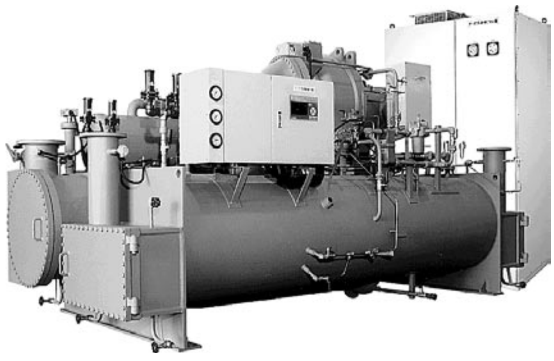

Latest Techniques for Multiple-function High-quality Centrifugal Chillers

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The latest AART and AART-I series of centrifugal chillers are characterized by high performance with good load and cooling water follow-up performance. Their energy-saving characteristics are due not only to the equipment's basic performance, but also to the dedicated microcomputer control panel with ample computing power. Their high level of flexibility, which includes the optimized control of six adjustable elements applicable to any set of conditions using numerical arithmetic control, satisfies user requirements that have previously not been met. We included an ultralow load area of almost 0% into the controllable range, thus making it possible for the centrifugal chillers to deal with chilled water temperature regulation in a continued ultralow load area or for load startup from an ultralow load area. In addition, the centrifugal chillers detect instantaneous voltage drops in a half cycle, making automatic recovery possible while maintaining self-sustaining operational signals. Furthermore, by making maximum use of high visibility liquid-crystal display panels and extended data communications functions, the centrifugal chillers have simplified user support functions, such as daily monitoring and maintenance, and performance evaluation after installation.

1. Introduction

Mitsubishi Heavy Industries, Ltd. (MHI) has been producing centrifugal chillers more than 40 years, and developing them with continuous performance enhancement as a top priority after 2000. Improvement of the coefficient of performance (COP) at the rated point has been the focus in the past. Over the past two to three years, however, development has concentrated on the challenge of reducing energy consumption and improving the annual energy efficiency under actual operating conditions.

Of the centrifugal chillers used in Japan, 60% to 70% are for industrial applications, such as semiconductor factories, while the remainder are for consumer applications, such as building air conditioning. These applications are very diverse, including heat source systems for clean rooms in semiconductor manufacturing and large scale thin panel display factories, heat sources for district heating and cooling, medium- to large-scale shopping centers, car painting facilities, chemical manufacturing, large-scale building air conditioning, and process cooling in chemical plants. It is extremely important to make products capable of meeting these diverse user needs.

In addition, other common requirements have recently become prominent, including the need to reduce CO_2 emissions, save energy, reduce operating costs, and achieve stable operating characteristics. Therefore, the essential product characteristics have now become clear.

Here, we report careful control and greater functionality in tune with actual operating conditions as technology to meet user needs.

2. Basic control of centrifugal chillers

About 90% of the energy used in a centrifugal chiller is consumed by the compressor as it compresses the refrigerant gas. The remaining 10% is lost through electromagnetic and mechanical losses in the electric motor and windage loss due to gas stirring.

As a centrifugal chiller is designed for optimum operation at the rated point, the loss in the refrigeration cycle is minimal at that point.

However, as the chilled water temperature, cooling water temperature, and cooling capacity move away from the rated point, the losses increase and the performance is degraded unless properly controlled. Therefore, control is very important.

(1) Optimal control

In the latest AART series and AART-I series of chillers, optimization is possible through the six controllable elements outlined below, even when operation is not close to the specification point (**Fig. 1**).

- First-stage inlet vanes: These are aerodynamically variable blades located directly in front of the impeller to perform a capacity control function.
- Second-stage inlet vanes: These complement the first-stage inlet vane, making it possible to improve the controllability.
- Variable speed control: This controls the rotary speed of the compressor making it possible to control the pressure of the exhaust gas and air volume during suction. This is achieved by controlling the frequency of the power supplied to the electric motor (AART-I series only).

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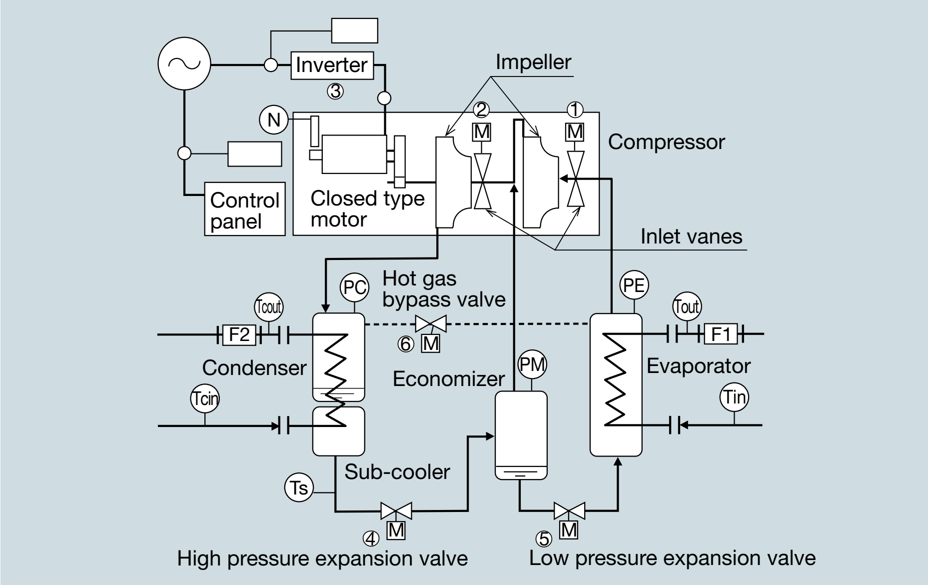

Fig. 1 Schematic diagram of centrifugal chiller showing the refrigerant system, water system, principal key elements, and each control element

- High pressure expansion valve: This circulates the amount of refrigerant required for the refrigeration cycle without waste. Only condensed refrigerant liquid flows downstream from the condenser, and not uncondensed refrigerant gas.
- Low pressure expansion valve: This controls only the refrigerant liquid expanded in the economizer so that it flows downstream to the compressor and not to the evaporator.
- Hot gas bypass: This connects the condenser and evaporator directly with piping and provides minimization control of the gas flow between the condenser and the evaporator, as occasion demands.

Numerical arithmetic control of all of these control elements is provided using an exclusive highly functional microcomputer control panel. The panel calculates the refrigeration capacity, the pressure in each section, the energy consumed, the weight flow rate of refrigerant circulated inside the chiller, the volumetric flow rate of the circulating refrigerant, the thermophysical properties of the refrigerant in each area, and the sound velocity. In addition, numerical arithmetic control includes the flow rate coefficient of each expansion valve, and the pressure and flow rate coefficients of the compressor as characteristics of the elements, and checks them against operating conditions.

Optimization of the refrigeration cycle is a result obtained by optimization of each control element. With this optimization, conditions close to the design target can always be obtained even if the conditions or specifications are different.

(2) Transient control

At first glance, it may seem that numerical control should concentrate on achieving optimal control given the current conditions. In actual operation, however, numerical control is usually designed to control the transition to a certain operating point. Therefore, given the target point and the current point, the equipment condition and operational values are brought to the target operating point over an appropriate interval. This makes it possible to include an appropriate transition in the control process.

Centrifugal chillers are available in several sizes and capacities. Inputting several pieces of information on equipment composition in the form of a constant makes it possible to achieve optimization on the same level for all centrifugal chillers.

3. Handling of superlow loads

The latest advanced numerical arithmetic control has made it possible to control superlow load areas with a very small heating value of 10% or less.

The range of standard capacity control for centrifugal chillers is 20%–100%. For loads of less than 20%, on-off control serves the purpose for single-unit operation. Depending on the specifications, there are cases in which 10% is the minimum. However, a detailed examination of actual use showed that there are also cases where a capacity setting in the range 0%–10% would be very effective for energy savings in heat source systems. Two such cases are as follows:

- During initial trial operation in new factory construction or introduction of a new heat source system.
- Standby operation in cases in which the startup load is known in advance according to the schedule.

3.1 Calibration of chilled water temperature

When the refrigeration capacity is near 0%, the inlet and outlet chilled water temperatures are almost the same. Thus, to measure loads close to 0%, it is necessary to pay close attention to the accuracy of the chilled water temperature measurements. This measurement accuracy is achieved

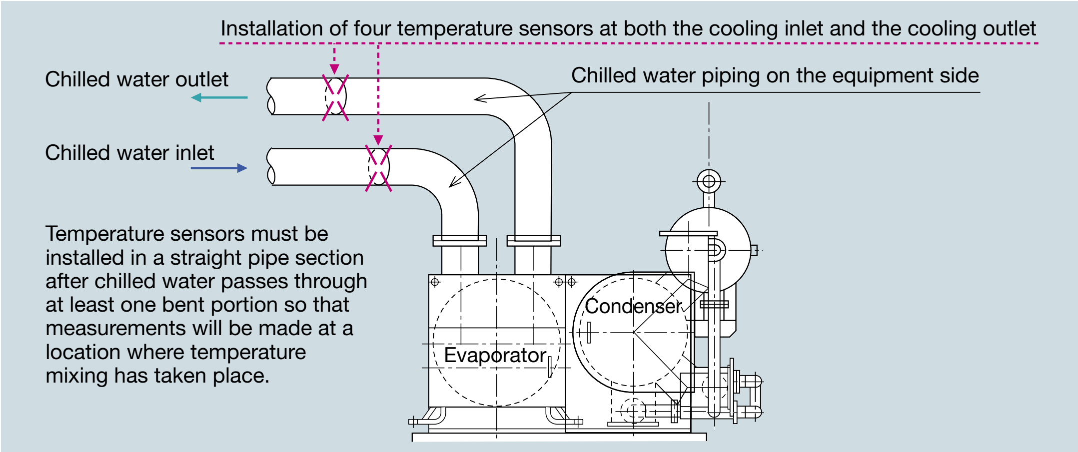

Fig. 2 Method of measuring chilled water temperature

by securing a portion of straight pipe and establishing temperature measurement points where sufficient stirring takes place, confirming the measurement variations in advance (**Fig. 2**).

Table 1 shows actual measurement values of the refrigerant charged state when the chiller is stopped. The sensor that shows a value closest to the average value of four points is selected, and calibration is done in such a way that inlet and outlet temperature values are the same. Then, this value is used.

3.2 No-load control during initial trial operation

In many cases, new installations or installations of additional equipment are completed close to the end of the fiscal year. That is, installation of heat source equipment often takes place during the winter months and before the manufacturing equipment that involves thermal loads is ready. In addition, during initial trial operation, there are often no cold or hot loads at all. Trial operations of heat source systems usually involve spending large sums to install temporary boilers for continuous operation of centrifugal chillers, along with the temporary piping required for drawing in existing steam.

Figure 3 shows the status of follow-up performance based on superlow load operation during actual trial operations in which a load of almost 0% was required. Note that when the cooling water temperature is about 15°C, the load continues

Table 1 Variations in chilled water inlet temperature and outlet temperature (°C)

Item	Range	Average	1	2	3	4
Chilled water inlet	0.11	14.783	14.85	14.77	14.74	14.77
Chilled water outlet	0.03	14.775	14.76	14.76	14.79	14.79
Cooling water inlet	0.08	14.295	14.26	14.34	14.32	14.32
Cooling water outlet	0.15	14.348	14.24	14.39	14.39	14.37

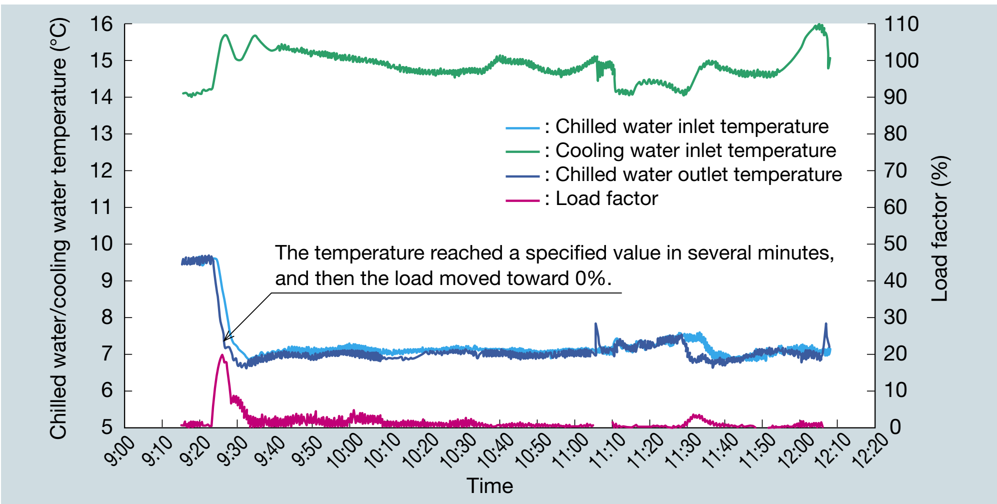

Fig. 3 Status trend graph for 0% load operation
The load dropped to almost 0% and water temperature control continued.

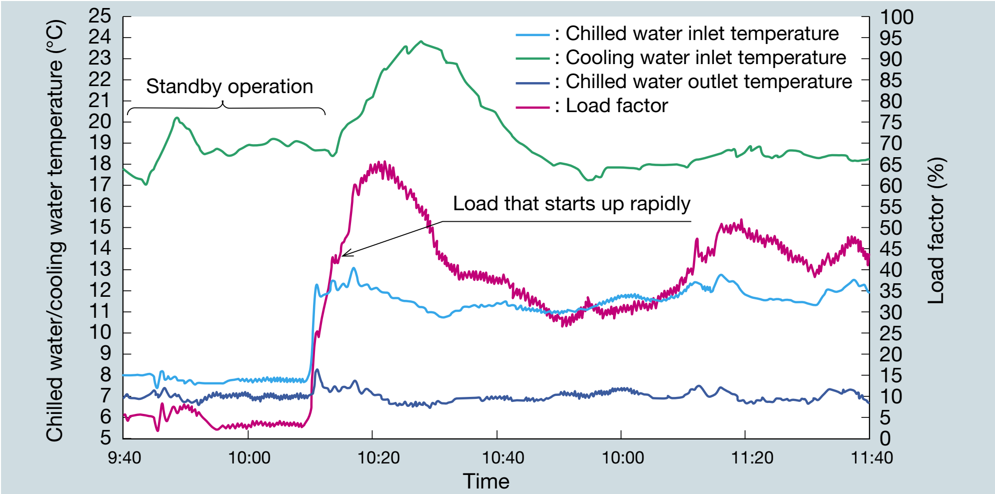

Fig. 4 Startup characteristics from standby operation
The status of follow-up from superlow load area to normal load area can be observed.

at almost 0%. By stopping the equipment once and then starting it at about 11:00, a load occurred temporarily, but soon returned to 0%. The chiller maintained water temperature control without stopping. Due to this superlow load handling function, a temporary steam installation was unnecessary during trial operation.

3.3 No-load control during standby operation

As described in the preceding section, no-load operation is often required. The main difference is that a load starts as soon as the superlow load handling function is deactivated. This means that upon deactivation, a transition occurs from superlow load to normal operation.

Figure 4 shows the state of follow-up under conditions where the cooling water temperature is approximately 18°C. The transition of a start-up load exceeding 60% from a 3–4% superlow load condition was handled correctly. It was confirmed that the chilled water fluctuation was also small and thus temperature control was possible.

4. Automatic return from power failure/ instantaneous voltage drop

In cases where centrifugal chillers are used in semiconductor or electronic device manufacturing factories, or used as the heat source for clean rooms or for chemical plant applications, loss of chiller operation has a very large impact on the quality of manufactured products. Therefore, even if a momentary voltage drop or power failure occurs, chillers must return to normal operation as quickly as possible.

Power failure phenomena in which the electric motor driving a centrifugal chiller stops due to a power supply abnormality include a power failure in which the voltage drops to 0 or sags to some intermediate value. Such power failures and voltage drops may be due to natural phenomena, such as a lightning strike on an electric power transmission system. In recent years, power transmission networks have been improved to the point where it is possible to isolate a failed electrical power transmission system using a high-speed breaker. This means that the time required for shut-off or switching has become much shorter. The instantaneous voltage drop time is on the order of 0.07–2 s depending on the transmission voltage. This is about 0.1–2 s for a 60-kV system and about 0.3–2 s for a 6-kV system.

What is important here is to detect a power failure or instantaneous voltage drop before the chiller closes down. If the operating conditions can be transited to automatic restart, the chiller returns to the normal state without stopping after a failure, thereby minimizing the time during which the refrigeration capacity is zero.

Table 2 shows abnormal conditions detected by centrifugal chillers due to a power failure or momentary voltage drop, and the means of avoiding them for automatic

Table 2 Means of recovering from power failures and instantaneous voltage drops

Details of effect	Means of avoidance
Failure due to power cut in control relay	1. Change the power supply for the control relay to an uninterruptible power system. 2. Detect a power failure before equipment stops, and stop the chiller. Then, restart the chiller in a controlled manner. 3. Detect a delay in the failure signals.
Failure due to stopping of oil pump	
Failure due to stopping of auxiliary machine	
Effect on the breaker for the customer's equipment due to inrush current caused by instantaneous restart of the electric motor	
Possibility of damage to the compressor due to excessive torque caused by instantaneous restart of the electric motor	

UPS : Uninteruptable Power System

restart. Conditions for automatic restart result mainly by combining the means of avoidance 1–3 shown in the table.

More details are described later. However, in the conventional microcomputer control panel, the upper limit of detection is 45 ms and a voltage of 80% with the use of a high-speed relay, whereas in the latest microcomputer control panel, detection within 10 ms and 70% or less can be achieved because processing is done on the chip.

In the case of an instantaneous voltage drop where the electrical power transmission system is the cause, if detection of the transmission voltage in a 60-kV system can be achieved within 0.1 s, it is possible to meet the requirements of many users to bring the chiller to a temporary safe stop, and then perform an automatic restart.

5. Highly functional customized microcomputer control panel

MHI has used customized microcomputer control panels for centrifugal chillers for more than 12 years. However, the latest added functionality requires significantly more advanced calculation and sensing functions than used previously. This section describes the functions and performance that the microcomputer control panels must have. The communications required for maintenance and other functions to maintain the performance of the equipment are also discussed.

(1) Enhancement of CPU speed and decentralization of processing

With the improvement of chiller performance, the amount of data to be handled has increased sharply because of the increase in the number of sensing points and the increased complexity of numerical operation for revolution control. This makes it essential to enhance the arithmetic capacity of the main CPU. The latest panels that MHI will supply in 2008 include a main CPU with double the clock frequency of the previous main CPUs. In addition, a 2-CPU configuration, a dedicated CPU for the liquid-crystal display processing not only enables high-speed graphic processing, but also reduces the load of the main CPU for the basic control.

(2) Handling of two or more models

The latest panel is compatible in its basic form with the AART and AART-I series of centrifugal chillers, and in its minimum form, with the Micro Turbo series. By providing commonality of control components, it is possible to select the number and types of module to be connected according to the chiller series, and this has greatly improved the expandability. Even for chillers with a special configuration, flexibility can be achieved through the combination of highly reliable standard control modules.

Furthermore, high-speed communication is used between modules to maintain expandability. Due consideration is given to noise immunity for high frequencies and harmonic currents in cases where an inverter is used (**Fig. 5**).

(3) Improvement of user interface

A 10.4-in liquid-crystal display is used for the display interface, with automatic backlight shutoff in power-saving mode, and automatic turn-on when human presence is detected. Being able to confirm a larger variety of information without having to touch the operational surface leads to a reduction of user stress and reduces the possibility of erroneous operation.

Graphics, in combination with large letters, make it easy to determine the state of equipment quickly to aid rapid decision making. This improves safety by reducing operator uncertainty (**Fig. 6**).

(4) Customer support function

Knowing the state of a chiller after it is installed is very important for predicting defects and for preventive maintenance. However, there are many cases where a LAN or telephone line is not available in the machine

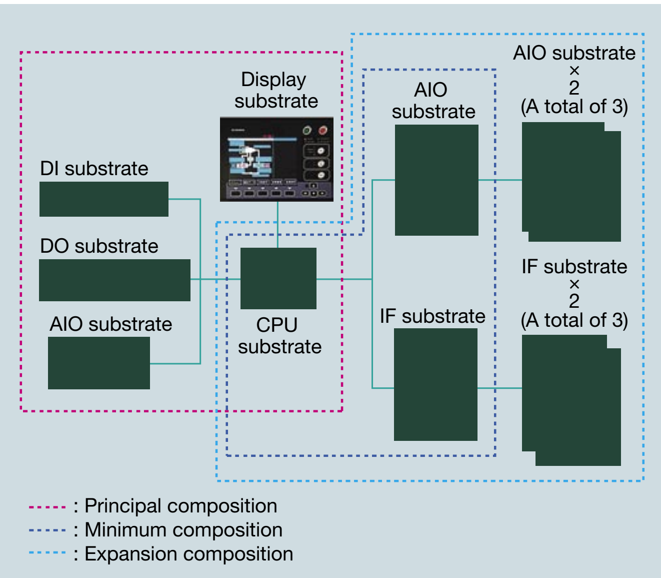

Fig. 5 Composition of microcomputer control substrate

Fig. 6 Display substrate
Display interface

room. Therefore, data recording or obtaining a log at the time of a failure was an issue to be resolved. Therefore, a general purpose memory card slot was included as a means of easily transferring large amounts of data to and from the chiller. In the past, it was necessary to perform measurements using a portable computer on-site along with specialized tools if remote monitoring was not available. However, it is now possible to collect data on trial operation easily with only a single card.

The historical log includes data on 16 events counting back from the latest. For each failure event, information on the time of occurrence, data on 256 analog items, and data on 512 digital items are stored with 50 samples before and 20 samples after the occurrence. This makes it possible to analyze the detailed state of the equipment at the time the failure occurred. In addition, the data logging (sampling) cycle can be changed in increments of 1 sec. This makes it possible to collect data at a rate suitable for the details of a failure.

Alarms (minor failures) that do not lead to failures that stop operation are also recorded. A total of 100 such alarms can be recorded counting back from the latest one. Thus, it is possible to collect information on past operations of a chiller to determine any signs of abnormality and to plan maintenance.

(5) Reinforcement of voltage drop detection

As described above, short-time detection of power failures and voltage drops is extremely important for stable operation and restart of the heat source system.

The latest MHI control module has a very high degree of accuracy, being capable of detecting instantaneous power failures within half a cycle or less of the power supply frequency, as it is equipped to monitor the AC voltage directly.

(6) Environmental responsiveness

The latest control modules comply with regulations on the restriction of hazardous substances. They use lead-free solder and component parts.

6. Conclusion

The improved centrifugal chillers should perform at least as well as the original basic machines. However, advanced and sophisticated control mechanisms are essential to achieve the highest performance in various situations.

For this reason, MHI has made advanced arithmetic control possible through the use of customized microcomputer control panels to meet new user needs, such as automatic restart from an instantaneous voltage drop or superlow load operation. We intend to pursue further development to meet new user needs that will become increasingly diverse and demanding in the future.


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