Study on Judgment and calculation method of two water column separation water hammer

Li Zhao 1,*, Yusi Yang 2, Tong Wang 2, Zhangchi Song 2, Faming Qin 1

1 School of Energy and Architecture, Xi’an Aeronautical University, Xi’an, China
2 School of Architecture and Engineering, Chang’an University, Xi’an, China

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

Abstract. Based on two water hammer experiments, a method of judging two water column separations in a pipeline and calculating the boosting pressure are put forward. By using the momentum theorem and the elastic water column theory of water hammer calculation, the calculation formula of the heave pressure in the case of equal and unequal water column velocities at both ends of the cavity is deduced.

Keywords: water hammer, water column separation, collapsing increase pressure, test.

1. Introduction

With the rapid development of long-distance water conveyance project, the safety protection of water hammer has been paid more and more attention. Due to the complexity of cavities water hammer, it is not enough understanding of its depth. In particular, there are multiple water column separation in the pipeline system at the same time, the situation is more complicated. In this paper, two calculation methods of water column healing are presented, and the simulation program of water hammer is improved.

2. Two water column separation judgment and in the simple case of water hammer wave propagation, reflection and superposition

In recent years, people in the water pipeline under what circumstances water column separation and water shut-off is very concerned about the harm of water hammer to discuss more. But the understanding is not very consistent. Here only use for the vast majority of the researchers recognized and meet the general criteria for the determination of the pressure in the pipe \( p \leq p_v \), (\( p_v \) is the temperature of the water pipe saturated vapor pressure), as the two stop flow judgment standard [1].
Suppose a simple water delivery system, see Figure 1. Figure X1 point for the tube head, X2 point for the pipeline in the knee, two points are possible separation of water column Department. There may be three cases: ① X1 at the first stop; ② X2 at the first stop; ③ two simultaneous drying [2].

Using the principle of water hammer wave propagation, reflection and superposition to take t1, t2, respectively, X1, X2 from the system began to step down to produce water column separation time, tx1 is the step-down wave propagation from X1 to X2 point time.

When the first stop at X1, the pressure reduction rate no longer increases, that is, t1 time pressure is reduced to a minimum, and to maintain the saturated steam pressure of water. At this point, the voltage drop to the X2 point is not sufficient to cause a break in this point, but the pressure at point X2 may drop below Pv for the next tx1 period. Let t1≤t2≤t1+tx1. If the X1 in the tx1 period after the cut-off period, X2 point does not cut off, then the X2 point is generally no longer broken.

When X2 first stop, X1 also continues to buck, but produced a boost to X1 at X2 wave propagation time, after TX1 arrived at X1, the blood pressure decreased, due to the general process of blood pressure (such as pump) step-down curve is concave down, so when X2 the pressure rises reflected wave arrived at X1, if X1 is not drying up, it will not happen again to stop. If flow, X1 occurred is: t2≤t1+tx1.

When X1 and X2 cut-off at the same time then t2=t1.

3. Cavities Collapsing two basic equations of water hammer
In recent years, domestic and foreign literature in the calculation of water hammer to close the flow, mostly ignore the free surface without cutting cavity surface water curve calculation. In the event of two shut-off, the theory and practice show that the order to bridge the great impact of Cavities Collapsing boost. Therefore, even in the case of small diameter, the surface curve of the account is also necessary. In the non-stop flow region, the well-known characteristic line equation is used, and in the cavity region, the non-full flow characteristic equation is used.
3.1. Full Pipe Flow Characteristic Equation.

\[
\begin{align*}
C^+ & \left\{ \frac{\Delta x}{\Delta t} = u + c \\
& \quad H_p = H_A + \frac{c}{g} (u_p - u_A) - \frac{c \Delta t}{2gD} \lambda u_A |u_A| = 0 \\
& \quad H_p = H_B + \frac{c}{g} (u_p - u_B) - \frac{c \Delta t}{2gD} \lambda u_B |u_B| = 0 \\
\end{align*}
\]

(1)

Where: \( u_p, u_A, u_B \) and \( H_p, \ H_A, \ H_B \), respectively, \( P, A, B \) flow rate and head; \( g \) for the acceleration of gravity, \( \lambda \) for the drag coefficient, \( D \) is the pipe diameter [3].

In order to facilitate Computing applications can be written as [4,5]:

\[
\begin{align*}
C^+ & \left\{ H_p = -\frac{c}{gA} Q_p + C_p \\
& \quad \frac{\Delta x}{\Delta t} = Q_p / A + c \\
C^- & \left\{ H_p = \frac{c}{gA} Q_p + D_p \\
& \quad \frac{\Delta x}{\Delta t} = Q_p / A - c \\
\end{align*}
\]

(2)

Among them,

\[
C_p = H_A + \frac{c}{gA} Q_A - \frac{8\Delta x}{g\pi^2 D^2} \lambda Q_A |Q_A| \\
D_p = H_B - \frac{c}{gA} Q_B + \frac{8\Delta x}{g\pi^2 D^2} \lambda Q_B |Q_B|
\]

(3) (4)

\( Q_A, Q_B \) is the flow rate at points A and B, and A is the cross-sectional area of the water.

3.2. Non-full pipe flow characteristic line equation

\[
\begin{align*}
C^+ & \left\{ Z_p = Z_A - \sqrt{\frac{A}{gB}} (u_p - u_A) - \Delta x \lambda \frac{u_A |u_A|}{8R_H} \frac{1}{g} \\
& \quad \frac{\Delta x}{\Delta t} = u_A + \sqrt{\frac{gA}{B}} \\
C^- & \left\{ Z_p = Z_B + \sqrt{\frac{A}{gB}} (u_p - u_B) + \Delta x \lambda \frac{u_B |u_B|}{8R_H} \frac{1}{g} \\
& \quad \frac{\Delta x}{\Delta t} = u_B - \sqrt{\frac{gA}{B}}
\end{align*}
\]

(5)
In order to facilitate Computing applications can be written as:

\[
\begin{align*}
C' & \quad \begin{cases} 
Z_p = -\frac{A}{gB}u_p + C_m \\
\Delta x = u_A + \frac{gA}{B} 
\end{cases} \\
C' & \quad \begin{cases} 
Z_p = \frac{A}{gB}u_p + D_m \\
\Delta x = u_B - \frac{gA}{B} 
\end{cases}
\end{align*}
\]

Among them,

\[
C_m = Z_A + \frac{A}{gB}u_A - \Delta x \lambda \frac{u_A |u_A|}{8gR_H}
\]

\[
D_m = Z_B - \frac{A}{gB}u_B + \Delta x \lambda \frac{u_B |u_B|}{8gR_H}
\]

Where: \(u_p, Q_p\), respectively, for the unknown point of the flow rate and flow; \(Z_p\) for the unknown point of the water level. \(B\) is the cross-section width; \(R_H\) is the hydraulic radius.

The characteristic line equation of the above-mentioned non-full-surface water surface curve can be obtained by analyzing the relevant literature at home and abroad [1]. \(B = 0\) at the boundary of the full and the non-full flow, as shown in the expression, \(\frac{A}{gB}\) and \(\frac{gA}{B}\) are infinite, it seems impossible to achieve the full flow to the non-full flow transition, but the transition in the non-full flow of the meaning of the calculation major. The characteristic line equation near the junction point can be obtained by taking the point of intersection as the known point, supposing \(P\) point as the unknown point, and taking the point \(P\) from the point of intersection (full flow) 1/2 as the calculated section:

Where: \(\frac{4A_p + \pi D_p^2}{4B_p}\) from the corresponding cross-section \(Z_p\) to determine, that is

\[
\sqrt{\frac{4A_p + \pi D_p^2}{4B_p}} = f(Z_p)
\]

\(A_p\) and \(B_p\) are the cross-sectional area and water surface width of \(P\) section. In addition, the characteristic equation at the junction point there is another significance, is to determine the current flow of the cavity shape. Where \(u_A\) is the flow rate at the moment before the current interruption occurs, which is generally called the residual flow velocity.
When \( u = 0 \), there is \( Z_p = D \), indicating that there is no cut-off cavity appears, only the vaporized vaporization area; \( u > 0 \), \( D > Z_p > 0 \) is not completely broken, when \( u > 0 \), \( Z_p < 0 \), there will be a completely cut-off cavity appears. Of course, this is only a preliminary judgment, because the positive and negative \( Z_p \) is also affected by the size of the impact of \( \Delta \chi \) value.

4. The increase pressure of collapsing column

When the separation of two separate water column, it will produce a lot of pressure rise, which has been confirmed by theory and practice, but the general literature on the described is not very clear. Using momentum theorem. The calculation formula of the water hammer bridging the rising pressure can be obtained in the case of equal and unequal wave speeds of the water columns at both ends of the cavity. [6].

4.1. Bridging the step-up circuit breaker cavity ends velocity equal.

Firstly assumed, the two-separation column is closed in a horizontal pipe bridge, the contact section of the two water column is perpendicular to the bottom of the horizontal pipe, the instantaneous velocity before closing were \( V_1, V_2 \), velocity both were C. The additional pressure on the two ends of the water column after the closing time respectively( \( \Delta t \) moment) is H1, H2.

According to the momentum theorem, get

\[
\Delta Pdt = \rho A dx(V_1 - V) = \rho A dx(V - V_2)
\]

\[
g\Delta H \rho A dt = \rho A c dt(V_1 - V) = \rho A c dt(V - V_2)
\]

That is \( \Delta H g = c(V_1 - V) = c(V - V_2) \)

\[
\text{Solution:} V = \frac{V_1 + V_2}{2}, \Delta H = \frac{c(V_1 - V_2)}{2g}
\]

\[\text{Fig 2. Water column bridge}\]

\( V' \) for the two water column impact velocity of common movement. The pressure H1 and H2 reflected from the non-colliding ends of the two water columns are controlled by F (t) + f (t) in the 0 ~ \( \Delta t \) period of the collision between the two water columns. the flow velocity of the water column has been changed firstly. Its value can be obtained from the following formula:

\[
A\rho g(H_1 - H_2) dt = 2\rho A dx \Delta V
\]

\[
\Delta V = \frac{g(H_1 - H_2)}{2c}
\]
\( \Delta V \) is the additional flow rate change, caused by the additional pressure is increased to

\[
\Delta H = \frac{(H_1 + H_2)}{2}
\]  

(16)

The interrupted cavity for bridge boost:

\[
H = \frac{(V_1 - V_2)}{2g} + \frac{(H_1 + H_2)}{2}
\]  

(17)

The flow rate of the interrupted cavity was

\[
V = \frac{(V_1 + V_2)}{2} + \frac{(H_1 - H_2)}{2c}
\]  

(18)

4.2. Drying the cavity ends when the water column velocity ranging from bridge boost.

If the pipe diameter, and the drying cavity at both ends of the pipe wall thickness has a different, it will make both ends of water wave speed range, the water column bridge boost also changed. The same momentum theorem analysis, available:

① Two water column impact sound pressure

\[
\Delta H_1 = \frac{C_1 C_2 (V_1 - V_2)}{g(C_1 + C_2)}
\]  

(19)

② Additional pressurerise

\[
\Delta H_2 = \frac{(C_2 H_1 + C_1 H_2)}{(C_1 + C_2)}
\]  

(20)

③ Total pressure after closing

\[
H = \frac{C_1 C_2 (V_1 - V_2)}{g(C_1 + C_2)} + \frac{(C_2 H_1 + C_1 H_2)}{C_1 + C_2}
\]  

(21)

④ Flow velocity after closing

\[
V = \frac{(C_1 V_1 + C_2 V_2)}{C_1 + C_2} + \frac{g(H_1 - H_2)}{C_1 + C_2}
\]  

(22)

Where: \( C_1, C_2 \) respectively, cut-off cavity at both ends of the water column velocity.
5. Conclusion.
Based on the principle of propagation, reflection and superposition of water hammer waves, the water hammer was determined by two breakwaters. This paper puts forward a model for considering the free surface of water hammer, puts forward a formula for the increase in pressure, and then puts it into the calculation program.

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