Analysis of Transient Pressure Source Characteristics of Trim Balance Pipeline System

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Abstract. Based on the hydraulic calculation of AMEsim software, adjust the pipeline and working conditions of the trim balance system, and explore the influence of water transfer pressure, pipeline length and valve closing time on the transient pressure fluctuation during the working process, and obtain the pressure change law and corresponding Relationship, according to the analysis gives preliminary optimization suggestions, sums up the scheme and scope of reducing water transfer pressure, shortening pipeline length, extending valve closing time, providing reference for optimizing system design and control, and proposing control from noise source level. The method of transient noise caused by water hammer phenomenon provides an idea for controlling the transient noise of pressurized pipelines of ships and underwater vehicles.

1. Introduction

The trim balance system is part of the pipeline system of the ship and the underwater vehicle. It consists of a high-pressure airline and a water-conveying line. The high-pressure air is passed into the water tank to press the water into the other side tank. The center of gravity is adjusted to balance the moment generated by the inclination of the pitch position due to various factors during navigation. Due to the characteristics of its emergency response, the flow rate in the water pipeline is very fast during the water transfer process, and the valve is suddenly opened and closed, which is prone to water hammer. The occurrence of water hammer not only causes great noise to affect the comfort of the ship and the concealment of the ship, but also causes great damage to the pipeline system and affects its reliability.

2. Calculation of transient flow in pressurized pipeline

The transient flow of a pressurized pipeline follows three basic laws of fluid mechanics: mass conservation, energy conservation, and momentum conservation. The momentum equation and the continuity equation can be obtained by combining the state equations as follows.

\[ pA = \left[ pA + \frac{\partial(pA)}{\partial x} \right] + \left( p + \frac{1}{2} \frac{\partial p}{\partial x} \right) \frac{\partial A}{\partial x} dx - \tau_0 \pi D dx - \rho g A x \cdot \sin \alpha = \rho A dx \frac{\partial V}{\partial t} \]  

\[ \frac{\partial p}{\partial t} + \frac{\partial A}{\partial t} + \frac{d(\delta l)}{dt} = 0 \]  

\[ (1) \]  

\[ (2) \]
Where: \( p \) is the section pressure, \( A \) is the section area, \( \tau_0 \) is the shear stress, \( D \) is the section inner diameter, \( \rho \) is the fluid density, \( V \) is the section flow velocity, \( g \) is the gravity acceleration, and \( \delta l \) is the length of the water flow micro section. Where \( \tau_0 \) is determined by the Darcy-Weisbach formula \( \tau_0 = \rho f V |V| / 8 \) with a friction coefficient \( f \).

Since the calculation needs to consider the influence of the material of the pipeline, the wave velocity formula is introduced, that is, the velocity wave propagation velocity for the transient flow in the thin-walled elastic circular tube is \( a = \sqrt{(K / \rho) / (1+KD / Ee)} \). \( e \) is the wall thickness; \( K \) is the fluid volume modulus; \( \rho \) is the fluid density; \( D \) is the inner diameter of the pipeline; \( E \) is the Young's modulus of the pipeline material; \( \mu \) is the hydrodynamic viscosity, and the dynamic viscosity of the water at 25°C is \( 0.8949 \times 10^{-3} \text{Pa·s} \).

In the calculation of the software, it is necessary to directly input the calculation result. The pipeline is set to a pipe wall thickness of 4 mm and an inner diameter of 100 mm. The round pipe of stainless steel material is calculated according to the relevant material parameters and the wave velocity is about 1481 m/s.

According to the description of the trim balance system in the searchable data, the default relevant parameters in the simulation calculation are set as follows.

| Table 1. Default parameter. |
|-----------------------------|
| Parameter                 | Water transfer pressure | Pipe length | Valve closing time |
| Numerical value            | 0.5MPa                  | 50m         | 1s                 |

3. Influence of pipeline water transfer pressure on transient pressure pulsation

Generally speaking, the balanced water transfer process will adopt a high-pressure air transfer method. The high-pressure air system is connected to the top of the tank through a four-way ball valve, the other side of the tank is maintained at atmospheric pressure, and the water is adjusted by the pressure difference. This section explores the effect of pressure pulsation on valve closing by controlling the high-pressure air pressure of the water transfer. Since the high-pressure air system continuously supplies air during water transfer, the resistance loss of the water tank can be neglected, and the pressure is set to a constant for calculation.

3.1. Calculation results of transient pressure pulsation under different water transfer pressures

![Figure 1. Law of pressure amplitude and peak by water transfer pressure.](image)

Set the line pressure to 0.3 MPa, 0.4 MPa, 0.5 MPa, 0.6 MPa, 0.7 MPa, and 0.8 MPa, respectively. According to the above calculation results, it can be observed that the water transfer pressure has a greater influence on the pressure peak (amplitude), and the pressure decay law has substantially no change. Therefore, comparing the law of amplitude variation, figure 1 is obtained.
3.2. Analysis of the influence of pipeline water transfer pressure on the maximum amplitude of pressure

It can be observed that, except for 0.5-0.6 MPa, it conforms to the linear law. Therefore, it is important to control the size of the water transfer pressure. Under the premise of ensuring the completion of the water volume within the specified time, minimizing the water transfer pressure can control the occurrence or reduce the harm caused by the water hammer.

3.3. Relationship between water transfer pressure and water transfer

Since a certain water transfer pressure is required to ensure the amount of water to be transferred, and the data in the relevant standards are incomplete, the water transfer amount cannot be directly obtained. However, we can still calculate the relationship between the amount of water transfer and the pressure of water transfer by calculation, for reference when optimizing the working conditions.

By integrating the curve, the amount of water transfer in the whole 40s working cycle under different water transfer pressures can be obtained, and figure 2 is obtained by comparing with the peak value of the pressure wave.

![Figure 2. Comparison of water transfer pressure and pressure peak law.](image)

It can be seen that 0.5MPa is an ideal water transfer pressure under the set pipeline conditions, but the optimization scheme should be determined in combination with the specific work requirements of the whole system.

4. Influence of pipe length on transient pressure pulsation

In the classic theory of water hammer, the length of the pipeline has a relatively important influence on the water hammer wave. It directly determines the size of the water hammer phase and affects the severity of the water hammer. For transient pressure changes in the trim balance system, pipe length is one of the direct factors.

4.1. Transient pressure pulsation calculation results under different pipeline lengths

When the pipe length is set to 20 m, 30 m, 40 m, and 50 m, the following pressure change law is obtained as figure 3, the maximum pressure and the maximum pressure fluctuation are summarized.
4.2. Analysis of the influence of pipeline length on maximum pressure and pressure amplitude
The function of the trim balance system is to offset the hull unbalance moment generated during the navigation through the gravity imbalance of the front and rear water tanks. Therefore, the longer the water transfer pipeline is, the more advantageous its function is, but the pipeline is actually connected. The length of the line in the water tank of the raft is only slightly less than the length of the entire hull or hull. However, calculations show that under the premise of ensuring the realization of the function, reducing the length of the pipeline as much as possible can reduce the impact of the water hammer. To this end, a balance needs to be found in the design, and the proper tank position and length of the pipeline are determined through comprehensive consideration.

5. The effect of valve closing time on transient pressure
The valve closing time has a great impact on transient flow noise. According to the Rukovsky theory, the maximum pressure of the water hammer will occur when the valve closing time is less than the water hammer phase, and the valve closing time is extended, which will reduce the pressure peak of the transient flow. However, due to the need to ensure the accuracy of the amount of water transfer and to avoid the occurrence of long-term throttling noise, the valve closing time should not be too long. Therefore, it is of great research value to explore the law of the effect of valve closing time on pressure.

5.1. Pressure variation law under different valve closing time
For the valve closing time of 1s to 5s, the pressure variation of the valve is shown in the figure 4.
5.2. Influence of valve closing time on pressure peak and fluctuation range

After the valve closing time is longer than 1 s, the effect of reducing the pressure peak caused by the extended time will gradually weaken. The extended valve closing time will not bring about the obvious effect of suppressing the water hammer, but will cause greater control of the water transfer strategy. Furthermore, during the voyage, the complex navigation conditions may require frequent reciprocating water transfer, and the water transfer process cannot be maintained for too long. Therefore, the valve closing time currently used is limited to between 1 and 5 s. According to the calculation results, it is recommended to control the water transfer time to more than 3 s, which can produce a better water hammer suppression effect.

6. Conclusion

1. Decreasing the water transfer pressure, shortening the length of the pipeline, and extending the valve closing time can effectively suppress the transient pressure pulsation during the working process of the trim balance system;

2. The above methods will affect the performance of the trim balance system, and have different degrees of negative impact on the total amount of water transfer, water transfer efficiency, water transfer flexibility and accuracy, and control difficulty. Therefore, adjustments cannot be made without restrictions. Appropriate adjustment according to specific working conditions, find a balance point, and determine the appropriate optimization plan;

3. According to the current calculation results, the significance of the pressure suppression effect is taken as a reference index. Combined with the information that can be checked, it is recommended to set the water transfer pressure to 0.5 MPa, the valve closing time to be controlled above 3 s, and the water tank to the valve line. The length should not exceed 40m (that is, the total length is 80m);

4. Under the premise of adjusting the above-mentioned pipeline characteristics and valve closing characteristics, it is also possible to further control the pressure pulsation by means of a pressure suppression device (such as a water muffler).

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