TOSHIBA

HYDRAULIC TURBINES
The words "Water Power" give an image of hydroelectricity... an ever-existent energy source on the Earth.

In these difficult times of supplying the Earth’s energy demands, broad attention is taking a new and closer look at the many advantages of water energy. Water has been always the cheapest, simplest and most maintenance free energy source due to its natural regeneration, and also it in no way provides any atmospheric pollution. The countries where the supply of water is abundant and reliable are realizing that the utilization of hydroelectricity to the full extent should be of high priority. Hydro power has become resurgent!
Since its establishment in 1875, TOSHIBA CORPORATION has installed or constructed over 1,900 units of hydraulic turbine with a total capacity of almost 32 million kW and over 1,200 units of hydro generator with a total capacity of almost 32 million kVA. Today, TOSHIBA is playing a world leader in the field of hydro-electricity. Especially, TOSHIBA water turbines have made outstanding progress and opened new applications to hydraulic design and structural development in the tradition of technological innovation. TOSHIBA’s many research laboratories have continued their efforts in the research and development of technology, including the advanced works of high head pump-turbines which are particularly one of big subjects in the field of modern hydro power engineering. Highly qualified engineers are developing computer programmes for studying the dynamic characteristics of the hydraulic systems and the mechanical designs of turbines and pump-turbines. Under rigorous quality assurance, TOSHIBA’s production facilities are prepared to accept equipment for the largest size to the smallest. During its long history, TOSHIBA’s attention has always been attentive to oversea, and consequently TOSHIBA has accumulated extensive experience in effecting export contracts throughout the world. In this regard, TOSHIBA is ready to cooperate with organizations of local manufacturers and of local labor and facilities for erection of the equipment at site. Together with its diversified technology, TOSHIBA has achieved an unexcelled position among leading manufacturers in the field of hydroelectricity.
To all countries blessed with an abundance of water resources, water represents a valuable energy source which may be stored and which is constantly available. TOSHIBA has participated in the construction of numerous power plants all over the world. TOSHIBA has five engineering principles, which can provide the modern hydro-turbine technology:

**Hydraulic Engineering**
TOSHIBA hydraulic turbines are designed with optimum characteristics including better operating efficiency, greater power output, and reduced cavitation damage. TOSHIBA constantly conducts extensive model testing to verify designs at its modern, fully computerized research laboratory. TOSHIBA also has developed various computer programs to simulate internal hydraulic behavior and transient phenomena.

**Structural Engineering**
TOSHIBA develops analytical design procedures and computer programs to obtain optimum design parameters, including stress analysis by the finite element method. This developmental work contributes for achievement of automated structural drawings and computer-aided fabricating machines. For the proper selection of materials TOSHIBA conducts continuous research on the practical application of appropriate materials to turbines with the objective of longer operating life span.

**System Engineering**
Toshiba, as a manufacturer of electricity equipment, is available for preparing an overall system design including the turbine, generator, transformer, control box, and switch gear equipment. Through close and mutual coordination, TOSHIBA’s design can ensure an optimum and reliable...
system in consideration of the respective phases of equipment comprising the power generating system. Especially, for a turn-key contract, this total system is a prime requisite which can develop cost-effective solutions to requirements in overall hydro installations.

**Manufacturing Engineering**
Through the application of outstanding manufacturing technology, TOSHIBA has produced record-breaking high-head and large-capacity turbines and pump turbines. This manufacturing technology provides TOSHIBA's products with high performance and high reliability with the aid of highly computerized, large-scaled manufacturing facilities such as automated gas-cutting machines and 5-axis NC machines, and also internationally qualified skilled welders and modern welding procedures. Such capability enables TOSHIBA to produce various accurately machined turbine parts whose dimensions and shapes completely satisfy structural designs required and sufficiently robust welded structures.

**Quality Assurance Engineering**
Close cooperation with all departments regarding non-destructive material testing and welding technology as well as inspection is required for high quality products such as turbines. TOSHIBA Quality Assurance Department supported by modern testing equipment and measuring devices, meets the basic requirements for excellent quality control. The results of quality control enable not only to improve the reliability and the fabricating sequence, but also to form the starting point for next developments in materials, welding technology or production procedures.
TOSHIBA New Hydraulic Research Laboratory is now on-line to meet the growing needs for generating efficient low-cost power. The facility features three test stands and a "real-head" high test rig. The capacity of each test stand is distinguished as one of the world largest, capable of meeting the requirements of larger unit capacity and higher head for turbines and pump-turbines.

The "real-head" high-power test rig can examined various operation data on a homologous model under a head up to 2000m. As other testing facilities, the Laboratory is equipped with automated measurement systems by high-accuracy instrumentation and a five-axis numerical controlled machine to curve out complex surface profiling of a model. Boasting of the most up-to-date facilities, the laboratory is expected to contribute to further up-grading TOSHIBA reliability.
Diagram of test circuit

Model test stand for high head turbine
Test head 200m, Discharge 50m³/min, Capacity 1000kW

Control room

Model runner under machining by a 5-axis NC machine
TOSHIBA has established exclusive system technology through extensive utilization of large-scaled computers for conducting effective operation of its total engineering.

TOSHIBA develops modern and highly sophisticated computer programs, which provide the technological tools and methods employed in various stages of turbine products.
Automated gas cutting machine with tracing device

Five axis NC machine (Runner machining)

Computer analysis of that system

Automated production of drawings
TOSHIBA’s huge Tsurumi Works, the center of TOSHIBA’s heavy machinery productions has accumulated high-grade technology which contributes to rationalizing production processes and improving product reliability. As for TOSHIBA’s large machining facilities there is a large vertical lathe which can accept a product weighing up to 350 tons and 16 meters in diameter, and a large horizontal-shaft lathe capable of machining a shaft up to 4.4m in diameter, 17.5m in length and 150 tons in weight. TOSHIBA’s Tsurumi Works is presently engaged in the all-round production of various sizes and types of hydroelectricity equipment supported by the world’s highest level production facility and exclusive technology.
Nondestructive test room employing a betatron

16m Vertical lathe

17.5m Horizontal lathe

Automatic welding positioner

2000 ton hydraulic press

Large-sized furnace
Francs turbines are most widely used among water turbines and the development of the Francis turbines in the last decade has opened up a large range of new application possibilities for this type. These advances, motivated by a search for maximum profitability, have become possible as the result of improved knowledge of the water flows in turbines and other hydraulic phenomena.

A complete investigation and intensive research are carried out and efforts are put forth in the improvement of turbine performance, the selection of suitable materials, and the construction design in consideration of difficulties imposed by mechanical, manufacturing, and maintenance factors at the design stage. Toshiba has already completed two of the world’s largest water turbines, for Guri PS. (Venezuela) and for Grand Coulee No.3 PS (USA).
SPIRAL CASE AND STAY RING

The hydraulic research of the water passage through the spiral case to stay vanes becomes very important in diminishing the losses of the flow and the angle and the shape of stay vane cascades are carefully designed. A new type of construction (parallel type) advantageous in structural design is applied to all the stay rings. The spiral case is made of steel plates for welded structures or high tensile strength steel plates.

**TOSHIBA** has used 60 or 80 kg/mm² high tensile strength steel plates for spiral case shell plates of a big turbine or a high-head strength turbine. From the view point of field welding, the spiral case shells are accurately cut out by automatic gas-cutting machines, contributing to perfect field assembly even without a temporary shop assembly check.

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TOSHIBA is always making best efforts to design and manufacture highly efficient runners to meet all requirements or specifications. The runner is designed in consideration of various parameters for computation by both theoretical analysis of internal flow and experimental investigation by model tests. The runner is usually made of carbon steel castings and overlay coating of stainless steel welding will be made on critical areas of cavitation if necessary. For higher head machines, the runner is made of stainless steel castings. Especially 13% Chrome steel with enriched Nickel content becomes widely used for its excellent anti-cavitation-corrosion characteristics and mechanical strength.

If a welded runner is required for large capacity turbines, the vanes, crown and band may sometimes manufactured separately and subsequently welded together into one runner. When a single piece runner is impossible due to transportation, the runner is split into two or more sections. The edges of runner blades are finished by numerical controlled machine to obtain accurate curvatures of the edges which contribute for high performance.
HEAD COVER AND BOTTOM RING

The head cover and the bottom ring are so designed as to avoid causing excessive deformation which may lead to seizure of wicket gate movement. Particular care is taken to ensure that the positioning of bores to receive the wicket gate stems which should be matched between the head cover and bottom ring.

For a larger diameter of bore size, these bores are accurately positioned and machined by using numerical controlled machines. Upon special request, seal packings of the trapezoidal section will be located in grooves machined in the distributor faces of the head cover and bottom rings to minimize water leakage through the wicket gates fully closed.

MAIN SHAFT

The main shaft for the turbine is made of high-grade forged carbon steel. When the size of the main shaft exceeds the limitation of forging capacity or transportation or it is economical, the main shaft is formed by welding steel plates or a combination of forged steel and steel plates.

The main shaft is connected to the generator shaft or the intermediate shaft by a flange coupling. The shaft surface passing through the shaft seal is protected with a stainless steel shaft sleeve to prevent the main shaft from wearing.
TOSHIBA adopts two types of shaft sealing systems; Labyrinth sealing system and Carbon ring sealing system. The labyrinth sealing system is made of bronze metal and its sealing part is provided with several circumferential grooves on its inner surface. Clean water under appropriate pressure is supplied to the middle of the sealing part so as to prevent river water from coming up. This system features extremely simple maintenance because of no shaft-contacting part. The carbon ring sealing system is of special construction, using two different ring materials. Since the bottom layer is exposed to river water, a synthetic resin ring with high wear-resistant is used, while the other layers are provided with extremely reliable carbon ring. These rings are arranged for depression against the shaft surface by springs and attachments. Clean water is also supplied to this system to cool the seals and to lubricate these seal surfaces which contact the main shaft. **TOSHIBA has** a shaft seal test facility that provides high design reliability through a series of investigations.

**Typical structure of shaft seals**
It is highly desirable that the bearing is of high rigidity capable of accommodating large load bearing capacity. In this regard segment-type bearings have been widely used for many years with self lubrication method which permits simplified construction. Lubricating oil in the oil reservoir is cooled by cooling water passing through a built-in cooling coil. The bearing segment itself is of steel plate with babbit lined and the adhesiveness of the liner is thoroughly checked by nondestructive examination at the works.

On the other hand, cylindrical bearings are used occasionally, considering their rigid, compact design. Depending on requirements, forced circulated lubrication may be used for the main bearings of small capacity turbines. TOSHIBA checks the dynamic response of the shaft system during the design stage, using an analysis computer program, in order to select most suitable shaft system.
WICKET GATES AND OPERATING MECHANISM

Design of the wicket gates must meet the requirements of both hydraulic and structural strength. The wicket gates are usually made of carbon steel castings for the low head, while stainless steel castings are adopted for the high head. Welded construction wicket gates may be used for a low head or a large turbine, if required. A wicket gate is usually manufactured in one piece together with its upper and lower stems, with one or two upper bearings and one lower bearing all of which are grease-lubricated or self-lubricated (oil-less) type. The self-lubricated (oil-less) bearing has a base metal of aluminummanganese bronze with a PTFE-type solid lubricating agent, offering excellent sliding characteristics and mechanical strength and it is also used for the link mechanism. The wicket gate operating mechanism is installed with eccentric pins between the gate operating ring and each wicket gate to allow individual adjustment of wicket gate openings. Shear pins with carefully calculated size are provided with an operating mechanism. A pin will shear, should a wicket gate become blocked, and the remaining gates can be operated as required. In some stations, a friction device is installed, which prevents a free wicket gate from flutter or erratic movement without restricting normal operation of the remaining gates when a shear pin break.
Wicket gates operating mechanism

Wicket gates servomotor

Wicket gates operating linkage

Self-lubricated bearing for wicket gate stem
The most commonly employed draft tube is of elbow type, in a concrete structure, fixed with anchoring materials. Overall configuration of the draft tube is thoroughly checked at TOSHIBA Research Laboratory to ensure effective use of the head energy. The draft tube liner, of welded construction, is made of steel plate for general structure. With a larger draft tube, the horizontal section of the draft tube liner outlet is constructed with one or two center piers. The draft tube liner is normally shipped or supplied to the site in several split pieces due to transportation limitation. These pieces are usually welded together during the field assembly. If necessary due to theoretical and practical reasons, a special air admission system is provided with a draft tube liner to reduce water-pressure pulsations in the draft tube.
ASSEMBLY OF FRANCIS TURBINE

325MW turbine with 116.2m head for Wivenhoe power station

10.6MW horizontal Francis turbine with 176m head for Sasakura No.2 power station

266MW turbine with 411m head for Arimine No.1 power station
KAPLAN TURBINE

Kaplan turbine is most appropriate for operation with a low head and a large amount of discharge. Owing to adjustable runner blades it offers the significant advantage to give high efficiency even in the range of partial load, and there is little drop in efficiency due to head variation or load. As a result of recent advances, the range of Kaplan turbine applications has been greatly improved, which favors numerous undeveloped hydro sources previously discarded for economic or environmental reasons. As having adjustable runner blades, the construction of Kaplan turbine becomes naturally a bit complicated. The runner blade operating mechanism consists of a pressure oil head, a runner servomotor, and the blade operating rod inside the shaft etc.
The runner blades are operated to smoothly adjust their blade angles by a link mechanism. Their mechanism is installed inside the runner hub, containing the runner blade and stem, the link crosshead and so on. A high quality lubricating oil is filled inside the runner hub to lubricate the mechanism interior.

The special packings are installed between the runner hub and blade stem to prevent both water intrusion from the outside of the runner hub and leakage of lubricant oil to the outside, as shown in the figure.
The pressure oil head supplies pressure oil for the blade servomotor and serves to feed back motion of the servomotor to the speed governor. It is usually install on the top of the generator.

The runner blade servomotor is installed between the main turbine shaft and the generator shaft or inside the runner hub as shown in the figure below. Suitable location of the servomotor is selected by duly considering mechanical and space factors.
The main guide bearing of Kaplan turbine is usually designed to have a construction with a grease-lubricated system. In turbines with large dimensions or high revolving speeds, an oil-lubrication guide bearing system is adopted, with a cooling coil located inside the bearing oil reservoir for cooling the oil. Recently, to fulfill requirements for easy maintenance and low friction loss of the bearings, water-lubricating guide bearings are widely used as a sort of oil-less bearing.

Air-vacuum valves are provided on the head cover for immediately supplying the air into the inside of the turbine to prevent vacuum when the wicket gates close rapidly.

In some power stations, Kaplan turbines have cases made of concrete of a semi-spiral shape. Their heads are comparatively low.
The Diagonal flow turbine has the remarkable features that excel Kaplan turbine in the performance for high head, through the former’s construction is very similar to that of Kaplan turbine in considering the adjustable runner blades. The Diagonal flow turbine, as a result of using adjustable runner blades, offering excellent advantages: (1) it becomes possible to operate smoothly and to display high efficiency over a wide range of head and load, so that this type turbine is suitable for a power station with wide variation of head or large variation of discharge, (2) it is available to select a higher revolving speed for given hydraulic conditions, compared with Francis turbine.
The Diagonal flow turbine has runner blade stems constructed at a certain diagonal angle to the vertical center line of the machine. Therefore, construction of the operating mechanism tends to be more complexity in a smaller space than that of Kaplan turbine. For these reasons, TOSHIBA Diagonal flow turbine employs compact, efficient arrangement for the runner blade operating mechanism, as shown in the figure. The runner blade servomotor is normally of rotary type, not like the type of Kaplan turbine, located inside the turbine shaft or the runner hub. Rotating movement of the servomotor piston is transmitted to the spider inside the runner hub through the piston rod. Slide block is provided for each connection of the spider and the blade arm, and it conveys the rotating motion of the spider to the runner blade stem.
Tubular turbine, gaining increasing interest throughout the world, is often selected in place of Kaplan turbine as a machine especially suitable for low-head development. Since the tubular type requires less space than other turbines, a saving in civil costs is realized due to a smaller powerhouse and shallow requirements for the draft tube. There are two types for this turbine, the pit type and the bulb type. The tubular turbine is equipped with adjustable wicket gates and adjustable runner blades. This arrangement provides the greatest possible flexibility in adapting to changing net head and changing demands for power output, because the gates and blades can be adjusted to their optimum openings.
The wicket gate operating mechanism is installed inside the inner casing or outside the outer casing; and in both cases, spherical bearings are used to ensure highly smooth operation.

The runner blade servomotor is contained in the runner hub, and the pressure oil for it is supplied from the oil head at the upstream end of the generator shaft. While, the runner hub is filled with lubricant oil fed from a gravity tank which is located on the upper floor of the power house.

As the turbine shaft seal, a mechanical seal or a labyrinth-type seal is adopted for easy maintenance. An opening in the concrete structure is provided around the discharge ring and the runner is installed or dismantled through that opening.
Since pumped storage power plants were constructed as a powerful and economical measure for the storage of electric power, various efforts have been undertaken to improve the economy and the reliability of these plants. Recent technology concerning single-stage pump-turbines has been explored and developed toward realization of higher head and larger capacity machines.

Figure in next page shows TOSHIBA remarkable trends of single stage pump-turbines towards higher heads since the 1960’s; 545m in Ohira Power Station is the world's highest pumping head in operation as of 1981 and it reached 621 m as represented by an installation at Bajina Basta Power Station. Based on these achievements, TOSHIBA is presently manufacturing 216MW pump-turbines with 701m head for Chaire Power Station in Bulgaria. The trend will continue further and will expectedly reach 800m or even 900m within the next decade.
To cope with further needs for higher head pump-turbines, extensive developmental work has been undertaken at the TOSHIBA hydraulic laboratory and the design department.

In case of a head exceeding the limit for single-stage pump-turbines, multi-stage pump-turbines are adopted.

To provide load regulation capability, developmental study is under way on multi-stage pump-turbines with movable wicket gates.

TOSHIBA has recently developed a model of a 2-stage pump-turbine with movable wicket gates for a head of 1,250m, and furthermore, the model characteristics under a real head were satisfactorily verified by using a "Real-head High-power Test Rig" which is capable of testing up to 2,000m in head for a multi-stage model. Based upon the model test results, the structural design and control methods of the prototype have also been established.
Impeller runner with split construction of 336MW pump-turbine with 264.4m head for Shin-Takasegawa power station

Impeller runner of 256MW pump-turbine with 545m head for Ohira power station

Installation of 207MW Pump-turbine with 539m head for Okuyoshino power

Shop assembly of 336MW pump-turbine for Shin-Takasegawa power station

Impeller runner with split construction of 336MW pump-turbine with 264.4m head for Shin-Takasegawa power station
Special attentions, in TOSHIBA design criteria, are given to the air release system after dewatering in pump start, the wicket gate sealing, compact type draft tube and so on.
A partition wall is provided near the air release pipes and it was proven to be greatly effective to prevent the choking of the air release pipes with water; consequently this construction contributes to the quick start-up of pump operation.
A special seal ring around the wicket gate stem is fitted for high head machines, in addition to seal packings installed between wicket gates and facing plates.
When the impeller-runner is rotating in air, the seal ring displays very satisfactory results for minimizing the power loss to about one-third of the value of a design without such a seal.
TOSHIBA has developed "the compact draft tube" which is appropriate for an underground power station. It has shorter vertical height and there is less area at each section than those of the conventional draft tube. This draft tube contributes greatly to a saving in the capital cost for excavation and reinforcement around the draft tube.

Comparison of draft tubes

Special seal ring for wicket gates

Compact draft tube
115.8MW pump-turbine with 182.2m head for Okuyahagi No.1 power station

Installation of 315MW pump-turbine with 621m head for Bajina Basta power station

Shop assembly of 315MW pump-turbine with 621m head for Bajina Basta power station
One of TOSHIBA achievements is the production of tandem type pump turbines. This type is selected specifically for a power plant installed in a small-capacity power network and it exerts only a slight influence on the network at start or stop operation.
TOSHIBA can supply a suitable inlet valve for a given condition. In spherical (rotary) valves there is slight leakage. In butterfly valve, though a small leakage is unavoidable, it can be minimized by adopting a special rubber packing. The thruflow valve features smaller loss head and leakage than the butterfly valve.
Spherical valve under pressure test

Thruflow valve with

Butterfly valve under operation test

Butterfly valve
The TOSHIBA Governor has established a reputation for reliable speed and power control of all types of water turbines and pump-turbines. The TOSHIBA Governor, together with its many optional functions, provides the best possible speed responsive control with modern electronics and simplicity of design.

TOSHIBA shares the concern of many customers over the specific functional requirements of control demanded from power network or hydraulic system by conducting dynamic analysis with computer simulation.
Quick & Stable Control
Combined Proportional, Integral and Derivative modules (PID) characterize the dynamics of the automatic speed regulation with rapid and stable response.

Easy Adjustment
The Individual Proportional, Integral and Derivative module can be adjusted due to accuracy of the scales over a wide range, covering all types of turbines and pump-turbines.

Utmost Reliability
Automatic PID regulation, utilizing a design with modern electronics (IC), realizes development of the speed regulation characteristics in conjunction with the hydraulic amplifying system (actuator).

Easy Maintenance
The modular system features a rational electrical unit arrangement offering easy mounting and wiring. Checking is possible by various test inputs available on each electric circuit board.