

DEVELOPMENT OF TURBOMACHINERY INDUSTRY IN JAPAN

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Professor Ichiro Watanabe graduated University of Tokyo in 1931, and had been associate professor of University of Tokyo and research member of the Aeronautical Institute of the University up to 1946, researching centrifugal superchargers and high altitude performance characteristics of aviation piston engines. After the World War, he was a professor at Keio University for 28 years, researching problems concerning

radial turbomachineries. After retirement from Keio University, he was a professor at Aoyama Gakuin University for 3 years. Presently, he is a professor at Kanto Gakuin University, as well as Professor Emeritus of Keio University. He received his Ph.D. degree from the University of Tokyo in 1947.

ABSTRACT

This paper deals with the development of the turbomachinery industry in Japan for the past five years. The machinery discussed includes gas turbines, gas expanders, turbobchargers, steam turbines, compressors, blowers, and water pumps. The illustrations include production statistics and photographs of various products.

1. TREND OF TURBOMACHINERY INDUSTRY IN JAPAN

1.1 TREND OF GAS TURBINE INDUSTRY [1]

The production statistics within recent 5 years from 1972 up to 1976 concerning land and marine gas turbines, turbojet and turboprop engines as well as turboshaft and turboprop engines are shown in Figures 1~3 respectively.

1.2 TREND OF STEAM TURBINE INDUSTRY [2]

The thermoelectric power plants belonging to the Electric Power Companies built during 1975 amounted to 8 units with a total output of 3730MW, which showed a considerable decrease compared with 14 units amounting to around 6400MW built during 1974. This decrease resulted from the difficulty of selecting adequate sites for thermoelectric power generation during 1972. Mean power output of a single unit has been increasing continuously for the last several years. Thus, the mean power output amounted to 360MW in 1972, 400MW in 1973, 460MW in 1974, and it settled at 470MW in 1975. The maximum output of a single unit amounted to 600MW in 1973, and increased rapidly to 1000MW both in 1974 and 1975.

Among the units belonging to the thermoelectric power stations of the Electric Power Companies built during 1975, four are supercritical pressure units (246kg/cm²), which account for 50% in number and 80% in the total output. The first

supercritical pressure unit was built in 1967, and after that, 39 supercritical pressure units amounting to 21500MW in total output were constructed within 9 years, which account for about 31% in the total thermoelectric power output by steam of around 69000MW.

For the thermoelectric house power plants built during 1975 having an output exceeding 10MW or the units having steam turbines with an inlet pressure larger than 60kg/cm², 27 steam turbines corresponding to a total output of 840MW and 30 boilers corresponding to a total capacity of 5100ton/h were constructed. Among them is included a steam turbine-boiler plant of 169kg/cm² pressure, 566°C/538°C temperature, 175MW capacity and evaporative capacity of 550 ton/h for house power plant which was constructed by IHI, and delivered to Mitsui Aluminium Co.

In 1975, the worldwide economic growth has slowed down. In Japan, however, 74 ships propelled by steam turbines were constructed, and the total output of the main propulsion engines amounted to 2,620,000HP. The total number of turbine ships worldwide in 1975 was 133, corresponding to a total horsepower of the main engines of 4,560,000HP. Thus, Japan's share of the steam turbine construction for ship propulsion turned out larger than before. But, because of the worldwide

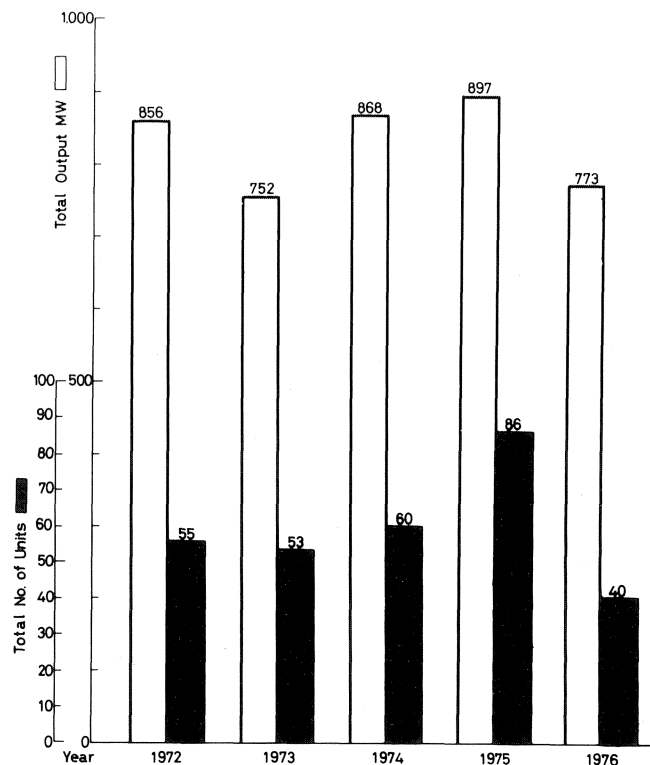


Figure 1. Production Statistics of Land and Marine Gas Turbines.

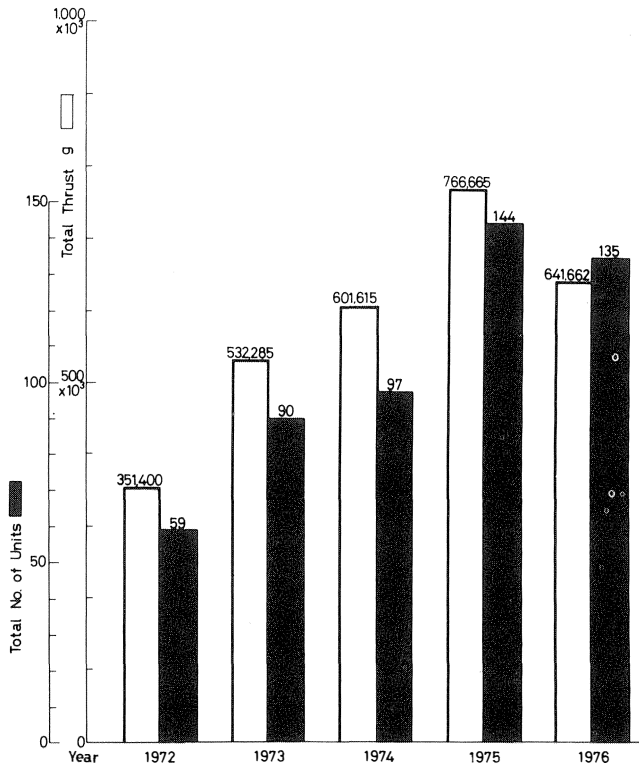


Figure 2. Production Statistics of Turbojet and Turbofan Engines.

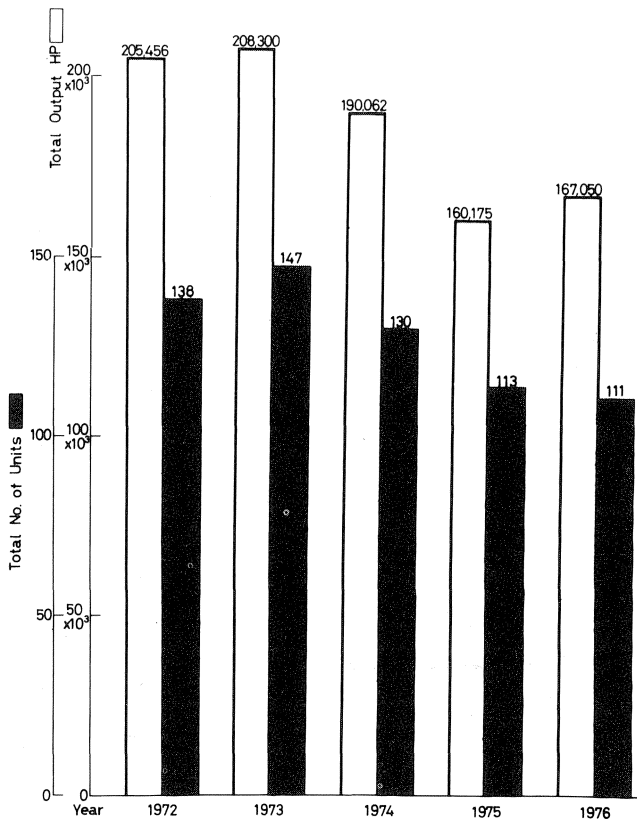


Figure 3. Production Statistics of Turbohaft and Turboprop Engines.

economic slump, orders for 190 ships, mostly oil tankers installed with steam turbines, have been cancelled. Thus, the production of turbines and boilers for marine use is expected to decrease sharply from 1976. In the circumstances like this, the development of steam turbine plants with high economic advantage in fuel consumption realized by adoption of reheat cycle as well as high temperature, high pressure steam is under consideration.

In 1975, steam turbines having a high output of 45,000HP ~ 50,000HP as well as boilers having an evaporative capacity of 100ton/h ~ 140ton/h were produced meeting the orders received previously when the economical state of affairs has been better. Among these, a steam turbine having an output of 50,000HP at 85 rpm manufactured by Toyo Turbine Co. was the largest one. In addition, KHI (Kawasaki Heavy Industries) built a 45,000HP steam turbine for reheat plant use and a boiler having an evaporative capacity of 140ton/h. MHI (Mitsubishi Heavy Industries) built a test rig for testing low pressure steam turbines having blade lengths up to 613mm(25in.) for the development of high output turbines.

Recent rise in fuel costs has aroused keen interest in the reheat plant.

As to the steam turbines for industrial use, the utilization of thermal energy of the exhaust gases hitherto thrown away as waste gases has become an important need. Thus, various exhaust heat boilers and total energy systems are under consideration or under development.

1.3 TREND OF NUCLEAR POWER AND NUCLEAR REACTOR

In Japan, we have six Nuclear Power Stations (Boiling Water Reactor Type), five Nuclear Power Stations (Pressurized Water Reactor Type), one Nuclear Power Station (Natural Uranium, Gas Cooled Type) named Tokai Nuclear Power Station, and one Breeder Reactor Type Nuclear Power Station for experimental use. In addition, we have one New Type Converter Reactor (Heavy Water Moderated, Boiling Light Water Cooled Type) and 11 Nuclear Reactors for research use. As to the Nuclear Reactor for marine use, the first Nuclear Ship "Mutsu" has been put to several tests since the accident of X-ray leakage.

The total amount of electricity generated by nuclear power amounts to around 6600MW as of 1977.

1.4 TREND OF THE HYDRAULIC PUMPS, TURBINES AND PUMP-TURBINES [2]

The total amount of the production of water pumps manufactured during 1975 is shown in Table 1. Among the pumps for agricultural use, the drainage pumps are predominant. The representative water pumps for circulating water at the thermoelectric as well as nuclear power station are listed in Table 2.

Trends concerning water turbines and pump-turbines will be explained later with typical examples of them.

1.5 TREND OF TURBOCOMPRESSORS AND TURBOBLOWERS [2]

Centrifugal compressors for deaerator having a capacity of 15,500kW were constructed. Centrifugal compressors of such a large capacity have been manufactured during the last several years.

TABLE 1. AMOUNT OF PRODUCTION OF PUMPS (STATISTICS MADE BY MINISTRY OF INTERNATIONAL TRADE AND INDUSTRY) EXPRESSED BY MILLION YEN. 1 MILLION YEN COSTS 3,330 U.S. DOLLARS APPROXIMATELY.

Kind of Pumps	Figures Expressed by 1 Million Yen
Centrifugal single stage	40,394
Centrifugal multi stage	19,719
Axial	4,433
Mixed flow	13,431
Rotary	4,231
Pumps for chemical plant (anti-corrosive)	15,183
Water proof	18,577
Reciprocating	5,940
Others	10,313
Total Sum	132,221

Trend of centrifugal compressors and axial compressors will be explained later with the typical examples of them.

2. TYPICAL TURBOMACHINERIES

2.1 GAS TURBINES

A National Research and Development Program of high bypass ratio turbofan engines has been in progress in Japan since 1971. [3] The 5 ton class engines have been obtained in the first phase of it with success, the second phase being started in 1976. The program is sponsored by Agency of Industrial Science and Technology as well as Ministry of International Trade and Industry.

Figure 4 shows a photo of the FJR 710/20 Turbofan Engine. The ultimate goal is to develop a high performance turbofan engine, in the 10 to 15 ton thrust class, capable of withstanding frequent take-offs and landings, economical cruising (low specific fuel consumption), with less noise and less air pollution.

In the first phase plan, National Aerospace Laboratory (NAL) assumed the role of the engineering center, carrying out

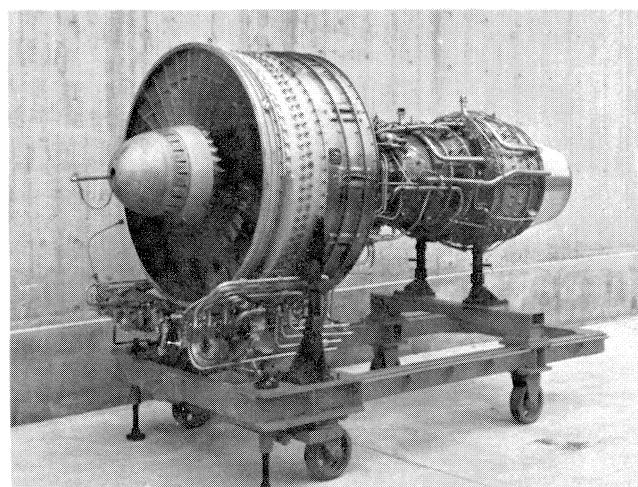


Figure 4. FJR710/20 Turbofan Engine.

all research works. IHI, KHI and MHI performed the design, construction and the assembly.

MHI (Mitsubishi Heavy Industries) has been manufacturing various kinds of gas turbines having capacities of 10,000 ~ 100,000kW by the technical tie-up with Westinghouse Corporation since 1951. These gas turbines are mostly of single shaft type for electricity generation. Recently, gas turbines for driving pumps or compressors for pipe line use as well as for driving compressors for chemical plants have become utmost needs. It is conceivable that a 2-shaft gas turbine would be adequate for the purpose. Thus, the gas turbine 252MW (Figure 5) was constructed.

In order to get stable operations with high efficiency for a wide range of variations in both revolutions and loads, an attempt to employ the movable stator blade of the power turbine was made. For this purpose, the so-called "flapper blade" was employed. The upstream half or the leading edge side of the stator blade is fixed, while the downstream half of the blade, having parallel shroud and hub contour, is made movable. Thus, reduction of the total length of the turbine was achieved. In addition, it is necessary that the resonance vibration of the power turbine blade be avoided, because of the wide variations in the revolutions. Thus, the "snapper shroud" was adopted for the rotor blades. By means of the centrifugal force, the contact

TABLE 2. TYPICAL WATER CIRCULATION PUMPS FOR THERMOELECTRIC AS WELL AS NUCLEAR POWER STATION

Sites of Installation	Number of Units	Type	Inlet Dia. mm	Delivery Volume Flow m ³ /min	Total Head m	Revolutions rpm	Prime Mover kW	Manufacturer
Kansai Electric Power Co.	2	Vert.-mixed flow	4000	2172.5	11	135	M-5100	MHI
Nihon Genshiryoku Power Sta.	3	" - "	3000	1237	10.7	173	M-2800	MHI
Shikoku Electric Power Co.	2	" - "	2800	1067	10.5	175	M-2400	MHI
Chubu Electric Power Co.	3	" - "	2700	980	14	208	M-2850	Dengyosha
Tokyo Electric Power Co.	2	" - "	2600	1106.8	15	230	M-3560	Hitachi
Tokyo Electric Power Co.	3	" - "	2400	930	12.8	225	M-2500	Ebara
Shikoku Electric Power Co.	2	" - "	1800	500	12.5	295	M-1350	Dengyosha
Sakata Kyodokaryoku Co.	2	" - "	1800	445	13	295	M-1300	Kubota

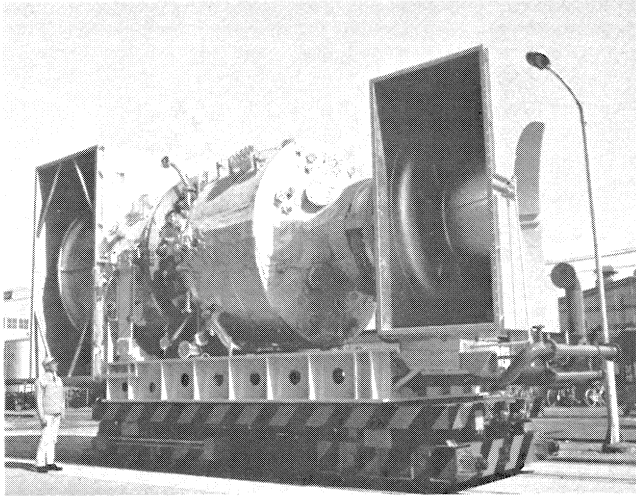


Figure 5. MW252 2-Shaft Gas Turbine (MHI).

surfaces of the shrouds are to be brought into tight contact with each other, and so the turbine blades act as a single rotor system having an infinite number of blades, thus the resonance vibration being avoided.

Figure 6 shows the industrial gas turbine SB90C constructed by Mitsui Shipbuilding & Engineering Company. The company has taken the first step to make an open cycle gas turbine of its own design in 1949. On the other hand, a license agreement with Escher Wyss Co. was signed in 1955, concerning the production of closed cycle gas turbine for marine use. A contract on manufacturing and testing the closed cycle gas turbine for naval use was made with Japanese Defence Agency in 1955. The shop run was started in 1961 and finished in 1963. In 1963, the company started to design a prototype open cycle gas turbine for industrial use.

General structural features of the turbines are as follows:

1. The housing is divided into two, i.e. the inner casing and the outer casing. The inner casing consists of blade row portion, while the outer casing acts as a pressure vessel.

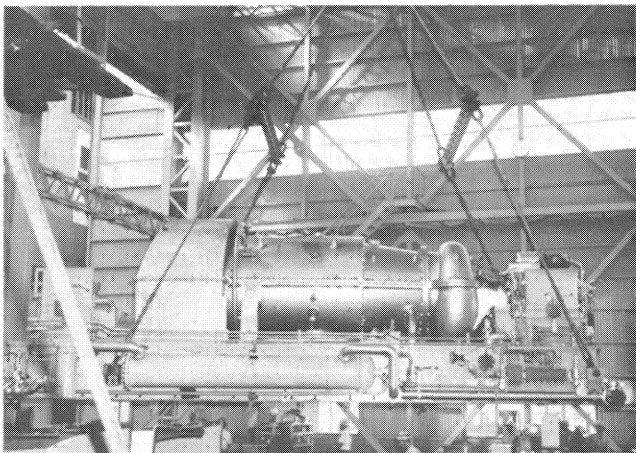


Figure 6. Industrial Gas Turbine SB 90C (Mitsui Shipbuilding & Engineering Co.).

2. The inner casing is sub-divided into 4 portions, i.e. the front and rear portions of the compressor, the turbine inlet and the blade row portions.
3. Quiet operation is ensured by the high sound attenuation effect of the double casing structure.
4. An output shaft is provided at the compressor suction side, and so eccentricity and displacement due to thermal expansion are kept small.
5. On account of the single-can type combustor installed on the outer casing, maintenance and inspection of the combustor are easy to carry out.

Figure 7 shows the IM5000 gas turbine unit IHI (Ishikawajima Harima Industries) has developed. This unit is applicable widely both for generator drive and for mechanical drive. The performance characteristics are as shown in Table 3.

TABLE 3. PERFORMANCE CHARACTERISTIC OF IM5000 GAS TURBINE.

Ambient Temperature °C	15	30	45
Power Output MW	37	31	26
Specific Fuel Consumption kg/kWh	0.23	0.24	0.25
Thermal Efficiency %	37	35	34

The IM100 land and marine use gas turbine was evolved from the T58 turboshaft engine. Because of light weight, small size and high reliability, IM100 is employed widely in mobile power supply vehicles, hovercraft and so on. Two versions of IM100 engine, i.e. IM100-2 and IM100-4, are now available, and more than 70 units have been sold in New Zealand and Japan. Performance characteristics are as shown in Table 4.

Figure 8 shows the PU200 Gas Turbine Generator, which KHI has developed recently by its original design. Official approval of the Fire Defense Board of Japan was given to the engine in July 1976. The engine delivers a rated continuous power output of 150kW/135kW at an altitude of 150m at ambient temperatures of 30°C/40°C. The specific fuel consumption amounts to 530g/kWh at power output of 150kW.

Quite recently, KHI has succeeded in developing another gas turbine generator PU1250 having capacity of 1250kW. This engine will be available as soon as the approval by the Fire Defense Board of Japan is given.

2.2 GAS EXPANDERS

Ever since the sharp oil price hikes occasioned by the oil crisis, voices demanding energy conservation, waste-heat recovery and more effective use of energy, have come to be frequently heard. IHI has been carrying out basic and development researches in the domain of industrial waste heat recovery. The fruit of these efforts is the IHI Fron Turbine System, embodying the organic Rankine Cycle turbine, which utilizes fluorocarbon having low boiling point.

Figure 9 shows the flow diagram of Fron Turbine System thus developed. Liquid fluorocarbon pressurized by the feed pump passes through the gas generator, where it receives heat from the heat source and vaporizes under constant pressure. The high-pressure fluorocarbon gas thus produced is led into the Fron turbine, where it undergoes adiabatic expansion, and

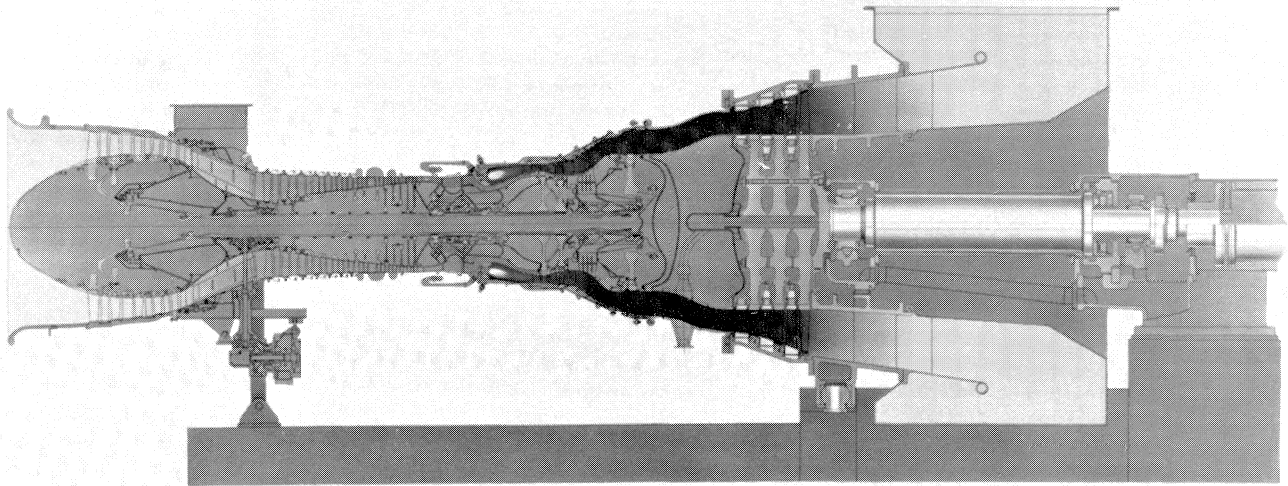


Figure 7. IM5000 Gas Turbine (IHI).

TABLE 4. PERFORMANCE CHARACTERISTICS OF IM100-4 GAS TURBINES.

	IM100-2			IM100-4		
	15	30	45	15	30	45
Ambient Temperature °C	15	30	45	15	30	45
Power Output kW	920	800	670	1100	960	810
Specific Fuel Consumption kg/kWh	0.42	0.44	0.48	0.37	0.39	0.43
Thermal Efficiency %	20.2	19.0	17.7	22.8	21.4	19.6

Features of these engines are: compact size requiring narrow installation area, high reliability, unmanned operation and so on.

the exhaust is conveyed to the condenser, which cools the gas to condense for recycling through the feed pump.

It is through adiabatic expansion that conversion to mechanical energy takes place. Thus, the driving of the refrigerating machine, electric generator or other machines is accomplished.

IHI Freon Turbine System can recover useful energy from waste steam discharged from factories and plants, fluids from chemical plants and oil refineries, hot effluent water and gases from steel works and steel mills. In addition, this is applicable also to solar heat utilization and geothermal power generation.

MHI is manufacturing gas expanders for high pressure and high temperature gases. MHI gas expanders are applicable in

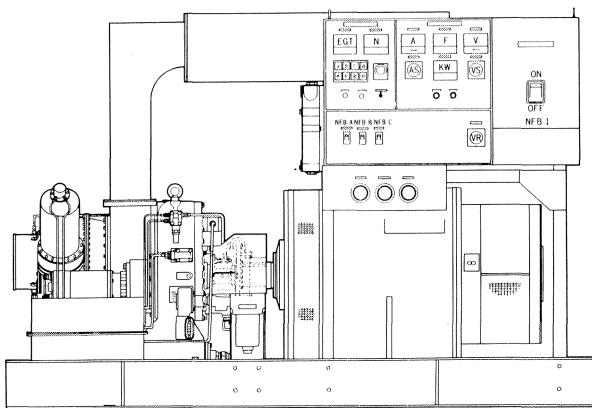


Figure 8. PU200 Gas Turbine Generator (KHI).

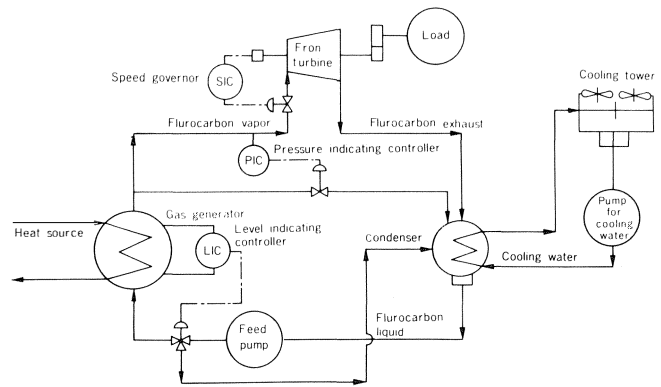


Figure 9. Flow Diagram of Freon Turbine System (IHI).

the range of inlet gas pressures up to 20kg/cm² as well as gas temperatures up to 700°C.

The steel industry has been making efforts to expand the capacity of the blast furnace and also to increase the working pressure. This tendency has resulted in a considerable increase in the pressure energy of blast furnace gas, discharged from the top of the furnace (hereinafter referred to as BFG). From the standpoint of energy conservation, the so-called top-pressure recovery generating plant, which expands the BFG through an expander turbine and utilizes it to generate electric power, has been investigated by Mitsui Shipbuilding and Engineering Co. (MSE).

MSE has developed a top-pressure recovery turbine (hereinafter referred to as TRT) of a wet, axial-flow type having the following features. It is conceivable that either axial-flow turbine or radial-flow turbine may be employed. Axial-flow turbine has an efficiency higher than the radial-flow one, and is compact in size, thus reducing the investment cost. Pressure energy is usually recovered in the form of electric power, which can be generated by a direct-coupled 2-pole alternator. In addition, by adopting an axial-flow turbine, enlargement of the machine becomes possible. Thus, BFG up to 800,000Nm³/h can be handled by a single machine, generating around 20,000kW. The number of stages in the TRT can be arbitrarily selected to match the BFG conditions. Dust-contaminated moisture is condensed on the turbine blading. Therefore, the turbine will also play the role of a dust and mist separator.

2.3 TURBOCHARGERS

Figure 10 shows the relation between the pressure ratios of superchargers and the brake mean effective pressures of the domestic diesel engines, and it is the recent trend that higher pressure ratios are required with an increasing brake mean effective pressure. IHI has been manufacturing turbosuperchargers having maximum pressure ratio of 3 at various volume flows corresponding to the engine outputs of 50~900HP.

Figure 11 shows the RH06 turbocharger, 3000~4000 units of which are produced per month by IHI. The overall length of the RH06 is roughly 200mm, its weight being 3.5kg, and so, this is the world's smallest turbocharger as is seen in Figure 11. IHI contracted technical tie-up with Brown Boveri & Co. in 1958, and has been manufacturing IHI-BBC VTR type turbochargers, in versions covering pressure ratios of 3.5~4.0 at volume flows of 0.4~40m³/sec.

Figure 12 shows the Super MET B type Exhaust Gas Turbocharger manufactured by MHI. MHI developed MET type turbochargers, non-water cooled, in 1965, and since then MET turbochargers amounting to 2,088 sets have been manufactured (as of the end of 1976). These turbochargers have been installed on UE engines, Sulzer engines and others. Five versions are available both for 2 cycle and 4 cycle engines ranging from 1,000 to 50,000HP. Super MET T type and Super MET B type turbochargers have improved performance characteristics (pressure ratio of 3.5 at maximum continuous revolutions and temperatures), and have been developed for the uprated engines having brake mean effective pressures ex-

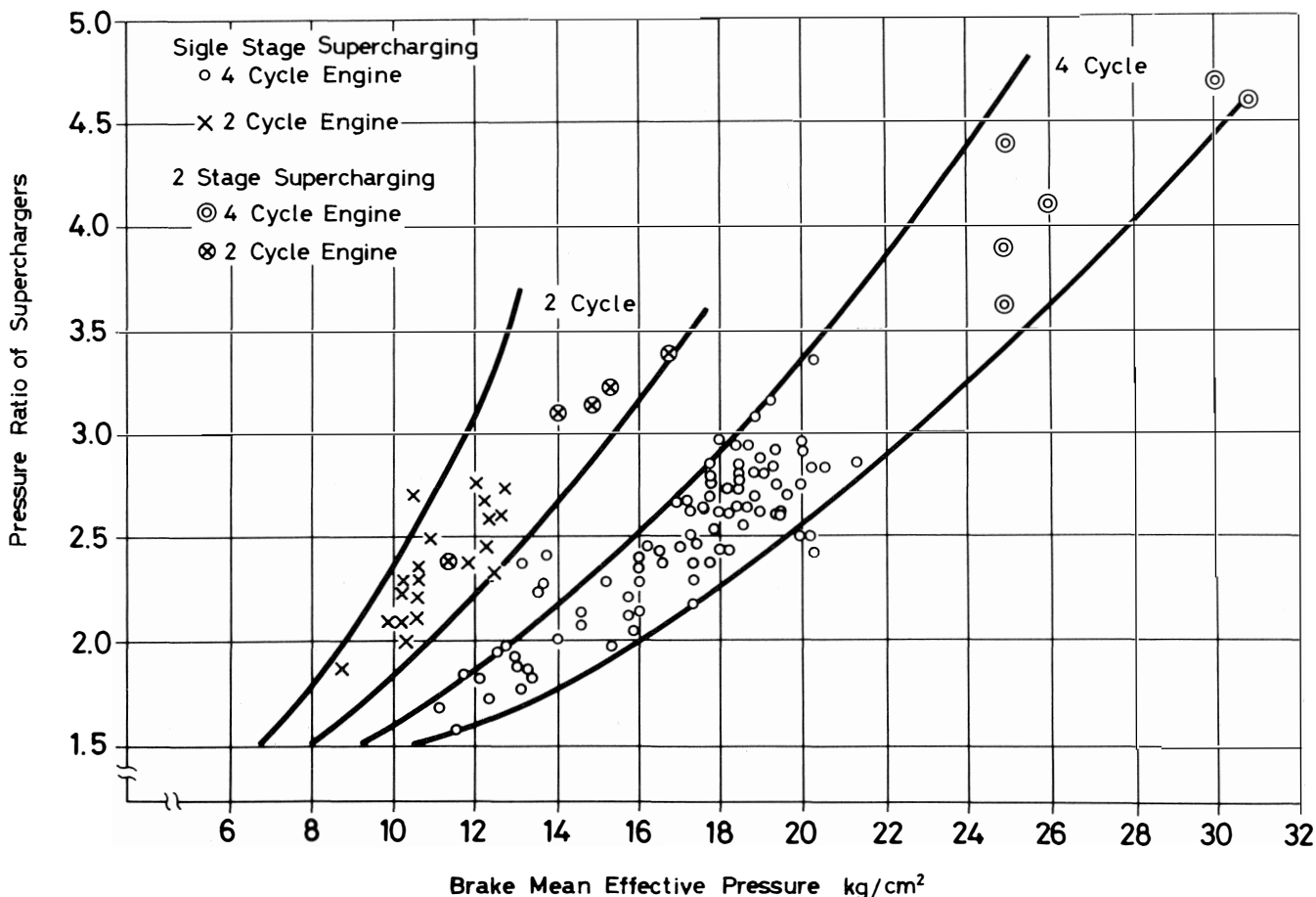


Figure 10. Trend of the Pressure Ratio of Superchargers Increasing with the Mean Effective Pressures of Domestic Diesel Engines.



Figure 11. The RH06 Turbocharger, the World's Smallest One.

ceeding 12kg/cm^2 . These turbochargers are applicable both for 2 cycle and 4 cycle engines ranging from 1,500HP to 60,000HP. T type and B type differ from each other with respect to the direction of flow of exhaust gases.

2.4 STEAM TURBINES

The state of affairs concerning steam turbines in Japan are as follows [4].

Reduction of running cost is of utmost importance on account of high costs of fuel. To meet these needs, steam conditions of as high pressure and temperature as possible are usually adopted. It has been a popular practice to adopt steam having supercritical pressure if possible. In like manner, steam temperatures amount to around 566°C (1050°F) when sub-critical pressure is employed. At supercritical pressures, the temperatures remain at around 538°C (1000°F), but reheating up to 566°C (1050°F) is usually done for the sake of efficiency improvement. This tendency is remarkable in the units having capacities exceeding 150MW.

Machines having large capacities are adopted to improve turbine efficiencies, thus enabling the reduction of the cost of electricity generation. The larger machines make it possible to decrease the number of operators by the adoption of computer-aided automatic system. Thus, adoption of long blade at the final stage becomes necessary. Blades having lengths of 33.5in. for 2 pole machine and 43in. for 4 pole machine when 60Hz is employed, and 33.5in. for 2 pole machine and 41in. for 4 pole machine when 50Hz is applied are actual examples.

It is necessary, further, to improve the strength of the blades of the first stage receiving large impulsive forces of steam. Thus, the method of halving the blade heights of the first stage by adopting double flow entry, thus decreasing bending stresses by steam, is adopted in actual machines having capacities of 700MW and 1000MW.

New material named 12 Cr has been adopted to withstand high centrifugal stresses caused by ever enlarging rotors. This material was found superior with respect to heat resistance and endurance.

A large sized machine necessitates bearings having large diameters like 22in. and so on. In case of bearings having such

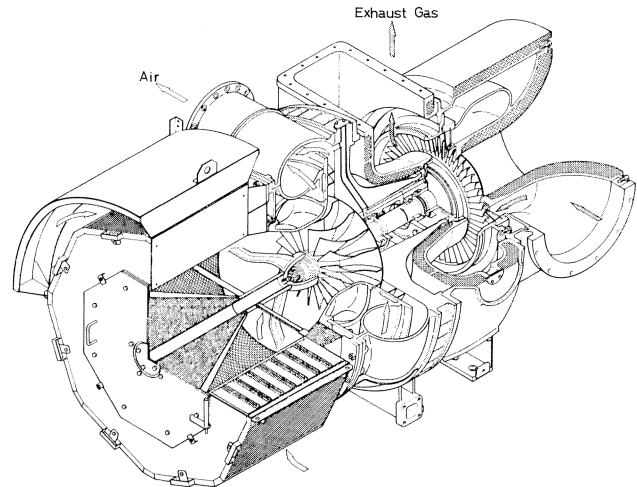


Figure 12. Exhaust-Gas Turbocharger Super MET B Type (MHI).

large diameters, the oil film may be of turbulent flow rather than of laminar flow, and so the hydrodynamical characteristics of the bearing vary largely. Thus, the dynamical stability of bearings is now under test using actual bearings.

When adopting a higher peripheral speed of the rotor, erosion of blade surfaces of the final stage due to the collision of water droplets within the wet steam is liable to occur. The prevention method for it is under investigation.

In Japan, the construction of steam turbines having large capacities for nuclear power application is going on at present. The large sized plants having steam turbines, the steam pressure of which amounting to 950psig, are under construction for the light water reactor, the boiling water reactor and the pressurized water reactor application. Under the limitations of pressure at the reactors, steam conditions of 66.8kg/cm^2 pressure and 281°C saturation temperature are adopted, and the outputs amounted to 780~1100MW. Improvements in reliability are of the utmost importance in machines for nuclear power application, and so considerations concerning quality assurance are of primary importance. Further, precautions for X-rays should be taken into account. In the boiling water reactor machines, separate steam seal system is usually adopted.

MHI has constructed a steam turbine of its original design for driving centrifugal compressors at chemical plants, i.e. ethylene plant, ammonia plant, LPG plant and so on. The capacity and the revolutions are 32,000kW and 12,000rpm respectively. The turbine is of variable speed, and operations at revolutions of 80~105% of the design rpm are available.

2.5 COMPRESSORS AND BLOWERS

Figure 13 shows a centrifugal compressor IHI developed recently. As shown, the centrifugal impeller milled from forged aluminium is driven by an electric motor through planetary speed-up gear, the revolutions of the impeller being 33000rpm when 60Hz is applied. The diffuser guide vanes are of movable type, which enable constant delivery pressure operation at varied volume flows automatically. The compressor, together with the control panel, is installed within a package. IHC-22P-L turboblower can deliver $1.1\text{kg/cm}^2\text{g}$ delivery pressure at $65\text{m}^3/\text{min}$, the motor output being 150kW. Other versions of 240kW and 300kW are also available.

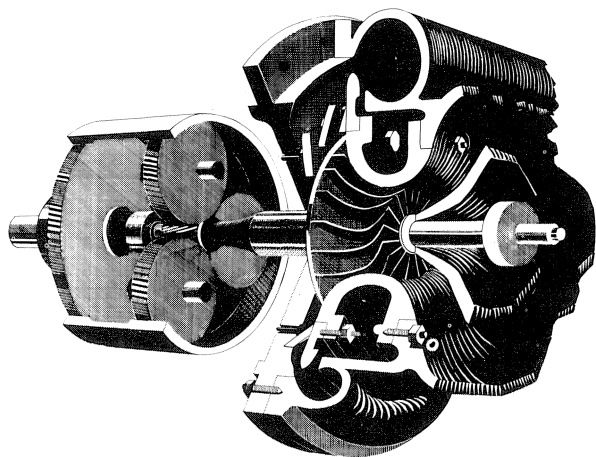


Figure 13. Centrifugal Compressor having Planetary Speed-up Gear (IHI).

An ultralow temperature LNG compressor, manufactured by IHI for delivery to Osaka Gas Co.'s Semboku LNG Terminal, was designed with the following specifications.

Type	Multi-stage, double casing centrifugal compressor, having speed-up gear
Suction gas temperature	-130~ -150°C
Discharge gas pressure	30kg/cm ² g
Revolutions	Low pressure 11048rpm High pressure 13911rpm
Gas handled	LNG boil-off gas
Capacity	15000kg/h
Motor capacity	4000kW

Ebara Mfg. Co. delivered an exhaust blower of 1000HP to the sintering equipment of Dewight-Lloyd System which was firstly installed at a domestic steel mill in 1938. Since then, Ebara Mfg. Co. has been manufacturing and delivering exhaust blowers to many sintering plants in Japan.

Based on the investigations since 1965, construction of large blowers having high performance characteristics became possible at Ebara Mfg. Co. At present, main blowers driven by motors having outputs ranging from 15,000kW to 19,000kW are in operation at sintering facilities and are producing steadily a high quality ore efficiently.

Depending upon the volume and the nature of the dusts contained in the gas flow, the degree of wear within exhaust blowers differs tremendously. The centrifugal impeller is either of turbo-plate type or aerofoil type, and the blades are made of Ni-Cr steel plate or high tension steel plate. As the impeller is of a rivetted construction, replacement is available if substantial wear develops. In addition, attachment of a liner or dust preventing construction was adopted for antiwearing purposes.

Ebara Mfg. Co. has been manufacturing high pressure blowers having maximum adiabatic temperature efficiencies of 85% or more, the surge limit of them being less than 60% of the capacity. When a silencer is attached, the noise level measured at the top of the chimney is usually less than 76phons.

Figure 14 shows the exhaust blower for sintering equipment delivered to Ooita Iron Plant, Nippon Steel Corp. in the

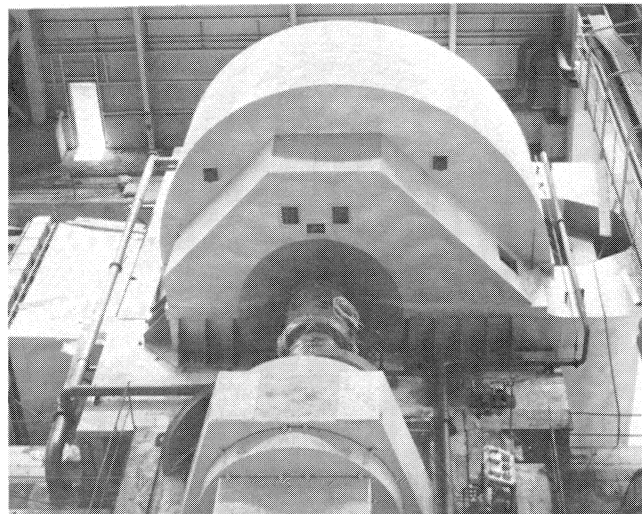


Figure 14. Main Exhaust Blower for Sintering Equipment Installed at Ooita Iron Plant, Nippon Steel Corp. (Ebara Mfg. Co.).

period 1971~1972. Its specifications were as follows: volume flow of suction air 40,000m³/min at suction air pressure and temperature of -1680mmAq and 150°C respectively, the motor output amounting to 14200kW at 900rpm. This blower was installed indoors, attached with a silencer.

As the production of crude steel increases, more oxygen is required, which in turn calls for larger air separation plants and process air compressors for use in steel-making industries. Axial flow compressors, suitable for large volume flow, are thus being adopted, replacing centrifugal compressors.

In view of the large effect the power consumption of the process air compressor has on the production cost of oxygen, all possible efforts should be made to minimize power consumption. Synchronous motors, which are characterized by easy maintenance and high efficiency, are usually employed as a prime mover to drive the compressor at a constant speed. It is essential that the compressors have a wider operating range to meet the maximum and minimum flow requirements of the plant without blowing-off. To meet such requirements, axial compressors manufactured by MSE have an adjustable stator blade system and an inter-stage cooling system.

Figure 15 shows a general view of the axial compressor manufactured by MSE with upper casings dismantled.

Figure 16 shows the high pressure fan for forced draft to boilers. To perform forced draft or induced draft to the boilers for thermoelectric power generation, centrifugal fans have been employed. MHI adopted, instead, axial fans having variable pitch rotor blades. Adoption of axial fans was initiated by Japanese companies including MHI, and recently, MHI is exporting this type of fans to the Combustion Engineering Co.

The CEMAX (CE-Mitsubishi Axial-Flow) controllable pitch fan developed for thermoelectric power plant application offers a more stabilized service than other types of fans as to the surge.

Figure 17 shows the 70,000kW axial compressor for Mizushima Works, Kawasaki Steel Corp. constructed by MHI, July 1973. This compressor is for supplying air to No. 4 blast furnace, volume of it being approximately 4300m³. Its maximum capacity of 70,000kW will be the largest in the world

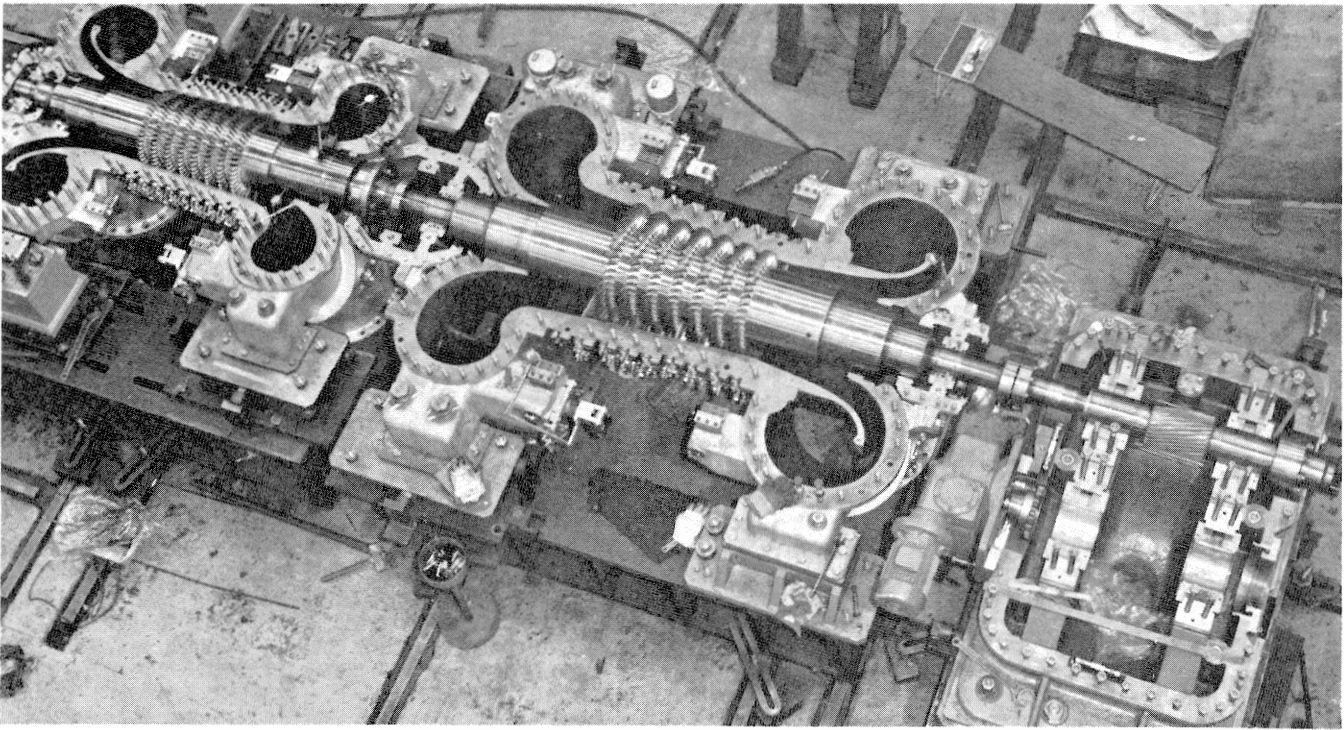


Figure 15. Axial Flow Compressors for Air Separation Plants (Mitsui Shipbuilding and Engineering Co.).

at present. It delivers pressures up to 7.0kg/cm^2 gauge at volume flows up to $10,000\text{ Nm}^3/\text{min}$, at atmospheric condition of 760mmHg , 30°C and relative humidity 85% . The steam turbine which drives the compressor is of single flow impulse type, the rated output being $70,000\text{kW}$ at $3,000\text{ rpm}$. The feature of this compressor is that all stages are installed with movable stator blades, thus widening the operation range.

MHI has been manufacturing many axial compressors and blowers for steel plants, chemical plants and so on. Especially, the $22,500\text{kW}$ blower for transonic wind tunnel constructed in 1960, the $23,000\text{kW}$ axial blower for blast furnace established in 1966, and the $60,000\text{kW}$ motor driven axial blowers for blast furnace use, together with the largest one shown in Figure 17, are the typical ones.

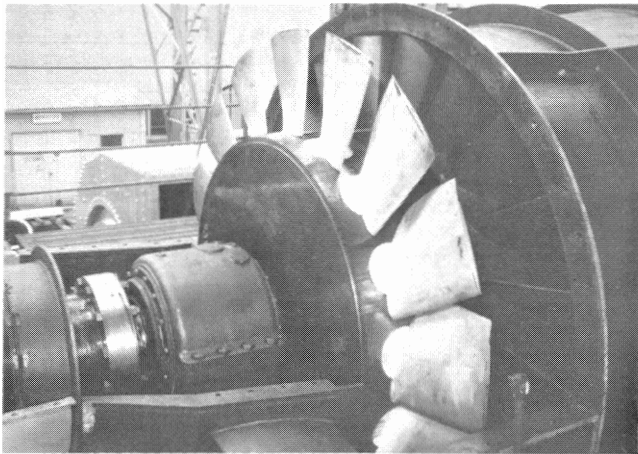


Figure 16. High Pressure Fan for Forced Draft to Boilers (CE-MHI Fans Co.).

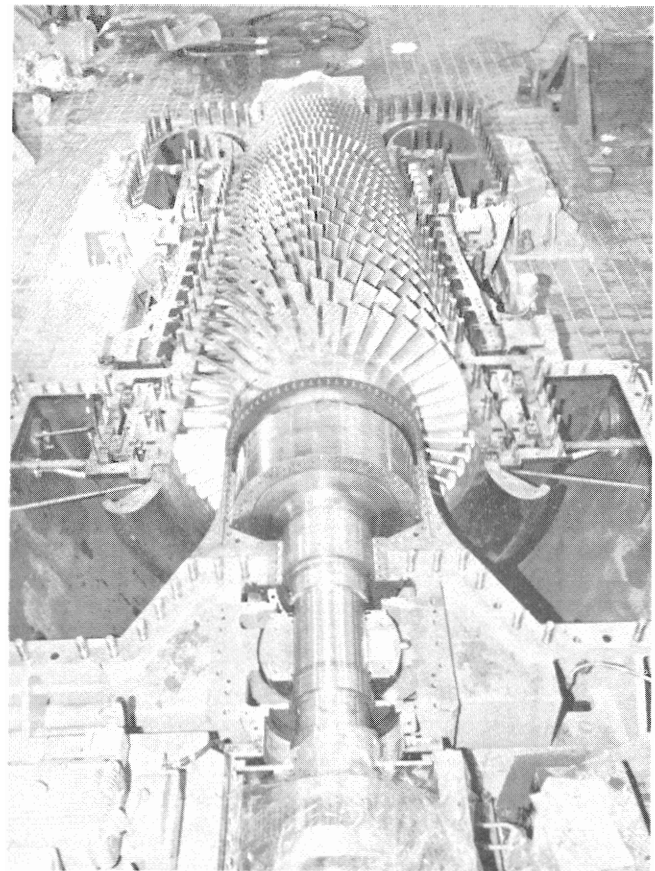


Figure 17. The World's Largest $70,000\text{kW}$ Axial Compressor for Blast Furnace (MHI).

Hitachi Co. has been producing large centrifugal fans having impellers of 3000~4000mm diameters, which are employed to force or suck in air to the boilers for thermoelectric power station. The objective of the research concerning this type of fan lies primarily in the reduction of production cost. Thus, the smaller size accompanied by improved performance characteristics and the light weight construction because of the strength consideration are the outstanding features.

Hitachi Co. has developed single stage centrifugal compressors having adiabatic efficiencies of 88%, specific speeds ranging from 150 to 450 and pressure ratios amounting to 1.5~2.0 for industrial use. Package type centrifugal compressors compressing air up to delivery pressures of 8~10kg/cm²g have been employed as air sources in various fields instead of reciprocating compressors. The former is compact in size, with low noise level and less vibration. In addition, maintenance and installation are easy and time between overhauls is longer than the latter because of no valves installed. The capacities are 200~3000kW, and the stages are usually four having an inter-cooler between them. Figure 18 shows the 2 stage centrifugal compressor Hitachi Co. developed. As shown, the unit is completely packaged.

In Japan, we have a very long tunnel having 8500m length at an elevation of 700m from sea level for automobile highway use, which ranks second in the world to the longest one, i.e., the Mont Blanc tunnel. The tunnel is located on the Central Expressway, and is named Enasan Tunnel. Four sites for ventilation were established, and two ventilating fans and two exhauster fans were installed at these sites respectively. These fans are of axial type, and they are computer-controlled from the control center located around 25km distant. IHI and MHI manufactured four ventilating fans and four exhauster fans respectively, and they have been operating satisfactorily since August, 1975.

Ebara Mfg. Co. constructed an OG blower, which has been used in the Oxygen Converter Gas Recovery Process.

Figure 19 shows the turbo refrigerator equipped with centrifugal compressor, the working media being Freon 11, 12 and 113. Recently, Hitachi Co. has succeeded in developing and producing tubes having high heat transfer capacity (this is called "Thermoexcel" commercially). Thus, Hitachi developed a small-sized light weight turbo refrigerator having high performance characteristics. The centrifugal compressor, for

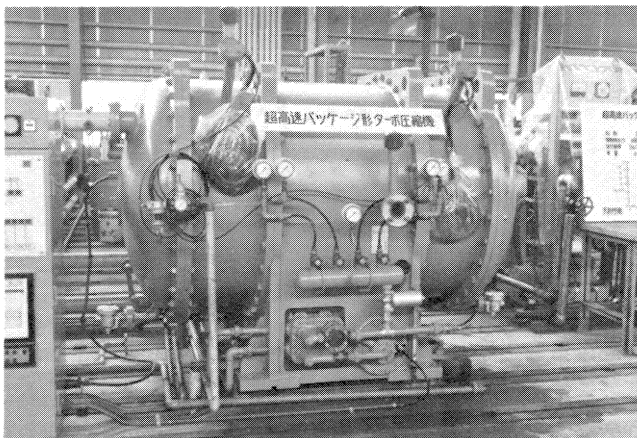


Figure 18. 2 Stage Centrifugal Compressor Completely Packaged (Hitachi Co.).

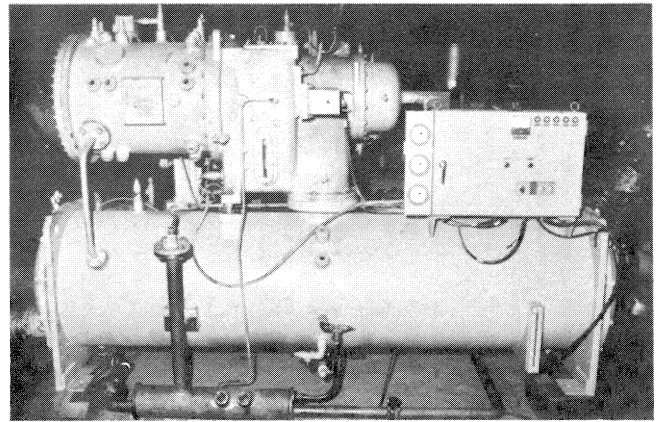


Figure 19. Turbo Refrigerator 200RT (Hitachi Co.).

example, is of specific speed of around 330, with rotation rate 23,000rpm and pressure ratio 4:1, the peripheral speed of the impeller at the impeller eye being nearly equal to sound velocity in case Freon 12 is employed. The impeller has splitter vanes, the location of which is a little deviated from the mid-position.

2.6 WATER PUMPS AND TURBINES, INCLUDING PUMP-TURBINES

Hitachi Co. constructed a mixed flow pump-turbine of 145MW unit capacity. The pump-turbine has an impeller having movable rotor blades, and this unit has proved to be of the largest capacity in the world. The unit was installed in Masegawa No. 1 Hydroelectric Power Station, and has gone into service operation in June, 1976. The success was brought about by the development of a runner having high specific speed, as well as the improvement of pump characteristics and cavitation characteristics. This pump-turbine was found to exhibit high performance characteristics for a wide range of variations in the head from 50 to 100m.

Researches concerning stabilization of performance characteristics are going on by Hitachi Co. concerning pumps for nuclear reactor as well as boiler feed water pumps. Especially, unstable operation at smaller flow rate should be avoided, and in addition, the reliability of the pump involving seal and vibration problems is to be secured.

Figure 20 shows a sectional view of pump-turbine and generator-motor installed at Okutataragi Pumped Storage Power Station of Kansai Electric Power Co. (MHI). This power station is one of the largest pumped storage power stations in Japan. It is equipped with four units of Francis pump-turbines and has a total power generating capacity of 1212MW.

Recently, to achieve greater economy, the main demands placed upon hydraulic turbines and pump-turbines have been higher capacities and higher heads. The trend is particularly notable in the pump-turbines built for pumped storage stations, and stations having capacities exceeding 1000MW are being constructed in this country. Besides Okutataragi Power Station, we have Shin-Takasagawa Pumped Storage Power Station of Tokyo Electric Power Co., the largest one in Japan, equipped with four Francis type reversible pump-turbines with a total generating capacity of 1280MW. In addition, we have Niikappu Pumped Storage Power Station of Hokkaido Electric Power Co., which is equipped with 2 sets of Deriaz type pump-turbines with a unit capacity of 103MW and

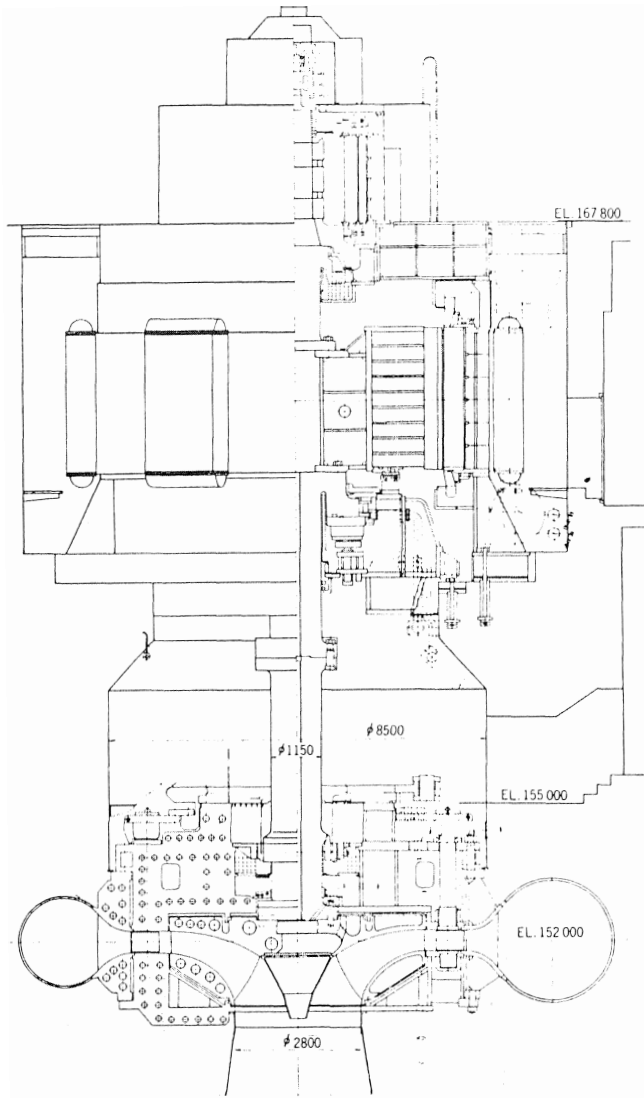


Figure 20. Sectional Arrangement of Pump Turbine and Generator-Motor Installed Okutataragi Pumped Storage Power Station of Kansai Electric Power Co. (MHI).

generator motors with a unit capacity of 105MVA. The station was completed in November, 1974 with successful field test. These pump turbines were manufactured by MHI.

Figure 21 shows the pump impeller of the worldwide largest pump installed at Misato Pump Station. The specifications of the pump are as follows: volume flow $50\text{m}^3/\text{sec}$, head 6.2m, 75rpm and 6200HP.

3. ACKNOWLEDGMENT

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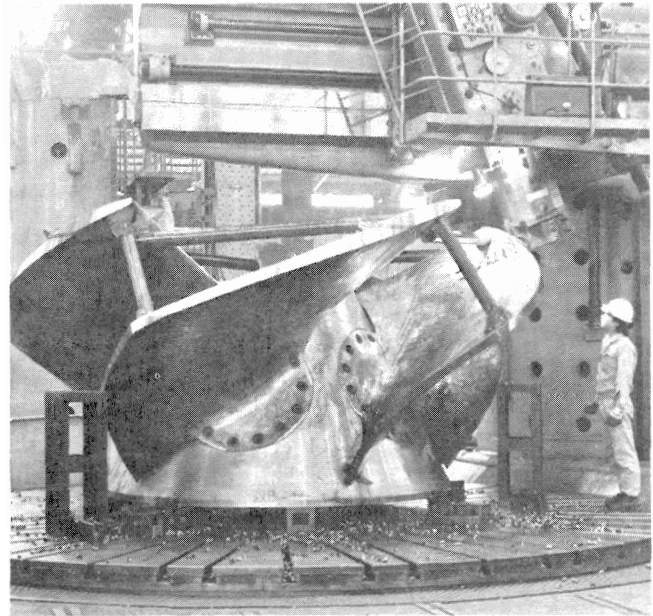


Figure 21. Pump Impeller of the Pump Installed at Misato Pump Station (Ebara Mfg. Co.).

