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曹, 琳琳

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氏　　名　：曹　 琳 琳

論 文 名　：High Performance Design of a Contra-Rotating Axial Flow Pump with Different Rotor-Speed Combination
（異回転数設計翼車を用いた二重反転形軸流ポンプの高性能設計）

区　　分　：甲

論　文　内　容　の　要　旨

The rotating machinery with contra-rotating rotor-rotor combination, in which two tandem rotors, front and rear rotors, rotate in the opposite direction, has been increasingly discussed in several industrial fields as a promising solution to energy conservation, performance optimization as well as machine size compacting. While for the contra-rotating rotors, the conversion of the outlet swirl velocity of the front rotor into additional pressure rise by the rear rotor has been found to be accompanied with the complex internal flow structures and the significantly enhanced blade rows interactions. To enlarge the benefits of this type of rotor-rotor combination, more careful design for the relevant parameters is imperative. In the axial flow pump field, based on the previous theoretical analyses and investigations on the prototype contra-rotating axial flow pumps, the work division between the front and rear rotors as well as their rotor-speed combination is considered as an important and decisive parameter to the pump performance. The present thesis discusses the possibilities to improve the hydraulic performances of the contra-rotating axial flow pump by rearranging the work division as well as the rotor-speed combination in the contra-rotating rotor pair. To do so, the new design method, which determines more reasonable work division and rotor-speed combination between two rotors, is proposed with theoretical considerations to improve the cavitation performance as well as to weaken the inevitable rotor-rotor interactions. The hydraulic performances of a new rotor pair designed based on the proposed method are thoroughly investigated by series of experiments and numerical simulations, from which the validity of the proposed design method is discussed.

This thesis consists of totally six chapters, which can be summarized as follows.

In Chapter 1, backgrounds of the developments of axial flow pumps and contra-rotating machines are described. Special emphasis is placed on the advantages and the related current problems of the application of contra-rotating rotors for axial flow pumps.

In Chapter 2, the experimental apparatus and procedures, the measurement techniques, and the numerical simulation method, which are common throughout this thesis, are well elaborated.

In Chapter 3, hydraulic performances of the prototype contra-rotating axial flow pump with equal-speed front and rear rotors are firstly analyzed comprehensively. Then, based on the obtained knowledge, the different-speed design method is proposed in expectation of the improved hydraulic performances of the contra-rotating axial flow pump. In this concept, the rotation speed combination of the two rotors is determined primarily to improve the cavitation performance of the pump. It is found that reducing the rear rotor speed with the slight increase of the front rotor is effective to maximize the cavitation performance of the whole pump due to the well reduced relative inflow velocity into the rear rotor. With the other minor

considerations to improve the hydraulic performances of the pump, the several rear rotors are designed based on the proposed different-speed design method. By the numerical simulation approaches, one of the new rotor combinations is proved with the hydraulic performances highly satisfying the design specification as well as the superior cavitation performance. Based on this result, the new rear rotor is manufactured, which is tested for the further validations of the proposed design method in the preceding chapters.

In Chapter 4, for the contra-rotating rotor pair with the new design method applied, the investigations of the hydraulic performances are pertinently carried out by the experimental and numerical approaches. The new rotor pair is found to achieve the well increased hydraulic head in a rather wide flow rate range including the design flow rate, showing the effectiveness of the design method on the head performance. However, in the fairly low flow rate range, a more pronounced positive slope on the head curve is observed, which is one of the undesirable characteristics in terms of the stability of pumping system. Using the measured and simulated results of the flow fields, the significant secondary flow structures and consequently severe passage blockage are observed in the new rear rotor, which are believed to be associated with the remarkable losses in the low flow rate range. They are majorly attributed to the remarkable blade loading as well as the overwhelming pressure gradient inside the flow passage of the new rear rotor which is designed with the rather large attack angles with the additional consideration for the prevention of cavitation.

In Chapter 5, the rotor-rotor interactions, which often become the sources of noises and vibrations, are investigated for the newly designed contra-rotating rotor pair by the casing wall pressure measurement methods. The pressure fluctuation modes with both synchronous and non-synchronous frequencies to the blade passing frequency (BPF) components are studied. The ensemble averaged blade-to-blade pressure distributions at the blade tip of two contra-rotating rotors are obtained. Concerning the strengths of the corresponding BPF modes, the rear rotor designed with the reduced rotation speed as well as the decreased stagger angle presents relatively weaker impacts on the front rotor both at the design and off design conditions. The pressure modes associated with the rotor-rotor interactions are also found to be relieved. Designed with the renewed work division between the front and rear rotors, the new rotor pair shows the enhanced high pressure regions of the front rotor and the weakened low pressure regions of the rear rotor at various operation conditions. As one of the essential results of the reduced rotation speed design, the lower stagger angle of the rear rotor results in the low pressure regions on the suction surface of the blade extending rather toward its own blade passage than toward upstream. All of these indicate the relieved potential interactions between two blade rows in the contra-rotating rotors with different-speed design method applied. And moreover for the new rear rotor, the favorable blade fore-loading situation is observed from the pressure distribution contours and the blade loading curves extracted from the casing wall pressure measurement results, which agrees with the design expectation of superior cavitation performances.

Finally, the conclusions obtained by this thesis are summarized in Chapter 6.

〔作成要領〕

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