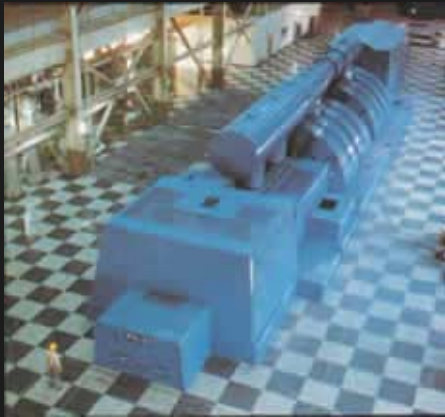




**TOSHIBA**

# Turbine and Auxiliaries



## CONTENTS

<b>Steam Turbines for Central Power Stations .....</b>	<b>2</b>
<b>Kinds and types .....</b>	<b>2</b>
<b>Performance .....</b>	<b>4</b>
<b>Structure .....</b>	<b>5</b>
<b>Structure of each turbine part.....</b>	<b>10</b>
<b>Control device .....</b>	<b>12</b>
<b>Safety device .....</b>	<b>15</b>
<b>Lubricating device .....</b>	<b>18</b>
<b>Steam Turbine Auxiliary equipment.....</b>	<b>19</b>
<b>Condensing equipment.....</b>	<b>19</b>
<b>Feed-water heaters and deaerators .....</b>	<b>21</b>
<b>Controls for auxiliary devices.....</b>	<b>23</b>

## STEAM TURBINES FOR CENTRAL POWER STATIONS

TOSHIBA started construction of steam turbines for use in central power stations in the early 1930's. During the 45 years since then, it has produced about 140 units (including those presently in production) of new-type efficient steam turbines with steam pressure of over 60kg/cm<sup>2</sup>, whose total output capacity has already reached 42,500,000kW. These units include nearly all machines that have established excellent records in respect to output capacity,

type, and so on. Maximum output capacities per unit so far attained are as follows- in steam turbines for thermal power generation-150,000kW for non-reheating type, 700,000kW for tandem reheating type, and 1,000,000kW for cross reheating type; 1,100,000kW for steam turbines for nuclear power generation; and 114,000kW for steam turbines for geothermal power generation.

In view of the trend to provide supercritical pressure and higher-temperature steam to be employed in the future, and to increase the capacity of single units, TOSHIBA stands ready to meet customer demands for any type of high-efficiency, large-capacity steam turbine for use in central power stations, supported by its advanced manufacturing technology and its innovative production facilities.

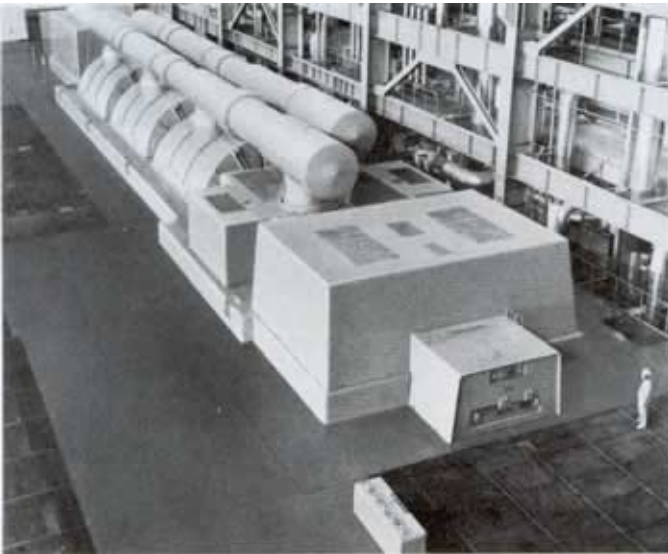


Fig. 1 600MW Tandem, 6-Flow-type Steam Turbine

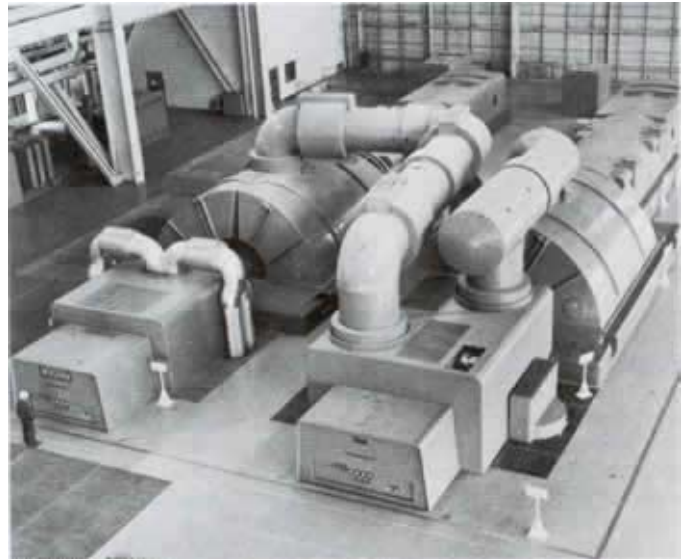


Fig. 2 600MW Cross, 4-Flow-type Steam Turbine

### Kinds and types

Steam turbines for central power stations may be broadly divided as to the kind of steam source into three types: steam turbines for thermal power generation, steam turbines for nuclear power generation, and steam turbines for geothermal power generation. Steam turbines for thermal power generation are further divisible into a non-reheating type (which requires comparatively simple facilities) and a reheating type (which is highly efficient but requires somewhat complex facilities). Although designed for indoor application, they may be used outdoors by providing an appropriate housing.

Steam turbines for central power stations are divided as to the pressure and temperature of the steam they use, their output and so on into high, intermediate, and low-pressure turbines. These turbines are arranged in a single row in the tandem type (TC type) and in two rows in the cross-compound type (CC type). In the cross-compound type, the speed of each turbine shaft is

sometimes fixed at 3,600 or 3,000 rpm. However, its high-pressure side may be made into a compactly constructed and highly efficient rotary machine operating at 3,600 or 3,000 rpm, and its low-pressure side may be made into a rotary machine equipped with large blades suitable for passing large quantities of low-pressure steam with high efficiency and operating at 1,800 or 1,500 rpm. Steam turbines for nuclear power generation are generally large-capacity rotary machines operating at 1,500 rpm. The construction of the exhaust chamber is divided as to the effective length of the last-stage blades, the quantity of steam and so on into single-flow (SF), double-flow (DF), triple-flow (TF), four-flow (4F), and six-flow (6F) types. If they further increase in size, a division of steam flow even more numerous is conceivable. By combining the above divisions of steam flow and the arrangement types of the high, intermediate- and low-pressure turbines, steam turbines for central power stations are produced in the following types:

- SCSF type: single-casing, single-flow exhaust type
- TCSF type: tandem-compound, single-flow exhaust type
- TCDF type: tandem-compound, double-flow exhaust type
- TCTF type: tandem-compound, triple-flow exhaust type
- TC4F type: tandem-compound, four-flow exhaust type
- CCSF type: cross-compound, single-flow exhaust type
- CCDF type: cross-compound, double-flow exhaust type
- CC4F type: cross-compound, 4-flow exhaust type
- CC6F type: cross-compound, 6-flow exhaust type

The relationship between the turbine type (in which the turbine exhaust flow is combined with the standard blade length of the last stage) and the approximate standard output is listed in Table 1.

**Table 1 Turbine Type and Output**

Speed (rpm)	Blade lengths (inch)	Annuals area/SF (ft <sup>2</sup> )	Turbine type-output ( MW)				
			SF	DF	TF	4F	6F
3600	20	24.88	35-53	70-105	105-160	140-210	210-320
	23	32.9	47-70	95-140	140-210	190-280	280-420
	26	41.1	59-87	118-175	175-260	235-350	350-520
	30	55.9	80-118	160-235	240-350	320-470	480-700
	33.5	66.1	95-140	190-280	280-420	380-470	480-700
3000	20	22.6	37-56	75-115	110-170	150-225	220-340
	23	36.4	52-77	105-155	155-230	210-310	310-460
	26	51.9	74-109	150-220	220-330	295-440	440-655
	33.5	72	104-153	210-310	310-460	415-615	625-920
1800	35	84.0	120-177	240-355	360-530	480-710	720-1060
	38	95.3	135-200	270-400	410-600	540-800	820-1200
	38	105.7	150-220	330-440	450-660	600-890	900-1330
	42	123.8	175-260	350-520	530-780	705-1040	1060-1560
	52	173.0	245-360	490-725	740-1090	980-1450	1480-2170
1500	35	84.0	120-177	240-355	360-530	480-710	720-1060
	41	116.3	165-245	330-490	490-740	660-980	990-1470
	52	176.0	245-360	490-725	740-1090	980-1450	1480-2170

**Performance**

The blade and nozzle of each turbine stage has a shape finely wrought from the viewpoint of fluid mechanics and is constructed to minimize the steam leakage from various turbine parts in order to improve mechanical efficiency. At the same time, by taking account of the feed-water temperature, pressure of extracted steam, reheating pressure, type and arrangement of the feed-water heater and so on which are best suited for the power plant under consideration, completion of a highly efficient turbine plant is always the prime objective.

Thermal efficiency of the non-reheating turbine cycle is governed mainly by conditions of the steam used, such as the main steam pressure, main steam temperature, exhaust pressure, number of extraction stages, feed-water temperature, efficiency of the boiler feed-water pump, and thermal efficiency of the turbine cycle in the case of a standard cycle. The net thermal efficiency of a plant when its output is 100MW is listed in Table 2.

**Table 2 Thermal Efficiency of Nonreheating Turbine (when out put is 100MW)**

Stream pressure (kg/cm <sup>2</sup> g)	Stream temperature (°C)	Turbine thermal efficiency (%)	Net efficiency of plant (%)
60	485	36.8	30.2
68	510	39.2	32.2
102	538	39.9	32.7
127	566	41.0	33.7

- a. Degree of vacuum of exhaust chamber: 722mmHg
- b. Reheater inlet pressure: main steam pressure x 0.22
- c. Feed-water temperature: as shown in Fig. 5
- d. Sum of steam pressure drops in reheating steam pipe and reheater: 10%

- e. Enthalpy rise of feed-water in each feed-water heater is assumed to be equal.
- f. Discharge pressure of boiler feed-water pump: 1.2 times the main steam pressure
- g. Efficiency of boiler feed-water pump: 70%
- h. Power of auxiliaries for boiler feed-water pump: 3.5% of generator output power
- i. Efficiency of boiler: 89%

The net thermal efficiency of a plant also varies according to the turbine type in addition to the above steam conditions. An example of this variation is shown in Fig. 6. Numerals at the end of the turbine names shown on the curves indicate the effective length (in inches) of the last stage blade

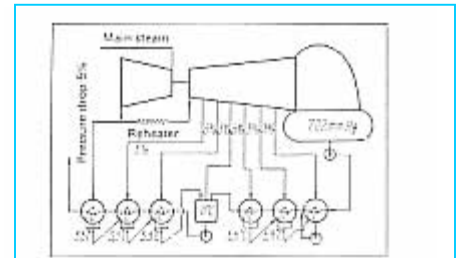


Fig. 3 Basic cycle

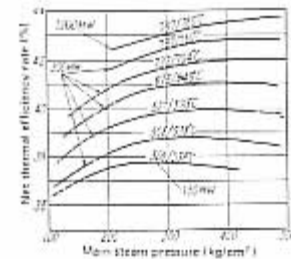


Fig. 4 Net Thermal Efficiency of Basic Cycle

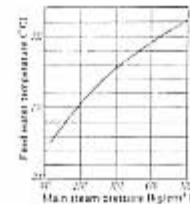


Fig. 5 Feed-water temperature of Basic Cycle

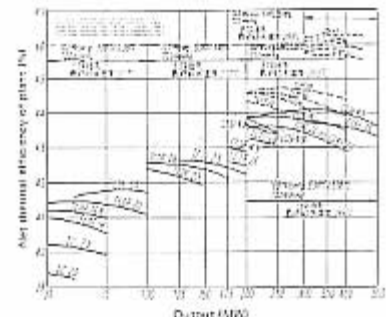


Fig. 6 Types of Turbines and Net Thermal Efficiency Net thermal efficiency of Plant (%)

## Structure

### Non-reheating turbines

As examples of structures of the nonreheating-type turbines, Fig. 7 is a diagram of an SCSF-type 66MW turbine and Fig. 8 is a TCDF-type 150MW turbine. In the former (Fig. 7), the high-pressure part and the low-pressure part of the turbine casing are fastened together by bolted vertical joint into a single casing. The rotor is a solid rotor produced by machining a single forging and is supported by two bearing units. The overall length is shorter than that up the TCDF-type (whose cross section is shown below), rendering the entire turbine shape compact. In the latter (Fig. 8), the casing is divided into two parts—a high-pressure part and a low-pressure part. The rotor is also composed of two rotors—a high-pressure rotor and a low-pressure rotor, each being a solid rotor produced by machining a single forging. They are combined by rigid couplings and supported by three bearings. By installing the center one of these three bearings. In the bearing seat, which is integral with the low-pressure exhaust chamber, the overall length of the turbine is shortened as much as possible, rendering the entire turbine shape compact. The steam path, which leads steam from the high-pressure turbine to the low-pressure turbine, is composed of a balancing-type crossover tube (independent of the casing) in order to minimize deformation of the low-pressure turbine. The thrust bearings of the two turbines are installed in the respective front bearing seats to cope with axial thrust developed in the rotor during operation and to hold the rotor in the correct axial position.

Since the low-pressure casing is axially fixed by the key driven into its central part, and the front bearing center maintains its center by means of the center key and is supported by the sliding surface, the casing, with its center maintained in position, moves axially forward due to thermal expansion during turbine operation. The front part of the high-pressure casing in the high-temperature part is constructed so that it can freely expand radically with its axis held stationary by the key.

The main steam stop valve is installed under the floor of the turbine front part, and steam control valves are installed above and below the casing so that steam is fed into the casing through these valves during turbine operation to prevent the casing from developing an extreme temperature difference between its upper and lower parts.

The gland part, where each rotor passes through the casing, is made of labyrinth packing as a steam seal. Thanks to the gland steam regulator valve, gland condenser and gland exhaust blower, there is no steam leakage into the atmosphere from the gland part.

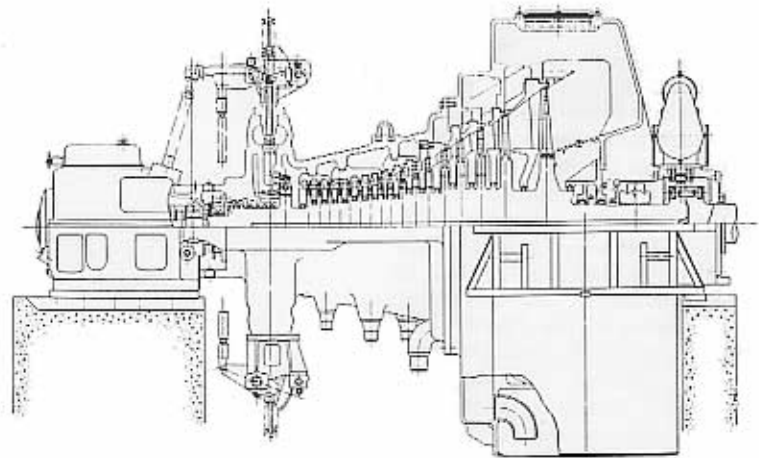


Fig. 7 SC-type Non-reheating Turbine (66MW)

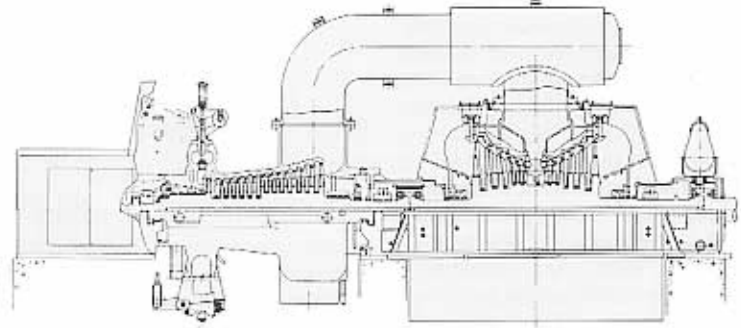


Fig. 8 TCDF-type Non-reheating Turbine (150MW)

### Reheating turbine

As an example of structure of the SCSF-type reheating turbine, Fig. 9 is a diagram of the SCSF-type reheating turbine 75MW. This turbine produces a main steam pressure of 102kg/cm<sup>2</sup>g and a reheated steam temperature of 538°C. It consists of a high-pressure part preceding the reheater, an intermediate-pressure part following the reheater, and a lower-pressure part.

The high- and intermediate-pressure parts and the low-pressure part are placed together in one casing. The inlet for turbine steam is located in the center of the high pressure parts, so that the direction in which steam of the high- and low-pressure parts flows is reversed to counterbalance thrust developed in the rotor, thus diminishing the thrust load and localizing the high-temperature part of the casing.

This design renders it possible to avoid an excessive temperature gradient. The rotor unit is constructed of a high-temperature part and a low-temperature part, having blades for both a high-temperature and low-temperature application.

The rotor is a solid rotor machined from a solid forging, secured by a rigid coupling and supported by two bearings. The structure of the gland packing and the arrangement of the steam regulator valve are the same as those for the nonreheating-type turbine formerly described. To quickly shut off an inflow of reheated steam in an emergency (such as shutoff of the load), the inlet for reheated steam is equipped with two combination reheating valves, each consisting of an interceptor valve and a reheated steam stop valve, installed under the floor on each side of the turbine. Fig. 10 is a diagram of the 156MW turbine as an example of a large-capacity TCDF-type reheating turbine. This turbine produces a main steam pressure of 169kg/cm<sup>2</sup>, a main steam temperature of 566°C, and a reheated steam temperature of 538°C. If the last stage of this turbine employs blades whose effective length is 660mm (26 in.), it will provide an output of 118 to 175MW; if it employs blades whose effective length is 765mm (30 in.), it will provide an output of 160 to 235MW. As with the casing of the 125MW, the high-pressure part of the casing (which precedes the reheater) and its intermediate-pressure part (which follows the reheater) are arranged so that the steam flows in them are opposed to each other. The two parts are installed together in a high-pressure casing. The low-pressure part is installed in a low-pressure casing. The rotor unit consists of two rotors—a high-and-medium-pressure rotor and a low-pressure rotor; they each are supported by two bearing units and joined by a rigid coupling. Thrust bearings are installed between the high- and intermediate-pressure casing and the low-pressure casing as a means of minimizing any difference in expansion between the casing the rotor. Each rotor is machined from engineering material appropriate for its working condition.

Since the casing is axially secured at the central part of its lower-pressure casing, it is constructed to elongate forward during turbine operation, as in the case of the turbine described above. Each casing is of double construction. The first-stage nozzle steam chamber installed within the inner high-pressure casing is of separate nozzle construction designed to diminish rigorous thermal strain caused by temperature variations when starting and stopping the turbine. The arrangement of the main steam stops valve, control valve, and combined reheat valve, and structure of the packing and so on are the same as those for the 125MW turbine already described. The steam path from the intermediate-pressure turbine to the low-pressure, double-flow turbine is constructed of a balancing-type crossover tube mounted independently of the casing.

and structure of the packing and so on are the same as those for the 125MW turbine already described. The steam path from the intermediate-pressure turbine to the low-pressure, double-flow turbine is constructed of a balancing-type crossover tube mounted independently of the casing.

Fig. 11 is cross section of the 375MW turbine as an example of the TC4F-type large-capacity, reheating turbine. By compactly combining the high-pressure casing and the intermediate-pressure casing into a unit, and by using two low-pressure casings, improvement in efficiency is attained. As for turbines whose output is less than 300MW, a control valve is installed on the high-pressure casing.

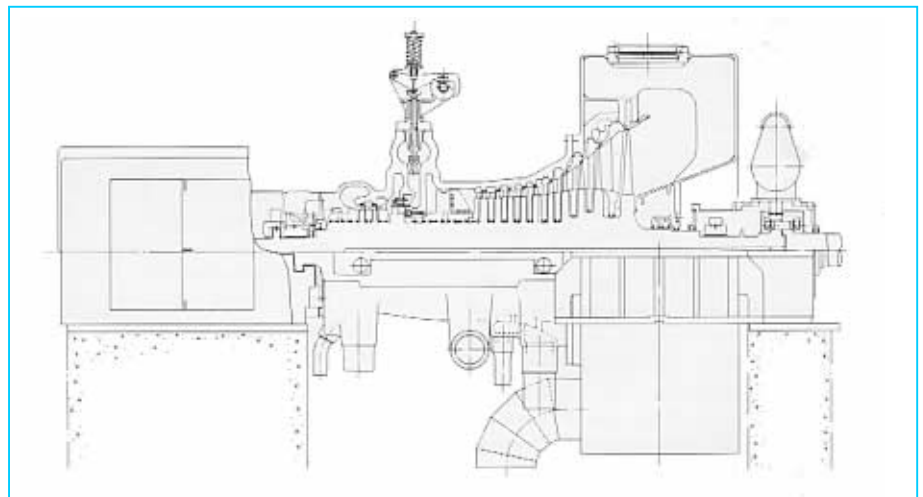


Fig.9 SCSF-type Reheat Turbine (75MW)

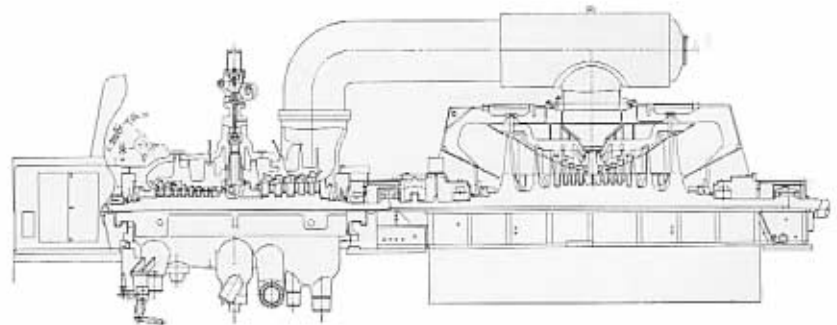


Fig.10 TCDF-type Reheat Turbine (156MW)

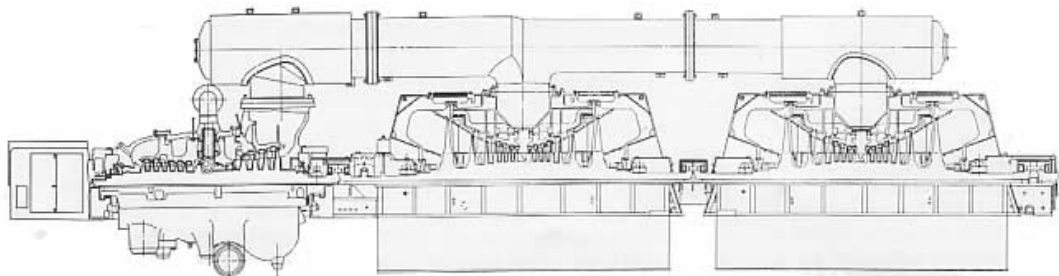


Fig.11 TCF-type Reheat Turbine (375MW)

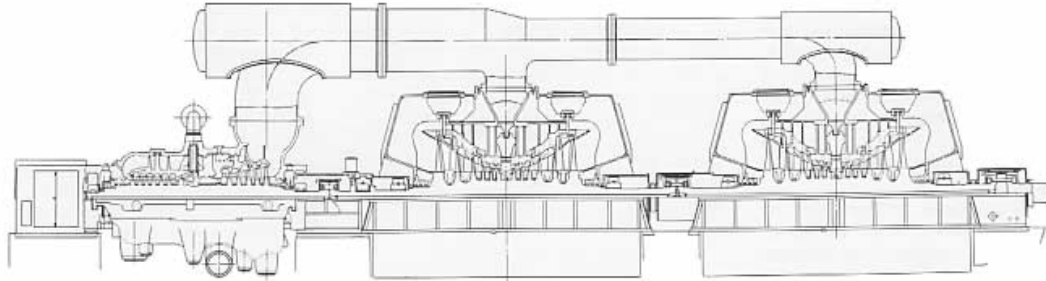


Fig. 12 TC4F-type, Single Reheat Turbine (600MW)

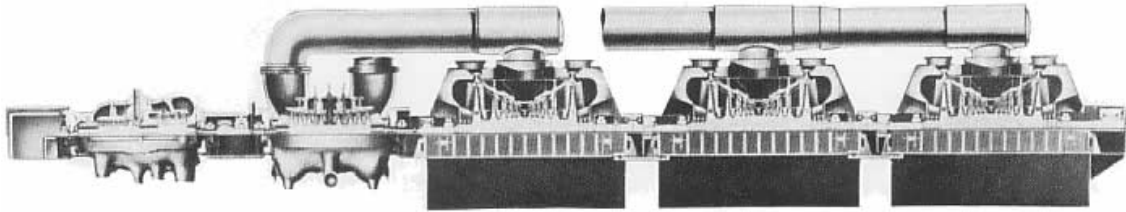


Fig. 13 TC4F-type, Double Reheat Turbine (600MW)

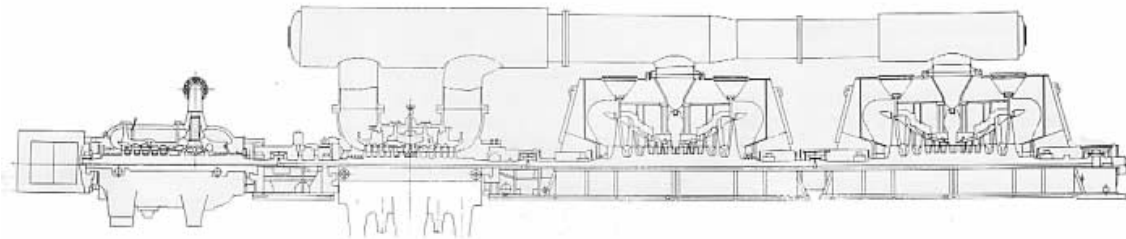


Fig. 14 TC4F-type, Single Reheat Turbine (700MW)

For turbines whose output exceeds 300MW, the control valve is independent of the casing, and is installed along with the main steam stop valve under the floor of the front part of the turbine; thus, the shape of the high-pressure casing is extremely simplified and convenient for providing large capacity.

Large-capacity turbines whose output exceeds 500MW are turbines of supercritical pressure, which produces a main steam pressure of 246kg/cm<sup>2</sup> g and a reheating temperature of 538°C. As shown in Fig. 12, it is composed of three casings, which are the high-pressure and intermediate pressure combined cylinder, and two double flow low-pressure cylinder.

The two-stage reheating turbine consists of four parts; namely the high-pressure, first reheating, second reheating, and low-pressure parts. The high-pressure part casing and the first reheating part casing are combined into a unit in which the two streams of steam flow against each other. The second reheating part is a double-flow type. Fig. 13 is a cross-sectional view of a TC6Ftype, 600MW double reheating turbine. In this case, although its performance can be improved, its overall length is increased. By increasing the length of its last stage blade, its capacity may be rendered still larger without increasing its overall length. Fig. 14 is a cross-sectional view of a TC4Ftype 700MW, single reheating turbine.

This turbine features a first stage nozzle made into a double-flow type nozzle box to diminish first-stage blade stress. As an example of the cross-compound steam turbine, Fig. 15 is a cross-sectional view of a CC4F-type 600MW turbine, each of whose two shafts can develop a speed of 3,000 rpm. Although the steam flow is somewhat complex in this turbine, outputs of the primary and the secondary turbines are almost uniformly distributed over the entire load, enabling the low-pressure turbines on its two shafts and the two generators connected to these shafts to be of identical rating. In the primary turbine, the high-pressure turbine and the low-pressure turbine are a contra flow type, and in the secondary turbine,

both the intermediate-pressure turbine and the low-pressure turbine are a double-flow type as a means of counterbalancing the axial thrust. Each of the high-, intermediate-, and low-pressure rotors is supported by two bearings, and thrust bearings for the primary and secondary turbines are installed in the intermediate standard, which are independent of the low-pressure casing. An interceptor valve, independent of the casing, is installed on either side of the lower part of the intermediate-pressure turbine. Other structures of this turbine are the same as those of the TCTF-type reheating turbine.

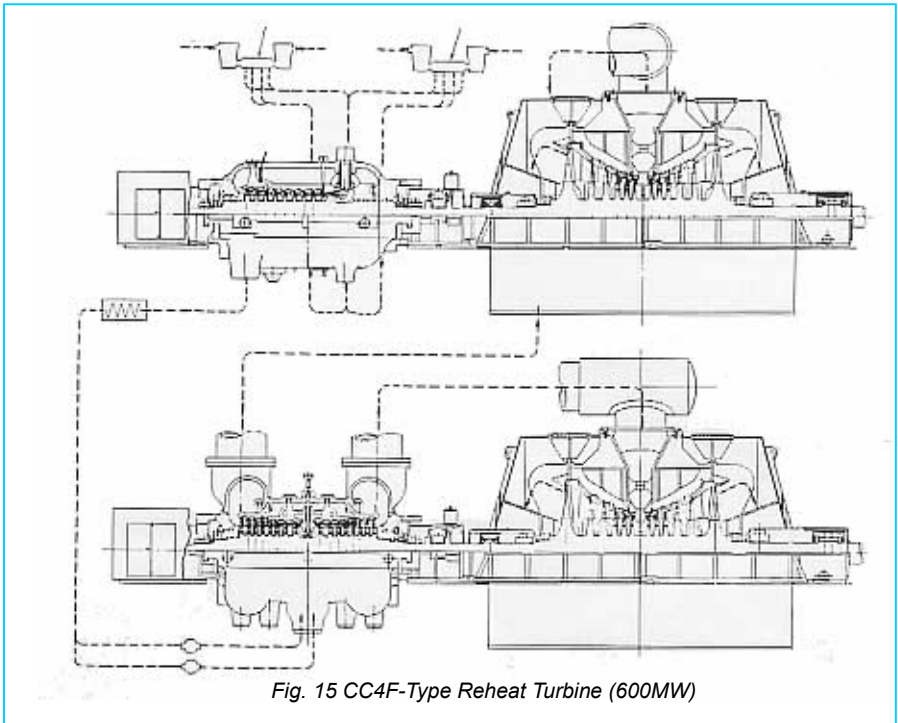


Fig. 15 CC4F-Type Reheat Turbine (600MW)

### Steam turbine for nuclear power generation

A steam turbine for nuclear power generation is characterized by:

- (1) Moisture content of the steam generated by nuclear energy is high because of the low-level steam condition.
- (2) Since the turbine consumes large quantities of steam, various parts of it are large-scaled.
- (3) Since it handles radioactive steam, a high level of reliability is demanded of it.

As an example of a large-capacity steam turbine for nuclear power generation, Fig. 16 is a diagram of the TC6F-type 784MW turbine. This turbine, combined with a boiling water reactor, provides a main steam pressure of 66.8kg/cm<sup>2</sup> g, a main steam temperature of 282.3 C, and consists of four casings, which are composed of the double-flow high-pressure part and 6-flow low-pressure part. A main steam stop valve and a steam control valve are installed under the front floor of the turbine, and the main steam flows-via these valves into the high-pressure casing from above and below.

Since the steam (which has accomplished its task in the high-pressure turbine) contains much moisture, it has its moisture separated by a moisture separator before entering the low-pressure turbine. The combined intermediate stop valve, a combination of an interceptor valve and an intermediate stop valve, is installed downstream from the moisture separator. Steam passes through such setups and is led to the low-pressure turbine via a cross-around pipe arranged on the floor. In this turbine type, both the high-pressure casing and the low-pressure casing are a double-flow type of which the axial thrust is balanced. Because of its low pressure and low temperature, the high-pressure turbine is of single-casing structure; however, its reliability level is enhanced by using oversize bolts to prevent steam from leaking from the horizontal coupling surface. The high-pressure rotor is a solid rotor formed by machining a solid forging.

Because of its large outside diameter, the low-pressure rotor is constructed so that the blades are shrinkage-fitted to its shaft mainly for manufacturing reasons. The rotors are combined with each other by rigid couplings, each of them supported by two bearings. Because of the enormous weight of the rotor, a jack-up device, which can float the rotor by using oil under high pressure, is provided for diminishing the turning motor load, for preventing the rotor from vibrating, and for protecting the bearings. Gland packing is of the same construction as that for the steam turbine for thermal power generation, but the steam seal system has been improved to avoid discharging radioactive steam.

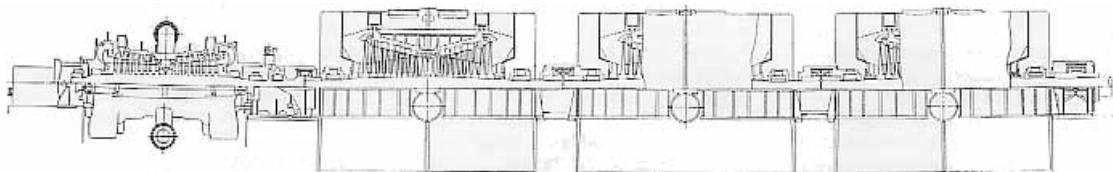


Fig. 16 TC6F-Type Nuclear Turbine (784MW)

In the steam turbine for nuclear power generation, special attention is paid to the prevention of corrosion and to the structure for positive removal of moisture. Corrosion prevention includes the following: shrinkage fitting of the sleeve for the rotor gland part; buttering with stainless steel for the steam seal surface of the casing, nozzle, and so on; application of highly anticorrosive steel plate containing copper.

Moisture removal involves application of a moisture-extracting bucket on the rear stage of the low-pressure turbine for removal of moisture from the inner stage. This blade provides the function of catching dew present in the steam and throwing it toward the periphery by centrifugal force, rendered possible by cutting several grooves into the backside of the blade inlet. Also, the nozzle diaphragm is shaped to discharge water without difficulty.

Since the size of this type of steam turbine is becoming increasing larger, it uses an electro hydraulic control device to further stabilize its control system. For details, refer to the chapter on the speed-governing device.

## Steam turbine for geothermal power generation

Although this type does not differ from that for thermal power generation, special care must be used in its design, since the steam used is natural steam. Geothermal steam possesses different properties according to the location where it is generated. It is impossible to artistically control its quality, quantity, pressure, temperature, and so on. Therefore, before designing a geothermal steam turbine for particular geothermal steam, it is necessary to closely study its properties and sometimes to conduct an entire series of experiments on it.

When designing a geothermal steam turbine, the following three points must be given emphasis:

### (1) Precautions against wet steam

Geothermal steam is often saturated steam whose pressure is low and whose wetness is in the order of several percent. The braking action exerted by hygroscopic moisture on the turbine blades leads to a deterioration of turbine performance, and drain erosion lowers turbine strength properties. Since the steam turbine for nuclear power generation has a similar weakness, it employs moisture separators and turbine blades of the moisture-separating type to improve its performance capabilities, and protects the casing against erosion by using erosion-shielding plates made of stainless steel.

### (2) Precautions against scale

Geothermal steam carries fragments of earth crust components in the form of micro-solids. The adhesion of such scale to the steam path of a steam turbine affects performance capabilities of the turbine. Depending on the hardness and size of such solid particles, various parts of the turbine become worn (solid particle erosion) and their strength deteriorates.

The best precautionary measure against this is to remove such scale before it enters the turbine, and for this purpose, centrifugal separation is effective.

The most rational way to cope with the inflow of scale that cannot be separated is to use a separating structure as simplified as possible, which will render it difficult for the scale to adhere to generator parts, and to make it easy for personnel to disassemble and clean it.

### (3) Consideration of corrosive gases

Some of the noncondensing gases contained in geothermal steam have metal corroding components (S, Cl, etc.). To prevent corrosive gases, properties of the geothermal steam under consideration are studied from the time of drilling an exploratory steam well in order to select suitable materials. A series of corrosion tests is sometimes conducted on various materials. Similarly to a steam turbine for thermal power generation, the high-strength materials used include high-Cr steel, low Cr-Mo steel, and anticorrosive stainless steel.

The aforementioned precautionary measures (1) through (3) taken are not limited only to the actual turbine; are applied as a matter of course to its auxiliaries, control system, and piping. Generally speaking, district where geothermal steam occurs are not rich in turbine cooling water such as rivers. Consequently, condensation of a turbine is cooled by an air-cooling tower to be used as condenser cooling water.

For this reason the degree of vacuum of the turbine's condenser is lower than that of the steam turbine for thermal power generation. Further, the low pressure and low temperature of geothermal steam work together to lower the effective heat head. Accordingly, the quantity of steam per unit output in this turbine is greater than that of the steam turbine for thermal power generation, while output control is a throttle adjustment type. For the above reasons, design of the overall structure of a geothermal steam turbine resembles that of the low-pressure part of a steam turbine for thermal power generation.

As an example of geothermal steam turbines, Fig. 17 is a diagram of a TC4Ftype 110MW 3,600-rpm turbine. The steam conditions of the turbine are a main steam pressure of 7.1 kg/cm<sup>2</sup>g, main steam temperature of 179°C, and degree of vacuum for exhaust of 660mmHg. The main steam, which leaves the steam control valve, is led by the communicating tube to the steam inlet located on the central side of the casing. Two steam inlets are installed symmetrically with respect to one casing. The steam, which has expanded and worked into the turbine, is condensed in the condenser. This condensation is cooled in an air-cooling tower and used as condenser cooling water.

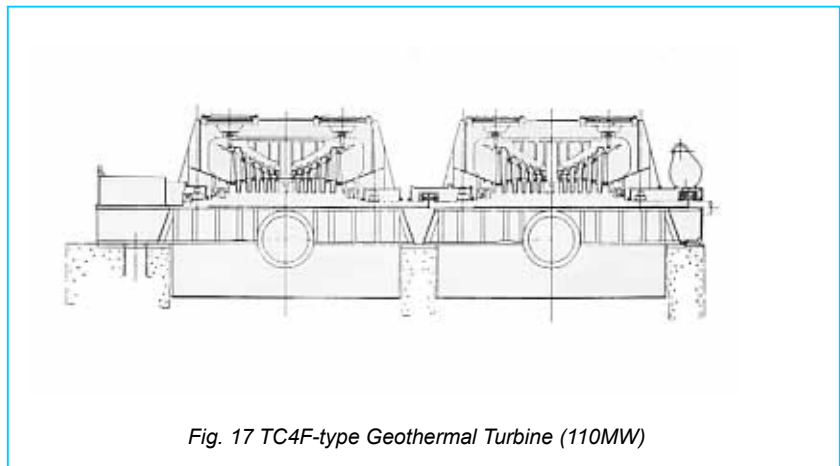


Fig. 17 TC4F-type Geothermal Turbine (110MW)

## Structure of each turbine part

### Casings

The high-pressure and intermediate pressure outer casings are made of alloy steel casting whose structure and shape are simplified to avoid as much as possible local stress and nonuniform expansion developed during turbine operation. Adoption of double casings has rendered it possible to reduce wall thickness of the inner and outer casings as well as width of the horizontal coupling flange. In turbines which use high-temperature steam of 566°C class, bolt-cooling, steam is run through the inner casing flange to ensure flange creep strength and to prevent steam

leakage from the flange as a means of starting the turbine without difficulty. The high-pressure and intermediate-pressure casings are made of either alloy steel casting or carbon steel casting according to temperature of the steam used.

The inner and outer surfaces of the inner and outer casings are rigidly tested by X-ray for osmosis, and their horizontal coupling flange parts are tested by a supersonic flow tester to ensure long, defect-free service life. As a result, their reliability level is quite high. All the low-pressure casings are made of welded steel plates. After completion of welding, the entire casing is annealed to remove stress.

### Rotor

The material for the high-, intermediate-, and low-pressure rotors is optimum for the working temperature, and their blade, shaft, coupling flange and so on are formed by machining solid forgings. However, the low-pressure rotor of the steam turbine for nuclear power generation, which is a large-diameter rotary machine usually developing a speed of 1,800 rpm or 1,500 rpm, has its impeller shrinkage fitted to its shaft. The composition, heat treatment, mechanical properties and so on of each rotor conform strictly to standards, proving to be highly reliable since its material has

undergone ultrasonic flaw tests before and during the manufacturing process. To remove residual strain caused by forging and machining, and to ensure stable performance of rotors, heat tests are conducted after rough machining in the stock manufacturing plant. After inserting the blades, dynamic balance tests are conducted to remove as much as possible any unbalance of the rotors, which tends to cause their vibration during operation.

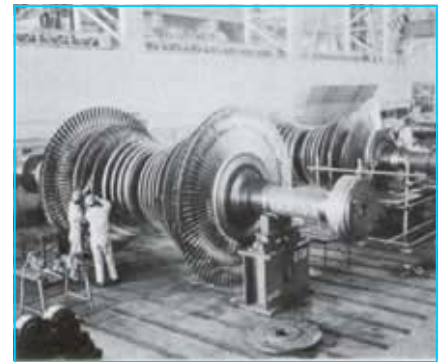


Fig. 18 Rotors

### Blades

Blades of the high-temperature part are made of Cr-Mo-V-W steel; blades of the low-temperature part are 13 Cr stainless steel. The blades are formed by milling bar stock and stamp work. Since the first-stage blades are subjected to great variations in steam impulse when the load changes, and to intermittent impulses of steam jetting from nozzle groups of the steam control valve, they are wide. Particularly, in the reheating turbine, blade tips are formed into shrouds, which closely contact the adjacent blades,

and whose periphery is encircled by an outer shrouding band, forming safe blades strong enough to resist impulses and vibrations caused by steam. The part where the blades are inserted is pine tree-shaped, formed by machining the impeller around its periphery. The last-stage blades, whose effective length exceeds 508mm (20 in.), are fork shaped and pin-fixed. To resist the erosion effect of dew present in the steam, strips of stellite are welded or silver-brazed to the

blade entrance. In the high-pressure stage blades, strips are formed around the entire periphery of the blade root part between the nozzle outlet and blade inlet, and radial stops are installed on the shell of the nozzle diaphragm to minimize steam leakage from the axial gaps between the nozzles and blades.

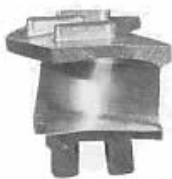


Fig. 19 Axial Entry-type Governing Stage-Blade



Fig. 20 Medium-stage Blades



Fig. 21 Last-stage Blades

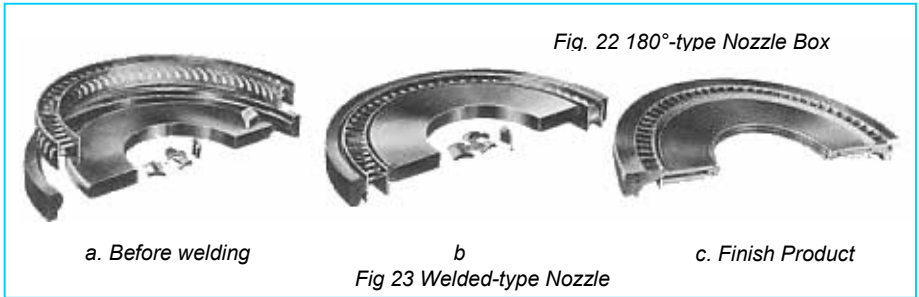
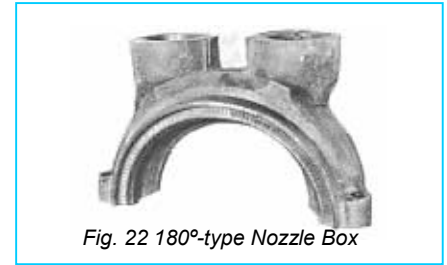
## Nozzles

Nozzles are either welded type or cast type.

The high-pressure, first-stage nozzle is often of separate nozzle box construction. This nozzle is exposed to steam whose variation in temperature and pressure is greatest. The first-stage nozzle is made into a simplified, small shape with thin walls and is separated from the casing. It is designed to minimize thermal stress and to freely perform thermal expansion. The nozzle of the high-pressure, high-temperature part is a welded type whose nozzle plate is welded to the alloy steel diaphragm. The nozzle of the low-pressure, low-temperature part is a cast type whose nozzle plate is cast into the diaphragm is made of cast steel or cast iron, depending on the temperature of the stage where it is used.

The diaphragm placed in the wet steam region has a drain separating part on its

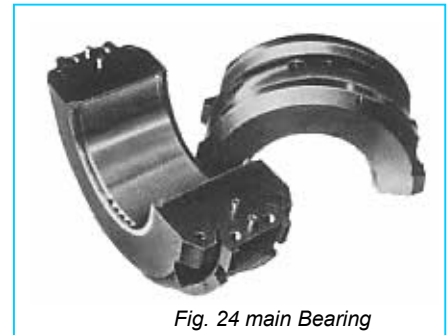
outer ring to separate harmful drain. Depending on the temperature of the stage where it is used, the nozzle plate is made of Cr steel containing Cb, CrMo steel, or Cr steel containing Al. It is precision machined to retain its high efficiency over long periods.



## Main bearing

The main bearing, consisting of a bearing proper and a shell, is a spherical surface, seat-supporting type. This is an elliptical shape, which, compared with conventional bearings, and offers a much greater effect in stabilizing the shaft during turbine operation. High- and low-pressure rotors of large capacity use tilting pad-type bearings, which provide a greater shaft-stabilizing function. Lubricating oil in the proper volume is fed to each bearing by an orifice installed in the feed-oil tube.

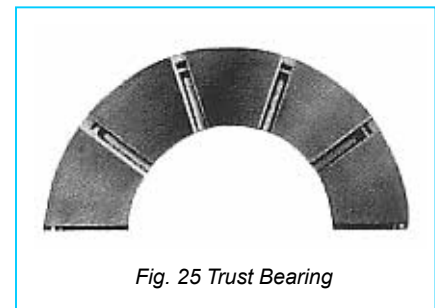
The lower half of shell which fits into the groove of the bearing stand is constructed so that its position can be adjusted by an adjusting plate. The upper and lower halves are bolted together to complete the shell, which is directly bolted to the horizontal coupling surface of the bearing stand to securely retain the bearing in position.



## Thrust bearing

The thrust bearing consists of the bearing proper and a thrust-receiving surface. The thrust-receiving surface is a taper-land type, which possess great resistance against pressure. Several radial oil grooves divide the surface into segments, the surfaces of which are radially and circumferentially precision machined and properly inclined. Lubricating oil is supplied from the inner thrust receiving surface to the oil grooves, and forced into the inclined surface by a rotating collar bearing to form a powerful pressure-resisting surface.

The thrust bearing is a split type having an adjusting plate inserted in its back to facilitate adjusting the thrust-bearing gap. The thrust bearing especially equipped with a thermostat for measuring the temperature of the front and rear thrust bearing metal as a means of sensitivity monitoring any abnormal condition of the thrust-bearing surface. Also, it is equipped with a protective device for automatically stopping the turbine in case of an unforeseen accident. For details, refer to descriptions concerning the control device.



## Gland packing

### 1. Labyrinth packing

Labyrinth packing is used for the gland part of the turbine and for the inner surface of the nozzle diaphragm. It consists of several circular segments fitted into the grooves of their mating parts and equipped with leaf springs on their backs. If the rotor and the labyrinth packing should contact each other, local heating of the rotor due to such contact can be reduced.

The labyrinth packing for high-temperature parts consists of an alloy steel labyrinth body inserted with Cr-Mo steel strips; that for low-temperature parts consists of a labyrinth body and strips integrally formed on nickel silver or phosphor bronze stock.



Fig. 26 Labyrinth Packing

### 2. Gland steam condenser and gland exhaust fan

When the gland seal is a steam seal type, a gland condenser and a gland exhaust fan are installed. Steam leakage and air from the gland are led to the gland condenser, where the steam is

condensed, and the air and gases are discharged into the atmosphere by the gland exhaust fan. Turbine condensation is used as cooling water for the condenser to reclaim heat.

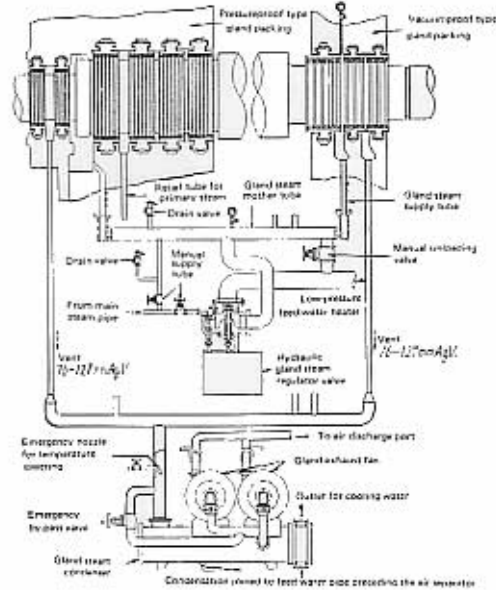


Fig. 27 Concept of Steam Seal System

## Control device

The control device is broadly divided into a governor device and a safety device. The governor device regulates the output and speed of the turbine generator, while the safety device stops the turbine generator quickly and safety should it has developed an abnormal condition during operation. The governor device is further divided into a conventional mechanical hydraulic governor and a new-type electro hydraulic governor used for large-capacity turbines.

### 1. Mechanical hydraulic governor Governor

The governor is a centrifugal weight-type, which detects variations in centrifugal force acting on the rotating weights. The speed (rpm) of this governor, driven by the turbine shaft via a reduction gear, is 581 rpm. This standard rpm, representing the fruits of TOSHIBA's years of experience and research activities, is adopted for the governor of all of TOSHIBA Steam Turbines such as the reheating, nonreheating, tandem compound, and cross compound types regardless of their type, speed, and other specifications.

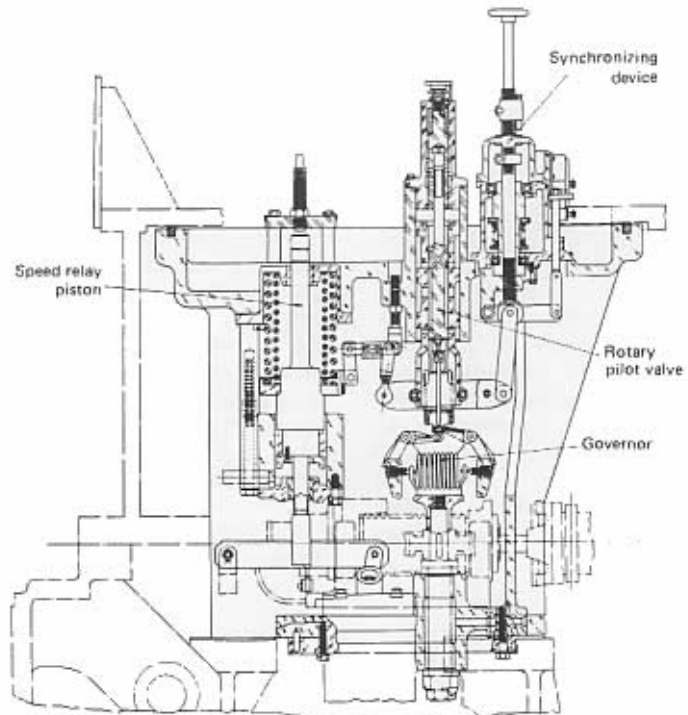


Fig. 28 Governor

Variations in the governor rpm are transmitted to a speed relay piston through a rotary pilot valve connected to the upper part of the governor by a spring coupling and a pivot. Controlling accuracy of the governor including the steam regulator valve, which is the final control element, is designed to be within 0.03% or less. Accordingly, variations in centrifugal force (detected by the governor weights) takes a very small value, which is quite difficult to be correctly transmitted and amplified. Since the rotary pilot valve is directly connected to the governor and is constructed to rotate in a ferrule tube, it can completely eliminate viscous resistance (unavoidable in the case of a conventional pilot valve) and can cause governor motion to be completely reproduced in the speed relay.

### Starting device and load limiting device

Turbine starting operation refers to raising the speed of a shutdown turbine to the rated rpm. Load limiting operation refers to limiting the maximum load to be borne by a turbine connected to an electric power feeder system. Since these two operations are

never performed simultaneously, standard governor construction is simplified so that after the turbine has been connected to the power feeder system, the starting device will act as the load-limiting device.

The control handle for the starting device is installed on the turbine front so that personnel can operate it while monitoring the tachometer, steam control valve-opening indicator, and load limit indicator. The starting handle can be operated from the central control room or another desired location by providing a remote-control motor. The starting device incorporates a trip piston, which immediately closes the steam control valve when the safety device is actuated to prevent turbine over speed. Moreover, this trip piston is designed with an interlock, so that once it is operated, it prevents the steam control valve from being opened again unless the valve is positively closed by fully closing the starting handle.

The load-limiting device is a hydraulic type which limits the steam control valve opening by an auxiliary pilot valve installed in the path for oil under pressure. Accordingly, even when this device operates, no additional load is

imposed on the governor, steam control valve, and so on. Any change in the set load, shifting to governor operation and so on, can be effected without difficulty.

### Synchronizing device

The synchronizing device, employed for setting the load on the turbine, is generally operated from the central control room, although it is also provided with a manual handle.

Since this device forms the receiver of signals from the AFC, APC, ALR, and so on, it is designed so that it can be equipped with a limit switch which indicates the upper and lower limits of a differential transformer, thus performing feedback operation for the aforementioned signal transmitters.

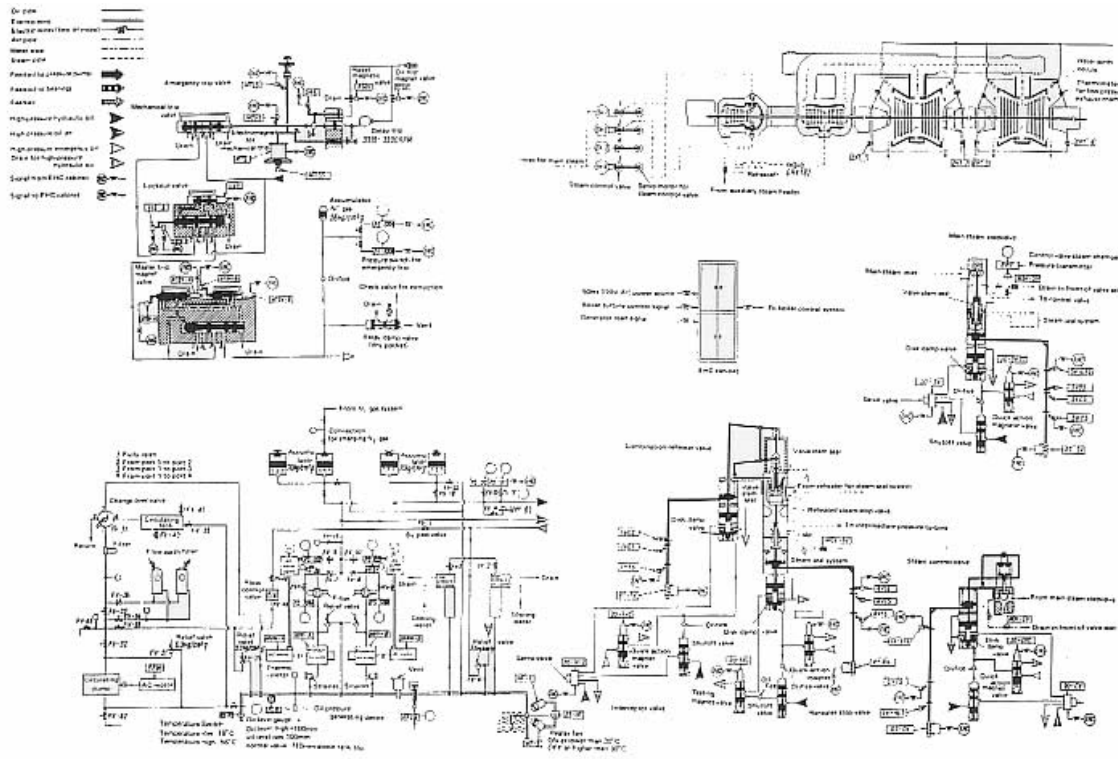


Fig. 29 High-pressure-type Electro hydraulic Control System

**Steam control valve and hydraulic cylinder**

Since the steam control valve is the final control element of the governor device, its operation must provide a sufficient linearity. The cam-lift-type globe valve, used for TOSHIBA Turbines, can readily and precisely determine the flow rate characteristic of the steam control valve by properly designing the cam shape. The valve and the valve stem are made of Ni-Cr series special steel, which has a high high-temperature impact value, and the slideway is nitrided to prevent seizure. Moreover, the cam is provided

with a dowel pin to prevent locking accidents. The contact surfaces of the valve and valve seat are deposited with stellite and polished into mirror smooth surfaces to completely eliminate steam leakage when the valve is closed. To prevent seizure due to thermal strain, that part of the turbine pierced by the valve stem diameter. Steam leakage from this gap in the high-pressure part is led to an appropriate turbine stage to have its heat recovered, whereas steam leakage from the low-pressure part is connected to the gland steam regulator valve to accomplish sealing at turbine start-up and to prevent steam leakage during turbine operation.

To provide a powerful force for opening and closing the steam control valve and to quickly follow up governor action, the hydraulic cylinder for the steam control valve is equipped with a double-acting differential cylinder and is generally of failsafe construction. The piston is usually of welded steel plate structure and the cylinder is cast iron. The pilot valve for the hydraulic cylinder is constructed of nitrided steel to avoid erroneous operation caused by wear.

**2. Electro hydraulic control device**

Despite the ever-increasing unit capacity of steam turbines for central power stations, the GD2 of their rotors is decreasing in a relative way. For this reason it has become difficult to limit the instantaneous speed rise to within 110% or less of the rated speed. Moreover, in nuclear power generation, the reactor pressure must be controlled from the turbine side in addition to the turbine output. For a control device,

which must deal with two quantities, which are entirely independent of each other, its controlling method is forced to become extremely complex. On the other hand, turbine automation is being promoted as a means of stabilizing the supply of electric power and saving on manpower. Since a hydroelectric control device conducts the detection, transmission, and arithmetic operation of signals using electric or electronic devices, it can effect complex arithmetic operations without

much delay of time, and it can construct an interface with a computer without difficulty when effecting its automation. Also, it uses hydraulic oil under high pressure to reduce servomotor size and valve closing time. Because high-pressure oil is used, the oil system is divided into high-pressure control oil system and lubricating oil system.

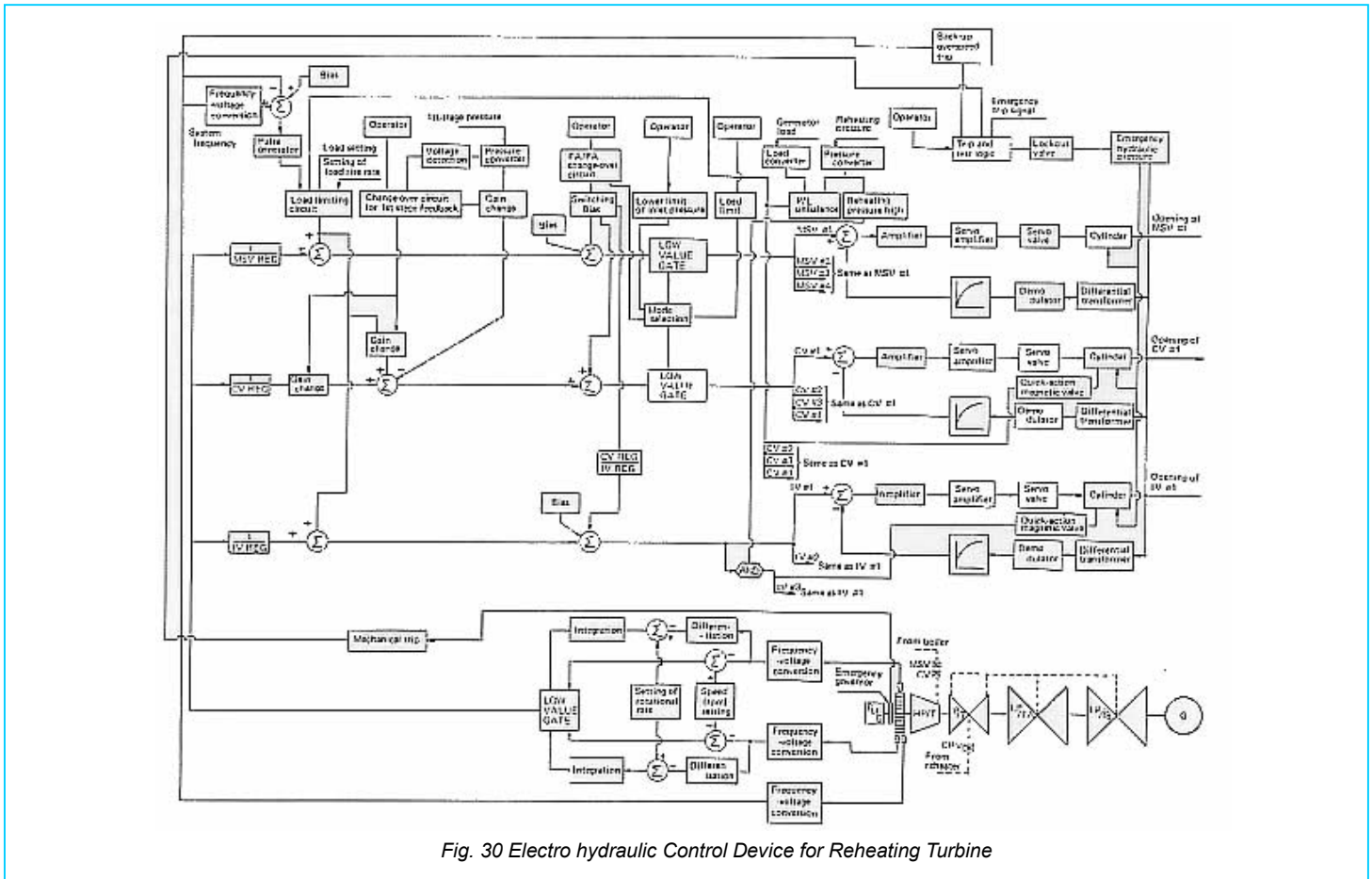


Fig. 30 Electro hydraulic Control Device for Reheating Turbine

The former is connected to the cylinders of the steam control valve, reheat stop valve, and interceptor valve. The electric control circuit, which organically interlocks and operates these valves, incorporates all of the mechanical control devices, which have been incorporated in conventional, large-scaled steam turbines, as well as newly devised mechanisms including an automatic starting device. Hydraulic servomotors are employed for converting electrical signals into hydraulic energy.

Features of the TOSHIBA Electro-hydraulic Control Device are as follows:

- (1) Accuracy in controlling the number of revolutions is within  $\pm 2$  rpm or less.
- (2) The speed-adjusting rate may be selected anywhere from 2 to 7%.
- (3) Since it incorporates an automatic starting device it can increase the rate of turbine speed (rpm) in three steps. Its effectiveness ranges from turbine start-up to the excess revolution test. It can maintain any desired turbine speed.
- (4) Equipped with a speed equalizing circuit and speed matching circuit (for a cross-compound type turbine), it can readily accomplish synchronous connection.
- (5) Provided with two systems of circuits for detecting the rpm, turbine operation can be continued so long as either of the two systems is normal.
- (6) Since all electric and electronic devices are solid-state of either flip-flop type or terminal point type, they have very few soldered parts.
- (7) Equipped with a feedback circuit for first-stage pressure, it can perform linear load control.
- (8) The standard power source is alternating type, and by mounting a PMG on the turbine, precautions against loss of alternating current are provided.

- (9) Switchover from full arc admission to partial arc admission and vice versa can be automatically provided.

### Hydraulic power unit

The hydraulic power unit is composed of a reservoir, pump, motor, filter, accumulator, cooler, heater, and control panel. The pump is an axial piston type. Since two pump systems are provided, should one of them malfunction, turbine operation can be continued during repair of the faulty one for increased reliability of the overall pump system. Accumulator capacity is large enough to hold oil under pressure corresponding to three strokes of all valves. Although large amounts of oil under pressure are needed for starting or stopping the turbine, the amounts required for normal operations are not large; thus, a small pump is provided for meeting normal requirements and energy stored in the accumulator is used when large amounts of oil are required.

### EHC cabinet

The EHC cabinet is an independent type, which houses the analog control circuit, logic sequence, circuits (such as the trip, reset and valve test) circuits, and electronic circuits for the power sources of those circuits.

### Control panel

The control panel, installed on the central panel, houses the operating switches and meters.

### Steam valve actuator (Control pack)

The control pack is composed of a hydraulic cylinder, disk damp valve, shut-off valve, quick-action magnet valve, and servo valve or testing magnet valve. The hydraulic cylinder, a single-acting type, is able to close valves despite a hydraulic pressure drop. Although it is controlled by the servo valve during normal operation, when quick closing of valves is signaled, the quick-action magnet valve is actuated, the disk damp valve is opened to relieve a large amount of oil, and the valves are quickly closed. The servo valve is a two-stage, amplification-type, flow rate controlling servo valve, which converts electrical signals to cylinder-operating hydraulic energy. The stroke of the hydraulic cylinder is fed back to the electric circuit by a differential transformer. To linearize the flow rate characteristic of the valve, the feedback circuit is provided with a nonlinear characteristic. Further, all valves can be tested during operation.

### Emergency device

When turbine speed becomes excessive, an emergency governor actuates a mechanical trip valve to drop the emergency hydraulic pressure applied to the underside of a disk damp valve and to quickly close the valves. A lockout valve, provided as an emergency device, can be tested at the rated speed (rpm) during operation. Two units of master trip magnet valves are provided, each of which can be tested separately. Since these emergency devices employ high-pressure oil, they are installed in a chamber, which differs from that of the lubricating oil, installed on the side of the front bearing stand.

---

## Safety device

### Emergency governor and emergency device

By detecting motion of an eccentric link mounted concentrically with the turbine rotor, the emergency governor device instantaneously closes steam valves such as the main steam stop valve and the reheated steam stop valve. The working speed (rpm) of the emergency governor is adjusted to  $110 \pm 0\%$  of the rated speed. Its resetting speed (rpm) is designed to be over 102% of the rated speed of revolution by taking account of an oil trip test conducted during continuous operation.

The emergency device is a 3-way, valve-type trip device, which operates by detecting the action of the emergency governor. It cuts off feed-oil to the hydraulic system of the safety device and discharges the oil under pressure into the return oil pipe. The working cylinder, tripping pawl and so on are made of quench-hardened, high carbon steel to withstand impulses when the eccentric link is operated.

The governor, the most important safety device for a turbine generator,

must constantly be ready to function when necessary; thus, it is equipped with a lockout device which enables it to be individually tested by the oil trip device. The lockout device, a bypass valve for the hydraulic system of the emergency device, is manufactured integrally with the emergency device.

These safety devices can be operated from the front part of the turbine.

## Backup governor

While testing the emergency device by locking it out, if the turbine should speed up excessively by some accident, the emergency governor (the turbine's last protective device) will not operate. This renders it necessary to provide a device for further backup to the emergency governor. The backup governor is formed integrally with the upper part of the rotating pilot valve of the pre-emergency governor, and when it detects that turbine rotor speed has reached 112%, it stops by operating the working piston of the vacuum trip device. Also, the test button of the back-up governor can trip the working piston of the vacuum trip device when turbine rotor speed has reached 109%, where the emergency device can operate.

## Vacuum trip device and solenoid

When the degree of vacuum of the condenser drops, the exhaust chamber temperature will rise and there is the possibility of the turbine axis becoming out of alignment.

If the degree of vacuum drops to 635mmHg, the vacuum trip device raised an alarm, and if it drops further to 500mmHg, this device—similarly to the emergency device—actuates its 3-way valve to stop the flow of feed-oil to the hydraulic system of the safety device and closes the turbine steam valves.

The vacuum of the condenser is led to the bellows chamber and converted to motion of a bellows made of phosphor bronze. This motion is enlarged by the pilot valve and the hydraulic piston, and by disengaging the 3-way valve pawl, actuates the 3way valve. This valve can also be actuated by the solenoid or the trip piston of the back-up governor. The standard excitation circuit for the solenoid incorporates all electrical stop signals of the breaker for generator, boiler trouble, protective device against thrust, and so on.

## Protective device against thrust

This device consists of a differential piston-type probe, which follows up the thrust collar position, the tripping pilot valve connected to this probe, and the measuring panel. Two hydraulic relays are mounted on the pilot valve ferrule, adjusted to operate when the thrust collar has moved 2mm from its position during normal operation. Contacts of the hydraulic relays are connected to the turbine trip circuit. The pilot valve ferrule position relative to pilot valve is varied by the measuring panel handle, so it is possible to measure the thrust

collar position during operation by changing the pressure relay circuit over to the test lamp circuit by pulling the test lever. The pilot valve ferrule and the pilot valve are made of nitrided steel to prevent their malfunctioning caused by wear.

## Trip device for main shaft oil pump

Similarly to the main shaft oil pump, the governor and the emergency governor are driven by the front spindle of the turbine. Thus, should the front spindle break down, both the governor and the emergency governor is unable to operate, involving serious hazards affecting the turbine. For this reason the main shaft oil pump is provided with a trip device.

The vacuum trip device is equipped with a trip piston to detect hydraulic pressure upstream from the check valve for the main shaft oil pump. If the discharge pressure of this pump drops below a certain value, the turbine is tripped by this device.

## Initial steam pressure regulator

The standard large-capacity turbine is provided with this device. When the main steam pressure of the boiler has dropped for a certain reason, this device limits the amount of steam entering the turbine and expedites recovery of the steam pressure.

Main steam pressure is converted to air pressure and fed to the bellows. After being amplified by the hydraulic system, this air pressure is caused to act upon the control device for steam control valve.

In addition, a lock device is provided to put this device out of operation at turbine start-up and during operation under varying pressure.

## Main steam stop valve

The main steam stop valve, the final control element of the safety device, must instantaneously shut off high-pressure, high-temperature steam. Accordingly, special consideration is given to its engineering material and structure. The valve body is made of Cr-Mo steel casting whose creep value at high temperature is high. The valve and valve seat are made of Cr-Mo-V steel forging whose high-temperature impact value is high. The valve and valve stem provide perfect spherical surfaces, and their contact surfaces are deposited with stellite and ground. The greatest technical difficulty that a high-temperature, high-pressure valve encounters is the obstruction of its stem caused by sticking.

To avoid this discrepancy, that part of a turbine pierced by the valve stem is provided with a 0.35 to 0.75mm gap, and the valve stem and the sleeve are hardened by nitriding process. Steam leakage through this gap is completely prevented by a back sheet coated with stellite and mounted on the upper part of the valve stem.

The hydraulic cylinder has a single-acting piston (equipped with an enclosed spring) and two piston rings. The main steam stop valve is provided with a relay damp valve which, by detecting any pressure drop of the hydraulic system of the safety device, instantaneously discharges oil (present in the lower part of the piston) under pressure into the return oil pipe. The relay damp valve is a 3-way valve actuated by hydraulic pressure of the safety device. When this pressure drops, it is switched over and discharges oil (present in the lower part of the piston) under pressure into its upper part. Accordingly, diameter of the return oil pipe can be rendered comparatively small. The hydraulic cylinder is designed so that a dashpot is formed between its bottom part and the piston to restrict impact when the valve is closed.

The standard hydraulic cylinder is equipped with a device to test its action even during operation. For this purpose, it is provided with a testing pilot valve operated by an air piston or diaphragm actuated by compressed air supplied via the magnet valve for remote testing. Since dry air for air piston control is employed, the slide surface of the piston cannot be lubricated; thus, the piston ring is made of Teflon.

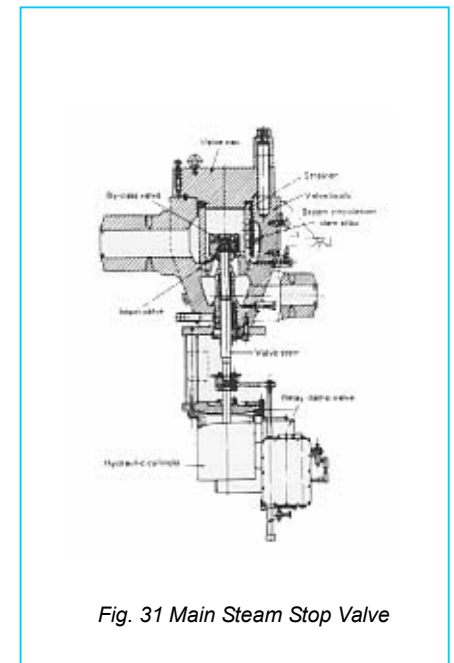


Fig. 31 Main Steam Stop Valve

## Interceptor valve relay and dashpot breakdown link

Since reheater system steam in the reheating turbine has sufficient energy to increase turbine speed to a hazardous degree, to preclude this danger, a dashpot breakdown link and an interceptor valve relay are installed on a lever mechanism located between the speed relay of the governor and the interceptor valve.

The dashpot breakdown link is a so-called dashpot mechanism consisting of a cylinder, piston (kept unidirectional depressed by a spring in the cylinder), and a small orifice to by-pass the piston. The piston is connected by the speed relay and the cylinder, via the interceptor valve relay to the interceptor valve lever. During normal operation, the piston (kept depressed by the spring) is in a pushed-up position in the cylinder. When turbine speed (rpm) begins to increase by degrees, the piston is depressed by the spring, and when the turbine speed attains 101%, the piston contacts the cylinder, and from this time on it functions as a fixed body and begins to close the interceptor valve. If turbine speed suddenly increases, such as when a heavy load is shut off,

oil enclosed in cylinder cannot escape through the small orifice; as a result, the link immediately functions as a fixed body and begins to close the interceptor valve. This eliminates a delay in setting, which allows the speed (rpm) to increase by 1% before the interceptor valve begins to close when a heavy load is shut off.

By means of the pilot valve (installed between the dashpot breakdown link and interceptor valve) and the oil cylinder, the interceptor valve relay expands movement up the dashpot breakdown link into a force and travel adequate to operate the oil cylinder mechanism of the interceptor valve. This relay is equipped with a return cam mechanism, which linearizes the steam flow characteristic of the interceptor valve in relation to movement of the speed relay. Since the dashpot breakdown link and the interceptor valve relay can open the interceptor valve before the steam control valve begins to open, the interceptor valve is nearly fully open when the steam control valve begins to open. Then, both valves are shut successively; however, the turbine attains its normal, instantaneous, maximum speed (rpm) increase. Then turbine speed begins to drop, and at about 107% speed, the interceptor valve begins to reopen, and via a no-load steam amount, it discharges the steam of the reheater.

When turbine speed has dropped to about 107%, the steam control valve begins to reopen, and at a speed slightly higher than 105%, no-load operation is effected. Because the valves are opened successively in this manner, a run-back device (installed on a turbine equipped with a pre-emergency governor) becomes unnecessary.

## Transmitter/receiver

Another method of transmitting signals from the governor to the interceptor valve is by utilizing a hydraulic device.

By using a hydraulic transmitter, dashpot breakdown link strokes are converted to hydraulic signals, converted into strokes by a receiver and transmitted to the interceptor valve. Through action of its double-spring mechanism, the hydraulic transmitter nonlinearizes the relationship between the stroke and the hydraulic pressure to compensate for the flow rate characteristic of the interceptor valve.

## Combined reheat valve (interceptor valve and reheat steam stop valve)

By installing the reheat valve in the vicinity of the intermediate-pressure turbine inlet, located on either side of the lower half of the center of the high-pressure casing, excess speed of the turbine due to reheated steam is prevented. The interceptor valve is a balancing sleeve type; the reheat steam stop valve is a globe type. Installed on a valve body, they use the valve seat in common.

Irrespective of the position of the reheat steam stop valve, the interceptor valve can operate the full stroke. A steam strainer is installed around it to prevent foreign matter discharged by the boiler from entering the turbine. The valve is fully open during normal operation, and by contacting the steam to the guide to form a back sheet, both the stem and the guide prevent steam leakage from this part. This permits a wide gap to be left between the valve stem and sleeve, minimizing the possibility of valve stem seizure.

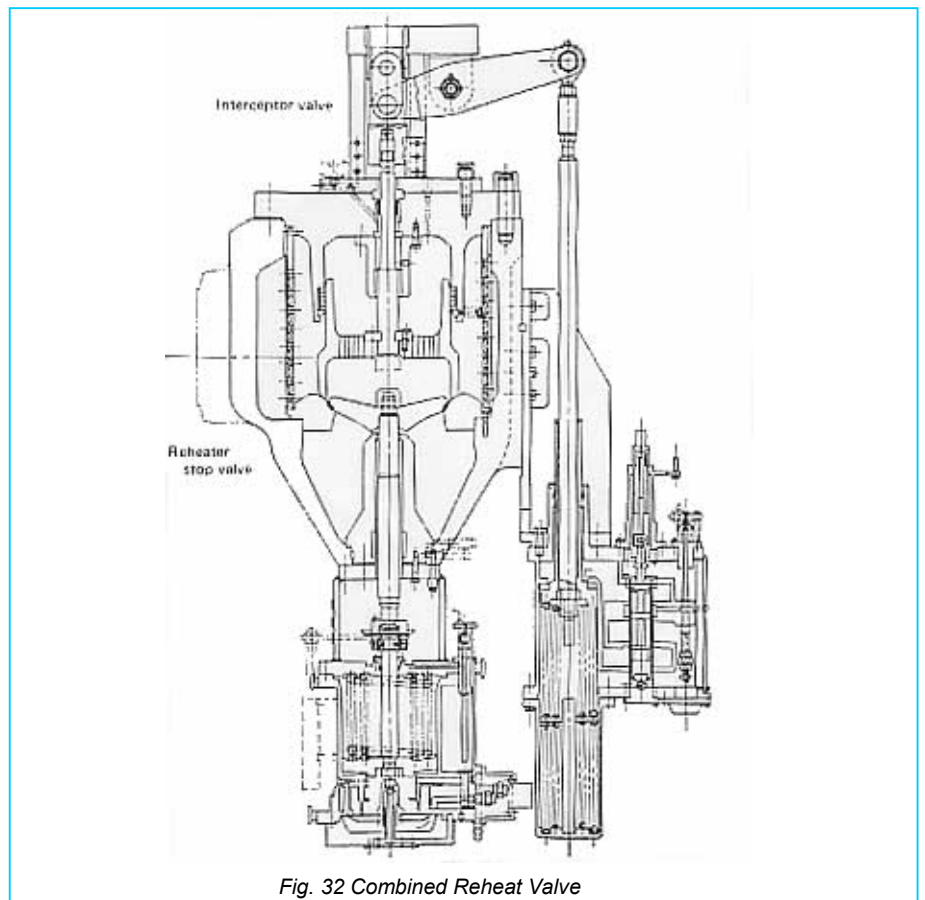


Fig. 32 Combined Reheat Valve

The interceptor valve is opened by hydraulic pressure developed by the oil cylinder installed by its side, and is closed by spring force. Also, a jacking device is provided which can close the interceptor valve when the turbine is at rest, when testing the safety valve for the reheat steam pipe and other parts.

The reheat steam stop valve is the No. 2 safety device against turbine excessive speed caused by reheated steam. When the emergency device operates, it closes quickly by spring force and shuts off the inflow of steam.

It is controlled initially by a 3-way, valve-type emergency trip device installed on the front bearing stand and secondly by a relay damp valve installed in the oil cylinder for the reheated steam stop valve.

When the emergency trip device or the vacuum trip device operates,

hydraulic pressure acting on the underside of the relay damp valve is removed, and the relay damp valve opens and discharges oil under the piston of the reheated steam valve into the upper side of the piston. This device can quickly shutoff the reheated steam stop valve by using no more than the two small-diameter oil tubes lead through the protective pipe.

Each valve incorporates limit switches used for interlocking the opening indicating lamp, generator shut-off devices and valve testing device. The reheated steam stop valve is tested by pressing the TEST push button to operate the air valve. However, an interlock is provided so that the two valves cannot be tested simultaneously, and so that a test may be conducted only when the interceptor valves on the same side are closed; consequently, no manual testing device is provided.

A testing device employing electric power, pneumatic pressure, and hydraulic pressure is provided for the interceptor valve. By depressing the push button located in the vicinity up the turbine, lagging tests on one of the valves for a totally closed condition may be conducted even during load operation. Also, by pressing the valve testing switch (installed in the central control room, a test may be conducted in connection with the corresponding reheated steam stop valve.

## Lubricating device

To supply each bearing with lubricating oil and each hydraulically operated control device with control oil, an oil reservoir of sufficient capacity is provided. The oil reservoir is equipped with an oil cooler, auxiliary oil pump, turning oil pump, emergency oil pump, booster pump, vapour extractor, and other devices. The main oil pump, a centrifugal pump direct-coupled with the high-pressure turbine rotor, is installed in the front bearing stand to supply various parts with lubricating oil or control oil. This type of pump feature extremely limited variation in its discharge pressure despite variations in its discharge amount. Further, the oil feed pipe is run through the oil discharge pipe to prevent oil from leaking out. It is designed to that the oil is run through oil cleaner in the reservoir during turbine operation to remove water and foreign matter that have infiltrated the oil.

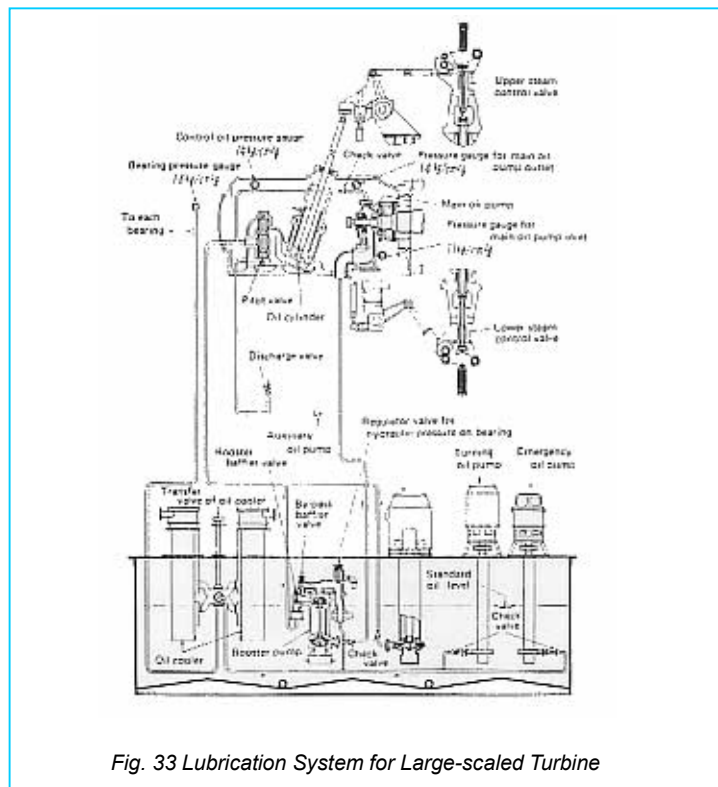


Fig. 33 Lubrication System for Large-scaled Turbine

# STEAM TURBINE AUXILIARY EQUIPMENT

Along with steam turbines, TOSHIBA has been designing and producing their auxiliary equipment, a number of which have been delivered to central thermal power generation plants, nuclear power generation plants, and various industrial power stations.

To efficiently operate a steam turbine, it is necessary that each of its auxiliary

equipment functions well, provides reliability, and harmonizes with the overall plant system. Turbine auxiliary equipment are designed and manufactured by TOSHIBA are based on comprehensive studies of the overall plant system.

Principal auxiliary equipment consists of

condensers, air ejectors, feed-water heaters, deaerators, moisture separators, evaporators, and heat exchangers for cooling equipment. These auxiliary equipment are produced by using TOSHIBA's outstanding manufacturing techniques based on our years of development, research, and experience in actual manufacturing processes.

## Condensing equipment

The condensing equipment is installed for condensing turbine. By decreasing turbine backpressure, it raises turbine cycle efficiency, recovering at the same time this condensate for reuse in the turbine cycle.

### Condenser

TOSHIBA has been producing a wide variety of condensers-large and small-for many years.

Although arrangement of the cooling tubes of TOSHIBA's condensers differ according to their size, our typical condenser is a double-steam-flow type whose construction and cooling tube arrangement are shown in Figs. 34 through 37.

### Features

Performance and structural features of the condenser illustrated in Fig. 35 are as follows:

1. The condenser is rectangular, a shape which can efficiently use the space of the turbine pedestal.
2. A tube sheet is divided into two parts-upper and lower so that turbine exhaust steam flows into two portions, one flowing into the upper tube nest and the other into the lower tube nest. This increases the area of the steam lane in the tube nest and thins the passing layer, improving the steam inflow condition. Therefore, pressure loss within the tube nest is limited, improving condenser performance.
3. Since the turbine exhaust steam is led to the lower tube nest through the steam flow path with a large area, steam pressure at the lower tube nest inlet differs little from that at the upper tube nest inlet. The limited pressure loss within the tube nest prevents the condensate from being undercooled. Moreover, when condensate from the upper tube nest flows outside the tube nest, by flowing on the divider plate between the upper and lower tube nests, it contacts exhaust steam flowing through the central lane,

And its air is removed. Condensate from the lower tube nest contacts steam flowing in from below, and its air are removed. Thus the condenser's deaerating ability is good.

4. Since the hot well is roomy, adjustment of the condensate water level is stabilized.

For a condenser with a large cooling area and with many cooling tubes contained within a tube sheet, the tube arrangement is as shown in Fig. 36. This tube arrangement, although based on the same concept as that in Fig. 35, is designed to have a larger inflow area by flowing steam from around the entire periphery of the tube nest to avoid an excessive inflow speed of steam caused by its high flow rate.



Fig. 34 Condenser Structure

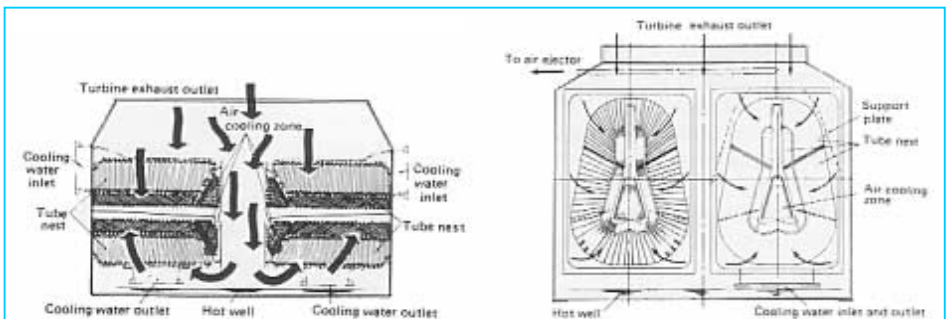


Fig. 35 Diagram of Steam Lane in Condenser

Fig. 36 Diagram of Steam Lane in large-scaled Condenser

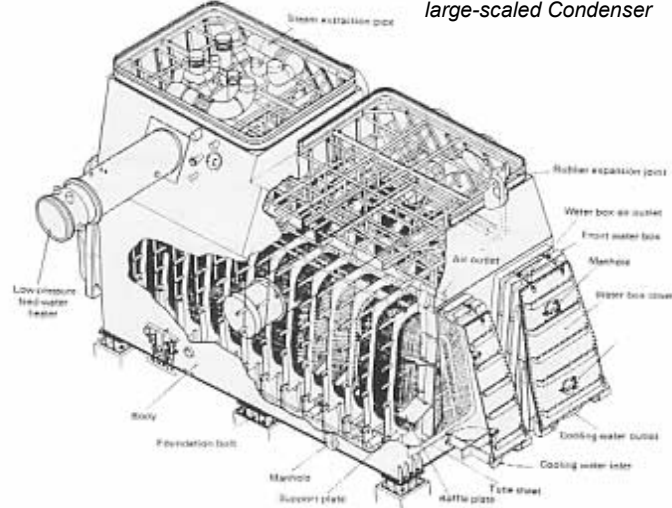


Fig. 37 Diagram of Condenser

## Performance

The condenser is designed on the basis of the approximate yearly average temperature of cooling water and the degree of vacuum of 722mmHg when the turbine develops its rated output. It is usually designed so that the turbine can perform safe operation at its rated output despite the maximum cooling water temperature. However, the condenser design may conform to the actual condition of the power generation plant where the turbine is installed.

## Structures and engineering materials of various condenser parts

### 1. Condenser body

The condenser body is of welded steel plates whose construction possesses adequate mechanical strength to withstand external pressure. Large condenser bodies are conveyed in sections and assembled at their installation sites, while the condenser body is usually shop-erected and minutely inspected before being shipped. After assembly, it is filled with water containing fluorescent dye and tested for leakage.

### 2. Support plates

Support plates, made of rolled steel plates, are carefully drilled for fitting in cooling tubes. The number and position of the support plates are chosen so that they can prevent the cooling tubes from vibrating during operation. They also serve to reinforce the condenser shell so that the shell strength is adequate to withstand external pressure.

3. Tube sheets  
The tube sheets, usually made of naval brass sheets, are drilled with special care to receive tube ends. Both ends of a cooling tube are generally expanded into a tube sheet and fastened.

### 4. Water boxes

Water boxes are made of cast iron or steel plates applied with an anticorrosive lining. A large one is equipped with a manhole and a small one with an inspection hole. A water box is subjected to a hydraulic test by using a testing pressure 0.4kg/cm<sup>2</sup> higher than its design pressure.

### 5. Cooling tubes

Many of the cooling tubes are aluminum brass series tubes; however, cuprous nickel or titanium tubes are sometimes used for the air cooler section.

## Barometric jet condenser

In addition to surface cooling-type condensers, TOSHIBA manufactures direct contact jet condensers (barometric or low-level jet condenser). This type of condenser is generally used for geothermal power plant in which steam recovery need cause no concern.

## Construction

The barometric jet condenser, shown in Fig. 38, has a water tray with a number of slits, through which cooling water is sprinkled, and steam is cooled and condensed while in direct contact with the cooling water. The condensed steam and the cooling water are mixed together and discharged from the condenser bottom. To isolate it from the atmosphere, it is installed to obtain an adequate hydrostatic head. The trays and other principal parts are made of stainless steel, and the main body and the shell inner surface are lined depending on properties of the fluid.

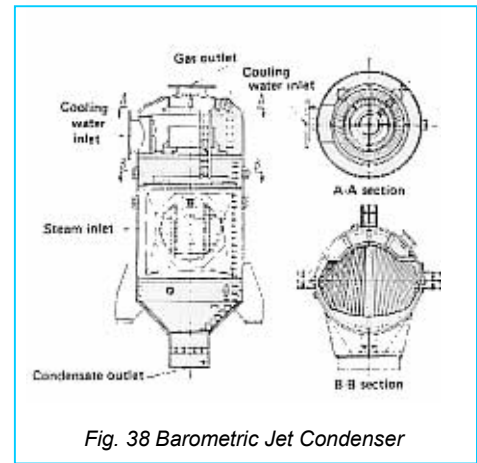


Fig. 38 Barometric Jet Condenser

## Air ejectors

The air ejector is a device for discharging to the atmosphere any air which leaks into the condenser. TOSHIBA produces steam-jet air ejectors of reliable performance and simplified construction.

### Types

The standard product of the steam-jet air ejector for condenser is a two-stage, twin-element type; however, a one-element-type standard product is also available.

In these standard types, the two-stage ejector is arranged with the intercooler and the after cooler, which are common to the two elements. The standard types have the capacities listed in Table 2. The air ejector type is selected according to the amount of condensed water produced by condensers.

The air ejector, employed in nuclear power generation plants using boiling water-type reactors, has the capacity to extract oxygen and hydrogen gases from the turbine exhaust in addition to air leaking into the condenser.

Working steam consists of turbine main steam or boiler auxiliary steam. The standard working steam pressure is 14kg/cm<sup>2</sup>.

## Performance

The two-stage twin element air ejector can extract a specified amount of dry air with its single element and maintain a vacuum of 735mmHg.

This air ejector is designed to extract saturated steam (simultaneously and along with the air) from the condenser 2.3 times the volume of air.

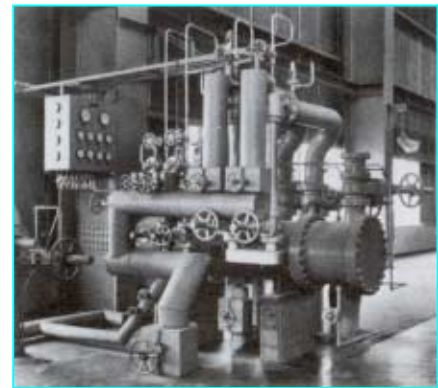


Fig. 39 Air Ejector

Table 3 List of Standards for Two-stage, Twin-element Steam-jet Air Ejector

Nomenclature	Amount of water condensed by condenser (t/h)	Amount of air extracted (kg/h)	Amount of steam extracted (kg/h)	Total amount of extraction (Kg/h)	Degree of suction vacuum (mmHg)	Steam consumption (kg/h)	Nominal diameter of air pipe (mm)	Minimum amount of cooling water (T/h)	Area of 1 <sup>st</sup> stage cooler (m <sup>2</sup> )	Area of 2 <sup>nd</sup> stage cooler (m <sup>2</sup> )
AEF6	0-11.3	6	14	20	735	81.5	80	3.4	5.0	2.0
AEF8	11.3-22.6	8	19	27	735	109	100	6.8	7.0	3.0
AEF10	22.6-45.4	10	24	34	735	136	100	9.1	8.0	4.0
AEF15	45.4-113	11.5	36	51.5	735	204	150	20.4	12.0	5.0
AEF20	113-226	20.5	48	68.5	735	272	150	27.2	16.0	6.0
AEF25	226-454	25.5	59.5	85	735	340	200	34	19.0	8.0
AEF30	454-907	30.6	71.5	102.1	735	408	200	91	25.1	10.2
AEF40	907-1814	40.8	95.3	136.1	735	544	200	170	33.4	13.9
AEF50	1814 or more	51.0	119.0	170.0	735	680	200	272	41.8	16.7

## Construction

Fig. 39 illustrates a typical air ejector. The cooler is divided into the intercooler and the after cooler, which are mounted on the outlets of two stages of the ejector respectively. It is designed to condense steam.

The second-stage ejector extracts air with a small amount of saturated steam, or discharges it into the atmosphere.

The ejector body is composed of the nozzle, diffuser, and extraction chamber. High-velocity steam jets from the nozzle entrain the air. The diffuser raises the entrained air pressure.

The materials for these components differ according to the condition of the steam used. The nozzle is usually made of stainless steel, while the extraction chamber and diffusers are of steel castings or steel plates.

## Starting air ejector and priming air ejector

When starting the turbine, a starting air ejector is employed to rapidly discharge a large amount of air from the condenser, and a priming air ejector is used to prime the cooling water system of the condenser.

Such an ejector is a single-stage, steam-jet air ejector type; descriptions on standard products of this type of air ejector are listed in Table 3.

**Table 4 Lists of Standards for Single-stage Ejectors**

Max. amount of condensed water from condenser (t/h)	Nomenclature	Nominal diam. Of suction pipe	Steam consumption (kg/h)	* Volume of air extracted (kg/h)
35 or below	SEF 3	80	340	306
35-115	SEF 4	100	680	612
115-340	SEF 6	150	1,450	1,308
340-907	SEF 8	200	2,040	1,835
907 or more	SEF 8A	200	2,720	2,450

\* Volume of air extracted is values at suction vacuum of 379mmHg.

## Feed-water heaters and deaerators

The feed-water heater heats the boiler feed water by using extraction steam from the turn to improve turbine cycle efficiency, and the deaerator removes oxygen dissolved in and carbon dioxide gas present in the boiler feed-water to protect the boiler against corrosion. TOSHIBA's products include low- and high-pressure feed-water heaters, deaerators, and drain coolers.

### Low-pressure feed-water heater High-pressure feed-water heaters

The largest of TOSHIBA's surface-heating-type, feed-water heaters ever produced has a heating area of 2,350M<sup>2</sup>; in some of the highest pressure types, the maximum working pressure on the water box side attains 351.5kg/cm<sup>2</sup>. The low-pressure and high-pressure feed-water heaters may be horizontal or vertical type. Fig. 41 is an example of the internal construction of a horizontal, high-pressure feed-water heater.

To improve turbine cycle efficiency as much as possible, occasionally a feed-water heater is equipped with a desuper-heating section and a drain cooling section in addition to a condensing section, with only a drain cooling section, or with only a condensing section. In high-pressure feed-water heaters, the higher the pressure and the larger the capacity, the higher the required wall thickness of the water chamber. The water chamber shown in Fig. 74 adopts a spherical water chamber and is designed to reduce wall thickness and thermal stress. This type of heater is equipped with a manhole to facilitate inspection and maintenance.

### Performance

In feed-water heaters, the difference between the saturation temperature corresponding to the heating steam pressure and the feed-water outlet temperature is termed the "terminal temperature difference," considered a yardstick for the performance of feed-water heaters. The smaller this difference, the lower the pressure of steam extracted from the turbine may be

to heat the feed-water to the same temperature. This improves turbine cycle efficiency, but increases the heating surface area of the heater.

A feed-water heater equipped with a desuperheating section may take a negative terminal temperature difference; that is, the feed-water outlet temperature is higher than the saturation temperature of the heating steam.

## Construction

### 1. Heater proper

The heater proper is of welded rolled steel plates. If the heating temperature is high, 0.5% Mo steel plates are used. In the low-pressure type, the water chamber is fastened to the heater with flanges or welded to the heater body; in the high-pressure and high-temperature type, they are welded together for complete air tightness.

### 2. Tube plates

Tube plates of the low-pressure type are made of steel plates while those of the high-pressure type are made of steel forgings formed integrally with the water chamber. They are drilled with special care to receive the heating tubes.

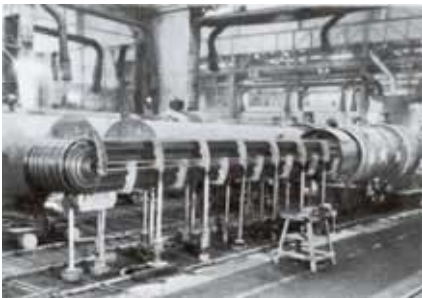


Fig. 40 Feed-water Heaters being assembled

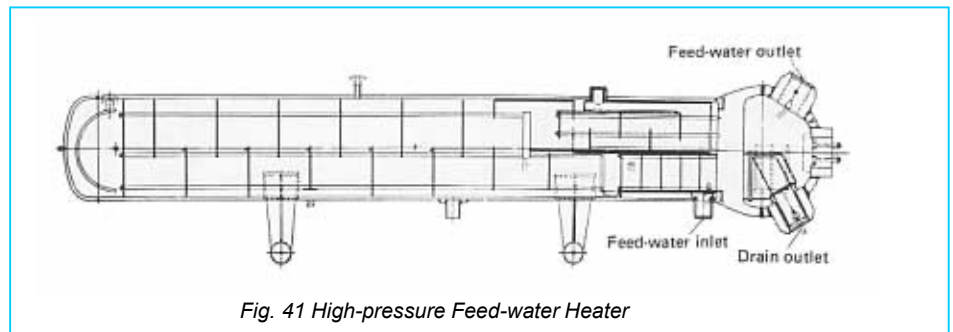


Fig. 41 High-pressure Feed-water Heater

### 3. Water chambers

In the high-pressure-type heater, the water chamber is specially constructed to withstand high-pressure feed-water, as shown in Figs. 41 and 42. The construction shown in Fig. 42 is a dia phragm type, in which high-pressure feed-water is held-via an airtight plate by a thick lid, supported by a shear piece inserted into the inner wall of water chamber. This type of water chamber is particularly employed for small-scaled feed-water heaters.

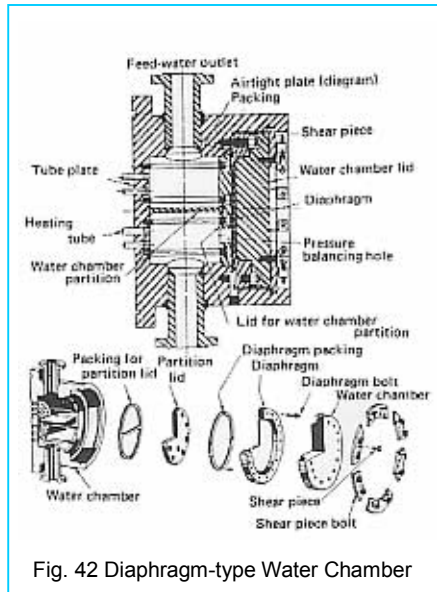


Fig. 42 Diaphragm-type Water Chamber

### 4. Heating tubes

Heating tubes are U-shaped seamless tubes. For low-pressure heaters, aluminum brass tubes, stainless steel tubes, or carbon steel tubes are used. For high-pressure heaters, copper nickel tubes, 70 - 30 nickel copper (Monel metal) tubes, or carbon steel tubes are used. In low-pressure heaters, heating tubes are fastened to the tube plate by being expanded into it. In high-pressure heaters, they are expanded into or welded to the tube plate to eliminate leakage.

Materials for heating tubes are selected by fully considering the boiler type and the method of treating the feed-water.

### Deaerators

TOSHIBA deaerators are a pressure/tray type. Feed-water is sprayed from a jet valve at the top of the deaerator, and while it successively drips through the trays, it is deaerated by heating steam.

Fig. 43 is an example of a deaerator for a large-capacity turbine generator. In some of the recently produced, large-size deaerators, the amount of water treated reaches 3,150 m<sup>3</sup> /h and the deaerating ability accomplishes a dissolved oxygen amount of less than 0.005cc/l.

In addition to deaerators for power stations, TOSHIBA produces industrial deaerators, whose deaerating ability can be designed at less than 0.03, 0.01, or 0.005cc/l of dissolved oxygen according to the user's request.

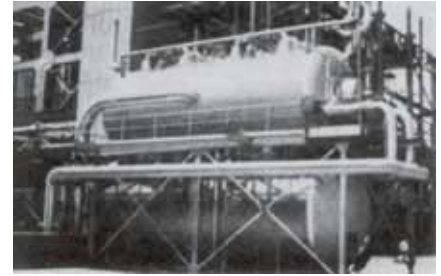


Fig. 43 Deaerator

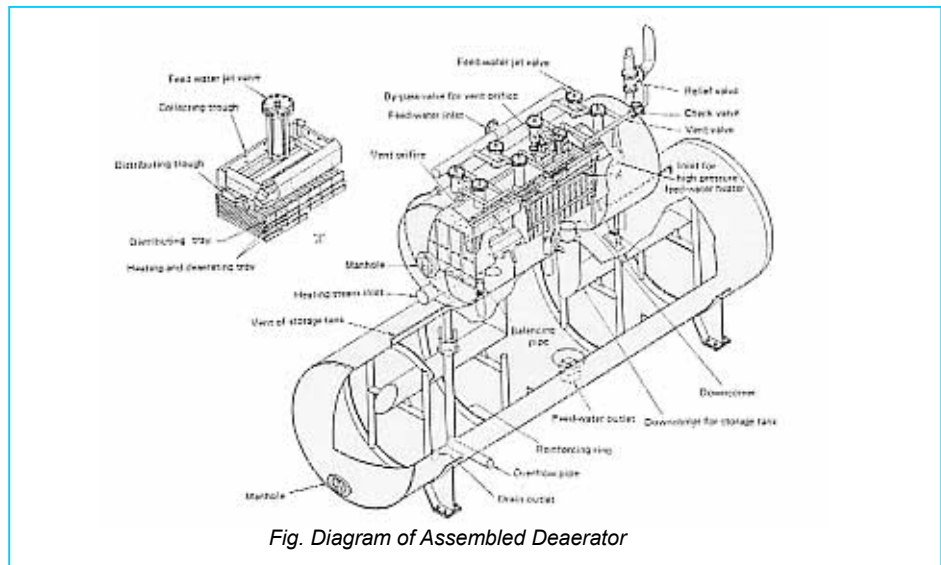


Fig. Diagram of Assembled Deaerator

### Heat exchangers

TOSHIBA produces a variety of heat exchangers and also a wide variety of heat exchangers for cooling systems of power stations. Some of the large-scaled ones have a cooling area of 2,200m<sup>2</sup>.

### Moisture separator

The moisture separator, installed at the central part of the expansion stage of a nuclear power steam turbine, is for removing the moisture content of steam, preventing the low-pressure part from being eroded by drain, and improving turbine efficiency.

Fig. 45 is an example of this moisture separator. By means of the baffle-board, distributor, and moisture-separating element, steam wetness is reduced from 12.5% at the inlet to less than 2% at the outlet, while steam pressure loss is quite limited.

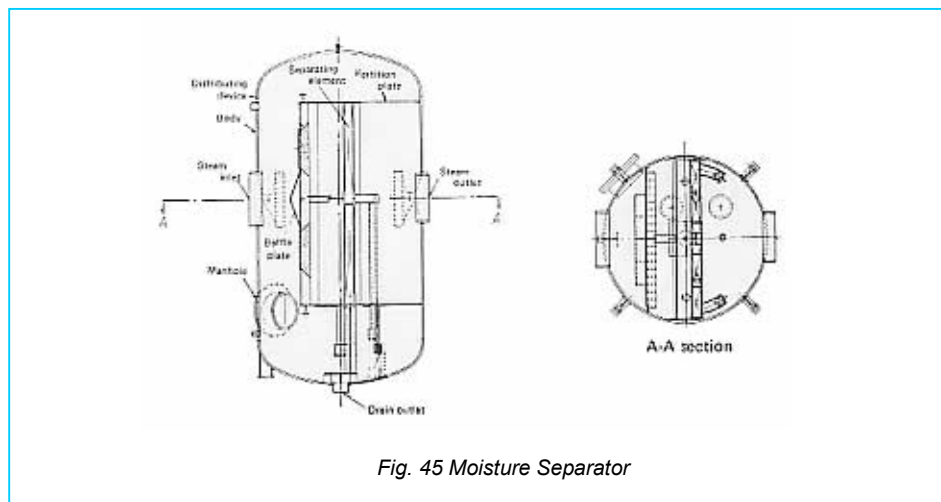


Fig. 45 Moisture Separator

## Controls for auxiliary equipment

Over recent years, power stations have tended to centralize the control and monitoring of various devices at their central control rooms. On the other hand, various devices are always operated under designed conditions and controlled for belt efficiency. For this reason, various devices and their parts requiring constant monitoring are indicated or recorded in the control room and the deaerator, water level of various tanks, flow rate of various systems, internal pressure, temperature and so on of devices required for monitoring are monitored to the control room or are recorded. Other devices and their parts that must be controlled (such as the water level of each feed-water heater, deaerator pressure, and temperature of auxiliary steam for deaerator) are automatically controlled by indicating controllers of the field. In this manner, various devices can be safely operated under specified conditions for attaining top efficiency by the least possible number of operators.

The control method is often pneumatic, and data transmitted to the central control room by pneumatic pressure and fluids of direct detectors are not introduced into indicating controllers.

The indicating controllers, by considering field operational condition, are of proportional control action (P), proportional plus integral control action (PI), or proportional plus integral plus derivative control action (PID) type.

They are operated stably despite disturbances while in operation.

### Water level control

The water level of the condenser, feed-water heater, deaerator, and various tanks must be maintained at a certain level. The water level is detected by a differential transmitter, and the transmitted pneumatic pressure is conveyed to the indicating controller. Another method employs a displacement type, which detects the water level by a float whereby variations in the water level is conveyed to the indicating controller. Pneumatic pressure transmitted by the indicating controller operates a regulator valve to maintain a certain water level.

Also, it is possible to remote-indicate data by obtaining pneumatic pressure transmitted by the differential pressure transmitter.

### Pressure control

Equipment sections requiring pressure control (such as the heating steam system for deaerator), which transform steam extracted from the turbine into use detection mechanisms composed of pressure transmitters (based on a Bourdon tube or bellows) and pressure indicating controllers, and the pneumatic pressure transmitted by indicating controllers operates the regulator valves. Also, pneumatic pressure transmitted by indicating controllers can perform remote indication.

Pressure is controlled by detecting pressure of the primary side of a regulator valve or by detecting that of its secondary side.

### Temperature control

When using superheated steam by reducing its temperature, as in the case of a temperature reducing device installed in a heating steam system for a deaerator, or a steam transmission system of a factory, the steam temperature is controlled by detecting the secondary side temperature of the temperature reducing device.

The temperature detecting section utilize a thermocouple, thermoresistor, expanding mercury-type or expanding gas-type detector. An appropriate detector is selected according to the temperature used and the condition of the detecting section. Temperatures detected are converted to pneumatic pressure by a temperature transmitter or a temperature regulator to control temperature by operating the cooling water regulator valve in the temperature control system. Also, pneumatic pressure transmitted by the temperature transmitter performs remote indication.

### Control valves

Many control valves operated by the pneumatic pressure transmitted by the indicating controller are equipped with a diaphragm in their drive part, and they function by pneumatic pressure acting upon the diaphragm. If a large driving force is required because of the valve's unbalancing force, a piston-type driver is employed, and the piston functions by using high pneumatic or hydraulic pressure.

The control valve is usually equipped with a valve positioner, which incorporates a feedback mechanism to rapidly operate the valve in response to variations in pneumatic pressure transmitted by the indicating controller, thus hastening determination of the regulator valve position. The valve positioner makes it also possible to use a regulator valve as a divided range.

Since the control valve can vary the flow rate characteristic by its inner valve shape, appropriate flow rate characteristics may be chosen according to operational conditions.

### Alarm switch

As alarm switches for the water level, pressure, and temperature, provided are level, pressure, and temperature switches.

Many auxiliary devices are equipped with level alarm switches, either a high- or a low-level switch or both, and an alarm is raised when the in-device water level rises above or drops below the specified level.

Occasionally, pneumatic pressure transmitted by various transmitters causes the pressure switch to operate as a level, pressure, or temperature alarm.

A mercury switch is often used as the electrical contact of a float switch, and a mercury switch or snap-action switch is used as a pressure switch.

These switches are also used for automatic start and stop of a pump. A magnet valve is sometimes installed in a pneumatic tube for a regulator valve, and by energizing or de-energizing the solenoid by switch (to operate the magnet valve), an on-off type regulator valve is operated. Further, a magnet valve is occasionally installed in a pneumatic tube between an indicating controller and a regulator valve for opening or closing the transmission circuit of an indicating controller.

**Overseas Office:**

Mexico City, Caracas,  
Rio de Janeiro, Buenos Aires,  
London, Wien, Berlin,  
Hong Kong, Bangkok, Manila,  
Jakarta, Sydney, Wellington,  
Johannesburg, **Beijing**

**Toshiba International Corporation:**

San Francisco, Houston,  
Vancouver

**Toshiba International Corporation**

**Pty. Ltd.:** Sydney

**Toshiba International Company**

**Limited:** London

# **TOSHIBA**

**TOSHIBA CORPORATION**

1-6, UCHISAIWAICHO 1-CHOME, CHIYODA-KU.

TOKYO, 100, JAPAN

TELEX: J22587 TOSHIBA CABLE: TOSHIBA TOKYO

PHONE:(03)3597-206B

- For further information, please contact your nearest Toshiba Liaison Representative or international Operations-Producer Goods.
- The data given in this catalog are subject to change without notice.