Research on the protection of pipelines with multiple column separation and water hammer of cavities collapsing

Li Zhao¹ *, Yusi Yang², Tong Wang², Rongchu Wu², Pengli Wang²
¹School of Energy and Architecture, Xi’an Aeronautical University, Xi’an, China.
²School of Architecture and Engineering, Chang’an University, Xi’an, China.

*Corresponding author e-mail: zhaoli200817@163.com

Abstract. In long distance water transfer project, pipeline fluctuation, easy to produce multiple column separation phenomenon, then the water hammer of cavities collapsing is greatest harm to the pipe. Summarizing the previous research results, mechanism analysis of water hammer of cavities collapsing and theoretical calculation model, and introduces the main protective equipment and boundary conditions. After long-term practice, constant speed buffer air valve and Two-way Surge Tower effect remarkable on water hammer of cavities collapsing.

Key words: Long distance water transfer project; water hammer of cavities collapsing; constant speed buffer air valve; Two-way Surge Tower.

1. Foreword
The water hammer theory of pump station is a subject that people have been working hard for many years. After great achievements have been made in the theory of continuous flow transients, more studies have been carried out on the problem of water hammer with more complex and more harmful discontinuous flow bridging, and some progress has been made. Since the beginning of the 20th century, scientists have been aware of the interruption of water column in the process of stopping the pump. Since the 1960s, the harm of water hammer caused by cut-off flow to bridge the gap has attracted sufficient attention from the scientific and technological community. Based on the hypothesis experiment, it is concluded that the pressure boost of water hammer caused by water-column separation is several times higher than that of ordinary water hammer. A lot of experiments have been carried out to analyze the causes of liquid column separation and the harm of water hammer caused by flow break to bridge the water hammer. However, at first, these results were obtained on the condition of simple or only one liquid column separation occurred in horizontal pipeline. The separation of multiple water columns in complex pipelines is a long-term problem to be solved by the scientific and technological community [1, 2].

In the long-distance water transmission pipeline, the topography fluctuates greatly, and there are often multiple water column separation phenomena on one pipe line at the same time. The discontinuity of water flow to bridge the uncertainty and great harm of water hammer has become a difficult problem for the protection of long-distance water transmission engineering. According to the engineering statistics at home and abroad, most of the pipe burst phenomenon is caused by water hammer. According to the characteristics of large cavity in pipeline, it can be divided into two types: steam cavity and air...
cavity. Steam chamber is when somewhere on the pipeline pressure drop to the environment temperature of saturated steam pressure, liquid water rapidly vaporized and generate big cavity, the flow continuity is destroyed, resulting in the water column separation phenomenon, according to the water hammer experiment device, combined with computer simulation has been repeatedly experimental analysis: the minimum head envelope is lower than the saturated vapor pressure point is easy to produce steam chamber. Air cavity: negative pressure appears in the pipeline, the air is sucked into the pipe through various valves installed in the pipeline and forms a large cavity, namely the air cavity, at this time can also produce water column separation phenomenon. In actual engineering, the pipe cannot be completely sealed, so the possibility of air cavity is greater. After long-term research, the damage degree of water column separation and water hammer with broken flow bridge is mainly related to the steady-state flow velocity of the system, the length of the broken flow cavity, the pressure fluctuation of the pipeline, the total length of the pipeline and the pipeline layout. Generally speaking, the greater the fluctuation of pipeline pressure, the more rapid the change of flow velocity, and the longer the length of the cut-off cavity, the higher the water hammer boost caused by the collision of two water columns, the greater the back pressure on the downstream side of the water column separation point, and the higher the bridge water hammer boost. On the contrary, if the back pressure on the downstream side of the water column separation point is not enough to cause the two water columns to collide, the water hammer of cut-off flow bridging will not occur [2]. If the air valve installed can buffer exhaust, then the remaining air will gradually be compressed, playing a cushion role, effectively reduce the impact of two streams of water boost [3,4].

2. Introduction to the protection principle and new protection equipment of water hammer with cut-off flow bridging

There exists gas-water two-phase flow in the water transmission pipeline. When designing the long-distance water transmission pipeline, it is necessary to analyze the flow state of water that may appear under different working conditions and select the appropriate location to install a certain number of protective equipment. Protection principle: all kinds of protective equipment can work harmoniously and give full play to their respective advantages. At present, the commonly used protective measures are mainly water (gas) pressure stabilizer, such as pressure regulating tower, air valve, air tank. The commonly used controllable valve has two stages to close the hydraulic control butterfly valve, slow closing check valve [5]. Drainage and pressure reduction measures, commonly used check valve plus bypass pipe, cancel check valve, water hammer eliminator, explosion-proof film, etc [5]. Generally preferred by the moment of inertia of large pump unit or add enough inertia flywheel, installed in the pump outlet two-phase closed hydraulic control butterfly valve, to control the water pump outlet pressure oscillation, the backflow of water and water pump reversal, generally occurs in the pump valve closed 70% ~ 80% within 3 ~ 7 s, and the remaining 20% ~ 30% of the closing time is according to the numerical simulation to determine the hydraulic pipeline, generally in 10 ~ 90 s scope; Exhaust device should be installed along the high point and break point of possible gas accumulation along the pipeline. If the pressure changes greatly, pressure stabilizing device should be set to control pressure fluctuation and effectively eliminate the phenomenon of vacuum and water column separation. When necessary, a two-stage slow-closing terminal valve is set at the end of the water transmission line. When the pump water hammer is stopped, its optimal valve closing time setting can control the water column separation in the pipeline and reduce the pressure shock of the pump water hammer [6].

Many equipment used for water hammer protection of pressure pipelines have shortcomings. One-way pressure regulating tower and water hammer eliminator are only suitable for water hammer or negative pressure water hammer. Pneumatic tank is generally large volume, high cost and operation management costs, rarely used in China [7]. The overpressure relief valve has the possibility of action lag and even action rejection, and the reliability is poor. The rapid opening and closing of the safety valve can easily lead to secondary water hammer in the pipeline. Theoretically, it is only suitable for extremely short pipelines and containers. The release pressure of blasting diaphragm is extremely difficult to be accurate [7]. It cannot be automatically restored and closed after water discharge. It is
easy to run water and difficult to apply. Float ball (canister) the big exhaust port of exhaust valve cannot or cannot successive discharge gas closes dead, rely on 3 ~ 5mm only small exhaust port, its effective discharge quantity is very small. Lever type, combined exhaust valve also did not solve the problem of high pressure in the discharge of pipe gas. In recent years, various water hammer protection equipment with good performance has been developed gradually, such as: high speed buffer air valve with check valve, high speed buffer air valve with flow limiting plate, constant speed buffer exhaust valve (cylinder type), box type two-way pressure regulating tower and so on. Compared with the traditional protective measures, they have their own advantages, this paper briefly introduces the latter two kinds of protective equipment [8].Box-type two-way regulating tower greatly reduced the installation height, the reason is that using box-type two-way regulating tower fluctuation range area of piston pressurization principle, reach the dynamic balance of piston, ensure the water hammer accident occurs, as long as the maximum design hydraulic pressure is greater than the normal operation, the lower part of the piston of the resultant force is greater than the upper part of the piston, piston up, open the discharge opening, to release, ultra-high pressure pipe to protect the safety of pipeline, when the pipeline pump to a sudden stop or open valve water hammer makes pipeline pressure drop to below the water depth in the cabinet or negative pressure, the water flow to the pipe in the cabinet, prevent or eliminate the phenomenon of pipe flow, Cut off flow to heal water hammer. It can be seen that the box-type bidirectional pressure regulating tower has the function of ordinary bidirectional pressure regulating tower, its height can be greatly reduced, and the reduced value can be appropriately expanded according to the specific situation of the upper piston area. The box-type bidirectional pressure regulating tower can be lowered to the height of 5 ~ 15 meters under any circumstances, and the function basically remains unchanged. The project cost has been greatly reduced [9].Are typically installed near the distance from the pump export box-type two-way regulating tower, is considering once the pump stop, according to the principle of water hammer wave propagation, often head end pipeline booster fastest, box-type two-way regulating tower installed on the pump stations catchment manager or water mains water column separation due to high or folding point, and consider the box-type two-way regulating tower had better install where convenient maintenance and management, so choose near the distance from the pump export, generally preferable 50 meters, is still in personnel management. Cylinder type constant speed buffer exhaust valve has the advantages of timely exhaust, fast speed, slow closure, the traditional floating ball exhaust valve, including combination, compound, power compound, this type of exhaust valve in the phase of water and gas, the large vent can only discharge the first gas, not continuous exhaust. It is not enough to exhaust by a small vent. And this type of exhaust valve does not move for a long time floating ball is easy to fail due to adhesion. Ball float valve caused by poor exhaust which in turn affect the occurrence of secondary water hammer, cylinder type constant speed bufferring exhaust valve is the latest results from this and further research, such as the use of buoy lever control pneumatic diaphragm moves in the cylinder, which makes the body big and small vent opening and closing, total pressure is the exhaust valve, the valve is under any pressure and flow conditions, as long as the gas pipeline into the exhaust valve, large and small vent exhaust valve opened. When the water into the exhaust valve, the large and small vent is closed, no leakage. Or perhaps this valve can accomplish to see gas namely high speed eduction, see water namely close, can successive a lot of exhaust, be accepted by place of personage inside broad course of study now, apply extensively on the project.

3. Establishment of theoretical model of water hammer with two broken flow Bridges
In order to deal with the hydraulic transition process of water hammer with two kinds of water column separation phenomena, steam type and air type, as well as the water hammer with discontinuous flow, the multi-point fixed and completely discontinuous cavitation mathematical model is applied. The main points of the model are as follows:
Judging basis of water hammer with cut-off flow bridging: when the pressure drop of water hammer is less than the pressure value that can be provided in the pipeline, water column separation will not occur; On the contrary, when the pressure drop of water hammer is greater than or equal to the pressure value that can be provided in the pipeline, water column separation will occur [3].
Boost analysis of water hammer with cut-off flow bridging: if water column separation occurs in the pipeline, when water column bridging, there will be a violent collision between two water columns — water-hammer with cut-off flow bridging. And the pressure generated by the collision between water columns increases [7, 12]:

$$\Delta H = \frac{a}{2g} (V_1 - V_2)$$ (1)

Where: $\Delta H$ —— pressure increment caused by collision between water columns;
$V_1, V_2$ —— The velocity of two separated columns of water;
a —— wave speed of pipeline system.

According to the above formula, it can be concluded that the boost size of water Column Bridge mainly depends on the bridge speed of two water columns. The key of water hammer is how to effectively control the water column bridge speed.

4. Boundary conditions of main protective equipment

Boundary condition of exhaust valve:

$$P_1 - P_{PP3} = C_p - B_p Q_{PP3}$$ (2)
$$P_2 - P_{PP4} = C_M + B_M Q_{PP4}$$ (3)
$$\gamma \left( H_p - Z + H \right) = P$$ (4)

$$P \left[ \int_0^{H} + 0.5 dt \left[ Q_i - Q_{PP3} - \frac{C_M + C_p}{B} + \frac{2}{B} \left( \frac{P}{\gamma} + Z - H \right) \right] \right] = \left[ m_o + 0.5 dt \left( m_o + \bar{m} \right) \right] RT$$ (5)

Formula (5) is a general calculation formula for all exhaust devices with exhaust function (1). Where $H$ is the pressure head of the barometer, $Z$ is the position height of the air valve.

Boundary conditions of pressure regulating tower [10, 11]:

According to the working principle and working place of the pressure regulating tower widely used at present, the pressure regulating tower can be divided into unidirectional pressure regulating tower, ordinary bidirectional pressure regulating tower and box-type bidirectional pressure regulating tower. The compatibility equation of the three pressure regulating towers is as follows [7, 12]:

$$Q_{p1} = \sqrt{2g(H_p - H_i)}$$ (6)
$$Q_{p2} = -\sqrt{2g(H_i - H_p)}$$ (7)

Where: $Q_{p1}, Q_{p2}$ —— flow in and out of the pressure regulating tower;
$H_p$ —— the depth of water in the pressure regulating tower after discharge or water injection;
$h$ —— the original depth in the pressure regulating tower.

5. Conclusion

The water hammer protection measures of box-type bidirectional pressure regulating tower combined with constant speed buffering exhaust valve can effectively reduce the occurrence of water column separation and water hammer with cut-off Flow Bridge. After repeated simulation calculation, the closing time of two-stage slow-closing valve at the pump outlet and the installation position of protective equipment can be determined, so as to ensure safe and reliable pipeline operation.
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