CHAPTER 6

Pelton Turbines

Introduction

The specified data of water flow rate, head and rotational speed determine the Pelton turbine designs.The number of jets depends on the speed number and stepping up values of the speed number means to step up in number of jets. For a certain plant that means often a matter of choise between numbers of jets for the turbine. If for example the design should be either four or five jets of the turbine, then the cost of the generator for a five jet turbine will be correspondingly lower than the alternative of a four jet turbine.

However, it is a serious demand that the jets enter the buckets so far from each other that no mutual disturbances can occur. In practise this means that six jets represent the upper limit of their number, and an evaluation of the speed number according to Equation (3.8) will show that speed numbers of Pelton turbines ranges below $^{*}\underline{\Omega} = 0.2$.

Pelton turbines can be arranged either by a horizontal or a vertical shaft. In general a horizontal arrangement is found only in the medium and smaller sized turbines with one or two jets. Some horizontal Pelton turbines have however, been built with four jets as well.

6.1 Horizontal Pelton turbine arrangement

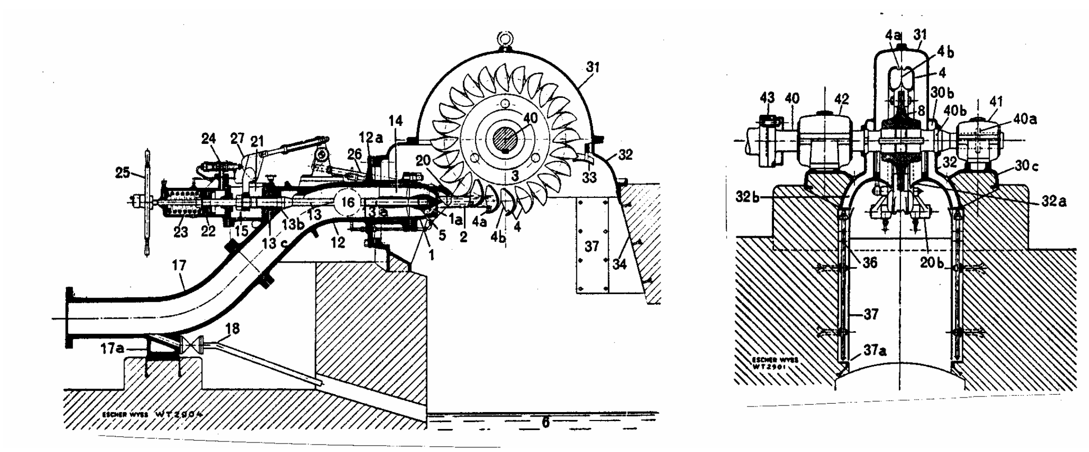


Fig.6.1 Horizontal Pelton turbine with one jet (To the left: Radiell section; to the right: Longitudinal section) (Courtesy of Escher Wyss)

Main details:

1. Nozzle
2. Jet
3. Runner
4. Runner bucket
5. Needle head
6. Tail water level
8. Runner disc
12. Inlet bend
13. Needle rod
17. Lower bend
18. Emptying pipe
20. Deflector
21. Feed back rod
22. Servomotor piston for needle movement
23. Closing spring for needle
24. Solenoid valve for the control of needle servomotor
25. Steering wheel for needle movement
31 and 32. Turbine housing
32a. Screen for guiding water from runner outlet to tail water
32b. Drain canals for for guiding spray water away from shaft
34. Steel lining
40. Turbine shaft
40a. Cam for axial bearing
42. The outer turbine bearing
43. Coupling

The flow passes through the inlet bend (12), the nozzle outlet (1) where it flows out as a compact jet through atmospheric air into the wheel buckets (4). From the outlet of the buckets the water falls through the pit down into the tail water canal (6).

Further comments to some of the details are given in Section 6.3.

Fig. 6.2 shows another example of a horizontal Pelton turbine with two runners and two jets on each runner.

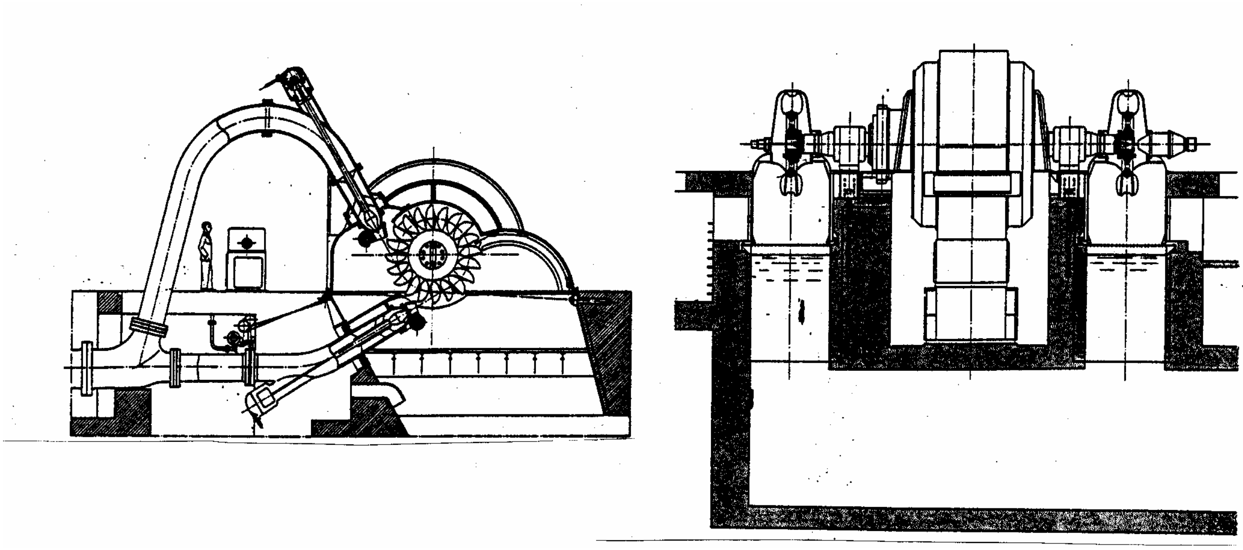


Fig. 6.2 Cross sections through a horizontal Pelton turbine with two runners and two jets to each runner. (Courtesy of Atelier des Charmilles)

6.2 Vertical Pelton turbine arrangement

Large Pelton turbines with many jets are normally arranged with vertical shaft. The jets are symmetrically distributed around the runner to balance the jet forces. The Fig. 6.2 and Fig. 6.3 show as an example of the vertical and horizontal section respectively of the arrangement of a six jet vertical Pelton turbine.

1. *Pipes for efficiency tests*
2. *Distributor pipe*
3. *Deflector mechanism*
4. *Turbine shaft*
5. *Deflector servomotor*
6. *Wheel pit cover*
7. *Guide bearing*
8. *Turbine housing*
9. *Main injector with needle servomotor*
10. *Runner*
11. *Runner cart rails*
12. *Runner cart*
13. *Inspection platform*

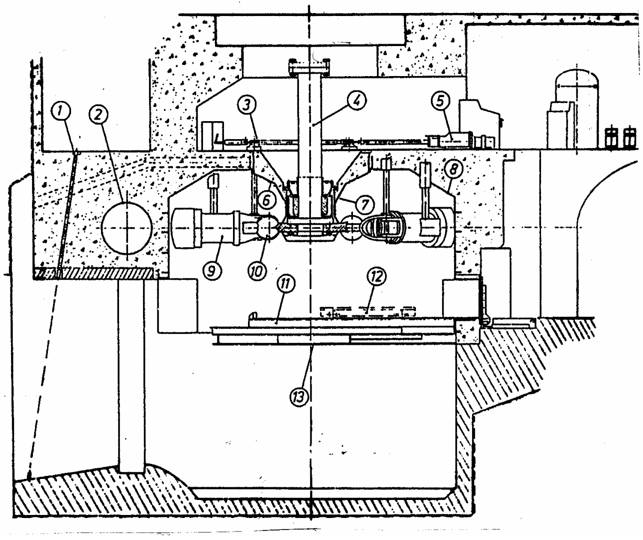


Fig. 6.3a Vertical multinozzle Pelton turbine, vertical section (Courtesy of Kværner Brug)

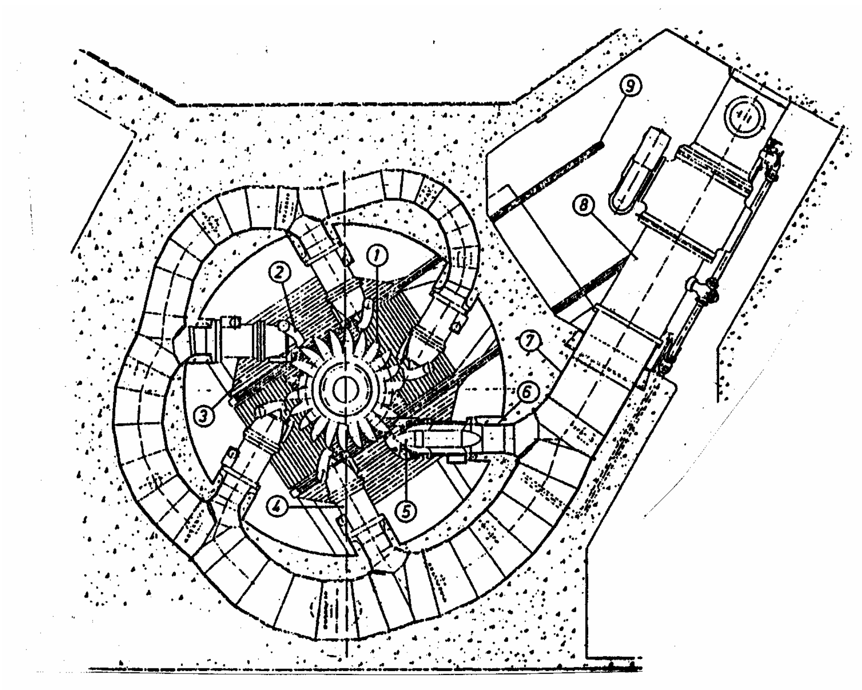


Fig. 6.3b Vertical multinozzle Pelton turbine, horizontal section (Courtesy of Kværner Brug)

Numbered details in Fig. 6.3b:

1. *Runner*
2. *Deflector*
3. *Inspection platform*
4. *Main injector with needle servomotor*
5. *Needle*
6. *Bifurcation*
7. *Distributor*
8. *Expansion/dismantling joint*
9. *Runner cart rail*

6.3Main components and their functions

The examples of Pelton turbines shown in the Figures 6.1, 6.2, 6.3a 6.3b, indicate that the turbine constructions consist of a rather great number of components. Naturally some of these do not exist in every manufactured Pelton turbine. This matter of fact imply that the constructions appear different from one manufacturer to the other or from a small to a bigger size of the turbine.

For these reasons our considerations will mainly according to ref. /*1*/, be dedicated to main components which are vital in all turbines. Of these components further attention will be paid to the following parts referred to Figs.6.1, 6.3a and 6.3b:

- runner
- shaft and bearings
- oil reservoir
- guide bearing
- bend and distributor
- straight flow injector
- deflector
- turbine housing

6.3.1 Runner

The Pelton runners may be designed either for casting of the disc and buckets in one piece, i.e. monocast, or the disc and each of the buckets are casted in separate pieces. The method first mentioned is preferred and common for the Pelton turbines in modern power plants where the the turbine units are of the high power and bigger sizes. Fig. 6.4 shows a photograph of a runner of monocast type, and Fig. 6.5 shows a runner with buckets having ears through which they are bolted to the disc.

Some details of such buckets on Fig. 6.5 show how some manufacturers in addition to bolts (9) also use pins (10) or wedges (11) between the buckets. The reason for this is that, while the runner is rotating, the buckets run in and out of the jets with a frequency according to the rotating speed and the number of jets. During this process they are exposed to shocks occurring with the same frequency. In the same way the bolts (9) are strained. To take care of these bolts conical pins (10) may be fitted into corresponding holes and driven in to a certain degree of prestressing between the buckets and the disc. If such pins are too weak, wedges (11) can be used as shown to the right on Fig. 6.5.

The material of the runner and buckets are chosen according to the head, stresses, content of sand in the water and other strain factors, and may be cast iron, cast steel or casted of high quality alloy steel. For the large high head turbines the main strain factors are cavitation, sand erosion and cycle fatigue. Runners working under such conditions are normally casted of 13%Cr4%Ni alloy steel. In addition to the strength qualities the material must be adequately weldable.

Fig. 6.4 A monocast Pelton runner

Fig. 6.5 Pelton runner with bolted buckets

The shape of the buckets is decisive for the efficiency of the turbines. For keeping and improving high efficiency characteristics great efforts of theoretical analysis and model tests follow the runner design. Limitations however, in these works are that bucket shape always will be a compromise between a hydraulically ideal and a structural optimum design.

The surfaces, over which the water jet flows are milled, ground and polished to the correct shape. The correctness is checked with templates. Surfaces close to jet flow out of the downstream neighbour bucket, and places where fatigue cracks may occur, are ground and polished as well.

Fig. 6.6 Rotating parts of a vertical Pelton turbine /1/

The runner disc is fastened to the shaft by bolts and nuts[1] as shown on Fig. 6.6. The bolts are screwn in threaded holes in the shaft flange and protrude through holes in the disc and have tightening nuts screwn on the other end. This connection establishes a pure frictional joint by a corresponding prestressing of the bolts by means of heat or a special oil hydraulic tool. This type of joint enables a simple dismantling and replacement of the runner. A shield to reduce windage losses caused by air and droplet circulation protects the nuts.

6.2.2 The turbine shaft

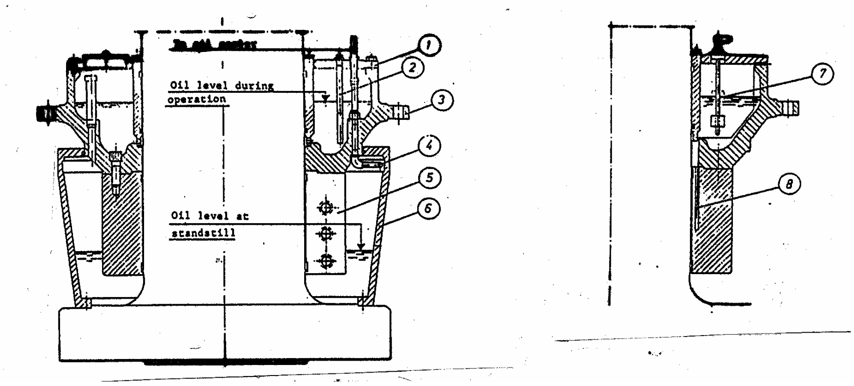
The turbine shaft of vertical Pelton turbines is made of forged Siemens-Martin steel with an integral flange at both ends as shown on Fig. 6.6. A hole is drilled centrally through the whole length of the shaft. The surface of the shaft is machined in a lathe to a final appropriate tolerance and even surface.

An oil reservoir is a rotating member bolted to the shaft flange[1] as shown on Fig. 6.6.

6.2.3 Turbine radial bearing

The details of a turbine bearing shown on fig. 6.7, is a radial guide bearing[1]. The bearing house (3) consists of two halves bolted together and mounted to a flange on the runner pit cover.

Two semicircular segments bolted together are



1. *Bearing cover*
2. *Oil temperature sensorl*
3. *Bearing house.*
4. *Scoop*
5. *Bearing shell*
6. *Lower rotating oil reservoir*
7. *Level switch*
8. *Temperature sensor, bearing shell*

Fig. 6.7 Turbine guide bearing (Courtesy of Kværner Brug)

forming the bearing shell (5) as a rigid cylinder, which is mounted to the lower side of the bearing house (3). These segments are provided with four fixed babbit bearing pads. They ensure a proper centring of the turbine shaft. Oil pockets between the four fixed bearing pads create the entrance of cooled lubricating oil to the bearing pads. At standstill the total oil quantity is staying in the rotating reservoir (6).

The rotating oil reservoir encloses the bearing shell. The oil rotates together with the reservoir as a layer on the wall. A stationary scoop (4) is installed with one end against the rotational speed of the oil in reservoir (6). The scoop is fastened to the bearing house (3) with a pipe connected to an external oil cooler. From the cooler a pipe returns to the upper oil reservoir of (3). The stagnation velocity pressure at the scoop opening causes an oil flow from the lower reservoir through the oil cooler to the upper reservoir.

To keep a certain oil quantity in the rotating reservoir the scoop is set at a predetermined distance from the wall. For large turbines however, two scoops are normally installed, and one of these with a larger distance from the wall than the other. This is advantageous under start while the oil layer in the rotating reservoir is thick enough for both scoops to deliver oil from the lower to the upper reservoir. Thus the time needed to establish the stationary oil circulation is decreased.

During the stationary circulation the oil flow exists as a continuous thin film along the wall of the rotating reservoir. An air stream outside the wall of the rotating reservoir mainly cools the oil layer. The slightly conical shape of the wall of the rotating reservoir is ideal for this cooling. Air-cooling may however be insufficient especially if the shaft rotational speed relative to the guide bearings is in the high-speed range. Therefore an external cooler is normally provided.

The cooled oil flows downwards along the shaft as it is distributed to the four pockets between the bearing pads. The oil film follows the shaft rotation, enters the bearing segments and establishes the load carrying coolant film in the bearing pads.
The bearing shell (5) is provided with a throttling edge at the lower end. The throttling edge controls the oil circulation in the bearing and ensures that the oil pockets in the shell are always filled with oil during operation.

6.2.4 Bend and distributor

The distributor pipe (7) for a multijet Pelton turbine[/1/] is shown on Fig. 6.3b. From this a bifurcation (6) is made to each of the injectors (4). The distributor is designed to provoke an acceleration of the water flow through the bifurcation towards each of the main injectors. This design is advantages by contributing to keep a uniform velocity profile of the flow.

The distributor pipe is a welded plate design manufactured completely from fine grain high tensile steel. The maximum main stress for this material must be limited to about 200 MPa. The bifurcation is reinforced with external and internal ribs. Because of the steel quality, welding of the distributor must be performed with a specified heat treatment.

The distributor is completely embedded in concrete when installed in the power house. However, to transfer the large axial forces to the power house an extension must be welded to the inlet flange. This is done for reducing the specific pressure on the concrete to avoid crushing and cracking.

The distributor is provided with a manhole with cover as access for internal inspection and maintenance. A manually operated drain valve is installed underneath close to the inlet flange of the distributor. This valve should be operated only when the main spherical valve upstream of the distributor is closed.

The distributor is joined to the main spherical valve via a joint, which is installed for dismantling purposes. This is furnished with a telescope flange connection to the distributor entrance. The main injectors are joined to the bifurcation by means of rigid flange connections.

An automatic relief valve is normally installed on the top of either the distributor entrance section or the dismantling joint. This valve closes automatically when most of the air in the distributor is let out during water filling, and remains closed as long as the distributor is pressurised.

For emergency stop a water jet braking system is provided to obtain a fast reduction of the rotational speed of the runner after the nozzles are closed. This system consists of one automatically operated needle valve connected to one or two brake jet nozzles, which are fed via pipes directly from the penstock. The braking valve is controlled by a solenoid valve operated by an emergency control system actuated by the water pressure from the penstock.

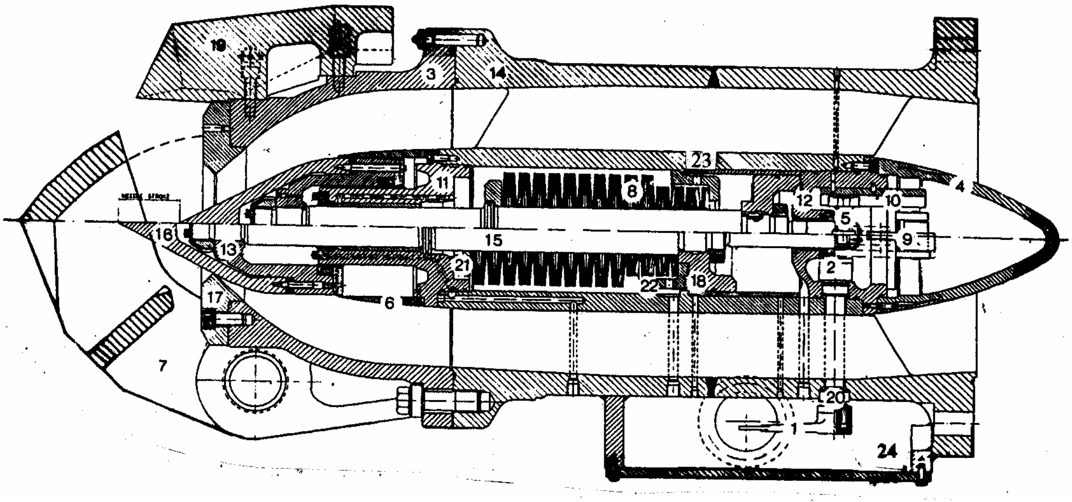
For emptying the penstock upstream of the spherical valve a draining system is provided. This consists of five parts: a pipe installed just upstream of the spherical valve, a manually operated gate valve with a bypass valve, one manually operated needle valve in series downstream of the gate valve and an outflow pipe. The outflow pipe has its outlet above the water surface in the turbine pit to prevent cavitation during drainage of the penstock.

6.2.5 Straight flow injector

The straight flow injector with needle servomotor is shown on Fig. 6.8.

The injector[1] consists of three outer parts bolted together, the main body (14), the beak (3) and the nozzle ring (17). The beak is provided with two external brackets with self-lubricating bushings for the deflector (7) support.

Inside the injector two fins to the main body fix the inner cylindrical body (23). The inner body contains: the needle, servomotor with needle rod (15), disc spring column (8) and feedback mechanism.



1. Arm
2. Arm with split boss
3. Beak
4. Cap
5. Carrier
6. Cover
7. Deflector
8. Disk spring
9. Elbow lever
10. Guide
11. Guiding piece
12. Lid
13. Needle head
14. Main injector
15. Piston rod
16. Needle tip
17. Nozzle
18. Piston
19. Shield for beak
20. Spindle
21. Spring plate
22. Spring retainer
23. Inner injector body
24. Oil box

Fig. 6.8 Straight flow injector (Courtesy of Kværner Brug)

The needle consists of two parts, the head (13) and the tip (16). The guidance for the needle is the guidance piece (11). A U-seal ring in the needle head seals against the water pressure outside the guiding piece. The seal ring is protected against sand by a synthetic rubber scraper ring. Another U-seal ring in the guidance piece seals against the oil pressure in the servomotor.

The needle servomotor is double acting and operated with oil pressure from the governor oil system through a control valve. Disc spring elements and the water pressure from the penstock balance the needle. The disc spring column (8) will function satisfactorily also when one of the discs is broken. With this spring design the servomotor will work even though the oil pressure should fall to about 25% of the normal level. If the oil pressure should be decreasing towards zero the water pressure will move the needle servomotor towards closed position and the turbine brought to stop if the generator is disconnected from the grid.

When the servomotor is out of operation and no pressure either from oil or water exists, the needle will be in the middle position and the spring discs relieved.

The governor feedback mechanism is located inside the upstream cap (4). The feedback shaft (20) is passing through one of the structure ribs into the external oil box (24). At the end of the shaft the arm (1) is fastened and further connected via a mechanical linkage system to a control cubicle on the turbine floor.

During operation with load alteration and corresponding regulation the feedback system will move the control valve in the control cubicle back to neutral position when the needle has reached correct position.

Due to the high exposure of sand erosion and cavitation the nozzle ring (17), the needle head (13), the guiding piece (11) and piston rod (15) with the nut are made of corrosion resistant steel normally 13% Cr 4% Ni. The beak is also lined with stainless steel.

The piston (18) is made of cast iron. The servomotor cylinder is lined inside with a cast iron bushing which cover the stroke length of the piston. On the upstream side the piston rod is supported in the servomotor cover with a bushing and a U-seal ring against the oil pressure.

The chamber bounded by the piston rod (15), the needle head (13) and the end of the guiding piece (11) has a volume varying with the piston movement. This chamber is vented to the atmosphere through a hole drilled along the guiding piece (11) and corresponding to a drilled hole in the wall of the inner injector body (23) and finally through the structure rib.

A replaceable cast steel shield (19) mounted on the beak protects the jet against exit water from the runner during normal operation.

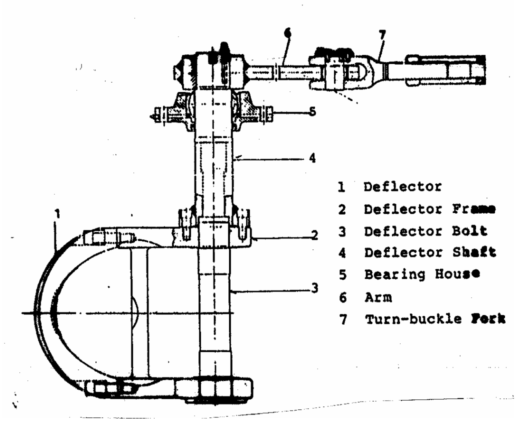


Fig. 6.9 Deflector mechanism (Courtesy of Kværner Brug)

6.2.6 Deflector mechanism

The deflector[1] has the function to bend the jet away from the runner at load rejections to avoid too high speed increase. Moreover it protects the jet against exit water spray from the runner.

The deflector mechanism is shown on Fig. 6.9. The deflector arc (1) is bolted to the deflector support structure frame (2). The deflector support frame is connected to the deflector shaft (4). The deflector pivot (3) is supported in the beak on water lubricated bearings. The deflector shaft (4) is supported in a self-lubricating spherical bearing located in the bearing housing (5) on the top plate floor. A seal ring around the deflector shaft bearing housing prevents water and moisture from penetrating into the bearing.

The deflector arc (1) is made of stainless corrosion resistant cast steel 13% Cr 4% Ni.

The governor deflector servomotor controls the deflectors through rods, turnbuckle forks and lever (6) which is fastened to the deflector shaft (4). In addition a dead band-eliminating servomotor is mounted in the deflector mechanism to prevent play in the governor lever system.

The control valve of the needle servomotors is joined by a link connection to feed forward mechanism connected to the deflector servomotor.

6.2.7 Turbine housing

The housing of a vertical Pelton turbine[/1/] is shown in Fig. 6.3a, pos. (8). This consists of an upper turbine housing and a lower pit lining. Both parts are made of steel plates welded together at site during construction. Moreover, cylindrical connections for the distributor inlet flanges are welded to the pit lining.

The pit lining is cylindrical and the upper turbine housing is externally reinforced by ribs and anchor bolts. The entire housing is embedded in reinforced concrete. Together these parts form a rigid unit with passages for needle servomotor piping and feedback mechanisms and the deflector shafts through the pit cover up to the turbine floor.

The wheel pit cover pos. (6) on Fig. 6.3a is conical. A plane top plate is provided with a flange for support of the turbine guide bearing, pos. (7). The shape of the wetted side of the wheel pit cover is important for leading the exit water effectively away from the runner.

The wheel pit cover is filled with concrete except for the canals of embedded pipes leading air from the tail race tunnel to the runner disc. The wheel pit cover is welded to the upper and lower plate on the turbine housing and forms a rigid support for the turbine guide bearing.

An inspection platform below the runner, pos. (13) on Fig 6.3, is designed to carry the weight of the runner and the main injectors during assembly and dismantling. Transport rails are mounted on the inspection platform, and a runner cart is provided for the transport of heavy parts in and out of the turbine pit.6.3 Condition control.

6.3 Condition control

6.3.1 Turbine guide bearing

The first oil change should be done after 3 - 6 months of operation[/1/]. The later oil changes have to be done as required by evaluating oil sample tests.

To empty the bearing for oil it has to be done at standstill by pumping through the oil level pipe in the bearing housing.

If babbit metal particles are found in oil samples, the bearing should immediately be dismantled for inspection.

6.3.2 Runner

The runner should be regularly inspected[1] to record possible damages from foreign objects in the water. The time interval between each inspection is dependent on sand content in the water.

The runner inspection is done visually by means of magnaflux and/or dyes penetrant. Particular attention should be paid to the area between the buckets.

If minor cracks or defects have been formed, these should be removed by grinding and polishing according to advises from the manufacturer.

The special shape of the runner buckets makes it difficult to detect material defects just below the surface. These defects may penetrate up to the surface during the first operation time period. To prevent an extensive crack propagation they must be rectified as soon as possible.

6.3.3 Main injector with needle servo motor

The needle tip and the nozzle should be inspected[1] with respect to cavitation damage and damage from foreign objects. If the water contains fine silt or sand, the needle tips may loose their original shape.

It is of great importance that the nozzle is inspected from the inside.

The needle servomotor should be run to neutral mid position and the oil pressure shut off for safety reasons. The leakage indicators should be regularly inspected.

6.3.4 Seal ring in deflector bearing

Leakage in this seal does not require immediate replacement of the seal ring, but replacement should be done as soon as possible to avoid bearing corrosion. The seal ring must be provided with a spring of stainless material.

6.3.5 Filter

Filter for breaking system control water supply should be checked and cleaned if necessary. It may be cleaned after closing of the valves for this water supply system from the penstock.

6.4 Monitoring instruments

The turbines are normally equipped with the following instruments:

- A contact manometer for reading of penstock pressure just upstream of the spherical valve. The manometer transmits signals either to the control room or to the operation control centre if the pressure exceeds or falls below certain pre-set values.
- A manometer for reading the pressure in the distributor.
- A contact thermometer for measuring the temperature of the turbine bearing. The reading instrument is mounted on the wall close to the governor control desk. The temperature sensor is located in one of the pads of babbit metal.

  The thermometer is provided with a contact that gives an alarm signal to the control room at a temperature which is normally 5 ^{o}C above the highest stable set temperature of the bearing. If the temperature should rise a further 3 ^{o}C, another contact will give automatic emergency shut down. The stable set temperature will vary from one bearing to another. By symmetric operation (i.e. balanced jet forces on the runner) the temperature will however, be approximately 75 ^{o}C. By unsymmetrical operation with a reduced number of jets in action, the unbalanced jet force must be carried by the turbine bearing. In this case an increase in the temperature of 5 - 7 ^{o}C will occur. Another sensor for direct transmission of the temperature reading to the control room is normally also installed in one of the bearing pads.

- A resistance thermometer is mounted in the upper oil reservoir with remote display in the control room for reading of the bearing oil temperature.
- Two oil level switches are installed to give warning signals at high and low oil levels in the bearing. Low oil level may be caused by oil leakage in the oil reservoir, or defects in the oil scoops that may lead to spraying oil so that an oil evaporation occurs.

  Cooling water leakage into the bearing normally causes a too high oil level. In this case an overflow may occur with oil pollution in the environment. This is also a warning against filling too much oil in the bearing.

6.5 Assembly and dismantling

The assembly operation is of great importance to the completed turbine quality. At first this has to do with the reliability of operation, the further maintenance and the hydraulic efficiency. Furthermore the progress of the assembly should be carefully planned, as it is essential for ensuring commissioning at the right time. The civil works, the turbine and generator assembly is often directly interdependent and must therefore be carefully co-ordinated. The use of the crane in the machine hall as well must be co-ordinated between the parties involved.

The turbine must in general be ready for embedding in concrete prior to the commencement of the formwork. Moreover the generator assembly cannot start before the turbine shaft alignment is completed. This is again dependent on the completed embedding of the turbine and the completion of cleaning operations.

The great advantage of the Pelton turbine compared with the Francis turbine is its simple maintenance and dismantling. The dismantling is almost without exception performed in the opposite sequence of assembly.

Reference

1. Kværner Brug: COURSE III, Lecture compendium. Oslo 1986.

Bibliography

1. Brekke, H.: Hydro Machines, Lecture compendium at NTNU, Trondheim, 1992.
2. Kjølle, A.: Water Power Machines (in Norwegian), 2. edition, Universitetsforlaget, 1980. ISBN 82-00-27780-1.
3. Nechleba, M.: Hydraulic Turbines. Artia-Prague. Constable & Co. Ltd., London, England 1957.
4. Raabe, J.: Hydraulische Maschinen und Anlagen. Zweite Auflage der Teile 1 bis 4 in einem Band. VDI-Verlag GmbH 1899.