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DISTANT MONITORING OF WATER PIPELINES WITH VARIABLE PIPE DIAMETERS

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Abstract

This paper describes the evaluation of municipal water works, defines the operating conditions of water pipelines, and the types of the distant monitoring of water supply pipes, including cases when the source of the probing acoustic signal is located inside a pipe of a non-constant (variable) diameter. It has been shown that when the pipe diameter changes, it is practical to apply the modal representation of the probing acoustic signal for each pipe segment in order to calculate the acoustic field.

Keywords: Distant monitoring, probing acoustic signal, acoustic pressure, system, municipal water works, reflection, reverberation, modes.

Introduction

Data concerning the current structural condition of the municipal water works in combination with statistically obtained empirical models of failures may increase their durability and allow for profitable control over water supply. Condition evaluation of municipal water works and taking decisions on their restoration includes several stages as follows:

- Modeling a water supply line for above-ground and underground installation options;
- Assessing the water supply line condition using measuring instruments, including pipe non-destructive testing;
- Interpreting the measured values defining the current condition of the line;
- Empiric modeling of failures in small diameter pipelines;
- Determining the service life of the pipeline;
- Assessing the consequences of emergency failures;
- Planning costs for the complete operation life of a pipeline (quantity, quality, endurance, etc.).

Determining the pipeline operating conditions shall not depend on those parameters only that characterize emergency cases; so, we need to have specific information on the properties of soil, climate, ground water, cap rocks, types of sounding devices used to generate an acoustic signal, design and geometry of pipes, etc.

Papers [1-3] consider the cases of distant monitoring of constant diameter water supply pipes. However, in practice, the municipal waterworks employ pipes of various diameters that imply certain limitations on the parameters of the probing acoustic signal (waveform, duration, duty cycle, etc.).

Methods

Let us consider the practicability of applying a distant monitoring method of modal representation for a probing acoustic signal (the parameters of the signal propagating in a water pipeline in places where a pipe with a certain diameter adjoins a pipe with a different diameter (Figure 1) are given in [1]. The modes of the propagating probing acoustic signal are different, so let us convert the acoustic pressure in the pipe with a certain diameter into the acoustic pressure in the pipe with a different diameter by assuming continuous acoustic pressure and velocity.

Here, we take into account that continuous acoustic pressure and velocity will be impossible for the acoustic pressure field transmitted into a smaller diameter pipe since some part of the field will be reflected from the edges of the connection between two pipes. The radius of the pipe under consideration is R at the interval $\left[x_0, x_1\right]$ and R_1 at the interval $\left[x_1, x_2\right]$, with $R > R_1$. We assume circular symmetry, so we preclude any modes caused by pipe irregularities. With respect to the expression given in [1, 4-10], at the interval $\left[x_0, x_1\right]$, the acoustic pressure will be:

$$p(r,\theta,x) = \sum_{n=0}^{N} A_n B_n e^{i\gamma(x_1 - x_0)} .$$

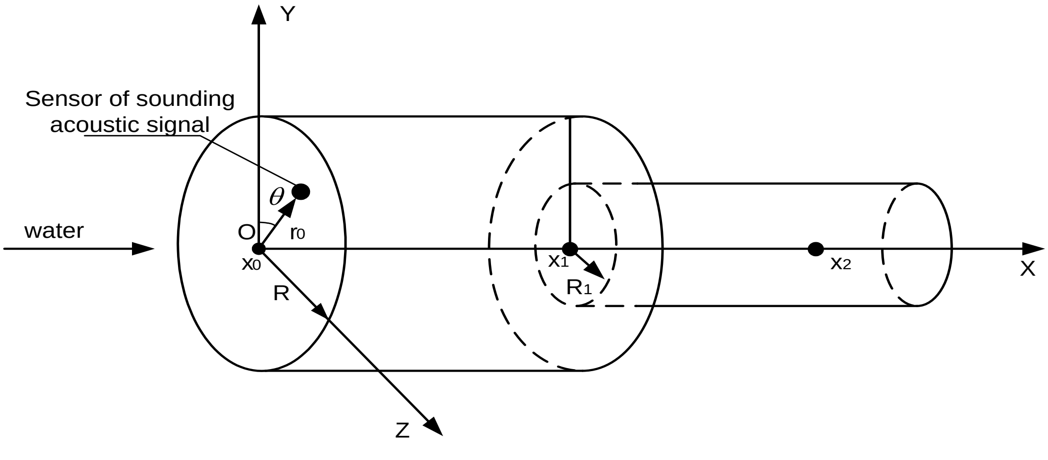


Figure 1. Pipe with a certain diameter connected to a smaller diameter pipe.

Point x_1 shows dissipation of acoustic pressure to the reflected wave:

$$p_{ref}(r,\theta,x_1)=\sum_{m=1}^{\infty}C_{nm}B_{nm}e^{i\gamma_{nm}x_1},$$

and to the transmitted wave:

$$p_{tr}(r,\theta,x)=\sum_{m=1}^{\infty}D_{nm}\tilde{B}_{nm}e^{-il_{nm}x_2},$$

where $C_{nm}=\sum_{v=1}^{\infty}H_{nm}A_n$; $\tilde{B}_{nm}=\tilde{\Theta}_{nm}(\theta)J_n(\xi_{nm}r)$; $D_{nm}=\sum_{v=1}^{\infty}K_{nm}A_n$; $\tilde{B}_{nm}$ and $\tilde{\Theta}_{nm}$ are generalizations B_{nm} and Θ_{nm} at the interval $[0,R_1]$.

We assume the convergence of an infinite series for radial and axial wave number of the reflected wave value η_{nm},γ_{nm}; and radial and axial wave number of the transmitted wave value ξ_{nm},l_{nm}:

$$\eta_{nm}=j_{nm}/R,\quad \gamma_{nm}=\sqrt{\omega^2-\eta_{nm}^2},\quad \mathrm{Im}(\gamma_{nm})\le 0;$$

$$\xi_{nm}=j_{nm}/R_1,\quad l_{nm}=\sqrt{\omega^2-\xi_{nm}^2},\quad \mathrm{Im}(l_{nm})\le 0;$$

$$j_{nm}\approx\left(m+\frac{1}{2}n-\frac{1}{4}\right)\pi.$$

We believe that at the point x_1 at the interval $[0\le r\le R_1]$, the compression and axial speeds are continuous, and there are no sources of probing acoustic signal at the edges.

In this case, we get the acoustic pressure continuity equation $\sum_{m=1}^{\infty}(H_{nm}+\delta_{nm})B_n=\sum_{m=1}^{\infty}K_{nm}\tilde{B}_n$ and the axial speed continuity equation $\sum_{m=1}^{\infty}\gamma_n(H_{nm}-\delta_{nm})B_n=-\sum_{m=1}^{\infty}l_nK_{nm}\tilde{B}_n$ ($\delta_{nm}=1$ if $n=m$, $\delta_{nm}=0$ if $n\neq m$).

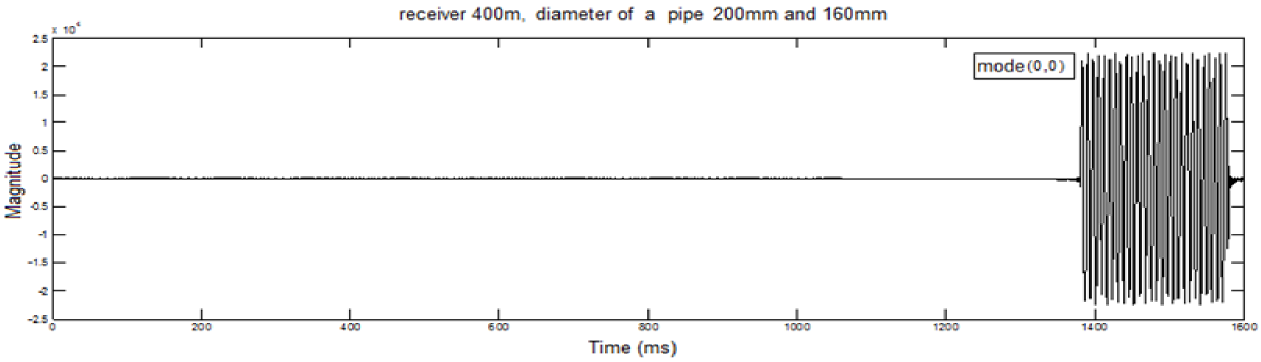
These acoustic pressure and axial speed continuity equations for the acoustic wave allow determining the acoustic pressure at the transition boundary of a certain diameter pipe to a smaller-diameter pipe, which enables revealing unauthorized inserts to a water supply pipe and pipe geometry changes caused by deposits and corrosion processes.

Results

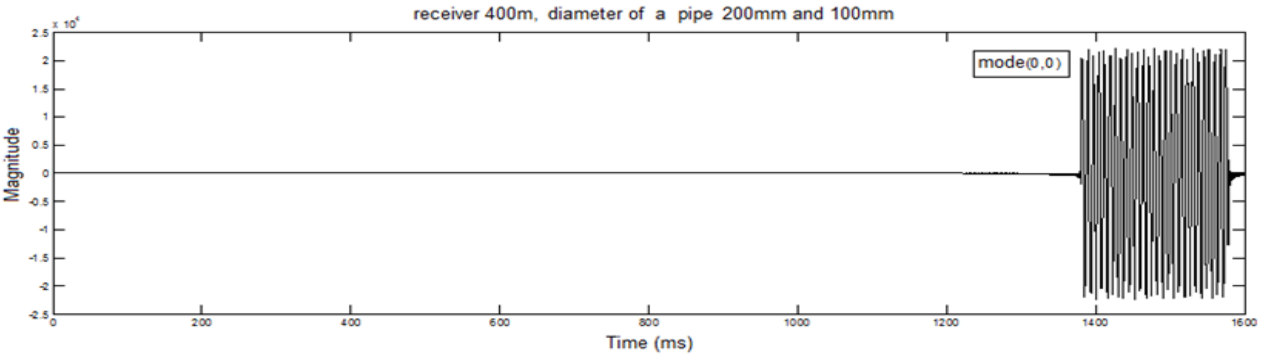
Now let us calculate the acoustic pressure propagation inside a PE water supply pipe using the MatLab interactive system. The acoustic signal source coordinates are ($r_0=0{,}5R$, $\theta_0=5^0$, $x_0=0$ m), water density is 1000 kg/m^3, sound velocity in water is 1500 m/s.

The acoustic pressure propagation areas for a flat wave mode (0,0) in the water supply pipe with probing signal frequency of 55.00 kHz are given in Figure 2. A pipe reduction from 200.00 mm diameter to 160 mm diameter causes mode attenuation (0,0) by 8.0 dB, with no waveform distortions. A pipe reduction from 200.00 mm diameter to 100 mm diameter increases mode attenuation (0,0) by 8.80 dB, pipe reduction to 20.00 mm causes mode (0,0) attenuation by more than 14.80 dB, with higher modes being attenuated by 16.90 dB.

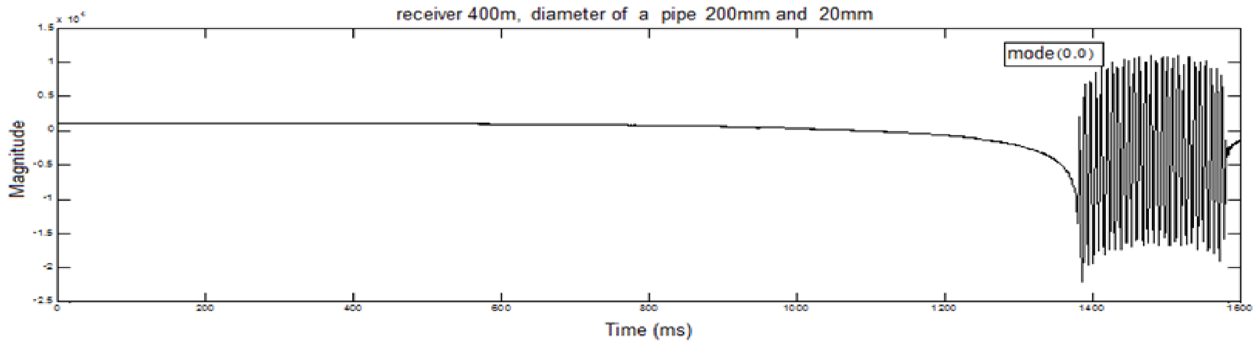
Acoustic pressure propagation areas for a flat wave mode (0,0) in the water supply pipe 800.00 mm in diameter are given in Figure 3. A pipe reduction from 800.00 mm diameter to 200 mm diameter causes mode attenuation (0,0) by 58.70 dB, and pipe reduction to 20.00 mm had no significant effect on mode (0,0), since for a pipe diameter of 20.00 mm, a 55.00 kHz signal causes wave that propagates irrespective of bends, corners and pipe branches.



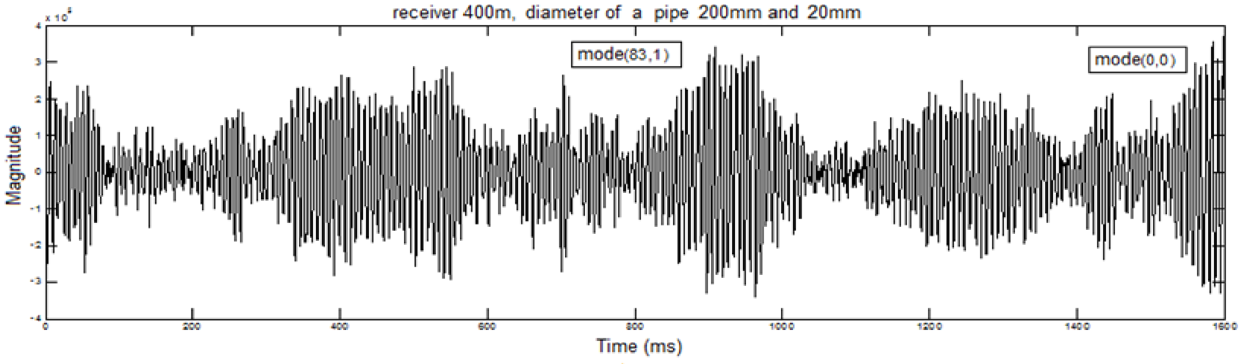
a)



b)

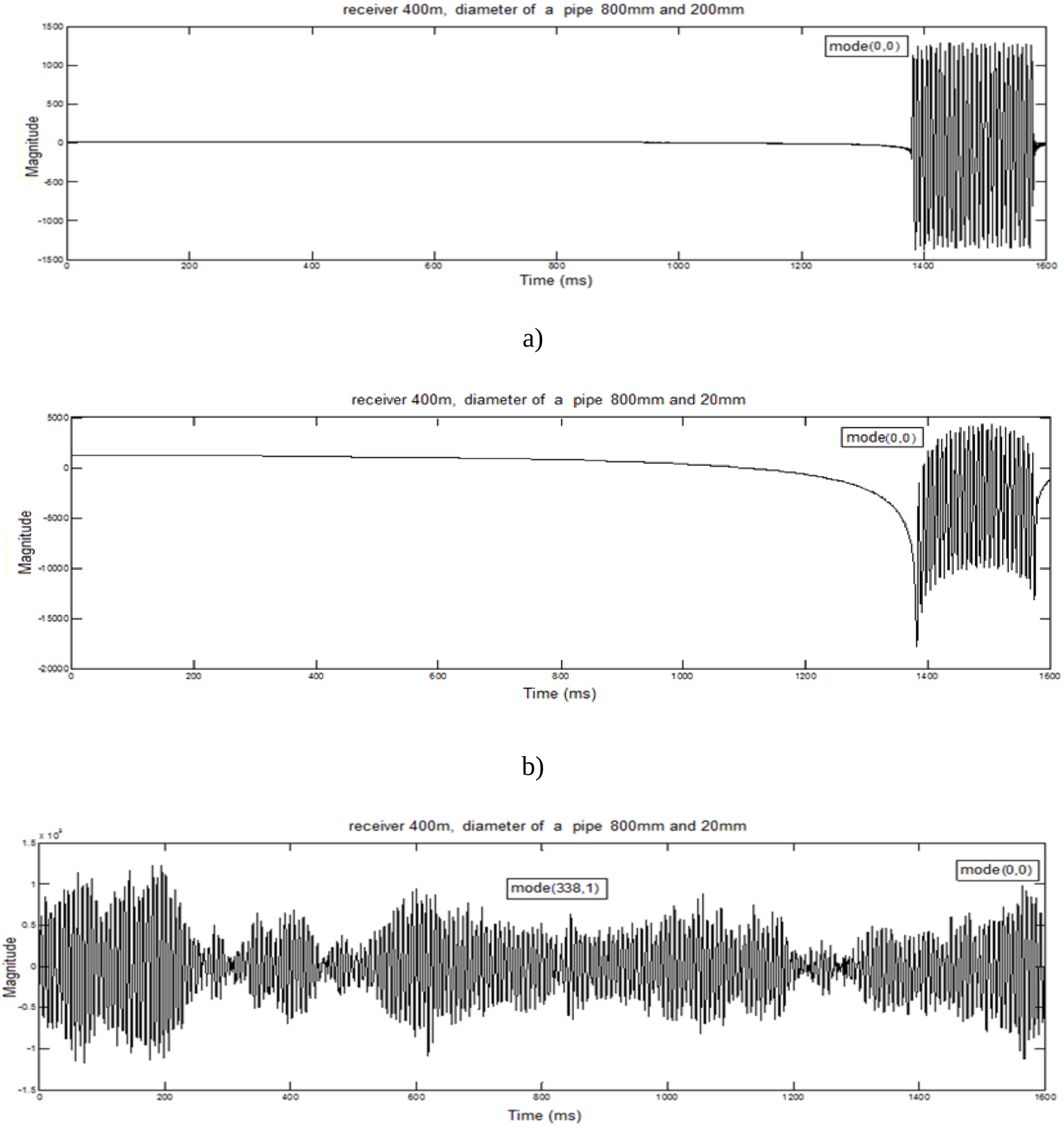


c)



d)

Figure 2 (a-d). Acoustic pressure propagation areas.



a)

b)

c)

Figure 3 (a-c). Acoustic pressure propagation areas.

Upon analyzing the obtained results of acoustic pressure calculation for pipe reduction, we should note as follows:

– a flat waveform is subjected to distortions if there is a reduction to a pipe diameter which is 10 or more times less, and a double decrease or increase in the pipe diameter causes mode (0,0) attenuation by 8.80 dB and 12.00dB for higher modes;

– pipe reductions from 400-1200 mm to 200-100 mm causes acoustic wave attenuation from 20.00 dB to 40.00 dB, for a 55.00 kHz probing acoustic signal.

Conclusions

To transmit a probing acoustic signal in municipal waterworks with pipe reductions, it is necessary to identify propagation conditions for the acoustic field with highest energy concentrated in the frequency spectrum with simultaneous minimal dispersion. To achieve it, the generated probing acoustic signal shall be throughly investigated and modes for each acoustic pressure propagation conditions shall be identified.

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