Optimization and Application of D850 Dredge Pump Blades under Medium Coarse Sand Condition of Cutter Suction Dredger

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Abstract. Regarding wear issues of a dredge pump’s impeller as a cutter suction dredger transports medium coarse sand slurry, blades of the D850 dredge pump are modified and optimized, which extends the distance from the blade inlet root to the impeller suction and avoids damages of the impeller suction anti-wear ring. Analyses via computational fluid dynamics (CFD) simulation show that the head and the efficiency after blade modification have little changes compared with before optimization in the construction flow range of 10000-12000 m³/h under coarse sand condition. While it improves the flow field of impeller’s channels, decreases the vortex at the inlet root of the blades, ensures more uniform distribution of the solid particles. Meanwhile, this is beneficial to reductions of the channels’ wears. Applications from constructions show some improvements in the wears of the blade root. Through the construction data comparison, after replacing the modified impeller, dredging productivity will be increased by 15.1% and the fuel consumption per 10000 m³ will be then reduced by 11.5%.

Keywords. Dredge pump, worn, CFD, blade modification, application.

1. Introduction

As a key equipment of cutter suction dredger, its performance of dredge pump has directly affects on efficiency of construction. There exist great differences in the characteristics of dredged soil during dredger construction [1-2], such that the dredge pump performs variously with different dredged soil. At present, although the design of dredge pump considers the influence of a certain transmission medium, the performance of dredge pump can not meet the construction requirements of dredger in the face of more and more complex dredged soil. This will result in low efficiency of dredge pump and serious wear of overflow parts. For example, in the land reclamation project in Xiamen, the D850 dredge pump of 3500 m³/h series cutter suction dredger was seriously damaged due to coarse sand wear and cavitation.

In order to improve the dredger construction efficiency under special conditions, the dredger shall be equipped with targeted special equipment. Many foreign R & D institutions carry out targeted research. Cutter suction dredgers are equipped with different mud pumps to meet the requirements of construction conditions. Bugdayci, H.H et al. [3] in the Netherlands, the large channel special pump, was specially used for heavy rock operations that is equipped with a curve blade impeller; Ukhin BV(Russia) [4], experimentally studied the effect of the number and shape of the blades on the performance of dredge pump. Domestic scholars have studied the influence of slurry on the performance of mud pump: e.g. Zhang Xiaosong et al. [5] have conducted a steady numerical study on
the cavitation performance of a six blade mud pump. The numerical simulation analysis shows that the
greater the mud concentration, the more likely the cavitation occurs in the mud pump. With the same
mud concentration, it is more likely that the cavitation happens at the mud pimp with the larger
diameter of solid particles in the mud. Cheng Zejiu et al. [6] studied the critical sediment concentration
in cavitation and abrasion under experiment tests. When the sediment concentration is lower than the
critical value, it promotes cavitation. And when the sediment concentration is greater than the critical
value, it inhibits cavitation. Li Longhua et al. [7] found that the cavitation wear occur at the same time
for the impurity pump, which is often difficult to be strictly distinguished. By the performance from
the centrifugal pump test, it can be found that the critical NPSH has little changes with increasing of
solid content. That is, it has little impacts on its cavitation performance. However, the performance of
the pump head and efficiency as well as the anti cavitation performance decreases rapidly with the
increase of particle size.

Scholars from many domestic universities and scientific research institutes have studied on the
blade design of the centrifugal pump: e.g. the author keeps the overall size of the impeller unchanged,
developed a twisted blade impeller with suction port diameter of 900 mm the pump for the cutter
suction dredge, which improves the construction efficiency [8]. Optimal the designs of the dredge
pump is implemented by combining numerical simulation and model test method, which improves the
efficiency of dredge pump [9-10]; Zhang Renhui et al. [11] improved the cavitation resistance under
high flow conditions by increasing the blade inlet placement angle; The analysis shows that the inlet
flow passage area and the projection surface of the impeller can significantly improve the pump
performance [12]. By comparing the numerical simulation results of five impellers, Luo Xianwu et al.
[13] analyzed the influence of impeller inlet geometric parameters on the cavitation performance of
centrifugal pump. The results showed that properly extending the blade inlet position and increasing
the blade inlet placement angle can improve the cavitation performance of centrifugal pump, and
pointed out that homogenizing the flow at the impeller inlet is a necessary measure to improve the
cavitation performance of centrifugal pump. Based on the numerical simulation and external
characteristic test, Wang Yanyan et al. [14] improved the design of the impeller by optimizing the
blade wrap angle and outlet placement angle. After this improvement, the head at the design working
point was increased by 2.74% and the efficiency was increased by 5.77%. Li Jing et al. [15] studied
the influence of blade profile on the hydraulic performance and impeller wear characteristics of slurry
pump. Under the condition that the parameters such as impeller axial surface and blade inlet and outlet
placement angle remain unchanged, logarithmic helix is used to control the blade profile. The numerical
results show that under different blade profile conditions, the hydraulic performance of slurry pump and its impeller wear characteristics restrict each other; The blade with small wrap angle
leads to the decline of the hydraulic performance of the pump, but the wear strength of the impeller is
relatively low, and the wear strength of the impeller is positively correlated with the solid
concentration. Zhao Wanyong et al. [16] numerically simulated and analyzed the impact of solid
particles at the inlet of centrifugal pump on the inlet wear of centrifugal pump blades. Under the
investigation, it was shown that reducing the inlet placement angle at the middle streamline of impeller
can improve the wear resistance of impeller within a certain range.

In view of the damage of the dredge pump blades of the cutter suction dredger under the coarse
sand mud condition, optimizing the pump blade enable a realization of the reasonable mud flow a
reduction of the sediment impact on the blade, wear and cavitation. These improve the efficiency of the
dredge pump and improve the dredging performance of the cutter suction dredger under the medium
course sand condition.

2. Impeller Damage and Cause Analysis

One month after the construction progress of a project in Xiamen, it was found that the dredge pump
was seriously worn. According to the engineering geological survey report, the soil in the construction
area is mainly medium coarse sand which containing a large amount of loose quartz sand particles and
shell debris. Samples are taken at three locations on the construction site, with average particle sizes of
0.58 mm, 0.36 mm and 0.49 mm. During the construction of cutter suction dredger, the main operating parameters of dredge pump are: flow rate of 5-6 m/s, concentration of 20-30%, and the diameter of delivery pipe is 850 mm.

The impeller suction port of D850 dredger dredged in Xiamen was seriously damaged (figure 1). The damage was mainly located near leading edge of the blade and had nearly worn through impeller body. The contact position between the impeller anti-wear ring and the impeller was the most seriously damaged. The perforation of impeller anti-wear ring causes leakage and backflow at the suction port of the dredger pump, which reduces the performance of the dredge pump and then reduces the construction efficiency of cutter suction dredger. The D850 dredge pump dredged in Quanzhou (D_{sp}=0.35 mm) was used for one month, and the same damage occurred at the impeller suction position.

![Figure 1. Damage position: impeller suction blade root and impeller wear ring.](image)

By investigating the impeller damage of D850 dredge pump in different soil construction, only when the construction soil is medium coarse sand, the impeller suction is seriously damaged. Therefore, it is considered that medium coarse sand is the main factor causing serious damage to the impeller suction. Relevant studies show that with the increase of particle size, the movement speed of particles to the leading edge of blade working face increases and forms point impact wear [17]; The motion track of large particles deflects greatly towards the blade working face, is easy to collide with the blade head, and there are multiple impact processes, which has a large degree of wear on the blade [18].

The main reasons for the increased damage of the suction port of the dredge pump impeller under coarse sand conditions are as follows: 1) The starting position of the impeller blade is very close to the suction port of the impeller, that is, it is very close to the installation position of the impeller and the impeller wear ring. The blade root and the clearance between the impeller and the impeller wear ring are all factors inducing vortex, which affect each other and further local wear and cavitation [19]. 2) The flow pattern at the impeller suction port is complex. When the mud enters the impeller suction port, the fluid pressure near the front cover plate is low and the flow rate is high. The blade root blocks the mud flow, changes the mud flow direction and forms a local vortex. Large particle sand can promote cavitation and produce local wear. Cavitation damage is induced by pits after wear, which will further aggravate cavitation and wear [19].

3. Blade Leading Edge Modification Optimization

The damage of the root of the suction port of the blade shortens the service life of the impeller, and the anti-wear ring of the suction port is perforated, which reduces the construction efficiency of the dredger. According to the medium coarse sand soil and the damaged position of the blade, the blade is modified. The modification includes increasing the distance between the root of the blade suction and the anti-wear ring of the impeller suction, and reducing the blade wrap angle. So as to improve the flow field at the inlet of the impeller and prolong the service life of the impeller.
As shown in the figure 2, the distance between the blade root and the suction port increases to 130mm after blade modification, while the distance between the blade suction port root and the suction port before modification is only 20-30mm. At the same time, the blade wrap angle is correspondingly reduced (about 30° less than that before modification). The projection of impeller shaft surface and blade outlet angle remain unchanged.

Figure 2. Schematic diagram of suction port root position after blade modification.

4. Performance Prediction and Flow Field Analysis before and after Blade Modification

4.1. Performance Curve Comparison
Computational fluid dynamics (CFD) technology has been successfully applied to the flow field analysis and external characteristic prediction of dredging pump. It has the advantages of low cost and short cycle. Especially when the laboratory test conditions of large dredge pump are limited, simulation can replace the test under certain conditions. Applying CFD technology to simulate and analyze the internal flow field of pump can not only save experimental resources, but also display many internal characteristic of flow field such as pressure distribution and velocity distribution [20].

Table 1. Comparison of performance data before and after import modification.

| Flow m³/h | Before modification | After modification | Contrast |
|-----------|---------------------|--------------------|----------|
|           | Head m              | Efficiency %       | Head m   | Efficiency % | Head m difference | Efficiency difference % |
| 10000     | 80.5                | 83.8               | 82.2     | 82.8         | 1.7                | -1.0                   |
| 12000     | 77.6                | 85.9               | 77.9     | 85.1         | 0.3                | -0.8                   |

As shown in table 1, after the blade modification, the average change in clean water head and efficiency is very small under the condition of construction flow 10000m³/h and 12000m³/h. That is, the external characteristics of the pump change little after the blade modification.

4.2. Blade Inlet Flow Field Analysis
Figure 3 shows the location of the velocity cloud. When the mud enters the impeller suction port, the blade root blocks the mud flow and changes the mud flow direction. The flow field at the impeller inlet forms turbulence (figure 4 (a)). After the blade is modified, the flow field at the same position is
improved (figure 4 (b)), decreasing the possibility of local vortex formed by turbulence and cavitation damage induced by coarse sand wear, and prolonging the service life of the impeller.

(a) Schematic diagram of section.  
(b) Before blade modification.  
(c) After blade modification.

**Figure 3.** Relative position between section (red surface) and blade at 200mm from impeller suction.

(a) Before blade suction modification.  
(b) After blade suction modification.

**Figure 4.** Section relative velocity at 200mm from impeller suction surface.

4.3. **Analysis of Solid-Liquid Two-Phase Flow Field**

The Euler-Euler model is used for the numerical unsteady calculation of two-phase flow. Taking the impeller rotation of 1.5 degrees as a time step, five cycles are calculated, and the data of the last calculation cycle is used as the basis for analysis. The boundary conditions of the dredge pump are velocity inlet and free outlet. It is assumed that the inlet velocity has no tangential and radial components and the outlet flow is fully developed. The wall surface is non slip wall surface and treated by standard wall function. The turbulence model adopts standard $k-\varepsilon$ turbulence model. The second-order upwind scheme is discretized in space to solve the turbulence equation.
Figure 5. Particle concentration distribution on the surface of the front cover plate of the impeller before (left) and after (right) improvement of blades.

Figure 5 shows that the particle concentration distribution of the front cover plate of the impeller before and after the improvement of the blade suction. It can be seen from the figure that the surface concentration of the front cover plate before the improvement is high and the high concentration area is large. After the improvement of the blade, the particle concentration distribution on the surface of the front cover plate is significantly reduced, meanwhile reducing the wear on the surface of the impeller channel. At this time, the high concentration area is mainly close to the blade suction. After the improvement of the suction port, the blade suction port is far away from the impeller suction port, which reduces the wear of the particles on the suction anti-wear ring, reduces the replacement frequency of the anti-wear ring during construction, and improves the dredging efficiency.

Figure 6. Particle concentration distribution on the surface of impeller rear cover plate before (left) and after (right) improvement of blades.

Figure 6 shows the particle concentration distribution shown on the rear cover plate of the impeller before and after the improvement of the suction port of the blade. It can be seen from the figure that before the improvement of the suction port, the particles are mainly concentrated near the back of the blade, and the mud concentration distribution is uneven. After the improvement of the impeller, the particle distribution uniformity on the surface of the rear cover plate is enhanced, the range of high concentration area is reduced, and local wear is reduced.

5. Tracking of Use of Mud Pump Impeller
Track and investigate the service condition of the improved impeller. The wear of the impeller is as follows: after the mud pump is replaced with the improved impeller, the intersection of the impeller blade inlet and the front cover plate (the root of the blade suction) is greatly worn. The wear starting surface is relatively smooth, and fish scale pits gradually appear with the aggravation of wear. The
damaged position gradually extends from the root of the blade inlet to the front cover plate, and the wear thickness reaches 40mm. The damaged pits of the impeller after 148 hours and 640 hours are shown in figure 7.

The suction port improvement impeller shortens blade suction port. Before the improvement, the damaged position of the root was changed from the position where the original suction anti-wear ring meets the impeller. After the improvement, there was still pit damage at the root of the blade, but the damaged position is moved back to avoid the damage of the impeller anti-wear ring. The impeller improves the blade wear to a certain extent, prolongs the service life of the impeller and reduces the repair frequency of the dredge pump, that ensures the continuity of dredging construction.

Figure 7. Modification impeller blade root (148 h and 640 h).

Comparison of construction data, "Xin Hai E" dredger pump impeller was constructed in a project before and after the suction port modification, with conveying distance of about 2.17km. The construction data of impeller under similar working conditions before and after the suction port modification were counted, and the productivity and energy consumption per 10000 m³ before and after the impeller modification were analyzed. The comparison results are shown in table 2. After the impeller modification, the productivity is increased by 15.1% and the unit fuel consumption is reduced by 11.5%, indicating that the dredger construction efficiency is significantly improved and the energy-saving effect is obvious under this working condition.

|                     | Before modification (397h) | After modification (439h) | Contrast % |
|---------------------|---------------------------|---------------------------|------------|
| Productivity(m³/h)  | 1351                      | 1555                      | 15.1       |
| Unit fuel consumption (ton/10^4 m³) | 11.3                     | 10.0                      | -11.5      |

6. Conclusion
- During the dredging construction of medium coarse sand soil, the erosion damage of the impeller is serious which is supposed to be repaired in time. In addition, the local pits shall be fixed to prevent local slurry backflow, induced vortex, cavitation and wear;
- After the blade modification, the distance from the blade inlet root of the dredge pump in to the impeller suction port is increased to 130mm. This is used to avoid the damage of the impeller suction anti-wear ring due to the damage of the blade root;
- After the modification, it brings little changes for the external characteristics of the dredge pump. According to the flow field analysis, the vortex at the root of the blade inlet is reduced after the modification of the blade. And a more uniform distribution of the solid particle is obtained, which is good for reducing the wear of the channel;
The application shows that the damage of suction port of dredge pump impeller is improved to a certain extent after blade modification, which provides a reference for further modification and optimization.

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