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SITE TEST OF 2-SPEED DERIAZ TYPE PUMP-TURBINE FOR KUROMATAGAWA NO. 2 POWER STATION, ELECTRIC POWER DEVELOPMENT CO., LTD.

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I. PREFACE

The two-speed Deriaz type pump-turbine and generator-motor for Kuromatagawa No. 2 Power Station are characterized by several outstanding features as equipment for pumping-generating plant. The pump-turbine in question is of the largest capacity in Japan as Deriaz type and the head utilized is the highest in the world. In constructing a Deriaz type pump-turbine, throughgoing model-tests and studies were made with many a prototype.

The generator motor, meanwhile, is the first pole-change type salient pole synchronous machine with large capacity that has ever been put to practical use and the system of pole-change employed is one which Fuji Electric Co., Ltd. has developed for a maximum utility value.

A magnetic thrust bearing is used, moreover, to reduce resistance torque at starting moment and also to increase operational efficiency. In summary, all kinds of measures are provided that are specifically designed to increased general performance efficiency as in the pump-turbine.

Both performance and constructional characteristics of these machines are given in detail in Fuji Electric Review, Vol. 10, No. 1.

The specifications of the pump-turbine and the generator-motor are as follows.

1) Pump-turbine

Vertical shaft Deriaz type pump-turbine

(1) In turbine operation

Effective head	max.	78 m
	normal	73 m
	min.	39 m
Output	max.	19,200 kw
	normal	18,000 kw
Discharge	max.	28 m³/s
Rated speed		300 rpm
Specific speed		189 (m-kw unit)
Runaway speed		710 rpm

(2) In pump operation

Net pump head	max.	80 m
	normal	75 m
	min.	41 m
Pumping discharge	at max. pump head	21.7 m³/s
	at average pump head	23.9 m³/s
	at min. pump head	16.5 m³/s
Input	max.	20,000 kw
Rated speed		333/300 rpm
Specific speed		63.5 (m-m³/s unit)
Static suction head		−9.5 m

2) Generator-motor

Vertical shaft 3-phase pole-change type a-c synchronouns generator-motor

Revolving field type closed ventilation circulation system

(1) In generator operation

Output	19,000 kva
Voltage	11,000 v
Current	997 amp
Power factor	0.9 (lag)
Frequency	50 c/s
Rated speed	300 rpm
Number of poles	20

(2) In motor operation

Output	20,500 kw (at 333 rpm)
	19,000 kw (at 300 rpm)
Voltage	10,500 v
Current	1159 amp (at 333 rpm)
	1075 amp (at 300 rpm)
Power factor	1.0
Frequency	50 c/s
Rated speed	333/300 rpm
Number of poles	18/20

3) Main transformer

Outdoor use, 3-phase core type oil immersed self-cooling system

Output	21,000 kva
Voltage, primary	10.7 kv (with 5.35 kv tap)
secondary	154 kv (161–154–147 kv with non-voltage tap changer)

With such machines as this with new features, it is natural that emphasis is attached to field running tests. The present equipment was tested on the field at the end of 1963 and, as anticipated, favorable results were obtained.

Tests and adjustment of this power station started on November 15, 1963, and continued until the middle of December when snowfall interrupted access to the station. By then, however, all kinds of tests had been completed including pump-turbine tests, pump tripping tests, motor starting tests of the generator-motor with two-speed in various cases, etc. that were considered necessary for the checking of facilities. It was ascertained at that time that everything functioned entirely satisfactorily.

The pumping test was carried out under the static pumping head of about 48 m, while the turbine test was conducted under the head of 48 and 65 m due to the particular water level that prevailed at the time. Consequently, another set of tests are scheduled for May, 1964, which will include pump-turbine tests under a maximum head and a continuous running test of motor on the high speed side.

In the meantime, we offer the first installment of such field test results as we have so far been able to get together for the benefit of interested parties, as we consider them of great significance in understanding the first full-fledged two-speed Deriaz type pump-turbine and pole-change generator-motor that Japan has ever produced.

In May, 1964, a turbine test at static head of 76.5 m and a pumping test at 333 rpm (18 pole) were both carried out and satisfactory results were obtained for both tests. These tests completed an entire series of tests envisaged for the Deriaz pump-turbine and the two-speed generator-motor.

Results of this test at high head will be briefly reproduced under Chapter V. Aditional information may be given at a later date.

II. DERIAZ TYPE PUMP-TURBINE

1. Turbine Operation

1) Load rejection of turbine

When a load rejection test was conducted for the head of 46 m, abnormal vibration of water pressure of spiral case and noise occured after several seconds following rejection of load over 6500 kw. For this reason, water pressures of spiral case, draft tube and runner sides were measured, and in every case there were big vibrations after several seconds following load rejection.

An example of it is shown in *Fig. 1*. This oscillogram displays that abnormal water pressure vibration developed after about 4.5 sec. following load rejection.

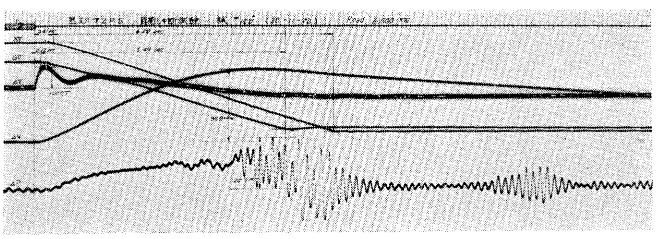


Fig. 1 Oscillogram of load rejection test

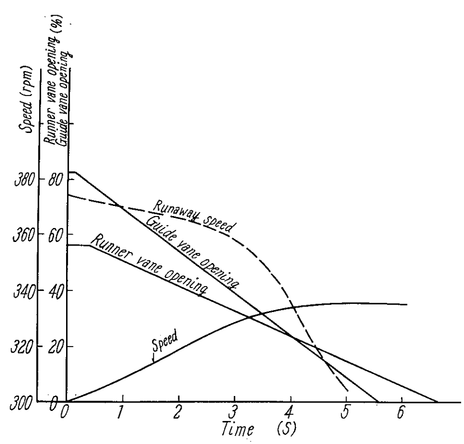


Fig. 2 Running speed at load rejection

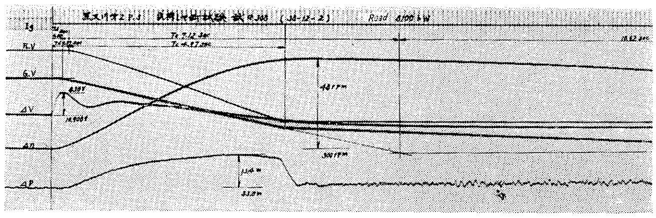


Fig. 3 Oscillogram of load rejection test

From many investigations we decided that after load rejection the status of on cam was disengaged and turbine entered into turbine brake range, then water pressure vibration became great suddenly.

Fig. 2, meanwhile, is a relational diagram of load rejection illustrated in *Fig. 1*. In this figure, a dotted line represents a runaway speed resulting from a transient combinated of the runner vane opening and the guide vane opening. This runaway speed curve crosses the rotating speed curve at about 4.1 sec. after load rejection, which indicates that after that point the turbine brake range commences.

In order to avoid abnormal water pressure vibration, therefore, it is necessary to shorten the closing time of the runner vane, to close it maintaining an opening relation near an on cam status between the runner vane and the guide vane, and to slowly close the guide vane after fully closure of the runner vane.

Adjustments were carried out on the basis of the foregoing theory and, as a result, it has been possible to completely dispose of abnormal water pressure vibration.

Fig. 3 indicates the result of a test after the adjustments.

During a load rejection test at the head of 65 m even, no abnormal water pressure vibration occurred.

2) Efficiency test

It is expected that efficiency tests of the turbine and pump operation will be conducted by a current meter at tailrace outlet.

2. Pump Operation

1) Pump starting

There are several ways in which the Deriaz type pump-turbine may be started, depending upon control of the runner vane and the guide vane. At the Kuromatagawa No. 2 Power Station, however, a simple control system was adopted.

Pump starting is effected in the following manner:

(1) After fully closure of the runner vane, both the by-pass valve and the main valve are fully opened. At the same time, the amperage at magnetic bearing is 130 amperes and a major part of rotating part-weight is increased.

(2) The pump starts as the starting switch #6 is thrown. Magnetic bearing current immediately after the start is brought down to 60 amperes. This amperage is set in such a manner that even when the upward water thrust is maximum it will not touch the upper thrust bearing.

(3) After acceleration, it is switched over to full voltage and then pull-in takes place. From the activation of #6 to switching to full voltage takes 55 sec. while from the activation of #6 to pull-in takes 60 sec.

The shut-off pump head and the shut-off pump input following pull-in correspond very well with values calculated from results of a model test as shown in *Table 1*. The fact

Table 1 Shut-off test

Runner vane opening (%)	Rotating speed (rpm)	Converted pump input (kw)	Test pump input (kw)	Converted pump head (m)	Test pump head (m)
0	300	1200	1423	59.7	58
0	333	1640	1780	73.3	70.0
100	290	2310	2900	82.5	78.5

that the test pump input is somewhat larger than the converted figure is due, it seems, to the absence of pieces to prevent gap cavitation corrosion in the model runner.

This shut-off input, moreover, is not subject to the influence of guide vane water leakage. This appears to be an advantage over the Francis type with which the simultaneous pump input varies drastically by reason of guide vane water leakage.

(4) After pull-in, a difference of water level of upper and lower reservoir is automatically detected to set a cam for pump operation and the runner vane is opened-rapidly up to a predetermined degree by this cam and then opens the guide vane by a load limit device in about 80 sec. and starts steady state pumping operation.

However, while opening the guide vane at partial discharge range, water pressure vibration in the draft and the spiral case and noise develop. It attains a maximum at about 40% of the steady state guide vane opening but when it goes beyond 75% it drops suddenly and quiet operation takes over. The time required from the activation of #6 to the start of steady pump operation is 2.5 min.

(5) Through the starting phase and the steady pump operation, both mechanical vibration and noise are by far smaller as compared with the Francis type and as far as steady pump operation is concerned in particular there is hardly any differency from the turbine operation. This may be termed as a great advantage of the Deriaz type pump-turbine.

(6) In neither steady nor transient state is there any guide vane vibration and it seems the guide vane brake is unnecessary.

2) Power failure

A power failure test was made with the guide vane opening of 25%, 50%, 75% and 100%.

By rapidly closing the guide vane to 30% guide vane opening and by reducing the closing speed afterwards to about 40%, pressure drop and pressure rise are reduced. The test result corresponds very well with the calculated result and a guaranteed minimum water pressure value is satisfied even with input failure at the minimum pump head condition.

Fig. 4 represents an oscillogram of 100% power failure.

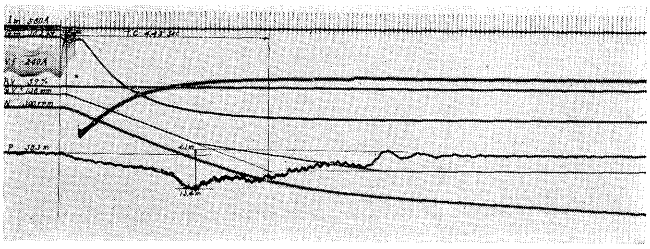


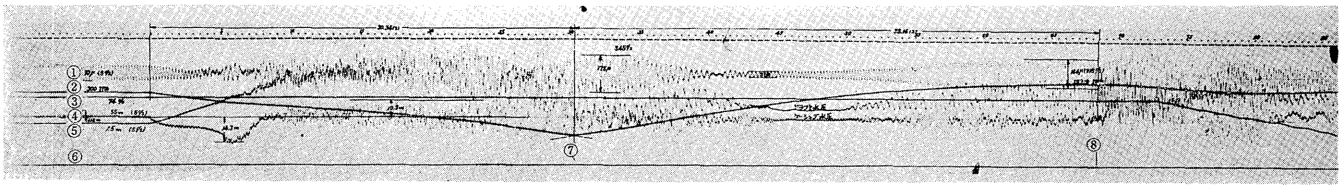
Fig. 4 Oscillogram of power-failure test

3) Pump trip test.

Power failure test with the guide vane and the inlet valve locked (pump trip test) was made.

Fig. 5 represents an oscillogram of pump trip test.

In about 30 sec. following power failure, reverse rotation commenced and in about 70 sec. the turbine reached a runaway speed of 383.8 rpm (128%). Water pressure vibration, mechanical vibration and noise reached maximum in the pump brake range (forward rotation reverse flow range) which became smaller as the turbine reached the on cam status but



① Horizontal vibration 70 μ (5%) at bearing
② Revolution 300 rpm
③ Guide vane opening 74%
④ Casing water pressure 55 m (5 c/s)
⑤ Draft water pressure 1.5 m (5 c/s)
⑥ Revolution mark
⑦ Standstill
⑧ Water pressure ripple in the casing (1.15 m)

Fig. 5 Oscillogram of pump trip test

which increased again as it reached the runaway speed. After it reached the runaway speed, it gradually stopped under turbine on cam condition in order to avoid abnormal water vibration referred to under load rejection. As was also mentioned under load rejection of turbine, it is clear from *Fig. 5* that in the turbine brake range (or speed reduction range) water pressure vibration and mechanical vibration are far greater than in the turbine range (or accelerating speed range).

3. Change-over between Generating and Pumping

Through a change-over of ≠43 *GP* switch for changing from generating to pumping and vice versa, change-over between generating and pumping takes place with the inlet valve opened.

Fig. 6 illustrates a change-over diagram from generating to pumping. The time required for this change-over was 7 min. 20 sec. Unlike the Francis type, control was simple due to the absence of the water level depression which contributes to reducing the change-over time.

Fig. 7 represents a change-over diagram from pumping to generating. The time required for this change over was 7 min. 35 sec.

The time required from a perfectly still condition (inlet valve closed) to steady pump operation was 5 min. 42 sec.

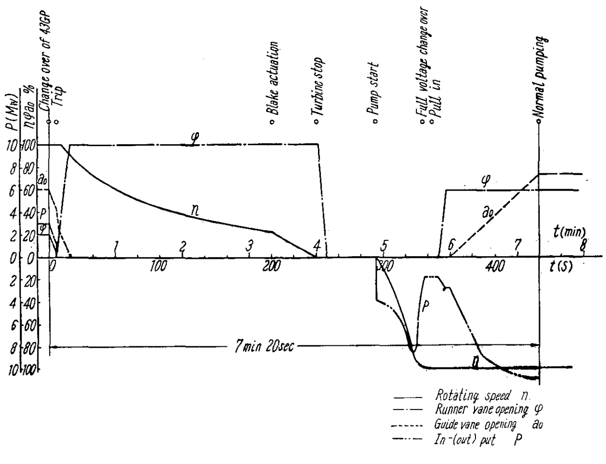


Fig. 6 Change-over diagram from generating to pumping

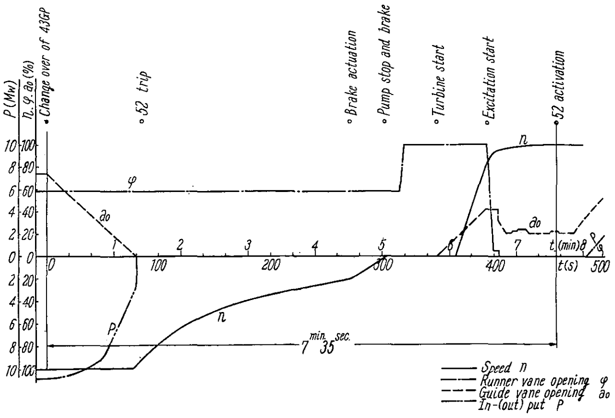


Fig. 7 Change-over diagram from pumping to generating

4. Shaft Displacement

With the Deriaz type pump-turbine, it is necessary to make the gap between the runner and the discharge ring as small as possible and yet at a constant figure in order to prevent drops in efficiency and to prevent development of gap cavitation. Runner gap is greatly affected by vertical displacement of the shaft. There are a variety of causes which bring about vertical displacement of the shaft including water thrust applied to each constructional part, temperature variation, etc. and, as far as temperature is concerned in particular, complex fluctuation of shaft displacement takes place transitionally since the thermal time constant of each constructional part is different.

With the present equipment, ample consideration has been paid to this point and to the installation. During the test, measurement was taken of shaft displacement, temperature of each part and water thrust in every conceivable range for a field test for running conditions.

1) Shaft displacement measuring instrument

This generator-motor is equipped with a shaft displacement measuring instrument to check on the gap between the Deriaz type pump-turbine runner and the discharge ring. This measuring instrument, as illustrated in *Fig. 8,* makes use of the theory of differential transformer. Upper and lower detector coils (inductance) are combined with resistance and con-

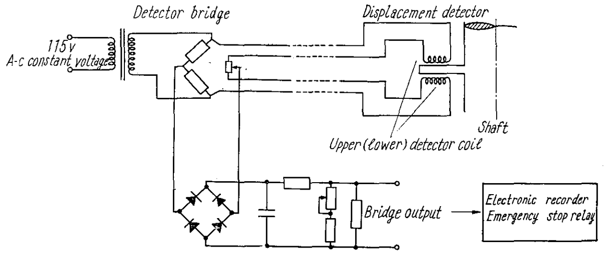


Fig. 8 Connecting of shaft displacement measuring instrument

nected as a bridge to which is applied a certain value of a-c voltage. Between the upper and lower detector coils is a disc fitted to the shaft, so that variation in the position of the shaft brings about a change in the coupling condition between the two detector coils and the bridge will obtain output voltage in harmony with shaft displacement. The bridge output voltage is related to an electronic recorder and to an emergency stop relay.

2) Result of shaft displacement measuring

(1) Shaft displacement in turbine operation

Fig. 9 shows the results of vertical displacement of the shaft in turbine operation at head 65 m. Water thrust increases remarkably for a time following the start of the turbine and the shaft descends. The amount of fall registered is about 0.4～0.45 mm from the time of stop. When it moved from start opening to no load opening, however, the shaft ascends and sets at a certain value. Going from stop to no load operation, the position of the shaft is about 0.45 mm upward due to the influence of upward water thrust. When load is dismissed, water thrust shoots up and the shaft descends. After that, the shaft gradually goes up and attains a certain value, tentatively, at about 1.5～2 hrs. Relation between time and this variation is identical to the variation in temperature of thrust bearing and upper guide bearing and it appears that the shaft ascends due to thermal expansion of thrust collar section. The ascending value of about 0.35 mm up to saturation corresponds perfectly to a calculation made on the foregoing basis. When the operation is continued for a longer time, the shaft descends by a very moderate rate of slope. This occurs mainly due to the elongation of the shaft as a result of rotor temperature rise. Since the thermal capacity of rotor is large, the descending slope is moderate. When the machine temperature attains perfect saturation, shaft displacement reaches a constant value. At load rejection, upward thrust temporarily becomes great and, on that account, the shaft ascends about 0.3 mm as compared with no-load operation.

(2) Shaft displacement in pump operation.

Fig. 10 shows vertical displacement of the shaft in pump operation at pump head of about 48 m. At the start there is atentative drop of about 0.1 mm but with the rising of rotating speed, the shaft rises. The ascending value is maximum when the runner vane is opened with the guide vane closed. As the guide vane is opened and water discharged, the shaft descends due to water thrust but after that it gradually ascends and again moderately falls, just as in turbine operation. The case of a normal stop presents a converse phenomenon to the start. At power failure, because of speed drop a momentary upward water thrust is small, and there is little ascension of the shaft in a temporary manner.

(3) Taking into consideration both turbine operation and pump operation, it is when the turbine starts, that the shaft descends most and it is at load rejection of the turbine that the shaft ascends most.

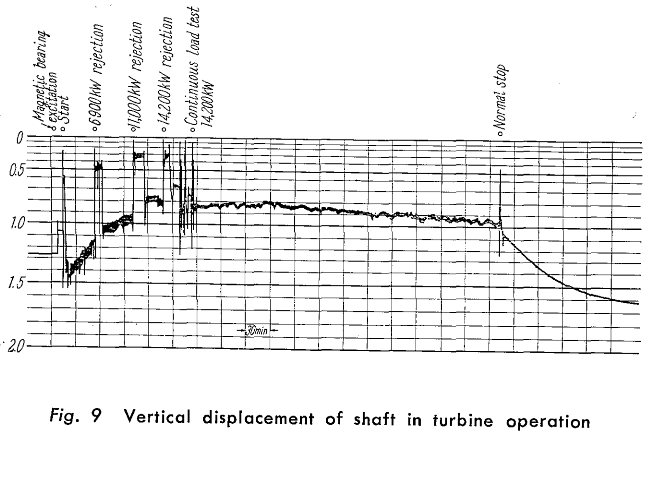


Fig. 9 Vertical displacement of shaft in turbine operation

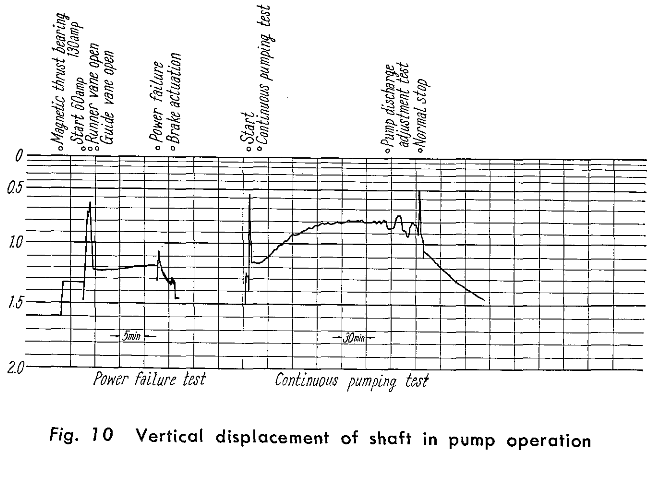


Fig. 10 Vertical displacement of shaft in pump operation

III. MOTOR STARTING TEST

Starting characteristics of a generator-motor as a motor are very important in the functioning of pumping equipment and need to be completely tested. It should be confirmed that the generator-motor is connected to a specified system, drives the pump-turbine, goes through each stage of starting and pull-in smoothly and proceeds to the pumping operation. However, since plant tests are limited to such local tests, generally speaking, as lock test, measuring of torque characteristics in the neighborhood of pull-in speed, etc., more emphasis is placed upon field tests and starting tests of the motor, in particular, in order to verify for the last time all of the functions. In case of Kuromatagawa No. 2 Power Station, there is an additional factor that the generator-motor has the largest capacity as a practical model of pole-change type. Torque characteristics in 18 poles, for instance, present unique problems of interest so that unusual concern was displayed over its starting test. Motor starting characteristics of the Fuji type pole change generator-motor have been tested in many different ways since their research stage and have been proven to be capable of full performance as pumping equipment. During the field test, sufficient tests were made as to the existence of unusual torque phenomena at start of the equipment, vibration, pull-in, temperature rise at start winding and effect of starting upon voltage of various parts of the system, and it was confirmed that it had all of the functions claimed for it. The following are results of the field test for starting of the motor.

1. Starting System

Starting system of the present generator-motor is a voltage reducing type start which utilizes 50% voltage tap fitted to low voltage winding of the main transformer connected to 160 kv transmission line that extends from Nagaoka Substation through Kuromatagawa No. 1 Power Station to the present power station.

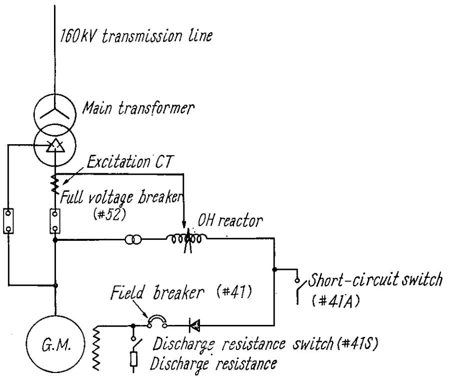
The present equipment is furnished with a Maglager (magnetic thrutst bearing) and, at start, this Maglager is force-excited to lift a major part of the weight of the generator-motor rotor and the pump-turbine runner and to lessen load on the thrust bearing, after which starting switch (♯6) is closed. As the resistance torque of the generator-motor set at the moment of starting is mainly due to static friction of the thrust bearing, this method reduces resistance torque and the generator-motor is able to start easily. At the speed increases, the magnetic attraction of the Maglager increases due to oil film influence, then, the exciting current of the Maglager returns to a set value, which is constant, as the rotation has begun.

As the generator-motor is accelerated and its slip becomes 1%, the ♯6 is released and full voltage switch (♯52) is activated to apply total voltage to the generator-motor. With the present equipment, since the pump-turbine directly connected is of Deriaz, no pushing down of water level takes place but the runner rotates in the water with the guide vane and runner vane totally closed. As the speed goes up, considerable resistance torque arises, so that our sequence is such that voltage switch is activated as explained above and that pull-in takes place under full voltage.

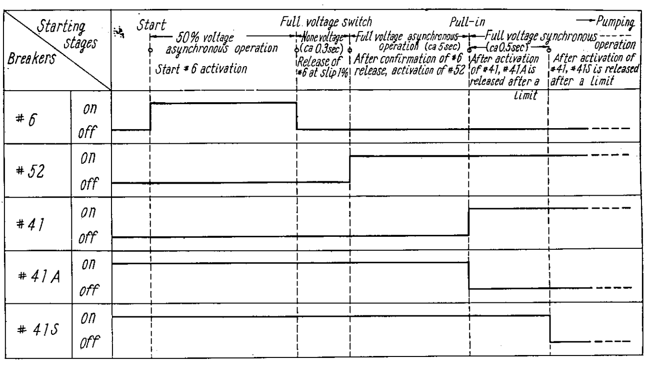
Following activation of ♯52, as the field braker (♯41) is activated at about 5 sec., pull-in takes place. Discharge resistance is connected to field winding during the starting period but this is removed by discharge resistance switch (♯41 S) within about 0.5 sec. following ♯41.

The system of excitation adopted on this equipment is a self-exciting system of type OH and CT for excitation is connected to the full voltage circuit. Consequently, in the half-voltage process, there is no influence of CT upon the excitation circuit but when it is changed over to full voltage the effect shows up and badly affects the rectifier, etc. so that on the a-c side of the rectifier is fitted a short-circuit switch (♯41A) to short-circuit it during the starting phase until ♯41 is activated.

Fig. 11 represents a diagram of start of the present generator-motor.



(a) Connection diagram of generator-motor



(b) Starting stages of generator-motor

Fig. 11 Procedure of motor start

2. Starting Test

This generator-motor is of the two-speed type Fuji pole-change system comprising 20 poles and 18 poles. The motor may start on either polarity and sufficient starting tests were conducted at both speed and it was confirmed that they functioned smoothly. *Fig. 12* represents an oscillogram of 20-pole motor start, while *Fig. 13* shows that of 18-pole motor start. In either case, the number of revolutions increases smoothly which indicates there is no abnormal torque. *Fig. 14* shows asynchronous torque speed characteristics on 18-pole running as obtained from the starting oscillogram. Comparative importance is attached to the turbine operation on 20 poles, so that the change system aims at 20-pole operation mainly and provisions are made to get better efficiency there. Therefore, although on an 18-pole operation the relationship between magnetic polarity and magnetic field is different from that of usual synchronous motors, there is no abnormality in torque characteristics as shown in *Fig. 14.* The following are test results at each stage of starting phase.

1) At activation of ♯6

Starting current kva and input at activation of ♯6 are as in *Table 2.* The rated kva on 18-pole motor operation of this generator-motor is 21,100 kva but the kva at start only requires about the same

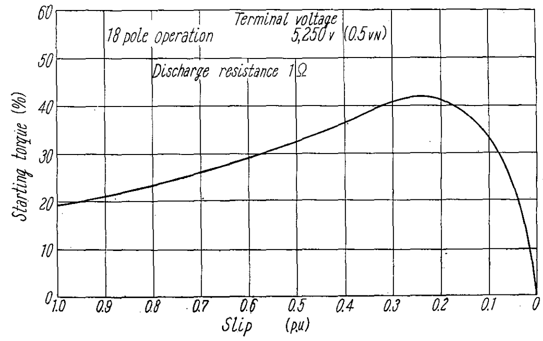


Fig. 14 Torque speed characteristics at 18 pole running

Table 2 Results of starting test

Item \ Number of poles	20	18
System voltage (immediately prior to making of ♯6) (kv)	160	160
System voltage (immediately after making of ♯6) (kv)	156	155
Terminal voltage (immediately after making of ♯6) (v)	4460	4820
Armature current (amp)	2640	2610
Starting (kva)	21,400	21,800
Motor input (kw)	ca. 4650	ca. 4700

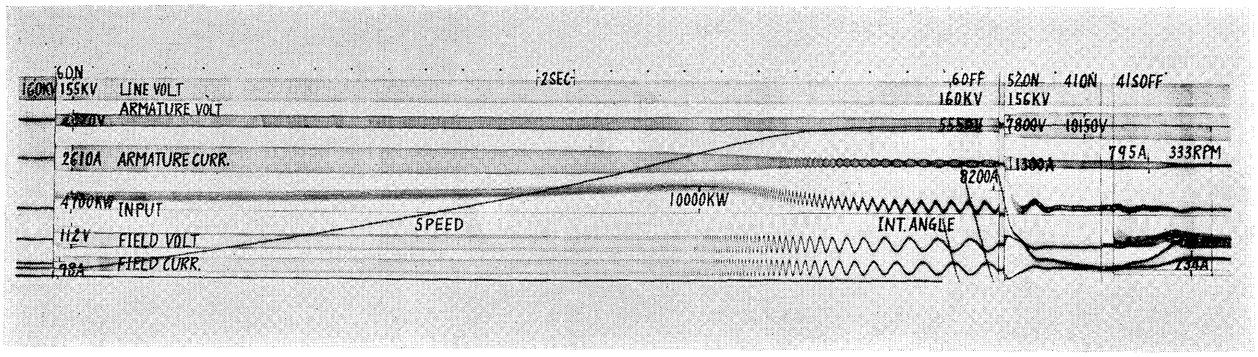


Fig. 12 Oscillogram of 20-pole motor start

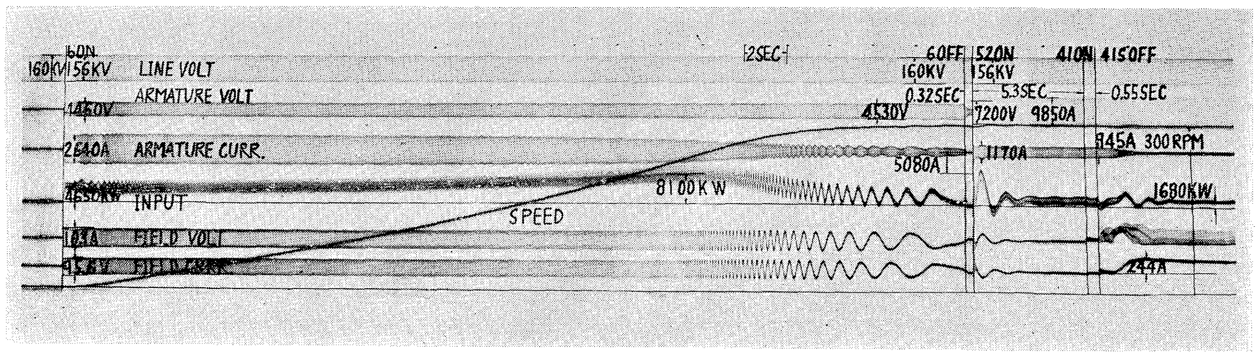


Fig. 13 Oscillogram of 18-pole motor start

Table 3 **Results of starting test**

Item \ Number of poles	20	18
System voltage (immediately before activation of ♯52) (kv)	160	160
System voltage (immediately after activation of ♯52) (kv)	156	156
Terminal voltage (immediately after activation of ♯52) (v)	7200	7800
Armature current (maximum value of transient component at activation of ♯52) (amp)	5080	8200
Armature current (steady immediately after value activation of ♯52) (amp)	1170	1300
Residual voltage (immediately preceeding activation of ♯52) (v)	1870	1300

degree of kva of rating.

2) At activation of ♯52 (process of full voltage change-over)

When generator-motor reaches 1% of slip under 50% of voltage, ♯6 is released and as soon as this action is confirmed ♯52 is activated. The time required in between is about 0.3 sec. Residual voltage of the generator-motor immediately preceeding activation of ♯52 went down below 20% of full voltage and activation of ♯52 may be done at random. *Table 3* shows measured values at activation of ♯52. Transient rush current that flows in with the activation of ♯52 is thoroughly diminished in about 0.1 sec. and the effect upon the system at this time is almost the same as the activation of ♯6.

3) At activation of ♯41 (pull-in process)

Transient phenomena that take place at activation of ♯41 are highly smooth as indicated in *Figs. 12* and *13*. Pull-in occurs very easily. In the pull-in process a measurement was taken of the internal angle of the generator-motor and an example is shown in *Fig. 15* on 20-pole operation. It shows trajectory of pull-in step, which displays that a point of stability is reached in about 5 sec. following ♯41 activation and that there is no major vibration of internal angle.

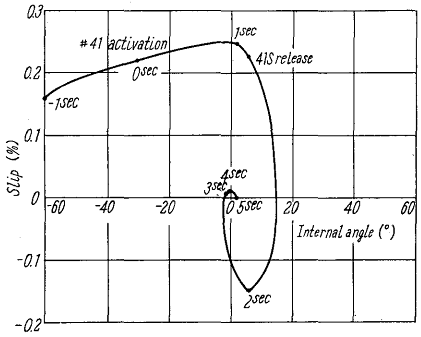


Fig. 15 Trajectory of pull-in step

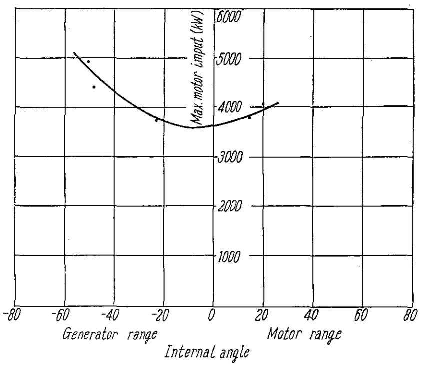


Fig. 16 **Relation between maximum motor input and internal angle at commencement of excitation**

♯41 is activated after activation of ♯52 in a time limit of 5 sec. and *Fig. 16* shows a relation between maximum motor input and internal angle at activation of ♯41 at commencement of excitation and the effect upon the system is not so sensitive to the internal angle at activation of ♯41 and it has been found that with our equipment the method of excitation by time limit creates inconvenience. This is because with the present system minimum slip under total voltage is small and because the load resistance torque is relatively stable due to the fact that the runner is rotating in water.

4) Starting time

Table 4 below shows the time required for starting the equipment.

5) Vibration of generator-motor in starting period.

On either 20 poles or 18 poles vibration of the generator-motor in the starting period is very little; it registered about 2/100 mm on the auxiliary stand fitted to the upper bracket. In the transitional following the activation of ♯52, there was but a slight shock. Vibration during regular operation is very little, or on the order of 0.5/100 mm.

Table 4 **Starting time**

Item \ Number of poles	20	18
From start (activation of ♯6) to pull-in (release of ♯41 S) (sec)	48.5	57.2
50% release voltage process (sec)	42.3	51.0
Non-voltage process (sec)	0.3	0.3
Full voltage asynchronous operation process (sec)	5.3	5.3

3. Temperature of Damper Winding

Temperature of damper winding poses a big problem on self-starting due to a heavy energy loss arising from acceleration at the moment of inertia of generator-motor.

Since the present equipment is connected directly to a Deriaz type pump-turbine with a great requirement of GD^2 this problem is intensified. On the field, two consecutive starting test were made on the 18 poles with greater loss of energy at start and the temperature was taken of the damper winding. Temperature measurement was done with thermo paint on the one hand and by a surface thermometer to record temperature variation after stop. *Fig. 17* shows results of these tests. It indicates that the temperature of the damper segment is not varying with the advance of time. On the other hand, the connecting piece which links the damper segments in between the poles shows an almost equal temperature to that of the joint between connecting pieces, and the damper segment and has a tendency of lowering temperature with the passage of time. As this trend is extended as indicated in diagonal lines and a certain amount of cooling by coolant ventilation during stop is taken into consideration, it is assumed that when the second start is completed the damper winding registered the temperatures as shown in *Table* 5.

No direct taking of temperature of the center of damper winding was attempted but assumption by calculation sets this to be an increase to the order of 150°C after two consecutive starts. Temperature of the end ring of damper winding as obtained on the same basis corresponds very well with the actual measurement, and it may be safely claimed that temperature rise in the center must have been 150°C.

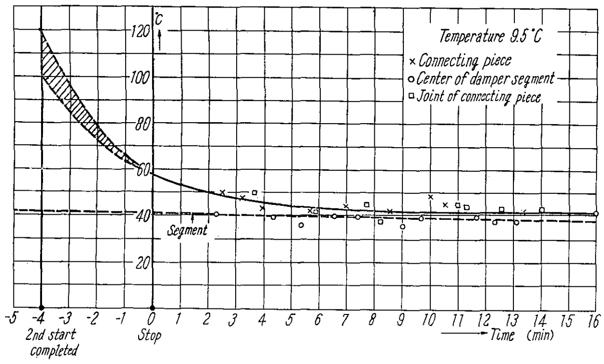


Fig. 17 Temperature of damper winding

Table 5 Temperature of damper winding

Place	Temperature (°C)
Damper segment	ca. 40
Connecting piece	ca. 100~120
Joint of connecting piece	ca. 100~120
Ambient temperature	9.5

4. Voltage Drop Test of System

When the generator-motor of a pumping power station commences motor operation, it has effects on the system connected with it, and how this effects other is an important question in the administration of pumping power stations. *Fig. 18* indicates a system in which Kuromatagawa No. 2 Power Station is located. Motor starting was attempted in the present test in two cases, i.e., first when the connecting Kuromatagawa No. 1 Power Station ($2\times35{,}000$ kva) is operating, and second when it is at a standstill. Voltage variation at a major points of the system was recorded as shown in *Table 6*, which corresponds with anticipated values at the time of the planning stage. The main transformer of the present power station does not have LRT but only no load changing taps. It has been confirmed, nevertheless, that operation goes on without trouble even when system voltage fluctuates, only with the tap that is set only once.

Table 6 Voltage drop test of system

Item \ System conditions	Kuromatagawa No. 1 P.S. operating	Kuromatagawa No. 1 P.S. stopping
Kuromatagawa No. 2 P.S. voltage (kv)	160→156	155→150
Kuromatagawa No. 1 P.S. voltage (kv)	161→157	157→153
Nagaoka S.S. voltage (kv)	158→157	157→154
Niigata S.S. voltage 270 kv system (kv)	No variation	279→278
Niigata S.S. voltage 160 kv system (kv)	No variation	156→155
Joetsu S.S. voltage (kv)	No variation	No variation
Honna S.S. voltage (kv)	No variation	159→158

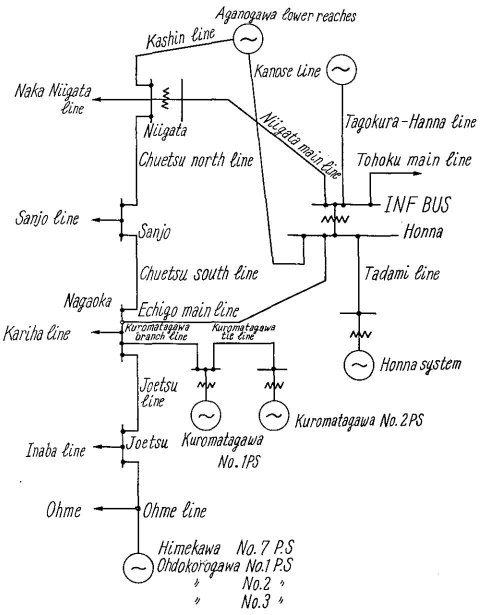


Fig. 18 Diagram of transmission system

IV. LOAD OPERATION TEST OF GENERATOR-MOTOR

Load operation test of the generator-motor either as a generator or as a motor was made not under maximum water level conditions for generation or pumping but under light load, but the results very well corresponded with those obtained at the plant test.

Fig. 19 shows a load test at 14,500 kw, 0.88 power factor, 20 poles and 300 rpm. The temperature in turbine operation of thrust bearing was 45°C at 300 rpm, and 43.5°C in pump operation at the same speed, and it has been confirmed that both forward and reverse rotations take place without trouble. It is expected that a more detailed load operation test will be conducted at a time when maximum head is obtained.

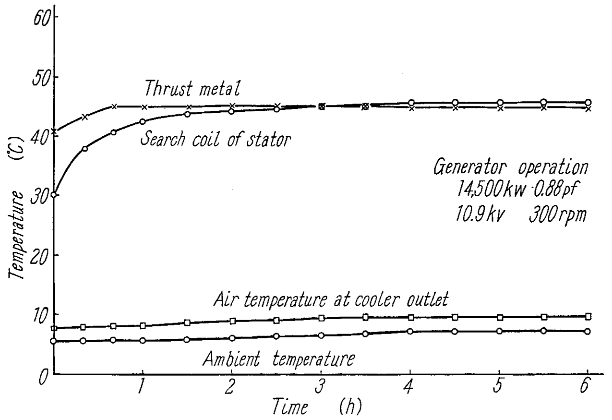


Fig. 19 Temperature test

V. RESULTS OF TEST AT MAXIMUM HEAD

In May, 1964, a turbine test and a pumping test at 333 rpm at static head of 76.5 m were carried out of which results are reproduced below in resume.

1. Deriaz Pump-turbine

1) Turbine load rejection test

A load rejection test was conducted at effective head of 75 m with the guide vane closing time which, was adjusted during low head load rejection tests It was found as a result of the test that when load rejected exceeded 17,000 kw abnormal water pressure vibration developed at the guide vane opening under 43%, vibration similar to that which took place during the low head load rejection tests. However the foregoing abnormal water pressure vibration was stopped by increasing the guide vane opening, at which the closing speed of the guide vane becomes slow, from 28% to 43%.

2) Pump input rejection test

An input rejection test was made at pump net head of 78 m, at 333 rpm and at 20,000 kw operation. It was found then that pressure rise 12.9% and drop 19% and thus it was confirmed that the turbine still left sufficient allowance before the guaranteed values are reached.

2. Generator-motor

The pole-change type generator-motor was subjected to a continuous operation on 18 poles at 333 rpm for 20,000 kw. No problem was detected.

VI. CONCLUSION

Equipment at Kuromatagawa No. 2 Power Station consists of the world's largest two-speed Deriaz type pump-turbine and pole-change generator-motor (with magnetic thrust bearings) which are both technically out of the ordinary. Final judgement of the equipment had to wait for a field test and every effort was put in model tests and toward theoretical analyses even during the planning and designing stage.

Although not under circumstances wherein all the conditions were available such as the water level, for instance, the tests that had been foreseen were completed and satisfactory results were obtained.