Recent Technology of Hydraulic Turbine Generators

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1. Introduction

In recent years, waterless and oilless technology aimed at maintenance-free products has been actively adopted for small to medium-sized power plants, the mainstream of today's hydraulic generation. The technogy has already entered the development stage and its application range is widening.

In this paper, we will introduce recent waterless cooling technology and its actual performance, widely used electromagnetic brakes, recent compact-sized brushless exciters, and other developments.

2. Bearing for a Waterless Cooling System

Several times in our journal, we have introduced the developing process of air cooling oil-immersed bearings and its application results. In this paper, we will describe its application technology and actual performance.

2.1 Air cooling of oil-immersed bearings in vertical machines

Table 1 shows the reference list of oil-immersed bearings cooed by air.

A compact cooler has been an essential requirement for the widespread use of oil-immersed bearings. Recently, we reduced the number of coolers and its dimension as well as simplified the design by adopting cooling tubes with inner fins.

Table 2 shows the construction and performance of conventional tubes and tubes with inner fins. **Figure 1** shows the external view of a generator mounted with this new type of cooler.

Air cooled, oil-immersed bearings are applied not only to new power stations but also to existing ones to be renewed. Shibakigawa No. 2 power station, listed in **Table 1**, is an example of the adoption of an outlet pipe ventilation system in place of an existing totally enclosed cooling system and oil-immersed bearings cooled by air were adopted to pursure full waterless cooling. If an existing

Table 2 Comparison between cooling tubes

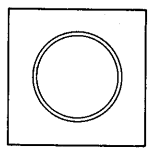
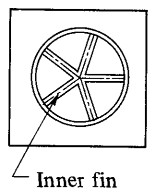
Item	Conventional tube	Tube with inner fins
Type of tube		
Area for heat transfer (%)	100	74
Heat transfer coefficient (%)	100	140
Dimension of cooler unit (%)	100	76

Table 1 Reference list of oil-immersed bearings cooled by air in vertical generators

Plant name \ Item	Output (kVA)	Rated speed (r/min)	Thrust load (ton)	Guaranteed bearing temp. (°C)	Kinds of oil	No. of cooler units	Manufactured
The Tokyo Electric Power Co., Inc. (Ohtsu)	2,800	333	54	65	VG56	–	1978
Mie Prefecture (Yamatodani)	7,200	514	30	80	VG56	2	1983
Nihonkai Hatsuden Co., Inc. (Katagaiminamimata)	5,300	450	31	75	VG46	2	1987
Kyushu Electric Power Co., Inc. (Kakibaru)	6,350	600	43	75	VG56	4	1989
Chubu Electric Power Co., Inc. (Hichiso)	2,380	200	60	75	VG46	2	1988
Tohoku Electric Power Co., Inc. (Ohzaso)	12,200	375	57	65	VG46	4	1988
The Hokkaido Electric Power Co., Inc. (Pirika)	4,450	500	100	75	VG46	2	1989
The Chugoku Electric Power Co., Inc. (Shibakigawa No. 2)	7,500	450	65	75	VG46	2	1991

Fig. 1 External view of a generator with the new type mounted cooler

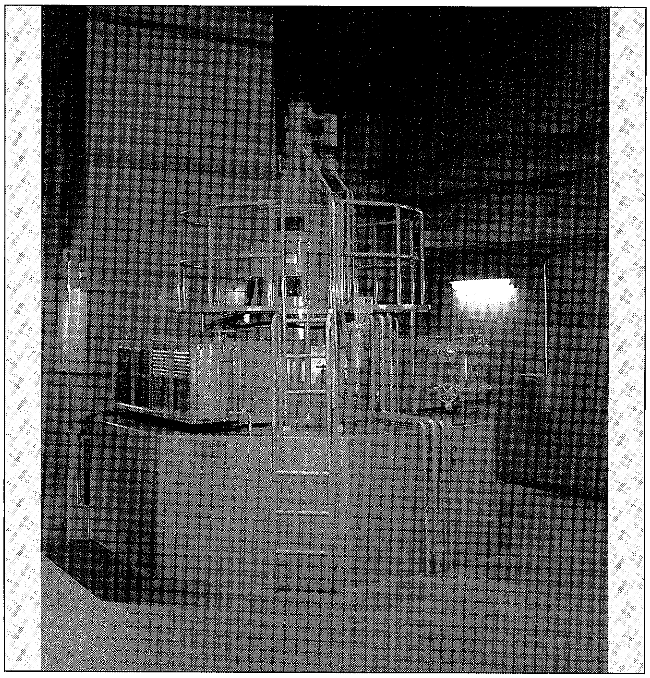
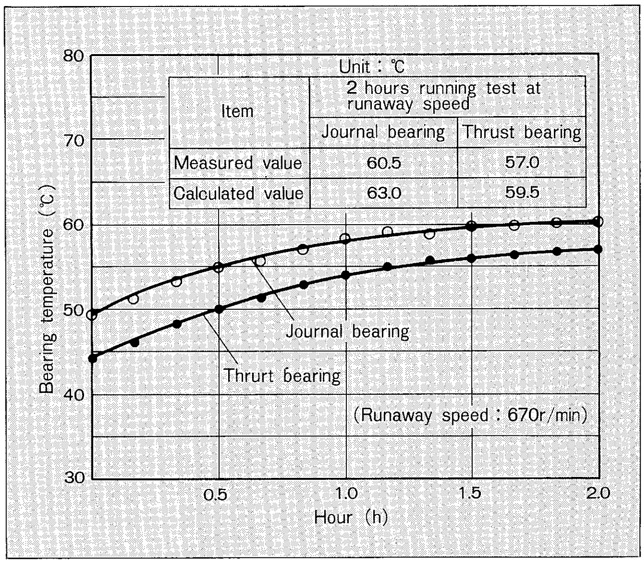


Fig. 2 Temperature characteristics of heat-pipe-cooled bearings in the runaway speed test



power station has a pipe ventilation system, the following matters should be considered:

(1) Because an additional cooler for bearing lubricating oil increases the pressure drop in the ventilating passage and decreases ventilating air, the temperature of air entering a generator could rise. This results in a higher temperature of the stator windings. In this case, it is necessary to consider adopting one of the following two measures:
    (a) Increasing fan capacity by the replacement of fans, considering if it is necessary to alter the building's air inlet and outlet air ducts and an air vent.
    (b) Replacing the insulation of the stator and rotor windings to make them F class/F rise.
(2) Because the dimensions of the lower bearing's oil reservoir with cooler fins is generally larger as compared with an existing one, it is necessary to consider if it accommodates the existing pit.

In addition, when adopting an outlet pipe ventilation system in place of an existing, totally enclosed cooling system, the necessity of inlet and outlet air ducts for the building and measures to counter outdoor noise should be considered.

2.2 Heat-pipe cooled bearings for horizontal machines

Since 1990, we have been using heat-pipe cooled bearings, which operate satisfactorily at three power stations listed in **Table 3**.

Figure 2 shows on site measurement results of bearing temperature after 2 hours running at the runaway speed for the first generator (1,400 kVA) to have heat-pipe cooled bearings.

As shown in the measurement results, cooling performance and design accuracy are fully satisfactory.

3. Fin Cooling System for Bulb Type Generators

Ways in which to dissipate heat generated in bulb type generators into surrounding river water are divided into two broad categories: direct cooling through the outer core frame rather than by cool air; and fin cooling, through fins attached to the inner bulb wall and by cool air.

Although both systems have been developed and put into use, we will introduce in this paper the fin cooling system, whose range of application is expanding.

3.1 Enhancement of fin cooling capacity

Heat transfer determining fin cooling capacity is given by the following formula:

Table 3 Reference list of heat-pipe-cooled bearings in horizontal generators

Plant name \ Item	Output (kVA)	Rated speed (r/min)	Thrust load (ton)	Journal load (ton)	Guaranteed bearing temp. (°C)	Manufactured
The Tokyo Electric Power Co., Inc. (Nikko No. 1)	1,400	375	11	4.3	65	1989
Kyushu Electric Power Co., Inc. (Kojikano)	4,580	600	7.3	6.5	75	1989
Kyushu Electric Power Co., Inc. (Shinsumiyougawa)	3,340	600	5.2	6.0	75	1991

$Q = K \cdot \Delta T \cdot A \propto K \cdot \Delta T \cdot \pi \cdot D \cdot L$

Q: Heat transfer (W)

K: Heat transfer coefficient ($W/m^2 \cdot K$)

ΔT: Temperature difference between cooling air and river water (K)

A: Fin setting area (m^2)

D: Bulb diameter (m)

L: Fin setting length (m)

Bulb diameter is determined by specifications for the water turbine, and hence the enhancement of cooling capacity requires research into the following items:

(1) Increase of the fin setting length

The longer fin setting length, achieved by making efficient use of the stator frame's inner wall as well as the top nose, increases the bulb's total length and incurs a space restriction in which to install the generator.

Further, a longer fin length is naturally limited in terms of blower design because of increase of pressure drop of air.

(2) Increasing the temperature difference between cooling air and river water

This measure requires a higher temperature of cooling air at the fin outlet. It is also useful for the widening range of application.

(3) Improvement of the heat transfer coefficient

This measure requires research of the shape and arrangement of the fins as well as the accumulation of experimental data.

Fig. 3 Improvement of the heat transfer coefficient

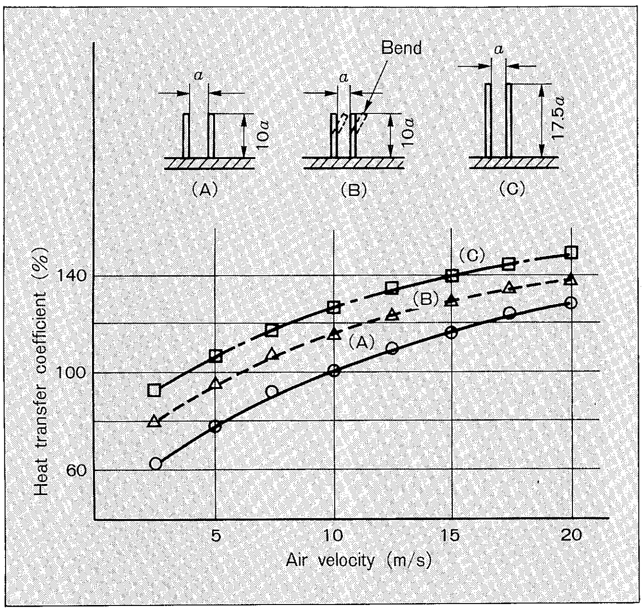


Fig. 4 Tube cooling system

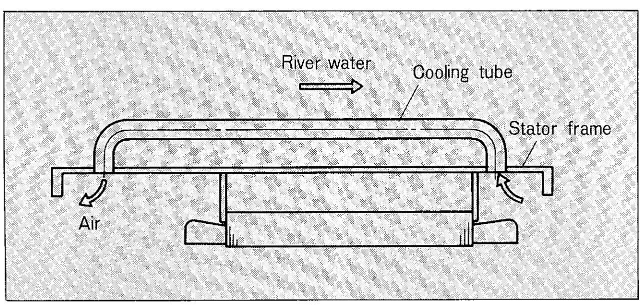
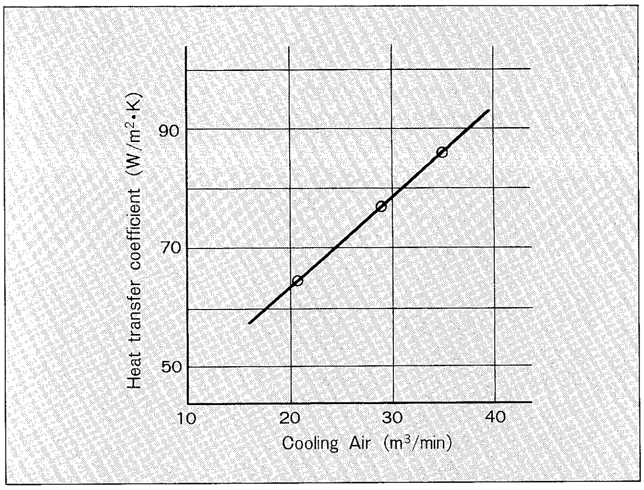


Fig. 5 Heat transfer coefficient of the cooling tubes



3.2 Improvement of the heat transfer coefficient

Since supplying Electric Power Development Co., Ltd.'s Sakuma Power Station with the first generator utilizing the fin cooling system, we have been researching ways in which to improve the heat transfer coefficient. In the precess, we have accumulated experimental data regarding the various shapes and arrangements of the fins.

Figure 3 shows the heat transfer coefficient characteristics in relation to typical fin shapes.

On the other hand, because improvement of the heat transfer coefficient causes the increase of pressure drop of cooling air, selection of the fin shape requires careful consideration in accordance with specifications of blower.

Figure 4 shows the arrangement of cooling tubes outside the stator frame. Its purpose is to enhance cooling capacity, now under research, as an application of the fin cooling method.

Fuji Electric has completed basic research on the above system, and **Fig. 5** shows the actual experimental values of the heat transfer coefficient in this system.

Through the above mentioned development and application research, this cooling system stands a fair chance of application in low speed, bulb type generators of less than 30MVA.

4. Electromagnetic Brake

Fuji Electric has completed the development of an electromagnetic brake as part of the transition from hydraulic and pneumatic operation to electric operation. **Table 4** shows power stations provided with electromagnetic brakes, which are outlined below.

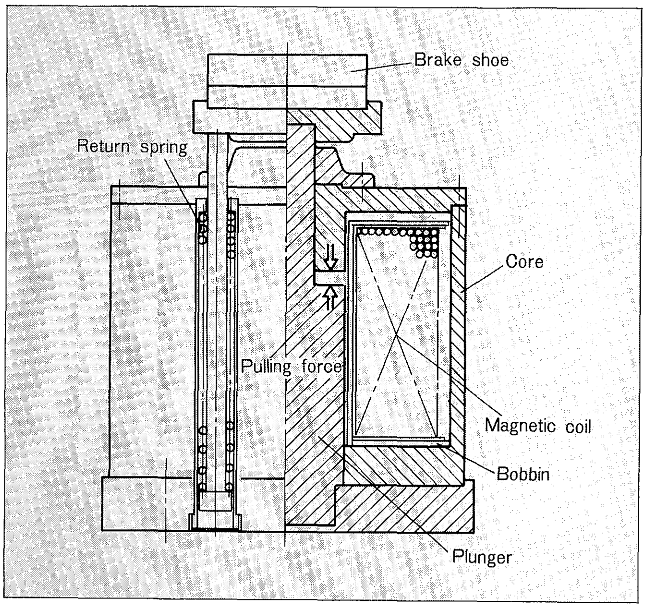
4.1 Specifications

The specifications of the electromagnetic brake are

Table 4 Reference list of electromagnetic brakes

Plant name \ Item	Output (kVA)	Rated speed (r/min)	Brake force/unit (N)	No. of brake units	Brake rating	Type of generator	Manufactured
Chubu Electric Power Co., Inc. (Hichiso)	2,380	200	2,350	3	Continuous (2 steps)	Vertical	1988
Kyushu Electric Power Co., Inc. (Shinsumiyougawa)	3,340	600	5,300	1	Continuous	Horizontal	1991
Fukui Prefecture (Nakajima No. 2)	2,500	514	5,300	1	Short time (10 min.)	Horizontal	1991
Chubu Electric Power Co., Inc. (Nikengoya)	27,400	400	9,800	4	Continuous (2 steps)	Vertical	1992

Fig. 6 Electromagnetic brake construction



as follows:

(1) Power source: DC 90 to 130V

(2) Rating: Continuous (2 step-control is available) or short time

During its development, we carried out an electromagnetic force characteristic test, a coil temperature-rise test and 7,000 repetitive operations to thoroughly confirm reliability.

4.2 Construction

Figure 6 shows the construction of a electromagnetic brake.

An F class-insulated magnetic coil in the bobbin is installed between the stator core and the movable plunger. When the coil is excited, the plunger is attracted by the electromagnetic force and the brake shoe rises up to bracking the generator rotor. The bult-in return spring resets the brake shoe.

An electromagnetic brake has no jack function; therefore, jack equipment is indispensable. Furthermore, because an electromagnetic brake is greater in size and weight than a mechanical brake, careful consideration must be given to space requirements as well as assembly and disassembly requirements in its application.

Fig. 7 Outline of the brushless exciter

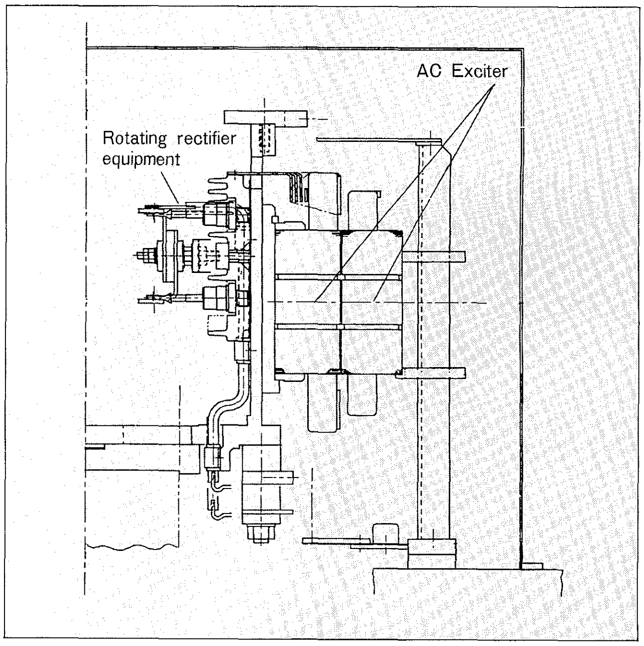
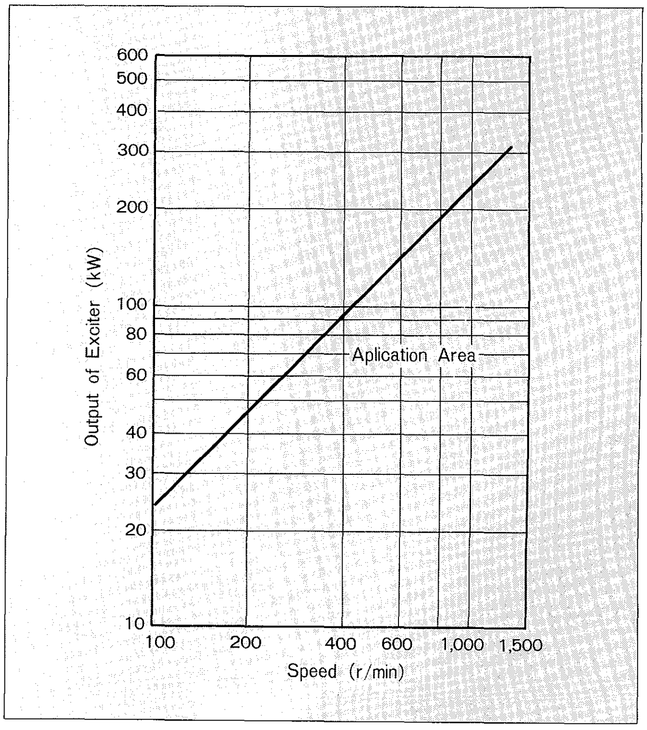


Fig. 8 Application area of the brushless exciter



5. Brushless Exciter

In modernizing an existing machine, a brushless exiter is increasingly adopted to attain a maintenance-free state. Because the exciter is generally heavier and bulkier than a slip ring, the critical speed of shafting will decrease, which is likely to hinder replacement.

Fuji Electric has been developing a small-sized, lightweight brushless exciter to broaden its application range on existing machines.

Following is the outline of its development.

5.1 Construction outline

Figure 7 shows the general view of the construction of the exciter.

As shown in the figure, the rectifier equipment is installed inside the rotor to reduce its total hight and to achieve compactness.

The rotary rectifier equipment has a 3 pahse, full wave bridge connection with diode rectifiers and a 1S1P construction, in which each arm consists of one diode, for compactness. If diode failure occur, the rotary rectifier equipment is protected by the normally supplied diode failure detector which judges the diode failure from the field current of the exciter and the running condition of the generator.

The AC exciter is a rotating, armature-type, synchronous generator with a cylindrical pole and windings are totally vacuum-impregnated.

Through the above development, we greatly reduced the exciter's weight and 60% of its total hight. As a result, we greatly lessened the drop in critical speed of shaft system and made the inspection of the rectifier equipment easier from the upside, resulting in better maintainability.

5.2 Range of application

Figure 8 shows the range of application for the brushless exciter we have developed.

This exciter is applicable for use in generators up to 30MVA, covering most small to medium-sized machines.

6. Postscript

In this paper we introduced recent technology and its effect on small to medium-sized generators. We are also actively engaged in the research and development of preventive maintenance, lowering noise from pipe ventilation systems as well as in other fields.