed.

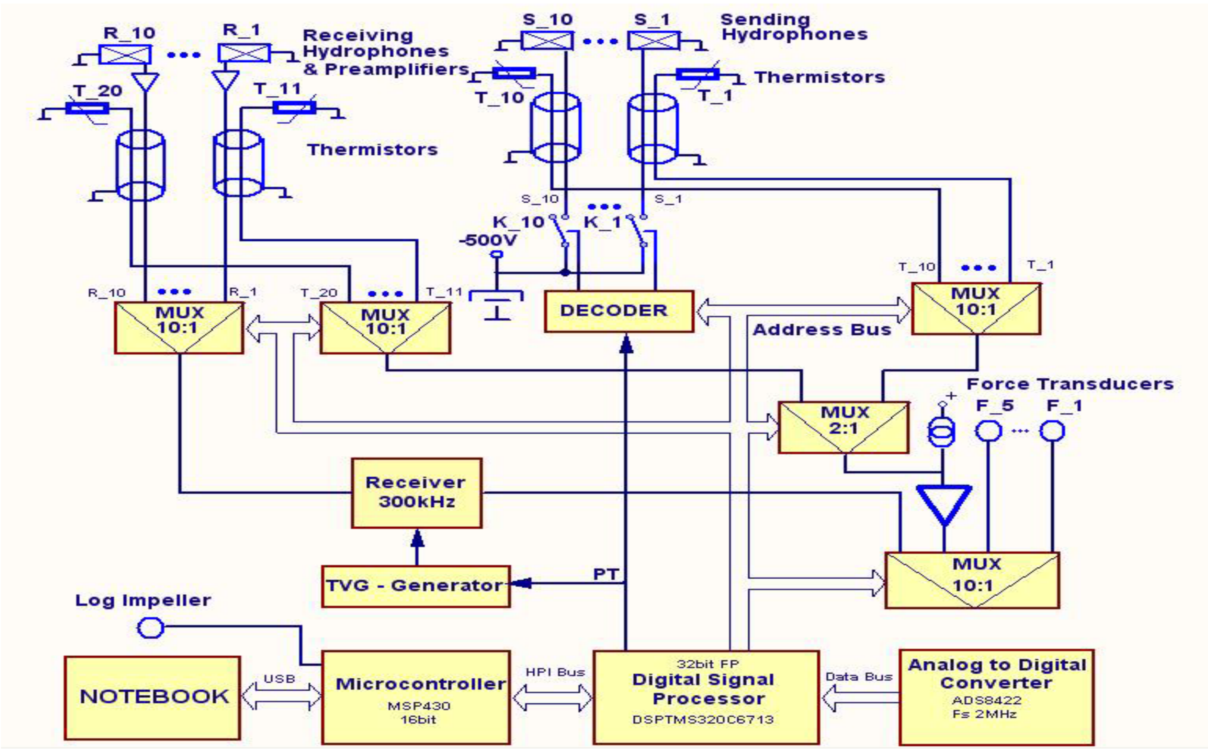

Fig.1 The block diagram of the system

The electronic sending, receiving and signal processing segment is responsible for generating, transmitting and receiving sequences of measuring pulses, and when they are processed to a digital form, for making the calculations in the Digital Signal Processor.

The transmitter comprises the following elements: source of high voltage -500 V, set of 10 analogue high voltage keys and a decoder.

The system's receiving section comprises a set of analogue multiplexers, band-bass analogue amplifier with time variable gain, source of power supply for the thermistors, analogue to digital converter ADS8422 with 2 MHz sampling frequency and a 16 bit resolution. In keeping with the measuring cycle the ADC converts also the voltages from thermistors placed on sending and receiving hydrophones.

Floating-Point 32-Bit Digital Signal Processor DSP TMS320C6713 is the main element of the measuring system. It controls the measuring cycle, carries out digital filtration of the acoustic signals received and all the necessary calculations involved in the measurements and results calibration. Microcontroller MSP430 via the Universal Serial Bus USB acts as an interface between the DSP and the notebook computer. The microcontroller is also responsible for controlling the measurements and counting the log impeller pulses.

A specialist software implemented in the notebook computer helps to select the parameters measured and records the results.

2. HYDROPHONES

Measuring hydrophones and the cables connecting them should be small enough not to obstruct the motion and shape of the trawl codend. The size of the hydrophone in the direction of distance measurement should be less than the assumed measurement accuracy. The hydrophone should maintain a uniform level of the beam pattern, especially within the distance measurements plane. Where the measurements will be transverse to the model's towing direction, the hydrophone may take the shape of an elongated cylinder with a diameter smaller than the distance measurement accuracy and with the light-gauge cable output towards the rear end of the model.

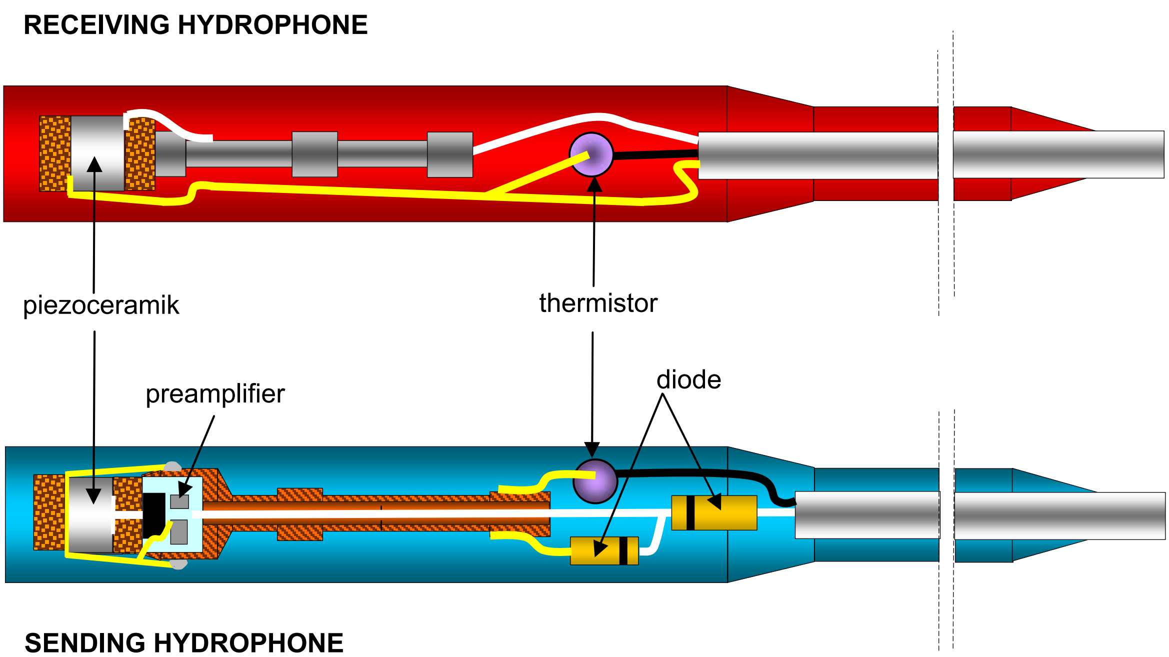

Fig.2 The cross-section of measuring hydrophones

The measuring hydrophones are built of Ø 5 mm x 3 mm cylindrical piezoelectric ceramic profiles. To obtain the desired beam pattern, the circular planes of the profiles were acoustically isolated using layers of cork. This ensured that the ceramics' dominant mode of operation is radial resonance at 300 kHz. As a consequence, the length of the acoustic wave in water is equal to 5 mm.

Fig. 2 presents the cross-section of the sending and receiving hydrophone. The ceramic profiles and structural elements were covered with polyurethane to form a Ø 9 mm x 90 mm cylinder externally. To ensure that noise level at the input of the receiver is low, an FET transistor preamplifier was placed inside the receiving hydrophone. The casing of the hydrophones also includes thermistors for measuring local water temperature.

3. MEASURING PULSE AND SIGNAL PROCESSING

To obtain high accuracy and resolution of the measurements, it is advisable to use measuring signals with a wavelength significantly below the assumed accuracy and a short duration. Because the length of an acoustic wave in water equal to 1 cm equals a frequency of 150 kHz, the measurement system should use a much higher frequency of operation. This will also help with keeping the measuring hydrophones small. Because very short distances are to be measured (from 10 cm), to ensure a sufficiently small dead zone, it is advisable to use signals with a duration less than 50 μs. Short measuring signals are also good for reducing the effects of multi-channel propagation on measurement results.

The sending hydrophone is excited with a 500 V amplitude voltage change. The short duration acoustic pulse is the hydrophone's response to the excitation. The mid-frequency of the measuring pulse in the system is equal to the resonance frequency of the piezoelectric profile about 300 kHz. The resulting duration of the measuring pulse is equal to 20 μs, which is consistent with 6 periods of mid-frequency.

Measurement accuracy and resolution are also affected by how the measuring signal is detected, and especially by how precise the receiving time is identified. In case of interferences, to ensure that false alarm levels are kept to the minimum, we are forced to raise the detection threshold. On the other hand, a high detection threshold increases the measuring error of the signal transmission time.

The measuring signal sent by the sending hydrophone and then received by the receiving hydrophone and recorded by the digital oscilloscope is presented in Fig. 3 a). The shapes of the pulses depending on the hydrophone pair differ only slightly. The differences are in the amplitude but the shape, phase and pulse duration are the same. Figure 3 b) shows the autocorrelation function computed numerically of a measuring signal. The autocorrelation function has a clear single maximum for time equal to zero. The curve in Fig. 3 a) was recorded in the DSP memory and is used as a template measure signal for digital matched filtration. The objective of the DSP is to compute the reciprocal correlation function [5] of the signal received and the template recorded as in the formula:

$$\varphi_{xy}(m) = \sum_{n=-\infty}^{\infty} x(n) y^*(n-m), \tag{1}$$

where:

φxy(m) – value of m sample of reciprocal correlation function,

x(n) – value of n sample of signal received,

y*(k) – conjugated value of k sample of the template.

Matched filtration improves the signal to noise ratio SNR , which can be clearly seen in Fig. 4. The improvement in SNR depends on the shape of the signal autocorrelation function.

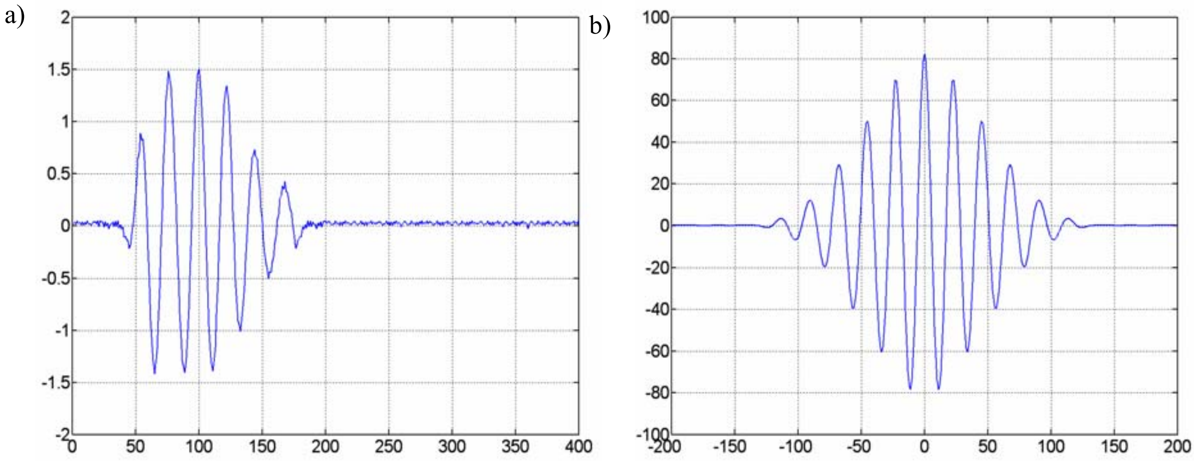

Fig.3 a) Measuring signal, b) Its autocorrelation function.

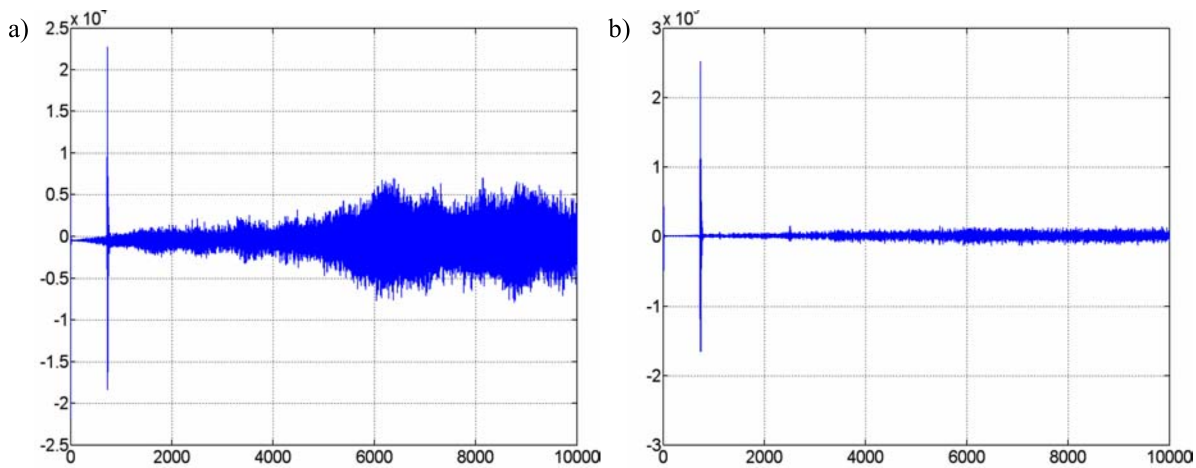

Fig.4 Receiving signal: a) before, b) after matched filtering

A higher SNR improves detection conditions, and the autocorrelation function with a single maximum makes an accurate measurement possible. The number of reciprocal correlation function sample with a maximal amplitude determines the duration of the measuring signal propagation time from the sending to receiving hydrophone.

4. SOUND VELOCITY ADJUSTMENT

Sound velocity in water depends greatly on water temperature and salinity. The measurement system is designed to operate in inland waters with no salinity. In this case the sound velocity depends only on the water temperature. Fig. 5 a) shows the relation between sound velocity in water and temperature varying from 0 to 30°C.

If a constant sound velocity were to be used for calculating the distances, an error of ± 3.7% would occur, which is significantly above the assumed measurement accuracy for the maximal scope. This is why sound velocity or temperatures have to be taken constantly to ensure that measurement results can be calibrated.

To ensure high measurement accuracy, the actual sound velocity should be measured or computed indirectly from water temperature. Placed in each hydrophone, the thermistors

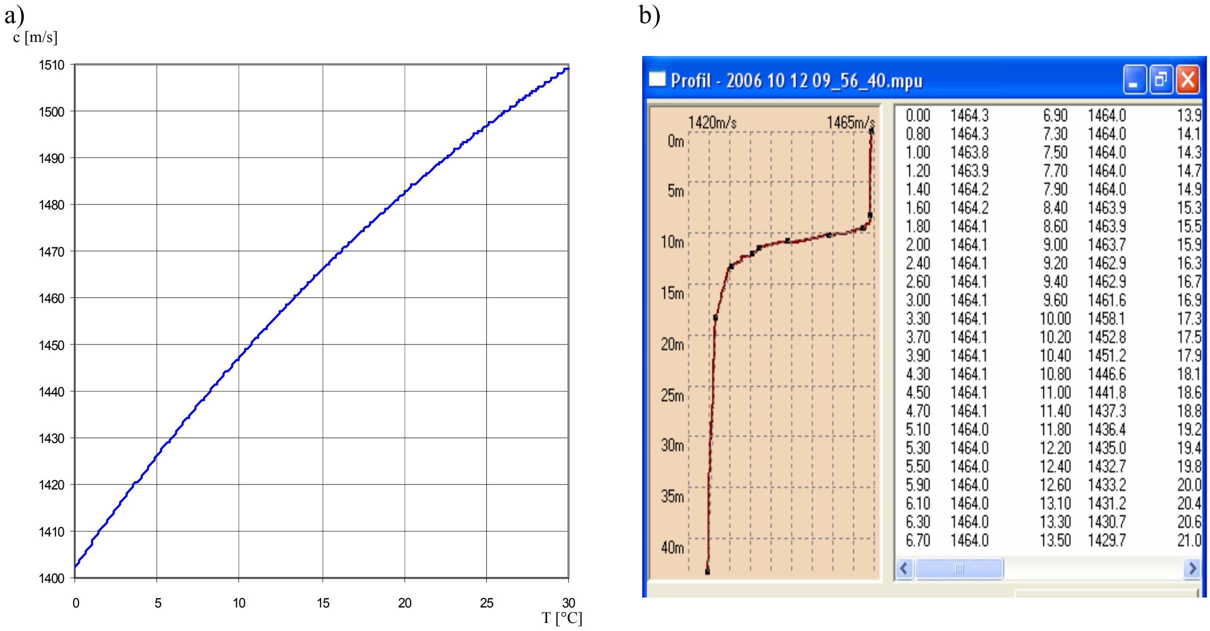

Fig.5 a) Change in sound velocity depending on water temperature;
b) Typical sound velocity profile in inland water

enable precision measurement of local temperature and when computing the distances for a given pair of hydrophones they take account of the average sound velocity computed using measurements at the sending and receiving hydrophone. To compute fresh water sound velocity Marczak's formula [6] was used:

$$c = 1.402385 \text{x} 10^{3} + 5.038813T - 5.799136 \text{x} 10^{-2} T^{2} + 3.287156 \text{x} 10^{-4} T^{3} - 1.398845 \text{x} 10^{-6} T^{4} + 2.787860 \text{x} 10^{-9} T^{5}, \tag{2}$$

where:

c - sound velocity in m/s,
T - temperature in °C.

Fig. 5 b) shows the typical distribution of sound velocity in inland water. The chart shows a rapid decrease in sound velocity at thermocline depth. Measurements taken at thermocline boundary, when one of the measuring hydrophones is above and the other under the thermocline, measurement accuracy may deteriorate and this should be avoided when planning measurements.

5. SYSTEM SOFTWARE

The "CODEND" application was developed for the purpose of operating the measurement system using the Notebook computer. It serves a Men Machine Interface MMI between the user and measurement system. The user can define his desired measurement configuration and visualise and record measurement results while operating the system.

The first step following the start of the application is to identify the number of measurements and define them. In the case of measuring the distances, the user is asked to complete a cross table with lines for the sending hydrophones and columns for receiving

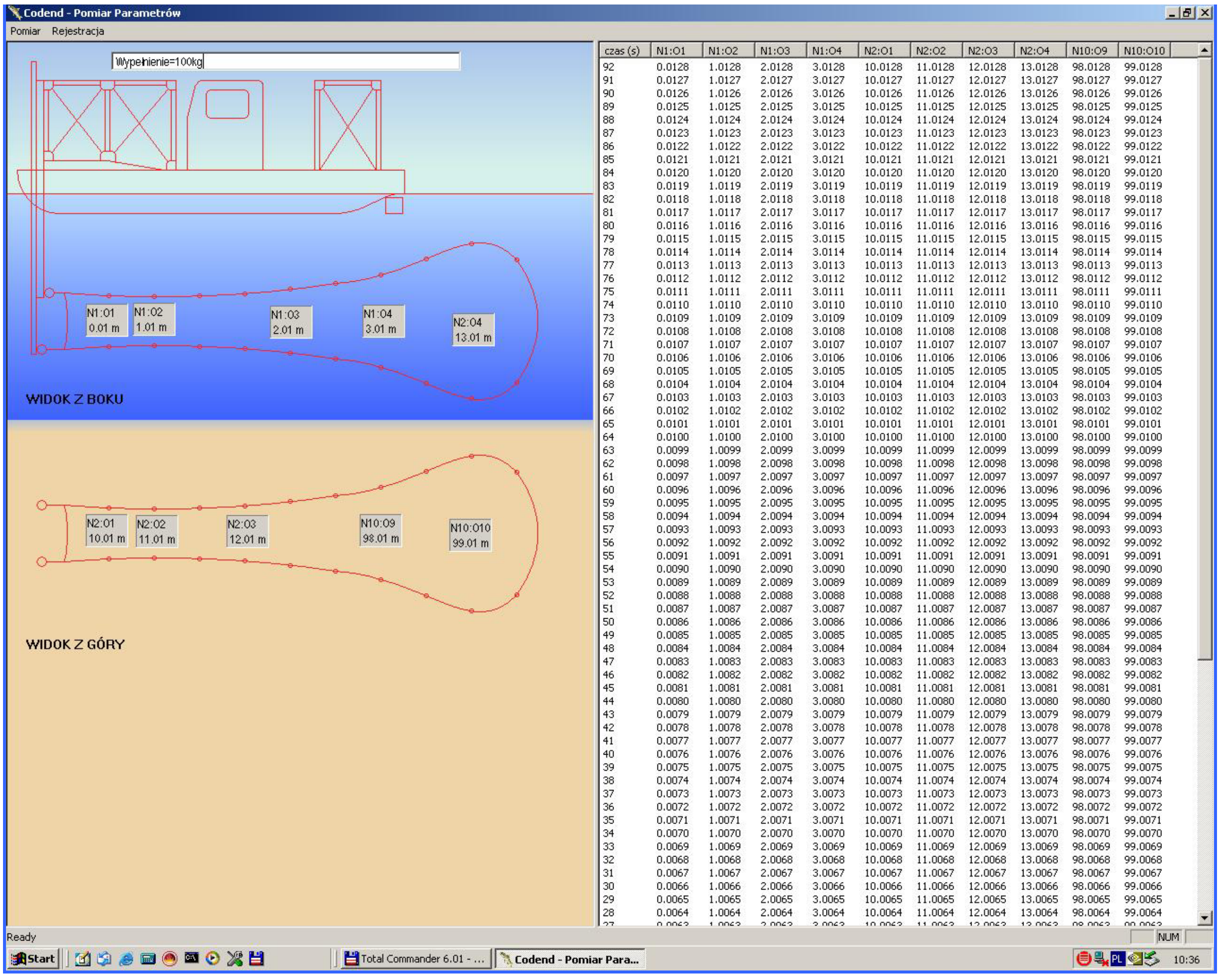

Fig.6 Graphic user interface of application „CODEND”

hydrophones. Because the number of sending and receiving hydrophones equals 10, the maximal possible number of distance measurements is equal to 100. “CODEND” application starts, puts on, hold and terminates a measuring cycle. While the system is in measuring mode, the main application window is active, as seen in Fig. 6. It is a typical Graphic User Interface GUI. On the left-hand side is a window illustrating the selected measurements and on the right-hand side is the measurement results table.

The application automatically records the date and time of the measurements and supports user comments, which will be helpful later when processing the results.

6. CONCLUSIONS

The presented hydroacoustic system and software to study codend model parameters have obtained the desired parameters. The small dimensions of hydrophones with light-gauge cable don't disturb the codends' shape. The software with user friendly graphic interface helps in operating the system and the collected data can be easy exported to off line processing to analyze the codend model parameters.

The system is now operational and serves as an important tool for verifying newly designed selective fishing gear developed by the Department of Fishing Technique from University of Agriculture in Szczecin.

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