Research of Forward Design Method of Contact Dynamic Seal

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Abstract. The development of forward design of contact dynamic seals is an inevitable way to realize the independent development of core key components based on the research results of existing rubber and plastic seals. This paper proposes a multi-index comprehensive evaluation system for sealing performance. Based on the requirements of multiple performance indexes of dynamic sealing systems, a comprehensive evaluation of multiple index functions is constructed to provide a comprehensive evaluation of the performance of rubber and plastic seals. Based on the specific design examples of air contact seals, the design process of a certain seal is explored. Finally, the article elaborates on the future work of the forward design method and its development direction.

1. Introduction

Rubber and plastic seals are important basic parts of mechanical systems, and their structure and performance are crucial to the operation, performance and service life of mechanical equipment. Relevant statistics in the United States in the 1970s showed that actuators must be repaired or replaced due to the failure of actuator reciprocating seals, accounting for more than 90% of the causes of aircraft actuator failure[1]. However, the study of rubber and plastic dynamic seals in China started late and there are few researches, mainly focusing on the finite element analysis of the seal ring and how to select and combine the seal ring. There is less research on the design method of the seal ring and it is in a catch-up status[2][3]. At present, most of the design of rubber seals adopts reverse design methods, that is, selecting advanced foreign products, conducting imitation studies on materials, structures, etc., and combining experimental research, finally obtain the required sealing rings.

Nowadays, with the changes in the environment and conditions of use of rubber and plastic sealing rings, especially in the face of extreme conditions and supercritical problems, such as: high-pressure high-speed reciprocating seals, ultra-deep marine detection seals, The higher requirements are placed on the reliability and service life of the seal ring. Under these conditions, it is impossible to learn from the existing sealing ring products, and the foreign closure of key sealing technology, it is difficult to find and produce suitable sealing ring. Developed countries have formed a relatively complete industrial system for sealing technology, including design, production, testing, and application. Faced with the lack of domestic basic research, technological backwardness, and the critical status of key equipment dependent on imports, a positive design method and comprehensive performance evaluation system are urgently needed to fill the gap in domestic rubber and plastic dynamic sealing technology.

Recently, the "US blocked ZTE" incident once again sounded the alarm for us. We must independently research and develop new types of sealing rings with intellectual property and carry out forward design method research.It lays a theoretical foundation for the development of China's high-performance rubber and plastic seals and intelligent seal design, and it not only helps to break the status quo of China's major equipment and key seals that are completely dependent on imports, but also helps to prevent major accidents and ensure the safety of major projects in China, therefore, it has important economic and social significance. In recent years, the Department of Mechanical Engineering of Tsinghua University has done relevant work on the forward design method of the seal ring in aviation and other fields, such as designing high-speed and high-pressure reciprocating seal rings[4], W-shaped metal seal ring design[5], etc.

2. Forward Design Method

2.1. Theoretical Research Content

Due to the multi-field coupling characteristics of rubber and plastic dynamic sealing system and the physical and chemical characteristics of rubber and plastic materials, such sealing products have complex working mechanisms, strong environmental dependence, and easy wear and aging. The theoretical research content of the forward design method includes: exploring the sealing mechanism, designing the sealing structure, studying the sealing performance, carrying out reliability analysis and testing, optimizing the sealing structure, and prolonging the life of the seal.

The seal lip pressure distribution is the research basis of the rubber and plastic dynamic seal system. By establishing the simulation model of the seal system, the lip pressure distribution of the reciprocating dynamic seal and the rotary dynamic seal can be obtained, and the next calculation is performed. Reverse pumping rate and friction torque can be used as an important indicator of sealing performance evaluation. Reverse pumping rate reflects the sealing effect of dynamic sealing. Friction torque reflects the degree of wear and the service life of the seal. Guo Fei of Tsinghua University[6] “Reverse pumping mechanism based on the lip seal of the rotating shaft” established a model of mixed lubrication under the steady state conditions of the simulated lip seal. The reverse pumping rate and the variation of friction torque with the rotation speed were calculated, and based on the calculation results, the design was optimized to improve the lip seal performance.

2.2. Forward design method system

The research on the dynamic seal performance of rubber and plastic involves many disciplines, including fluid mechanics, solid mechanics, contact mechanics and thermodynamics, and they interact and interact with each other (as shown in Figure 1).

First of all, the fluid mechanics analysis obtains the initial oil film pressure distribution curve of the sealing lip part through the relationship between the oil film thickness and the bearing capacity of the oil film. Considering the coupling relationship between the contact surface mechanics and the oil film pressure distribution curve, the roughness peak of the sealing lip surface is obtained, and the corrected oil film pressure distribution curve of the lip is obtained. The frictional force produced by the contact pressure influences the hydromechanical analysis results. Secondly, the oil film pressure and the rough peak contact pressure affect the results of fluid mechanics analysis through solid mechanics analysis. Thirdly, the solid-mechanical analysis using finite element analysis of the static contact pressure of the sealing lip and the change of the roughness peak will also affect the contact mechanics analysis results. Finally, as the speed of the lubricant changes, the viscosity of the lubricant changes accordingly, and changes in the viscosity affect the results of the fluid mechanics analysis.

Therefore, how to establish a multi-scale and multi-field coupled full-system sealed lubrication model is the key to the forward design method. The pumping rate and friction torque of the sealing system can be obtained through this model. Then by studying the system structure parameters, material parameters, operating parameters and micro-morphology parameters, etc. on the sealing mechanism of action and influence rules, design and optimization to get the required rubber seals.The forward design method flow is shown in Figure 2.

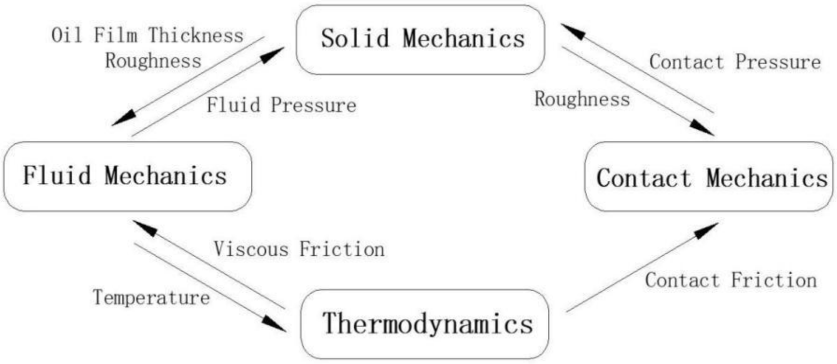

Figure 1. The contact of each disciplines.

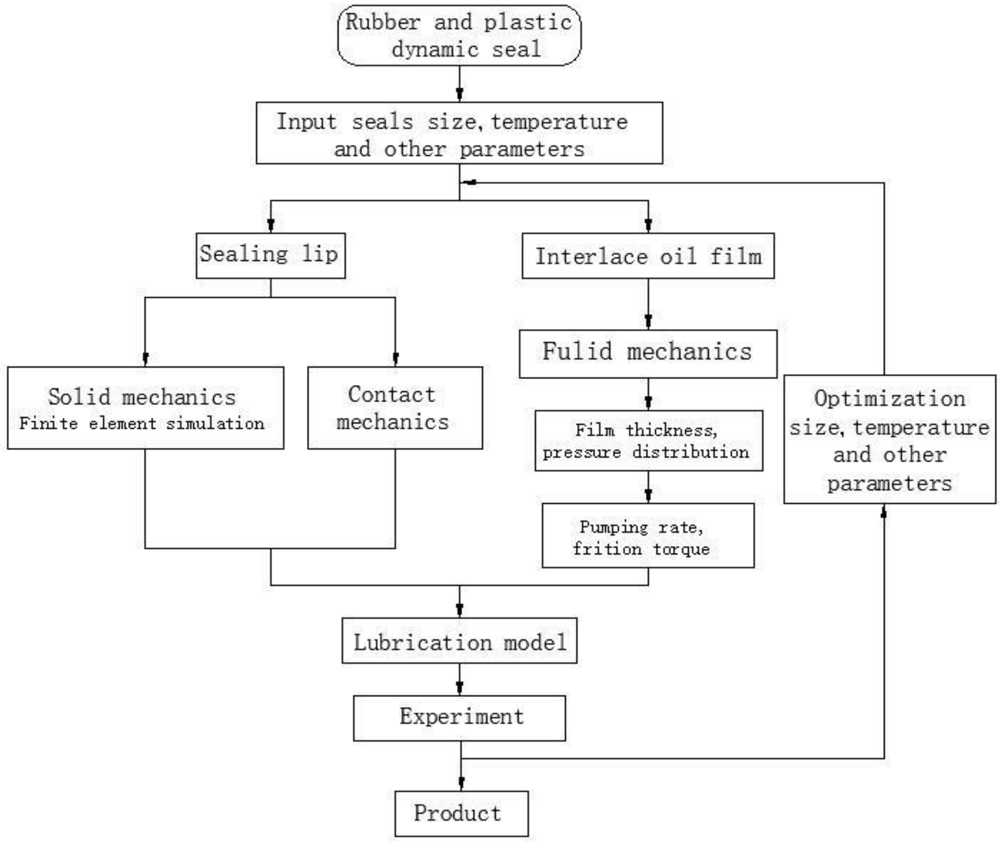

Figure 2. The forward design method flow.

3. Sealing Performance Evaluation System

Good sealing performance is the ultimate goal of the design of the sealing system. The indexes for evaluating the sealing performance include: leakage amount, sealing life, quality stability, and even leak detection system to detect the sealing performance of the sealing system. In recent years, researchers have used single performance indicators to evaluate the sealing performance of sealing systems. However, the evaluation of the sealing performance of the entire sealing system based on only one performance index is one-sided and inaccurate. Therefore, there is an urgent need for a method for comprehensively evaluating the sealing system by integrating a plurality of performance indexes, and to provide an accurate and reliable performance evaluation of the rubber-plastic dynamic sealing system.

For this purpose, we build an equilateral polygon based on multiple indicators that determine the sealing performance, where each point of the polygon represents an indicator. According to the standard and size distribution of different indicators, a polygon reflecting the measured performance index of the sealing system is constructed to construct a comprehensive evaluation index function(as shown in Figure 3). According to the index polygon and data processing of multiple indexes, the comprehensive performance of the sealing system is obtained and the performance is judged to be qualified. This method can not only accurately reflect the overall performance of the sealing system, but also compare the size of each sub-indicator, more intuitive to get the impact of a single indicator.

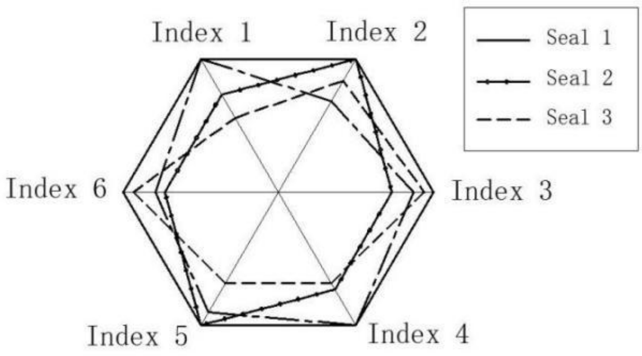

Figure 3. Example of equilateral polygon.

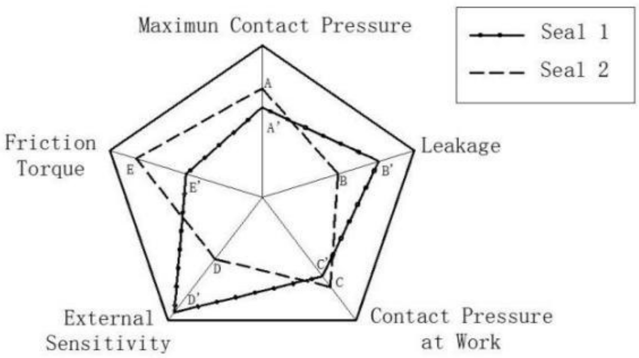

Figure 4. Instance analysis.

At present, the multi-objective optimization does not have a forming method in the study of mathematics, we have transformed the multi-objective problem into a single objective function to solve it.That is, according to the convergence areas of multiple objectives often in the feasible region, the n-multi-objective optimization problem is used to find the constraints of n-1 targets one by one, and then the layered solution is used to reduce the feasible region, the final conversion to a single-objective problem is solved.

As shown in Figure 4, set the comprehensive evaluation index to 5, namely: the maximum contact pressure, leakage, contact pressure at work, external sensitivity and friction torque, draw a regular pentagon. Set the qualified area is S. The evaluation rule is to compare the size of the pentagon. When the area is ≥S, the seal is not qualified. On the contrary, when the area is ≤S, the seal is qualified. According to the five evaluation indexes, the pentagonal patterns ABCDE and A'B'C'D'E' corresponding to the seal 1 and the seal 2 are respectively drawn, and two pentagonal areas are respectively found, Comparing with the qualified area S, the qualified seal can be obtained.

4. Conclusion

The mastery of the core component technology is one of the important contents of China's 2025 manufacturing planning. The core technology is controlled by others is the biggest hidden danger, and the core technology depends on the affinities or not, only self-reliance. Therefore, it is very urgent and necessary to carry out research on the forward design method for dynamic seal of rubber and plastic in aviation, nuclear power, military, marine and other fields.

The forward design method of rubber and plastic dynamic seal proposed in this paper can design suitable high performance rubber and plastic sealing ring according to the actual environmental conditions. This article also mentions a multi-index sealing performance comprehensive evaluation system, which can comprehensively, accurately and comprehensively evaluate the performance of rubber and plastic sealing ring based on multiple performance indexes of rubber and plastic dynamic sealing system.

Acknowledgments

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