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SELECTION OF TYPE OF PUMP-TURBINE

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I. INTRODUCTION

Our Company is now manufacturing a Deriaz type pump-turbine (80 m, 20,000 kW, 300/333 rpm) and a pole-change type generator-motor (20,000 kVA 11 kV 300/333 rpm 50 c/s) for the Kuromata River No. 2 Pumping-up Power Station of Electric Power Development Co., which is expected to put in business operation since 1963.

This is really a Deriaz type pump-turbine of the highest head in the world.

On this opportunity, we wish to discuss chiefly on the selection of type of pump-turbine how to decide from a view-point of pumping-up generating equipment.

Which is better Francis type (2 speed plan) or Deriaz type (one speed plan) ?

Isn't it a matter of dissipation which means only an experimentation that the Deriaz type pump-turbine is operated on two speeds by means of coupling with a pole-change type generator ?

We are much appreciated if you understand that the above questions may be solved to some extent, and either plan is sometimes rationable as the case may be.

As the pump-turbine of our country has already been leveled up to the first class, there is no anxiety for this machine. On the other hand, the pole-change type generator has been developed its system more progressively than any other countries, especially Fuji System is very superior in utilization of excitation flux (also superior in efficiency), which results in cost down.

At present in foreign countries, because of the considerable uneconomy, the pole change type generator is not put in practical operation but in Japan, it is needless to say, it is now very actively put in operation.

There are various methods of comparison for these plans but we have adopted here a method, whereby approximate numeral figures are obtained by examples of calculation and moreover, omitting possibly explanations by literatures, explanations by graphs have chiefly been taken up.

II. PERFORMANCES OF FRANCIS TYPE AND DERIAZ TYPE PUMP-TURBINE

1. Performances of Francis Type Pump-Turbine

1) *Fig. 1* shows pump characteristics of Francis type pump-turbine with a specific speed 53 (m-m^3/s). In the drawing, σ_A shows a limit when cavitations are produced. Around the maximum efficiency, the relative velocity at vane inlet is as shown in *Fig. 2* (*2*) and value σ_A becomes minimum, however when discharge increases from the point of

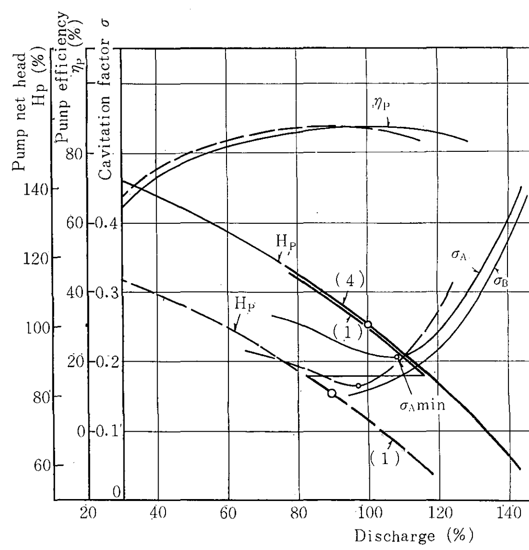


Fig. 1 Pump characteristics of Francis type pump-turbine

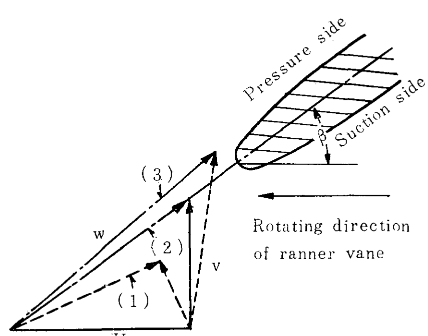


Fig. 2 Velocity diagram at inlet of runner vane

σ_A min., it becomes as (*3*) and cavitation occurs at the vane inlet pressure side and value σ_A increases suddenly according to an increase of discharge.

Moreover if the discharge decreases from the point of σ_A min., the relative speed becomes as shown in (*1*), cavitation occures at the suction side of vane inlet and value σ_A increases according to a decrease of discharge.

The curve σ_B illustrates a limit when cavitation of the pressure side is developed and the efficiency and head suddenly decrease. And the dotted line shows a characteristic when the revolution becomes 90%. Further the cavitation factor in the drawing is a converted one to the normal head.

2) *Fig. 3* shows turbine characteristics. The abscissa

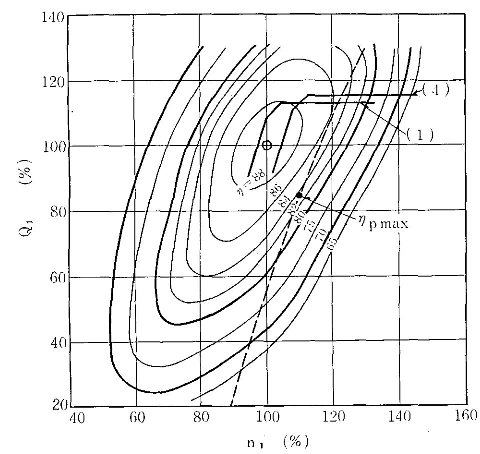


Fig. 3 Turbine characteristics of Francis type pump-turbine

is $n_1' = \dfrac{n \cdot D}{\sqrt{H}}$ and the ordinate is $Q_1' = \dfrac{Q}{D^2 \sqrt{H}}$ (where D=diameter of runner in m, n=rpm, H=effective head in m, Q=discharge in ℓ/s).

In the Francis type pump-turbine, in general, contour lines of efficiency extend to the right-upwards, accordingly in the case of low head, if it is used to keep the openning of guide vane large and Q_1' is made large, the characteristics of variable heads become better. The dotted line is a converted one from the pump characteristics of *Fig. 1* into n_1' and Q_1'.

The relation between n_1' and Q_1' at the point of maximum efficiency when operating as turbine and pump is as follows.

$$\frac{n_{1P}'}{n_{1T}} \fallingdotseq 1.10, \qquad \frac{Q_{1T}'}{Q_{1P}'} \fallingdotseq 1.18$$

2. Performances of Deriaz Type Pump-Turbine

1) *Fig. 4* shows pump characteristics.

The characteristics in the case of constant opening of runner vane, are similar to the characteristics of Francis type of *Fig. 1* and the discharges at the maximum efficiency and the point of

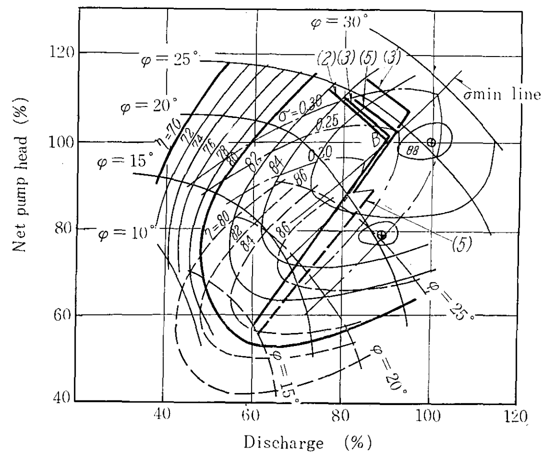


Fig. 4 Pump characteristics of Deriaz type pump-turbine

σ min. variate approximately proportional to $\tan\beta$ (*Fig. 2*). The right downward of σ min. line at σ contour line of the drawing shows a limit when cavitation occurs at the pressure side of vane inlet and the left upward shows a limit when cavitation occurs at the suction side of vane inlet. Further the cavitation factor is converted into a normal head. Accordingly if used near by σ min. line, a flat characteristic of σ for variable heads can be obtained.

In case of low head, it is possible to make operation with an increased pump discharge (efficiency is rather better), because it is rather easy compared with operation in case of high head in point of cavitation.

2) *Fig. 5* shows characteristics of turbine when n_1' is taken as abscissa and Q_1' as ordinate.

Fig. 6 shows variable discharge characteristics,

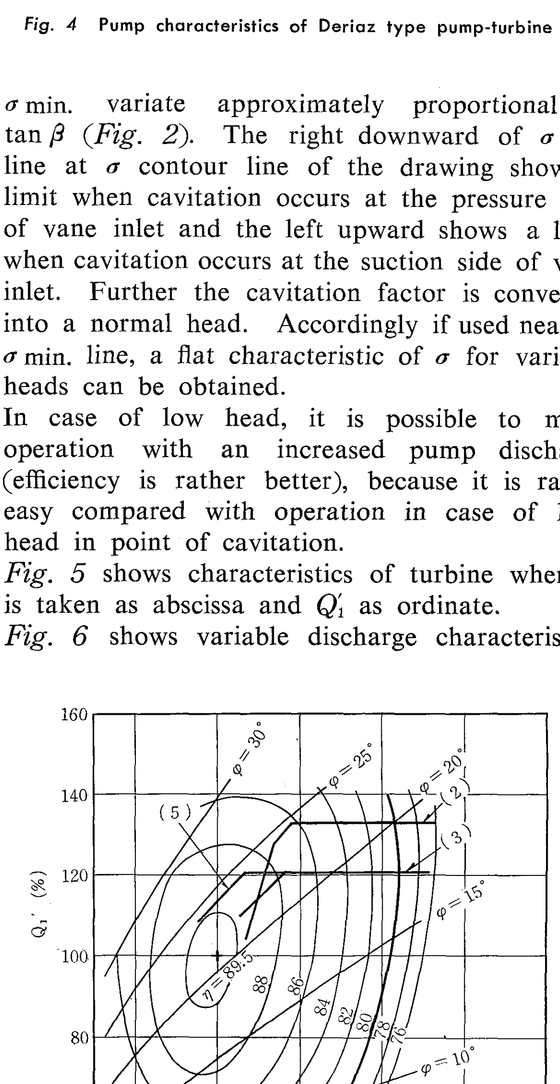


Fig. 5 Turbine characteristics of Deriaz type pump-turbine

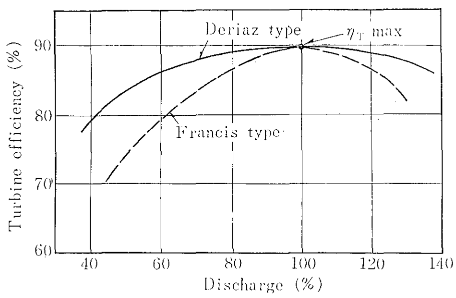


Fig. 6 Turbine efficiency of Deriaz type pump-turbine compared with Francis type pump-turbine

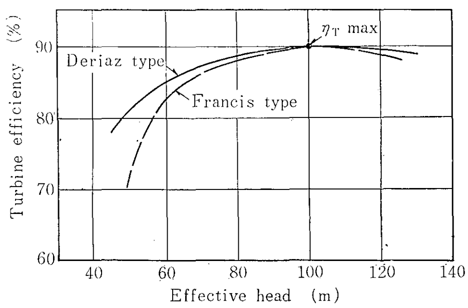


Fig. 7 Turbine efficiency of Deriaz type pump-turbine compared with Francis type pump-turbine

Fig. 7 variable head characteristics compared with Francis type pump turbine, in which Deriaz type shows very superior characteristics for variable discharges.

The relation between n_1' and Q_1' at the maximum efficiency in case of pump and turbine opeation is,

$$n_{1P}'/n_{1T}' \doteqdot 1.10, \quad Q_{1P}'/Q_{1T}' \doteqdot 1.17$$

and ratio n_1' is same as Francis type, but Q_1' shows larger figures in pump than in turbine, contrary to Francis type.

This fact shows that pump input has a tendency to become larger than turbine output (this is the same tendency as in the foreign Deriaz type pumps ever published).

REMARK 1 The above is characteristics when used a radial flow type scroll casing, but when used a diagonal flow type scroll casing, efficiency becomes

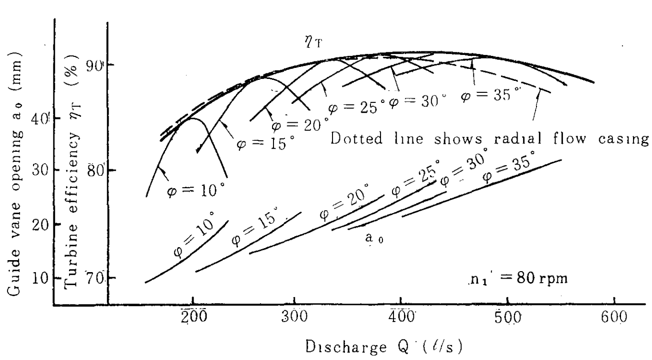


Fig. 8 Comparison between turbine efficiency of Deriaz type pump-turbine with diagonal casing and with radial

higher in case of large discharge as shown in *Fig. 8*. Moreover the discharge at maximum efficiency of pump is nearly equal and total head becomes somewhat high. Accordingly the value of Q_{1P}'/Q_{1T}' at the maximum efficiency becomes smaller in diagonal flow type scroll casing than in radial flow type scroll casing. This is a fact that the diagonal flow type scroll casing is superior as a hydraulic characteristic.

Nevertheless, the radial flow type scroll casing is used in general, because of extreme superiority in its construction.

III. SUITABLE EXAMPLES FOR EACH TYPE

When comparing each type, the following conditions have been taken into consideration.

(1) Because the Francis type is advantageous in case of high head and the Deriaz type in case of low head at the maximum efficiency, suitable head where the maximum efficiencies for both types become nearly equal has been selected.

(2) When the range of variable head is small, one speed Francis type is naturally superior and when the range of variable head is especially large, Deriaz 2 speed type is more superior than any other type, therefore the variable head range has been decided here where both Deriaz type one speed plan and Francis type 2 speed plan can be applicable and also Deriaz type 2 speed plan has been considered together.

(3) The characteristics of Francis type and Deriaz type are shown in *Fig. 1, 3, 4 & 5*, and in the under-mentioned examples of calculation, as difference of specific speed is very small, we have assumed that the charcteristic of cavitation and the characteristics besides n_1', Q_1' at the maximum efficiency are not variated. Further the cavitation factor is proportional to the four-third power of specific speed. By considering the above, the specification for examples of calculation has been decided as follows.

Effective head :	79～39 m
Maximum flow :	90 m^3/s
Net head :	80～40 m
Suction head :	approx.-11 m

1. Suitable Example for Francis Type 2 Speed Plan

It is correspondent to case *1* of *Table 1* and its characteristics are shown in *Fig. 9*. Further $\eta_{T\,100}$ in the drawing shows efficiency of turbine at maximum output at each head, $\eta_{T\,70}$ shows efficiency of turbine at 70% output.

Further its condition in service are illustrated by thick lines (1) respectively on the curves of models in *Fig. 1* and *Fig. 3*.

For the Francis type, pump input, in general, is small compared with turbine output. Accordingly at

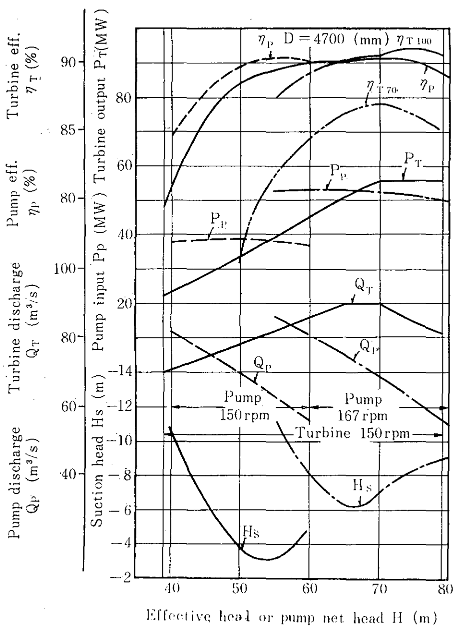


Fig. 9 Performance curves of 2 speed Francis type pump-turbine (case 1)

a high head, the capacity of generator-motor can be made small by limitting the turbine output. Consequently the conditions to which the Francis type 2 speed plan meets are as follows.

(1) Turbine output is limitted at high head.
(2) Pumping-up is done at full pump head range.
(3) Partial load is not used.
(4) Small pump discharge will be enough at high pump head.
(5) Efficiency at middle head is important.

The Deriaz type has such a tendency that its pump

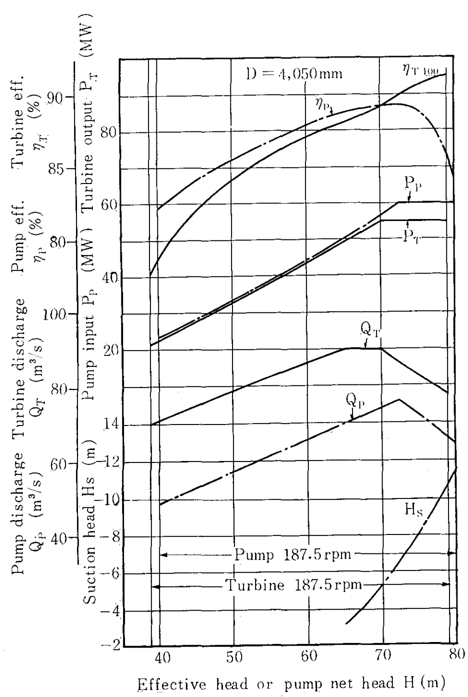


Fig. 10 Performance curves of 1 speed Deriaz type pump-turbine (case 2)

input becomes large compared with its turbine output.

Accordingly when capacity of generator-motor is made small by limitting the turbine output at high head, a smaller size of pump-turbine must be used as a water turbine at over gate, thus efficiency at maximum output will be lowered. Moreover efficiency at high pump head and cavitation factor become worse as a pump owing to limitation of input, so that it is desirable that motor output will be made larger by several % than turbine output.

The Deriaz type with one speed under the same condition as the above Francis type with 2 speed is shown in case *2* of *Table 1* and its characteristics are shown in *Fig. 10.* Further its condition in service is illustrated by thick lines (*2*) in *Fig. 4* and *Fig. 5.* In case *2*, pump input is increased by 9% above turbine output but if pump input is further reduced, the curve *A–B* in *Fig. 4* is shifted more to the left and then efficiency and cavitation become worse.

2. Suitable Example for Deriaz Type One Speed Plan

In the Deriaz type pump turbine, its cavitation factor at maximum pump head is largest and its efficiency is also very low. Accordingly if cut off pump head near to the maximum pump head, the Deriaz type becomes advantageous. Moreover at partial loads, the Deriaz type is extremely superior and it has such a merit as to be able to adjust the pump discharge in a certain degree. (In the Francis type it is almost impossible)

Consequently the conditions to which the Deriaz type meets are as follows.

(1) It is needless to pump up at high pump head.
(2) Turbine output is not necessary to limit at high head.
(3) Partial loads are important.
(4) Pump discharge is adjusted.
(5) It is not so important that efficiencies at middle and low heads are somewhat lowered.
(6) Such cases when, it is more fabourable that driving power of motor is larger, so the rated power factor of generator becomes smaller and also kVA becomes larger for turbine output.

The above conditions are mostly required for such power station where natural flow is aboundant and turbine operation is required first, and pumping-up is second.

The examples of calculation are shown in case *3* of *Table 1* and *Fig. 11.* Curve (*3*) in *Fig. 4* and *Fig. 5* shows the case when above 77 m of total pump head are cut off. Curve (*3*)′ shows that pump input increases by about 7% when pumping-up up to 80 m.

3. Suitable Examples for Francis Type One Speed Plan

This is applied, as a rule, in the case of small variable range of pump head, but even in the case of wide variable range, when variation of water level of tailrace is large, suction head becomes large at

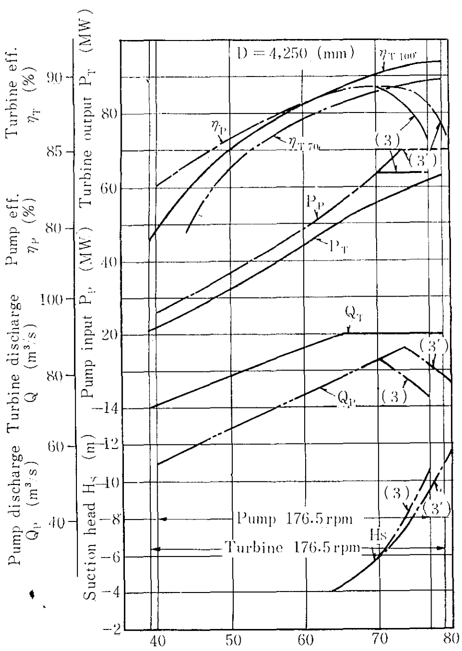


Fig. 11 **Performance curves of 1 speed Deriaz type pump-turbine (case 3)**

low pump head, so that it is possible to compensate the increase of cavitation factor. Accordingly the conditions to which Francis type 1 speed meets are as follows.

(1) Variation range of water level of tailrace is wide or pumping-up is not necessary when low pump head.
(2) Efficiency at low head is not deemed important.
(3) Partial loading is not important.

Calculation examples are shown in case *4* of *Table 1* and *Fig. 12*. Further the thick lines (4) in *Fig. 1* and *Fig. 3* show the conditions in service.

When tailrace water level does not almost change and yet variation range of pump head is large as this example, in Francis type 1 speed plan suction head is to be extremely large or speed is to be low, which is not a good idea. As to the details, please refer to writer's paper described in the Journal 'Ohm' of March, 1960.

4. Suitable Examples for Deriaz Type 2 Speed Plan

In this case, it is also desirable that motor output is made somewhat larger than turbine output.

The conditions to which Deriaz type 2 speed meets are as follows.

Table 1 **Comparison of pump-turbines**

	Case	1	2	3	4	5	Remarks
	Type	Francis type 2 speed	Deriaz type 1 speed	Deriaz type 1 speed	Francis type 1 speed	Deriaz type 2 speed	
Turbine	Effective head (m)	79～39	79～39	79～39	79～39	79～39	
	Speed (rpm)	150	187.5	176.5	150	167	
	Max. output (kW)	56,900	55,000	63,500	55,500	63,500	
	Eff. at max. head (%)	90.5	91.3	91.1	90.5	91.3	
	Eff. at min. head (%)	79.5	77.8	78.8	65.5	83.9	
	Max. eff. (%)	91.5	91.3	91.3	91.5	91.5	
	Head at max. eff. (m)	70	79	79	79	74	
Pump	Net pump head (m)	80～40	80～40	77～40	80～40	80～40	
	Speed (rpm)	167/150	187.5	176.5	150	187.5/167	
	Max. pump input (kW)	53,000	60,000	63,500	50,500	68,000	
	Eff. at max. head (%)	89.0	84.0	85.6	88.0	86.5	
	Eff. at min. head (%)	84.5	82.1	82.6	75.0	85.3	
	Suction head (m)	−11.1	−12	−10.6	−11.5	−11.4	
	Run-away speed (%)	166	205	207	158	228	Ratio for turbine speed for each type
	Required GD² (%)	100	65	83	100	93	100% for case 1
	Thrust for pump turbine (%)	100	310	340	109	320	100% for case 1
	Runner dia. (mm)	4,700	4,050	4,250	5,050	4,250	
	Pump turbine weight (%)	100	97	101	107	101	100% for pump turbine in case 1
	Generator weight (%)	136	127	145	125	159	
	Total weight (%)	236	224	246	232	260	
	Characteristic curve	Fig. 9	Fig. 10	Fig. 11	Fig. 12	Fig. 13	
	Remarks	Above H_T=70 m, turbine output is limitted	Above H_T=70 m, turbine output is limitted	Above H_P=77 m, pump head is cut off	Variation of tailrace level is large		

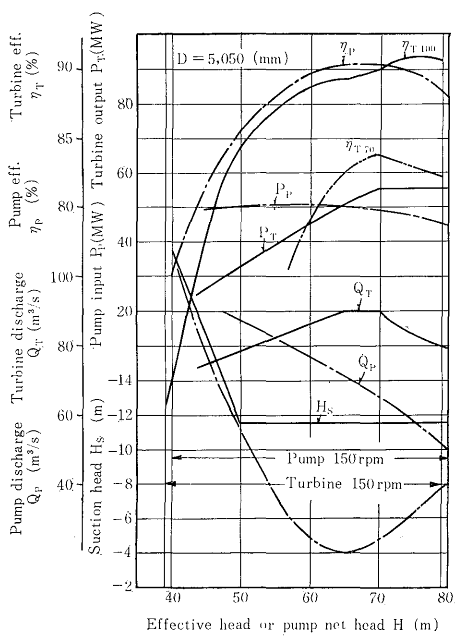


Fig. 12 Performance curves of 1 speed Francis type pump-turbine (case 4)

(1) Efficiency at low head is considered important.
(2) Turbine output is not limitted at high head. (This is same when the rated power factor is small and kVA of generator is large)
(3) Efficiency at partial load is important.
(4) Variable range of head is larger than this example of calculation.

The examples of calculation are shown in case *5* of *Table 1* and *Fig. 13*. And the thick lines (5) of *Fig. 4* and *Fig. 5* show the conditions in service.

When the partial load is considered important, Francis type 2 sets plan are taken up, however it is not advantageous because its weight increases compared with one set of Deriaz type. On the other hand, by development of a large output Deriaz type pump-turbine and operation with 2 speeds, it may be possible to replace 2 sets of Francis type with one set of Deriaz type.

When head is lower than this example of calculation the Deriaz type, in general, has such a tendency as its efficiency becomes better than Francis type, so that Deriaz type becomes a little more advantageous than Francis type.

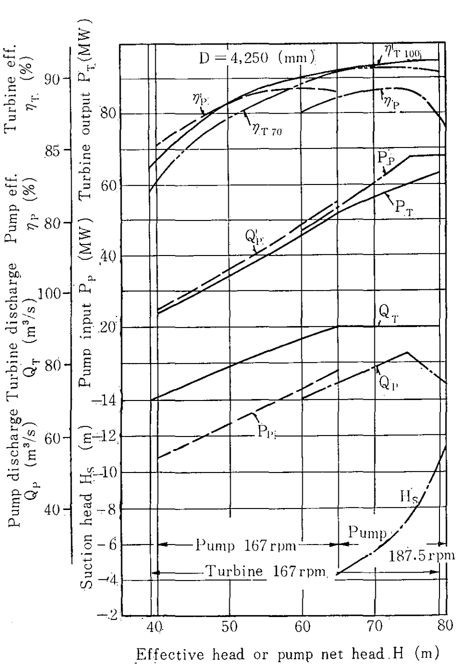


Fig. 13 Performance curves of 2 speed Deriaz type pump-turbine (case 5)

IV. ORDINARY TYPE AND POLE-CHANGE GENERATOR-MOTOR

1. Output Ratio of Motor/Generator

(1) It is enough to consider that power factor is 1.0 when motor operation, so exciting current is small.
(2) When motor is operated on 2 speeds, more cooling effect is given when operating on higher speed.
(3) Generator kVA is larger than turbine output even at the rated power factor.
Under the above condition, even a motor output is larger by several %, it is mostly the cases that it is not necessary to make a generator output larger thereby.

2. Pole-Change Type Generator

It is said that the weight of pole-change type synchronous generator is heavier by 50~60% or by 80% than the conventional ordinary type.

However we have persisted in that the weight of the machine manufactured in Siemens-system is heavier by 30% and in Fuji-system by 10%.

It is well-known that the fact has recently been recognized gradually.

We wish to introduce here an actual test result on Fuji 5,000 kVA 6.6 kV 50 c/s 8 p/6 p generator.

As shown in *Fig. 14*, two kinds of large and small magnet poles are arranged.

If exciting as (*a*), a magnetic field for 8 pole is obtainable and if exciting as (*b*), a magnetic field for 6 pole of unequal interval is obtainable. If the 6 pole fundamental wave for this magnetic field is calculated by Fourier series, we obtain a maximum flux density equal to 0.83 × 8 pole, which is very large in the utility the factor. The stator winding is changed its connection by the unit winding. Thus as the winding factor is rationally designed, the wave form in case of 6 pole becomes nearly equal to the ordinary generator. *Fig. 15* shows wave forms in case of 3 phase short- circuit. Further the motor starting

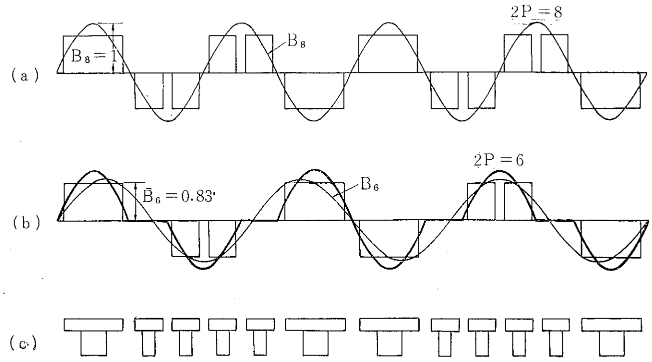


Fig. 14. Pole change with a ratio of 6 : 8 for a salient pole machine

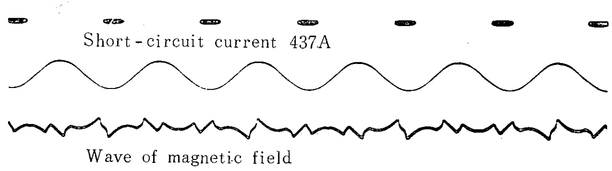


Fig. 15 Wave form at three phase short-circuit

characteristic in case of 6 pole has not shown any phenomena of abnormal torque and synchronization was quite normal.

Various kinds of systems have recently anounced by the other manufacturers, however our system is most superior on the point of the utility factor of magnetic flux, accordingly it is also very high in efficiency (even taking into consideration for the utility factor when numbers of pole are not reduced), further its construction being very simple, it is really a rational method, we believe.

One of Fuji-system examples of starting torque curve for less numbers of pole (higher speed) when motor operation is shown in *Fig. 16*. The starting characteristic may be considered same as the ordinary type.

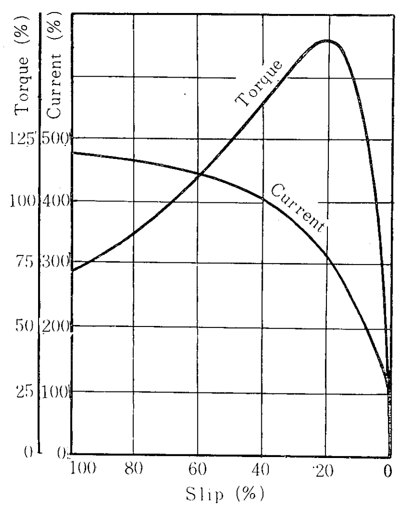


Fig. 16 Starting performance of synchronous motor

V. PROBLEMS ON COMPARISON

In the above III, the suitability of the characteristics has been discussed by the examples of calculation, however the followings must further be taken into consideration for comparison of each type.

1) In the Francis type its construction of pump-turbine proper is simple compared with the Deriaz type. Unless the speed of Deriaz type is considerably raised up, its weight can not be made equal to that of the Francis type.
2) Compared with the Francis type, the Deriaz type is able to raise up its speed, as clear from the above described characteristics of cavitation.
3) Run-away Speed and Thrust.
   The Run-away speed of the Deriaz type is larger by about 30% and the thrust relating to the pump-turbine becomes as large as 3 times, so that the generator for the Deriaz type turbine becomes heavier by about several % to 10% than that for the Francis turbine so long as the speeds for both turbines are same.
4) Required GD^2 (Condition of Penstock)
   In case of two speeds, in general, the weight of generator becomes heavier by about 10% than that in case of one speed, however when the condition of penstock becomes worse and the required GD^2 is larger than the normal design, a difference between both becomes small, thus two speed has a tendency to be advantageous.
5) Requirement for Starting.
   Since in case of the Deriaz type, the pump can be started under water while fully closing the runner vanes, the water-level depressor is not necessary, thus the control can be symplified and changing over time can be minimized.
   Accordingly when frequent operations for starting and stopping are required, the Deriaz type is advantageous, however it requires a larger pull-in torque compared with the Francis type which is rotated in compressed air. (Consequently it sometimes happens that synchronization is impossible at ½ voltage).
   REMARK 2 *Fig. 17* shows an experimental result of shut-off pump input when guide vanes of the Deriaz type pump-turbine with a specific speed 70 m-m³/s is fully closed.
   The shut-off pump input at full closing of runner vanes is equal to about 8% of maximum pump input at the rated speed. Outline of starting system in case of our Francis type shall kindly be referred to Remark 3.
6) Transportation.
   In the Deriaz type plan, it sometimes happens that restriction for both weight and size is required as its runner boss is very large. In the Francis type plan, even in case of two division of runner, it has already been solved technically and on the

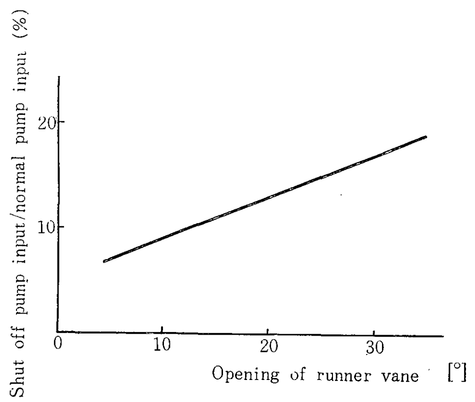


Fig. 17 **Shut off pump input of Deriaz type pump-turbine (at guide vane full closing)**

other problems including generator, we may consider that suitable divisions can be selected.

REMARK 3 Starting system of Francis type.

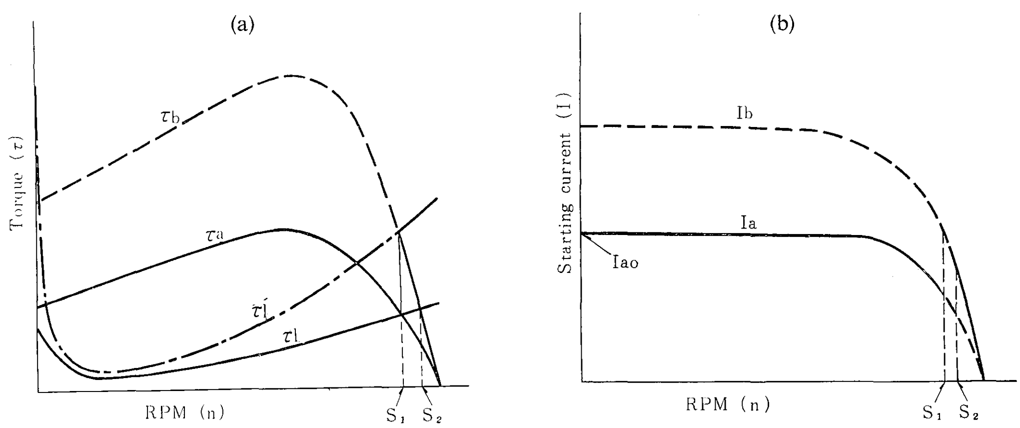
The required torque becomes considerably large when starting the turbine while loading a total weight on the thrust bearing, and putting the runner under water as it is. Therefore a special consideration must be taken in the design of the damper winding of main generator, however this is not desirable on the stability of operation of generator. Fuji Denki adopts such starting systems that i) by fully closing the guide vanes (movable), the runner is started in air perfectly by means of a compressed air device ; ii) by use of a magnetic thrust bearing the rotating part is lifted up to start. These devices are used not only at starting time but also at the time of ordinary operation in order to attribute to raise up the efficiency of generator. These devices are quite different from a simple oil pressure lifting device used for starting and are not expensive in cost. The same devices were actually applied to the 70,000 kVA 300 rpm water turbine generator for the Wadagawa No. 2 Power Station, Hokuriku Power Company, which have been operated quite successfully since. By means of this system, the required starting torque becomes bellow 10% as shown in *Fig. 18*. It has recently been demanded increasingly that compared with a scale of system a large unit capacity of the machine is used so that any large shocks may not be given the system. We wish to recommend the following system to satisfy this requirement by improvement of the characteristics of the generator as much as possible.

(1) △ connection winding of main transformer (½ voltage to be supplied to generator).

(2) Only one of double star windings of generator is connected and the other is opened. By the above, supplied voltage becomes to ½ and internal impedance becomes to 2 times, so that starting kVA becomes to 50% of the rated kVA. When, as shown in *Fig. 18* it does not attain to speed S_1, i.e. slip at the cross point of torque curve and required load torque curve, the neutral of the other winding of double star windings of generator is closed at this point, then a torque by double star is obtainable and it attains to the speed of slip S_2, thus the synchronization can easily be performed.

The current increases to I_b from I_a when changing over to the double star but it can be made smaller than starting current I_{a0}.

In case of the Deriaz type, the runner is rotated under water, so the required pull-in torque is large and it is difficult to start with one winding, therefore all the double star windings are used for starting at ½ voltage for instant.



I_a : Starting current at single star
I_b : Starting current at double star
τ_a : Torque produced at 1/2 voltage & single star connection
τ_b : Torque produced at 1/2 voltage & double star connection
τ_l' : Required torque in case lifter is not used and runner is rotated under water
τ_l : Required torque in case magnetic lifter is used and runner is rotated under air

Fig. 18 **Starting performance of motor**

VI. PUMP TURBINE AND GENERATOR-MOTOR FOR THE KUROMATA RIVER NO. 2 POWER STATION OF ELECTRIC POWER DEVELOPMENT CO.

Because of wide range of variable heads, also importance of efficiencies at partial loads and low head of the water turbine, two speed Deriaz type pump-turbine has been adopted for the Kuromata River No. 2 Pumping-up Power Station (refer to III–4).

1. Pump Turbine

1) Specification of Pump Turbine

Turbine operation

Effective head	78/73/39 m
Discharge	28/28/20.7 m^3/s
Speed	300 rpm
Turbine output	19,200/18,000/6,500 kW

Pump operation

Pump net head	77/75/41 m
Pump discharge	23.4/23.9/16.5 m^3/s
Speed	333/300 rpm
Pump input	20,000/20,000/7,900 kW

Fig. 19 shows turbine performances and *Fig. 20* shows pump performances. The pump is operated at a speed 333 rpm above a net head 60 m and a speed 300 rpm below a net head 60 m.

The hatching parts in the drawing show a range capable to adjust the pump discharge.

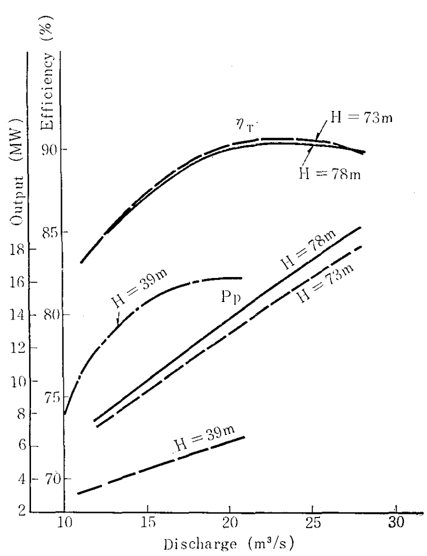


Fig. 19 Turbine performance curves

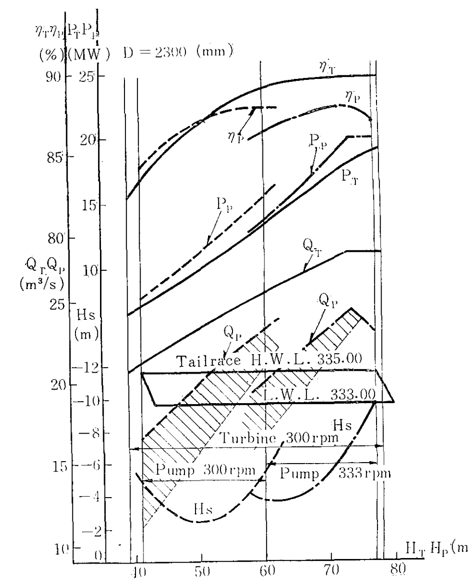


Fig. 20 Pump performance curves

2) Model Test

The efficiency tests and cavitation tests etc. when operating as a turbine and a pump respectively with 4 runners *A*, *B*, *C* & *D* each having a diameter 450 mm were carried out. *Table 2* shows the comparison for the turbine maximum efficiency and the pump maximum efficiency, however after various discussions, runner *C* was finally decided to be adopted. *Fig. 4* and *Fig. 5* show pump performances and turbine performances for runner *C* and *Fig. 21* shows the model of the runner and *Fig. 22* shows the photograph under the cavitation test.

3) Construction of pump-turbine.

Fig. 23 illustrates a section of assembly of the pump-turbine and the generator-motor. The runner vane consists of 10 blades and the conical angle formed by runner vane stems is 98 degree. As shown in *Fig. 24*, the fork and slider are used in two steps and such a mechanism as to convert the rotation of the runner vane into the movement of the axial direction of the turbine are used. Accordingly similarly to the conventional Kaplan

Table 2 **Comparison of best efficiencies**

Runner	A	B	C	D
Turbine operation	88.7	89.2	89.7	89.3
Pump operation	88.7	88.7	88.2	88.3

Fig. 21 Model runner of Deriaz type pump-turbine

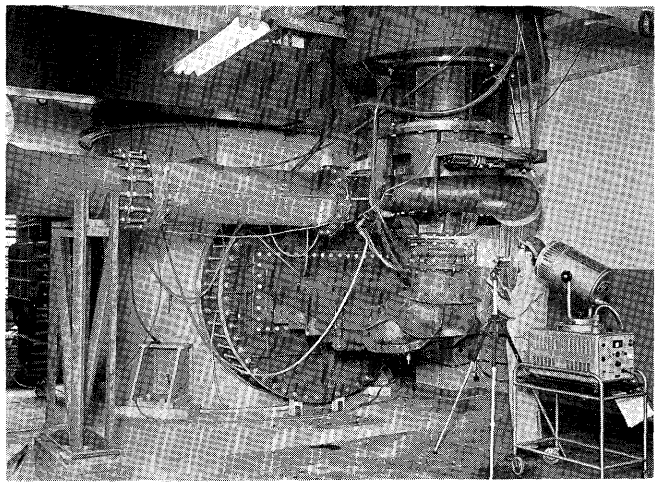


Fig. 22 Deriaz type pump-turbine model on testing

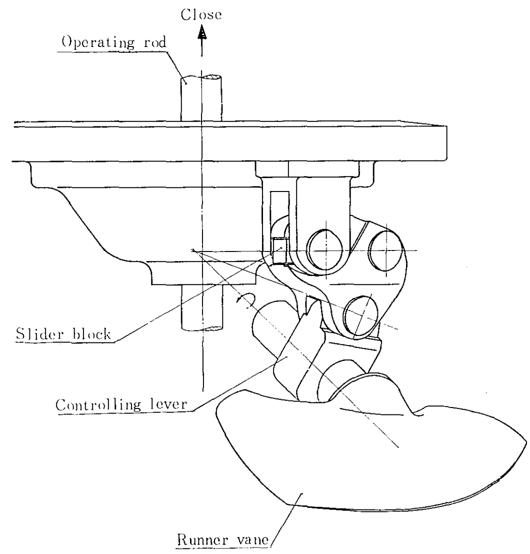


Fig. 24 Operating mechanism of runner vane

turbine, the servomotor of runner is contained inside the rotor of generator and the oil supply to the servomotor is carried out from the top of generator. Moreover a ring servomotor is adopted as a guide vane servomotor.

Fig. 25 illustrates a photograph for its assembly at our works' shop.

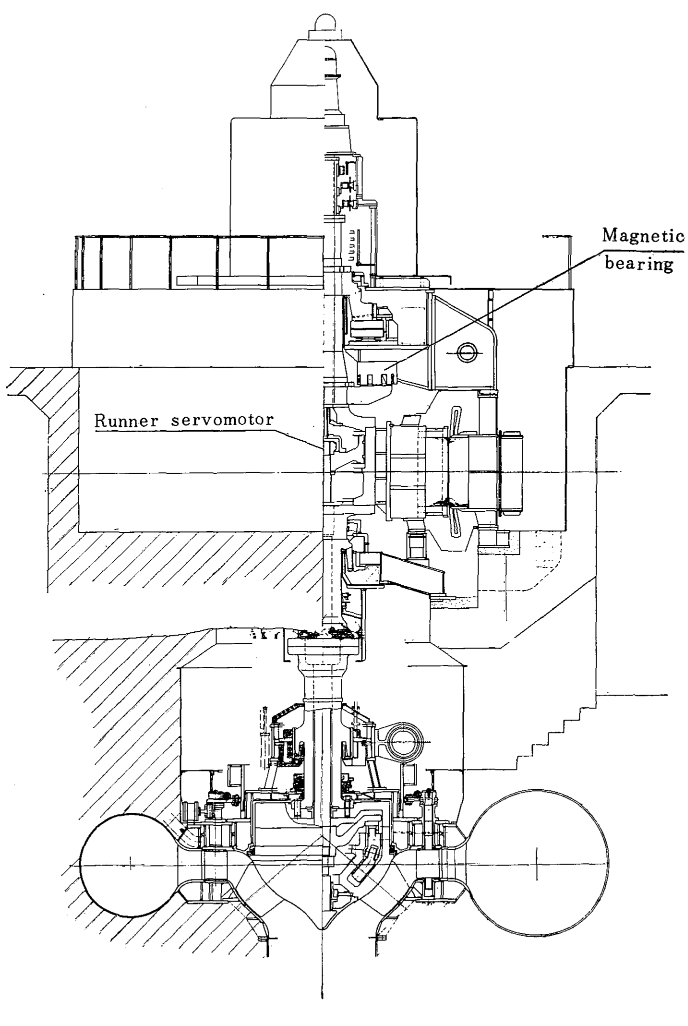


Fig. 23 Sectional view of Deriaz type pump-turbine and generator-motor of Kuromatagawa No. 2 Power Station

2. Pole-Change Type Generator-Motor

The specification for the generator is as follows.

When operating as generator
19,000 kVA 11 kV 50 c/s pf 0.9
300 rpm (20 pole)

When operating as motor
20,500 kW 10.5 kV 50 c/s pf 1.0
333 rpm (18 pole)
19,000 kW 10.5 kV 50 c/s pf 1.0
300 rpm (20 pole)

When operating as generator, as all the poles are utilized, the generator efficiency is very high, which is considerably fabourable.

Efficiency (pf 1.0)	100% load
Generator (300 rpm)	97.1%
Motor (333 „)	96.6%
Motor (300 „)	97.0%

As described above, by means of the magnetic thrust bearing, the rotating part is lifted up and is started at ½ voltage.

VII. CONCLUSION

In Japan, many pump-turbines and pole-charge type generators are now being manufactured.

These machines have many special features, such as superior functions, economical design

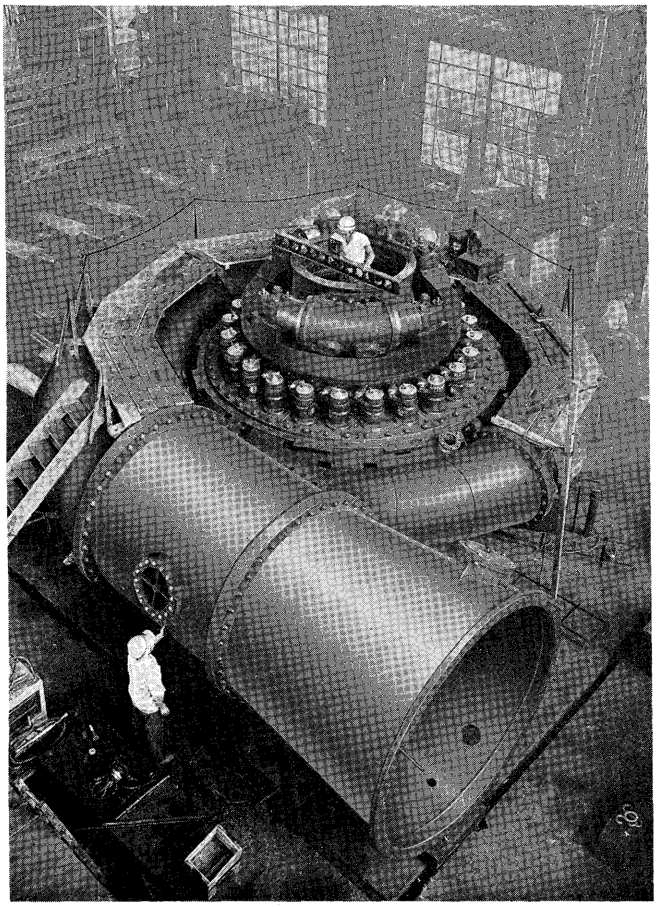


Fig. 25 Assembled Deriaz type pump-turbine

etc. compared with the products of the foreign countries.

In *Table 1*, weight % is shown for each plan.

The cost per unit weight for each machine is not same but it shows a tendency for cost. We can say that the Deriaz type one speed plan is inferior economically (also inferior in efficiency) to the Francis type two speed plan (case 1) with exception of the case when the pump operation at high pump head is not carried out like case 2 (in such a case as case 3).

When the efficiency at light load operation is considered important or the range of pump head is large, the Deriaz type 2 speed plan (case 5) is not expensive economically and is extremely superior in performances compared with the Deriaz type one speed plan (case 3).

As to the future problems to be researched by Manufacturers, the development of the Deriaz pump-turbines which have an excellent performance for variable heads and yet small pump input will be of great significance, because such pumps have not yet been developed in the world.