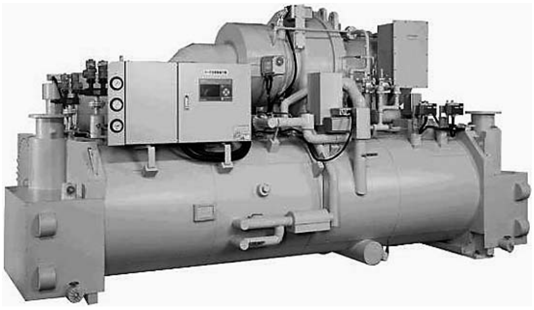

Variable Speed Drive Turbo Chiller NART-I Series Featuring World's Highest Efficiency

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1. Introduction

Turbo chillers are heat source equipment used in various applications including air conditioning of buildings, district heating and cooling in heat supply business, factory air conditioning for manufacturing electronic devices, and process cooling of chemical plants. Using centrifugal compressors, these machines produce chilled water ranging from 350 kW to 7 000 kW (maximum 35 000 kW). Mitsubishi Heavy Industries, Ltd. (MHI) uses HFC-134a gas with zero ozone depleting potential (ODP) as the refrigerant for turbo chillers in the course of activities to protect the global environment, and has been endeavoring to enhance the performance of the equipment in order to save energy demanded by the society.

The turbo chiller using HFC-134a was introduced in 1994. This was followed by the ARS series in 1998 and the NART series in 2000, and efficiency has been improved by more than 20% during this period. COP 6.1 (chilled water exit temperature 7°C) of NART series has the world's highest level, but customers' needs are for high-efficiency operation and reduction of power consumption throughout the year, that is, year-round saving of air conditioning cost. To meet such needs, inverter-driven turbo chillers were developed in 2002 for the purpose of enhancing operation efficiency, and were put on the market in January 2003.

2. Detailed description of high efficiency

In chillers, a chain reaction takes place consisting of higher ambient temperature followed by higher cooling water temperature, higher condensation temperature and pressure, higher compression ratio of compressor, and increase of required power; the power consumption thus depends on the ambient temperature. Since turbo chillers use a centrifugal compressor, unlike the volumetric type (reciprocating type, screw type), the compression ratio and motor input are characteristically determined by the rotating speed of the compressor. Hence, by optimum control of the rotating speed, energy can be saved significantly in year-round operation. Accordingly, based on the high-efficiency standard machine NART series, NART-I series has been developed by using an inverter in the motor power source and installing a rotating speed control mechanism.

2.1 Optimum control

In a centrifugal compressor, inlet vane control and hot gas bypass valve control are employed for the purpose of load control (**Fig. 1**), but since the inlet vane control generally has increased resistance loss in a region of small opening degree, it is preferable to control at as high a degree of opening as possible. In addition, since the hot gas bypass valve control used in low load region is accompanied by loss on cycle, it is preferable to control at the minimum possible degree of opening. With the variable speed control designed in consideration of these points, a control map as shown in **Fig. 2** has been realized, the performance drop is minimized in the entire region of operation, and operation at high efficiency is possible over a wide load range.

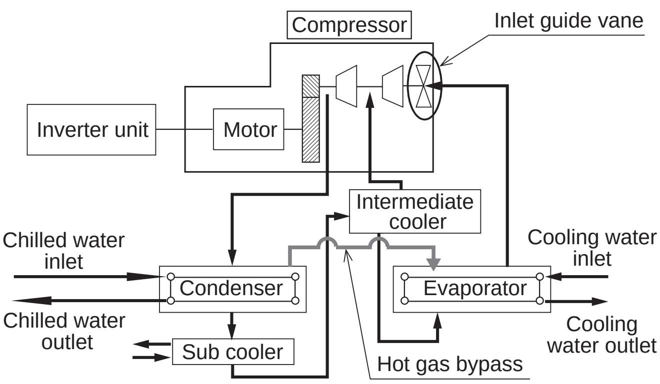

Fig. 1 Block diagram of turbo chiller
The turbo chiller system is shown together with inlet vane and hot gas bypass.

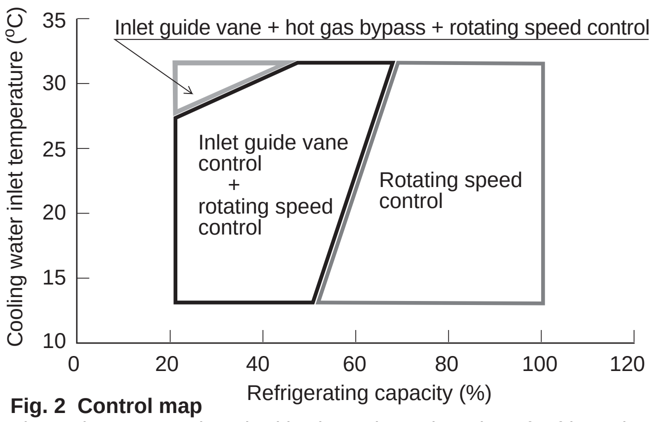

Fig. 2 Control map
The optimum control method is shown in each region of refrigerating capacity and cooling water inlet temperature.

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2.2 Microcomputer control panel

Characteristic formulas for realizing optimum control are complicated, and a high speed capacity is required in order to compute without delay from temperature control of the chiller. Accordingly, a high-performance CPU is used in the core of the next-generation control panel. Further, to enhance visibility and controllability, a 7-inch TFT liquid crystal display device as shown in **Fig. 3** is included in the standard equipment.

3. Energy saving effects

As variable speed control has been added to the high-efficiency standard NART series, performance is greatly enhanced in the partial load region (**Fig. 4**), and the highest COP of 17.8 has been achieved at chilled water outlet temperature of 7°C in the general condition of air conditioning turbo chillers in Japan. As a result, energy can be saved substantially in year-round operation.

The energy saving effects of variable speed operation by inverter driving were assessed, and the results are shown in **Fig. 5**. Conditions of assessment include general factory heat source load pattern and ambient temperature condition in the Tokyo district.

In variable speed chillers, as compared with standard machines, energy saving effects of 10 to 15% are expected in July - August, and as much as 50% in mid-season to winter. In terms of annual power consumption and CO_2 emission, 45% is saved as compared with high-efficiency standard chillers (fixed speed), which corresponds to reduction of 35% in energy bills. The overhaul interval is extended by about 50 000 hours, and by rotation control, the load on the rotation system can also be reduced during operation. Moreover, by operation management using the communication function of the new microcomputer control panel, a much longer interval between overhauls is realized.

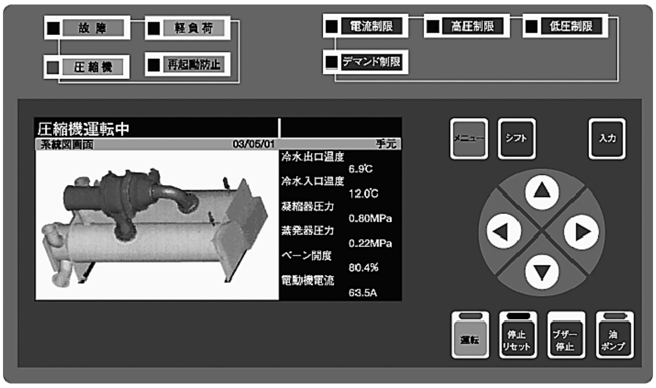


Fig. 3 New microcomputer display panel
Color display of operation panel is shown.

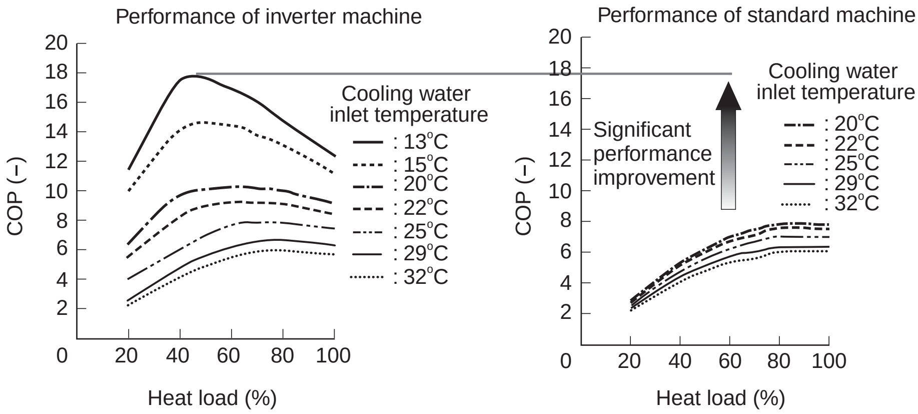
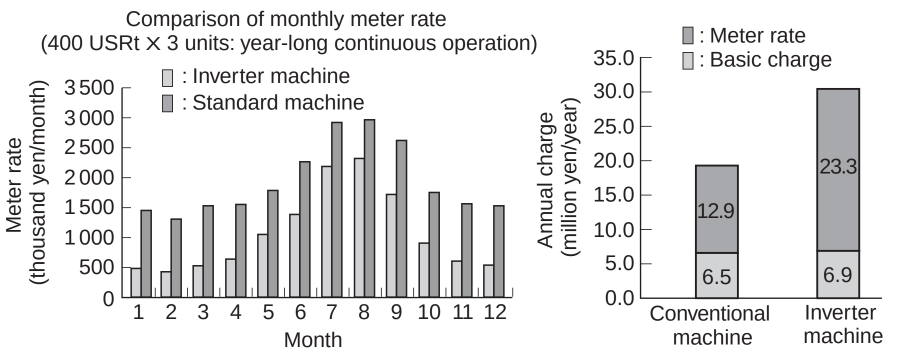


Fig. 4 Comparison of performances of variable speed chiller and conventional chiller
In partial load region, the variable speed chiller displays significantly enhanced performance.



(a) Power consumption and CO_2 emission both reduced by 45%

(b) Energy bill reduced by 35%

Fig. 5 Energy saving efficiency of variable speed machine
Annual energy saving efficiency is converted into energy bill.

Table 1 Main specifications of NART-I series

Item		Specification				
Machine type	(-)	NART-40I	NART-50I	NART-70I	NART-100I	NART-145I
Capacity	(USRt)	400	570	800	1 130	1 610
	(kW)	1 407	2 004	2 813	3 973	5 661
Chilled water inlet temperature	(°C)	12	12	12	12	12
Chilled water outlet temperature	(°C)	7	7	7	7	7
Chilled water flow rate	(m^3/h)	241	345	484	683	974
Chilled water pressure loss	(kPa)	115	131	58	54	69
Cooling water inlet temperature	(°C)	32	32	32	32	32
Cooling water outlet temperature	(°C)	37	37	37	37	37
Cooling water flow rate	(m^3/h)	286	404	566	798	1 138
Cooling water pressure loss	(kPa)	60	71	55	51	53
Motor output	(kW)	212	305	424	599	864
Inverter input	(kW)	245	343	475	680	972
Supply voltage	(V)	400 V class	400 V class	400 V class	6 000 V class	6 000 V class
Motor type	(-)	NCHP-4	NCHP-5	NCHP-9	NDHP-10	NDHP-13
COP	(-)	5.74	5.84	5.92	5.84	5.82

The standard specifications of NART-I series are shown in **Table 1**. Since being marketed in January 2003, NART-I series chillers have been chosen by electric power companies, factory heat source users and users requiring replacements, and have acquired a high reputation. Several chillers are in service in Japan as shown in **Table 2**, and the orders and inquiries are increasing. NART-I series is expected to contribute greatly to high-efficiency operation throughout the year and energy-saving operation as demanded by customers, as air conditioning applications for industries and heat source for factory processes.

4. Conclusion

(1) The turbo chiller has recorded the world's highest level of COP = 17.8 (chilled water temperature 12°C/7°C base) in partial load, using HFC-134a refrigerant.

(2) Thanks to the optimum rotating speed control, load tracing performance and cooling water following performance, excellent high-efficiency operation is possible throughout the year, and energy is saved by 45% (in plant load condition) as compared with conventional standard machines.

(3) Thanks to the improved control panel, function is enhanced and superior controllability and communication function are realized.

(4) Several units have already been put into commercial operation, and are gaining high reputation for performance and reliability.

Table 2 History of installation of NART-I series

Model	Capacity (RT)	District	Application	Date of installation
NART-40I	400	Kanto	Factory air conditioning	2002/12
NART-50I	420	Kanto	Factory air conditioning	2003/01
NART-50I	570	Tohoku	Factory air conditioning	2003/03
NART-50I	570	Tohoku	Factory air conditioning	2003/03
NART-50I	570	Tohoku	Factory air conditioning	2003/05
NART-50I	500	Tohoku	Factory air conditioning	2003/08
NART-35I	350	Kanto	Factory air conditioning	2003/08

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