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## ACOUSTIC FLOW MEASUREMENT IN WIDE RIVERS

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This paper deals with an acoustic flow measurement system, that is installed in a relatively wide and shallow channel of the Oosterschelde. The system features two 65 kHz transducers located on poles in the channel, a wide band radio communication system to transmit the electrical equivalents of the transmitted and received acoustic signals to the coastal processing unit and three standard-frequency receivers to synchronize the system parts. A summary is given of the acoustic transmission characteristics and some results are discussed.

## 1. INTRODUCTION

The Department of Oceanology of the Technisch Fysische Dienst (TPD) has been active in the development of river discharge measurement systems for several years. This research was done on behalf of the department of Hydro-Instrumentation of Rijkswaterstaat (Governmental Department of Public Works). At this moment the standard TPD system for measuring discharge is suitable for rivers up to 300 m in width. In 1975 research started on the application of ultrasonic techniques for measuring discharge in estuaries up to 1000 m in width. In this paper the experimental system is described that has been installed at the Burghsluis test site in the Hammen channel of the Oosterschelde.

## 2. THEORY

Two electro-acoustic transducers are located on each side of a channel, such that the angle  $\phi$  between the acoustic path defined by the transducers and the flow direction is  $30^\circ$  to  $60^\circ$ . These transducers are then, alternately, excited to send acoustic wave trains to each other. The acoustic wave train in the upstream direction will have a propagation velocity

$$c_1 = c - v_L = \frac{L}{t_1} \quad (2.1)$$

and in the downstream direction

$$c_2 = c + v_L = \frac{L}{t_2} \quad (2.2)$$

where  $c$  = velocity of sound in water  
 $v_L$  = mean projected flow velocity component along the acoustic path  
 $L$  = length of the acoustic path  
 $t$  = propagation time.

By eliminating  $c$  from (2.1) and (2.2) we obtain the well-known expression

$$v_L = \frac{1}{2}L \left( \frac{1}{t_2} - \frac{1}{t_1} \right) = \frac{1}{2}L \frac{t_1 - t_2}{t_1 \cdot t_2} \quad (2.3)$$

The mean total velocity of the flow can be evaluated by multiplying (2.3) by  $\cos \phi$ . When the angle of the flow relative to the acoustic path is not constant it is possible to evaluate

the mean total velocity by using two measuring lines crossing each other at an angle of  $60^\circ$  to  $90^\circ$ . If the vertical flow velocity profile, the cross-section of the channel and the waterheight are known or measured, the discharge in the channel can be evaluated.

At the Burghsluis test site the path length  $L \sim 1000$  m and the velocity of sound  $c \sim 1,5 \cdot 10^3$  m/s, hence if the flow velocity  $v_L \sim 0,1$  m/s then the propagation time difference to be measured is  $t_1 - t_2 \sim 10^{-4}$  s. The accurate measurement of such a time interval is not difficult. However, complications arise from the fact that when temperature and/or salinity gradients occur the acoustic path is no longer well defined.

## 3. EXPERIMENTAL SYSTEM

A test range was built in the Hammen, one of the channels of the Oosterschelde, near Burghsluis. Here two transducers are located on poles in the channel approximately two meters above the bottom. The waterheight above the transducers varies between four (low tide) and eight (high tide) meters. The acoustic path is 1000 m, with a transmission loss due to spherical spreading of 60 dB.

Figure 1 shows a block diagram of the experimental system that is installed at the test range. The transducer is a cylindrical piezo electric resonator, placed in a conical reflector. Its resonant frequency is 65 kHz, the bandwidth is 16 kHz and the beamwidth is  $10^\circ$ . At this frequency the absorption in seawater is  $\sim 30$  dB/km, so that the total transmission loss is 90 dB. To synchronize the systems on the poles and the processing unit on the coast, a radio-clock, tuned to the standard frequency transmitter DCF 77 in Mainflingen, Western Germany, is used. In this radio-clock the carrier of DCF 77 is employed in a keyed phase-locked loop to obtain a stable frequency. This stable frequency is employed in a second phase-locked loop, whose internal oscillator can also be corrected by a signal obtained from the 1 Hz standard frequency given by DCF 77. The synchronisation of all system parts is within 1 ms.

At each odd second the transducer on pole 1 emits a short acoustic wave train, initiated by the timing circuit.

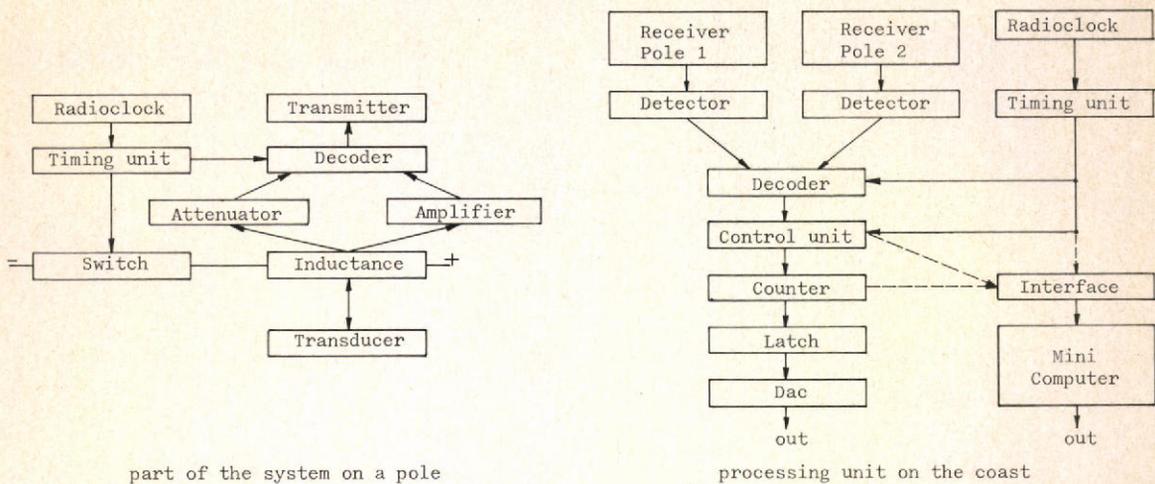
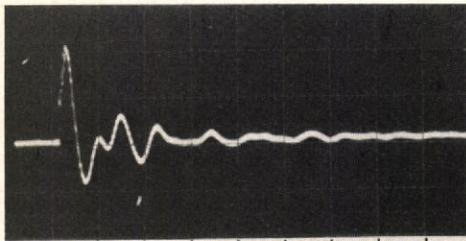


FIGURE 1: Block diagram of the system.

The electrical equivalent of the wave train is attenuated and transmitted to the processing unit on the coast. About 700 ms later the transducer on pole 2 receives the acoustic signal and after amplification this signal is also transmitted to the processing unit on the coast. (figures 2, 3 and 4).

Every even second an acoustic wave train is sent in the opposite direction from the transducer on pole 2 to the transducer on pole 1. A radio communication system is used for the signal transmission between the poles and the processing unit on the coast (the use of cables is unacceptable). Presently a 200 MHz wide band simplex radio communication system is being used, but by the end of 1978 this system will be replaced by a 14 GHz communication system.

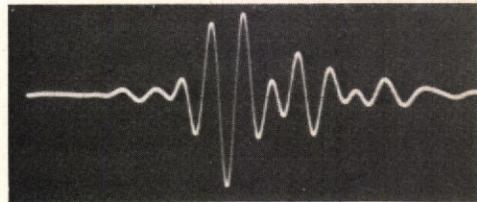
The detectors convert the received signals into "start" and "stop" pulses. Time windows, controlled by the timing unit, define whether a signal corresponds to the transmitted wave train or the received acoustic signal. These pulses are then used by the control unit to start and stop a counter.

FIGURE 2: Transmitted acoustic wave train (hor. 20  $\mu$ s/div)

The signals from the timing unit are used by the control unit such that the counter is incremented at the clock frequency when sound propagates from pole 1 to pole 2 and decremented when sound propagates from pole 2 to pole 1. The content of the counter is then a measure of the propagation time difference. Every (odd, even or both) second the content of the counter is latched and presented at the output terminals as an analog voltage.

This experimental system has been installed at the testrange in the beginning of 1977. It soon became evident that the 200 MHz radio was the limiting factor for the signal to noise ratio. After having reduced the distance of the radio-links, recordings were made over prolonged periods of time, that have a definite correlation with hydraulic measurements made in the area. An example of such a recording is given in chap. 5.

After having evaluated the system and the acoustic transmission characteristics, a mini computer will be added to expand the control and processing functions. The control unit will then be changed such that the hardware counter is continuously incremented at the clock frequency. The content of the counter will be latched into the computer by the "start"

FIGURE 3: Received acoustic signal at the laboratory (hor. 20  $\mu$ s/div, pathlength 1 m)

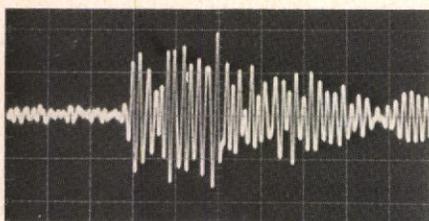


FIGURE 4: Received acoustic signal at the testrange (hor. 100  $\mu$ s/div, pathlength 1000 m)

and "stop" pulses and then, together with a software counter, which was incremented by each overflow signal from the hardware counter, processed to obtain the mean total velocity of the flow. The advantage of a continuously running counter is that more than one measuring line can be controlled at the same time.

#### 4. ACOUSTIC TRANSMISSION CHARACTERISTICS

The transducer receives a complex signal consisting of the direct acoustic wave train plus indirect wave trains via single and multiple reflections at the sea surface and bottom (figure 4). Fluctuations in the received signal amplitudes, especially in the second part, are found, because of the varying interference between the direct and the indirect wave trains. This is caused by the tidal changes of the waterheight and the changes in the wave pattern of the sea surface.

In the absence of a vertical sound velocity gradient the direct wave train at our testrange arrives at least 21  $\mu$ s ( $\sim 1.4$  period of the 65 kHz main component) earlier than the sea surface reflected wave train and  $\sim 100$   $\mu$ s earlier than the bottom reflected wave train. So to determine the receiving time of the direct wave train a leading edge detector can be used.

If a vertical sound velocity gradient occurs, the amplitude of the whole signal can fluctuate or even, due to severe interference, the direct wave train can almost completely disappear. The detector then triggers at the bottom reflected wave train. It is also possible that an indirect wave train arrives first and triggers the detector. A vertical sound velocity gradient also causes bending of the acoustic paths in the direction of the higher sound velocity. A sound velocity gradient caused by temperature and/or salinity gradients will bend all acoustic paths in the same direction. A gradient caused by a flow velocity gradient will split the up- and downstream acoustic paths.

The accuracy of the measured flow velocity is determined by:

1. the accuracy of the detector. A detection error of one period (15  $\mu$ s) gives a flow velocity error of  $\sim 1.7$  cm/s

2. the difference of the flow velocity along the direct path and the mean of the actual up- and downstream acoustic paths
3. the difference in length of the up- and downstream acoustic paths
4. the difference in sound velocity along the up- and downstream acoustic paths.

As long as the detectors trigger at the same (direct or indirect) wave train, 3. and 4. are either zero or nearly compensate each other. Furthermore the Oosterschelde is a well mixed water basin with almost no incoming fresh water from rivers, thus vertical salinity gradients are not likely to exist frequently or for long periods of time. The total inaccuracy is thus determined by 1. and 2. and is at our testrange estimated at less than 0.1 m/s.

#### 5. RESULTS

During the preliminary measurements, carried out in the summer of 1975, a very useful acoustic signal was received during most of the time. Periods of a low signal to noise ratio and of large amplitude fluctuations of the whole received acoustic signal seemed to correspond with the periods of outgoing tidal currents at the end of a day. A few times a considerable reduction of the amplitude of the first wave train was observed at low tide (destructive interference). Recordings of the propagation time difference made in 1977 also show that the receiving times of the acoustic signals are harder to detect correctly during the periods described above.

Figure 6 shows a curve made from the recorded propagation time difference during 19 hours on 77.09.02, together with some parts of the original recording. The parts of the original recording show irregularities with an amplitude of  $\pm 15$   $\mu$ s (= one period of 65 kHz), especially during the outgoing tidal current, that are caused by the amplitude fluctuations of the signal discussed before. The leading edge detector, that is used in the experimental system, is triggered if a certain level is exceeded and gives at the same time a pulse. In this type of detector small amplitude fluctuations cause fluctuations in the detected receiving times. In a new system a detector is used that is triggered if the leading edge exceeds two levels and gives a pulse at the

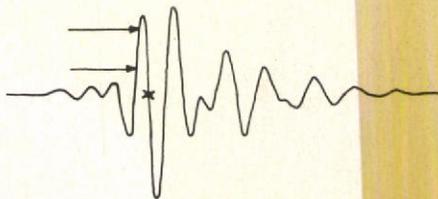


FIGURE 5: Alternative detection method

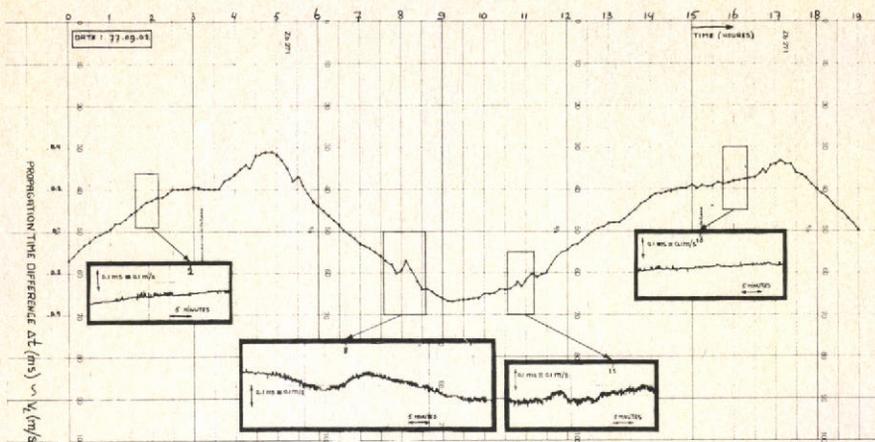


FIGURE 6: Recording of the propagation time difference

following zero crossing. This detector is insensitive to small amplitude fluctuations and with the two trigger levels it is possible to let the shape of the acoustic wave train influence the detector and so avoid the small irregularities (figure 5). Recently research started to study the feasibility of applying pulse compression techniques to the received acoustic signals, in order to obtain a better definition of the detected receiving times. Results thusfar are encouraging and it is hoped that in a future system this technique can be applied on line.

Figure 7 shows three curves made from the recorded vertical tidal movement, propagation time and propagation time difference during one day, 77.10.30. Within a few percent the curve of the propagation time difference (in ms) is equal to the curve of the flow velocity (in m/s). Comparing figures 6 and 7 it is obvious that the curves reproduce in time. The curve of the propagation time shows that the incoming water from the sea is warmer than the outgoing water from the Oosterschelde. This is explained by the relatively cold air in October and the smaller heat capacity of the Oosterschelde compared to that of the North sea.

A second measuring line is now being built, crossing the first one at an angle of  $51^\circ$ . The new poles are placed in 10 m deep water and the minimum waterheight above the transducers will be 6 meters. It is expected that at this depth the destructive interference, that has been observed only during low tide, can be avoided.

#### 6. ACKNOWLEDGEMENT

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#### 7. REFERENCES

- (1) Botma, H.C., Klein, R.E., "Some notes on the Research and Application of Gauging by Electromagnetic and Ultrasonic Methods in The Netherlands", Symposium on rivergauging by ultrasonic and electromagnetic methods, Reading UK, org. by Water Research Center & Department of the Environment Water Data Unit, (december 1974).
- (2) Wolff, Ch.J.M., "Acoustic Discharge Measurement in Rivers and Canals", (in Dutch) publ.no. 41 of the Dutch Acoustic Society, p. 29-40, (1977).

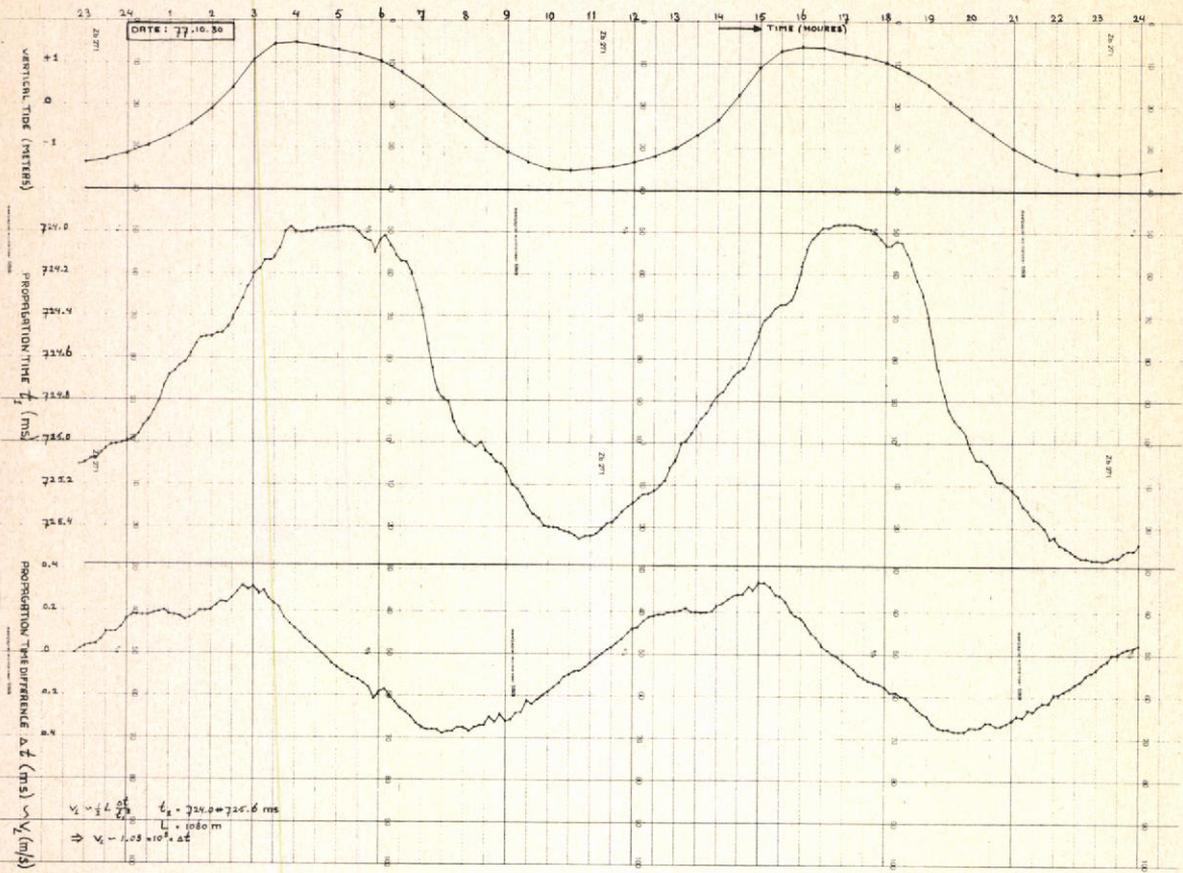


FIGURE 7: Recordings made during one day