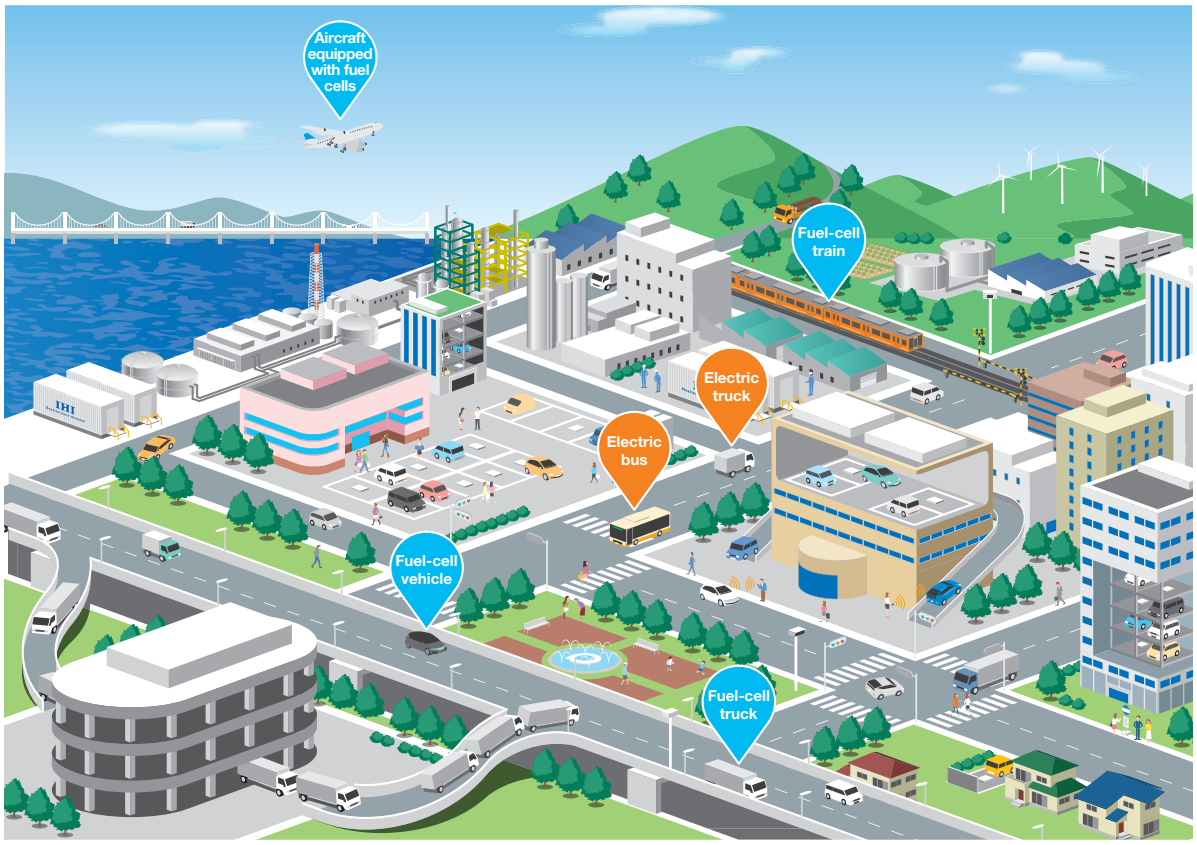
Striving to Realize a Sustainable Mobility Society

Oil-free motorized turbocharger effectively utilized in an air supply system for fuel-cell vehicles

We have developed a motorized turbocharger for fuel-cell vehicles, the environmentally friendly cars of the future. Leveraging our unique oil-free device technologies, electrical machine technologies, and thermal management technologies, we have realized a small lightweight air supply system that supplies air (oxygen) necessary for fuel cells to generate electricity. We have successfully brought this product to market as a key component of passenger fuel-cell vehicles, thus contributing to the realization of a mobility society in which clean energy is used effectively.



Sustainable mobility society in which clean energy is used effectively

The sustainable mobility society

Cars, trains, ships, aircraft, and various other vehicles are effective means of providing mobility all over the world. Among these, cars have spread across the globe as a means to provide mobility with a high degree of flexibility. For example, we can go anywhere anytime by car. However, with the spread of cars, the atmospheric pollution caused by harmful gases and global warming caused by carbon dioxide (CO_2) have come to be seen as environmental problems throughout the world.

In Japan, the Ministry of Land, Infrastructure, Transport and Tourism announced that CO_2 emissions in the transportation sector (206 million t) account for 18.6% of

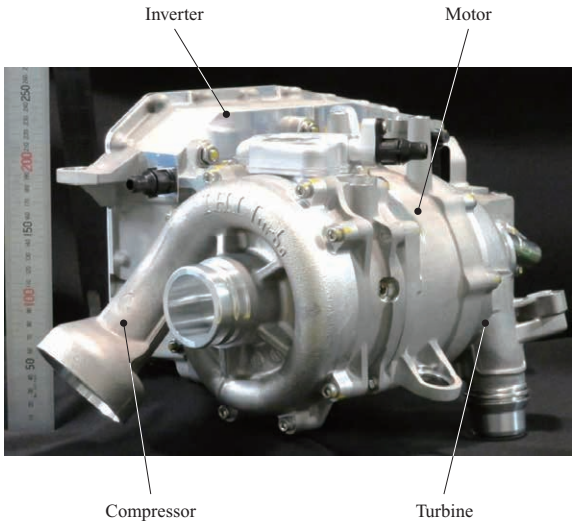
those nationwide (1.108 billion t). CO_2 emissions from cars account for 86.1% of transportation sector emissions.

Not to leave such problems to the next generation, people today must establish a sustainable mobility society with the aim of realizing a carbon-free society. Measures to solve environmental problems are being studied and taken around the world. For example, in California, U.S.A., Zero-Emission Vehicle (ZEV) program has come into effect. In France and the U.K., the sale of new cars powered by internal combustion engines will be banned by 2040. Given these circumstances, car manufacturers are fiercely competing to develop cars that have minimal environmental impacts — namely, electric vehicles (EVs), fuel-cell vehicles (FCVs), and plug-in hybrid vehicles (PHVs) — aiming to realize a sustainable mobility society.

The IHI Group is working to develop products that go beyond the boundaries of business fields by combining the rotating machine technologies we have developed for vehicle turbochargers and in the aviation and space fields with the power electronics technologies we have developed in industrial fields. We are making great efforts to develop a new market for turbochargers with the aim of contributing to the realization of the sustainable mobility society.

The promising fuel-cell vehicles

Hydrogen can be produced from a variety of primary energy sources. A reaction between hydrogen and oxygen can produce electricity without generating any harmful substances. Therefore, hydrogen is considered to be an excellent source of clean energy. FCVs are a type of car fueled by hydrogen; they have little environmental impact. In recent years, several car manufacturers have launched FCVs, which are gradually coming into use. However, we have cost- and infrastructure-related issues, such as a shortage of hydrogen stations, to be solved before widespread use of FCVs.



Oil-free motorized turbocharger

Meanwhile, FCVs have advantages such as the facts that they can be filled up with hydrogen faster than charging EVs and that they have a mileage comparable to that of conventional cars. This makes FCVs readily acceptable to users as vehicles that add no stress. Accordingly, not only passenger cars but also buses, trucks, forklifts, and many other vehicles equipped with various fuel cells are beginning to be put to work around the world.

This report introduces a motorized turbocharger developed by the IHI Group that is being employed in passenger FCVs. It also describes some of our unique technologies, including oil-free device technologies, leveraged based on our turbocharger development.

Overview of the new product

To enable fuel cells to generate electricity, air (oxygen) must be supplied to a fuel cell stack. The motorized turbocharger we developed is a rotating machine that works effectively as a main device in a system that supplies air to a fuel cell stack, and thus it serves as an important device for FCVs. This motorized turbocharger is comprised of a compressor, turbine, motor, and inverter.

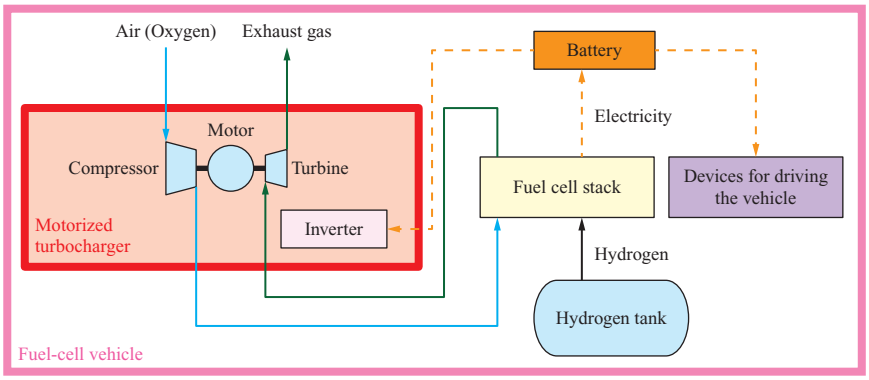
When an FCV is operating, a chemical reaction occurs in the fuel cell stack between air (oxygen) compressed in the motorized turbocharger and hydrogen supplied from a hydrogen tank. This generates electricity, which is used to charge the battery and drive the traction motor. The electricity accumulated in the battery is used for purposes such as driving the traction motor and driving the motorized turbocharger. The exhaust gas (moist air) generated by the chemical reaction is discharged externally after its energy is recovered by the turbine.

Features of the new product developed by leveraging IHI's technologies

This motorized turbocharger has many features, including the following.

(1) By employing a low-specific-speed impeller and a diffuser with vanes to improve efficiency at the operating point, we successfully increased the pressure inside the fuel cell stack, thus accelerating the chemical reaction between air (oxygen) and hydrogen. This enables the fuel cell stack to generate electricity with a high degree of efficiency while having a smaller size and lighter weight, thereby contributing to improved fuel efficiency, reduced cost of the fuel cell stack, and effective use of vehicle space.

(2) We equipped the motorized turbocharger with not only a motor but also a turbine, which recovers power from the exhaust gas emitted from the fuel cell stack, in order to reduce the motorized turbocharger's power consumption and to further reduce the size and weight of the fuel cell system as well as to further improve efficiency. Accordingly, efficiency across the fuel cell system's entire operating range as a compressor system was improved to



Flow of substances and energy in an FCV in operation

be about 1.5 times that of the efficiency of a compressor system with no turbine; therefore, this contributes to improving the fuel cell system's efficiency.

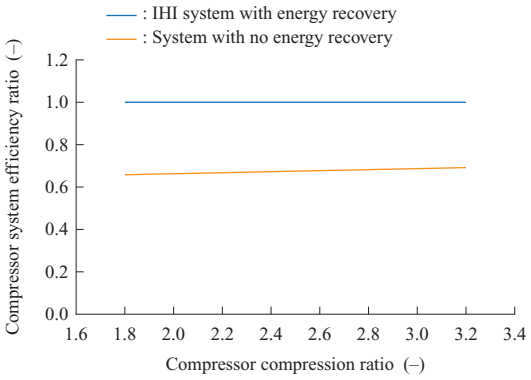
(3) The exhaust gas emitted from fuel cells contains much water vapor and water droplets. The motorized turbocharger has a motor, which is an electric device not found in ordinary turbochargers for engines. Even in such a special environment, devices must work properly. However, we cannot employ a lip seal or the like for the motor shaft because this motorized turbocharger is a machine that rotates at high speed, and such a seal generates heat in the area that is in contact with the shaft surface, which causes excess loss. In view of this, we worked to develop a motor coil manufacturing process, a mold filling process, and other processes; as a result, we succeeded in ensuring the dielectric strength and watertightness despite the special environment.

(4) To allow the exhaust gas containing water vapor and water droplets to flow into the turbine and to recover power from the gas, it is necessary to ensure airtightness between the motor and inverter. We ensured airtightness by connecting the motor and inverter using an easy-to-assemble connector to bring them together. We also ensured watertightness to prevent entry of water from the outside, thereby eliminating the problem we had faced in designing the product as an on-board device. This improved not only the power electronics' reliability but also productivity.

(5) Recently, there is growing demand for comfort and quietness in cars. While running, FCVs provide drivers with a much quieter environment than conventional cars. Nevertheless, there is demand for further noise reduction from on-board devices. This motorized turbocharger is a centrifugal turbocharger, so it emits less noise than a positive displacement compressor with an intermittent flow. The noise is 7 dB lower than that from IHI's positive displacement compressor. Thus, this motorized turbocharger contributes to ensuring comfort and quietness in cars.

(6) Small-sized motors rotating at high speed and delivering large amounts of power have a high heat density, and thus they require thermal management to achieve continuous operation. In this motorized turbocharger, heat is generated mainly by the ultra-high-speed motor, which has a high heat density. To cope with this problem, we adopted an effective cooling technique that uses cooling water and cooling air, which enables the motor to continue to run stably even at high speeds.

(7) If oil leaked from the turbocharger and reached the fuel cell stack, the stack would be poisoned and degrade in performance, and, in the worst-case scenario, be damaged. For this reason, the oil-lubricated ball bearings typically



Improved compressor system efficiency

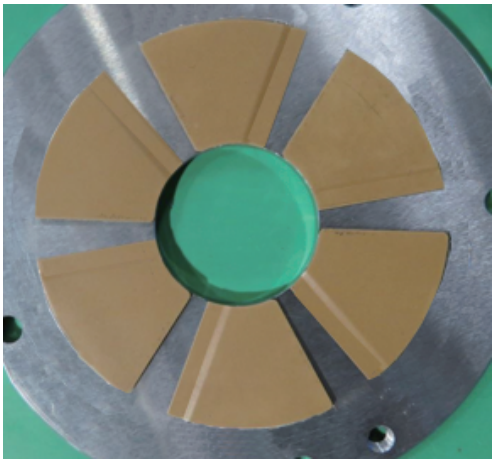
Watertightness evaluation

used in ordinary turbochargers cannot be used with this turbocharger. Therefore, we employed our own oil-free foil air bearing instead. With this air bearing, the shaft is supported by a low-viscosity air film and thus can be rotated stably with little loss even at high speed. This air bearing can be started even in a frozen state and can work even when a foreign substance has entered into it. Moreover, the bearing is maintenance-free because it uses no oil. In addition to these advantages, it is vibration resistant, meaning that it can work continuously even in an on-board environment.

The oil-free device technologies that the IHI Group has developed over many years improve the reliability of high-speed rotating machines and also contribute to reducing the size and weight of the motorized turbocharger.

(8) We have independently designed all elements of this motorized turbocharger, including the on-board inverter and control software, so that this product can fully meet the requirements specific to electric products, such as electromagnetic compatibility and electrical safety requirements. We can adjust all elements in-house. This has helped us to increase the concurrency of design and development as well as to improve development speed.

As described above, we have developed a motorized turbocharger that enables fuel cells to improve power generation efficiency and also itself to reduce power consumption thanks to compressed air supply, thereby making it possible to create a high-efficiency fuel cell system. In addition, by bringing the motor and inverter together, we have succeeded in making the turbocharger compact and safe as well as much quieter than positive displacement compressors. This contributes to achieving comfort inside the vehicle and makes the motorized turbocharger a high-value-added product. Thus, this motorized turbocharger is highly appreciated by our customers, attracting much interest and contributing to the spread of FCVs.



Newly developed air bearing

Towards the realization of a sustainable mobility society

FCVs powered by clean energy produced using hydrogen will undoubtedly be an attractive means to provide mobility as vehicles that can solve global environmental problems and that do not cause users stress. Car manufacturers are positioning FCVs as a leading next-generation means to provide mobility and expect such vehicles to come into widespread use not only as passenger cars but also as large commercial vehicles, which are required to have a long mileage and high power. The IHI Group continues to develop high-power-type motorized turbochargers that can be employed in large buses and large commercial vehicles in addition to those for passenger cars, such as this product. We will make efforts to this end by, for example, developing motors that rotate at higher speeds and deliver higher power, optimizing thermal management, and improving productivity.

FCV technologies are expected to be further developed for trains, ships, and aircraft as well as for industrial applications. These technologies will be advanced more in the future with the aim of realizing a hydrogen energy society. When the clean energy produced using hydrogen becomes a familiar type of energy and then means to provide mobility that effectively use clean energy become widespread around the world, diversified means to provide mobility will coexist amidst a low-carbon, recycling-oriented society in harmony with nature.

The IHI Group will continue to contribute to realizing a sustainable mobility society through manufacturing that leverages our technical capabilities.

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