Research on the water hammer protection of the long distance water supply project with the combined action of the air vessel and over-pressure relief valve

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Research on the water hammer protection of the long distance water supply project with the combined action of the air vessel and over-pressure relief valve

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Abstract. We take a concrete pumping station as an example in this paper. Through the calculation of water hammer protection with a specific pumping station water supply project, and the analysis of the principle, mathematical models and boundary conditions of air vessel and over-pressure relief valve we show that the air vessel can protect the water conveyance system and reduce the transient pressure damage due to various causes. Over-pressure relief valve can effectively reduce the water hammer because the water column re-bridge suddenly stops the pump and prevents pipeline burst.The paper indicates that the combination set of air vessel and over-pressure relief valve can greatly reduce the quantity of the air valve and can eliminate the water hammer phenomenon in the pipeline system due to the vaporization and water column separation and re-bridge. The conclusion could provide a reference for the water hammer protection of long-distance water supply system.

1. Introduction

Due to the undulating terrain and the presence of the local high point in the long-distance water supply system， when suddenly stop pump or power failure, the line pressure of the liquid, especially the pressure in the local high point, is more easily reduced to below the vapour pressure and causing the phenomenon of vaporization and water column separation and re-bridge,which may produce a remarkably large amount of harm to the pipeline. In order to protect the piping system,it usually install air valves, one-way tanks, air tanks and other protective measures to eliminate the phenomenon of the vaporization and bridging water hammer.This paper analysis the presence of water hammer problem that the pump stations have and put forward economical, reliable, reasonable water hammer protection measures to ensure the safe operation of

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the water supply system.

2. Calculation methods and mathematical models

2.1. Water hammer calculation of the characteristic line method

Pumping water hammer calculation is to analysis and calculation the entire pumping system,and the calculation of the piping system interior point is to solve the basic equations of water hammer, which is the hyperbolic partial differential equations consist of the equations of motion and continuity equationsing. In order to achieve a computer program to calculate, using the method of characteristic the discretization of partial differential equations, and then calculate the solution.

2.2. Air vessel

Air vessel is a cylindrical device that filled with a certain amount of compressed gas within the tank, which is installed near the outlet of the pump. Its working principle is: When water hammer occurs its internal compressed air can play a role of cushion to eliminate the rise pressure inside the pipeline, and can also expand to push the water to pipeline and eliminate vaporization generated by column separation phenomenon. The physical model is shown in Figure 1.

The air tank pressure is assumed to be the same throughout the internal gas and meet changing reversible relationship, so the boundary condition can be expressed as:

$$\begin{cases} pV^k = C \\ Q_{in} = Q + Q_s \\ h_p = (p/\rho g - h_b) + h_s + h_l + z \end{cases} \quad (1)$$

Where, p and V is the pressure and volume of the gas tank; k is the Air condition index;C is the costant; Q_{in} is the flow into the node; Q is the flow Outflow the node； Q_s is the flow into the vessel; h_p is the bottom Pressure of air vessel; h_b is Standard atmospheric pressure; h_s is Air tank water level; z is the elevation that air vessel location。

2.3. Over-pressure relief valve

Over-pressure relief valve is usually installed in the inlet of supply line or the highest pressure point; its working principle is that when the pressure before the valve exceeds a predetermined pressure setting value, the valve opens and release part of the high-pressure water; when the pressure before the valve decreases the valve automatically closes. The physical model is shown in Figure 2.

The boundary condition can be expressed as:

$$\begin{cases} H_{P1} = H_{P2} + \xi {Q_{P2}}^2 / S \\ Q_{P3} = C_S \cdot \Delta H^{0.5} \\ Q_{P2} = Q_{P1} - Q_{P3} \end{cases} \quad (2)$$

Where, H_{P1} is the node pressure before the relief valve; H_{P2} is the node pressure after the relief valve;

ξ is the drag parameter of the valve; S is Characteristic length of the pipe; C_S is flow coefficient of Drain water; ΔH is the pressure value between the relief valve front and back; Q_{p1} is the flow into the node ; Q_{p2} is the flow Outflow the node; Q_{p3} is the vent flow.

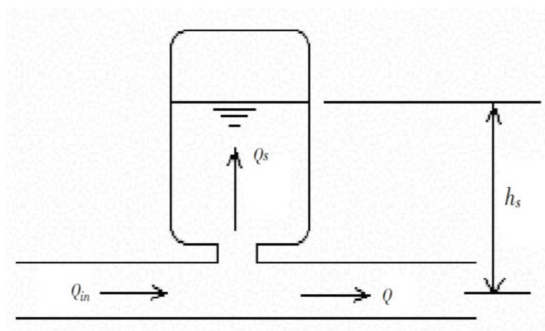

Figure 1. The boundary conditions of air vessel.

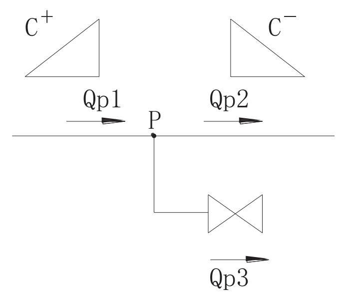

Figure 2. The boundary conditions of Over-pressure relief valve.

3. Project Overview

The total length of system piping is 10.3km. The pipes is the steel pipe and the diameter is 800mm; pipe laying methods is single conveyance arranged. Pump sumps design water level is 1062m and outlet sump design water level is 1181m;The station consists of three horizontal single-stage double-suction centrifugal pump (A dual-use equipment). Pump rated head is 158.8m, rated flow is 0.35m3 / s,and rated speed is 1450r/min. Longitudinal section of a concrete pump station pipeline is shown in Figure 3.

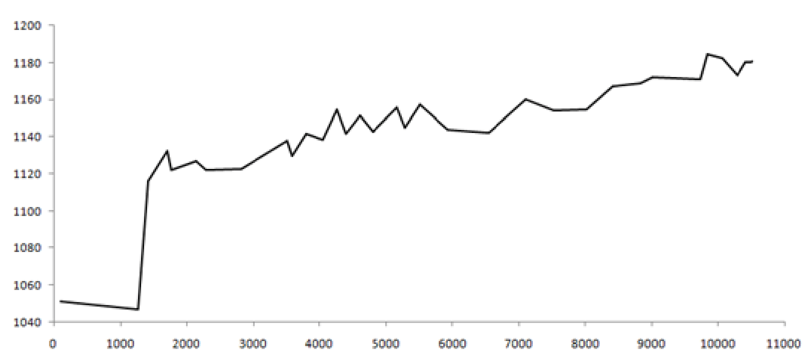

Figure 3. Pipeline profile of water supply project.

4. Transition Process Simulation

4.1. No water hammer protective measures

In the absence of protective measures,when two units suddenly stop , the maximum pressure is 221.13m, the minimum pressure is -8m in the piping system; along the pipeline majority appeared vaporized. This indicates that the pipeline generate column separation after the pump stops, and pressure is reduced to below the the steam pressure, which cause the vaporization in the pipeline. pressure envelope is shown in Figure 4.

4.2. Apply water hammer protective measures

Arrange a air vessel in the dry pipe inlet that diameter is 4m, height is 4m, initial meniscus height is 2m, and the gas reference pressure in the tank is 165m; In the State mark where is 0+981.07 install a over-pressure relief valve that caliber is 400mm and could completely open in 2s. In the State mark where is 1+935.9, 4+414.7, 5+283.67, 7+007.8, 7+371.7, 8+783.8 install the air valve (Total 6) whose inlet diameter is 200mm and outlet diameter is 3mm.

When the proposed two units shut down, the pump outlet valve with 0s-3.5s off 80% and 3.5s-13s fully closed. The maximum pressure of the piping system is 189.02m in the 0+919.2, the minimum pressure is -0.79m in the 7+138.17, and pipeline without vaporization.Maximum pump outlet pressure is not exceeded 1.2 times the rated pressure,so the system is security. Transient process curve shown in Figure 5-9.

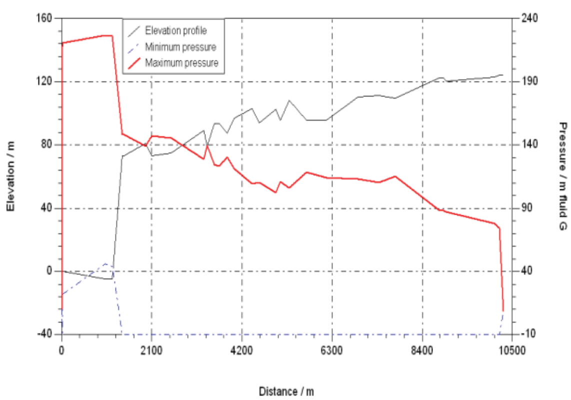

Figure 4. Maximum and minmum head envelopes without protective measures.

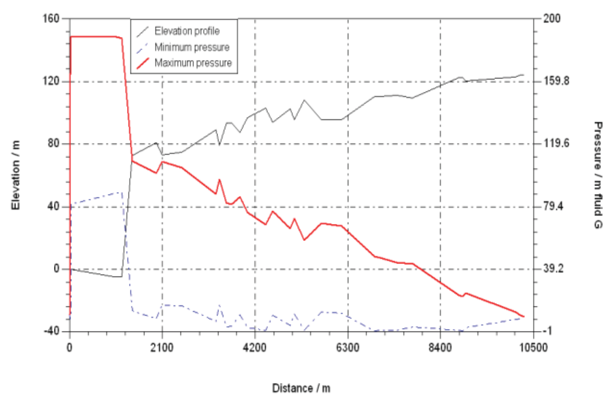

Figure 5. Maximum and minmum head envelopes with protective measures.

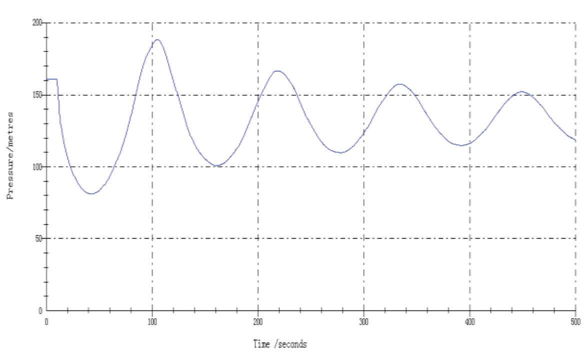

Figure 6. The highest point pressure variation curve.

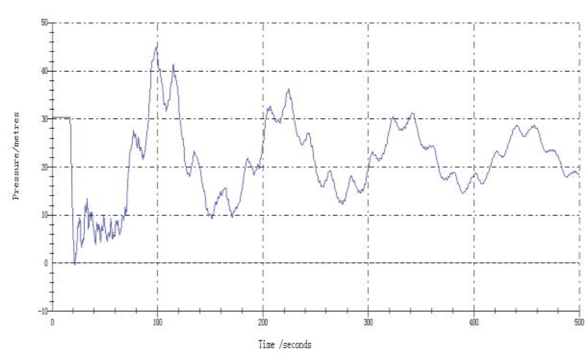

Figure 7. The lowest point pressure variation curve.

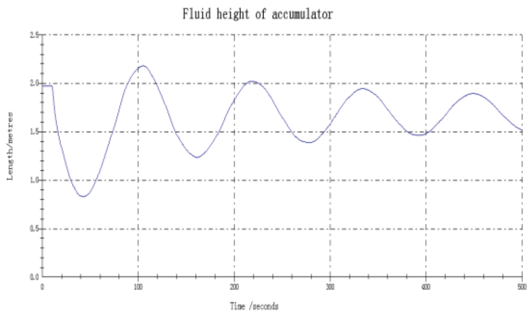

Figure 8. The liquid level variation curve of the vessel.

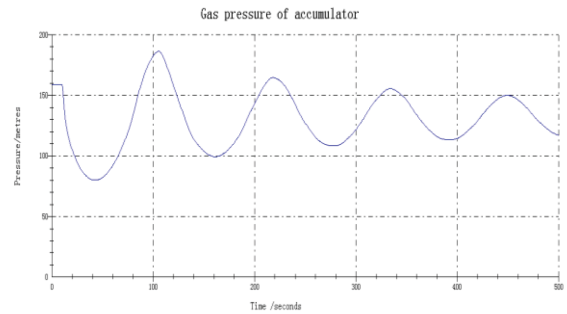

Figure 9. The gas pressure variation curve of the vessel.

5. Conclusion

For the long-distance water supply project water hammer protection, along with a growing number of protective measures, it often choose the combination set of two to three kinds of protective measures in the engineering. Taking into account of the feasibility of the construction and economic costs, which kind of the protective measures can be can be both good and economical to achieve the protective effect, become a problem can not be ignored. Through the above scheme, we can find that he combination set of air vessel and over-pressure relief valve can greatly reduce the quantity of the air valve, not only could avoid construction difficulties caused by too close distance between two air valve, but also can reduce the damage on the pipeline system due to the air valve failure.

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