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Micro Gas Turbines, Risks and Markets

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Executive Summary

Because of increased awareness of environment-related issues, it becomes more and more difficult to find new sites for the constructing of new power plants. Power plants must now be located in remote areas some hundreds of kilometers away from the urban core. As a result, enormous loss of electric power in transmission and distribution occurs, and since it is actually difficult to utilize waste heat of power plants, the present electric power supply system has a big problem from the aspect of effective utilization of energy.

Based on the above understanding, the importance of distributed generation has increased. Micro gas turbine (MGT) is a generic name of small-scale gas turbines with power generation output of about 300 kw or lower, and one of major types of the distributed generation. This paper outlines the development history of the technology, its technical features, current market situation and future perspective of the technology.

□. Introduction

Micro gas turbine is a generic name for small-scale gas turbines with power generation output of about 300 kw or lower, and we must go back into development history of gas turbines to know the background of its development.

1. Development History of Gas Turbines

Development of gas turbines dates back to the 19th century and was begun in the period nearly similar to that of other heat engines, such as steam turbines and reciprocating combustion engines, but their practical use fell greatly behind other heat engines. There was no combustion chamber or turbine material which could withstand high temperature gas; as a result, almost all turbine output was consumed for air compressor motive power and net output was unable to be obtained. In 1939, a prototype of the world's first power generation gas turbine was fabricated and its practicability was confirmed. However, because of low efficiency of power generation, gas turbines were unable to become a mainstream of power generating facilities, and have been used as emergency power generators or power generators for peak load in the summertime and wintertime.

It was in their application as aircraft power generators that gas turbines were practically used before they were accepted in areas of power generation, vessels, automobiles, etc. Although gas turbines provide poor thermal efficiency compared with other prime movers like steam turbines, gasoline engines, diesel engines and gas turbines have features of small size, light weight and large output, and practical use in this field rapidly took place.

It was the use of combined cycle power generation system that gave a chance for gas turbines to gain rapid popularity as utility generators. This system combines two types of prime movers, i.e., gas turbine and steam turbine. It utilizes high temperature exhaust gas of gas turbines for steam turbines' power generation and achieves high thermal efficiency. Therefore, the system has rapidly been introduced into the market and the trial of capacity expansion has also been continued to date.

2. Background of Appearance of Micro Gas Turbines

The development of small gas turbines in the U.S. dates back to the gas turbine vehicular engine programmes in the 1970's where the desire to improve efficiency was being driven by the U.S. Department of Energy. At that time, General Motors (Detroit Diesel and Allison Divisions), Garrett AiResearch, and Ford Motor Company had development and test programs which evaluated regenerative and recuperative gas turbine engine designs and sizes (few hundred horsepower) in vehicles (trucks and buses). Unfortunately, as the performance of these gas turbines improved through the use of ceramic components, the performance of competing reciprocating engines improved more such that these gas turbine engine efforts were abandoned. Subsequently the U.S. Department of Energy sponsored gas turbine development efforts for a 100 horsepower automotive engine utilizing ceramics but that was also subsequently abandoned.

Because the ratio of zero emission vehicles and partial emission vehicles was made compulsory by the environmental control laws of the State of California State in 1990, gas turbines which have outstanding characteristics as compared to gasoline engines from the viewpoint of environment and compactness that accommodate them to limited installation spaces, attracted attention and development of small-size turbines took place and these formed the basis of present micro gas turbine technologies.

In the early 1990's, Volvo evaluated vehicular gas turbine hybrids for trucks, buses, and cars. About the same time, Capstone began development of microturbines for commercial applications by using turbocharger components (compressors and turbines) coupled with a small combustor, recuperator, and high speed permanent magnet generator designs, similar to that used in aircraft auxiliary power units. From that time period, the microturbine industry for stationary commercial use was launched.

As mentioned above, at first people tried to enlarge gas turbines capacity to get high efficiency from the power generation. However, from the viewpoint of effective utilization of energy, in recent years, the importance of decentralized energy systems has been increased. Under these circumstances, micro gas turbines were developed and put into practical use with know-how accumulated in developing small-size aircraft engines and automobile engines best adopted primarily by American companies, and nowadays, still more intense development competition has been taking place with European and Japanese manufacturers. Although there are many types of other distributed power generation systems such as gas engines, diesel engines, fuel cells, solar thermal power generation and wind turbines, as micro gas turbines have many advantages like small size, high thermal efficiency, high power generation efficiency and low environmental load and if it continues to show stable performance, they are expected to increase their market share in future.

II. Market Situation of Micro Gas Turbines

1. Necessity of Distributed Generation

Electric power companies have tried to enlarge power generation units to reduce their cost price. As a result, at present the electric power supply system using large-size power couple of plants and large-scale power transmission lines prevails. However, in constructing new power plants, it becomes more and more difficult to find new sites because of peoples increased awareness of environment-related issues, and power plants must now be located densely in remote areas some hundreds of kilometers away from the urban core. As a result, enormous loss of electric power in transmission and distribution occurs, and since it is actually difficult to utilize waste heat of power plants, the present electric power supply system has a big problem from the aspect of effective utilization of energy.

Based on the above understanding, the importance of distributed generation has increased. The distributed generation is a power generation system using small-scale power supply of about 5,000-kw or less output, which is installed in the vicinity of consumers, and is called on-site power generation. There are a advantages as follows:

(1) Because power is generated in the vicinity of energy consumers, it is possible to effectively utilize waste heat of engines and turbines in the form of steam and hot water for hot-water supply and air-conditioning, and to improve the overall heat efficiency.

(2) Loss of electric power in transmission is almost none as it does not use power lines.

(3) Installers can reduce the contract demand with an electric power company by carrying out peak-cut operation that meets the power peak and can enjoy economic advantages.

(4) Because of utilization of natural energy like solar power and wind, or that of clean energy like natural gas or city gas, environmental loads can be reduced, resulting in contribution to the global environment.

2. Outline of other types of distributed generation

Gas Engine

[1] Working principle

Gas engines are reciprocating internal combustion engines which reciprocate pistons by mixing gas fuel such as natural gas, or propane gas, with air, compressing the mixture in the cylinder, and combusting and expanding it by spark ignition, convert this reciprocating motion into rotating force, and generate electric power.

[2] Advantages

a) Because the exhaust gas temperature is comparatively high, heat recovery is easy and high total heat efficiency can be expected as cogeneration.

b) Because comparatively clean fuel such as city gas is used, sulphur oxide (SOx) or nitrogen oxide (NOx) concentration is low, and the system provides superb environmental characteristics.

[3] Disadvantages

Because gas engines are reciprocating internal combustion engines, they have many sliding sections, generating comparatively large vibrations and noise, and requiring measures for vibration isolation and sound insulation. In addition, gas engines provide poor maintainability.

Diesel Engine

[1] Working principle

Like gas engines, diesel engines are reciprocating internal combustion engines, but they differ from gas engines in sucking air only into the cylinder and naturally igniting gas by atomizing fuel over compressed air.

[2] Advantages

a) Reliability is very high because the technology is mature.

b) Power generating cost is low because low-grade fuel such as heavy oil is used.

[3] Disadvantages

a) Because diesel engines use low-grade fuel, uniform combustion is difficult as fuel is atomized, and the discharge concentration of sulphur oxide (SOx), nitrogen oxide (NOx), and soot and dust is extremely high due to high combustion temperature; diesel engines are also inferior in terms of environmental characteristics.

b) It has large vibration and noise because diesel engines are reciprocating internal combustion engines. Also proper maintenance is relatively difficult.

Fuel Cells

[1] Working principle

Fuel cells generate electric power by allowing hydrogen to react with oxygen. Specifically, fuel cells allow oxygen to react with hydrogen in hydrocarbon-based fuels, such as natural gas and methanol.

[2] Advantages

a) High power generation efficiency equal to diesel engines.

b) The discharge concentration of sulphur oxide (SOx), nitrogen oxide (NOx), and soot and dust is extremely low, fuel cells are superior in terms of environmental characteristics.

c) Low vibration and low noise.

[3] Disadvantages

a) Fuel cells are still at the research and development stage and have problems in durability and system dependability.

b) As compared to other power generating apparatus, fuel cells are expensive and fall behind in terms of economy.

Solar Thermal Power Generation

[1] Working principle

Solar thermal power generation directly converts solar energy into electric power by utilizing the phenomenon in which electric power is generated when light is struck against silicon semiconductors. Specifically, when light comes in contact with a solar battery with P-type semiconductor connected to N-type semiconductor, (+) positive hole and (-) electron are generated. The (+) positive hole moves to the P-type semiconductor and the (-) electron to the N-type semiconductor, respectively, voltage is generated between electric powers, and electricity is generated.

[2] Advantages

a) Since no fossil fuel is used, no exhaust gas is generated, achieving outstanding environmental characteristics.

b) Because the system is simple, maintenance is easy.

[3] Disadvantages

a) Because of low energy density, a vast area is required for carrying out power generation of a specified scale.

b) Solar thermal power generation is unable to generate electric power in the nighttime or in bad weather and is an unstable power supply that depends on weather.

c) Cost is still high.

Wind Power Generation

[1] Working principle

Power is generated by transmitting the energy of windmill blades which receive wind and rotate to a power generator.

[2] Advantages

Since no fossil fuel is used, no exhaust gas is generated, achieving outstanding environmental characteristics.

[3] Disadvantages

a) Because of low energy density, a vast area is required for carrying out power generation of a specified scale.

b) Sites where stable wind power can be obtained are frequently remote places distant from inner-city districts, and large-scale construction of power transmission lines must sometimes be required.

c) Wind velocity varies violently between seasons and time zones, output is unstable, and storage power supply such as batteries and diesel engines are required.

d) Cost is still high.

2. General Information on Micro Gas Turbines

[1] Working principle

In most designs, the microturbines utilize a single shaft design with the generator rotor shaft directly connected and/or integral with the compressor and turbine rotor of the gas turbine. Some models utilize a two-shaft design where the turbine is split into two sections; one drives the compressor, and one drives the generator. A typical single shaft microturbine cross section is shown below in Figure 1.

As can be seen in the cross section, air to this model microturbine passes through the generator for cooling and is directed to a centrifugal compressor, which raises the pressure approx. 0.3-0.4Mpa and temperature of the incoming air. This air is further heated as it passes through the cold side of a heat exchanger called a recuperator. This air then is directed to a reverse flow annular combustion chamber where fuel is injected through fuel injectors to raise the temperature of this pressurized and heated air to a radial turbine to 800-900C (1472-1652F). Power is produced as this hot air expands across the turbine.

The hot exhaust air of the turbine is ducted to the hot side of the recuperator which provides the energy to heat the compressor air prior to combustion. The recuperators are usually fabricated metal and are of a primary-surface type design. The centrifugal compressor and radial turbine are connected together to the generator rotor shaft. These type systems operate from 40,000 RPM to near 100,000 RPM depending on the manufacturer and model. Some models will use air bearings to support the generator, compressor and turbine rotor system while others will use oil lubricated, anti-friction bearing systems.

The generator, gas turbine (compressor, combustor, and turbine), and recuperator are typically assembled as an integral unit or core and are installed in an enclosure as shown below in Figure 2 in the upper right hand compartment (silver coloured assembly). In the upper left hand compartment, air to the generator and gas turbine is filtered and a fan is provided for enclosure cooling. Because the generator is turning at 40,000-100,000 RPM, it is necessary to convert the generator power to 60 Hz. This is accomplished by means of inverters or power electronics that are located in the bottom of the enclosure.

Since exhaust gas from the turbine has high heat energy, approx. 500-600□, the recuperator works to enhance thermal efficiency by doing heat exchange between the exhaust gas and the air for combustion. The exhaust from the microturbine recuperator is shown at the pipe at the top. These are connected to small heat generators (hot water heaters) or air conditioning absorption chillers in many applications. Depending on the pressure of natural gas to the microturbine, it may be necessary to have a gas compressor skid to increase gas supply pressure to the fuel injectors.

<u>Figure 1 - Model C60 Single Shaft Microturbine</u>
<u>(Courtesy of Capstone Turbines)</u>

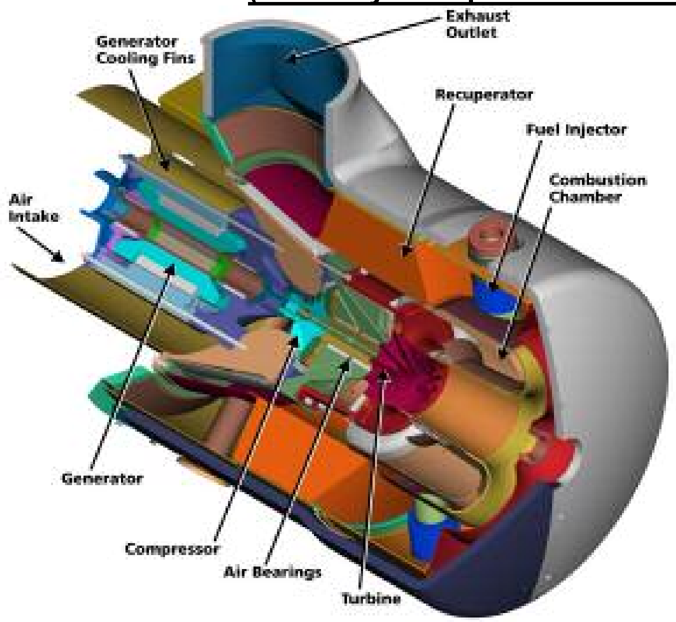


Figure 2 - Model 60 Microturbine Enclosure (Courtesy of Capstone Turbines)

[2] Advantages

a) Small number of parts and compact-size

Micro gas turbines have achieved super-high-speed rotations of 96,000 rpm which have never been achieved by conventional gas turbines, and this is greatly attributed to the development and the adoption of an air bearing, a system for allowing a shaft to float up by the use of air pressure generated by rotations.

Major difference between conventional bearings using lubricants and air bearings is whether there is friction. Air bearings have no friction. Conventional bearings are used for conventional gas turbines and automobile engines as their rotation speed is relatively low.

However, as MGTs require very high speed rotation like 96,000 rpm, conventional bearings are not suitable. They inevitably suffer some friction. So the more rotation speed increases, the more friction in conventional bearings increase, and as a result, the efficiency of electric power generation becomes lower.

Also friction raises durability and maintainability issues for conventional bearings.

On the other hand, in the case of air bearings, the shaft and the bearing do not come into contact with each other and frictional resistance greatly decreases and no lubricant system is required.

In addition, since permanent magnet is used for a generator, no exciter is required, and no cooling water is required, either, because the generator is cooled by the combustion air.

Also, because the generated high-frequency a. c. current is converted into d. c. current and the current is converted into the commercial frequency by an inverter, there is no need to keep the generator to a synchronizing speed and, therefore, speed governors and speed reducers are no longer required.

Furthermore, the generator also works as a starting motor, starter is not required. As mentioned above the small size, simple structure and small number of the parts are the feature of micro gas turbines in comparison with conventional large gas turbines.

b) High power-generating efficiency and thermal efficiency

The adoption of a regenerative cycle has achieved the power generation efficiency as high as around 26%. In addition, since the exhaust gas temperature is as high as about 260°C, it becomes possible to increase the total thermal efficiency to 60-80% if it is used as a cogeneration system.

c) No power system operation required

Since the high-frequency a. c. power generated is converted into d. c. current, which is converted into commercial frequency by an inverter, operation such as adjustment of system frequency or synchronous parallel operation is completely eliminated.

d) Outstanding environmental characteristics

Clean fuels such as natural gas, propane gas, kerosene, and light oil can be used, sulphur oxide (SOx) and nitrogen oxide (NOx) concentrations are low, proving its excellent characteristics from the viewpoint of environment.

[3] Disadvantages

a) Because high-frequency noise of a specified level is generated, measures for shielding noises are required when micro gas turbines are used in inner-city districts.

b) The cost is still high.

3. Acquisition and Maintenance Costs

The acquisition cost for microturbine generator sets range from $700-$1,000 (USD) per kW regardless of manufacturer for grid connected units. The smaller cost per kW applies to larger size units while the large cost per kW applies to the smaller size units. The costs for the gas compressor and stand-alone capability are extra. Installation costs may vary from 30% of the acquisition cost to 100% for highly customized installations. This includes electrical grid connections and the associated building modifications for indoor units or pads for outside installations. Exhaust heat exchanger costs for heating (hot water boiler) or cooling (absorption chiller/heater) are in addition to the previously discussed costs.

The maintenance on the units are minimal during the first year, typically consisting of 6,000-8,000 hour service which includes air filter and fuel filter cleaning/replacement as well as fuel injector and igniter service. The gas turbine overhaul interval varies by manufacturer from 20,000 hours to 40,000 hours of operation. Design lives of the units range from 50,000 hours to 80,000 hours. Maintenance contracts are available and usually recommended to minimize down time. Most generator, gas turbine and recuperator modules can be replaced within 8-24 hours, not including shipment time. A similar time applies to troubleshooting, replacement, and installation of the power electronics and control system components. The operational and maintenance costs have been typically estimated to range from $0.005 to $0.015 per kWh in USD. Subsequent experience has ranged from $0.025 to $0.060 per kWh in USD, depending on application and model.

4. Market Situation in Major Countries

[1] Service Experience

The leader in microturbine experience is Capstone Turbines. Over 2,400 engines have been sold with over 3,300,000 hours of operation. Several Model C30 units reached 25,000 hours of operation in 2002. These units are located worldwide with most units in the United States, Japan, Europe, Canada, and South America, in that order. The high time engine in Europe has 13,000 operating hours at Putten, The Netherlands. There are two stand-alone Model C30 units in Russia at an advanced oil extraction location in Siberia.

There are over 250 Model TA-80 units sold by Elliott directly or through Bowman Power Systems (U.K.). Most of the units are in Europe with only 5% each in the U.S., Canada, and Japan. The high time unit has approximately 6,000 total operating hours. The Model TA-100 unit was released in 2003. A 60 kW model is planned for release by the end of 2003.

There are approximately 60 Ingersoll-Rand units operating with the high time Model 70 unit in operation for about 1.5 years. The 250 kW model was released in late 2002.

Turbec has delivered over 160 units with the high time unit having reached over 15,000 operating hours. Over 90% of the units are in Europe with only a small percentage in the U.S.

To date, the primary problems have been with the power electronics, core (bearings and recuperators) and gas compressors (when used).

[2] USA

The primary applications for microturbines are combined heat and power (CHP), peak shaving, power-only, power quality/power integrity, and niche resource recovery. In addition Capstone has entered the hybrid electric vehicle market with units to server as battery chargers for electric-drive buses.

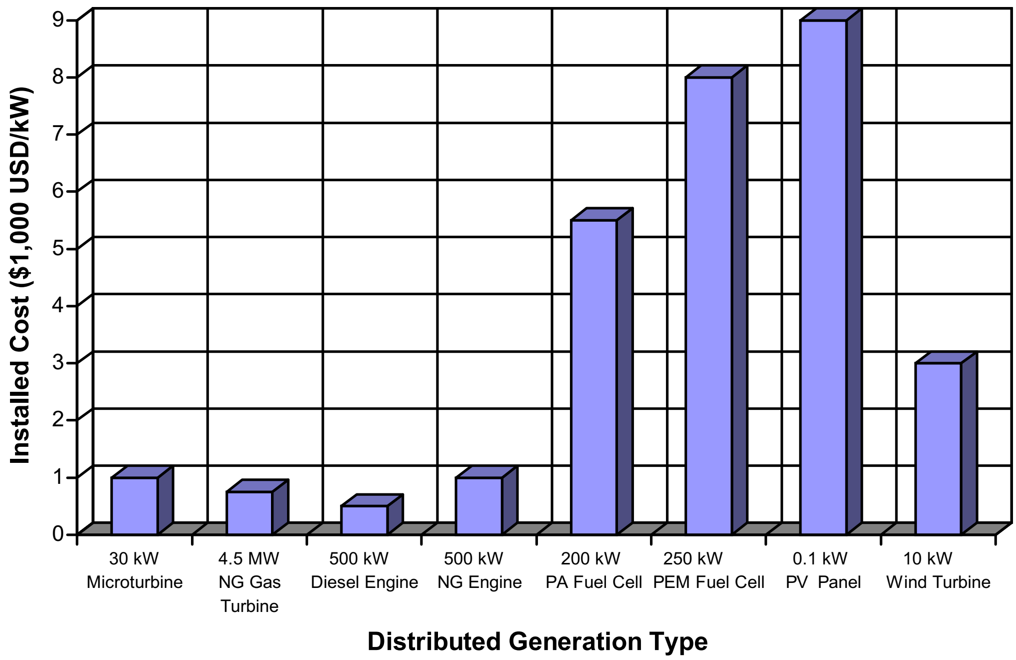
In general, the market expectations in these areas have been quite high but actual sales have been lower. At one time, the production estimates ranged from 6,000 to 12,000 units per year; unfortunately, the market did not respond. Capstone is the leader and roughly accounts for over 75% of the market. Capstone shipped its first 3 units in 1998, 211 units in 1999, 790 units in 2000 representing about 19 MW, and 38 MW's of units in 2001. Total sales for 2002 have yet to be reported 12.7 MW's of units were shipped by midyear with 24-34 MW estimated for the total year. Other manufacturers' production plans are in the 200-500 units per year range.

Phenomenal growth has not been experienced even though Distributed Generation is being touted in many areas as a way of increasing electrical capacity while not having to make major infrastructure changes to fuel supplies, transmission and distribution systems. Current market forecasts conducted for the U.S. Department of Energy are estimating 11.700 MW for CHP, 17.600 MW for peak shaving, 2,600 MW for power only, and 3,500 MW for waste fuels and oil/gas industry applications. These reflect a share of the total economic potential market for these applications where the value proposition for microturbines is good.

Even so, the difficulty for microturbines is that they are high priced compared to some other technologies. A comparison conducted by the California Energy Commission for different Distributed Generation equipment types is shown in Figure 3. As usual, the larger $/kW capital costs apply to smaller size units and while the larger $/kW capital costs apply to smaller units, fuel cells are currently exceptionally expensive.. The net result is that microturbines are more expensive on a $/kW basis than internal combustion engines (diesel and natural gas (NG)) and most gas turbines. Fuel cells (PA and PEM types), photovoltaic (PV) systems, and small wind turbines are much higher. It is noted that the installed cost of large wind turbines (1MW and larger) is about $1,000 USD/kW.

Figure 3 – Comparison of the Capital Costs of Distributed Generation Types

(Courtesy of the California Energy Commission)



[3] Japan

Hitherto, even for the decentralized energy system of less than 100 kw, a boiler/turbine engineer must be stationed when installing the system, constituting one factor of interfering the popularization of micro gas turbines. However, in April 2001, the regulation was relaxed, and in the case of the system of 100 kw or lower, the boiler/turbine engineer is no longer required to be stationed, and the adoption by convenience stores, buildings and small-size offices is expected.

a) Examples of adoption by convenient stores, fast food restaurants and hotels

In stores of one of the leading convenience store chains, demonstration tests of micro gas turbine/cogeneration air-conditioning system has been underway as part of a promotion of energy saving.

This system is an air-conditioning system utilizing energy generated by home-generated energy and waste heat with city gas used as fuel, and the total energy efficiency is as high as 70-80%, and it is expected to reduce the yearly electric power cost by about 30%.

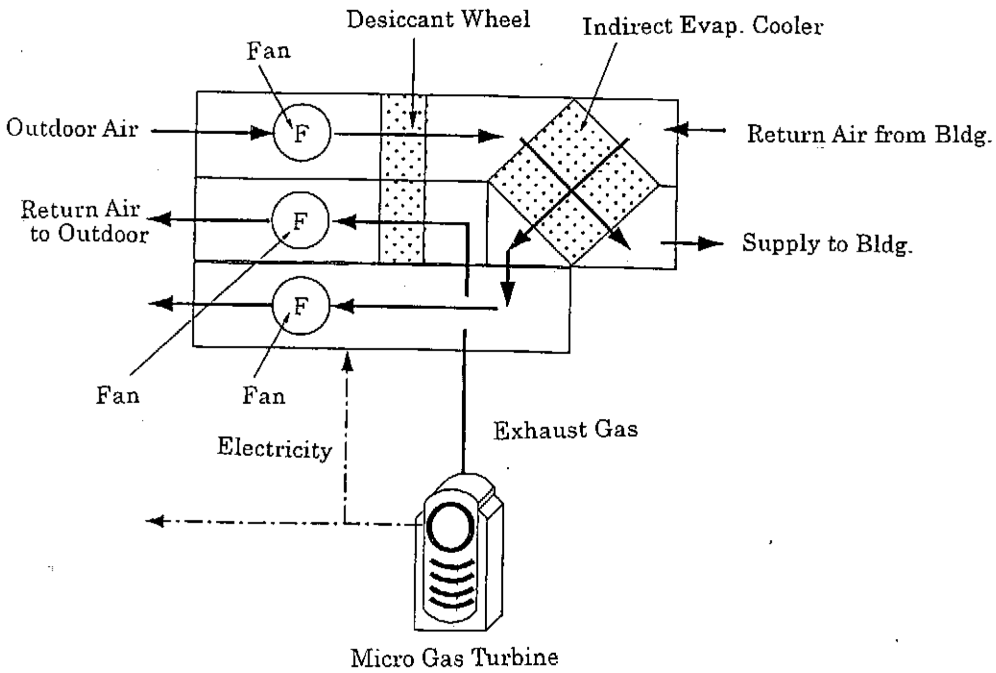
Also one of the major fast food chains started demonstration tests of micro gas turbine/co-generation system has been underway setting those systems on the roof of their fast food restaurants.

Figure 4 Example of adoption by fast food restaurant

b) Examples of adoption by combination with desiccant air-conditioner

As summer in Japan is very warm and humid, in order to utilize the waste heat more a co-generation system combined with a desiccant air-conditioner has been developed and commercialised. The system air-conditions by allowing the absorbent material to absorb the moisture content in ambient air and lowering the humidity inside the room, and waste heat of the micro gas turbine is utilized for drying the absorbent material which has absorbed the moisture content. As illustrated, a dehumidifying rotor located at the centre of the air-conditioner slowly rotates, absorbs the moisture content of high-temperature high-humidity air present outside the room and deprives latent heat to lower the temperature.

Figure 5 Examples of adoption by combination with desiccant air-conditioner



III. Development in Technology

1. It is said that the turning point of putting micro gas turbines into practical use is found in the severe environmental regulation of California State established in 1990. This is a severe control for exhaust gas of automobiles, which California Air Resources Board established as a means for atmospheric scavenging, and makes it compulsory for each automaker to include zero-emission vehicles in automobiles sold at a specified ratio. However, this regulation was slightly relaxed, and in 1998, not only zero-emission vehicles but also partial zero emission vehicles (PZEV) were accepted. Under these conditions, gas turbines with a low NOx discharge level are re-examined in comparison with the development of electric vehicles which have a big problem of battery performance. The gas turbines are requested to reduce output to scores of kilowatts as well as to reduce the size, and it is said that this laid the technical base of present micro gas turbines.

2. Structural and Technical Features and Advantages of Micro Gas Turbines

(1) Extremely high rotating speed

Because in general, engines and turbines increase output as the rotating speed increases, it is possible to reduce the size by increasing the rotating speed. The biggest factor that has enabled micro gas turbines to be dramatically downsized lies in the achievement of super-high-speed rotations of 96,000 rpm, which have never been achieved with conventional power generation gas turbines (rotating speed of conventional GT is supplemented). The use of air bearings can be mentioned as the big factor.

(2) Compact engines

Because the regenerator is located as if it enwraps the turbine, combustor, etc., the engine proper is microminiaturized. Furthermore, since high-temperature portions of turbine section and combustor are separated from the engine surface layer by the regenerator whose temperature is lower than those, it achieves an advantage of suppressing the loss by heat radiation from the engine surface.

In addition, since it is a single-shaft solid rotor, no speed reducer is required. In addition, because the generator is of a permanent magnet system and no exciter is present, extremely simple and compact design has been achieved.

(3) Small-size and maintenance-free because of small number of accessories.

Because not only the engine itself is compact but also less number of accessories are equipped as compared to conventional internal-combustion engines, and lubricant equipment, cooling apparatus, etc. are no longer required by the adoption of air bearings, the number of parts is remarkably reduced, and the simple structure and downsizing as well as maintenance-free operation have been achieved.

(4) Turbine inlet temperature

In micro gas turbines, it is not suited to adopt expensive heat-resistant material from the viewpoint of economy, and it is difficult to provide complicated cooling channels inside the blade because the blade itself is small. Therefore, turbine blades are designed using metal-based turbine material to stand about 800-900°C, which is the limit at which turbine blades can be used without cooling.

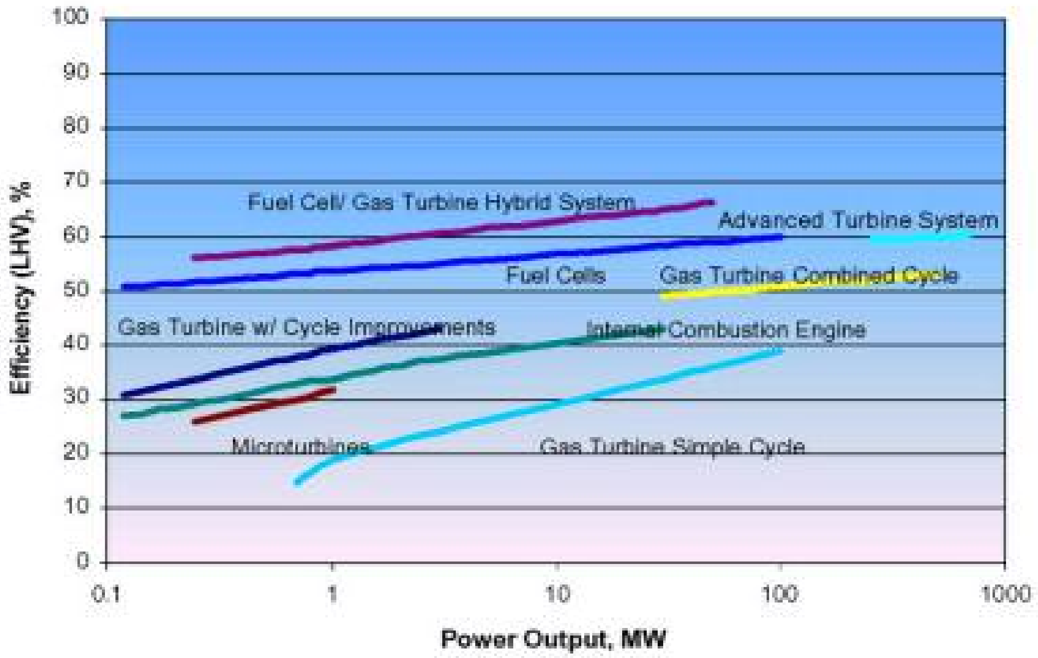
(5) Compressor

A centrifugal type single-stage compressor with a simple structure is used, in which the pressure ratio is set to about 3 to 4. This is assumed to be best suited for micro gas turbines because it has advantages of high pressure ratio per stage, small loss of efficiency due to downsizing, simple construction, and low price.

□□□ High power-generating efficiency by adopting regenerating cycle

The efficiency of microturbines is quite low as compared to other technologies and components. This is exemplified in the graph of efficiency versus size in Figure 6. Typically, microturbines efficiencies are in the 22-28% (net) when the power required for driving gas compressors is considered. The lower efficiencies are the result of microturbines operating at low compressor pressure ratios (nominally 4:1) and low firing temperatures (< 871ºC/1,600ºF) as compared to industrial and utility gas turbines which operate at pressure ratios from 12:1 to 30:1, utilize firing temperatures from 1093ºC (2000ºF) to 1500 ºC (2732ºF), and achieve net cycle efficiencies of 28% to 42%. Without the recuperator to heat the compressor air, the microturbine efficiencies would be reduced by 5-10% depending on the model.

Figure 6 – Comparison of Microturbines with Different Technologies/Components (Courtesy of the National Energy Technology Laboratory, U.S. Department of Energy)



(7) Outstanding environmental characteristics

Nevertheless, microturbines have found applications in several industry segments – combined heat and power (CHP), peak shaving (500-2,000 hours per year), power-only in high electric price areas, power quality/power integrity, and niche applications in resource recovery (landfills, municipal waste locations, small gas wells, oil extraction, etc).

The economic benefits of microturbines are substantially improved when the turbine is used in combined heat and power applications. This results in efficiencies from 69% to 85%. Similarly, where the cost of fuel is free (i.e., landfills, wells), the economics are good although fuel content and quality can have an effect on the reliability, operations and maintenance costs. For other applications, it is highly dependent on the economic difference between current systems energy costs and the cost of using a microturbine with CHP.

The other advantage of microturbines is low emissions. The emissions performance of the various model microturbines, based on their published literature, is indicated in Table 1. While the concentration of emissions production (i.e., parts per million volumetric (PPMV)), is not much different than industrial and utility gas turbines, the total mass produced per megawatt hour (lbm/MWh) is quite small. As such, it is an environmentally friendly application as compared to larger gas turbines and reciprocating engines, regardless of the fuel type, and has found applications in hotels, apartment buildings, office buildings, hospitals, nursing homes, laundries, retail stores, greenhouses, and small industrial manufacturers,

Table 1 – Comparison of Emissions Performance of Microturbines

Mfr	Model	Rating*	NOx Emissions*		CO Emissions*	
			PPMV	LBM/MWh	PPMV	LBM/MWh
Capstone	C30	30 kW	< 9	< 0.49	< 40	Not Available
	C60	60 kW	< 9	< 0.49	< 40	Not Available
Elliott Energy Systems	TA-80	80 kW	< 25	Not Available	< 30	Not Available
	TA-100	100 kW	< 20	Not Available	< 40	Not Available
Ingersoll-Rand Power Works	70 SM 70 LM	70 kW	< 9	< 0.413	< 9	< 0.252
	250 SM	250 kW	<9	< 0.413	< 9	< 0.252
Turbec	T100CHP	105 kW	< 15	Not Available	< 15	Not Available

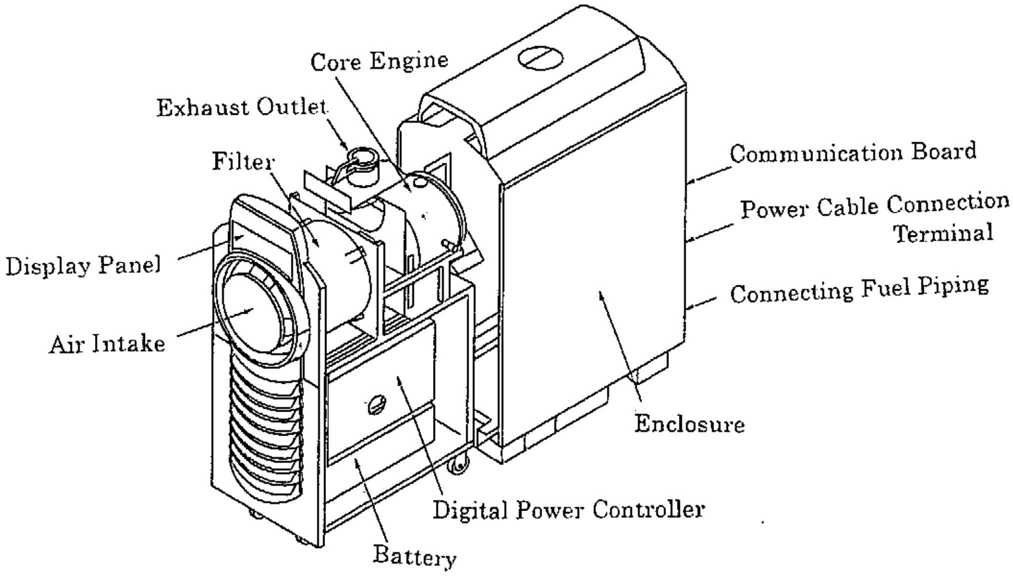
* ISO Day, Corrected to 15% Oxygen

3. Construction of a Micro Gas Turbine

(1) Overall construction

A micro gas turbine is generally divided into a core engine section comprising a generator, compressor, turbine, combustor, and regenerator, power controller which takes charge of power conversion (converting high-frequency a. c. power generated in the generator to commercial power frequency) and automatic control of the micro gas turbine, fuel feeder, and air filter for combustion.

Figure 7 - Configuration of Micro Gas Turbine



As clear from the figure above, an air intake port and filter are arranged in the axial direction of core engine section, and exhaust gas discharged from the turbine passes the regenerator arranged in a form to concentrically wrap in the turbine, combustor, etc. and is discharged from the top of the enclosure to the outside of the apparatus. At the bottom of the apparatus, a digital power controller and fuel feeder are located. Since all the components are housed inside the enclosure as described above, the apparatus is designed compactly and conveniently to be operated only by connecting fuel piping, power cable, and exhaust gas tube.

(2) Specifications of major type of Micro gas turbine

There currently are four manufacturers of microturbines. These include Capstone Turbines, Elliott Energy System (Ebara), Ingersoll-Rand, and Turbec (joint venture of Volvo and ABB). Two manufacturers have withdrawn or changed their approach to the market. Allied Signal/Honeywell has withdrawn and bought back its 75 kW Parallon model from the market after producing approximately 330 units through 2000. Pratt & Whitney is pursuing joint efforts with Capstone Turbines and has halted development of their 400 kW microturbine program with DTE Energy Technologies. The ratings, performance, and model characteristics of the current manufacturers are summarized in Table 2.

Table 2 – Summary of Current Microturbine Manufacturers and Models

Mfr	Model	Rating*	**Efficiency @ LHV *,****	**Heat Rate* (LHV)**	**Exhaust Temp. ***	Speed (RPM)	Type	**Comments**
Capstone	C30	30 kW	26% +/- 2	13,800 kJ/kWh (13,100 BTU/kWh)	275ºC (530ºF)	96,000	Single Shaft with 2 Pole PMG	Air bearings
	C60	60 kW	28% +/- 2	12,900 kJ/kWh (12,200 BTU/kWh)	305ºC (580ºF)	96,000	Single Shaft with 2 Pole PMG	Air bearings
Elliott Energy Systems	TA-80	80 kW		12,900 kJ/kWh (12,200 BTU/kWh)	288ºC (550ºF)	68,000	Single Shaft with 4 Pole PMG	Oil bearings; Oil cooled generator
	TA-100	100 kW		12,230 kJ/kWh (11,600 BTU/kWh)	279ºC (535ºF)	68,000 (Est.)	Single Shaft with 4 Pole PMG	Oil bearings; Oil cooled generator
Ingersoll-Rand Power Works	70 SM 70 LM	70 kW	28%	14,9280 kJ/kWh (13,550 BTU/kWh)	232ºC (450ºF)	44,000 for Power Turbine	Two Shaft	Oil bearings; Indoor units only
	250 SM	250 kW	32%	11,600 kJ/kWh (11,000 BTU/kWh)	260ºC (500ºF)	Not Avail.	Single Shaft	Oil bearings
Turbec	T100 CHP	105 kW	30% +/- 1	11,990 kJ/kWh (11,371 BTU/kWh)	85ºC (185ºF) @ water heater exit	70,000	Single Shaft with 2 Pole PMG	Oil bearings Sold only with water heater. Indoor only

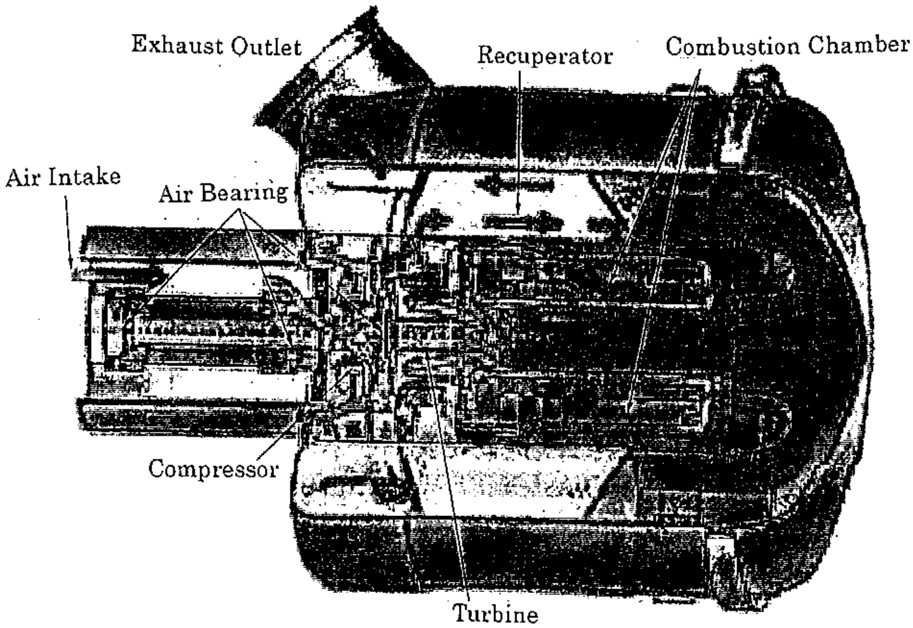
* ISO Standard Day ** Efficiencies generally do not take into account power for gas compressors (1-2% less)

(3) Core engine

The core engine comprises a compressor, combustor, turbine, regenerator, and generator. The air sucked from the left in the figure below passes the generator and is guided to the compressor. The compressed air compressed to pressure ratio of about 3.7 passes the regenerator on the circumference, is mixed with fuel and combusted in the combustor, becomes high-temperature high-pressure gas of about 840°C, expands in the turbine, and rotates the turbine to produce motive power. The high-temperature exhaust gas discharged from the turbine enters the regenerator and is discharged from the top after exchanging heat with compressed air.

As clear from the figure below, since the regenerator is arranged as if it wraps the turbine combustor arranged around the turbine shaft, there is no piping between components, thereby microminiaturizing the engine proper. In addition, since the high-temperature portion of the turbine section and combustor are separated from the engine surface by the regenerator whose temperature is lower than those, there is an advantage in that loss by heat radiation from the engine surface can be suppressed.

Figure 8 - Configuration of Core Engine



(4) Single-shaft solid rotor

Because the turbine, compressor, and generator are all integrally installed on the same shaft, no speed reducer is required. In addition, since the generator is of a permanent-magnet system, no exciter is installed, thereby enabling remarkably simple and compact design.

(5) Air bearing

As features of micro gas turbine bearings that support high-speed rotation, development and use of air bearings can be mentioned. The air bearing allows the shaft to float by the use of air pressure generated by rotations.

In the conventional GT and automobile engines, lubricants were used, but as the apparatus size is reduced and the speed is increased, problems of influence of increased friction on the efficiency and maintainability as well as durability resulting from metal touch in bearings were focused. As against this, since air bearings do not come in contact with the shaft, frictional resistance can be reduced to the utmost limits, and at the same time, the lubricant system can be eliminated, which requires troublesome handling from the viewpoint of maintenance and disaster prevention. The viscosity coefficient of air is in the order of 1/1,000 of lubricant, and as compared to conventional oil-lubricated bearings, loss and heat generation caused by friction scarcely occur. Consequently, in the case of high ambient temperature or very low temperature, there are cases in which efficient operation is disabled due to the problem of lubricant viscosity in the case of oil-lubricated bearings, but air bearings are free of this kind of problem, and a wide application range to the surrounding environment can be mentioned as one of the advantages of air bearings. In addition, no inspection and replacement of lubricants are required and no maintenance is required, either, and the maintenance cost can be thereby held low. Troubles hardly occur in the air bearing proper but should any trouble occur, damage could be limited to the surface between the bearing and the shaft, and can be easily met by replacement or repair.

(6) Generator

The adoption of permanent magnet and the use of combustion air for cooling the generator can eliminate the exciter and cooling water required for regular generators. The reason why permanent magnet is used is that it is difficult to fix the coil to prevent it from jumping out from the rotor due to centrifugal force generated by high-speed rotation, when electromagnet is used for generating the magnetic field as is the case of conventional type of generators. In addition, because the high-frequency a. c. power generated is converted into direct current by a converter, which is then converted into commercial frequency (50 Hz or 60 Hz) by the inverter, there is no need to achieve the synchronizing speed for the generator. Consequently, a speed generator or a speed reducer for controlling rotating speed is no longer required, and mechanical loss can also be suppressed. In addition, this enables the rotor to be arranged on the same shaft (generator, compressor, and turbine are of the one-shaft solid type). Furthermore, since this generator also serves as a motor for starting, it has also a feature of requiring no starter which is required for regular gas turbines.

□. Major perils and Loss Experience

From an insurability standpoint, microturbines present unusual risks. The typical normal loss event (NLE) would generally be failed fuel valves, minor control issues, and bearings. However, given the speed of these units and that bearing failures result in significant damage to the rotors (generator, compressor and turbine), consideration has to be given to setting this event to represent probable maximum loss (PML) events. For microturbines, the replacement costs for the generator, gas turbine and recuperator are typically 40-50% of the cost of the capital cost of the unit. In addition, power electronics failures are more significant that minor control issues and consideration for these failures have to be given to setting values near PML levels. The replacement cost for the power electronics is typically 40-50% of the capital cost of the unit. As such, regardless whether the generator, gas turbine and recuperator unit fails or whether the power electronics fails, PML costs will be on the order of 40-50% of the replacement costs.

From a business interruption standpoint, replacement of the generator, gas turbine, and recuperator or the power electronics can be accomplished in 8-24 hours once the troubleshooting and replacement parts are on site.

□. Conclusion and Outlook

It can be concluded that the micro turbine is, in short, a supercharger, high-speed generator, and heat exchanger when individual elements are taken up and discussed, and is a compilation of existing technologies only, with no inexperienced elements such as new cycle, material, etc. included. However, because of its small size, the micro turbine provides extremely high rotating speed, blades may be broken due to defects in design, material, and workmanship, or defective maintenance and spillover damage to casing and ancillary equipment may be feared. Furthermore, because of its small size, should any accident occur, it is highly possible that total loss results.

In addition, micro gas turbines (MGT) are frequently used for co-generation, and may be located below waste-heat boilers, which have a risk of water leakage, and this kind of risk cannot be realized until such accident actually occurs.

Furthermore, since micro gas turbines are popularly used as generating facilities of auto producers, spending of additional charge such as cost for purchasing electricity for backup power when accident occurs would be considered as a characteristic risk.

With several problems involved as described above, development of micro gas turbines would be further intensified, such as popularization of micro gas turbine cogeneration and improvement of power generation efficiency, because effective use of energy will be more and more required for achieving the CO_2 reduction target. With respect to the improved efficiency, because low NOx combustion technology would become the problem as the temperature increases, investigation should be made on the development of catalytic combustion technology which provides a high potential of achieving low NOx, in addition to the conventional premixed combustion system. In addition, a development project for aiming at the power generation efficiency exceeding 60% by hybrid power generation combining micro gas turbines and fuel cells is now underway.

In the future, popularization of the decentralized energy system centering on MGT will be received with open arms, but on the other hand, we must be keen to see the appearance of new risks.

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