Orthogonal test and experimental study on fire floating pump

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Abstract. In order to develop high efficiency fire floating pump, 250YYB-250 fire floating pump was taken as an example. The orthogonal experiment of $L_9(3^4)$, which contains factors with three levels of blade numbers of impeller, outlet angle, impeller fold-angle, was performed to design nine types of impellers. Numerical simulation of whole flow field based on Fluent was adopted to perform an orthogonal test, the order of geometric parameters affects the performance of fire floating pump with complex impeller. The best design scheme for pump model was acquired. Meanwhile, the optimized design scheme was determined, and corresponding test was carried out. It demonstrated that the efficiency of the final optimal design model pump at rated flow point is of 85%. The efficiency is higher than the national standards, which verified the feasibility of the method of orthogonal design in pump design.

1. Introduction
Fire floating pump which can float on the water is important equipment for extinguishing forest fire, oil and chemical fire (Figure 1). It’s also important equipment of city emergency drainage of buildings and fire fighting. It performed important functions in major disasters. Presently, the Fire floating pump has been used abroad widely, but it is less-used at home. The research and appliance of Fire floating pump in china is just at the beginning. Improvement of the efficiency constitutes the key issues in designing fire floating pump.

At present, the orthogonal test method has been widely used in the design of water pump. By orthogonal experiment, author Cong Xiaoqing thoroughly investigated the effects of geometrical parameters of the impeller on pump performance [1]. By orthogonal table, author Yuan Shouqi investigated the effects of geometrical parameters of the impeller and the area of throat on pump performance. By quadric regression orthogonal experimentation, author Wang Hongliang Studied on the impeller outlet angle, outlet width influence rules to the deep well pump efficiency [2]. Therefore, the orthogonal design method is a scientific experiment designing method. It can be used for the optimization design of water pump.

This thesis uses the numerical simulation method and orthogonal test to research and design the fire pump 250YYB-250. The effects of geometry parameters of the impeller for passing performance and efficiency were analyzed and the better hydraulic design method was introduced.
2. Orthogonal test
Orthogonal experimentation is the one method using orthogonal table standardization to arrange experimental plan scientifically, to calculate and analyze the testing results [3-4).

2.1. Test objective
(1) To explore the effects of geometry parameters of the impeller for passing performance and efficiency.
(2) To find the Optimal design scheme for the fire floating pump, flow rate $Q=900\text{m}^3/\text{h}$, Head $H=20\text{m}$, speed $n=2000\text{r/min}$, specific speed $n_s=386$.

2.2. The determination of the test plan and test parameters
The main factors influencing the fire pump efficiency and head contain the blade numbers of impeller-$Z$, the outlet blade angle-$\beta_2$, the impeller fold-angle-$\varphi$, the impeller outside diameter-$d_2$, the impeller outlet width-$b_2$, and so on. According to the requirement of special structural design for fire pump, The orthogonal experiment of $L_9(3^4)$, which contains factors with three levels of blade numbers of impeller, outlet angle, impeller fold-angle, was performed to design nine types of impellers. Table 1 was used for the test of the four factors and with its three levels. Table 2 was used for the Test scheme.

### Table 1 Orthogonal experimental factors and level

| Level | $A$ | $B$ | $C$ | $D$ |
|-------|-----|-----|-----|-----|
| 1     | 4   | 25  | 90  | 1   |
| 2     | 5   | 28  | 100 | 2   |
| 3     | 3   | 30  | 110 | 3   |
Table 2 Test scheme

| Number | A  | B  | C  | D  | Z  | Parameter | β₂ | φ | Null |
|--------|----|----|----|----|----|-----------|----|---|------|
| 1      | A₁ | B₁ | C₁ | D₁ | 4  | 25        | 90 | 1 |      |
| 2      | A₁ | B₂ | C₂ | D₂ | 4  | 28        | 100| 2 |      |
| 3      | A₁ | B₃ | C₃ | D₃ | 4  | 30        | 110| 3 |      |
| 4      | A₂ | B₁ | C₂ | D₃ | 5  | 25        | 100| 3 |      |
| 5      | A₂ | B₂ | C₃ | D₁ | 5  | 28        | 110| 1 |      |
| 6      | A₂ | B₃ | C₁ | D₂ | 5  | 30        | 90 | 2 |      |
| 7      | A₃ | B₁ | C₃ | D₂ | 3  | 25        | 110| 2 |      |
| 8      | A₃ | B₂ | C₁ | D₃ | 3  | 28        | 90 | 3 |      |
| 9      | A₃ | B₃ | C₂ | D₁ | 3  | 30        | 100| 1 |      |

3. Numerical model

3.1. Basic parameters of pump

In this paper, the performance design parameters: flow rate \( Q = 900 \text{m}^3/\text{h} \), Head \( H = 20 \text{m} \), speed \( n = 2000 \text{r/min} \), specific speed \( n_s = 386 \).

3.2. Computational region

![Figure 2. Computational model](image)

The numerical domain was composed of several modules (figure 2); from left to right is the outlet pipe, the volute, the impeller, the inlet pipe. In the process of modelling considering pump high speed rotating blade inlet interfere with strong action against speed entrance upstream pump distribution, it will extend the appropriate entrance section of the pump; the outlet boundary conditions of outflow, in order to ensure the flow at the exit of the accords with the preset export requirements, also need to pump outlet is properly extended. After modelled by using Pro/E, The computational domain was meshed by mixed grid with unstructured grid as the main body; the whole regional grid number is 3,399,400, shown in Figure 3.
3.3. Boundary condition
Inlet axial velocity is determined by the law of conservation of mass and assumption of irrotational flow. Considering the relative motion of the impeller and flow, the relative velocity distribution of inlet section in the impeller is given. The flow rate and pressure in the outlet of the mixed-flow pump are unknown, so the flow outlet boundary condition is set to (outflow) form; All physical surfaces of the pump are set to be no-slip wall. In the near wall region of turbulent non-fully developed turbulent flow surface were processed by standard wall function [5-6].

4. Results and analysis of orthogonal test
Through the numerical simulation calculation, using the head and efficiency as the evaluating index, the head and efficiency of the 9 impellers are shown in Table 3. In order to evaluate the effect of three factors on the performance of the pump, to find the main factors and optimization scheme, the range analysis of orthogonal experiment results, the data was analyzed with range analysis; the results are shown in Table 4 and Table 5.

Table 3 Orthogonal experimental factors and level

| Number | H/m   | η/%  | P/Kw |
|--------|-------|------|------|
| 1      | 21.08 | 72.24| 71.49|
| 2      | 21.15 | 74.75| 69.32|
| 3      | 20.21 | 73.79| 67.10|
| 4      | 22.48 | 76.25| 72.23|
| 5      | 22.68 | 77.04| 72.13|
| 6      | 24.74 | 81.76| 74.13|
| 7      | 17.64 | 74.99| 57.63|
| 8      | 18.8  | 71.58| 64.35|
| 9      | 18.84 | 72.25| 63.98|
Table 4 Variance analysis (Head)

| Factor | Z    | $\beta_2$ | $\phi$ |
|--------|------|-----------|--------|
| $K_1$  | 62.44| 61.2      | 64.62  |
| $K_2$  | 69.9 | 62.63     | 62.47  |
| $K_3$  | 55.28| 63.79     | 60.53  |
| $H/m$  | $K_1$| 20.81     | 20.4   | 21.54 |
|        | $K_2$| 23.3      | 20.88  | 20.82 |
|        | $K_3$| 18.43     | 21.26  | 20.18 |
|        | $R$  | 4.87      | 0.86   | 1.36  |

Table 5 Variance analysis (Efficiency)

| Factor | Z    | $\beta_2$ | $\phi$ |
|--------|------|-----------|--------|
| $K_1$  | 2.2078| 2.2348    | 2.2558 |
| $K_2$  | 2.3505| 2.2337    | 2.2325 |
| $K_3$  | 2.1882| 2.278     | 2.2582 |
| Efficiency | $K_1$| 0.7539    | 0.7449 | 0.7529 |
|         | $K_2$| 0.7835    | 0.7446 | 0.7442 |
|         | $K_3$| 0.7294    | 0.7593 | 0.7527 |
|         | $R$  | 0.0541    | 0.0147 | 0.0087 |

Each column range represents its influence factors on index. The influence orders of geometrical parameters to the head at the rated conditions were $Z, \phi, \beta_2$ by using range analysis. The influence orders of geometrical parameters to the efficiency at the rated conditions were $Z, \beta_2, \phi$, the factor order of influencing on the head is $A_2 A_1 A_3, B_3 B_2 B_1, C_1 C_2 C_3$, on the efficiency is $A_2 A_1 A_3, B_3 B_2 B_1, C_1 C_2 C_3$. The relationship of every factor and the efficiency and head was shown in Figure 4.

![Figure 4](image)

**Figure 4. Relation of level and index**

The main purpose of this orthogonal test is to design a high efficiency fire floating pump. The optimal parameters obtained through orthogonal experiments were: $Z=5, \beta_2 =30^\circ, \phi=90^\circ$.

5. Performance test
According to the optimal scheme, one true pump has been made and tested on the open water pump experimentation table and the full flow field of the pump was numerically simulated. The results were shown in Figure 5.

![Figure 5](image)

**Figure 5.** Comparisons between calculation and measurement result

From the Figure 5, we can see: The simulation results are very close to the experiment results. The head and the efficiency simulation value is higher than the experimental values, the maximum relative error is 5.36% and 4.58%, respectively. The agreement of numerical and experimental results shows this mathematical model could also predict pump performance with an acceptable accuracy. Compared with those numerical simulations, the results of the pump test show the correctness of the method using the orthogonal test design the pump.

6. Conclusions

In order to develop high efficiency fire mixed-flow pump, orthogonal numerical simulation test and experimental investigations have been studied. The influence orders of geometrical parameters to the efficiency at the rated conditions were $Z, \beta_2, \varphi$.

By the range analysis, the optimum combinations of working parameters were found out. The order is $Z=5, \beta_2 = 30^\circ, \varphi = 90^\circ$.

The comparison of test result and numerical simulation result indicate that the predicted results tallied with the simulations, with maximum error less than 5%. The Prototype pump hydraulic performance meet the design requirements, it verified the correctness of the method using the orthogonal test design the pump.

References

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