

### 3. Design of Generation Equipment

#### 3.1 Turbine

##### (1) Turbine Types

Turbines are classified into two types according to their water energy utility:

**Impulse Turbines:** all available water energy is converted by a free jet through a nozzle into kinetic energy before water contacts the moving blades (runner peripheral). The energy is then taken from the jet by suitable flow through moving vanes. The vanes are partially filled, with the jet open to the atmosphere throughout its travel through the runner. Losses occur in flow from the reservoir through the penstock to the base of the nozzle.

**Reaction Turbines:** a portion of the water energy is converted into kinetic energy by the water passing through adjustable wicket gates before entering the runner, and the remainder of the energy conversion takes place through the runner. All passages are filled completely with water, including the draft tube from the runner to the downstream water surface. The static water pressure occurs on both sides of the vanes and hence does not work. The work done is entirely due to the conversion to kinetic energy.

Furthermore, there are many types of turbines according to head, discharge, speed of rotation, structure, etc. Specific speed is a constant widely used in selecting the type of turbines and in preliminary design.

##### 1) Specific Speed

Specific speed is defined as the speed of rotation of a geometrically similar turbine working under a unit head of pressure exerting a unit power. Specific speed is given by the following formula:

$$n_s = \frac{N\sqrt{P}}{H^{5/4}}$$

$n_s$ : Specific speed (m-kW)

$N$ : Revolution speed ( $\text{min}^{-1}$ )

$P$ : Turbine output (kW)

$H$ : Effective head (m)

There are limitations for  $n_s$  for respective turbine types and its applicable range is defined as parameter of effective head.

## 2) Type and selection of Turbine

Turbines mainly applied for small hydro are categorized in the following table.

**Table 3.1 Type of Turbines and Applicable Range**

Type	Form	Applicable range		
		$n_s$ (m-kW)	Effective head (m)	Maximum output (kW)
Impulse Turbine	Pelton turbine	12~25	75~500	300~5,000
	High relative speed Impulse turbine	55~65	40~300	300~5,000
	Crossflow turbine	90~110	8~60	50~1,000
Reaction Turbine	Francis turbine	50~350	20~300	300~5,000
	Package type bulb turbine	600~950	6~18	300~2,000
	S-shaped Tubular Turbine	500~850	3~18	100~3,000

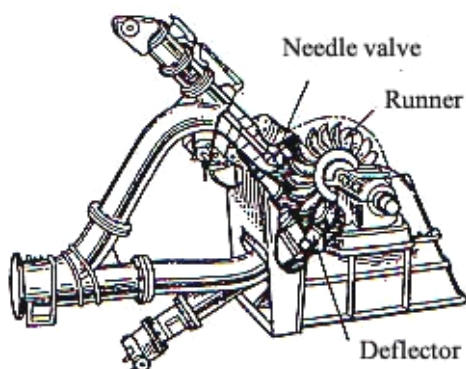
Source: JICA Study Team

The above table includes only horizontal turbines, which are easy to install, operate, and maintain for small hydro and their applicable output range is less than 5,000 kW.

### (2) Structure and Features of Turbines

#### 1) Horizontal Axis Pelton turbine

In this turbine, the free jet from the nozzle strikes double-cupped buckets, which are coupled with the runner. The turned jets over the buckets exert a balanced



force that rotates the turbine shaft. There are two types of Pelton turbines, one nozzle type and two-nozzle type.

Figure 3.1 shows a structure of two-nozzle type Pelton turbine. One nozzle type turbine is applied to high head and low discharge. Two-nozzle turbine is used with relatively large discharge. In general, two-nozzle type is widely used.

**Figure 3.1 Structure of Pelton Turbine**

The nozzle is needle valve type. Discharge of the water jet can be adjusted by moving the needle valve.

The efficiency depends on discharge. For one nozzle Pelton turbine, efficiency change is about 2-3 % against discharge change of around 40% from needle full-open valve. Thus, it is possible to have high efficiency operation up to around 20% of maximum discharge for two-nozzle turbines. The  $n_s$  value of Pelton turbine is given for single nozzle.

When the effective head is  $H$  m, maximum power output is  $P$  kW, and the speed of rotation is  $N$  min<sup>-1</sup>, the specific speed of a two-nozzle Pelton turbine is given by:

$$n_s = \frac{N\sqrt{P/2}}{H^{5/4}} = \frac{1}{\sqrt{2}} \frac{N\sqrt{P}}{H^{5/4}}$$

A deflector is attached between the top of nozzle and the buckets that enables adjustment of the speed of rotation and sudden intercept of water jet flows into the runner.

The runner of a Pelton turbine needs be positioned high enough so that the runner does not touch the surface of the discharged water. The height between the bottom of the nozzle and the surface of the discharged water is the head loss.

The structure, however, is rather simple. The turbine is suitable for middle and small hydro since pressure rise and speed rise at load rejection can be controlled with low value by the use of deflector.

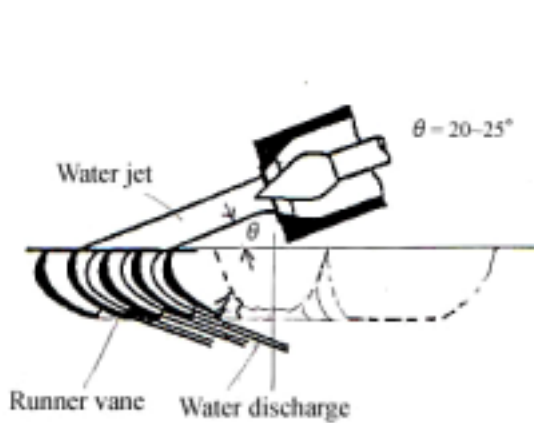
## 2) High Specific Speed Impulse Turbine

It is known as Turgo Impulse turbine, which is applied for high specific speed range of 65~55 m-kW as an impulse turbine and so it is applicable to relatively large discharge against head compared to Pelton turbine.

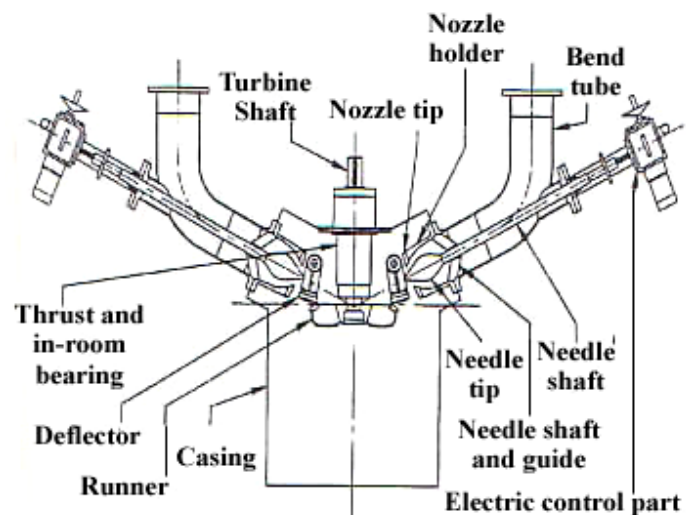
As for its structure, it has one runner and one to two nozzles, and is similar to a Pelton turbine. However, the water jet action to the runner is quite different.

Figure 3.3 shows the structure of Turgo impulse turbine with the runner and nozzle inside a casing.

Figure 3.2 shows the flow through Turgo impulse turbines. Water jet from the nozzles strikes the runner at an angle of 20°-25° at the top of the inlet of horizontal vanes each of three or four runner blades. The water jet is discharged toward about the same direction of the shaft from the outlet side and opposite to the inlet direction.



**Figure 3.2 Water Flow in Turgo Impulse Turbine**



**Figure 3.3 Structure of Turgo Impulse Turbine**

The efficiency characteristic is similar to that of the Pelton turbine. However, at a horizontal jet flow, the efficiency decline at low load is small, but the maximum efficiency is lower than the Pelton turbine at 2~3 %.

Water jet of a Turgo Impulse turbine enters between the outer circumference of the runner and shaft, while the water jet of a Pelton turbine comes in contact with the outer circumference of the runner. Thus, the radius of the radial pitch at which the water jet operates is small in the Turgo Impulse turbine. It gains

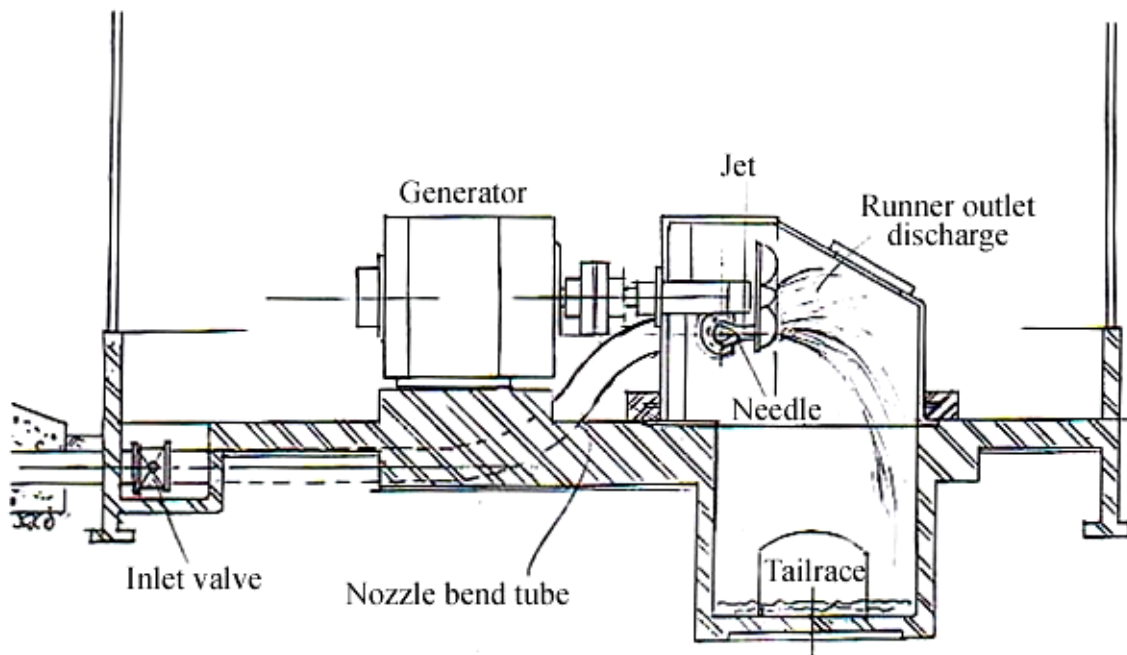


**Figure 3.4 Inner Shape of Turgo Impulse Turbine**

20-40% higher speed of rotation than a Pelton turbine at the same head. The shape of the turbine is determined by the standard runner diameter. Graphs are shown in Appendix 7 to determine the runner diameter by means of head and discharge and the turbine dimensions from runner diameter.

Figure 3.5 shows the installation of a Turgo Impulse turbine. The nozzle is directly connected to the inlet valve through a bend tube passing through the side of the generator. Thus, a part of the pipe is buried so that it does not disturb operation and maintenance.

Aluminum-bronze is generally used for the material of runner. When the head is especially large or sand is expected to be mixed with the flow, it is made of cast stainless steel.



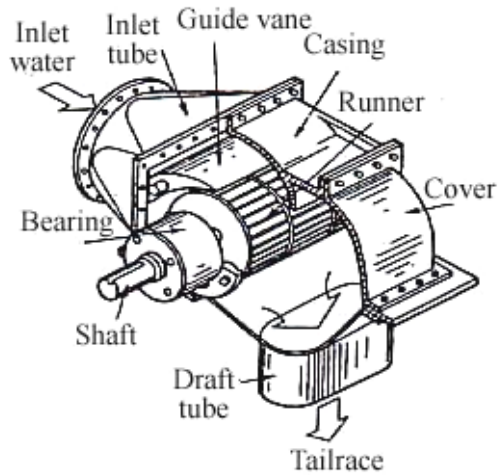
Source: JICA Study Team

**Figure 3.5 Installation of Turgo Impulse Turbine and Tailrace**

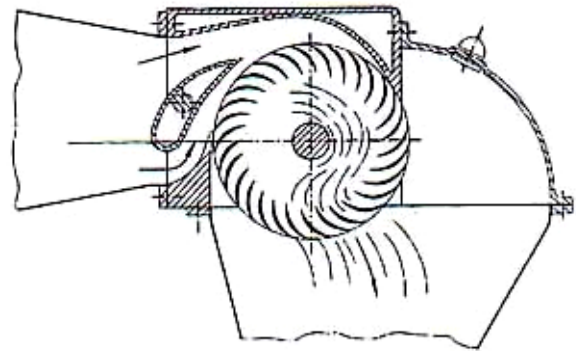
The structure of the deflector for this turbine is simple and durable, which enables the turbine to be stopped by the deflector when the nozzle is fully opened and continuing to discharge. Accordingly, the inlet valve and spillway can be omitted. It can also be applied to river maintenance discharge.

### 3) Cross Flow Type Turbine

It is generally called as the cross flow turbine. The prototype of the cross flow turbine is referred to as the Michel turbine or a modification, the Banki turbine, which is applied to relatively high head. German maker modified them for low heads, and this design was also applicable for large discharges, which led to adoption of the name cross flow.



**Figure 3.6 Structure of Cross Flow Turbine**



**Figure 3.7 Water Flow in Cross Flow Turbine**

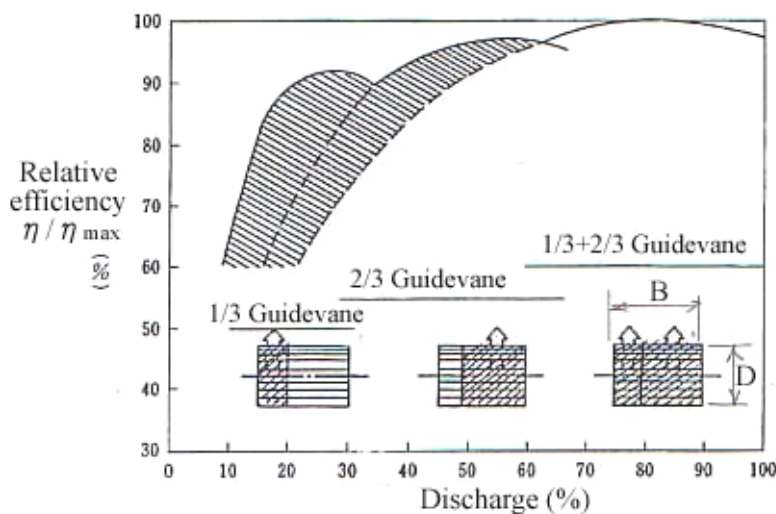
Figure 3.6 shows the structure of a cross flow turbine. The structure is simple. The main part consists of a runner with slender vanes on the outer circumference and one or two guide vanes.

Water passage inside a cross flow turbine is shown in Figure 3.7. The water is led by the guide vane and flows in through the outer side of the runner. It strikes the vanes, passes inside the runner to move the vanes again from inside, and is then discharged.

The runner is cylindrical in shape with a long in axis direction. It includes one or two guide vanes depending on the inlet width.

A turbine with large maximum discharge has two guide vanes. The vanes lengths are  $1/3$  and  $2/3$  of the inflow width, respectively. When the discharge is

small, only the shorter vane is used. When the discharge is more than  $1/3$  of the maximum discharge, the longer vane is used. If the discharge exceeds  $2/3$  of maximum discharge, both vanes are used at the same time, which enables operation with small reduction of efficiency against discharge change.



**Figure 3.8 Characteristics of Cross Flow Turbine**

Figure 3.8 shows the characteristics of the cross flow turbine.

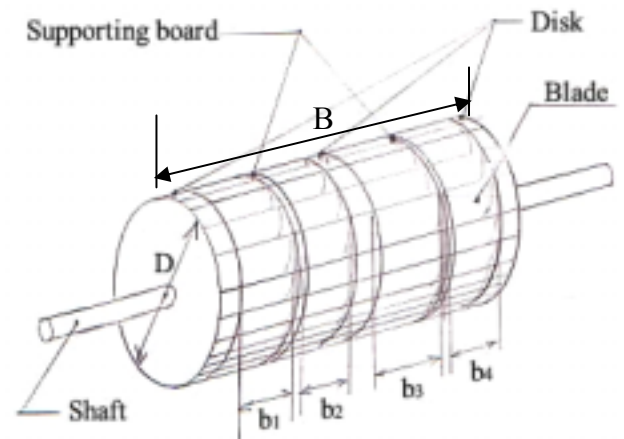
As shown in the figure, a high relative efficiency can be obtained at up to 15% of the rated discharge. This characteristic is similar to that of the low head Kaplan turbine. Therefore, the efficiency is low and smoothness of characteristics is not better than Kaplan. However, because the structure is simple, maintenance is easy, and both equipment price and installation cost is low, it is widely used in small hydro.

The standard runner diameter lies between 0.30 m and 1.25 m. The maximum width of the guide vane is generally some 3.5 times the runner diameter.

The runner diameter and runner width can be combined at random. Thus,  $n_s$  of this turbine is calculated by assuming a unit runner output. A unit runner is defined as a runner for which the ratio of the width and diameter is 1:1, and  $n_s$  is given by the following formula:

$$n_s = NP_r^{\frac{1}{2}} D^{\frac{1}{2}} B^{-\frac{1}{2}} H^{-\frac{5}{4}}$$

$n_s$ : Specific speed	m
$N$ : Rated revolution speed	min <sup>-1</sup>
$P_r$ : Rated output of one turbine	kW
$D$ : Runner diameter	m
$B$ : Total width of Guide vane	m
$H$ : Effective head	m



Source: JICA Study Team

**Figure 3.9 Runner Diameter and Width**

The value of  $n_s$  is between 90 and 100 m-kW.

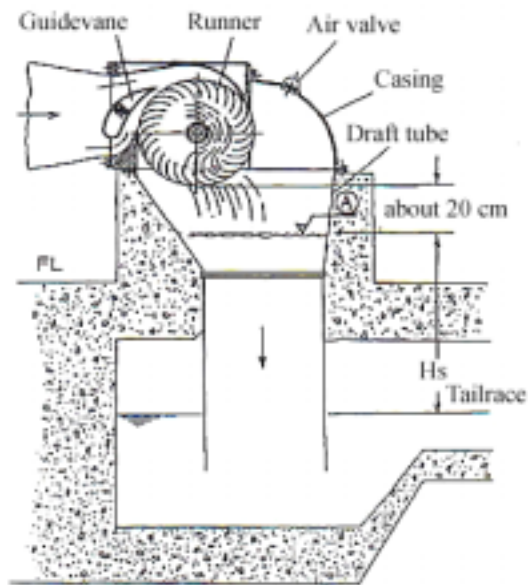
Assuming that the specific speed is  $n_s'$ , where;

$$n_s' = NP_r^{\frac{1}{2}} H^{-\frac{5}{4}}$$

$$\text{Then; } \frac{n_s'}{n} = \left( \frac{D}{B} \right)^{-\frac{1}{2}}$$

$$\text{Thus; } \frac{B}{D} = \left( \frac{n_s'}{n_s} \right)^2, \text{ by which the runner width is calculated.}$$

Cross flow turbine is an impulse turbine, and thus a space between the runner and the water surface of the tailrace is a basic needed. However, it is possible to utilize the draft head equivalent to 'H<sub>s</sub>' shown in Figure 3.10 as an effective head in attaching such a draft



Source: JICA Study Team

**Figure 3.10 Draft Head of Cross flow Turbine**

tube as shown in Figure 3.10 to the Cross flow turbine which can absorb air through the air valve of the casing and cause about 20 cm space between the lower part of runner and the water level inside the draft tube. It is noted that the 80% of  $H_s$  is effective for the head in the consideration that the draft tube contains air, therefore, the specific gravity of the water inside the draft tube will be reduced.

In general, the effective head of a cross flow turbine is calculated as the head to the turbine center. However, it is possible to increase the output power by adding the draft head described above. This is particularly effective when the head is less than 15 m or when the position of the turbine installation is designed to be high considering flood level fluctuation.

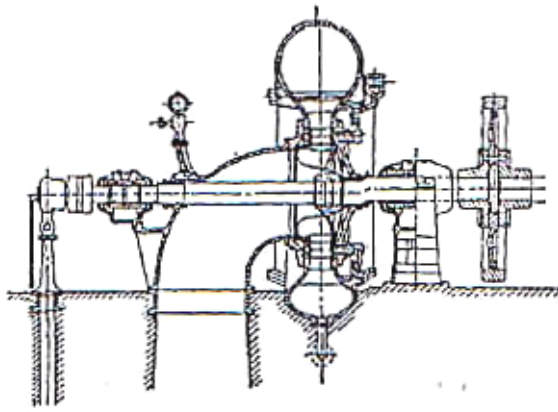
#### 4) Horizontal shaft Francis Turbine

Francis turbines are applied mostly to middle and small scale hydro schemes. They are applicable for a wide range of heads and capacity with high efficiency, and gross head is available down to the tailrace level by draft tube effect that enables a high speed of rotation.

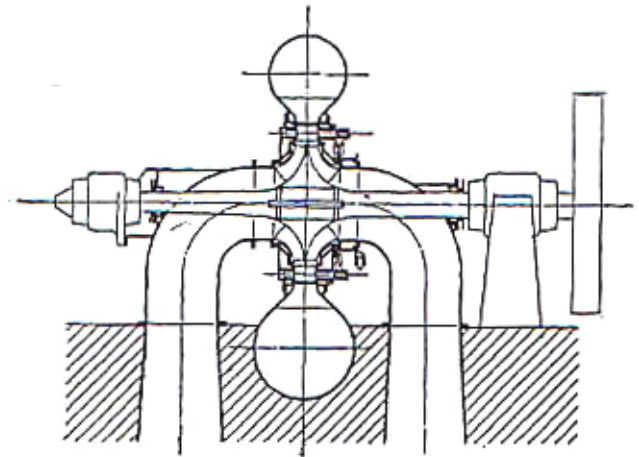
Vertical turbines are mainly applied to medium and small hydro of more than 5,000 kW output. As for horizontal axis Francis turbine less than 5,000 kW output, there are many types according to discharge as follows:

- i Horizontal shaft single runner - single discharge spiral Francis
- ii Horizontal shaft single runner - double discharge spiral Francis
- iii Horizontal shaft single runner - single discharge front inlet Francis
- iv Horizontal shaft two runner - single discharge front inlet twin Francis
- v Horizontal shaft two runner - single discharge exposure twin Francis

Among the above turbines, the most frequently used are single runner - single discharge spiral Francis turbines as shown in Figure 3.11, and single runner - double discharge spiral Francis turbine as shown in Figure 3.12.



**Figure 3.11 Spiral-type Francis Turbine with Horizontal Shaft, Single Runner and Single Discharge**



**Figure 3.12 Spiral-type Francis Turbine with Horizontal Shaft, Single Runner and Double Discharge**

Other Francis turbines mainly work under low heads and large discharges, and are big in size, costly, and difficult to maintain. Thus, they are rarely adopted recently and are replaced by other turbines such as Kaplan, Tubular, cross flow turbines.

Among single runner - single discharge spiral Francis turbines, those of  $n_s$  less than 100 m-kW tend to be replaced by Turgo Impulse turbines, which have better characteristics under low loads. Problems such as vibration and cavitation may take place when the load is less than 40%. It should not be selected for powerhouses that will experience long operation under low load.

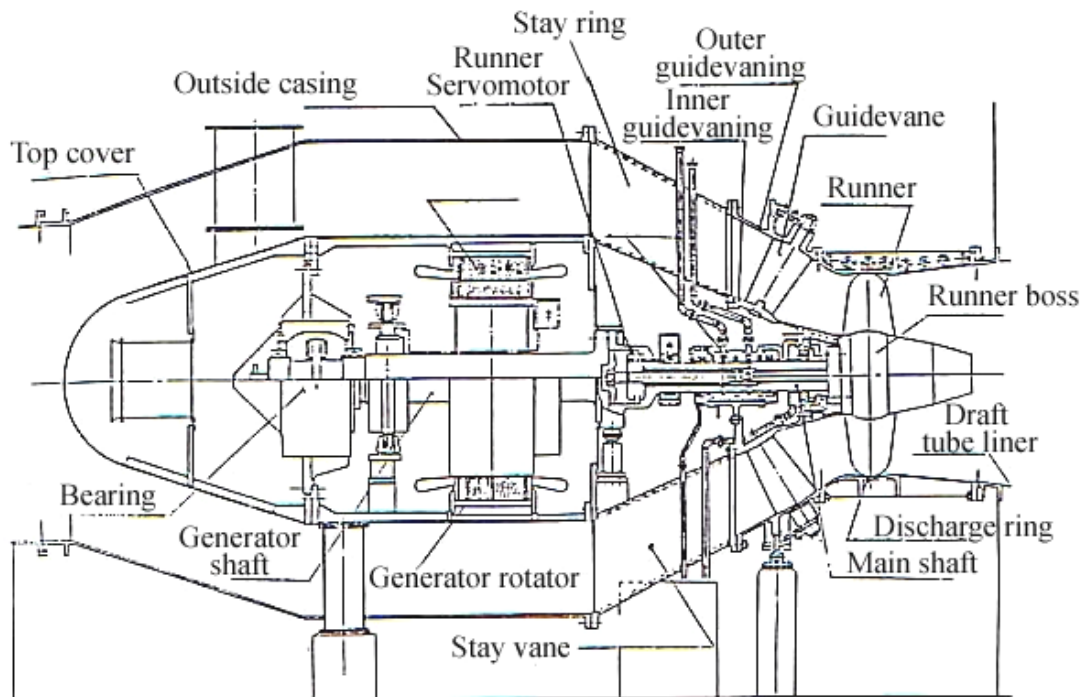
#### 5) Tubular Turbine

Tubular turbine is a tubular shaped horizontal propeller turbine that is applicable under low heads and relative large discharges.

It can maintain high efficiency against change of head and discharge by rotating both or either runner blades or guide vane. So far, vertical Kaplan turbine is used in this range of low head and large discharge. Horizontal type turbines have advantages for construction, maintenance and operation for small scale hydro and are widely adopted recently.

There are many types of Tubular turbine. Among them, the following two types are the most popular:

a. Package type Bulb Turbines



**Figure 3.13 Structure of Package-type Bulb Turbine**

The structure has a bulb in the flow path, in which the turbine shaft, bearings, and generator are combined together as shown in Figure 3.13. Because it is inserted in the middle of the turbine pipe, the installation area is small. It is applied where there is a large fluctuation in head and discharge and for low head with relatively large discharge utilizing surplus head in the water supply pipe.

However, there are many issues in design. When the runner diameter is less than 1.0 m, it is not easy to make the runner vane movable, it is difficult to enlarge the diameter of the generator rotating parts, and the flywheel effect  $GD^2$  is limited.

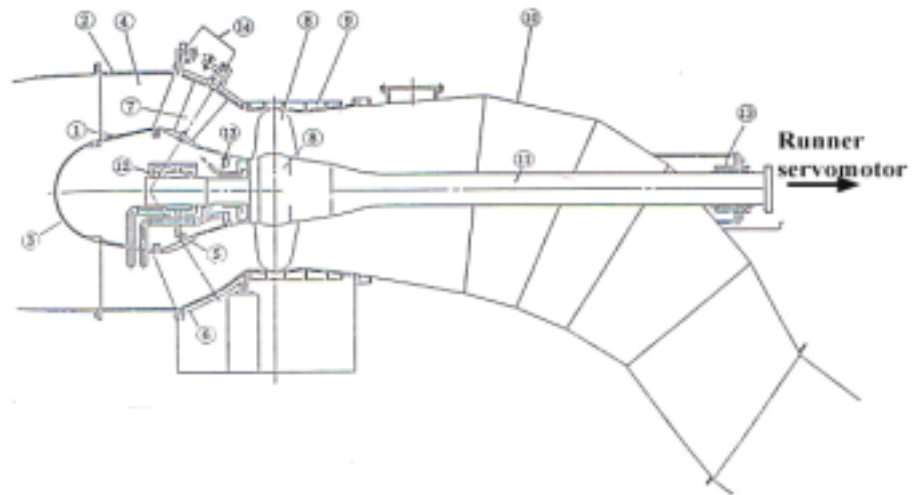
b. S-shaped Tubular Turbine

It is a characteristics of the S-shaped tubular turbine that the turbine shaft of S-shaped tubular turbine is stretched to the outside of the part of draft tube as shown in Figure 3.14, by bending the draft of turbine in the shape of 'S'.

Basically, the guide vane and runner parts are the same as in a bulb turbine, but the diameter of the rotating parts can be smaller and thus it is applicable to smaller capacities. It can have a variety of designs such as a combination of fixed guide vanes and movable runner vanes, movable guide vanes and fixed runner vane, or both fixed.

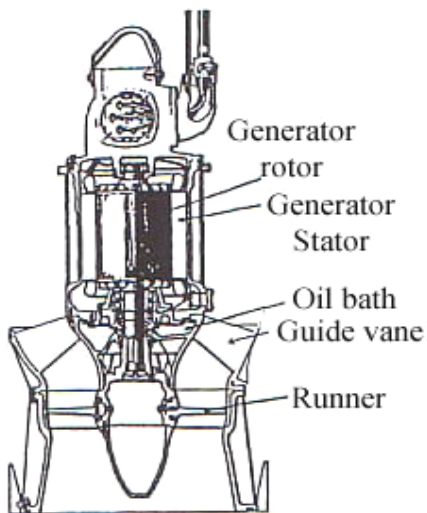
It is possible to install a fly wheel and to use a speed increaser, especially if the generator is set outside of the flow path. Cost performance is good and the operation is easy.

Inside casing	Outside casing	Top cover
Stay vane	Inside guidevane ring	Outside guidevane ring
Guidevane	Runner vane, runner boss	Discharge ring
Draft tube	Main shaft	Main bearing
Main shaft water sealing	Guidevane operation system	



**Figure 3.14 Structure of S-shaped Tubular Turbine**

6) Reversible Pump Turbine



When water flows from the outlet to the inlet of a pump, the pump wheel rotates and becomes a reaction turbine by the operating water. It can also generate electricity if an induction electric motor is directly coupled with the wheel, and thus operates as an induction generator. This type of pump is called a Reversible Pump turbine and is applied to small hydro schemes since the cost is low, operation is simple, and commercially produced pumps can be utilized.

**Figure 3.15 Reversible Pump Turbine**

Figure 3.15 shows the structure of the Reversible Pump turbine working under water pumped through vertical shaft axis flow. In this type of turbine, the runner vanes and guide vanes are fixed. One disadvantage of this type of turbine is that the applicable heads and discharges are limited. Besides, it is not

originally designed as a turbine. It is difficult to grasp the characteristics when applied, and data have to be determined experimentally.

(3) Selection of Turbines

Turbine type is selected according to operating head and maximum discharge taking the range of specific speed of each type of turbine into account. Figure 3.16 shows a diagram for selecting applicable turbine type for given discharge and head. Size, speed of rotation, and efficiency of selected turbine type are given in Appendix 7. In the diagram, many types of applicable turbines may be selected for the same discharge and head. The most appropriate turbine will be selected according to the location conditions with consideration of size and efficiency and comparison of characteristics.

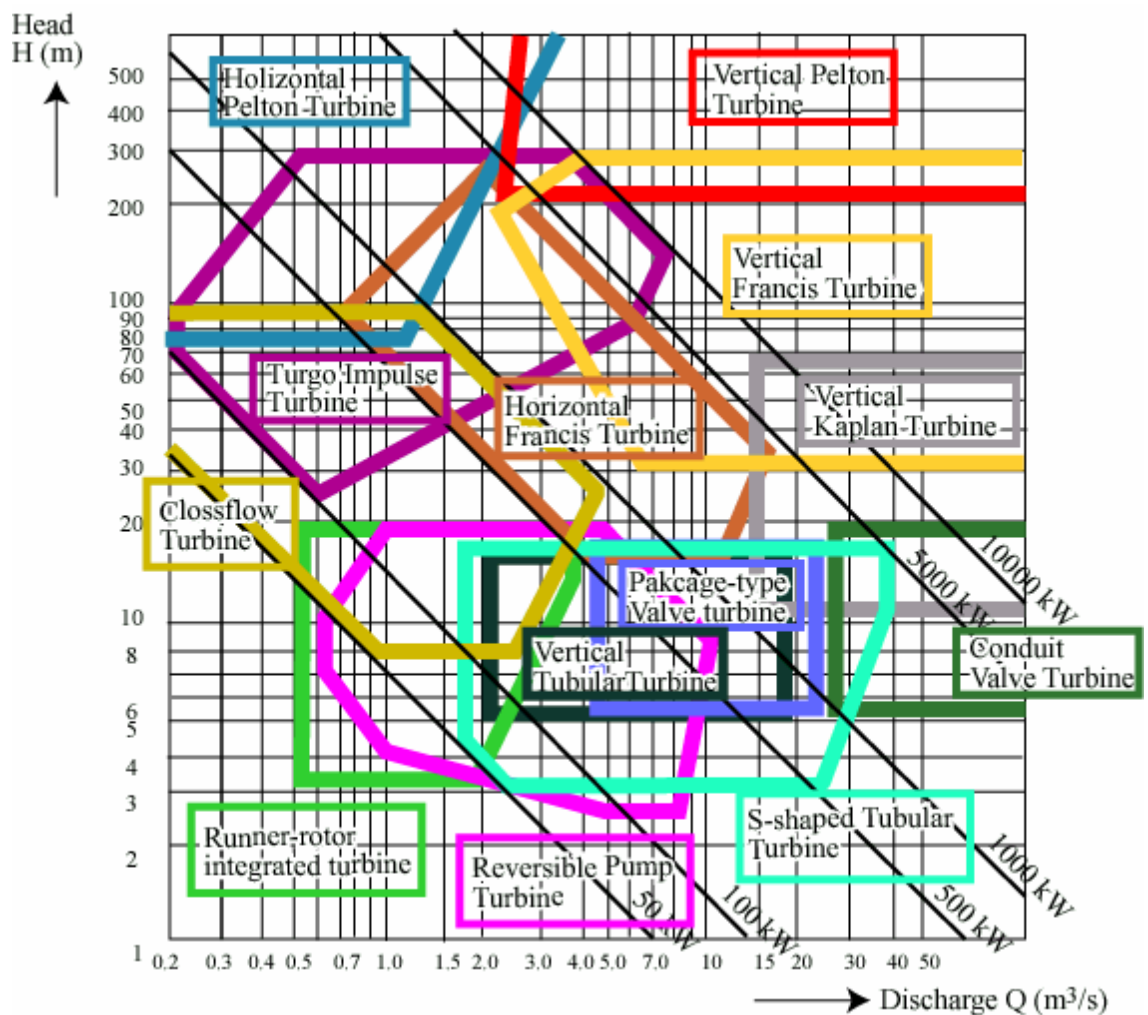


Figure 3.16 Turbine Selection Diagram

3.2 Generator

There are two types of generators for hydropowers, synchronous and induction. Synchronous generators are widely used and generate three-phase alternating

current with low-voltage terminal voltage for small capacity, but in case of more than 1,000 kVA capacity, 11,000 V voltage might be applicable.

(1) Synchronous Generator

This generator type induces a voltage in armature coils by rotating magnetic poles. There are several types of exciter system such as Separate Excitation type, Static Excitation type, and Alternate Current Excitation Brushless type. Brushless type generators are often employed in small hydro plants because they are easy to maintain.

Rotation Speed of the generator is determined by the following equation based on the rated frequency of generated electricity and number of poles.

$$N = 120 f / P$$

$N$ : rated revolution speed ( $\text{min}^{-1}$ ) ,  $f$ : rated frequency (Hz)

$P$ : no. of poles

Since it is desirable to directly couple turbine and generator, the turbine speed will be selected to be equal to that of the generator as much as practically possible. However, when it is very difficult to select the same speed between turbine and generator or when the turbine speed is very low to need many magnetic poles of the generator (required to obtain rated frequency at the low speed given, and will be complicated, expensive, and not readily available in the market), a speed-up gear system is employed to couple the turbine and generator. The speed-up gear is referred to as a gear system in this manual (in some references it is also referred to as a speed increaser).

For small hydro, the number of poles used is generally up to 12. For more than 12 poles, the generator size is generally larger and more expensive, therefore, application of speed-up gears is necessary for increasing the turbine speed together with application of a 4-6 pole high-speed generator, especially for cross flow turbine those are necessary.

The following items constitute the specifications of a synchronous generator.

Direction of shaft	Horizontal
Capacity	kVA
Voltage	V
Current	A
Power factor	(0.8 ~ 0.5)
Frequency	Hz

Revolution speed	$\text{min}^{-1}$
Insulation class	(F class)
Type of bearing	(thrust bearing required or not ?)
Type of excitation	
Short circuit ratio	(specified in case of large size)

(2) Induction Generator

Induction generators are a rotating structure composed of a primary winding and secondary winding, electricity is generated through electromagnetic induction between the windings.

It is applied to powerhouse less than 1,000 kW connected to power grid in parallel. Generator structure can be simple and low cost by applying a squirrel cage type secondary winding. Generally, this type of generator cannot generate independently. Operation must be established by supplying an excitation current to the primary winding from other power source. In addition, the generator causes such a rush current as is corresponding to several times in the rated current when it is connected to the power system on null voltage.

However, it tends to be applied to small hydro because of low cost, simple maintenance, and easy operation and control. Induction motors are applied to generators at low cost. In this case, it should be noted that the induction motor is not able to withstand the over speed condition.

The following items constitute the specification of induction generator.

Axis direction	Horizontal
Rated	Continuous
Output	kW
Voltage	V
Current	A
Power factor	(Manufacturer's specification)
Frequency	Hz
Revolution speed	$\text{m}^{-1}$
Slip	%
Insulation class	(F class)

Because induction generators operate by excitation current from a connected power grid, isolated operation and power factor adjustment are not possible.

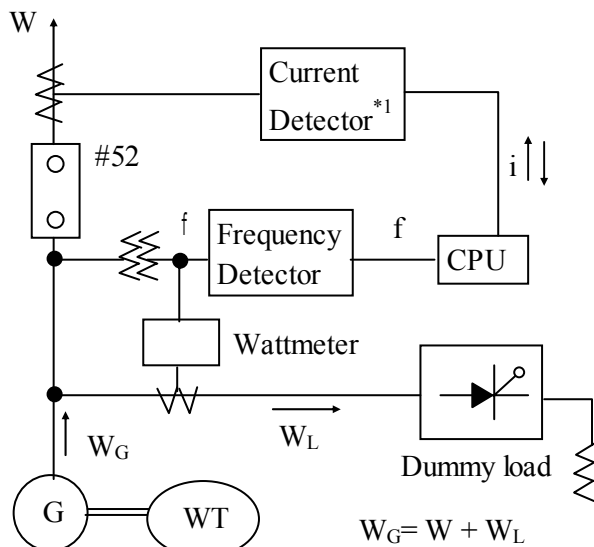
To improve the power factor, a parallel condenser is connected with the generator. When load shedding occurs with a large condenser in place, it is required to pay attentions to the following fact: As the rotational frequency of generator increases, the generator is excited by the leading current of condenser, which causes eventually a self-excitation phenomena with a high voltage.

### 3.3 Control Unit

#### (1) Governor

The governor adjusts the water inflow mechanism such as guide vanes, needle valves and deflectors, and controls water inflow, turbine rotation speed, and output. As the parts that directly adjust water inflow require large force, a hydraulic servomotor is used for medium-small scale hydro.

For small hydro, an electric servomotor is applied since control is accurate and maintenance and inspection are easy. A CPU and electronic circuit detect control parameters (such as speed, water level, discharge, and output) compute the required range for control, and transmit the control signal to the servomotor. The CPU tends to be included in an integrated control unit with another operation control unit. For units less than 200 kW, a Dummy Load Governor may be applied.



\*1 detect current and its director

Source: JICA Study Team

**Figure 3.17 Concept Figure of Dummy Load Governor**

Accordingly, the control characteristics are fine and it can respond to sudden output change even from minimum to maximum. This governor is applicable for turbines without a water inlet adjusting mechanism, such as the Reversible Pump turbine or isolated operation in a small grid.

#### (2) Integrated Control Panel

An integrated control panel uses a CPU to perform integrated operations of control, operations of protective equipment, and storage of an operation record for the powerhouse. It is contained in a small board.

Examples of the functions included in an integrated control panel are as follows:

Control functions	Operation sequence, starting speed control, voltage control, power factor control, frequency control, load control, water level control, discharge control, program operation control, etc.
Protective functions	Over current, over voltage, under voltage, bus ground fault, lack of phase fault
Display functions	Voltage, current, power output, power factor, frequency, water level, opening, bearing temperature, faults, etc.
Recording functions	kWh, discharge, historical record of fault , daily operation report, monthly report, annual salary, testing record, etc.

### (3) Direct Current Power Source Unit

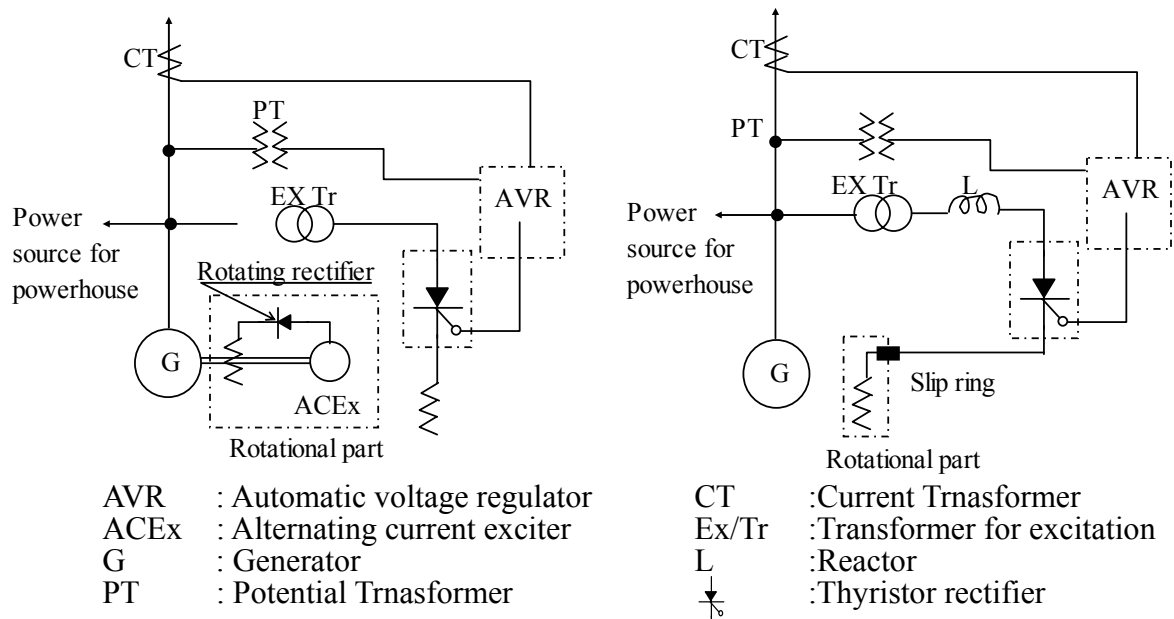
Batteries with chargers are used as a power source for operation control and protective relay. Commonly, 100 V is used, but 24 V may be applicable for small capacity power station.

There are two types of batteries, lead acid and alkali. Alkali batteries adopted more commonly these days because of simple maintenance.

### (4) AVR

This device controls the generation of power by adjusting the excitation current of Synchronous Generator. The following figures show two types of AVR application.

In both types of AVR, the AVR detects a voltage change in the generator bus and adjusts the excitation current by controlling the SCR gate. Brushless Excitation AVR has small excitation current and are easy to control. Static Excitation AVR requires a large current and the time constant of the magnetic field circuit is rather long, so they need careful attention for control.



(a) Brushless excitation type

(b) Static excitation type

Source: JICA Study Team

**Figure 3.18 Excitatory Circuit with AVR**

Both AVR's of brushless excitation and static excitation use the exciting current of generator, accordingly. Therefore, such a way can compensate a voltage drop caused by the load current, which is so called "compound-wound characteristics". The power factor in isolated operation is given by the load power factor, which can not be improved by adjusting the excitation current. In grid parallel operation, some AVR's are equipped with a power factor control unit and reactive power adjustment by excitation current.

### 3.4 Inlet valve

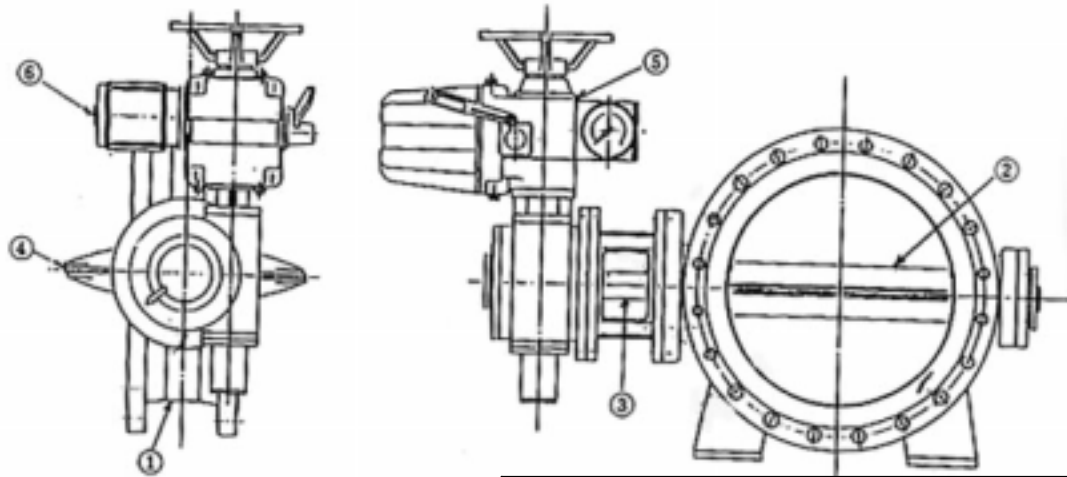
The inlet valve is installed near the turbine inlet at the end of the penstock.. The usage and purpose are as follows:

- Shutting off a flow path when the turbine is stopped
  - In this case, water inflow to the runner is closed off by a preceding operation of the guide vane or the needle.
- Shutting off the water flow when the guide vanes and/or needles cannot be controlled.
- Stopping water flow during turbine inspection

When the diameter of the inlet valve is large and there is a low head and large discharge, the inlet valve may be omitted by providing a regulating gate at the inlet of the penstock in the head pond.

Butterfly Valves, Double Leaf Valves, and Sluice Valves are applied as inlet valves.

(1) Butterfly valve

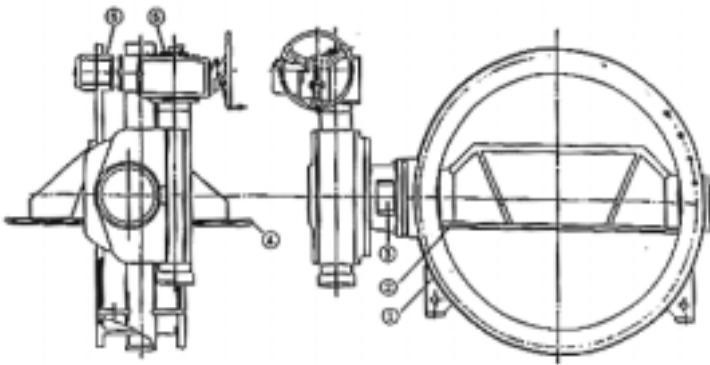


No.	Items	Material
	Valve Frame	Pressed and stretched steel plate for general structure
	Valve Body	Ditto
	Valve Axis	Stainless steel, Cast carbon steel, or carbon steel for mechanical structure
	Valve Sheet	Rubber
	Speed Reducer	-
	Electric Motor	-

**Figure 3.19 Structure of Butterfly Valve**

Butterfly Valves are applied for heads of less than 150 m. The structure is shown in Figure 3.19. There are horizontal axis type and vertical axis type valves as shown in the above table. Horizontal axis type valves have the advantage that the weight of the valve body is easy to support.

The valve diameter is generally be 1.1 to 1.2 times the turbine inlet diameter. The structure is simple. Sealing method is good in rubber seal type valves. The head loss is rather large compared to other valve types, but this valve type is still applied in relatively small diameter because of the low cost.

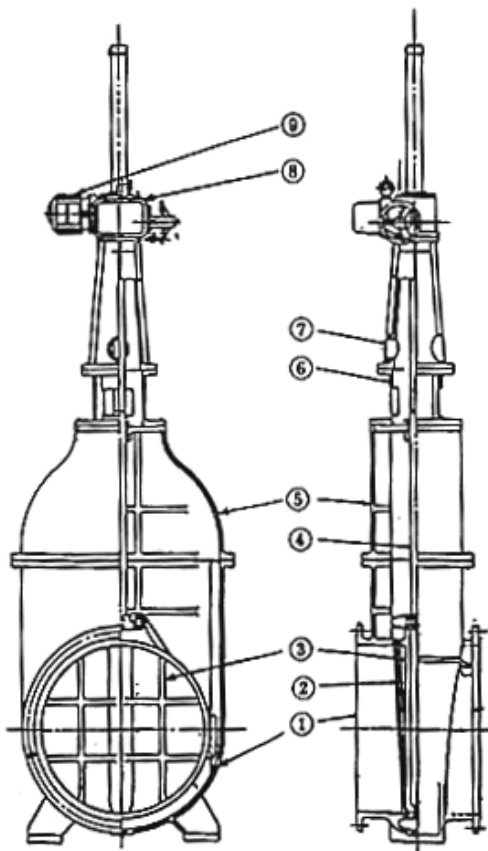


No.	Items	Material
	Valve Frame	Pressed and stretched steel plate for general structure
	Valve Body	Ditto
	Valve Axis	Stainless steel, Cast carbon steel, or carbon steel for mechanical structure
	Valve Sheet	Rubber
	Speed Reducer	-
	Electric Motor	-

**Figure 3.20 Structure of Through-flow Valve**

The Double Leaf Valves are suitable for heads of less than 200 m. The structure is the same as Butterfly Valve, but the valve body is thin and obtains strength by combining two pieces in order to reduce head loss. The structure is shown in Figure 3.20.

Valve diameter is 1.1 to 1.2 times the turbine inlet pipe diameter, similar to the Butterfly Valve.



No.	Item	Material
	Valve Frame	Cast carbon steel
	Valve Sheet	Bronze
	Valve Body	Cast carbon steel
	Axis of Valve	Stainless steel or carbon steel for mechanical structure
	Cover	Cast carbon steel
	Stand	Cast iron
	Stand	Ditto
	Speed Reducer	-
	Electric Motor	-

**Figure 3.21 Structure of Sluice Valve**

The Sluice Valves are applied to high heads and small discharges. It has small head loss. The structure is shown Figure 3.21.

There are two types of spindles that operate the valve electrically. One is an inner screw type with a female screw attached to the valve body and a male screw on a spindle is turned for up-down movement. The other type, the outer screw, turns a female screw at the top of the spindle. The former is for relatively large diameter applications, but the latter has the advantage of safety and is applied for hydro more frequently.

(4) Types of Operation and Drive

In case of automatic operation, there are two types of drives: motor driven and hydraulic oil driven types.

Hydraulic type drives are used for large diameter applications, such as Tubular turbines. Generally, motor drives are widely adopted. Power source for the driving motor is basically direct current, but alternate current may be applied. It is said that opening and closing time is set at less than 180 seconds.