TAKUMI

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Select Japanese Skills

A promising technology for powering humanoid robots?

Development of an Ultra-compact Gas Turbine Capable of Generating Large Amounts of Power Anywhere

Photography: Satoru Naito /Interview and Text: JQR

Kosuke Isomura, Engineering Head, Corporate Business Development Division, IHI Corporation
Dr. Isomura's extensive range of R&D experiences includes the development of micro energy and the development of aircraft engines. His current focus is the commercialization of his ultra-compact gas turbine.

Gas Turbines are what power jet engines and electricity generation plants. They are capable of producing extremely large power outputs, but their gigantic size has prevented them from entering our everyday lives, and few people are personally familiar with the technology. If gas turbines could be reduced in size to the point we could handle them with ease, and this miniaturization could be achieved without compromising power output, gas turbines would offer tremendous benefits and serve as a valuable power source. I heard the news of the recent development of an ultra-compact gas turbine of unprecedented size. This was the brainchild of IHI Corporation, a company that played a key role in Japan's post-war industrialization as a champion of heavy industries.

I was ushered into a reception room at IHI's headquarters in Toyosu, Tokyo. I asked Dr. Kosuke Isomura, Engineering Head of IHI's Corporate Business Development Division, if I could take a look at this gas turbine. I thought I would be escorted into a lab or workshop to view the machine in operation, but instead Dr. Isomura pointed to a duralumin case in the corner of the room. "Over there," he said matter-of-factly. The case housed an ultracompact gas turbine power generation system. I was pleasantly surprised to see a gas turbine at work in an ordinary place like a reception room.

The metal mass with a dull shine on it in the front center of the case was the gas turbine. As Dr. Isomura turned on some switches in succession, the machine emitted a shrill sound. This noise was almost completely removed by noise cancellers and the sound of the cooling fans placed on both sides of the case, but the shrill definitely resembled the sound of a jet engine. In the meantime, the revolution speed of the turbine rapidly increased. When it reached 400,000 revolutions per minute, Isomura flipped the switch for some electric bulbs, and voila, the bulbs began emitting glaring light in an instant.

"The output you witnessed just now was 200 watts, but the system is designed to generate up to 400 watts," Dr. Isomura explained. "It can achieve up to 470,000 revolutions per minute on a stable basis."

The sliver case became very hot as I listened to his explanation. But the heat wasn't accompanied by any unpleasant noise. The gas fed into the system came from a cartridge-type compressed gas cylinder of a type often used on hiking trips.

Aiming to become a power source for robots

ASIMO and a score of other robots are currently being developed. One of the challenges faced by robot developers is finding suitable batteries, and this issue will become increasingly pronounced as development reaches more advanced stages.

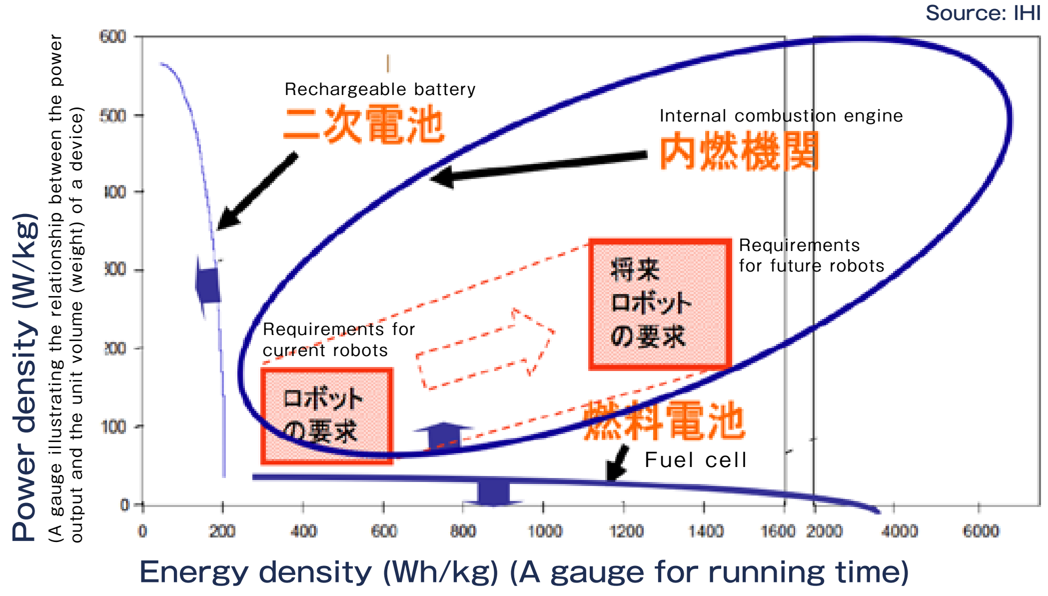
"ASIMO, as it is now, requires about 500 watts of power. Developers are so preoccupied with researching visual cognition and movement that they pay little attention to the battery systems. They just make do by using the batteries currently on the market. You take one of these batteries, charge it for half a day, and your robot will only work for thirty minutes or an hour. Imagine a robot on a disaster rescue mission running on this battery. If it lasts for only an hour, it may attract some curious attention, but it definitely won't do much good. A humanoid robot that can assist people needs a battery capable of providing power all day."

According to Dr. Isomura, an energy density of around 500Wh/kg or a power density of around 200W/kg would be the minimum requirement for a robot capable of performing human tasks for a few hours on a continuous basis. This energy requirement is best met by an ultra-compact gas turbine, as it does not suffer the disadvantages of rechargeable batteries (lithium-ion batteries) such as low running time despite high power density, or fuel

In addition to the turbine placed in the front center, the photo also shows the fuel feed (upper right), the controller (upper left), and an air inlet and a noise canceller to the right of the turbine and another noise canceller on the left.
The entire system including the case weighs about 13 kilograms but further miniaturization will reduce the size of the case by half and slash the weight to eight kilograms.

Characteristics of Power Sources by Type

Source: IHI



Neither rechargeable batteries nor fuel cells can fully satisfy the dual requirement of high current and long running time needed for robots. All internal combustion engines, including gas turbines, can satisfy the dual requirement. However, gas turbines emit no exhaust gas, making them the most promising solution for use in sealed environments such as indoor areas.

cells, whose substantial weight makes them unsuited for mounting on robots.

Advantages of gas turbines

One of the most common internal combustion engine mechanisms is the reciprocating engine found in motor vehicles. It converts fuel into pressure, which in turn forces pistons in cylinders to move and rotate the crankshaft. Energy is extracted in the form of crankshaft power. In contrast, the gas turbine mechanism converts thermal energy into kinetic energy by directing the gas flow through a nozzle, and the high-speed thrust generated in the process rotates the turbine with its impact and reactive forces. The main difference between the two is that the former mechanism is based on intermittent combustion while the latter relies on continuous combustion.

“Reciprocating engines invariably result in uncombusted gas, as the temperatures attained by the mechanism vary widely. In contrast, the temperatures obtained by gas turbines are more stable, and this stability allows us to concentrate primarily on the points in the structure where we would ordinarily focus and design the system in accordance with heat loss trends and the distribution of temperature.”

Moreover, friction losses are an unavoidable and unchangeable characteristic of reciprocating engines. In gas turbines, the rotor itself is not in contact with anything except the bearing, and the friction caused by this contact can be eliminated altogether with the use of an air bearing, which allows the rotor shaft journal to be suspended in the air.

The quest for an ultra-compact gas turbine began in 2000 as a study project in collaboration with Tohoku University. The key challenge the team faced from the start was the number of revolutions produced at the bearing. The performance of the system depended upon the speed achieved at the outermost part of the moving component.

Development of ultra high-speed bearings

Suppose a rotor with a diameter of one meter is replaced by a rotor with a diameter of one centimeter. In order to obtain the same effect, the one-centimeter rotor must rotate 100 times faster. In other words, if a jet engine capable of 10,000 revolutions per minute (RPM) is reduced to a hundredth of its original size, the downsized engine has to be equipped with bearings capable of rotating the one-centimeter rotor at 1,000,000 RPM in order to achieve the same effect.

“There was no bearing that met this requirement at the time, so our first step was to develop appropriate bearings,” explained Dr. Isomura.

He succeeded in creating a bearing capable of achieving a rotor speed of 870,000 RPM after five years of development, but it did not work without a large external power source. Then a U.S. venture came to his rescue with a foil bearing capable of rotating by pulling the air into the empty space next to it.

“The foil bearing mechanism causes only the center of the shaft to rotate. The interior of the cylindrical housing of a foil bearing is lined with spring-loaded bump foil that looks like a series of wave-like semi-circles, and another layer of spring-loaded foil rests on the peaks of the waves forming a circle. A shaft is placed through the interior of the bearing, and as the bearing begins to spin, the viscosity of the interior surface draws air into the space and leaves the journal of the shaft suspended on a thin layer of air. The spring construction of the foil has the effect of stabilizing the air layer, which may be as thin as five to six microns, allowing the journal to be suspended in the air.”

A development project based on this foil bearing technology began in 2007, and Dr. Isomura devoted most of his time to creating the bearing through to 2011. The next challenge concerned temperatures.

“As a heat engine, the system should support temperatures that vary at different points within the structure. For instance, the maximum temperature at the exit of the combustion chamber reaches as high as 900 degrees Celsius, while the temperature remains at around 20 degrees Celsius at the coldest point at the inlet of the compressor. In a large engine, the distance between the hottest and the coldest points might be as much as a meter, but I was trying to create an ultra-compact engine where the two points were within a centimeter of each other.”

The main body of a palmtop gas turbine. A power output of 400W and rotation speed of 400,000 RPM is achievable. In addition to propane gas, it has run successfully on light oil and kerosene. Theoretically, bio fuels could be used as well. The photo on the left shows a gas turbine with a heat exchanger, which elevates the heat efficiency to a level equivalent to that of a gasoline-powered engine.

Dr. Isomura successfully developed ultra-compact gas turbines that met the aerodynamic requirements. However, heat transfer is based on the material being used. How did Isomura overcome this challenge?

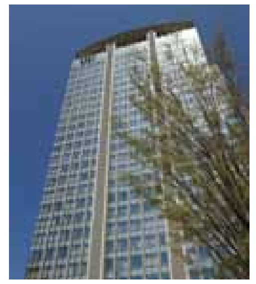
“I discovered a method to block heat using a layer of air, and together with simulation technology developed with the help of MIT and the University of Tokyo, I was able to devise a way to ensure stable rotations in a small turbine.”

Manipulating heat with a thin layer of air

“People thought my attempt would end in failure because there was no prior technology based on the same approach,” Isomura told me with a laugh. My question was: how does a layer of air affect the temperature of a material? He declined to provide specific details due to the trade secrets involved, but did give me some hints.

“I started out by asking: how can I bring in air from somewhere to serve as a coolant, form it into a thin layer and circulate it to block heat? Well, one approach would be to create a narrow air passage in the wall that separates the turbine and the generator. This was the idea behind our development project. Our goal was to design a mechanism that would ensure consistent airflows from the lower temperature zones to the higher temperature zones while efficiently removing the heat along the way. Because the passageway is so narrow, temperatures cannot be measured at most points, but based on the limited areas where temperatures can be measured, we ran calculations and devised an air flow simulation model that allows for the prediction of the thermal flow and thermal transfer. This simulation allows us to guess the likely temperature distribution inside the passage based on the temperatures measured at those select points.”

If commercialized, ultra-compact gas turbines will doubtlessly be useful as lightweight power generators free of harmful or unpleasant exhaust and loud noises. Perhaps humanoid robots powered by improved ultra-compact gas turbines will become a reality one day, empowering humans with their non-stop assistance. I am looking forward to the progress made in the development of ultra-compact gas turbines with great interest and high expectations.



IHI Corporation
Toyosu IHI Bldg. 1-1,
Toyosu 3-chome, Koto-ku, Tokyo
Phone: 06-6204-7800 (Main)
http://www.ihi.co.jp