

# **DESIGN AND DEVELOPMENT OF MICRO TURBINE**

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology**

**In**

**Mechanical Engineering**

**By**

**SIBASISH PATNAIK**

**and**

**ANKUR SACHDEV**



**Department of Mechanical Engineering**

**National Institute of Technology**

**Rourkela**

**2009**

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**Under the guidance of**

**K. P. MAITY**



**Department of Mechanical Engineering**

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**National Institute of Technology**

**Rourkela**

**CERTIFICATE**

This is to certify that the thesis titled, “**DESIGN AND DEVELOPMENT OF MICRO TURBINE**” submitted by **Ankur Sachdev and Sibasish Patnaik** in partial fulfillment of the requirements for the award of **Bachelor of Technology** Degree in **Mechanical Engineering** at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

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*Last but not the least we thank our parents and the Almighty whose blessings are always there with us.*

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## **ABSTRACT:**

Micro turbines are a relatively new type of combustion turbine that produces both heat and electricity on a small scale. Micro turbines offer an efficient and clean solution to direct mechanical drive markets such as compression and air-conditioning. This report focuses on the design and development of a micro turbine driven by compressed nitrogen gas. The available literature regarding the design aspects of micro turbine were reviewed in detail. Gas turbine cycle and operation of micro turbine was studied and reported. The turbine blades and nozzles were designed with the help of Gambit software using a given set of cylindrical coordinates. The turbine has a radial inlet and axial outlet. A proper meshing scheme was used to mesh the turbine and nozzle assembly. CFD analysis was carried out by Fluent software to get the velocity vectors using a set of suitable inputs.

Keywords: Gas turbine, turbine blade, nozzle, nitrogen

# Chapter 1

## LITERATURE REVIEW

Micro turbine is one of the important components in a micro gas turbine engine. Micro gas turbine engine is a promising solution to provide high-density power source for micro systems. A micro gas turbine engine consists of a radial inflow turbine, a centrifugal compressor and a combustor. This thesis mainly deals with the design aspects of a micro turbine. Various journals has been published on designing of various types of micro turbines. Exhaustive study has been done on these papers and the major points have been highlighted here.

In the paper “Design, fabrication and characterization of an air-driven micro turbine device” by X. C. Shan, and Qide Zhang, development and investigations of a micro turbine device driven by compressed air, which consists of three layers of silicon wafers and two layers of acrylic plates has been presented. The key challenges to develop a successful high-speed turbine device are geometry design and fabrication of micro blade profiles as well as air- bearings. The micro air bearings have been designed, and a deep reactive ion etching (DRIE) process has been used for fabricating micro journal bearings with high aspect ratio

“Design of turboexpander for cryogenic applications” by Subrata Kr. Ghosh , N. Seshaiiah, R. K. Sahoo, S. K. Sarangi focuses on design and development of turbo expander. The paper briefly discusses the design methodology and the fabrication drawings for the whole system, which includes the turbine wheel, nozzle, diffuser, shaft, brake compressor, two types of bearing, and appropriate housing. With this method, it is possible to design a turbo expander for any other fluid since the fluid properties are properly taken care of in the relevant equations of the design procedure.

A simple method sufficient for the design of a high efficiency expansion turbine is outlined by Kun et. al. A study was initiated in 1979 to survey operating plants and generate the cost factors relating to turbine by Kun & Sentz. Sixsmith et. al. in collaboration with Goddard Space Flight Centre of NASA, developed miniature turbines for Brayton Cycle cry coolers. They have developed of a turbine, 1.5 mm in diameter rotating at a speed of approximately one million rpm.

Yang et. al developed a two stage miniature expansion turbine made for an 1.5 L/hr helium liquefier at the Cryogenic Engineering Laboratory of the Chinese Academy of Sciences. The turbines rotated at more than 500,000 rpm. The design of a small, high speed turbo expander was taken up by the National Bureau of Standards (NBS) USA. The first expander operated at

600,000 rpm in externally pressurized gas bearings. The turbo expander developed by Kate et. al was with variable flow capacity mechanism (an adjustable turbine), which had the capacity of controlling the refrigerating power by using the variable nozzle vane height.

In another paper on “A micro turbine device with enhanced micro air bearings by “X. C. Shan , Q. D. Zhang , Y. F. Sun and R. Maeda design, fabrication and testing of a silicon-based micro turbine device, which is driven by compressed air has been shown. The thrust air bearings are utilized for supporting the rotor from both its top- and bottom- sides.

India has also started devoting attention to this field of research work and significant progress has been made during the past two decades. In CMERI Durgapur, Jadeja et. al developed an inward flow radial turbine supported on gas bearings for cryogenic plants. The device gave stable rotation at about 40,000 rpm. Another programme at IIT Kharagpur developed a turbo expander unit by using aerostatic thrust and journal bearings which had a working speed up to 80,000 rpm. The detailed summary of technical features of the cryogenic turbo expander developed in various laboratories has been given in the PhD dissertation of Ghosh. Recently Cryogenic Technology Division, BARC developed Helium refrigerator capable of producing 1 kW at 20K temperature.

# Chapter 2

## GAS TURBINE

## 2.1 Gas Turbine

A gas turbine is a rotating engine that extracts energy from a flow of combustion gases that result from the ignition of compressed air and a fuel (either a gas or liquid, most commonly natural gas). It has an upstream compressor module coupled to a downstream turbine module, and a combustion chamber(s) module (with igniter[s]) in between.

Energy is added to the gas stream in the combustor, where air is mixed with fuel and ignited. Combustion increases the temperature, velocity, and volume of the gas flow. This is directed through a nozzle over the turbine's blades, spinning the turbine and powering the compressor. Energy is extracted in the form of shaft power, compressed air, and thrust, in any combination, and used to power aircraft, trains, ships, generators, and even tanks.

## 2.2 Types of Gas Turbine

There are different types of gas turbines. Some of them are named below:

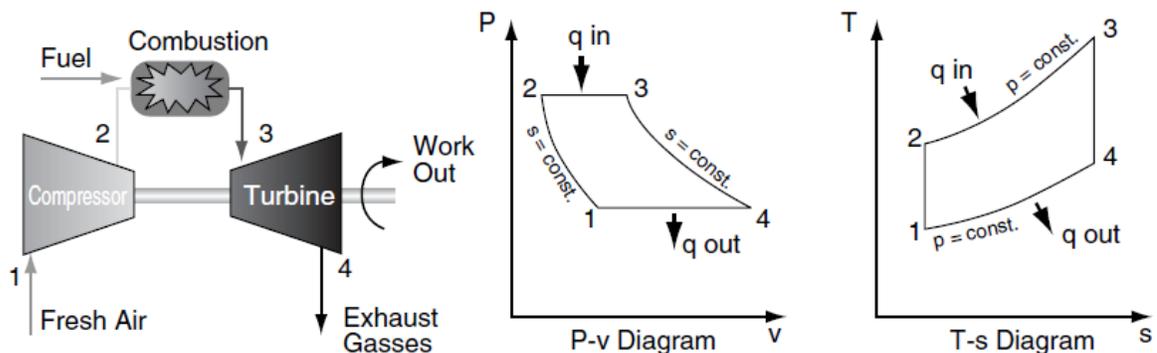
1. Aero derivatives and jet engines
2. Amateur gas turbines
3. Industrial gas turbines for electrical generation
4. Radial gas turbines
5. Scale jet engines
6. Micro turbines

The main focus of this paper is the design aspects of micro turbine.

## 2.3 Gas Turbine Cycle

The simplest gas turbine follows the Brayton cycle (Figure 1.1). In a closed cycle (i.e., the working fluid is not released to the atmosphere), air is compressed isentropically, combustion occurs at constant pressure, and expansion over the turbine occurs isentropically back to the starting pressure. As with all heat engine cycles, higher combustion temperature (the common

industry reference is turbine inlet temperature) means greater efficiency. The limiting factor is the ability of the steel, ceramic, or other materials that make up the engine to withstand heat and pressure. Considerable design/manufacturing engineering goes into keeping the turbine parts cool. Most turbines also try to recover exhaust heat, which otherwise is wasted energy. Recuperators are heat exchangers that pass exhaust heat to the compressed air, prior to combustion. Combined-cycle designs pass waste heat to steam turbine systems, and combined heat and power (i.e., cogeneration) uses waste heat for hot water production. Mechanically, gas turbines can be considerably less complex than internal combustion piston engines. Simple turbines might have one moving part: the shaft/compressor/ turbine/alternator-rotor assembly, not counting the fuel system. More sophisticated turbines may have multiple shafts (spools), hundreds of turbine blades, movable stator blades, and a vast system of complex piping, combustors, and heat exchangers.



**Figure 1.1- Idealized Brayton Cycle**

The largest gas turbines operate at 3000 (50 hertz [Hz], European and Asian power supply) or 3600 (60 Hz, U.S. power supply) RPM to match the AC power grid. They require their own building and several more to house support and auxiliary equipment, such as cooling towers. Smaller turbines, with fewer compressor/turbine stages, spin faster. Jet engines operate around 10,000 RPM and micro turbines around 100,000 RPM. Thrust bearings and journal bearings are a critical part of the design. Traditionally, they have been hydrodynamic oil bearings or oil-cooled ball bearings.

## **2.4 Advantages of Gas Turbine**

1. Very high power-to-weight ratio, compared to reciprocating engines.
2. Smaller than most reciprocating engines of the same power rating.
3. Moves in one direction only, with far less vibration than a reciprocating engine.
4. Fewer moving parts than reciprocating engines.
5. Low operating pressures.
6. High operation speeds.
7. Low lubricating oil cost and consumption.

# Chapter 3

## MICRO TURBINE

## **3.1 Micro turbine**

Micro turbines are small combustion turbines with outputs of 25 kW to 500 kW. They evolved from automotive and truck turbochargers, auxiliary power units (APUs) for airplanes, and small jet engines. Micro turbines are a relatively new distributed generation technology being used for stationary energy generation applications. They are a type of combustion turbine that produces both heat and electricity on a relatively small scale.

A micro gas turbine engine consists of a radial inflow turbine, a centrifugal compressor and a combustor. The micro turbine is one of the critical components in a micro gas turbine engine, since it is used for outputting power as well as for rotating the compressor. Micro turbines are becoming widespread for distributed power and combined heat and power applications. They are one of the most promising technologies for powering hybrid electric vehicles. They range from hand held units producing less than a kilowatt, to commercial sized systems that produce tens or hundreds of kilowatts.

Part of their success is due to advances in electronics, which allows unattended operation and interfacing with the commercial power grid. Electronic power switching technology eliminates the need for the generator to be synchronized with the power grid. This allows the generator to be integrated with the turbine shaft, and to double as the starter motor.

They accept most commercial fuels, such as gasoline, natural gas, propane, diesel, and kerosene as well as renewable fuels such as E85, biodiesel and biogas.

## **3.2 Types of Micro turbine**

Micro turbines are classified by the physical arrangement of the component parts: single shaft or two-shaft, simple cycle, or recuperated, inter-cooled, and reheat. The machines generally rotate over 40,000 revolutions per minute. The bearing selection—oil or air—is dependent on usage. A single shaft micro turbine with high rotating speeds of 90,000 to 120,000 revolutions per minute is the more common design, as it is simpler and less expensive to build. Conversely, the split

shaft is necessary for machine drive applications, which does not require an inverter to change the frequency of the AC power.

### 3.3 Characteristics of Micro turbine

Some of the primary characteristics for micro turbines include:

- **Distributed generation**—stand-alone, on-site applications remote from power grids
- **Quality power and reliability**—reduced frequency variations, voltage transients, surges, dips, or other disruptions
- **Stand-by power**—used in the event of an outage, as a back-up to the electric grid
- **Peak shaving**—the use of micro turbines during times when electric use and demand charges are high
- **Boost power**—boost localized generation capacity and on more remote grids
- **Low-cost energy**—the use of micro turbines as base load or primary power that is less expensive to produce locally than it is to purchase from the electric utility
- **Combined heat and power (cogeneration)**—increases the efficiency of on-site power generation by using the waste heat for existing thermal process.

### 3.4 Advantages

Micro turbine systems have many advantages over reciprocating engine generators, such as higher power density (with respect to footprint and weight), extremely low emissions and few, or just one, moving part. Those designed with foil bearings and air-cooling operate without oil, coolants or other hazardous materials. Micro turbines also have the advantage of having the majority of their waste heat contained in their relatively high temperature exhaust, whereas the waste heat of reciprocating engines is split between its exhaust and cooling system. However, reciprocating engine generators are quicker to respond to changes in output power requirement and are usually slightly more efficient, although the efficiency of micro turbines is increasing. Micro turbines also lose more efficiency at low power levels than reciprocating engines.

Micro turbines offer several potential advantages compared to other technologies for small-scale power generation, including: a small number of moving parts, compact size, lightweight, greater efficiency, lower emissions, lower electricity costs, and opportunities to utilize waste fuels. Waste heat recovery can also be used with these systems to achieve efficiencies greater than 80%. Because of their small size, relatively low capital costs, expected low operations and maintenance costs, and automatic electronic control, micro turbines are expected to capture a significant share of the distributed generation market. In addition, micro turbines offer an efficient and clean solution to direct mechanical drive markets such as compression and air-conditioning.

### **3.5 Thermodynamic Heat Cycle**

In principle, micro turbines and larger gas turbines operate on the same thermodynamic heat cycle, the Brayton cycle. In this cycle, atmospheric air is compressed, heated at constant pressure, and then expanded, with the excess power produced by the expander (also called the *turbine*) consumed by the compressor used to generate electricity. The power produced by an expansion turbine and consumed by a compressor is proportional to the absolute temperature of the gas passing through those devices. Higher expander inlet temperature and pressure ratios result in higher efficiency and specific power. Higher pressure ratios increase efficiency and specific power until an optimum pressure ratio is achieved, beyond which efficiency and specific power decrease. The optimum pressure ratio is considerably lower when a recuperator is used. Consequently, for good power and efficiency, it is advantageous to operate the expansion turbine at the highest practical inlet temperature consistent with economic turbine blade materials and to operate the compressor with inlet air at the lowest temperature possible. The general trend in gas turbine advancement has been toward a combination of higher temperatures and pressures. However, micro turbine inlet temperatures are generally limited to 1750°F or below to enable the use of relatively inexpensive materials for the turbine wheel and recuperator. For recuperated turbines, the optimum pressure ratio for best efficiency is usually less than 4:1.

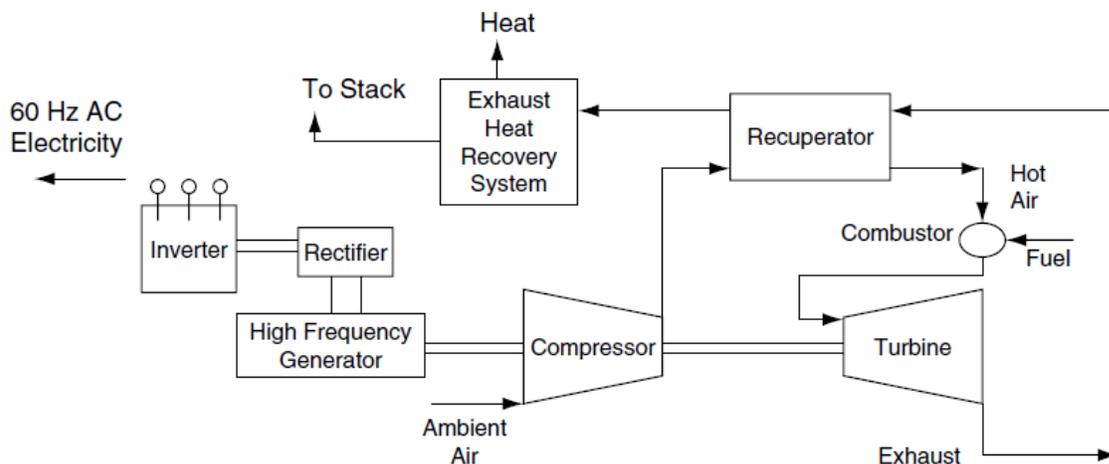
## 3.6 Components of Micro turbine

Micro turbines are very small gas turbines (30 to 400 kilowatts [kW]) that usually have an internal heat-recovery heat exchanger (called a recuperator) to improve electric efficiency. In typical micro turbines, the cycle is similar to that of a conventional gas turbine. It consists of the following processes:

- Inlet air is compressed in a radial (centrifugal) compressor, then
- Preheated in the recuperator using heat from the turbine exhaust.
- Heated air from the recuperator is mixed with fuel in the combustor and burned.

The hot combustion gas is then expanded in one or more turbine sections, which produces rotating mechanical power to drive the compressor and the electric generator. The recuperator efficiency is the key to whether a particular micro turbine is economically viable. By comparison, in a conventional gas turbine, the gas flow path is as follows: compressed air from the compressor (more air mass can be “introduced” by inter-cooling) is burned with fuel. Gaseous products expand through the turbine section (where more power can be extracted by reheating the gaseous products). Exhaust gases can provide waste heat recovery or cogeneration potential, as those gases may produce steam to drive a steam turbine, may be led into a greenhouse system, or may optimize thermal efficiency by some other means. Without waste heat recovery or cogeneration of some sort, a gas turbine is said to operate in “simple cycle” mode. With the addition of a boiler (to get steam from waste heat recovery) and a steam turbine, the gas turbine package is said to operate as a “combined cycle.” However, most micro turbines, to be financially viable, have a recuperator (to recover waste heat). This is not quite a simple cycle, but the micro turbine can be said to operate “solo” in power-only applications. Frequently, micro turbines are used to extract heat as a product. This then would be called combined heat and power (CHP) applications. In single-shaft micro turbines, a single expansion turbine turns both the compressor and the generator. Two-shaft models use one turbine to drive the compressor and a second turbine to drive the generator, with exhaust from the compressor turbine powering the generator turbine. The power turbine’s exhaust is then used in the recuperator to preheat the air from the compressor.

The basic components of a micro turbine are the compressor, turbine, generator, and recuperator (Figure 2-1). The heart of the micro turbine is the compressor-turbine package, which is most commonly mounted on a single shaft along with the electric generator. The single shaft is supported by two (or more) high-speed bearings. Because single-shaft turbines have only one moving shaft, they have the potential for lower maintenance and higher reliability than turbines with two or more shafts. There are also two-shaft versions of the micro turbine, in which the turbine on the first shaft only drives the compressor while a second power turbine on a second shaft drives a gearbox and conventional electric generator producing 60 or 50 Hz of power. Moderate- to large-sized gas turbines use multistage axial flow compressors and turbines, in which the gas flows parallel to the axis of the shaft and then is compressed and expanded in multiple stages. Most current micro turbines are based on single-stage radial flow compressors and either single- or double-stage turbines.



**Figure 1.2-Microturbine based combined heat and power system**

### 3.7 Applications

Micro turbines can be used for stand-by power, power quality and reliability, peak shaving, and cogeneration applications. In addition, because micro turbines are being developed to utilize a variety of fuels, they are being used for resource recovery and landfill gas applications. Micro turbines are well suited for small commercial building establishments such as: restaurants, hotels/motels, small offices, retail stores, and many others.

# Chapter 4

## DESIGNING OF MICRO TURBINE

## 4.1 Design of Turbine Blade

The modelling of the blades and nozzles was done using Gambit 2.3.16 software. Gambit is a software package designed to help analysts and designers build and mesh models for computational fluid dynamics (CFD) and other scientific applications. It includes both geometry modelling and mesh generation tools for structured, unstructured and hybrid meshing.

The main features of the geometry i.e. the blades, nozzles, diffuser were created using Gambit. They were then assembled to construct the 3-D geometry.

A method of computing blade profiles has been worked out by H.Hasselgruber(1958).The rotor blade geometry comprises of a series of three dimensional streamlines which are determined from a series of mean line distributions and are used to form the rotor blade surface. The coordinates needed for the purpose were obtained from the available literature.

Table 1.1 shows qualitatively the computed hub and tip streamlines as well as the resulting stream surface. These data are used to create NURBS (Non-Uniform Rational B Splines) for solid models in Gambit. A ruled surface is created by joining the hub and tip streamlines with a set of tie lines. The surface so generated is considered as the mean surface within a blade. The suction and pressure surfaces of two adjacent channels are computed by translating the mean surface in the +ve and -ve  $\theta$  directions through half the blade thickness. Coordinates of all the blade surfaces are computed by further rotating the pair of surfaces over an angle  $2\pi / Z$ , i.e.  $51.43^\circ$  for  $Z = 7$ .

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.

TIP CAMBERLINE			HUB CAMBERLINE		
z(mm)	r(mm)	phi(deg)	z(mm)	r(mm)	phi(deg)
-0.4775	2.2615	0	0	0.7915	0
-0.35975	2.28025	5.502	0.1065	0.84575	5.502
-0.2375	2.28225	10.61	0.20875	0.9165	10.61
-0.11725	2.2835	15.347	0.31275	0.9885	15.347
0.0005	2.28575	19.732	0.41875	1.06075	19.732
0.11575	2.2895	23.786	0.52675	1.13325	23.786
0.2285	2.29525	27.524	0.6365	1.2065	27.524
0.33825	2.30325	30.961	0.7475	1.28125	30.961
0.4455	2.314	34.111	0.85925	1.358	34.111
0.55025	2.32775	36.987	0.971	1.438	36.987
0.65175	2.34525	39.602	1.082	1.52125	39.602
0.751748	2.3665	41.966	1.1915	1.609	41.966
0.84825	2.3925	44.091	1.29825	1.7015	44.091
0.943275	2.42325	45.989	1.4015	1.799	45.989
1.0275	2.45975	47.672	1.50025	1.902	47.672
1.1175	2.50225	49.15	1.593	2.0105	49.15
1.2075	2.5515	50.435	1.679	2.124	50.435
1.2825	2.60775	51.54	1.757	2.24225	51.54
1.3575	2.6715	52.475	1.82625	2.36425	52.475
1.4325	2.74475	53.253	1.8865	2.4895	53.253
1.5	2.8205	53.891	1.93725	2.617	53.891
1.55775	2.906	54.38	1.979	2.7455	54.38
1.6095	2.9975	54.752	2.012	2.86725	54.752
1.65375	3.09475	55.007	2.037	3.00225	55.007
1.69125	3.19675	55.154	2.05475	3.1295	55.154
1.72275	3.279	55.202	2.06675	3.279	55.202

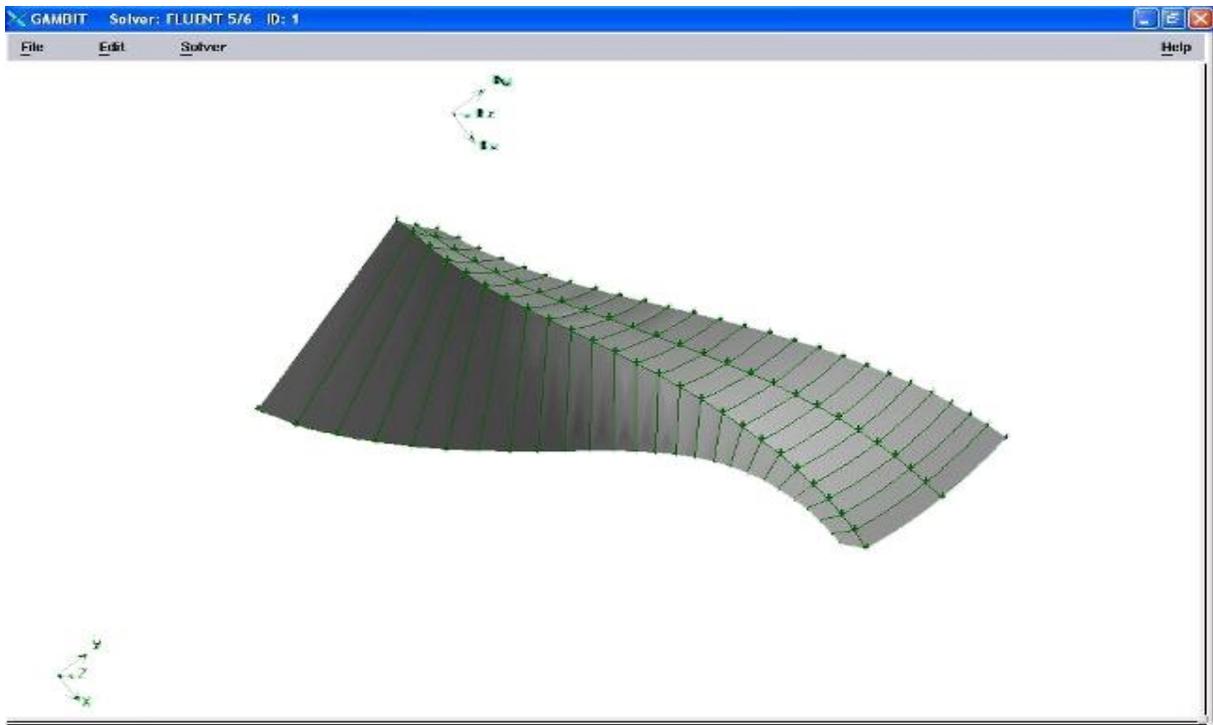
**Table 1.1- Data for blade design**

where,

z = axial length

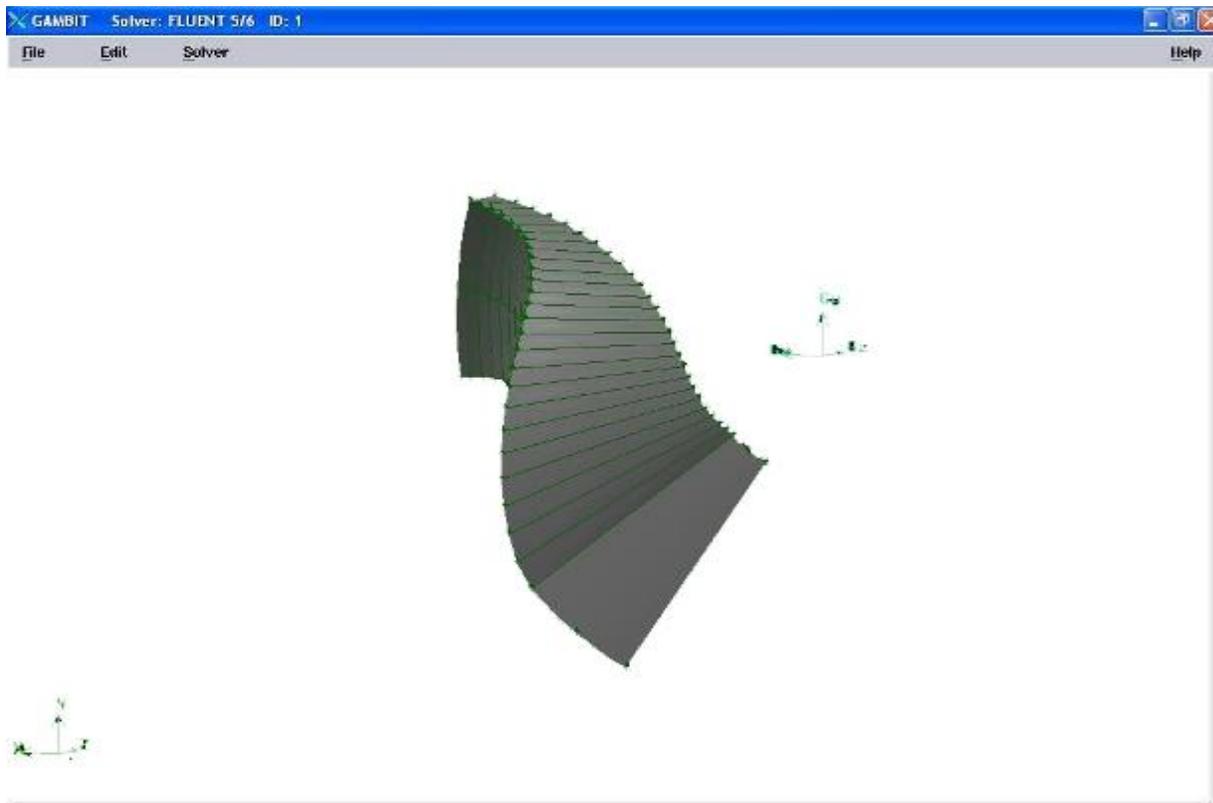
r = radius

phi = angle of deflection measured in clockwise direction



F

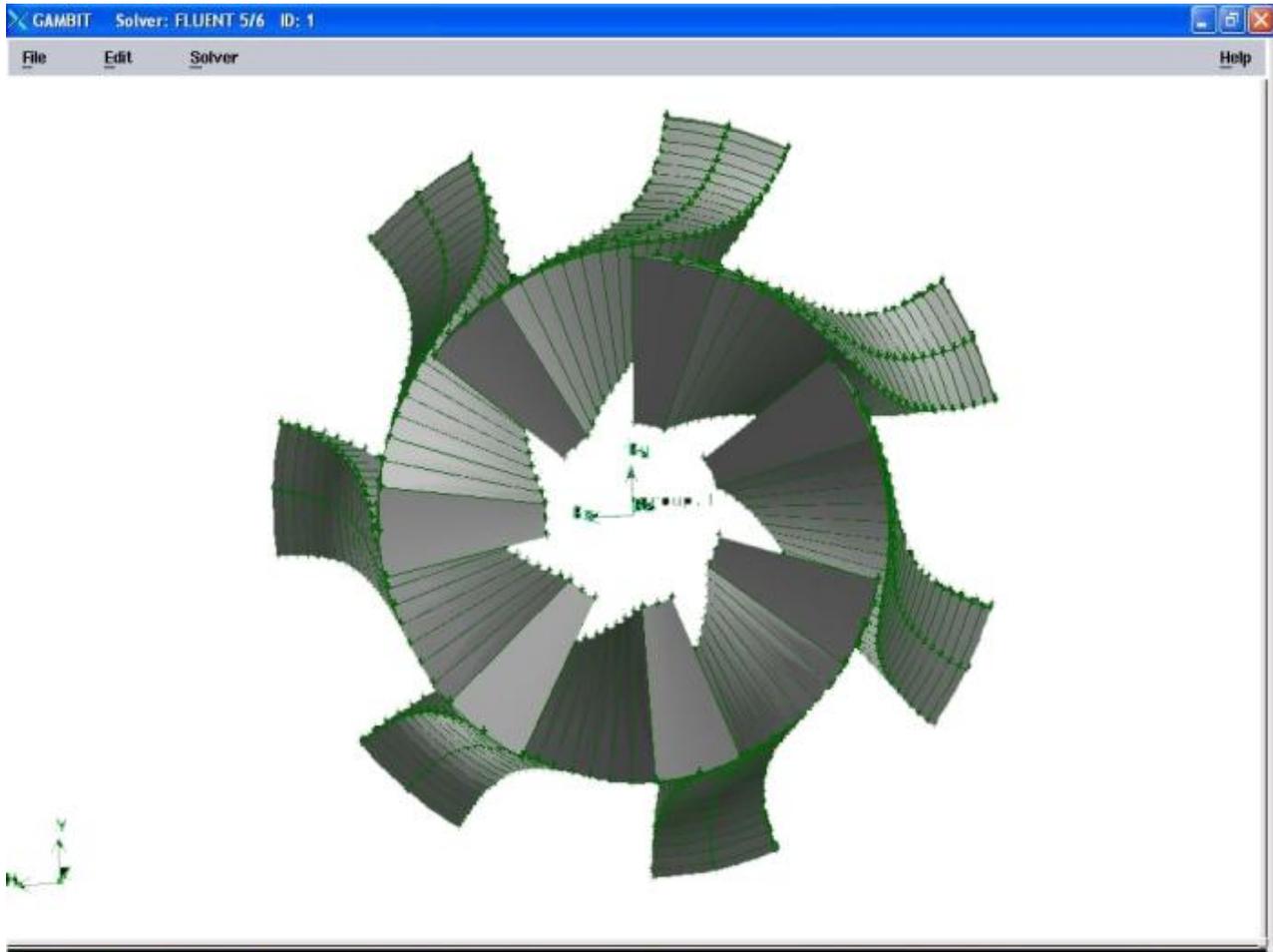
**IG 1.3-Blade Profile**



F

**IG 1.4-Blade Profile (Different view)**

The obtained blade profile is then rotated about z-axis by using the copy option in Gambit to create the turbine blade assembly. The blades are rotated by  $2\pi / Z$ , i.e.  $51.43^\circ$  for  $Z = 7$ .

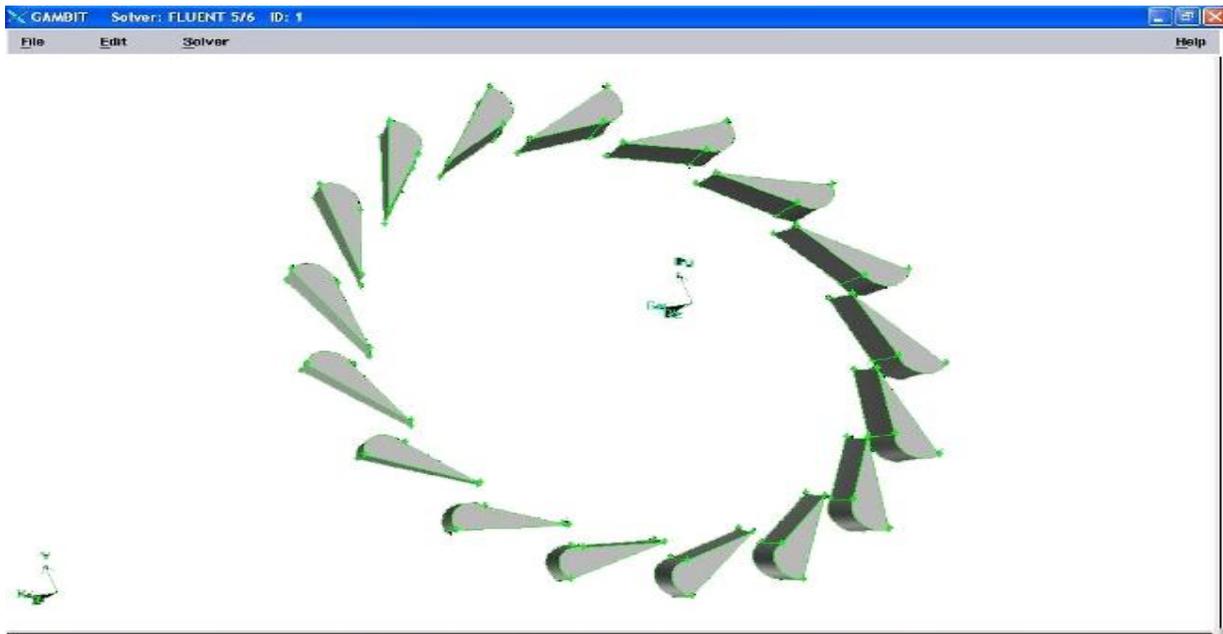


**FIG 1.5-Turbine Blade Passage**

## 4.2 Design of Nozzle

A set of static nozzles must be provided around the turbine wheel to generate the required inlet velocity and swirl. The working fluid accelerates through the converging passages of the nozzles. Pressure energy is transformed into kinetic energy, leading to a reduction in static temperature. The high velocity fluid 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.

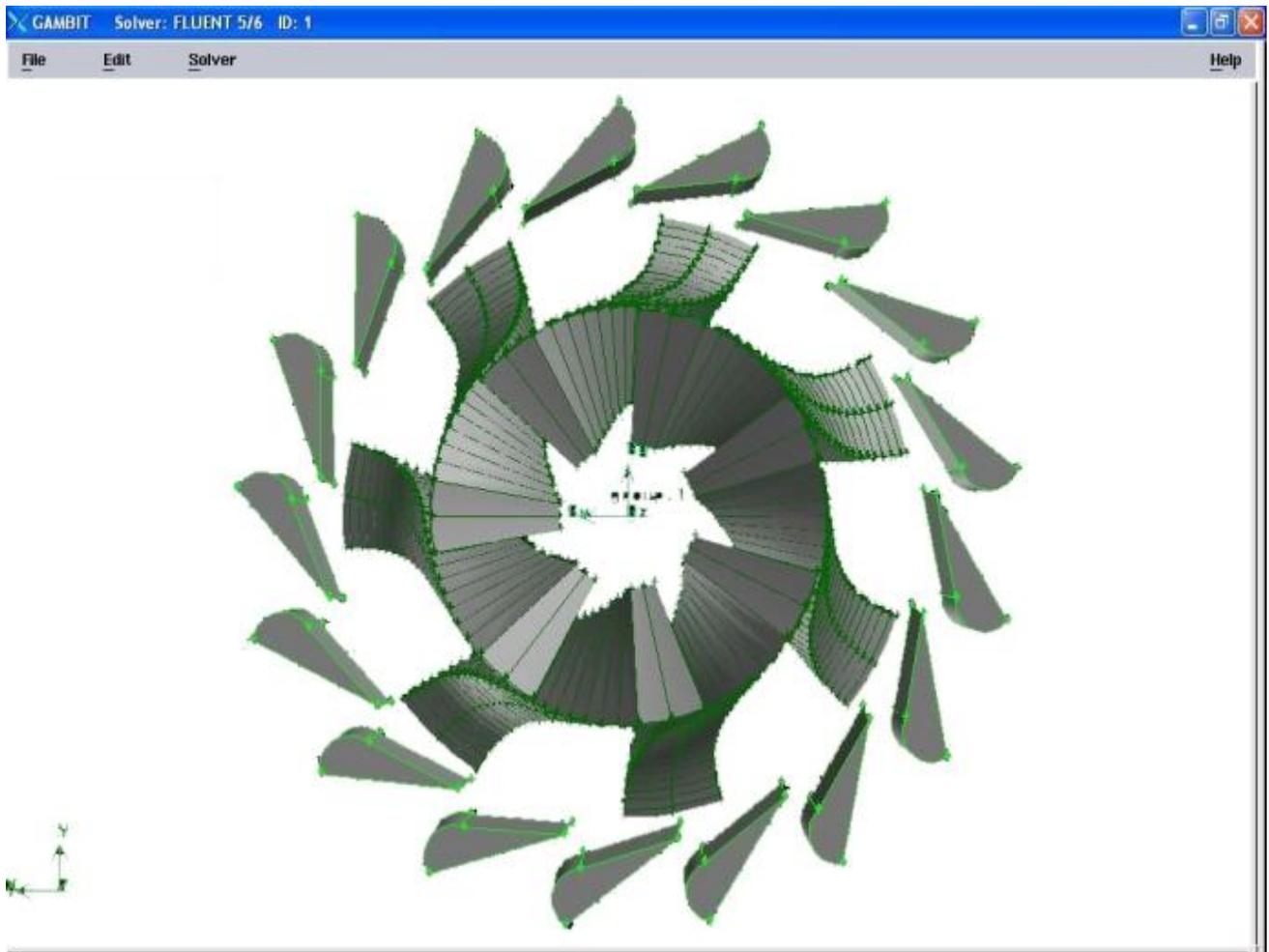
Kun, L .C. and Sentz, R. N.(1985) proposed that the number of nozzle blades is normally dictated by mechanical design consideration, particularly to ensure that nozzle discharge does not excite some natural frequency of the impeller. The number of blades in the nozzle and that in the wheel should be mutually prime in order to raise this excitation frequency well beyond the operating speed and to reduce the overall magnitude of the peak force. The number of nozzle blades has been taken as 17 for 7 blades in the turbine wheel. The nozzle was designed in Gambit using data from available literature. The obtained nozzle profile was then rotated about z-axis over an angle  $21.18^\circ$  to create the complete nozzle assembly.



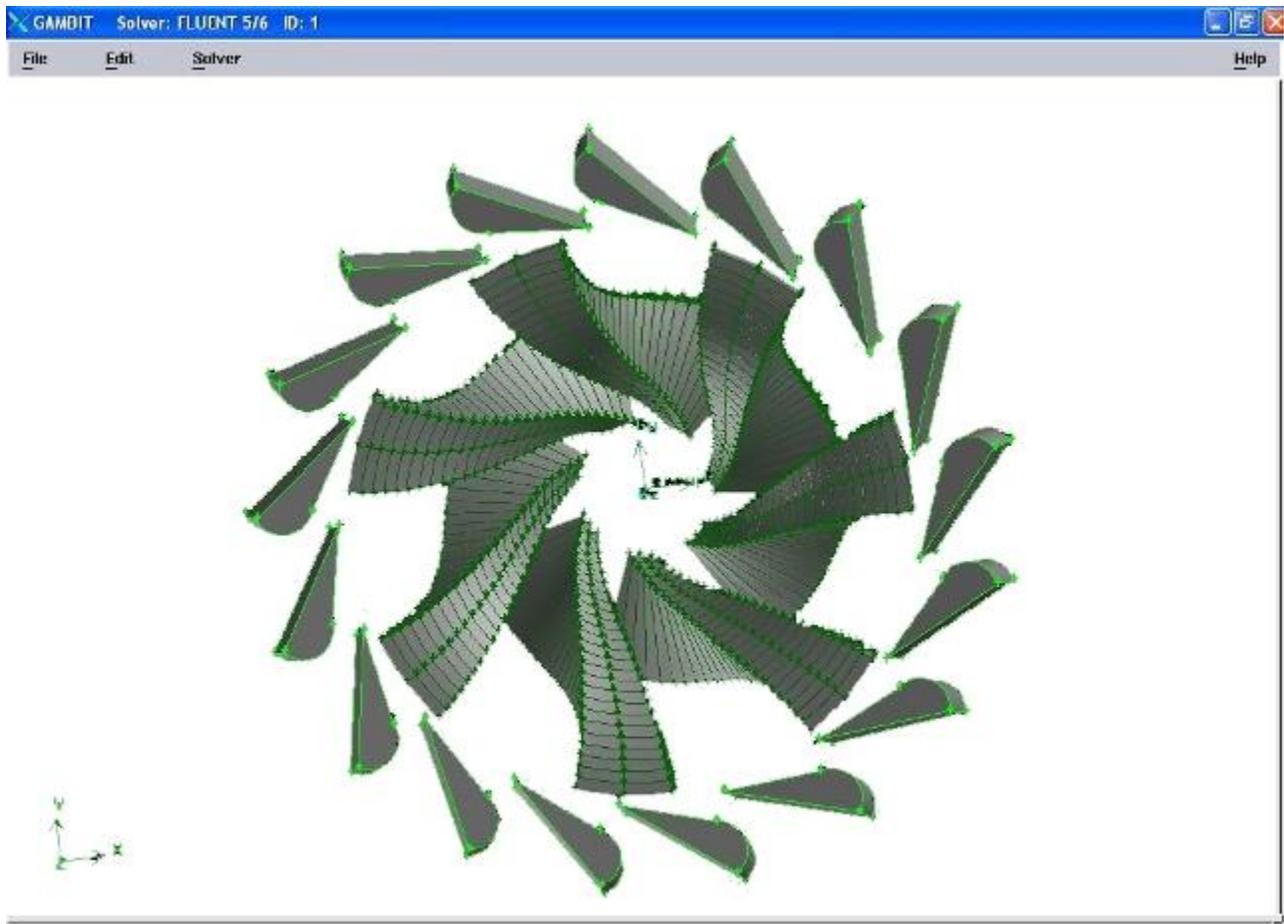
**FIG 1.6-Nozzle Assembly**

## 4.3 Assembly

The turbine blades and nozzles were then assembled to give the complete turbine profile. The high-pressure process gas enters the turbine through the converging passages of the nozzles. Pressure energy is transformed into kinetic energy, leading to a reduction in static temperature. The high velocity fluid streams impinge on the rotor blades, imparting force to the rotor and creating torque. The turbine wheel is of radial or mixed flow geometry, i.e. the flow enters the wheel radially and exits axially. Work is extracted as the process gas undergoes expansion with corresponding drop in static temperature.



**FIG.1.7-Turbine assembly**



**Fig.1.8 Turbine Assembly (Reverse view)**

## **4.4 CFD Analysis**

The CFD analysis has been carried out by the help of Fluent 6.2 software. Fluent enables engineers and designers to simulate fluid flow, heat and mass transfer, and a host of related phenomena involving turbulent, reacting, and multiphase flow. The broad physical modelling capabilities of Fluent have been applied to industrial applications ranging from airflow over an aircraft wing to combustion in a furnace, from bubble columns to glass production, from blood flow to semiconductor manufacturing, from clean room design to wastewater treatment plants. The ability of the software to model in-cylinder engines, aero acoustics, turbo machinery, and multiphase systems has served to broaden its reach.

Advanced solver technology provides fast, accurate CFD results, flexible moving and deforming meshes, and superior parallel scalability. User-defined functions allow the implementation of new user models and the extensive customization of existing ones. Fluent's interactive solver set-up, solution, and post-processing make it easy to pause a calculation, examine results with integrated post-processing, change any setting, and then continue the calculation within a single application.

Fluent is written in the C computer language and makes full use of the flexibility and power offered by the language. Consequently, true dynamic memory allocation, efficient data structures, and flexible solver control are all possible. All functions required to compute a solution and display the results are accessible in Fluent through an interactive, menu-driven interface.

The analysis of a turbine with similar profile has been carried out in a previous literature. The procedure and results of that analysis are reported here.

The material selected was nitrogen gas.

The properties of Nitrogen used are as follows:

Density = 1.138 kg/m<sup>3</sup>

Cp (specific heat capacity) = 1040.67 J/kg K

Thermal conductivity = 0.0242 W/m K

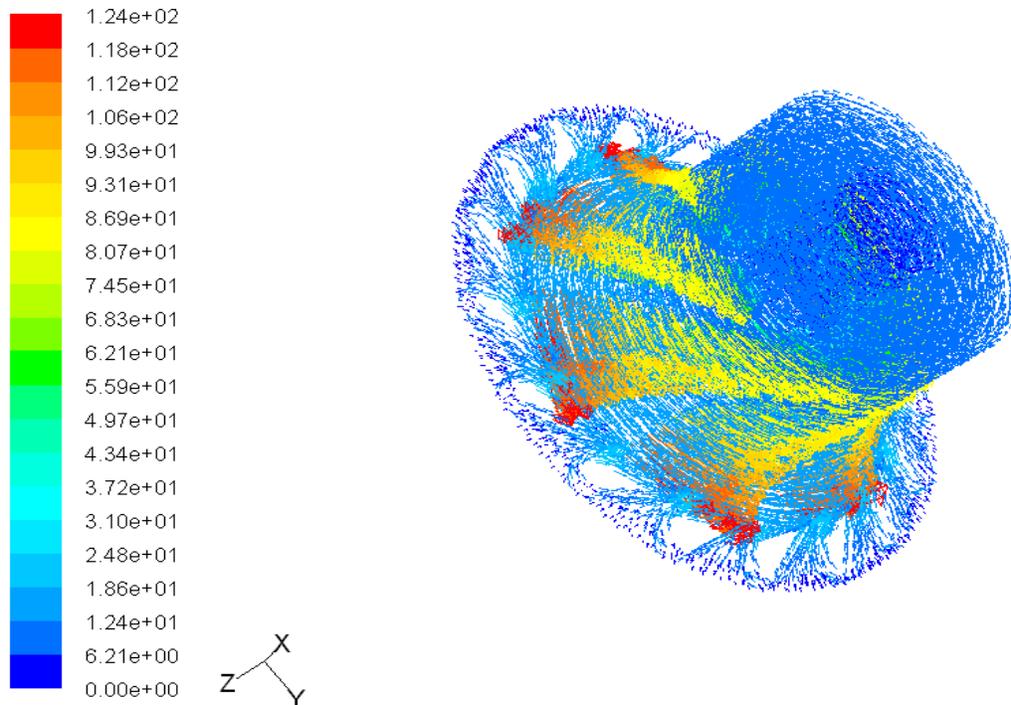
Viscosity = 1.663 x 10<sup>-5</sup> kg/m s

The analysis was done at atmospheric pressure condition and with given conditions. The nozzle inlet was defined as the mass-flow-inlet with a mass flow rate of 0.0606 kg/s. The total temperature was taken to be 120K and initial Gauge pressure was taken as 5 bar. The mixing plane model was used. Two mixing planes were needed, one at the interface between the pressure outlet of the upstream nozzle outlet region and the pressure inlet at the adjacent face of the blades passage region. It was defined as radial mixing plane geometry. Similarly, the second mixing plane was defined at the pressure outlet of blades passage and the pressure inlet to the downstream diffuser inlet region. It was defined as axial mixing plane geometry. For the mixing

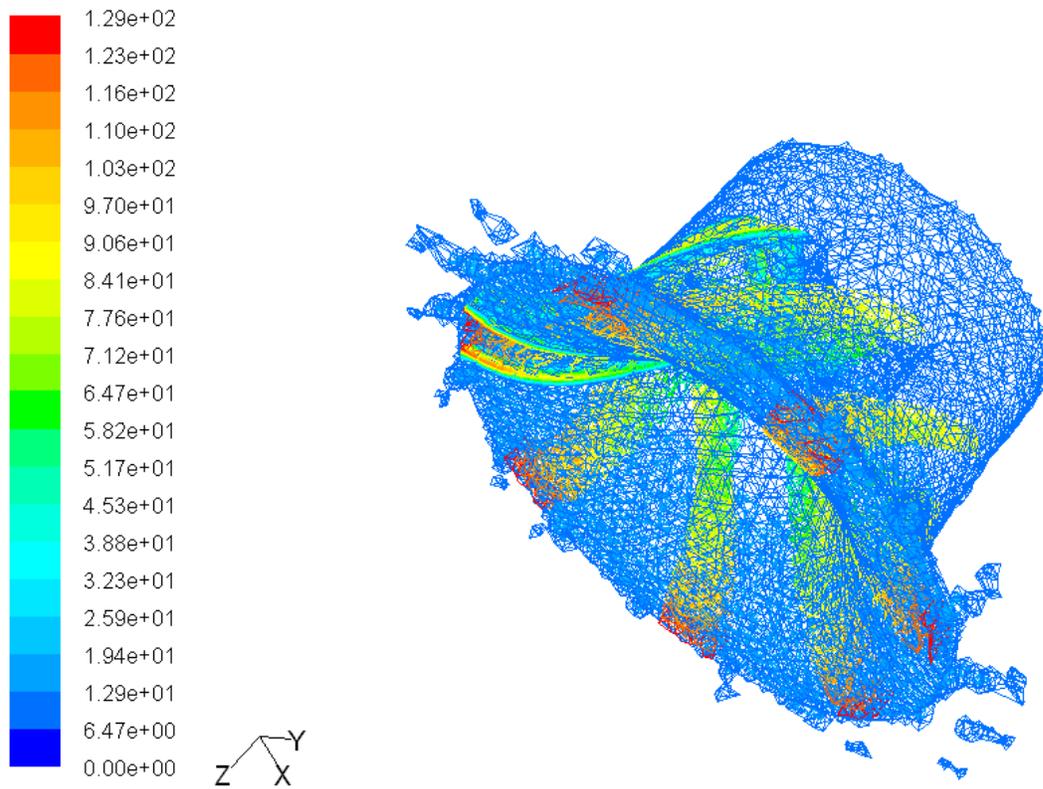
planes as defined earlier, the boundary conditions were set to default. The z-axis was selected as the rotation axis and moving mesh type was selected with a rotational speed of 10400 rad/sec. The diffuser outlet was defined as pressure outlet. The backflow temperature was set to 80K and the pressure was set to default value of 0 bar.

The steady state as well as unsteady state analysis was carried out in Fluent. The turbulent flow analysis was done using k-epsilon method. The Pressure-velocity coupling was done using SIMPLE algorithm. The SIMPLE algorithm uses a relationship between velocity and pressure corrections to enforce mass conservation and to obtain the pressure field. The second order upwind scheme, PRESTO scheme and second order upwind scheme was used for momentum, pressure and energy equations.

The suitable under relaxation factors were given, depending upon the nature of the model selected. The residuals were plotted. Initialization was done and the solution was subjected to iterations till convergence was obtained. The different contours of pressure and velocity, and the velocity vectors were plotted and the results were analyzed for the different cases.



**FIG 1.9- Velocity contours for steady state with laminar flow**



**FIG 1.10- Velocity contours for unsteady state with laminar flow**

# Chapter 5

## CONCLUSION

The work presented in the report is an attempt at designing a micro turbine of a given dimension. Extensive literature review was carried out to study the various aspects and applications of micro turbines. A suitable design procedure was chosen from the available methods to design the turbine blades and nozzles. Modelling of blade profile was done using a set of given coordinates. Gambit was used for creation of a single blade and then they were assembled to give the complete turbine wheel. CFD analysis of a turbine with similar profile has also been reported from an available literature.

Micro turbines are relatively new in the market and are attracting wide attention due to their varied applications. Development of a sophisticated engineering product like micro turbine is a continuous process. A lot of work is yet to be done on the design aspects before the micro turbine can be readied for market consumption. The design procedure has to take into various other parameters to make it suitable for practical applications. Also, manufacturing of such complex shapes of minute size is another ongoing research work. Further research into the design and manufacture process would result in production of even better micro turbines.

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