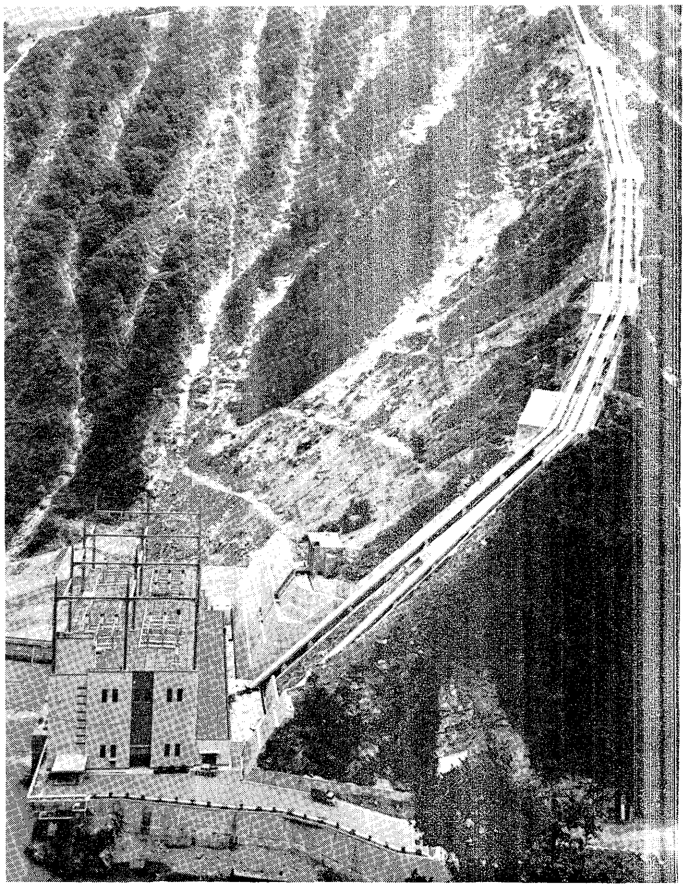

Wadagawa Power Station

UDC 621.224+621.313.322

FUJI HYDRAULIC TURBINE AND GENERATOR (I)

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I. GENERAL DESCRIPTION

Fuji Electric concluded a technical assistance agreement in 1938 with the J.M. Voith GmbH (German) concerning hydraulic turbines and in 1922 with the Siemens-Schuckertwerke AG of the same country for generators, transformers, breakers, distribution and other electrical equipment, and manufactured these products. Following the war termination, Fuji Electric made a similar agreement with these same two companies and has been manufacturing the above items.

Fuji Electric is a manufacturer which is able to make composite planning, designing, and manufacturing of prime movers and electrical equipment. Differing from other foreign manufacturers where turbines and generators are separately produced by different manufacturers, Fuji Electric has a top arrangement and rationalization of machinery. Fuji Electric built the famous hydraulic laboratory as well as top research and manafacturing facilities.

Fuji Electric received orders and manufactured approximately 30% of Japan's total hydraulic power generation facilities constructed immediately following the war termination, and gained a high reputation due to the facilities' superior performance.

Table 1 shows the supply list of Fuji Electric in Japan in the post-war days (The horizontal shaft Francis turbine and the horizontal shaft Pelton turbine are omitted).

The following turbines and generators are being planned for installation in Japan. These could be manufactured by Fuji Electric with present equipment and facilities.

1. "A" power station

1) Vertical shaft Francis turbine
140 m, 190 Mw, 150 m³/s, 138.5 rpm

2) Three-phase synchronous generator
200 Mva, 24.2 kv, 60 c/s, P.F.=0.9, 138.5 rpm

2. "B" power station

1) Vertical shaft Francis turbine
290 m, 162 Mw, 64 m³/s, 333 rpm

2) Three-phase synchronous generator for the above turbine
160 Mva, 50 c/s, 15.4 kv, P.F.=0.95, 333 rpm.

Fig. 1 shows a Francis turbine spiral casing being processed on a 12 m. Vertical Turning and Boring Mill. This unit is for delivery to Akiba No. 1 Power Station.

Fig. 2 shows a profile type Vertical Turning and Boring Mill. (manufactured by Berthiez Company)

Max. turning diameter	6300 mm
Table diameter	4000 mm
Max. turning height	3500 mm

Fig. 3 shows a Horizontal Boring and Milling Machine (manufactured by Schiess Company) being used to process a Kaplan turbine blade from a model.

Fig. 4 shows a generator being assembled by two

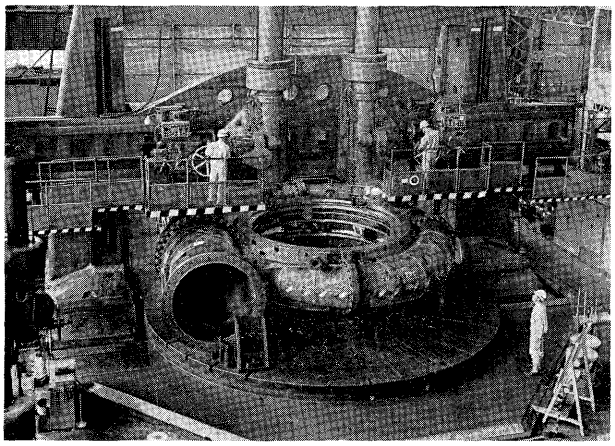


Fig. 1 Vertical turning and boring mill

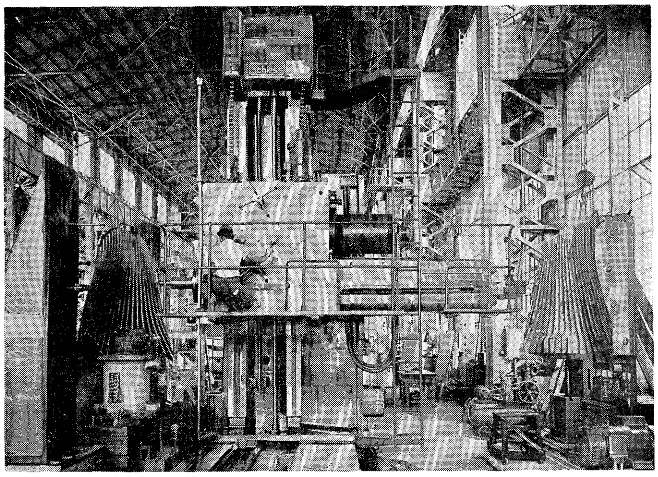


Fig 3 Horizontal boring and milling machine

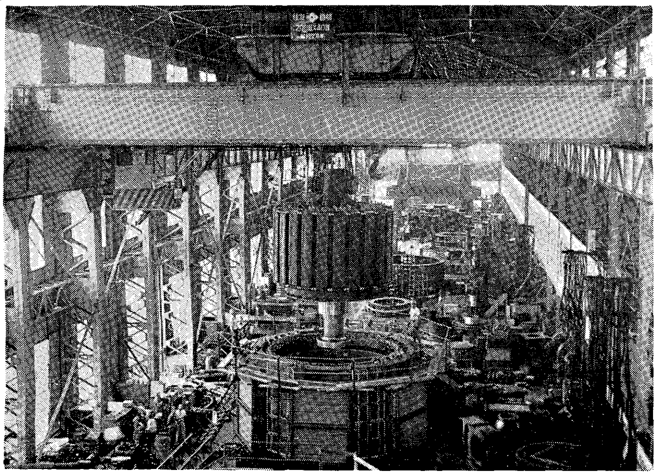


Fig. 4 Two sets of 240 ton cranes

240-ton cranes. The cranes are able to lift 480-ton rotors.

Fig. 5 shows heavy duty Lathe processing of the main shaft.

Max. turning diameter	3200 mm
Max. turning length	12,000 mm
Max. weight of work	100 tons

The assembling pit is 8 m in diameter and 7 m in depth. With generator test drive motors of 4000 kw, 200 to 700 rpm and 1000 rpm available, any and all types of generators can be tested at the factory.

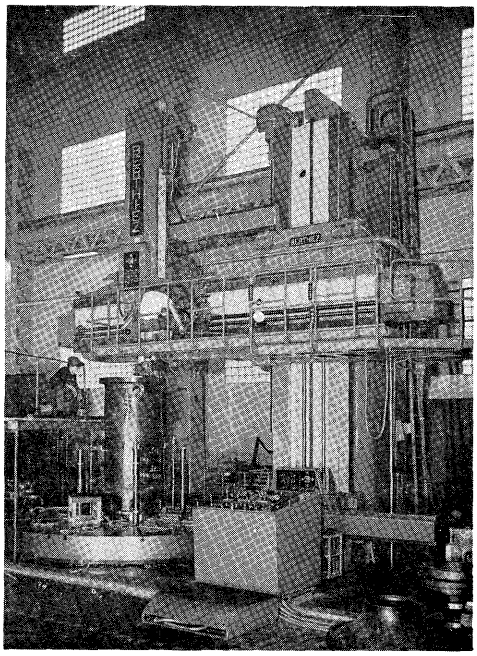


Fig. 2 Vertical turning and boring mill

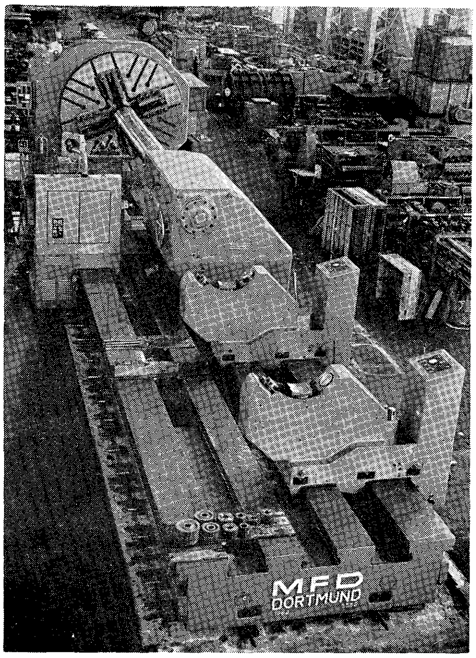


Fig. 5 Heavy duty lathe

Table 1 shows the items ordered for export. Fuji Electric is determined to exert utmost efforts in order to develop export to many countries.

In addition to model turbines designed by Voith Company, Fuji Electric has developed many model turbines through its own skill. Fuji Electric is prepared to submit data for whatever model turbine is required by the customer. Efficiency of these turbines is the

best in the world and superior cavitation characteristics are widely recognized by users. An example is given below:

Francis turbine

Specific speed	150 (Unit: m-kw)
Runner diameter	400 mm
Maximum efficiency	92.0%
Head	4 m
σ_B (critical cavitation coefficient)	0.047

Kaplan turbine with five vanes

Specific speed	600 (Unit: m-kw)
Runner diameter	400 mm
Head	3.5 m
Max. efficiency	90.9%
σ_B	0.65

Vertical shaft Pelton turbine

Specific speed	20 (Unit: m-kw)
Runner diameter	400 mm
Head	60 m
Max. efficiency	90.0%

The site testing efficiencies recorded at Wadagawa No. 2 Power Station, and Kurobegawa No. 4 Power Station are far superior to those of other manufacturer's products. The testing efficiency of generators is also remarkably high, with a generator efficiency of 98.3% for Wadagawa No. 2 Power Station.

The welding techniques of Fuji Electric are highly evaluated and were fully displayed in the work on a spherical type pressure vessel with plate thickness of 86 mm and inside diameter of approximately 19 m at Tokai Atomic Power Station.

Table 2 shows Fuji Electric's welding technicians. Fuji Electric has succeeded in reducing the weight of turbines and generators, based on superior welding techniques.

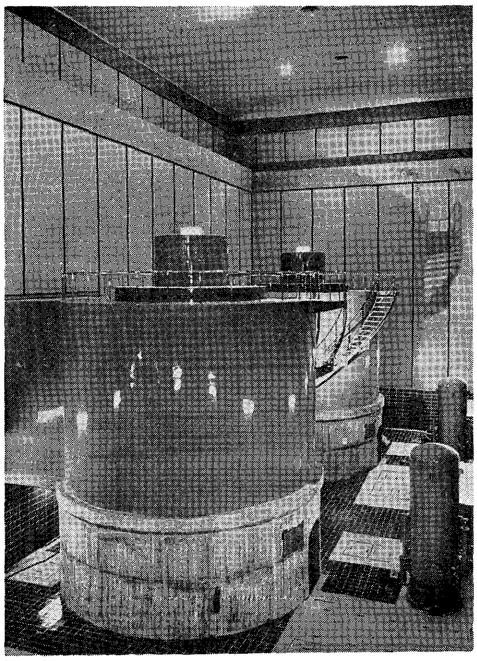


Fig. 6 74,200 kva generators

II. ACTUAL INSTALLATIONS (FOR EXAMPLE) (I)

Vertical Shaft Francis Turbine and Generator Shimotaki Power Station, Tokyo Electric Power Co.

High-head Large-capacity Francis Turbine

Turbine specifications

Type:	Vertical Francis Turbine
No. of units:	2
Effective head:	330 m
Discharge:	24 m^3/s

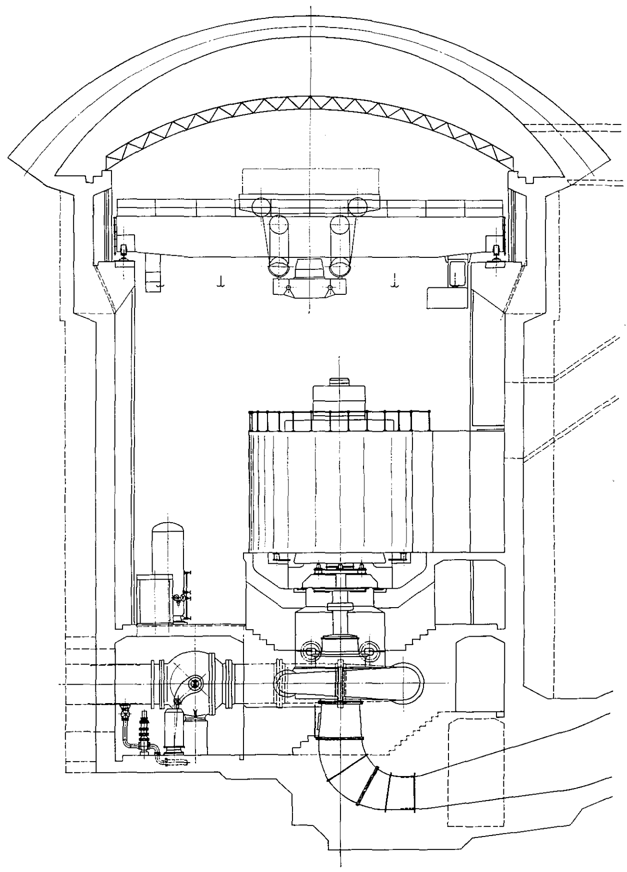


Fig. 7 Machine arrangement (side view)

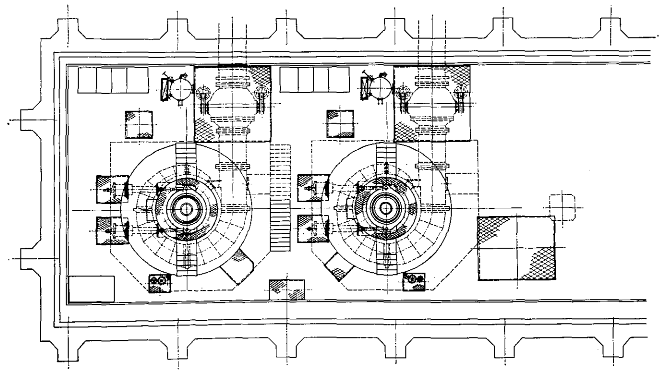


Fig. 8 Machine arrangement (plan view)

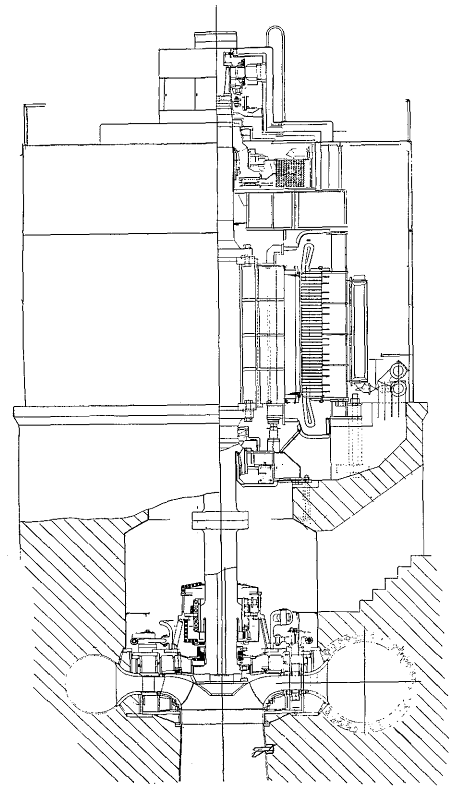


Fig. 9 Sectional view of Francis-turbine generator

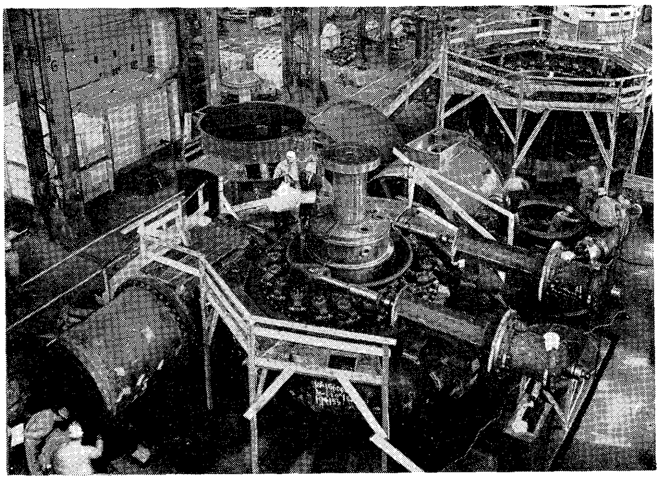


Fig. 10 Francis-turbine under assembling at shop

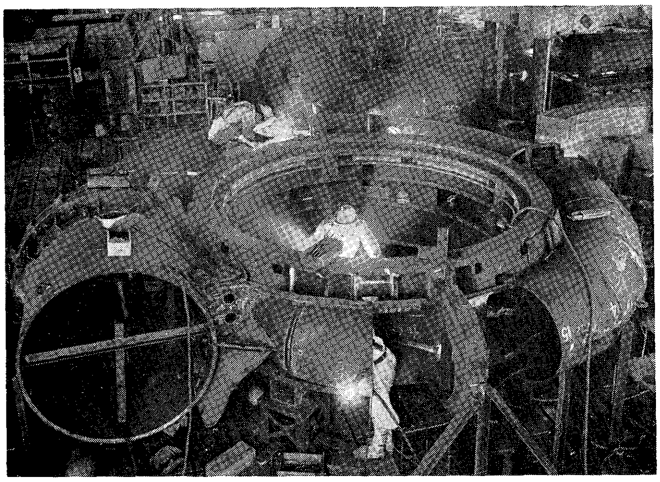


Fig. 11 Spiral casing of turbine under welding

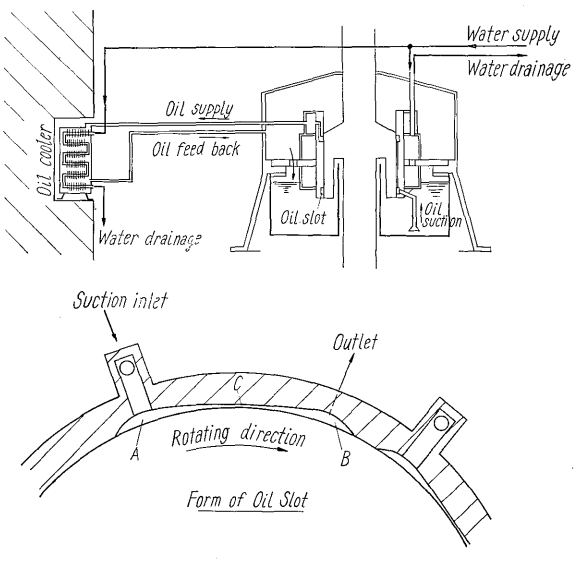


Fig. 12 Lubricating system of main bearing

Output :	69,000 kw
Speed :	500 rpm
Specific speed :	93 (Unit : m-kw)
Runaway speed :	850 rpm
Generator specifications	
Capacity :	74,200 kva
Voltage :	13.2 kv
Frequency :	50 cps
GD^2 :	640 t-m^2
P.F. :	0.91

Turbine outline

This power station is a typical Japanese type with high-head and large capacity (Francis Turbine). A turbine with a high specific speed of $ns=93$ at a head of 330 m is rare in the world. The generator is installed on a concrete barrel. This station is built as a perfect underground power station and single floor station.

For the turbine body, a welded construction of steel plates is primarily employed, with full consideration for safety against a high head and for economy.

Welded construction was also employed for the turbine casing with an inlet diameter of 1600 mm. The material used for the welded construction was rolled steel [JIS SM 50 B (meeting ASTMA 242–60)] with superior notch ductility tensile strength and yield point.

The entire welding work was performed with a full complement of Fuji Electric techniques. A quality annealing process was conducted at the

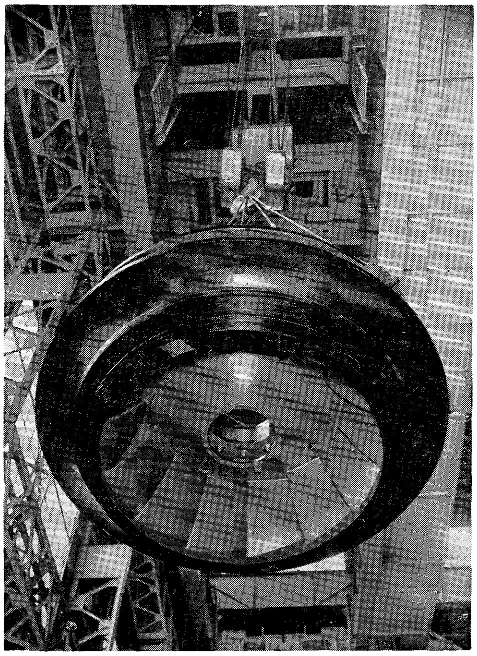


Fig. 13 Francis-turbine runner

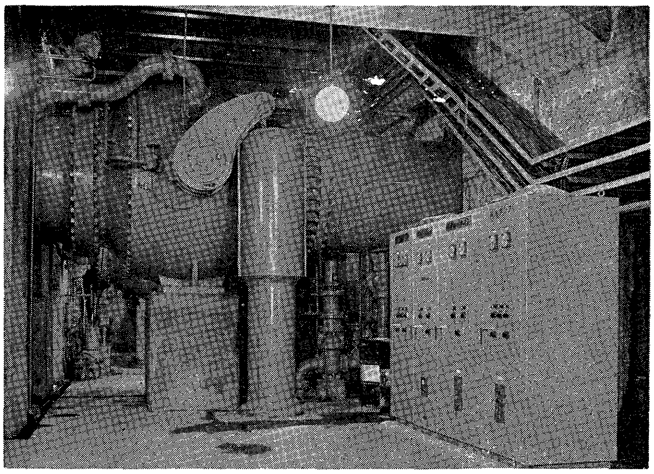
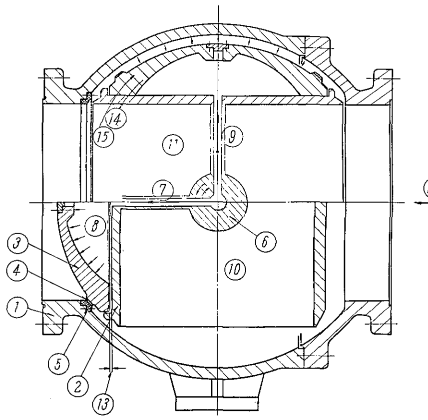


Fig 14 Rotary valve



① Valve body
② Valve rotor
③ Choking plate
④ Seal
⑤ Valve seat
⑥ Trunnion
⑦ Pressure water
⑧ Water pressure
⑨ Discharge
⑩ Valve closing
⑪ Valve opening
⑫ Water flow
⑬ Stroke of choking plate
⑭ Closing
⑮ Opening

Fig. 15 Rotary valve (section)

factory. The turbine was divided into four units for transport convenience and assembling at the site was made by flange tightening. The guide bearing of hydraulic turbines is provided with suitable oil grooves to circulate oil in an oil sump by means of pumping action caused by rotation of the main shaft. For the cooling system, an oil cooler separate from the water jacket is accommodated in the interior wall of the barrel, through which oil is circulated by the viscous pump for perfect cooling performance.

The runner is made of 13% Cr cast steel.

Fuji Electric's unique rotary valve is employed for the main valve and is controlled by an oil pressure system.

The generator utilizes Fuji standard construction for high speed machines and is provided with various features regarding ventilation, lubrication, and mechanical construction. The peripheral speed of the rotor is 84 m/s (at 500 rpm). 143 m/s at the runaway speed (850 rpm), no question arises concerning the

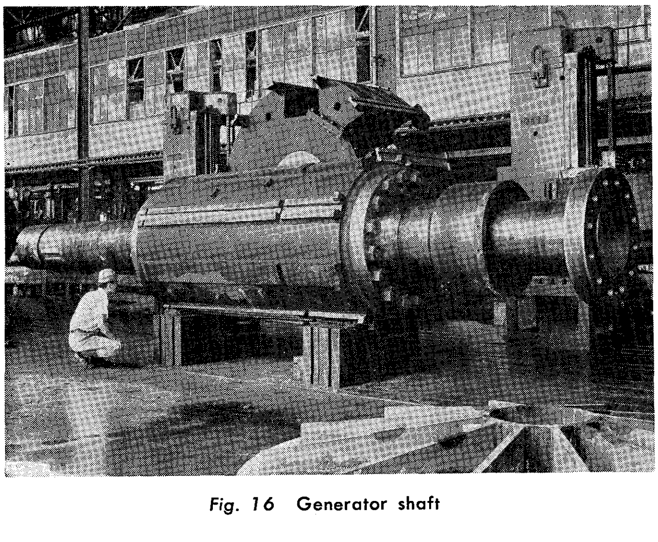


Fig. 16 Generator shaft

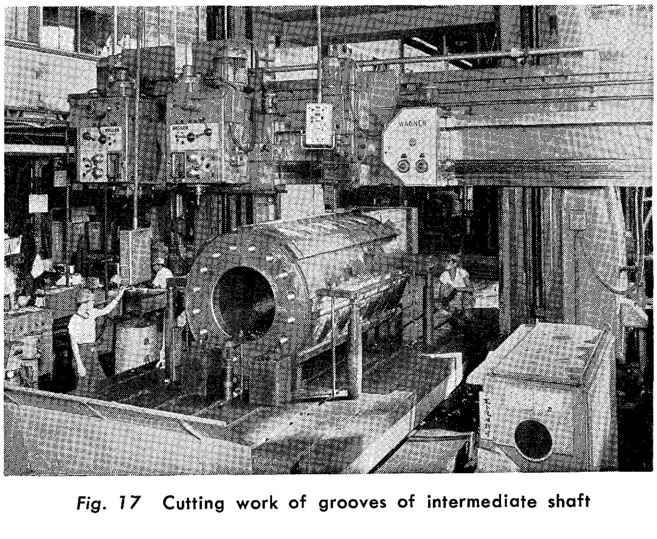


Fig. 17 Cutting work of grooves of intermediate shaft

safety factor of more than 1.5 for the yielding point. The rotor is disassembled into three sections (upper, medium, and lower) for transporting and is as shown in *Fig. 16*.

The intermediate shaft is fabricated of welded steel in a logical box type "skin stress construction".

Fig. 17 shows a 10 m Plano Miller cutting the groove of the intermediate shaft.

Plano Miller

Planing length of work	10 m
Width of work	3.5 m
Height of work	3.5 m
Milling head	3
Planing head	2

The rotor rim is a "forged steel massive ring" divided axially into four sections. *Fig. 18* shows the groove cutting work.

Fig. 19 shows the pole coil clamps. The magnetic pole (iron core) uses high tensile strength steel plate of 1.6 mm in thickness, which is built in a layer to 2.5 m (core length) by a hydraulic press.

Fig. 20 shows the installation construction of the pole and rotor yoke.

Fig. 21 shows the Mitchel type thrust bearing.

Fig. 22 shows the super-finish work of the thrust bearing runner.

Fig. 23 shows the thrust bearing pad.

Particularly in this type of generator (with long length iron cores), it is important in ventilation to distribute air in order to provide equal temperature all along the iron core.

Since the mechanical loss is 56% of the entire loss, it is necessary to reduce "eddy loss" by employing the variable angle axial flow fan shown in *Fig. 24* (runner for brake also used).

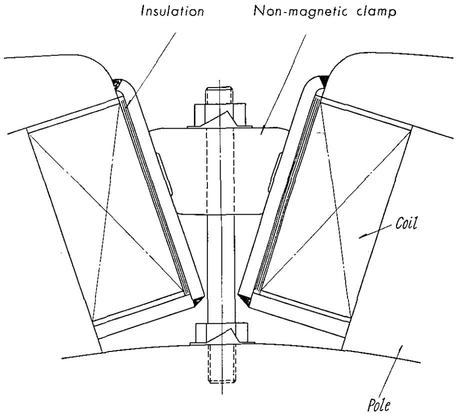


Fig. 19 Construction of pole coil clamp

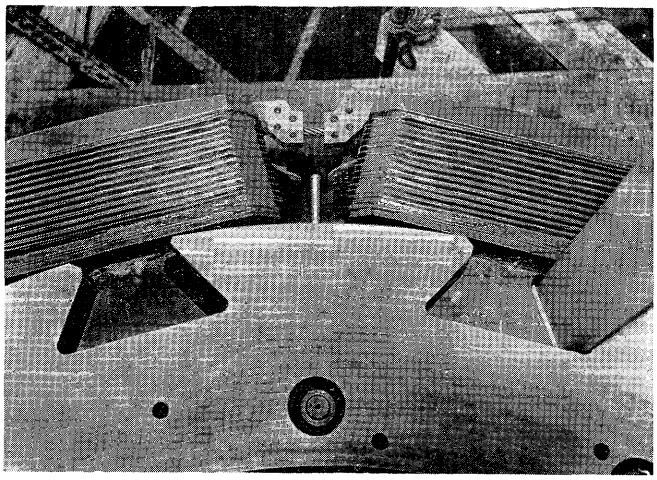


Fig. 20 Installation construction of pole and rotor yoke

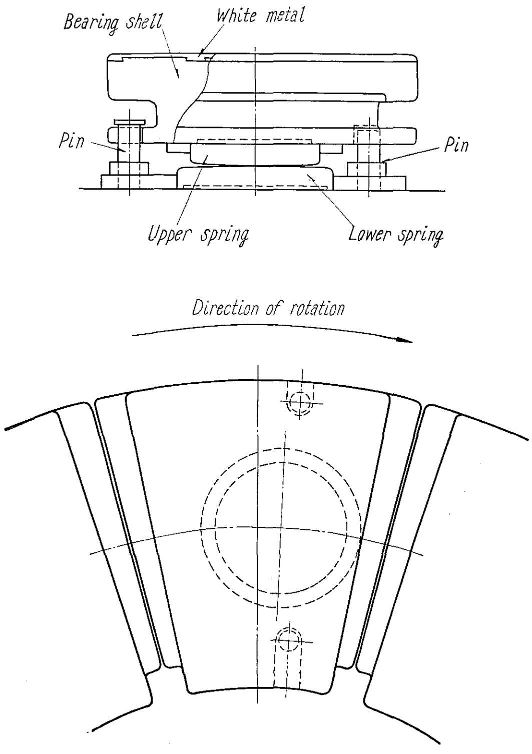


Fig. 21 Mitchel type thrust bearing

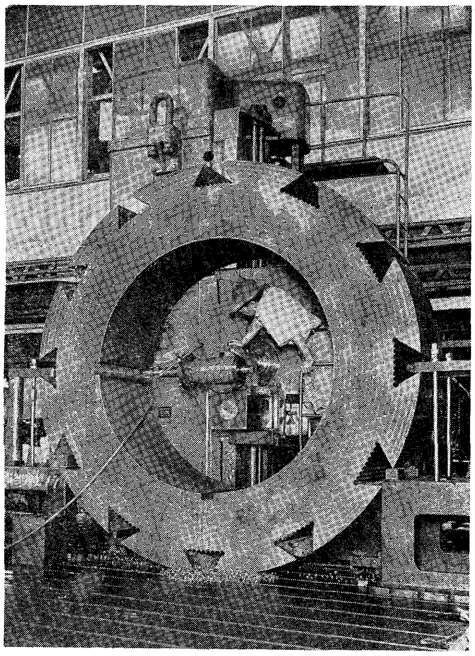


Fig. 18 Cutting work of massive generator rotor yoke

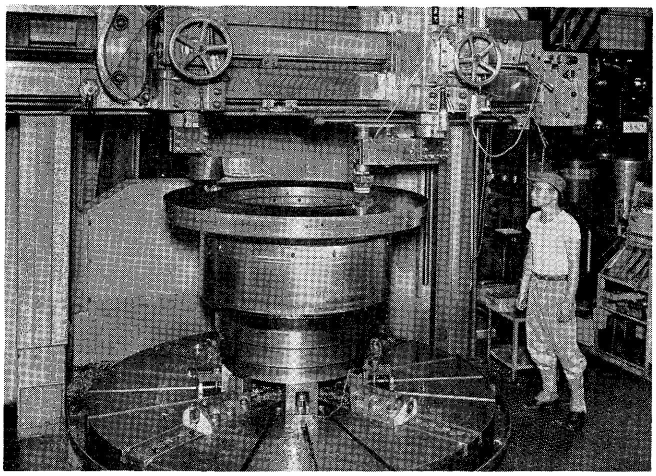


Fig. 22 Super-finish of thrust bearing runner

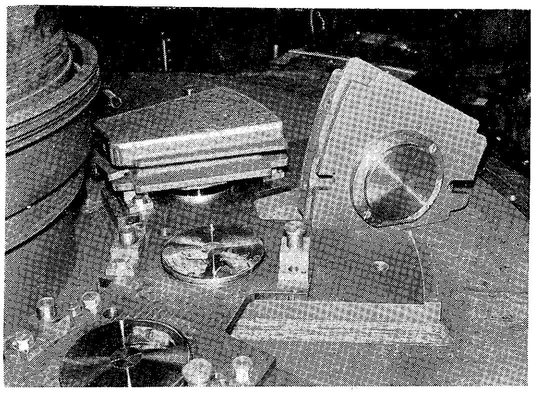


Fig. 23 Thrust bearing pad

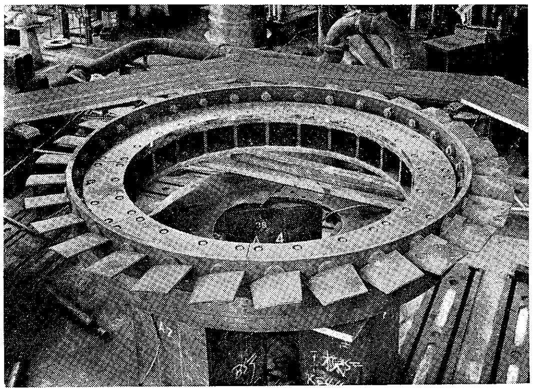


Fig. 24 Axial flow fan

After the factory test is completed, the vane angle is determined and fixed. The stator is a welded type construction where as many pipes and frames as possible are used. For the stator iron core, 0.35 mm high grade silicon steel plate is used.

Fig. 25 shows the stator iron core being tightened by a hydraulic press. The tightening of the iron core to the stator frame is performed with what is generally called "Laschen construction" (*Figs. 26, 27*).

Fig. 28 shows the stator coil (one turn Gitter coil in which F resin, epoxide resin, are used) being voltage tested. The superior characteristics astonished engineers in Europe.

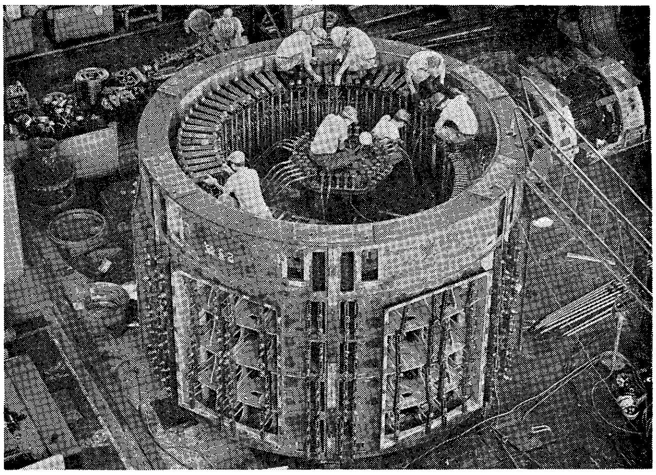


Fig. 25 Stator iron core tightening

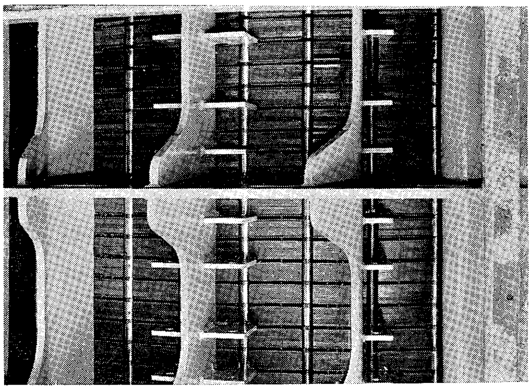


Fig. 26 "Laschen construction" of generator stator

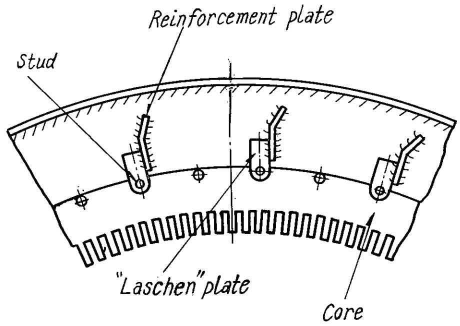


Fig. 27 "Laschen construction" of generator stator

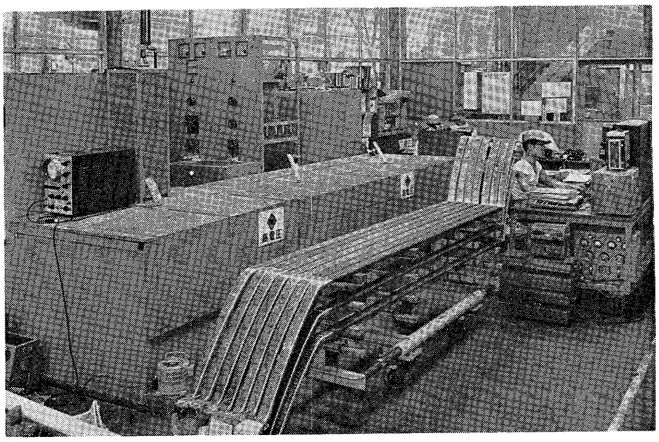


Fig. 28 Voltage test of stator coil

Fig. 29 shows the results of tan δ and corona discharge tests on the Shimotaki Power Station generator coil (13.2 kv). The measured value of tan δ was less than 1%, and no increase in tan δ was observed following voltage rise. That is, the highest tan δ characteristics were displayed. In addition, slot discharge was measured through the recently developed Void discharge measurement technique of slot insulation interior. This measurement is also listed. This results in detecting an extremely small value of Void which can not be found by tan δ. It has been said the corona discharge of more than 1000 P.C. is harmful to the insulation effect. However, the test reveals that no slot discharge reaching 1000 P.C. was generated under the rated voltage.

Fig. 30 shows the stator coils being put in stator slots at the factory.

Fig. 31 shows the rotor being assembled at the factory. A " U " fin tube is used for the air cooler.

Fig. 32 shows the generator slip ring chamber. (The commutator can be seen in the exciter, above).

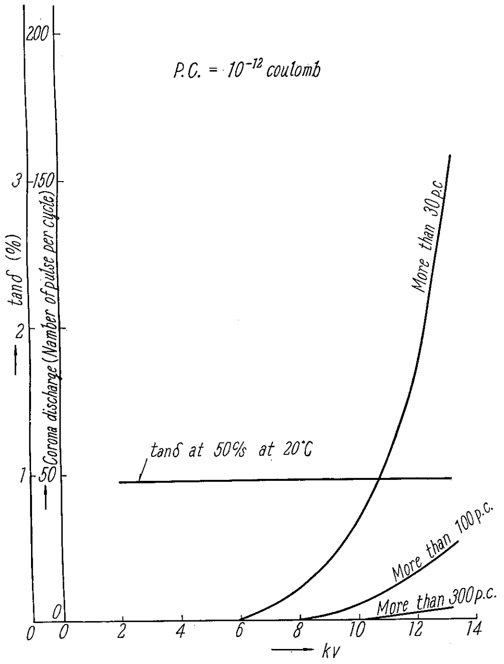


Fig. 29 tan δ and corona discharge-voltage characteristics

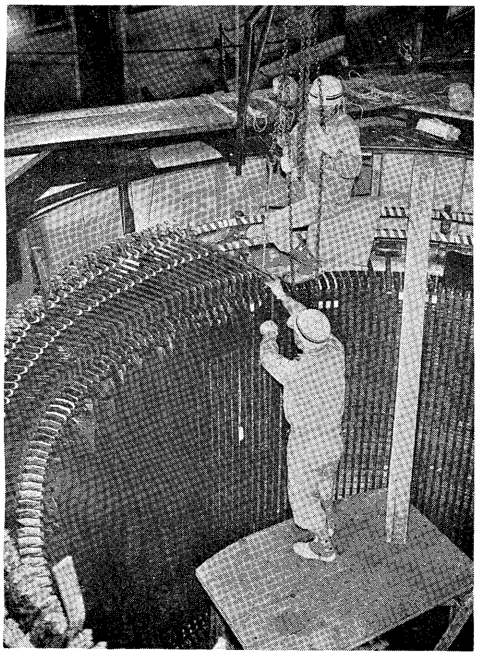


Fig. 30 Stator coils being put in stator slots

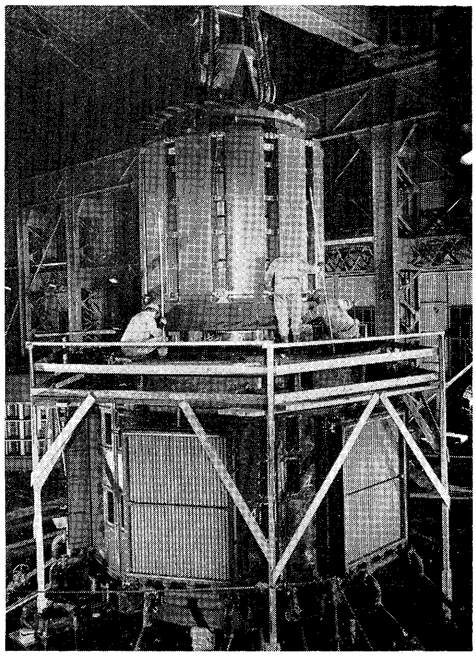


Fig. 31 Rotor being assembled at the factory

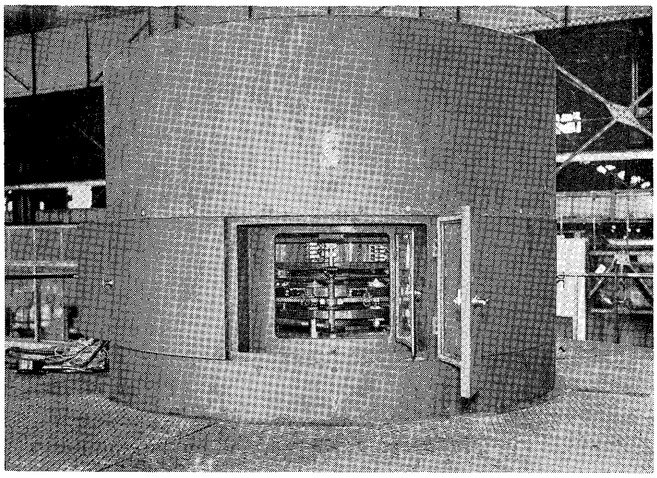


Fig. 32 Exciter of generator

***Table 1* Supply List of Hydraulic Turbines & Generators**

(Manufactured since 1946)

Vertical Francis Turbine and Directly Coupled Generator

G : Generator

Customer	Plant Name	Unit	Turbine			Generator			Remarks
			Output (kw)	Head (m)	Speed (rpm)	Output (kva)	Voltage (kv)	Frequency (c/s)	
Tokyo Electric Power Co.	Shimotaki	2	69,000	330	500	74,200	13.2	50	
NPC, Philippines	Maria Cristina	1	58,800	166.6	300	—	—	—	For Philippines
Chubu Electric Power Co.	Yokoyama	2	37,000	68.8/60.3 141.7	200	40,000	13.2	60	
Tokyo Electric Power Co.	Komatsu No. 2	1	35,000	144	375	35,000	11.0	50	
Hokuriku Electric Power Co.	Omata	1	33,800	128.9	360	34.500	11.0	60	
Hokkaido Electric Power Co.	Shunbetsu	1	30,000	108	333	30,000	11.0	50	
Kansai Electric Power Co.	Utsubo	1	27,000	69	200	30,000	11.0	60	
Electric Power Development Co.	Owase No. 2	1	27,000	121	360	28,000	11.0	60	G : Self-excited type
Electric Power Development Co.	Akiba No. 1	2	26,300/ 25,000	48.8	200/167	27,000/ 30,000	11.0	50/60	
Oita Prefecture	Kitagawa	1	26,000	116.63	360	29,600	11.0	60	G : Self-excited type
Tokyo Electric Power Co.	Fujihara	1	23,000	92.5	250	24,000	11.0	50	
Tokyo Electric Power Co.	Sudagai	2	22,400	83	250	24,000	11.0	50	
Tokyo Electric Power Co.	Hayakawa No. 3	1	21,500	149	428.5	21,500	11.0	50	G : Self-excited type
Tohoku Electric Power Co.	Kajikawa	1	18,500	203.8	600	20,000	6,6	50	G : Self-excited type
Yamanashi Prefecture	Narada No. 1	2	14,100	251.3	750	16,000	11.0	50	
Furukawa Mining Co.	Hosoo	1	12,000	220	750	14,500	11.0	50	G : Self-excited type
Nippon Electric Power Generation & Transmission Co.	Yoshigase	2	11,700	114.5	450	12,000	11.0	50	
Tohoku Electric Power Co.	Katsukonda	1	11,500	211	600	13,000	11.0	50	
Fukui Prefecture	Nakajima	2	10,600	153	600	11,000	11.0	60	
Tokyo Electric Power Co.	Shioya	1	10,400	61/59/56	333	9400	6.6	50	
Yamanashi Prefecture	Nishiyama	2	9600	147	600	10,800	11.0	50	
Tokyo Electric Power Co.	Hakojima	1	9400	81.90	375	10,000	6.6	50	
Hokuriku Electric Power Co.	Iori	2	9400	240	600	10,000	6.6	60	
Hokuriku Electric Power Co.	Gojyoho	2	9100	129.85	600	10,000	6.6	60	
Kyushu Electric Power Co.	Jikumaru	1	9100	62.793	400	9500	11.0	60	
Tochigi Prefecture	Kawaji No. 1	2	8300	108	500	9000	11.0	50	
Hokkaido Electric Power Co.	Kubonai	1	8000	122.0	600	9500	11.0	50	
Electric Power Development Co.	Izawa No. 1	2	8000	110	500	8500	6.6	50	
Hokkaido Electric Power Co.	Shikaribetsu No. 2	1	7700	102	500	8000	6.6	50	
Yamagata Prefecture	Sonooka	1	7000	179.4	750	7400	6.6	50	
Chugoku Electric Power Co.	Shibakigawa No. 2	1	6900	72.24	450	7500	11.0	60	
Shin Nippon Chisso Hiryo K.K.	Memaru	1	6000	188.4	1,000	6500	6.6	50	
Shin Nippon Chisso Hiryo K.K.	Uchitani No. 2	2	4800	188.0	600/740	5000	6.6	50/60	
Tohoku Electric Power Co.	Shitokigawa No. 1	1	4180	122.0	750	5000	6.6	50	
Tochigi Prefecture	Kawaji No. 3	1	3600	92	750	4000	6.6	50	G : Self-excited type
Tohoku Electric Power Co.	Ogawa	1	2600	106.7	1,000	2400 (kw)	6.6	50	G : Induction generator

Vertical Pelton Turbines and Directly Coupled Generators

T: Turbine, G: Generator

Customer	Plant Name	Unit	Turbine				Generator			Remarks
			Output (kw)	Head (m)	Speed (rpm)	No. of Nozzles	Output (kva)	Voltage (kv)	Frequency (c/s)	
Kansai Electric Power Co.	Kurobegawa N. 4	2	95,800	580	360/300	6	—	—	—	T: Voith-Fuji (casing)
Hokuriku Electric Power Co.	Wadagawa No. 2	2	68,900	470	300	4	70,000	13.2	60	G: With magnet bearing
Kerala State Electricity Board, India	Kuttiadi	3	28,784	662	600	4	28,000	11.0	50	For India
Hokuriku Electric Power Co.	Banbajima	1	22,000	319	450	5	23,000	11.0	60	T: 5 nozzles G: Self-excited type
Hokuriku Electric Power Co.	Tochio	1	16,000	292	400/333	4	17,000	11.0	50/60	
Japan Light Metal Co.	Motosu	1	12,700	457.233	720	4	13,000	6.6	60	G: With magnet bearing
Mie Prefecture	Miyagawa No. 3	1	12,500	477.2	720	4	14,000	6.6	60	G: Self-excited type
Yakushima Electric Co.	Anpogawa No. 1	1	12,200	326	514	4	14,000	6.6	60	G: Self-excited type
Yakushima Electric Co.	Anpogawa No. 1	1	12,200	326	514	4	14,000	6.6	50	G: Self-excited type
Tacna Prefecture, Peru	Aricota No. 2	1	12,200	311.8	514	4	14,000	11.0	60	G: Self-excited type For Peru
Hokuriku Electric Power Co.	Nakazaki	1	10,800	253	400/333	4	11,000/ 12,000	6.6	50/60	
Hokuriku Electric Power Co.	Okuyama	1	10,500	336	600	4	11,000	6.6	60	G: Self-excited type

Vertical Kaplan Turbines and Directly Coupled Generators

T: Turbine, G: Generator

Customer	Plant Name	Unit	Turbine			Generator			Remark
			Output (kw)	Head (m)	Speed (rpm)	Output (kva)	Voltage (kv)	Frequency (c/s)	
Kyushu Electric Power Co.	Oyodogawa No.1	1	43,800	40.4	180	45,000	13.2	60	
Electric Power Development Co.	Akiba No. 2	1	38,000/ 35,000	36.6	180/150	35,000/ 38,000	11.0	50/60	
Tohoku Electric Power Co.	Shin-ochiai	1	22,000	65/52/47	273	25,000	11.0	50	
Hokuriku Electric Power Co.	Jintsugawa No. 2	2	21,500	31.2	200	23,500	11.0	60	
Hokuriku Electric Power Co.	Tomita	1	20,800	28.2	200	22,000	11.0	60	
Tohoku Electric Power Co.	Kamigo	1	17,000	18.1	167	18,000	6.6	50	
Hokuriku Electric Power Co.	Kabekura	2	13,900	37.7	300	15,000	11.0	60	
Kansai Electric Power Co.	Tsunokawa	1	13,000	36.5	300	13,000	11.0	60	
Kansai Electric Power Co.	Tsunokawa (extension)	1	13,000	36.5	300	13,000	11.0	60	
Arakawa Hydro-electric Power Co.	Iwafune	1	12,500	20.93	214	13,500	6.6	50	G: Self-excited type
Hokuriku Electric Power Co.	Jintsugawa No. 3 (Right bank)	1	10,200	9.72	100	11,000	11.0	60	
Electric Power Development Co.	Sendaigawa No.2	2	8800	19	225	8500	6.6	60	G: Self-excited type
Hokuriku Electric Power Co.	Jintsugawa No. 3 (Left bank)	1	8250	16	180	8500	6.6	60	T: Propeller type
Tohoku Electric Power Co.	Obari	1	7700	32.27	333	8500	6.6	50	G: Self-excited type
Tohoku Electric Power Co.	Horyo	1	7200	34.8	333	8500	6.6	50	
Tohoku Denkiseitetsu Co.	Ishihane	1	6000	17.0	231	6300	6.6	50	
Yamanashi Prefecture	Narada No. 2	1	4600	35.57	428.5	5200	11.0	50	
Furukawa Mining Co.	Setoyama	1	1000	14	428.5	1150	3.3	50	T: Propeller type

Tubular Turbines and Directly Coupled Generators

T: Turbine, G: Generator

Customer	Plant Name	Unit	Turbine			Generator			Remarks
			Output (kw)	Head (m)	Speed (rpm)	Output (kva)	Voltage (kv)	Frequency (c/s)	
Hokuriku Electric Power Co.	Joganjigawa No. 2, 3, 4	3	5340	15.1	240	5500	3.3	60	G: Self-excited type synchronous generator
Hokuriku Electric Power Co.	Omata Dam	1	3350	13/9/4.5	200	3600	3.3	60	〃
Oita Prefecture	Shimoaka	1	1840	10.65	240	1900	3.3	60	〃

Vertical Pump-turbines and Generator-Motors

T: Turbine, G: Generator

Customer	Plant Name	Unit	Pump-Turbine Output (kw)	Head (m)	Speed (rpm)	Generator-Motor Output (kva)	Voltage (kv)	Frequency (c/s)	Remarks
Chubu Electric Power Co.	Hatanagi No. 1	1	(T) 51,800 (P) 39,700	101.8 103.2	200/166.7 200	(G) 58,800/49,000 (M) 41,800	11/10 11	60/50 60	T: Francis type, Allis-chalmers made (Casing: Fuji made) G: With magnet bearing
Electric Power Development Co.	Kuromatagawa No. 2	1	(T) 19,200 (P) 20,000	78/73/39 80/41	300 333/300	(G) 19,000 (M) 20,000/19,000	11.0 10.5	50 50	T: 2 speed diagonal flow type G: 2 speed pole change type, with magnet bearing

Exported Hydro-electric Power Equipment

Customer	Plant Name	Unit	Turbine Output (kw)	Head (m)	Speed (rpm)	Type	Generator Output (kva)	Voltage (kv)	Frequency (c/s)	Remarks
NPC, Philippines	Maria Cristina	1	58,800	166.6	300	Vertical Francis	—	—	—	For Philippines
Kerala State Electricity Board, India	Kuttiadi	3	28,784	662	600	Vertical Pelton	28,000	11.0	50	For India
Tacna Prefecture, Peru	Aricota No. 2	1	12,200	311.8	514	Vertical Pelton	14,000	11.0	60	For Peru
Snowy Mountains Hydro-electric Authority, Australia	Murray 1	1	950	410	1000	Horizontal Pelton	900	0.415	50	For Australia
Korea Electric Power Co.	Suiho (Yalu)	2	—	—	—	Vertical Francis	100,000	16.5	50 (150 rpm)	S.S.W. made Both installation and adjustment were carried out by our company.

Table 2 **Qualified Welders of Our Kawasaki Factory**

JIS		LSB		MITI
Class 1	Class 2	Special class	Ordinary class	Thermal power plant
41	10	8	4	8

MITI & LLOYD'S Nuclear Power Plant	JPI	MTB
23 + (54)	14	5

( ): Welders from sub-contractors who are specialy trained in the welding school of our Kawasaki Factory

JIS: Welder qualification in accordance with specification No. Z-3801 of Japanese Industrial Standard (JIS)

LSB: Welder qualification for boiler welding in accordance with specification of Labor Standard Bureau.

MITI: Welder qualification for welding of thermal power plants in accordance with specification of Ministry of International Trade & Industry (MITI)

MITI & LLOYD'S: Welder qualification for welding of reactor pressure vessel of nuclear power plants in accordance with MITI & LLOYD'S special specification.

JPI: Welder uqalification for welding of petroleum plants in accordance with specification of Japanese Petroleum Institute (JPI).

MTB: Welder qualification for welding of marine engines in accordance with specification of Maritime Transportation Bureau (MTB).

(To be continued)