Scientific Journal of Impact Factor (SJIF): 4.14
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 3, Issue 10, October -2016

COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF CRYOGENIC TURBOEXPANDER

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Abstract — *A turboexpander is a centrifugal or axial flow turbine through which a high pressure gas is expands to produce work to drive compressor. Cryogenic turboexpanders are used in many applications, including ethylene plants, refineries, gas processing plants and air separation facilities. It is widely used as sources of refrigeration in industrial processes such as the extraction of ethane and natural gas liquids (NGLs) from natural gas, the liquefaction of gases (e.g. Oxygen, Nitrogen, Helium, Argon, Krypton) and other low temperature processes.*
The work presents here is computational fluid dynamics (CFD) analysis of high speed radial flow turboexpander compressor wheel. This analysis done in Solidworks flow simulation software. This project work deal with two major parts; first one is form existing compressor wheel model and data, find out efficiency of turboexpander and compare the output result with theoretical calculations. Second part is to modify profile of blades to increase the efficiency. This involves three dimensional analysis of flow through radial expansion turbine using nitrogen as flowing fluid, flow behavior at inlet and outlet area of turboexpander, thermal properties of fluid like pressure, temperature, entropy, enthalpy at various stages of cryogenic turbine.

Keywords-*Cryogenic Engineering, Liquid Nitrogen, CFD, turboexpander*

I. Introduction

Compared to the high and medium pressure systems, turbine based plants have the advantage of high thermodynamic efficiency, high reliability and easier integration with other systems. The expansion turbine is the heart of a modern cryogenic refrigeration or separation system. Cryogenic process plants may also use reciprocating expanders in place of turbines. But with the improvement of reliability and efficiency of small turbines, the use of reciprocating expanders has largely been discontinued.

Turboexpanders have come a long way in the last 20 years. Their high efficiency and reliability have led to widespread use around the world. The use of magnetic bearings in many critical turboexpander applications such as ethylene plants has become common, and in the natural gas processing market, they are making inroads as well. Computational Fluid Dynamics (CFD) programs are providing windows into aerodynamic improvements and new applications that were unheard of in the past.

II. Structure of cryogenic turboexpander

A turboexpander consider as a radial inflow turbine connected to a load device (typically a centrifugal compressor) by means of a single rigid shaft. The radial and thrust bearings discussed herein are thus located between the expander and compressor impellers, as in Figure 1.1.

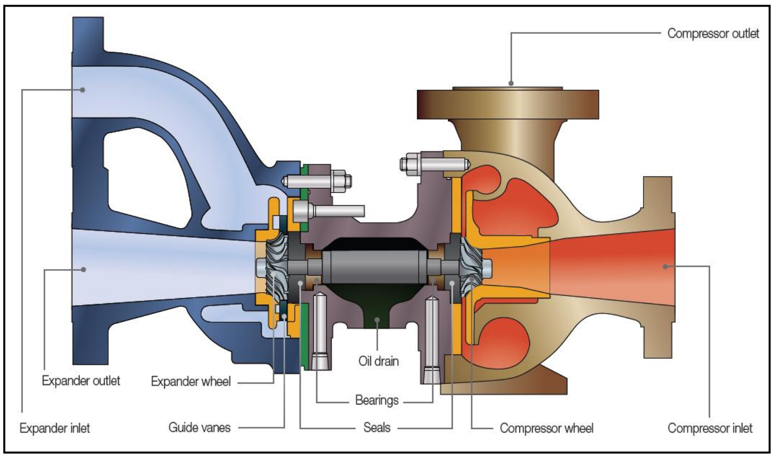

Figure 1.1 Turboexpander assembly

High-pressure process gas enters the turbine through piping to the cold end housing and, from there, into the nozzle ring. The fluid accelerates through the converging passages of the nozzles. Pressure energy is transformed into kinetic energy, so that reduction in static temperature takes place. The high velocity gas streams impinge on the rotor blades, imparting force to the rotor and creating torque. The nozzles and the rotor blades are so aligned as to eliminate sudden changes in flow direction and consequent loss of energy. The turbine wheel is of radial or mixed flow geometry, i.e. the flow enters the wheel radially and exits axially. The blade passage has a profile of a three dimensional converging duct, changing from purely radial to an axial-tangential direction. Work is extracted as the process gas undergoes expansion with corresponding drop in static temperature.

III. Objective

Industrial gas manufactures in the technologically advanced countries have switched over from the high-pressure Linde and medium pressure reciprocating engine based Claude systems to the modern, expansion turbine based, low pressure cycles several decades ago. Thus in modern cryogenic plants a turboexpander is one of the most vital components- be it an air separation plant or a small reverse Brayton cry cooler. Industrially advanced countries have already perfected this technology and attained commercial success. However, this technology has largely remained proprietary in nature and is not available in open literature. To upgrade the technology in air separation plants, as well as in helium and hydrogen liquefiers, it is necessary to develop an indigenous technology for cryogenic turboexpanders.

IV. Literature survey

Since the turboexpander plays the role of the main cold generator, its properties – reliability and working efficiency, to a great extent, affect the cost effectiveness parameters of the entire cryogenic plant.
For many years the design of modern turboexpanders has relied heavily on CFD to develop three-dimensional blade sections. The benefits of CFD range from shorter design cycles to better performance and reduced costs. Also, details of aerodynamic data that are now accessible during the design process and increased performance have without a doubt been made possible.
The performance chart has become commonly accepted mode of presenting characteristics of turbomachines. Several characteristic values are used for defining significant performance criteria of turbomachines, such as turbine velocity ratio, pressure ratio, flow coefficient factor and specific speed. Balje has presented a simplified method for computing the efficiency of radial turbomachines and for calculating their characteristics. The specific speed and the specific diameter completely define dynamic similarity. The physical meaning of the parameter pair ns, ds which is taken with consideration with the efficiency is that, fixed values of specific speed ns and specific diameter ds define that combination of operating parameters which permit similar flow conditions to exist in geometrically similar turbomachines.

A) Design of Helium Cryogenic Turboexpander: Renu Kushwah1 Prof. N.V. Bora2

This paper work is aimed at the design of helium cryogenic turboexpander of mixed flow impellers with radial entry and axial discharge. To determine the principal dimensions of the turbine wheel, optimum operating speed has been taken from design charts based on Similarity principles. The main dimensions, thermodynamic properties at different states, velocity and angles at entry and exit of the turbine wheel were worked out. A modest attempt has been made to understand, standardize and document the design of cryogenic turboexpanders.

B) DESIGN OF BACKWARD SWEPT TURBINE WHEEL FOR CRYOGENIC TURBOEXPANDER: BALAJI K. CHOUDHURY, RANJIT K. SAHOO, SUNIL K. SARANGI

This paper work is a programed on development and study of a low capacity (20 liters/hr.) Turboexpander based Nitrogen liquefier. Hence a process design was carried out and a turboexpander was designed to meet the requirement of the liquefier. The turboexpander is used for lowering the temperature of the process gas (Nitrogen) by the isenthalpic expansion. The efficiency of the turboexpander mainly depends on the specific speed and specific diameter of the turbine wheel. The paper explains a general methodology for the design of any type of turbine wheel (radial, backward swept and forward swept) for any pressure ratio with different process gases. The design of turbine wheel includes the determination of dimensions, blade profile and velocity triangles at inlet and outlet of the turbine wheel. Generally radial turbine wheels are used but in this case to achieve the high efficiency at desired speed, backward curved blades are used to maintain the Mach number of the process gas at the nozzle exit, close to unity. If the velocity of fluid exceeds the speed of sound, the flow gets choked leading to the creation of shock waves and flow at the exit of the nozzle will be non-isentropic.

C) A numerical model for the design of a mixed flow cryogenic turbine: Subrata Kr. Ghosh

This paper based on improved methods of turbine wheel design. The present study is aimed at the design of the turbine wheel of mixed flow impellers with radial entry and axial discharge. In this paper, a computer code in detail has been developed for designing such turbine wheel. To determine the principal dimensions of the turbine wheel, optimum operating speed has been taken from design charts based on Similarity principles. The algorithm developed, allows any arbitrary combination of fluid properties, inlet conditions and expansion ratio, since the fluid properties are properly taken care of in the relevant equations. The computational process is illustrated with an example. The main dimensions, thermodynamic properties at different states, velocity and angles at entry and exit of the turbine wheel were worked out. The work may help the researchers for further design and development of cryogenic turboexpander depending on their operating parameters.

D) Computational Fluid Flow Analysis of High Speed Cryogenic Turbine Using CFX: Sushant Upadhyay1, Shreya Srivastava2, Siddharth Sagar3, Surabhi Singh4 and Hitesh Dimri5

This paper based on attain a minimum temperature and pressure and to study the variation of Mach number and entropy. This is done by computational fluid flow analysis of high speed rotating turbine. This involves with the three dimensional analysis of flow through a radial expansion turbine, using nitrogen as flowing fluid. The work is performed on various modules of Ansys that is BladGen, TurboGrid, CFX-Pre, CFX-Post. Bladegen is used to create the model of turbine using available data of hub, shroud and blade profile. Turbogrid is used to mesh the model. CFX-Pre is used to define the physical parameters of the flow through the Turbo expander. CFX-Post is used for examining and analyzing results. Using these results variation of different thermodynamic properties like Temperature, Pressure, Mach number, entropy etc. inside the turbine can be seen.

V. Proposed work

All air flow components are optimized with regard to flow configuration and stress reduction using CFD analysis. The result is a turbine with wide-chord blades arranged in a fir-tree root in the turbine disc. A characteristic feature of such blades is their very high chord-to-high ration, this creating a compact, very stiff and hard-wearing blades. The turbine blades can be of varying angles and lengths. With the aid of advanced design tools, it is now possible to dispense with lacing wire to dampen exhaust-generated vibrations. MAN Diesel explains that apart from improving the blade profile, this has significantly boosted efficiency.

The above analysis result shows values of different permeates at different stages of fluid flow path at 90% efficiency considered for compressor wheel. Proposed work is based on efficiency improvement and so that we will modify profile of compressor wheel blades and base on smooth flow of fluid data will be freeze. Compressor wheel power dissipated based on below equation…

$$P = \frac{\dot{m}_b \Delta h_{0s}}{\eta_b}$$

Where $\dot{m}_b$ is mass flow rate (44.7568 kg/s), will have no change and Δh_{0s} (ideal static head across the compressor) will be change accordingly the efficiency of the compressor wheel and power as well.

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