High-Performance Direct-Driven Transport Refrigeration Units Using 3D Scroll Compressor

MASAKAZU KAI*1
KAZUMI OSADA*1
YASUSHI WATANABE*2
TAKASHI TANAKA*1
KOUSHI TARUMA*1

The transportation industry has undergone many changes in recent years. The strict control of truck exhaust emissions, increase in fuel costs, and increase in efforts to prevent global warming have all had an impact on transportation. Mitsubishi Heavy Industries, Ltd. (MHI) has responded to these environmental changes by developing the S-series of direct-driven transport refrigeration units. These units have the advantages of reduced compressor size and increased refrigeration efficiency.

1. Introduction

The transportation industry produces about 20% of the CO_2 emissions in our country, and we must do everything possible to reduce them. The need to enhance the efficiency of transport refrigeration units has increased sharply because of skyrocketing fuel prices. At the same time, the additional emission control equipment required for compliance with truck exhaust emission control measures is competing for the physical space required to mount compressors for refrigeration on vehicles. A reduction in compressor size is an important consideration in the design of new vehicles to comply with the post new long-term regulations for exhaust gases.

To achieve a substantial reduction in energy consumption and a simultaneous decrease in physical size, MHI has developed a special compressor for transport refrigeration applications that uses three-dimensional compression scroll technology (3D scroll). MHI developed this technology through its experience with air-conditioning compressors. We describe the characteristics of S-series direct-driven transport refrigeration units using the new type of 3D scroll compressor in this report.

2. Characteristics of the S-series

2.1 Open 3D scroll compressor

A reciprocating compressor, which has been used in direct-driven refrigeration units for a long time, decreases in efficiency as the rotation speed increases. This is illustrated in **Figs. 1** and **2**. For this reason, it is extremely difficult to reduce the size and improve the efficiency of a reciprocating compressor at the same time.

A scroll compressor, on the other hand, has a high volumetric efficiency and maintains its high efficiency even when the rotation speed is high. However, a conventional scroll compressor is not easily mounted on vehicles because when the high-pressure ratio is designed according to the operating point of the refrigeration unit, the number of turns in the scroll increases and the barrel diameter expands.

We addressed this technical problem in our S-series units. We succeeded in obtaining an appropriate design compression

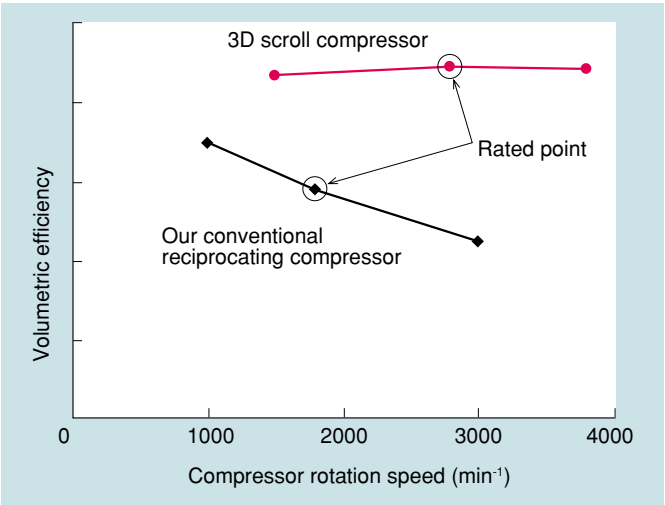

Fig. 1 Volumetric efficiency characteristics

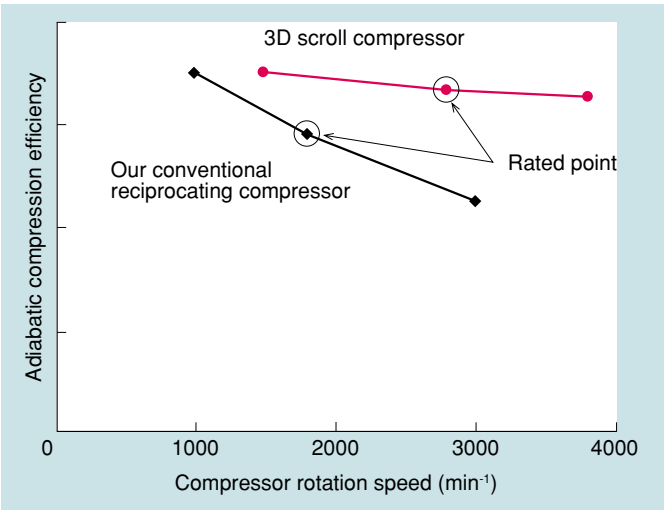

Fig. 2 Adiabatic compression efficiency characteristics

*1 Air-Conditioning & Refrigeration Systems Headquarters
*2 Nagoya Research & Development Center, Technical Headquarters

ratio suitable for refrigeration units without expanding their barrel diameter by adopting a 3D scroll with an axial compression mechanism. As a result, we achieved substantial reductions of 60% in the compressor volume and 50% in the compressor weight compared to our conventional reciprocating compressors with equivalent capacities. In addition, the compression efficiency at the rated rotation speed improved by about 15%.

2.2 Improvement of the availability factor due to the expanded operation range

For a direct-driven refrigeration unit in which the compressor is driven by the vehicle engine, the rotation speed of the compressor is determined by the rotation speed of the vehicle engine and cannot be controlled by the unit itself. A scroll compressor delivers a high volumetric efficiency for the entire rotation speed range, and therefore, the change in the operating pressure due to variations in rotation speed is larger than that of a reciprocating compressor. In the S-series, a pressure transducer is mounted on the high- and low-pressure sides of the unit, and the operating pressure is controlled on a two-dimensional map, i.e., high pressure and low pressure. This means that the allowable operating range for the compressor will be used to the maximum extent possible, and the frequency of protective stopping for the unit due to transitional engine speed variations will be minimized.

2.3 Reduction of electric power consumption

A direct-driven refrigeration unit operates on electric power supplied by the vehicle power source. Because the power generation efficiency of the alternator is about 50% at the engine's medium speed range, the reduction of electric power consumption of the refrigeration unit is highly effective for engine load reduction, and thus it reduces the fuel consumption of the vehicle. In the S-series, we focused our attention on the air blower system, which consumes at least 80% of the electric power. We reduced the eddy loss by enlarging the condenser fan diameter and adopting an impeller with serrations (**Fig. 3**). We also improved the efficiency by eliminating brushes from the condenser fan motor, and improved the air flow inside the container. These measures reduced the electric power consumption by a maximum of 23% compared with our conventional unit. At the same time, we substantially reduced the blowing air noise of the condenser.

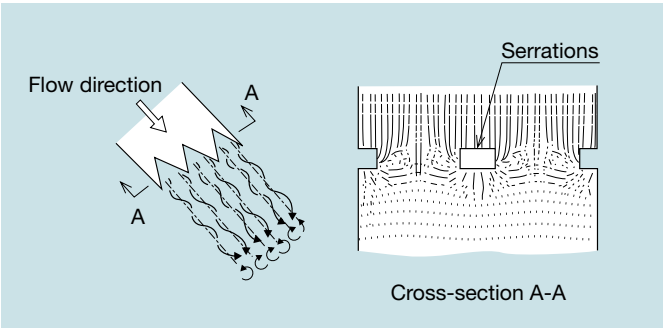

Fig. 3 Reduction of eddy losses using an impeller with serrations

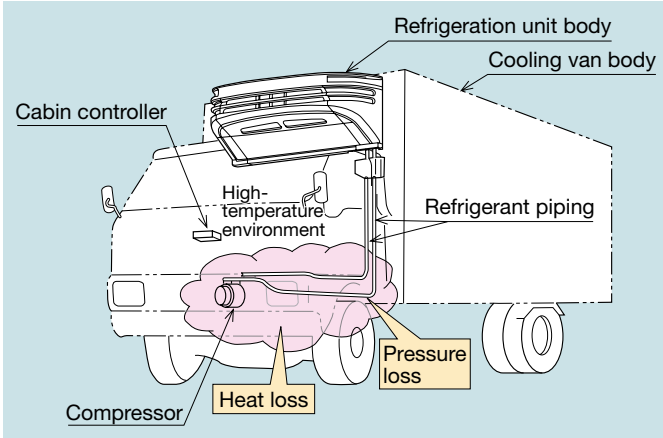

Fig. 4 Vehicle installations

2.4 Reduction of heat loss and pressure loss

A compressor mounted on the vehicle engine and a refrigeration unit mounted on the wall of a cooler van body are connected by refrigerant piping through the engine compartment, which is a high-temperature environment, as shown in **Fig. 4**. For this reason, the low-pressure and low-temperature gas refrigerant, which evaporates in the evaporator, absorbs a large amount of heat until it is sucked into the compressor. This reduces the operating efficiency. In addition, there is generally little room in the engine compartment to allow for the passage of thick refrigerant piping. This often means that smaller diameter refrigerant piping is used, which increases the pressure loss and greatly reduces the operating efficiency. In the S-series, a large internal heat exchanger is installed as standard equipment, and the amount of heat that is thermally exchanged uselessly in the high temperature engine compartment is effectively used by the heat exchanger to increase the refrigeration capacity of the unit itself, and thus increase the efficiency. In addition, the increase in supercooling by the internal heat exchanger reduces the amount of refrigerant required to obtain the specified refrigeration capacity, and it also has a large effect on pressure loss reductions.

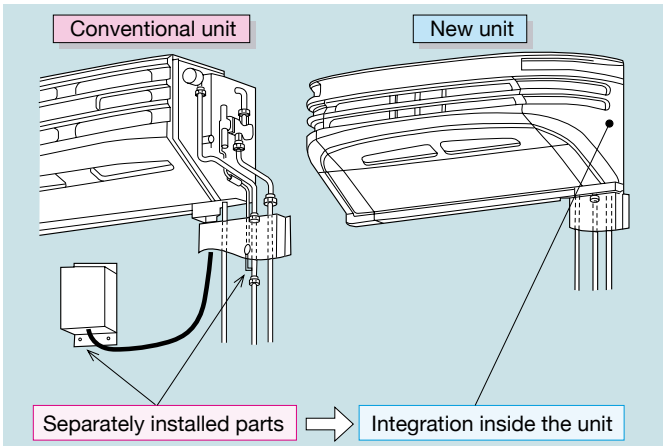

Fig. 5 Integration of separate components in a unit

2.5 Streamlining of installation work

Direct-driven refrigeration units are installed on vehicles at the reefer box manufacturer or installation company. In the S-series, the components such as the unit controller that were installed separately in the past are now integrated in a unit, as shown in **Fig. 5**. This reduces the installation time and cost, while increasing the system quality after installation.

2.6 Enhancement of reliability

For transport refrigeration units where warming of the compressor by a heater is not possible while the operation is suspended, migration of the refrigerant into the compressor is liable to occur. The start of liquid compression and poor lubrication caused by refrigerant flushing are major causes of compressor failures. In the S-series, measures to prevent migration of the refrigerant are introduced in which valves provided on the suction and discharge sides of the compressor close when the unit is stopped. The compressor is also equipped with a multi-relief port, which greatly reduces the stress that develops when liquid compression occurs.

3. Energy-saving properties when used on an actual vehicle

We installed our conventional refrigeration unit and the latest S-series unit with an equivalent refrigeration capacity on the same cooling van one after the other to compare the annual fuel consumption. We calculated the annual fuel consumption of the vehicle using the data measured by operating the van under the JE05 mode and the operating conditions frequency allocation shown in **Fig. 6**, with the vehicle speed and air temperature as parameters based on air temperature data from Tokyo, Nagoya, and Osaka.

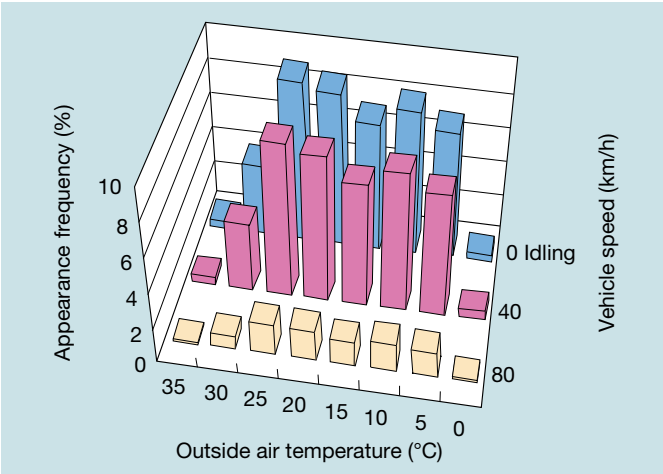

Fig. 6 Cooling van operating conditions frequency distribution

Table 1 Annual fuel consumption

Item	Conventional unit	New S-series unit
Fuel consumption	365 L	267 L

A reduction of 27%

Table 1 shows the fuel consumption of the units by comparing the data with and without the refrigeration unit for an assumed annual operating time of 2000 hours. The new S-series unit reduced the amount of fuel consumed by 27% compared to our conventional unit.

4. Conclusion

By using 3D scroll compression technology, we have simultaneously achieved a substantial improvement in efficiency and a reduction in compressor size, which are both excellent marketing features. We currently have products for small and medium refrigerated vehicles in our lineup, and are working on products for large vehicles and multi-temperature units. To help reduce CO_2 emissions in the transportation industry, we will make every effort to distribute this new series of direct-driven refrigeration units which provide a substantial improvement in energy efficiency.


Masakazu Kai


Kazumi Osada


Yasushi Watanabe


Takashi Tanaka


Koushi Taruma