A Review on Centrifugal Compressor Design Methods

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Abstract

The use of turbochargers has increased in response to strengthened automotive exhaust emission and fuel consumption regulations for global environmental protection. Most centrifugal compressors are required to operate over a broad range of flow rates and to provide a high pressure ratio with high efficiency. The internal flow of a centrifugal compressor is very problematic with 3-dimensional and unsteady flow phenomena, and the analysis of flow phenomena and expansion of the operational range are difficult problems. Review is done for gathering the efficient method for designing and analyzing the centrifugal compressor. In order to meet these demands the application of variable geometry techniques is often considered and applied.
Keywords: Ansys fluent, CAD modeling, Compressor design, compressor of turbocharger, computational fluid dynamics (CFD), Meshing, Review of compressor, Simulation

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I. Introduction

With the ongoing movement towards global environmental protection, regulations related to the exhaust emissions and fuel consumption of automobiles is being strengthened. To cope with these requirements, turbochargers provide an effective tool for improvement of fuel consumption and reducing carbon dioxide emissions, by reducing engine weight and friction loss. Since the turbocharger supplies compressed air to an engine, it can reduce the engine displacement relative to a naturally aspirated engine.
The centrifugal compressor in an automotive turbocharger is required to have wide range of operation to cover automotive driving, a high pressure ratio, and high efficiency. Performance betterment has been carried out utilizing computational fluid dynamics and experiments to measure the performance and internal flow.
There is no standard procedure of design calculation of centrifugal compressor. Since every engineer relies on some empirical relation, we have to study different design paper to adopt design procedure. While designing centrifugal compressor a number of non-aerodynamic considerations have to be made. The modern CFD solver is capable in predicting the off-design performance of centrifugal compressor.

II. Literature review

Tamaki Hideaki[1] designed AT14 turbocharger which had high pressure ratio compressor used for 500kW class diesel engines. Their preliminary design was carried out using the one-dimensional analysis. After this, the authors had conducted detailed design analysis using CFD simulations. Oliver Velde[2]improved turbochargers components such as compressor by means of virtual methods which can be done in most efficient way if those component's geometries are given in a parameterized format. The authors had shown how the geometric description of compressors of turbochargers that have a neutral format can be transformed in a parameterized description. Claudio Bettini[3] presented the design process for a centrifugal compressor that will be part of a demonstrative micro-gas turbine plant. The design methodology developed at Dimset has been used for the fluid dynamics design of a centrifugal compressor for a small microgasturbine plant.

AdnanHamzaZahed[4] presented the development of a preliminary design method for centrifugal compressors. The design process started with the aerodynamic design and its reliance on empirical rules limiting the main design parameters. This procedure can be applied to the compressors for the pressure ratios of 1.5,3.0 and 5.0. Design considerations of mechanical stress for the impeller and minimum inlet Mach number were taken into consideration. In this research work, the authors had done the preliminary design in which the work input and compressor efficiency was considered. The impeller design at different pressure ratios has been done.

H. Ali Marefat[5] presented the design procedure of multi-stage centrifugal compressor, by considering one dimensional flow design. The design procedure started from calculation of impeller inlet and it is continued for the other sections including impeller exit, diffuser and volute. The total efficiency, stage efficiency, correction factors and leakages are calculated. From the procedure it was revealed that there are essential parameters such as tip speed Mach number, flow co-efficient at inlet and diameter of impeller which will play major roles in determining compressor polytropic head and consequently compressor polytropic efficiency. The designed volute is different than that the referred one. The dissimilarity rises on the grounds that the mentioned method considers minimum optimum values rather than most efficient ones, which lead to an economical design.

P. Kmoch[6]had concentrated on the possibilities of extending the stable operation region of the centrifugal air compressor by altering its intake system. For this experimental work, the inlet system of the small jet engine TJ100 that was produced in Czech Republic was used. The Test Bench had the following main parts: centrifugal air compressor with its intake and exhaust parts, pressure air tank and supply pipe. S. K. Kurauchi[7]presented the design of a centrifugal compressor for natural gas in 3 steps in which the first step has 1-D preliminary design heavily based on empirical data, the second step is the flow analysis in the meridional plane and the last step involves the CFD analysis to check if the 1-D methodology is adequate. The point of departure for the centrifugal compressor design was appropriately selected following Vavra'ssuggestion.

Ming Yao Ding[8] presented results from research into the performance and operation of a centrifugal compressor at off-design operating conditions using computational fluid dynamics (CFD) techniques. The off-design cases included compressor operations at various percentages of the off-design rotational speeds. The investigation of the benefits of unsteady (time accurate) simulation of centrifugal compressor performance. The compressor geometry was provided CATIA format, ANSYS ICEM CFD was used to generate the appropriate mesh and ANSYS CFX was used to solve the off-design compressor flow problem.

Pei-Yu Li[9]presented an optimization design method for centrifugal compressors based on one dimensional calculations and analysis. It consisted of two parts which are centrifugal compressor geometry optimization based on one dimensional calculations and match the optimization of the vaned diffuser with an impeller based on the required throat area.

A. Laveau[10] presented preliminary design of a meso-scale centrifugal compressor. Three dimensional flow analyses qualitatively confirmed the expected flow behavior and also underlined some improvements have to be made on the inlet section, the impeller blade profile and the diffuser inlet angle. The fabrication process showed the feasibility of producing the meso-scale compressor using DRIE (deep reactive ion etching) and anodic bonding techniques on silicon wafer.

Dr. M Akhtar[11] examined reasons for the low performance of centrifugal compressors operating in the oil and gas production facilities which are compared with the original design. The differences in factory test and field test results were measured. The flow measurements in the field were influenced by higher internal leakages within the machines, which distorted the performance values.

K. A. R. Ismail[12] presented a computational procedure for the analysis of steady one-dimensional centrifugal compressor. The numerical model was based on the conservation principles of mass, momentum and energy, and had been utilized to predict the operational and aerodynamic characteristics. The conclusion of the study was that the proposed model was able to predict the overall working parameters, the local flow properties, the compressor performance characteristics and finally enabling refining the rotor geometry and predicts its new performance.

Kai U. Zeigler[13]presented the test rig and the compressor concerning design and capabilities. Then a survey of present research goals and the experimental work carried out since 1992 is given. The results were summarized and an outlook on possible future research projects has been conveyed.

Michael R. Galvas[14] presented aFORTRAN program for calculating the off-design performance of centrifugal compressors with channel diffusers is presented. Individual losses were computed using analytical equations and empirical correlations which relate loss with overall geometry and velocity diagram characteristics overall geometry. On a given speed line compressor performance was calculated for a range of inlet velocity levels. At flow rates between surge and choke of compressor, individual efficiency decrements, overall efficiency and total pressure ratio were tabulated.

F. Gui[15]described a design and experimental effort to develop small centrifugal compressors for aircraft air cycle cooling systems and also for small vapor compression refrigeration systems. Several low-flow-rate centrifugal compressors which are featured with three-dimensional blades have been designed, manufactured and tested in this study. An experimental investigation of compressor flow characteristics and efficiency had been conducted to explore a theory for mini-centrifugal compressors. The effects of the number of blades, overall impeller configuration, and the rotational speed on compressor flow curve and efficiency were studied.

M. V. Casey[16]described recent experience in the development and application of several ultra-high-speed miniature centrifugal compressors with an impeller diameter which are less than 30 mm and using high speed electric motors to provide rotational speeds between 200,000 and 600,000 rpm. With a growth in number of applications at low flow rates such micro-compressors have been strongly used to replace larger centrifugal compressors operating at lower rotational speeds.

D. R. Pandy[17]] for United Technologies Research Center and Carrier Corporation have investigated the potential for high-speed centrifugal compressors to compete with current positive displacement compressors at minimal capacities. Some of the critical design issues are discussed, along with concept demonstrations, and performance comparisons. A production 25-ton centrifugal compressor with a high efficiency permanent magnet motor, combined with bearing losses and low wind age, would achieve an ASRE-T EER nearly 25 percent higher than current compressors.

MichaleCzarnecki[18]presented the modern design process which is based on multi-criteria optimization methods. Reverse engineered map are used to generates correct values at compressor contour map nodes. Method is chosen which will be characterized by less demands in terms of computational power requirements, which makes it suitable to use also in embedded microprocessor control systems.

Leonid Moroz[19]presented a method for centrifugal and mixed type compressor flow paths design based on a unique integrated conceptual design environment. The approach provided in the paper gives the designer the opportunity to design axial, radial and mixed flow turbomachinery using the same tool.

AshishBowade[20] presented a step by step guidance to design a radial type vane profile. In radial type vanes, the vane profile is a curve that joins the inlet and outlet diameter of the impeller which can be done in infinite number of curves and so it is required to define proper shape of the vane. In this paper, simple arc, double arc, circular arc and point by point methods were stated.

III. OBSERVATION

Results from thermal design analysis into the performance and operation of a centrifugal compressor at off-design operating conditions were deduced using advanced computational fluid dynamics (CFD) techniques.

The effects of the number of blades, number of blades overall impeller configuration, and the rotational speed on compressor flow curve and efficiency were studied.

Step by step guidance to design a radial type vane profile.

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