

# New Suggestions for Centrifugal Chiller Technologies to Realize High Efficiency and High Functionality



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*The efficiency and functionality of centrifugal chillers has improved in recent years. Centrifugal chillers have reached maturity as commercial products in terms of reduced energy consumption of heat source equipment. However, there is still room for improvement in the extent of system operation-related interaction between the heat source equipment and the system in terms of energy saving, and Mitsubishi Heavy Industries Ltd. (MHI) considers that reinforcement of technology to support highly efficient operation of the heat source system and operational support service is important. This paper introduces one way to enable further energy saving operation through new operation support technology, including the expected COP, a load zone sign for highly efficient operation, and a flow rate detector for chilled water and cooling water equipped as standard, as well as operation support services including a heat source total control system and real-time monitoring system on the web.*

## 1. Introduction

A centrifugal chiller is a large-capacity heat source system that can precisely control the temperature of not only chilled water, but also low-temperature (below 0°C) brine or hot water, and supply users with it. Because of its characteristics, the centrifugal chiller was historically used by local heat supply service providers, industry heat source system users, and general large air conditioning system users. It has recently been increasingly used as a replacement for absorption water cooling and heating units, and is now also used in heating sources. In this way, the centrifugal chiller has been widely used because its energy-saving ability is superior to that of other heat source equipment. MHI has recently been working to improve the efficiency of centrifugal chiller equipment and to develop technology for user support in the maintenance and operation of the highly efficient equipment.

This paper presents a method to improve efficiency of a centrifugal chiller. It also introduces technologies and functions to support the maintenance of highly efficient operation and explains operation-monitoring technology.

## 2. Improving the Efficiency of Centrifugal Chillers

MHI has been continually improving the efficiency of centrifugal chillers to meet recent demand, stemming from the need to prevent global warming and ensure energy savings, especially since the introduction of the NART series of highly efficient centrifugal chillers in 2000. As the result, the rated COP under JIS conditions was improved, to 6.4, in 2004 and the maximum COP of a chiller equipped with inverter technology in part-load operation was improved to 24.2 in 2010 (**Figure 1**). Additionally, MHI has developed a small-capacity class (150-500 USRt) for application in business air conditioning systems, which have been in great demand recently for energy-saving modifications. That is the ETI series, which has both high mountability and high performance, thereby improving performance and introducing high-efficiency machines with a wide range of capacities<sup>1</sup>. The following description focuses on technologies for improving the efficiency of centrifugal chillers; it begins by presenting technologies for basic performance (rated performance), and then presents technologies for part-load performance.

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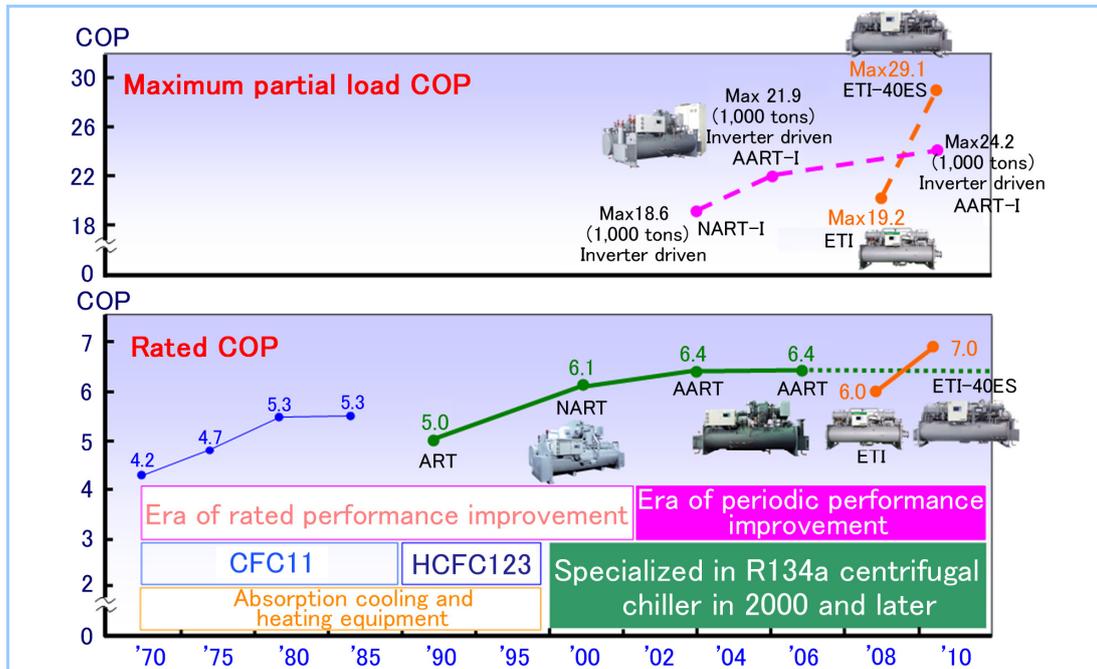


Figure 1 History of centrifugal chiller performance

## 2.1 Technologies to improve the basic performance of a centrifugal chiller

The major technologies for improving the efficiency of a centrifugal chiller include:

- optimized refrigeration cycle (two-stage compression and two-stage expansion sub-cool cycle),
- high-precision machined blade,
- low-loss multiplying gear and low-loss bearings, and
- improved efficiency of the heat exchanger (evaporator and condenser) with optimized tube shape and layout of the tube.

Through these technologies, chiller performance can be improved entirely from large- to small-capacity chillers; even the 200 USRt class (about the smallest centrifugal chiller) can attain a very high rated performance, with a COP as high as 6.0, based on electric power consumption, including power for auxiliaries.

## 2.2 Technologies for further improving the efficiency of a centrifugal chiller

To further improve efficiency, MHI has developed technologies including a double refrigeration cycle, which ensures optimized operation in each of the two compressors. Here, one-path bidirectional-flow evaporator and condenser are positioned inside the centrifugal chiller and the double refrigeration cycle is separated into a high-pressure side (the chilled water inlet and the cooling water outlet) and a low-pressure side (the chilled water outlet and the cooling water inlet) to reduce the compression ratio and the power required by the compressors. Use of this double refrigeration cycle increased the rated COP to 7.0<sup>Note</sup> and the maximum COP at part-load operation increased to 29.1<sup>2</sup>. This technology not only improves chiller efficiency, but also reduces the power required to carry chilled water due to the increased difference in temperature of the chilled water, helping to improve the efficiency of the entire heat source system. **Figure 2** displays the ETI-40ES, which has the highest COP in the world.

Note : 400 USRt, chilled water 17/7°C, cooling water 32/37°C.



Figure 2 Appearance of ETI-40ES

### 2.3 Technologies to improve part-load performance of a centrifugal chiller

Recently, the way of thinking about performance improvement has been shifting to periodic efficiency, which involves performance under part-load conditions and low temperature cooling water conditions, which is more typical of the majority of annual operation hours versus the COP under the rated condition. In 2003, MHI also launched the variable speed controlled series with an inverter to enable effective reduction of annual energy consumption; this evolved into the current AART-I series. Part-load performance is improved primarily through the following two technologies:

- (1) Improvement of part-load performance using an inverter; a variable speed control for the compressor using an inverter can minimize the capability control by the inlet vane installed on the compressor, which generates loss.
- (2) Improvement of part-load performance through a two-stage vane.

Regarding the capacity control mechanism of the compressor, an inlet vane is installed in front of the two-stage impeller inlet in addition to the inlet vane installed on the inlet of the single-stage impeller to improve throttling ability (**Figure 3**). The capacity (air flow) control by two vanes enables increased throttling ability at a certain vane opening, which can thereby minimize loss generated when the vane opening is small.

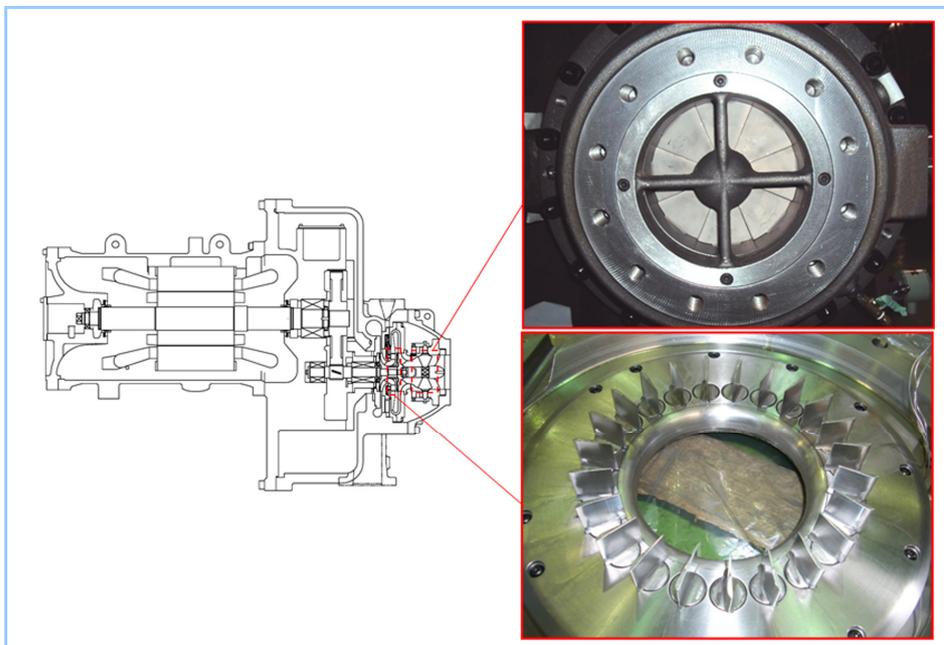


Figure 3 One-stage/two-stage vane structure

## 3. Technologies to Support Highly Efficient Operation of Centrifugal Chillers

MHI has recently been focusing on developing technologies that allow users to maintain favorable conditions in a centrifugal chiller the efficiency of which has been improved as discussed above. Specifically, MHI provides indication of operating performance and the load zone in which the optimal operation occurs and a function that continuously responds to variations in load and temperature to maintain high performance.

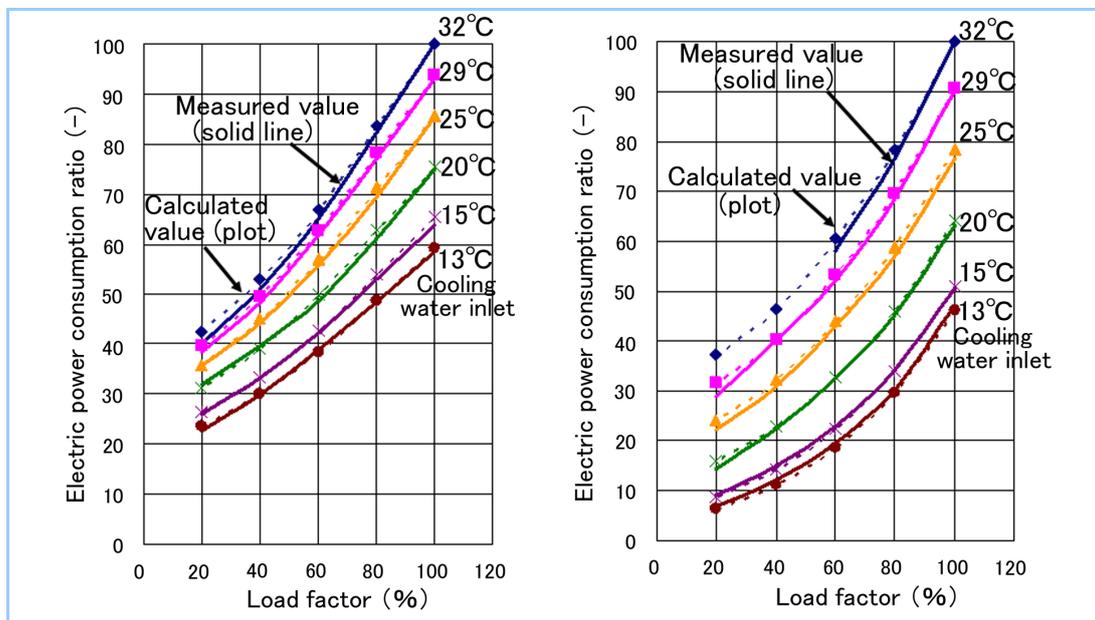
### 3.1 Real-time indication of scheduled COP

It is important to be able to judge the appropriateness of current operation to ensure the centrifugal chiller operates at high performance. In the case of the rated conditions, such a judgment can be made through comparison with specifications. In actual operation, however, cooling water temperature and/or load differs from the rated specification conditions, so performance (COP) to be expected is different from that under the rated conditions.

Although it is possible to estimate performance (COP) accurately using a method of calculation on a desk, based on actual measured operational data, this is not applicable to all cases, which was a challenge. Thus, MHI has established a method of calculating partial load performance, consisting of simple formulas based on theoretical principles<sup>3</sup>.

Performance estimation involves separate methods for the inverter-driven centrifugal chiller with variable speed control and the fixed-speed centrifugal chiller. The reason for this is that the two differ in their capacity control methods: one uses a compressor speed control, the other does not. For the fixed-speed centrifugal chiller, partial load performance is estimated based on the loss characteristics along with the inlet vane control and the hot gas bypass, taking control of the capacity. For the inverter-driven centrifugal chiller, a performance estimation formula was created to reflect characteristics under all chilling capabilities and chilled water and cooling water temperature conditions according to an index based on theoretical properties of the pneumatic equipment in the centrifugal compressor; this performance can be estimated more generally because loss at the inlet vane and the hot gas bypass valve can be identified. Regarding both control types of centrifugal chillers, the difference between estimated and measured value was less than 3% in rated power equivalent, so the results demonstrated that the electric power consumption of the chiller can be determined with a practical degree of accuracy (**Figure 4**).

The method of calculating performance can be installed on a microcomputer board of the chiller, which does not have as much computing power as a typical personal computer, and can indicate the chiller's feasible scheduled COP on the display screen of the chiller operation panel in real time for comparison with the actual measured COP. Comparison of the results should result in improved chiller operation and early detection of abnormalities.



**Figure 4 Comparison between estimated and measured values of partial load COP**

### 3.2 Chilled water and cooling water flow rate detector as standard equipment

#### (1) Chilled water and cooling water flow rate detection

To reduce energy consumption of the entire heat source system, a variable flow control of chilled water (or brine) and cooling water for reduction of the electric power consumption of the chilled water and cooling water pumps has been widely spread. A variable flow control usually involves electromagnetic flow meters mounted on the chilled water and cooling water pipes to obtain flow rate signals to control the inverter frequencies of the motors driving the chilled water and cooling water pumps, based on the signals obtained. However, a centrifugal chiller is a high-capacity heat source equipment with a large water pipe size and an electromagnetic flow meter suitable for such a large pipe size is expensive. Thus, the chiller is equipped with a sensor, instead of a flow meter, to provide signals of chilled water and cooling water used to control the flow of the pumps. Additionally, the expansion valve, the compressor speed, and the hot gas bypass valve, excluding the inlet vane which performs PID control of the chilled water outlet temperature, are controlled based on cooling water inlet and outlet temperature, cooling water flow rate, pressure at each point, and the refrigerant circulating amount calculated with chilling ability to optimize control of the centrifugal chiller. For variable flow control of chilled water, calculation of chilling ability requires chilled water flow

rate information, so the signal from the relevant sensor is used as a substitute for an electromagnetic flow meter. Additionally, for systems not using variable flow control, robustness is ensured by allowing adjustable control with detection of departure or staggering by continuously monitoring the flow rate of chilled water and cooling water, which affects operational conditions.

(2) Detection of chilled water and cooling water stoppage

A chiller must be equipped with water stoppage detectors in both chilled water and cooling water systems to prevent freezing in the heat exchanger tube of the evaporator or rapid increases in condenser pressure. In the past, differential pressure at the heat exchanger under a specified flow rate of chilled water (or brine) and cooling water was used as the detection criterion, and a situation in which differential pressure reached the value equivalent to a certain flow rate was judged to be water stoppage. However, this detection method required an expensive fine differential pressure detector when the flow rate was low. Thus, MHI used the flow rate measuring function described above to detect water stoppage under a wide range of conditions, regardless of the specification conditions. This enables a wider range of chilled and cooling water flow control for the heat source system.

Although measurement of flow rate and detection of water stoppage involve the same sensor, separate arithmetic processing for each signal can ensure both a quick response, which is required for water stoppage detection, an equipment-protecting function, and accuracy, which is required for flow rate measurement.

## 4. Centrifugal Chiller Total Operation Support Service

In the past, most user needs for centrifugal chillers were related to improving efficiency and operation stability. Today, users are also demanding sophisticated and diverse functions including (1) simple control for efficient operation, (2) the ability to check and evaluate operation data, and (3) the ability to determine optimized operation, based on feedback evaluation. In response to such demands, MHI continually works to develop and market products that can make heat source system operation “sustainable, simple, and high performance.”

### 4.1 Technologies to support highly efficient operation

To support highly efficient operation of centrifugal chillers, MHI released the Ene-Conductor heat source total control system in April 2010. This system can control heat source systems simply and in an integrated manner by controlling a variety of heat source equipment and their optimum load distribution, variable flow rate of chilled water and cooling water, and airflow of the cooling tower, with the goal of improving COP in the entire heat source system<sup>4</sup>. Figure 5 shows an example estimation of Ene-Conductor’s energy-saving effect.

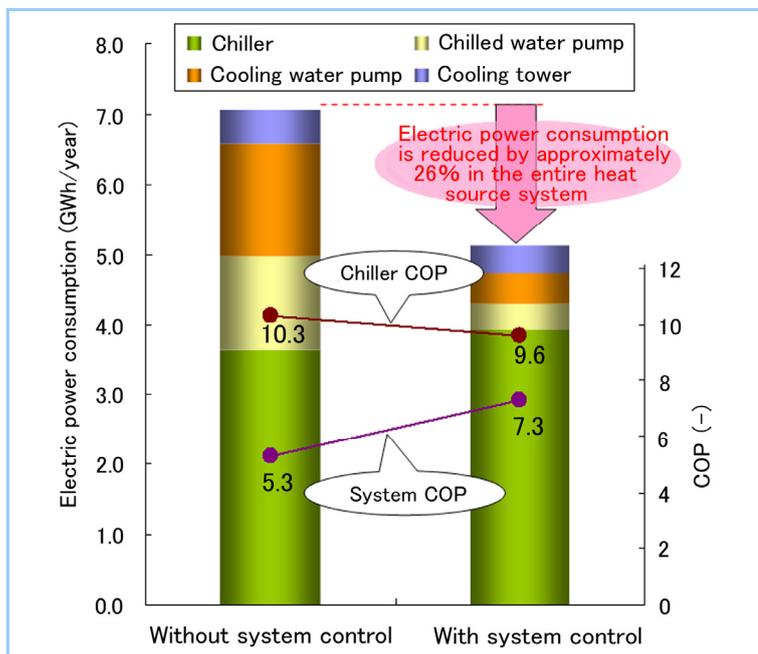


Figure 5 An example estimation of the effect of operational support

For this estimation, simulations were conducted for equipment configuration of the heat source system shown in **Table 1**; the assumed load was 24 hours a day and 365 days a year and results were obtained for systems with and without optimized system control by the Ene-Conductor. Application of chilled water and cooling water variable flow rate controls and a cooling tower air flow control reduced chiller operation efficiency by approximately 9%, but system efficiency could still be increased by up to approximately 26% because electric power consumption by the auxiliaries (the chilled water pump, cooling water pump, and cooling tower) decreased significantly. This result demonstrates that Ene-Conductor is very effective in improving system COP under conditions where performance improvement and energy-saving of heat source equipment have already been maximized.

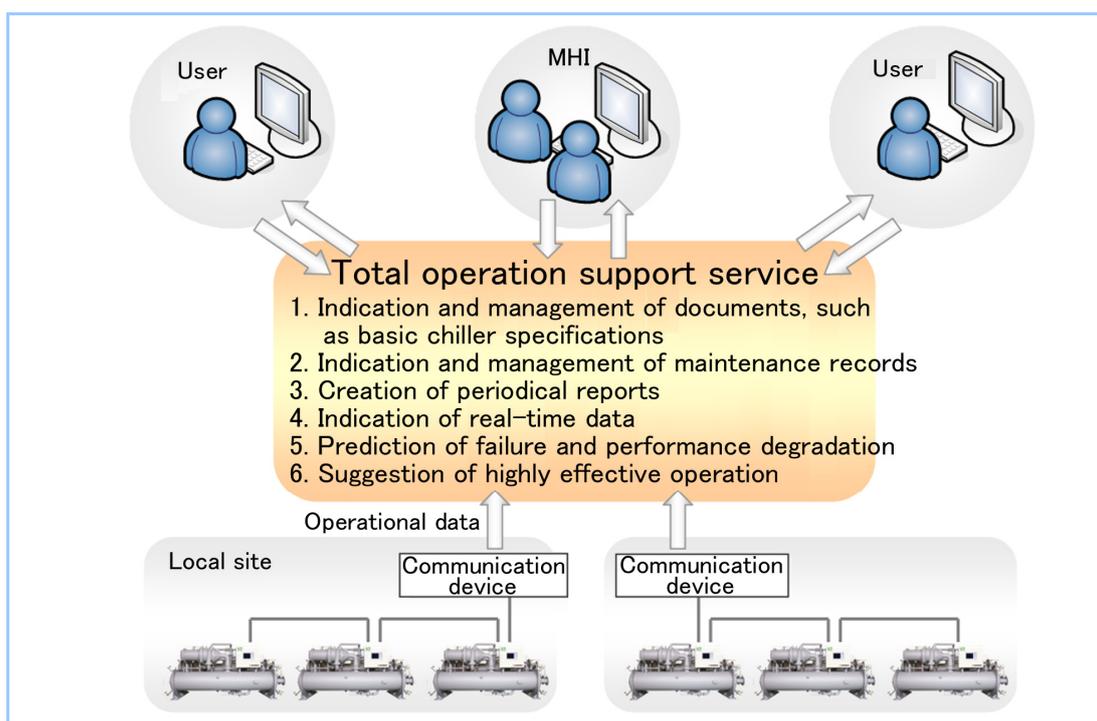
**Table 1 Conditions for estimating the effect of operational support**

Centrifugal chiller (inverter driven)	Quantity	3
	Chilling capacity	1,000 USRt
	Rated COP	6.1
Cooling tower	Quantity	3
	Electric power consumption of fan	7.5 kW × 2
Chilled water pump	Quantity	3
	Electric power consumption	37 kW × 2
	Pump efficiency	0.75
Chilled water pump	Quantity	3
	Electric power consumption	45 kW × 2
	Pump efficiency	0.75

#### 4.2 Indication and evaluation technology of real-time operation data

In response to the need to check and evaluate operation data and to optimize operation, MHI has established an environment in which operation data about the centrifugal chiller can be displayed and checked by users in real-time on the web. Now, MHI is consolidating this environment and the existing service that evaluates operation data to suggest ways to optimize operation. MHI has always provided a menu in which remote monitoring is available, depending on the user's maintenance contract, but only some users use this menu because the initial cost is high. To allow all users to take advantage of this function, MHI will bear the expense of communication devices, installation, and usage charge of the web system for the first year, which is the length of the chiller's guarantee period. Thus, a user can check operation conditions of their chiller through the user portal site if they bear the expenses for the internet environment and provider fee.

**Figure 6** shows a conceptual diagram for this service.



**Figure 6 Conceptual diagram of the total operation support service**

MHI's scope of supply is scheduled to include aggregated management of documents such as specifications and maintenance records and indications of operating conditions. Optional menus are also scheduled to include the generation of periodic reports based on data obtained and accumulated through the web, predictions of failure and performance degradation, and evaluations of operating conditions and suggestions for optimized operation. Through these efforts, MHI can offer highly value-added services, such as suggestions for optimized operation, to more users and establishment of an interactive support system in which a heat source user and MHI can share operating information.

## 5. Conclusions

Technologies that should be implemented on heat source equipment for improving the efficiency of heat source systems including centrifugal chillers are performance improvement and functionality improvement, and their latest technologies are as described above. In the past, development has focused on performance improvement. However, the major emphasis has been shifting toward functionality improvement, such as optimization of heat source system component operation and selection of additional functions to maintain high performance. In response to the increasing need for functionality improvement, this paper introduced technology and services to support operations and demonstrated that they can contribute to highly efficient system operation.

The current trend is towards further functionality improvement, so additional functions of the chiller to improve functionality at both user or system components will likely be required in the future.

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