Design and modeling of axial micro gas turbine engineering essay

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 . different parts of turbine is designed with the help of CATIA(Computer Aided Three Dimensional Interactive Analysis) software . The turbine is of Axial input and axial output type.

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

Chapter 1

LITERATURE REVIEW

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 applicationsâ€- 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.

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.

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 modeling. 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

CATIA(Computer Aided Three Dimensional Interactive Analysis)

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.

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.

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 areaC: Documents and SettingsSatiraDesktopwindow. JPG

C

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

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Chapter 3

GAS TURBINE

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 :

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.

Applications Of Gas turbine :

Jet Engines

Mechanical Drives

Power automobiles, Trains, tanks

In Vehicles(Concept car, racing car, buses, motorcycles)

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.

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.

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

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.

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.

Basic Parts of Micro turbine

Compressor 2. Turbine

3. Recuperator 4. Combustor

5. Controller 6. Generator

7. Bearing

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.

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.

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 .

Chapter 5

DIFFERENT PARTS AND THEIR DESIGNING OF MICRO TURBINE

ROTOR

The rotor is mounted vertically. The rotor consists of the shaft with a collar integrally machined on it to provide thrust bearing surfaces, the turbine wheel and the brake compressor mounted on opposite ends. The impellers are mounted at the extreme ends of the shaft while the bearings are in the middle.

NOZZLE

The nozzles expand the inlet gas isentropically to high velocity and direct the flow on to the wheel at the correct angle to ensue 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. Filippi has derived the effect of nozzle geometry on stage efficiency by a comparative discussion of three nozzle styles: fixed nozzles, adjustable nozzles with a centre pivot and adjustable nozzles with a trailing edge pivot. At design point operation, fixed nozzles yield the best overall efficiency. Nozzles should be located at the optimal radial location from the wheel to minimize vaneless space loss and the effect of nozzle wakes on impeller performance. 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 t