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LARGE FRANCIS TURBINE FOR JORDAN RIVER REDEVELOPMENT IN CANADA

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I. FOREWORD

The 183 MW Francis turbine for the Jordan River Project (British Columbia Hydro and Power Authority, Canada) was completed in July 1970 and shipped. It is now being installed, with operation scheduled for October 1971. The site of installation is on the west (Pacific) coast of Canada, at the Jordan River (Vancouver Island). This installation will make the present 26.4 MW power plant obsolete and provide for maximum output of 180 MW. Vancouver Island is some 456 km long and 64～128 km wide, with an area of 32,135 square kilometers). This is a little less than the area of Kyushu (41,946 square kilometers). DC transmission (130 kV, 78 MW) is used between the Jordan River and Vancouver on the Canadian mainland, a distance of 70 kilometers. Eventually, the transmission capacity will be boosted to ±260 kV, 624 MW.

This water turbine has the largest capacity of any 300 m head class Francis turbine in the world, necessitating thorough evaluation in the design and manufacture of system component, in order to get most economy and maximize reliability. New engineering approaches have been used. The successful completion of this turbine employing various new techniques has given us a new confidence in the pursuit of greater economy and reliability in the design and manufacture of large capacity turbines. This article will introduce principal features of the system and new engineering techniques.

II. OUTLINE OF GENERATING PLANT

The Jordan River Power Plant is located near the mouth of the Jordan River, at the south end of Vancouver Island. Water from a dammed reserve passes through a very long pressure tunnel and penstock (in all, 7.2 km) to the plant.

The surge tank was omitted because the terrain made its installation difficult. Although load limiting operation is the rule at this point, operation under isolated load is also used. During operation under isolated load, the pressure regulator is opened only when the load must be reduced rapidly. Ordinarily, water saving bypass operation is employed. During operation under isolated load, operation of governor free is required. Therefore, for rapid load changes, the wicket gates are opened or closed as required. In this case, the pressure regulator opens and closes in accordance with the wicket gates, holding flow in the penstock at a fixed rate and effecting synchronous bypass operation.

Fig. 1 **Location of power station**

To satisfy requirements, a new control system for pressure regulator was developed, a system which holds pressure rise to a very small value for any and all operating conditions. Concerning design of the plant facilities, considerable attention was given to such points as reduction of main machine dimensions (to limit construction costs) and simplification of construction. Let's take a look at the principal features:

1) To limit GD^2 of the generator, a high value of momentary speed rise (50%) was used.

2) The turbine shaft was made an integral part of the generator shaft. Direct connection to the spider of the generator is employed.

3) The inlet diameter of the spiral casing is 2,750 mm, the casing material is SM50B, and the maximum plate thickness is 51 mm. For shipping purpose, the casing was divided into nine sections. These sections were welded together at the site,

under supervision of Fuji Electric engineers.

4) In order to limit the size of the oil pressure system, the control pressure was made 36 $km/cm^2 \cdot g$, a very high value.

5) To facilitate disassembly and reassembly, construction was arranged so that the runner could be removed from the bottom.

6) To make the draft head zero even though the turbine head was 300 meters, the runner was designed to have an extremely small coefficient of cavitation (σ : 0.0374).

Turbine details are presented under the following section.

III. TURBINE

1. Turbine specifications

Number of units :	One
Type :	Vertical shaft Francis Turbine (VF-IRS)
Output :	183,000 kW (245,000 BHP)
Effective head :	289.5 m (950 ft.)
Speed of rotation :	257 rpm
Specific speed :	97 m–kW

2. Turbine performance

To make the draft head zero even though the turbine head is 300 meters, the coefficient of cavitation has been made 0.0374, a very low figure. For this reason, a runner offering a high level of performance in respect to cavitation became necessary. Some model runners were constructed. Thorough model tests were performed in respect to both cavitation and efficiency. In this manner, a high performance runner was developed.

A site efficiency test for the turbine was performed by the use of an ultra-sonic method, but its procedures differed from those used in the past in Japan. The major features of this test are :

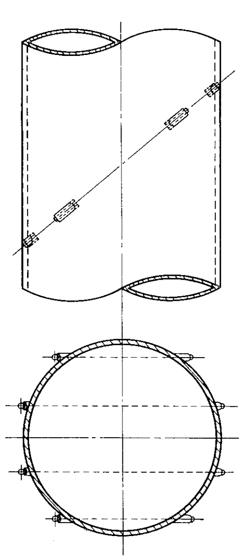
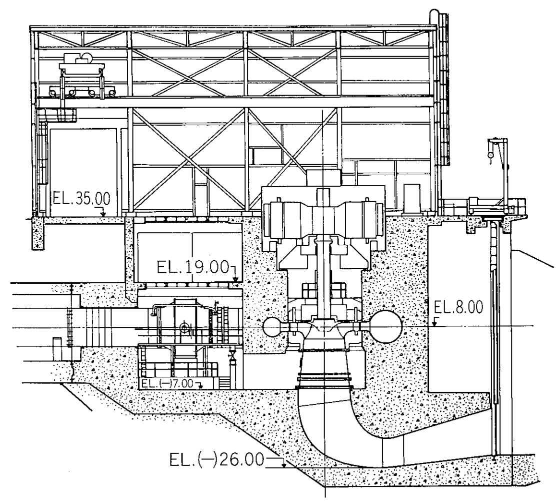
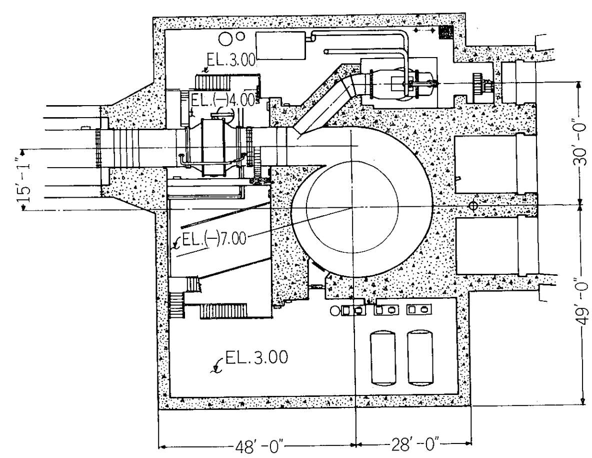


Fig. 2 Transducer installation

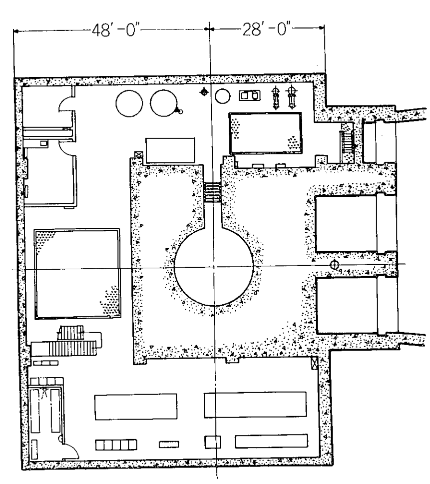
1) Measurements are performed on cross-section planes parallel to the axis of the penstock and which included the four parallel cords. Therefore, effects



(a) Profile view



(b) Main valve room



(c) Turbine room

Fig. 3 Machine hole layout

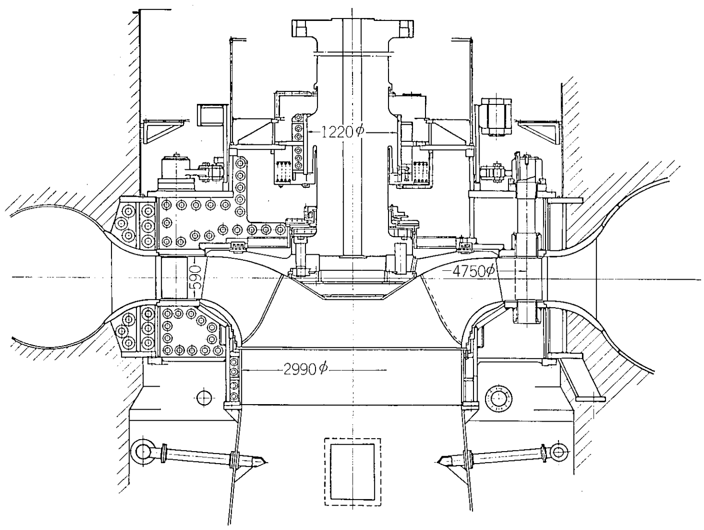


Fig. 4 Section of water turbine

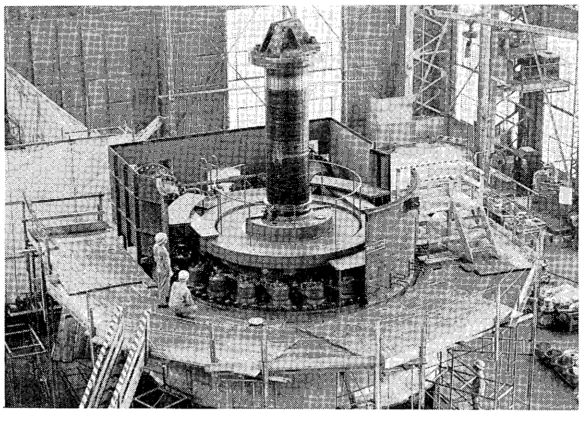


Fig. 5 Trial assembly of turbine at factory

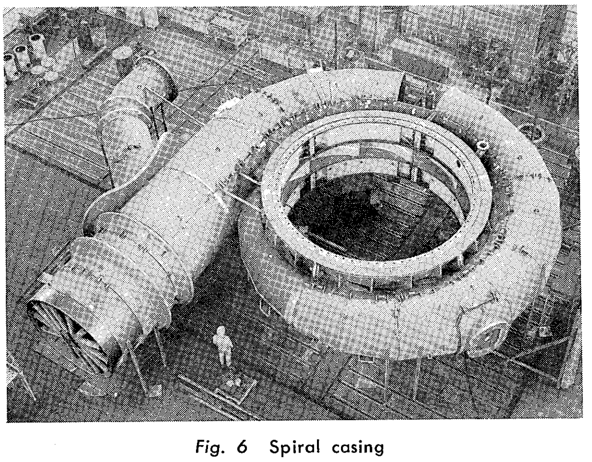


Fig. 6 Spiral casing

of flow rate distribution are very small.

2) Ultrasonic sounds are transmitted simultaneously from upstream and downstream probes (transducers). Thus, there are no effect from time variations in flow rate distribution.

3) The probes are installed in the penstock, imparting ultrasonic energy directly to the water. Thus, the penstock walls have no effect.

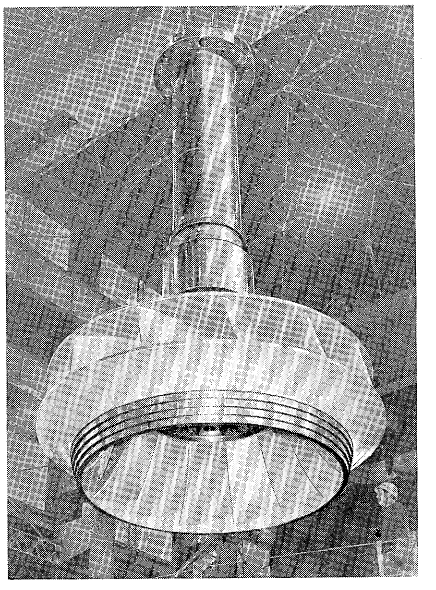


Fig. 7 Turbine runner

Test equipment developed by Westinghouse is used in the tests.

3. Turbine construction

Fig 4. shows a cross-section of the turbine. As described before, the spiral case is made of SM50B plate steel fabricated construction (maximum plate thickness of 51 mm). For shipping purposes, the spiral case was divided into nine sections. These sections are welded together and to the stay rings at the site under the supervision of Fuji Electric engineers. After pressure tests were completed, water pressure equivalent to the effective head was applied. In this state, concrete is poured around the spiral case. The stay rings are of a four sections welded plate flange construction.

Wicket gates are made of cast steel, while the wicket gate stems are fabricated from structural steel. Stainless steel is welded at closed surfaces and top-bottom seat surfaces. Profile of wicket gate was selected so that self closure to 20% opening could take place in the event of loss of servomoter pressure. Provision are made for adjustment of wicket gate by eccentric pin. As a protective device, a shear pin is provided between each wicket gate link and the regulating ring.

The runner is of 13% chrome steel cast in one piece. The runner liner on the runner band side was not provided. The reason for this is that only the liner of the discharge ring side will have to be replaced in the event of increasing the runner gap.

A single shaft is used for the turbine and generator, with direct coupling to the generator spider.

The turbine is equipped with oil immersed self-lubricating cylindrical bearings. Carbon rings were used for vertical seals of the shaft sealing system. Ample attention was given to wear of the carbon, leakage of water during turbine operation, and leakage of air during synchronous condenser operation. Therefore, we confirmed that the shaft sealing system would provide excellent service in respect to stopping leakage of air during synchronou condenser operation.

The discharge ring and top part of the draft tube are not embeded in concrete, that is, are left exposed, so that the runner could be removed from the bottom. Therefore, arrangement was made so that the wicket gate bearings could be disassembled in the space around the upper part of the draft tube, facilitating maintenance work. A system for hoisting the runner was necessary. Requirements were fulfilled by passing a chain through the inside of the generator and the center hole of the main shaft, so that the platform for the runner could be lifted. This approach made disassembly of the generator unnecessary during runner disassembly.

A draft tube liner is provided only for the portion of the draft tube in which the flow rate exceed five meters per second. A horizontal needle type pressure regulator with inlet diameter of 1,400 mm is provided for maximum discharge of 70 cubic meters per second. In the case of operation under isolated load, arrangement is made for the pressure regulator to operate in accordance with the wicket gates, to satisfy the requirement for a constant flow rate in the penstock. Design was such that flow control characteristics would be linear in respect to wicket gate operation. As vibration of the pressure regulator was conceivable in the case of large water discharge, the pressure regulator control system was separated from the pressure regulator proper.

The pressure regulator is connected to a branch line located near the inlet of the spiral case. A model test was also conducted in respect to cavitation developed at the branch when water was discharged from the pressure regulator. In this manner, the shape of the branch line was determined.

So that synchronous condenser operation will be possible, the turbine is equipped with a water level depressing system, cooling water supply system for the runner labyrinth, and water level indicator. To eliminate leakage of air from the wicket gates, the spiral case is maintained at a water pressure somewhat higher than the sealing air pressure and a bypass valve and drain valve provided.

A speed governor of the electro-hydraulic actuator type are used. For the load limiting motor to hold momentary water pressure variation within ten per cent, a potentio-resistor was equipped and a two-speed type was use. Wicket gate closing speed was limited to around one-third of the opening speed. Too, overspeed protection devices were incorporated for use under conditions encountered when the pressure regulator was idle or when starting was in progress.

To make the pressure oil system smaller, the control pressure was raised to the high value of 36 kg/cm^2·g. The pressure oil pump is on-off operated, interlocking to an unloader.

4. Turbine control system

Even though the pressure tunnel and penstock were quite long (7.2 km) at this installation, a surge tank could not be installed because of the terrain. Hence, the turbine is equipped with a pressure regulator which holds the momentary pressure variation within ten per cent. Ordinarily, when a pressure regulator is equipped, rapid closing of the wicket gates at the time of sudden load reduction is possible, but there is no effect in the case of an sudden load increase. As scheduling called for both load limiting operation and operation under isolated load at this installation, the operation of governor free become necessary, due to the necessity of action in respect to sudden load increases.

Thus, a new control system was employed. In this new control system, the pressure regulator acts not only well known as a water saving bypass but also as a synchronous bypass which keeps the rate of flow in the penstock constant in response to wicket gate operation.

Fig. 8 shows details of the turbine and pressure regulator control mechanisms. The pressure regulator control mechanism is connected to the restoring mechanism of the wicket gate servomotor and load limiting device by means of rigid links. At wicket gate openings below those set by the load limiting device, the pressure regulator operates in reverse in respect to opening-closing motion of the wicket gates.

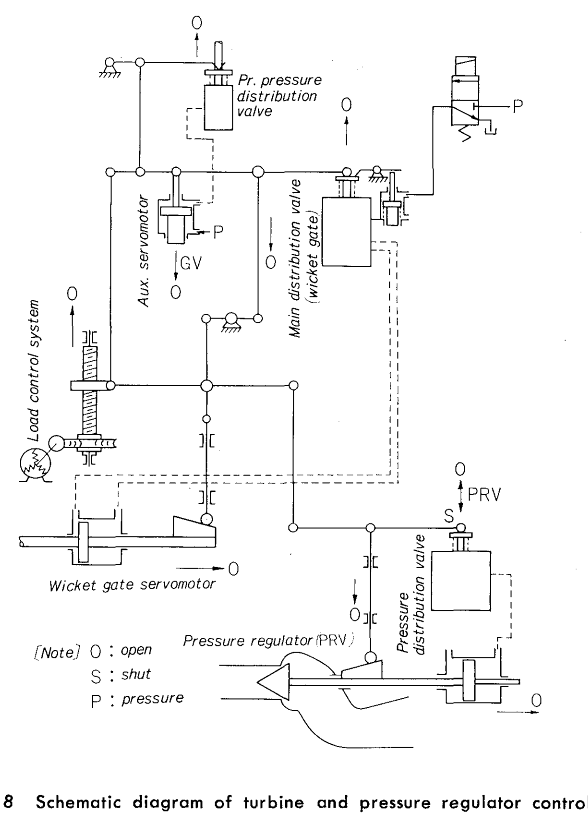
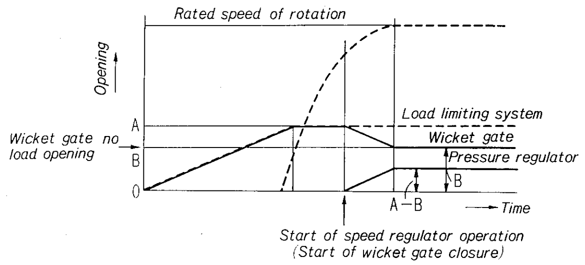
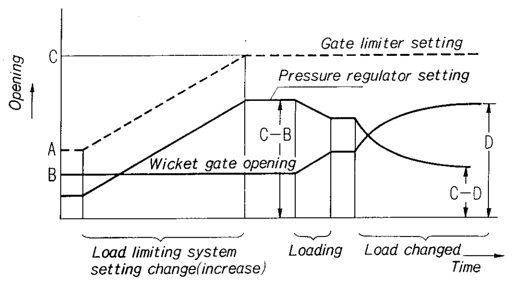


Fig. 8 Schematic diagram of turbine and pressure regulator control



(a) Turbine starting



(b) Isolated load operation

Fig. 9 **Operation of pressure regulator**

The pressure regulator becomes fully closed when the wicket gate opening reaches that set by the load limiting device.

When operation is at an opening below that set by the load limiting device, that is, speed governer free operation is performed, the pressure regulator opens or closes in accordance with the movement of the wicket gates and acts as a synchronous bypass which keeps the rate of flow in the penstock constant. Thus the new control system allows the wicket gates to close or open rapidly in respect to a sudden increase or decrease of the load and to respond rapidly to load variations under any and all operating conditions.

In the case of load limiting operation, the pressure regulator functions as a water saving bypass which opens only in the event of a sudden load reduction.

Let's think about operation of the control mechanism. First of all, the turbine starting (magnetic) valve 65S is energized. Due to action of the load limiting device, the wicket gates open to starting position A and the turbine begins to turn. As the speed of rotation rises, the speed governor begins to function, initiating closure of the wicket gates. The pressure regulator opens only to an extent corresponding to the wicket gate opening. In short, the wicket gate moves to no-load position B and the pressure regulator settles at a corresponding opening (A—B). (Rerer to *Fig. 9* (a)).

The system is placed in parallel with the network and then the mode of operation is selected. In the

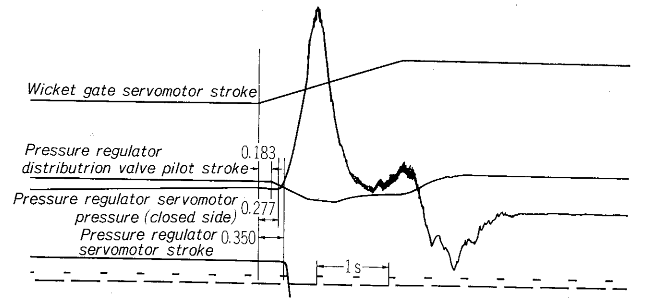


Fig. 10 **Combined test results of speed regulator, wicket gate servomotor, and pressure regulator**

case of water saving bypass operation, the load limiting device automatically closes to the no-load position and the pressure regulator goes to the fully closed position. Then, by setting the load limiting device to the desired point, ordinary load limiting operation is obtained, at which time the pressure regulator opens only in the event of a sudden load decrease.

In the case of synchronous bypass operation, the load limiting device is set to position C (which gives ample margin against the anticipated load). (Refer to *Fig. 9* (b)). If, during no-load operation, the wicket gate position is represented by B, the pressure regulator opens to (C—B) only. Therefore, in the case of speed governor free operation at this time, the pressure regulator will close or open in accordance with the movement of the wicket gates up to opening C, and the rate of flow in the penstock will be held constant. Water will be wasted, to be sure, but excellent control characteristics are realized. *Fig. 10* shows the results of tests performed at the factory with the speed regulator, guide vane servomotor, and pressure regulator assembled.

A mechanism which slowly opens and closes the wicket gates by the switching of the main distribution valve if the pressure regulator fails to operate is provided.

IV. CONCLUSION

We have described a high head, large capacity Francis turbine being completed by Fuji Electric, and feel confident that various new techniques employed will lead the way to even larger installations. The points which show that problems can be resolved through special operation and control of the pressure regulator have much merit, specially in the sites in which the penstock is long and installation of a surge tank is difficult due to the terrain.

We sincerely hope that information presented here will serve in some way in planning for economical construction of hydroelectric power plants.