Study on adaptive technology for flow regulation of cooling water system

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Abstract. Through the transient simulation analysis of flowmaster, the flow characteristic method of ship cooling system pipe network was studied, and the pipe network was optimized by adding bypass branch, which was consisted of the flow balancing assembly. The results show that the bypass branch can automatically balance the flow rate of the system, the system can adapt to the change of different working conditions, the pump group can work stably at the rated point, and the flow rate of each user can be guaranteed within 3m/s. The system realizes self-adaptive control. The simulation results were verified by experiments. It provided a design idea for the stable and low noise operation of a typical ship cooling system.

1.Introduction
Cooling water system is widely used in municipal and ship systems. The pump valve water supply system usually has many users, and the pipe network and working condition are extremely complex. Due to the different frequent switching modes of the water supply system, long pipeline and complicated hydraulic conditions, some users of the system are overspeed in actual use, or the pump group deviates from rated operating point, which poses a serious threat to the stability of equipment and system in serious cases.

Aiming at the characteristics of cooling water pipeline system, this paper simulates several users, builds a system simulation model for typical working conditions by using flowmaster software. The flow characteristics of the system are analysed and the improvement measures are proposed.

2.Hydraulic characteristics
For the hydraulic characteristics of the system, the internal flow is simplified as one dimensional pipeline flow.

\[ \Delta P = K \frac{\rho V^2}{2} \]  

(1)
\[ V = \frac{m}{\rho A} \quad (2) \]

Substitute formula 2 into formula 1,
\[ \Delta P = \frac{Km^2}{2\rho A^2} \quad (3) \]

For node 1 and node 2,
\[ m_1 = \frac{-2\rho A^2}{K} m_1 P_1 + \frac{2\rho A^2}{K} m_1 P_2 \quad (4) \]
\[ m_2 = \frac{2\rho A^2}{K} (P_1 - P_2) \quad (5) \]
\[ A_1 = -A_2 = \frac{-2\rho A^2}{K} m_1 \quad (6) \]
\[ B_1 = B_2 = 0 \quad (7) \]

• \( m \) was mass flow of node.
• \( P \) was the pressure of node.
• \( A \) and \( B \) were linear coefficient.

3. Numerical simulation of system

3.1 System model

The marine cooling water system is taken as a typical example. The pump group is multi-user water supply, and the system schematic diagram is shown in figure 2. The pipelines of import and export for pump are the φ106x3 steel pipe. The cooling water system mainly consists of pump sets, globe valves, check valves, flowmeter and pipelines.

![Figure 2. Schematic diagram of marine supply water system by pump and valves](image)

3.2 Simulation model

A one-dimensional flowmaster is a professional engineering piping fluid analysis software, it’s good at fluid piping system for the overall analysis, and flowmaster is geared to the needs of project completion fluid system simulation software package, for a variety of complex fluid pipe network system, flowmaster can quickly and effectively establish flow control system model, and conduct
comprehensive analysis. Flowmaster is the world's leading one-dimensional fluid pipe network simulation tool, which has been widely used in the design, optimization and performance simulation of various high-pressure air systems, hydraulic systems, water systems and thermal management systems. The flowmaster simulation model of the system is shown in figure 2. Replace the flow resistance element in the system with the discrete loss component, and ignore the less resistant parts of the system.

![Flowmaster simulation model](image)

Figure 3. The model of marine supply water system by pump and valves

It is assumed that users 1- user 3 are fluctuating users, and users 4 -user 7 are common users according to operating conditions. The simulation time is set 0 s to 480s, and the valve conditions of the users in each time period are shown in the table below.

| Time(s) | User 1 | User 2 | User 3 | User 4-User 7 |
|---------|--------|--------|--------|---------------|
| 0-60    | off    | off    | off    | running       |
| 61-120  | off    | off    | running| running       |
| 121-180 | running| off    | off    | running       |
| 181-240 | off    | running| off    | running       |
| 241-300 | off    | running| running| running       |
| 301-360 | running| running| off    | running       |
| 361-420 | running| off    | running| running       |
| 421-480 | running| running| running| running       |

### 3.3 Simulation result

The main parameters of the pump group are set as follows:
- Rated flow: 50m³/h.
- Rated head: 30m.
- Rated speed: 1450r/min.
- Rated power: 7.5kw.
- Absolute roughness of rigid pipe: 0.025mm.
According to the above simulation results, when the user's working condition changes, the flow rate of user 1 - user 3 changes between 11.3 m$^3$/h and 18.8 m$^3$/h, and the flow volatility is 66.3%. The flow rate of users 4- user 7 varied between 4.2 m$^3$/h and 11.2 m$^3$/h, and the flow volatility is 116%. The flow rate of the pump group varied between 43.7 m$^3$/h and 50.5 m$^3$/h, and the flow volatility is 15.6%. The system is sensitive to the changes of working conditions, and the user flow varies greatly in different working conditions, especially user 4 - user 7. The flow volatility is 116%. The whole dynamic process is accompanied by air noise caused by excessive water hammer and velocity, and the system stability is poor.

4. System network optimization

4.1 The optimization model
Reduce the impact in different working conditions of the system, flow balancing assembly was added to the system supervisor, and the system flow was dynamically adjusted. The optimized pipe network model was shown in figure 7.

![Figure 7. Schematic diagram of marine supply water improvement system by pump and valves](image)

**4.2 Optimized simulation model**

The cooling water system pipe network is improved by adding a flow balancing assembly between the fresh water pump inlet main pipe and the fresh water pump outlet main pipe with the diameter of DN50. The improved system pipe network simulation model was established by flowmaster, as shown in figure 8 to figure 11.

![Figure 8. The optimized model of marine supply water system](image)

The results of the simulation analysis of the optimized pipe network are as follows.

![Figure 9. Flow rate diagram of user 1- user 3](image)
According to the above simulation results:

- When user operating conditions change, the system pipeline network is optimized. The flow rate of user 1 - user 3 changes between 8.2m³/h and 12.0m³/h, and the flow volatility decreases from 66.3% to 50%.

- The flow change of user 4 - user 7 is between 4.1m³/h and 6.6m³/h, and the flow volatility decreases from 116% to 60%.

- The flow rate of the pump group varied between 49.0m³/h and 51.1m³/h, and the flow volatility decreased from 15.6% to 4.1%.

- The bypass flow rate of the flow balancing assembly is between 12.0m³/h and 22.9m³/h. The system is not sensitive to the change of operating conditions, and there is little difference in user flow under different operating conditions.

Assuming that 60s - 240s in table 1 is condition 1, 241s - 420s in table 1 is condition 2, 421s - 480s in table 1 is condition 3, the maximum user flow rate is shown in table 2.

**Table 2. Parameter of user velocity**

| User 1 – User 3(m/s) | User 4 – User 7(m/s) | bypass (m/s) | condition     |
|----------------------|----------------------|--------------|---------------|
| 2.9                  | 2.3                  | 2.6          | condition 1   |
| 2.3                  | 2.1                  | 2.5          | condition 2   |
| 1.5                  | 1.4                  | 1.6          | condition 3   |

Under the condition of working condition 1, the maximum flow rate of user 1 - user 3 is 2.9m/s, and the bypass pipeline of the system is 2.6m/s.

Under the condition of working condition 2, the maximum flow rate of user 1 - user 3 is 2.3m/s, the maximum flow rate of user 4 – user 7 is 2.1m/s, and the maximum flow rate of bypass pipes of the system is 2.5m/s.
Under the condition of working condition 3, the maximum flow rate of user 1 - user 3 is 1.5m/s, the maximum flow rate of pipes of user 4 - user 7 is 1.4m/s, and the maximum flow rate of bypass pipes of the system is 1.6m/s.

- When the system is balanced by the bypass pipeline of the flow balancing assembly, the user flow and flow rate can be guaranteed within the specified range, and the flow by the bypass can automatically outflow the excess flow rate of the pump. At the same time, the flow rate of different users in each working condition are not much different.
- The maximum flow rate of each user is 2.9m/s, not exceeding 3m/s, meeting the low noise requirements of the system.
- When the system flow distribution component and flow bypass component are fully open, the water supply main pressure of fresh water is 0.032MPa, and the main pressure of backwater is 0.018MPa. The resistance coefficient of flow balancing assembly is 6.3.
- The system realizes self-adaptive control.

5. Experiment

Establish the test bench of water supply system, the pump group flow is 50m³/h, and the lift is 30m, as shown in the figure 12.

![Figure 12. The picture of pump](image)

The flow rate of each user under conditions of working condition 1 - condition 3 are simulated.

|               | condition 1 | condition 2 | condition 3 |
|---------------|-------------|-------------|-------------|
| User 1        | 12.1        | 9.8         | 8.1         |
| User 2        | 0           | 9.8         | 8.1         |
| User 3        | 0           | 0           | 8.0         |
| User 4        | 4.8         | 3.9         | 3.4         |
| User 5        | 4.8         | 3.9         | 3.4         |
| User 6        | 4.8         | 3.9         | 3.4         |
| User 7        | 4.8         | 3.9         | 3.4         |
| bypass        | 16          | 15          | 13          |
| pump          | 47.5        | 50.2        | 50.8        |

The test results can verify the simulation results well, and the errors of each user flow are within 10 percent.
When the flow balancing assembly was added to the system, the system can adapt to the change of working condition, without large flow fluctuation, and the pump group operates stably. The system optimization effect is obvious.

6. Conclusions
As for the important issues related to stable reliability and low noise operation in the cooling water pipeline system, this paper establishes the marine cooling water system through the transient analysis function of Flowmaster, simulates the operation of the cooling water system and obtains the flow change curve of different users under different working conditions. According to simulation results, increase the flow balancing assembly between main import and export of the pump can optimize the original cooling water pipe network. Bypass branch flow rate can automatically balance the system. The flow rate of each user is not sensitive to the change of working condition. The pump can work stable at rated flow rate point, and the velocity of each user can be controlled below 3m/s. The system realizes self-adaptive control. It provides an effective method for stable and low noise operation of the cooling water system.

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