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The Aerodynamic Design and Investigation of Loading Distribution of a Mixed Flow Compressor

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Abstract

In this paper, the design for the mixed flow compressor is based on the results of a S2 through flow aerodynamic design program and a general arbitrary curved blade design method for axial, centrifugal/mixed compressors. Three different mixed flow compressors with different circulation distributions were studied. The results show that different circulation distributions should be utilized from blade hub to tip. For blade hub, more loading in posterior area should be chosen, while for blade tip more loading in frontal area of the blade is available. With this loading distribution, the separation flow in blade hub is controlled, along with the reduction of separation flow in blade tip. The performance of the mixed flow compressor can be boosted with a more homogeneous distribution of aerodynamic parameters from blade hub to tip, a more homogeneous flow field and a higher pressure recovery coefficient.

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Keywords: mixed flow compressor; aerodynamic design; loading distribution; numerical simulation; circulation distribution

1. Introduction

The mixed flow compressor has a structure between axial compressor and centrifugal compressor. It has the high flow capacity in the frontal area and high efficiency of axial compressors as well as high pressure rate of centrifugal compressors. Under the same working condition, the mixed flow compressors have less flow losses, a larger flow

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coefficient and a higher efficiency compared to centrifugal compressors. The mixed flow type is more suitable for the compressors whose sizes are limited.

The researches on mixed flow compressors were carried out in 1950s. However, the investigations in this very field were not adequate and the mixed flow compressor didn't show a good performance in early days because of the limit of computational and experimental methods. The CFD technology provides an advanced method for the research of mixed flow compressors. It embraced a booming development for the research of mixed flow compressors. Musgrave and Plehn [1] designed a single stage mixed flow compressor which had a pressure ratio of 3.02 and efficiency of 0.91 for its rotor, which was higher than any mixed flow compressor at that time. Monig [2,3,4] designed a mixed flow impeller which has a pressure ratio of 5, and the experiment research was carried out later. The result showed that the impeller had a narrow working range and the outlet Mach number was too high for diffuser. The compressor failed to achieve a good performance. Mert Cevik [5] from Middle-East Technology University in Turkey designed and modified a mixed flow rotor based on a centrifugal impeller. The result showed that the mixed flow impeller had a better performance. In 2011, Mert Cevik designed a mixed flow compressor for a gas turbine engine [6]. By analyzing its flow field, a shock structure and the obstruction of shock and boundary layer can be seen clearly in its flow passage, which may have a bad effect on its performance.

The study of mixed flow compressor in China has started only in recent years and recorded investigations cannot be substantially founded. Liu Baojie and Gao Xing [7,8] analyzed two high specific speed centrifugal and mixed flow compressors. The overall performances were also studied. The result showed that there were similar flow structures in two impellers' inducers. Mixed flow compressor achieved better performance and lower tip leakage loss, and flow field outlet was more uniform in mixed flow impeller than in centrifugal impeller. In the same year, Liu Baojie [9] investigated the impact of loading distribution in blade hub and blade tip on outlet flow homogeneity. The result showed that increasing hub design circulation could make impeller achieve better performance and lower tip leakage loss, and make flow field at outlet more uniform, but increasing tip design circulation could make impeller achieve higher ratio of total pressure in surge condition.

As the design tendency of compressors are pursuing higher through flow capability and higher loading capability. The design of mixed flow compressor will get a higher application in the future. So it is necessary to carry out deeper and more comprehensive investigations on mixed flow compressors.

2. Methods

The design for a single stage mixed flow compressor and the choice of design parameters are based on the results of a S2 through flow aerodynamic design program and a general arbitrary curved blade design method for axial, centrifugal/mixed compressors [10,11]. This program has succeeded in designing several compressors, such as ATS-2. After through flow design and 3-D CFD simulation analysis, the conclusions were drawn with comprehensive analysis. Numerical simulation software NUMECA was used to simulate the 3-D flow field of the mixed flow compressor and analyze its performance. The loading distribution can be regarded as circulation distribution. By studying three different impellers with different circulation distributions in chord direction, the impact of loading distribution on the performance of mixed flow compressor can be observed. Table 1 shows the design parameters of the mixed flow compressor.

Table 1. Parameters of mixed-flow compressor

	Designed value
Pressure ratio	2.8
Adiabatic efficiency	0.87
Corrected mass flow (kg/s)	16.988
Inlet total temperature (K)	526.78
Inlet total pressure (Pa)	663295.5