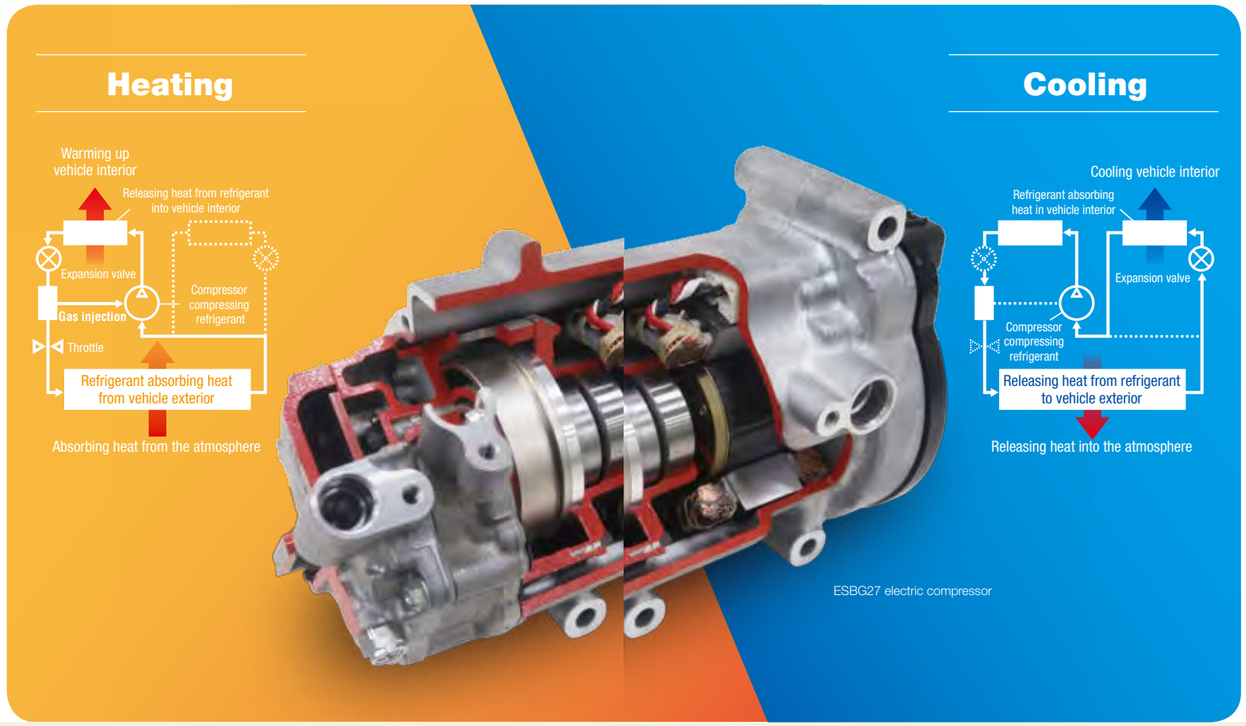
Special Feature 1

Development and Production of Car Air-Conditioning Compressors Geared toward the Age of Electric-Powered Vehicles Ahead of the World

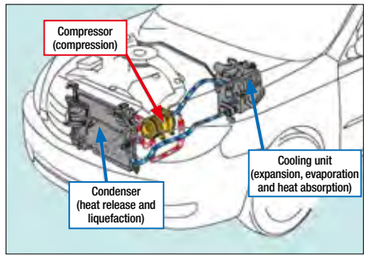
The new Prius Plug-in Hybrid (PHV) released by Toyota Motor Corporation (TMC) in February 2017 is fitted with the ESBG27 car air-conditioning compressor newly developed and produced by Toyota Industries. The compressor enables the vehicle's air conditioner to demonstrate sufficient heating capability under sub-zero temperatures while in EV mode that does not run the engine. It contributes to an improvement in both in-vehicle comfort and environmental performance.

Toyota Industries' Electric Compressors Sought after in the Age of Electric-Powered Vehicles

We have always remained the leader of the global electric compressor market, with our products constantly evolving with time. In the first-generation Prius hybrid vehicle (HV), our compressor was powered by the vehicle's engine, which was a cause of lower fuel efficiency because the engine had to be always turned on to operate the air conditioner. For the second-generation Prius, we took advantage of the HV's high-capacity battery and developed a compressor that was powered by a motor instead of the engine. This was the world's first electric compressor mounted on a mass-produced car. Following that, we released a compressor integrated with an inverter, which controls the motor's revolutions, and achieved reduced size, lighter weight and significantly easier vehicle mounting. Then, as HVs became ever more popular, we considerably improved the compressor's heating and cooling capability and operational quietness, for which we have earned high acclaim among many customers. Consequently, in April 2016, our cumulative unit sales reached a milestone of 10 million electric compressors.



How a Car Air-Conditioning System Works



What is a car air-conditioning compressor?

Heart of a car air-conditioning system, powered by the engine or a motor to compress refrigerant used for cooling vehicle interior

ESBG27 Offering Much Higher Heating Performance in EV Mode

A conventional electric-powered vehicle needs to operate both its air conditioner and electric heater to warm up the vehicle interior when the engine is not operating, such as in EV mode. This consumes a considerable amount of electricity, resulting in a shorter EV driving range.

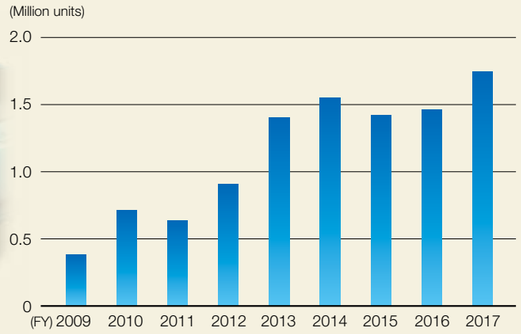
The new Prius PHV has adopted an air conditioner with a heat pump, which can efficiently warm up the interior on its own in a cold climate, even at –10°C, without using heat from the engine or an electric heater. This was made possible by our originally developed ESBG27, the world's first electric compressor with a gas injection function to be installed in a mass-produced car. The product has contributed to a longer EV driving range, greater fuel efficiency and higher in-vehicle comfort.

Toyota Industries Continuously Meeting Changing Customer Needs

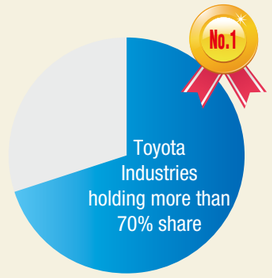
Toyota Industries offers a range of car air-conditioning compressors, from a compact, lightweight fixed-displacement type and a variable-displacement type with greater fuel efficiency for internal-combustion vehicles to an electric type for electric-powered vehicles. With this broad product lineup, we have satisfied the diverse needs of customers.

In recent years, enforcement of more stringent environmental regulations around the world and growing environmental consciousness among users have encouraged an increasing number of governments to implement a tax break program for electric-powered vehicles, including PHV, electric vehicles (EV) and fuel cell vehicles (FCV). These trends have spurred electrification of vehicles by automakers. Amid this environment, we have been leveraging our accumulated strengths in developing electric compressors that meet customer needs at a higher level and providing these compressors to automakers worldwide.

Electric Compressor Sales



World Market Shares of Electric Compressors



Survey by Toyota Industries Corporation (FY2017)

Development and Production of a New Electric Compressor Effectively Utilizing Our Accumulated Technologies and Know-How Matched to the Age of Electric-Powered Vehicles

The launch of production of the new ESBG27 electric compressor presented the world's first challenge for us to ensure stable mass production of the product that has become more complex with the addition of a gas injection function while maintaining a high level of quality.

Design, production engineering, quality assurance and manufacturing departments utilized their expertise in respective fields and closely collaborated to overcome issues one by one. As a result of their concerted efforts, mass production of the ESBG27 successfully commenced as planned in September 2016.

In this section, four key project members talk about efforts undertaken in each department and about the strengths of Toyota Industries underpinning its development capability.

Development Targets of the New ESBG27 Electric Compressor

Tsubai: Even though the development of the ESBG27 was officially launched in 2012, we actually started developing an electric compressor utilizing a heat pump for better heating performance in 2010, along with research into a gas injection method, anticipating market needs and more stringent environmental regulations. The overall goal was to achieve sufficient heating capability at sub-zero temperatures by using only an air conditioner. This objective was made in response to customer complaints that the conventional heating technique requires the engine to run and thus consumes more fuel. While keeping that goal in mind, we set high targets from a comprehensive viewpoint for operational quietness, power saving, compactness, weight reduction and cost benefits in developing this compressor.

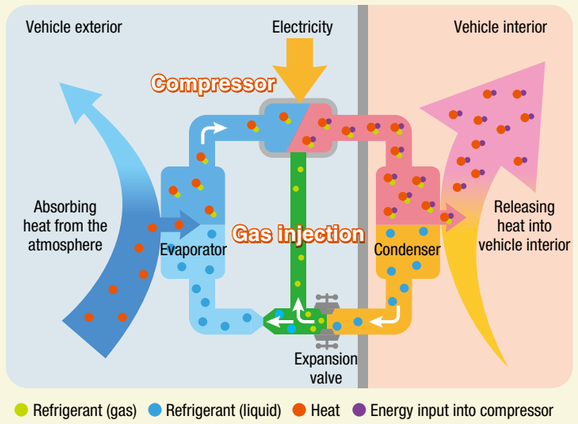
Shinji Tsubai
Group manager, Group No. 31, Engineering Office No. 3, Engineering Department, Compressor Division

Okagawa: In the area of production engineering, our work was to integrate two sets of additional processes into an existing electric compressor production line: one for mounting new structures and functions added to the ESBG27 and one for inspecting these. I remember that in the very initial stage of development when the product specifications were not yet finalized, project members from the four departments got together and examined every detail of the design drawings of the production line. It had to be easy for operators to work with, both in terms of assembly and inspection, and less prone to errors.

Yoshihiro Okagawa
Group manager, Electric Products Assembly Group, Assembly Production Engineering Office, Production Engineering Department, Compressor Division

Maeda: Our objective in the field of quality assurance was to establish processes to assemble components into a product in the simplest possible manner for reducing quality risks and preventing defects. Initially, the ESBG27 had a rather complex shape and structure, so we worked closely with members of the other three departments to make it simpler.

Heating by a Heat Pump with Gas Injection Function



The conventional heat pump heating technique shows lower heating performance in a cold climate, as it absorbs less heat from the atmosphere. The gas injection function serves to expand the possible heating temperature range by recompressing a portion of compressed refrigerant by a compressor.

Car air conditioner of the Prius PHV

Takayama: In terms of manufacturing, we also dealt with the addition of new processes resulting from an increase in the number of components in the ESBG27 through collaboration among the four departments. As a result, we were able to ensure that the new line allows operators to work easily and efficiently, eliminating the need for increased staffing.

Characteristics of the ESBG27 and Issues Associated with its Development and Manufacture

Tsubai: The adoption of a new "gas injection" mechanism in the ESBG27 imposed challenges such as creating a route in which refrigerant flows. But ultimately, we were able to achieve the targeted heating capability. The ESBG27 contributed to a nearly 30% increase* in the heating capability of the car air-conditioning system of the new Prius PHV in a cold climate. In recognition, we received the Technology Development Award from TMC. Of course, this was not an accomplishment of the design process alone; we all faced and overcame difficulties.

Okagawa: The most difficult challenge in the area of production engineering was to deal with an increase in the number of components used in the ESBG27 compared with our conventional electric compressors and integrate corresponding processes into a production line. We had to come up with the best way to incorporate processes to mount new functional components and inspect the proper functioning of these components. Working with the Quality Assurance Department, we devoted considerable efforts to determine reliable inspection conditions in order to assuredly perform a quality check during the limited time that components flow on the line and to define a method and level of inspection that can satisfy automakers.

Maeda: We should obviously challenge ourselves in pursuing higher performance in our compressors whether it is a new structure, new mechanism or new assembly process. On the other hand, new things always entail quality risks and likely create more defects. In resolving this contradiction and finding a trade-off, we sought to faithfully follow the concept of "*jikoutei-kanketsu* (build in quality with ownership)" to ensure that no defective products are sent to post-processes, along with measures to prevent defects in the first place.

Hiroki Maeda
Working group leader, Electric Products Group, Quality Assurance Office No. 3, Quality Assurance Department, Compressor Division

Takayama: The mass production line of the new compressor went into operation in September 2016, and currently we manufacture around 5,000 units each month. We meticulously created a robust line and were able to meet the performance and quality targets and the scheduled launch of production. A very important point was to devise standardized procedures for processes that had relied on operators' experience and skills, so that anyone can perform the task.

* Compared with the conventional heat pump heating system at the temperature of –10°C. Surveys by Toyota Industries Corporation and DENSO Corporation.

Strengths Underpinning Toyota Industries' Development Capabilities That Generate a Number of World Firsts

Maeda: While I was working on this project, I realized that our process from the launch of product design to mass production has become increasingly mature. This can be attributed to many factors. One of them is our accumulated know-how from the development of previous models. Thus, we did not have to struggle with anything that was unexpected. Our strengths stem from activities to carefully identify defects in each process and eliminate various risks. I think we should continue to hone our strengths in the future as well.

Okagawa: In the field of production engineering alone, we have an advanced set of proprietary technologies derived from the in-house development of production equipment. We also have achieved higher degrees of speed, precision and automation throughout the entire production lines. These enable us to excel in swiftly manufacturing products that demand extremely high quality and at the required quality level.

Tsubai: We hold the world's top share in the compressor market. As such, we do business with various automakers and are well positioned to capture information on what their next goals are and what kind of vehicles they envision, which allows us to provide designs finely matched to these needs. With demand for electric compressors expected to progressively increase, I hope to start development of a next-generation model soon, which is quieter to operate and demonstrates better heating performance at even lower temperatures with less energy consumption.

Takayama: Setting our sights higher, those of us at manufacturing departments would like to promote human resources development, engage in improvement activities and enhance our manufacturing capabilities further. Our goal is to combine the comprehensive strengths of Toyota Industries to gain greater customer satisfaction and continue to win out over the global competition.

Hideki Takayama
Supervisor, Assembly Section, Manufacturing Department No. 1, Compressor Division

Tsubai: Exactly. We will continue to develop compressors with greater product appeal.