

Management of in-tube projectiles using acoustic channel

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Abstract. The article describes the method of measuring the distance from the operator's console installed outside the pipe to the in-tube projectile. A method for measuring distance in the absence of an echo signal is proposed. To do this, two identical ultrasonic locators operating at different frequencies were installed inside and outside the pipeline. The change in the duration of an acoustic pulse propagating in a circular waveguide with rigid walls is shown, which leads to a decrease in the data transfer rate.

1. Introduction

The practice of oil pipeline operation assumes a wide use of in-tube projectiles, which monitor the condition of the internal surface, clean up the deposits of paraffins and are also used to repair a variety of defects [1-6]. Timely detection of defects can prevent sudden shutdowns of oil pumping equipment due to accidents, environmental pollution and man-made disasters.

2. Problem statement

The task is not only to obtain operational information from control devices that is inside of a projectile, but also to control its operation [7-9]. Development of such equipment was carried out by a team of employees at the Department of industrial and medical electronics of Tomsk Polytechnic University. The device is designed to determine the distance from the location of the acoustic sensor to the in-tube projectile, as well as to transmit and receive the control signals. The sensor is located on the outside of the pipeline.

3. Solution method

The principle of operation of the equipment is based on an active response. To increase the accuracy of the distance measurement, a two-channel location method was proposed (Fig. 1) [10-12].



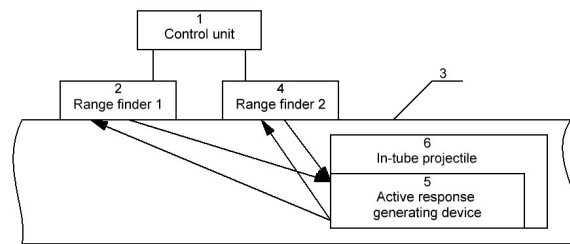


Figure 1. Block diagram of a two-channel locator

The circuit proposed in [13] was used to power the device for generating the active response, and the principle described in [14] was applied to power the ultrasonic range finders.

The acoustic ranging device implementing the proposed method consist of a control unit 1, a first range finder 2 installed in some point on the outside of the pipe 3, a second range finder 4 installed in another point on the outside of the pipe 3, and an active response generating unit 5 mounted on the in-tube projectile 6.

Unit 1 controls the alternate operation of first-range finder 2 and second-range finder 4. Range finders 2 and 4 are set at a fixed distance from each other. Initially, control unit 1 issues an enabling signal to first-range finder 2, which supplies the probe signal to in-tube projectile 6 moving inside pipe 3 and receives a response signal from active response generating device 5 located on in-tube projectile 6. After receiving the response signal, first-range finder 2 determines the bi-directional propagation time of the ultrasound to in-tube projectile 6 and transmits it to control unit 1. Control unit 1 then issues an enabling signal to second-range finder 4 which provides a probe signal to in-tube projectile 6 moving inside pipe 3, and receives a response signal from active response generating device 5 located on in-pipe projectile 6. Upon receiving the response signal, second-range finder 4 determines the bi-directional propagation time of the ultrasound to in-pipe projectile 6 and transmits it to control unit 1.

Control unit 1 calculates the propagation velocity of ultrasound in a medium inside the pipeline by the formula:

$$C = \frac{2 \cdot L}{t_1 - t_2}, \quad (1)$$

where t_1 is the bi-directional propagation time of ultrasound from first-range finder 2 to in-tube projectile 6; t_2 is the bi-directional propagation time of ultrasound from second-range finder 4 to in-tube projectile 6; L is the distance between the first 2 and the second 4 range finders.

After that, control unit 1 uses the obtained value of the speed to calculate the distance to in-tube projectile.

The algorithm for the operation of the equipment at the operator console and the other one for the device placed on in-tube projectile are shown in Figure 2.

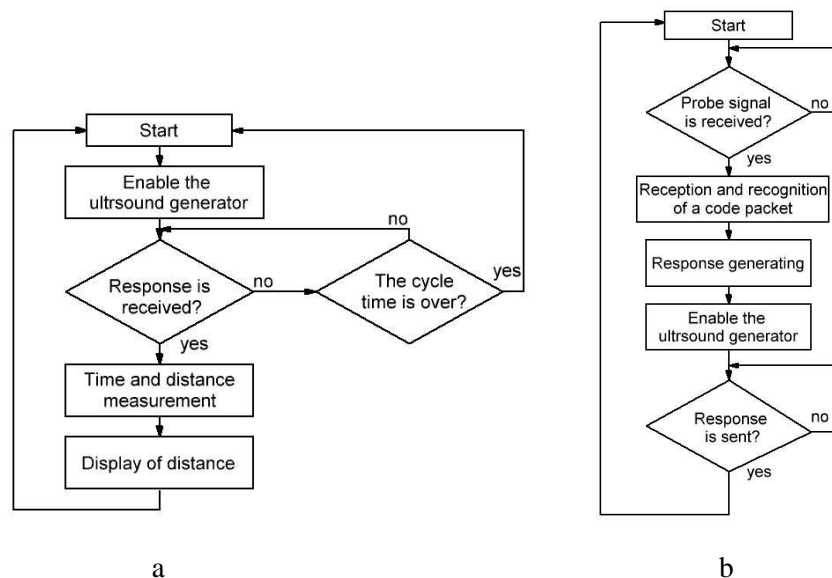


Figure 2. The algorithm of the ultrasonic locator of the in-tube projectile with the system for transmitting and receiving information on the acoustic channel:
 a - the algorithm of the electroacoustic path of the operator console;
 b - algorithm of operation of the electroacoustic path of the in-tube projectile

Such an algorithm of operation is specific for the devices in which the principle of pulsed echolocation is used [15]. The difference is that the response echo is formed by a special device placed on the in-tube projectile. This signal is generated in automatic mode immediately after the probe pulse is fixed by the receiving part of the equipment placed at the monitoring and control facility.

Such algorithm is due to two factors:

- need to transmit and receive information between the operator console and the in-pipe projectile;
- increase in the range of the locator.

A block diagram of one channel of an ultrasonic locator [16] with a channel for transmitting and receiving information is shown in Figure 3.

The hardware implementation of a locator with an active response requires the presence of two autonomous units, one of which is placed inside the pipeline on a moving projectile, and the second is at the operator console. At the initial time, determined by the control circuit of operator unit 5, the ultrasound generator of operator unit 3 is excited and the acoustic transmitter of the operator unit 1 emits an acoustic pulse.

Simultaneously, a strobe is formed, which serves to lock the amplifier of operator unit 4 for the duration of the radiation. After the end of all transient processes, block 5 enables the delay circuit of operator unit 7, which forms a "start" signal for the measuring trigger. After some time, necessary for overcoming the distance along the acoustic path, from the location of the operator unit to the in-tube projectile, the signal is received by the acoustic receiver of in-tube projectile 12, amplified and sent to comparator 16.

From the output of the comparator, the normalized pulse arrives at the control circuit of in-tube projectile 19. Firstly, a strobe is formed in the strobe generator of in-tube unit 17, which serves to lock the amplifier of in-tube projectile 14 during the operation of the acoustic transmitter of in-tube projectile 13. Secondly, a delay pulse which time is equal to the delay time of the operator unit is formed. This is necessary to compensate for the systematic error caused by the delay in setting measuring trigger 9 to the "1" state.

Then, a sounding pulse-tube in ultrasonic generator unit 15, which radiates acoustic transmitter 13 to the side of the operator unit. This signal is received by the acoustic receiver of operator unit 2 is amplified and then comparator 8 is supplied to a second input of measuring trigger 9 of the operator unit. As a result, a measuring pulse is generated, the duration of which is proportional to the doubled distance from the operator's unit to the in-tube projectile. This interval is measured by time interval meter 11 and is used to calculate the range [17] in accordance with the expression:

$$L = \frac{C \cdot T_p}{2},$$

where T_p is a duration of the measuring pulse; C is the speed of sound in the acoustic path, calculated in accordance with expression (1).

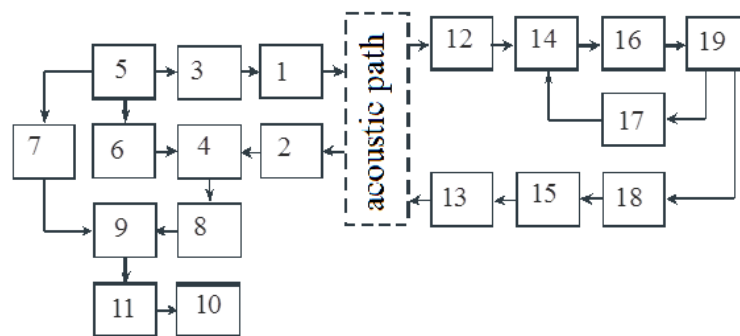


Figure 3. Block diagram of one channel of an ultrasonic locator with a channel for transmitting and receiving information:

1-acoustic transmitter of the operator unit; 2 -acoustic receiver of the operator unit; 3 - ultrasonic generator of the operator unit; 4 - the amplifier of the operator unit; 5 - control circuit of the operator unit; 6 - strobe generator of the operator unit; 7 - delay circuit of the operator unit; 8 - comparator of the operator unit; 9 - measuring trigger; 10 - indicator; 11 - time interval meter; 12 - acoustic receiver of the in-tube projectile; 13-acoustic radiator of the in-tube projectile; 14 - amplifier of the in-tube projectile; 15 - ultrasonic generator of the in-tube projectile; 16 - comparator of the in-tube projectile; 17 - strobe generator of the in-tube projectile; 18 - delay circuit of the in-tube projectile; 19 - control circuit of the in-tube projectile

The time interval meter is made according to the scheme given in [18]. The measurement result is displayed on the digital display of range indicator 10 shown in Figure 3.

To control the in-tube sealer, an adjustable information premise was used, which is a sequence of pulses, the repetition rate and duration of which can be varied within small limits. This pulse sequence arrives at the ultrasound generator, operating at the resonant frequency of the piezoelectric transducers. The operating frequency of the emitting transducer is 100 kHz. Thus, a bundle of amplitude-modulated pulses, representing a code packet, is emitted into the waveguide. An acoustic signal is received by a piezoelectric transducer identical to the emitting one, operating at the same resonant frequency.

4. Experimental studies

The experiments were carried out at different positions of the emitting and receiving piezoelectric transducers and at different distances between them. The oscillograms of the received acoustic signals are shown in Figures 4-6. Experiments have shown that the multimode nature of the propagation of ultrasonic oscillations in the waveguide leads to the fact that the received signal is several tens of times longer than the transmitted one (Figure 4) [19].

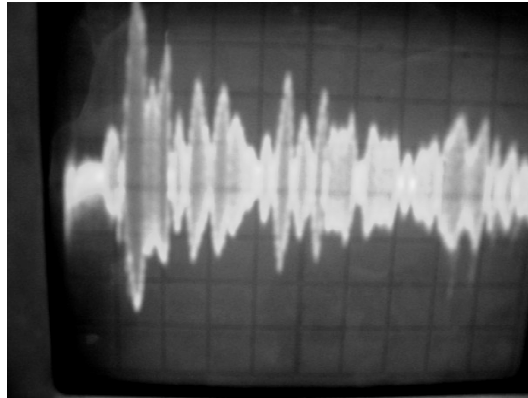


Figure 4. Oscillogram of the received code packet consisting of one pulse, at a distance of 30 meters from the transmitter

To control the in-tube projectile, it is necessary to transmit control signals represented by eight-bit code packet. These code packets are transmitted over an acoustic channel that is a circular waveguide. When such commands are transmitted in the form of several pulses with a small duty cycle, there is a problem of determining the number of transmitted pulses due to the increase in the duration of acoustic oscillations in propagation along the waveguide. Therefore, to increase the reliability of the received information, it is necessary to increase the duty cycle, but this results in a velocity decrease.

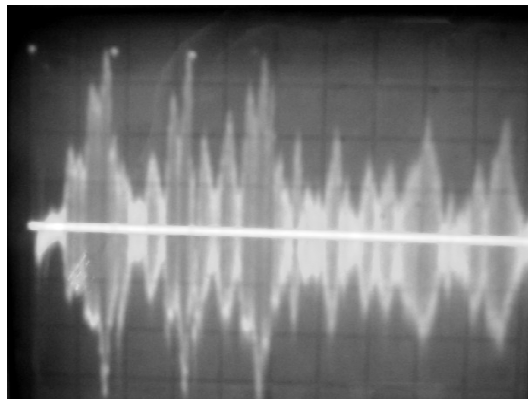


Figure 5. Oscillogram of the code packet consisting of 3 pulses, at a distance of 30 meters from the transmitter

Fig. 5 shows the oscillogram of the received code sequence of 3 bits. This code sequence can be recognized by simple methods. However, if the number of transmitted bits is increased, the reliability of the received information for the same code sequence length can not be guaranteed. Fig. 6 shows the oscillogram of a 6-bit code sequence.

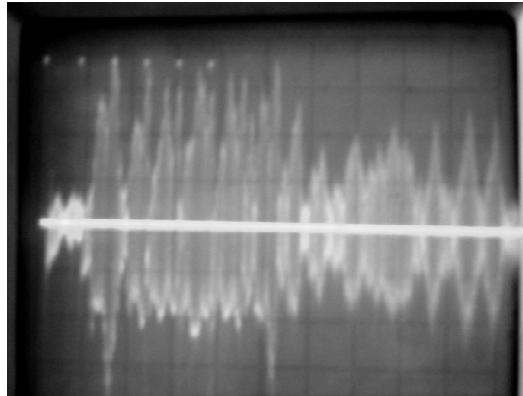


Figure 6. Oscillogram of the code packet consisting of 6 pulses, at a distance of 30 meters from the transmitter

It can be seen from the oscillogram that such a code packet is practically not recognizable. Figure 7 shows the appearance of an external acoustic sensor, equipped with a magnetic sucker.

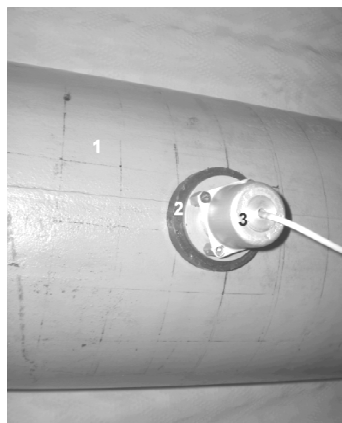


Figure 7. The appearance of the sensor located on the pipeline:
1 - pipeline, 2 - magnetic sucker, 3 - sensor protective cover

Acoustic contact with the pipeline wall is provided by a thin immersion layer of lubricant. The radiating surface of the piezo transducer is protected by a protector having a concave shape of the outer surface. The radius of curvature of this concave surface is equal to the radius of the pipeline. This ensures maximum acoustical contact area.

5. Conclusion

At this stage of the research it was possible to obtain a data transfer rate of 80 bps. This information transfer rate allows real-time control of the in-tube projectile. However, in order to increase the speed of data transfer through the acoustic channel, further research is needed to study the mechanism of propagation of ultrasonic oscillations in waveguides of circular cross section. On the basis of research, the authors choose the optimal structure of the electroacoustic path, which significantly attenuates the higher-order modes, and also develop special methods for processing received signals. This will optimize the process of transferring information and increase the velocity.

6. Acknowledgments

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