ACOUSTICAL TRANSMISSION CHANNEL OF THE INFORMATION IN UNDERGROUND TURNPIKE WATER SUPPLY SYSTEMS

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Abstract

In the given operation agency of the reflected radial waves on interfaces of the several medium having different density, on the «plane» wave which is passed round in the underground turnpike water pipeline is observed.

Keywords: an acoustical wave, the turnpike water pipeline, reflexions, reverberation, modes.

The field of examinations of an acoustical transmission channel of the information (ATCI) in the closed underground water pipeline is feebly studied now. Unlike the acoustical communications applied in open water medium where impairment is a principal cause of decrease of a signal, acoustical applied reverberation in the water pipeline is the most important factor of signal alteration. The limited space of the water pipeline creates a serious multiple-beam advance of waves. For acoustical radiation of long-range act in open water medium of theoretical and scientific bottoms it is usually enough for exposition ATCI, but for modeling ATCI in the water pipeline the complicated methods are required applications enough. Whereas various parameters characterizes the water pipeline: pressure, temperature, viscosity and a conductivity of water, mechanical impurities and air bells in water, a material, diameter of the water tube, etc. Gives the warrant to guess, that these parameters will call certain difficulties at organization ATCI [1,2,3].

Paper purpose is definition of agency of the mirrored radial waves on interfaces of the several medium having different density, on extending by a «plane» wave.

The underground water tube is subject to act of radial loads of squeezing and the circle loads of detrusion calling strain of a pipe and short-term decrease of diameter. We will observe a case when the underground pipe is not elastic (an acoustical wave it is passed round, both in a pipe, and through pipe walls in a ground), and also it is not subject to strains and modifications of diameter (fig. 1).

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Fig. 1. Extending of an acoustical wave to an underground pipe

The transfer function linking state variables of acoustical pressure p_r in the radial direction and a radial velocity v_r in interior and exterior boundary

lines of a pipe ($r = r_1$ and $r = r_2$) looks like: $\begin{bmatrix} p_{r_2} \\ v_{r_2} \end{bmatrix} = \begin{bmatrix} L_1 & L_2 \\ L_3 & L_4 \end{bmatrix} \begin{bmatrix} p_{r_1} \\ v_{r_1} \end{bmatrix}$, where

$$L_1 = \left. \frac{p_{r_2}}{p_{r_1}} \right|_{v_{r_1}=0}, \quad L_2 = \left. \frac{p_{r_2}}{v_{r_1}} \right|_{p_{r_1}=0}, \quad L_3 = \left. \frac{v_{r_2}}{p_{r_1}} \right|_{v_{r_1}=0}, \quad L_4 = \left. \frac{v_{r_2}}{v_{r_1}} \right|_{p_{r_1}=0} \quad - \text{coefficients; } r_1$$

and r_2 – interior and exterior radiuses of a pipe (fig. 2).

Fig. 2. Model of a pipe in the form of the four-terminal network

Expressions of acoustical pressure in the radial direction and the radial undular velocity look like [4, 5]:

$$p_r(\eta, \omega, r) = -i\omega\rho[aH_0^1(\eta r) + bH_0^2(\eta r)];$$

$$v_r(\eta, \omega, r) = \frac{i\eta}{\omega\rho}[aH_0^1(\eta r) + bH_0^2(\eta r)],$$

where $H_0^1(\eta r)$ – function Hankel of the first sort, for the waves which are passing round in a direction of a ground; $H_0^2(\eta r)$ – function Hankel of the second sort, for the reflected waves which are passing round in an internal area of a pipe of a ground; a, b – constants.

$$\text{In the matrix form: } \begin{bmatrix} p_{r_1} \\ v_{r_1} \end{bmatrix} = [M_{r_1}] \begin{bmatrix} a \\ b \end{bmatrix}; \quad \begin{bmatrix} p_{r_2} \\ v_{r_2} \end{bmatrix} = [M_{r_2}] \begin{bmatrix} a \\ b \end{bmatrix},$$

$$\text{where } [M_{r_1}] = \begin{bmatrix} -i\omega\rho H_0^1(\eta r_1) & -i\omega\rho H_0^2(\eta r_1) \\ \frac{i\eta}{\omega\rho} H_1^1(\eta r_1) & \frac{i\eta}{\omega\rho} H_1^2(\eta r_1) \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} \\ r_{13} & r_{14} \end{bmatrix};$$

$$[M_{r_2}] = \begin{bmatrix} -i\omega\rho H_0^1(\eta r_2) & -i\omega\rho H_0^2(\eta r_2) \\ \frac{i\eta}{\omega\rho} H_1^1(\eta r_2) & \frac{i\eta}{\omega\rho} H_1^2(\eta r_2) \end{bmatrix} = \begin{bmatrix} r_{21} & r_{22} \\ r_{23} & r_{24} \end{bmatrix}.$$

Values of constants $\begin{bmatrix} a \\ b \end{bmatrix} = [M_{r_2}]^{-1} \begin{bmatrix} p_{r_2} \\ v_{r_2} \end{bmatrix} = [M_{r_1}]^{-1} \begin{bmatrix} p_{r_1} \\ v_{r_1} \end{bmatrix}$. We multiply parts of the gained expression by a matrix $[M_{r_2}]$ end $[M_{r_1}]$:

$$\begin{bmatrix} p_{r_2} \\ v_{r_2} \end{bmatrix} = [M_{r_2}] [M_{r_1}]^{-1} \begin{bmatrix} p_{r_1} \\ v_{r_1} \end{bmatrix}; \quad \begin{bmatrix} p_{r_1} \\ v_{r_1} \end{bmatrix} = [M_{r_1}] [M_{r_2}]^{-1} \begin{bmatrix} p_{r_2} \\ v_{r_2} \end{bmatrix}.$$

Product $[M_{r_2}] [M_{r_1}]^{-1}$ – matrix of transfer from interior field in exterior field and accordingly $[M_{r_1}] [M_{r_2}]^{-1}$ – matrix of transfer from exterior field in an internal area.

Let's spend replacements in matrixes:

$$[M_{r_1 r_2}] = \frac{\begin{bmatrix} (r_{21}r_{14} - r_{22}r_{13}) & (-r_{21}r_{12} + r_{22}r_{11}) \\ (r_{23}r_{14} - r_{24}r_{13}) & (-r_{23}r_{12} + r_{24}r_{11}) \end{bmatrix}}{\Delta r_1}, \text{ where } [M_{r_1 r_2}] - \text{transfer matrix}$$

in a direction from radius r_1 to r_2 ; $\Delta r_1 = r_{11}r_{14} - r_{12}r_{13}$.

We spend replacements in expression Δr_1 functions Hankel, we discover a Wronskian for functions Hankel, and further we define coefficients $L_1 - L_4$:

$$L_1 = -i\frac{\pi}{4}\eta r_1 [H_0^1(\eta r_2)H_1^2(\eta r_1) - H_0^2(\eta r_2)H_1^1(\eta r_1)];$$

$$L_2 = \frac{\pi}{4} \eta r_1 \rho \omega [H_0^1(\eta r_2) H_0^2(\eta r_1) - H_0^2(\eta r_2) H_0^1(\eta r_1)];$$

$$L_3 = \frac{\pi}{4} \frac{\eta r_1}{\rho \omega} [H_1^1(\eta r_2) H_1^2(\eta r_1) - H_1^2(\eta r_2) H_1^1(\eta r_1)];$$

$$L_4 = -i \frac{\pi}{4} \eta r_1 [H_1^2(\eta r_2) H_0^1(\eta r_1) - H_1^1(\eta r_2) H_0^2(\eta r_1)].$$

Thus, gained rated by coefficients $L_1 - L_4$, through a transfer matrix, allow to spot magnitude of the acoustical wave which are passing round through walls of a pipe and a ground and to size up its agency on a «plane» wave.

Let's carry out calculation of acoustical pressure, by means of interactive system MatLab, in a turnpike steel water pressure tube jointless (diameter 199mm, a thickness 2.0mm). Frequency of an initial pulse 55kHz; distance to the audible signal receiver 400m. Time fields of extending of acoustical pressure, are resulted in a figure 3.

Acoustical velocity of extending of a wave depends on a strength of materials (water, a steel, a ground) which distribute power waves. In a figure 3, a reduced form of the pulses which have transited in a ground through a steel pipe. On a pulse shape it is visible, that in a ground the plane wave will not be passed round, therefore it is possible to guess, that the given pulse in the form of noise will be superimposed on a plane wave which is passed round in a pipe. Also on a receiver entry the faster modes which have arrived on walls of a steel pipe arrive. Other modes which are passing round through longer paths of transfer, including possible reflexions from walls of a steel pipe and the past through a ground of various density are observed also [6,7]. At decrease of frequency of an initial pulse to 5kHz not changing diameter of a pipe, we observe fadings of the mirrored signals which have transited through walls of a steel pipe and fields of a ground on 14dB.

Fig. 3. Fields of extending of acoustical pressure

The pulse with frequency 55kHz energises more amount of modes that leads to serious reverberation of a signal, thus, high-frequency modes damp more sweepingly, than low-frequency.

Thus, reflexions of an acoustical wave on an interface of the several medium having different density, will reduce energy of passed round acoustical pressure in a pipe and to increment the multiple-beam advance of waves. Therefore, in a cylindrical underground pipe the filled water, it is desirable to transmit information by means of a wave with a mode (00) and to apply the filter to education of a mode (00) of the accepted pulses.

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