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The performances optimization of finger seal based on fuzzy game theory

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Abstract

Leakage and abrasion are two key performances of finger seals (FS). They not only contradict each other in FS design but also relate to many design parameters. Moreover, in the multi-objective optimization progress, the problems of optimizing results decision and preference requirement for optimization objectives are still challenge to researcher. So far, they are still important influence factors for advanced FS design. Therefore, the current work presents a new multi-objective optimization method by introducing game theory and fuzzy comprehensive evaluation theory. The optimizing results are compared to that of the general optimization method and finite element method (FEM). The study show that the FS, which is obtained by presented optimization method, has good performances. Compared respectively with the general optimization method and FEM, the computational results indicate that the presented method can effectively reflect the different response requirements of optimization objectives. Furthermore, the decision-making difficulty for multi-objective optimization of FS performances is significantly reduced.

Keywords: game theory, fuzzy comprehensive evaluation, FS, multi-objective optimization, FEM

1. Introduction

FS is a revolutionary technology in air-to-air sealing for secondary flow control and gas path sealing in gas turbine engines. It has been demonstrated to be considerably cheaper than a brush seal but the sealing

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performance is similar to brush seal and better than labyrinth seal. The cost to produce FS is estimated to be 40 to 50 percent of the cost to produce brush seals [1]. Therefore it is promising in improving aero-engine performance, increasing operation life and decreasing operation cost.

Research indicates that increasing stiffness can decrease the hysteresis and leakage of FS, while the contact pressure between finger feet and rotor increases synchronously and leads to the reduction of operation life for FS[2]. This contradiction is a key problem for FS application. Furthermore, the sealing performance and operation life perhaps have different response requirements in FS application. Sometimes the requirement, called "preference", is unclear. For the FS multi-objective optimization with unclear preference, it is found that the results gained by general optimization methods are still unsatisfactory in preference and decision-making. Therefore, it is necessary to present an effective method to solve the above problems for FS.

For the FS multi-objective optimization, the leakage (Q) and operation life (expressed by using wear ratio V generally) are taken as the two conflicting objectives. By combining fuzzy theory and the game theory, the multi-objective optimization results of different preference requirement for FS could be gained.

2. FS Structures

The structure of FS is shown in Fig 1. The FS is to process a set of finger beams in the thin slice and make the finger slices staggered close together to cover the adjacent interstice. The multiple finger slices and two cover plates are assembled with the rivet tightly. The seal is fitted over the rotating shaft or rotor with a small amount of clearance or interference, depending on the application. The fluid through the seal is impeded by the staggered fingers/pads as well as the radial contact between the rotor and the FS feet. From the FS geometric characteristics, we find that the angle of finger stems (φ), thickness of the finger element (s), finger length (The finger length is control by the radius of base circle (r) if the shape-curve of finger stems is involute), the height of finger foot (h) and the angle between finger stems (δ) are the main parameters for FS.

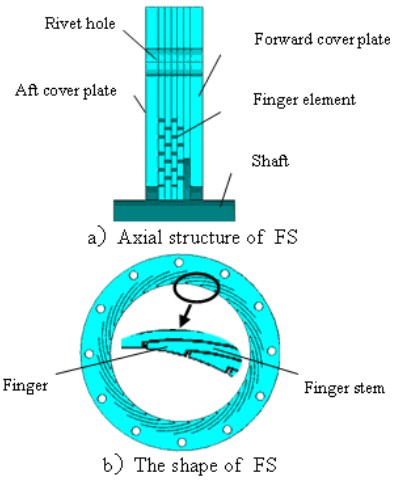

Figure 1 Structure of FS

The fingers' compliance allows radial adjustment to rotor excursions when operation. With the runout of shaft, the fingers move out radially but do not recover to their original position, since the friction between the aft cover plate and fingers is greater than the restoring force in the fingers. Then the seal fails to work with appearance of leakage. The previous research work indicates that increasing the finger stiffness can reduce leakage. However, the increase of stiffness leads to the rise of contact pressure between the finger pad and the rotor. Thereby, it worsens the wear and decreases the operation life.

3. Performance optimization model for FS based on fuzzy game theory

3.1 Optimization model based on fuzzy game theory

Nash equilibrium is a game theory first proposed by J. F. Nash in 1951[3]. It was initially developed to solve problems in economics. For an optimization problem with N-objectives, a Nash strategy consists of N players. Each player is in charge of one objective and has its own strategy group and criterion. To improve its criterion, each player searches its own best strategy in the search space. And now all the criteria of other players are fixed. At the end of each game circulation, the players exchange their best