EXPERIMENTAL AND NUMERICAL INVESTIGATIONS OF WATER HAMMER ANALYSIS IN PIPELINE

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Introduction

A hydraulic shock is a physical phenomenon occurring in pipelines, characterized by a sudden change in pressure due to rapid variations in fluid flow velocity. Unsteady fluid flow in pressurized pipelines leads to the formation of zones with sharp pressure changes. The hydraulic shocks (HS) resulting from abrupt pressure increases or decreases can cause emergency situations due to damage to pipelines, pumping systems, connecting elements, and fittings [1].

Undoubtedly, hydraulic shock is a significant and relevant phenomenon in the field of hydraulics and pipeline system design. In modern industrial and urban infrastructure contexts, where complex and highly loaded systems are utilized, the consequences of hydraulic shock can lead to substantial economic losses and environmental issues. A sudden pressure increase during a hydraulic shock can cause irreparable damage to structural components.

Fig. 1. Examples of damage in piping systems due to hydraulic shock

To protect against the consequences of hydraulic shock in pipeline systems, provisions for pressure changes during hydraulic shock are established, along with various methods and technical means for stabilizing pressure within the pipeline.

Main part

Common pressure control methods include increasing the operating time of valves and pumps, enhancing the rotational inertia of pumps by installing flywheels, optimizing pipe materials, properly organizing the pipeline layout, and integrating pressure control devices such as surge tanks and pressure vessels [2–5]. Among existing methods, the installation of surge tanks is one of the most frequently used due to its strength and reliability under intense pressure fluctuations [6]. Additionally, existing tunnels can often be converted into pressure relief reservoirs, significantly reducing costs compared to other supplementary pressure control devices [7].

To mitigate hydraulic shock, several methods are employed:

1. Smooth operation of shut-off valves: implementing gradual opening and closing of valves.
2. Use of safety valves for fluid extraction: incorporating pressure relief valves.
3. Utilization of vibration dampers: employing devices designed to absorb pressure fluctuations.
4. Implementation of constant pressure control technology: ensuring stable pressure conditions.

The smooth opening and closing of valves involve using various types, such as check valves, surge dampers, and air inlet and vent valves. Fluid extraction before shut-off valves is facilitated by liquid extraction valves, which are set to specific pressure values and rupture membranes.

Hydraulic shock modeling in COMSOL Multiphysics 6.0 environment

The model consists of the following elements: tank block, pipeline and valve (fig.2).

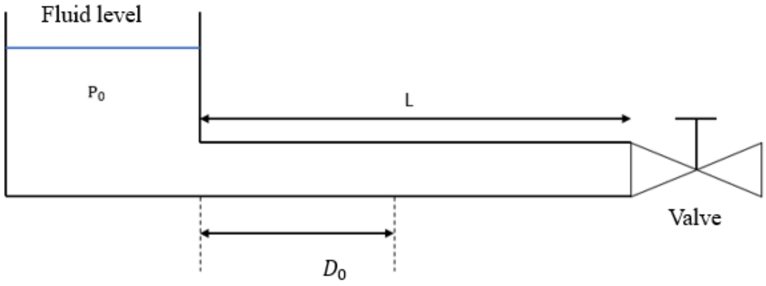

Fig. 2. Schematic diagram of the model of the pipeline system

The model includes a pipe length of 20 m with an internal diameter of 398.5m, connected to a reservoir. A valve is installed at the end of the pipeline. The pipe material is steel, with a Young's modulus of 210,000 MPa and a wall thickness of 8 mm. A pressure measurement point is installed at a distance D_0 from the reservoir. The reservoir has a constant pressure source, $P_0 = 1$ bar. Initially, the valve is opened with a fluid flow rate of $Q_0 = 0,5\ m^3/s$, and the fluid gradually flows from the reservoir into the pipeline. At time $t = 0$ s, the valve is abruptly closed. Due to the compressibility of water and the elasticity of the pipe, a sharp pressure impulse will occur before the valve. The speed of the hydraulic shock wave is determined by the formula [8]:

$$\frac{1}{c^2} = \frac{1}{c_s^2} + \rho\beta_A \tag{1}$$

where c_s is the isoentropic speed of sound in a bulk fluid (1481 m/s for water), ρ is the density of water, β_A– is the compression coefficient of the pipe cross section.

Next, consider the pressure distribution over the entire pipeline at different valve closing times and the pressure variation at the pressure measuring point.

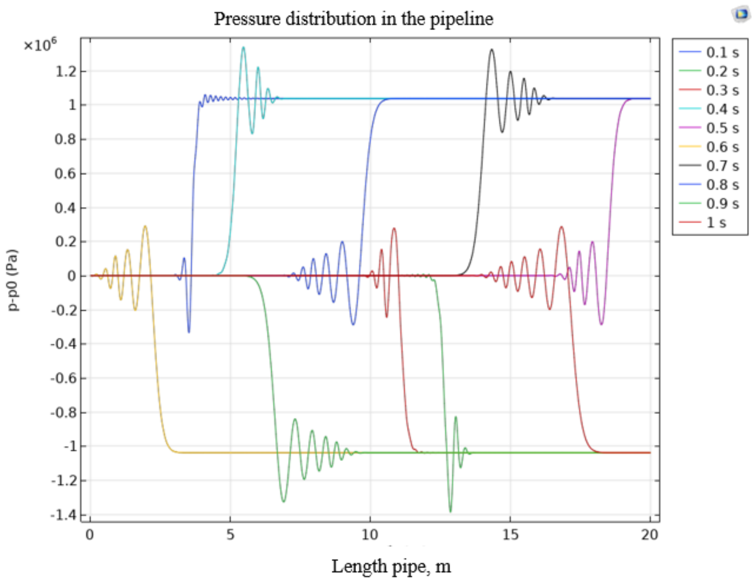

Fig. 3. Pressure distribution on the pipeline at closing time with a step of 0.1 s

As can be seen from Fig. 3, the amplitude of the hydro stroke overpressure completely coincides with the theoretical prediction of positive oscillations and, according to Zhukovsky's theory, is based on instantaneous valve closure.

Conclusion

Hydraulic shock in pipeline and water supply systems is a significant phenomenon for studying fluid flow characteristics and analyzing the state of liquid transport systems. The search for the optimal measurement points in the pipeline (to determine where to install the pressure sensor) depends on pressure changes over time, as well as the sensor characteristics, such as the sampling rate of the output signal. Proper placement of the pressure sensor is crucial to accurately capture transient pressure fluctuations and ensure effective monitoring and control of the system.

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