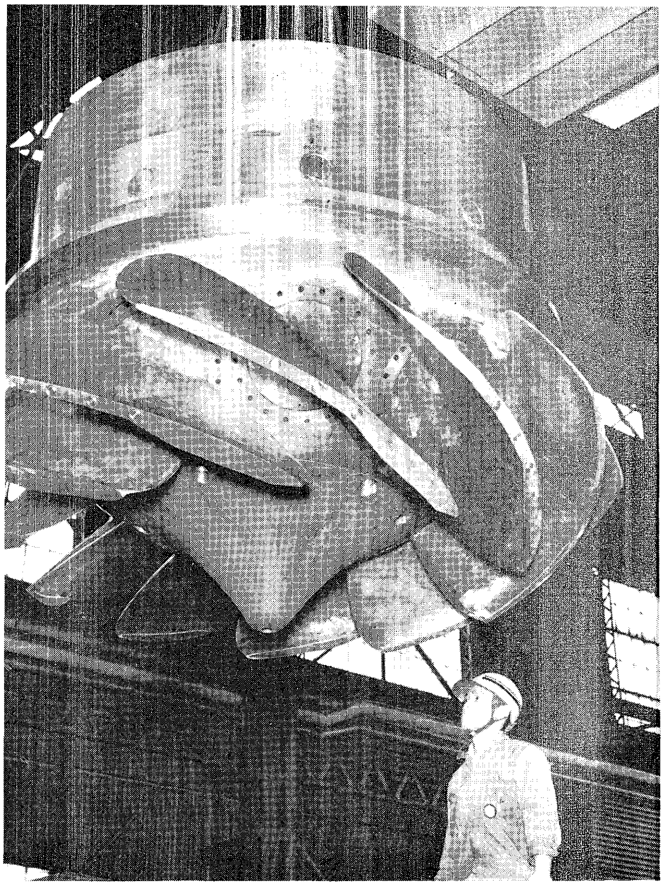

Two-speed Deriaz type pump-turbine
for Kuromatagawa No. 2 Power Station

Turbine :	78/73/39 m	19.2/18/6.5 Mw	300 rpm
Pump :	80/75/41 m	20 Mw	333/300 rpm

UDC 621.224.018+621.313.12-82

FUJI HYDRAULIC TURBINE AND GENERATOR (II)

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III. HYDRAULIC RESEARCH LABORATORY

In response to new increases in the capacity of turbines, a new research laboratory for developing new types such as pump-turbines was completed in 1960. **Constructed as the best in the world, this new laboratory has a higher capacity and is capable of greater precision in testing than existing laboratories.** Excellent results have been obtained in the many model tests.

Features are as follows:

(a) **A large size model can be used. For example, in a Francis turbine, the dimensions are 400 mm for runner discharge diameter, in a Kaplan turbine, 400 mm for runner diameter, and in a Pelton turbine, 400 mm for runner pitch circle diameter.**

(b) **The same model is used in both the cavitation test and the efficiency test.**

(c) **The test head is high. The cavitation test head of the Francis turbine, and the test head of the Pelton turbine and pump test head can be performed up to 100 meters.**

(d) **Using faultless automatic operation of the test equipment, high precision measurements are obtained under stabilized testing conditions.**

The tests are performed under one man control and special devices have been installed in order to obtain high precision measurements. **A difference of 0.1% efficiency can be determined.** The measuring instruments employed function as follows:

(a) Head: Head is measured with a water-column manometer and a mercury-column manometer.

(b) Discharge: Discharge is usually measured with a rectangular weir without end contraction, calibrated by the volumetric method.
Discharge can be, of course, directly measured by the volumetric method.

(c) Torque: Torque is measured with an electric d-c generator type dynamometer.
Output 24 kw
Speed of rotation 750 to 1300 rpm

(d) Speed of rotation: Speed of rotation is measured with an electronic pulsecounter.

In this laboratory, we have already performed many efficiency tests of the Francis turbines ($N_s = 70 \sim 300$), Pelton turbines ($N_s = 13 \sim 27$), Kaplan turbines ($N_s = 250 \sim 700$), Francis type pump turbines ($N_s = 70 \sim 260$) and Diagonal flow type turbines ($N_s = 150 \sim 305$).

(N.B. N_s: Specific speed in m-kw unit)

In some of these tests, measurement of the velocity distribution of various sections has also been performed.

In the cavitation test of a model turbine, water is fed into the upper water tank by means of the pump, with its pressure and level kept constant, and is fed into the model turbine.

Water coming from the model turbine goes into the lower water tank, and returns to the pool after the discharge has been measured by the measuring weir.

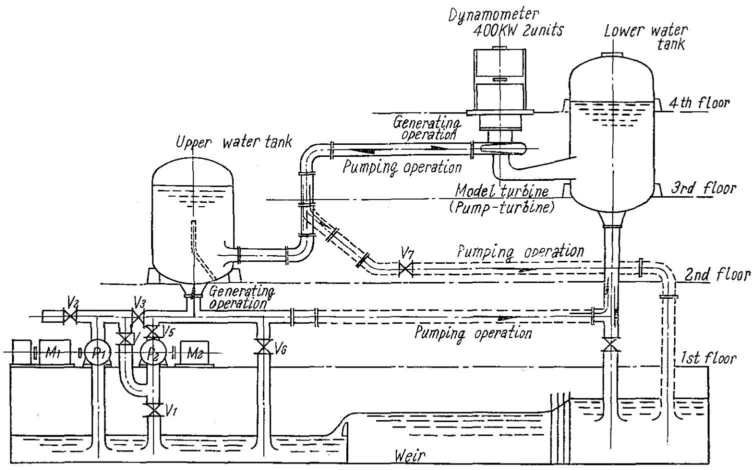
In the efficiency and cavitation test of a model pump, water flows as follows: It is pumped up into the lower water tank and with its pressure and level kept constant is fed into the model pump.

Water, pumped up out of the lower water tank by the model, flows through the delivery valve (V7) which controls the discharge and head of the model pump. It returns to the pool after the discharge has been measured by a measuring weir. Fuji Electric's Hydraulic Research Laboratory provides cavitation testing with a head near that of the actual head, by the use of a large size model turbine. Accordingly, the model turbine which has been used for the efficiency test (the runner discharge diameter of the model is about 400 mm) may be used as it is.

The test head is about 40 to 100 m for Francis and diagonal-flow turbines, and the majority of propeller turbines cavitation tests are conducted with the actual head.

For Francis or diagonal-flow type pump-turbines, both the pumping characteristics test and the turbine cavitation test can be conducted at the same place without reassembling the test set.

Fig. 35 illustrates how the cavitation test is conducted while *Fig. 36* shows the model of a diagonal-flow pump-turbine which is under test.



P_1: No. 1 pump (H=30 m, 9m, Q=1700 l/s, 975 l/s, n=715 rpm, 410 rpm)
P_2: No. 2 pump (H=70 m, 9m, Q=1400 l/s, n=715 rpm)
M_1: 750 kw motor (n=715 rpm)
M_2: 1500 kw motor (n=715 rpm)

Fig. 35 Description of cavitation test rig

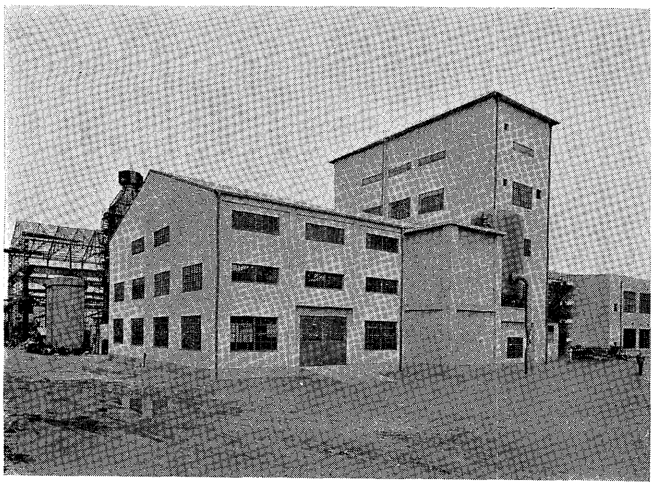


Fig. 33 Hydraulic Research Laboratory

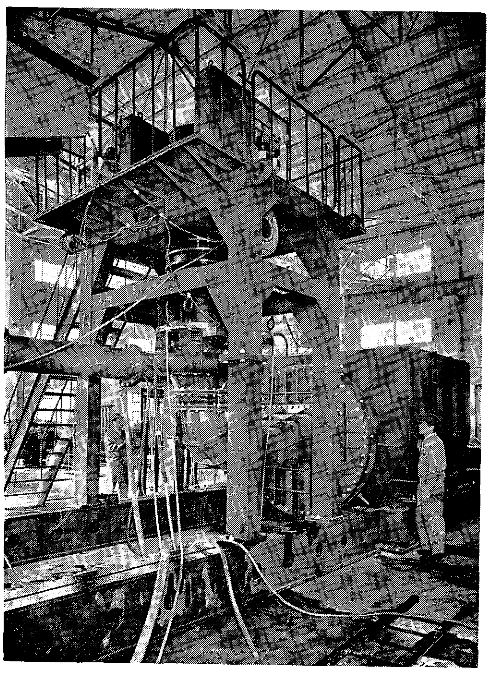


Fig. 34 Model efficiency test

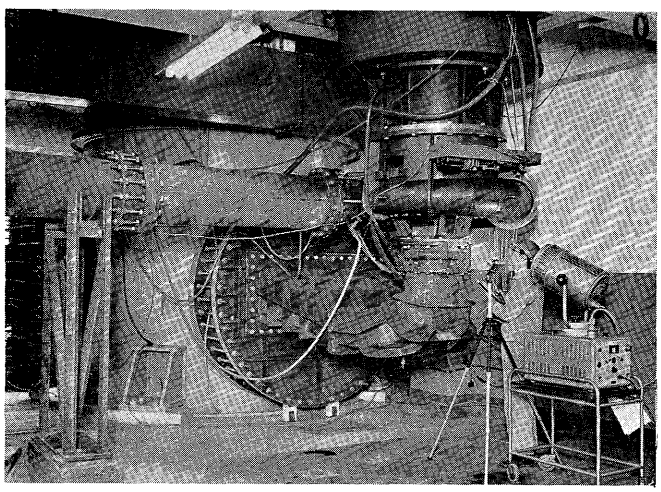


Fig. 36 Diagonal flow pump-turbine model under cavitation test

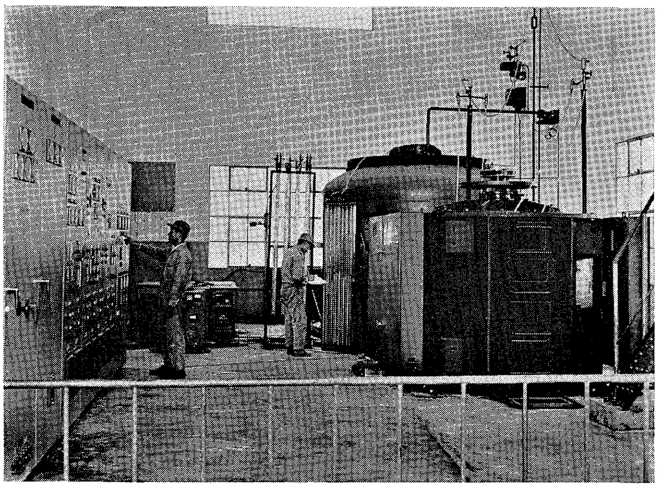


Fig. 37 Electric dynamometer and control board

Fig. 37 shows the electric dynamometer and control board.

The cavitation phenomenon is observed by a stroboscope equipped with xenon lamp.

The measuring instruments are employed as follows:

a) Head: Lower water level is measured with a mercury-column manometer. Upper water level is measured with a mercury-column manometer or a diaphragm-type precision manometer.

b) Discharge: Discharge is measured with a rectangular weir without end contraction, calibrated by the volumetric method.

c) Torque: **Torque is measured with an electric d-c generator type (motor type) dynamometer.**

Output	**400 kw (single drive)**
	800 kw (tandem drive)
Speed of rotation	1250 to 2300 rpm

Many tests have been performed with this cavitation test rig, such as:

- Tests of Francis and Kaplan turbines
- Tests of the relationship between runaway speed and cavitation coefficient
- Measurement of the hydraulic torque of the runner vane and guide vane
- Others, as follows

(a) Pump turbine: Pump test of the Francis and diagonal flow type. Many runners have undergone this test, especially on the Kuromatagawa No. 2 P.S. diagonal flow pump turbine, and excellent performance has been displayed. The pump-turbine is already in successful operation.

Fig. 38 shows the cavitation test of the diagonal pump-turbine.

(b) Air supply test into the draft tube of the Francis turbine: In order to prevent draft surging due to the circulating flow in the draft tube at partial and full load for the Francis turbine, air supply into the draft tube by air pipe is generally employed.

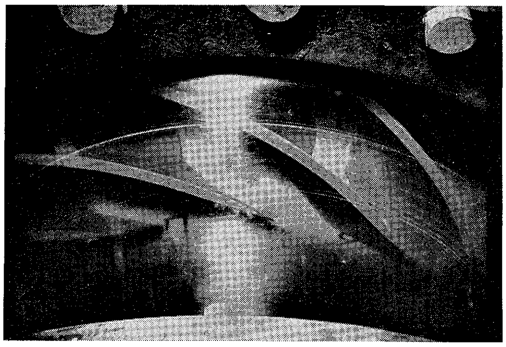


Fig. 38 Cavitation test of diagonal flow pump-turbine

Methods employed for effective air supply even when a negative suction head is used, the limits of the suction head in performing a natural air supply, and the minimum air flow rate required for preventing surging were studied.

In addition, some interesting results were obtained concerning the relationship between surging strength and draft head.

IV. ACTUAL INSTALLATION (EXAMPLE 2)

1) Pelton turbine

The recent large output high speed vertical shaft Pelton water turbine is now popular all over the world because of economical cost and high efficiency, as compared with horizontal type.

Examples of vertical Pelton turbines of Fuji Electric.

Four-nozzle large capacity turbine
Wadagawa No. 2 Power Station
(68,900 kw 470 m 300 rpm)

Six-nozzle large capacity turbine
Kurobegawa No. 4 Power Station
(95,800 kw 580 m 360 rpm) (Voith-Fuji)

Five-nozzle turbine (very rare in the world)
Banbajima Power Station
(22,000 kw 319 m 450 rpm)

Export turbine
Kuttiadi Power Station
(28,800 kw 662 m 600 rpm)

We have completed the model tests for every type, number of nozzles and specific speed.

The features of the Fuji Pelton turbine are descrided below with above example:

Fig. 39 is a cross-sectional view of the Wadagawa No. 2 turbine and generator. In order to decrease the weight, steel sheet welded construction is employed for the turbine to a greater extent. Double wall construction is employed for the housing, supporting the entire weight of the turbine generator.

Fig. 40 shows the turbine under assembling in the factory. A water pressure test is being performed. *Fig. 41* shows the runner which is "13% chrome cast steel" with 19 buckets cast integrally with the

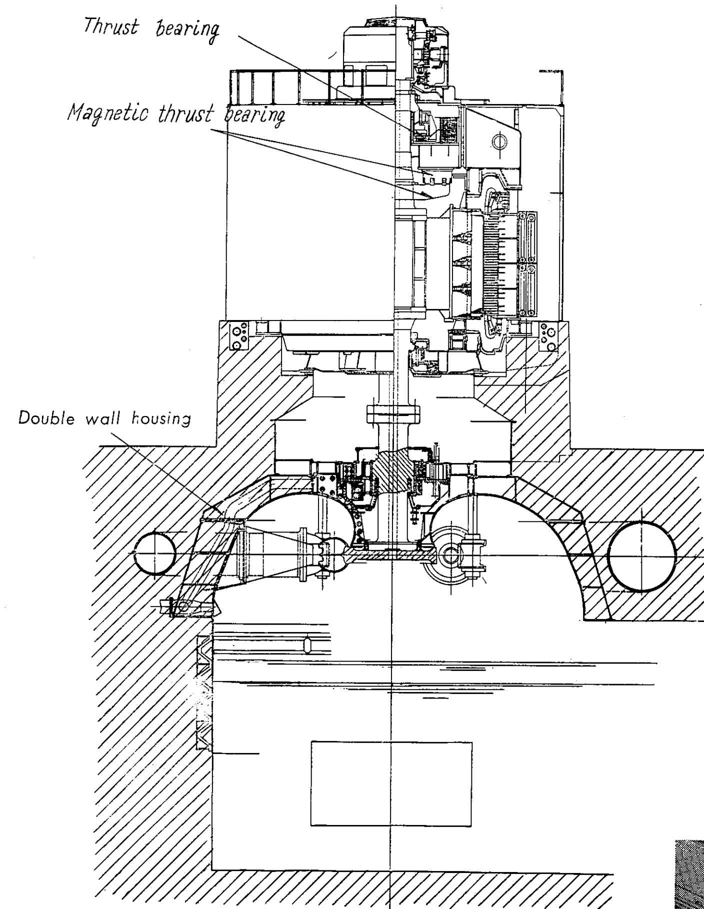


Fig. 39 Cross-sectional view of vertical Pelton turbine and generator (Wadagawa No. 2 Power Station)

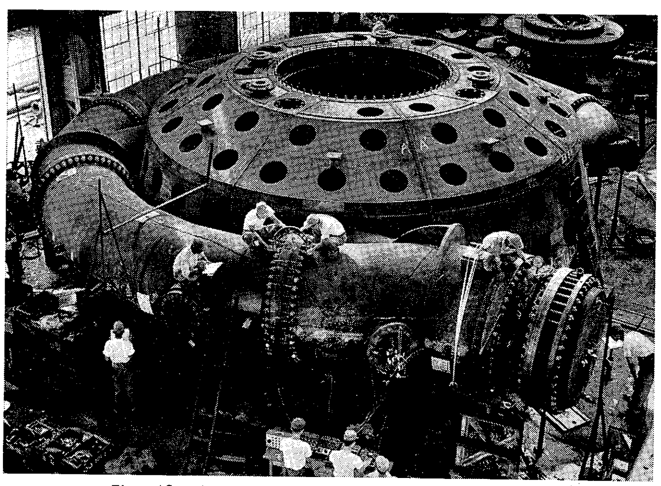


Fig. 40 68,900 kw vertical Pelton turbine under pressure test at shop

disc and a pitch circle diameter of 2780 mm. Maximum diameter is 3530 mm. Particulars of the generator are 70,000 kva, 13.2 kv, 300 rpm 60 c/s, 0.85 power-factor, GD^2 1600 tm^3, 2380 mm iron core length, and 4250 mm stator inner diameter.

Magnetic thrust bearing is employed in this generator to improve efficiency *(Fig. 42)*.

By decreasing the thrust load, this new improved method resulted in a decrease of bearing loss and an increase of generator efficiency by approximately 0.2%.

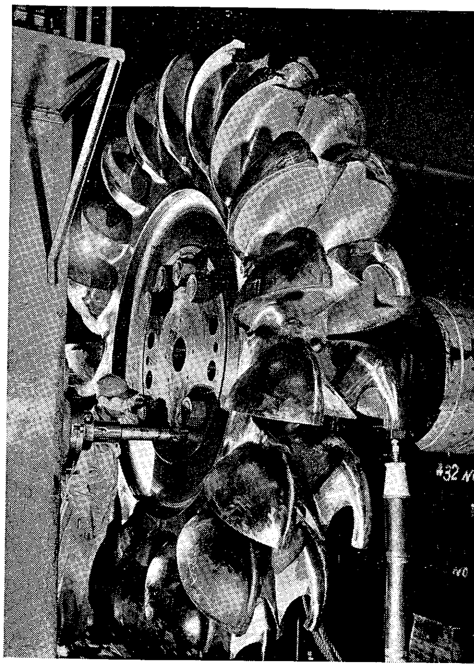


Fig. 41 13% chrome cast steel Pelton runner

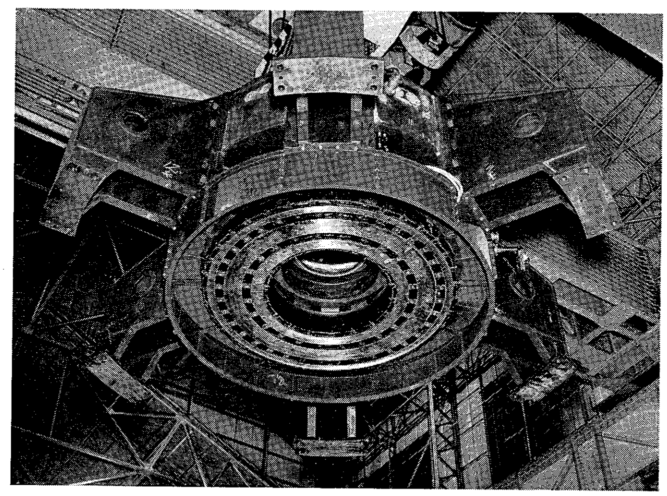


Fig. 42 Magnetic thrust bearing

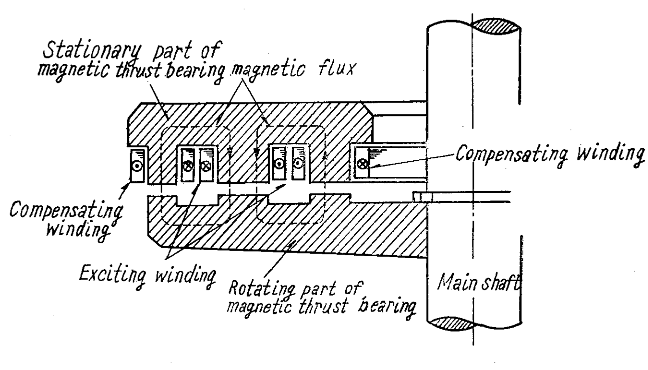


Fig. 43 Principle of magnetic thrust bearing

The improved method was derived from a really new idea. This is the largest practical generator with a magnetic thrust bearing in the world.

In principle, in addition to the excitation winding which generates effective magnetic flux as shown in *Fig. 43*, a compensation winding is also provided. The compensation winding is provided for cancelling magnetic flux in the axial direction leaking from the electro-magnet and for preventing shaft current.

Table 3 shows the list of magnetic thrust bearings manufactured by Fuji Electric.

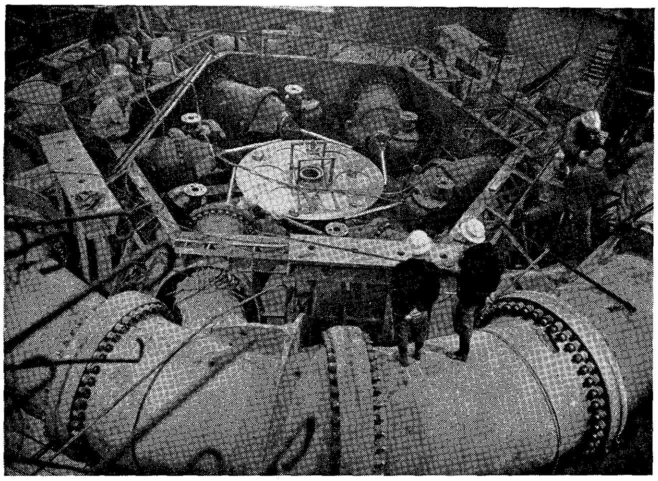


Fig. 44 95,800 kw six-nozzle Pelton turbine under installation (Kurobegawa No. 4 Power Station)

Fig. 44 shows Kurobegawa No. 4 turbine (95,800 kw 580 m 360 rpm) under installation.

The ring pipe is welded high tensile strength steel (Nozzle branch pipes are made of cast steel).

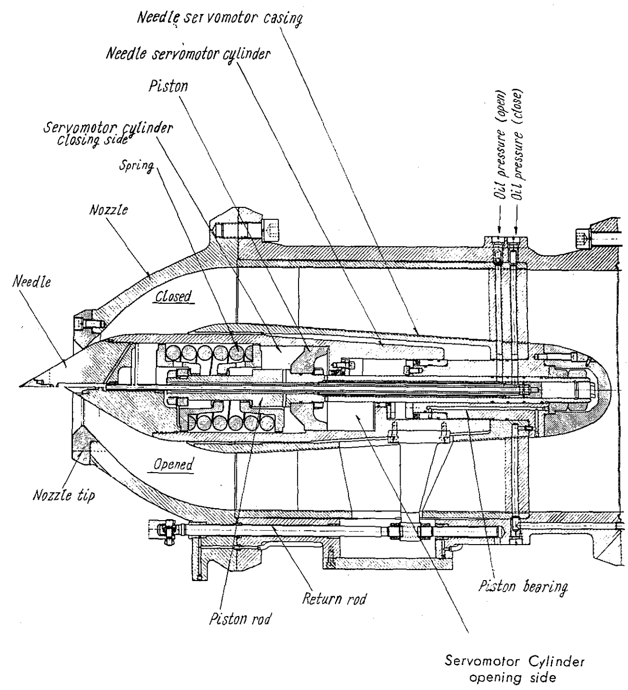


Fig. 45 Explanation drawing of inside controlled nozzle

Table 3 **Suppiy List of Magnetic Thrust Bearing**

Delivery Place	Type of Machine	Output of Machine (kva)	Number of Unit	Speed (rpm)	Weight of Rotor (ton)	Lightened Thrust by Magnetic Thrust Bearing (ton)	Exciting Capacity of Magnetic Thrust Bearing (kw)	Gain of Friction Loss (kw)	Capacity of Magnetic Thrust Bearing (ton)
Shin-sapporo S.S. (Hokkaido Electric Power Co.)	Synchronous Rotary Condenser	30,000	1	1000	42	38	5	21	38
Tochio P.S. (Hokuriku Electric Power Co.)	Water Turbine Generator (Pelton)	17,500	1	400	67	62	6.4	37	80
Motosu P.S. (Japan Light Metal Co.)	Water Turbine Generator (Pelton)	13,000	1	720	32	27	3.4	24	33
Wadagawa No. 2 P.S. (Hokuriku Electric Power Co.)	Water Turbine Generator (Pelton)	70,000	2	300	207	202	5	89	236
Hatanagi No. 1 P.S. (Chubu Electric Power Co.)	Motor-generator (Pump-turbine)	58,800	1	200	249	244	5.5	70	288
Muroran S.S. (Hokkaido Electric Power Co.)	Synchronous Rotary Condenser	30,000	1	1000	42	38	5	21	38
Fuji Electric Co. Ltd. Kawasaki Factory	Short-circuit Testing Generator	60,000 (1500 Mva)	1	1000	130	125	4.6	75	120
Kuromatagawa No. 2 P.S. (Electric Power Development Co.)	Pole change Motor-generator (Pump-turbine)	19,000/20,500 (kw)	1	300/333	107	102	3.7	30/33	145

As a feature of the Pelton turbine manufactured by Fuji Electric, the structure (*Fig. 45*) in which a needle servomotor is include in the nozzle provides a decrease in installation space to a great extent when compared to the formerly used method (a method where it projected outside the ring pipe).

Fig. 46 shows the hydraulic turbine employed in the Kuttiadi Power Station (28,800 kw 662 m 600 prm).

The housing is a single wall type and is designed simply as a liner against water flow. The upper cover is a steel sheet box type construction and is welded to the housing. High rigidity is obtained but the weight is very low.

Fig. 47 shows the arrangement plan of the Banbajima five-nozzle hydraulic turbine.

Attention should be directed to the nozzle including the needle servomotor.

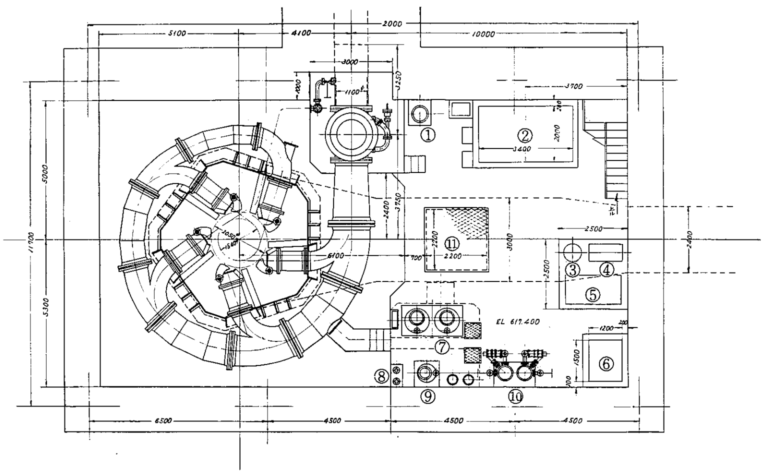
2) Kaplan Turbine

Many excellent results with high head Kaplan hydraulic turbines may be found in Fuji records.

For outstanding examples, the following is shown :
Shin-ochiai Power Station 62/52 m,
23,000 kw 273 rpm, runner with eight blades.
Oyodogawa No. 1 Power Station 40.4 m,
43,800 kw 180 rpm, runner with seven blades
Akiba No. 2 Power Station 36.6 m,
38,000/35,000 kw 180/150 rpm

Leading the world after the war, Fuji manufactured many high head Kaplan turbines and proceeded into the field which was formerly considered to be the range of Francis turbines.

Fig. 48 and *49* shows the Oyodogawa No. 1 Power Station arrangement.



1. Strainer for water intake pipe
2. Pressurized oil supply equipment
3. Air tank
4. Operating air compressor (small type)
5. Standby air compressor (large type)
6. Lubricating oil tank
7. Supply pump
8. Jet pump
9. Drain pump
10. Supply pump strainer
11. Runner hatch

Fig. 47 **Machine arrangement of five-nozzle Pelton turbine**
(Banbajima Power Station)

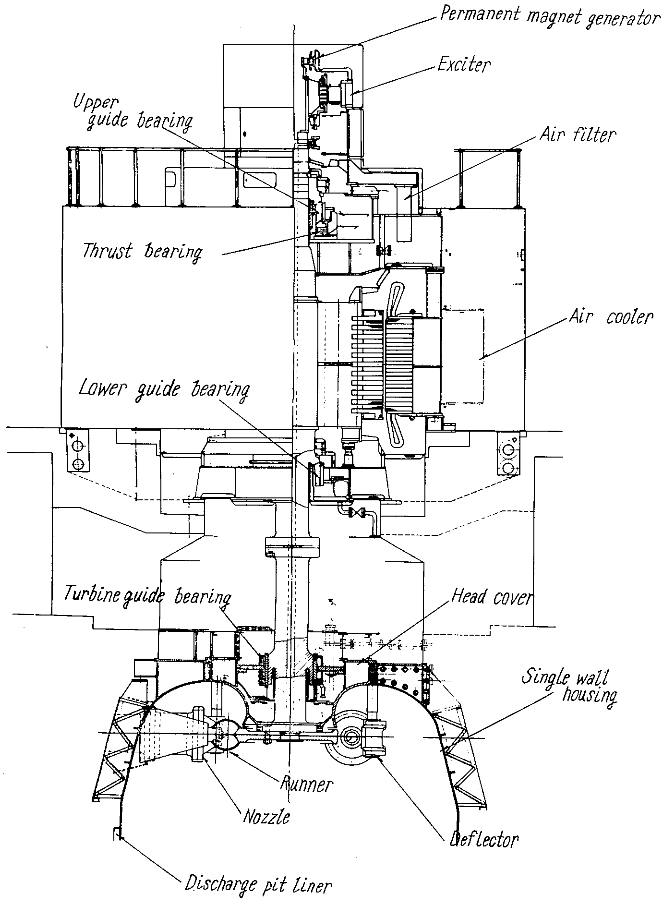


Fig. 46 **Cross-sectional view of Pelton turbine and generator**
(Kuttiadi Power Station)

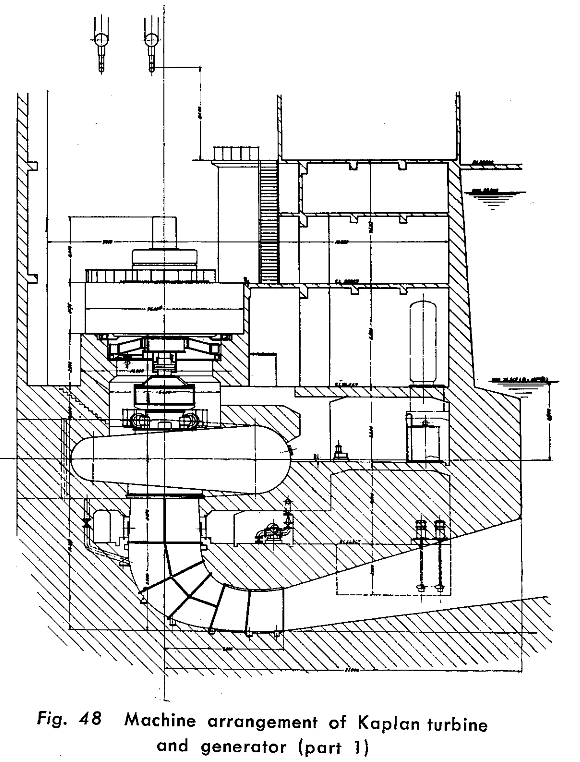
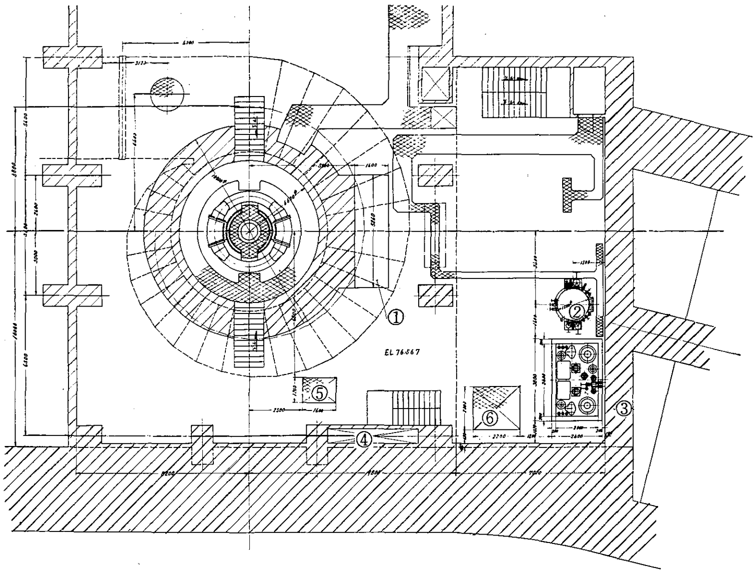
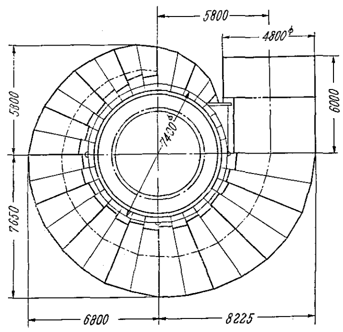


Fig. 48 **Machine arrangement of Kaplan turbine and generator (part 1)**
(Oyodogawa No. 1 Power Station)



1. Cabinet type governor
2. Pressurized oil tank
3. Pressurized oil supply equipment
4. Air duct
5. Unloading hatch
6. Runner hatch

Fig. 49 **Machine arrangement of Kaplan turbine and generator (part 2)**
(Oyodogawa No. 1 Power Station)



(Heavy lines show the dividing sections)

Fig. 50 **Dimension of spiral casing (field weld)**

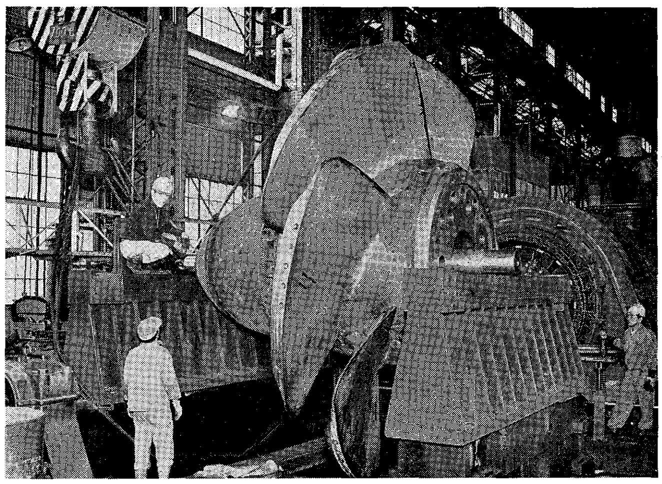


Fig. 51 **Kaplan turbine runner**

Casing inlet diameter : 4800 mm,
Runner diameter : 4080 mm

For the turbine body, steel sheet welded construction is employed to a great extent.

The casing was assembled in the field by welding but annealing was not performed.

Fig. 51 shows the runner. The thrust bearing is arranged on the top cover of the turbine and the runner servomotor is installed in the generator rotor (*Fig. 53*).

The turbine guide vane servomotor is installed on the turbine cover as a special ring servomotor (*Fig. 52*) and directly drives the gate operating ring.

For the discharge ring, a double globe type is employed which satisfies the requirements in high head Kaplan turbines.

Fig. 53 shows the cross-sectional view of Kaplan turbine and generator.

Fig. 54 shows the structure manufactured by punching high tensile strength steel sheet (yoke 3.2 mm thick) in sector form and by laminating with a venti-

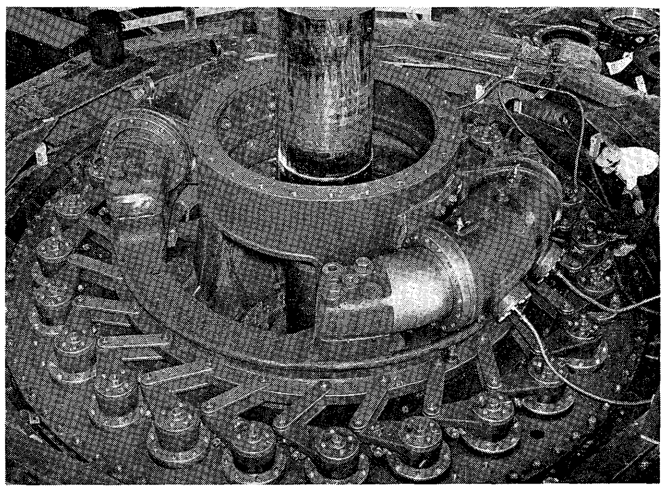


Fig. 52 **Ring sevomotor**

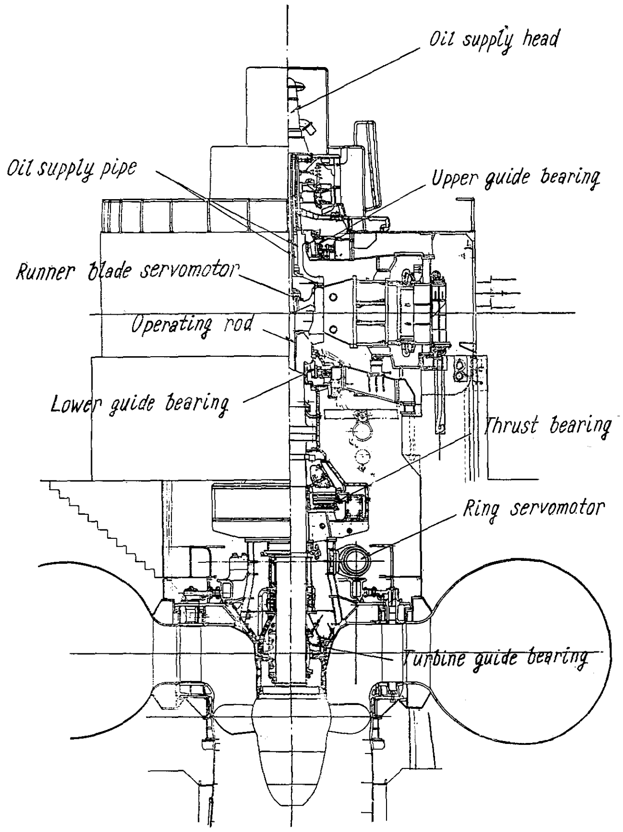


Fig. 53 Cross-sectional view of Kaplan turbine and generator
(Oyodogawa No. 1 Power Station)

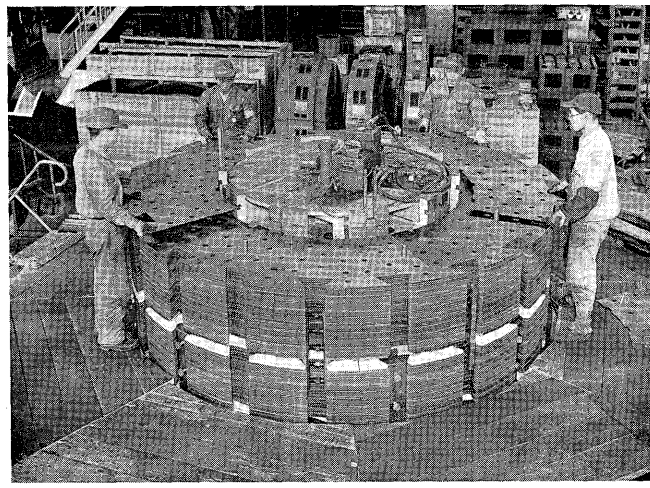


Fig. 54 Laminated rotor yoke

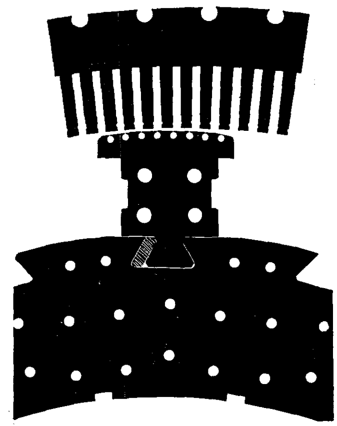


Fig. 55 Construction of yoke, pole core and stator core

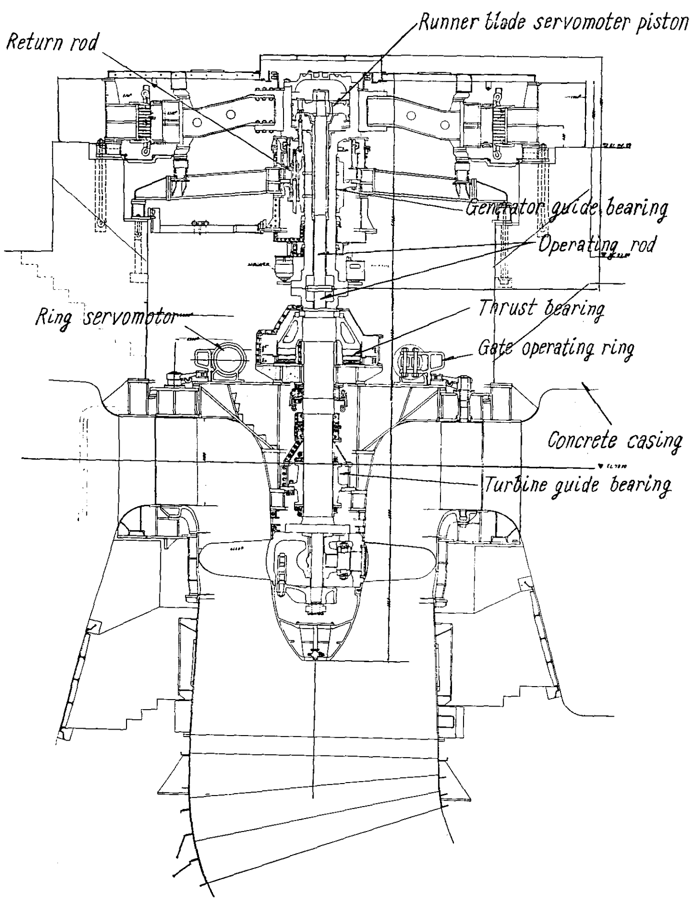


Fig. 56 Cross-sectional view of low head Kaplan turbine and generator
(Jintsugawa No. 3 Power Station)

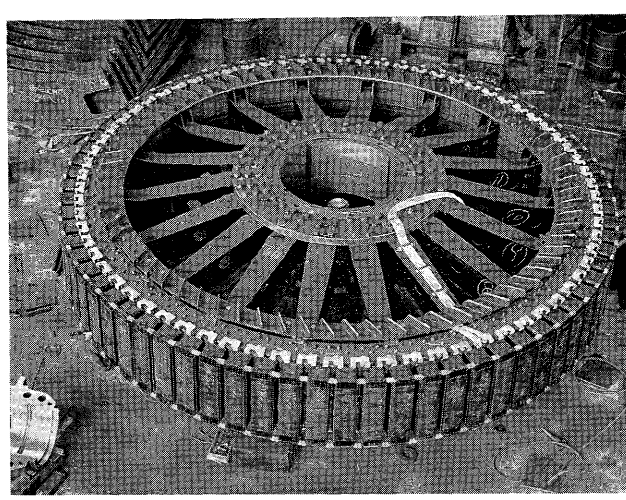


Fig. 57 Generator rotor

lating duct in between, making one unit by using reamer bolts.

Fig. 55 shows the construction of the yoke, pole core, and stator core.

Fig. 56 is the cross-sectional view of Jintsugawa No. 3 Power Station (10,200 kw, 9.72 m, 100 rpm), as representative of low head, large size Kaplan turbines. (N.B. Runner diameter is 4550 mm. Stator inner diameter is 6500 mm).

The thrust bearing is installed on the turbine cover and the upper guide bearing of the generator is eliminated (umbrella type).

Fig. 57 shows the rotor and *Fig. 58* shows a shop assembled view of generator.

(To be continued)

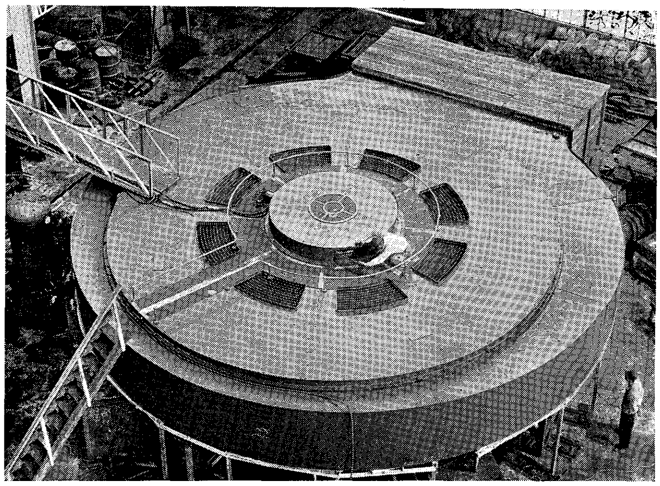


Fig. 58 Assembled generator at shop
(Jintsugawa No. 3 Power Station)