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MAIN EQUIPMENT FOR 500M, 400MW CHONGPYONG PUMPED-STORAGE POWER PLANT, KOREA

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I. FOREWORD

The Chongpyong pumped-storage power plant, the Korea Electric Co., is a 400 MW underground pumped-storage power plant planned for rational system operation with the large capacity nuclear power plants and steam power plants constructed sequentially to cope with the sudden demand increase for electricity caused by the high growth of the Korean economy in recent years, and is scheduled to begin service operation in 1979.

We got the order for almost all the generating equipment, including the pump-turbines, generator-motors, and main transformers, for the Chongpyong pumped-storage power plant, and are proceeding with their design and manufacture. The pump-turbines are the highest head class pump-turbines (2 x 206 MW 500m) in the world, and the direct-coupled generator-motors (2 x 220 MVA 450 rpm) are also the highest speed class large capacity machines.

The cross section of the waterway of the power plant is shown in *Fig. 1*, and the cross section of the power house is shown in *Fig. 2*. The water from the man-made upper pondage is led to the pump-turbines by two penstocks. The two tailraces merge into a single tailrace tunnel, after passing through the lower surge tank, and are connected to the lower pondage.

The main transformers, as well as the pump-turbines and generator-motors, are installed in the underground power house. The main transformers are connected to the outdoor switchyard by 154 kV OF cable run through a cable tunnel. All the equipment is controlled from the con-

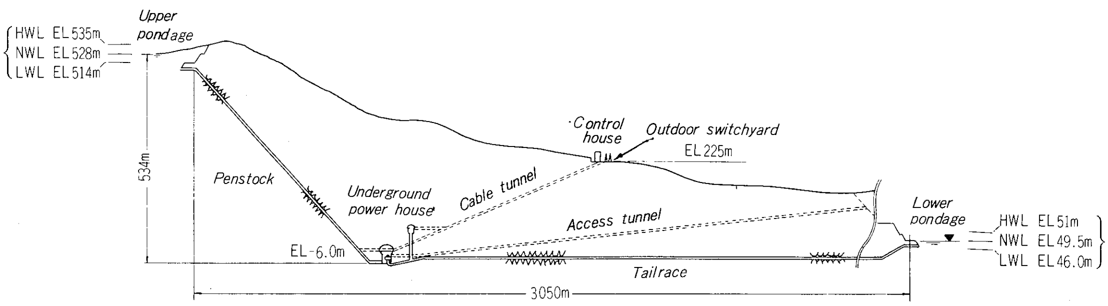

Fig. 1 Cross section of waterway

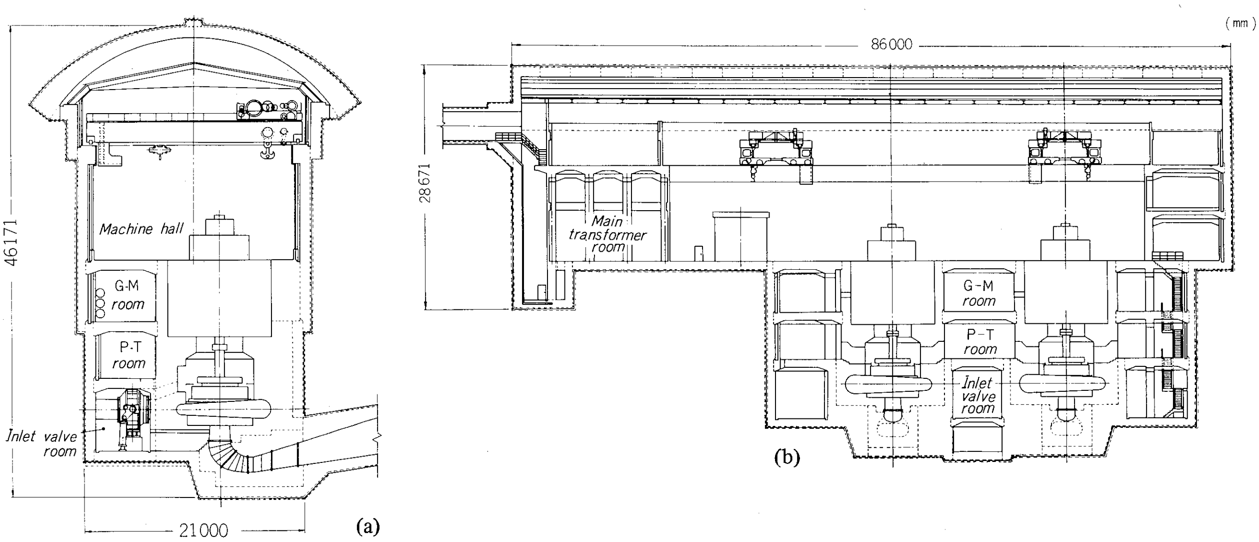

Fig. 2 Cross section of power house

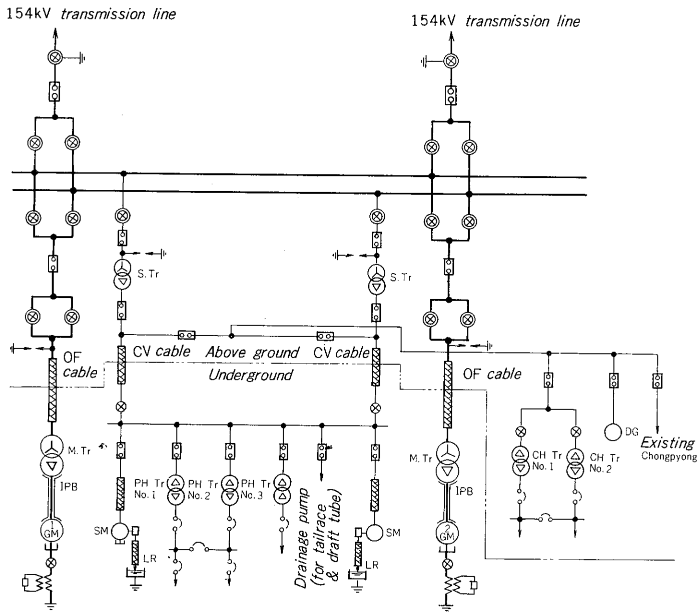

Fig. 3 One line diagram

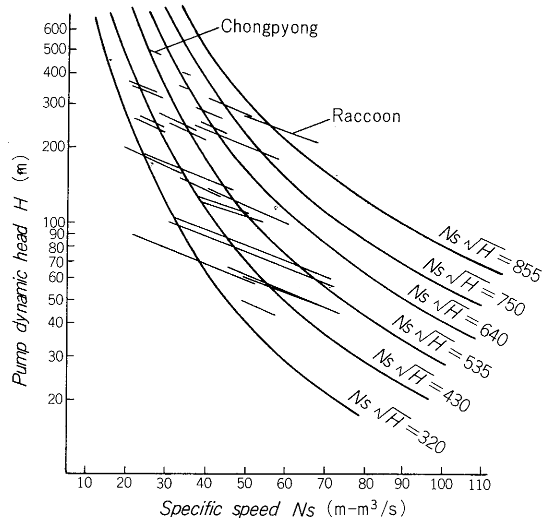

Fig. 4 Relation between pump specific speed and pump head

trol house above ground.

The one line diagram for the power plant is shown in *Fig. 3*. The high voltage side of the main transformers is connected through a double tie bus to a 154 kV two transmission lines. The starting transformer connected to 154 kV double bus is also used as the station service power supply.

II. SEVERAL STUDY FOR SPECIFICATION DECISION OF MAIN EQUIPMENT

Part of the results of various studies conducted to decide the final specifications during the customer's planning stage or after bid is described here.

1. Selection of Unit Capacity and Main Machine Speed

Both a 300 MW plan and 400 MW plan were studied as the power station output in the planning stage, but a 400 MW plan was finally adopted, from the standpoint of system operation. During this period, we cooperated with the customer by conducting various analysis on the affect of the 400 MW pumped-storage machines to the customer's power system. A comparative study of 3 plans of 514.3 rpm, 450 rpm and 400 rpm was conducted to decide the rotating speed. The main data comparison table is given in *Table 1*. In the case of the 400 rpm plan, the pump-turbine runner inlet height was too small for runner vane grinding work and welding repair work, and machine cost and civil engineering costs were high, and it was not recommended. Moreover, the 514.3 rpm plan still had a margin when viewed from the standpoint of the specific speed limit [pump specific speed (m-m^3/s) x head (m)≒850, see *Fig. 4*] in current engineering level, but couldn't meet the civil engineering cost, and 450 rpm was, therefore, selected as the ideal rotating speed.

Table 1 Economical comparison with machine speed

	Speed		514.3rpm	450rpm	400rpm
Pump-turbine	Pump specific speed	(m-m^3/s)	31.6	27.7	24.6
	Suction head	(m)	−62	−52	−44
	Turbine maximum efficiency	(%)	+0.7	0	−1.7
	Pump maximum efficiency	(%)	+0.7	0	−1.7
	Runner inlet diameter	(mm)	3,600	4,055	4,450
	Guide vane height	(mm)	360	334	284
	Casing inlet diameter	(mm)	1,900	1,900	2,050
	Cost	(%)	95	100	110
Generator-motor	Optimum bearing arrangement		Thrust bearing above rotor	Thrust bearing above rotor	Semi-umbrella type
	GD^2	(%)	80	100	136
	Stator inside diameter	(mm)	4,100	4,650	4,800
	Core length	(mm)	3,500	2,990	3,250
	Cost	(%)	99	100	105
	Crane capacity	(%)	98	100	106

2. Pump Starting System

For the starting the pumping operating mode, both a starting motor system and a thyristor starting system were studied.

The starting motor system was finally adopted from the standpoint of economy. The economy of the thyristor starting system is generally displayed when there are three or more nos. of the unit.

3. Generator-motor Bearing Arrangement

The semi-umbrella type bearing arrangements was studied for the generator-motor. In case of this machine, if the semi-umbrella type was employed, the cost would be somewhat lower, but for such a high speed machine having a long core length, a large reduction of height couldn't be expected. And so, the thrust bearing was decided to be located at the upper side of the rotor, considering the easy disassembly and inspection as shown in *Fig. 6.*

4. Generator-motor Braking System

Reducing the changing over time for the pumping and generating mode is an important factor of a pumped-storage power plant. Therefore, a combined mechanical brake and electric dynamic brake plan was studied to reduce the generator-motor stopping time. A comparison of the stopping time of both plants is given in *Fig. 5*. As a result, an exclusive mechanical brake plan was adopted because the stopping time was only reduced approximately 100 seconds even when combined with an electric brake and because of the cost and space required by the electric brake.

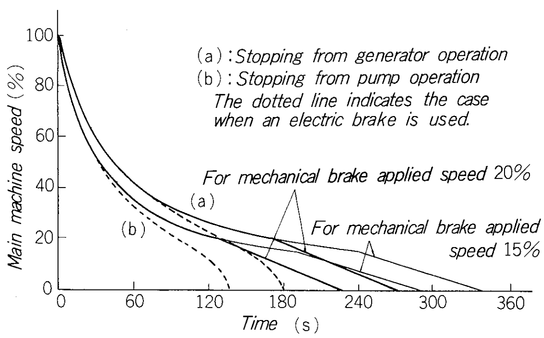

Fig. 5 Characteristics of breaking time

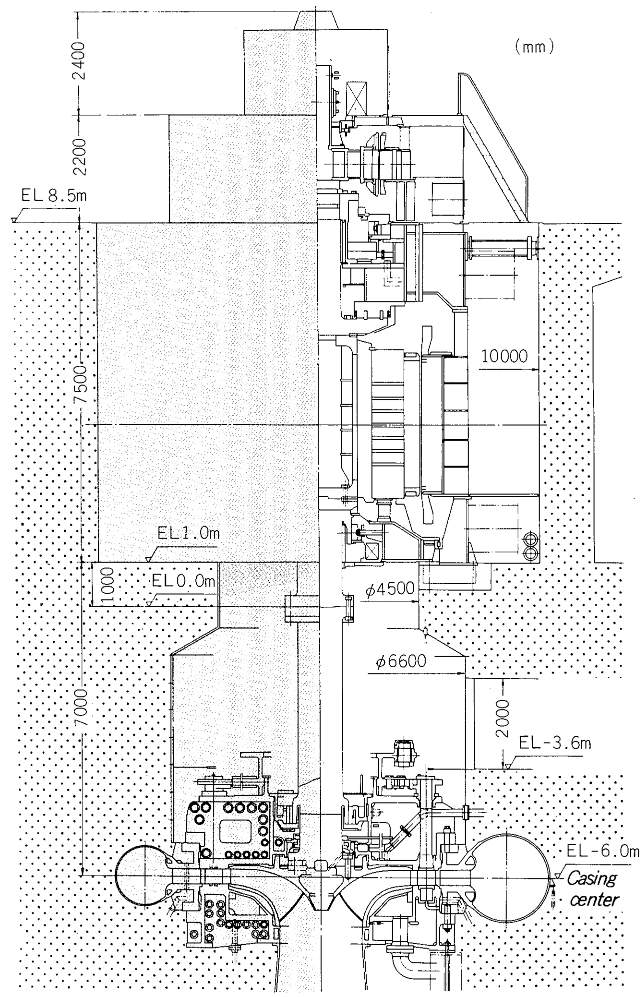

Fig. 6 Section of pump-turbine and generator-motor

III. SPECIFICATIONS AND CONSTRUCTION OF MAIN EQUIPMENT

1. Pump-turbine

1) Specifications

The main specifications of the pump-turbine are as follows:

Type
Vertical shaft Francis type reversible pump-turbine
Turbine specifications
Maximum output: 206,000 kW
Effective head: 473/452/437.5 m (maximum/normal/minimum)
Speed: 450 rpm
Specific speed: 98.0 (m-kW)
Pump specifications
Total head: 498.5/474 m (maximum/minimum)
Flow: 39 m^3/s
Input: 206,100 kW (maximum)
Speed: 450 rpm
Specific speed: 27.7 (m-m^3/s)

2) Construction

The sectional view of the pump-turbine and generator-motor is shown in *Fig. 6*.

Since this machine has a record high head and capacity, the construction and material of each part was conscientiously decided, based on the results of experiments with various reduced models or actual prototype test machine and the results of analysis on various performances, stress, distortion, vibration characteristic, etc. using the newest computerized technology.

The spiral casing is made of 60 kg/cm^2 high tension steel plate having a maximum thickness of 47 mm. The casing is connected to the stay-ring by the welding at the factory and divided into four parts, together with the stay ring, except the inlet pipe part, and welded into a single unit at the site.

The stay-ring is made of our special parallel type welded steel plate construction having superior performances and strength, and has four sections of flange-connection construction due to the limit of transportation. The casing and stay-ring welded into a single unit at the site are subjected to a hydrostatic pressure test, and then the top of the casing is roofed by the cushioning materials and buried

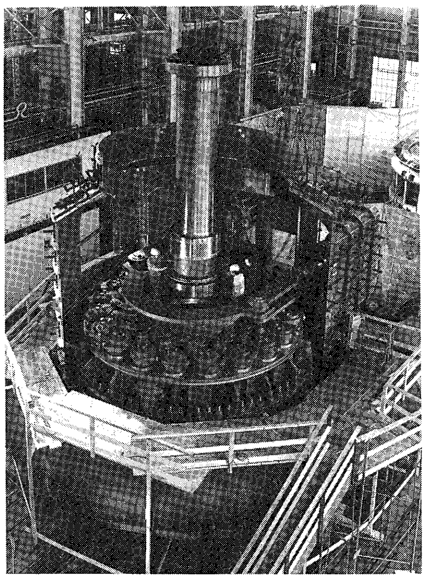

Fig. 7 Pump-turbine under shop assembly

in concrete.

The runners are made of 13% Cr-high Ni stainless steel casting featuring superior weldability, and has six vanes. The dimensions of each part, vane shape, etc. were decided from the results of computer flow analysis and detailed model tests.

Since it is a high head machine, and to suppress the effects of the water pressure pulsations or vibration produced from the runners, to a minimum, and to assure adequate rigidity, both the head cover and bottom cover are a thick steel plate welded construction.

The head cover is divided into four parts in the radial direction for convenience of disassembly and reaseembly. The bottom cover is constructed as a unit with the discharge ring, and is divided into two parts for transportation.

The guide vanes are the same high Ni stainless caststeel as the runners. Stress analysis and fatigue strength studies were conducted, in addition to hydraulic performance, and the ideal shape is adopted for all operating conditions.

A shear pin is provided inside a link mechanism and a brake to prevent collision with the adjacent guide vane when the shear pin is sheared off is provided at the top of vane stem for guide vane protection.

The main shaft is made of forged steel. The main bearing is a segmental type. The lubricating oil passes through a separately installed water-cooled oil cooler in the valve room, and is circulated by two motor driven pumps (one is for stand-by).

The segmental metal support section is supported by a system that amply withstands the large radial thrust and vibration caused by the runner, and makes gap adjustment simple.

The water sealing devices are equipped with our unique axial direction pressure balance type carbon packing whose superior water sealing performance and air tightness have been proved by numerous actual machines.

The draft tube liner is the elbow type, and is shipped in five parts and welded into a single unit at the site.

3) Auxiliary equipment

(1) Inlet valve

The inlet valve is a double seal water pressure operated spherical type having a diameter of 1900 mm. The both valve casing and valve body have a steel plate welded construction.

(2) Governor

The governor is our standard solid-state "Transidyne" type electro-hydraulic governor having a record of numerous achievements. And a optimum operating divice due to the water level difference for pump operation is added.

(3) Others

The pressure oil supply system is a unit system and 50 kg/cm^2 of oil pressure is used. The compressed air is supplied from the water depression system described next.

The water depression system employs a 70 kg/cm^2 of system pressure, and consists of 3 air compressors (one for common stand-by use) and two air tanks for two pump-turbines. Each tank has sufficient capacity for two times of water depression without supplying the air from the compressor.

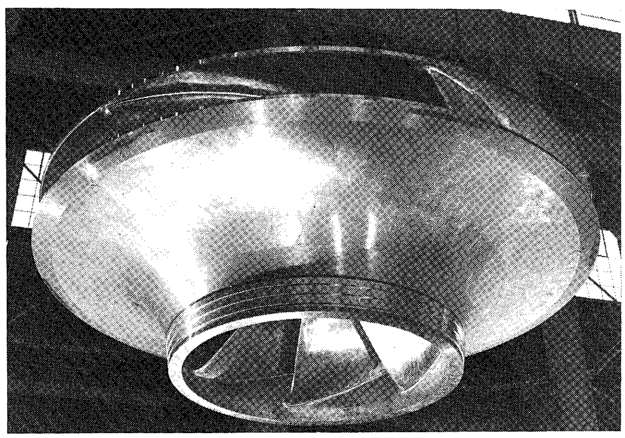

Fig. 8 Finished runner

The water supply system consists of three water supply pumps (one for standby). The cooling water is taken from the draft tube. Each liquid resistor for starting motor is equipped with a special cooling pump because cooling water is required even when the main machine is stopped.

The water drainage system inside the station employs a central system, and consists of three motorized drainage pumps (one for stand-by) that discharge the water of the drainage pit inside the station to the tailrace surge tank through the cable tunnel.

Moreover, one drainage pump is installed for draft tubes and tailrace, in addition to the above.

2. Generator-motor

1) Specifications

The main specifications of the generator-motor are as follows.

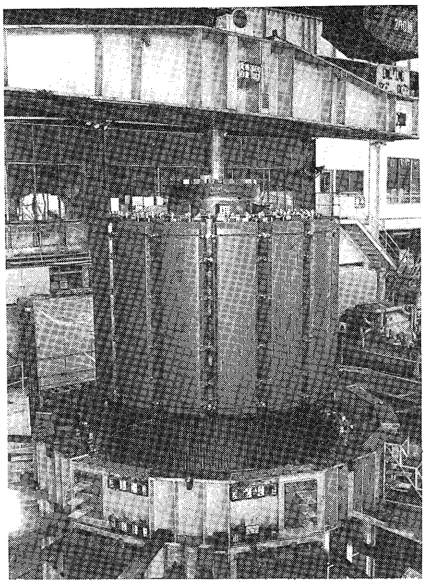

Fig. 9 Rotor of generator-motor, under shop assembly

Type	Vertical shaft totally enclosed internal cooling type 3-phase synchronous generator-motor.	
Ratings	(Generator)	(Motor)
Capacity	220,000 kVA	220,000 kW
Voltage	13.8 kV	13.8 kV
Frequency	60 Hz	60 Hz
Speed	450 rpm	450 rpm
Power factor	0.91 (lagging)	1.0

Bearing arrangement: Thrust bearing above rotor.

2) Construction

The generator-motor is installed on the concrete barrel, and is surrounded by a concrete wall.

Since it is a high speed reversible machine having a comparatively large core length, a separate ventilation system by separately installed axial flow fan is employed, and is cooled by air coolers arranged around the periphery of the stator.

The stator is divided into four parts, together with the core and coil, for shipment. The stator winding is our F resin/F insulation (Class B) type 1-turn coil four parallel star connection.

The rotor consists of a welded steel plate intermediate shaft (so-called rotor center), thick steel plate laminated construction yoke and poles. The intermediate shaft and yoke are shrink-fit, and the inverted-T type key system effective in high speed machines is used to install poles to the yoke.

Both the upper shaft and lower shaft are made of forged steel. The upper shaft is provided with a magnetic bearing's rotating part. Special consideration has been given to the strength of the upper and lower bracket so that the rigidity of the upper and lower guide bearings is high, from the results of analysis on the vibration response characteristic of the entire shaft system for the vibration from the pump-turbine, etc. Moreover, antivibration measures have been taken around the outside of the upper bracket.

A magnetic bearing's stationary parts and thrust bearing are provided at the upper bracket, and a lower bearing and brake are provided at the lower bracket.

The thrust bearing is the reversible Michel type with 10 segments, and employs a forced lubrication system using two motor driven pumps (one of which is for standby). The oil cooler is installed outside the ventilation housing. In addition, the guide bearing is the segmental type. The upper guide bearing is installed inside the common oil tank with the thrust bearing, and the lower guide bearing employs an oil bath self-lubrication system.

3) Magnetic bearing

The magnetic bearing is installed at the top of the rotor to reduce the static friction torque at starting, and bearing loss during normal operation, and assure smooth starting and increased operating efficiency. The magnetic bearing pulling force is controlled in two steps, at starting and at normal operation.

4) Starting motor

A wound-rotor induction motor (19.5 MW 6.6 kV 514 rpm 15 minutes rating) is installed at the top of the main generator-motor for pump starting. To make the starting time short, its capacity has been made slightly larger than that of the normal selection practice (5~8% of main motor capacity) and is approximately 10% of the generator-motor.

The speed of the starting motor is controlled by a separately installed liquid resistor. The liquid resistor has sufficient capacity to start up the pump 2 times successively.

The liquid resistor consists of a resistor body, electrolyte auxiliary tank, electrolyte circulation pump, and cooler, and maintains the output of the starting motor during starting acceleration at 1 pu, and permits fine speed adjustment at synchronizing of the generator-motor.

5) Excitation system

The excitation system is the thyristor static type. The AVR is our standard "Transidyne" type having a numerous record of achievements. Moreover, a power system stabilizer (PSS) is installed so that normal system disturbances and disturbances caused by power variations at synchronizing of the generator-motor are suppressed. Moreover, the

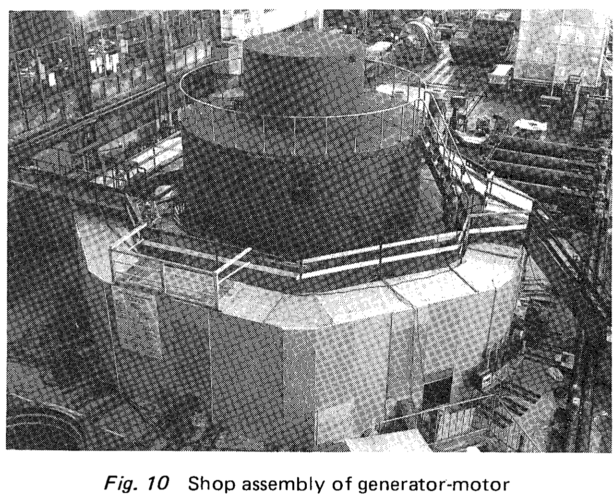

Fig. 10 Shop assembly of generator-motor

moulded transformer developed by Fuji Electric is used as the exciting transformer.

3. Main Transformer

1) Specifications

The step-up and power receiving main transformer has the following specifications,

Type	Indoor, forced oil water cooled, special three single-phase system (with on load tap changer)	
Specifications	Rated output:	225,000kVA
	Rated voltage:	Primary: 13.8kV
		Secondary: 154kV (168~140kV)
	Frequency:	60Hz
	Connectios:	Primary: Delta
		Secondary: Star (neutral point directly grounded)

2) Construction

The main transformer is a special three single-phase type for the transportation limit. After the completion of factory test, it is separated into each phase tank and tap switching tank and shipped to the site where it is reassembled as a three-phase unit.

The main transformer high voltage side is connected through reverse elephant head to 154kV OF cable. Moreover, the low voltage side is connected to the generator-motor through an Al made isolated phase bus. This transformer is installed in the transformer room inside the underground power house, and equipped with a water injection type fire extinguishing system.

4. Switchboard and Control Equipment

The supervisory and control system is a one man control system in which future remote supervision and control has been considered.

The main machine is controlled from a switchboard installed in the above ground control house. Therefore, the monitor panel and operator desk, etc. required for normal supervision and operation are installed in the above ground control house, and the automatic control panel, protection relay panel, exciter panel, governor control panel, and main transformer control panel required for main machine control are installed at the underground power house.

The control signals are relayed between the control house and underground power house by means of electric relays to reduce the number of cables. A relay panel is installed at both the control house and underground power house. The relays of control house relay the conditions, status, and trouble indication of each underground device. The relays of power house control each device by relaying the control signals and above ground conditions, etc. from the control house.

One set of DC power supply equipment is installed at both the control house and underground power house. The capacity of both the above ground and underground storage batteries is decided for a 30 minutes power interruption.

5. Other Devices

1) 13.8kV bus run

The 13.8kV bus run employs a 10,000A Al isolated phase bus. The bus has a total length of approximately 41m (No. 1 machine)/70m (No. 2 machine). However, they are divided into lengths of 5.3m or less for shipment, and welded together at the site. The bus sheath is one-point grounded.

2) 154kV OF cable

The 154kV OF cable installed in the approximately 700m cable tunnel is single-core 900mm^2/phase lead covered PVC sheathed cable. The difference in altitude between the main transformer and outdoor switchyard is approximately 250m, but interim joints are omitted. The sheath is of single-end ground, and is grounded at the above ground switchyard.

3) Outdoor switchgear

The 154kV circuit breaker is our standard SF_6 gas tank type circuit breaker having a capacity of 50kA.

4) Overhead travelling crane

Two 200/45 ton overhead travelling cranes (with 10 ton auxiliary trolley) are installed for installation and maintenance of the equipments installed in the underground power house. Simultaneous linked operation of these two cranes is considered to lift the rotor of the generator-motor.

5) Diesel generator facility

In addition to the feeder line from the existing power station, an automatic starting type air cooled 940kVA (750 kW) Diesel engine generator is installed in the above ground control house as an emergency power supply. The drain pump for drainage pit, emergency lights, and part of the air conditioning system are considered as emergency power load inside the underground power house. These loads are usually connected to a specific station service transformer as the essential source.

6) Others

Independent air conditioning and ventilation system are installed at the above ground control house and underground power house. At the underground power house, the air sucked in from the access tunnel, is cooled, circulated at each part inside the house and then exhausted above ground through the cable tunnel to maintain the temperature at 29°C or less and the relative humidity at 40~70%.

Moreover, the air inside the above ground control house is controlled at a temperature of 20~26°C and a relative humidity of 30~70%.

IV. CONCLUSION

The main equipment for the high head large capacity Chongpyong pumped-storage power plant of Korea have been outlined here. Further details will be presented upon initial of operation.

We are confident that the manufacture of this machine, the highest head large capacity machine in the world, will contribute considerably to future development of pumped-storage generation technology, make all efforts for its success in cooperation with the related parties.