Modeling and Simulation of Hydropower Station Diversion System's characteristic line method by introducing water head to flow feedback

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Abstract. To solve the damping problem of water hammer wave in the modeling method of water diversion system of hydropower station, this paper introduces the feedback regulation technology from head to flow, that is: A fixed water head is taken out for flow feedback, and the following conclusions are obtained through modeling and simulation. Adjusting the feedback coefficient F of the water head to the flow rate can change the damping characteristic of the system, which can simulate the attenuation process of the water shock wave in the true water diversion pipeline. Even if a small feedback coefficient is introduced, the damping effect of the system is very obvious, but it has little effect on the amplitude of the first water shock wave after the transition process. Therefore, it is feasible and reasonable to introduce water head to flow rate feedback coefficient F in hydraulic turbine diversion system.

1 Introduction

In order to make rational use of water energy and take account of the feasibility and economy of hydropower development, the layout and structure of diversion system of hydropower stations are usually varied. Generally speaking, it is mainly composed of upstream and downstream reservoirs, pressure conduit, turbine runner and draft tube [1]. A simple single pipe and single machine diversion system is simply shown in Figure 1.
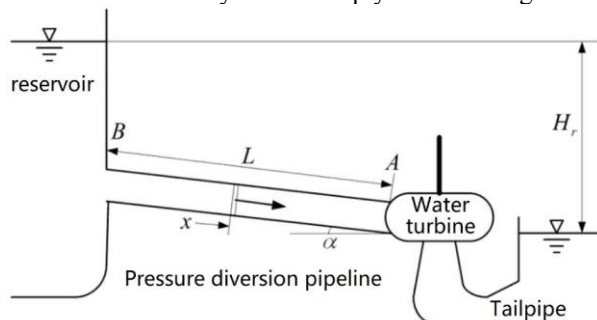

Fig. 1. Water diversion system of a typical hydropower station.

For the modeling or calculation method of the water diversion system, the linear transfer function description method [2] can be used when the length of the pipe is less than 600~800 meters. If the diversion pipe is longer, the effect of the elastic water hammer.

should be considered [3-5], and the characteristic line method is usually used. It is pointed out that when the flow of water in the diversion pipeline is rapidly cut off, the pressure wave in the pipeline is very slow, which is not consistent with the actual situation. In order to overcome these defects, in the nonlinear simulation calculation of the hydraulic turbine governing system, this paper improves the characteristic line method, and introduces the water head to the flow feedback to the modeling of the water diversion system of the hydropower station, and the simulation is carried out. The results are reasonable and credible.

2 Basic characteristic line method and calculation example

2.1 An example of the basic characteristic line method

The basic characteristics of line method for modeling as shown in Figure 2, figure symbol "| - |" absolute value calculation
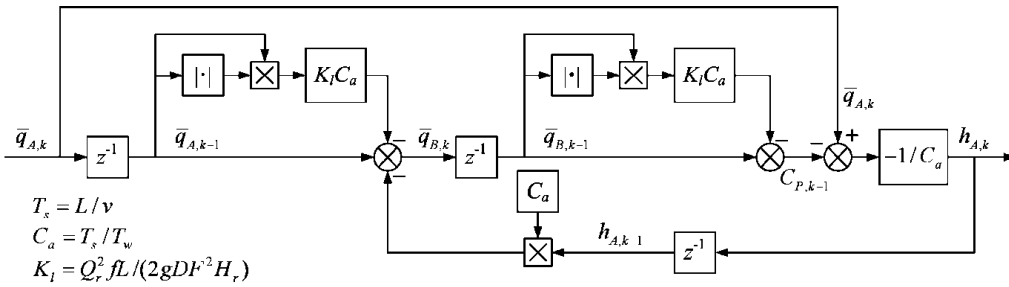

Fig. 2. The basic characteristic line block diagram for single section calculation of simple water diversion pipeline.

2.2 Calculation example

The parameters of a hydraulic turbine guide system are as follows: the length of the equivalent water diversion pipe: L=200 meters; water hammer wave speed: V=1000 M / sec; calculation step length: T_s=L/v=0.2; the speed constant of water flow: T_w=2 seconds; the water head

loss coefficient is K_l=0.02 and K_l=0.1, respectively, assuming that the flow of the turbine is proportional to the opening of the relay, and is linear from full open to full or full off in 5 seconds. The initial conditions of all the variables were 0. The simulation results are shown in Figure 3 and Figure 4.
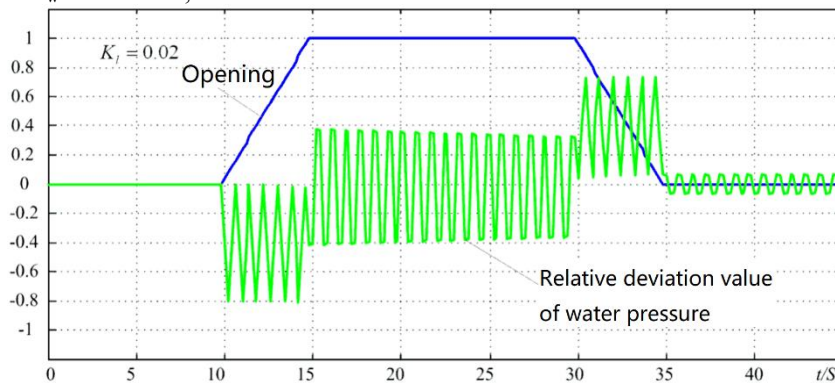

Fig. 3. Water pressure deviation response process of basic characteristic line method at K_l=0.02.
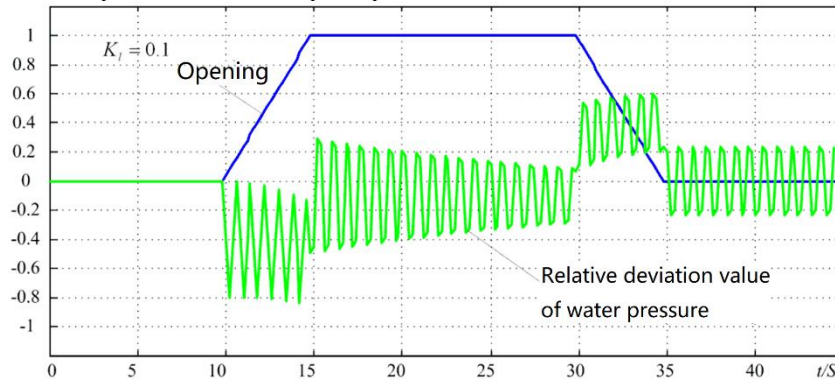

Fig. 4. Water pressure deviation response process of basic characteristic line method at K_l =0.1.

As can be seen from Figure 3 and Figure 4, the basic characteristic line method discussed can show the properties of elastic water hammer, but the elastic water strike wave attenuates slowly and the damping is smaller, especially after the water flow is cut off. This situation is usually not in conformity with the reality. It is generally considered that the attenuation of elastic water hammer wave is related to the head loss coefficient Kl, and the larger the head loss coefficient is, the faster the attenuation is. However, the two diagram shows that the underdamped condition has a certain relationship with the water head loss coefficient, but the correlation is not significant. Even if the K_l is increased from 0.02 to 0.1, the damping condition does not improve when the flow is cut off. This further verifies the damping problem of the head wave in the basic characteristic line method

proposed at the beginning of this section, especially after the sudden flow cut-off.

3 Improved characteristic line method and its calculation example

3.1 A linear discrete model with water head to flow feedback

Since the damping of the head wave has little relation with the loss coefficient of the head, the water head loss item in the characteristic line algorithm can be removed and the linear model based on the characteristic line method is established. Moreover, based on the linear model, it is easy to control damping and transform the sampling period. On the basic characteristic line block

diagram of single section calculation of water diversion pipeline, after removing the head loss item and

introducing the feedback from water head to flow, the algorithm block diagram is changed to figure 5.
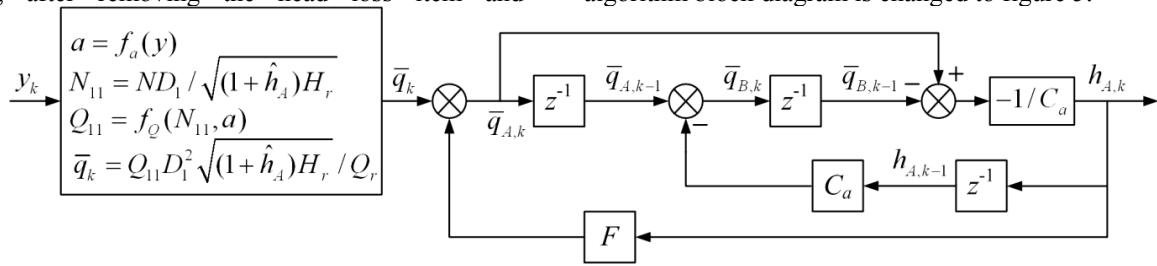
Fig. 5. Water pressure deviation response process of basic characteristic line method at K_l =0.1.

In Figure 5, F is the feedback coefficient of additional water head to flow, $\overline{q}_k$ is the relative flow volume of turbine and $\hat{h}_A$ is the estimated value of water head increment during iteration. Here we only discuss the linear model from the $\overline{q}_k$ to $h_{A,k}$ .First, we write the discrete form of the system (Z transfer function) equation according to the 5 column of block diagram.

$$Q_B(z) = Q_A(z)z^{-1} - C_a H_A(z)z^{-1} \qquad (1)$$

$$H_A(z) = -\frac{1}{C_a}(Q_A(z) - Q_B(z)z^{-1}) \qquad (2)$$

$$Q_A(z) = FH_A(z) + Q(z) \qquad (3)$$

For the sake of derivation, the Z transformation of all variables is expressed by capitalized letters of variables. Take (3) into (2) and (1).

$$Q_B = (FH_A + Q)z^{-1} - C_a H_A z^{-1} \qquad (4)$$

$$H_A = -\frac{1}{C_a}(FH_A + Q - Q_B z^{-1}) \qquad (5)$$

Then bring (5) into (4)

$$H_A = \frac{1}{C_a}(-FH_A - Q + FH_A z^{-2} + Qz^{-2} - C_a H_A z^{-2})$$

After arranging

$$(F + C_a - (F - C_a)Z^{-2})H_A = Q(-1 + Z^{-2})$$

The corresponding Z transfer function is

$$G(z) = \frac{H_A(z)}{Q(z)} = \frac{-1 + z^{-2}}{(F + C_a - (F - C_a)z^{-2})} \qquad (6)$$

If F = 0, it is equivalent to the case of no additional water head to the feedback coefficient of flow, which is equivalent to the basic characteristic algorithm model without considering head loss.

$$G(z) = \frac{H_A(z)}{Q(z)} = \frac{H_A(z)}{Q_A(z)} = \frac{1}{C_a} \frac{-1 + z^{-2}}{1 + z^{-2}} \qquad (7)$$

3.2 Calculation example

In order to verify the feasibility of the proposed method, the improved characteristic line method is simulated by combining 2.2 sections of turbine intake system parameters.

The feedback coefficients of the head to flow are taken as F = 0, F = 0.001, F = 0.01 and F = 0.1, and assume that the flow of the turbine is proportional to the opening of the relay and linearly from full open to full or full off in 5 seconds. The initial conditions of all the variables were 0. The simulation results are shown in figure 6~9.

When the feedback coefficient is F = 0, the system is unstable and its time domain response is an obvious equal amplitude oscillation. With the increase of the feedback coefficient, the damping of the response output increases and the attenuation accelerates. When the feedback coefficient is F = 0.1, the system has the characteristic of over damping and has no oscillation characteristics; the adjustment of the feedback coefficient F can change the damping characteristic of the system and thus can change the damping characteristic of the system. The attenuation process of water hammer wave in real water diversion pipeline is simulated. Even if a small feedback coefficient is introduced, it is very obvious to increase the damping of the system, but it has little effect on the amplitude of the first water shock wave after the transition process. Therefore, it is feasible and reasonable to introduce water head to flow rate feedback coefficient F in hydraulic turbine diversion system.
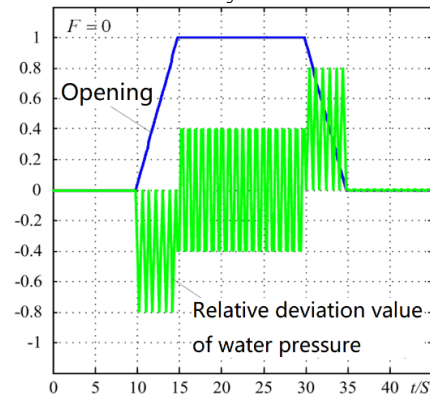
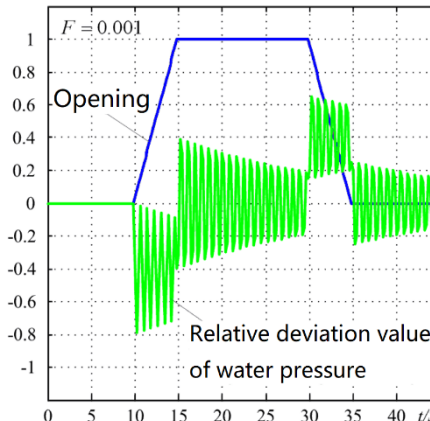

Fig. 6. Response of the system to feedback，F=0.

Fig. 7. Response of the system to feedback，，F=0.001。
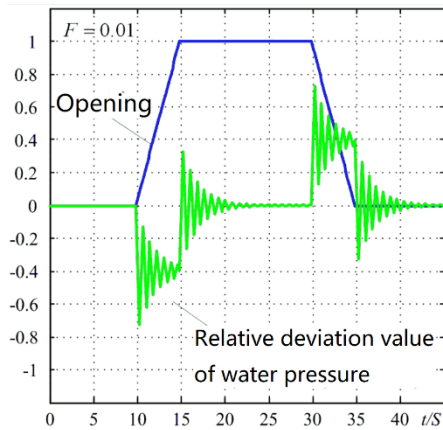
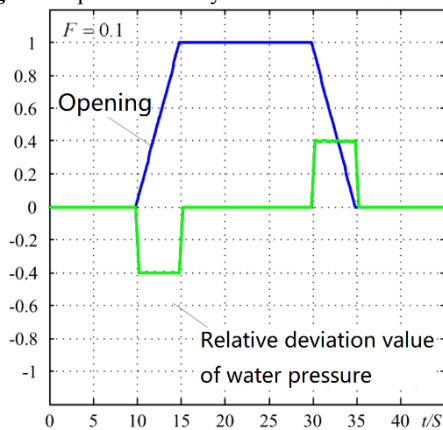**Fig. 8.** Response of the system to feedback，F=0.01.

Fig. 9. Response of the system to feedback，F=0.1.

4 Conclusion

The modeling method of water diversion system of hydropower station, that is, the characteristic line method, even to the solution of a pair of nonlinear hyperbolic partial differential equations, is to solve the damping problem of water shock wave. In this paper, the feedback regulation technology of water head to flow is introduced in this paper, and a fixed head of water head is taken out to feed back the flow. The results show that the reasonable feedback coefficient is helpful to the damping of water shock wave. The modified model is reasonable. The adjustment of the feedback coefficient F can change the damping characteristic of the system, which can simulate the attenuation process of water shock wave in the true water diversion pipeline. Even if a small feedback coefficient is introduced, the damping effect of the system is very obvious, but the amplitude of the first water shock wave after the transition process has little effect. Therefore, it is feasible and reasonable to introduce water head to flow rate feedback coefficient F in hydraulic turbine diversion system.

Acknowledgments

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