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THE MASTER PLAN STUDY ON SMALL-HYDRO IN NORTHERN LAOS

FINAL REPORT : VOLUME 3

SMALL-HYDRO MANUAL

PART A	SMALL-HYDRO PLANNING MANUAL
PART B	**OPERATION & MAINTENANCE MANUAL**

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THE MASTER PLAN STUDY
ON
SMALL-HYDRO IN NORTHERN LAOS

FINAL REPORT

VOLUME 3 SMALL-HYDRO MANUAL
PART-B: OPERATION AND MAINTENANCE MANUAL

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1.1 NECESSITY OF GOOD OPERATION AND MAINTENANCE

1.1.1 GENERAL

A small-hydro plant has an advantage that it does not need fuels for its operation as compared with diesel power plant. However, there is no essential difference between both types of plant on that **an appropriate operation and maintenance (O&M) is essential for sustainable operation**. It is able to be operated for long time period if its facilities are properly operated and maintained.

We have to operate and maintain small-hydro plant with strict compliance to the operation and maintenance manuals. In general, operators of small-hydro plants should understand followings:

(i) Operators must efficiently conduct operation and maintenance of a plant complying with the work plan, rule and regulation.

(ii) Operators must familiarize themselves with all the power plant components and their respective performance or function of corrective and preventive. Furthermore, they must also be aware measures against various accidents for prompt recovery.

(iii) Operators must always check conditions of facilities and equipment. When they find some troubles or accidents, they must inform of it to a person in charge and try to recover it.

(iv) Operators must try to prevent any accidents. For the purpose, they should repair or improve facilities preventively as necessary.

Operation and Maintenance Manual should basically be prepared for each power plant individually before beginning of its operation. In order to achieve the effective operation of a power plant, to meet the initial objectives of the plant, and to achieve a long operating life by maintaining the working functions of facilities and equipment, **a staffed organization for O&M shall be required**.

Various operating rules and manuals will be required as the basis of operation and maintenance works. Usually, the following components have the highest priority:

- Operation rules;
- Manual for maintenance works;
- Collection and provision in the plant of relevant technical references.

Also, special attention shall be paid to ensuring safety. ***A Safety Manual*** is essential to secure the safety of personnel, equipment, and facilities and to cope with the consequential losses resulting from their abnormal performances. By having these rules and manuals prepared together with the instruction and management provided by a responsible manager, the power station will exert its original functions effectively over a long period.

1.1.2 HOW TO MAKE A GOOD OPERATION

The small-hydro will ensure electric power supply to non-electrified areas and areas and thus much contribute to rural electrification. On the other hand, the small-hydro has some disadvantages:

(i) River flow varies from rainy to dry seasons of the year and from year to year. Thus, the annual energy generation highly depends on river conditions.

(ii) Energy generation is forced to stop when river flow seriously decreases or for the worst dries up due to severe drought.

The operation of small-hydro plant is not only to generate electric power but also to control generation equipment and to supply electricity of stable quality to consumers (village people), keeping good condition of all the facilities related. As a power plant has an automatic load stabilizer (load control), the operators do not always have to control equipment except in case of starting, stopping and emergency. ***The operators preferably shall stay at the power plant to control equipment or prepare to rush to the plant in order to immediately take measures in case of trouble.***

1.1.3 HOW TO MAKE A GOOD MAINTENANCE

In order to operate small-hydro plants in good condition for longer period, water intake facilities, waterway facilities, electric equipments, and distribution lines should be maintained adequately. The operators must try to observe even a small trouble and prevent accidents of facilities. For this purpose, ***daily and periodical inspections*** are essential and ***recording and keeping of those data*** are also important. The check items and the frequency of the patrol and inspection should be decided considering the condition of facilities and operation method.

1.2 POWER STATION STAFF AND ORGANIZATION

1.2.1 DETERMINATION OF NUMBER OF STATION STAFF

The number of staff of the power station should be determined from a comprehensive viewpoint with reference to the following matters:

- Output of power station: This is a major factor to represent both of the scale and the importance of the power station.
- Numbers of installed units: Number of hydraulic turbines, generators, main transformers, etc is relevant to determination of number of station staff.
- Type and scale of civil works facilities: Dam type, or run-of-the-river type, scale, etc.
- Power station control: Automatic control, remote control, manual control, etc.
- Power plant operation with system: Isolated operation, parallel operation with grid, time-scheduled operation, etc.
- Location of power station: Distance from staff residence, conditions of access roads, etc.
- Conditions of infrastructures: Means of commuting to the Station (car, motor-bike, etc.) and communications
- Economy: In determination of number of station staff, it is required to secure with cheaper cost for power generation.

1.2.2 DEMARCATION OF OPERATION AND MAINTENANCE

Although the above factors are taken into consideration, the total number of staff should be determined mainly from the required number for an emergency case. The daily workload of the staff is then determined by the requirement to either undertake relevant work of O&M in parallel or to do the works alternately between O&M. The operational tasks and maintenance tasks are substantially different from each other. If these are to be undertaken by the same person or by the same Shift Team, there would be idle time for one party or there would be a tendency to lack genuine effort for pursuing improvement in the technology level.

To avoid such defects, the staff should be divided into a group exclusively responsible for Operation and the other group exclusively responsible for Maintenance. By having the two groups exclusively undertake their respective assigned tasks, an improvement in the work quality and upgrading of technological level can be planned. Even an economic effect can be expected through reduction in the manpower input that would result from rationalization of the working regime in the power station.

The demarcation of O&M, when applied to a power station under isolated operation, may not have an appreciable effect due to adverse effects from other constraints. However, if it is applied to a power station under one of the following conditions, a positive effect would be expected:

- Numbers of power stations that are such located in the same river basin or are arranged systematically as to manage system control as one unified group;
- A power station that is connected to a grid in parallel with other power stations which are not limited to hydro power;
- A power station that feeds the grid but has only a little amount of operation tasks;

- A power station that has been fully automated in its operation.

Table below presents the work allocation under an conventional work management and an example of rationalization by the demarcating of O&M.

Table 1.2.1 Example of Rationalization by Demarcating of O&M

Items		Power Station A	Power Station B
Station Scale	Station Output Nos. of Installed Units Mode of Control System Type of Power System Operation	1,500 kW 3 units One-man Isolated operation	1,000 kW 2 units One-man Isolated operation
Conventional configuration	General Manager Daytime staff Shift workers (nos. of staff per shift) 3 shifts-2 shifts per day, a total number of staff Daytime workers (spare for shift) (Sub-Total)	1 3 (night shift 5) 15 2 (21)	1 2 (4) (night shift 4) 12 1 (16)
Configuration after Demarcation of O&M	General Manager Daytime workers Shift workers (nos. per shift) Total workers of 3 shifts-2 changes (Sub-Total)	1 （also the GM of Power Station B） 2 (3) (night shift 3) 9 (12)	0 1 (2) (night shift 2) 6 (7)
	(Newly established) General Manager Daytime Workers (Sub-Total)	Maintenance Centre 1 7 (Of these, 2 are standby for shift works) (8)	
Comparison	Total Conventional management 37 After demarcation of O&M 27	Daytime Shift 10 27 12 15	

1.3 OPERATION AND MAINTENANCE RECORDS MANAGEMENT

The operational records of a power plant and its equipment, together with the contents of all maintenance works performed are important data in managing the power station and, therefore, these data should be sorted out and managed in accordance with an logging format.

(1) Operation Record

A. Daily Operation Logs

In order to keep records on the daily operational conditions, the following major operational data should be recorded at one hour intervals using a log sheets. Those figures in parentheses are to be recorded when a suitable meter is provided in the Station.

a. Operation Outputs Data

Power, energy generation, (turbine discharge), outgoing energy

b. Operational Data

Voltage, current, power factor, frequency, revolution speed, opening of water inlet (guide vane or needle valve), water pressure, oil pressure, water level of head tank, oil level of pressured oil tank.

c. Maintenance Data

Temperature of guide bearings, temperature of generators, (temperature of cooling water).

d. Other Data

Date, weather, atmospheric temperature, station temperature, (relative humidity).

e. Particular Data (may also be recorded and reported using a separate form).

Unexpected incidents, scheduled works.

B. Monthly Operation Report

The following comprehensive data should be prepared in every month in a Monthly Report based on the Daily Logs:

Monthly energy generated, maximum and minimum power, maximum and minimum voltage, maximum and minimum current mean daily power (mean daily discharge used for power generation).

When there are numbers of generating units in the Station, the above data should be prepared for each unit as well as for the whole Station. The records should be sorted out for permanent reference.

(2) Records of Maintenance Data

In order to maintain the Station equipment and facilities, daily and periodical inspection, maintenance, and incident management should always be recorded and kept as Station maintenance records.

A. Daily Inspection Records

The following inspection items shall be recorded using an prescribed Form of Daily Log:

a. Outside Appearance

Water leakage, oil leakage, sparks of slip-ring, cooling water, tailrace channel, dew condensation

b. The sense of touch, feeling of touch, and other individual feelings

Vibration, noise, abnormal sound, unusual smell, intrusion of small animals, birds, and insects, dirt and stain.

c. Daily maintenance works

Adjusting, caring, cleaning, filling up of oil and grease, and so forth.

B. Records of Periodical Work

Inspection with standstill condition of the unit, and internal inspection with caring and disassembling works, etc. should be recorded in detail with photographs.

C. Records of Incident Restoration

In particular, the cause, parts of failure, affects of incident to the other Units, extent of restoration, countermeasures to be followed up, countermeasures to prevent a recurrence of a similar incident, etc. should be recorded in detail together with contents of the Incident Restoration Process, photographs, and its reference technical data.

The records of items B and C above should be well shared and known to everybody in the Station and shall also be reported to the Upper Management, in order to contribute to improving the technical knowledge. Since these records have important information also as reference for the further maintenance works, these records should be kept inside the Station with copies distributed to relevant Agencies for his data base.

The method of storage of these records should be prescribed as a rule, taking into consideration the existing document system and particular situation, the environment of the Station and consultation with the concerned authorities.

1.4 COMMUNICATION AND REPORTING SYSTEM

1.4.1 COMMUNICATION AND REPORTING SYSTEM

A. Daily Collaboration

Regular handing over items to the next Shift, from the Daytime Maintenance Team, etc. should be confirmed in the form of written documents with the joint names of the former and later which should be exchanged at every handing over time.

In case no-regular information should be made, it is recommended to establish the basic document flow with the items of required Information so as to secure the successful transmission of information. When such information was to be advised verbally due to an unavoidable reason, a written information should be prepared so as to confirm such verbal information later on.

B. Confirmation of Activities.

The confirmation on the maintenance activities, etc., should be exact and safety, so, the written documents should be required for checking and approving by a responsible staff member.

In particular, works with power outage, transportation of heavy goods, and joint works with different workers/parties needs a systematic approach by clearly establishing the Rules of Pre-work Meeting and Method of Communication to avoid unexpected event.

C. Reporting System

All the reporting should be made in accordance with an prescribed criteria and standard. Depending on the contents of the reports, it is required to establish such proper system that the copy of the report should be clearly identified, the manner of document be standardized, the organization responsible for recording storage be determined, and the method of transmitting reports be confirmed.

1.4.2 RESPONDING SYSTEM FOR EMERGENCY

Occurrence of the following events will require urgent countermeasures. Prompt and exact reporting system and countermeasures should be confirmed and well known through regular training, of all the staff concerned.

- Casualty: Special attention should be paid to night work when there are few shift operators and if works requires in remote places like the head tank, intake, etc.
- Fire accidents.
- Bursting of penstock pipes.
- Serious failures of main unit, breaking of main shaft, burning damages of generator winding, etc.
- Serious failure of power transmitting facilities.
- Accident due to disaster, like flooding.
- Receiving an emergency information from outside or third party.
- Recognition and judgment of emergency situation by the Shift in Charge

1.4.3 PREPARATION FOR IT ERA

It is anticipated due to the worldwide development of IT (Information Technology) that there will be revolutionary changes in the hardware of communication and reporting systems. The existing system has been established based mainly on paper documentation. It now requires consideration to adaptation to the forthcoming IT Era. In particular, it is likely that there will be confusion and disorder during the transition period of any system change and countermeasures for such change are needed beforehand to counter this.

1.5 CUSTODY OF MANUALS AND DRAWINGS

It will be important to provide in the Station with relevant drawings, etc., manuals for reference and technical references so as to properly and smoothly execute the Operation and Maintenance of the Power Station. The basic references are listed below:

1.5.1 OVERALL MANAGEMENT ASPECTS

Equipment Inventory	Rated features of the Power Station should be recorded as Equipment Inventory in accordance with the unified format. The Equipment Inventory should be kept at the Power Station as well as at the relevant Regulating Agency. The format is usually prescribed by Electricity Business Law or similar.
Records in Custody	Monthly Operation Report (abstraction of Monthly Operation Logs), Periodical Reports to Regulating Agency, Accident Reports, Statistics.
Drawings (preferably to be bound in A3 reduced size)	Location Map, General Plan, Location of Intake, Basin Map, Weir Structures, Waterway Profiles, Power Station Structure, Layout of Main Units, Section of Main Units, Single Line Diagram, Steel Structure of Outdoor Switchyard, Power Transmission Network Diagram.
Documents related to Regulating Agency	Copy of Official Documents etc. that were submitted to the relevant Agency at the time of planning, implementation and construction.

1.5.2 OPERATIONAL ASPECTS

Operation Rule (or Manual)	Method of Water Diversion, Operation Rule of Intake Gates, Manual of Start and Stop of Main Units, Operation Rule of Switching Equipment, Countermeasures for Emergency.
Operation Chart	Graphical presentation of operation chart for easy review and understanding.
Chart for Emergency Communications	Emergency Communication Routes, Method of Communications, to be arranged in a poster-like table for easy reference.
Tables and charts of Transmission Lines	Single Line Connection Diagram and Power Transmission Network Diagram are to be presented in one single poster, to clearly show the relationship between Switching Equipment and corresponding Charged (energised) Section.
Daily Operation Logs, etc.	Daily Operation Logs, Monthly Operation Logs, Accident Reports, and other reports to the Maintenance on the Station operation.

1.5.3 MAINTENANCE ASPECTS

Equipment Inventory	The same as for Overall Station Management
Maintenance Rule (or Manual)	Rules that prescribe the intervals and method of Daily and Periodical Inspections and Precise Repairing for each equipment.
Records in Custody	Reports on Daily and Periodical Maintenance Work, Accident Report, Maintenance Records, etc.
Drawings	Drawings for Overall Station Management and Civil Structures. Turbine Structure, Generator Structure, Details of Shaft Bearing, Inlet Valve Structure, Structure of Loose Coupling, Pressure Oil System Diagram, Structure of Unloader, Structure of Governor, List of Consumable materials, Structure of Control Panels, Sequence Diagram, Electric Cable Connection Diagram, Arrangement Drawings of Cabling Works, Cooling Water System Diagram, Components Drawing of Consumable items, and other drawings necessary for maintenance work.
Reference for Maintenance	Manufacturer's operation and maintenance manuals on Pressure Oil System, Governor, and AVR. Characteristic curves of Turbines, Generators, Exciters, Characteristic of Turbine Output-Guide Vane Opening, and other Technical References. Test reports at the commissioning Test.

1.5.4 MANAGEMENT ASPECTS

Safety Rule	Safety of daily work, Accident Management, Hygienic Management for the Station staff, Manual for Safety Management, and so forth should be prescribed.
Manual for Risk Management	Method of Communication, Method of First Aid, Provision of Equipment and Consumable for First-Aid, Practical countermeasures taking into consideration the site-specific conditions, and so forth should be provided.

1.6 CAPACITY BUILDING OF MAINTENANCE AND MANAGEMENT ENGINEERS

The engineers engaged in the management of a power station can be grouped, by their expertise, into the three fields of Civil, Electrical, and Mechanical Engineering.

The expertise of the civil engineering constitutes the trunk of hydropower. It consists of hydrometeorology, hydraulics, engineering geology, structural analyses, topographic survey, spanning over the wide range of technology and occupies most of the works during the planning and construction time of a hydropower facility.

Electrical engineering covers power generation, control, and power transmission. Mechanical engineering requires knowledge of hydraulic turbine technologies among the fluid machinery.

After the power station has been commissioned upon completion of the construction works, daily work will mainly be in the electrical and mechanical fields and the O&M staff will require Electrical and Mechanical engineers. However, a recent trend is not to separate the electrical and mechanical work but to engage in the power generation technology as comprehensive electrical work.

The management of the power station can be broadly classified into three groups: Management, Operation, and Maintenance. However, each Engineer should acquire, in addition to basic knowledge of their professional field of Civil, Electrical, or Mechanical Engineering, expertise and knowledge of new fields related to the work he/she undertakes as well as suitable practical skills.

Capacity building is essential for fostering the expertise of the staff. There are two approaches to such capacity building: Education in relevant expertise and knowledge, or training in practical skills. Education includes preparation of textbooks, conducting seminars, OJT by secondment to other organizations, etc. Skill training is implemented by OJT.

Capacity building can be implemented by the individual efforts of each engineer. The Power Utility needs to plan and implement the education systematically. Samples of the expertise knowledge and practical skills to be acquired and enhanced through the capacity building are presented in the table below:

Table 1.6.1 Expertise Knowledge and Practical Skills Required to Power Engineers (Sample)

Items	Operation		Maintenance		
Expertise Knowledge	**Electrical**	**Mechanical**	**Electrical**	**Mechanical**	**Civil**
Transient Analysis of load rejection (shutdown)	×	×			×
Characteristics of turbine output-opening and efficiency	×	×		×	
Generator characteristics and voltage regulation	×		×		
Governor control theory	×	×	×	×	
Power factor of load and its improvement method	×		×		
Power transmission lines theory	×		×		
Measurement/metering method			×	×	×
Pressure oil Technology				×	
Machine design and manufacturing methods				×	
Practical Skills					

Items	Operation		Maintenance		
Expertise Knowledge	**Electrical**	**Mechanical**	**Electrical**	**Mechanical**	**Civil**
Welding Skill				×	
Operation of Overhead Traveling Crane				×	
Seal Technology and Packing				×	×
Technique for Parallel Operation	×				
Operation Practice of Governor	×	×	×	×	
Operation Procedure of Hydraulic Gates/ Valves		×			×
Maintenance Practice of Storage Batteries			×		
Machine Processing Practice				×	
Electric Wiring Technique			×		
Fire Fighting Practice	×	×	×	×	×

CHAPTER 2 OPERATION OF ELECTRIC FACILITIES

2.1 OPERATION PROCEDURE

2.1.1 GENERAL

From a long-term point of view, the most important aspect of a power generation business is the task operation of the power station. In accordance with the natural changes of the river flow and change of power demand at random, the generating plant available should be effectively utilized for generating and supplying a stable and good quality power to the Customer.

The Station Operator should have thorough knowledge, not only of the various equipment within the station, but also of the surrounding topography and conditions of communication facilities available. In addition, with care of stable operation of the generating equipment in daily works, the Station Operator should perform operational tasks with the utmost attention in order to avoid occurrence of accidents incurring casualties.

To this purpose, the Station Operators must make all effort to become familiar with the practical skills necessary for the operation, not only by respecting the operation rules, but also by careful reading of the detailed maintenance manual for the related equipment.

It is recommended that the details of the Operational Procedures, Electrical Network Diagrams, Emergency Communication Rules, and so forth, should be posted at a readable place in order to enable proper operation and management of the Station.

In case of the occurrence of flooding, landslide, and so forth, an urgent report should be promptly prepared and delivered to the relevant units and agencies.

Regular training should be given to enable thorough knowledge of relevant rules and regulations so that operators can take a proper action without any upset in accordance with the instructions of the Shift in Charge.

2.1.2 OPERATION METHOD

Operation of equipment can be divided into two categories,; i.e. occasional operations like water diversion (intake), initial filling of penstock, etc. and normal operations such as the start and stop of main units, power transmission, etc.

The occasional operation is important work that is executed by collaboration of all the station staff under the instructions of the responsible staff member, while the normal operation is work that will be executed whenever necessary, based on the self-judgement of the Operator.

The operational method depends on station output, numbers of main units, type of control, and so forth. The operation method for standard plant is presented in the table below:

Table 2.1.1 Operation Methods

Steps	Operation Outline	Remarks	Responsible Person
Water Filling of Intake to Head Tank	To open the water regulating control gate of the intake to release the required water into the waterway	To confirm safety condition by pre-inspection of the waterway; To arrange monitoring staff at necessary locations. To slowly open the control gate to prevent rush discharge	×
Initial filling of Waterway, Desander, Head Tank/ Regulating Pond	With released water to Waterway by the above Intake operation, foreign materials and sand to flush out from sand-flushing gates, and fill the waterway system with water thereafter	Before the above Intake operation, the condition of the following gate operation shall be confirmed. To fully open all the sand-flushing gates of desander, head tank/regulating pond To fully close the control gate of head tank (inlet gate of penstock)	×
Initial Filling of Penstock	To open the control gate of head tank and to discharge water into the penstock pipe (when there is no control gate at the inlet of the penstock, sand-flushing gate is to be opened and wait for arrival of the water from the intake at the head tank. Upon confirmation of the water arrival, the sand- flushing gate shall gradually be closed to fill water with careful monitoring of the water volume flowing into the penstock.)	To keep the Drain Valve of Penstock fully opened. To confirm closure of all the valves related to the water pipe system inside the station including the inlet valves of main units, bypass valves, cooling water valves, and so forth. To gradually open the control gate and to limit the water inflow into the penstock to within 20% of the penstock section area. To close the drain valve after confirming that the flow has reached the bottom part of the penstock, to start and complete discharging of so-called “sweeping water” that flushes and contains dusts deposited on the low side internal surface of the penstock.	×
Items to be Confirmed before Start	To confirm the following items before start: To release mechanical locks of inlet valves, bypass valves, and servomotors		
	To close main circuit disconnecting switch		
	To open main circuit Circuit breaker	To confirm the green light is ON	
	To inspect Pressure Oil System	To check oil level of pressure oil tank, oil level of oil sump tank (oil collection tank), opening position (or closing position) of each valve. Attach air-inflow pipe	
	To confirm oil level of guide bearing To check indication of guide bearing		

Steps	Operation Outline	Remarks	Responsible Person
	thermometer To release break		
Items to be Confirmed before Start	To check position of load limiter	To be positioned at the start opening	
	To check the flow of cooling water	To be confirmed sufficient flow.	
	To close generator dumper		
	To check conditions of brush	To check appearance of rectifier in case brushless type adopted.	
	To assume the prospected load at the consumer end	To predict a speed drop at the time of parallel operation with system and provide the preventive measures To adjust the turbine output To confirm the transmission network	
	To check emergency lights in the station		
	To station operators	To confirm by rolling call of each operator	
Start	To open inlet valve of the 1st unit	(In the case of manual operation, bypass valve should first be opened.) To confirm full open	×
	#1 start ON	(In the case of manual operation, to start by gradual opening with handle operation)	
	(To open guide vanes) (To start rotation)	(In the case of manual operation, operator to operate manually with step by step)	
	(Rated voltage) (Rated speed at no load condition)	Coordination works between main panel operator and turbine room operator is required	
	To open inlet valve of the 2nd unit (Rated speed at no load, rated voltage)	To follow the procedures of the foregoing unit	
	Parallel operation Voltage balance Adjust speed	To make following unit parallel with the foregoing unit Voltage difference to be within 5% of rated voltage Speed difference to be within 0.3% of rated speed To increase the speed of following unit from the slow side to become parallel with the speed of foregoing unit	
	Synchronizing with the system	(In the case of manual operation, circuit breaker shall be closed about 0.5 seconds before achieving the synchronizing point.)	
Power Transmission	To close circuit breaker for power transmission	Communication and confirmation between the main panel operator and turbine room operator shall be confirmed.	×
Normal Operation	Operation to maintain rated voltage and rated frequency	To monitor outputs and power factor. (Refer to operational skills in Section 2.2)	
Stop No-load	To decrease the output to no-load condition. To open circuit breaker for power transmission To lower 65P and 77 To close Inlet valves and bypass valves	To report to units and agencies concerned (disconnecting switch to be opened.) until the lower limit To confirm lamp, eye confirmation by the turbine room operator	
Full Open of Guide Vanes	(To operate with manual handle)		
Stop rotation	To apply break	To confirm the speed lower than 30% of the rated revolution speed	
Shutdown of cooling water			

Steps	Operation Outline	Remarks	Responsible Person
Air-duct of generator	To close dumper		
Confirmation Items after Stop	Overflow conditions of head tank Remaining water flow in the station Flow conditions in the tailrace channel	Visual-inspection, confirmation of safety inlet valve, bypass valves, cooling water, and so forth Visual-inspection, confirmation if there is any unusual flow condition	

2.2 OPERATIONAL SKILLS

2.2.1 PARALLEL OPERATION

(1) Adjustment of Excitation

When a multiple number of generating units are operated in parallel (here described for the case of 2 units), the terminal voltage of both the units become the same on the bus-bar. When the capacity of both Units is the same and both are under operation at the same load and if the excitation level is raised on one unit, the current of that unit will increase. That is:

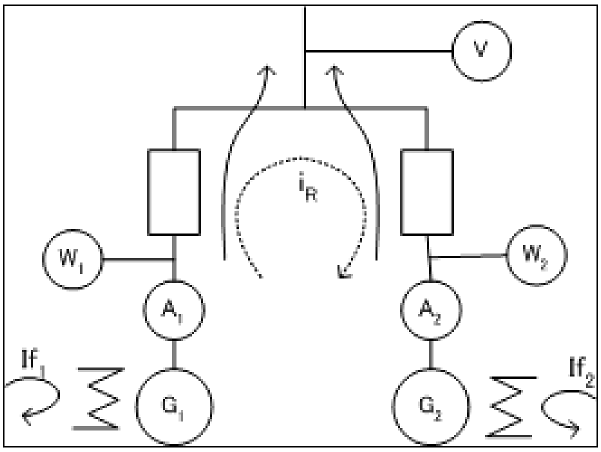


Figure 2.2.1 Circulating Current and Excitation

$$G_1 = G_2, W_1 = W_2$$

$$If_1 > If_2 \quad \text{then} \quad A_1 = A_2$$

This is because there is Wattles Current i_R flowing between G_1 and G_2. It will cause unnecessary heat generation in the generators, which is not advisable. To avoid this, the excitation should be adjusted so that the power factor between the two units becomes the same. Attention should be paid to keeping the busbar voltage at the rated value when this excitation adjustment is executed.

(2) Load valance Operation

When multiple numbers of generating units having the same unit capacity are in parallel operation, the output of each unit is kept at the same level. This type of operation is called Load valance Operation.

The sharing of load of each unit will be determined by the speed droop setting of governor for each unit.

2.2.2 GOVERNOR

(1) Characteristic Constants

The characteristic constants of the governors should always be adjusted to be common among the units before operation.

- Permanent Speed Regulation
- Transient Speed Regulation
- Dash Pot Time

(2) Load Limiting

If the load of plant can be shared by other plant, and the output is obliged to be limited due to the water drought conditions, a Load Limiting Operation shall be executed. If there is a Load Limiting device, the load can be adjusted with reference to its indication of the opening. If there is no such device, the load is adjusted positioning of the manual handle of the servomotor. However, since there is no fixing mechanism for the handle, there is a possibility of movement and subsequent changes of the position set. Accordingly, it is better not to adjust with the manual handle but place leave it in the full open position.

(3) Adjustment to Standard Frequency

The target frequency is set by the Speed Governor (65F/P). However, since there is no graduation or calibration scale, the 65F/P of each unit is alternately adjusted to achieve the standard frequency, such that the frequency can be kept within a specified range, while maintaining the same unit output among the multiple units.

From the time of adjustment, it can take from several seconds to a few 10 seconds until the output of each unit is stabilized i.e. when the effect of the Dash Pot time has vanished. Therefore, the adjustment should be executed slowly.

(4) Opening at Start

The governor is always at such a position as to move towards opening, whenever it is stopped. Accordingly, at an automatic start, the load limiter will limit the opening to the position of turbine start. This opening is referred to as the opening at start. If the opening at start is bigger than the proper setting value, there is a possibility of causing over-speed at the start. If it is small, the speed will not reach to the rated speed. Accordingly, a suitable position should be adjusted and set as the minimum limit of the load limiting device. Attention shall be paid to the fact that the presetting position would be altered with changes in the water level of the tailrace channel, etc.

2.2.3 OPERATIONAL CHARACTERISTICS

(1) Voltage Regulation

Voltage regulation is defined as the change in the terminal voltage of generator, expressed as a percentage of the rated voltage that will take place when the generator output is increased, at the rated speed, from zero to the rated output while keeping the excitation constant. It is usually about 10-15%.

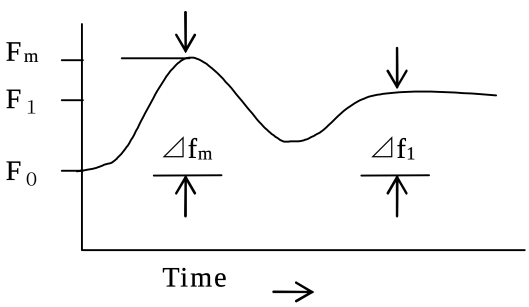
In the case of generator without AVR (automatic voltage regulation), the excitation current is manually adjusted in order to keep the terminal voltage constant. Although AVR is to automatically adjust the excitation current to keep the terminal voltage constant, it incurs a rate of voltage regulation of about $\pm$1%.

When the load fluctuates abruptly, there will be a voltage fluctuation ranging 5-8% due to delayed response of automatic control system. This is referred to as the transient voltage regulation. When there is a change in the revolution speed accompanying a load change, the voltage fluctuation would further increase.

When the voltage rises by more than 30% due to a transient voltage fluctuation, the Over-Voltage Relay (59) will detect the high voltage and at the same time excitation system is disconnected and the turbine is stop.

(2) Momentary Speed Variation

In case the load is forced to change without adjustment of governor, the frequency (revolution speed) changes. Figure 2.2.2 shows frequency changes along with time when load is reduced. The frequency, once jump up largely, repeats up and down and converges to and get stabilized at a level a little higher than the frequency before the load reduction.



Source: JICA Study Team

Figure 2.2.2 Load and Frequency

Speed variation (or speed rise) is defined as the ratio of F_m and F_0 that will take place when the load is shutdown from Full Load. This is an important characteristic for operation of the turbine-generator. Also, a ratio of F_m to F_0 is referred to as speed droop, which is set by governor.

(3) Momentary Pressure Variation

The acting pressure on the turbine under steady condition will change depending on the turbine discharge rate. The pressure change is caused by the friction between the penstock pipe and flowing water. The change is proportional to the square of the discharge.

When the discharge is abruptly changed, a pressure change much greater than the rate above condition. This phenomenon is called water hammer and the pressure change is expressed as a percentage of the design head (static head) and is referred to as the momentary pressure variation.

The pressure increases when the discharge is reduced and the pressure lowers when the discharge is increased. The pressure change will be much greater when the rate of the discharge changes so faster.

If the pressure rise is too high, it will burst the penstock pipe. If the pressure lowering is too much, the penstock pipe will buckle and collapse due to the external atmospheric pressure. Accordingly, the operating time of servomotor is adjusted to a certain time level not so as to cause breakage of the Penstock pipe even at full load shutdown.

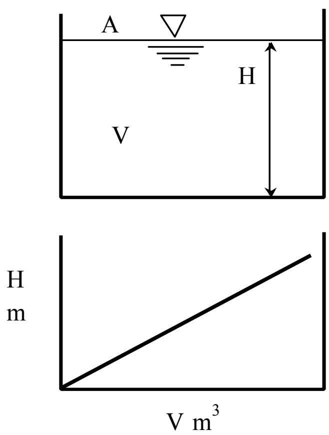
These rates will frequently change during the operation of the turbine-generator. However, if the safe value or allowable value specific to the machine is well known, rapid changes or trip incident can be coped with without any upset and with presence of mind. For this purpose, there should be thorough knowledge of the machine characteristics of the main units in the power station being operated. Since the percentage figure is difficult to judge, especially in the case of incident or emergency, it is advised that the maximum permissible value be expressed in the direct (absolute) figure and displayed in a prominent place so that the operator can easily refer to it during operations.

2.3 OPERATIONS FOR PEAK LOAD

2.3.1 UTILIZATION OF REGULATING POND

The regulating pond will store the water when the river discharge (precisely speaking, the discharge diverted at Intake and flowing down the waterway) is greater than that required for power generation (turbine discharge). The pond will release the water out of its storage when the river discharge is smaller than the turbine discharge and the stored water in the Pond will decrease.

(1) Relationship between Stored Water Volume and Water Level of Regulating Pond



Source: JICA Study Team

Figure 2.3.1 Water Level & Volume (1)

When the surface area of the regulating pond does not change by depth, the stored water volume V is expressed by:

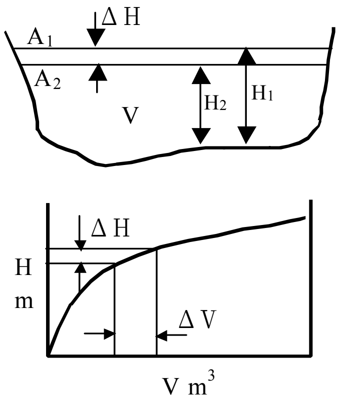
A: Surface area of regulating pond, in m^2

H: Depth of regulating pond, in m

$$V = A H \quad (m^3)$$

The relationship between the stored water and the water level is shown in Figure 2.3.1. If the water surface area changes by water depth, the water surface area at each depth is measured to calculate the water volume of each unit depth of dV.

$$\Delta V = \frac{A_1 + A_2}{2} \times H$$



Source: JICA Study Team
Figure 2.3.1 Water Level & Volume (2)

By summation of these volumes from the bottom to the water surface, the volume at each water level can be obtained, to get a relationship between depth (water level) and volume as shown in Figure 2.3.1. Thus, the stored water volume in the regulating pond can be known for any desired depth (water level) and for any shape of the Pond (reservoir).

In the hydropower station, the elevation of water surface is measured in place of water depth and is referred to as "water level." The water level is an essential parameter for operation of the regulating pond. The water level is measured by a water level gauge and is displayed on the control panel.

(2) Utilization of Regulating Pond

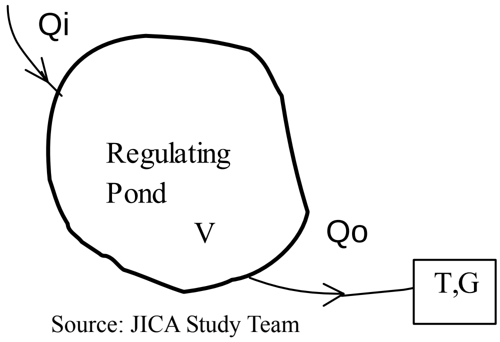
In the Figure 2.3.2 above, the relationship among the inflow, power discharge, and storage volume is expressed by:

Q_i : inflow m^3/s

Q_o: power discharge m^3/s

A value "Q_i - Q_o" gives a change in the stored water volume of the Regulating Pond. If "Q_i - Q_o" is positive (+) and the value continues for T_p seconds, then a water volume of V_p will be stored in the Regulating Pond:

$$V_p = (Q_i - Q_o)\ T_p \quad m^3$$



Source: JICA Study Team
Figure 2.3.2 Regulating Pond

If "Qi - Q_o" is negative (-) and the value continues for T_m seconds, then a water volume of $V_m$will be released from the regulating pond:

$$V_m = (Q_i - Q_o)\ T_m \quad m^3$$

Utilizing this phenomena (regulating effect) during a drought when inflow is low, the inflow may be stored by stopping power generation. During the evening peak load time, the stored water can be released in addition to the inflow in order to generate more power.

A utilization method of Regulating Pond is shown below as a sample:

- A Sample Calculation of Peak Operation using Regulating Pond

With a regulating pond having an effective storage capacity of V = 10,000 m^3, the time required to fully fill the ond at an inflow of 0.4 m^3/s will be:

$$10{,}000 \div 0.4 \div 3{,}600 = 7 \text{ hours}$$

If 2.5 hour peaking operation is made using the regulating pond, the following amount of flow can be released from the pond;

$10,000 \div (2.5 \times 3,600) = 1.1\ m^3/s$

Adding natural inflow of 0.4 m^3/s to the above, peaking operation can be made at a power discharge of 1.5 m^3/s for 2.5 hours.

(3) Notes for Operation

a. Water Level of Regulating Pond

In order to effectively utilize the storage capacity of the regulating pond, there will inevitably be water level changes between the Full Supply Level (FSL, also denoted as HWL) and the Minimum Operation Level (MOL, also referred to as LWL). Attention is required as the daily draw down of the water level would have impact on the hydraulic function of the related desilting basin, connecting channel or approach channel, and, in particular, to the front of the inlet to the penstock.

In particular when operating around MOL, as there is a possibility of occurring super-critical flow at various places of the waterway system, a sufficient study on these aspects is needed. (A review of hydraulic design would be required in such cases.)

Also, a power station in isolated operation cannot freely change its output due to the conditions of the power station, unlike those power stations that are in parallel operation with the power network. Therefore, preceding the lowering of the water level of the regulating pond to the MOL with time allowance, a preparatory operation such as partial shedding of transmitting load and so forth will be required.

b. Water Level Gauge

The water level of the regulating pond fluctuates in a range of 2-3 m. If the water level is measured by a single water level gauge of analogue type, the minimum reading becomes large and accurate reading difficult.

In such case, a water level gauge measuring around overflow crest and second gauge around MOL may be used. Also, taking into consideration the accuracy of the gauge at about 2%, it is also possible to operate the Regulating Pond with certain allowance above the MOL.

c. Operation Rule

Operation of the regulating pond incurs many related factors such as inflow, operating output, planned operation hours, and so forth and has, therefore, a degree of difficulty. Accordingly, an operation rule should be established to specify the method of the operation of the pond. The actual operation should be carried out in accordance with the rule in order to avoid incorrect operation.

2.3.2 HYBRID OPERATION WITH OTHER POWER PLANT

Parallel operation with other power plant is employed to augment the shortage of power during the peak time. This operation method is a concept constituting a small power network. A case with small hydro as the main unit and other generating facilities as auxiliary units is explained below:

A diesel generator is most suitable for the use as an auxiliary unit due to its ability to be easily started and stopped. The key points for parallel operation with diesel are as follows:

a. Study on Excitation Characteristics

The characteristics of AVR of both hydro and diesel generators should be studied beforehand so as to avoid a cross current flowing between the main unit (hydro) and the diesel generator.

If there is a risk of racing due to non-matching of the AVR characteristics, the diesel generator, having a smaller generating capacity, can be operated at constant excitation. In the case of automatic control, the machine having the smaller generating capacity is made as the AQR (Automatic Var Controller). A 100% operation of APfR (Automatic Power Factor Regulator) lowers synchronization at low load and incurs a risk of hunting.

b. Study on Governor Characteristics

The governor of a diesel generator has a quick response time. Therefore, the diesel governor should take the role of frequency control while the hydropower is operated with limited load. If hydropower has a water level governor, then the hydropower should be operated under water level droop control.

CHAPTER 3 INSPECTION/MAINTENANCE /REPAIRING OF HYDRO-MECHANICAL AND ELECTRICAL WORKS

3.1 MAINTENANCE WORKS

3.1.1 GENERAL

Maintenance is important works to maintain the functions of the power station in sound conditions for long-term efficiency. The maintenance works include a wide range of work such as inspection and caring of equipment, based on the inspection results, testing to confirm machine functions, repairing and recovery from damages caused by accidents, and so forth. Accordingly, appropriate and detailed planning and timely implementation of the works is required for proper maintenance. The maintenance staff need to have a thorough knowledge on the technical matters, of the equipment as well as adequate experience in practical skills such as equipment adjustment.

3.1.2 MAINTENANCE REGIME

Since the number of staff of a hydropower station is usually limited, O&M works are not separated and operators usually undertake the maintenance work also. While this regime for O&M may seem economic with a limited number of staff processing all the different various type of required works. However, the time allocated to the maintenance duties is usually limited and the maintenance works cannot be executed with the required concentration. Thus the maintenance becomes insufficient, causing deterioration in the performance of the power station, ultimately leading to a reduction of its lifetime.

Accordingly, it is recommended to have an exclusive maintenance team, apart from operations, and to establish a maintenance regime to secure the optimum benefit from the maintenance work. The concept of a maintenance centre is presented below as a sample of such a maintenance regime:

(1) Maintenance Centre

a. A Maintenance Centre may be provided to cater for a group of several power business points such as power stations, substations, switching stations, and so forth. This is suitable for a region that has a series of power stations built on a river system.

b. Work Shift (Daytime Work)

- ♦ Manager : one person
- ♦ Technical in Charge : one person
- ♦ Works in Charge : one person
- ♦ Maintenance staff : several persons (electrical, mechanical)

c. Work Contents

1) Area of Coverage: Management of equipment of all the power business points within the area

- ♦ Inventory Book of Equipment, Inventory Book of Maintenance Works, List of Accidents and Repairing, Inventory Book of Spare Parts, List of Maintenance Equipment and Materials
- ♦ Rules, Drawings, Manuals, Technical References
- ♦ Management of spare parts, equipment and materials for Maintenance

2) Planning and implementation of inspection, maintenance, and repairing work

3) Supervision of subletting maintenance works

4) Education and training of technical staff within the service area of maintenance centre

d. Equipment

1) Measuring instruments, tools, multi-purpose processing machine, welder, potable engine generator

2) Testing device for various tests

3) Vehicles (work vehicles, 4WD, motorcycle, etc.)

(2) Management

The Manager of the maintenance centre will dispatch the maintenance teams to the sites to undertake the works and should keep in close contact with the manager of each power business unit. The staff of the maintenance centre should comprise mainly those who have working experience of maintenance in power stations, especially in maintenance in-charge positions, etc. and following the principle of splitting operation and maintenance, mixed with engineers who can provide a high level of expertise and technical knowledge. An effort should be exerted to raise the technical level of the whole organization by exchanging staff positions between the operators and maintenance staff and implementing mutual improvements of the technology to assist with future maintenance.

The maintenance staff should positively participate and concentrate on the urgent recovery work from accidents and take the role of the Work Leader to enable the earliest recovery from these events.

3.2 OUTLINE OF MAJOR EQUIPMENT AND KEY POINTS OF MAINTENANCE

3.2.1 TURBINES

(1) Pelton Turbine

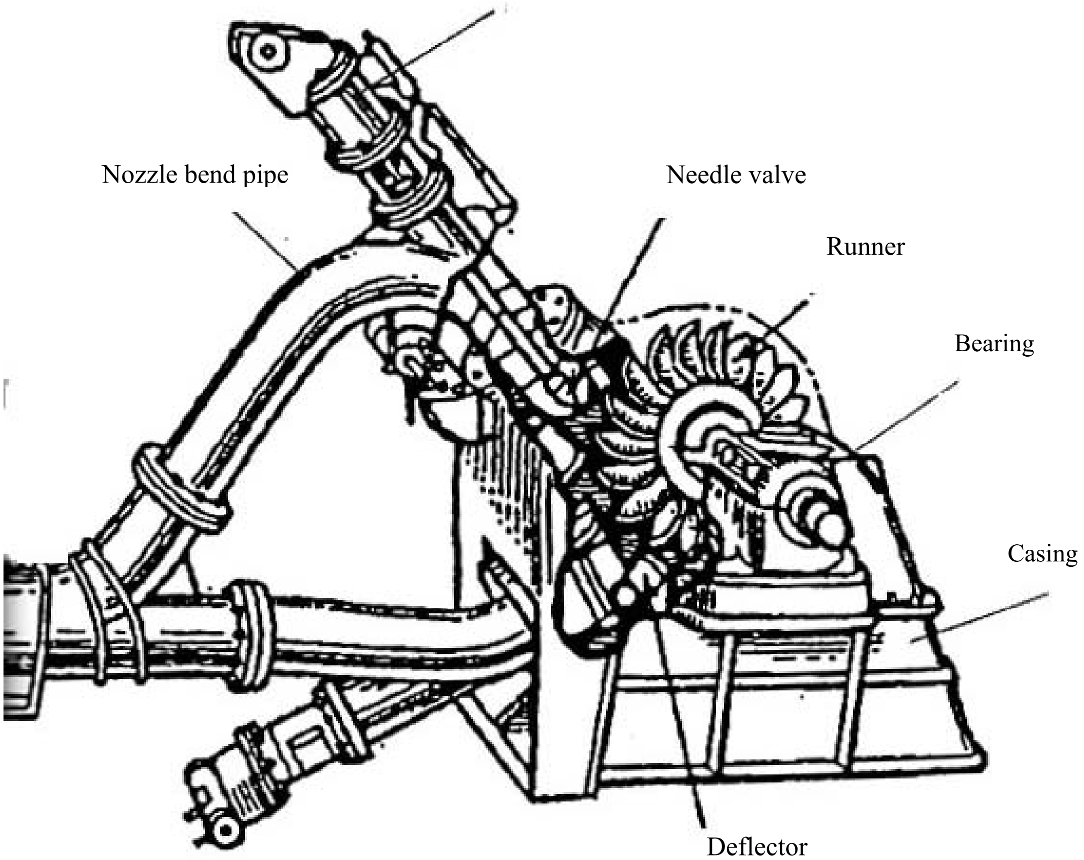


Figure 3.2.1 Structure and Name of Pelton Turbine

A. Outline of Structure

Figure 3.2.1 presents the structures of a horizontal axis, 2-nozzle, Pelton turbine and names of its elements.

The Pelton turbines have been adopted mostly for a head range of 75 m - 400 m. A high pressure water jet is ejected from nozzle. The water jet will operate and rotate the Bucket Wheel. The turbine consists of the following major components:

- Nozzle: An opening combined with a needle valve for discharge adjustment to eject the water jet
- Bucket Wheel: Also referred to as the runner. There are two types of bucket wheel: a disk is fixed to the main shaft by the shrink-fit method and buckets are attached to the disk with bolts; boss, together with the buckets arranged around wheel, is cast as an integral unit.
- Main Shaft: To coupled with the runner and take the rotating torque outside
- Deflector: To cut the water jet by changing the jet direction in order to prevent pressure rise due to an abrupt reduction of load

- Casing: A part forming foundation of the turbine and to accommodate the main parts so as to prevent the operating water from scattering outside.

B. Points of Maintenance

- Water Leakage: Since high pressure water is used, water leakage can be observed at the flange joints of the nozzle-related tubes (piping); erosion or damage at the ground packing of the needle rod, stuffing box or the labyrinth seal between main shaft and casing.
- Nozzle: Inspect by touching and feeling the needle tip and the nozzle tip as these wear due to erosion by jet. Damage of this part affects the proper shape of the water jet and causes lowering of turbine efficiency and, therefore, attention is needed.
- Bucket: Inspection is required since the cut-out part of the bucket and rear surface of the bucket around the cut-out would receive damage due to cavitations.

  The erosion of the internal surface of bucket, shaped like waves, suggests a possibility of sand mixed in the water jet. In such cases, the head tank (regulating pond) should be inspected. If these damages will progress, there will be a risk of bucket failure and, therefore, attention is needed.

Source: SCO

Figure 3.2.2 Erosion of Bucket Outlet

- Vibration, Noise: When vibration or noise is observed, there could be clogging by foreign materials to the nozzle, occurrence of jet cutting phenomena due to the insufficient adjustment of the deflector, jet spreads to outside of the Bucket and parts of the jet stream directly hitting the deflector and casing. In such cases, the earliest inspection and adjustment are required.

(2) Francis Turbine

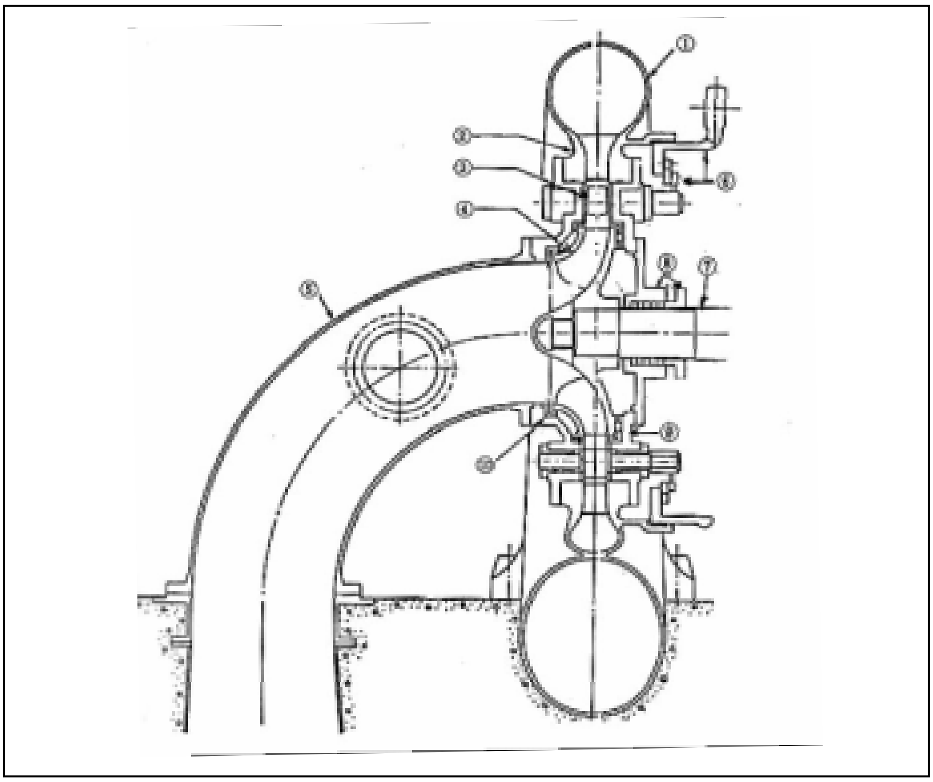


Figure 3.2.3 Structure and Name of Francis Turbine

A. Outline of Structure

Figure above presents a section of the Francis turbine of horizontal axis, single wheel, single jet volute type. The Francis turbine has been adopted, mostly among the existing power stations, for a range of effective head of 15 m - 280 m.

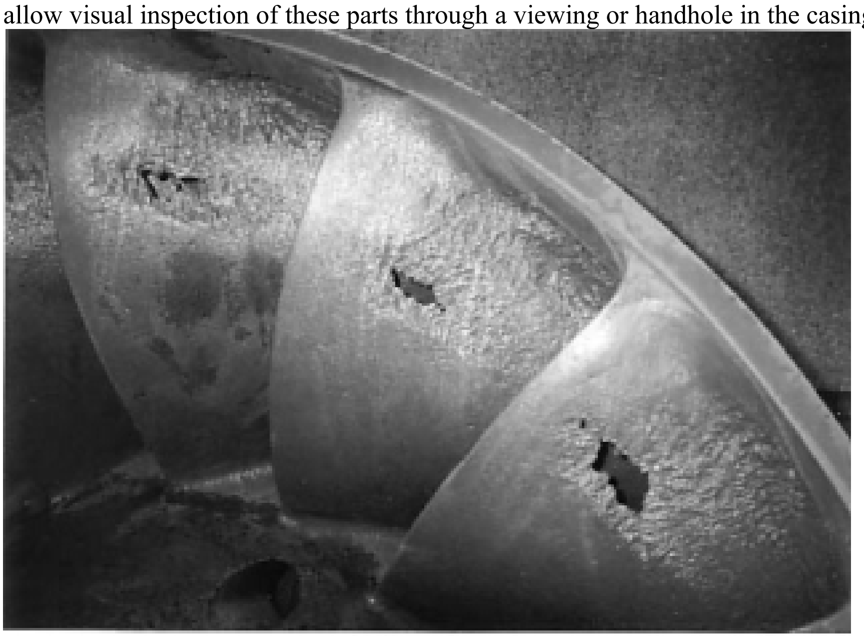
The main parts are the volute-shaped casing leading the water with the rotating power and guides it towards the Runner, the Stay Vane to adjust flow direction., the Guide Vane to adjust the flow volume into the Runner and determine the incident angle of flow, the Runner and the Main Shaft that rotates by reaction to the inflowing water and the Draft Tube. Furthermore, there is a link mechanism to operate the Guide Vanes, Guide Operating Rings, and many other components.

B Points of Maintenance

- Water Leakage Most water leakage is observed in the part of the packing of the Guide Vane Spindle, Stuffing Box or Labyrinth Seal of the Main Shaft. In particular, there are often conspicuous water leakage's observed from the Guide Vane Spindle due to frequent operation and a great number of Spindles. Figure 3.2.4 shows such an example.

Source: JICA Study Team **Figure 3.2.4 Water Leakage**

- Cavitations of Runner: Many of the runners of the Francis Turbine get erosion due to cavitations. The cavitation mainly appears on the rear surface of the Runner Vane at its outlet. This part of the Runner can be easily inspected by removing the Draft Bend Pipe. However, actual inspection can not be made in many cases because the time required for the operation shutdown cannot be spared, the removal work is difficult, and so forth. If the erosion progresses unchecked, a large scale incident such as drop out of the Runner Vane could occur, therefore, attention is needed to this maintenance point.
  In the case of a Low Specific Speed Runner (of Ns below 70 m-kW) cavitations could also take place on the rear surface of the Runner Vane at the inlet point. Some turbines allow visual inspection of these parts through a viewing or handhole in the casing.



Source: SCO

Figure 3.2.5 Cavitations

- Vibration, Noise: The Francis turbine has, as its specific characteristic, noise and vibration at around 1/3 output. This phenomenon is due to the occurrence of cavitations and development of vacuum core inside the Draft Tube. Operation is recommended to avoid this output range as much as possible. There is a countermeasure by injecting air into the Draft Tube.

- Clearance between Runner and Cover Liner: The Runner and the Cover Liner is designed to keep a small gap with 1-1.5mm so that the Runner does not touch the Cover Liner. A smaller clearance yields a higher turbine efficiency. Although the gap is adjusted to be small at the time of installation, the gap becomes large due to wearing as the operating hours progress. In this case, the wearing will cause not only a lowering in the efficiency but also a rising back pressure of the Runner that increases water leakage from the Main Shaft seals and the temperature rise of the Thrust Bearing. The gap is, therefore, to be measured periodically.

C. Other Type of Francis Turbines

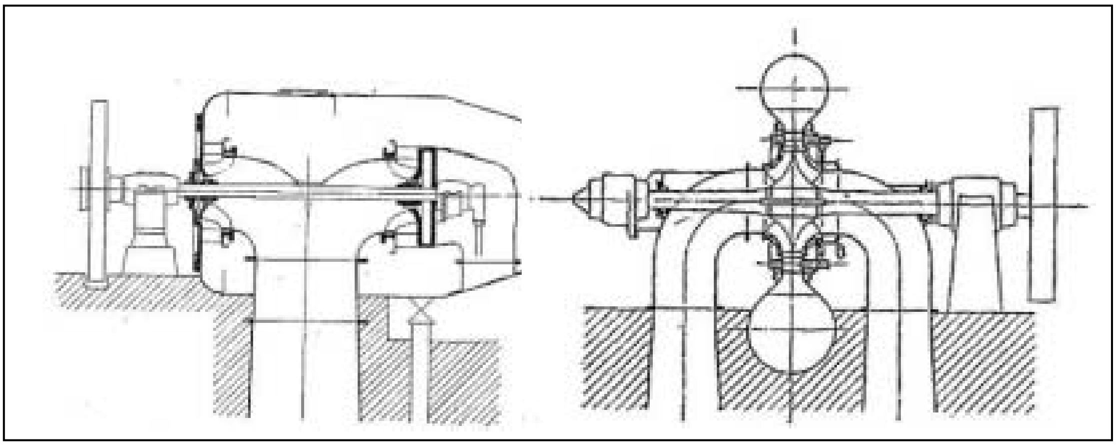


Figure 3.2.6b Francis Turbine of Horizontal Axis, Double Runners, Frontal Type

Also among the Francis turbines are horizontal axis, single runner, double flow type as shown in the figure above left and horizontal axis, double runner, front type as shown in the figure above right.

The double flow type has no substantial difference from the single flow type. In the case of the frontal type, most of the regulating mechanism is submerged under water. Therefore, there are many points of maintenance that require attention such as conversion of parts to oil-less, use of stainless steel, etc.

(3) Crossflow Turbine

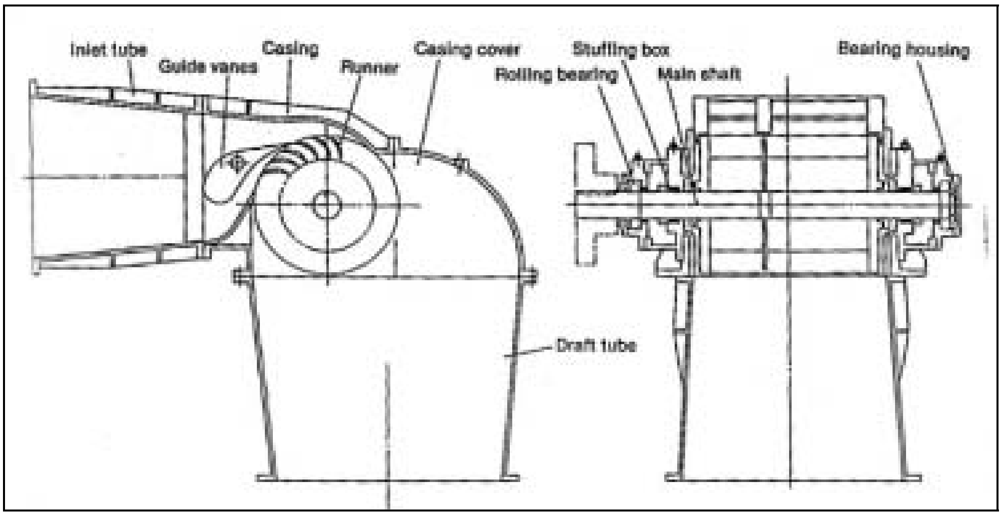


Figure 3.2.6 Structure and Name of the Parts of Crossflow Turbine

A. Outline of Structure

Figure above shows the structure and name of elements of a Crossflow turbine. The Crossflow turbine is applied to a range of effective head of 7.5 - 100 m and less than 1,000 kW in output.

The principal feature of this turbine is in the flow pattern in that the water entering into the Vanes from the outside Runner first passes through the Vanes and inside space of the Runner and then re-enters again into Vanes but from inside the Runner, then goes out of the Runner to be discharged off.

Accordingly, the Runner has a cylindrical cage-shape having Vanes in parallel with the Main Shaft. It also has one or two Guide Vanes in parallel with the Shaft.

The Draft Tube is usually not provided. In the case of a low head plant however, a Draft Tube may be provided in combination with an Automatic Air Supply Valve in order to harness the remaining head below the Shaft level by suction effect. This turbine uses a roller bearing for the Main Shaft.

B. Points of Maintenance

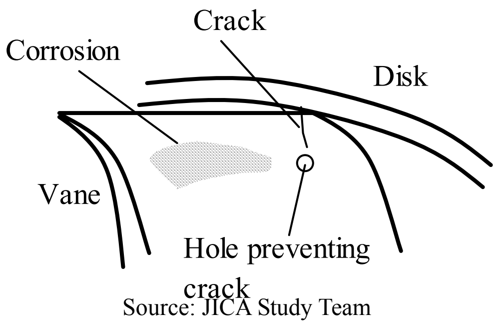
- Water Leakage

The main points for water leakage are the ground packing of the Guide Vane Spindle and Stuffing Box of the Main Shaft. Compared with other types of turbine, maintenance is relatively easy owing to its application from a low head. Points of Maintenance are similar to those of the other types.

- Cracks in Runner Vane

The Runner Vanes of a Crossflow turbine are usually made by cutting steel plates into an arc shape and welding onto a disk. After the starting operation, there are cases of cracks occurring as shown in Figure 3.2.7 due to the residual strain from the welding process. The cracks can not be found without close and careful inspection. It is important to have detailed checking for the cracks using the colouring method, etc. since the cracks are difficult to find without utmost care.

If a crack is found, a hole having a diameter of 3 mm is to be opened in order to stop any further progress of the crack. Repairing by welding will aggravate the condition and, therefore, repair should not be executed by this method. It is better to replace with a new Runner, during an appropriate shutdown time. Also, a crack may occur as shown in Figure 3.2.5. In this case also, repairing by welding cannot be adopted, since the Vanes are so thin.



Source: JICA Study Team

Figure 3.2.7 Cracks of Runner Vane

- Operation of Air Supply (Suction) Valve

When an Air Supply Valve becomes non-operative, the water level inside the Draft rises. When the water level rises above the lowest position of the Runner, a foreign sound will be emitted and the turbine output will significantly decrease. It is important to detect this phenomenon by paying attention to the turbine sounds.

- Maintenance of Roller Bearing

The lifetime of a roller bearing is in the region of 20,000-30,000 hours. However, there are examples of achieving operation for 150,000 hours by ensuring good oiling. In order to achieve such long lifetimes, grease oil (to the Bearing Manufacturers specification) should be used at specified intervals and specified quantity. To avoid oiling work in the case of a roller bearing of 60mm diameter, double seal, oil-less bearings could be used to facilitate good operation for about 50,000 hours.

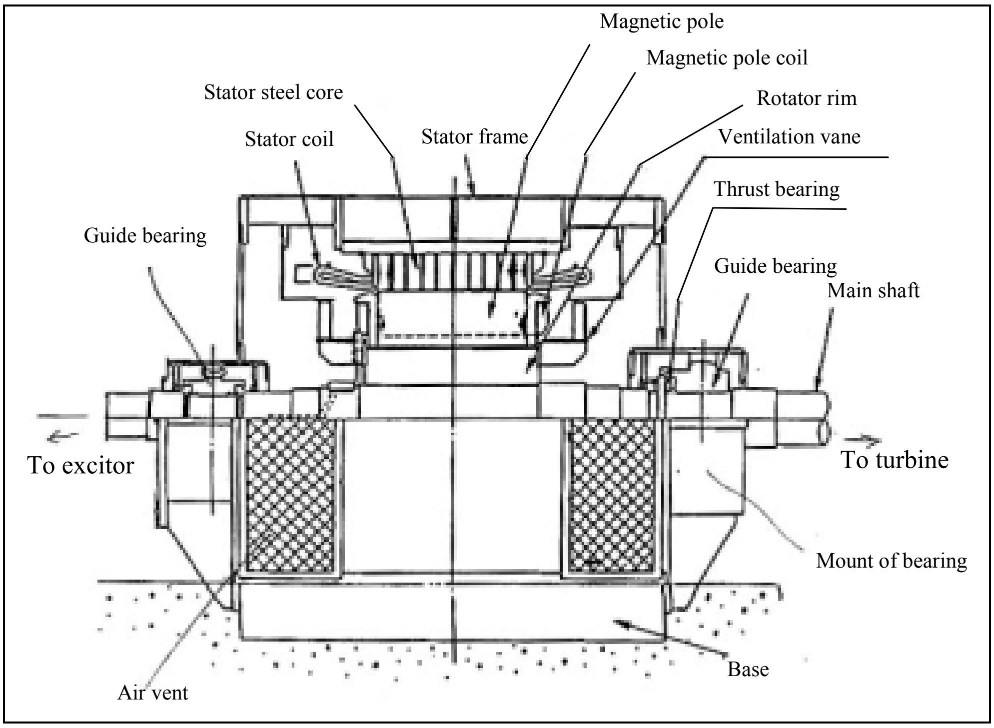
(4) Other Types of Turbines

The other types of turbines include the following:

- Turgo impulse turbine
- Propeller or Kaplan turbine
- Diagonal flow water turbine

Points of Maintenance are similar to those of other types.

3.2.2 GENERATORS



Source: JICA Study Team

Figure 3.2.8 Generator

A. Outline of Structure

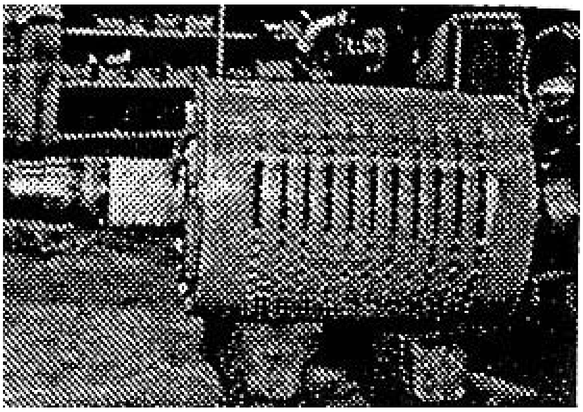
Figure above shows the structure and names of components of an Alternating Current Synchronous Generator. The main parts of Synchronous Generator are the Stator, Rotor, Main Shaft, and Main Guide Bearing.

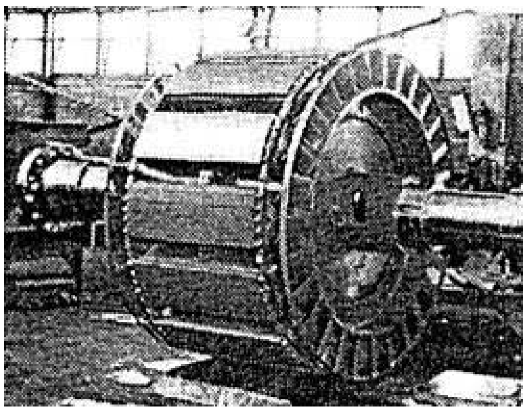
- Stator

The Stator consists of i) Laminated steel cores made by laying and firmly compressing thin electric steel plates, ii) Generator coils made by winding copper wires and insulating them and, iii) Wedges to prevent the generator coils dropping out from the winding slots on the stator cores.

- Rotor

The Rotor is the part that forms the poles of revolving electric magnet. It is classified into two types, based on the shape of the magnetic core: Cylindrical type and Sailent type.





Source: SCO

Figure 3.2.9 Cylindrical Type Rotor **Figure 3.2.10 Salient Type Rotor**

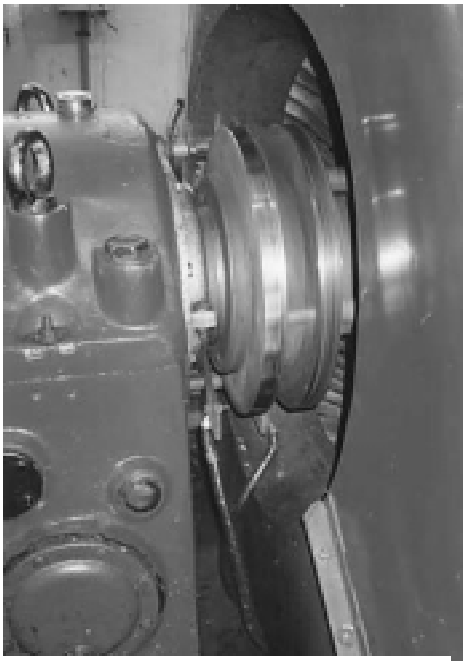


Figure 3.2.11 Collector

A cylindrical type has been employed in many generators recently. The salient type is employed for multi-pole generator or in older generators. The magnetic poles are also provided with short-circuit bars other than exciting winding, which is referred to as a Damper Winding.

- Collector

The Collector is provided to supply direct current for excitation to the revolving magnetic poles. It consists of a Slip Ring and Brush.

The Slip Ring is fixed on the Main Shaft with insulation materials. There are two methods of fixing: i) The Slip Ring is directly fixed to the Main Shaft by a shrink-fit method with insulation materials, and ii) the Boss is directly fixed to the Main Shaft by a shrink-fit method or by inserting with pressure and a Slip Ring consisting of two semi-circular pieces is attached to the Boss by bolting with insulation materials between the Boss and Ring. Recent generators are mostly by the former method while the older ones are mostly by the latter. As for the Shaft Bearing, a sliding bearing with lubricating oil is employed in many generators. In the case of small generators, a roller bearing is also employed. The Rotor provide with ventilation blades to cool the whole Generator.

B Point of Maintenance

- Stator

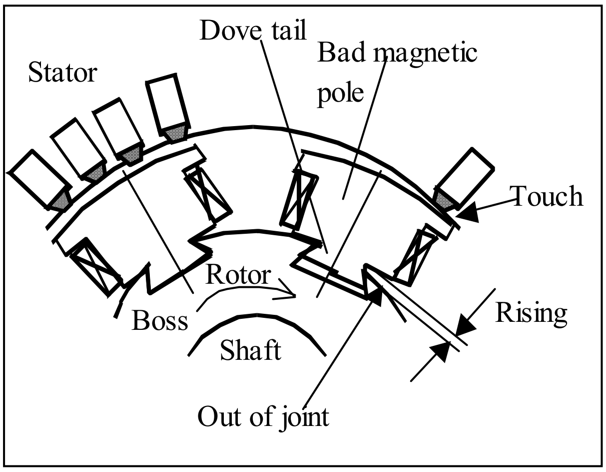
The iron cores of the Stator are made by arranging laminated steel cores of several centimeters in height with about 1cm clearance. The clearance is required to circulate air for cooling the coils and iron cores. If insect's bodies and dust is deposited into this clearance to block air flow, the cooling effect lowers and the generator temperature rises. It is important to inspect and keep clear the clearance.

The electrical steel cores constituting the armature iron core are formed by forming oxidised insulating film to both sides of thin steel plates or by insulation painting. If a part of the iron core is melted due to the affects of wound coil burning incidents, careful repairing such as removing the melted materials by all means, re-stacking of arc-shaped steel cores, and so forth is required. Otherwise, partial heating will take place after the starting operation and limiting of generating output will occur.

In the case of generators that have been operating for a long time or generators that have been operated with high temperatures condition, the deformation of the wound coils would be appeared due to drying up , of which condition causes relaxation tightness of the iron cores and coils and bring dropout of the wedges. Also, since there is a possibility that the coils could be damaged due to electric micro-vibration, it is important to make a detailed inspection and investigations of the coils.

- Rotor

The Rotor also incurs relaxation in its fixing mechanism of coils and magnetic poles of salient type due to ageing. In particular, the field pole is fixed with rotor by wedge effect which is formed the bottom end of magnetic pole dovetailed shape and inserting it into the grooves on the Main Shaft Boss. If relaxation will takes place due to centrifugal force effect or reiterating loading-unloading stresses, the magnetic pole will rise due to the centrifugal force as shown in Figure



Source: JICA Study Team

Figure 3.2.12 Rotor

3.2.12. In the worst case, it would touch the internal surface of the Stator to cause serious damage. An indication of the relaxation is dull knocking sounds like "Gotton, Gotton," when the generator speed descends to very low just before stopping. If such sounds are heard, a detailed inspection and maintenance is urgently required. Also, turbine and governor should be adjusted in order to avoid over-speed of the turbine-generator.

- Collector

Careful maintenance is needed so that the Collector will not throw off sparks between the Slip Ring and Brush.

The sparks occur when the material of the Brush does not match that of the Collector. A specification of brush material should conform to the Manufacturer's instructions.

If a Slip Ring is damaged due to the throwing of sparks, the sparking part of the Slip Ring mechanically worsens the contact with the Brush and the sparks increase and become intensive. The surface of the Slip Ring is further roughened at an increasing tempo and wearing of the Brush accelerated.

Sparks usually take place lopsidedly either pole of DC supply voltage. Therefore, the polarity of connecting cables should be periodically changed and the contact pressure of the Bush should be properly adjusted. Regular maintenance is important to reduce the wearing of Slip Ring surface.

Figure 3.2.13 Worn Collector

- Guide Bearing

With the Guide Bearing, the temperature indication should be carefully checked together with the flow amount and the temperature of the cooling water, to avoid burning incidents due to abnormal temperature rise. At the inspection during operation, the external surface of the Shaft Bearing should be checked by hand-touching to check the temperature. Attention is also needed for any occurrence of vibration and unusual sounds.

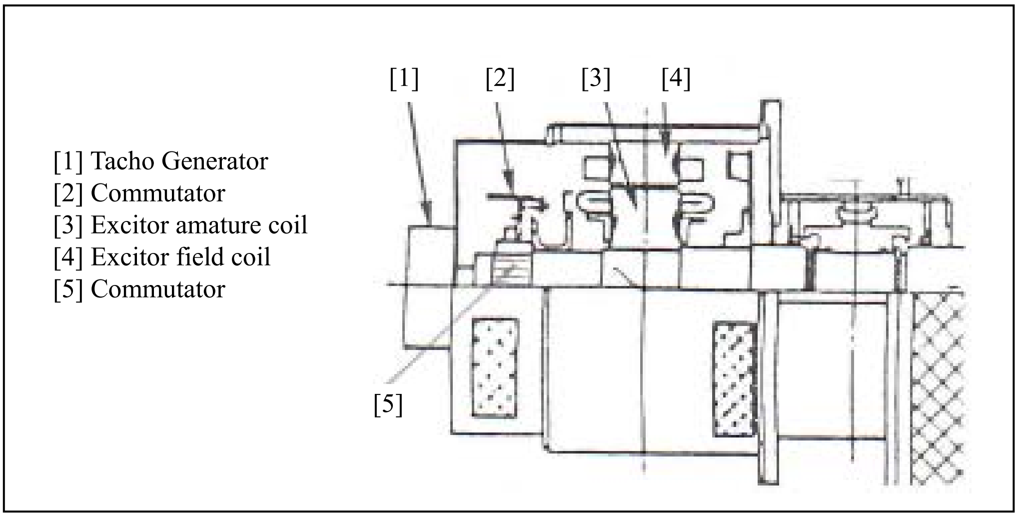
The temperature problem is not apparent in the absolute rise and fall of the temperature but rather in the speed of temperature change. If severe trend of temperature rise is observed, its cause should promptly be investigated and counter-measures taken.

When the Oil Ring is blocked due to the intrusion of foreign matter such as insects, etc. or the temperature of the white metal on the surface of the Shaft Bearing has risen to a level of burning, the temperature will thereafter rise rapidly. Therefore, when such an sign is observed, cooling measures should be immediately taken such as load reducing, adding some new oil and cooling water, and to stop the operation.

3.2.3 EXCITATION EQUIPMENT

There are three types of excitation equipment to get DC voltage as listed below:

- Exciter by DC generator (DC Exciter)
- Exciter by Static Rectifier (Static Exciter)
- Brushless Exciter



Source: JICA Study Team

Figure 3.2.14 D.C. Exciter

A. Outline of Structure

Figure 3.2.14 presents structure and name of elements of DC generator (DC excitor).

A DC generator consists form the field coil as stator and amature coil as rotor. The generated voltage is taken out through brushes and commutators from the amature coil. The brushes and the commutators rectified A.C gneratoed current to DC.

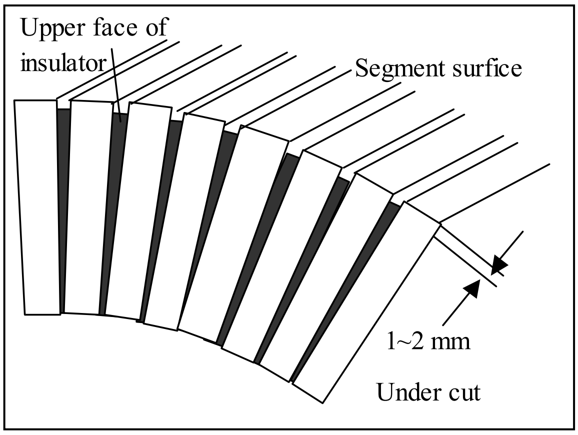
The Commutator has commutator segments connecting both ends of respective generating coil. The segment is made of copper bar shaped in same size and placed in the electrical order with insulating each and pressing together.

B. Points of Maintenance

- Commutator

The commutator has a function to take out the maximum coil voltage through brushes that occur periodically and accompany the revolution and by switching from one coil to another by keeping in contact with the brushes.

Accordingly, the position and contact force



Source: JICA Study Team

Figure 3.2.15 Commutator

of the brush should be adjusted to avoid throwing off sparks, as much as possible. The segment surface should be kept shining and should be a “Chocolate Color.”

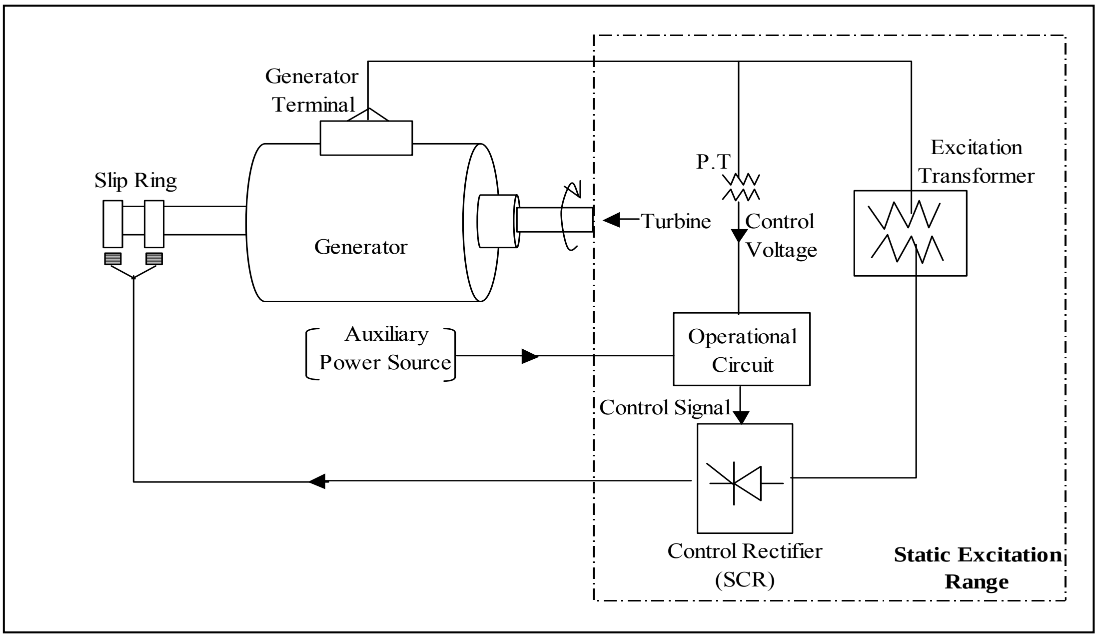
The copper of the segment will wear out due to friction after long-term operation and then the mica plates used as insulation will appear on the surface, of which condition cause sparks. The surface level of the mica plates should be cut below that of the segment bar by processing timely. This processing work is referred to as an “Undercut.” The undercut should be carefully executed so not to damage the segment surface, using the cutting edge of a metal saw or a special tools like a chisel.

- Residual Magneticsm

The Exciter establishes voltage by so-called build-up action, that is, self-excitation is repeated at the start of operation by a weak voltage generated by residual magnetism on the stator pole and the voltage rises gradually. There are cases where the voltage cannot be established due to loss of the residual magnetism. This is due to causes such as when Rapid De-magnetism control is employed in the excitation system, or induce of a Reverse-Electromotive Force at the opening of the magnetic field circuit, or after disassembling works. In such cases, a weak excitation should be imposed to the field poles from an external source such as a dry batteries at about 3 volts so as to build-up the voltage.

The recent generation system employs Initial Excitation System to avoid such phenomenon, that is, at the time of start, a small current for magnetizing is taken from a station battery system. In this case, if the Initial Excitation level is too high, delayed building up of the excitation may take place at the transient time of change over from Initial Excitation to Self-Excitation. It is important to check the level of Initial Excitation at the time of maintenance inspection.

- Static Excitation



Source: JICA Study Team **Figure 3.2.16 Static Exciter**

Figure above presents the structure of a Static Exciter.

C. Construction and Principle

A Static Exciter rectifies the self-generated voltage for supplying excitation current. This type is referred to as a Self-Excited AC Generator.

The circuit to receive the excitation current consists of an Excitation Transformer that step down high voltage to low voltage, a control rectifier for AC rectification with control of the excitation level, an operational circuit for calculate control signal level referred to generator voltage. All of these components have no mechanical parts and are, therefore, referred to as a Static Exciter.

Actually, the operational circuit employs either an analogue circuit or a digital circuit with CPU (Central Process Unit). The main component of the control rectifier is a SCR (Silicon-Controlled Rectifier). One of old type adopts a combination of super saturation reactor and silicon rectifier.

D. Points of Maintenance

The Static Exciter has been developed to save work of maintenance and to provide ease of automation of operation and control. The maintenance is easier compared with that of rotating machines.

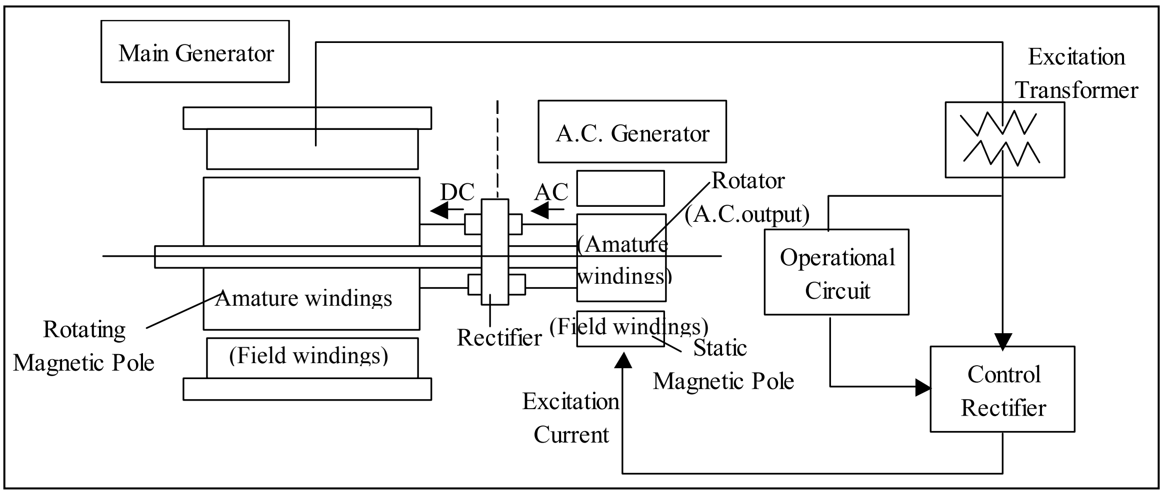
- Operation Circuit

Since many electronic parts are used, parts temperature, environment temperature, dust, etc. need to be cared for in accordance with the basic requirements for handling electronic products. As for dust in particular, it is difficult to remove like moisture. The parts surface should be kept clean by blowing dry with warm air.

- Control Rectifier

The Control Rectifier has heat radiation and needs, therefore, maintenance to remove insects on radiator, spider nets, etc.

(3) Brushless Exciter



Source: JICA Study Team **Figure 3.2.17 Brushless Exciter**

Figure above shows the diagram of a Brushless Excitation type.

A. Outline of Structure

The Brushless Generator adopts a rotating-amaturetype A.C. generator which is referred to as A.C. exciter. The A.C. exciter's rotor (amature winding) is coppled to its Main Shaft with a main Rotor (field windingfs of the main generator), and rotating Rectifiers. The AC Exciter's amature windings generates alternative current, and it is rectified the DC current by the rotating rectifiers. The field current of main generator is fed from the rotating rectifiers without brushes or commutators.

B. Point of Maintenance

Generally, this type of exciter is maintenance free. Since the brushes usually require the most maintenance work in the rotating generator, and they are omitted in this type of machine, it is considered the original objective has been achieved.

The other points of maintenance are similar to those of a Static Exciter. However, since there are rotating parts, the amount of looseness of fixing mechanisms, due to continuous centrifugal force, should be checked upon a machine stop with periodical maintenance intervals.

3.2.4 GOVERNOR

A. Outline of Governor

The Governor has various types and construction depending on the maker, manufacturing year, size and type of Main Unit, and so forth. Accordingly, it is difficult to explain the structure and specify the way of handling.

Figure 3.2.18 presents a Hydro Mechanical Governor, made in China, that has been employed in many horizontal axis turbines of 500 kW-3,000 kW.

Figure 3.2.18 Governor

This governor pick up the turbine speed by a thacho-generator. The output of tacho-generator is provided to the penduram drive motor (Induction motor) on the governor. The pendurum moves up or down by the centrifugal force produced by the inductionmotor lotation. The pendulum links to the sliding sleeve. This sliding sleave moves up when the rotation of the induction-motor to increase by the turbine speed increase, and moves down when the turbine speed to decrease. The sliding sleeve link to the piston of the distribution valve. The movement of the piston of the distribution valve control the pressure oil flow to the servo-motor. The Servomotor moves a guide vane or a needle valve via gate ring (Guide Vane Ring).

B. Points of Maintenance

Once the governor is adjusted, its tuning up will not be required so often. The governor does not need complicated maintenance, however, since small components are functioning at high precision, partial failure of component may hamper proper functioning of governor.

- Speed Detect Adjuster

The parts that incur the highest probability of trouble are the Speed Detector and Adjuster, the weight and spring of the pendulum, which keeps a sensitive balance and rotates together with Pressure Distribution Valve.

Since any trouble with this part cannot be remedied on the site, spare parts with good quality should always be kept in hand and replaced upon trouble. If the Maintenance Staff have a thorough knowledge of the replacement procedure and have acquired the practical skills needed for the replacement, then the recovery from such trouble will be achieved quickly.

- Indicator

A large Indicator is provided to show three types of data: i) position of Governor, ii) selected position of Load Limiter, and iii) opening of Servo-motor. The consistency of each Pointer indication and actual opening position, etc. should be checked periodically.

- Oil Leakage

The Actuator is housed in a cabinet. Since the interior space is small, oil leakage is easy to find. Since oil leakage become cause of trouble, it is important to inspect with utmost care and execute any remedial work if any.

- Crosshead

The Crosshead transfers the reciprocating motion of the piston in a straight line to the rotating angle of the arm. The top of the arm tends to move upward or downward from the axis of spindle accompanying the horizontal movement of the Crosshead. The Crosshead, controlling the upward/downward movement of the arm, transmits a great force to the arm, and the friction force operating to each sliding surface becomes large.

Accordingly, a lubricant having a higher coefficient of viscosity than grease oil is more effective for lubrication of these surfaces. The sliding surfaces should be cleaned and always be applied with lubricant without interruption.

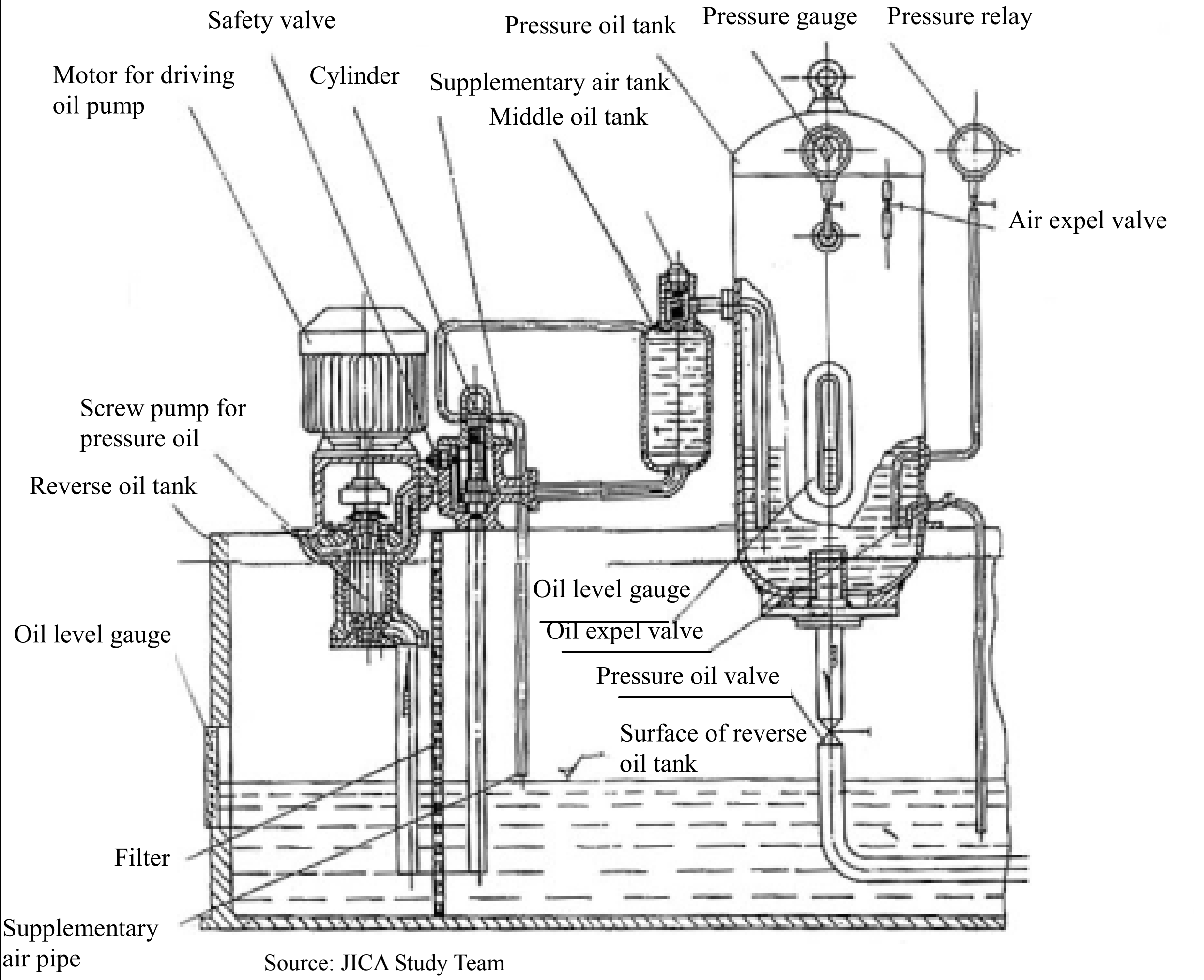
3.2.5 PRESSURE OIL UNIT

A. Construction and Outline of Function

Figure 3.2.19 shows a all-in-one Pressure Oil Unit assembled together with governor. The Pressure Oil Unit consists of principal parts of the Reverse Oil Tank, Oil Pump, Middle Oil Tank, Supplementary Air Tank, and Pressure Oil Tank. As auxiliary tools, the unit employs many parts such as Oil Level Indicator of Pressure Oil Tank, Pressure Gauge, Pressure Relay, Air Expel Valve, Oil Discharge Valve, Safety Valve, Motor for driving Oil Pump, Filter, Supplementary Air Valve of Supplementary Air Tank, attached valves and cocks, and forth.

The Pressure Oil Unit is an important device to supply pressure oil to the governor for activating the Hydraulic Automatic Governor. The stabilized oil pressure and sufficient supply volume of pressure oil have to be always maintained and secured.

Figure 3.2.19 Pressure Oil Unit



Source: JICA Study Team

Figure 3.2.20 Structure and Name of Oil Pressure Unit

Figure above is an explanatory drawing of the functions of the Pressure Oil Unit presented in Figure 3.2.19.

- Pressure Oil Tank

The Pressure Oil Tank is to keep the specified volume of oil within a specified range of pressure. It has a valve to send oil to the governor and inlets to receive oil and air supply.

The specified oil volume should be checked and confirmed on the Oil Level Indicator attached to the front surface of the Pressure Oil Tank. If the pressure rises from oil being supplied by the Oil Pump, the air inside the Pressure Oil Tank is compressed and the oil level rises. When the oil that the governor uses is supplied from the Pressure Oil Tank, the oil level lowers with the air expanding to lower the oil pressure.

In such a way, the oil pressure and the oil level are closely related to each other. The Pressure Oil Tank is under ideal conditions if the oil pressure is at the upper limit of the specified pressure range , when the oil level is at the maximum level of the specified range, and if the oil level is a little above the minimum level, with allowance when the oil pressure lowers to reach the minimum limit.

- Oil Pump

Oil Pump supplies the specified volume of oil to the Pressure Oil Tank against the internal pressure of the Tank. Accordingly, the Oil Pump is a high pressure type such as a Gear Pump, Screw Pump, etc.

- Pressure Gauge and Pressure Relay

The Pressure Oil Tank is equipped with a Pressure Gauge and a Pressure Relay. The Pressure Gauge indicates pressure by a pointer. A Burdon Pipe type pressure gauge is used to indicate the internal pressure of the Tank. Two Needle Limiters are also provided, one at a high position, the other at a lower position, thereby putting the pointer between the Limiters. If the pointer touches one of the Needle Limiters, an electric signal is given for warning or automatically stop of the Main Unit.

The Pressure Relay is of a similar structure to that of the Pressure Gauge. It activates the Oil Pump whenever the pointer touches the Low Side Limiter and stops the Oil Pump whenever the pointer touches the High Side Limiter. Accordingly, the Oil Pump is in operation when the indicator of the Pressure Relay is in the high side position and is in stop when it is in the low side position, which means that the oil pressure in the Pressure Oil Tank lowers due to no supply of oil.

- Middle Oil Tank and Supplementary Air Tank

These two components function to automatically adjust the oil level of the Pressure Oil Tank. When the Oil Pump stops, the oil pressure in the oil path between Oil Pump and Middle Oil Tank is reduced and Non-return Valve, provided at the top of the Middle Oil Tank, activates to block the oil flowing into the oil path from the Pressure Oil Tank. At the same time, a cylinder of the Supplementary Air Tank lowers to form an air path connecting into the Air Suction Pipe that is suspended in the Reverse Oil Tank.

At this time if the bottom end of the Air Suction Pipe is above the oil level of the Reverse Oil Tank, the oil in the Middle Oil Tank moves towards the Reverse Oil Tank through the Air Suction Pipe and falls and flows into the Reverse Oil Tank. In place of the oil movement, air moves into Middle Oil Tank to fill this space.

If the bottom end of the Air Suction Pipe is below the oil level of the Reverse Oil Tank, the Pipe is closed by oil in the Reverse Oil Tank. Since the air cannot flow between the two Tanks, the oil in Middle Oil Tank remains as is. In this case, since the oil volume in the Pressure Oil System is constant and a certain volume of oil is circulating, if the oil level of the Reverse Oil Tank is low it means that the oil in the Pressure Oil Tank is sufficient and the oil level there is rising.

If the Oil Pump starts under this condition, the oil sent out by the Pump first enters the Supplementary Air Tank to press and make the air flow into the Middle Oil Tank, followed by oil flow. It functions to lower the oil level of the Pressure Oil Tank that has been rising, to balance the pressure.

- Oil Discharge Valve and Air Expel Valve

The oil and air are supplied as required by the joint functioning of the Supplementary Air Tank and the Middle Oil Tank.

There would be such a case when the bottom end of the Air Suction Pipe is at a level above the oil level of the Reverse Oil Tank, being open to air for a long time due to a decrease in the oil inside the Reverse Oil Tank. In such cases, air would excessively supplied to the Pressure Oil Tank via the Middle Oil Tank to lower the oil level of the Pressure Oil Tank even though the pressure of the Pressure Oil Tank is within the specified range. In this case, the Air Expel Valve should be opened to release the excess air to outside. Since the release of this air reduces the oil pressure of the Pressure Oil Tank, the releasing operation should be carefully executed while watching the Oil Gauge so not to cause an excessive lowering in the oil pressure, just after the oil pressure rises to reach the Upper Limit of the specified oil pressure range.

During the functioning of the Governor, there will be oil leakage from the Pilot Valve, the Main Pressure Distribution Valve, etc. Accordingly, the oil level and pressure of the Pressure Oil Tank gradually lowers and when the oil pressure reaches the lower limit, the Oil Pump starts. If oil is excessively supplied to and the oil level of the Pressure Oil Tank is rising at an oil pressure within the specified range, the Oil Discharge Valve should be opened to drain away the excessive oil. The way of oil discharging is similar to that of operating the Air Expel Valve.

B. Points of Maintenance

The Oil Pressure Unit is the most important device for operation of the Turbine-Generator. Both Operators and Maintenance Staff should pay attention to maintaining its function and all effort is needed to maintain the unit under normal conditions.

The main reason for manpower and time for this specific maintenance work is that the automatic adjustment for pressure stabilization and the keeping proper oil level are essential for proper operation but these cannot easily be achieved.

The principle function of the inspections of the Pressure Oil Unit is, as described in the foregoing section, well elaborated so as not to require much maintenance. However, there are omissions of some equipment and a reduction in the design allowance made from a consideration of simplicity and economic requirement of a small-hydro plant. As a result, there are many equipment that is difficult for maintain in the best condition for the long-term.

Accordingly, the utmost care of Operation and Maintenance is needed in implementing routine maintenance work such as countermeasures for oil leakage, cleaning, etc. Also it is effective to recognize the value set, value for activation, optimum value for operation time, and to install a signboard beside the machine showing these target values.

- Pressure Oil Tank

Maintenance is to be carried out with attention to the following devices attached to the

Pressure Oil Tank:

Since a stain on the Oil Level Gauge affects reading of the correct oil level, it should be periodically cleaned to facilitate the correct reading of the oil level.

The Pressure Gauge and the Pressure Relay should be observed with care at the daily inspection to see if there is any difference between the two indicators, if the motion of the indicators is smooth, if there is not large change in the on-loading and unloading time of the Oil Pump compared with normal conditions. The results should be noted including the time of inspection.

The Air Expel Valve should be confirmed by hand touching, after the air-releasing operation, to check if the valve is properly closed.

The opening of the Oil Discharge Valve is difficult to fix and, therefore, adjustment of the oil discharge by valve opening is not recommended. The Oil Discharge Valve should be adjusted to yield a suitable oil discharge when fully open by inserting the Orifice Plate to the joint with the discharge pipe.

- Supplementary Air Tank and Middle Oil Tank

There are no parts that need adjustment from outside, however, since there are many connection joints, oil leakage needs attention.

- Reverse Oil Tank

The level of the bottom end of the Air Suction Pipe and the oil level of the Reverse Oil Tank can hardly be coordinated. The Oil Level Gauge should be marked with the level of the bottom end of the Air Suction Pipe as a reference for inspection. If there is a difference for a long time between the marked level and the oil level, it means that there may be a oil leakage from the Reversed Oil Tank or from some other part to outside or there may be an over supply or shortage of oil. Such a difference disturbs the smooth adjustment of the oil level of the Pressure Oil Tank. The oil volume should be maintained at a proper level by supplying new oil or discharging from the Tank.

Attention should be paid that the operating oil should not be mixed with dust and all openings should to be kept free of dust. The Filter should be periodically cleaned and the oil of the Reverse Oil Tank should be taken out and cleaned and the Pressure Oil System cleaned by oil flushing.

When the operating oil is reused after the cleaning works, the oil should be filtered and shortage oil should be added.

- Operating Oil

Operating Oil should be selected from the Manufacturers specified brands. Oil that has been used for a long time becomes oxidized and changes color through heating while passing through the Oil Pump, heating by insulated compression in the Middle Oil Tank, discharging as a high velocity flow through the Safety Valve. The oil may lose its nature by emulsification resulting from the mixing of moisture or droplets of water from the suctioned air. In these cases, the accurate operating time cannot be secured. The oil quality should periodically be checked.

- Safety Valve

The Safety Valve should activate and discharge oil at a pressure higher than normal upper limit of 0.1-0.2 MPa. An operation test should periodically be executed and recorded its pressure value.

3.2.6 OTHER EQUIPMENT

(1) Inlet Valve, Bypass Valve, and Others

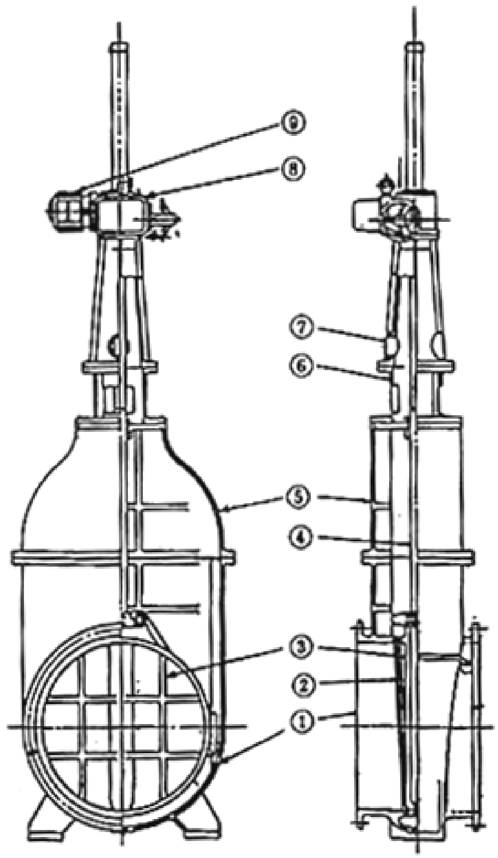
A. Type and Outline of Structure

As shown in Figure 3.2.21a, the type of valve is grouped into two groups: Sluice Valve and Butterfly Valve.

a. Sluice Valve

The Sluice Valve is operated by sliding of the Valve Seat and Valve and is suitable for shutoff against high pressure. The contact surfaces are closely fitted to each other over the whole surface. Since there is wear on seal surfaces due to sliding and the occurrence of scratch damage, a liner made of bronze etc. that is stainless and has a good performance of sliding is fitted to the sliding seal surfaces of both the Valve Seat and Valve.

The hoisting of the valve is by a Spindle attached to the valve. There are two ways of Spindle connection: one is by an External Screw to directly connect the Valve body and Spindle and to operate up and down the Spindle outside the Valve body; the other is by an Internal Screw which fits the Spindle to a nut fixed to the valve and to rotates the Spindle to directly hoist the Valve.



No.	Item	Material
①	Valve Frame	Cast carbon steel
②	Valve Sheet	Bronze
③	Valve Body	Cast carbon steel
④	Axis of Valve	Stainless steel or carbon steel for mechanical structure
⑤	Cover	Cast carbon steel
⑥	Stand	Cast iron
⑦	Stand	Ditto
⑧	Speed Reducer	-
⑨	Electric Motor	-

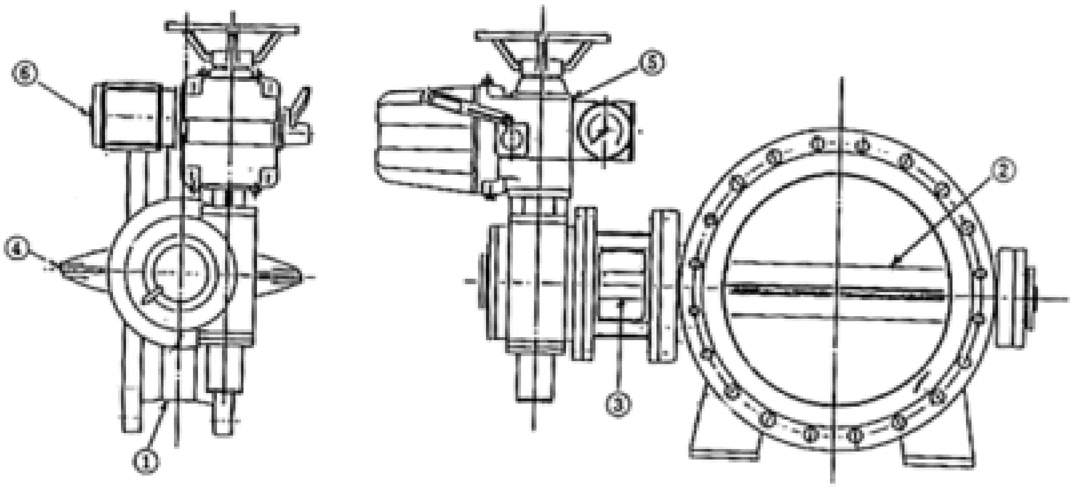
Source: JICA Study Team

Figure 3.2.21a Sluice Valve

b. Butterfly Valve

The Butterfly Valve is equipped with a circular valve disc attached to a valve axis that is provided perpendicular to the pipe axis. It shut the water off by changing the direction of Valve through rotation of the valve axis. Since the resistance force of flowing water operates symmetrically with respect to the valve axis, the force required for rotating that valve is small. Therefore, the Butterfly Valve is employed in many large scale valves.

The Butterfly Valve is positioned, at full opening, in the same direction with the flow. The friction loss of the valve is reduced by making the valve thickness thinner and streamlining the section shape of the valve leaf. In the case of a large scale valve, in order to reduce the loss of axis, two valve discs are used with a space between the two discs and attaching the axis to both ends as shown in Figure 3.2.21 b. With this arrangement, the valve axis does not cross the flow and the water can flow also between the two valve disc at full opening. Such valve types are called Double Leave Valves and are distinguished from Butterfly Valves.



No.	Items	Material
①	Valve Frame	Pressed and stretched steel plate for general structure
②	Valve Body	Ditto
③	Valve Axis	Stainless steel, Cast carbon steel, or carbon steel for mechanical structure
④	Valve Sheet	Rubber
⑤	Speed Reducer	-
⑥	Electric Motor	-

Source: JICA Study Team

Figure 3.2.21 b Butterfly Valve

c. Inlet Valve

As Inlet Valve, Butterfly Valve or Double Leaves Valve are mainly used and mostly operated by electric motor with DC power source.

In the case of a large scale valve or high pressure that needs a large operation force, hydraulic operation may be adopted with a hydraulic cylinder.

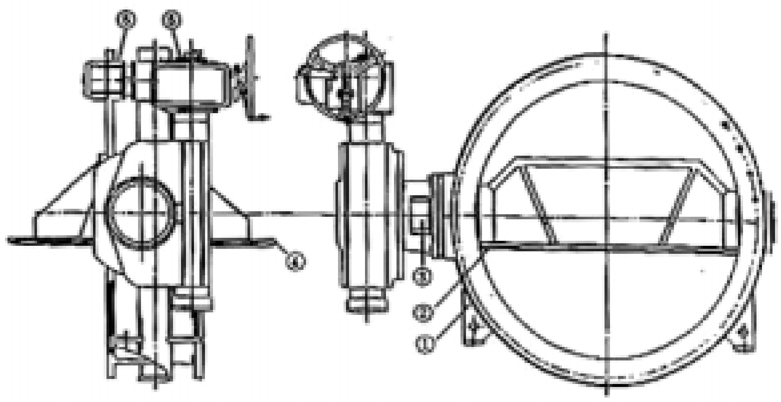
In addition, some valves provide with a counterweight mechanism for automatic closure in case of a loss of electric power or pressure oil.

d. Bypass Valve

When the Inlet Valve is of a large size and needs a large force for operation, in order to reduce the force required as a result of hydraulic pressure operating on the upstream surface of the Valve, at the start of the Sluice Valve in particular, a small valve is provided to bypass the upstream and downstream sides of the Main Valve and to fill water the turbine side with water from penstock. This is called the Bypass Valve. Since the Bypass Valve has a small diameter, a Sluice Valve is employed in many cases. However, in the case of a high pressure system like a Pelton turbine, a special needle valve is also used.

e. Drain Valve and Others

The Drain Valve is provided for dewatering at the end of the Penstock pipe or turbine casing. A Sluice Valve is mainly adopted. A hydropower station is equipped with many types and numbers of valves including ones provided in the Cooling Water System for cooling the Shaft Bearing and Pressure Oil, small motor-operated valves for strainer operation, etc., solenoid-operated valves used in the Pressure Oil System, and so forth.



No.	Items	Material
①	Valve Frame	Pressed and stretched steel plate for general structure
②	Valve Body	Ditto
③	Valve Axis	Stainless steel, Cast carbon steel, or carbon steel for mechanical structure
④	Valve Sheet	Rubber
⑤	Speed Reducer	-
⑥	Electric Motor	-

Source: JICA Study Team

Figure 3.2.22 Double Leaves Valve

B. Points of Maintenance

The maintenance of valves to avoid leakage is the main maintenance needed.

Since a hydropower station uses many valves, it is not easy to keep all of these valves free from leakage. If no water leakage and no oil leakage is observed at the hydropower station, it could be said that the maintenance of the other equipment must also be executed in the same satisfactory manner. In particular, water leakage, unlike oil, will not cause any stain and is often kept as flows. However, water leakage can cause unexpected large adverse effects such as when spouting water is splashed over electric parts, water mixed in oil, etc. Such leakage problem should not be overlooked and should be repaired at the earliest point in time.

a. Inlet Valve

If a Butterfly Valve or Double Leave Valve is over closed with torque, its contact with the

Valve Seat is tightened by wedge effect and re-opening requires an unexpectedly large force. Accordingly, in the case of motor-driven valves, the adjustment of the Limit Switch provided at fully closed position is a delicate task. In many cases, the Limit Switch is adjusted to a little bit shorter than fully closed position, to prevent excessive closing. The adjustment of full closing position of Limit Switch should be repeatedly executed with utmost care.

Also, if a valve is blocked by foreign material like wood tip under closing condition, the valve will be stalled by hitting materials at halfway position to the full closing and the Limit Switch for full close does not activate. In such cases, the motor for the valve operation exceeds its rated output due to continuous operation and over-torque is to be forced to the driving mechanism of the valve operation. Accordingly, Instantaneous Over-current Relay is provided for motor protection to prevent burnout by such over-current. Whenever the valve will be open or closed, driving motor for valve start with full voltage from the standstill condition and its starting current become a severalhold, which condition will initiate the instantaneous over current relay and cause the starting failure. Hence, the blocking sequence on instantaneous over current relay circuit is required at the time of starting valve operation, of which setting time is about 2-3 seconds.

There is often a found that the actual position of closed valve does not correspond to the reading on indicator. Internal inspection should periodically be executed to correctly adjust the opening indicator and take records of relationship of scale label and valve angles. A modern big scale valve uses sealing rubber inserted around the valve leaf. The damage and dropout of such sealing should be checked upon periodical inspection.

b. Common Points

The leakage accompanying valves may be classified into 1) leakage due to improper ground packing of the operating spindle, and 2) leakage from joints between the valve and pipe and other equipment. The former case is observed much more than the latter.

It is important for avoiding leakage to use packing of the proper shape and material and to have a proper setting of the packing without deficient or excessive bolt tightening.

c. Storage Batteries

The Storage batteries are provided in a power station to supply DC for the operation of the Station. These are either lead storage batteries or alkaline storage batteries.

DC is used as the operating power source of station equipment and protection relays. It plays an important role to maintain the functions of the station.

The discharge capacity of the storage battery depends on the magnitude of discharge current, duration time, repeated pattern of discharging and charging, etc. If a battery is used exceeding the discharge capacity, the voltage abruptly lowers. At the time of station design, a case that requires the maximum discharging capacity of battery like operation of the Inlet Valves is assumed and the battery capacity is determined. However, the battery capacity lowers through deterioration and improper maintenance.

When the battery is charged under floating, the voltage alone cannot indicate the lowering of the battery capacity. If an unexpected accident takes place causing concurrent trips of the two main units and the lowering of the battery capacity has not been recognized, and all the related equipment activates concurrently to exceed the battery capacity, to lower DC supply voltage, to interrupt operation of the relevant equipment, then an unforeseen large accident may eventuate. Accordingly, batteries should be well maintained.

3.3 CHARACTERISTICS & TESTS OF PRINCIPAL EQUIPMENT

The maintenance staff should have a thorough knowledge of the basic principle and characteristics of the equipment they handle. Also, the staff should grasp and analyzes the phenomena occurring on the actual machines. The staff should have confidence in the restoration of the machine characteristics after repair of the damaged parts. This knowledge should be fully applied to achieve good maintenance work.

The characteristics of the principal equipment that are used in small-hydro stations are described below:

3.3.1 TURBINES

(1) Opening-Output Characteristics

The relationship between the opening of water inlet adjuster of turbines like Guide Vanes, Needle Valves, etc. and the turbine output is as shown in Figure 3.3.1(1). (Since the turbine output cannot directly be measured, the generator output is usually used in place of the turbine output.)

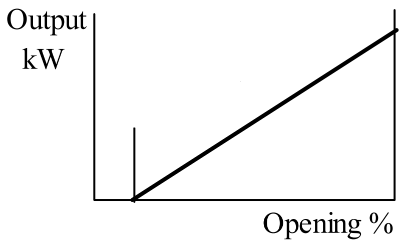
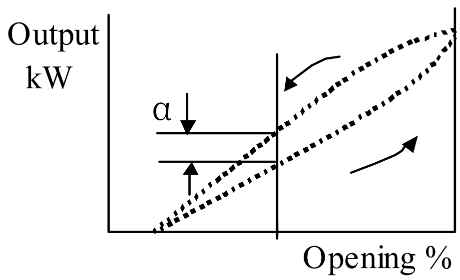


Figure 3.3.1 (1) Output and Opening of Turbine



Source: JICA Study Team

Figure 3.3.1 (2) Output and Opening of Turbine

The characteristics are featured by the magnitude of No Load Opening and shape of the relationship curve, both of which are inherent to the Turbine-Generator.

The No Load Opening is the opening when the Turbine-Generator is maintaining the rated speed without being connected to the load. The No Load Opening is sometimes confused with the Start Opening. The Start Opening is the opening when the turbine starts to rotate. In view of the time required from the start to achieve the Synchronizing Speed, the Start Opening is usually set at a position greater than No Load Opening.

The shape of the curve is close to a straight line in many cases. It differs by type of turbine. In the case of a Kaplan turbine, the relationship becomes complicated, being affected by the adjustable runner vanes.

Also this curve is affected by various factors and changes its shape and values, such as erosion of guide vanes and needles through long-term operation, development of runner erosion due to cavitations, increased gaps between the runner and cover liner, clogging of leaves inside guide vanes, nozzles, etc.

The measurement of the Opening-Output is to be made by gradually increasing the opening from Full Close to Full Open, and then gradually reducing from Full Open to Full Close. Thus the Opening-Output relationship is obtained as shown in Figure 3.3.1 (2). If the value of α in the figure is large, it indicates a relaxation in the Operating Mechanism of Water Inlet. This reference is important measurement in the maintenance of Francis turbine, Kaplan turbine, etc. such that has complicated Link Mechanisms.

If the direction of valve operation is reversed in the course of the measurement, a correct shape of the curve cannot be obtained. The measurement needs to be from Full Close to Full Opening and then from Full Opening to Full Close without any interruption and reversing from an intermediate opening. Also such reverse order should be avoided as from Full Opening to Full Close and then from Full Close to Full Opening.

The Maintenance Rule prescribes an Opening-Output test be executed once in every 2 years. This means even if no abnormal condition is observed, the test should be executed once in every 2 years. It is recommended to be carried out so as to know the characteristics change, it will be confirmed always after execution of disassembling and cleaning of guide vanes, adjustment of the governor, and so forth.

Note: The Opening-Output Characteristics are very simple. However, it indicates various conditions as described above and will contribute to proper maintenance.

(2) Characteristics of Efficiency

a. Turbine Efficiency

Turbine efficiency is expressed by the following equations:

η_T : turbine efficiency
H_e : effective head, in m
Q : turbine discharge, in m^3/s
P_T : turbine output, in kW

$$\eta_T = \frac{P_T}{9.8 \times H_e \times Q}$$

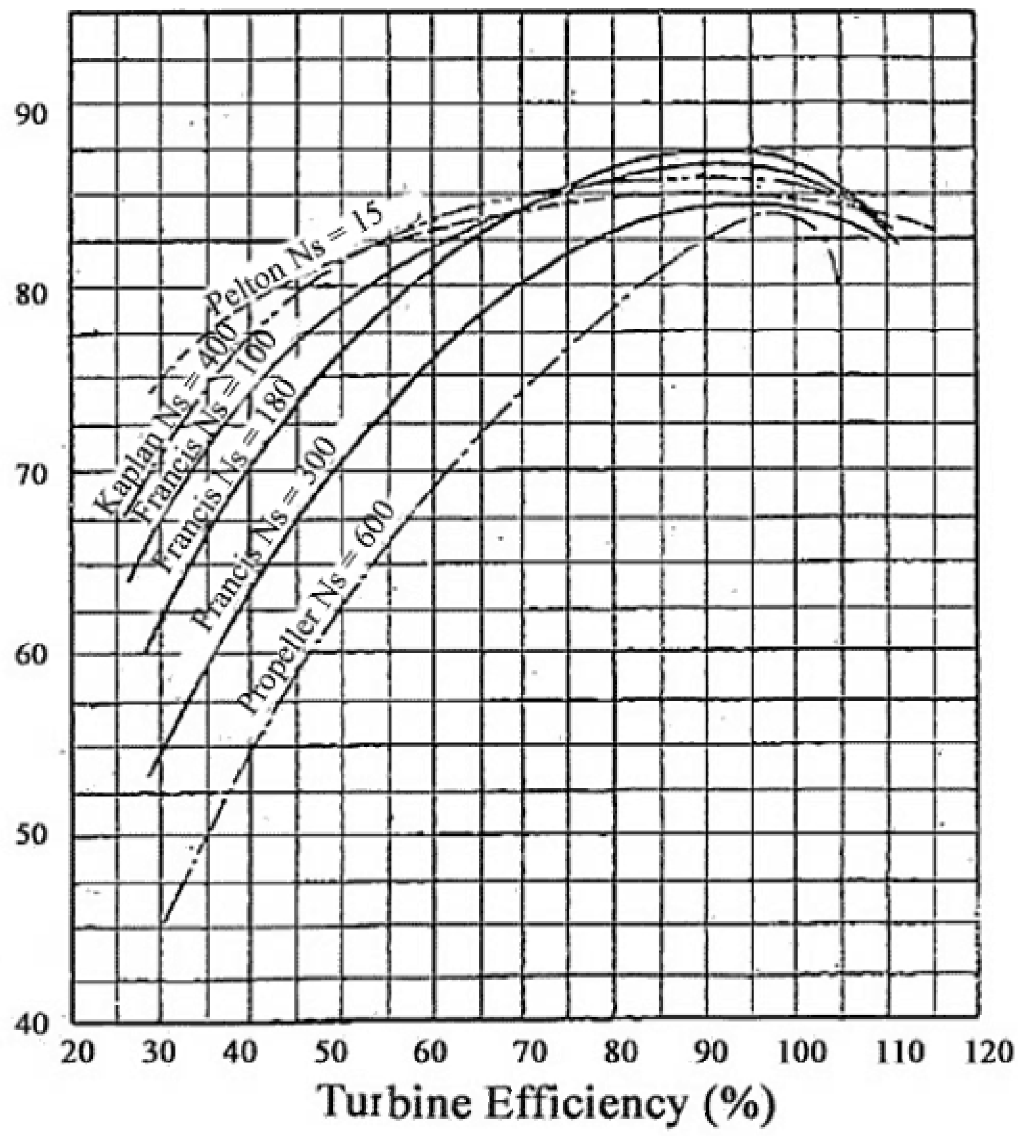
Turbine output can hardly be measured in general, it is calculated using the generator output by the following equation:

η : combined efficiency
η_G : generator efficiency
P_G : generator output, in kW

$$\eta_T = \frac{P_G}{9.8 \times H_e \times Q}$$

H_e is a net acting head on the turbine. It is obtained by summing up 1) static head just upstream of turbine inlet, 2) velocity head of inflowing water, and 3) drafting head in the draft tube. Actually, it is almost equivalent to the height difference of the water level of the Head Tank and the elevation of the turbine centre level, deducted by losses of head in Penstock, and added by drafting head.

The loss head in the Penstock vary in proportion to the square of discharge Q, and turbine efficiency also changes with Q. The turbine efficiency varies with certain correlation with the discharge Q due to a difference in the discharge operating to the runner. With the discharge as the abscissa and efficiency as the ordinate, the relationship between the turbine discharge and efficiency can be expressed as shown in the figure below.



Source: JICA Study Team

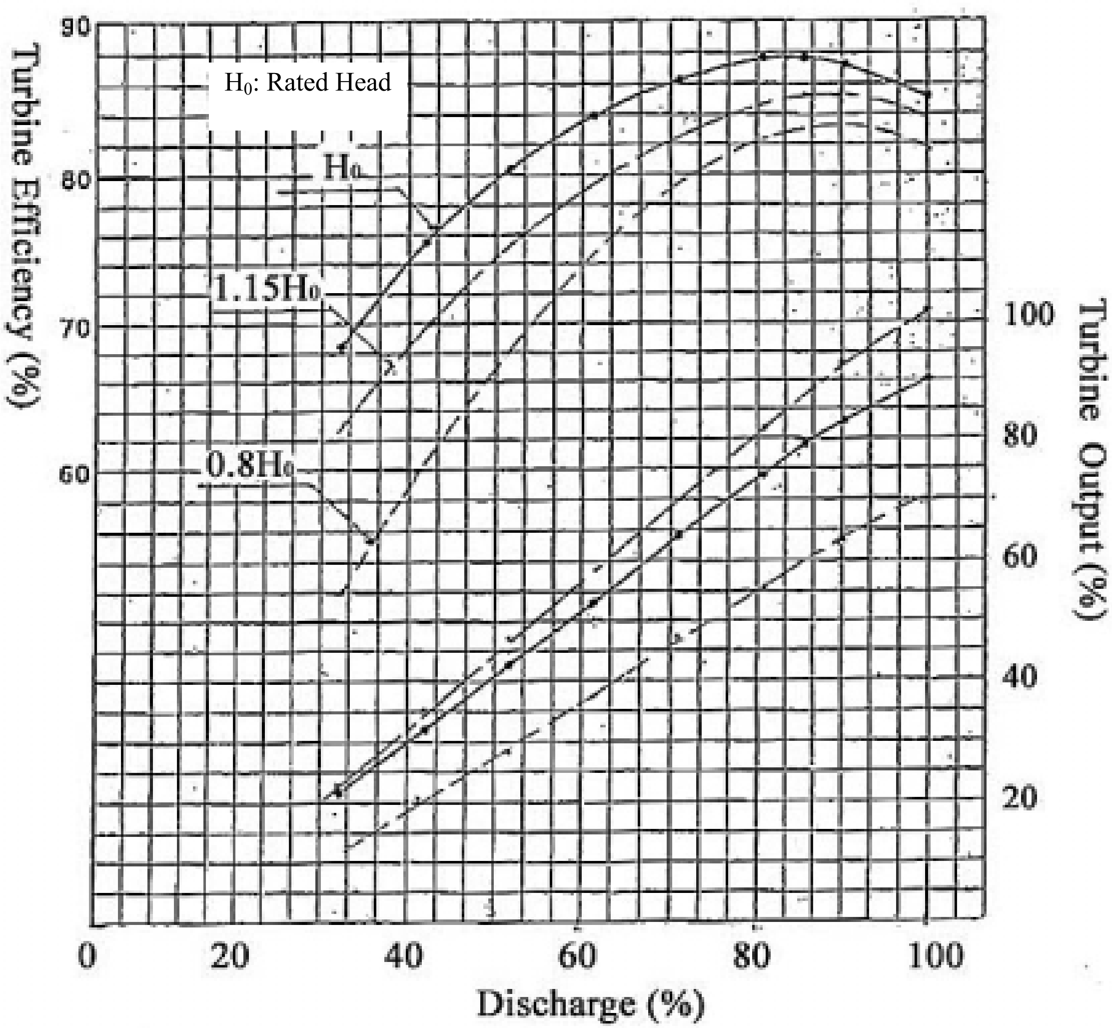
Figure 3.3.2 Comparison of Efficiency of Various Turbine

The curve presented in the figure is called the Efficiency Curve. The shape has, as shown in Figure

The characteristic shown in the figure above is the relationship between the discharge and the efficiency under a constant effective head and a constant revolution speed. The efficiency when the revolution speed is constant while the effective head varies is referred to as the

Variable Head Characteristic, which is shown, with effective head as the parameter, in Figure 3.3.3.

The characteristic under a constant effective head is applicable to many run-of-the-river type hydropower stations while the Variable Head Characteristic is applicable to dam type hydropower stations.



Source: JICA Study Team

Figure 3.3.3 Variable Head Characteristics

Figure 3.3.3 presents a Discharge-Output curve together with the Discharge-Efficiency curve. The curve is similar to the Opening-Output curve described in the foregoing section because the Opening and Discharge has a correlation approximated by a straight line. It should be noted that the Opening-Output curve has a close relationship with turbine efficiency.

b. Efficiency Test

The test to measure efficiency is called the Efficiency Test.

The measured item for the efficiency test is the Generator Output (to estimate turbine output by dividing the generator output by generator efficiency), Effective Head, and Turbine Discharge. The generator output can easily be measured by a power meter. The effective head can be obtained by calculation of the static head measured and the in-pipe flow velocity obtained from the turbine discharge.

One method for discharge measurement is to measure the velocity in the Penstock and to obtain the discharge by multiplying the sectional area of Penstock by the velocity. There are other methods for discharge measurement, as listed below, including velocity measurement in a headrace channel, provision of a measuring overflow weir on a tailrace outlet, and so forth.

Table 3.3.1 Methods for Discharge Measurement

Methods	Place of Measurements
◎Current meter measurement	Headrace channel, Penstock
◎Pitot-tube method	Penstock
・ Salt water dispersing velocity method	Penstock
・ Salt content method	Penstock
※◎Gibson method	Penstock
※◎Ultra-sonic method	Penstock
◎Electro-magnetic discharge measurement method	Penstock
・ Venturi-tube method	Penstock
・ Weir method	Tailrace channel
・ Index method	Turbine casing

Source: JICA Study Team

The methods notated with the mark ◎ have been in practical use. Among these, the ones notated with the mark ※ have been applied on many sites.

For the measurement method of efficiency, the IEC (International Electric Commission) has detailed a definition and specifications. A maker-guaranteed efficiency of newly installed turbines may be confirmed in accordance with the IEC standard.

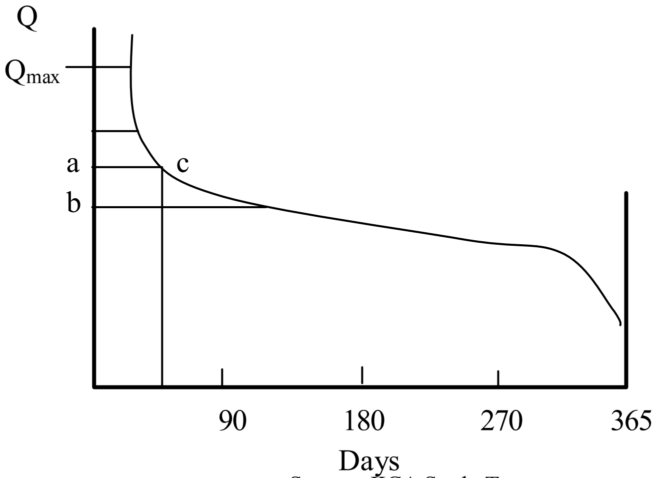
The implementation of these tests needs specific measuring instruments and budgets to cover the cost of instrument installation and measurement. It is common that such measurements and testing are not implemented due to economic reasons, and the maker-guaranteed efficiency curve is often used as submitted. The timing to execute any maintenance of turbines and other equipment can well be judged from the actual Opening Output curve characteristics as explained in the foregoing section.

The turbine efficiency is a parameter used to judge if the turbine output is adequate, in view of proper turbine performance, at the turbine discharge point. Accordingly, in the case of isolated operation of a run-of-the-river hydropower station which may be operate with a certain allowance in output by overflowing a little water from the Head Tank, the turbine efficiency can not be utilized to contribute to more effective operation.

If it is desired to generate as much energy as possible at a Power Station in parallel operation with the grid, the following is a way to utilize the efficiency feature:

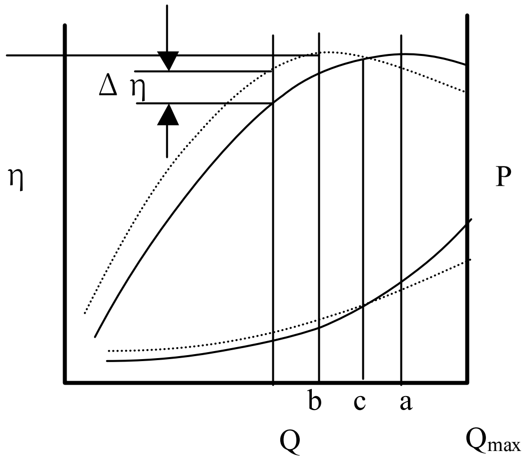
- High Efficiency Operation

As described in the Section for Operation, when multiple units of turbine-generators are operated in parallel to each other, the total discharge is divided and allocated to each unit so that the total power output becomes the maximum.



Source: JICA Study Team

Figure 3.3.4 Flow Duration Curve



Source: JICA Study Team

Figure 3.3.5 Turbine Efficiency Curve

- Improvement of Characteristic

In the case of run-of-the-river power station, there are often such cases when the actual maximum plant discharge was determined to be on the higher side than the typical position on the natural Flow Duration Curve.

Figure 3.3.4 presents a sample duration curve when the turbine is Q_{max} is only 7 % of a year.

Figure 3.3.5 presents the Efficiency Curve of this power station. The existing turbine has the highest efficiency point “a” at 90-95% of the maximum discharge as shown by solid line in the figure. If the turbine is a Francis type, it is possible to alter this by changing the Runner design, producing an efficiency characteristics to a Runner that has the highest efficiency point at “b”, as shown in broken line in the figure.

Comparing the operation between the two efficiency curves, the output of the modified runner is greater than the original runner when the turbine discharge is lower than ”c” while the original runner generates more output when the discharge is higher than ”c.”

The duration of operation at a discharge higher than “c” is about 7%. Accordingly, the modified runner generates a greater output for the duration of 93% of the year. As a result, the annual energy output of the modified runner will be greater than that of the original. In this example the annual energy output has been increased by 5-6%.

However, the turbine efficiency cannot be modified for all types of turbines. In particular, impulse type turbines such as Pelton turbine, Turgo impulse turbine, etc. cannot be modified. A Francis turbine in the range of Ns = 100-200 m-kW can be improved in their efficiency by runner modification.

From the viewpoints above, the maintenance work needs efforts to fully grasp the characteristics of the equipment as well as a positive mind to improve these.

3.3.2 GENERATORS

(1) Basic Characteristics

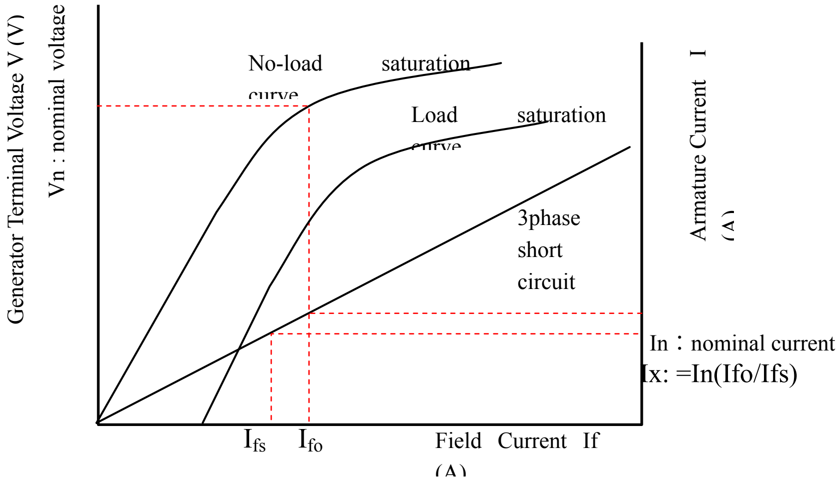


Figure 3.3.6 Basic Characteristics

The characteristic of generators include a No-Load Saturation Characteristic and a Short Circuit Characteristic. The No Load Saturation Characteristic is a curve of the generator terminal voltage against field current, which can be measured when the Excitation Current is gradually increased from zero without connecting load to the terminals and keeping the rated Revolution.

The Short Circuit Characteristic is a character of the generator current against the field current when the generator terminals are shorted. It can be measured when the Excitation Current is gradually increased and keeping the rated Revolution. These characteristics are shown in Figure 3.3.6.

The tests to obtain these characteristics can be carried out also at a Power Station in the case of a manually operated power station equipped with DC Exciter.

If AVR is installed, separate exciting equipment will be required to change the excitation current. Also the Governor cannot be used and the manual adjustment of revolutions, while watching the revolution meter will be required. Thus this characteristic test requires complicated procedures and involves points of difficulty.

The generator characteristics will not change by ageing. Accordingly, the tests at a Power Station are usually executed only upon installation. There are few cases where there is a need to execute such tests as part of the maintenance after commissioning. In many cases, the characteristics obtained by the Maker's Factory Tests are referred to as submitted.

(2) Various Constants

Generator Constants include the following (refer to Figure 3.3.6):

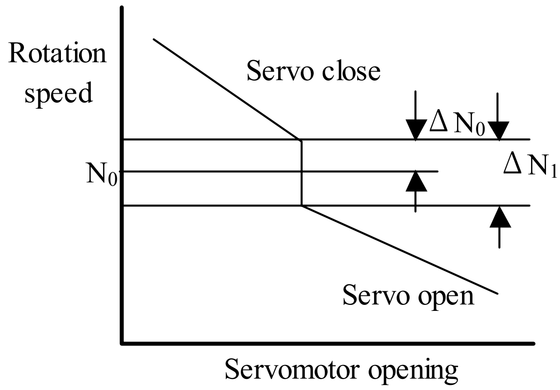
- Short Circuit Ratio, Ifs /Ifo
- Synchronous Impedance, Zn=Vn/Ixn=Vn/In(Ifs/Ifo)

- Transient Impedance
- Transient Time Constant
- Impedance at Sudden Short Circuit
- Time Constant at Sudden Short Circuit
- Fly-wheel GD2, kg-m2
- DC resistance of each coil (generator coil, exciter coil)

(3) Constants Required for Maintenance

- Weight of Stator
- Weight of Rotor
- Generator Efficiency Curve (efficiency against output (kVA), power factor)
- Insulation resistance
- Insulation class and Limit of temperature rise
- Guaranteed temperature of Shaft Bearing
- Cooling water volume and itstemperature

The constants above are important for maintenance works. These constants should be checked and confirmed with the Manufacturer's guaranteed values, records of the factory tests, testing records upon installation in power station, and records of inspection and maintenance, and kept in sequential order.



Source: JICA Study Team

Figure 3.3.7 Servomotor Opening

3.3.3 GOVERNOR

(1) Sensitivity and Speed Dead Band

When input to the Governor, that is, revolution is changed a little bit, the changes in the revolution until the Main Servomotor operates (either open or close) expressed in a percentage to the Rated Revolution Speed is referred to either as the Sensitivity or Speed Dead Band.

$$\text{Sensitivity} = \pm \frac{\Delta N_0}{N_0} \times 100\%$$

$$\text{Speed Dead Band} = \frac{\Delta N_1}{N_0} \times 100\%$$

These characteristics could be obtained by site test.

In general, the servomotor opening is set close to its centre, and the revolution speed is changed at an extremely slow rate. The distance of servomotor movement should be precisely measured with a dial gauge to identify Speed Dead Band.

At this time, the change in the revolution speed is extremely delicate and needs measurement by a Digital Revolution Meter or high precision Frequency Meter. The adjustment of the revolution speed is made by a temporary installation of a variable load of 1-2 kW to the Generator.

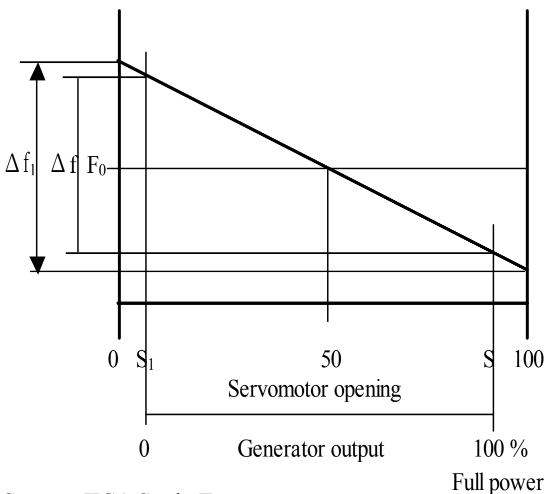
The Speed Dead Band is usually at 0.02-0.04%, and Sensitivity ±0.01%-0±0.02%. These will change with ageing.

The reason of the change with ageing is through increased relaxation of the various mechanisms constituting the Governor and rapping of the Pressure Distribution Valve due to friction with flow. The former relaxation increases the Speed Dead Band while the latter decreases it. Both of these phenomena have adverse effects on the Governor characteristics. If the Speed Dead Band is decreased to a large enough extent, the stability decreases and racing may occur.

This characteristic will not change greatly. Although frequent testing is not required, it should be tested upon detailed inspection at 10 year intervals and the testing results should be recorded and filed.

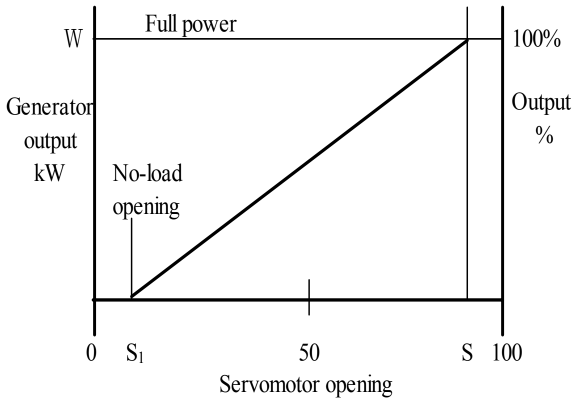
(2) Speed Droop and Permanent Speed Variation

The Governor feedbacks to the Servomotor Opening via a return mechanism. Changes in the Turbine Speed and Servomotor Opening have a relationship as shown in Figure 3.3.8. That is, when the Input Frequency is changed by Δf_1 without any adjustment and keeping the Governor under free conditions, the Servomotor moves from fully closed to fully open. At this time, the value of Δf_1 divided by the Rated Frequency (F_0) and expressed in a percentage is called the Speed Droop.



Source: JICA Study Team

Figure 3.3.8 Regulation Characteristics



Source: JICA Study Team

Figure 3.3.9 Opening-Output Characteristics

$$\text{Speed Droop} = \frac{\Delta f_1}{F_0} \times 100\%$$

As shown in Figure 3.3.9, the generator output will be 0% at the no load opening of servomotor (S_1), and 100% at the Full Output Opening (S), in accordance with the Opening-Output Characteristics of the Turbine-Generator. It has an allowance on the Full Open side.

Frequency changes, relating to a generator output change from 0-100%, correspond to the changes in Servomotor Opening from S_1 to S as shown in Figure 3.3.8. The range of frequency change becomes Δf. The ratio of Δf and F_0 is called Permanent Speed Variation.

$$\text{Permanent Speed Variation} \quad = \quad \frac{\Delta f}{F_0} \times 100\%$$

Frequency changes occur when a difference is growing between the Generator Output and the Load. The Governor will be activated to stop the changes in frequency. It should be clearly understood that the parameter to be controlled and adjusted is not the Servomotor Opening but the Generator Output.

In this context, Permanent Speed Variation is an important and prerequisite constant showing a ratio at which a frequency change causes a Generator Output Change. When multiple numbers of Turbine-Generators are operated in parallel or when operated in parallel with the Grid, load sharing in response to frequency change is determined by the speed regulation of each generator. As shown in Figure 3.3.9, by the broken line, the Opening-Output Characteristic changes by ageing and accordingly, speed regulation also inevitably changes. Upon every Opening-Output test, the value of speed regulation should be confirmed.

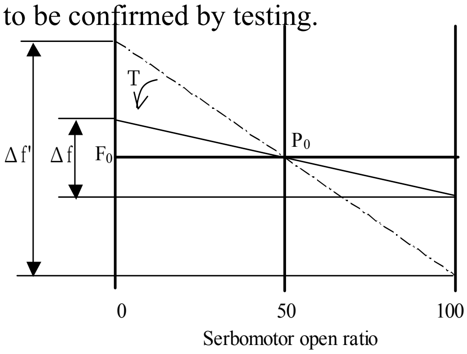
(3) Speed Adjuster (65P)

The Governor has a mechanism called the Speed Adjuster so as to operate at rated speed at any load. The Speed Adjuster is referred to as 65P in the technical term of Automatic Control.

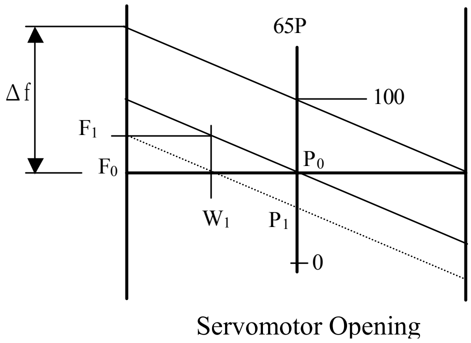
The standard condition of the Governor is at basic frequency at one half of Full Output when the position of 65P is at P_0 as shown in Figure 3.3.10. With such a governor position, if the load is decreased to W_1, the frequency rises to F_1. If the position of 65P is adjusted to P_1 at this time, the inherent regulation characteristic changes to the broken line, and the Turbine can be operated at the basic frequency (F_0) with load (W_1).

In the same manner, the position of 65P is set at 100% and load is also set at 100%, the frequency becomes F_0. If the load is reduced to zero under the same conditions, the frequency rises by Δf. Utilising this characteristic, it is possible to estimate the speed regulation.

The relationship between the position of 65P and frequency is called the Speed Regulation Characteristic, which is to be confirmed by testing.



Source: JICA Study Team
Figure 3.3.11 Transient Speed Droop



Source: JICA Study Team
Figure 3.3.10 Setting of 65P

(4) Transient Speed Droop and Time Constant of Damping

In order to secure the stability, the Governor has mechanisms of Double Returns, that is, to set the servomotor response on the greater side at the beginning of speed regulation and to gradually, but within a certain time limit, adjust the speed to within the speed droop. As shown in Figure 3.3.11, this operation will gradually reduce, along with time, the response initially set (broken line). The gradient of the broken line will approach that of the speed droop. The ratio of $\Delta f'$, which is determined by the gradient of broken line, and F_0 is called the Transient Speed Droop.

$$\text{Transient Speed Droop} = \frac{\Delta f'}{F_0} \times 100(\%)$$

The time constant of Damping is the time taken for the displacement of the Dash Pot to return to the position of zero, as a response to a frequency change (Δf).

The Transient Speed Droop changes its value along with time. It is, therefore, difficult to execute a test to practically move the Servomotor at a frequency change of $\Delta f'$. Accordingly, the value setting of the return mechanism is mechanically measured and the Transient Speed Droop is determined comparing with the recovery of speed drop.

(For example, if the recovery is 3 mm when the speed droop is at 4%, and if the recovery of the transient speed droop is at 15 mm, then the Transient Speed Droop is referred to as 15%).

The time constant of Damping is measured with a stopwatch as the time when the Dash Pot alone, given a displacement corresponding to full recovery, returns to the position of zero.

3.3.4 PRESSURE OIL UNIT

(1) Loading Time and Unloading Time

The Loading Time is defined as the time from when the Oil Pump is activated and reaches the upper pressure limit that automatically switches the Oil Pump off. Also the Unloading Time is defined as the time from when the Oil Pump is stopped at the upper limit pressure to that when the Oil Pump resumes its operation at the lower limit pressure. Both are important constants for maintenance work and should be measured periodically.

The tests are to be executed keeping the Governor under operation but activating the Load Limiter so as not to cause movement of the Servomotor. Since Loading Time is governed by the discharge capacity of the Oil Pump, it is almost unchanged. The Unloading Time, however, changes due to oil leakage from the Distribution Valve, clearance of Servo-piston, etc. Therefore, when the Unloading Time becomes short, careful inspection is required.

(2) Discharge of Oil Pump

At the same time, with measurement of the Loading Time, changes in the Oil Level of the Pressure Oil

Tank should be measured. From this value, discharge of Oil Pump can be determined by the following equation:

l : Change in Oil Level, in cm

A : Internal horizontal area of Pressure Oil Tank, in cm^2

t : Loading Time, in seconds

q : Discharge of Oil Pump, in l/min.

$$q = \frac{lA}{t} \times 60 \times 10^{-3}$$

Since this test incurs errors if there is air in the Middle Oil Tank, it should be executed when the bottom end of the Air Suction Pipe is submerged below the oil surface. If the value of "*q*" is lower than the specification, there is a possibility of trouble with the Oil Pump and adjustment and remedial work are required.

(3) Minimum Operating Pressure

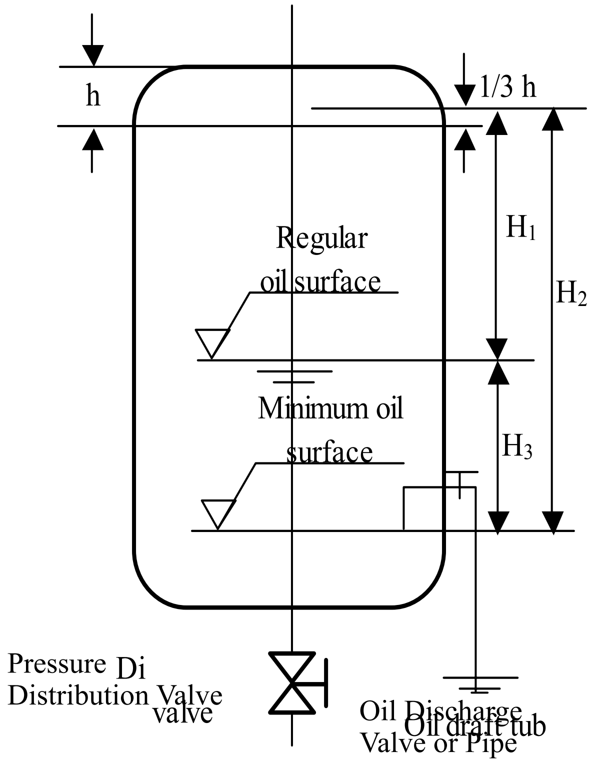
The Minimum Operating Pressure is defined as the pressure when the Servomotor becomes unable to operate.

This value is usually provided by Manufacturer. If it is not given or known, it should be confirmed by testing since the Minimum Operating Pressure is an important constant for Maintenance.

The method of testing is 1) to stop the Oil Pump by turning off the power switch, 2) to monitor the lowering in oil pressure by repeated opening and closing the Servomotor slowly at about 10%, 3) to confirm the oil pressure when the Servomotor becomes unable to operate.

During this test, Servomotor cannot be automatically controlled. If the turbine is tripped in the course of the test, it is dangerous and, therefore, a countermeasure is to be taken to enable manual operation with the Handle.

If Oil Level cannot be read on the Oil Gauge even when the oil level lowers to an oil pressure higher than Lower Limit Pressure, attention is required not to lower the oil level to below the lower limit, with reference to the storage capacity of the Pressure Oil Tank, as described in the following section.



Source: JICA Study Team

Figure 3.3.12 Pressure Oil Tank

(4) Storage Capacity of Pressure Oil Tank

The relationship between the pressure inside the Pressure Oil Tank and air volume is given by the following equation:

P : Pressure, in MPa

V : Air volume, in l

$PV^{1.3}$, constant

From this relationship, under a specified pressure S1 and specified Oil Level at H1, the following equation can be derived, where A denotes the internal area of Tank.

$$V_1 = AH_1$$

$$P_1V_1^{1.3} = P_1 A^{1.3} H_1^{1.3} = C$$

The test of the storage capacity of the Pressure Oil Tank is 1) to confirm the value of constant ©, 2) to stop the Oil Pump, 3) to drain oil from the Oil Discharge Pipe while keeping the Oil Distribution Valve closed, 4) immediately to stop draining oil if air ejects from the bottom end of the Air Suction Pipe. Denoting the oil pressure at this time as P2, the air volume can be obtained by:

$$V_2 = AH_2$$

$$P_1V_1^{1.3} = P_2V_2^{1.3} \text{ and then,}$$

$$H_2 = H_1(P1/P2)^{0.769}$$

The storage that can be used from this Pressure Oil Tank without oil supply is given by:

$$V = (H2-H1)A$$

The following conditions should be checked based on the test results:

$$P_2 > \text{Upper Limit Pressure}$$

$$V \div v > 3$$

Where, v： unit oil consumption of Servomotor per stroke, liter

If the conditions above are satisfied, the Servomotor situated at the full open position can be fully closed, fully opened again, and fully closed even if the power source of the Oil Pump is totally lost. In this case, the pressure of the Pressure Oil Tank will be higher than the Minimum Operating Pressure and the tank storage capacity is considered sufficient for automatic control.

P_1 of this test should be started from the Minimum Operating Pressure.

(5) Safety Valve

The operational test of the Safety Valve is to be carried out in the similar way to that of the storage capacity test of the Pressure Oil Tank: 1) to keep the Oil Distribution Valve closed, 2) to raise the Upper

Limit of the Pressure Relay to a level higher than the specified value by 0.3 MPa, 3) to continuously operate the Oil Pump, 4) Operation of the Safety Valve is to be confirmed by sound and oil drain from the Oil Discharging Pipe. 5) At this time, the pressure shall be read on the Oil Gauge mounted on the Pressure Oil Tank. After operation of the Safety Valve, 6) to keep the Oil Pump running, 7) to confirm the stop or lowering of oil pressure rising, 8) to measure the pressure when the Safety Valve is continuously discharging oil. This pressure is referred to as the Full Open Pressure.

Next, 9) to stop the Oil Pump, 10) to confirm the pressure when the Safety Valve closes. This pressure is referred to as the Return Pressure. In the course of this test, the pressure of operation start of the Safety Valve and the Full Open Pressure can be read but the Return Pressure may be difficult to read due to effect of the Middle Oil Tank.

The Safety Valve is an important device to prevent abnormal pressure rise of the Pressure Oil System when the Oil Pump cannot stop due to trouble at the contact point of the Pressure Relay or the electric circuit of pump motor, and so forth. In particular, the Pressure Oil System of the three power stations inspected in November 2002 had only one safety valve. Maintenance with utmost care is essentially required.

3.3.5 TESTS ON OVERALL CHARACTERISTICS

Power Station is operated to supply stable power through full utilization and integration of characteristics of each equipment.

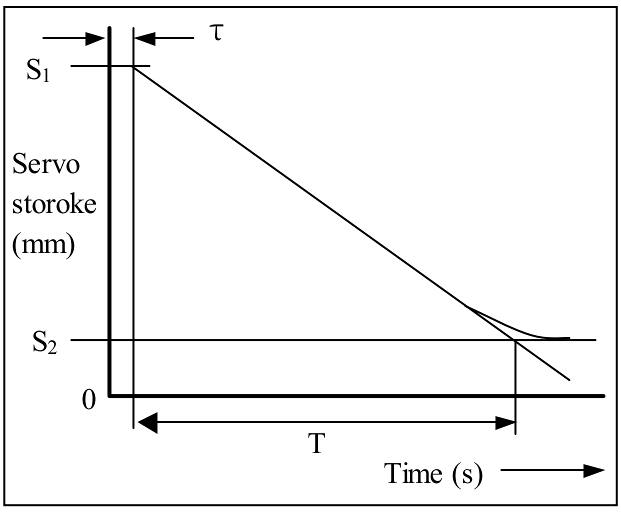
If there is an abrupt change in the Load, AVR, Governor, etc. will jointly operate to minimize the fluctuations of voltage and frequency to achieve a stable condition. The transitional phenomena before and after the Load change is called as Overall Characteristics of Power Station.

As tests of the Overall Characteristics, there are Loading Test and Load Shutdown Test. The most important in these tests are the changes in the Revolution Speed, Voltage, and Water Pressure.

(1) Operating Time of Governor

In response to the change of Revolution Speed, Governor will operate to open or close the turbine but with certain time lag from the beginning time of the revolution change.

Figure 3.3.13 shows the closing operation of Servomotor with time origin zero at when the revolution starts to rise upon Load Shutdown.



Source: JICA Study Team

Figure 3.3.13 Opening and Closing of Servomotor

Servomotor situated at S_1 at the beginning starts to move with a dead time τ seconds. This dead time lag is referred to as No Move Time and is defined as the time from when Rotation Speed has exceeded Dead Band of Governor till when the pressure oil operates on the piston inside the cylinder of Servomotor following the operation of Pilot Valve and Main Pressure Distribution Valve.

The time from when Servomotor starts to move after elapse of No Move Time and till it reaches position S_2 to stop is called as Closing Time. The operating speed of Servomotor is defined by:

Servomotor Speed = (S1 - S2)/ T (mm/s)

The values of τ and T are to be measured by operation test of Servomotor. τ is to be measured with stopwatch upon Load Rejection after positioning Servomotor at arbitral intermediate point.

Figure 3.3.13 shows a record of measurement with oscillograph. An oscillograph facilitates precise measurement. If it is measured by eye-observation, observation should be repeated for several times in order to obtain a likely value.

T is the time for Servomotor to continuously mover over the entire stroke and is referred to as Closing Time (or Opening Time) of Servomotor. It is a constant of Governor.

(2) Flywheel Effect GD^2

When a force is given to a Rotating Object to change its revolution speed, the Rotating Object has inertia that operates to resist such change. The magnitude of inertia is called as Moment of Inertia, which is expressed as a product of the mass of the Rotating Object and a distance of its center of gravity measured from the axis of revolution. It is denoted as GD^2 in the practical use. GD^2 is defined by the following equation:

$$\text{Moment of Inertia} = I = GR^2 / G = GD^2 / 4g$$

or

$$GD^2 = 4gI \quad \text{kg-m}^2$$

where, G : mass of Rotating Object, in kg

R : radius of gyration of the rotating mass, in m

GD^2 of Turbine-Generator is a sum of GD^2 of Rotor, Flywheel, Runner, Main Shaft, Coupling, etc.

GD^2 of generator is given by manufacturer as a constant of generator. That of flywheel effect can be easily calculated for its simple shape. Those of Runner, etc. are small compared with that of generator and flywheel and are often neglected.

As a test of obtaining GD^2, there is a theoretical approach to estimate GD^2 based on the changes in Revolution Speed measured along with time upon Load Rejection. However, it incurs significant errors due to air resistance, friction loss of Shaft Bearing, etc. Accordingly, site test is not executed.

(3) Momentary Speed Variation

When a generator, rotating at Rated Speed under steady condition, changes its Revolution Speed due to a change in Load, the speed change divided by Rated Speed is referred to as Momentary Speed Variation and is given by:

$$\delta = \frac{N_m - N_0}{N_0}$$

where, δ : Momentary Speed Variation

N_0 : rated revolution speed, in $\min^{-1}$

N_m : max. (or min.) revolution speed, in $\min^{-1}$

Momentary Speed Variation of Turbine-Generator is expressed in percentage. A Rate of Speed Rise at 30% is usually allowed.

There is the following simplified equation to calculate Momentary Speed Variation from the opening and closing characteristics of Governor and GD^2 of Turbine-Generator:

$$\delta = \frac{364(L_1 - L_2)(\tau + \frac{T}{2})}{GD^2 {N_0}^2} \times 10^5$$

δ : Momentary Speed Variation, in%

L_1 : load before the change, in kW

$L2$: load after the change, in kW

τ : Dead Time, in seconds

T : operating time of Servomotor, in seconds

GD^2 : GD^2 of Turbine-Generator, in kg-m^2

N_0 : rated revolution speed, in $\min^{-1}$

It is possible with this equation to estimate Speed Drop Ratio upon sudden Load increase and Speed Rise Ratio upon Load Rejection. It is to be noted that the equation above assumes effective head of turbine be constant. Accordingly, there will be some errors in the calculated rate and actual operation.

(4) Momentary Pressure Variation

The static water pressure in Penstock and pressured headrace tunnel changes accompanying to a change in the flow velocity. A ratio of the pressure change to the static head under no operation of turbine is referred to as Momentary Pressure Variation.

A change in the flow velocity is resulted from a change in the discharge. Accordingly, if the discharge, at steady flow under stable operation of Turbine-Generator, is decreased by sudden closure of Servomotor due to a load change, the water pressure rises. If Servomotor is opened to increase the discharge, then the water pressure lowers.

The Ratio of Water Pressure Change will be greater when the pressured waterway becomes longer, the diameter of the pressured waterway becomes smaller, and the speed of velocity change is faster.

Δp : Momentary Pressure Variation
P_1 : water pressure before the change in discharge, in m
P_2 : max. (min.) momentary water pressure after the change in discharge, in m
P : static head under no operation of turbine, in m

If the Momentary Pressure Variation is too high, it would cause burst of Penstock pipe.

$$\Delta p = \frac{P_2 - P_1}{P}$$

If the Momentary Pressure Variation is too much, it would cause collapse of Penstock pipe due to buckling.

It is easy to calculate with Allievi's equation the pressure changes based on the length and diameter of the waterway and a given change in the discharge.

The Closing Time of Servomotor is usually determined so that Ratio of Water Pressure Rise becomes smaller than 0.35 when Servomotor is closed in its rated closing time at the maximum plant discharge. It is noted that the detailed study shall be carried out for determination of the ratio of water pressure rise in the case of application of long penstocks.

(5) Voltage Regulation

The terminal voltage of generator under isolated operation changes accompanying to a change in the load and frequency.

If AVR is provided, the voltage change will be controlled to be a very small range. During an extremely short time of transient period, there will be a voltage change due to a delayed response of voltage control. Ratio of the voltage change in this transient period and rated voltage is referred to as Voltage Change Ratio.

If AVR is not provided with generator and its Exciter is fixed with the same Main Shaft, the voltage change in Exciter will be added to voltage change of generator, and then the Voltage Change Ratio of Generator will become larger.

Voltage Change Ratio of generator is in generally expressed by a ratio of the maximum voltage in the transient period and rated voltage without altering preset values of excitation circuit or AVR and keeping the generator at rated speed.

However, Voltage Rise Ratio upon Load Rejection is measured as observed including influence of the changed revolution speed.

Since excessive voltage rise will cause dielectric breakdown of generator windings, the voltage rise should be limited to below 25% when AVR is used. In the case of manual voltage control, the voltage rise should be suppressed by Over-Voltage Relay.

(6) Sudden Load Increase Test

Test of Load Sudden Load Increase is to measure the Ratio of Speed Drop, Ratio of Pressure Drop, and Ratio of Voltage Drop that occur to a generator, under operation at rated revolution speed and rated voltage.

The measuring items are as listed below:

Table 3.3.2 Measuring Items of Load Increase Test

○ denotes items to be measured

Item	Before Increase	In Progress	After Stabilization	Remarks
Load	○		○	
Voltage	○	○min.	○	oscillograph
Current	○		○	
Frequency	○	○min.	○	oscillograph
Water pressure	○	○min.	○	at the inlet of turbine, oscillograph
Revolution speed	○	○min.	○	
Opening of Servomotor	○		○	
Opening time of Servomotor				oscillograph
Time	○		○	
Items to be recorded for reference: Date of test, weather, outside temperature, in-station temperature, Presence (or none) of paralleled operation generators, time from change to stabilization, water level of Head Tank, water level of tailrace				

Source: JICA Study Team

Water Rheostat is used as load for the test. It should be avoided to execute the test with load taken from the actual grid since it will cause fluctuating power to customers. If the load increased in this test becomes so big, Speed Drop and Voltage Drop may become significant and stable operation could not be achieved after the said load increase. The output at this condition is the maximum supply limit to the isolated operation grid not energized. Such data of load limitation, etc. recorded in the test should be taken account for the actual operation of the Power Station as when the unit start power supply it is confirmed that the predicted grid load is smaller than this limit.

(7) Load Rejection Test

Load Rejection Test is to measure Speed Rise, Voltage Rise, Water Pressure Rise that occur to a generator, under operation at rated revolution speed and rated voltage with certain load, when its load is suddenly rejected. The test also measures the operation characteristic of Governor until Turbine-Generator get stabilized under No Load Condition.

The test is usually executed at 1/4, 2/4, 3/4, and 4/4 load of the rated output.

The measuring items of this test is the same as listed in Table 3.3.2,but the measurements during transient period are for the maximum values. The test is important to secure the safety and dependability of the generating equipment.

It is desirable to measure the transient phenomena upon Load Rejection using oscillograph. However, if the oscillograph is not available, measurement by eye-observation is also acceptable.

3.3.6 EQUIPMENTS AND TOOLS FOR MEASUREMENTS AND MAINTENANCE AND SPARE PARTS

(1) Measurements

Measurements in the daily operation and maintenance are carried out with those meters equipped in the Station such as meters on Control Panel, etc.

The measuring instruments will incur errors by aging and, therefore, need calibration with Standard Meter periodically. Special measuring devices are also needed to measure some items which are not measured in the daily operation. The measuring devices and equipments necessary for these measurements and testing are as listed below:

- Standard Meters (potable type)

3 phase power meter	100V-10A, or 200V-5A	1 unit
AC voltage meter	Multi-range, 300V, 100V, 30V	2 units
AC current meter	Multi-range, 30A, 15A, 3A, 300mA	3 units
DC voltage meter	Multi-range, 300V, 150V	1 unit
DC current meter	Multi-range, 30A, 15A, 3A	1 unit
DC current meter	Multi-range, 10A, 5A, 1A	1 unit
Frequency meter	48 Hz-52 Hz	1 unit

- Measuring devices for Maintenance

Megger	2,000MΩ 1,000V	1 unit
Megger	1,000MΩ 500V	1 unit
Megger	1,000MΩ 250V	1 unit
Grounding resistance meter		1 unit
Recording type voltage tester		1 unit
Recording type current meter		1 unit
Recording type thermometer	6 elements	1 unit
Line Current meter		3 units
Stick type thermometer	200 ºC	10 nos.
Circuit tester		2 units
Sliding transformer	Single phase, 0-250V 10A	2 units
Pressure tester	50 kg/cm^2	1 unit
Stopwatch		3 units

- Special measuring device and equipment

Oscillograph	12 elements	1 unit
Relay tester		1 unit
Water rheostat	3 phase, 11,000V, 100A	1 unit

The quantities above are estimated for a Maintenance Center that services for several power stations under management.

(2) Devices and Tools for Maintenance

Devices and tools necessary for Maintenance are as listed below:

- Tools for general maintenance works

General tools	Driver, spanner, pliers, hammer, etc.
Measuring devices	Dial indicators, venire calipers, internal calipers, external calipers, micrometers, straight rulers, measuring tapes, gap gauges, vibration meters, noise meters, current meters for discharge measurements

- Equipments for maintenance works Welder

  Portable engine generator
  Electric drill
  Chain block
  Hydraulic jack
  Tools for taking out pulley
  Tap and dice set
  (Univerasal processing machine)

(3) Spare Parts

Spare parts are to be provided for those items i) ordinary consumables that require periodical replacement, ii) those parts that require long time for purchase, iii) those special parts that cannot be obtained in the market. These spare parts are to be checked and supplied so that these can be used whenever needs arise. The representative spare parts are listed below:

◎ Ordinary consumables

Items	Specification/Storage	Required Q'ty
Brush	Maker-specified brand	Double of actual use numbers
Ground packing	Maker-specified brand	Same as actual use numbers
Packing for Guide Vane Spindles	Of design dimensions	Same as actual use numbers
Lubricating oil	Maker-specified brand	For one unit of Thrust Bearing
Hydraulic oil	Maker-specified brand	For the oil capacity of Pressure Oil Tank
Electrolyte for battery		
Lamp for indicator		

◎ Special parts

Spare windings of generator	Care to keep dry to avoid moisture absorption	1/3 of the total coils
S pare printed control board of electronic circuit	Care to handling of storage	For one unit of equipment
Various relays		For one unit of equipment

◎ Consumables for Maintenance works

Sander, grinder, grindstone	
Washing oil	
Waste cloths	
Paints	For primary and finishing paintings, of maker's specified brand

3.4 MAINTENANCE CRITERIA

Maintenance Criteria is to be provided to the Maintenance works in accordance with the schedule to be prepared. The Criteria is to be prepared adjusting to the specific conditions of the site like inspection frequency of the waterway, etc. A sample is presented below:

3.4.1 CLASSIFICATION OF MAINTENANCE

(1) Daily Inspection

General cleaning and sort-out	Daily (to be done by operators)
Inspection of external appearance of Main Units	Twice a week
Cleaning of Main Unit	Twice a week
Inspection of waterway	Once a week
Inspection of outdoor structures and facilities	Once a week

(2) Periodical Inspection

Normal inspection and maintenance of Turbine	Once in 6 months	Inspection under stopping turbine
Partial disassembling, inspection and maintenance	Once in 2 years	Inspection of worn parts and interior
Generator (in accordance with turbine inspection)		
Normal inspection and maintenance of Governor	Once a year	To measure opening and closing time
Pressure Oil Unit (in accordance with inspection of Governor)		
Meters calibration test	Once in 2 years	
Check of battery capacity	Once in 2 years	
Test of protective relay	Once in 2 years	

(3) Detailed Inspection

• Disassembling and interior inspection of Main Unit	Once in 10 years	including inlet valve
• Disassembling and interior inspection of Racking machine	Once in 3 years	
• Oil sampling test of Main Transformer	Once in 10 years	

3.4.2 TESTING

(1) Load Rejection Test (upon every disassembling)

This is the test to grasp Overall Characteristics of Turbine-Generator using oscillograph and the recording charts are to be filed.

(2) Test of Opening-Output Characteristic (once in 2 years)

To measure the relationship of Guide Vane Opening and Generator Output.

(3) Operation Test of Safety Valve (once a year)

To raise the oil pressure of Pressure Oil Tank, to measure the operation pressure of Safety Valve, and to file the records.

(4) Meter Calibration Tests

To calibrate Power Meters, Pressure Gauges, Water Level Gauges, and Thermometers in comparison with Standard Meters.

(5) Relay Test

To test operation of Protective Relays and to file the records.

(6) Turbine Efficiency Test

Turbine efficiency test is to be executed before and after replacement of Runner and the results are to be filed.

3.4.3 RECORDING AND REPORTING

(1) The records of Daily Inspection are to be kept in the Maintenance Center after filling into the specified Form and obtaining signature of Station Manager.

(2) The records of Periodical Inspection are to be kept one set each at Power Station and Maintenance Center after filling into the specified Form attached with particular data and obtaining signature of Station Manager.

(3) Detailed Inspection

To be prepared in detail using A4 size papers. Form is not specified. Figures, tables, and pictures are to be attached for easy reference. The records are to be kept one set each at Power Station and Maintenance Center.

CHAPTER 4 INSPECTION, MAINTENANCE AND REPAIR FOR CIVIL WORKS

4.1 MONITORING OF HYDRO-METEOROLOGICAL CONDITIONS AND RECORDING

(1) Objectives of Monitoring

It is essential for the correct operation and maintenance of hydroelectric power stations and related hydraulic structures to grasp the hydro-meteorological conditions surrounding the stations.

The hydro-meteorological information is gathered through the monitoring of rainfall and water levels. The collected data are useful for forecasting water levels of reservoirs and regulating ponds in both normal and flood conditions and the efficient operation of the stations.

- It is recommended that monitoring of the following items be carried out:
  - (i) Rainfall at sites surrounding the powerhouse and intake.
  - (ii) Water levels of reservoirs (and regulating ponds for run-of-river type station) and also the water levels in the river downstream of the tailrace.
- To accomplish effective operation and maintenance of hydroelectric power stations and their relevant hydraulic structures, the rainfall and water level monitoring results are to be recorded, reported and kept in accordance with the regulations on operation and maintenance.

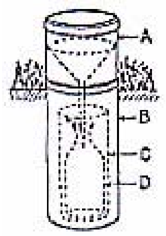
(2) Monitoring of Rainfall

<u>**Daily Monitoring of Rainfalls**</u>

The daily monitoring of rainfall is recommended at the sites surrounding the powerhouse and intake.

Daily observation of rainfall by a rainfall gauge of conventional type is to be carried out at 09:00 a.m. or at some other specified time.

The volume of rainfall is to be represented at a water depth (unit: mm) which could be obtained by the assumption that rainfall has passed a pan within certain hours and be stored at the horizontal surface of the pan.



Source: Manual of Hydrological Analysis, Nippon Koei Co., Ltd.

Figure 4.1.1 Rainfall Gauge

The minimum reading unit is to be 0.1 mm.

Hourly Observation of Rainfalls during Flood

The hourly observation of rainfall during floods is useful for forecasting water levels of reservoirs and regulating ponds during future floods. However, because the hourly observation of rainfall during floods may endanger the observer, hourly observations should be carried out only using automatic rain gauges.

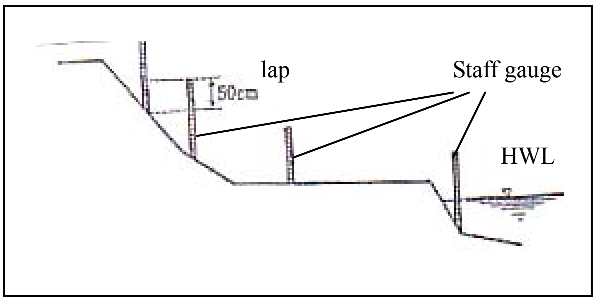
(3) Monitoring of Water Levels

Daily Observation of Water Levels

The daily observation of water levels is recommended at both reservoirs and regulating ponds for run-of-river type power stations.

Also, it is recommended to carry out daily observation of water levels in the river downstream of the tailrace to grasp the volume of river flow.

Staff gauges are to be installed at such locations so as not to be affected by backwater and the water levels are to be observed daily at 10:00 a.m. or at some other specified time.



Source: Manual of Hydrological Analysis, Nippon Koei

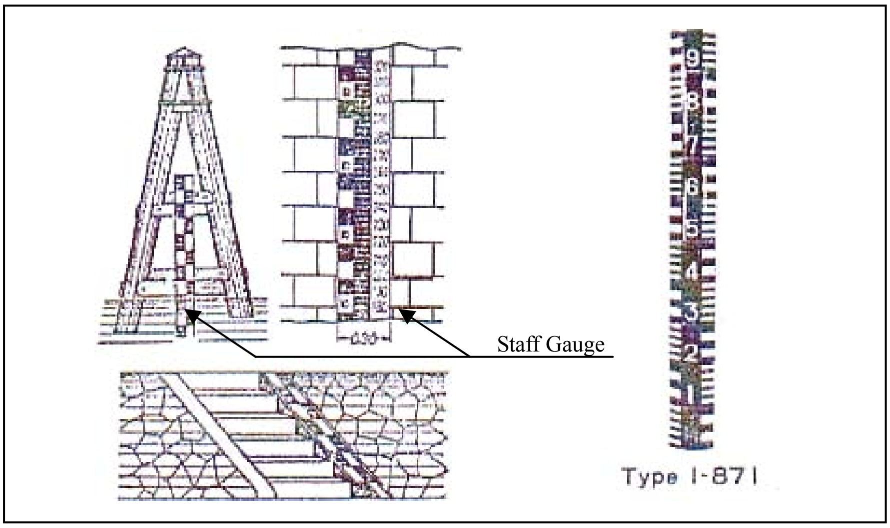
Figure 4.1.2 Installation of Staff Gauge in River

The readings of staff gauges should be accurate and recorded to the nearest centimeter.

An example of a staff gauge is shown below with the specification as follows:

(i) Minimum reading: 1 cm

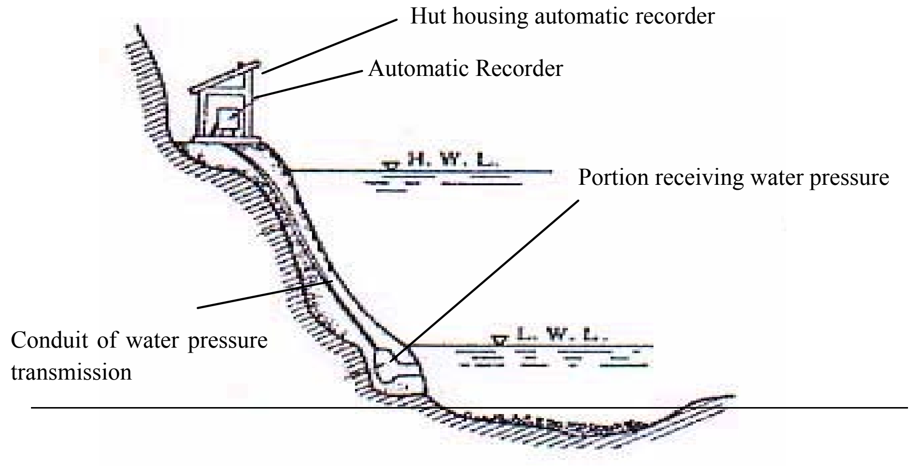
(ii) Dimensions: length: 1,000 mm, and width: 130 mm



Source: Manual of Hydrological Analysis, Nippon Koei Co., Ltd.

Figure 4.1.3 Detail of Staff Gauge

The installation of automatic water level gauges is convenient for the observation of water levels in regulating ponds where the water levels are always variable.



Source: Manual of Hydrological Analysis, Nippon Koei Co., Ltd.

Figure 4.1.4 Water Level Gauge Housing Automatic Recorder with Water Pressure Type

Hourly Observation of Water Levels during Floods

The hourly observation data of water levels during floods is useful for forecasting water levels of reservoirs and regulating ponds during floods in future. In addition, the hourly observation of water levels in the river downstream of the tailrace during the flood is also useful. However, in due consideration that hourly observation of water levels during floods may endanger the observer, hourly observation is recommended to be carried out only when an automatic water level gauge is installed.

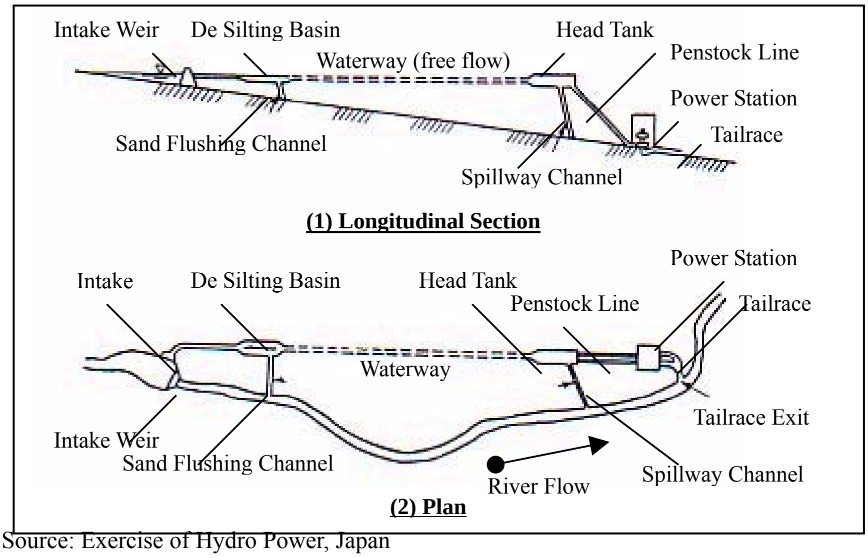
Further to the recording of water levels observed in the river downstream from the tailrace during floods, the data of the maximum water level will be useful for further confirmation of the safety of hydraulic facilities relevant to the hydroelectric power station.

4.2 INSPECTION FOR CIVIL STRUCTURES

4.2.1 CIVIL STRUCTURES

Failure or partial failure of the hydroelectric power facilities (see the following figure) could jeopardize operation of the facilities, endanger the lives and safety of the public and staff or cause substantial property damage.

- It is essential to constantly evaluate the surrounding conditions of the hydroelectric power facility by periodical inspection, i.e. a periodical patrol of observation in order to ensure the stable operations of the plant and ensure its safety and efficient operation.

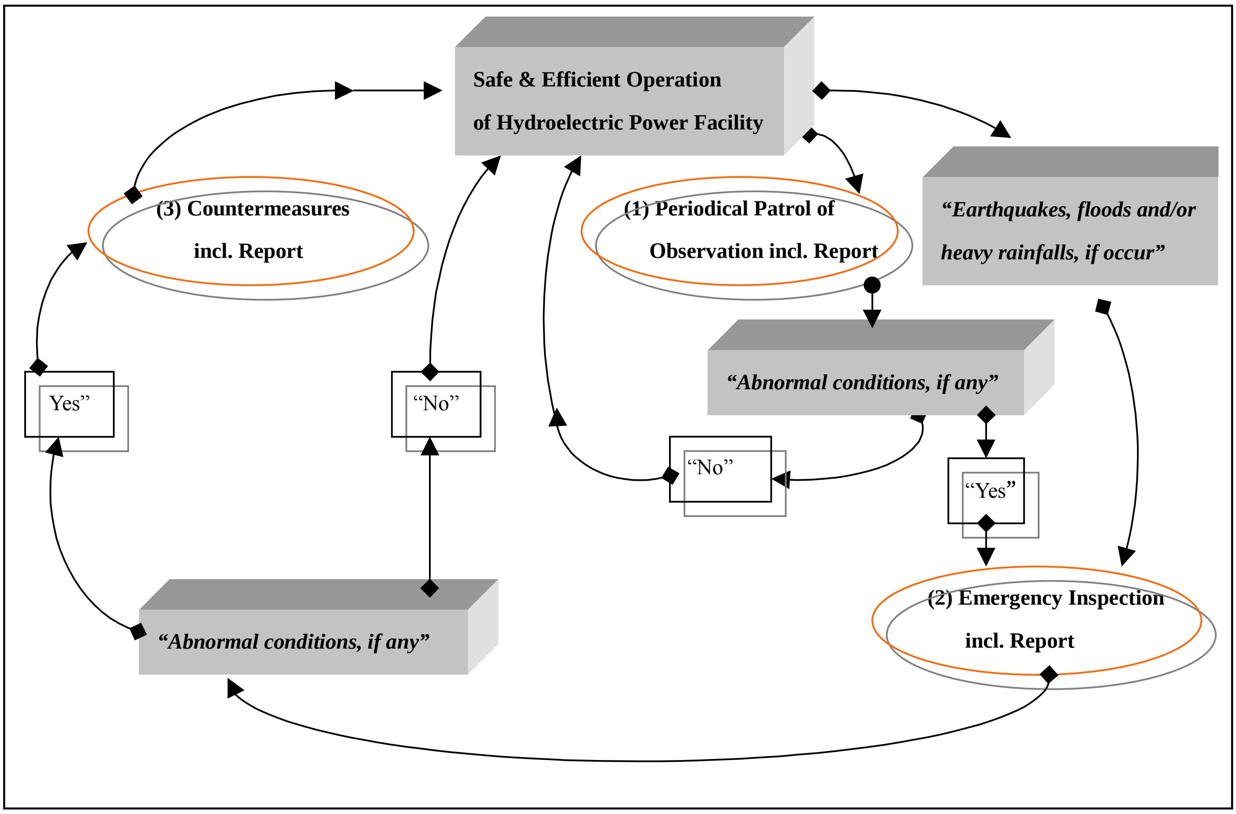


Source: Exercise of Hydro Power, Japan

Figure 4.2.1 Hydroelectric Power Facilities with Run-of-River Type

- In addition, an emergency inspection should be carried out; (i) to confirm the safety of the hydroelectric power facilities and their surroundings, (ii) to maintain stability and safety of each facility, and (iii) to evaluate quantitatively the degree of ageing and deterioration of each facility based on the results of periodical inspection showing abnormalities in the facilities or after the occurrence of an earthquake, flood and/or heavy rainfall.

The results of these evaluations will be useful for provision of countermeasures inclusive of repairs against the abnormal conditions of facilities in reference to Figure 4.2.1.



Source: JICA Study Team

Figure 4.2.2 Cycle of Inspection

(1) Periodical Patrol Observation

The periodical patrol observation is aimed to grasp: (i) whether abnormal conditions exist in the hydroelectric power facilities, and (ii) their fulfillment of functions. It is to be carried out periodically once or twice a year in line with the patrol route, and the items to be observed, both of which should be determined in advance.

(2) Emergency Inspection

The emergency inspection is to be carried out based on the results of periodical patrol observation, if necessary

In addition, the emergency inspection is to be carried out after earthquakes, floods and/or heavy rainfalls, if necessary.

The emergency inspection includes inspection and confirmation of the inner conditions of waterway after de-watering as to whether the condition of waterways are abnormal or not, and its fulfillment of functions. It should be carried out once every five years regardless of any other event.

(3) Items to Be Inspected for Civil Works Structures

The items to be inspected for Civil Works structures are as shown in Table 4.2.2.

Table 4.2.1 Items to Be Inspected for Civil Works Structures

Civil Works structures	Locations	Items to Be Inspected							
		Damage	Crack	Water leakage	Displacement	Erosion/ Scoring	Clogging	Sediment	Land slide
1. Intake weir	(a) Body of intake weir	x	x	x					
	(b) Surrounding areas of intake weir		x	x		x			x
	© Related structures		x		x				
	(d) Other facilities such as water level gauges, staff gauges, safety fences and lighting facilities	x							
2. Waterway									
(1) Intake	(a) Intake body	x	x		x	x			
	(b) Screen	x					x		
(2) De-silting basin	(a) Inside of de-silting basins							x	
(3) Headrace channel	(a) Surrounding areas of headrace channel								x
	(b) Inside of headrace channel		x	x		x		x	
(4) Head tank and	(a) Body of head tanks/ spillway channels,	x	x		x	x			

Civil Works structures	Locations	Items to Be Inspected							
		Damage	Crack	Water leakage	Displace ment	Erosion/ Scoring	Clogging	Sediment	Land slide
spillway channel	water level gauges and staff gauges								
	(b) Surrounding areas								x
(5) Foundations of	(a) Body of penstock foundations	x			x				
penstock	(b) Surrounding areas								x
(6) Power station	(a) Foundations of powerhouses and related structures		x		x				
(7) Tailrace	(a) Body of tailraces, water level gauges and staff gauges	x	x		x	x			
3. Inspection and insitu roads	(a) Road surfaces, side ditches, retaining walls, bridges, etc.	x	x		x				

Note: The mark denoted as "x" means a item to be inspected

4.2.2 GATES, TRASHRACKS AND PENSTOCKS

The items to be inspected for gates, trashracks and penstocks are shown in Table 4.2.2.

Table 4.2.2 Items to Be Inspected for Gate, Trashrack and Penstock

Steel structures	Locations	Items to Be Inspected						
		Damage	Deformation	Abrasion	Oiling	Painting	Water leakage	Vibration
1. Gates and hoist	(a) Gate sheet	x	x					
	(b) Gate leaf and hoist	x	x	x	x	x		
2. Trashracks	(a) Screen	x	x			x		
3. Penstock	(a) Pipe	x	x			x	x	x
	(b) Bearing	x	x			x		x
4. Others	(a) Steel ladder, steel cover, etc.	x	x			x		

The operational check points of discharge control gates for the intake and head pond, when provided, are as follows:

(1) Normal Conditions

Gate leaves are to be in complete contact with the gate sheets to secure water tightness and appropriate countermeasures are to be taken for the prevention of water leakage, if any.

Each lifting location of the control gates for both the intake and head tank is to be determined to ensure the lowest point of the gate leaves does not touch the water surface.

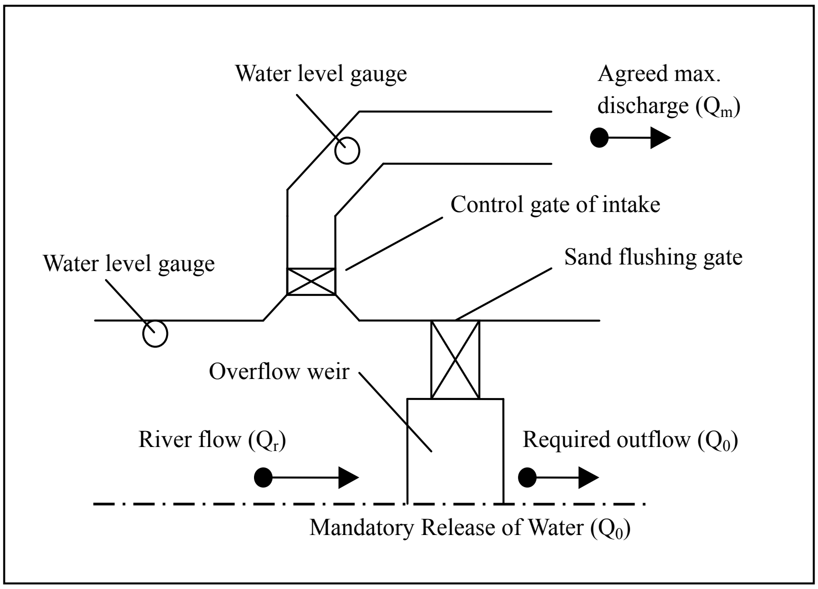
(2) Flood Conditions

During floods, it is recommended to stop power generation and to close the control gates of the intake to prevent sediment and drift wood from affecting the associated structures.

4.2.3 GATES OPERATION IN INTAKE

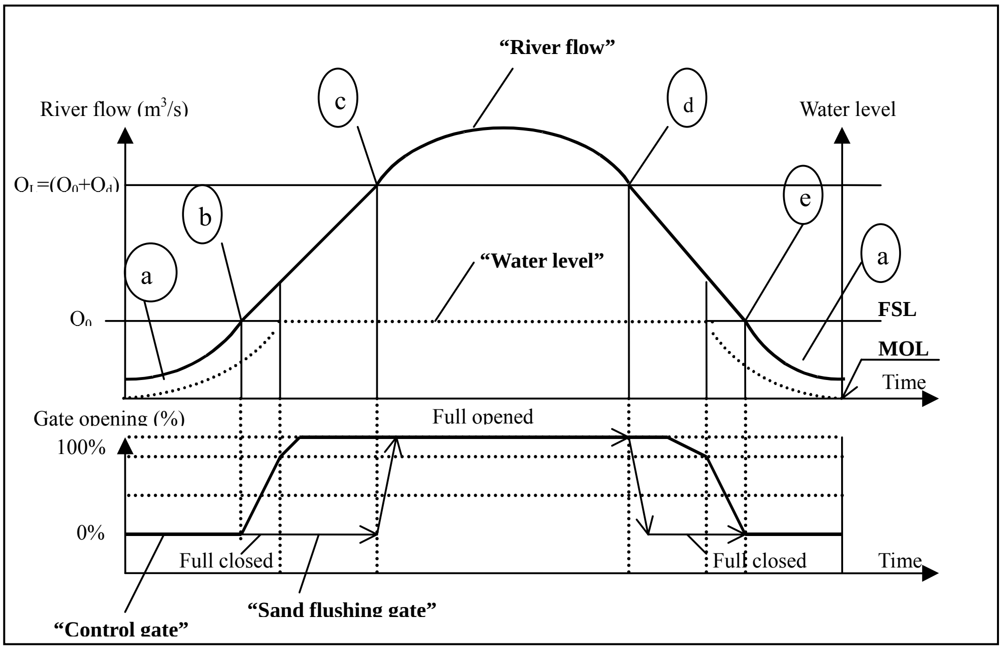
Operations of the control gate of the intake are generally required for: (i) the mandatory release of water for irrigation and environmental requirements in downstream reaches, even with the reduction of discharge for power generation, (ii) water filling and de-watering for the purpose of inspection and repairs of the waterway structures, and (iii) prevention of waterway structures from sediment and drift wood during flood conditions.

In Japan, it has been recently required to achieve appropriate and precise gate operations for the water intake and the mandatory release of water, being subject to the quantity of river flow and the regulations for utilization of river flow. In reference to the run-of-river-type hydroelectric power stations in Japan, the control of water intake and the mandatory release of water are explained as follows:



Source: Compiled by JICA Study Team

Figure 4.2.3 Gates and Water Level Gauge in Intake



Source: JICA Study Team

Figure 4.2.4 Operation of Control Gate and Sand Flushing Gate

It is noted that in respect of the gate operation for the intake gate of Zi Chaung power station, which is located about 3.4 km from the powerhouse, the daily gate operation is not necessary as there are no requirements for mandatory release of water and there are a side-spillway just downstream of the intake gate and another side-spillway in the regulating pond neighboring the powerhouse.

Procedure of Gate Operation:

Step-1 (See (a) in Figure 4.2.4)

Operation of Control Gate to Secure Mandatory Release of Water for Irrigation and Environmental Requirements:

In the case when the river flow (Q_r) is smaller than the mandatory water for irrigation and environmental requirements (Q_o), the control gate of the intake should be operated to secure the mandatory release of water for irrigation and environmental requirements and to head for achievement of the FSL (Full Supply Water Level) in the upstream of the overflow weir.

Step-2 (See (b) in Figure 4.2.4)

Operation of Control Gate to Maintain FSL:

In the case when the river flow (Q_r) is greater than the mandatory water for irrigation and environmental requirements (Q_o) and it is smaller than the total of the mandatory water for irrigation and environmental requirements (Q_o) and the design discharge of waterway for power generation (Q_d), the control gate of the intake will be gradually opened to the full opening and maintain the FSL.

Step-3 (See (c) in Figure 4.2.4)

Opening of Sand Flushing Gate:

In the case when the river flow (Q_r) becomes greater than the discharge limit (Q_L), i.e. the total of the mandatory water for irrigation and environmental requirements (Q_o) and the design discharge of waterway (Q_d), the full opening of the control gate will continue to keep the FSL and opening of the sand flushing gate will start for the purpose of sand flushing.

Step-4 (See (d) in Figure 4.2.4)

Closing of Sand Flushing Gate:

In the case when the river flow (Q_r) becomes less than the discharge limit ($Q_L = Q_o + Q_d$), the sand flushing gate should be fully closed and the control gate of the intake should be gradually closed.

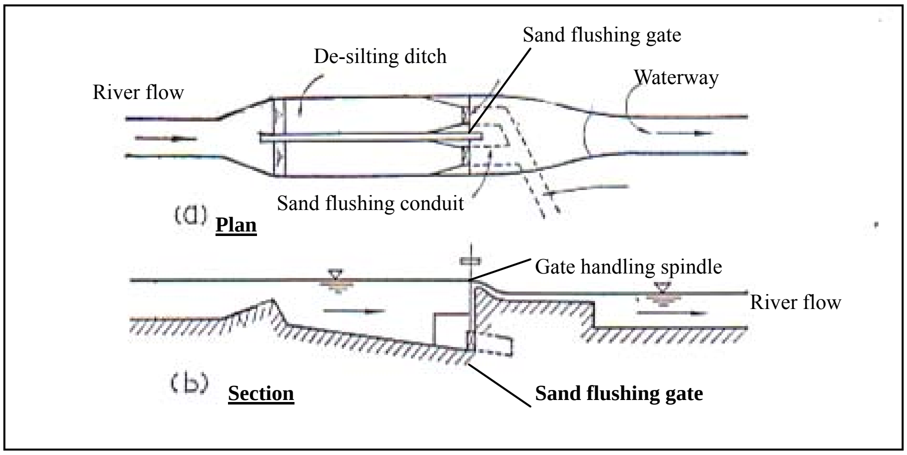
Step-5 (See (e) in Figure 4.2.4)

Operation of Control Gate to Secure Mandatory Release of Water for Irrigation and Environmental Requirements :

In the case when the river flow (Q_r) becomes less than the mandatory water for irrigation and environmental requirements (Q_o), the control gate of the intake should be fully closed for achievement of (Q_o).

4.3 SAND-FLUSH OPERATION AND SEDIMENT CONTROL MEASURES

De-silting basins are provided for the settling and flushing of sediment particles to reduce abrasion of the waterway, penstock pipe, hydraulic turbines, etc., and eventually to achieve stable and efficient operation of the hydroelectric power plant.



Source: Compiled by JICA Study Team

Figure 4.3.1 De-silting Basin

Operational Check Points of Sand Flushing Gates

For Normal Conditions

Sand flushing gates are provided for flushing out sediments.

Upon observation of sediment deposits, sand-flushing gates are to be opened for flushing of sediment deposits.

No operation of sand-flushing gates for a long time may cause serious sediment deposits which may not be able to be removed by operation of the sand-flushing gates. It is essential to carry out periodical sand flushing.

For Flood Conditions

During and after floods, the sand flushing gates are to be opened for flushing of sediments deposits.

Also during and after floods, drift leaves and driftwoods may cause clogging of the screen, and eventually may cause crushing of the screens due to the water pressure acting on the upstream surface of the screens resulting from the raised water level by clogging. Accordingly, together with operation of the sand flushing gates it is very important to remove such drift leaves and driftwoods from the screen.

The application of reliable and efficient methods of sediment control and removing sediment from waterways is one of the most important considerations for the successful utilization of water resources in a hydroelectric power scheme. It is generally expected that appropriate operations of both the sand-flushing gates installed in neighboring dams or weirs and the sand flushing gates in the de-silting basin will effectively return sediment back to the river.

However, it is a fact that run-of-river projects and storage schemes with large dams for hydroelectric power projects have suffered from serious sediment deposits that have not been removed by the sand-flushing gates.

To overcome the severe sediment transportation problems, a recent study* demonstrated sediment control methods utilizing a suction head, i.e. (i) a sand flushing through the use of a *'Saxophone' suction head**

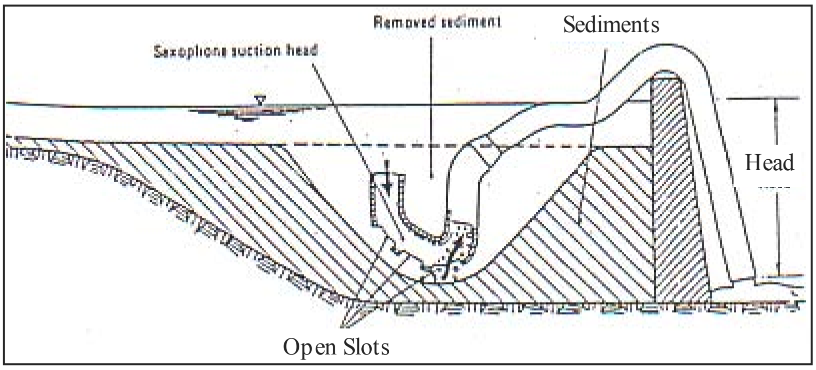
Sand Flushing through 'Saxophone' Suction Head

To utilize a head between the poundage and outlet without using other energy such as electricity or diesel.

Sand flushing can be made under power generation, therefore it is not necessary to stop power generation during a sand flushing operation.

There is a experimental data reported that about 10% of the sand volume density can be flushed. However, it is noted that such a flushing percentage is subject to the nature of sediment deposit.

It is reported that this method is suitable to flush sediment in a poundage or a de-silting basin where sediment is light and particle size small. Consequently, simple and small-scale flushing facilities are needed for such a poundage or a de-silting basin.



Source: D.K.Lysne, New Norwegian Institute of Technology

Figure 4.3.2 'Saxophone' Sand Flushing

Example:

- Pipe ϕ = 15 cm, L = 20 m

$$V = \sqrt{\frac{2g \cdot H}{1 + f_e + N \cdot f_b + f}}$$

f_e = 1.00 (inlet loss), $N \cdot f_b$ = 0.40 (bend loss), $f = f_r$(L/D)=4.5 (friction loss)

f_r = 12.7g・n^2・$D^{1/3}$= 0.03373 and n = 0.012 (roughness coefficient)

When H (head) = 1.5 m, V (velocity) = 2.06 m/s,

- Pipe ϕ = 15 cm, L = 20 m, H = 1.5 m, V = 2.06 m/s

Q = 0.036 m^3/s (= 2.19 m^3/min = 131 m^3/hr) : discharge flushed

Sand= 131 m^3/hr x 10%*1= 13.1 m^3/hr (= 315 m^3/day*2): sand volume flushed

Note:

**1: In reference to the experimental data as a calculation example.*

**2: In application of 24 hours as a calculation example for the daily working hours of the sand flushing device.*

Table 4.3.1 Sand Flushing Capacity of 'Saxophone' Suction Head

Dia. (m)	L (m)	H (m)	V (m/s)	Q (m^3/s)	Q (m^3/hr)	Sand (m^3/hr)	Sand (m^3/day)
0.1	10	1.5	2.17	0.017	61	6.1	146
0.1	10	3	3.06	0.024	86	8.6	206
0.1	20	1.5	1.7	0.013	47	4.7	113
0.1	20	3	2.41	0.019	68	6.8	163
0.1	30	1.5	1.45	0.011	40	4	96
0.1	30	3	2.05	0.016	58	5.8	139
0.1	40	1.5	1.28	0.01	36	3.6	86
0.1	40	3	1.82	0.014	50	5	120
0.1	50	1.5	1.16	0.009	32	3.2	77
0.1	50	3	1.65	0.013	47	4.7	113
0.1	60	1.5	1.07	0.008	29	2.9	70
0.1	60	3	1.52	0.012	43	4.3	103
0.15	10	1.5	2.51	0.044	158	15.8	379
0.15	10	3	3.56	0.063	227	22.7	545
0.15	20	1.5	2.06	0.036	130	13	312
0.15	20	3	2.92	0.052	187	18.7	449
0.15	30	1.5	1.79	0.032	115	11.5	276
0.15	30	3	2.54	0.045	162	16.2	389
0.15	40	1.5	1.61	0.028	101	10.1	242
0.15	40	3	2.27	0.04	144	14.4	346
0.15	50	1.5	1.47	0.026	94	9.4	226
0.15	50	3	2.08	0.037	133	13.3	319
0.15	60	1.5	1.36	0.024	86	8.6	206
0.15	60	3	1.92	0.034	122	12.2	293

Source: JICA Study Team