Numerical Simulation Study on Hydraulic Transients in Hydropower Station with Trigeminy Surge Tank

Gaohui Li¹,², Fei Yang¹, Tianchi Zhou¹, Weijie Cui¹, Shaojia Yang¹,²,*

¹Powerchina Huadong Engineering Corporation Limited, Hangzhou 311122, China
²College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing 210098, China

*Corresponding author e-mail: yang_sj@hdec.com

Abstract. A static and dynamic model for hydraulic transient calculation of three-throttled-orifice surge tank was established based on the basic equations of surge tank, by using structure matrix method (matrix analysis of structure?). Control conditions in an engineering practice were calculated by a simplified model and a three-throttled-orifice model respectively. The results indicate that the maximum pressure at the volute end, the maximum rising rate of unit speed and the water level extremum of the surge tank are basically identical by using these two models, but the minimum pressure at draft tube inlet is significantly different. The three-throttled-orifice model was found capable of calculate the flow between throttled orifices at constant state and the pressure behavior at draft tube inlet during the transition accurately. The selection of the resistance factor is discussed in the end, and it is proved that the resistance factor is allowed to have a certain tolerance in the transition calculation, which will not obviously affect the maximum pressure at draft tube inlet and water level extremum of the surge tank. This research can provide reliable reference for the transient calculation of three-throttled-orifice surge tank in similar engineering practice.

1. Preface

In order to reduce carbon dioxide emissions and protect the ecological environment, China is actively developing green renewable energy. Hydropower is a mature green renewable energy source and has become a priority choice for the country. With the completion of a large number of water conservancy and hydropower projects such as the Three Gorges and Jinping II, most of the hydropower stations developed currently are pressurized diversion power stations in the southwestern region. These power stations often use long diversion tunnels or tailwater tunnels to obtain hydraulic head. For the long-water-type power station, unit load variety lead to change of opening degree of the turbine guide vane, which leads to frequent severe water hammer problem in the pressure pipeline, threatening the safe operation in the power station. An upstream or downstream surge tank is usually built in the water conveyance system to release water hammer pressure in the pipeline with its large cross-section and free surface. For hydropower station water supply systems in which multi-machine share one tail water tunnel, the impedance hole of the surge tank is usually placed on the branch pipe, and multiple units share one large surge tank through connecting pipes, such as Baihetan, Xiluodu, Longtan, etc. Fig. 1 shows a typical three-throttled-orifice surge tank.
Compared with common surge tank, more difficulty occurs in the numerical simulation of the hydraulic transition process in multi-pressure surge tank, and the main difficulty lies in the determination of the initial steady state. Taking three-throttled-orifice surge tank as an example, in the initial steady state, the head loss of each branch pipe may be different, and the impedance coefficients of the three impedance orifices may not be exactly the same, and the accurate calculation of inflow and outflow through the impedance orifice is most essential and difficult. Many scholars have studied this problem. In general, simplified process is taken for the calculation: the multiple impedance holes are combined and placed in the manifold, and the inertia of the water in the pressure surge chamber and the friction between the well wall and the water are not considered. Ju Xiaoming studied the hydraulic calculation of the impedance differential pressure surge chamber of a two-liter tube with an impedance orifice. Although the numerical simulation calculation is facilitated after the simplified processing, the water flow between the impedance orifices is neglected. In addition, Yu Xiaodong applied the method of characteristic to derive the mathematical model of the surge chamber in the form of post-chamber intersection, and studied the influence of the impedance orifice size on its transition process; He Dongyang adopted the state space method to study small fluctuation stability problem of the hydropower station in which the water conveyance system is intersect after the chamber, and the influence of the impedance orifice size on the system regulation quality. Liu Jiachun studied the transition process of the dual-machine co-tail water surge chamber, focusing on the surge tank surge problem in transition process.

According to the structural matrix method for complex waterway system calculation, a constant flow model and a transient process model for three-throttled orifice surge tank transition process calculation derived. Also, considering the large cross-sectional area of the three-throttled-orifice surge tank and the mild variation of the water level during the transition process, the transient process model is simplified appropriately. A computation program is developed for calculation in engineering practice, and numerical simulation is conducted for an engineering project, which proves that this model can provide satisfying simulation for the hydraulic transition process of three-throttled-orifice surge tank.

2. Model derivation
H. Brekke (reference) proposed a structural matrix method to develop computation models for complex waterway systems, which is applied to study the small fluctuation stability problem in hydropower stations. With similarity between pressurized water network systems and structural beams, it applies the rigid matrix method to establish mathematical models for complex pressurized waterway systems. Since the rigid matrix method in structural analysis is only applicable to linear conditions, the structural matrix method for waterway systems is only employed for small fluctuation analytical calculations of hydropower station systems at the beginning. In 1993, this method was extended to conduct mathematical models for large fluctuations in hydropower systems. Compared with the method of characteristics, the structural matrix method is more simple in programming and modularization.
2.1. Basic equations

Compared with common surge tank, the structural matrix of three-throttled-orifice surge tank is more complicated, but the principles are also based on the concept of hydraulic impedance. In addition, in specific treatment, there are also something simpler for three-throttled-orifice surge tank: the cross-section size of the ordinary pressure surge tank is often small, so it is necessary to calculate the inertia of the water inside and consider the damping effect and other factors of the wall; while three-throttled-orifice surge tank has larger horizontal cross-section, the water level varies slowly during the fluctuation process, and the flow velocity inside is extremely small. Considering the flow velocity inside has little significance in engineering practice, the inertia and damping effect of the wall can be ignored. Therefore, the hydraulic impedance of the three-throttled-orifice surge tank is mainly the hydraulic impedance of the three impedance ports. A brief calculation diagram for the three-throttled-orifice is shown in Fig. 2.

\[ H_4 - H_i = k_i |Q_i|Q_i \]  
\[ H_4 - H_2 = k_2 |Q_2|Q_2 \]  
\[ H_4 - H_3 = k_3 |Q_3|Q_3 \]  
\[ A \frac{dH_4}{dt} = -Q_4 = -(Q_1 + Q_2 + Q_3) \]

where \( H_1, H_2, \) and \( H_3 \) are the heads at joints of three impedance orifices and the pipe; \( Q_1, Q_2, \) and \( Q_3 \) are the flowrate at the joints of three impedance orifices and the pipe; \( H_4 \) is the head of the surge tank; \( Q_4 \) is the flow rate in the tank; \( k_1, k_2, \) and \( k_3 \) are impedance coefficients of three impedance orifices respectively; \( A \) is the cross-sectional area of the surge tank.

In the iterative calculation process, for the flowrate at each impedance orifice, the current \( Q_i \) (\( i = 1, 2, 3 \)) can be obtained from the previous \( Q_{i0} \), so the following approximation can be made for the equation (1):

\[ H_4 - H_i = k_i |Q_i|Q_i = k_i |Q_{i0} + \Delta Q||Q_{i0} + \Delta Q|| \approx 2k_i |Q_{i0}|Q_i - k_i |Q_{i0}|Q_{i0} \]

yields

\[ H_4 - H_1 = 2k_1 |Q_{i1}|Q_{i0} - (H_{i0} - H_{i0}) = \]
\[ 2k_1 |Q_{i1}|Q_{i0} - 2k_1 |Q_{i0}|Q_{i0} \]
\[ H_4 - H_2 = 2k_2 |Q_{i2}|Q_{i0} - (H_{i0} - H_{i0}) = \]
\[ 2k_2 |Q_{i2}|Q_{i0} - 2k_2 |Q_{i0}|Q_{i0} \]
\[ H_4 - H_3 = 2k_3 |Q_{i3}|Q_{i0} - (H_{i0} - H_{i0}) = \]
\[ 2k_3 |Q_{i3}|Q_{i0} - 2k_3 |Q_{i0}|Q_{i0} \]

Then let \( R_1 = 2k_1 |Q_{i1}|, R_2 = 2k_2 |Q_{i2}|, R_3 = 2k_3 |Q_{i3}| \), and bring it into equation (3), yields:
Equation (1-4) and equation (4) make up the basic mathematical model for the calculation of the transition process of the three-throttled-orifice surge tank. Based on these four equations, the static and dynamic models of the triplex surge chamber are derived.

2.2. Static model for constant flow state
When the water conveyance system is at a constant flow state, the water level in the pressure surge tank remains unchanged, and the total flow rate of the surge tank is \( Q_4 = 0 \), so it can be obtained by equation (1-4):

\[
Q_1 + Q_2 + Q_3 = 0 \tag{12}
\]

Substitute equation (5) into equation (4), and transform equations into matrix form, yields

\[
\begin{bmatrix}
Y_{11} & Y_{12} & Y_{13} \\
Y_{21} & Y_{22} & Y_{23} \\
Y_{31} & Y_{32} & Y_{33}
\end{bmatrix}
\begin{bmatrix}
H_1 \\
H_2 \\
H_3
\end{bmatrix}
= \begin{bmatrix}
Y_{11} & Y_{12} & Y_{13} \\
Y_{21} & Y_{22} & Y_{23} \\
Y_{31} & Y_{32} & Y_{33}
\end{bmatrix}
\begin{bmatrix}
Q_1 \\
Q_2 \\
Q_3
\end{bmatrix}
+ \begin{bmatrix}
Y_{11} & Y_{12} & Y_{13} \\
Y_{21} & Y_{22} & Y_{23} \\
Y_{31} & Y_{32} & Y_{33}
\end{bmatrix}
\begin{bmatrix}
H_1 \\
H_2 \\
H_3
\end{bmatrix}
- \begin{bmatrix}
Q_{10} \\
Q_{20} \\
Q_{30}
\end{bmatrix} \tag{13}
\]

Where

\[
Y_{11} = -\frac{R_2 + R_3}{R_1R_2 + R_2R_3 + R_1R_3},
\]

\[
Y_{12} = \frac{R_3}{R_1R_2 + R_2R_3 + R_1R_3},
\]

\[
Y_{13} = \frac{R_2}{R_1R_2 + R_2R_3 + R_1R_3},
\]

\[
Y_{22} = -\frac{R_1 + R_3}{R_1R_2 + R_2R_3 + R_1R_3},
\]

\[
Y_{23} = \frac{R_1}{R_1R_2 + R_2R_3 + R_1R_3},
\]

\[
Y_{11} = -\frac{R_3 + R_2}{R_1R_2 + R_2R_3 + R_1R_3},
\]

\[
Y_{21} = Y_{12}; Y_{31} = Y_{13}; Y_{23} = Y_{32}.
\]

Where \( H_{i0} \) is the water head of the previous iteration step; \( Q_{i0} \) is the flowrate of the previous iteration step.

Equation (6) is the boundary connection matrix of the three-throttled-orifice surge tank at constant flow state. Substituted it into the matrix of the water supply system, the head and flowrate of each impedance orifice and the surge tank at the initial moment can be solved.

2.3. Dynamic model for hydraulic transients
During the transition process, the water flows into or out the surge chamber through the impedance orifice, and the water level in the surge chamber fluctuates. Integrate time \( t \) to formula (1-4) and take a second-order approximation yields:

\[
H_4 - H_{40} = \frac{-\Delta t}{2A} \left[ (Q_1 + Q_2 + Q_3) + (Q_{10} + Q_{20} + Q_{30}) \right] \tag{14}
\]
Equations at the initial moment, the previous moment, and the current moment can be derived from equation (7):

\[ H_{40} - H_{4t-} = \]
\[ \frac{dt}{2A} \left[ (Q_{1t-}+Q_{2t-}+Q_{3t-}) + (Q_{10}+Q_{20}+Q_{30}) \right] \]

\( (15) \)

\[ H_4 - H_{4t-} = \]
\[ \frac{dt}{2A} \left[ (Q_{1t-}+Q_{2t-}+Q_{3t-}) + (Q_1+Q_2+Q_3) \right] \]

\( (16) \)

Where \( H_{it-} \) is the the head at the previous moment, and \( Q_{it-} \) is the flowrate at the previous moment, \( (i=1\sim4) \).

From equation (8) and (9), we have

\[ H_4 - H_{40} = \]
\[ \frac{dt}{2A} [(Q_1+Q_2+Q_3)-(Q_{10}+Q_{20}+Q_{30})] \]

\( (17) \)

Substituting equation (10) into equation (6) and transform the equations into matrix form, yields

\[
\begin{bmatrix}
Y_{11} Y_{12} Y_{13} \\
Y_{21} Y_{22} Y_{23} \\
Y_{31} Y_{32} Y_{33}
\end{bmatrix}
\begin{bmatrix}
H_1 \\
H_2 \\
H_3
\end{bmatrix} =
\begin{bmatrix}
Y_{11} Y_{12} Y_{13} \\
Y_{21} Y_{22} Y_{23} \\
Y_{31} Y_{32} Y_{33}
\end{bmatrix}
\begin{bmatrix}
Q_1 \\
Q_2 \\
Q_3
\end{bmatrix} +
\begin{bmatrix}
Y_{11} Y_{12} Y_{13} \\
Y_{21} Y_{22} Y_{23} \\
Y_{31} Y_{32} Y_{33}
\end{bmatrix}
\begin{bmatrix}
H_{10} \\
H_{20} \\
H_{30}
\end{bmatrix} -
\begin{bmatrix}
Y_{11} Y_{12} Y_{13} \\
Y_{21} Y_{22} Y_{23} \\
Y_{31} Y_{32} Y_{33}
\end{bmatrix}
\begin{bmatrix}
Q_{10} \\
Q_{20} \\
Q_{30}
\end{bmatrix}
\]

\( (18) \)

Where

\[ Y_{11} = \frac{1}{\left( \frac{2A}{dt} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) R_1^2 - \frac{1}{R_1}} \]
\[ Y_{12} = \frac{1}{\left( \frac{2A}{dt} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) R_1 R_2} \]
\[ Y_{13} = \frac{1}{\left( \frac{2A}{dt} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) R_1 R_3} \]
\[ Y_{22} = \frac{1}{\left( \frac{2A}{dt} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) R_2^2 - \frac{1}{R_2}} \]
\[ Y_{23} = \frac{1}{\left( \frac{2A}{dt} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) R_2 R_3} \]
\[ Y_{33} = \frac{1}{\left( \frac{2A}{dt} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) R_3^2 - \frac{1}{R_3}} \]

Equation (11) is an accurate simulation model of three-throttled-orifice surge tank in hydraulic transient process. The cross-sectional area of three-throttled-orifice surge tanks in practical projects are usually large. When applying small time steps, the water level variation during the transient process in the surge tank is negligible, which makes it possible to simplify the model. The simplification process will be presented in the follow. The principle of simplification is: \( Q_{i0} \) \( (i=1\sim3) \) is only related to \( H_1, H_2, H_3 \) and \( H_{40} \) in each iteration step.

Since \( H_{40} \) is the result of the previous iteration step, it is irrelevant to result of this step. Let \( H_4=H_{40} \), then the relation between 6 variables \( H_{i0}, Q_{i0} \) \( (i=1,2,3) \) becomes simple, that is, \( H_1 \) is related to \( Q_1 \), and \( H_2 \) is related to \( Q_2, H_3 \) is related to \( Q_3 \), and other combinations are irrelevant, therefore formula (6) can be written as:

\[ -H_1 = R_1 (Q_1 - |Q_{10}|) \quad Q_{10} - H_{10} \]

\( (19) \)
22 \begin{align}
H_2 &= R_2(Q_2 - Q_{20}) \quad Q_{20} - H_{20} \\
H_3 &= R_3(Q_3 - Q_{30}) \quad Q_{30} - H_{30}
\end{align}

Write the system of equations as a matrix:

\[
\begin{bmatrix}
Y_{11} & Y_{12} & Y_{13} \\
Y_{21} & Y_{22} & Y_{23} \\
Y_{31} & Y_{32} & Y_{33}
\end{bmatrix}
\begin{bmatrix}
H_1 \\
H_2 \\
H_3
\end{bmatrix}
= \begin{bmatrix}
Q_1 \\
Q_2 \\
Q_3
\end{bmatrix}
+ \begin{bmatrix}
Y_{11} & Y_{12} & Y_{13} \\
Y_{21} & Y_{22} & Y_{23} \\
Y_{31} & Y_{32} & Y_{33}
\end{bmatrix}
\begin{bmatrix}
H_{10} \\
H_{20} \\
H_{30}
\end{bmatrix}
- \begin{bmatrix}
Q_{10} \\
Q_{20} \\
Q_{30}
\end{bmatrix}
\]  

(22)

Where

\[Y_{11} = -\frac{1}{R_1}; \quad Y_{22} = -\frac{1}{R_2}; \quad Y_{33} = -\frac{1}{R_3};\]

\[Y_{21} = Y_{12} = Y_{31} = Y_{13} = Y_{33} = Y_{32} = 0\]

Formula (13) is a numerical calculation model of the three-throttled-orifice surge tank that can be used for actual engineering calculations. It is substituted into the matrix of the water delivery system. Combined with the initial conditions, each impedance orifice and pressure regulation can be solved at each moment.

3. Practical application

3.1. Project Background

A power station is equipped with three 800 MW Francis turbines with a total installed capacity of 2,400 MW and a rated turbines flow of 437.9 m³/s. The power station diversion tunnel adopts single-machine and single-hole water supply, and the tail water system adopts a layout scheme in which three units share one tail water hole. A long corridor-shaped impedance tail water surge tank is arranged above the tail water support hole. The distance between the tail water surge chamber and the plant centre line is 150.0 m. The size of the surge tank is 25 m × 105 m, with the lower part of the surge tank divided into 3 chambers by 2 partition walls, and a tail pipe maintenance gate is provided at the upstream side of the pressure surge tank. The gate well also serves as an impedance orifice, whose size is 3 m×14.4 m and the net area is 42.24 m².

3.2. Calculation of large fluctuation transients

According to the static and dynamic models of the three-throttled-orifice surge tank derived above, two situations are considered, that is, simulating the large fluctuation transition process with the simplified model and the triple model, in the former the impedance holes are considered as one and placed at the manifold position and the latter represents three-throttled-orifice surge tank. The simplification principle is that the area of the single impedance hole in the simplified model is equal to the sum of three impedance areas in the three-throttled-orifice surge tank.

Calculated working conditions: normal upstream water level is 825.00 m, normal downstream tail water level is 583.81 m, and three machines are operated at a rated output of 1000 MW. When all the units reject all the load in a sudden, the unit guide vanes are closed in a straight line for 13 s.

|          | The maximum pressure at the volute end (m) | The maximum rising rate of unit speed (%) | The minimum pressure at draft tube inlet (m) |
|----------|------------------------------------------|------------------------------------------|--------------------------------------------|
|          | simplified      | triple       | simplified      | triple       | simplified      | triple       |
| 1#       | 267.80          | 267.08       | 38.26           | 37.33        | -3.85           | -0.55        |
| 2#       | 269.32          | 268.83       | 38.38           | 37.78        | -2.97           | -0.49        |
| 3#       | 270.86          | 270.77       | 38.66           | 37.87        | -3.27           | -0.39        |
(a) Process line of the inlet pressure of the draft unit of Unit 1 over time

(b) Process line of water level in the surge tank over time

(c) Three-throttled-orifice surge tank model impedance orifice flow into the surge chamber flow over time process line

Fig. 3 Calculation results of the transition process of the two models

It can be seen from the results in Table 1 that for calculation of large fluctuation transition process in three-throttled-orifice surge tank, the maximum pressure at the end of the volute and the maximum unit speed growth rate have little difference between the simplified treatment of combining the impedance orifices and the treatment as actual situation. The reason is that the maximum unit speed growth rate is less affected by the surge tank, and the surge tank is placed above the tail water system, which has no capability in adjusting the pressure at the end of volute. Therefore, for the maximum pressure at the end of volute and the maximum unit speed growth rate, the two models have the similar results. However, while the minimum pressure at the draft tube inlet is of interest, the calculation results from the two models differ greatly.

The influence of the surge tank on the pressure at draft tube inlet consists of two stages: the water hammer wave stage and the surge wave stage. While the guide vane is not completely closed, which is the water hammer wave stage, the area of the impedance hole of the surge tank and the impedance
coefficient govern the reflection effect on water hammer, and it turns effect on the pressure at the draft tube inlet; and the surge wave stage begins after the guide vane completely shut down, the water level variation in the surge tank affects the pressure at the draft tube, in this stage, pressure at the draft tube inlet changes as the water level in the surge tank fluctuates. In order to find the specific reasons, the process lines of pressure at the draft tube inlet, water level and inflow (or outflow) at the surge tank of Unit 1 is drawn in Fig. 3.

Fig. 3(a) illustrates that for the calculation of the large fluctuation transition process of three-throttled-orifice surge tank hydropower station, there is no difference in the initial value of the tail water inlet pressure between the simplified model and the triple model while the difference during the transition process is significant. Specifically, before the vanes are completely closed, the pressure drop at the draft tube inlet of the triple model is smaller than that of the simplified model, indicating it has better behaviour on the water hammer reflection; as the vanes closed completely, the pressure at the draft tube inlets of the two models has little difference, and it was expressed as a cyclical fluctuation of water level in the surge tank. For the minimum pressure at the draft tube inlet, the results of the simplified model calculation are more dangerous than the triple model.

Fig. 3(b) shows that the initial values of the water level in the surge tank obtained by the two models are different, which is due to the hydraulic loss at surge tank in these two models is not equal. If the influence of the initial value is neglected, the water level fluctuation in the surge tank is almost identical. The reason is that the sum of three impedance orifices cross-section area in the three-throttled-orifice surge tank is equal to the area of the large impedance orifice in the simplified model. Hence, when the three units reject load suddenly simultaneously, the total amount of inflow (or outflow) in the surge tank is almost equal. As shown in Fig. 3(c), water level fluctuation process at the surge tank matches well.

In summary, compared with the load rejection process simulation results of the simplified model, the triple model can reflect flow state at the bottom of surge tank in steady condition more accurately, and reflect the variation of tail water pressure during the transition more realistically. Specifically, if the water level change in the surge tank is the only factor considered, the simplified model is consistent with the calculation result from the triple model if the impedance orifice areas are consistent. However, for the tail water inlet pressure, the calculation result of the simplified model is not reliable, and the triple model is closer to practical scenario.

3.3. Influence of impedance coefficient on water level in surge tank

In the previous section, the impedance coefficients of the impedances at the three-throttled-orifice surge tank are assumed to be same. In engineering practice, the impedance coefficients at the three impedance orifices may not be exactly the same. The change of the impedance pore coefficient will not only affect the flowrate at each orifice at constant flow state, but also affect the water level extremum in the surge tank during the transition process. In order to analyse the influence of the impedance coefficient variation on the transition process simulation, rejecting load transition process under measured value and average value of the impedance coefficient are calculated respectively.

The actual value and the average value of the impedance coefficient are taken for calculation. The calculation conditions are the same as the last section. The initial steady state calculation results are presented in Table 3.
Table 3. Initial steady state flow rate of each orifice and water level of surge tank

| Unit | Impedance hole flow (m³/s) | Pressure tank water level (m) |
|------|---------------------------|-----------------------------|
|      | Measured value | average value | Measured value | average value |
| 1#   | -70.32     | -74.85    | 582.97 | 582.97 |
| 2#   | 37.69      | 44.76     | 582.97 | 582.97 |
| 3#   | 32.63      | 30.09     |          |           |

Table 2 indicates that different impedance hole coefficients can significantly affect the flow rate at each orifice in the steady state, but the influence on the water level of the surge tank under the constant flow state is extremely small, since the impedance coefficient of the impedance hole has less effect on the head loss at the surge tank under steady state.

During the transition process, the water level in the surge tank and the flowrate at the impedance orifice are shown in Table 4 and Fig. 4.

Table 4. Calculation results of transition process of different impedance coefficients

| Unit | the maximum pressure at the volute end (m) | the maximum rising rate of unit speed (%) | minimum pressure at draft tube inlet (m) |
|------|--------------------------------------------|------------------------------------------|----------------------------------------|
|      | Measured value | average value | Measured value | average value | Measured value | average value |
| 1#   | 267.08 | 267.04 | 37.29 | 37.30 | -0.81 | -0.92 |
| 2#   | 268.59 | 268.64 | 37.74 | 37.72 | -0.98 | -0.87 |
| 3#   | 270.46 | 270.52 | 38.00 | 37.97 | -0.99 | -0.86 |

Fig. 4 Calculation results of transition process of impedance coefficient of different impedance holes

Table 4 shows that the impedance coefficient of impedance orifice at triple surge chamber has relatively small influence on maximum pressure at the end of volute, the maximum unit speed growth rate, and the minimum pressure at the draft tube inlet of the unit during the load rejection transition process calculation. The inflow (and outflow) rate at the pressure surge tank fluctuates with the water level variation. This shows that the impedance coefficients of impedance holes at three-throttled-orifice surge tank have little effect on the accuracy of the simulation though the value chosen may differ from the reality. Therefore, the impedance coefficient can come out from engineering experience or numerical simulation results in the model calculation.

4. Conclusion

Based on the structure matrix method, the constant flow state model and transient process model for transition process calculation in three-throttled-orifice surge tank are derived, and a simplified mode for transient process is also given. An accurate model for three-throttled-orifice surge tank transient process simulation is obtained. The calculation results of the triple model for a typical engineering condition are compared with the results from the simplified model to verify the accuracy of the triple model. The
impedance coefficients value choice of the impedance holes in the triple model is analyzed and the conclusions are as follows:

(1) The triple model can reflect the flow state at the bottom of the surge tank more accurately in a stable working condition, reflecting the variation of the tail water pressure during the transition better. If only the water level fluctuation in the surge tank is considered, the results from simplified model is consistent with the calculation results from the triple model as long as the impedance orifice areas are consistent. As for the minimum pressure at the tail water inlet, the calculation results from the simplified model is less reliable, and the triple model simulates the practical condition better.

(2) In the transition process simulation, the impedance coefficients of impedance holes at three-throttled-orifice surge tank does not affect the accuracy of the simulation results though its value may differ from the reality. The impedance coefficient can come out from engineering experience or results obtained by numerical simulation.

In addition, the small fluctuation problem of the triple model is more complicated than the simplified model, and it is necessary to conduct further research on the small fluctuation transition process.

References
[1] Wu Jiang, Yang Jiandong. Three-dimensional Flow Field Analysis of Erect Swirl in Strip-shaped and Restricted-orifice Surge Chamber [J]. International Journal Hydroelectric Energy, 2008(4): 105-107.
[2] Cheng Yongguang, Liu Xiaofeng, Yang Jiandong. Optimization of the converging type of conduit of tailrace surge tank by CFD method [J]. Journal of Hydroelectric Engineering, 2007(5): 68-74.
[3] Ju xiaoming, Chen jiayuan. A Hydraulic Calculation Study on New type Differential Surge Tank [J]. Journal of Hydroelectric Engineering, 1996(4): 54-60.
[4] YU Xiaodong, ZHANG Jian, CHEN Sheng. Hydraulic transients in hydropower station with bifurcated pipes converging behind tailrace surge tank [J]. Journal of Hydroelectric Engineering, 2014, 33(6): 142-148.
[5] He Dongyang, Zhang Jian, Yu Xiaodong, et al. Influence of Impedance Orifice Size on Hydraulic-mechanical System in Hydropower Station with Long Corridor Tailrace Surge Chamber [J]. International Journal Hydroelectric Energy, 2016, 34(11): 171-174.
[6] Liu Jiachun, Zhang Jian, Yu Xiaodong. Study on transition process of tailrace overflow surge chamber shared by two units [J]. Yangtze River, 2016(10): 72-75.