

DIRECTIONAL SUB-BOTTOM PROFILER AND HYDROPHONE ARRAY

Pipeline Survey with Acoustics

A method is presented which greatly increases the efficiency of pipeline survey using sediment echo sounder. These surveys are mostly done sailing cross courses; adding receiving directionality, a course can be sailed along the pipeline. This means 100% inspection of pipe coverage can be obtained in far less time than that required for cross-sailing survey.

The receiving element is an array of sixteen hydrophones with optimal signal processing (Kalman filtering). The position and orientation of the transmitting transducer and receiving hydrophone array are also estimated, optimally using a Global Position System and a Motion Reference Unit. A sediment echo-sounder transducer with an array of hydrophones is used to obtain the coordinates of the acoustic reflection spot on the pipeline. These coordinates are presented to the surveyor and the helmsman in a manner suitable for sailing a course along the pipeline, making possible 100% survey inspection.

Sensor System

The sensor configuration of such a system is presented in Figure 1 and consists of a transmitting transducer and array of hydrophones for the reception of signals. A low-frequency pulse is transmitted into the water, partly reflected by the pipe wall and received by the hydrophones. The length of the propagation path of the received pipe echo by the k th hydrophone is $r + r_k$, (see Figure 2). Note that the diameter of the pipe can be easily taken into account. We can combine all phases of the hydrophone signals S_k with a reference phase function in a cost function. Minimising this cost function by varying the distance r and angle parameters are obtained regarding pipe positions. The reflection spot is on a cone described by the distance r and angle. Since we know the direction of the pipe and the reflection is perpendicular to pipe direction, the coordinates of the reflection spot are obtained. By also taking into account the history, system and observations, with their respective errors, we obtain a new estimate for the position, leading to optimal estimating procedure, also known as "Kalman filtering"™.

Simulation

The monitor screen, with simulated pipe and soil and a signal-to-noise ratio (S/N) of 10dB, is shown in Figure 3. The upper left sub-picture shows sixteen hydrophone signals of the present record. The sea-bottom echo is shown by the equal-time black responses in the hydrophone signals. The green lines indicate pipe echo. The lower left sub-picture shows the navigation screen. The red line is the pipe position. The zig-zag line and the arrow show the simulated sailed course of the ship, respectively the present position and orientation towards the pipeline. Every point on the line corresponds with one record of the upper left sub-picture. The transmission rate is 25Hz. The lower right sub-picture shows the acoustic record in false colours. This record corresponds with normal survey records. Clearly shown are the hyperbolic curves of acoustic echoes from the pipe on the sea bottom. The middle lower sub-picture shows the spectrum of the present record. The moment of the green arrow corresponds with the displayed spectrum and with the small hyphen on the line between the spectrum record and the survey record. At the upper right in Figure 3 are numbers produced for testing and operational purposes.

Real Test

The hardware is based on a personal computer (PC) with 2,500-MHz Celeron processor with AD-DA card from Realtime Devices. Transmission rates up to 30Hz with all real-time graphics are possible, as shown in Figure 4. The non-linear echo sounder SES-96 from Innomar was used as transmitter. The receiving hardware consisted of an array of sixteen hydrophones and a filter bank. The system is programmed in C language under 32-bit DOS control, with direct graphics control, and has simulation, real-time and playback modes. For the latter a logging facility is incorporated. Kalman filtering in the PC system allows estimation of position information based on a Motion Reference Unit (MRU) and a Global Positioning System (GPS). Logged data is all raw data from the hydrophones, the MRU, the GPS and the intermediate results of the signal processing. Since non-linear echo-sounder transmitters have a small transmitting aperture and it is possible to steer the beam, an estimate of transmission angle was supplied to the echo sounder by the PC system. Information concerning the moment of transmission and type of pulse was also exchanged via links between transmitter and PC system.

A test in 2003 involved the "Eemsinker"™ pipe, diameter 47 inches, located near the Dutch town of Delfzijl in the Wadden Sea. Weather and sea conditions were calm. As a reference and for test purposes, pipe position was determined in the classic way by sailing cross courses. One record was made with a large GPS aerial offset relative to the transmitting transducer, and the second record without horizontal offset. Figure 4 shows a screen dump of the monitor display during real-time operation. A navigation sub-picture has been added lower right and a compass card upper right. No noticeable swell is present in the survey sub-picture.

The survey produced a geophysical record with pipe, as shown in upper picture of Figure 5. The lower picture shows information concerning horizontal positions of some variables. Real pipe position is drawn in heavily in black in the geophysical record, and red in the position record. Pipe coverage is clearly shown. In the position record, the green line indicates position of the ship. In contrast to the course shown in Figure 5, Figure 6 shows sailing course deviating greatly from pipe position. The measured pipe positions of Figures 5 and 6 correspond rather well. At the detection stage correspondence varies. It is difficult to extract pipe position from the geophysical record alone. No trace at all is visible at the start or at the end. Although the wrong transmission angle is given to transmitter during the test, this has hardly any effect on reception and signal processing. Detection and tracking are quite satisfactory.

Concluding Remarks

In 1980 a pipe-survey system with directivity was envisaged, designed and simulated, based on charge bucket devices by Osiris. No proven hardware was available at that time. Currently available hardware and signal-processing technology make possible construction of a low-cost pipe-survey system. Simulation showed that such a system works correctly. The test carried out on the Delfzijl Eemzinker shows the same result, as clearly illustrated in Figures 5 and 6. The SES-96 system was used as transmitter. The PC system can also transmit low-frequency (~10kHz) chirps with large aperture, greatly enhancing the capture range of the system and adding a very low chirp sub-bottom profiling option to pipe tracking.

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