DESIGN AND MODELING OF AXIAL MICRO GAS TURBINE

Mr. Rathod N.R.[1], Mr. Sayyad L.K.[2],

[1] *Student (ME II), Mechanical Engineering, Aditya Engineering College, Beed, India*
[2] *Assistant Prof., Mechanical Engineering, Aditya Engineering College, Beed, India*

ABSTRACT

Micro turbines are becoming widely used for combined power generation and heat applications. Their size varies from small scale units like models crafts to heavy supply like power supply to hundreds of households. Micro turbines have many advantages over piston generators such as low emissions less moving parts, accepts commercial fuels. Gas turbine cycle and operation of micro turbine was studied and reported. Brief description on CAD software and CATIA studied and reported. Different parts (Inlet. Storage, Nozzle, Rotor , coupling ,outlet ,clip ,housing) of turbine are designed with the help of CATIA (Computer Aided Three Dimensional Interactive Analysis) software. Then they were assembled to a single unit and coupled to a generator to produce power. The turbine is of Axial input and axial output type. Finally rapid prototyping machine features and parts were discussed and presented.

Keyword: - Gas turbine, CATIA, Rapid Prototype, parts of turbine, nozzle, rotor

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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.

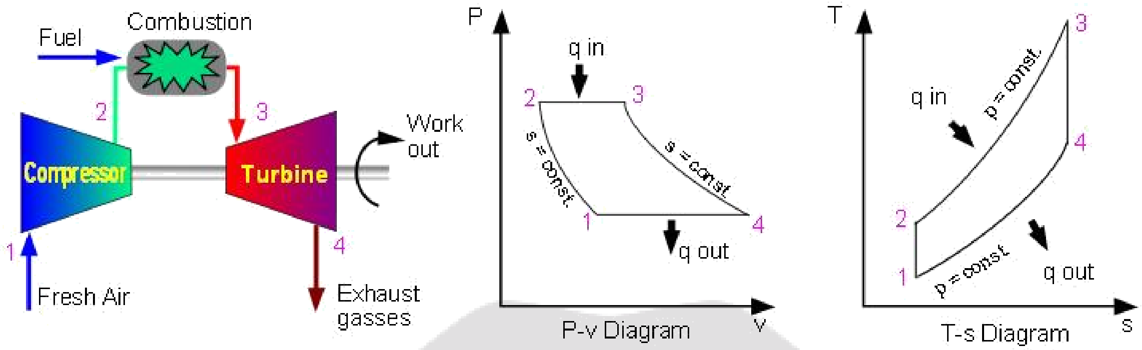
1.1 Chronology Of Gas turbine Development :

Date	Name	Invention
130BC	Hero of Alexandria	Reaction Steam Turbine
1550	Leonardo da Vinci, Italy	Smoke Mill
1629	Giovanni Branca, Italy	Impulse Steam Turbine
1791	John Barber, England	Steam Turbine and Gas Turbine
1831	William Avery, USA	Steam Turbine
1837	M. Bresson	Steam Turbine
1850	Fernimough, England	Gas Turbine
1872	Dr. Stolze, Germany	Gas Turbine
1884	Charles A. Parsons	Reaction Steam Turbine & Gas Turbine
1888	Charles G.P. de Laval	Impulse Steam Turbine Branca type
1894	Armengaud+Lemale, France	Gas Turbine
1895	George Westinghouse	Steam Turbine Rights
1896	A.C. Rateau, France	Multi Impulse Steam Turbine
1896	Charles Curtis	Velocity Compound Steam Turbine/Gas Turbine
1895	Dr. Zoelly, Switzerland	Multi Impulse Steam Turbine

Table No. 3.1

2. Gas Turbine Cycle

The simplest gas turbine follows the Brayton cycle .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.



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.

3 Micro turbine

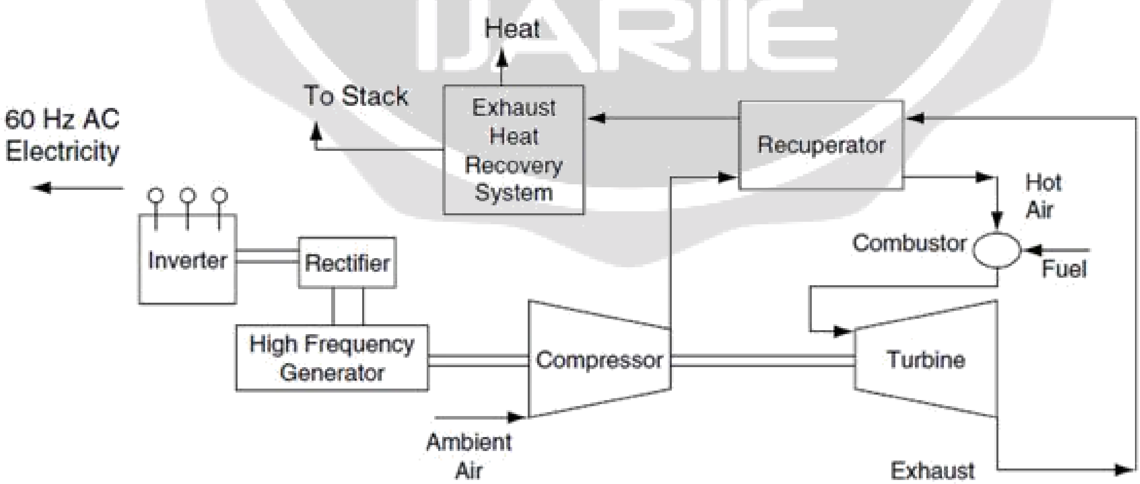
Micro turbines are small combustion turbines which are having output ranging from 20 kW to 500 kW. The Evolution is from automotive and truck turbochargers, auxiliary power units (APUs) for airplanes, and small jet engines. Micro turbines are a relatively new distributed generation technology which is used for stationary energy generation applications. Normally they are 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 combustor and a centrifugal compressor. It is used for outputting power as well as for rotating the compressor. Micro turbines are becoming widespread for distributed power and co-generation (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.

4 Thermodynamic Heat Cycle

In principle, micro turbines and larger gas turbines operate on the same thermodynamic heat cycle, the Brayton cycle. Atmospheric air is compressed, heated at constant pressure, and then expanded, with the excess power produced by 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, inlet temperatures are generally limited to 1750°F or below to enable the use of relatively inexpensive materials for the turbine wheel and recuperator. 4:1 is the optimum pressure ration for best efficiency in recuperated turbines.

4.1 Power Range for diff. Applications .

Convenience/Fast Food Store	40-50 kW
Restaurant Chain/Gas Filling Station	50-70 kW
Supermarkets (Old)	150-300 kW
Supermarkets (New)	300-2,000 kW
Hospitals	100-6,000 kW
Large Office Building	400-3,000 kW
Factories	500 kW and up



Microturbine based combined heat and power system

4.2 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.

4.3 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

No. of nozzles = 10

It has two phases 1^{st} 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. 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.

4.4 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 spring 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.

4.5 Outlet:

Main solid dia.=12.42mm

Central hole dia=26mm

4 holes of dia = 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.

5 Rapid Prototyping

Rapid prototyping (RP) refers to a class of technologies that can automatically produce solid models from Computer-Aided Design (CAD) data. It is a freeform fabrication technique in which the object of prescribed shape, size, dimension and finish can be directly constructed from the CAD based geometrical model stored in a computer, with little human intervention.

The fabrication processes in a rapid prototyping can basically be divided into three categories which are additive, subtractive and formative. In the additive or incremental processes, the object is divided into thin layers with distinct shape and then they are stacked one upon other to produce the model. The shaping method of each layer varies for different processes. Most of the commercial Rapid Prototyping systems belong to this category. Such processes can also be called layered manufacturing (LM) or solid freeform fabrication (SFF). Layer by layer construction method in LM greatly simplifies the processes and enables their automation. An important feature in LM is the raw material, which can be either one-dimensional (e.g. liquid and particles) or two-dimensional (e.g. paper sheet) stocks. Whereas in case of subtractive RP processes three-dimensional raw material stocks are used. Stereo-lithography apparatus (SLA), three dimensional printing, selective laser sintering (SLS), contour crafting (CC), fused deposition modelling (FDM), etc. are few examples of LM. Subtractive or material removal (MR) processes uses the method of cutting of excessive material from the raw material stocks. There are not as many subtractive prototyping processes as that of additive processes. A commercially available system is DeskProto, which is a three-dimensional computer aided manufacture (CAM) software package for Rapid Prototyping and manufacturing. As in case of pure subtractive RP processes the model is made from a single stock, fully compact parts of the same material as per actually required for end use is possible. The other advantages like accuracy of the part dimensions and better surface quality can be achieved by the subtractive machining approach. However if we compare geometric complexity the MR processes are limited than the LM processes. Different types of cutting methods used are computer numerical control (CNC) milling, water-jet cutting, laser cutting etc. In formative or deforming processes, a part is shaped by the deforming ability of materials. At present there is no commercial forming-based RP system in the market. In case of LM process the geometric complexity of objects is relaxed upto a significant extent due to the layer by layer manufacturing. Some features which are difficult to obtain using MR process can be achieved using LM process. Raw material is one of the limitations in case of LM process. Both the LM and MR processes can be integrated to obtain more benefits. This integration creates a hybrid RP system which can produce better surface quality without tempering the manufacturability in case of complex features.

5.1 Working Principle behind Rapid prototyping:

Although several rapid prototyping techniques exist, all employ the same basic five-step process. The steps are:

1. Creation of the CAD model of the design
2. Conversion of the CAD model to STL format
3. Slicing the STL file into thin cross-sectional layers
4. Layer by layer construction
5. Cleaning and finishing the model

5.1.1 Creation of CAD Model:

First, the object to be built is modelled using a Computer-Aided Design (CAD) software. Solid modellers, such as Pro-E, CATIA and Autodesk Inventor tend to represent 3-D objects more accurately than wire-frame modellers such as AutoCAD, and will therefore yield better results. A pre-existing CAD file or a newly created CAD file for prototyping purpose can also be used. This process is identical for all of the RP build techniques.

5.1.2 Conversion of CAD model to STL Format:

Different CAD software save the modelled files in different formats. To establish consistency, a standard format has been adopted which is known as STL (stereolithography, the first RP technique) format for rapid prototyping industry. The second step, therefore, is to convert the CAD file into STL format. This format represents a three-dimensional surface as an assembly of planar triangles. Increasing the number of triangles improves the approximation and result, but the file size gets bigger. As the large and complicated files take more time for construction the designer should consider for both accuracy and manageability while creating the STL file. Since the STL format is universal, this process is identical for all of the RP build techniques.

5.1.3Slicing of the STL File into layers:

In the third step, a pre-processing program is used to prepare the STL file for construction. For this purpose several programs are available and the size, location and orientation of the model can also be adjusted by the user. Build orientation is important for several reasons. As the layers are formed in x-y plane, the properties of the prototyped model are weaker and less accurate along z-direction. So part orientation is used to make the orientation of the model such that the minimum dimension lies along z-direction which not only improves the quality and accuracy, also reduces the time due to decrease in number of layers. The STL model is sliced into a number of layers from 0.01 mm to 0.7 mm thick using the pre-processor software and it also depends on the building technique. pre-processor software is supplied by the manufacture of the rapid prototyping machine.

5.1.4 Layer by Layer Construction:

In the fourth step the actual construction of the part is done. Layers can be produced by different methods. Therefore several types of techniques are available for the production of layers. One of these techniques can be used to produce the part.

5.1.5 Cleaning and Finishing:

The final step is post-processing. In this step the prototyped model is taken out of the machine and supports are detached. Prototypes may also require minor cleaning and surface treatment. Sanding, sealing, and/or painting the model will improve its appearance and durability.

6 Rapid Prototyping Techniques

Most commercially available rapid prototyping machines use one of six techniques.

6.1 Stereo lithography

This technique works on the principle that when liquid photosensitive polymers are exposed to ultraviolet light they get solidified. In this process the platform is situated in liquid epoxy or acrylate resin. When the UV light falls on the liquid layer, the part that is to be constructed gets solidified and remaining part stays liquid. An elevator is used to lower the platform to form successive layers. In this way the process is repeated to finally get the final model. After that the model is taken out and excess liquid is removed and then placed in a UV oven for complete curing.

6.2 Laminated Object Manufacturing

This technique was developed by Helisys of Torrance, CA. in this method layers of adhesive-coated sheet material are bonded together to make the prototype. Here a feeder mechanism is used to prepare the sheet over the build platform. A heated roller is used to apply pressure for bonding of paper to the base. Laser cutting is used to cut the outline of the layers. After each layer is prepared and cut, the platform lowers and fresh material is used for another layer. As the model is prepared from paper, after completion of the prototyping the model must be sealed and finished with paint to prevent it from moisture damage.

6.3 Selective Laser Sintering

This technique has been developed by Carl Deckard and was patented in 1989. A laser beam is used to fuse powdered materials such as elastomer, nylon into a solid object. Here the platform is situated just below the surface in bin containing heat-fusable powder. After fusing of the first layer by the laser beam, the platform is lowered by the height of a layer and powder is applied again. This process is repeated until the completion of the model. Excess powder helps in supporting the model during the process.

6.4 Fused Deposition Modelling

In this method some thermoplastic material is heated and extruded from a tip. The tip moves in x-y plane and very thin beads are deposited on the platform to build the first layer. Low temperature is maintained at the platform so that the thermoplastic will get hard quickly. Then the platform is lowered and the second layer is formed over the first one. In this way the model is prototyped.

6.5 Solid Ground Curing

In this method ultraviolet light is used to harden photosensitive polymers. It is a bit similar to stereo-lithography method but here the curing of the entire layer is done at a time. A photomask is developed according to the layer and placed above a glass plate, which is over the platform containing photosensitive resin. The mask is then exposed to UV light, which only passes through the transparent portion and hardens the required shape of the layer. After completion of each layer vacuum is used to remove excess liquid resin and wax is applied for support. This process is repeated till model is complete.

6.3 D Ink-Jet Printing

Ink-jet printers employ ink-jet technology. Z corporation uses this technology in its 3-D printers. Here a printing head deposits a binder over the powder material to fuse them together in the required areas according to the model. Unbounded powder is used as support. After completion of one layer the platform is lowered and excess powder is blown off. Then the next layer is printed and this process is repeated till the model is complete. This process is very fast and the parts produced have a bit grainy surface.

7. CONCLUSIONS

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 different parts of micro turbine. CATIA is used extensively for making parts with diff types of operations. Then all the parts are assembled for making a complete turbine in CATIA Assembly section. Then they are send for rapid prototyping .

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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