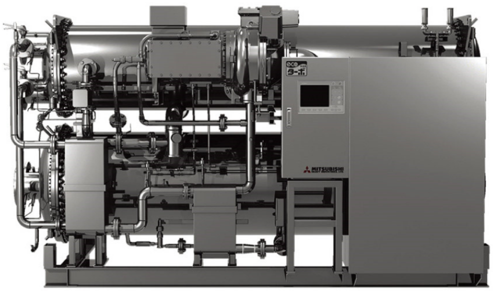
First Domestic High-Efficiency Centrifugal Chiller with Magnetic Bearings: The ETI-MB Series



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The efficiency and functionality of centrifugal chillers has improved, and they have reached maturity as commercial products. Therefore it is necessary to employ new technologies and develop new products even more superior to existing ones. So far Mitsubishi Heavy Industries, Ltd. (MHI) has worked on the enhancement of the rated performance and year-round efficiency by integrating an inverter as standard equipment, as well as the improvement of functionality with technologies for determining operational conditions and the support of highly-efficient operation. This paper describes the application technology of magnetic bearings to centrifugal chillers targeting a reduction of maintenance burden by customers. MHI has attained the further improvement of efficiency and maintainability in comparison to that of existing machines as a result of the proper handling of problems through the application of magnetic bearings to centrifugal chillers, commercializing a centrifugal chiller with magnetic bearings for the first time in Japan.

1. Introduction

Due to growing social concern related to energy conservation and the reduction of CO_2 emissions, high-efficiency centrifugal chillers are now widely used, not only in industrial applications such as heat sources in factories, but also in building air conditioning systems.

However, centrifugal chillers consume large amounts of energy because of the large-capacity heat pumps they contain. In terms of the reduction of CO_2 emissions, technical improvements and product development aiming for high performance are very important. Therefore an inverter, with which a significant reduction of year-round energy consumption can be expected, is included as standard equipment. Chillers also integrated with an inverter for the enhancement of installation properties have been developed and increasingly introduced. On the other hand, to operate centrifugal chillers without failure and maintain high performance, proper maintenance service is required, but demand from customers for a reduction of maintenance burden is growing.

This paper describes recent trends and requirements for the main components in heat sources, and discusses the new "eco Turbo ETI-MB" series of high-efficiency centrifugal chillers with magnetic bearings developed in 2013.

2. Centrifugal chiller market and product concept

Over the past several years, the approach to technical enhancement has shifted from offering a certain level of performance under rated conditions to providing year-round efficiency, even under conditions of partial loading or low-temperature cooling water, which are more representative of how the chillers are actually used most of the time. MHI has marketed a centrifugal chiller series using inverter-driven variable-speed controls since 2003. Today's AART-I series effectively reduces annual energy consumption, and it is also necessary to incorporate inverter-driven variable-speed controls into new centrifugal chiller models as standard equipment.

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Increasing demand for the replacement of absorption cooling units targeting the reduction of CO_2 emissions has resulted in customers requesting a reduction of the footprint and weight of the unit in order to improve the ease of installation in typical buildings. As a result of the shrinkage of large-scale industrial plant applications and the expansion of general air conditioning applications, the average refrigeration capacity of centrifugal chillers has decreased from around 700 USRt in the mid-2000s to approximately 550 USRt in 2012.

To respond this trend in demand, in 2008 MHI released the ETI series small capacity (up to 500 USRt) centrifugal chillers integrating an inverter as standard equipment with the concept of high performance, compact, and light in weight, and has since been expanding the series continuously in order to meet most needs for air conditioning applications.(1)(2) In addition to the improvement of performance, the enhancement of functionality for easier and more efficient operation, including the facilitation of operation monitoring using highly-efficient operation indexes and the improvement of system efficiency using a comprehensive heat source control device, is being promoted.(3)

In this way, the efficiency and functionality of centrifugal chillers has improved, and they have reached maturity as commercial products, and therefore it is necessary to employ new features to secure superiority over competing products. This time, MHI has developed high-performance and high-functionality centrifugal chillers equipped with magnetic bearings in order to differentiate MHI's products from those of its competitors and to meet the demands of customers for a reduction of maintenance burden.

3. Problems with the installation of magnetic bearings and solutions therefor

In the global market, there are already compressors equipped with magnetic bearings with a motor power output of 100 kW or less, and they have also been employed on many centrifugal chillers. In the Japanese market, where higher performance is required, magnetic bearings have not been employed because of the following problems with performance and reliability resulting from their use.

- Decline in the efficiency of the compressor and increase in leakage loss resulting from the enlarged clearance in the compressor and seals
- Increase of windage loss resulting from the increased speed of the motor
- Protection of the compressor and motor in the case of power supply loss
- Increase of initial costs for equipment

MHI, with successful developments of compressors using magnetic bearings since the 1980s, has solved the aforementioned problems as described in the following (1) to (4), and then enabled the use of magnetic bearings without compromising high performance to attain commercial production of a centrifugal chiller equipped with magnetic bearings for the first time in Japan.

(1) Decline in efficiency of the compressor and increase in leakage loss

Magnetic bearings have lower loss and are more suitable for high-speed rotation than roller bearings, but the clearance between the magnetic bearing and the supported shaft is comparatively larger. A unit equipped with magnetic bearings has auxiliary bearings for the stopping period, etc., and they need a certain clearance for both the axial and radial directions because they are required to not come into contact with the shaft except in the case of an emergency stop or during stopping. This large clearance between the bearings and the shaft necessitates an increase of clearance in the compressor and seals, resulting in a decline in the efficiency of the compressor and an increase in leakage loss, leading to the lowering of cycle efficiency. MHI has taken the following measures [1] to [3] as solutions to this problem (**Figure 1**).

[1] A reduction of the radial and axial ranges of the gaps when controlled by magnetic bearings during transitional operation through the use of a higher-speed magnetic bearing controller and then the minimization of the clearance between the shaft and the auxiliary bearing

[2] The application of axial direction control for magnetic bearings for the reduction of clearance in the compressor during operation

[3] The employment of a sealing material combination that consists of a metal moving part and a resin stationary part for the reduction of the initial clearance, as well as the lessening of the sealing clearance in operation due to the deformation of the moving part in the direction of the sealing clearance along with the rotation.

As a result of these measures, compressor performance equal to or higher than that of compressors equipped with ball bearings, as well as sealing leakage that is equivalent or lower, can be attained.

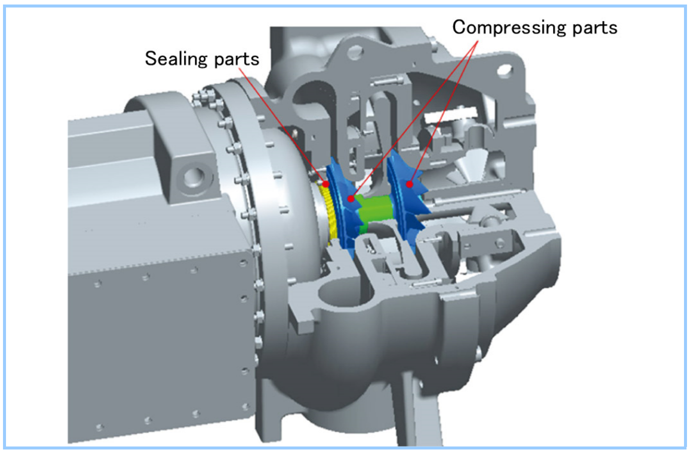

Figure 1 Compressor structure

(2) Increase of windage loss resulting from the increased speed of the motor

The compressor needs to be directly connected to the motor when magnetic bearings are employed, due to their characteristics (rigidity and damping). Such direct connection between the compressor and the motor leads to a significant increase of the motor speed in comparison to the speed at commercial power frequency. This results in a significant increase of windage loss at the motor in cases where a higher density medium such as refrigerant liquid is used for cooling. To solve this problem, the cooling system is divided into the moving part of the motor where lower density refrigerant gas is used, and the stationary part where refrigerant liquid with a higher cooling effect is used, resulting in the simultaneous realization of windage loss reduction at the motor and efficient cooling.

(3) Protection of the compressor and motor in the case of (electrical) power failure

A unit equipped with magnetic bearings has auxiliary ball bearings to support the shaft when the magnetic bearings cannot be activated due to the interruption of the power supply. However, these ball bearings have a finite service life and therefore the number of emergency stops (touch-downs) using these bearings is limited. To solve this problem, a UPS (an uninterruptible power supply system) for the magnetic bearings is included as standard equipment in order to allow the chiller to stop without touch-downs on the auxiliary bearings, even when the power supply fails. In addition, to ensure the reliability of the system, it can be operated only when the UPS battery is in a normal condition. The sufficient reliability of the system has been verified in a power interruption test using an actual unit.

(4) Increase of initial costs for equipment

There are prospects for offsetting the increase of the initial costs for equipment resulting from the installation of magnetic bearings, the high-speed motor rotation, the protection against power interruption, etc., by suppressing maintenance costs as described later, in addition to the reduction of running costs through the suppression of the decline in compressor efficiency, resulting in the realization of a level of performance higher than that of existing machines.

4. Specifications of ETI-40MB and 50MB

4.1 High performance

The combination of measures to solve the performance problems with the installation of magnetic bearings described above and the employment of functionality improvement technological elements that have been proven in existing large high-efficiency centrifugal chillers allows the realization of high-performance centrifugal chillers equipped with magnetic bearings.

Typical examples of the elements are shown below.

- Two-stage compression and single-stage expansion sub-cool cycle
- Latest high-efficiency blade shape
- High-precision machined impeller
- Load and cooling-water temperature follow-up controls using six-element mathematical operational control including first- and second-stage vane control and inverter-driven compressor variable speed control
- High-efficiency heat transfer tubes of heat exchanger and optimization of layout

The use of the high-efficiency technologies shown above allows the rated COP (Note 1) to reach 6.3, the highest level in the world among inverter-driven chillers with a similar capacity (**Table 1**). The IPLV (Note 2), a substantial performance criterion for annual power consumption, is as high as 9. In addition, the employment of a parallel-mounted compressor for the ETI-40MB and 50MB (**Figure 2**) allows a capacity of up to 1000 USRt. As a result, capacity demand of up to 1000 USRt can be fulfilled by a series of chillers including an inverter with a 400 V-class power source as standard equipment along with existing models.

Note 1: Coefficient of Performance. A higher value means higher performance.

Note 2: Integrated Part Load Value. According to the calculation standard of JIS B 8621 (2011).

Table 1 Comparison between ETI-40MB/50MB and existing models (specification table)

Model	ETI-40MB (developed model)	ETI-50MB (developed model)	ETI-40 (existing model)	ETI-50 (existing model)
Cooling capacity	400USRt	500 USRt	400 USRt	500 USRt
	1407kW	1758 kW	1407 kW	1758 kW
Chilled water temperature	12°C in/7°C out			
Chilled water flow rate	241.3m^3/h	297.0m^3/h	241.3m^3/h	297.0m^3/h
Cooling water temperature	32°Cin/37°Cout			
Cooling water flow rate	280.9m^3/h	354.2m^3/h	282.6m^3/h	353.6m^3/h
Power consumption	223kW	297 kW	228 kW	288 kW
Dimensions	3.9m×1.8m×2.3m		4.4 m×1.9m×2.2m	
Weight	5.5 t		7.4 t	
Refrigerant	HFC-134a			
COP	6.31	5.92	6.14	6.08
IPLV	9.0	9.2	7.9	8.6

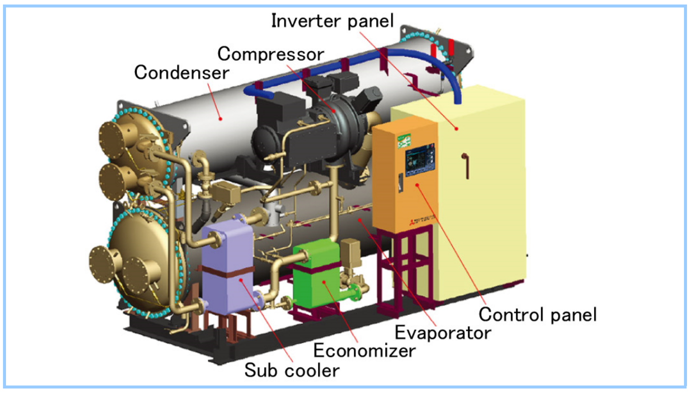

Figure 2 ETI-40MB/50MB external view

4.2 Compact and light in weight

These chiller models equipped with magnetic bearings also follow the design concept of compact and light in weight for the ETI series, which offers ease of installation. The design improvements include the following elements.

- Miniaturization of compressor unit due to direct connection between compressor and motor and increased speed of motor rotation speed.
- Elimination of oil tank and lubrication piping due to the employment of oil-free concept
- Optimum design of heat exchanger for miniaturization
- Optimum layout of components (e.g., vertically stacking of evaporator and condenser)

As a result of these optimizations, the ETI-40MB and 50MB attain a reduced footprint of approximately 15% and a reduced machine weight of approximately 20% in comparison to MHI's existing models with equivalent capacity. Therefore the ETI-40MB and 50MB can be more easily installed as replacements for existing equipment.

4.3 Maintenance saving

The employment of magnetic bearings can eliminate periodical changes of lubrication oil and filters for the lubrication system, as well as oil system management (e.g., oil level, lubrication oil temperature, etc.) in daily operation. In addition, the use of noncontact magnetic bearings supported by a UPS that can in principle avoid touch-downs of the emergency auxiliary bearings makes overhauls for changing mechanical driving components unnecessary. Therefore the overhaul cycle depends on the service life of seals such as O-rings and gaskets, not on the service life of mechanical driving components. Along with the extended life of sealing materials due to the employment of the oil-free structure, this results in an overhaul cycle longer than that of existing models. In this way, standard maintenance costs for the service life cycle can be reduced (**Figure 3**), resulting in prospects for offsetting the increase of the initial costs.

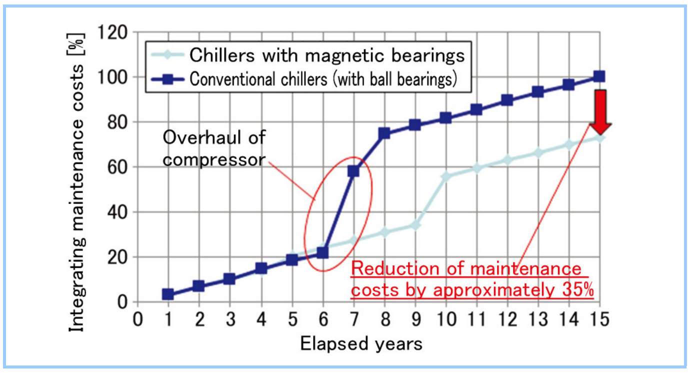

Figure 3 Maintenance costs comparison between chillers with magnetic bearings and conventional chillers

5. Conclusion

MHI has developed, based on the existing ETI series, the ETI-MB series equipped with magnetic bearings targeting a reduction of maintenance burden. The ETI-MB series attains one of the highest levels of performance anywhere in the world among equivalent chillers equipped with magnetic bearings, using proper measures to solve problems with the installation of magnetic bearings and employing proven technologies for functionality improvement. This series can also reduce maintenance burden by eliminating the need for some maintenance services and extending the maintenance cycle. In addition, a highly reliable system that avoids compressor damage during stopping, or even in an operational state with sharp load fluctuations such as surging (Note 3) or a trip stop, can be established due to the improvement of magnetic bearing control and the employment of a UPS as standard equipment.

Based on this development of centrifugal chillers equipped with magnetic bearings, MHI is planning to extend the capacity of machines with magnetic bearings on the theory that they will be installed as more versatile equipment. MHI will continuously promote the development of products that meet market demand in order to satisfy customer needs.

Note 3: Surging is intense vibration in the flow direction or backflow of compressed gas in the compressor, and causes the occurrence of sharp load fluctuation on the compressor.

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