Development and test of a plastic deep-well pump

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Abstract. To develop a plastic deep-well pump, three methods are proposed on structural and forming technique. First, the major hydraulic components are constructed by plastics, and the connection component is constructed by steel. Thus the pump structure is more concise and slim, greatly reducing its weight and easing its transportation, installation, and maintenance. Second, the impeller is designed by maximum diameter method. Using same pump casing, the stage head is greatly increased. Third, a sealing is formed by impeller front end face and steel end face, and two slots are designed on the impeller front end face, thus when the two end faces approach, a lubricating pair is formed, leading to an effective sealing. With above methods, the pump's axial length is greatly reduced, and its stage head is larger and more efficient. Especially, the pump’s axial force is effectively balanced. To examine the above proposals, a prototype pump is constructed, and its testing results show that the pump efficiency exceeds the national standard by 6%, and the stage head is improved by 41%, meanwhile, its structure is more concise and ease of transportation. Development of this pump would provide useful experiences for further popularity of plastic deep-well pumps.

1. Introduction

In recent years, it has shown a rapid profit growth in deep-well pumps in Wenling City, which is known for its pump manufacture and export. This kind of pump is widely used in water supply of household and building, which is especially welcome in America, Mideast and domestic market. However with intense competence amongst local manufacturers, the profit is showing a decreasing tendency. To deal with this crisis, more compact structure, finer manufacturing technique, and more rapid development procedure, etc. are urgently needed.

A new multistage pump is proposed by Shi [1] which outperforms the traditional multistage pumps with less stage and larger head. Through optimization of 18 different configurations of impeller, a superior hydraulic model is obtained with non-overloading characteristic [2]. Similarly, 10 sets of configurations are numerically examined and an optimization equation is found which is useful for improving pump efficiency [3]. Based on 150QJ20 multistage pump, different configurations of grid size, turbulence model, numerical scheme, etc. are examined and an optimized setting strategy is obtained [4]. This work is further conducted by Wang [5]. With these optimized settings, the numerical result becomes more accurate for multistage pump simulation. Wang [6] proves that the steel plate width is crucial for the pump performance. Through modifying the leading edge of impeller, the rated flow rate of 150QJ20 pump is adjusted to be identical with the maximum power and maximum efficiency [7]. Zhang [8] further develops a hydraulic design system for the guide vanes of multistage pumps. Small improvement of guide vane was given by Roclawski [9], but the systematically research has not been conducted. Though many achievements have been obtained, it is noticed that the specific speed of these multistage pumps is comparatively small. For comparatively large specific speed, it is still not considered and is seldomly found in the past literatures.

In this paper, a moderate specific speed multistage pump is developed. The hydraulic components are made of plastic and the connection component is made of steel. Thus this pump is more compact and light-weight, which is preferable for the customers.
2. Structural principle

2.1. Maximized impeller method
Traditional multistage pump is made of iron and its structure is depicted in Fig. 1. It can be seen that there is a large free space between the pump casing and the impeller. To utilize this space, the first strategy is to maximize the impeller diameter, thus the stage head can be fully enlarged.

![Figure 1. Structure of traditional multistage pump.](image)

2.2. Steel barrel structure
To match the maximized impeller method, the pump structure is designed to be slim cylindrical shape. The merit is compactness and convenience of manufacture and installation. A single stage is shown in Fig. 2, the front end-face of impeller is attached on the steel barrel and the guide vane is attached to the steel barrel, thus a compact stage is formed.

As shown in Fig. 2, within the cylindrical steel barrel, the impeller diameter can be maximized, and only a small clearance between the barrel and the impeller wheel can be remained. To facilitate passing of small sands carried by water, the clearance should be comparatively larger.

![Figure 2. Diagram of a single stage.](image)

The second merit of this structure is that there are two slots on the front end-face of impeller. Water enters into the clearance between the steel barrel and the impeller when impeller rotates, thus a couple of lubrication face is formed, reducing the mechanical loss and enhancing the sealing ability. On the other hand, this structure reduces the axial length of the pump.

The third merit of the structure is that the impeller outer wheel is cut as shown in Fig. 2, thus the through flow performance can be enhanced.

2.3. Space guide vane
Generally, there are two types of guide vane widely used in multistage pumps, as shown in Fig. 3. The first type uses fully twisted blade, which widely adopts iron casting. The second type is twisted at the inlet edge and the remaining part is cylindrical, which widely uses plastic molding. The merit of second type is its compactness. However, for larger flow rate, the axial velocity is comparable with the radial velocity. Thus adopting the first type is beneficial for improving pump through flow performance.
2.4. Fully twisted plastic molding
Plastics are widely used in many industrial fields, such as automobile, electronics, etc. In pumps, it is still not common. In the present study, the hydraulic components are made of plastics, and the connection part is made of steel. Thus plastic molding and stamping techniques are utilized to manufacture the major components. Adopting these techniques greatly improves the development efficiency. And it is especially important that the product quality is finer than the iron casting, which is beneficial for pump performance.

3. Hydraulic design

3.1. Impeller design
A set of parameters for a moderate specific speed pump is considered in this study. The flow rate is $Q=32\text{m}^3/\text{h}$, the head is $H=6\text{m}$, the rotating speed is $n=2850\text{r/min}$, which is listed in the deep-well pump standard. And its specific speed is 256.

As mentioned before, the traditional multistage pump impeller is relatively small, and its stage head can be enlarged by extending the impeller outer wheel diameter. The benefit is to reduce its specific speed, that is, for a pump at $Q=32\text{m}^3/\text{h}$, $n=2850\text{r/min}$, and $H=10\text{m}$, the specific speed is 174, which is greatly reduced compared to 256. With these thoughts in mind, the impeller is designed with the maximum diameter and its major parameters are listed in Table 1.

| $Z$ | $D_1(\text{mm})$ | $D_h(\text{mm})$ | $D_{21}(\text{mm})$ | $D_{20}(\text{mm})$ | $b_2(\text{mm})$ | $\beta_1(\text{°})$ | $\beta_2(\text{°})$ | $\phi(\text{°})$ |
|-----|----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|
| 5   | 62            | 29              | 119             | 103            | 15             | 33             | 22             | 100            |

The impeller is designed as mix-flow style, as shown in Figure 4.

3.2. Guide vane design
The error-triangle method is used to design the guide vane. The horizontal expansion line is calculated as follows.

$$L = \frac{D_h \pi}{360} \times \phi$$  (1)
Where $\phi$ is blade wrap angle, $D_3$ is guide vane inlet diameter, which is between $[1.1, 1.5] D_2$. $D_2$ is calculated as follows

$$D_3 = \frac{D_{w3} + D_{w1}}{2} \quad (2)$$

The guide vane inlet angle is calculated as follows

$$\alpha_3 = \arctan \left( \frac{V_{m3}}{V_{u3}} \right) \quad (3)$$

Where $V_{m3}$ and $V_{u3}$ are axial and radial velocity respectively.

To eliminate the rotating velocity at the guide vane outlet, the outlet blade angle is $90^\circ$. Then with the above parameters, the blade profile can be drawn. First, with the horizontal expansion line, the blade angle distribution profile can be drawn by error-triangle method. With the angle distribution, the blade profile can be drawn. Then the flow path area can be checked to examine the through flow performance. Commonly, these steps will be repeated for several time to obtain an optimal design configuration. The drawing of guide vane is shown in Figure 5. And the detailed process is not described and only the structural parameters are listed in Table 2.

![Figure 5. Dimensions of guide vane.](image)

As shown in Figure 5, the guide vane is space guide vane with fully twisted surface. To reduce its axial length, the size is designed to be 55.3mm, thus the whole stage is more compact.

![Figure 6. Schematic diagram of pump and guide vane.](image)

**Table 2. Guide vane design parameters**

| Z | $D_{w3}$ (mm) | $D_{w1}$ (mm) | $D_{w2}$ (mm) | $D_{w0}$ (mm) | $b_3$ (mm) | $\beta_3$ ($^\circ$) | $\beta_4$ ($^\circ$) | $\phi$ ($^\circ$) |
|---|---|---|---|---|---|---|---|---|
| 7 | 125.6 | 100 | 62 | 33 | 15 | 35 | 90 | 83 |

**4. Experimental test and analysis**

In this study, the hydraulic components are shaped by molding machine with fully twisted surfaces. In plastic molding, the 3D geometrical model is directly imported to molding machine to produce these components. As shown in Fig.6, the molding machine forms the product for only several minutes. And the error between the model and the exact 3D model is very small. Thus the product quality and efficiency can be greatly improved.
To verify the hydraulic design, an eight-stage pump is developed, and the samples are shown in Fig. 7. The hydraulic components are made of PPO plastics which can guarantee the strength under high rotating speed.

![Sample plastic impeller and guide vane](image)

**Figure 7.** Sample plastic impeller and guide vane.

| Performance Solutions | Efficiency (%) | Head (m) |
|-----------------------|----------------|----------|
| National Standard     | 66             | 6        |
| Pedrollo              | 70.6           | 7.2      |
| This study            | 72.39          | 10.6     |

From Table 3, it can be seen that the pump performance is more superior than the national standard and the Pedrollo pump from Italy. Figure 8 shows the performance curves of centrifugal pump, where the rhombic symbol denotes the head $H$, triangle symbol denotes the efficiency $\eta$, and square symbol the shaft power $P$, varying with flow rate $Q$.

The results show that the highest efficiency of this deep-well pump is 72.6% at flow rate 36 m$^3$/h and the head 10.3 m. And the maximum power is located near 36 m$^3$/h, which shows a non-overloading characteristic. Meanwhile, this deep-well pump has a wide range of high efficiency around the design point and a wide stable operation region.

![Performance curves of prototype deep-well pump](image)

**1. Figure 8.** Performance curves of prototype deep-well pump

**5. Conclusions**

A moderate specific speed pump is developed. Plastics are successfully applied to manufacture of the major hydraulic components. The steel barrel is used to connect the stages, which reduces the pump weight and makes the pump more compact.

The fully twisted surfaces are shaped by plastic molding techniques, which enhances the product quality and improves the pump hydraulic performance, which has been validated by the prototype pump test. In addition, the steel barrel and the plastic impeller front end-face forms the lubrication and the sealing effect is also be enhanced. To conclude, it is obvious that these techniques is feasible and can be applied for development of compact, light-weight, and cost-saving plastic deep-well pumps.


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