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Computational Fluid Flow Analysis of Cryogenic Turboexpander

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Abstract

Cryogenic turboexpander is the most critical component of cryogenic plant to achieve low temperature refrigeration. A cryogenic turboexpander has many components like expansion turbine, compressor, heat exchanger, instrumentations etc. Expansion turbine is the component where temperature of gases decreases due to expansion and produce the coldest level of refrigeration in the plant.

This project deals with the computational fluid flow analysis of high speed expansion turbine. This involves with the three dimensional analysis of flow through a radial expansion turbine using nitrogen as flowing fluid. This analysis is done using cfd packages, bladegen, turbogrid and CFX. 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 and specify the simulation settings and physical parameters required to describe the flow through turboexpander at inlet and outlet.CFX-Post is used for examining and analyzing results. Using these results variation of different thermodynamic properties inside the turbine can be seen.

Various graphs are potted indicating the variation of velocity, pressure, temperature, entropy along streamline to analyze the flow through cryogenic turbine.

1. Introduction

Turboexpander are used in all areas of the gas and oil industries to produce cryogenic refrigeration. A turboexpander, on other hand, is a pressure let-down device that produces cryogenic temperature while simultaneously recovering energy from a plant stream in form of shaft power that can be used to drive other machinery such as compressor.

Though nature has provide danabundant supply of gaseous raw materials in the atmosphere (oxygen, nitrogen) and beneath the earth's crust (natural gas, helium), we need to harness and store them for meaningful use. For large-scale storage, transportation and for low temperature applications liquefaction of the gases is necessary. The only viable source of nitrogen, oxygen and argon is the atmosphere. For producing atmospheric gases like nitrogen, oxygen and argon in large scale, low temperature distillation provides the most economical route. The low temperature required for liquefaction on of common gases can be obtained by several processes.

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.

1.1 Anatomy of Cryogenic Turboexpander

The turboexpander essentially consists of a turbine wheel and a brake compressor mounted on a single shaft, supported by the required number of journal and thrust bearings. These basic components are held in place by an appropriate housing, which also contains the fluid inlet and exit ducts. The basic components are turbine wheel, brake compressor, shaft, nozzle, bearing, diffuser, seals, etc.

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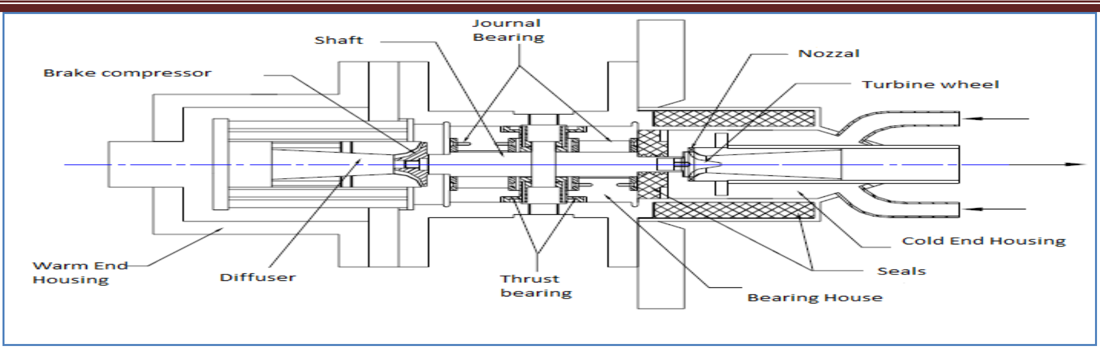

Fig: 1. Division of cryogenic turboexpander

1.2 Objective of the Present Investigation

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 cycle several decades ago. Thus in modern cryogenic plants a turboexpander is one of the most vital components-beitanair separation plant or a small reverse Bray to n cry ocooler.

For the development of computational fluid flow analysis of turbo expander system this project thas been initiated. The objective esinclude: (i) building computational fluid dynamic knowledge base on cryogenic turboexpanders (ii) construction of a computational fluid flow model and study of its performance.

2. Literature Review

The concept that an expansion turbine might be use din cycle for the liquefaction of gases was first introduced by Lord Rayleigh in a letter to “Nature” dated June 1898. He discussed the use of a turbine instead of a piston expander for the liquefaction of air. In 1898, a British engineer named Edgar C. Thrupppatenteda liquefying machine using an expansion turbine [1]. In1958, the United Kingdom Atomic Energy Authority developed a radial inward flow turbine for a nitrogen production plant [2]. Izumiet. al [3] at Japan developed a micro turboexpander for a small helium refrigerator based onClaudecycle. A simple method sufficient for the design of a high efficiency expansion turbine is outlined by Kun et. al [4-5].

Agahiet. al. [6-7] have explained the design process of the turboexpander utilizing modern technology, such as CFD software, Computer Numerical Control Technology and Holographic Techniques to further improve anal ready impressive turboexpander efficiency performance. During the pasttwodecades, performance charthas become commonly accepted mode of presenting character istics of turbo machines [8]. Several characteristics values are used for defining significant performance criteria of turbo machines such as turbine velocity ratio, pressure ratio, flow coefficient factor and specific speed [8]. Balje has presented a simplified method for computing the efficiency of radial turbo machines and for calculating their characteristics [9].The concept of specific speed was first introduced for classifying hydraulicmachines. Balje [10] introduced this parameter in design of gas turbines and compressors.

India has been lagging behind the rest of the world in this field of research and development. Still, significant and decentprogress has been made during the pasttwodecades. In CMERI Durgapur, Jadejaet. Al [11-12] developedan in ward flow radial expansion turbines upportedong as bearings for cryogenic plants. This device gave stablerotationat about 40,000 rpm. This programme was, however, discontinued before any significant progress could be achieved. Another programme at IIT Kharagpur developeda turboexpander unit by using aerostaticthrust and journal bearings which had a working speed up to 80,000 rpm. The detailed summary of technical features of the cryogenic turboexpander developed in various laboratories has been given in the PhD dissertation of Ghosh [13]. Recently Cryogenic Technology Division, BARC developed Helium refrigerator capable of producing 1 kW at 20Ktemperature.

3. Computational Fluid Flow Analysis

Computational fluid flow analysis of turboexpander can be done in three steps. 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 and specify the simulation settings and physical parameters required to describe the flow through turboexpander at inlet and outlet. *CFX-Post* is used for examining and analyzing results. The present design procedure is available in literature [14], [15].

3.1 Bladegen Designing of the Model

Bladegen designing of model is done by using available hub, shroud and blade profile coordinates. The hub and the tip streamlines are available in the table below. A surface is created by joining the hub and tip streamlines with a set of tie lines. Blade Editor will loft the blade surfaces in the streamwise direction through curves that run from hub to shroud. The surface so generated is considered as the mean surface within a blade. Non Uniform Rational B Splines are used to develop the solid surface. The suction andpressuresurfacesoftwoadjacentchannelsarecomputedbytranslatingthemeansurfacein the positive and negative theta direction through half the blade thickness.

After making all the surfaces when blade merge topology property is used, then blade faces will be merged where they are tangent to one another. Create fluid zone property is selected, to create a stage fluid zone body for the flow passage, and an enclosure feature to subtract the blade body. This resulting enclosure can be used for a CFD analysis of the blade passage. Create all blades this property is used to create all the blades using the number of blades specified in the Bladegen model. Here we are using ten numbers of blades.

Different views and curves of radial expansion turbine in bladegen are as following.

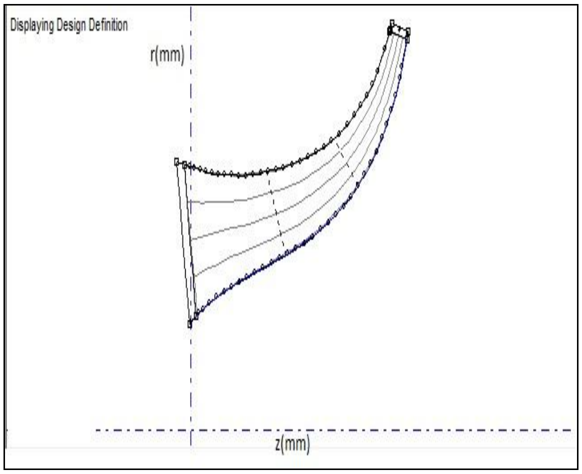

Fig: 2. Meridional blade profile with different spans

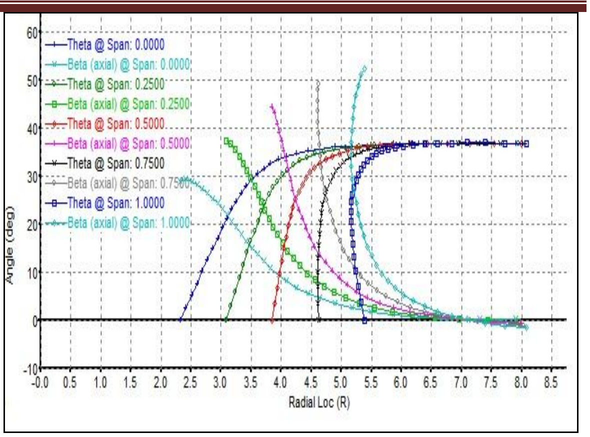

Fig: 3. Variation of Beta and Theta at different spans along radius

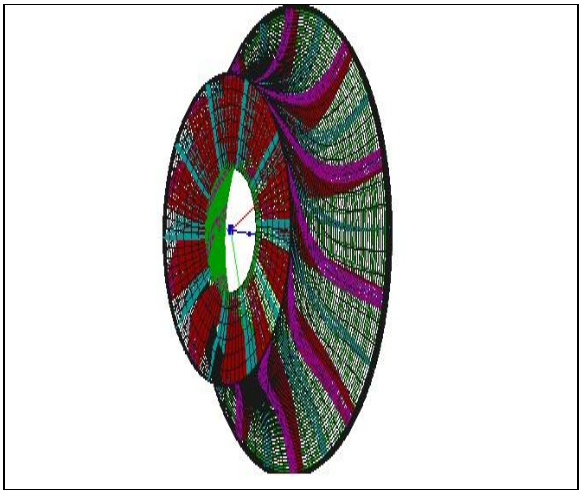

Fig: 4. Wireframe model of turbine generated in bladegen

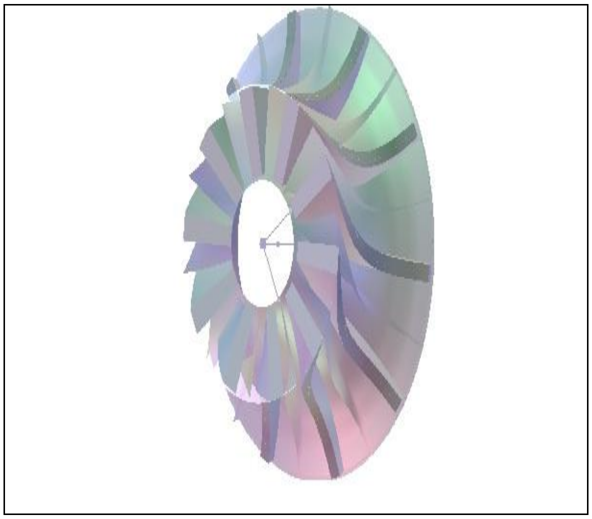

Fig: 5. Solid model of turbine generated in bladegen

3.2 Meshing of Turbine Model

Meshing of model is done in turbogrid. It creates high quality hexahedral meshes that are tuned to the demands of fluid dynamic analysis in turbine rotor. Turbine rotor geometry information is imported from bladegen. Turbogrid uses this bladegen file to set the axis of rotation, the number of blades, and a length unit that characterizes the scale of the machine. After setting topology definition, mesh data setting is used to control the number and distribution of mesh elements. Here we set the target number of nodes to 250000 to produce a fine mesh. Before generating the 3D mesh, mash quality should check on the layers, especially the hub and shroud tip layers. After correcting mash quality on layers, we generate the mesh with 228640 nodes and 206368 elements.

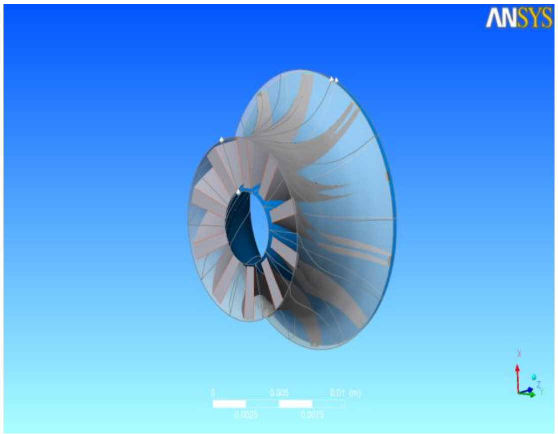

Fig: 6. Turbine rotor view after importing from Bladegen

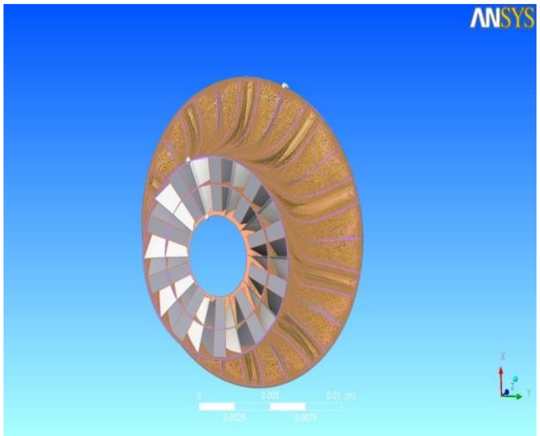

Fig: 7. Turbine rotor view after setting topology

3.3 Physics Definition of Meshed Model in Cfx-Pre

CFX-Pre is known as physics-definition pre-processor for ANSYS CFX. In cfx, turbo mode is used to define physic of meshed turbine rotor. Under basic setting in turbo mode, we set the machine type as radial turbine and rotation axis to z. In component definition we set component type rotating and set rotation value 218780 rev/min. Turbo mode will automatically select a list of regions that correspond to certain boundary types. This information should be reviewed in the Region Information section to ensure that all is correct. This information is used to set up boundary conditions and interfaces. In wall configuration option we set tip clearance at shroud.

Physics definition tab is used to set fluid type, analysis type, model data, inflow and outflow boundary templates and solver parameters. Physics definition used for turbine rotor is given in the table below.

After setting physics definition Cfx-Pre will try to create appropriate interfaces and boundary conditions using the region names presented previously in the region information.

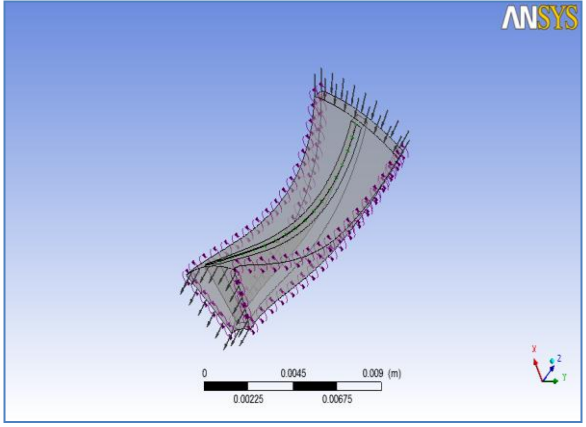

Fig: 8. Flow direction at inlet and outlet

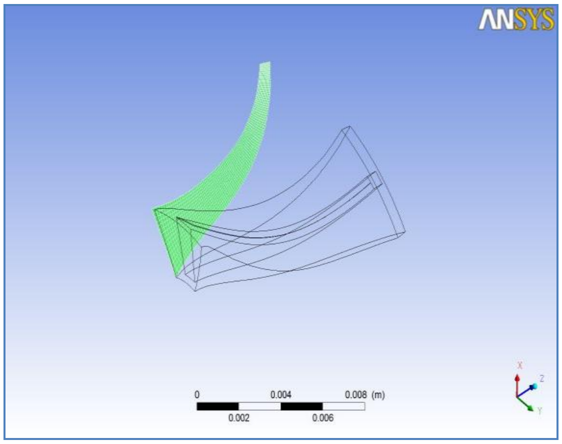

Fig: 9. Wireframe and Meridional model of turbine rotor

3.4 Obtaining Results in Cfx Cfd-Post

CFD-Post is a flexible, state of art post-processor. It is used to allow easy visualization and quantitative analysis of results of CFD simulations. Turbo workspace is used to improve and speed up post-processing for turbo machinery simulation. It includes all the expected plotting objects like, plans, isosurfaces, vectors, streamlines, contours, animations, etc. It allows precise quantitative analysis as, weighted average, forces, results, comparisons, built in and user defined macros. It can create user defined scalar and vector variables. CFD-Post includes automatic reports, charts, and tables.

4. Results and Discussion

Various graphs and contours available from generated results are as following.

4.1 Pressure Variation Along Streamwise

Static and total pressure variation can be seen from the graph below. Total pressure varies from 3 bar to 1.6 bar while static pressure varies from 2.4 bar to 1.27 bar along streamline from inlet to outlet of turbine rotor.

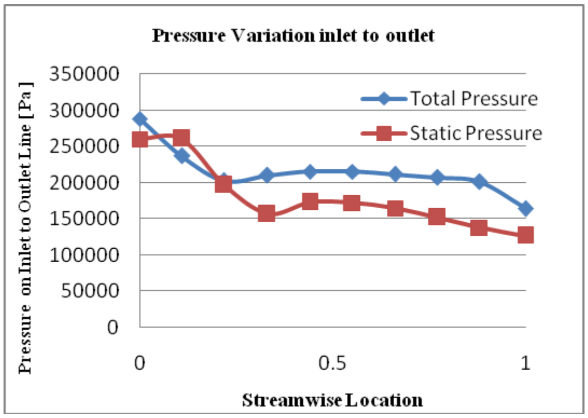

Fig: 10. Pressure variation along streamwise inlet to outlet

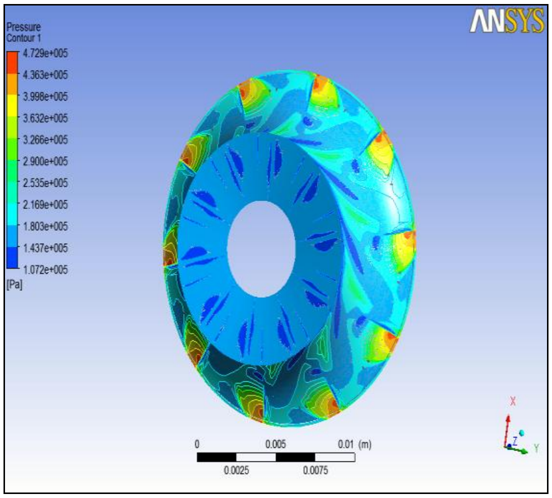

Fig: 11. Isometric 3D view of pressure variation

4.2 Temperature Variation Along Streamwise

Static and total temperature variation can be seen from the graph below. Total temperature varies from 99.6K to 96.7K, while static temperature varies from 88.2K to 90K along streamline from inlet to outlet of turbine rotor.

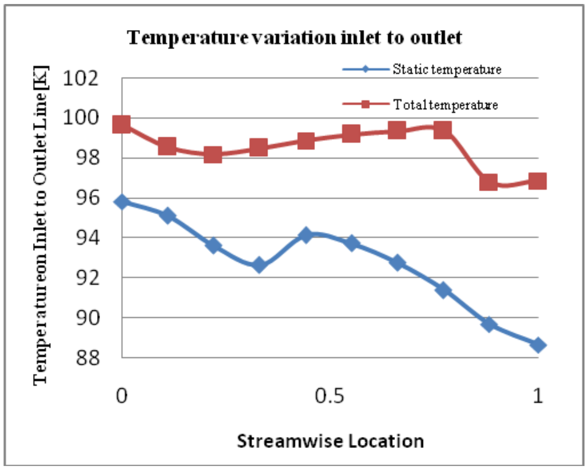

Fig: 12. Temperature variation along streamwise inlet to outlet

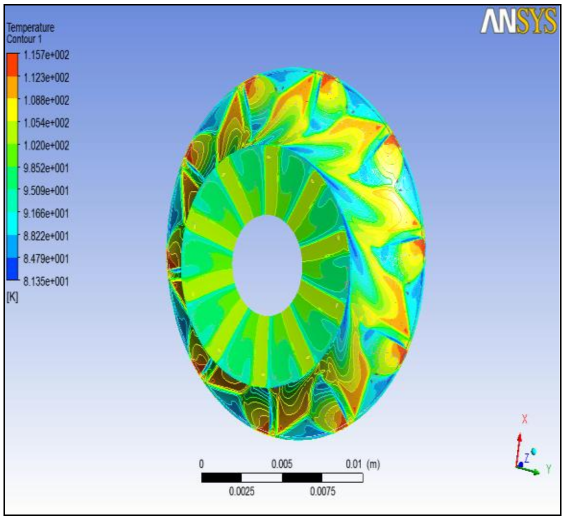

Fig: 13. Isometric 3D view of temperaturevariation

4.3 Velocity Variation Along Streamwise Inlet to Outlet

Velocity variation can be seen from the graph below. Velocity is decreasing inside the turbine from inlet to outlet, 186.90 m/s to 130.146m/s respectively.

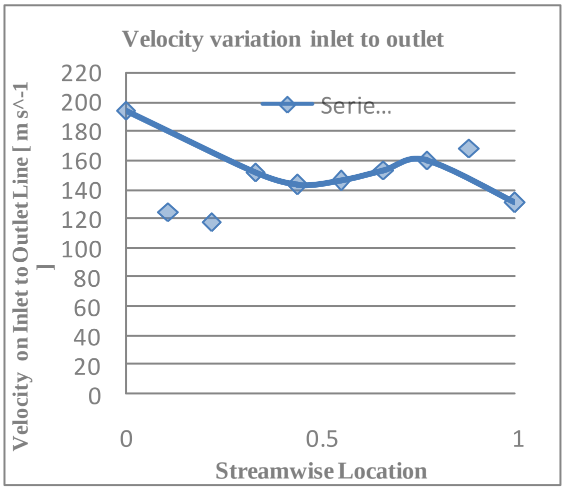

Fig: 14. Velocity variation along streamwise inlet to outlet

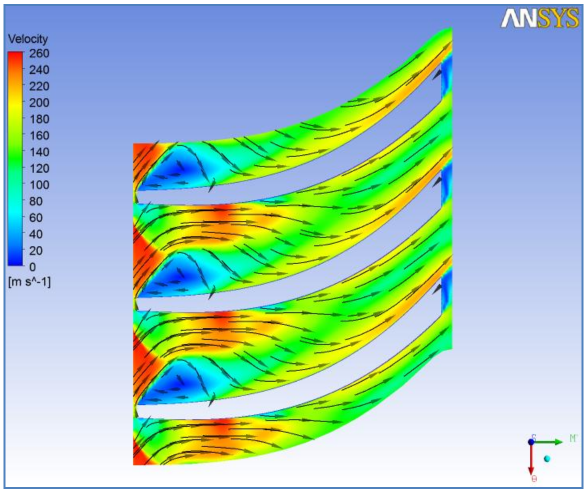

Fig: 15. Velocity Vectors at 50% Span

5. Conclusion

Thiswork isamodest attempt at flow analysing inside acryogenic turboexpander through computational fluid dynamic. A prototype expander has been designed, meshedand simulated using this recipe. The design procedure covers the designing of hub, shroud and blade profile of turboexpander in Bladegen. A cfx model has been developed for flow analysis inside the turbine rotor. The modelling of the various parts of the turbine is done in Bladegen and the computational fluid flow analysis is done using CFX. Various graphs and contours indicating the variations of temperature, pressure, velocity inside the turbine along the streamline are given.

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