UDC 621. 224+621. 313. 12-82

FUJI HYDRAULIC TURBINE AND GENERATOR (III)

Model test of vertical shaft Pelton turbine

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V. TURBINE ACCESSORIES

1. Inlet Valve

For the inlet valve of a turbine, butterfly valves, rotary valves, and sluice valves are used within an applicable range as shown in *Fig. 59*. From these three types of valves, however, the sluice valve has become less often used due to the large servomotor, heavy weight, and larger space for installation.

1) Butterfly valve

The butterfly valve is smaller in weight and requires less space for installation as compared to other types of valves. When the head is high, sealing becomes difficult; this type of valve is normally used when the head is less than 200 meters.

Fig. 60 illustrates construction of the butterfly valve. The valve body is welded and the valve disk is welded when the head is low, although it is usually made of cast steel. Around the circumferential edge of the valve disk, a hard rubber packing is provided. A counter weight is often provided when the head is low so that the valve can be safely closed

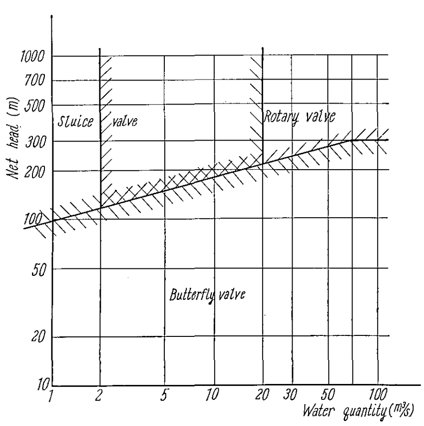


Fig. 59 Applicable range of butterfly valve, rotary valve and sluice valve

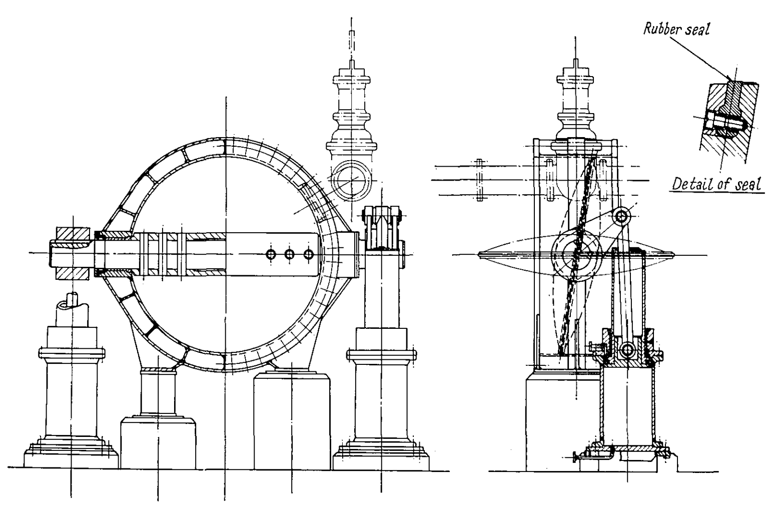


Fig. 60 Construction of butterfly valve

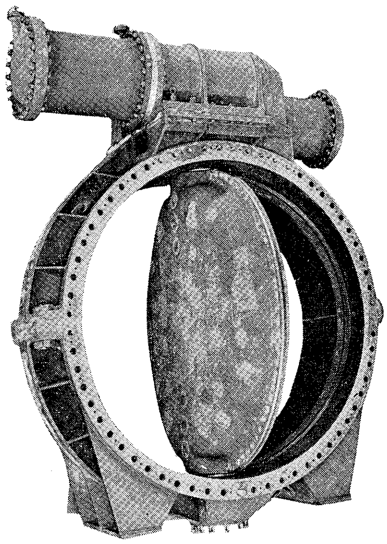


Fig. 61 Butterfly valve (inlet dia. 3200 mm, head 100 m)

even when operating oil pressure is lost.

Fig. 61 shows a photograph of an inlet valve used for a pump turbine with a head of 100 meters and an inner diameter of 3200 mm.

2) Rotary valve

The rotary valve has an improved sealing capability with almost no head loss. This type of valve is usually used when the head is more than 200 meters.

Fig. 62 illustrates construction of a rotary valve which is used for a power house with a head of 670 m. A system is employed where water sealing is made when water pressure is applied inside the choking plate located in the down-stream side of the valve rotor. This allows the choking plate to be pressed against the seat surface of the valve body. For material in the seat section, 18–8 stainless steel and aluminum bronze are used. When the penstock is branched, sealing is also provided on the up-stream side of the valve in order that the down-stream seal of the inlet valve can be repaired when defective, during operation by another turbine. *Fig. 62* illustrates an example of such a double sealing system, where up-stream sealing can be made when water pressure is applied to the seal of the up-stream side when the valve is fully closed. For rotary valves, penstock water pressure is often used for operation. The valve shown in *Fig. 62* is opened by oil pressure and closed by water pressure.

2. Governor

The governor, as shown in *Fig. 63*, consists of an actuator, a main distributing valve and a main servomotor; the actuator consists of a governor head, a pilot valve, an auxiliary servomotor, a speed adjusting device, a load limiting device, and a restoring mechanism. The actuator is what is usually referred to as a " universal type actuator ". It can be applied to all types and capacities of turbine.

Fuji Electric manufactures both mechanical actuators and electrical actuators and has an excellent record of actual applications. Main distributing valves of varying capacities corresponding to various types and capacities of the servomotors are available. In the case of the cabinet type governor more often used in recent times, the actuator and main distributing valve together with the solenoid valves are arranged on a common bed, as shown in *Fig. 64*.

On the front of the cabinet, various types of indicators and controls are provided as illustrated in *Fig. 65*.

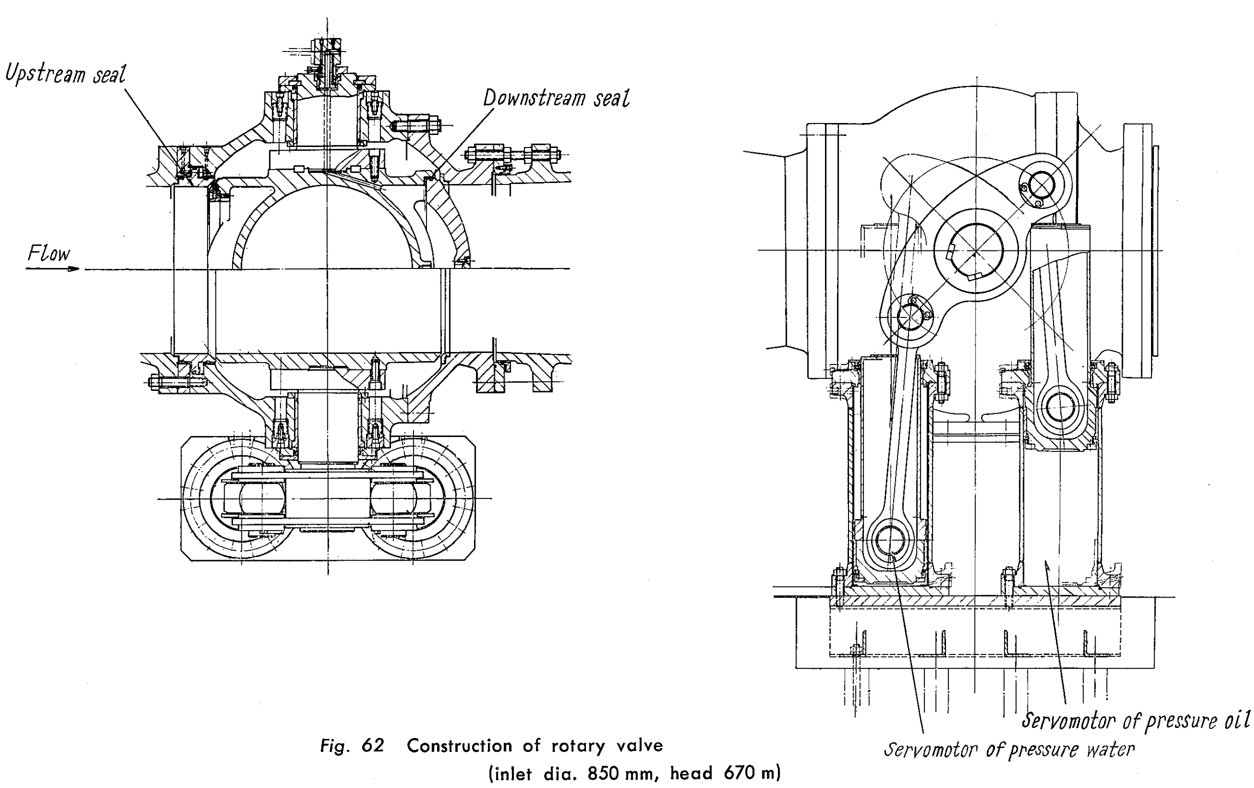


Fig. 62 Construction of rotary valve (inlet dia. 850 mm, head 670 m)

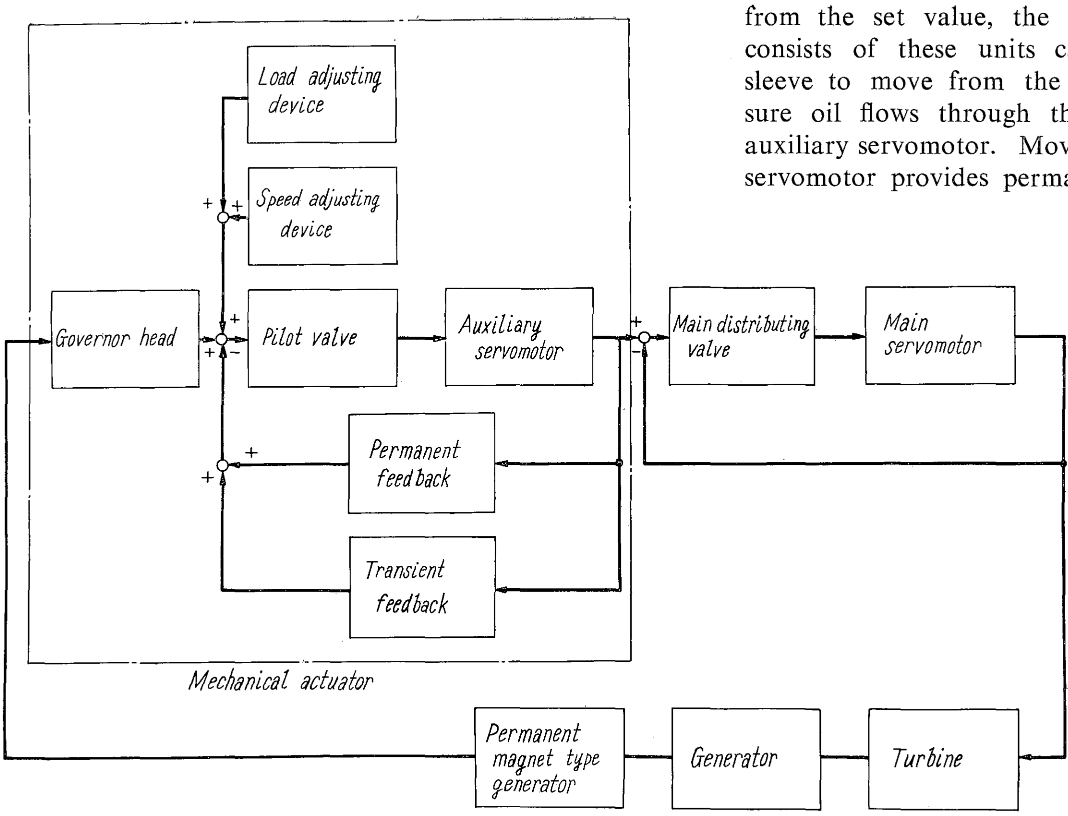


Fig. 63 **Block diagram of governing system**

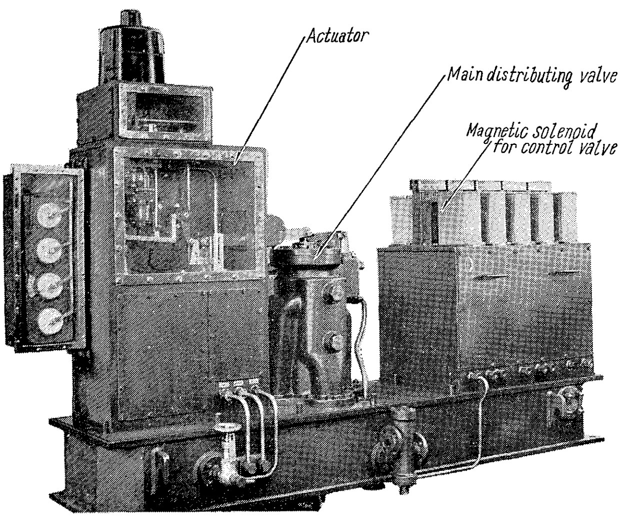


Fig. 64 **Inside of cabinet type governor (electro-hydraulic governor)**

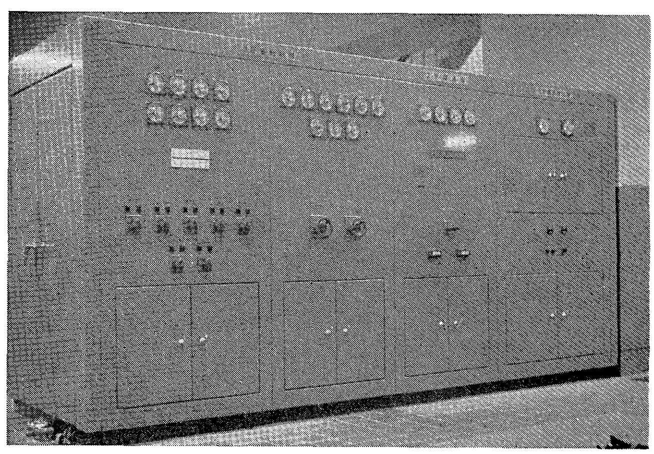


Fig. 65 **External view of cabinet type governor**

Complete control ranging from start to stop of the operation can be made from the front of the governor cabinet according to the customer's request.

1) Mechanical actuator

(1) General description of construction and operation

Fig. 66 illustrates general information concerning construction.

A permanent magnet type generator directly coupled to a main generator shaft is connected to the pendulum driving motor and a leaf type pendulum is directly coupled to the pendulum driving motor. When the turbine speed changes from the set value, the governor head which consists of these units causes the pilot valve sleeve to move from the neutral point. Pressure oil flows through the pilot valve to the auxiliary servomotor. Movement of the auxiliary servomotor provides permanent feedback to the stem of the pilot valve through the link. Transient feedback by the link and the dashpot is also provided. This permits quick and stable control of the auxiliary servomotor.

The auxiliary servomotor provides proportional control of the main servomotor through the main distributing valve.

Fig. 67 shows the construction of the governor.

(2) Features

a) **High sensitivity**

The pendulum and pilot valve greatly affect the sensitivity. These are designed and manufactured with special precision and care and only those units which have passed strict tests

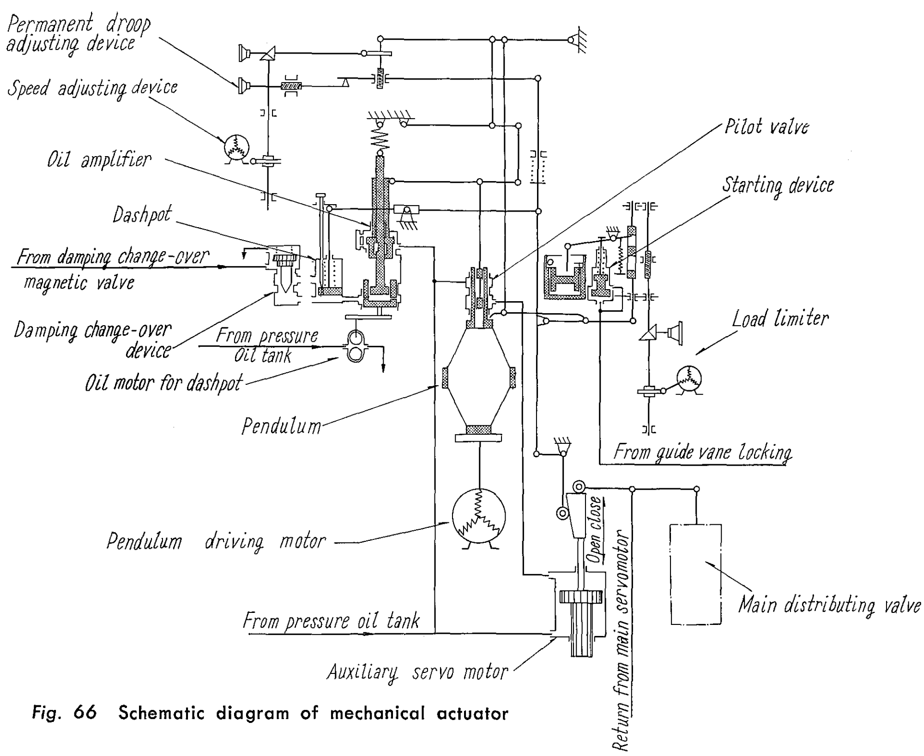


Fig. 66 Schematic diagram of mechanical actuator

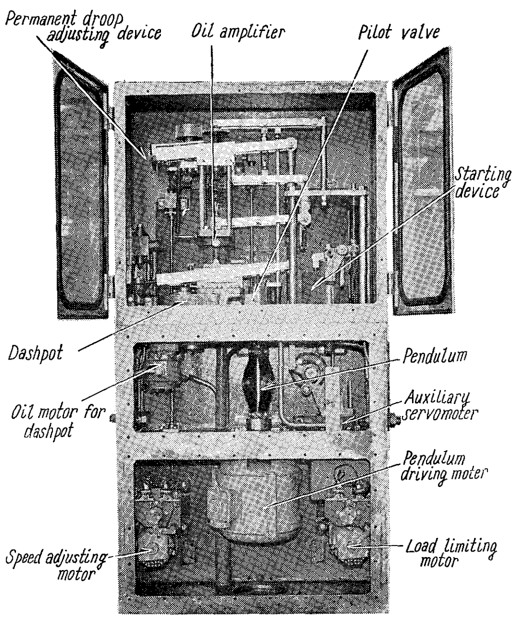


Fig. 67 Mechanical actuator

are used. In order for the pendulum to smoothly rotate, the pendulum and the pendulum driving motor are directly coupled to each other without gearing between them. **The sensitivity is 0.02%.**

b) Stability

The dashpot is formed by a double piston construction and is provided with a damping strength changeover device to strengthen damping at no load. The output of the dashpot is amplified by the oil amplifier to obtain improved stability. Therefore good stability is gained.

c) Governing speed

By weakening damping in parallel operation to increase governing speed, response to frequency variation is very rapid, making the actuator extremely suitable for automatic frequency control.

d) Easy maintenance and inspection

The actuator is arranged on the back of a cabinet panel which allows easy access and electrical parts are housed in a separate area which is completely isolated from oil. This arrangement allows maintenance and inspection to be accomplished with extreme ease.

2) Electrical actuator (Electro-hydraulic governor)

In the postwar days in Japan, the manufacture of electro-hydraulic governors has been prevalent and has contributed a great deal to actual applications. Magnetic amplifier type electro-hydraulic governors which Fuji Electric manufactured have already reached a total of approximately thirty units in operation. Their superb performance plus high reliability have made them both popular and renowned.

(1) General

a) Block diagram

A general description of the construction is as shown in *Fig. 68* and *Fig. 69*. The output frequency of the pilot generator which is driven by the turbine shaft is measured by a special frequency bridge of high sensitivity and accuracy; current in proportion to deviation between the frequency and the standard value is obtained. This current is then mixed with current from the power adjustment unit and restoring unit and is amplified by the synchro-

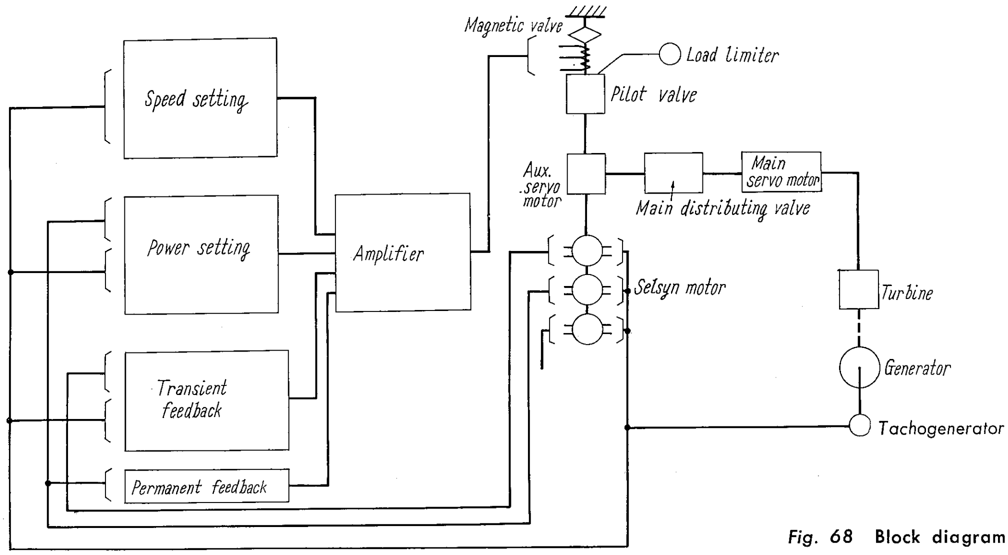


Fig. 68 **Block diagram**

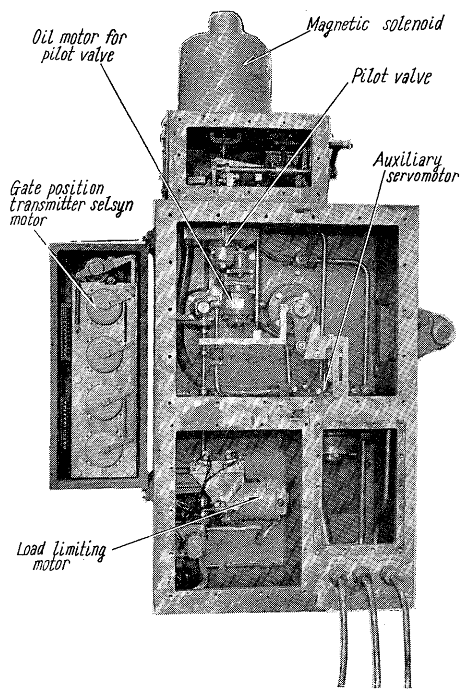


Fig. 69 **Electrical actuator**

nous rectifier type quick response magnetic amplifier. The output thus obtained is used to control the pilot valve. Hence, the hydraulic control device is actuated to control the servomotor which allows the guide vane to open or close. The output voltage of the restoring device (electromagnetically generated in proportion to the position of the servomotor) is fed back to the previously described electromagnetic amplifier where the signal of the frequency deviation is given, and also the the signal from the transient feedback is given through the *RC* circuit.

b) Characteristics

(a) Free remote control type for obtaining various characteristics. (Changes of the composite ratio can be readily made. Hence, characteristics of the control equipment itself can be improved for permitting free automatic output control. Reasonable composite quality in various elements of the power system such as water level or the program made in assumption of changes of these due to elapse of time are also obtained).

(b) **The frequency detection unit uses a special high sensitivity and high accuracy type frequency bridge. The magnetic solenoid is a permanent magnet moving coil type which has low inertia and a very small dead band. The detection sensitivity is 0.01%.**

(c) **With a magnetic amplifier used, the characteristics are superior and the construction is rigid.**

(d) For detecting the position of the servomotor, an electromagnetic converter is used.

(e) Droop characteristics of transient speed feedback is automatically selected according to the guide vane position.

(f) With electrical and mechanical shut down devices used in combination, stop operation can be made accurately and safely.

(g) The speed detection pilot generator is driven by the shaft of the turbine and generator to obtain reliability.

(2) Function

a) Frequency detection unit

For electrical governors, frequency accuracy is one of the most important and indispensable requirements. Hence, this unit is one of the units which were most carefully designed. Inductance which is easily affected by temperature variations was not used; in its place an *RC* bridge usually called a " Twin-T-type filter (as shown in *Fig. 70*) was used. Change of setting value is made by applying another

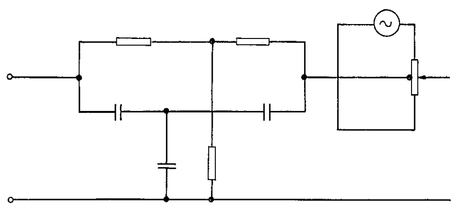


Fig. 70 Twin T bridge circuit for speed detector

voltage to the output of the detector unit (as shown in *Fig. 71*). The frequency setting can be made by the setting resistor *70F* which has a range from -5% to $+10\%$.

b) Power setting unit

This unit is featured for the characteristics shown in *Fig. 73.*

The same speed droop exists in the portion between A and $B \sim C$ and D; this can be varied at an interval of 1% over a range from 0 to 6%. The portion between B and C has a larger speed droop as it is provided with con-

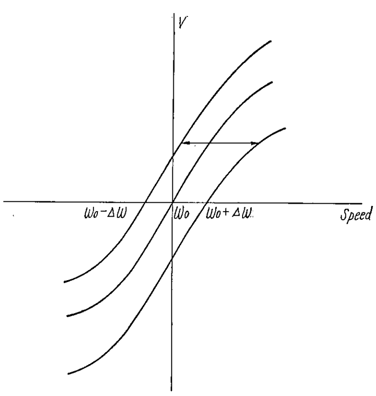


Fig. 71 Characteristics of speed setting

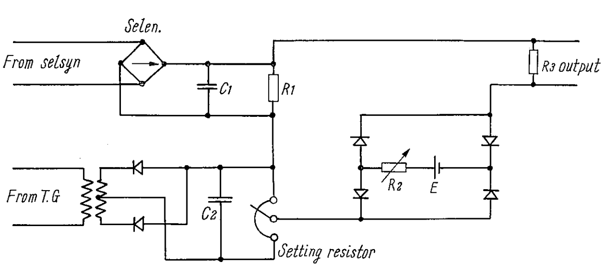


Fig. 72 Power setting

stant output characteristics. The cycle width (Δf) between B and C is continuously variable in a range from 0 to 1%. The basic circuit is as shown in *Fig. 72.*

c) Restoring unit

As shown *Fig. 74,* this unit extracts ac voltage which is proportionate to the movement of the servomotor by the selsyn motor. This circuit consists of R, C, and several rectifiers. The automatic change-over of the transient feedback characteristics (damping) can be done without any relay contact according to the guide vane opening as shown in *Fig. 75.*

d) Detection conversion and amplifier unit

The outputs of the frequency detection unit, the power setting unit, and restoring unit are all added together and made into an input for the synchronous rectifier type magnetic amplifier, by which the ac and dc detected output of each unit is converted into a push-pull dc output signal and connected to the magnetic valve.

The following shows major features:

(a) Input resistance extremely high
(b) Sufficiently large output
(c) Stabilized rectification
(d) Even number harmonics at high frequencies eliminated

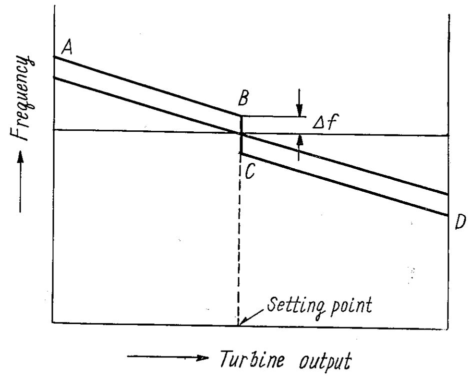


Fig. 73 Characteristics of power setting and speed drooping

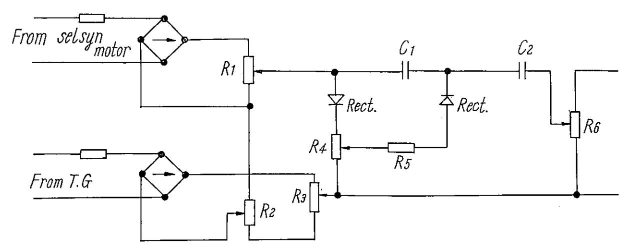


Fig. 74 Basic circuit for transient feed back

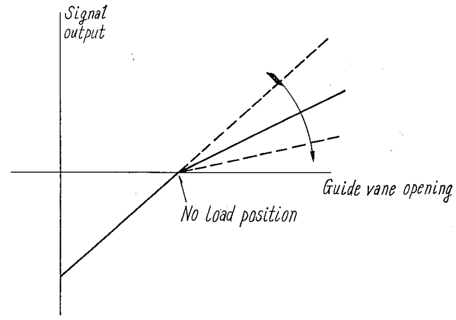


Fig. 75 Characteristics of transient feed back

e) General description of governor operation

The equipment which consists of the above units operates as shown in the following:

When the frequency is at the predetermined value, detection unit output is zero and output of the amplifier unit is also zero, with the pilot valve positioned at the neutral non-controlling point and the entire unit in the hydraulic servo-system not in operation. When the frequency or the power deviates from the predetermined value (the guide vane should be controlled in a direction for opening or closing), ac voltage which is in-phase (or out-of-phase) as compared to the pilot generator is generated in the detector bridge output.

This voltage is applied to the synchronous rectifier type magnetic amplifier in accordance with the phase, where it becomes push-pull dc output.

This push-pull dc output provides positive/negative power to the pilot valve through the magnetic valve, conveying information for opening (or closing) the guide vane to the hydraulic servo-system. When the servomotor starts operating, the permanent and transient feedback systems operate and thus the control loop is stabilized.

3. Oil Pressure System

In usual cases, the oil pressure system consists of two oil pumps (which are driven by either a motor or a small turbine), two unloader valves, safety valves, a pressure tank, a sump tank, an oil cooler, etc. It is usual that one of the two pumps is used for standby with the other used for normal operation.

The standby oil pump is automatically started when the motor of the normal running oil pump or the oil pressure in the pressure tank fails. Usually, a high performance vertical shaft type screw pump or horizontal shaft type gear pump is used.

The adapted normal oil pressure is 24 kg/sq. cm. for a large capacity turbine and 18 kg/sq. cm for a small capacity turbine. Air supply for oil level control in the pressure tank is automatically made with the unloader valve and air chamber.

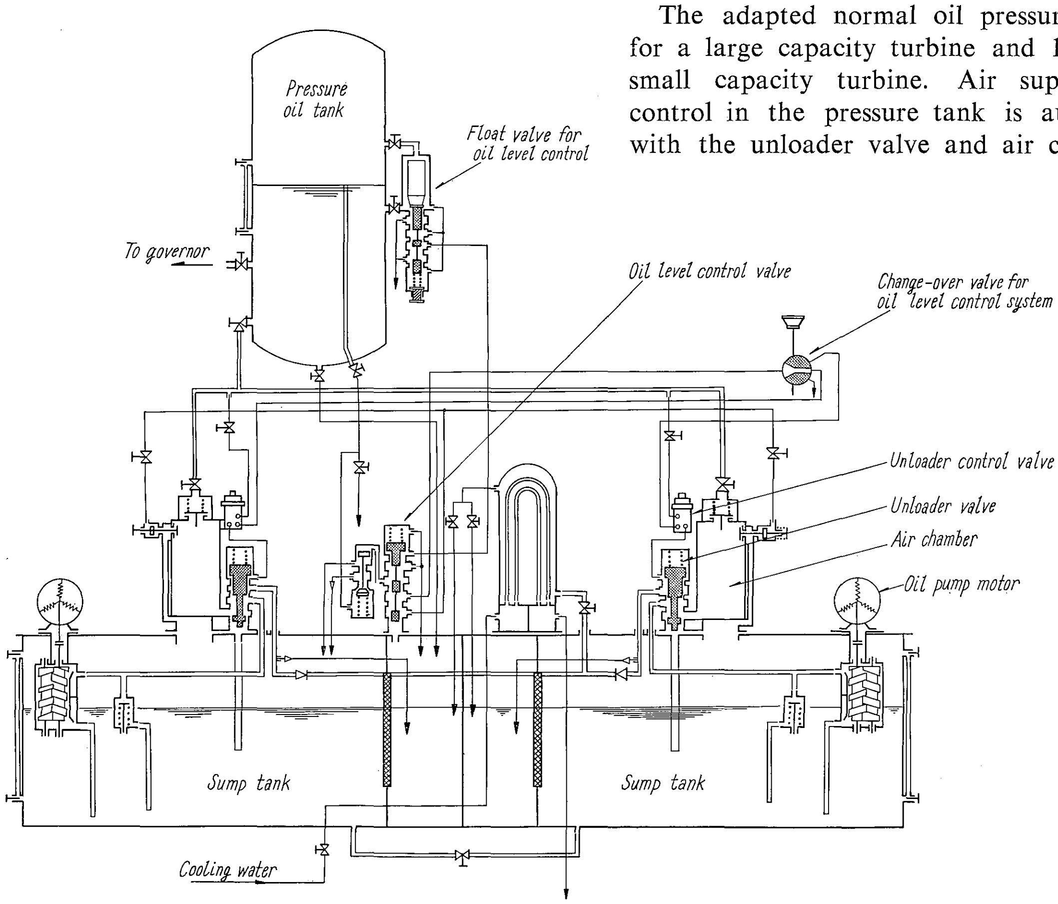


Fig. 76 **Schematic diagram of pressure oil system**

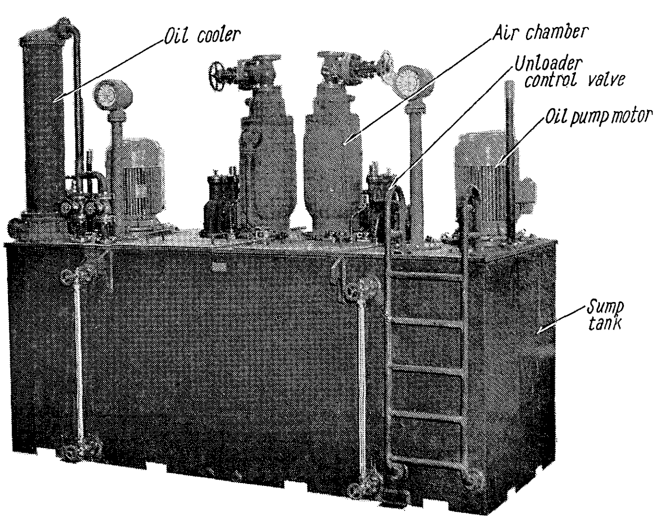


Fig. 77 **Oil pressure system**

In the oil pressure system, an alarm device for the oil level of the pressure tank and the sump tank together with a supervisory device for the thermometer are provided. This makes the accomplishment of maintenance quite easy.

Fig. 76 shows one example of the schematic diagram of an oil pressure system.

Generally, the oil pump, oil pump motor, and unloader valve are arranged on the sump tank and the pressure tank is installed separately from the sump tank.

Fig. 77 is a photograph of the oil pressure system.

VI. AUTOMATIC VOLTAGE REGULATOR

1. General

In Japan, a self-excited compound type generator employing a static excitation system consisting of a rectifier and a reactor, etc. is widely employed. We also have our own special systems of static excitation. However, for export, generators employing dc exciters are usually required. Hence, a description is given below on the typical magnetic amplifier type automatic voltage regulator.

The Fuji Magnetic-Amplifier Type Automatic Voltage Regulator is designed for terminal voltage and power factor control of a synchronous generator.

It can be applied to a generator which has a main exciter. A skeleton diagram of the exciting system is shown in *Fig. 78*. The exciter has a self-excited winding and two control windings. Normally, the exciter is excited by the self-excited winding through the field regulating resistor. When the generator terminal voltage or the power factor deviates from the predetermined value, the exciter is controlled by its control windings through the automatic voltage regulator.

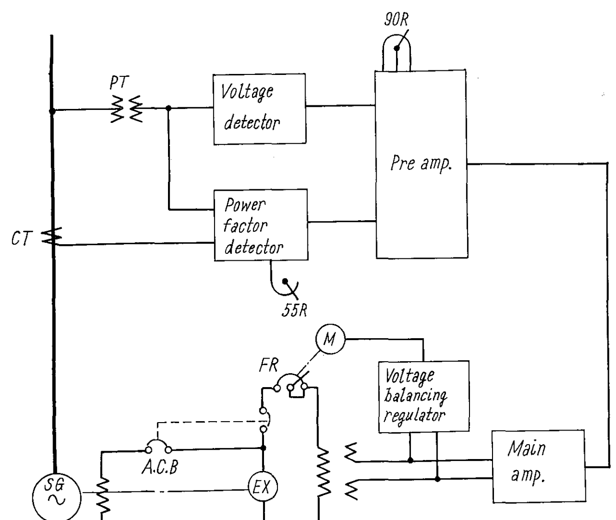


Fig. 78 Skeleton diagram of exciting system

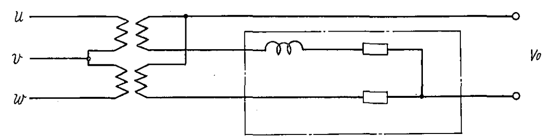


Fig. 79 Positive phase filter

The special features of this regulator are:

- No moving parts
- High sensitivity ±0.5%
- Positive phase sequence voltage control
- Easy maintenance

Although the construction is compact, this regulator has the following distinctive functions:

- Voltage control
- Power factor control
- Kva limitation (lagging and leading side)
- Overcurrent limitation

In combination with a balancing regulator in the output circuit of the main amplifier shown in *Fig. 78*, the field regulating resistor (*F.R.*) is adjusted so that output of the voltage regulator is usually set to the zero point.

Furthermore it is very easy to change the exciting system from "Automatic Voltage Control" to "Manual Voltage Control", even if trouble occurs in "Automatic Voltage Regulator".

2. Function

1) Voltage control

The terminal voltage of the synchronous generator is detected through the positive phase filter as shown in *Fig. 79*. The generator operates more usefully for dynamic network stability.

The regulator has a permanent magnet type constant current device which is used as the standard for setting voltage, as shown in *Fig. 80*. The setting voltage is adjusted from the main control desk and the standard setting ranges from +10% to −20% of the rated voltage. The setting resistor is shown as *90R* in *Fig. 78*.

2) Power factor control

The power factor of the generator is detected by means of the circuit shown in *Fig. 81*.

The vector diagram for a power factor of 1.0 is

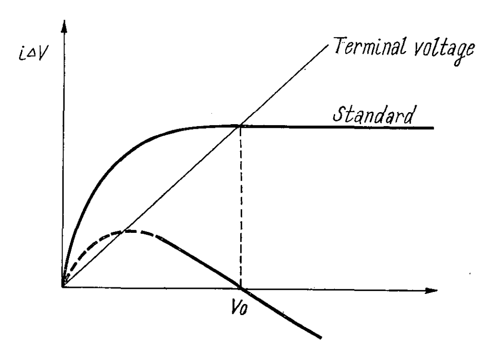


Fig. 80 Standard voltage

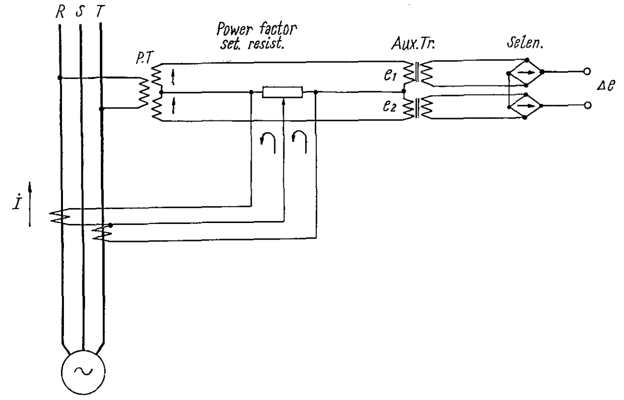


Fig. 81 Power factor detector

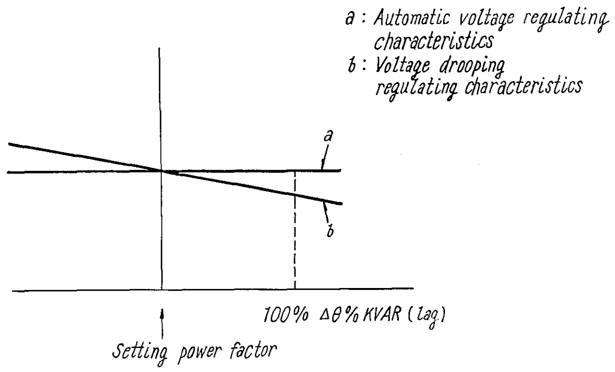


Fig. 83 Voltage drooping characteristics

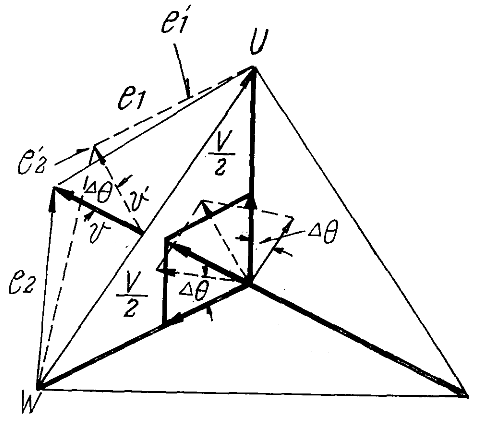


Fig. 82 Vector diagram of power factor detector

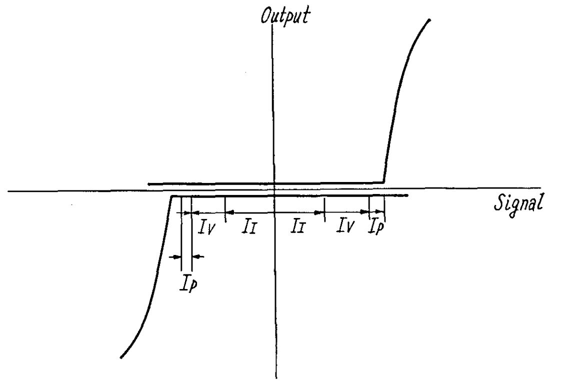


Fig. 84 Characteristics of kva limiter

shown in *Fig. 82.* For this power factor, *55R* is set to the neutral point. When the current vector of the generator lags ($\Delta\theta$), the resultant vector v of the terminal voltage U–W and the phase current R–T shifts to v by $\Delta\theta$.

The vector formula is shown in the following:

$$e_2' - e_1' = \left(\frac{V}{2} + v\sin\Delta\theta\right) - \left(\frac{V}{2} - v\sin\Delta\theta\right)$$

$$= 2v\sin\Delta\theta$$

$$\Delta e = e_2' - e_1'$$

$$= kI\sin\Delta\theta$$

Deviation Δe is fed to the pre-amplifier.

If the deviation signal is fed to the pre-amplifier in parallel with the voltage deviation, the automatic voltage regulator can be used to regulate voltage drooping characteristics, as shown in *Fig. 83.*

These characteristics can be applied for limiting cross-currents between two generators running in parallel.

3) Kva limitation and overcurrent limitation

This regulator has a kva and overcurrent limit control section which consists of two magnetic amplifiers whose output signal is connected to the pre-amplifier.

The amplifier is highly biased as shown in *Fig. 84* in order to obtain step characteristics. Bias consists of the following signal.

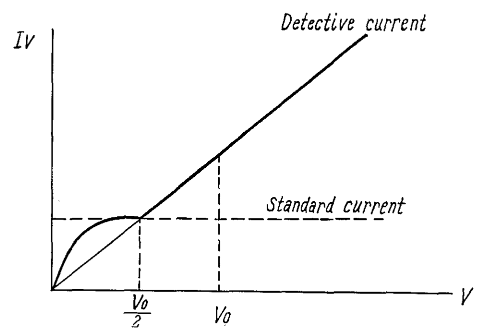


Fig. 85 Characteristics of over current limiter

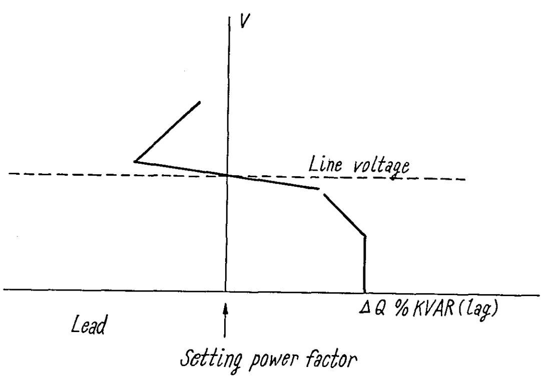
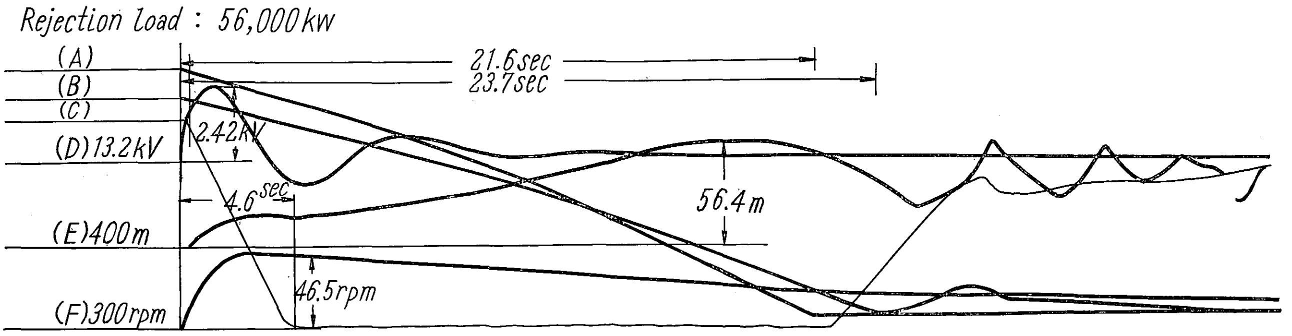


Fig. 86 Overall characteristics of A.V.R.



(A) : Needle opening (group A)
(B) : Needle opening (group B)
(C) : Deflector opening
(D) : Generator voltage
(E) : Head
(F) : Speed

Fig. 87 Example of load rejection test (Wadagawa No. 2 Power Station)

I_V : proportional to terminal voltage
I_I : proportional to generator phase current
I_P : pilot signal of wattless current deviation to the lagging or leading side.

For example : If the bias exceeds the determined value and if the wattless current pilot signal I_P is lagging, the kva limit amplifier sends a signal to the pre-amplifier. This signal causes the terminal voltage to be reduced.

Conversely, if the pilot current is leading, a signal is sent which causes the terminal voltage to be increased. If the terminal voltage of the generator were to drop excessively, this device acts to prevent the current of the generator from rising to more than the pre-determined value. This action is accomplished by using voltage detection characteristics, as shown in *Fig. 85*.

The overall characteristics of this automatic voltage regulator are as shown in *Fig. 86*. *Fig. 87* shows an example of load rejection test results of 70,000 kva generator employing the automatic voltage regulator.

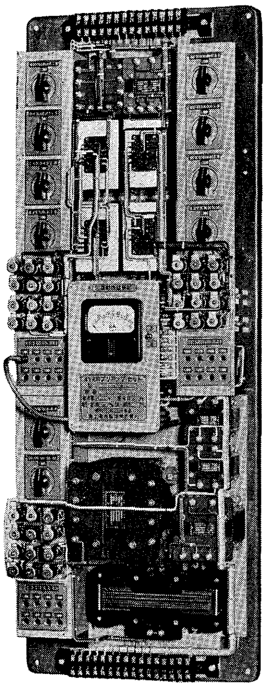


Fig. 88 External view of pre-amplifier set

VII. CONCLUSION

Even though a full description was not given concerning some parts due to lack of space, general explanation on hydro-turbines and generators is complete.

Please feel free to consult Fuji Electric for information concerning complete power plants. In any case, complete and prompt information on all facts of machines for hydro-electric power plants will be given.