

TOSHIBA

110MW GEOTHERMAL STEAM TURBINE



110MW

GEOHERMAL STEAM TURBINE

Introduction

The 10th geothermal steam turbine manufactured by Toshiba Corporation represents the geothermal steam turbine for Unit 11 at the Geysers Power Plant, Pacific Gas and Electric Co., U.S.A. This turbine with 110MW rated output started commercial operation in May 1975. In addition to this turbine, both turbines for Unit 12 (110MW) and Unit 14 (114MW) were shipped from Toshiba Works. Moreover, two turbines with 124MW rated output for Unit 16 and Unit 17 at the Geysers are being manufactured by Toshiba.

These turbines boast the world's largest capacity of a single geothermal steam turbine. We have supplied six 55MW turbines (from Unit 5 through Unit 10) to the Pacific Gas and Electric Co., contributing-together with the new 11th turbine-to supplying power to the San Francisco area. Table 1 shows the specifications of geothermal turbines manufactured by Toshiba. The geothermal steam turbine is, so to speak, a thermal turbine in which mother nature plays the role of a boiler. However, since geothermal steam

contains gaseous impurities in the volume of several percents, geothermal steam turbines require much more technical consideration than do thermal steam turbines, involving such phenomena as corrosion of turbine component parts, and the accumulation of and erosion by solid substances in the steam paths. The following covers the structural and control devices features of the Toshiba 110MW geothermal steam turbine. This turbine reflects the results of our exhaustive research and development activities as well as our rich experience gained by actual operation of turbines.

Table 1 Specifications of geothermal turbines manufactured by TOSHIBA

Where installed	Japan		Mexico	Philippines	U.S.A.			
Purchaser	Japan Metals and Chemicals Co., Ltd.	Tohoku Electric Power Co., Inc.	Comision Federal de Electricidad	National Power Corporation	Pacific Gas and Electric Co.			
Station	Matsukawa	Kakkonda	Cerro Prieto	Tiwi	Geysers			
Rated output (kW)	22,000	50,000	37,500	55,000	55,000	110,000	114,000	124,000
Speed (rpm)	3,000	3,000	3,600	3,000	3,600	3,600	3,600	3,600
Throttle pressure (kg/cm² g)	3.5	3.5	5.27	5.68 /0.76	7.04	7.04	7.04	6.95
Throttle temperature (°C)	147.4	147.4	160.0	162.3 /115.6	179.4	179.4	179.4	169.4
Vacuum (mmHg abs.)	110	100	89	100	102	102	102	76
Type of turbine	SCSF	SCDF	SCDF	SCDF	SCDF	TC4F	TC4F	TC4F
No. of turbine stages	4	4x2	6x2	5x2	6x2	6x4	6x4	6x4
No. produced	1	1	4	4	6	2	1	2
Operation started (month and year)	10/66 (Operated at 20,000 kW until April 1973)	5/78	#1 8/73 #2 4/73 #3 (1/80) #4 (10/82)	#1 5/76 FOB #2 8/76 FOB #3 (9/77) FOB #4 (12/77) FOB	#5 9/71 #6 9/71 #7 7/72 #8 9/72 #9 9/73 #10 11/73	#11 5/75 #12 (2/79)	#14 (2/80)	#16 (1/80) FOB #17 (5/19) FOB

Planning Specifications and Steam System

Planning specifications

The planning specifications for the 110MW turbine are as follows:

Type: Tandem compound, four-flow condensing turbine

Rated output: 1 10,000kW

Speed: 3,600 rpm

Main steam pressure: 7.04 kg/cm²g

Main steam temperature: 179.4 C

Gas contents: 0.1 - 2.2% (weight percentage)

Exhaust pressure: 102mmHg abs.

Governor: Mechanical hydraulic

Main stop valve: 34 inches (bore) x 2

By-pass valve: 10 inches (bore) x 1 (for main steam stop valve)

Control valve: 24 inches (bore) x 4

Figure 1 illustrates a cross section of the turbine; Fig. 2 shows the turbine under shop assembly; a 6stage, four-flow turbine is now being assembled. This size corresponds to that of a thermal turbine low-pressure section with 200 - 300MW rated output.

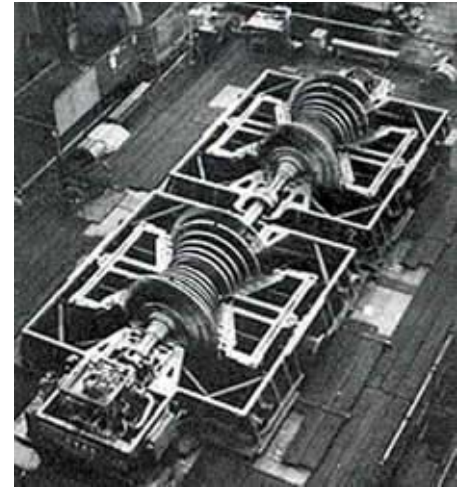
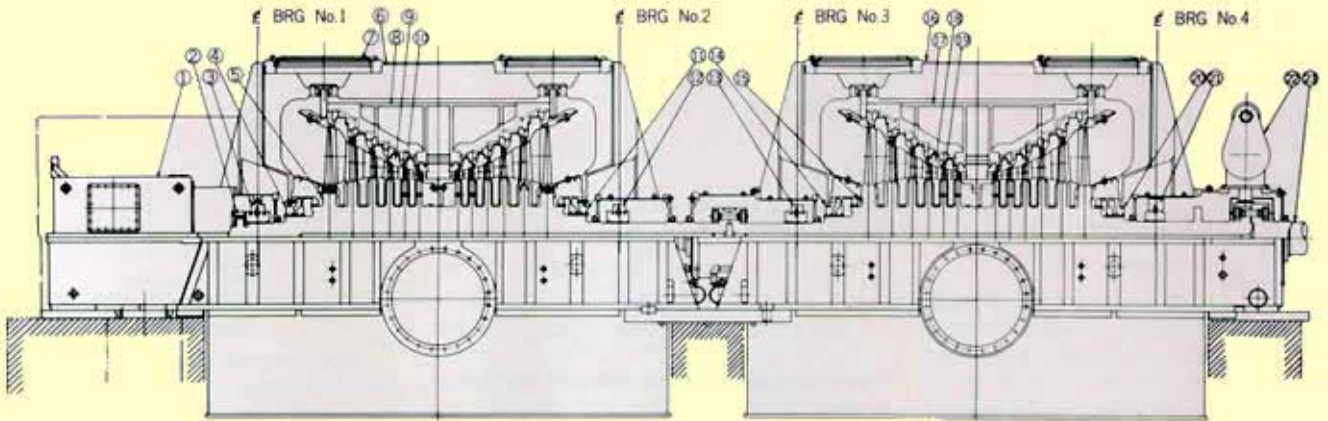


Fig. 2 110MW geothermal turbine under shop assembly



Nomenclature of main parts

1. Front standard	7. Exhaust casing relief diaphragm	12. Bearing No. 2	18. Nozzle, turbine B
2. Thrust bearing	8. Inner casing, turbine A	13. Bearing No. 3	19. Blade, turbine B
3. Bearing No. 1	9. Nozzle, turbine A	14. Labyrinth packing No. 3	20. Labyrinth packing No. 4
4. Labyrinth packing No. 1	10. Blade, turbine A	15. Turbine rotor B	21. Bearing No. 4
5. Turbine rotor A	11. Labyrinth packing No. 2	16. Outer casing, turbine B	22. Turning device
6. Outer casing, turbine A		17. Inner casing, turbine B	23. Generator rotor

Fig. 1 Cross section of 110MW geothermal steam turbine

Steam system

Figure 3 shows the steam system of the 110MW unit.

Since the steam does not contain hot water and its maximum superheating degree is 9°C, no flashing was required. Consequently, direct condensing system utilizing natural steam spurting out from production wells was employed for the power plant. Superheating steam is changed into wet steam from the turbine second stage and is expanded up to 102 mmHg absolute, 52°C. When contacting and mixed with sprayed cooling water in the condenser, which is directly connected to the turbine, the wet

steam becomes condensed water at 49°C. This condensed water is pumped to the cooling tower by a condensate pump and is cooled to 27°C. Cooled water is used as condenser cooling water, oil cooling water, etc. This cooling water is delivered to the condenser by utilizing potential energy between the cooling tower and the condenser rather than by pumping, and also by vacuum conditions in the condenser interior. Since the condensed water is recycled in this system, no water replenishment is required from the exterior.

Overflowing condensed water is fed back to the underground through injection wells. No condensed gases contained in the steam are continuously ejected from the condenser by using steam ejectors. Steam flowing through the ejectors amounts to approximately 34 tons per hour, about 4% of the total steam. Since 4,000kW power is consumed for driving the condensate pump and the cooling fans and other pumps, the net power output at high tension side of step-up transformer is 106,000kW.

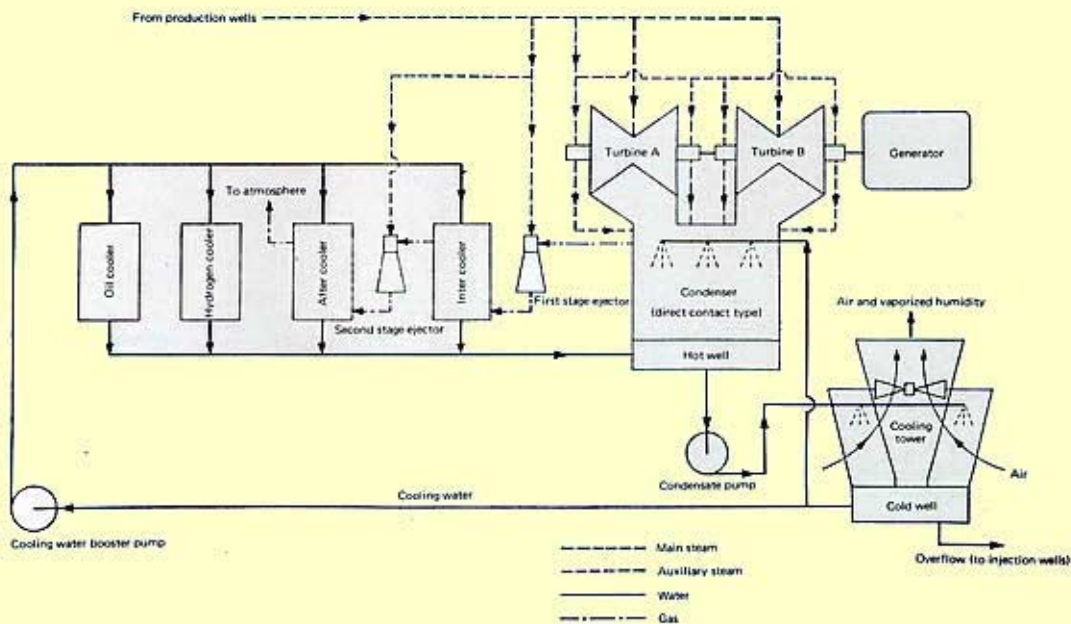


Fig. 3 Geothermal power cycle for 110MW unit

Consideration Given to Planning the Turbine and its Structural Features

Steam properties and their influence

Corrosive gas

The geothermal steam at the Geysers usually contains 1% or maximum 2.2% of gaseous impurities. Although they are mainly composed of carbon dioxide and hydrocarbon, they also contain such corrosion gases as hydrogen sulfide. In an atmosphere containing these impure gases, metallic materials of equipments become corroded and deteriorated during operation. The corrosion results in reduced material thickness, on the other hand deterioration decreases fatigue strength and increases sensitivity toward

stress corrosion cracking. The effect of corrosion and deterioration is frequently observed on blades to which high stress is repeatedly charged.

Dust

At the Geysers, centrifugal-type separators and strainers are mounted at well outlets to purify the geothermal steam as much as possible. A strainer (five-mesh) is mounted immediately before the main stop valve to prevent dust from entering into the steam turbine interior. However, dust of about 10 microns particle size may freely enter into the turbine interior in spite of such preventive devices. This dust is

composed of rock particles mainly comprising a-quartz and substances produced by corrosion of the transporting pipe internal wall, both being causes of eroding the steam paths. Since dust is deposited at corners of the turbine interior or accumulated in openings, it also causes troubles regarding performance and maintenance.

Drain

Since superheating steam becomes wet steam from the second stage on, it is also mandatory to give due consideration to drain erosion. This type of erosion

differs in its process from that by dust. However, similarly to erosion by dust, erosion by drain can be categorized into two types.

- (1) erosion by collision or tamping of drains particles, which strike the metal surfaces at an incident angle near 90°.
 - (2) erosion by collision and scratches of drain particles, which strike the metal surfaces at an incident angle near 0°.
- The former is often observed in fragile materials, displaying an erosion process similar to fatigue in cracking material

surfaces. On the other hand, the latter is often observed in ductile materials, revealing an erosion mechanism similar to wear. In addition, wet steam produces deep notches on wall surfaces when it passes through narrow openings where a pressure difference exists (termed "wire drawing"). Due consideration must be given to this point. The abovementioned influences by corrosive gases, dust, and drain are characteristic problems of geothermal steam turbines. These factors

often interact with each other to reduce steam turbine strength, to degrade performance, and to render it difficult to disassemble a turbine for inspection. Unless appropriate countermeasures are taken when planning turbines, the reliability and maintainability of geothermal steam turbines will be degraded during operation. Figure 4 illustrates the relationship of major consideration to be given in planning turbine design.

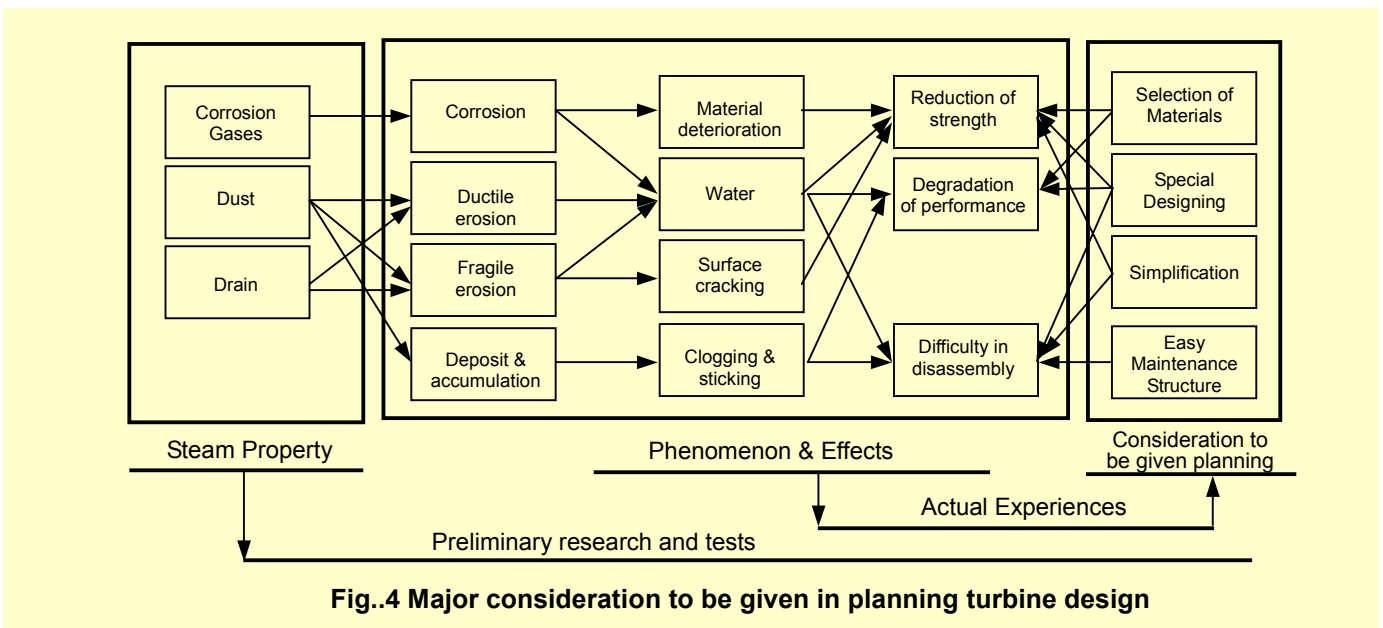


Fig.4 Major consideration to be given in planning turbine design

Consideration to be given in planning

planning turbine design

Unlike steam produced by boilers for which stringent property control of feed water is conducted, the above-mentioned properties of geothermal steam dictate that geothermal steam turbines be operated under extremely severe conditions. Even when compared with geothermal steam turbines, which utilize flashed steam, the operating conditions for these natural steam-utilizing turbines are quite severe, because both dust and water-soluble gases can be normally removed together with exhausted hot water under the flashing process of flashed steam-type turbines. Based on such terms and conditions, Toshiba's 110MW geothermal steam turbine was designed by giving special consideration to selection of material, "special designing," simplification, and easiness of disassembling and inspection, so that the turbine could be operated with enhanced reliability and maintainability.

Selection of material

Selecting the proper materials is a key element in enhancing the reliability of a geothermal steam turbine. Usually, to enable selecting optimal materials, general corrosion, erosion, and stress corrosion cracking tests are conducted prior to the start of designing. Various types of materials are tested by applying geothermal steam produced at the job site. When selecting materials for our 110MW geothermal steam turbine, we were able to refer to our past experience in selecting materials for 55MW turbines as well as observation results obtained by actual operation of such turbines over a long period, thereby ensuring further reliability of material selection.

"Special designing"

We term the designing processes peculiar to geothermal steam turbines as "special designing" only for the sake of convenience. We have much experience obtained from the actual operation of turbines Toshiba has already supplied

and from periodic disassembling and inspection results. This experience is constantly reflected in subsequent designing processes. As a result of this "special designing," Toshiba 110MW Geothermal Steam Turbine features a structure in which dust is rarely deposited or accumulated, drain particles can be easily exhausted, and bead welds are not exposed to steam flows, in addition to a reduced load on blades and rotors.

Simplification

Simplification in turbine design (namely simplified shape and structure and reduced numbers of parts, elements, and connections) is extremely effective in enhancing the reliability of geothermal steam turbines. Some examples of simplified structure include steam inlets mounted symmetrically on both sides of the turbine casing and elimination of bellows, which were once adopted between the main steam pipe and the casing in former 55MW turbines. When determining how to remove the bellows, research was

conducted on the piping loops and expansion joint fixing positions. At the same time, the degree of deformation and stress was measured through load tests using actual casings, to ensure safety during operation.

Easiness of disassembling and inspection

Those portions where dust will inevitably adhere or deposit are structured to ensure easy removal of such dust when disassembled. Disassembling ease is ensured, for example, by providing protective covers on bolts exposed to steam to protect their head angled portions from being rounded by erosion. Manholes and peepholes are mounted at appropriate portions to facilitate inspection of the turbine interior.

Structural features

Rotor

The rotor rotates at high speed and is always surrounded by a corrosive atmosphere. Consequently in planning turbine design, a prerequisite is to employ uniform materials as well as to minimize the centrifugal stress level caused by rotation. Toshiba employs large forged material to machine out a one-piece structured rotor, thereby removing the malinfluences of welding and a boundary between heterogeneous materials, preventing seam corrosion caused by shrinkage fit, and enhancing reliability. Chromium-molybdenum steel from which ingredients sensitive to corrosive atmospheres are removed is forged and formed as the rotor material. After confirming that nondestructive inspections (especially a high-sensitivity ultrasonic test) indicate internal defects are too small to develop into cracks, the forged steel is machined. There are two reasons for this: (1) the rotor should be provided with long blades because the steam volume flow rate is large, the stress level sometimes reaching as high as 60% of the material yield point and (2) even if minute corrosion traces caused by a corrosive atmosphere should create stress concentration, the compound defect size on the rotor surface should be sufficiently small to assure safety. Wheels machined out of forged material are provided with balance holes. Since steam flows through the pass ways in the form of an opposite-flow, thrust is balanced under normal conditions. The rotating portions driven by geothermal steam might sometimes be damaged by foreign matter such as rock particles. Balance holes are provided to cover any unbalance in thrust caused by such damage. Since steam flows from upstream

to downstream as a result of a pressure difference between the fore and aft wheels, wheels are sufficiently polished to minimize the influence of moisture and corrosive gases. In a rotor, which transmits generated torque to a generator, shaft torsional strength is a vital factor. Since geothermal steam turbine capacity is determined by the steam-producing capacity of the area, turbine capacity is often smaller than that of the electric system incorporated. Abnormal torque caused by disturbance in the electric system is sometimes heavily charged to the turbine (4 - 8 times the turbine rated output). Because of the reduced fatigue limit of materials caused by corrosive atmosphere in addition to such unusual torque, it is indispensable that the torsional stress level be kept as low as possible. The journal diameter of a 110MW geothermal steam turbine is almost the same as that of a 220MW thermal turbine.

Blades and nozzles

Employing a free-vortex-type flow pattern design in the steam paths, the vortex flow element is reduced as much as possible at both the inlet and the outlet ports of each turbine stage, thereby enhancing the efficiency of each stage. In addition to this, moisture extracting blades which have been widely adopted in nuclear turbines are employed so as to remove moisture and dust contained in the steam, so performance of the geothermal steam turbine is enhanced still more. Several grooves are cut out in the back of the moisture extracting blade tip, and moisture and dust accumulated along the grooves are exhausted to the external periphery pockets by the pumping effect of the grooves. For this reason, stainless sheets are lined along the bottom wall of that pocket to protect it from erosion. Blades are made of chromium alloyed steel high in vibratile damping coefficient and durable against erosion and corrosion. Shapes of blades were fully studied so that the blades would not be resonant with the nozzle passing frequency ((no. of nozzle) x (revolutions per second)) and so on, and that the blades would be adequately stiff to overcome bending stress caused by steam or other external forces. And in planning blade design, due consideration was paid to the fact that the fatigue strength of materials would decrease in corrosive atmosphere. Compared with blades, nozzles are rarely cracked or damaged, because they are free from the influence of stress repeated under high centrifugal force. However, their pressure side external periphery is subjected to erosion by colliding with

moisture and dust separated by sudden changes in the flow directions caused by nozzles. So nozzles are made of the same chromium alloyed steel as the blades. Moreover, the nozzle shape was designed to cope with any possible reduction in thickness caused by erosion, and also designed to enable repairing the nozzle by welding (if necessary), depending on the extent of erosion.

Casing

The casing, of welded steel plates divisible into upper and lower half portions, is of a double structure composed of outer and inner casings. The outer casing is made of welded carbon steel plates for structural use. Its lower half is of one-piece structure with a bearing pedestal. Outer casing elongation caused by thermal expansion can be absorbed by sliding movement between the basement and the casing lower part. The outer casing interior is reinforced with thick-plated ribs and round-piped stays, so that the casing is stiff enough to endure a large downward vacuum load, which may be caused by a vacuum in the condenser. Although the outer casing is subjected to a vacuum load under normal operating conditions, it is possible that, should trouble occur in the condenser or the cooling water system, internal pressure equivalent to the maximum pressure at production wells would be charged to the outer casing. As a countermeasure to such an instance, exhaust casing relief diaphragms composed of thin lead plates supported by knife edges was provided at the casing upper end. At the same time, the casing has been strengthened to fully endure such pressure. Structure of the inner casing enables to absorb a relative thermal expansion to the outer casing, due to hotter steam passing through the inner casing, so the inner casing can freely expand in the axial direction as well as in the radial direction. Moisture, dust, and corrosive gases contained in steam usually gather in pockets of the inner casing. Particularly, a higher density has been observed in pockets of the inner casing lower pressure part. By letting a portion of the steam escape through the connecting pipe between the pockets and the turbine exhaust hood, drain and dust can be efficiently exhausted together with that flow of steam.

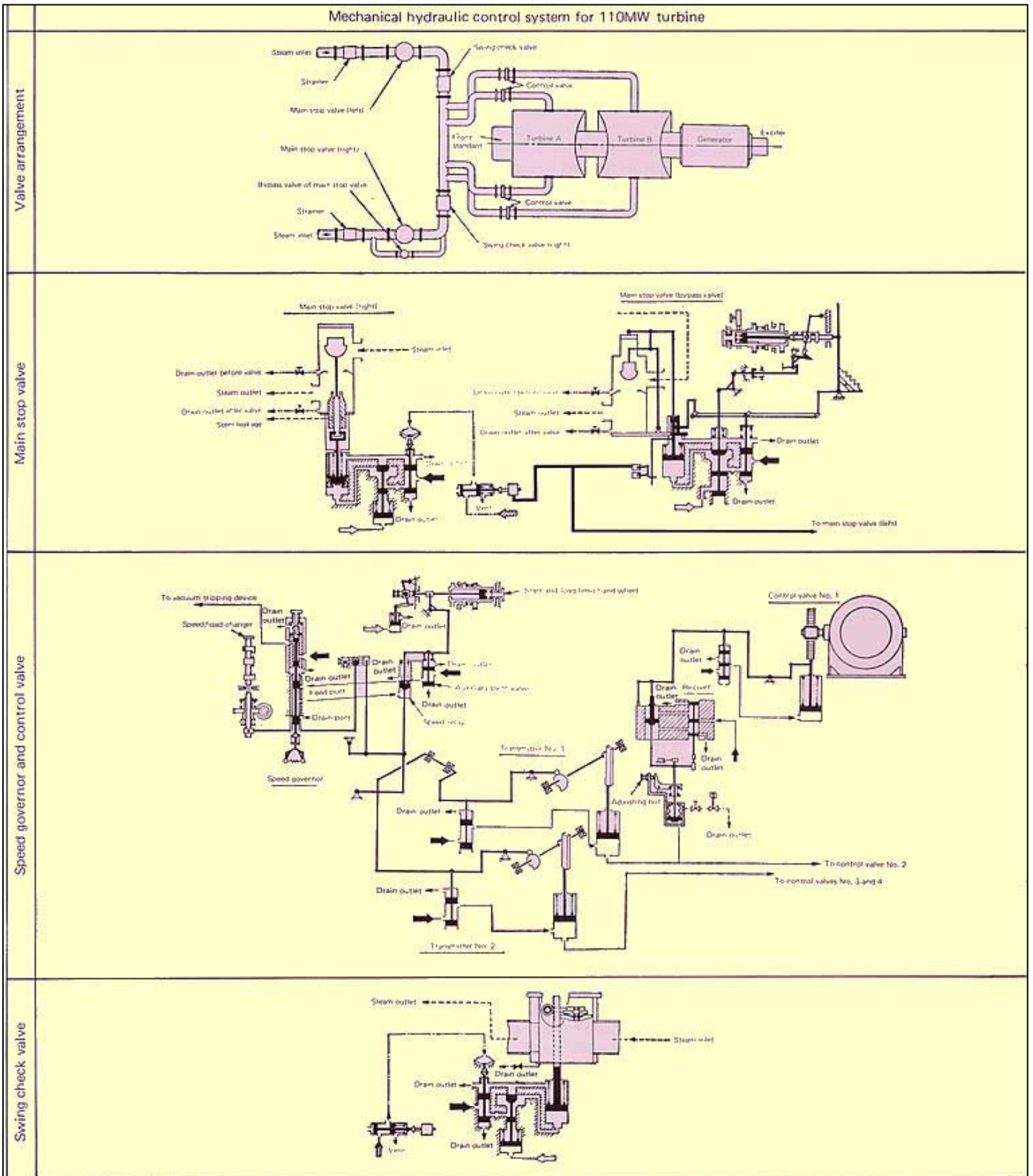


Fig. 5 comparison of control systems between 55MW and 110MW geothermal steam turbines. (1/2)

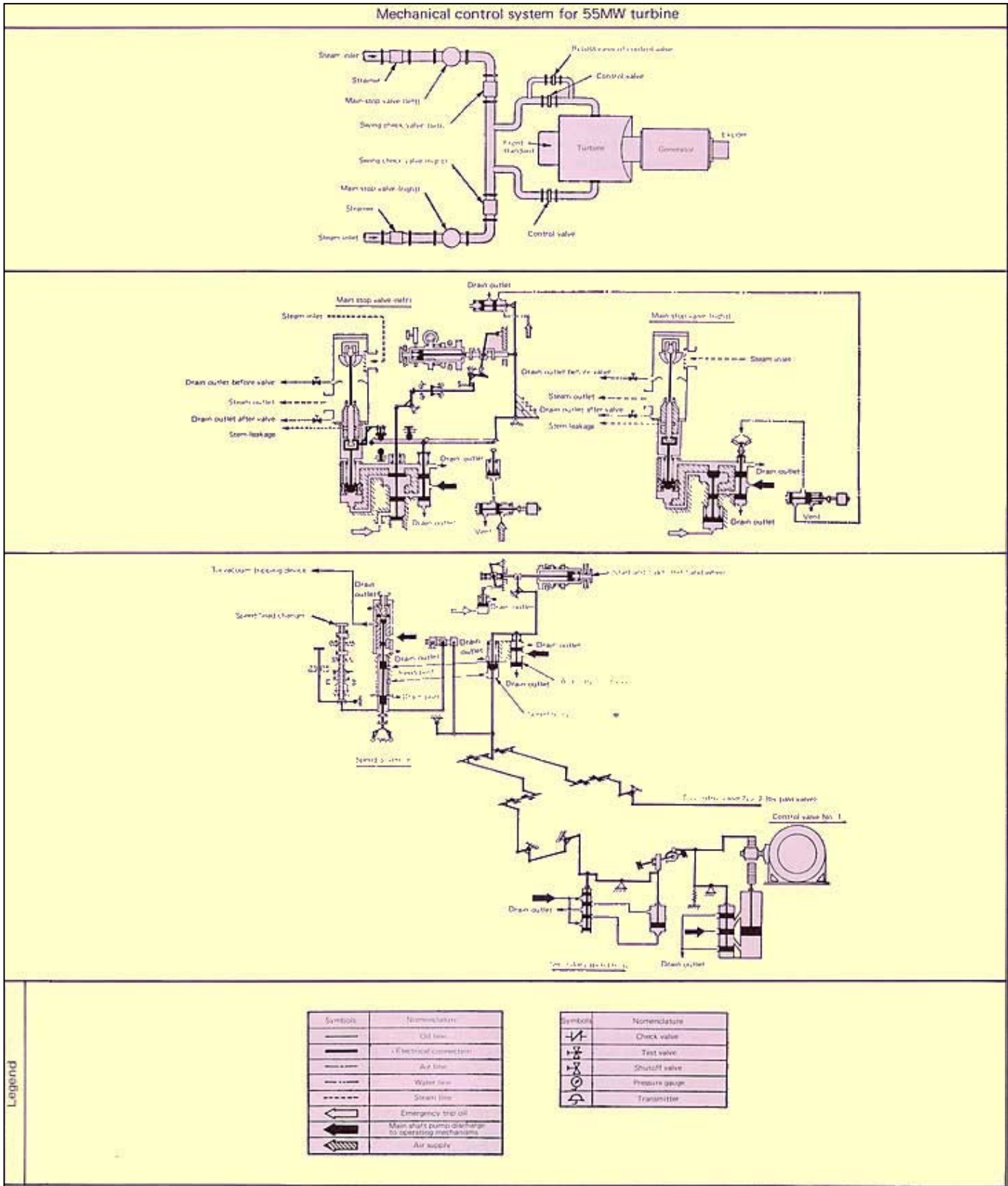


Fig. 5 comparison of control systems between 55MW and 110MW geothermal steam turbines. (2/2)

Control System and Equipment

Mechanical-hydraulic control system

Figure 5 illustrates a comparison of control systems between 55MW and 110MW geothermal steam turbines installed at the Geysers Power Plant. The former adopts a mechanical control system using a lever. However, this system would require an excessively long control transmitting section if applied to a 110MW turbine, thus degrading control performance. So a new mechanical hydraulic system was developed for the 110MW turbine. The new system opens and closes control valves (using receiver devices annexed to the control valve oil cylinder) by changing stroke signals coming from the speed relay of the speed governor into hydraulic signals with a transmitter. The transmitter is provided with a cam mechanism to linearize the flow rate characteristic of the control valve. By adopting a mechanical-hydraulic control system, unstable factors in the control system (such as complicated structure and bending or twisting caused by loosened parts or thermal deformation, which are inherent to lever mechanism) were eliminated. As a result, reliability in the control system has been greatly enhanced.

Control valve

From the viewpoint that geothermal steam spurting out of the ground should be utilized as much as possible, a throttle-governing method was employed for this 110MW turbine with butterfly valves adopted as the steam control valve. On the contrary, a nozzle-governing method is usually employed in thermal power plant turbines, since this method features high efficiency at the partial load. However, the geothermal steam turbine is usually operated at base load, thereby keeping the control valve almost fully opened during operation. As a result, even if tightness during a fully closed condition and the flow rate characteristic during a slightly opened condition may be sacrificed, the throttle governing method is appropriate for the objective since the control valve (adopting a butterfly valve) enables a large volume of steam containing dust to pass (for example, the steam volume is almost three times larger than a thermal turbine, in terms of volume flow). Four 24inch diameter control valves are provided. To ensure no-load stability and low-load control characteristics, the primary valve is driven prior to the other three valves.

Bypass valve of main stop valve

Under a fully closed condition the butterfly valve is designed to allow leakage equivalent to several percent of the flow rate under a fully opened condition. To control the steam flow rate during the speed-increasing duration from turbine start-up to reaching 95% of the rated speed, a 10-in diameter poppet valve was provided as the bypass valve of the main stop valve. The control valve is kept fully opened during the speed-increasing duration. The speed/load changer handle set at 95% of the rated speed (the lower speed limit). It is already known that if the steam flow rate from a geothermal well is suddenly changed, the steam contains a large volume of moisture, rock particles, and foreign matter solids. As a result, sudden changes in the load should be avoided, while a slow turbine speed increasing ratio as well as a slow load increasing ratio should be maintained during starting the turbine. In duly considering these points, Toshiba adopted not only a low-load control characteristic, but also a

Main stop valve and swing check valve

Two 34-inch diameter poppet valves are provided as main stop valves, which instantaneously stop the steam flow in an emergency. When a few solids are contained in the steam, the stem in this main stop valve may pick up these solids during the operation and, on account of sticking in time of tripping, the valve may not always be shut perfectly. For this reason, the valve design is a double structure with an emergency swing check valve inserted between the main stop valve and the control valve. These valves are operated by oil pressure. The by-pass full-open signal causes the main stop valve to fully open. To prevent turbine tripping which may be caused by erroneous operation of a valve closing test during turbine operation, each valve is electrically interlocked respectively, enabling the confirmations of closing operation of one valve at one time.

In addition to the above-mentioned features, valves are protected against geothermal steam by the same countermeasures as those in the main turbine.

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