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Analysis of the causes of damage to centrifugal pumps during operation and methods of their elimination

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Abstract

The paper reviews the research on improving the efficiency of operation and service life of centrifugal pumps, which are widely used in machinery for pumping various liquids. The main reasons for the failure of centrifugal pumps, as well as modern approaches to their prevention, are considered. It is established that increasing the efficiency of pump operation can be achieved by analyzing, modeling and optimizing their design. It was found that modeling the operation of smaller pump models and comparing surrogate models with the original ones is a modern, highly effective method of optimizing pump performance. The important role of protective coatings in increasing the wear resistance of parts is established, and the experience of introducing innovative coating technology at enterprises is described.

Keywords: analytics, pump shaft, centrifugal pump, mechanical seal, coating, wear resistance, adhesion.

Introduction

Today, an important technical challenge is to improve the reliability of machine parts and mechanisms that are subject to intense damage under high contact loads, elevated temperatures, aggressive media and abrasives. One of these mechanisms is centrifugal pumps, which are widely used for pumping liquids in many industries, including oil and gas.

High performance and long periods between failures or overhauls can usually be quite long as long as centrifugal pumps operate in conditions close to their design. However, it should be noted that "design" refers not only to pressures, flow rates, temperatures and other process parameters, but also to frictional torque forces, bearing and seal lubrication. Conservatively designed pumps can withstand only a certain amount of overload caused by technical processes or mechanical failure, so their components already begin to suffer damage before reaching the operating mode. Pumps should be selected for operation near the point of maximum efficiency[1].

Due to the high intensity of pump use in industrial sectors, it is important to ensure maximum durability and reliability of the equipment. One of the key factors affecting the durability and performance of pumps is the various lubrication and friction components, such as the shaft, mechanical seal, bearings, and shaft seal. This paper aims to analyze the causes of centrifugal pump failures and to study the data on the impact of shaft wear resistance and mechanical seals on pump performance and durability.

During operation, the motor or electric motor drives the rotor, converting the kinetic energy of rotation into hydrodynamic energy of the fluid flow. The fluid enters the pump axially through the casing eye, is captured by the impeller blades, where it gains speed and pressure. Then it moves tangentially and radially outward, exiting through the circumferential parts of the impeller into the diffuser part of the casing, which slows the flow and further increases the pressure.

The rotor shaft is subject to both cyclic and partial loads. Starts and stops cause voltage fluctuations with high average values. Multi-cycle fatigue analysis is often used to ensure shaft reliability. Stress analysis takes into account stress increasers due to design features such as threads, grooves, slots, and screw holes. The presence of these elements, combined with complex loads, requires finite element calculations to assess the reliability of the shaft. In addition, rotor dynamics and critical shaft speeds must be taken into account.

Article [2] notes that centrifugal pumps are subject to premature rotor shaft failures, even if all design standards are met. The causes of these failures fall into several categories: design errors or improperly selected materials of critical components, defects in manufacturing or processing, and reduced component performance due to wear. One of the main problems is the concentration of stresses due to design features, which causes excessive plastic deformation and contributes to the formation of fatigue cracks. These cracks can also occur due to internal material defects, such as non-metallic inclusions or microcavities, as well as irregularities created by machining. In addition, the authors of paper 3 note that operational wear of the working surfaces of pump parts gradually leads to degradation of the physical and mechanical properties of the material, in particular its elasticity and strength.

Other factors that can accelerate shaft failure are failure to maintain proper maintenance and errors during repairs. In the event of an equipment failure, it is important to assess the extent of damage to individual components and their impact on the functionality of the entire system. During operation, shaft damage occurs as a result of fretting corrosion and abrasive wear, which is the result of constant contact with aggressive liquids and mechanical friction. Fretting corrosion typically occurs in areas of micromovement between the shaft and surrounding parts, such as bearings or joints. This process causes rust formation and surface erosion, reducing the mechanical performance of the shaft.

Abrasive wear is often caused by solid particles from the operating environment entering the contact surfaces of the shaft and sealing elements or bearings. This results in grinding of the shaft surface, which can significantly reduce the shaft diameter at critical points, causing misalignment and increased stress on the bearings.

The pump shaft has several critical wear points, including contact points with seals, bearings and joints, as well as areas where torque is transmitted. Constant mechanical impact at these points causes microcracks, which can develop into larger damage over time. Regular shaft inspection and timely maintenance are therefore key to extending the service life of the pump.

Similar studies on shaft wear and critical damage are presented in [3]. In particular, the authors of this paper consider the consequences of an emergency due to the failure of a centrifugal pump used to pump a mixture of hydrocarbons to deliver the final petroleum product to a refinery. The shaft failure resulted in a fire of the pump and refinery pipelines within the block, with an estimated total loss of USD 48,000. The centrifugal pump was installed and commissioned about 30 years ago. There have been three major repairs of the pump due to gland leaks. The mechanical seal was installed on the threaded part of the shaft with a preload corresponding to 25-30% of the yield strength of the material. However, no abnormalities were reported on the shaft during operation and maintenance.

The typical operating cycle of a centrifugal pump consists of starting and running the pump at a nominal rotor speed of 2975 rpm for 14 hours, with a 2-hour shutdown interval. An inspection of the faulty centrifugal pump revealed catastrophic destruction of the rotor shaft surface, with the bushing remaining on the shaft.

Another basic element in a pump is a mechanical seal, designed to prevent leakage of working media, liquid or gas, at the points where the rotating shaft crosses the casing. It is used in various types of pumps, in particular centrifugal pumps, where it is necessary to ensure a tight seal between moving and stationary parts.

A mechanical seal works by the interaction of two main components: a stationary ring and a moving ring, which are pressed together by an elastic element such as a spring or bellows. The stationary ring is typically fixed in the pump casing, while the movable ring rotates with the shaft. This design minimizes friction and prevents leakage of the pumped medium, while ensuring reliable seal function under various operating conditions.

Selecting seals and sealing systems for pumps is a complex task. Cartridge seals offer significant maintenance advantages because they simplify the process of mounting and dismounting from the pump shaft. In the case of large oil seals, bellows and spring-sealed cartridges can be used. Cartridge seals are easier to replace, reducing the risk of assembly errors and damage compared to traditional mechanical seals.

The materials from which the rings are made are selected depending on the operating conditions. Fixed rings are often made of materials such as ceramics or carbon, which are highly resistant to wear. Moving rings can be made of metals or other materials that provide a snug fit and minimal friction. Their use becomes critical in conditions of high pressures, temperatures, or when dealing with aggressive media, where traditional seals such as glands may not be effective.

When selecting a sealing surface material, keep in mind that the heat generated on the sealing surface must be quickly dissipated to avoid evaporation of the liquid. High thermal conductivity and hardness make silicon carbide the preferred sealing surface material.

Many pumping systems require the mechanical seal environment to be maintained at a moderate temperature. This is sometimes achieved by external flushing. Another option for achieving moderate seal temperatures is to cool the stuffing box. In many pumps, the stuffing box cavity is remote from the sealing surfaces that require cooling.

Seals fail for two reasons: the lapped surfaces open up or one of the seal components is damaged. When the lapped surface is opened, solid particles penetrate between the lapped surfaces by the lapped surfaces. The hard particles penetrate the softer carbon/graphite surface, causing it to act like a grinding wheel. This grinding action will cause the hard surface to wear down heavily.

Article [4] states that most mechanical seal failures occur due to the destruction of the bearing and sealing surfaces for the following reasons:

– a dynamic elastomer cannot slide or move freely on a rotating shaft or sleeve. This can happen if the shaft is too large, the shaft finish is too rough;

– the product is viscous or the product crystallizes;

– the shaft is displaced, causing the seal to hit something during rotation or the rotating surface to slide off a stationary surface. This can happen if the pump is running far from its BEP; the shaft is bent; the rotor is unbalanced; the shaft deformation twists the pump seal, or due to cavitation;

– the product evaporates between the sealing surfaces of the surfaces, which leads to their rupture;

– poor quality of the end seal.

According to statistical data in [5,6], the failure rate of centrifugal pump parts is indicated, the bulk of which falls on (Fig 1):

– hydraulic wear (32%): impeller (blade wear, corrosion, cavitation), body (wear of the inner surface, corrosion);

– mechanical wear (25%): bearings (wear and tear, breakage), seals (wear and tear, loss of tightness), shaft (wear, bending, breakage);

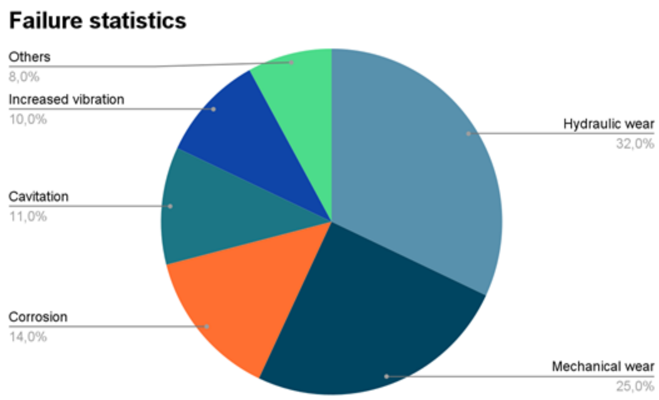

Fig 1. Statistical data on the failure of centrifugal pumps.

– corrosion (14%): all parts (corrosion can affect any part of the pump, especially in aggressive environments);

– cavitation (11%): impeller (cavitation causes the surface of the blades to be destroyed);

– increased vibration (10%): rotor imbalance, damage to the bearings, loosening of fasteners, hydraulic imbalance.

– other reasons (8%): installation errors, damage by foreign objects.

It should be noted that the data above is an average value, as each pump has its own individual performance characteristics [7].

Purpose

To analyze the dominant types of wear of centrifugal pumps of the Dickow Pumpen type and methods of increasing wear resistance through various types of hardening

Object of research

The object of the study was a Dickow Pumpen 125/320 centrifugal pump for the transportation of fuels and lubricants (Fig 2). This type of pump was used in the company's pile-lubricant warehouse.

Fig 2. Dickow Pumpen NCR 125/320 centrifugal pumps

The Dickow NCR pump is a heavy duty centrifugal pump for the oil, petrochemical and gas industries, manufactured in accordance with API 610 standards. Available in a wide range of sizes and specifications, it has a maximum flow rate of up to 700 m^3/h and a maximum head of 145 m at 2900 rpm and 220 m at 3500 rpm.

Results

The pump is operated in an aggressive environment (kerosene) with an average operating time of 6 hours per day with interruptions. The total continuous service life was 3 years. The shaft, bearings, and mechanical seal are subject to the highest loads, with the mechanical seal experiencing the most significant wear (Fig 3).

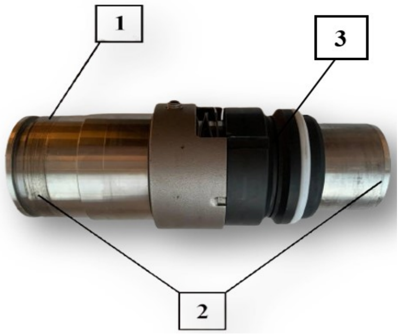

Fig 3. Dickow Pumpen mechanical seal part, operating time 6500 hours: 1 – abrasive wear of mechanical seal components; 2 – fretting corrosion due to friction and operation in aggressive environments; 3 – after abrasive wear, additional vibrations were generated on the mechanical seal part, and the graphite rings began to break down.

After 6500 hours of operation of the pump unit, significant wear of the mechanical seal was detected, which manifested itself in the form of abrasive damage and traces of fretting corrosion. These defects were caused by prolonged operation in an aggressive environment (kerosene) and constant exposure to mechanical and chemical factors. The first signs of damage were leakage of working fluid and abnormal noise during pump operation, which indicated a violation of the seal tightness. In order to prevent further malfunctions, the pump was shut down for diagnostics and inspection. As a result, it was decided to replace the damaged seal to restore normal operation of the pump. Based on the experience gained, it is now possible to implement technical solutions that will extend the mechanical seal's service life. Therefore, a lot of research is currently focused on analyzing and finding relevant solutions to improve the performance of centrifugal pumps. In particular, experimental work is carried out under unstable conditions at partial load, and the results at different operating points are compared with available experimental data, such as hydraulic performance and flow field information by measuring the particle image velocity [8,9].

It is important to note that design optimization is quite effective in improving the performance of centrifugal pumps by reducing flow recirculation and cavitation [10,11,12]. To improve pump efficiency, the design of pump impellers was optimized in [13] by numerical modeling, Latin Hypercube (LHS) sampling, a surrogate model, and a genetic algorithm (GA). The results showed that the simulated results are consistent with the experimental performance results of the original pump. Compared with the simulated efficiency of the original pump, the optimization improved the efficiency by 8.34% beyond the design point can be used to model the design of other pumps. Increasing the service life can also be achieved by increasing the performance of the centrifugal pump through independent rotation of the inductor and centrifugal impeller [14]. An inductor that provides independent rotation of both the inductor and the centrifugal impeller. Unlike conventional designs, this configuration allows for differential speeds and controlled rotation directions. In particular, the independent rotation of the inductor extends the operating range of the pump, while the rotation of the inductor and impeller in opposite directions significantly increases the pressure generation and efficiency of the pump compared to rotation in the same direction. However, along with increasing productivity, an important aspect of ensuring the durability of pumping equipment is protecting its components from wear. One of the most effective methods of improving the wear resistance of the working surfaces of pump parts is the application of protective coatings. By increasing the wear resistance, such coatings can significantly extend the service life of mechanical seal parts, shafts and bearings. The coatings can be applied by plasma or detonation spraying, laser or electric spark alloying [15]. In [16], wear-resistant WC-Co coatings were applied to pump impellers using the method of spark alloying. The resulting coatings are uniform and continuous without obvious cracks and holes, there is no clear line of separation, and a strong metallurgical bond is formed between the coating and the substrate material [17]. Coatings can also be applied to the shaft, mechanical seal, and other parts of the pump [18]. TST Coatings is a company that applies coatings to various pump parts. Their methods use gas-thermal spraying to apply tungsten carbide-based materials with 12% cobalt. These coatings have high hardness, excellent adhesion and a very dense structure. They provide excellent wear protection for several different wear mechanisms. An alternative is offered by the Ukrainian company TRIZ [19], which manufactures and improves mechanical seals and pump shafts by applying coatings that also use tungsten carbide-based materials. Currently, new wear-resistant materials and coating methods are being developed, which in the future can be used to improve the performance properties of pump working surfaces.

Conclusion

The following conclusions can be drawn from the analysis of the papers on the causes of failure of centrifugal pumps during their operation and possible methods of their elimination:

To ensure the long and trouble-free operation of centrifugal pumps, it is critical to regularly perform in-depth analysis and modeling of possible failures. This process includes not only identifying the most frequent causes of failure, but also predicting potential problems, which allows you to take preventive measures and minimize the risk of accidents.

One of the most serious problems that lead to early pump failure is the wear of the shaft and bearing running surfaces. This process can be caused by various factors such as friction, corrosion, cavitation, and vibration. To increase the wear and corrosion resistance of pump parts, an effective solution is to use protective coatings. Modern technologies make it possible to apply various materials, such as ceramics, metals or composites, to the surface of the parts, which significantly increase their service life. Another important aspect is the modernization of the design of key pump components. Replacing worn or outdated parts with more modern and reliable ones, such as the shaft, mechanical seals, seals, and bearings, can significantly increase the efficiency and durability of the pump. Optimizing flow recirculation and improving the interaction between the impeller and shaft will also help reduce wear and improve pump performance.

In further research, it is planned to study in detail the effect of different types of wear-resistant coatings on pump parts. A comparative analysis of their properties, such as hardness, wear resistance, corrosion resistance, and adhesion to the base, will be conducted. This will help determine the optimal coating option for each specific pump part, taking into account its operating conditions and requirements.

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Морщ І. В. Аналіз причин пошкоджень відцентрових насосів в процесі експлуатації та способи їх усунення

У статті здійснено огляд сучасних підходів до підвищення ефективності та довговічності відцентрових насосів, які широко використовуються для транспортування рідин. Визначено основні фактори, що впливають на зниження їх продуктивності та можливі методи покращення експлуатаційних характеристик. Аналіз причин виходу з ладу відцентрових насосів показав, що найбільш поширеними проблемами є зношення робочих поверхонь, гідравличний знос, корозія, кавітація та вібраційні навантаження. Для запобігання цим явищам доцільним є застосування сучасних рішень, зокрема використання захисних покриттів, оптимізація конструкції та впровадження інноваційних технологій у виробництво.

Одним із перспективних напрямів насосного обладнання є математичне моделювання та створення зменшених прототипів для тестування. Це дозволяє оцінити ефективність конструктивних змін без необхідності дороговартісних експериментів. Дослідження показують, що використання сурогатного моделювання дає змогу значно знизити витрати на розробку та підвищити точність прогнозування поведінки насосів у реальних умовах експлуатації.

Також значну увагу приділено ролі зносостійких покриттів, які можуть значно продовжити термін служби основних деталей насосів. Сучасні технології дозволяють наносити на поверхні робочих елементів захисні покриття, що підвищують їхню стійкість до механічних та хімічних впливів. Подальші дослідження у цьому напрямку спрямовані на аналіз ефективності різних типів покриттів, їх адгезії та зносостійкості залежно від умов експлуатації. Таким чином, підвищення ефективності та надійності відцентрових насосів можливе завдяки комплексному підходу, що включає оптимізацію конструкції, використання сучасних матеріалів та впровадження цифрових методів аналізу. Це дозволить значно покращити робочі характеристики насосів та зменшити витрати на їх обслуговування.

Ключові слова: аналітика, вал насоса, відцентровий насос, торцеве ущільнення, покриття, зносостійкість, адгезія