

Research on Functional Integration Principle and Feasible Region of Magnetic Balancing Disc & Thrust Bearing

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Abstract. An idea of controlling or restricting axial movement of the rotor system using magnetic force was proposed in this paper. A device named Magnetic Balancing Disc (MBD) was developed which could play a role better than general fluid balance disc in certain compressor. Basis principle of magnetic balancing disc was introduced including basic structure of physical integration and feasibility of balancing point. Discussion of functional integration principle based on the design point of view was presented including three design patterns of rotor system, mathematical expressions for design and graphic method. Feasible region analysis based on the balancing point was proposed including working point design under ideal conditions and feasible region assessment under service state.

Introduction

There are many researches on electromagnetic force used in rotor system. Some researchers [1,2] gave the review and development trend. The magnetic bearings was the most typical application of magnetic force. These bearings included magnetic suspension in artificial heart pump [3-6], flywheel energy storage [7-9], bearing less drivers [10,11], electro-magnetic exciter [11-17] and bearings using in special turbo pumps [18,19]. The structure designing, magnetic force analysis, controller and application of magnetic bearings were studied in the references mentioned above. These studies regarded magnetic devices as a functional unit and studied from the structure and the force characteristics all in all. This paper differs from the above researches which using magnetic force device as a function guarantee one. We formed a concept of magnetic balance disc which was a device of function realization. The magnetic balance disc was used in certain compressor for axis force balancing.

The rest of this paper is organized as follows. First, basis principle of magnetic balancing disc was introduced including basic structure of physical integration and feasibility of balancing point. Second, discussion of functional integration principle based on the design point of view was presented including three design patterns of rotor system, mathematical expressions for design and graphic method. Third, feasible region analysis based on the balancing point was proposed including working point design under ideal conditions and feasible region assessment under service state. At last, a brief conclusion is proposed.

Basic Principle of Magnetic Balancing Disc (MBD)

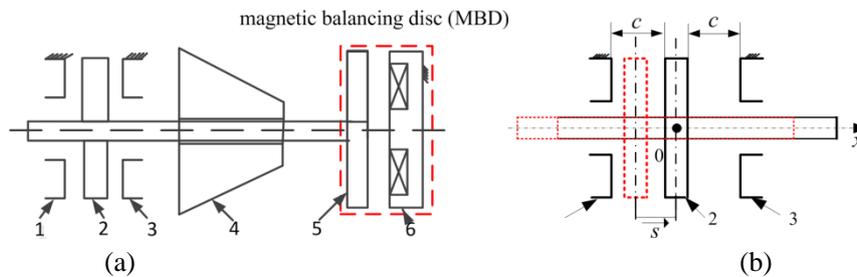
In order to give the functional integration principle of magnetic balance disc & thrust bearing's balancing and positioning and to reveal the coupling characteristics of balancing and positioning, the positioning function of the thrust bearing and balancing function of the magnetic balance disc are studied relatively. Because the understanding of the positioning function of the thrust bearing has been comparatively depth, this section only analysis of the balancing function of the magnetic balance disc. Specifically, this section will describe the basic principle of magnetic balance disc

and its balancing function from aspects of the basic structure of the magnetic balance disc, physical integration with the thrust bearing as well as the existence and feasibility of the balancing point of the rotor system.

Basic Structure and Physical Integration

The magnetic force balance device is a device using magnetic axial force to balance axis. The magnetic force include electromagnetic force, constantmediatedpermanentmagnetic force, supper-conducting permanent magnet force, etc. The magnetic force balance device is also a set of functional components. The main function of MBD is to achieve the balance of the axial force of turbine pumps, centrifugal compressors and other turbo-machinery. The magnetic force generating device and a load-bearing device consists it's basic structure. The magnetic balance disc is a type of magnetic balance device, in which the magnetic force generating device is electromagnet and the bearing device isa soft iron of a discoid form, that's why it is called balance disc which is shown in the right end of Figure 1(a).

Main function of magnetic balance disc is to balance the axial force of the rotor system, another functional requirements of the rotor is axial position which is completed by the bi-directional thrust bearing, physical components integrated to achieve these two functions is shown in Figure 1 (a). Impeller group is the main reason for the axial force, and this is not included in this article.



1 main thrust bearing 2 thrust plate 3 secondary thrust bearings 4 impeller group 5 pure iron 6 electromagnet

Figure 1 rotor containing a magnetic balance disc and thrust plate displacement

The Existence and Feasibility of Balancing Point

Quantitative concept able to explain this principle is needed to study the integration principle of magnetic balance plate and thrust bearing's balance and positioning. Balancing point is used to describe this principle in this study, specifically, study the existence of balancing point firstly, and then measure this principle through the feasibility of change of the balancing point.

With the existence of balancing point, this paper introduces a clearance ratio ε which is clearence ratio. When the thrust plate is located in the main and secondary thrust bearing axial centerline, intermediate position is the initial position. At this point, the distance between the thrust plate and the main and secondary bush equal to the distance of the unilateral clearance c , and thrust plate displacement is shown in Figure 1 (b). Displacement along the positive x direction is positive, clearance ratio ε is in equation (1) in which $\varepsilon \in [-1, +1]$.

$$\varepsilon = s/c \tag{1}$$

The feasibility of the balancing point is analysed. First, the balancing point ε^* is defined. The rotor system is force balance when the clearance ratio ε is equal to ε^* . For rotor without balancing device, the balancing point close to 1. The physical meaning is that the thrust plate is too close to the side of thrust bearing which means easily lead to bearing failure. The balancing point is moved to position near the center after the introduction of axial balance force as shown in Figure 2. F_a is the axial force generated by the impeller group, F_m is balance force, and F_b is bearing force. The value of F_a , F_m and F_b is only representative the size of force.

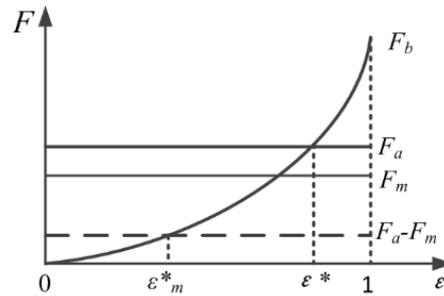


Figure 2 Impact of balanced magnetic force F_m on rotor balancing point

Discussion of Functional Integration Principle Based on the Design Point of View

Faced to the design of balancing point, this paper study the functional integration principle of magnetic balance disc & thrust bearing’s balancing and positioning in rotor system. Specifically, three design patterns, mathematical expressions for design and calculation, as well as graphic method solving the balancing point in force balancing of the rotor system are studied.

Three Design Patterns of Rotor System

Rotor mainly affected by the axial force F_a generated by the impeller group, bearing force F_b generated by the thrust bearing and balancing force F_m generated by the thrust bearing. And magnetic balance disc is presented as in Figure 3(a). These three forces have different design patterns as shown in Figure 3(b), in which blue represents the axial force F_a , axial force is mainly balanced by the balancing force F_m generated by the balance disc, different force balancing design patterns will affect the position of the rotor axial balance point.

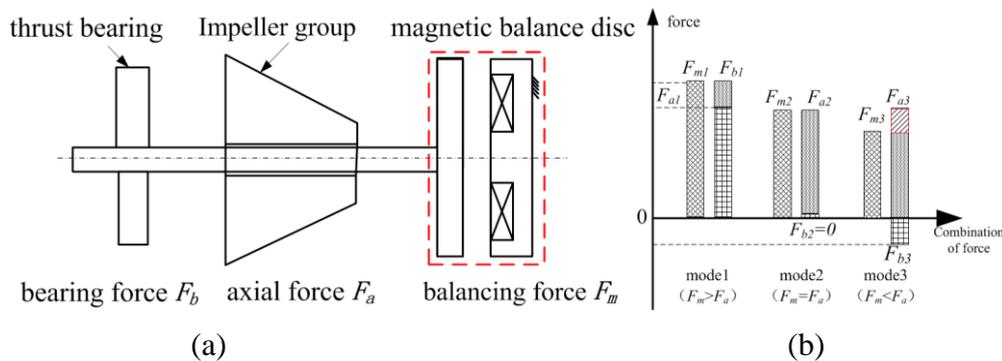


Figure 3 Combination of balancing magnetic force F_m , axial force F_a and bearing force F_b

Mathematical Expressions and Graphic Method of Designing

To study functional integration principle of positioning and balancing as well as to describe the principle of the solving balancing point in rotor system should focus on using a simple mathematical expression of the three forces rather than the use of more complex, in-depth mathematical model. For the solution of the balancing point, the graphic method is used which is a method with features articulate, clear and easy to understand or use.

The three main force of the balancing force is the axial force F_a of the flow passage system, bearing force F_b of thrust bearing and balancing magnetic F_m provided by magnetic balancing disc. Axial force is composed of two parts, pressure gradient force F_p generated by pressure gradient and misalignment forces caused by impeller axial displacement as shown in formula (2). Oil film force of the thrust bearing is inversely proportional to the square of the minimum film thickness which is related to displacement. Forces generated by main and secondary bearing has two-way features as shown in formula (3). Electromagnetic force has inversely proportional, nonlinear relationship with the square of displacement as shown in formula (4). The relationship of these three forces and axial

displacement as well as balancing point ε_m and ε_b the role of the magnetic balance disc and thrust bearing separately is shown in Figure (4).

$$F_a = F_{\Delta p} + k_s x \tag{2}$$

$$F_b = \frac{k_{b1}}{(c-x)^2} - \frac{k_{b2}}{(c+x)^2} \tag{3}$$

$$F_m = k_m \frac{i^2}{x^2} \tag{4}$$

In the formula (2) mentioned above, $F_{\Delta p}$ represents pressure gradient force generated by the pressure difference before and after the impeller as well as the different force area, k_s is misalignment the axial force coefficient caused by impeller misalignment, and x is axial displacement of the rotor. In impeller, centrifugal compressors and other turbo-machinery axial force caused by rotor misalignment under the constraints of the small clearance is not large, which can be considered does not change with vary of axial displacement. Thus using F_a represent F_a' in Figure 4. In the formula (3) mentioned above, k_{b1} and k_{b2} are load capacity coefficient of main and secondary thrust bearing, and $c-x$, $c+x$ represents the minimum film thickness of the main and secondary thrust bearing respectively. Bearing force is the sum of main and secondary thrust bearing.

In formula (4), k_m is the displacement-current coefficient, i is the current, and x is axial displacement whose values is $[2c+g_0, g_0]$ in which g_0 refers to the distance between the magnetic balancing disk soft iron and electro-magnet when the thrust disc is contact with the secondary thrust bearing.

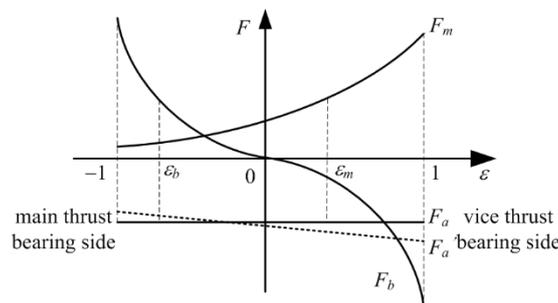


Figure 4 Relationship between three forces (balancing magnetic force F_m , axial force F_a and F_b) and displacement

Feasible Region Analysis Based on the Balancing Point

The functional integration principle studied in this paper is based on the design point of view and aimed at feasible balancing point of the rotor system. However, during actual service process of the rotor, three forces in the force balance system is distributed within a certain range and cannot be able to accurately access. Thus the feasible balancing points of actual rotor system falls within a certain interval that we called feasible region.

Working Point Design Under Ideal Conditions

The ideal state means the appropriate balancing point can be achieved when the curve of the three forces in the force balance system has been obtained, and can be expressed accurately as shown in Figure 5. In Figure 5(a) when balancing force F_m of electromagnetic balance disc is smaller, the balancing point is close to the main thrust bearing side. With the increasing of F_m , the balance point gradually move to the right as shown in Figure 5(b) and Figure 5(c), that is, close to the secondary thrust bearing. The process of the moving of balance point verifies the feasibility of functional integration principle of magnetic balance disc and thrust bearing's balance and positioning.

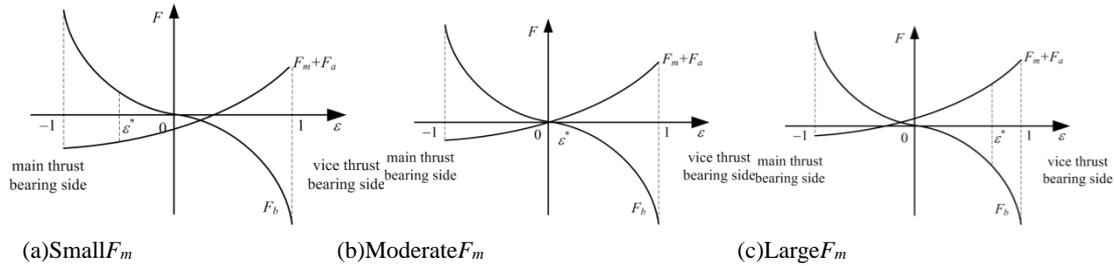


Figure 5 Feasible working point design of rotor system with magnetic balance disc under ideal conditions

Feasible Region Assessment under Service State

Under service state the relationship among bearing force F_b , balancing magnetic and axial force F_m+F_a and rotor axial displacement is uncertain. Certain error exists which using error function to express in this paper. As shown in Figure 6, $(F_m+F_a)_A$ and $(F_m+F_a)_B$ present the upper and lower tolerance function respectively, F_{bA} and F_{bB} represent the upper and lower tolerance function of F_b respectively. The band formed by the intersection of these two tolerance band is the service design area of the rotor, its projection on the horizontal axis is the axial force balanced range. According to experience, the clearance ratio greater than 0.7 is defined as dangerous area in Figure 6(a) part of the balance range is located within the dangerous area which easily lead to bearing wear and bush-burning phenomenon. Appropriate adjustments of the curve in Figure 6 can move the balance range and avoid the dangerous area as shown in Figure 6 (b).

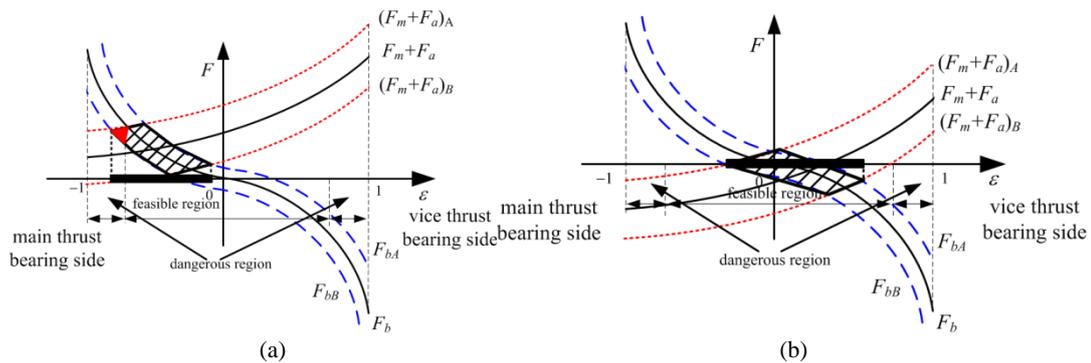


Figure 6 Rotor axial feasible area assessments under service state

Conclusions

In this paper a concept of magnetic balance is formed, functional integration principle of magnetic balance disc and thrust bearing are provided, and the balance point and feasible area of the rotor system are analyzed. Three conclusions are shown as follows:

- 1) A conception of controlling or restricting axial movement of the rotor speed rotating machinery using magnetic force was proposed in this paper which could play a role better than general fluid balance disc in certain compressor. The principles, structure and feasible region formed a concept of magnetic balance disc.
- 2) The balance function of magnetic balance disc used for balancing axial force and the positioning function of thrusting bearing has integrate feature, the integrate feature can be described through the concept of balancing point.
- 3) The existence of balancing point explained the principle of functional integrate, the designable characteristic of balancing point and feasible area verifies and measures the usefulness of this principle.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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