Micro Gas Turbine – A Review

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***Abstract* – Turbomachines is a class of machines which comprise of turbines and compressors. These machines are widely used for power generation, aircraft propulsion and in a wide range of heavy and medium industries. When we scale down these large turbines, we get micro turbines, which are compact and miniaturized form of these large turbines. The process of scaling down a turbine is not as simple as it looks like, it is a very tedious job and researches are going on in this area. These micro gas turbines are usually found with a power generating capacity of 250kW. They use any gas like natural gas, biogas, etc. as its input. The advantages of a micro gas turbine are that it has high expansion ratio and less moving components. The drawbacks of these turbines are that it requires high angular velocity as well as advanced electronics which can convert electricity of high frequency which gets produced into useful frequency of 50/60 Hz. This turbine is a very viable solution for distributed power generation which can be used for stationary energy applications. Also, micro gas turbine has found great use as cogeneration systems. These micro gas turbines can produce power between less than a kilowatt to hundreds of watts, which can be used for various purposes like electricity generation or head creation. These turbines are cost-effective, eco-friendly and pollution free as they can work by burning any gas like natural gas, land fill gas, etc. The manuscript presented gives an outlook on the past, present and future of these micro gas turbines. This paper will discuss the advantages and its uses. It will also discuss the drawbacks and the limitations of these turbines. This manuscript will prove to be a reference to all the researchers who want work in this field.**

Index Terms- Cogenerator, Gas Turbines, Micro Gas Turbines, Power Generations

I. INTRODUCTION

Turbomachines defines those machines which transfer energy between a rotor and a fluid. It includes turbines and compressors, turbine transfer energy from fluid to the rotor while a compressor does the opposite [1], [2], [3].From an ancient age, these machines are in use. The steam turbines were the earliest to come in use, commercially. Those turbines used energy of steam and converts that into kinetic energy of rotor of turbine and the work output at shaft was used for different purposes.

After some advancement in technology, gas turbines came into existence, which were based on Brayton Cycle. It is said that principle of these gas turbines had existed around 100 years ago. The first person heard of applying for patent was John Barber in 1791 [4]. These turbines used gases instead of steam for its functioning. The gases were burnt in a combustion chamber and then the energy released due to it was used for rotating the rotor of turbine. In the year 1930, Sir Frank Whittle devised a jet engine which made the gas turbine the talk of the town and led to the flurry of research in its field. The gas turbines have a history older the history of reciprocating engines [4].

When we miniaturize or scale down a gas turbine, what we get is a micro gas turbine. They have a power output less than 500 kW. The process of scaling down a gas turbine is not as easy as it looks like, it possess great difficulties. These gas turbines are used for power generation; also they can be used for distributed power supply system. These micro gas turbines have also found its application in cogeneration systems, which supply steam and power at the same time. The hybrid electric cars also use these turbines as one of its source. The Capstone Engineering was the first one to build a Micro Gas Turbine [5].

II. CONSTRUCTION OF A MICRO GAS TURBINE

In a micro gas turbine, a miniaturized compressor is attached to a micro gas turbine; they both are mounted on the same shaft. A detailed sketch is provided in Fig. 1. A generator is also attached to that shaft. A power generating unit which comprise of a rectifier and an inverter is also present. A recuperator is also used for heat exchanging process. Combustion chamber is placed before the turbine for the combustion of gas. At the end

of the system, a heat recovery system is placed so as to extract the heat of the exhaust gases.

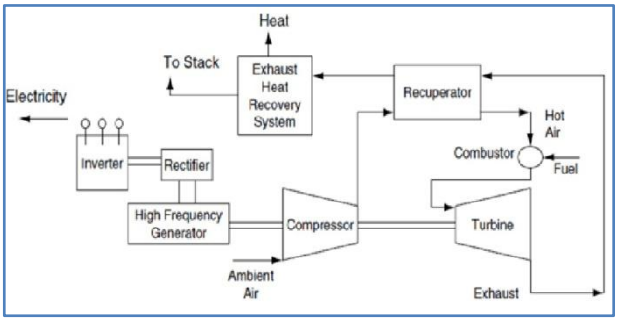


Fig. 1- Block diagram of a Micro Gas Turbine

III. WORKING CYCLE OF A MICRO GAS TURBINE

As it is earlier said, gas turbines are based on Brayton Cycle. A T-S and P-V diagram of an ideal Brayton Cycle is shown in Fig. 1. The operations of a Brayton Cycle referenced from [6] are as follows:

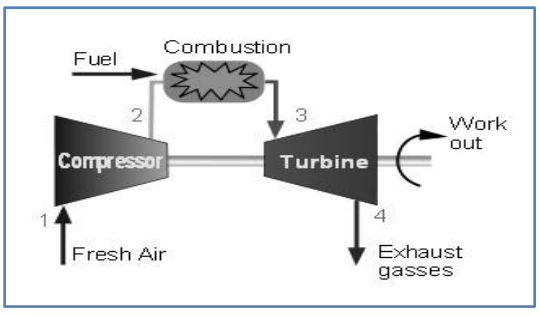
Operation 1-2: The air is compressed is entropically from the lower pressure P_1 to the higher pressure P_2, the temperature rising from T_1 to T_2. No heat flow occurs.

Operation 2-3: Heat flows into the system increasing the volume from V2 to V3 and temperature from T_2 to T_3whilst the pressure remains constant at P_2. Heat received = $mc_p(T_3-T_2)$.

Operation 3-4: The air is expanded is entropically from P_2 to P_1, the temperature falling from T_3 to T_4. No heat flow occurs.

Operation 4-1: Heat is rejected from the system as the volume decreases from V_4 to V_1 and the temperature from T_4 to T_1 whilst the pressure remains constant at P_1. Heat rejected = $mc_p(T_4-T_1)$.

A micro gas turbine same as gas turbines is based on a Brayton Cycle. The operation 2-3, is where combustion of gas takes place. Since micro gas turbines are based on open gas cycles, so every time a fresh gas mixture is burnt in the combustion chamber and after using it, it is released as exhaust.



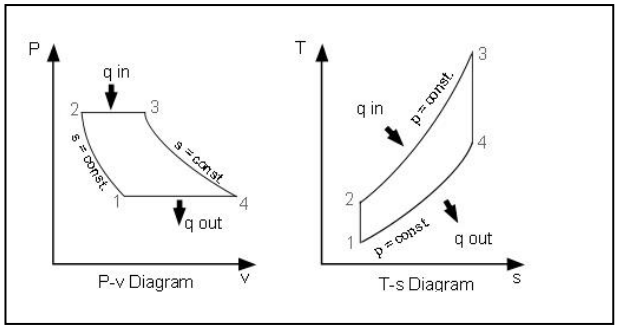


Fig. 2- Ideal Brayton Cycle

IV. WORKING OF A MICRO GAS TURBINE

In a micro gas turbine, gas is allowed to enter the apparatus in ambient conditions. Firstly, it enters a compressor where its pressure is increased along with the temperature. The gas is passed then through a recuperator where its temperature further increases, since recuperator is a type of heat exchanger, where the heat of the exhaust gases is used to increase the temperature of the inlet gases. Then the gas is burnt in a combustion chamber, where its energy gets increased and then this gas is allowed to work on the turbine, where the transformation of energy takes place, i.e. energy of gas is converted into the kinetic energy of the rotor of turbine. Since the turbine and compressor are mounted on same shaft that means turbine will drive the compressor. The gas is then allowed to enter the recuperator where it will increase the temperature of the next gas mixture which is inputted in to system, and at the end this gas is released as exhaust. But before the exhaust, a heat recovery system is installed in some cases where the left out heat of the exhaust gases is recovered and used for some secondary operation.

The rotations of shaft is sometimes used directly, but sometimes the same shaft is connected to a high frequency generator and used for generation of electrical energy, and a rectifier and inverter arrangement is also present for converting this high frequency electrical energy into useful 50/60 Hz useful electrical energy.

V. PAST RESEARCH OVER MICRO GAS TURBINE

The idea of micro gas turbine came from the gas turbines. The first gas turbine for power generation was built by BBC (Brown Boveri & Cie) in 1939 [7], [8]. The output power was 4000 kW. The thermal efficiency was 17.4% and the turbine inlet gas temperature was 550^0 C. With further advancement in technology of heat resistant materials and advances in turbine blade cooling technology, the turbine inlet gas temperature has raised to values exceeding 1500^0 C. Today's gas turbine plants

produce approximately 200 MW. In some cases, where the combined plants are used, this value approximately becomes 1000 MW. When the output is less than 500 kW, then the turbines are called Micro Gas Turbines. Their efficiency varies from 25% to 33% which is higher than the simple-cycle gas turbines [4]. From the 1960s to 1990s, the American, European and Japanese car makers had invested much in the research of Micro Gas Turbines so that they can use that technology for powering vehicles. The reason behind this was a gas turbine will be much more compact than the typical engine. But due tocertain problems faced like fuel efficiency and cost of Micro Gas Turbines, the vehicles were never commercialized [4].

Then came a Micro Gas Turbine built by Capstone Engineering, USA, in late 1990s, the machine was built for distributed electricity generation systems. The design was based on a miniaturization technique. The power output was 28 kW, and it was compact and stylish [5]. Then by seeing that, companies like General Electric, Ingersoll-Rand Energy Systems, etc. started there venture in the field of Micro Gas Turbines (MGTs). They were successful and they developed some of MGTs whose power output ranged from few kilowatts to 300 kW.

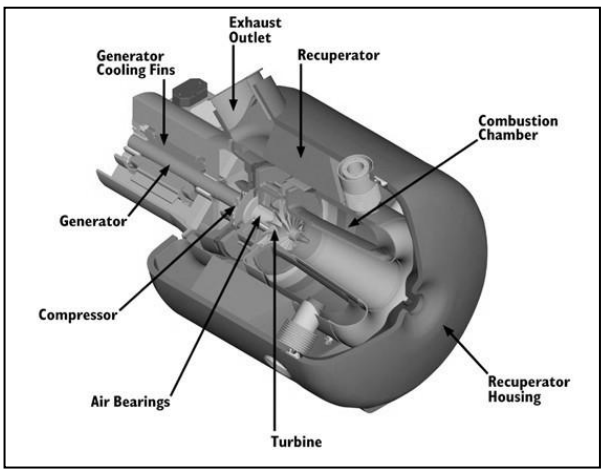


Fig. 2- Capstone C30 Micro Gas Turbine. This picture has been referred from [12].

VI. PRESENT SCENARIO OF MICRO GAS TURBINE

In Today's era, people think it is very plausible that future generation will have to live without fossil fuels as the rate at which we are consuming those fossil fuels; they will all be finished up soon. So, people are trying to figure out the alternatives so that our future generations can also use these fossil fuels. Another thing, researchers are trying out in this field is that the use of more fuel efficient methods so as to shun the wastage of inputs. Micro Gas Turbines are more fuel efficient and it can have any gas mixture as its input for its functioning.

Presently, researches are being carried out to make these Micro Gas Turbines cost efficient. Further, companies, industries, researchers and organizations are working on its operations, trying to make them more steadfast. With advancements in electronics, the high frequency inverters are now available, which are supposed to increase the efficiency of Micro Gas Turbine upto 40% [4]. Presently, researches are also being going on,to use the MGTs for the distributed power supply systems. Also, with Micro Electro Mechanical Systems (MEMS), it is now possible to duplicate the power density as that achieved by their more familiar, full-sized brethren, at MIT these researches are going on [9]. Also, with advancement in heat resistant materials, now it has become easy to increase the turbine inlet gas temperature so as to increase efficiency.

Companies like, Capstone Engineering, General Electric, Toyota Turbine & Systems, Ingersoll-Rand Power Works are now manufacturing MGTs with efficiencies varying from 25% to 35%. The use of MGTs as cogeneration systems also has many advantages when compared with conventional reciprocating engines like compact and multi-fuel capability, moreover, it has less NOx and CO/HC emissions [4]. Some MGTs use a self-acting air lubricated bearing which require neither oil nor an oil supplying device. One more reason behind why these MGTs are more qualified to be used in cogeneration systems is that, since the temperature of exhaust gases is very high in MGTs thus it can be used in a more effective way for supplying both the steam and electric power at the same time. Even in the automotive industry, the use of MGTs for powering the vehicle has got many eyes. People are trying to manufacture the vehicle which uses a gas turbine for its functioning. The eminent Japanese company Toyota has manufactured its Toyota GTV gas turbine passenger car which is powered by GT41 gas turbine engine [4].

VII. MERITS OF A MICRO GAS TURBINE

The Micro Gas Turbine is full of advantages. Starting with its efficiency, the efficiency of a MGT is approximately 25%-30% which is expected to raise upto 40%. This makes the MGT fuel efficient. Also, the MGT uses any gas like the natural gas, land fill gas, biogas, etc. as its input. That gives it multi-fuel capability. This is very advantageous as we all know that sooner or later people are going to shift to the unconventional gases as the fossil fuel gases are not present everywhere and are not in plethora. Another

merit of the MGT is that its low emission of NOx and CO/HC. Over a power range of 18-28 kW, NOx emission of Capstone's MGT is less than 5ppm [5]. MGTs are also nearly vibration less, which increase its service life, which is one advantage. The use aerostatic bearings in MGT helps in reducing the vibrations along with eschewing the use of oil or any type oil supplying device in MGTs. It has better part load efficiency through variable speed operation. The temperature of exhaust gases in MGTs is very high which can be used more productively. The most important advantage of an MGT is that it is very compact and very less in weight. The size of an MGT is very less when compared to a reciprocating engine with same power output.

VIII. DRAWBACKS OR LIMITATIONS

The major drawback of an MGT is that it is very costly. Researches are going on around the world to make it cost efficient. Also, the manufacturing of an MGT is difficult, as the size of an MGT is very small, so we can imagine how difficult is to manufacture those turbines and compressors whose dimensions are in millimetres. The most prominent limitation of an MGT is that high angular velocity around 40,000 to 120,000 rpmhas to be achieved for its proper working [10]. One more limitation is that high electronics are required for converting high frequency power into useful 50/60 Hz [10]. Researchers are working on these limitations and it is expected, soon these limitations will be removed.

IX. USES OF MICRO GAS TURBINES

Micro Gas Turbines can be used for various purposes. MGTs most commonly are used for electricity generation process, where the power generated by a MGT is used to drive a generator which generates electricity and then this high frequency electricity is converted into usable 50/60Hz electricity using a rectifier and inverter assembly. Recently, MGTs have found there uses in area of distributed power supply.

MGTs are being used to power vehicles also. The companies like GM, Toyota, Ford, Daimler Benz, etc. have invested much in the research regarding the use of MGT in vehicles, but due to certain aspects, they never commercialized any of the vehicles. But still, researches are being performed to use the same for powering vehicles. In this field, some of the hybrid vehicles have also come in the picture which uses the gas turbines as one of its source.

A MGT is most fit for the use in cogeneration systems, where both the steam and power is required. Since the temperature of exhaust gases is very high in MGTs, so that temperature can be used to heat water and convert it into steam. Along this process, the MGT is also providing power. So, it is the most effective use of MGTs.

X. FUTURE PROSPECTS OF MICRO GAS TURBINES

Micro Gas Turbines can prove to be a boon for future generations, if developed with care. The development in MGTs can be in many directions, but mostly it will be in field where hybrid systems will be generated, which will combine fuel cells with the MGTs. These systems can be very useful for power generation. Due to its compactness, these can be used for powering houses, vehicles, etc. Also, the efficiency of these hybrid systems will increase and can reach upto a level of 60%.

Another field where researches can be done is miniaturizing the MGT and making them smaller, by using Micro Electro Mechanical Systems (MEMS). Those miniaturized MGTs can be used for powering electronic devices such as laptops, etc., since the power density of these MGTs is 100 times the power density of a normal lithium battery [11].

Also, the DOE, USA is promoting these MGTs because they can be used for distributed power supply which can relieve the load of highly loaded electric lines. The future of MGT is very crucial for us and it, both, as these machines can be used to fulfil the energy needs of people without burdening their pockets.

XI. CONCLUSION

Gas turbines from the day they arrived, they have become a centre of attraction. Research and development made them what they are today. They are the foundation stone of the aircraft industry and without them, they will all fall. These have been used even for generating electricity. The miniaturized form those turbines known as Micro Gas Turbines is also an area which has been an interesting topic of research from last 50 years. These machines due to its various advantages like compactness and multi-fuel capability is now trying to snatch the market from its substitutes. Various researches are being carried out for making MGT cost effective. These MGTs can be used for distributed power supply i.e. electricity generation. Also, many companies are trying to use these MGTs for powering vehicles. Also they have found application in the cogeneration systems, i.e. generating both the steam and power at the same time. The Micro Gas Turbines can be used for various purposes in the future, and it may be able to abate the rate at which we are consuming fossil fuels. These MGTs can prove to be a life changing solution. This manuscript will provide a ready reference

to all those who want to work in the charismatic field of Micro Gas Turbines.

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