As per UGC guidelines an electronic bar code is provided to seure your paper

International Journal for Modern Trends in Science and Technology, 8(09): 33-41, 2022

ISSN: 2455-3778 online
DOI: https://doi.org/10.46501/IJMTST0809005
Available online at: http://www.ijmtst.com/vol8issue09.html

Design Analysis and Development of a Micro Gas Turbine Components

Pasupuleti.Hari Krishna[1] | K. Chandra Sekhar[2]

[1]PG Scholar, Department of Mechanical Engineering, QIS College of Engineering and Technology, Ongole.
[2] Associate Professor, Department of Mechanical Engineering, QIS College of Engineering and Technology, Ongole.

To Cite this Article
Pasupuleti.Hari Krishna and K. Chandra Sekhar. Design Analysis and Development of a Micro Gas Turbine Components. International Journal for Modern Trends in Science and Technology 2022, 8(09), pp. 33-41. https://doi.org/10.46501/IJMTST0809005

Article Info
Received: 02 August 2022; Accepted: 28 August 2022; Published: 01 September 2022.

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 focussed 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 solid works 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 Ansys fluent software to get the velocity vectors using a set of suitable inputs.

Keywords: Gas turbine, turbine blade, nozzle, Gambit, CFD.

1. INTRODUCTION

Most of the energy consumed worldwide, except form nuclear and hydroelectric sources is from coal, petroleum and natural gas. It is well known that these sources are limited and will exhaust in long term. India imports about 70% of its petroleum from the gulf countries that are most of the time under political turmoil. By the end of 2010, this percent is likely to increase to 82%. In India, Nearly 80% of the country's population being dependent on agriculture, and unemployment is rampant. Thus, For India, like many other nations in the world, national security for energy supply, rural employment and concern for the environment are the main driven forces for the search of renewable and clean source of energy for the transportation. Micro gas turbines are one of the answers of this search.

1.1Micro 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.

1.2Types 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.

1.3Advantages

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.

2. LITERATURE REVIEW

A turbine can be used as a refrigerant machine was first introduced by Lord Rayleigh. In a letter June 1898 to Nature, he suggested the use of turbine instead of a piston expander for air liquefaction because of practical difficulties caused in the low temperature reciprocating machines. He emphasized the most important function of and cryogenic expander, which is to production of the cold, rather than the powerproduced.

In 1922, the American engineer and teacher Harvey N Davis had patented an expansion turbine of unusual thermodynamic concept. This turbine was intended to have several nozzle blocks each receiving a stream of gas from different temperature level of high pressure side of the main heat exchanger of a liquefaction apparatus.

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.

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 3 | P a g e 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.

First successful commercial turbine developed in Germany which uses an axial flow single stage impulse machine. Later in the year 1936 it was replaced by an inward radial flow turbine based on a patent by an Italian inventor, Guido Zerkowitz.

Work on the small gas bearing turbo expander commenced in the early fifties by Sixsmith at Reading University on a machine for a small air liquefaction plant. In 1958, the United Kingdom Atomic Energy Authority developed a radial inward flow turbine for a nitrogen production plant. During 1958 to 1961 Stratos Division of Fair child Aircraft Co. built blower loaded turbo expanders, mostly for air separation service. Voth et. developed a high speed turbine expander as a part of a cold moderator refrigerator for the Argonne National Laboratory (ANL). The first commercial turbine using helium was operated in 1964 in a refrigerator that produced 73 W at 3 K for the Rutherford helium bubble chamber. A high speed turbo alternator was developed by General Electric Company, New York in 1968.

Summary based on literature, 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. My work focussed 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 is 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 Ansys fluent software to get the velocity vectors using a set of suitable inputs.

3.0 DESIGN OF MICRO GAS TURBINE COMPONENTS

3.1 Turbine Inlet: Inlet hollow cylinder = 12 mm dia, Length = 10.265 mm, Outlet Diameter = 13.8 mm, Length = 6.4 mm, Octagonal diameter = 18.3 mm, Length = 4.42 mm.

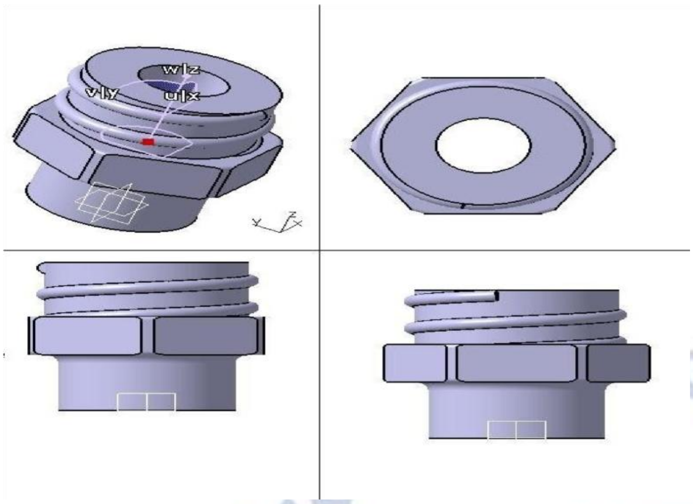

Figure 1: Design of turbine inlet

3.2 Temporary storage: This is basically a hollow cylinder which used as a temporary storage of hot gases .It lies between the Inlet and the nozzle.

Its Outer diameter = 14 mm, Inlet diameter = 12 mm, Length = 7 mm.

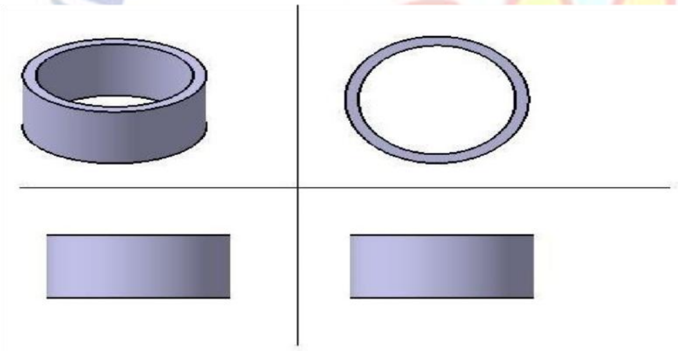

Figure2: hallow cylinder

3.3 Nozzle: No. of nozzles = 10

It has two phases 1st 1.263 mm has a diameter of 13.66 mm and 2 nd 7.1 mm has a diameter of 12.4 mm.

The nozzles expand the inlet gas isentropically to high velocity and direct the flow on to the wheel at the correct angle to ensure smooth, impact free incidence on the wheel blades. A set of static nozzles must be provided around the turbine wheel to generate the required inlet velocity and swirl. The flow is subsonic, the absolute Mach number being around 0.95. At design point operation, fixed nozzles yield the best overall efficiency. Fixed nozzle shapes can be optimized by rounding the noses of nozzle vanes and are directionally oriented for minimal incidence angle loss. The throat of the nozzle has an important influence on turbine performance and must be sized to pass the required mass flow rate at design conditions. The exit flow angle and exit velocity from nozzle are determined by the angular momentum required at rotor inlet and by the continuity equation. The throat velocity should be similar to the stator exit velocity and this determines the throat area by continuity. Turbine nozzles designed for subsonic and slightly supersonic flow are drilled and reamed for straight holes inclined at proper nozzle outlet angle.

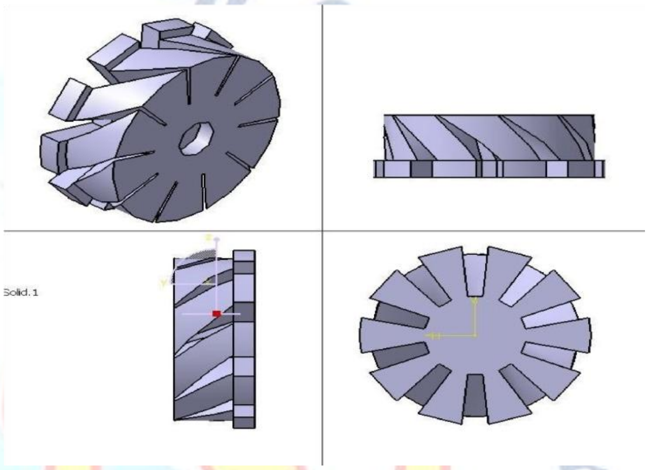

Figure3: Throat of the nozzle

In small turbines, there is little space for drilling holes; therefore two dimensional passages of appropriate geometry are milled on a nozzle ring. The nozzle inlet is rounded off to reduce frictional losses. An important forcing mechanism leading to fatigue of the wheel is the nozzle excitation frequency. As the wheel blades pass under the jets emanating from the stationary nozzles, there is periodic excitation of the wheel. 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.

3.4 Rotor: Diameter = 12 mm, Length = 3.474 mm.

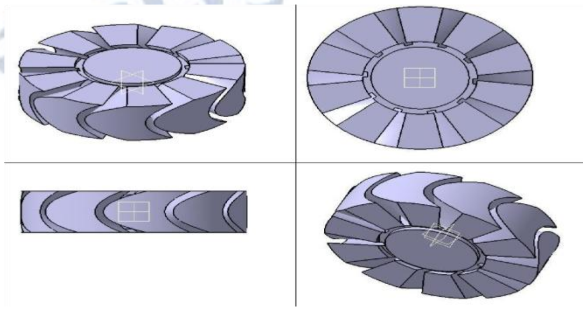

Figure 4: Rotor design

3.5 Coupling with shaft: It has basically 2 parts one is the rod and the other is the coupling which is in turn attached to the counter part of the Generator.
Rod diameter = 2.6 mm Length = 25 mm, Coupling main shoe diameter = 8 mm,
Individual coupling hole diameter = 1.5 mm.

The force acting on the turbine shaft due to the revolution of its mass center and around its geometrical center constitutes the major inertia force. A restoring force equivalent to a spring force for small displacements, and viscous forces between the gas and the shaft surface, act as espring and damper to the rotating system. The film stiffness depends on the relative position of the shaft with respect to the bearing and is symmetrical with the center-to center vector.

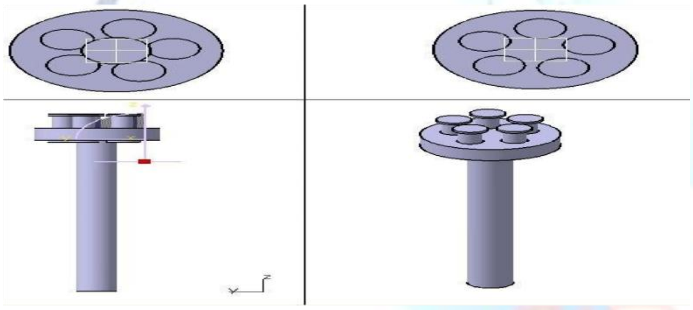

Figure5: Coupling with shaft

3.6 Outlet: Main solid diameter = 12.42 mm, Central hole diameter = 2.6 mm, 4 holes of diameter = 1.56 mm, Width is = 3.6 mm

It basically the 2nd last part of turbine mainly used to put out the exit gases to outside easily.
It holds to the housing tightly inside a slot.

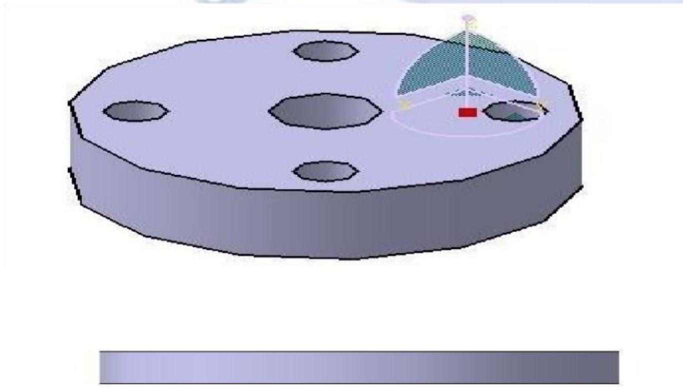

Figure6: Outside holes

3.7 Housing/Cover

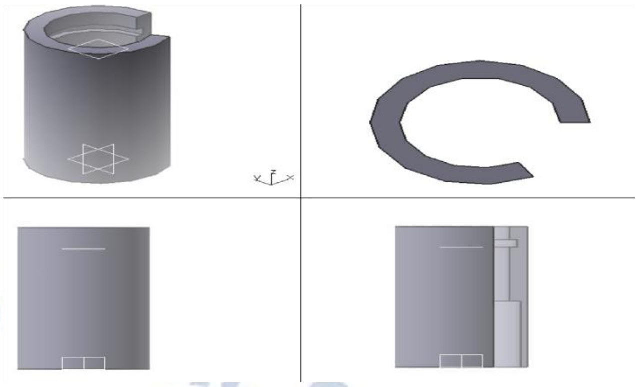

Figure7: Housing cover

This is the outer most part of the turbine which covers all the components outside.
The cut mark is given for easy viewing of parts after assembly.
Outer diameter = 17 mm, Diameter for diff. parts to be fixed is different, Total Length = 32 mm (Which is turbine length indirectly).

3.8 Generator with coupling

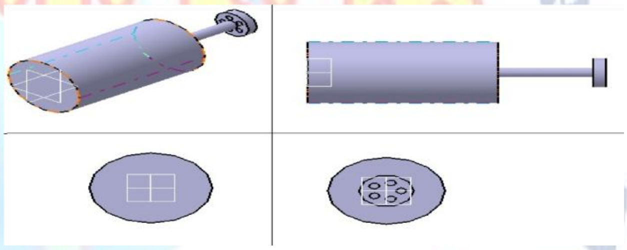

Figure8: Generator with coupling

3.9 Assembly of parts :

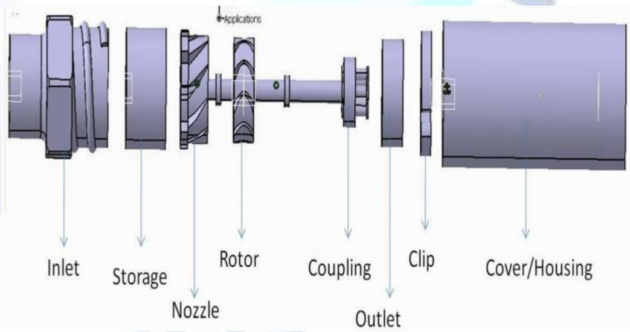

Figure 9: Assembly of micro gas turbine parts

4. 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. The coordinates needed for the purpose were obtained from the available literature.

Table, 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 θ 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^o for Z = 7.

Table-1 Data for blade design:

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

where, z = axial length r = radius phi = angle of deflection measured in clockwise direction

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.

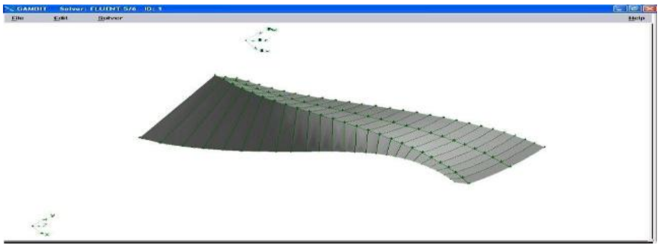

FIG10-Blade Profile

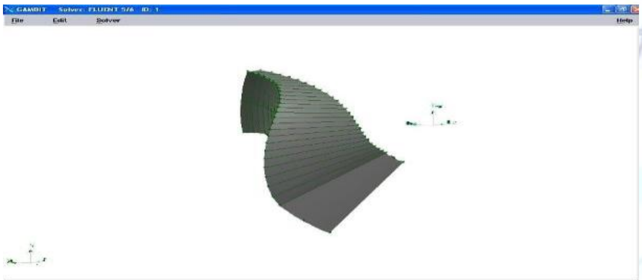

FIG11-Blade Profile (Different view)

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 2π / Z, i.e. 51.43^o for Z = 7.

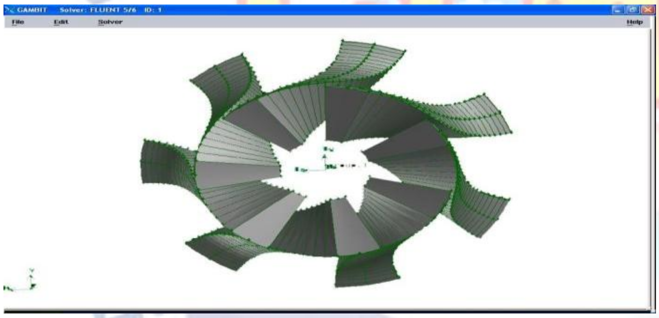

FIG12-Turbine Blade Passage

5. 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.

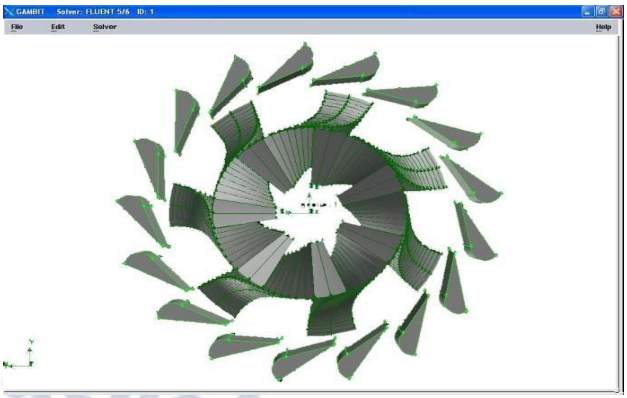

FIG14-Turbine assembly

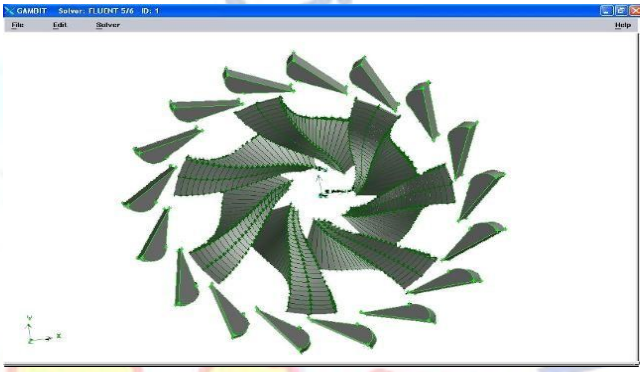

Fig.15 Turbine Assembly (Reverse view)

6.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 setup, 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/m3, Cp (specific heat capacity) = 1040.67 J/kg K, Thermal conductivity = 0.0242 W/m K, Viscosity = 1.663 x 10-5 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.

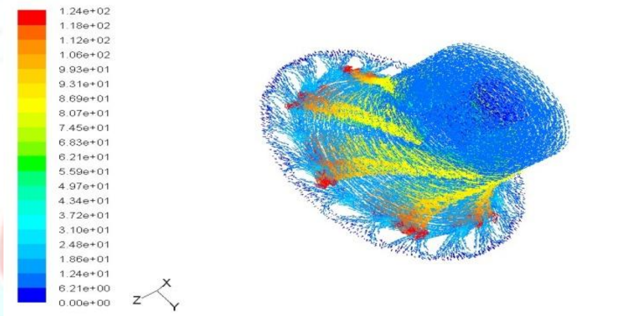

FIG16- Velocity contours for steady state with laminar flow

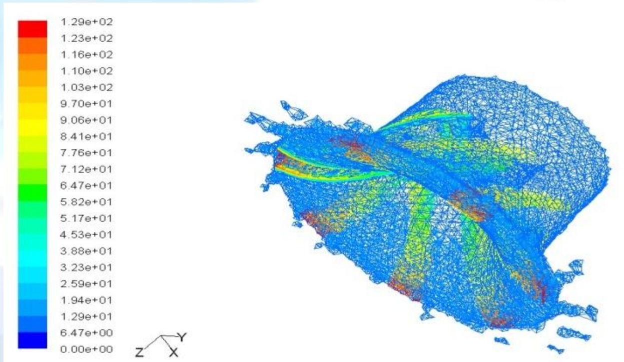

FIG17- Velocity contours for unsteady state with laminar flow

7. 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. Calculated various parameters of performance influenced the micro gas turbine. CFD analysis of a turbine with similar profile has also been reported from an available literature.

8. SCOPE FOR FUTURE WORK:

From the design experience detailed in this report, conclusions and ideas for possible future work were made. A main goal of any future project should be to increase power output of the micro-turbine. Possible methods to accomplish this include using modern airfoil shapes instead of flat flats for turbine blades and adding a fixed stator stage (pre-swirler) upstream of rotating turbine to direct inlet flow into turbine stage. Use different motors as generators might also change the power outputs. Development of composite materials having higher tensile strengths is a promising technology for the development of these components. The machining of the complicated micro components can be accomplished using MEMS technology. Since there is a significant development in MEMS technology, the production of these components using MEMS technology is quite possible. Combustion chambers can be developed to bear higher temperatures which leads to increase in power output. Engines will be developed to have lower specific fuel consumption by improving the fuel inlet nozzles. Burning fuel more cleanly with fewer emissions which will run more quietly is also possible. More air borne and ground engine-conditioning- monitoring equipment will be used such as vibration and oil analysers and radiometer sensors to measure turbine blade temperature while the engine is operating.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

REFERENCES

[1] Benini, E., & Giacometti, S. (2007). Design, Manufacturing and Operation of a Small Turbojet-engine for Research Purposes. Applied Energy, 1102-1116.

[2] Boyce, M. P. (2012). Gas Turbine Engineering Handbook (4th ed.). Amsterdam:Boston: Elsevier/Butterworth-Heinemann.

[3] Britannica, E. (2018). Afterburner. Retrieved from Enyclopedia Britannica : https://www.britannica.com/technology/afterburner-mechanical engineering Demirel, Y. (2012). Energy: Production, Conversion, Storage, Conservation, and Coupling. Lincoln, NE: Springer.

[4] El-Sayed, A. F. (2015). Aircraft Propulsion and Gas Turbine Engines . Boca Raton: CRC Press.

[5] Flack, R. (2005). Fundamentals of Jet Propulsion with Applications. Cambridge, UK: Cambridge University Press.

[6] Garret. (2017). Compressor Maps. Retrieved from Honeywell Garret: https://www.turbobygarrett.com/turbobygarrett/compressor_maps.

[7] Hill, P. G., & Peterson, C. R. (1992). Mechanics and Thermodynamics of Propulsion. Reading, MA: Addison-Wesley Pub. Co.

[8] Kamps, T. (2005). Model Jet Engines (3rd ed.). United Kingdom: Traplet Publications.

[9] Retrieved from Limit Engineering:

[10] http://www.limitengineering.com/Turbos/GT4202/GT4202.html

[11] History and working of gas turbine are studied from “Gas Turbine Theory” by Cohn H Rogers.

[12] The blade life predication of turbine is reviewed separately and it is taken from research paper published by Iran university of science and technology under ISO conditions.