The Research and Development of the Amphibious Disaster-Resistant Submersible Pump with Dual Pump and Dual Motor

Feng Yicheng*

Department of Electrical Engineering, Tsinghua University, Peking, 10084, China

Abstract: This thesis introduces a kind of horizontal wet electric submersible pump unit with both submersible and non-submersible operational models that could be installed permanently. Then, it analyses the structural features, operating principles, main component performance and rotor system. A series of technical advantages show that this kind of submersible pump has a bright application prospect in conventional drainage and disaster-resistant emergency drainage of deep mines.

Keywords: Amphibious, disaster-resistant, dual pump and dual motor, submersible pump.

INTRODUCTION

According to the two hundred and seventy-third regulation of the new edition of Coal Mine Safety Regulations, when the hydro geological conditions are complicated or the mine is risk in water flooded wells, the water proof gate should be set around the shaft station or the other independent power supply system should be installed on the basis of normal drainage around the bottom, of which the drainage capacity not less than the maximum yield of Submersible Pump [1]. This regulation indicates that the Submersible electric Pump around the bottoms should be installed fixedly and can be standby for long years. The traditional Submersible Pumps must dive when running and it used in a pump off the plane on the vertical installations [2]. These traditional Submersible Pumps applied in resisting disaster in the bottom for long years are required to set the bottom water that would increase the quantities of mine and the difficulty of installment. Moreover, they are more likely to be corroded severally and buried by sludge because of placing in the mine water in the long term. Based on this, this dissertation introduces a horizontal installation of Amphibious Disaster-resistant Submersible Pump which can not only be drained off water in mine as normal pump, but also as a submersible pumps to support disaster and disaster relief drainage in the mine. The amphibious pump usually don't have to dive into the water that can avoid the mine water erosion of the pump body. At the same time, it is convenient for daily maintenance and maintenance.

OVERALL STRUCTURE AND WORKING PRINCIPLE

Structural Features

The amphibious disaster-resistant submersible pump’s structure is shown in Fig. (1), the pump is composed of the two same specifications of horizontal pumps and electric motors. Horizontal pump is fixed a suit on the pump shaft through the pump shaft, water outlet, water inlet, mesomere, blast hole, guide vane and impeller. In addition, the pump shaft passes through the position of pump shell’s tail so as to be sealed mechanically. The right and left position of horizontal pump is symmetric and concentric whilst the pump shaft end of middle of horizontal pump is connected permanently by using the coupling shaft. The electric motor is comprised of the motor shaft, motor case, front cover, mechanical sealing device, stator assembly, rotor assembly, thrust bearing, adjusting bag, back cover and other parts [3]. The motor shaft and rotor assembly penetrates to the internal motor as well as being supported by the front bearing and rear bearing. There is a mechanical seal device arranged between the front case and front bearing and the adjusting bag is fixed on a back cover. Therefore, the shafts of these two horizontal pumps are respectively connected with a motor by a coupling. The motor casing is fixed on the mounting by a screw, and there is an outer channel setting on the motor casing. In this way, the inlet could be connected with the outer channel on the motor casing whilst the outer channel is connected with the suction of horizontal pump by a clamp, and the horizontal pump outlet is connected with whole drainage pipe by three links. The Submersible motor is installed the friction materials of friction resistance on both ends, which is used to eliminate the residual axial force of manufacturing errors.

Operating Principle

When the amphibious disaster-resistant submersible pump is running, the two pumps arranged symmetrically could be driven by two sets of the same type of submersible motor so as to balance the pump axial force produced by the runtime [4]. The mine water will from water inlet to flow through the web of dome, casing pipe, spherical shell in sequence, and then entering into the horizontal pump. In the meantime, the water flow will flow within the web of the cooling water channel in the web of pipeline internal flow in order to sufficiently exchange the heat with the motor, which can guarantee the normal operation of motor driving the
pump. Besides, when the mine water inflow has increased dramatically and even exceeds the mine drainage ability, the water level will rise sharply. If the amphibious pump can be started before being inundated, it can be served as a normal drainage pump to assist the mine drainage system’s normal work, which can effectively increase the mine drainage ability and inhibit or delay the time of mine flooding so as to save more time for the escape of staff underground the mine well and the rescue of follow-up. On the contrary, if the water inflow has increased continually that leads to the mine flood and the entire submergence of amphibious pump in the mine water, the amphibious pump as relief submersible pumps will also lay a foundation for subsequent drainage after accident Wells that can reduce the loss caused by accidents [5]. The flow direction of amphibious disaster-resistant submersible pump is shown in the arrow direction of Fig. (1).

STABILITY ANALYSIS AND PERFORMANCE REQUIREMENTS

The Rotor System Characteristics Analysis

By comparing with ordinary vertical submersible pump, the rotor system is the key of realizing amphibious pump horizontal running [4]. Therefore, it is necessary to analyze the characteristics of rotor load, critical speed and dynamic deflection.

The simplified model of amphibious disaster-resistant submersible pump with rotor system is shown in Fig. (2).

![Fig. (1). Amphibious type submersible electric pump overall structure diagram.](image)

![Fig. (2). Simplified model of amphibious disaster-resistant submersible pump with rotor system [5].](image)
**Force Analysis of Rotor System**

The Amphibious disaster-resistant submersible pump belongs to horizontal multistage centrifugal pump. The load on the rotor system includes:

1. The radial force, including the additional radial force on the impeller rotation due to the uneven distribution of pressure along the outer edge of the impeller, the centrifugal force resulting from the residual unbalance weight when the rotor system is rotating and the radial force produced by the weight of the overall rotor system.

2. The Axial force, which mainly refers to the axial force produced by the imbalance of multiple impeller.

3. Torque passing by the pump shaft. Radial force is balanced by the thrust bearing, and the pump shaft ‘own weight could be ignored. The situation on the pump shaft and the influence of the coupling and horizontal axis to descend to point C, as is shown in Fig. (3).

As the two structures of both right and left horizontal pumps of this kind of submersible electric pump are exactly the same, it can generate the equal and opposite axial force on the rotor system. It is also the key factor of influencing the stable operation of pump.

**Critical Speed and Dynamic Deflection of Rotor System**

The impeller of two pumps in this device are fixed suit on the pump shaft and the influence of the coupling and pump shaft’ own weight could be ignored. The situation could be assumed that the impeller is in the middle level of pump shaft and without damping. The influence of the impeller’ own weight on critical speed will be researched.

The quality of the impeller \( F_c = \frac{mu^2}{R} \) could lead the axis of horizontal axis to descend to point C, as is shown in Fig. (3). The static deflection \( A_0 \) is formed. Considering the gravity eccentricity of impeller \( u_{c_{\max}} \leq \sqrt{\frac{gR(f - \tan \theta)}{f \tan \theta + 1}} \), the distance of the impeller center C deviating from the bearings \( (F_c \cos \theta + G \sin \theta)h_g \leq \frac{(G \cos \theta - F_c \sin \theta)B}{2} \) (dynamic deflection of the axis) will make the radius of the impeller gravity W centering rotating about point C to be \( u_{c_{\max}} \leq \sqrt{\frac{gR(B - 2h_g \tan \theta)}{2h_g + B \tan \theta}} + u_{c_{\max}} \leq u_{c_{\max}} \). The impeller center of gravity W rotates about the line connecting of the bearing O, the gravity center producing the centrifugal force is:

\[
\frac{gR(f \cos \theta - \sin \theta)}{f \sin \theta + \cos \theta} \leq \frac{gR(B \cos \theta - 2h_g \sin \theta)}{2h_g \cos \theta + B \sin \theta}
\]

The change of the pump shaft is within the elastic range. Its force has direct ratio relations with the strain, which is shown:

\[
f \leq \frac{B}{2h_g} \frac{1 + \frac{t^2}{\theta}}{1 - \frac{t^2}{\theta}}
\]

sup(\( X \)) < s x d_i - Rigidity coefficient of the pump shaft

The critical speed \( Sup_{(\Delta, \theta)} > \min_{\sup} \) is:

\[
n_c = \frac{30w_c}{\pi} = \frac{30K}{\pi \sqrt{m}}
\]

Based on the formula above, even if there is no gravity eccentricity shaft in rotor pump, which means that \( \Delta = \theta \), the angular frequency vibration of the rotor could be still ensured as \( w_c \) on the base of the quality of the rotor \( CV \) and the rigid coefficient \( A \Rightarrow B \). So, from the perspective of the angular frequency vibration of the rotor, the rotor critical speed is not related with eccentricity.

Merging the formulas of (3), (4), (5):

\[
A = \frac{m(A_0 + \Delta)w^2}{K - mw^2}
\]

When the angular velocity of pump shaft is increased to the angular frequency, which means that the dynamic deflection \( A = \infty \). It will be the critical angle frequency (\( A \Rightarrow B \)):

\[
w_c = \frac{K}{\sqrt{m}}
\]

The critical speed \( Sup_{(\Delta, \theta)} > \min_{\sup} \) is:

\[
n_c = \frac{30w_c}{\pi} = \frac{30K}{\pi \sqrt{m}}
\]

According to (6), if \( n < n_c \), the dynamic deflection \( A \) will increase with the increase of rotational speed; If \( n = n_c \), the dynamic deflection \( A \) will decrease with the increase of rotational speed (absolute value); If \( n = n_c \), the dynamic deflection \( A \) will reach maximum.
The submersible electric pump manufacturing error and setting error of rotor system and other factors will lead to the forced vibration of submersible electric pump rotor system because of the unbalanced eccentric quality.

In the actual operation, in addition to the eccentric quality caused by pumps forced vibration, the other influenced factors of dynamic deflection $A$ are due to the misalignment issue of three couplings linking with the four axis, the gap issue of shaft and bearing’s cooperation. It is shown as follow.

$$A = \gamma \left( \frac{w^2}{W} \right) (A + \Delta)$$

In this formula above, $\gamma$ is the influence coefficient of dynamic deflection due to the misalignment rotor and the fitting clearance.

Therefore, the rotor system must be checked carefully before assembly according to the static and dynamic balance so as to enable the eccentricity $\Delta i$ of the gravity center $W_i$ of each of the impeller close to zero and make the dynamic deflection $A$ and centrifugal force smaller to slow down the bearing load of radial shaft. It is necessary to strictly control the problems about the misalignment rotor and the fitting clearance.

Performance Requirements of the Main Components

In order to realize the horizontal running with high flow, high lift and high efficient, the main components of the amphibious disaster-resistant submersible pump should meet the following requires by considering the installation conditions, working conditions and other factors [6].

Water Pump

The two water pumps should be controlled by the same switch that ensures the start and stop of two motors at the same time and relative rotation. Water will enter into the pump body respectively from the water inlet of the two pumps. Then, the working of impeller could increase the energy. After this, water will output from the water outlet and flow though the coupling flange and check valve to lifting pipe. There are two bearings on the each side of the water pump shaft and the check valve is installed on the total drainage pipeline, which could avoid the water pump reversal caused by the back in water when parking.

Pump Case

Pump will suffer from great pressure when working. So, it should be manufactured by using the high strength ductile iron. Parts should be conducted through a hydrostatic test according to the provisions of the state standard. Gasket and seal gum are placed between the level shells to prevent leakage to ensure the good performance of the pump. Due to the quality of water, both the internal and external of pump case should use antirust processing.

Impeller and Guide Blade

The Impeller is comprised of the front cover, back cover, blades and impeller ring. The advanced casting method has been adopted to make sure the geometrical shape of the impeller and high surface finish. The smooth operation can be guaranteed by conducting the static balance test after the processing completion.

Both the Impeller and guide blade have been dealt with the special materials or the processing of surface properties so as to contain the performances of wear-resisting and corrosion resistance. The stainless steel impeller ring can be inlayed at the impeller seal.

Pump Shaft

The material of the pump shaft is 40Cr through thermal refining and qualitative processing. Generally, the chrome plated collar and interstage sleeve would protect the pump shaft. And the two pump shafts are connected with coupling.

Coupling

When the pump is launching, the overload phenomenon may be happening during the process of dynamic load operation. The maximum torque in the shaft torque should be served as the calculation torque $T_m$, the torque formula [7] is:

$$T_m = K_u T$$

In this formula, $T$ is nominal torque ($N\cdot m$); $K_u$ is work situation coefficient. According to the characteristics of bigger pump shaft torque and moderate impact load, $K_u$ takes 1.9.

Bearing

Horizontal dual pump has four radial bearings, which is lubricated by water. Lubrication bearing’s water keeps recycle by the pressure difference. All of them are made of tin bronze.

Adjusting Ring

This pump is the multiple-stage centrifugal pump, of which the assembly cumulative error and adjusting loop compensation error are great. The centerline of the impeller outlet is higher than the centerline of the vanes entrance (It is advisable to 0.5 $-$ 1.0 mm).

THE MAIN INNOVATIVE POINTS

Amphibious disaster-resistant submersible pump provides a new way of drainage in the mine disaster and disaster relief. By comparing with ordinary submersible pump, there are the following innovation points:

1. Using the same pump symmetrical layout structure can realize axial force balance when running.

2. Using the fission horizontal installation of submersible motor and horizontal pump is convenient for transportation, installation, lifting and removal.

3. It can be installed under mine near the main water storehouse for long year, which can not only be able to work as normal mine drainage pump, but also work as a submersible pump in the anti-disaster and disaster relief. When the mine water is gushing normally, it works as a dewatering pump to assist in the main drainage pump inside the pump house to drain away water, which can improve the pump house’s capacity of pump drainage. When the mine water...
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water inflows increase and even are occurring the accident, it can participate in the drainage of fighting disaster, which could save valuable time for the miners out of the mine and reduce the flooded well accident probability. When the mine is submerged completely, this equipment can be converted to the submersible pump to participate in the rescue and drainage, keep mine and reconstruct mine so as to reduce the damage caused by accident [8].

At ordinary times, it is not necessary to subduct into water that could monitor and observe the pump running status at any time to make maintenance convenient at any moment. Not only can the reliability of this pump be ensured, but also reduce the difficulty of maintenance and the cost of maintenance. It also enables the annual routine submersible pump commissioning not to be carried into the water. At the same time, it doesn't need to be flooded in water as usual, which can avoid the silt, minerals and impurities erosion of submersible motor and submersible pump. In this way, the service life could be extended.

Increasing the flexibility of amphibious pump as the drainage pump, because the length of suction pipe could be extended.

Being able to share the same water sump with underground drainage system to reduce the project amount of mine.

CONCLUSION

Amphibious disaster-resistant submersible pump not only provides a new draining way for the mine, but also confers the dual function for high-power submersible pumps, in terms of resisting and relieving disaster. Therefore, it provides the reference for the construction of Chinese coal mine disaster in deep draining system. Furthermore, it is successful to increase the scope of application of the power submersible pumps because of the development of amphibious disaster-resistant submersible pump, which has also offered the supports of equipment and technique for constructing the safe, efficient and modern mines.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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REFERENCES