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306 MW FRANCIS TURBINE FOR PEACE RIVER HYDRO-ELECTRIC PROJECT, CANADA

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I. INTRODUCTION

A 306 MW Francis turbine for the Portage Mountain Development, Peace River Hydro-Electric Project in British Columbia, Canada was completed in September, 1973 in our works and delivered. At present, the turbine is being installed and is expected to go into operation in October, 1974.

Fuji Electric has already delivered a 183 MW Francis turbine to the Jordan River power station and a 60 MW Francis turbine to the Whatshan power station in British Columbia and both are operating successfully.

This power station is located in the central part of British Columbia which is on the Pacific coast of Canada and is being constructed as part of the Project on the Peace River which arises in the Canadian Rocky Mountains. Finally 10 turbines will be installed and the total power of this station will become approximately 2,700 MW.

Since the turbine for this power station is one of the largest capacity in the world, various investigations were performed at the time of design and manufacture in order to improve reliability and economy and several new techniques were used.

Through the completion of this turbine, Fuji Electric has gained sufficient confidence in the design and production of large capacity turbines.

This article introduces the features of the power station equipment and the new techniques used.

II. OUTLINE OF POWER STATION

This power station is of the underground type to which water is led via a penstock about 294 m (965 ft) in length from the Portage Mountain dam (earth fill dam) with a height of 180 m (591 ft).

At present turbines Unit 1~8 are in operation and the Fuji Electric turbine delivered will be Unit 9. The maximum capacity of turbines Unit 1~5 is

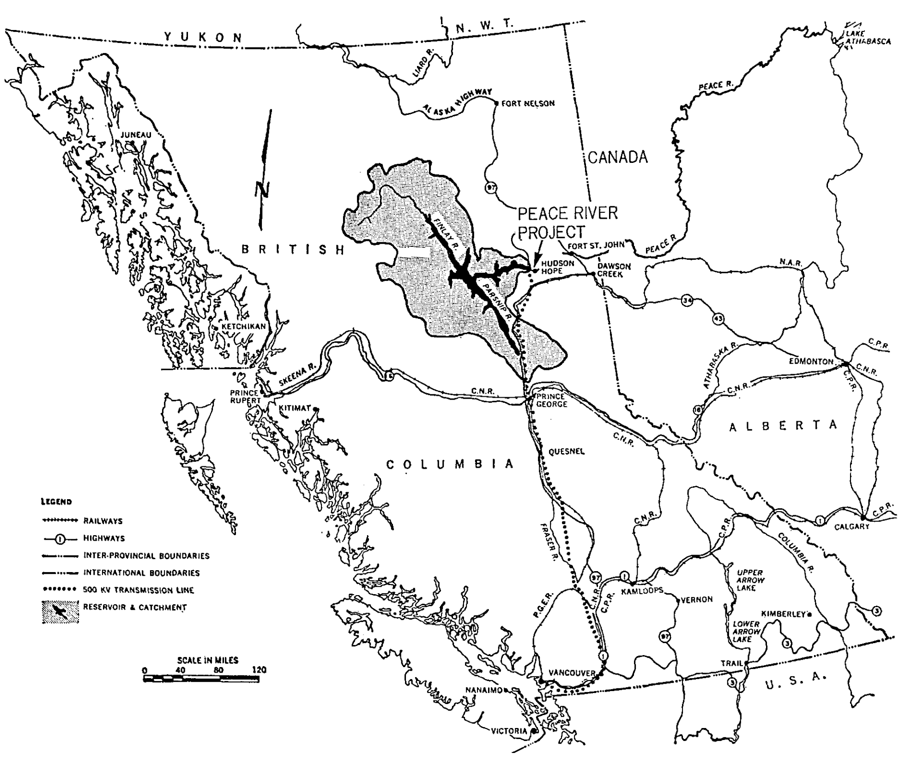


Fig. 1 Location of power station

266 MW, Unit 6∼8 are 282 MW and Unit 9 is increased further to 306 MW. However, since the power station buildings have already been completed, it was necessary to keep the dimensions of the new turbine within the same space. Therefore developing a new hydraulic design as well as new construction as will be described later were necessitated.

The main features of the turbine are as follows:

(1) In order to reduce the machine height and simplify assembly, a common shaft is provided for both the turbine and generator. Shaft is direct connected to the generator thrust block.

(2) A new construction is adopted on the stayring to decrease the dimensions of turbine spiral case and improve the efficiency.

(3) The spiral case has an inlet diameter of 4,900 mm (16 ft 1 in) and a maximum thickness of 58 mm (2.3 in) and is made of SM50B Modify. For transport, the spiral case was divided into 10 pieces which were welded together at the site.

(4) The runner is a single cast steel with an outer diameter of about 5,500 mm (18 ft).

(5) Joint control equipment is provided in the governor so that the whole power station can be operated as if it had only one turbine.

III. TURBINE

1. Turbine Specification

No. of units	1		
Type	Francis turbine		
Output	at max. net head	410,000 BHP	(305,737 kW)
	at rated net head	375,000 BHP	(279,637 kW)
	at min. net head	310,910 BHP	(231,845 kW)
Net head	Maximum	540 ft	(164.59 m)
	Rated	500 ft	(152.4 m)
	Minimum	445 ft	(135.64 m)
Speed	150 rpm		
Specific speed	148.1 m-kW		

2. Turbine Performance

Since this turbine is intended to be Unit 9, the power house dimensions and turbine center level were already determined. In spite of this turbine output of new machine was increased by 15% than the existing units therefore, great effort was made to develop a new model runner with excellent cavitation characteristics and high efficiency.

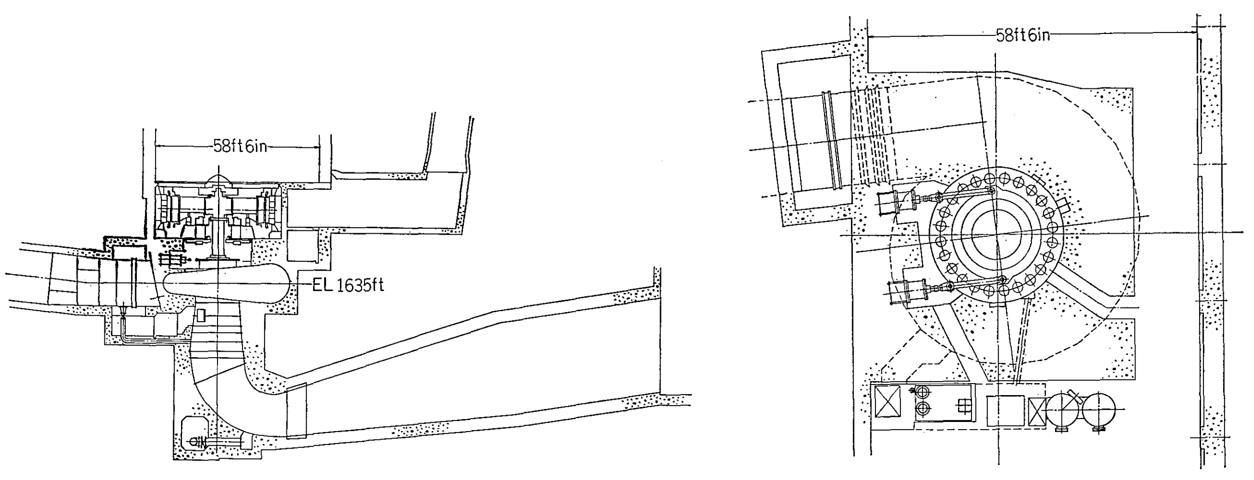
The runner was designed by means of a computer program developed especially by Fuji Electric and as a result, a runner with 10% smaller height, and with a 5% smaller outlet diameter compared with normal runners of same specific unit was developed. The results of the model tests also showed that both the efficiency and the cavitation characteristics were excellent, and no overlay on the runner was needed but from the standpoint of the safety, a limited part has been overlayed.

3. Turbine Construction

In this power station, the installation of the penstock and the lower draft tube has already been completed, and the main turbine parts were designed under various dimensional limitations such as the limitation caused by the rock wall in the vicinity of the spiral case.

Between the existing penstock and the spiral case, a penstock transition, a flexible coupling and a closure piece are connected.

The penstock transition has an inner diameter of 5,486 mm (18 ft) and the closure piece has an inner diameter of 4,900 mm (16 ft 1 in). The penstock transition was divided into 6 parts for transport. At the site, a longitudinal weld was first performed and after annealing, it was placed in the power station and circumferential welding was performed. The closure piece was divided into three pieces for installation adjustments between the pen-



(a) Section (b) Plan

Fig. 2 General arrangement of machine hall

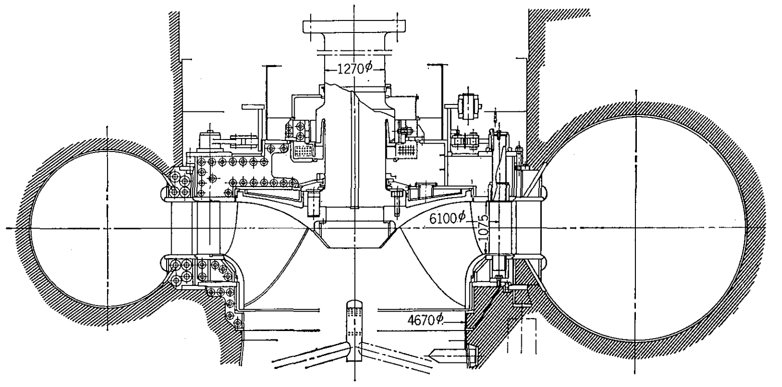


Fig. 3 Sectional view of water turbine

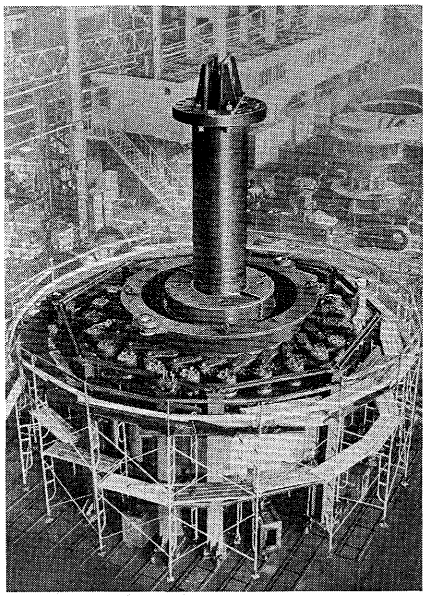


Fig. 5 Water turbine under factory trial assembly

stock transition and the spiral case and is provided with a thrust ring to receive the water thrust force. A flexible coupling is provided between the penstock transition and the closure piece.

Fig. 3 shows a sectional view of the water turbine and *Fig. 4* the spiral case and closure piece under factory trial assembling.

The spiral case was constructed to be welded at the site and had a design pressure of 325 psi, an inlet diameter of 4,900 mm (16 ft 1 in) with a maximum plate thickness of 58 mm (2.3 in).

The material used is rolled steel for welded structure (SM 50B Modify) with the Charpy V-notch impact value (over 15 ft-lb) specified in 0°F. The manufacture was based on Section VIII of the ASME Boiler and Pressure Vessel Code.

After welding at the site a 450 psi pressure test of spiral case was carried out and after that, the pressure embedment is adopted to minimize the effects on the surrounding concrete.

The stay ring was divided into 4 sections for flange jointing, and it to be welded to the spiral case at the site. A new type of construction is used in which the force from the spiral case plate due to hydraulic pressure is transmitted to the center of gravity of the stay ring in order to minimize the torsional moment applied to the stay ring. With this construction, stress concentration in the stay vane and spiral case plate is reduced, and since the crown plate is arranged on the inside compared with ordinary structures, the casing inlet offset is reduced and the casing can be accomodated in the limited dimensions of the power house. The stay ring of this turbine forms a rational water flow inside the stay vane so that the turbine efficiency is better than with the ordinary type. This has been confirmed in model tests.

Fig. 6 shows the ordinary type stay ring and the new type used in this turbine.

At the time of the structural design of the turbine, stress and distortion of spiral case, stay ring and head cover were analyzed by axial symmetric program of the finite element method.

These results confirmed that there were very little deformation and sufficient strength.

Fig. 7 shows the stress and displacement analysis diagrams for the spiral case, stay ring and head cover.

The main shaft seal employs an axial seal type carbon packing with self-adjustment action. The

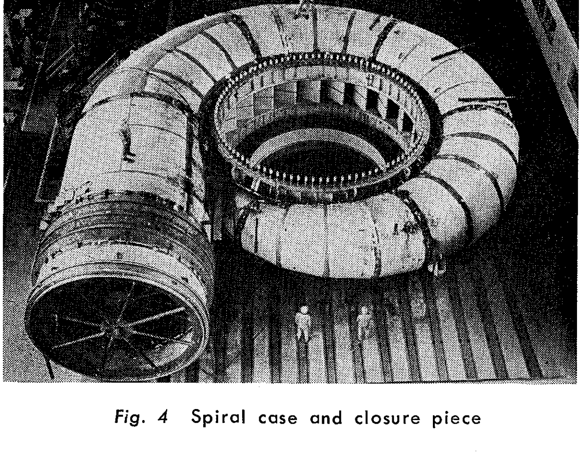
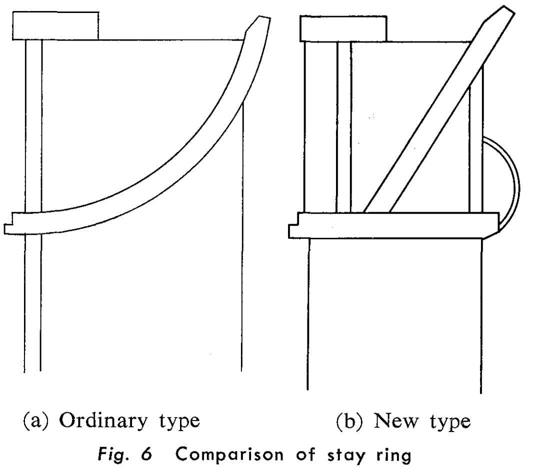
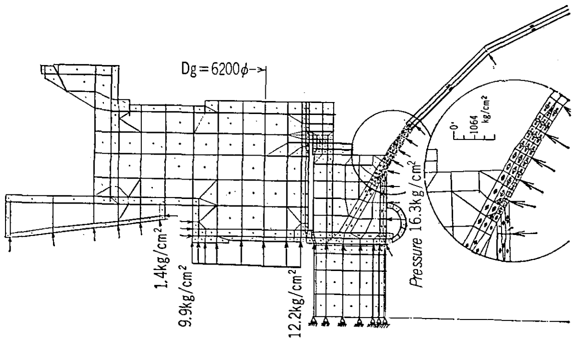


Fig. 4 Spiral case and closure piece

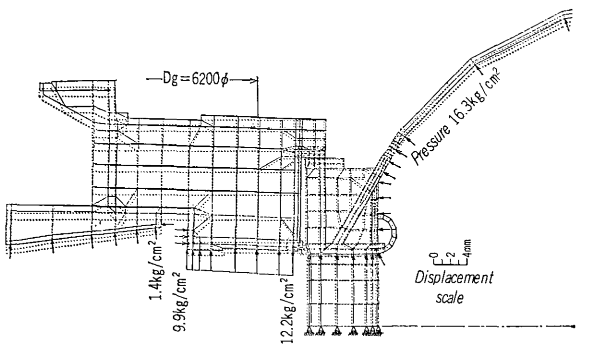


(a) Ordinary type (b) New type

Fig. 6 Comparison of stay ring



(a) Stress



(b) Dsiplacement

Fig. 7 Finite element method analysis of spiral case, stay ring and head cover

carbon packing provides water proofing action via the sealing water in respect to the main shaft seat attached above the main shaft flange. This type of main shaft seal has been used widely by Fuji Electric and results have shown that it has excellent water-proofing effects and there is little wear. It has been used in the 183 MW Francis turbine delivered to the Jordan River power station for the same customer and the operating results have been excellent.

Water leakages from the main shaft seal flow downward naturally through the drainage chamber located in the head cover and via the drainage hole in the stay vane. There is a water level warning device located in the drainage chamber in the head cover.

A maintenance seal operated by compressed air is located on the bottom of the main shaft seal and operates so that the carbon packing can be disassembled without draining the water in the spiral case.

The guide vane is of cast steel and the vane shape is such that there is self-closing characteristic up to 20% opening when there is a loss of oil pressure. Since this power station is not provided with inlet valve, a rubber seal is provided on the guide vane closing surface and there is a special bronze seal between the head cover and bottom ring. These seals prevent water leakage when the guide vane is completely closed. The guide vane link mechanism is regulated by an eccentric pin and a shear pin broken

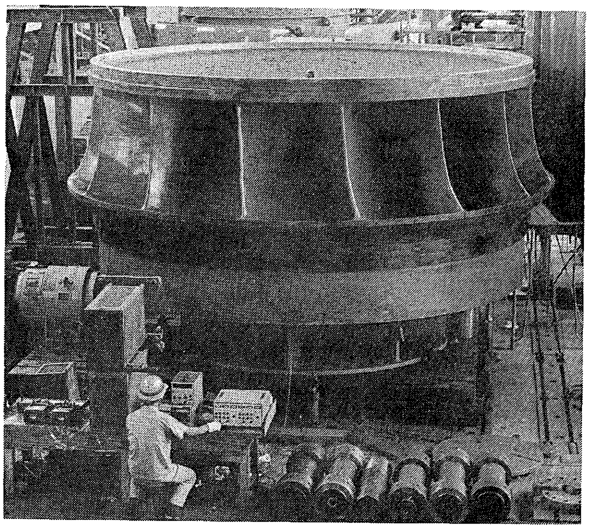


Fig. 8 Dynamic balance test of runner

warning device is provided. A special tool is also attached so that the pin can be replaced with the turbine still operating when the shear pin breaks.

The main bearing is a segment bearing and the bearing gap is adjusted by means of an adjusting bolt. A cooling coil is located in the inside of the bearing oil tank.

The runner is of a single cast steel construction with an outer diameter of about 5,500 mm (18 ft) and a weight of about 77 ton (170,000 lb). An 18–8 stainless steel overlay is provided in the critical area and there are no wearing ring on the runner crown or band side. The balance of the runner was proven sufficiently in the factory by means of a dynamic balance device. *Fig. 8* shows the dynamic balance test on the runner in the factory.

The turbine shaft is of forged steel construction and it is 6,560 mm (21 ft 2 in) in length and about 80 ton (176,000 lb) in weight. It is coupled to the generator thrust block by reamer bolts.

The draft tube is of the elbow type and only 7,620 mm (25 ft) of the vertical part and 2,134 mm (7 ft) of the pier nose cap are provided with steel plate liners. The other parts are made of concrete.

4. Manufacture of Turbine

The problems concerning the manufacturing techniques of large scale turbines include welding techniques for extra-thick plates, site welding techniques for the spiral case and machining equipment for the stay ring, head cover, etc. In the manufacture of this turbine, there were no special problems with factory equipment and a description will be given of the welding techniques used for the stay ring and the spiral case.

1) Manufacture of stay ring

The maximum plate thickness of the stay ring in this turbine is 130 mm (5.1 in) and the main problem which arises in the welding of such extra-thick plates is the prevention of weld crack. The follow-

Table 1 **Site welding casings (more than 30 mm and 80 MW)**

Customer	Power station	Output (kW)	Casing inlet diameter (mm)	Casing material	Maximum casing thickness	Year delivered
Canada	PEACE RIVER	306,000	4,900	SM50B	58	1973
Canada	JORDAN	183,000	2,750	SM50B	51	1970
Australia	GORDON	157,000	2,800	ASB250-5	45	1973
Korea	SOYANG GANG	113,000	4,200	SM50B	30	1972
Argentina	FUTALEUFU	112,000	3,400	SM58Q	35	1972
South Africa	HENDRIK VERWOERD	101,000	5,486	SM50B	38	1970
Anstralia	CETHANA	100,000	3,900	Welcon 2H	31	1970
Tokyo Electric Power Co., Ltd.	NAKATSUGAWA NO. 1	89,000	1,600	SM58Q	35	1971

ing special considerations were given for this turbine:

(1) Design and manufacture were carefully investigated and the structure was such that the stress during welding was as small as possible and in particular, there was as little welding stress as possible in the plate thickness direction of the plates. When it was unavoidable, special specifications were used for the selection of materials.

(2) The material, as was described previously, was SM50B Modify but sufficient consideration was given to the detection of interior defects, mechanical characteristics in the plate thickness direction, etc.

(3) Preheating and the welding rod drying were very carefully controlled and the welding sequence was controlled by the PERT system for higher quality.
Hand-welding, semi-automatic welding and automatic welding were adopted adequately considering purpose of welding.

(4) To ensure the maximum level of quality control, the so-called non-destructive test including ultrasonic inspection, radiographic inspection, magneticflux inspection, visual inspection and dye penetrant inspection was performed.

2) Manufacture of spiral case

Table 1 shows the site welded spiral case which Fuji Electric has supplied recently. However, since annealing at the site is extremely difficult after site welding, it is necessary to investigate the low temperature brittleness characteristics when using thick plates as casing materials. Therefore, many basic tests were performed and mechanical investigations were carried out on the materials, material thickness, welding rods, etc. to confirm the weldability, mechanical characteristics, low temperature impact values, etc.

In the customer's specifications, it was stipulated that the spiral case materials meet Canadian standard (CSA G 40.8) and the use of high tensile strength steels was prohibited.

The maximum plate thickness of the spiral case is 58 mm (2.3 in) and there have been almost no cases in the world of the site welding of spiral cases of more than 2 inches. For this reason, careful investigations were conducted concerning the problems of low temperature brittleness, site welding deformations, etc. on the basis of fundamental tests and the manufacturing was performed as follows:

(1) The longitudinal weld line was increased and the circumferential welds decreased. The length of the overall site weld line was reduced so that the work time was shortened and the effect of deformations in the stay ring was reduced.

(2) The spiral case was provided with no special make-up piece and after mechanical finishing of the stay ring, the spiral case was temporarily assembled in the factory. At that time, a space was made between the spiral case and the stay ring so that deformations and welding stress on the stay ring due to site circumferential welding of the spiral case could be minimized.

(3) Low temperature brittleness was considered and materials with high impact values were selected as was explained before. Quality control procedure during the welding process such as preheating and drying of the welding rods was carried out carefully. After the welding radiographic and magneticflux inspections were performed in all seames and with the addition of visual checks all sharp notch defects could be eliminated.

At the site welding in September and October, 1973, the same quality control procedure as in the factory was used and site pressure tests were performed but it was found that there were less deformations in the stay ring than usual and the specifications were fulfilled.

IV. CONCLUSION

It is hoped that this completion of a turbine with a record capacity using many new techniques will pave the way for the future design and manufacture of large capacity turbines and pump turbines. As demands for the reduction in cost of hydroelectric power equipment increase, the new techniques used in this turbine will lead to greater economy in future equipment.

Finally, it is hoped that this article will be of use in the future planning of economic hydroelectric power stations.