"DESIGN AND MODELING OF AXIAL MICRO GAS TURBINE"

A REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING
BY

SITAKANT PATRA

Roll No. - 10603030

Under the guidance of
***Prof.* K. P. MAITY**

DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
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CERTIFICATE

This is to certify that the Project report entitled "**DESIGN AND MODELING OF AXIAL MICRO GAS TURBINE**" submitted by **Sri Sitakant Patra** in partial fulfilment of the requirements for the award of Bachelor of technology Degree in Mechanical Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him 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:
PLACE: ROURKELA

Prof. K.P. MAITY
Mechanical Engineering Department
National Institute of Technology
Rourkela-769008

ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude and respect to my supervisor **Prof. K.P. Maity** for his excellent guidance, suggestions and support. I consider myself extremely lucky to be able to work under the guidance of such a dynamic personality also the comments given in the Viva-voice is really valuable.

I am also thankful to **Prof. R. K. SAHOO**, H.O.D, Department of Mechanical Engineering, N.I.T Rourkela for his constant support and encouragement.

I would like to render heartiest thanks to my friend who's ever helping nature and suggestion has helped us to complete this present work.

DATE:
PLACE: ROURKELA

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Roll No. - 10603030
8th Semester, B. Tech.
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National Institute of Technology
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CONTENTS

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.

Key words: Gas turbine, CATIA, Rapid Prototype, parts of turbine, nozzle, rotor

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Chapter 1

LITERATURE REVIEW

1.1 Development of Micro turbine:

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 power produced.

In 1898 The British engineer Edgar C Thrupp patented a simple liquefying system using an expansion turbine. Thrupp's expander was a double flow machine entering the center and dividing into two oppositely flowing streams.

A refrigerative expansion turbine with a tangential inward flow pattern was patented by the Americans Charles F and Orrin J Crommett in 1914. Gas was to be admitted to the turbine wheel by a pair of nozzles, but it was specified that any desired numbers of nozzle could be used. The turbine blades were curved to present slightly concave faces to the jet from the nozzle. These blades were comparatively short, not exceeding very close to the rotor hub.

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.

First successful commercial turbine developed in Germany which usea 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 Fairchild 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, which ran on a practical gas bearing system capable of operating at cryogenic temperature with low loss.

Design of turboexpander for cryogenic applications‖ by Subrata Kr. Ghosh , N. Seshaiah, R. K. Sahoo, S. K. Sarangi focuses on design and development of turbo expander.The paper briefly discuses 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.

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.

India has been lagging behind the rest of the world in this field of research and development. Still, significant progress has been made during the past two decades. In CMERI Durgapur, Jadeja developed an inward flow radial turbine supported on gas bearings for cryogenic plants. The device gave stable rotation at about 40,000 rpm. The programme was, however, discontinued before any significant progress could be achieved. 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. Recently Cryogenic Technology Division, BARC developed Helium refrigerator capable of producing 1 kW at 20K temperature.

1.2 Solid Modeling using CAD software

CAD software, also referred to as Computer Aided Design software and in the past as computer aided drafting software, refers to software programs that assist engineers and designers in a wide variety of industries to design and manufacture physical products.

It started with the mathematician Euclid of Alexandria, who, in his 350 B.C. treatise on mathematics "***The Elements***" expounded many of the postulates and axioms that are the foundations of the Euclidian geometry upon which today's CAD software systems are built.

More than 2,300 years after Euclid, the first true CAD software, a very innovative system (although of course primitive compared to today's CAD software) called "Sketchpad" was developed by Ivan Sutherland as part of his PhD thesis at MIT in the early 1960s.

First-generation CAD software systems were typically 2D drafting applications developed by a manufacturer's internal IT group (often collaborating with university researchers) and primarily intended to automate repetitive drafting chores. Dr. Hanratty co-designed one such CAD system, named DAC (Design Automated by Computer) at General Motors Research Laboratories in the mid 1960s.

In 1965, Charles Lang's team including Donald Welbourn and A.R.Forrest, at Cambridge University's Computing Laboratory began serious research into 3D modeling CAD software. The commercial benefits of Cambridge University's 3D CAD software research did not begin to appear until the 1970 however, elsewhere in mid 1960s Europe, French researchers were doing pioneering work into complex 3D curve and surface geometry computation. Citroen's de Casteljau made fundamental strides in computing complex 3D curve geometry and Bezier (at Renault) published his breakthrough research, incorporating some of de Casteljau's algorithms, in the late 1960s. The work of both de Casteljau and Bezier continues to be one of the foundations of 3D CAD software to the present time. Both MIT (S.A.Coons in 1967) and Cambridge University (A.R.Forrest, one of Charles Lang's team, in 1968) were also very active in furthering research into the implementation of complex 3D curve and surface modeling in CAD software.

CAD software started its migration out of research and into commercial use in the 1970s. Just as in the late 1960s most CAD software continued to be developed by internal groups at large automotive and aerospace manufacturers, often working in conjunction with university research groups. Throughout the decade automotive manufacturers such as: Ford (PDGS), General Motors (CADANCE), Mercedes-Benz (SYRCO), Nissan (CAD-I released in 1977) and Toyota (TINCA released in 1973 by Hiromi Araki's team, CADETT in 1979 also by Hiromi Araki) and aerospace manufacturers such as: Lockheed (CADAM), McDonnell-Douglas (CADD) and Northrop (NCAD, which is still in limited use today), all had large internal CAD software development groups working on proprietary programs.

In 1975 the French aerospace company, Avions Marcel Dassault, purchased a source-code license of CADAM from Lockheed and in 1977 began developing a 3D CAD software program named CATIA (Computer Aided Three Dimensional Interactive Application) which survives to this day as the most commercially successful CAD software program in current use.

After that many research work has been done in the field of 3-D modeling using CAD software and many software have been developed. Time to time these software have been modified to make them more user friendly. Different 3-D modeling software used now-a-days are AUTODESK INVENTOR, CATIA, PRO-E etc.

1.3 History of rapid prototyping

Rapid prototyping is a revolutionary and powerful technology with wide range of applications. The process of prototyping involves quick building up of a prototype or working model for the purpose of testing the various design features, ideas, concepts, functionality, output and performance. The user is able to give immediate feedback regarding the prototype and its performance. Rapid prototyping is essential part of the process of system designing and it is believed to be quite beneficial as far as reduction of project cost and risk are concerned.

The first rapid prototyping techniques became accessible in the later eighties and they were used for production of prototype and model parts. The history of rapid prototyping can be traced to the late sixties, when an engineering professor, Herbert Voelcker, questioned himself about the possibilities of doing interesting things with the computer controlled and automatic machine tools. These machine tools had just started to appear on the factory floors then. Voelcker was trying to find a way in which the automated machine tools could be programmed by using the output of a design program of a computer.

In seventies Voelcker developed the basic tools of mathematics that clearly described the three dimensional aspects and resulted in the earliest theories of algorithmic and mathematical theories for solid modelling. These theories form the basis of modern computer programs that are used for designing almost all things mechanical, ranging from the smallest toy car to the tallest skyscraper. Volecker's theories changed the designing methods in the seventies, but, the old methods for designing were still very much in use. The old method involved either a machinist or machine tool controlled by a computer. The metal hunk was cut away and the needed part remained as per requirements.

However, in 1987, Carl Deckard, a researcher form the University of Texas, came up with a good revolutionary idea. He pioneered the layer based manufacturing, wherein he thought of building up the model layer by layer. He printed 3D models by utilizing laser light for fusing metal powder in solid prototypes, single layer at a time. Deckard developed this idea into a technique called Selective Laser Sintering. The results of this technique were extremely promising. The history of rapid prototyping is quite new and recent. However, as this technique of rapid prototyping has such wide ranging scope and applications with amazing results, it has grown by leaps and bounds.

Voelcker's and Deckard's stunning findings, innovations and researches have given extreme impetus to this significant new industry known as rapid prototyping or free form fabrication. It has revolutionized the designing and manufacturing processes. Though, there are many references of people pioneering the rapid prototyping technology, the industry gives recognition to Charles Hull for the patent of Apparatus for Production of 3D Objects by Stereo lithography. Charles Hull is recognized by the industry as the father of rapid prototyping. Today, the computer engineer has to simply sketch the ideas on the computer screen with the help of a design program that is computer aided. Computer aided designing allows to make modification as required and you can create a physical prototype that is a precise and proper 3D object.

Chapter 2

CAD/CAM/CAE AND CATIA (Computer Aided Three Dimensional Interactive Analysis)

2.1 Introduction To CAD/CAM/CAE

The Modern world of design, development, manufacturing so on, in which we have stepped can't be imagined without interference of computer. The usage of computer is such that, they have become an integral part of these fields. In the world market now the competition in not only cost factor but also quality, consistency, availability, packing, stocking, delivery etc. So are the requirements forcing industries to adopt modern technique rather than local forcing the industries to adapt better techniques like CAD / CAM / CAE, etc.

The Possible basic way to industries is to have high quality products at low costs is by using the computer Aided Engineering (CAE), Computer Aided Design (CAD) And Computer Aided Manufacturing (CAM) set up. Further many tools is been introduced to simplify & serve the requirement CATIA, PRO-E, UG are some among many.

This penetration of technique concern has helped the manufacturers to

a) Increase productivity
b) Shortening the lead-time
c) Minimizing the prototyping expenses
d) Improving Quality
e) Designing better products

CAD: Computer Aided Designing (Technology to create, Modify, Analyze or Optimize the design using computer.

CAE: Computer Aided Engineering (Technology to analyze, Simulate or Study behaviour of the cad model generated using computer.

CAM: Computer Aided Manufacturing (Technology to Plan, manage or control the operation in manufacturing using computer.

2.2 Need for CAD, CAE & CAM :

The usage of CAD CAE & CAM have changed the over look of the industries and developed healthy & standard competition , as could achieve target in lean time and ultimately the product reaches market in estimated time with better quality and consistency . In general view, it has lead to fast approach and creative thinking.

ADVANTAGES:

- Cut off of the designing time
- Cut off of the editing time
- Cut off of the manufacturing time
- High & controlled quality
- Reduction of process cost.
- Consistency
- Maintenance of Universal accessing data

DRAWBACKS:

- Requires skilled operators
- Initial setting & assumption consumes time
- Setting cost is more
- Over heads are high and
- Applicable if production is high

2.3 Introduction to CATIA

CATIA is a robust application that enables you to create rich and complex designs. The goals of the CATIA course are to teach you how to build parts and assemblies in CATIA, and how to make simple drawings of those parts and assemblies. This course focuses on the fundamental skills and concepts that enable you to create a solid foundation for your designs

What is CATIA .

CATIA is mechanical design software. It is a *feature-based, parametric solid modeling* design tool that takes advantage of the easy-to-learn Windows graphical user interface. You can create *fully associative* 3-D solid models with or without *constraints* while utilizing automatic or user-defined relations to capture *design intent*. To further clarify this definition, the *italic* terms above will be further defined:

Feature-based

Like an assembly is made up of a number of individual parts, a CATIA document is made up of individual elements. These elements are called features.

When creating a document, you can add features such as pads, pockets, holes, ribs, fillets, chamfers, and drafts. As the features are created, they are applied directly to the work piece.

Features can be classified as sketched-based or dress-up:

- Sketched-based features are based on a 2D sketch. Generally, the sketch is transformed into a 3D solid by extruding, rotating, sweeping, or lofting.
- Dress-up features are features that are created directly on the solid model. Fillets and chamfers are examples of this type of feature.

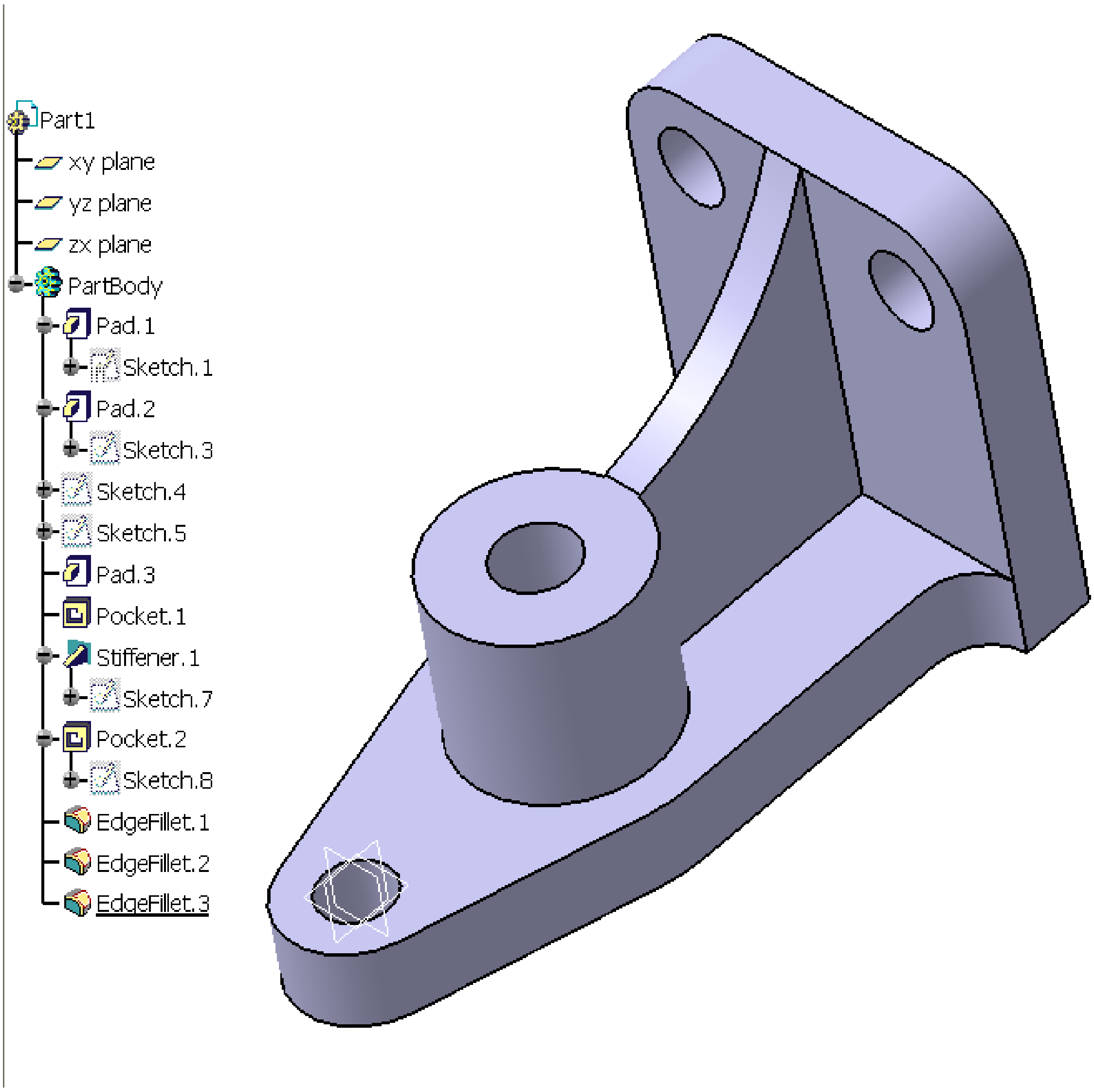


Figure No. 2.1

Parametric

The dimensions and relations used to create a feature are stored in the model. This enables you to capture design intent, and to easily make changes to the model through these parameters.

- Driving dimensions are the dimensions used when creating a feature. They include the dimensions associated with the sketch geometry, as well as those associated with the feature itself. Consider, for example, a cylindrical pad. The diameter of the pad is controlled by the diameter of the sketched circle, and the height of the pad is controlled by the depth to which the circle is extruded.

- Relations include information such as parallelism, tangency, and concentricity. This type of information is typically communicated on drawings using feature control symbols. By capturing this information in the sketch, CATIA enables you to fully capture your design intent up front.

Solid Modeling:-

A solid model is the most complete type of geometric model used in CAD systems. It contains all the wireframe and surface geometry necessary to fully describe the edges and faces of the model. In addition to geometric information, solid models also convey their "topology", which relates the geometry together. For example, topology might include identifying which faces (surfaces) meet at which edges (curves). This intelligence makes adding features easier. For example, if a model requires a fillet, you simply select an edge and specify a radius to create it.

Fully Associative:-

A CATIA model is fully associative with the drawings and parts or assemblies that reference it. Changes to the model are automatically reflected in the associated drawings, parts, and/or assemblies. Likewise, changes in the context of the drawing or assembly are reflected back in the model.

Constraints:-

Geometric constraints (such as parallel, perpendicular, horizontal, vertical, concentric, and coincident) establish relationships between features in your model by fixing their positions with respect to one another. In addition, equations can be used to establish mathematical relationships between parameters. By using constraints and equations, you can guarantee that design concepts such as through holes and equal radii are captured and maintained.

2.4 CATIA User Interface :

Below is the layout of the elements of the standard CATIA application.

A. Menu Commands

B. Specification Tree

C. Window of Active document

D. Filename and extension of current document

E. Icons to maximize/minimize and close window

F. Icon of the active workbench

G. Toolbars specific to the active workbench

H. Standard toolbar

I. Compass

J. Geometry area

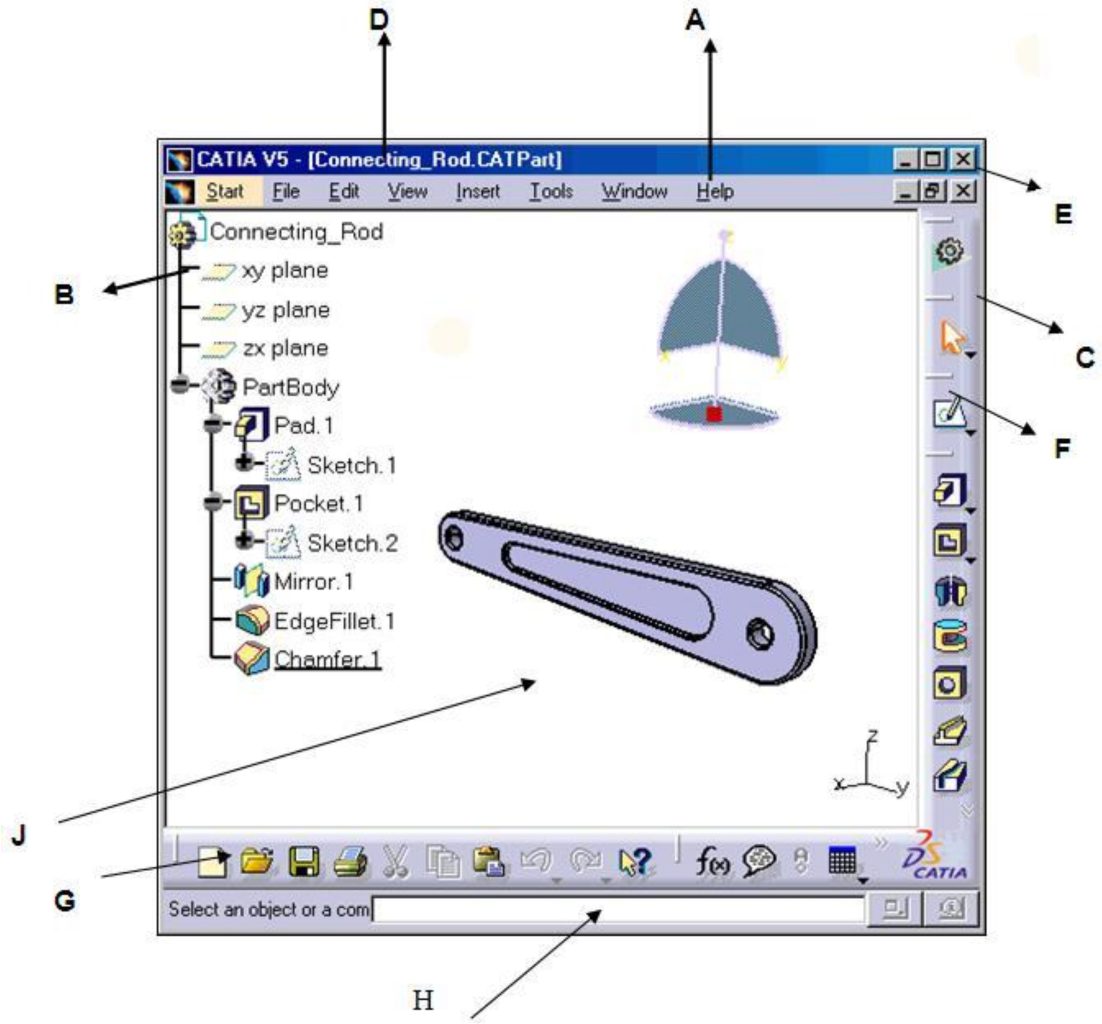


Figure No. 2.2

C

Different types of engineering drawings, construction of solid models, assemblies of solid parts can be done using inventor.

Different types of files used are:

1. Part files: .CATPart
2. Assembly files: .CATProduct

Workbenches

Workbenches contain various tools that you may need to access during your part creation. You can switch between any primary workbenches using the following two ways:

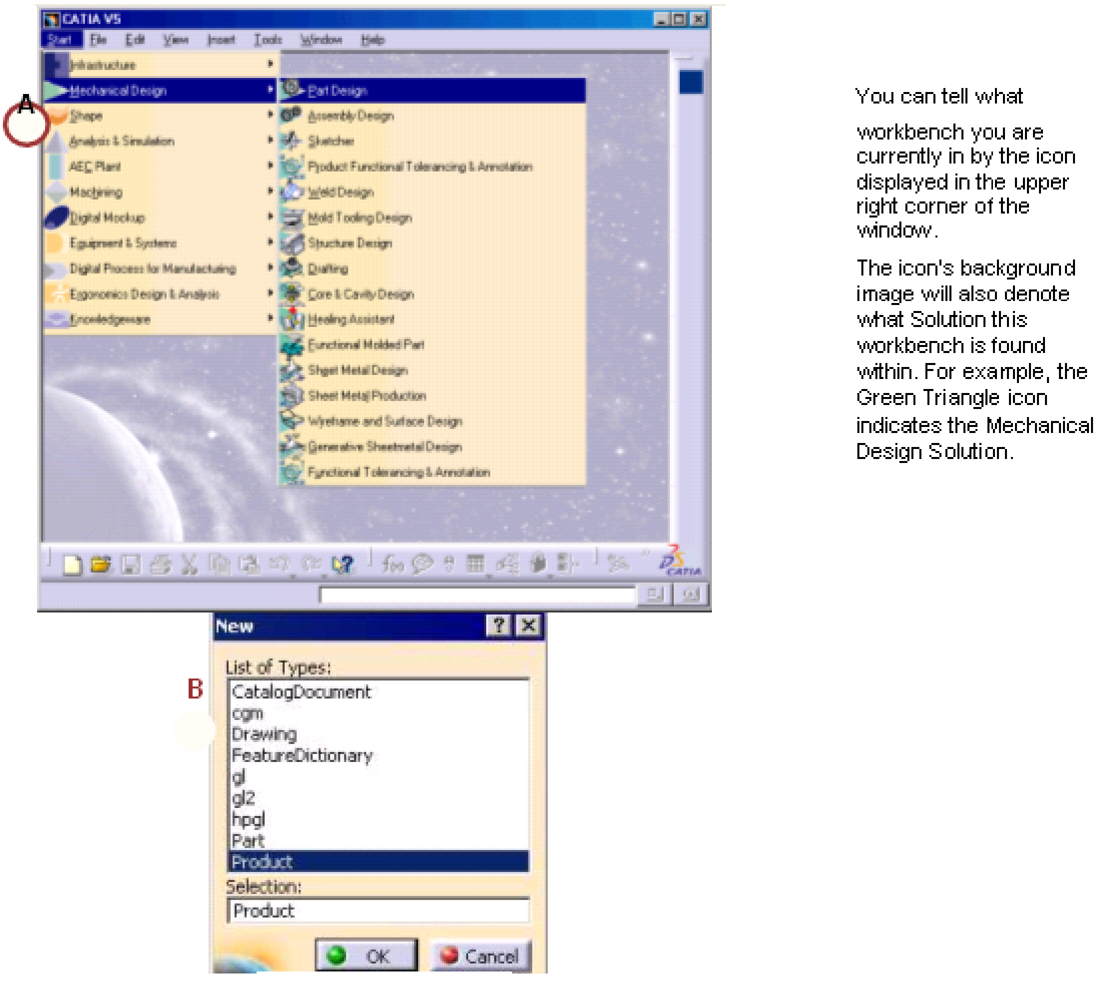


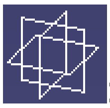
Figure No. 2.3

A. Use the Start Menu.

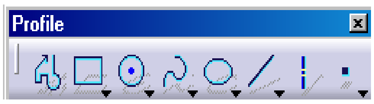
B. Click File >New to create a new document with a particular file type. The associated workbench automatically launches.

The parts of the major assembly is treated as individual geometric model , which is modeled individually in separate file .All the parts are previously planned & generated feature by feature to construct full model

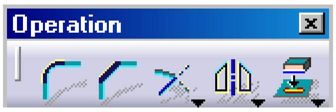
Generally all CAD models are generated in the same passion given bellow :

-  : Enter CAD environment by clicking, later into part designing mode to construct model.
- : Select plane as basic reference.
-  : Enter sketcher mode.

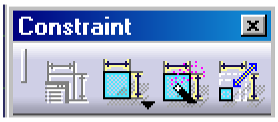
In sketcher mode:



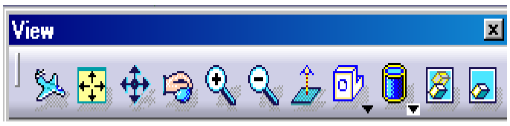
: Tool used to create 2-d basic structure of part using line, circle etc



: Tool used for editing of created geometry termed as operation



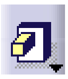
: Tool used for Dimensioning, referencing. This helps creating parametric relation.

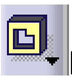


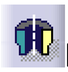
: Its external feature to view geometry in & out

 : Tool used to exit sketcher mode after creating geometry.

- **Sketch Based Feature** :

 **Pad** : On exit of sketcher mode the feature is to be padded .(adding material)

**Pocket**: On creation of basic structure further pocket has to be created (removing material)

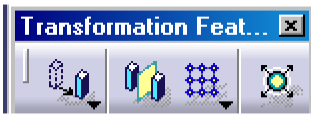
**Revolve**: Around axis the material is revolved, the structure should has same profile around axis.

 **Rib:** sweeping uniform profile along trajectory (adding material)

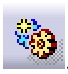
**Slot:** sweeping uniform profile along trajectory (removing material)

 **Loft:** Sweeping non-uniform/uniform profile on different plane along linear/non-linear trajectory

: Its 3d creation of features creates chamfer, radius, draft, shell, th …

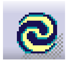


: Its tool used to move geometry, mirror, pattern, scaling in 3d environment On creation of individual parts in separate files,

- **Assembly environment**: In assembly environment the parts are recalled & constrained..

Product structure tool: To recall existing components already modeled.

: Assembling respective parts by mean of constraints

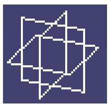
 **Update**: updating the made constrains.

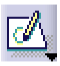
- Additional features are: Exploded View, snap shots, clash analyzing numbering, bill of material. etc
- Finally creating draft for individual parts & assembly with possible details

The parts of the major assembly is treated as individual geometric model , which is modeled individually in separate file .All the parts are previously planned & generated feature by feature to construct full model

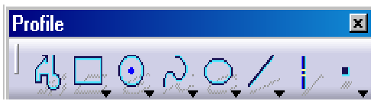
Generally all CAD models are generated in the same passion given bellow :

 : Enter CAD environment by clicking, later into part designing mode to construct model.

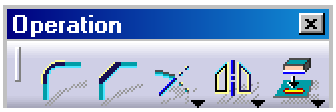
 : Select plane as basic reference.

 : Enter sketcher mode.

In sketcher mode:



: Tool used to create 2-d basic structure of part using line, circle etc



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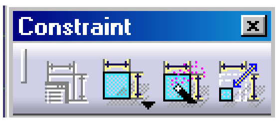

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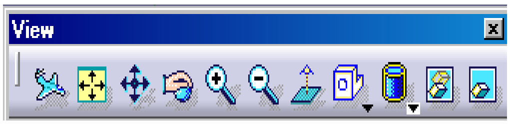
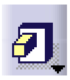
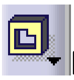


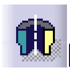
: Its external feature to view geometry in & out


: Tool used to exit sketcher mode after creating geometry.

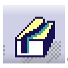
Sketch Based Feature :


Pad: On exit of sketcher mode the feature is to be padded. (Adding material)


Pocket: On creation of basic structure further pocket has to be created (removing material)

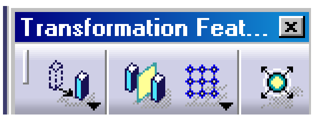

Revolve: Around axis the material is revolved, the structure should have same profile around axis.


Rib: sweeping uniform profile along trajectory (adding material)


Slot: sweeping uniform profile along trajectory (removing material)


Loft: Sweeping non-uniform/uniform profile on different plane along linear/non-linear trajectory

: Its 3d creation of features creates chamfer, radius, draft, shell, thread…



: Its tool used to move geometry, mirror, pattern, scaling in 3d environment

Chapter 3

GAS TURBINE

3.1 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.

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

1900	F. Stolze, Germany	Axial Compressor & Turbine Gas Turbine
1901	Charles Lemale	Gas Turbine
1902	Stanford A. Moss, USA	Turbo-Charger/Gas Turbine
1903	A. Elling	Gas Turbine
1903	Armengaud+Lemale	Gas Turbine
1905	Brown Boveri	Gas Turbine
1908	Karavodine	Gas Turbine with deLaval Steam Turbine
1908	Holzwarth	Gas Turbine with Curtis + Rateau Compressor
1930	Frank Whittle, England	Aero Gas Turbine (Jet Engine)
1938	Brown Boveri—Neuchatel, Switzerland	1st Commercial Axial Compressor & Turbine

Table No. 3.1

3.2 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.

3.3 Applications Of Gas turbine :

1. Jet Engines
2. Mechanical Drives
3. Power automobiles, Trains,tanks
4. In Vehicles(Concept car, racing car, buses, motorcycles)

3.4 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.

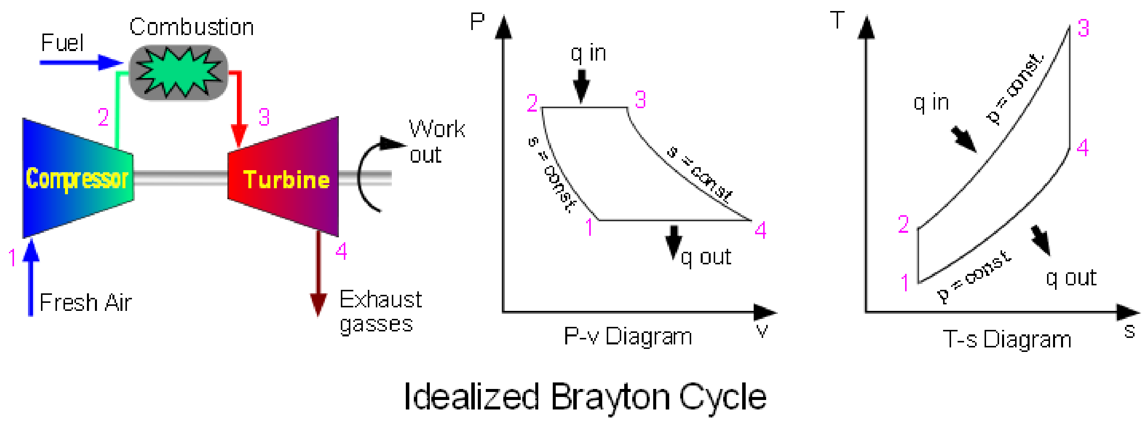


Figure 3.1

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.

3.5 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 4

MICRO TURBINE

4.1 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.

Type$^{\alpha}$	*Power Range*
Heavy Industrial & Aero-derivative	1000 kW and up
Mini-Turbine	500 kW – 1000 kW
Microturbine	20 kW – 500 kW

Table No. 4.1

4.2 Types of Micro turbine

Micro turbines are classified by the physical arrangement of the component parts: 1. Single shaft or two-shaft, 2. Simple cycle, or recuperated, 3. Inter-cooled, and reheat. The machines generally rotate over 50,000 rpm. 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.

4.3 Basic Parts of Micro turbine

1. Compressor
2. Turbine
3. Recuperator
4. Combustor
5. Controller
6. Generator
7. Bearing

4.4 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.

4.5 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.

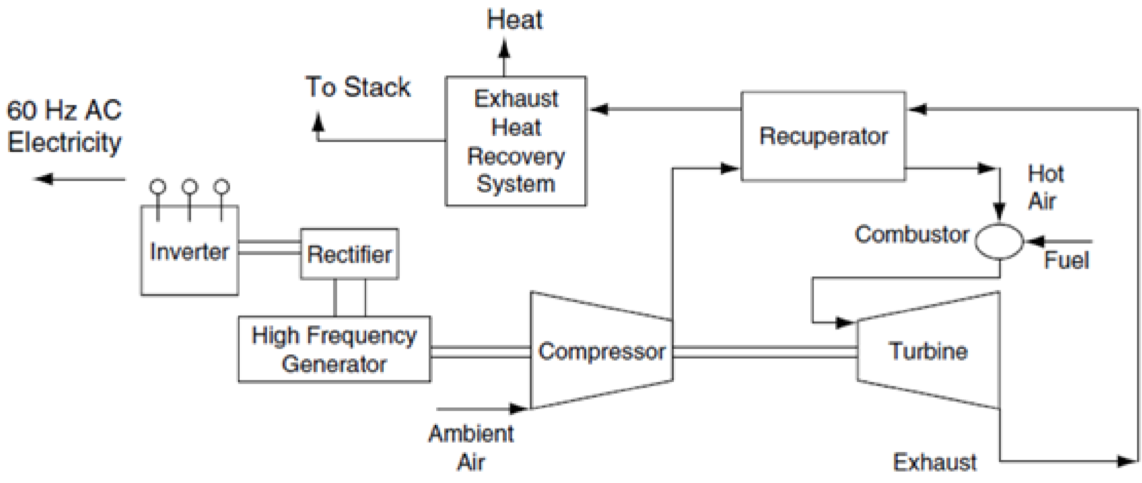
4.6 Applications

Micro turbines are used in distributed power and combined heat and power applications. With recent advances in electronic, micro- processor based, control systems these units can interface with the commercial power grid and can operate “unattended.”

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

Table No. 4.2



Microturbine based combined heat and power system

Figure 4.1

Chapter 5

DESIGN OF DIFFERENT PARTS MICRO TURBINE

5.1 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.

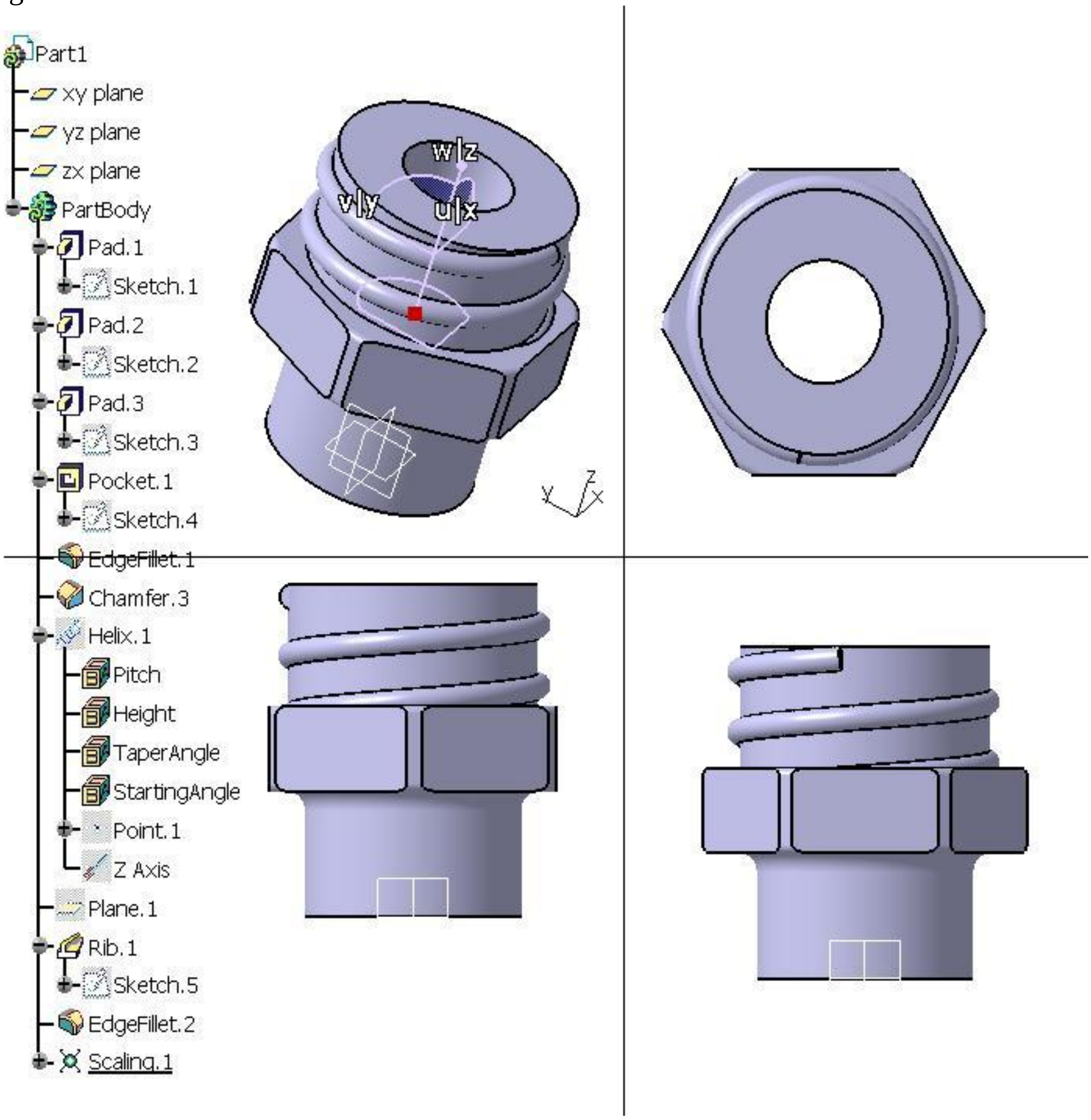


Figure 5.1

5.2 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

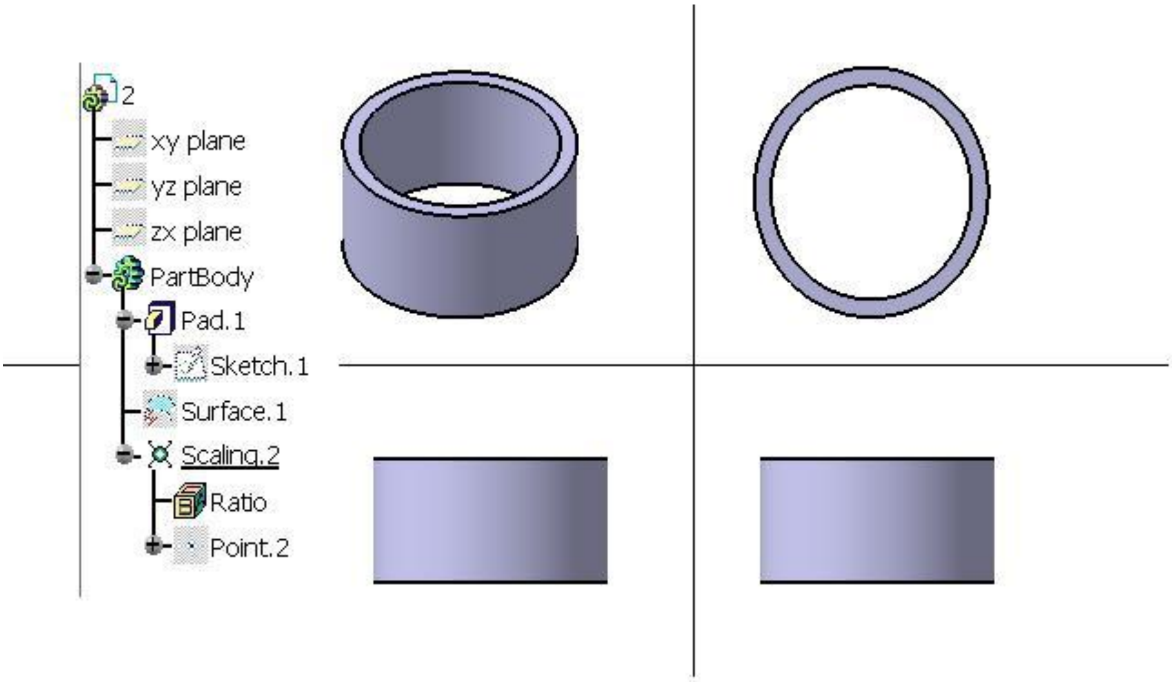


Figure 5.2

5.3 Nozzle:

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.

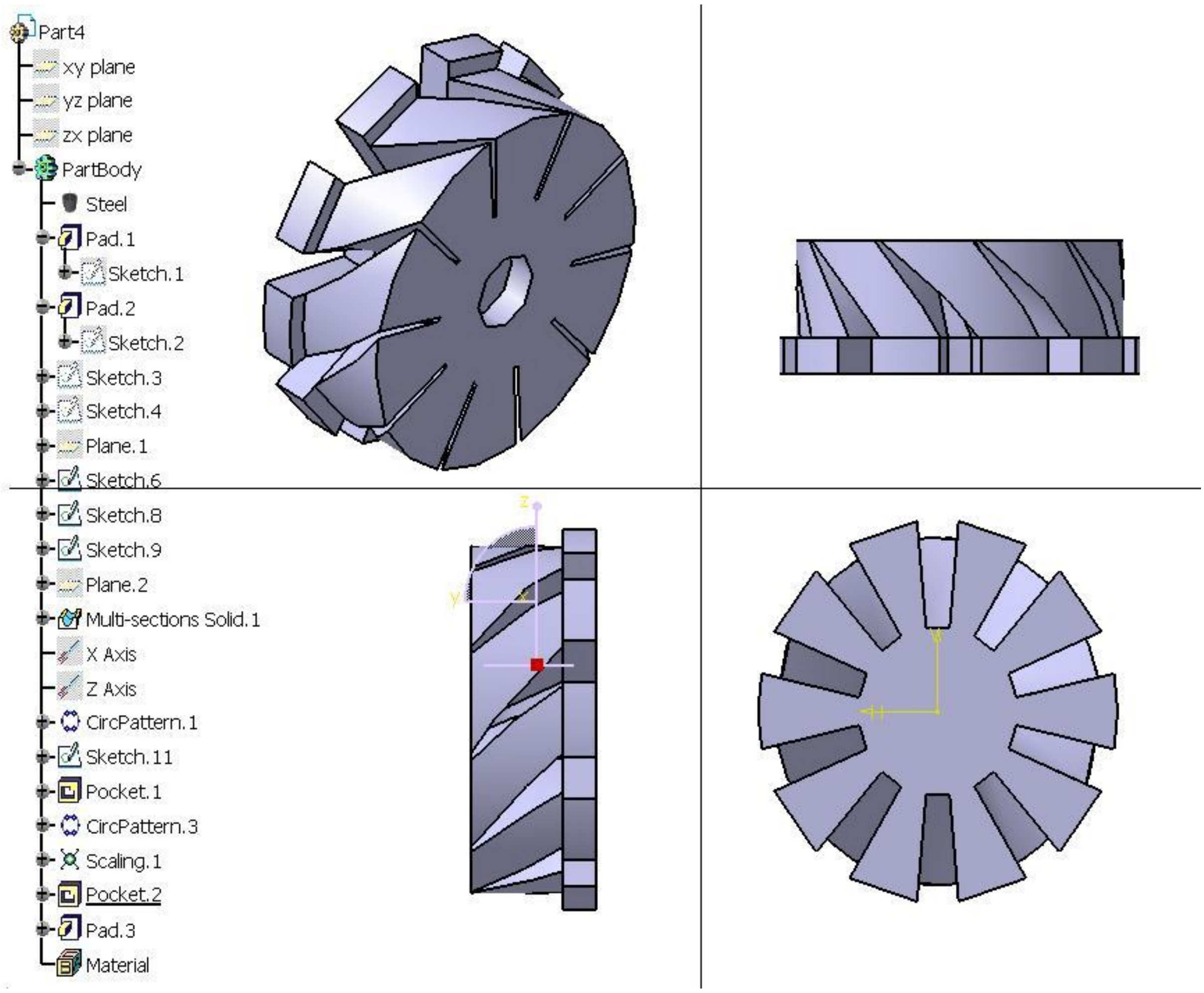


Figure 5.3

5.4 Rotor:

Diameter = 12 mm.
Length = 3.474 mm.

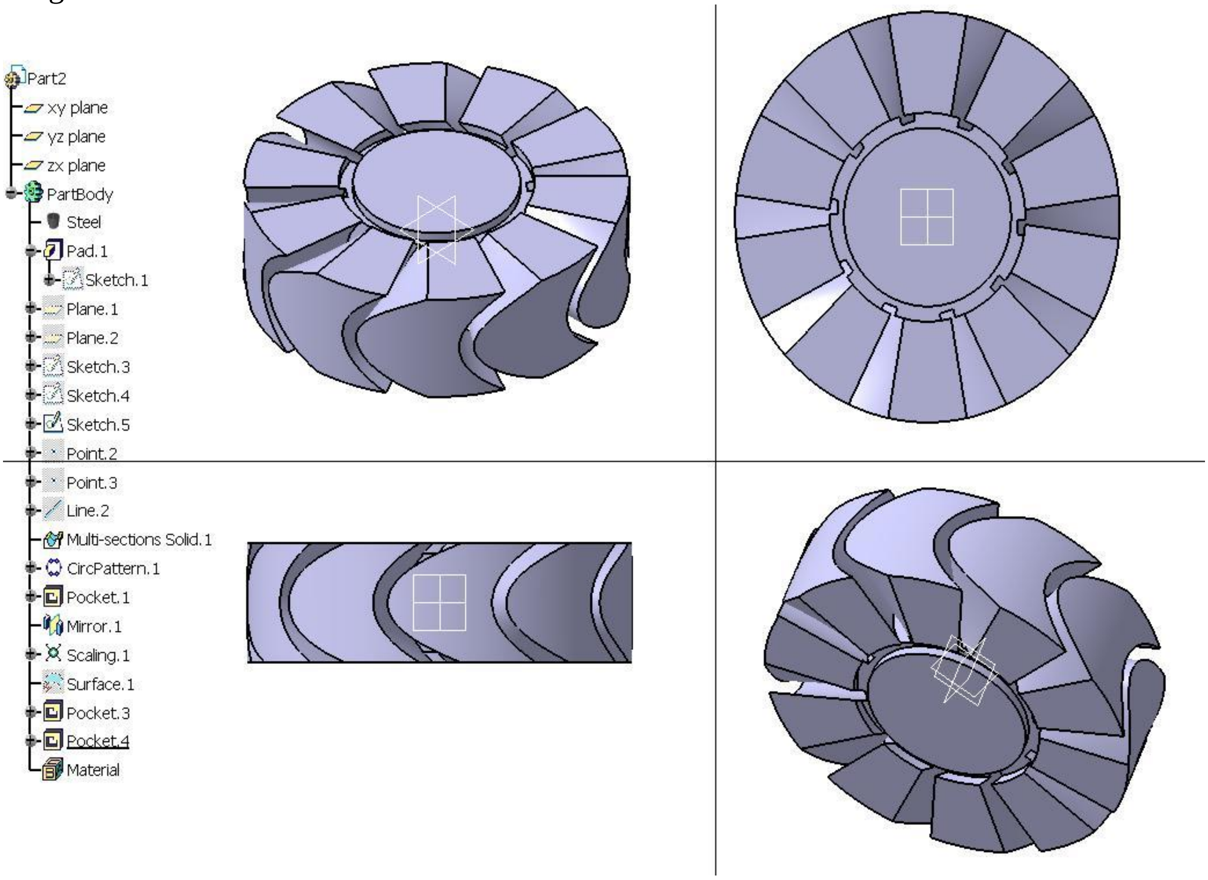


Figure 5.4

5.5 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 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.

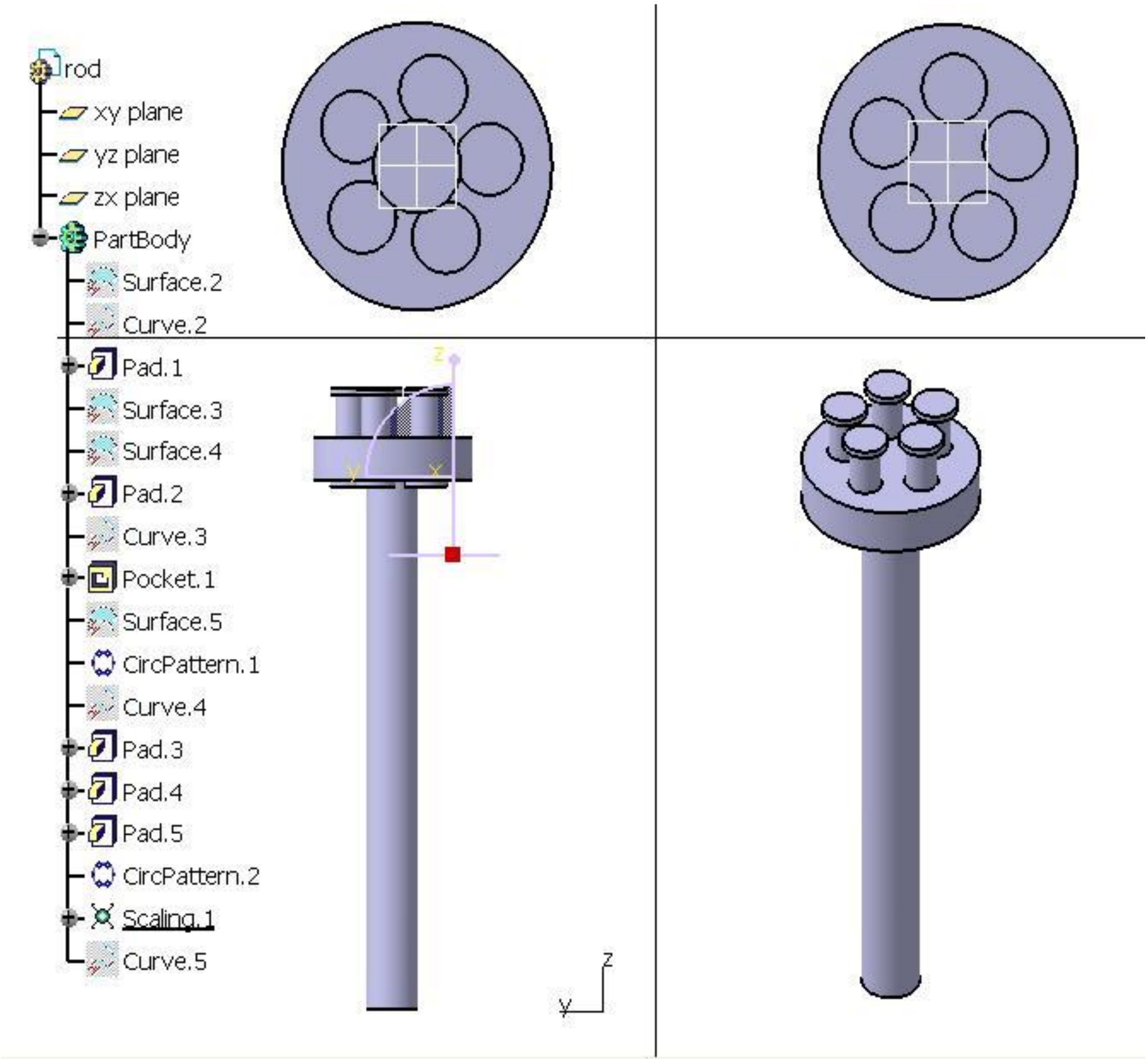


Figure 5.5

5.6 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.

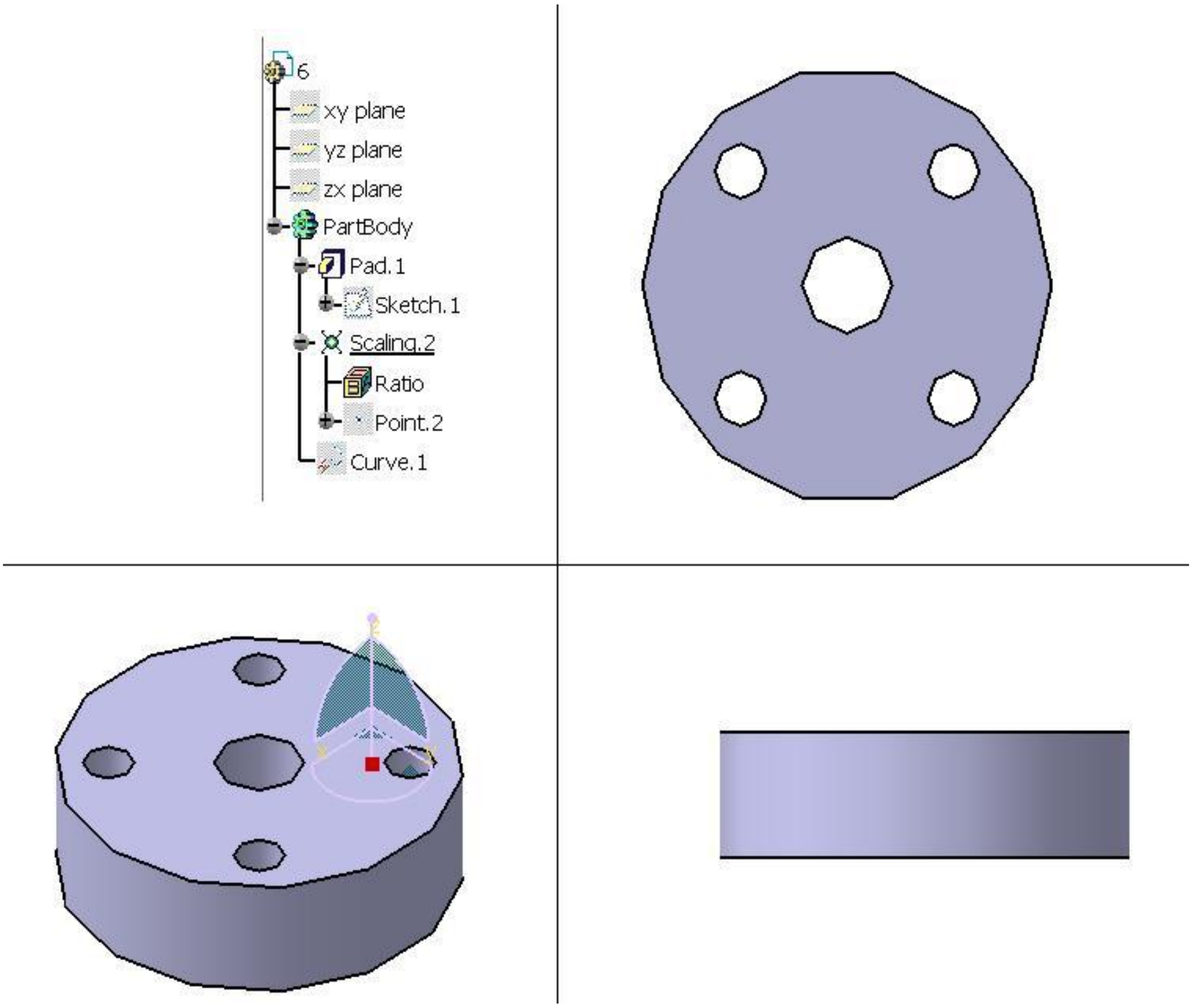


Figure 5.6

5.7 Clip:

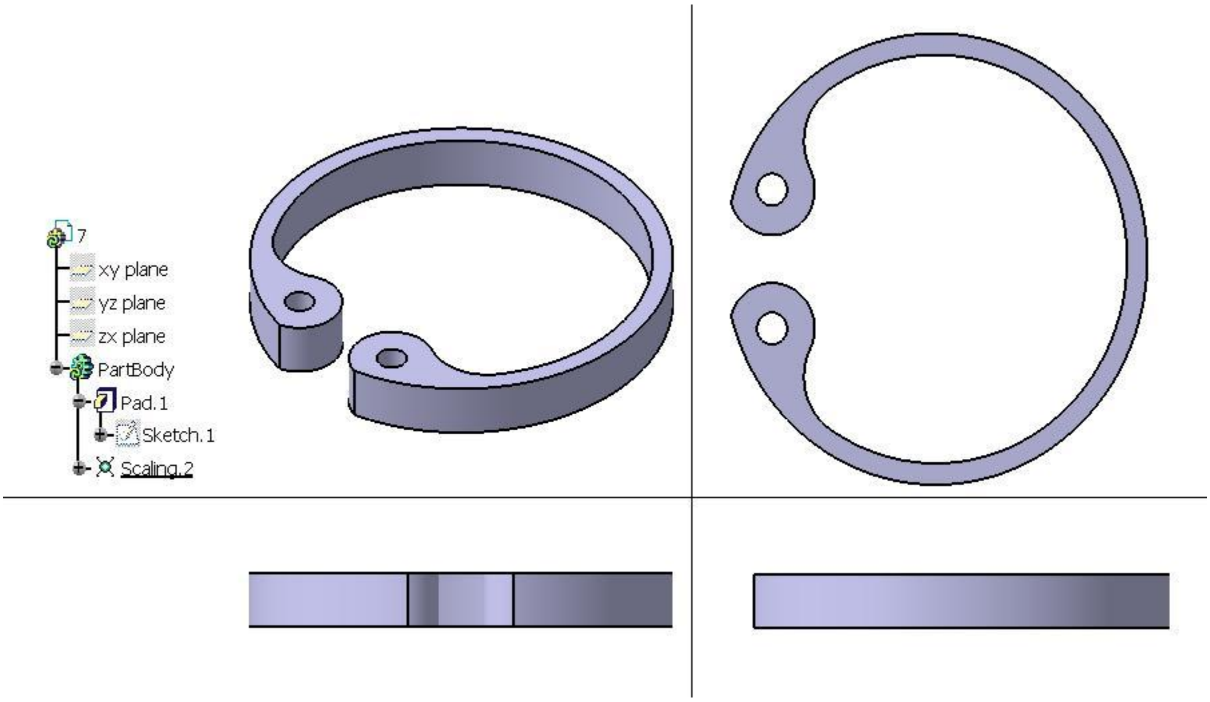


Figure No. 5.7

5.8 Housing/Cover:

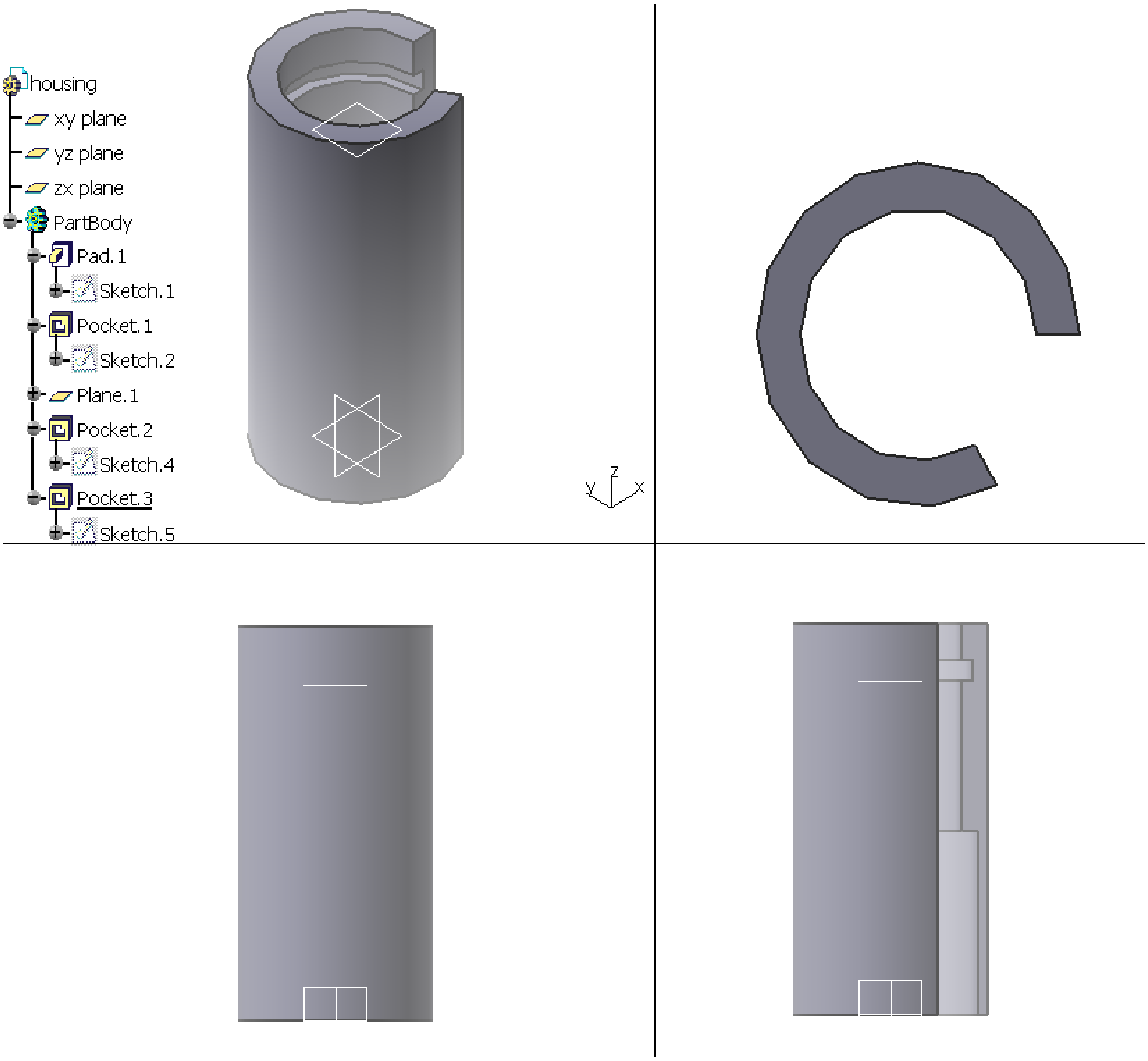


Figure 5.8

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).

5.9 Generator with coupling:

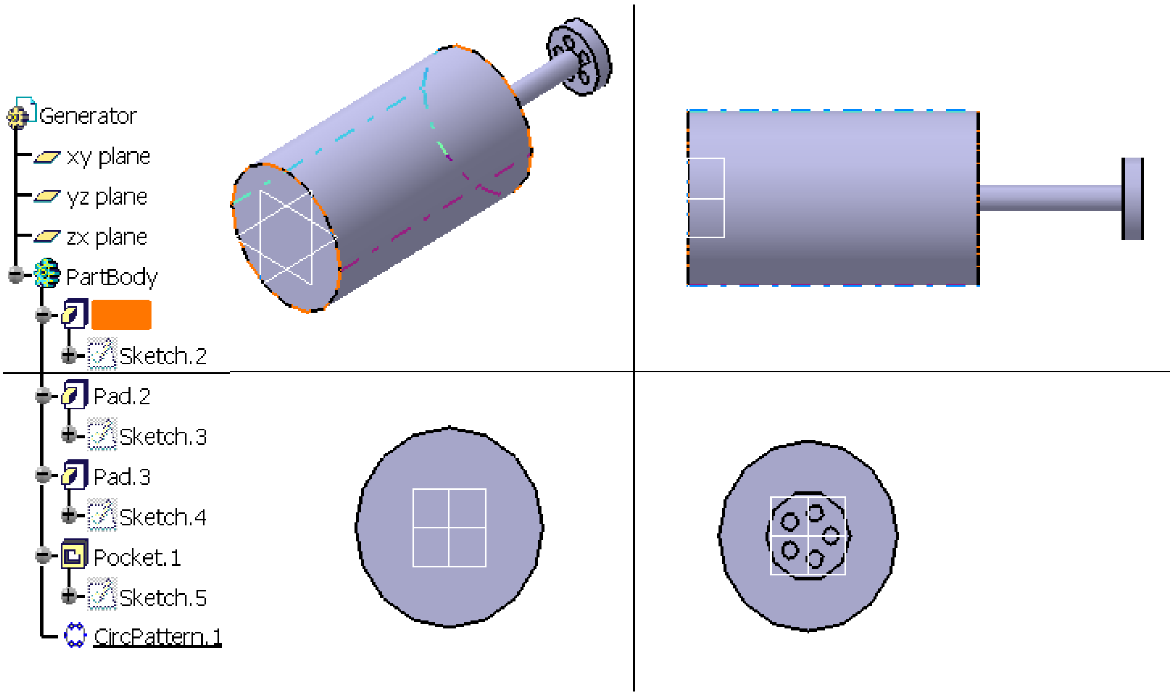


Figure 5.9

5.10 Assembly of parts :

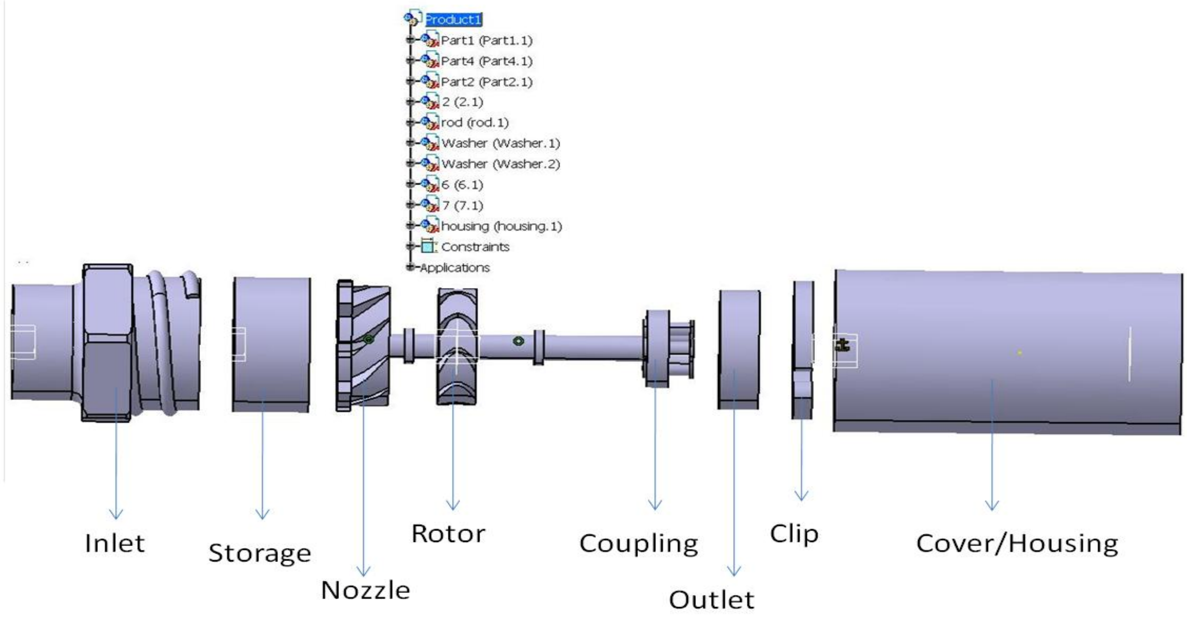
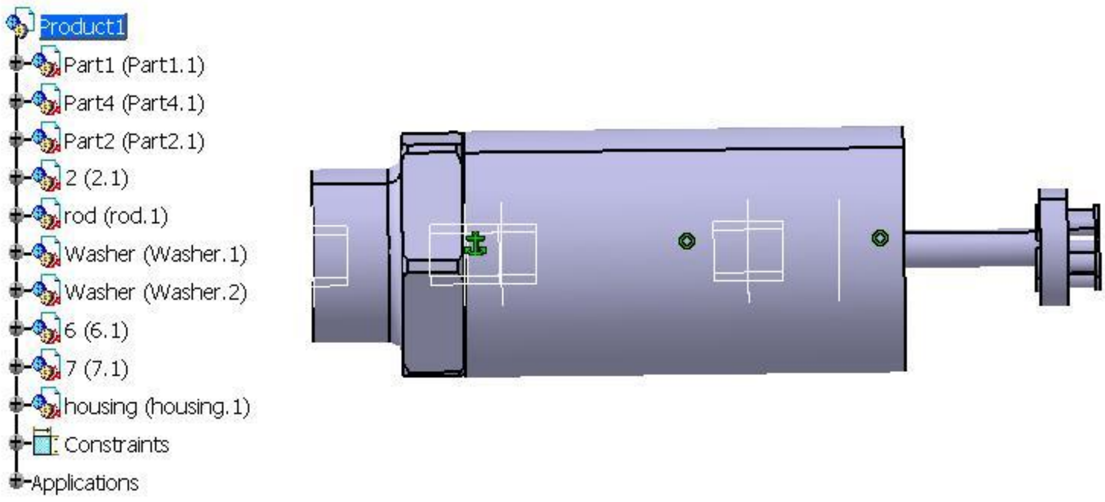
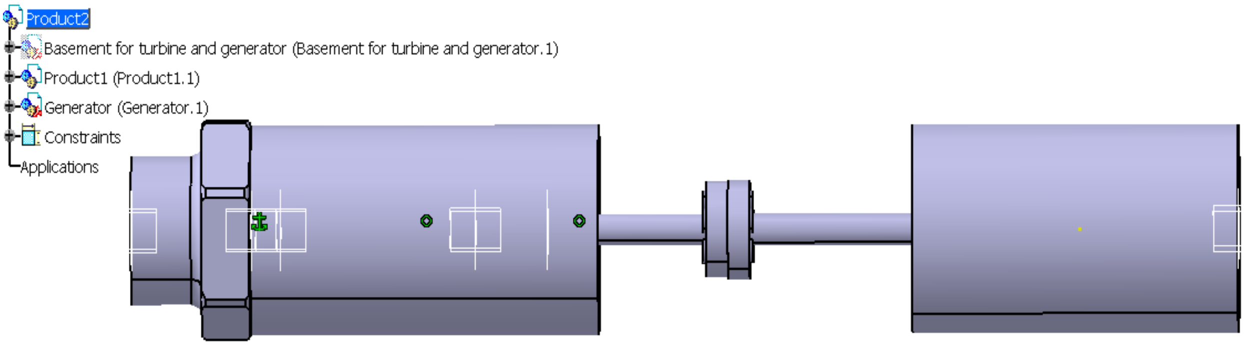


Figure 5.10



Compact packing of all the parts to make the assembly

Figure 5.11



The Generator is coupled to the Micro turbine

Figure 5.12

Chapter 6

RAPID PROTOTYPING

6.1 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.

6.2 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

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.

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.

Slicing 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.

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.

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.

6.3 Rapid Prototyping Techniques

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

6.3.1 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.

6.3.2 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.

6.3.3 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.

6.3.4 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.

6.3.5 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.

6.3.6 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.

6.4 Advantages of RP

The main benefits of RP are:

- Production of parts is faster and less expensively.
- Material savings in comparison to other methods.
- Product testing is quickly possible.
- Design improvements can be achieved.
- Error elimination from design can be fast.
- Experiments can be done on physical objects of any complexity in a relatively short period of time..
- Using a prototype development of a system can be done with less effort in comparison to development without prototype.
- Labour cost due to manufacturing, machining, inspection and assembly is reduced.
- Reduction in material cost waste disposal cost, inventory cost, material transportation cost.
- Design misinterpretations can be avoided.
- Quick design modification is possible.

- Better communication between the designer and user because of 3-d presentation of the model to be prototyped.

6.5 Disadvantages of RP

Some of the disadvantages of rapid prototyping are described below.

- According to some people rapid prototyping is not an effective model of instructional design because it does not replicate the real thing.
- Many problems may be overlooked that results in endless rectification and revision.
- Rushing in to develop a prototype may exclude other design ideas.
- Design features may get limited because of the limitation of the prototyping tool.
- Sometimes the prototyping machine may not deliver product upto expectation.
- The system could be left unfinished due to various reasons or the system may be implemented before it is completely ready.
- The producer may produce an inadequate system that is unable to meet the overall demands of the organization.

6.6 Applications of Rapid Prototyping

Rapid prototyping is widely used in the automotive, aerospace, medical, and consumer products industries.

Engineering

In aerospace industries rapid prototype method is used for production of complex parts. For space shuttle and space stations also parts are manufactured using RP. Boeing's Rocket-dyne has used RP technology to produce hundreds of parts of space shuttle and international space station. To manufacture parts for fighter jets also RP technology is used. In labs for testing of a new concept rapid prototyping is done and experiments are executed.

Architecture

In the field of architecture, new designs and ideas can be shown using rapid prototyped models. It helps for better understanding and analysis.

Medical Applications

RPT has created a new market in the world of orthodontics. Instead of using metal teeth straighter rapid prototyped teeth can be used for better appearance. The stereo lithography technology can be used to produce custom-fit, clear plastic aligners in a customized mass process. The RP technique is also used to make hearing instruments. The instrument shells produced are stronger, fit better and are biocompatible to a very high degree. The ear impression is scanned and then digitized with the help of an extremely accurate 3-D scanner. Then using the software developed the digital image is converted into a virtual hearing instrument shell .Thanks to the accuracy of the Rapid Prototyping process, instrument shells are produced with high precision and reproducibility. In the case of repairs, an absolutely identical shell can be manufactured quickly, since the digital data are stored in the system.

Arts and Archaeology

Selective Laser Sintering with marble powders can be used to restore or duplicate ancient statues and ornaments, which suffer from environmental influences. The originals are scanned to derive the 3D data, damages can be corrected within the software and the duplicates can be created easily. One application is duplicating a statue. The original statue was digitized and a smaller model was produced to serve a base for a bronze casting process.

Chapter 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 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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