UDC 621. 165. 52-185

FUJI STANDARD GEARED TURBINES

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I. INTRODUCTION

Recent trends in Japan concerning the expansion of plant facilities have emphasized shortening of the time needed for construction by means of expanding the scale of unit production and rationalizing process control. In this connection, there has been increased demands for larger general power plants and power plants producing steam as well as shorter delivery periods. Therefore, the selection of the main units of equipment for use in the power plants requires careful studies of plant expansion plans. Higher pressures and temperatures for thermal economy are especially important in directly coupled turbines of over 20 MW. The 120 kg/cm^2·g class and over is becoming standard and capacities are being enlarged from 50 to 100 MW. In the design of units of under 20 MW, higher efficiency and more compactness is being achieved by the use of geared turbines. Even in the 10 to 20 MW class where it was previously customary to use directly coupled turbines, large capacity geared turbines are now being utilized more and more.

In order to meet the demands of industry, Fuji Electric has introduced techniques related to high speed turbines developed by Siemens for power generation and compressor operation. Since the first 5,500 kW back pressure turbine was delivered in 1958, 32 standard geared turbines for power generation with a total output of 180,000 kW have been delivered or are now being manufactured as can be seen in *Table 1*.

A prefabrication system through which the delivery time can be shortened and quality considerably improved is employed and there is a wide selection covering 26 series of the 5 types of standard turbines. Mass production and complete after-service have been achieved through close cooperation with Siemens in the development, planning, manufacture and sale of these turbines.

In this article, the concepts behind the design of the Fuji standard geared turbines for power generation as well as results achieved so far will be introduced and expectations for future large capacity turbines for power generation will be discussed. It is hoped that it will be of service when customer's select the type of turbine to use when planning expansions in power plants. High speed large power turbines for compressor drive and reduction gears for use in geared turbines will not be covered. For these points, refer to the list of references given at the end of the article.

II. GEARED TURBINES FOR POWER GENERATION

There are several types of turbines: the reaction type and the impulse type differ according to blade design; the axial type and the radial type differ according to construction; and the back pressure, extraction back pressure, condensing and extraction condensing types differ according to use. In the case of turbines for power generation, there are the geared and directly coupled types which differ according to the method of coupling between the generator and the turbine. Generally, the reaction or impulse type with direct axial coupling is used in the case of large capacities and the reaction or impulse type with an axial geared system in the case of small capacities. Blading loss can be divided into end loss, leakage loss, leaving loss, etc.

In turbines with capacities of under 20 MW and a small steam flow, the blade length is generally very small when the direct coupling system is used and the part played by the first two losses in the efficiency of the machine becomes much greater. Therefore, the speed can be increased so that the mean blading diameter becomes smaller and the blade length larger. In this way, the efficiency of small capacity turbines can be raise to the same level as that of large capacity units. At the same time, the weight of the turbine is decreased condsiderably and the casing becomes much thinner. This is favorable in terms of thermal stress, the quick starting properties are excellent, and there is flexibility in respect to rapid changes in steam conditions as well as alteration in the load or extraction amount. When considering high speeds in respect to blade strength, there are increases in the stress due to centrifugal force and the steam power stress caused by the increasee amount of steam per blade. Generally,

Table 1 Supply list of Fuji standard geared turbine

No.	Customer	Location	Type	Year	Power (kW)	Speed (rpm)	Inlet pressure (kg/cm²·g)	Inlet temp. (°C)	Extraction pressure/Back pressure (kg/cm²·abs)
1	Nippon Light Metal	Shimizu	TG250-2	'57	5,500	6,000	84	510	11.5
2	Furukawa Mining	Yoshima	TG250-2	'58	4,087	7,000	84	520	15
3	Yokohama Suger Refining	Okayama	G300-2	'59	1,500	7,000	29	390	4
4	Idemitsu Kosan	Tokuyama	G400-2	'60	3,400	5,000	41	350	15.5
5	Idemitsu Kosan	Chiba	G400-2	'60	3,200	6,000	50	410	24
6	Nippon Kokan	Mizue	TG300-2	'60	6,870	6,000	99	525	30
7	Nippon Kokan	Mizue	TG300-2	'60	6,870	6,000	99	525	30
8	Fuji Seito	Aomori	G400-2	'61	2,200	8,000	39	370	4
9	Daishowa Paper	Yoshinaga	G500-2	'62	6,000	5,000	22	375	4.5
10	Kyushu Oil	Oita	G300-2	'63	2,500	8,000	54	420	14
11	Idemitsu Petrochemicals	Tokuyama	EK600-2	'63	5,750	6,000	68.5	468	43/0.1
12	Sanko Paper	Sobue	TG300-2	'63	6,000	6,000	100	500	15
13	Japanese Geon	Takaoka	G400-2	'63	7,140	8,000	80	465	5
14	Asahi Chemical	Nobeoka	G250-2	'64	1,500	10,750	26	350	5
15	Asahi Electrochemical	Oku	TG300-2	'64	6,000	6,000	111	525	33
16	Chisso Cor.	Minamata	G400-2	'64	7,900	8,000	64	445	8
17	Japanese Geon	Tokuyama	EG400-2	'64	7,000	6,000	55	415	13/5
18	Nippon Light Metal	Shimizu	TG250-2	'67	6,900	7,000	129	535	33
19	Oriental Chemicals	Korea	EK800-2	'67	5,000	8,000	39	435	2.5/0.079
20	Toa Oil	Kawasaki	G300-2	'68	3,000	8,000	40	385	11
21	Japanese Geon	Tokuyama	EG500-2	'68	11,500	6,000	55	415	13/5
22	Jujo Paper	Miyakojima	EK1100-2	'69	7,000	6,000	45	445	5/0.07
23	Korea Electric	Cheju Island	K1100-2	'69	5,000	6,000	42	440	0.0517
24	Korea Electric	Cheju Island	K1100-2	'69	5,000	6,000	42	440	0.0517
25	Fuji Oil	Hannan	G300-2	'69	5,100	8,000	59	450	5.5
26	Yokohama Suger Refining	Okayama	G250-2	'70	1,550	10,000	30	390	3.5
27	Chisso Cor.	Goi	G400-2	'70	9,200	8,000	74	470	7
28	Sanko Paper	Sobue	EK800-2	'70	10,000	6,000	89	490	5/0.04
29	Samitt	Thailand	G300-2	'70	6,000	8,000	80	470	23
30	Samitt	Thailand	G300-2	'70	6,000	8,000	80	470	23
31	Nippon Petroleum	Mizushima	G300-2	'71	4,000	8,000	40	355	6
32	Ube Ammonia	Ube	EK800-2	'71	5,000	8,000	41	375	4.5/0.109

therefore, there are inherent limitations when increasing the capacities of geared turbine. According to Fuji Electric tests, geared turbines up to 21 MW have advantage over the directly coupled types in respect to the balance between reduced turbine costs due to higher speeds and higher costs due to the addition of a reduction gear, the balance between increased efficiency and the added mechanical loss of the reduction gear, and the balance between the overall unit costs and delivery time and operating costs.

Since geared turbines are coupled to a reduction gear, the reduction gear must be designed and manufactured with ideal properties for use with a geared turbine.

The characteristics required of geared turbines for power generation are as listed below.

1) Reliability for continuous operation under large loads (highly flexible design)

2) Ability to withstand shock loads during generator short circuits and sudden load changes

3) High efficiency over a wide operating power range and no drops in efficiency due to operation stoppages

4) Profile design for high efficiency and excellent strength and vibration properties

5) Good quick starting properties and operating characteristics

6) Quiet operation with no vibration noise with or without load

7) Simple operation and high level of automation Must be possible to add a simple control system using external control signals from automatic power control devices, etc.

8) Simple construction and easy inspection and maintenance

9) High reliability with few parts, especially in the control system

10) Control equiment with high response and stability

11) Stable vibration balance of the shaft. Shaft should be as rigid as possible and of a simple shape using highly reliable forged materials

12) Appropriately designed journal and thrust bearings. If possible thrust should be automatically balanced
13) Wide selection, short delivery peried and low price
14) Flexibility to allow for compact arrangement in plant
15) Easy installation of standardized spare parts
16) Design providing balance with auxiliary devices such as heat exchangers and lublicating oil devices

III. FEATURES OF FUJI STANDARD GEARED TURBINES FOR POWER GENERATION

Fuji standard geared turbines for power generation are highly economical for large scale thermal power production and facilitate maintenance and inspection since they employ a reaction blade, rigid shaft and oil hydraulic governor. New cocepts not found in previous geared turbines are employed and these turbines are taking the lead in the conversion of small capacity turbines to the geared type. Their high reliability is appreciated by users both in Japan and overseas as is evident by increased imports such as the two 5,000 kW units delivered to the Cheju Island station of the Korean Power Co. and the two 6,000 kw units delivered to Thailand. The design of these turbines is in keeping with recent trends to higher capacities in geared turbines. They can be delivered in a short time no matter what the specifications because of the wide selection and prefabrication system used throughout.

Fig. 1 shows the 11,500 kW extraction/back pressure turbine for the Tokuyama Works of the Japanese Geon Co., Ltd. and *Fig. 2* shows the 7,000 kW extraction/condesing turbine for the Miyakojima Works of the Jujo Paper Co., Ltd. The main features of the Fuji geared turbines are as follows:

1) Reaction type
2) High quality round nose profile and free-standing type standard low pressure blade system
3) Rigid shaft
4) Oil hydraulic control and safety system
5) Rationally designed heat exchange system
6) Wide selection and prefabrication system

Details concerning these features are as follows:

1) Reaction type

The world's major turbine makers can be generally divided into two groups: those who use the reaction type and those using the impulse type. These makers have a long history of using one type or the other and they have developed the advantages inherent in their particular type.

The main differences between the reaction type and the impulse type are that in the former, the effective heat drop of the steam is expanded by the division of the blade into a static and a moving blade, the steam velocity in the blade canal is kept low and there is generally expanded flow so that there are no efficiency drops or stalls in the steam flow. In the latter, the effective heat drop is expanded entirely by a nozzle so that the steam velocity is high and there are comparatively few blading stages. When compared with the impulse type, the reaction type has a lower blade stress level due to steam power and the speed and capacity can therefore be easily increased. The leaving loss in geared turbines due to the high speed is large because of the fewer number of blading stages than in the case of direct coupling, but in the reaction type there are more blading stages than in the impulse type and the effect of the leaving loss on the turbine efficiency is too small to be a problem.

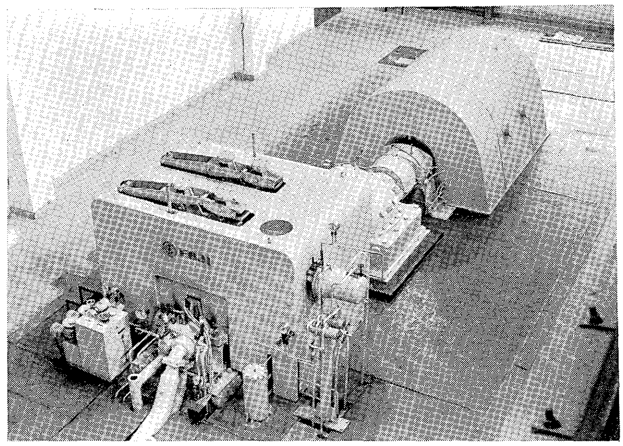


Fig. 1 11,500 kw extraction back pressure turbine for Tokuyama Works, Japanese Geon Co., Ltd.

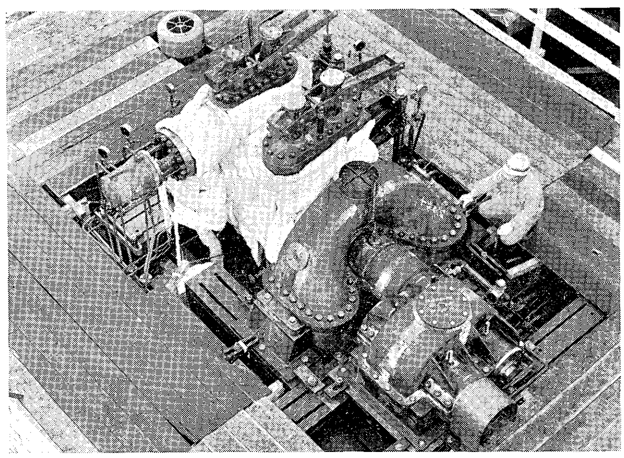


Fig. 2 7,000 kW extraction-condensing turbine for Miyakojima Works, Jujo Paper Co., Ltd.

In Fuji turbines, the first impulse stage only is used as the governing stage, and this is meant to perform nozzle cut-off governing. The heat drop is small since it is eliminated as much as possible at this stage but there is a considerable heat drop in the reaction blades. For this reason, high efficiency is maintained and the stress level of the impulse blade is kept low.

In the reaction type, the leaving angle is large enough that the axial clearance in front of and behind the impulse blade can be large without any drop in efficiency, and there are no operating limits when starting or load changing due to different shaft elongations. Since the loss of blade top clearance is smaller than that in the impulse type, the radial clearance can be large enough that there is no need to consider efficiency drops when operation is interrupted like those which are encountered in turbines with the very small radial clearances required for blade tip contact. The thrust caused by the steam power in the reaction blade section is automatically balanced by a balance piston and kept sufficiently low under all operating conditions. Safety is therefore very high since there is automatic balance even when silica or some other substance adheres to the blades.

2) High quality round-nose profile and free-standing type standard low pressure blade system

The round nose profile blade which resembles the blades used in large capacity industrial turbines is employed as the static blade. The excellent performance of this blade in respect to a wide variation of inflow angles has been confirmed by water canal and high speed blading tests. This is highly advantageous in Fuji turbines which have little drop in efficiency at partial loads. This type of blade is very strong with almost no stress concentration and high surface strength and vibration coefficients. The high pressure dynamic blade has a integral shroud ring so that blade end loss is minimized and vibrations are effectively attenuated. A rivet type shroud ring is not used. A three-dimensionally designed low pressure blade is standard in the low pressure part of the condensing turbine. Racing wires are not used so as to avoid resonance with the rotating frequency. The blade is thus " free standing " and there are no efficiency drops due to racing wires. A high level of safety is guaranteed since there is no need to worry about resonance loss accidents due to loosening of soldered parts of racing wires during operation. Blades for use in damp areas or areas with slightly overheated steam are made especially strong by incorporating techniques used in turbines for compressor drive. Frame hardening is used to prevent erosion and there is no stellite filling.

1) Rigid shaft

In the impulse type turbine, leakage loss due to the large pressure difference in front of and behind the nozzle must be kept as small as possible. Therefore, a diaphragm is used and steam tightness is provided near the core of the shaft. For this reason the shaft becomes like disks arranged on a spindle and the critical speed of the shaft becomes lower than the rated speed so that the shaft is what is known as an elastic shaft. The shaft in the reaction type, however, is of a simple cylindrical shape and is what is known as a rigid shaft since the critical speed is higher than the rated speed. Thus there is no need to worry about resonance with the critical speed when the turbine is started or stopped. The vibration mode during operation is simple and no oil whip occurs in the bearing so that it is stable against vibrations. Balancing is performed only once before the turbine leaves the factory and field balancing is not required. There is also no need for any special techniques concerning radial clearance adjustment when the rigid shaft is assembled, and disassembly and reassembly for periodic inspections is not required. In the rigid shaft, stress concentration is lower than in the disk type shaft and reliability of the forged materials is high. With the disk type shaft, it is necessary to consider damage due to deformations even when contact is made with the steam tight part. Since the part where the stress is concentrated is an steam tight part, the steam velocity is high, the heat transfer coefficient is large and it is easy for thermal stress to occur.

4) Hydraulic control and safety system

There are two types of controllers used in Fuji turbines : the electro-hydraulic type and the hydraulic type. The former is used in large capacity industrial turbines or for complex control such as three-stage extration pressure control. The latter type is standard in all other turbines including geared turbines for power generation. All parts are interchangeable and reliability is improved because of this standardization *Fig. 3* shows the control and safety system for the extraction/condensing turbine and *Fig. 4* is an oscillogram of the full-load dump test of a 7,000 kw extraction/condensing turbine. The overspeed is +6.14% of the rated speed and excellent stability is achieved.

The number of parts used in the hydraulic system is few when compared with the mechanical system and there are few link devices or parts exposed to shock. Therefore, the response is high and maintenance and inspection are simple. Since signals are transmitted hydraulically, it is easy to add external control devices to the system such as those for fore pressure control, extraction pressure control, back pressure control and automatic power regulation. This system is in keeping with automation trends for turbines.

5) Rationally designed heat exchange system

As can be seen in *Fig. 5,* condensers used in the condensing and extraction/condensing turbines are of the cylindrical shell, steel-plate, rigid-support type. A bellows is located at the part where the condenser is connected to the turbine exhaust part. The size of the condenser can be indicated by the surface area of heat transfer but in order to obtain flexibility in respect to plant arrangement, Fuji Electric devised a series of equations by combining the cylinder diameter and the cooling tube length. All calculations including those for the cooling tube arrangement were made with a FACOM 230–50 computer. In this way, the system was rationally planned with no heat unbalances. In small capacity condensing turbines of 1,000 to 3,000 kW, the condenser, oil tank, turbine and reduction gear base plate are being planned and in

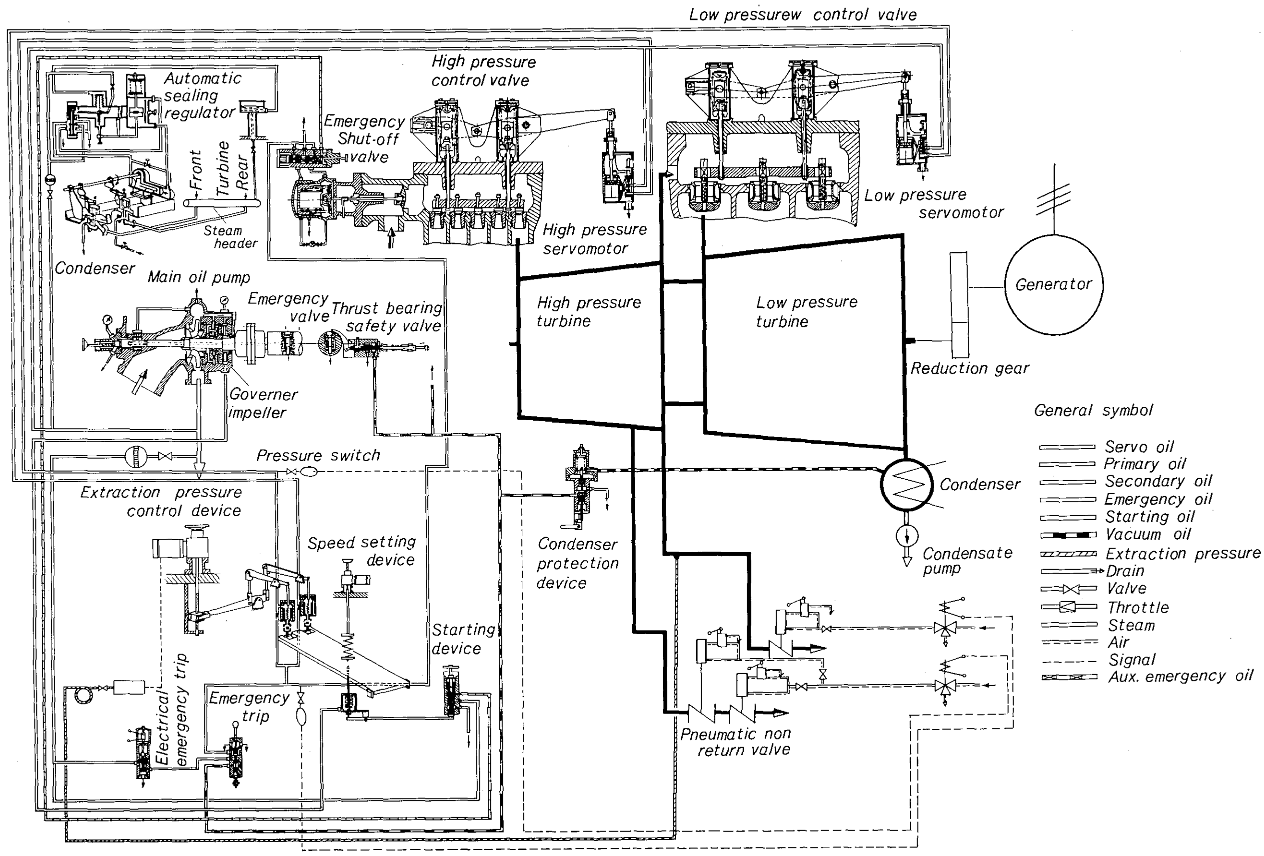


Fig. 3 Control and safety system diagram

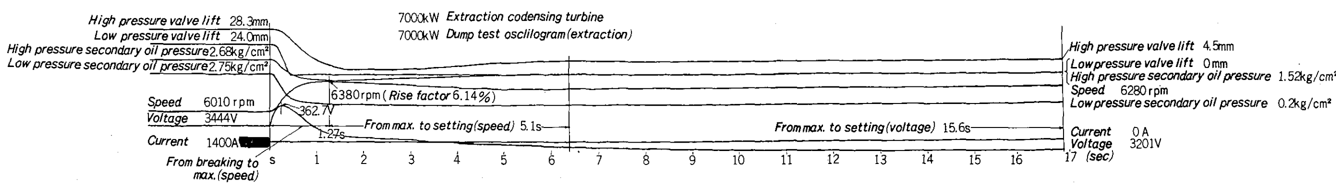


Fig. 4 Dump test diagram of the 7,000 kW extraction condensing turbine

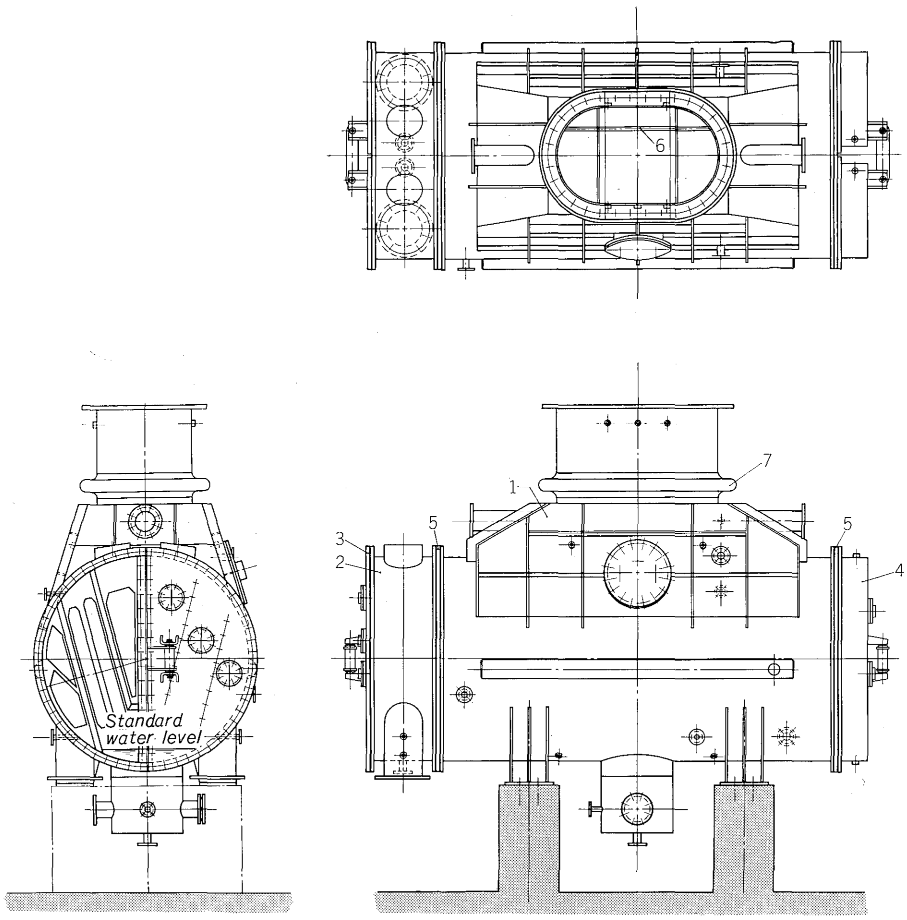
part executed as single units for compactness. Such a construction is also now in the planning stage for this standard series. In Japan, the pollution of sea and river water has increased considerably in recent years and the selection of materials for the cooling tubes is an important factor in assuring normal operation of the turbine plant. For this reason, Fuji Electric's main laboratories are conducting independent withstand tests on various types of cooling tubes.

In addition to the surface condensing system, a nozzle ejection direct mixed condenser without cooling tubes is now practical. This is ideal for power plants using hot water. Other heat exchanging devices include the packing steam condenser, the steam ejector cooler and the oil cooler. They have all been standardized.

6) Wide selection and prefabrication system
   Refer to sections IV. and V.

IV. OPERATING RANGES AND TYPES OF FUJI STANDARD GEARED TURBINES FOR POWER GENERATION

Unlike large power plants turbines, turbines for domestic power generation and power plants which also supply steam must be designed to match various specific application objectives and must be delivered in a comparatively short period in keeping with process side delivery periods. Because of severe operating conditions, operation and maintenance by as few personnel as possible and recent widespread improvement in process techniques, there are few plants using waste heat and as the amount of private generation including factory power requirements increases, demands for greater power plant economy and reliability are increasing. To meet the requirements of industry, a wide selection is offered so that suitable equipment can be chosen to fill any specifications. In this way, it is possible to increase



1	*Body*
2	*Front water chamber*
3	*Front water chamber cover*
4	*Back water chamber*
5	*Pipe plate*
6	*Cooling pipe*
7	*Bellows*

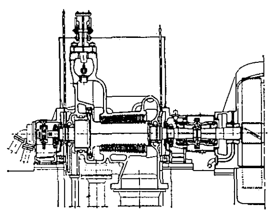
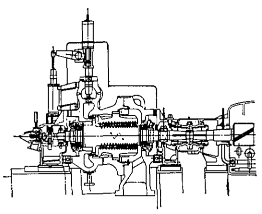
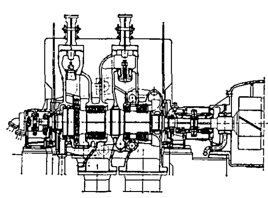
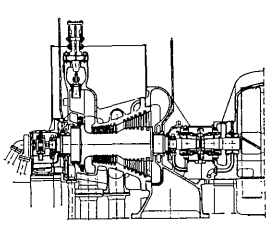
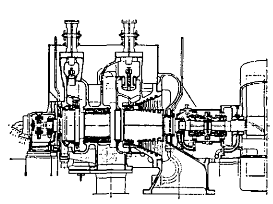
Fig. 5 **Outer view of condenser**

efficiency and suitability not only in design and manufacture but also in power plant planning. *Table 2* shows the types of turbines and *Table 3* the operating ranges. The G series and TG series are back pressure turbines. The TG series turbines can be used under high pressures and temperatures with steam input conditions of up to 140 kg/cm^2·g and 540°C since a pot type casing is used. With this as top turbine, it is possible to plan a plant with a high level of thermal economy. The K(00) and K(01) series are both condensing turbines but the K(01) series are low pressure turbines for use with steam input conditions of up to 40 kg/cm^2·g and 400°C. The EG and 400°C. The EG and EK series are extraction/back pressure or extraction/condensing turbines. The numbers following each of the series

Table 2 **Fuji standard geared turbine types**

Type	Symbol	Explanation
Back pressure turbine	G TG	The steam from the turbine can be utilized for process heating at a required temperature and pressure (back pressure). The TG type is especially suitable for high pressure and high temperature steam.
Extraction back pressure turbine	EG	A back pressure turbine in which steam of a required temperature and pressure can be extracted from some level in the turbine and used for process heating.
Condensing turbine	K	The steam from the turbine is lead to a condenser, expanded until a vacuum is formed and converted as specified.
Extraction condensing turbine	EK	A condensing turbine is which steam of a required temperature and pressure can be extracted from some level in the turbine and used for process heating.

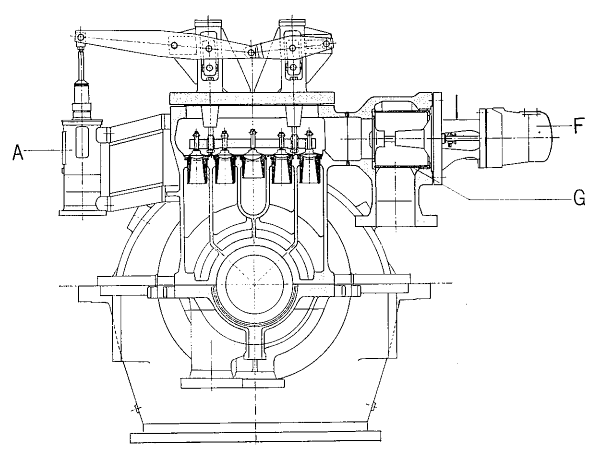
Table 3 **Fuji standard geared turbine series**

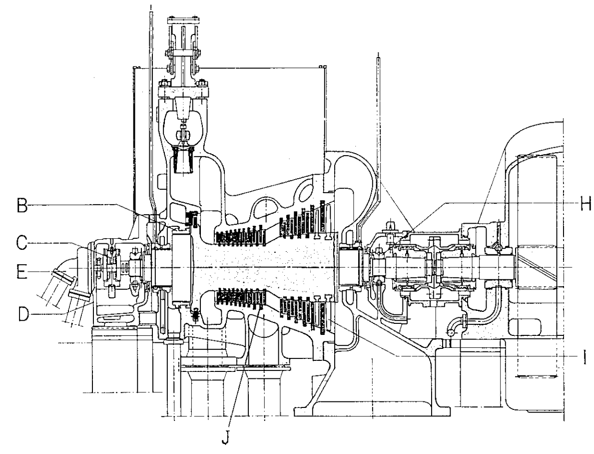
Type	Cross section turbine	Series	Max. speed (rpm)	Max. power (kW)	Max. inlet steam condition	
					Pressure (kg/cm²·g)	Temperature (°C)
G		G 250-2	12,000	3,000	70	500
		G 300-2	10,000	6,000	70	500
		G 400-2	8,000	10,000	70	500
		G 500-2	5,500	14,000	70	500
TG		TG 250-2	8,000	8,000	140	540
		TG 300-2	7,000	12,000	140	540
		TG 400-2	6,000	20,000	140	540
EG		EG 250-2	12,000	3,500	70	500
		EG 300-2	10,000	7,000	70	500
		EG 400-2	8,000	11,500	70	500
		EG 500-2	5,500	15,500	70	500
K		K 600-2	10,000	3,000	70	500
		K 800-2	8,000	8,000	70	500
		K 1000-2	8,000	10,000	70	500
		K 1100-2	7,000	13,000	70	500
		K 1400-2	5,500	21,000	70	500
		K 601-2	10,000	3,000	40	400
		K 801-2	8,000	8,000	40	400
		K 1001-2	8,000	10,000	40	400
		K 1101-2	7,000	13,000	40	400
		K 1401-2	5,500	21,000	40	400
EK		EK 600-2	10,000	3,500	70	500
		EK 800-2	8,000	8,000	70	500
		EK1000-2	8,000	10,000	70	500
		EK1100-2	7,000	15,000	70	500
		EK1400-2	5,500	21,000	70	500

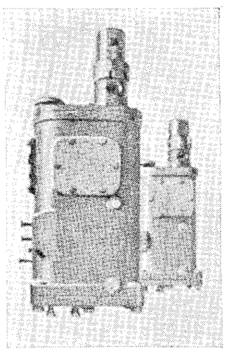
symbols show the nominal diameter (mm) of the exhaust port. All series except for the TG and K(01) series have maximum steam input conditions of 70 kg/cm²·g and 500°C. Since the maximum power for each series is the maximum value for each air cylinder, it is possible to couple turbines of the G and EK series and TG and EG series in tandem to form the GEK and TGEG series respectively. Diagrams showing the external dimensions are not included because of space limitations but these turbines are arranged in the two levels as formerly or in one level in two or three plants where the oil tank, turbine and reduction gear base plate have been combined in a single unit recently on a trial basis. In all cases, a more compact arrangement and reductions in crane equipment, foundation and building costs are possible in comparison with direct coupled turbines.

V. PREFABRICATION SYSTEM

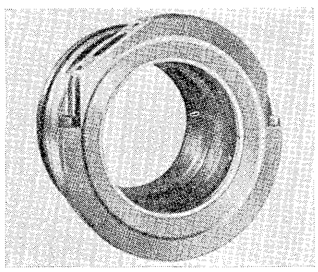
The prefabrication system is intended to achieve high level of quality and a short delivery period in terms of both planning and production. With this system a very wide selection is possible. *Fig. 6* shows an example of the K type prefabrication system. All



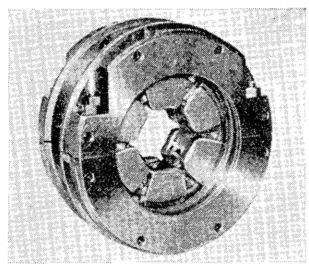




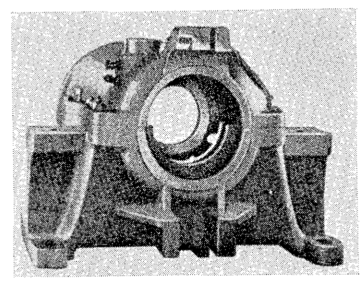
(A) Servomotor



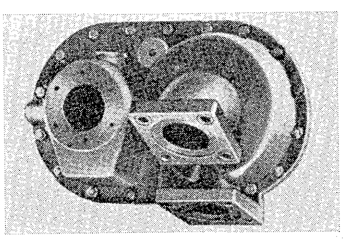
(B) Labyrinth ring



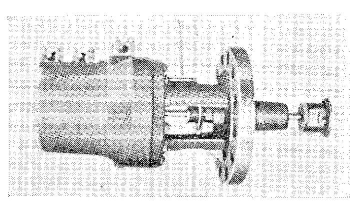
(C) Thrust bearing



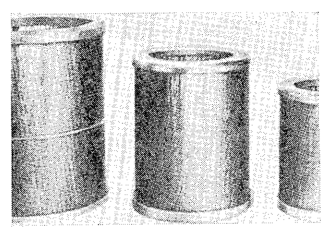
(D) Bearing holder



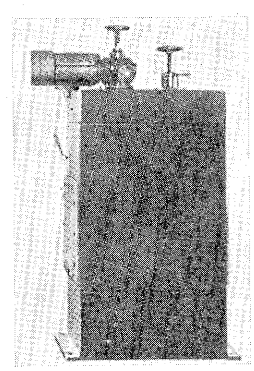
(E) Main oil pump



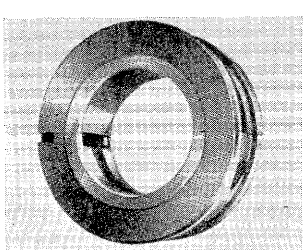
(F) Emergency shut-off valve



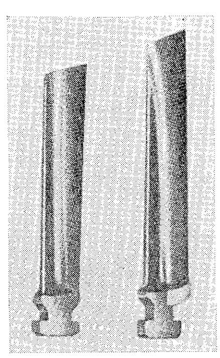
(G) Steam strainer



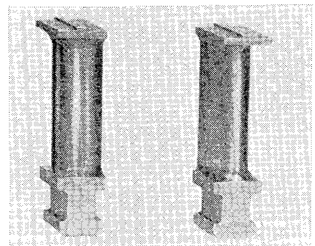
Control box



(H) Journal bearing



(I) Standard low pressure blade



(J) Reaction blade

Fig. 6 **Prefabrication system (K type)** turbine parts are divided into standard series of (1) control valves and blading parts related to turbine efficiency, (2) heavy, large parts such as shaft and casing which take a long time to deliver and (3) parts such as the low pressure final standard blades, bearings and control and safety equipment for which there are problems related to strength and vibrations. Only the control valves and blading parts are planned in accordance with various specifications and all calculations for these parts are performed on a FACOM 230–50 computer. At present the large forging and castings for the shaft and casing form a bottleneck in shortening the delivery period but in the near future this bottleneck should be eliminated by shifting the steps when the planning and production system is established. There are five standard series of low pressure final blades. The bearings and control and safety equipment are common parts which are also interchangeable with Siemens' parts. The materials for the casing and the rotor which make up a majority of the material costs are chosen in accordance with inlet steam, extractian and back pressure conditions. The rotational speed of the turbine is chosen in accordance with the relations between the generator and reduction gear.

VI. LARGE CAPACITY GEARED TURBINES FOR POWER GENERATION

In Europe, there are many cases where the custom is to use several comparatively small capacity geared turbines together. However, in Japan where the power system is large, there are economic requirements in respect to equipment costs and there is a strong tendency toward technical progress or in developing countries where industrialization takes place in a single step through the introduction of established techniques and comparatively large scale plants are constructed, there is a strong trend to larger scale geared turbines. In geared turbines, there is an obstacle to larger capacities on the steam turbine side in operation under high temperature and pressure steam conditions but very large capacity, high speed geared turbines (rotational speed: 8,000 to 20,000 rms and power: 10,000 to 56,000 kW) for compressor drive have been developed to meet international demands for large scale, high speed compressors in ultra-high capacity chemical plants and also operation of the prime movers directly coupled to these compressors. These turbines were designed so that the former large capacity bottlenecks concerning the strength of moving blade were solved by electrochemical machining of the moving blade. Fuji Electric standard geared turbines are developed from the beginning for both compressor drive and power generation and they can be used for both applications. Under these conditions, a high speed, large capacity reduction gear (high speed shaft speed: 15,000 rpm, gear ratio: 5 and transmission power: 20,000 kW) is being developed and will soon be ready for practical application.

VII. CONCLUSION

This article has described the technical features, the wide selection and prefabrication system of Fuji standard geared turbines for power generation from a maker's stand point. It is hoped that it will help users in choosing equipment when they are planning construction of a power plant. The large scale trends in geared turbines were not described in detail due to space limitations and the authors with to discuss these points at a later date.

In a country like Japan which is poor in raw materials, makers must supply highly economical geared tbrbines for power production. It is hoped that the users will aid in these endeavors.

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