CHAPTER 7

Francis Turbines

Introduction

In Chapter 3 the hydro turbines are classified by speed numbers, and the Francis turbines are in the range $0.2 < {}^*\underline{\Omega} < 1.5$. This wide range imply that the hydraulic design of the runner in these turbines differ rather much from the lowest to the highest speed numbers.

In general the Francis turbines have a guide vane cascade encompassing the whole circumference of the runner. Adjustable vanes in the cascade create the canals which are equal in shape and size, for regulation of the discharge and flow direction before entering the runner. The water flow fills up all canals completely in the guide vane cascade and the runner respectively. Therefore the water is under pressure when it enters the runner.

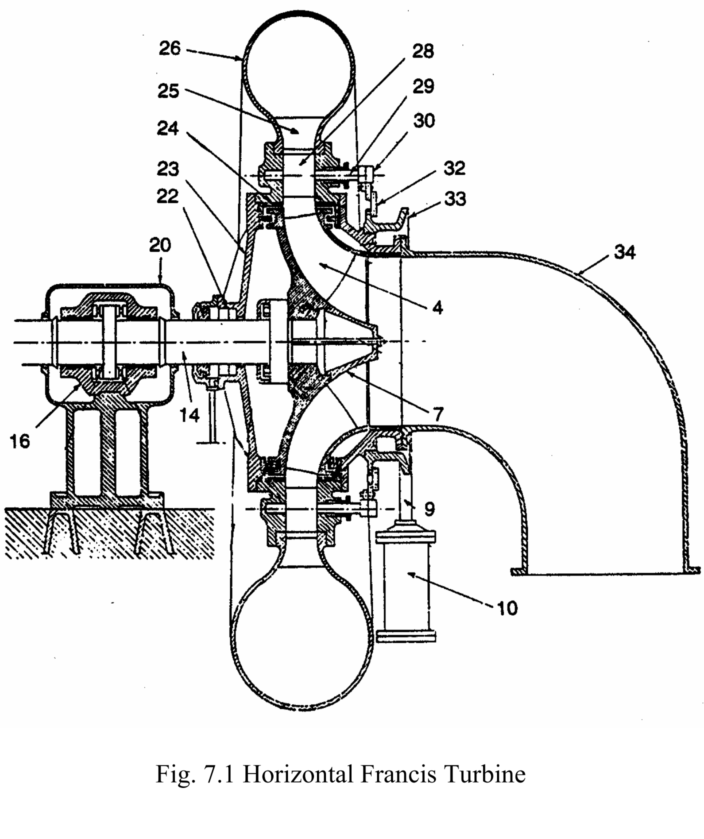


Fig. 7.1 Horizontal Francis Turbine

The Francis turbines may be divided in two groups, the one group with horizontal and the other with vertical shaft. In practise it is normal that turbines with comparatively small dimensions are arranged with horizontal shaft, while larger turbines have vertical shaft. The vertical arrangement is normally used also for small dimensions if the tail race water level is above the turbine centre.

7.1 Horizontal Francis turbine

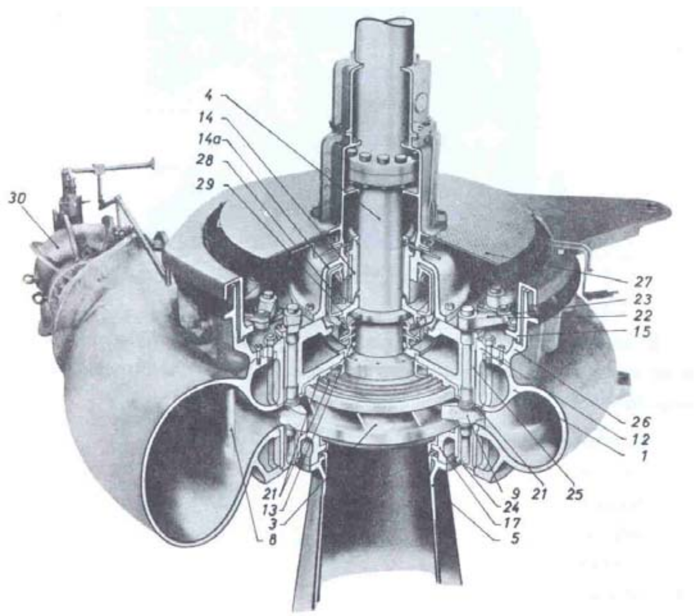
A design example of a horizontal Francis turbine is shown in Fig. 7.1, which is an axial section through the turbine. The water from the supply penstock flows through the scroll casing (26), the guide vane cascade (28), the runner (4), the draft tube (34) and into the tail race canal. To obtain an even, quite undisturbed water flow without thrust losses through the turbine, it is of great importance that any sharp edges or any sharp bends in the flow path should never exist.

The numbered details on Fig. 7.1 are:

4. Runner
7. The runner cone
9. Servomotor rod
10. Servomotor
14. Turbine shaft
16. Bearing pad
20. Bearing cover
22. Shaft sealing box
23. Turbine cover
24. Runner seal ring
25. Stay vane
26. Scroll case
28. Guide vane
29. Guide vane stem
30. Guide vane lever
32. Link
33. Regulating ring
34. Draft tube

7.2 Vertical Francis turbine

An illustration of a vertical Francis turbine is shown in Fig. 7.2. This figure represents a

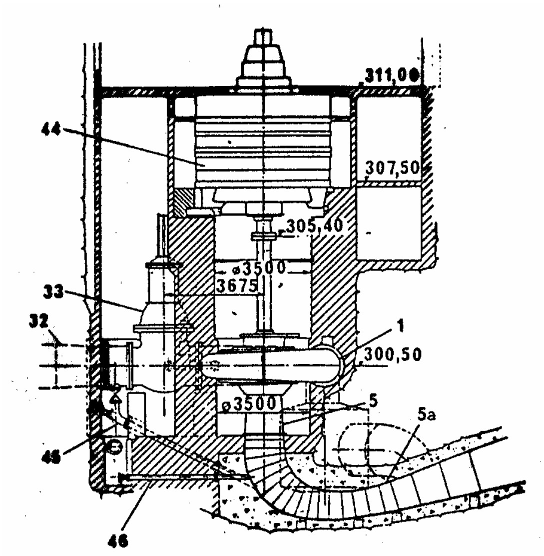


1. The scroll casing
3. Runner
4. Shaft
5. Draft tube cone
8. Stay vanes
9. Guide vanes
12. Upper cover
13. Sealing box
14. Guide bearing
14a. Bracket for the bearing(14)
15. Regulating ring
17. Lower cover
21. Replaceable wear and labyrinth rings
22. Link
23. Lever
24. Lower bearing for guide vane
25. Upper bearing for guide vane
26. Bearing for the regulating ring
27. Floor
28. Rotating oil cylinder
29. Oil scoop fastened to (14a) and (14) with the opening against the rotating oil in rotating oil cylinder (28)

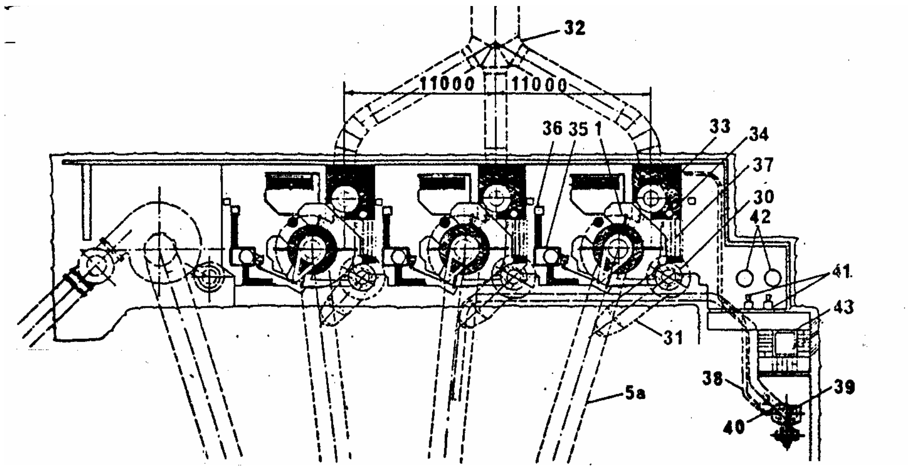
Fig. 7.2 Perspective of an axial section through a Francis turbine perspective of an axial section through the turbine. The position numbers point to details that are named in the list underneath.

An illustration of a vertical Francis turbine arrangement is given in Fig. 7.3, where the units are built up in an underground cavern. A vertical section through a unit is shown to the left and a horizontal section across all units in the cavern is shown to the right at the bottom of the figure.

The water flow enters the turbine through the pipe (32), the gate valve (33), scroll casing (1) and further through the guide apparatus and runner, draft tube cone (5), bend (5a) out in the tail race tunnel. The other position numbers are listed below.



Vertical section



Horizontal section

30. Relief valve and energy dissipation chamber
31. Outlet from energy dissipation chamber
34. Valve in the bypass pipe for pressurising the scroll casing before opening the gate valve
35. Governor housing with servomotor and accumulator
36. Pilot control of the governor
37. Ejector pipes
38. Penstock for auxiliary turbine
39. Auxiliary turbine
40. Tail race pipe from the auxiliary turbine
41. Vertical drain pumps
42. Motors for water cooling pumps
43. Staircase and conveying pit
44. Generator (above highest level of the tail water)
45. Emptying the penstock
46. Emptying pipe from the draft tube

Fig 7.3 Power plant with vertical Francis turbines

7.3 Main components and their functions

The examples of the building up of Francis turbines in Figs. 7.1 to 7.4, show that these turbine constructions consist of a great number of components. Many of these components are tailor made, and not all of them are found in every turbine. The constructions are to some extent time dependent and the different manufacturers construct some details different. Moreover the turbine constructions depend on the turbine size.

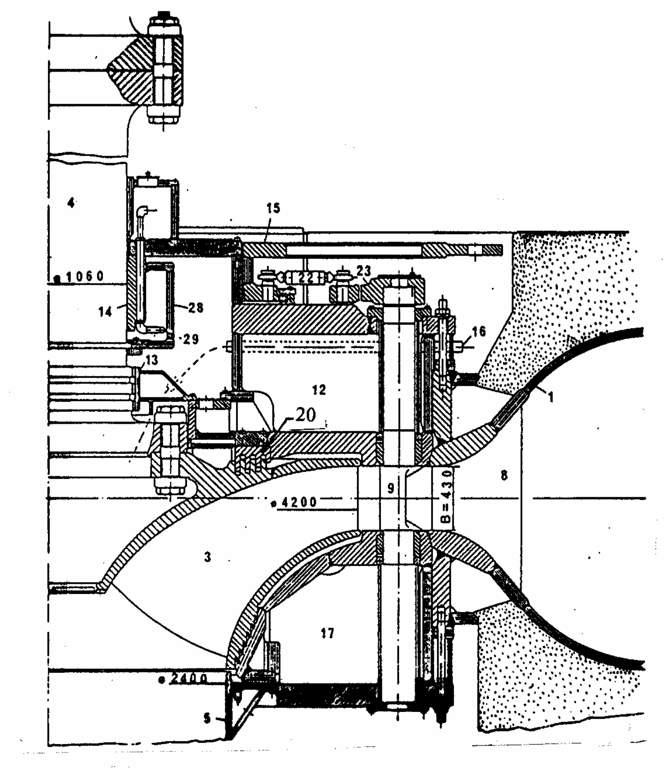


Fig.7.4 Vertical Francis turbine, axial section (Courtesy of Kværner Brug)

In the following considerations only main components[1] which are vital are dealt with. These components are:

- Scroll casing
- Guide vane cascade
- Turbine covers
- Runner
- Shaft
- Bearing
- Shaft seal
- Regulating mechanism
- Draft tube

7.3.1 Scroll casing

The water from the penstock is conducted through the scroll casing and distributed around the stay ring and the complete circumference of the guide vane cascade.

The scroll casings are normally welded steel plate constructions for turbines at low, medium as well as high heads. An example of this type is shown on Fig. 7.4. This type is made for heights of 600 m to 700 m. However, scroll casings are also made as a combination of cast steel and steel plates in a welded construction.

The stay ring as shown on Fig. 7.4, consists of an upper and a lower ring to which the stay vanes (8) are welded. The stay vanes are given a favourable hydraulic shape to conduct the water towards the guide vanes with minimal losses. The stay vanes also carry the axial forces inside the scroll casing.

The scroll casing is provided with taps for pressure measurements, drain, air vent outlets and a manhole.

Analogous to Fig. 7.3 the scroll casings are partly or completely embedded in reinforced concrete.

7.3.2 Guide vane cascade

The guide vane cascade is represented by pos. (9) on Fig. 7.4. The openings of the guide vanes are adjustable by the regulating ring (15), the links (22) and levers (23).

The vanes are shaped according to hydraulic design specifications and given a smooth surface finish. The bearings of the guide vane shafts are lubricated with oil or grease.

7.3.3 Turbine covers

The covers are represented by pos. (12 and 17) on Fig. 7.4. These covers are bolted to the stay ring of the scroll casing. They are designed for high stiffness to keep the deformations caused by the water pressure at a minimum. This is of great importance for achieving a minimal clearance gap between the guide vane ends and the facing plates of the covers. Between the runner and the covers the clearance is also made as small as possible.

For high head turbines with sand in the water flow an intense wear is expected. Therefore it is common to weld layers of wear resistant stainless steel on the exposed surfaces. The upper and lower cover facings adjacent to the guide vanes are normally lined with high tension stainless steel. This may either be fastened to the covers with screws or clad welded.

The covers are supporting the guide vane trunnion bearings. The upper cover supports also the regulating ring bearing, the labyrinth ring, the turbine bearing and the shaft seal box. The lower cover supports the lower labyrinth ring and the draft tube cone.

The stationary labyrinth rings fixed to the covers are usually made of Ni-Al bronze, and they are replaceable. For large turbines the labyrinth rings are replaceable for the runners as well. The rings for the runners are usually made of stainless steel 13 % Cr 4 % Ni.

7.3.4 Turbine runner

The turbine runner pos. (3) on Fig. 7.4, may either be of cast steel or a welded construction where hot pressed plate blades are welded to the cast hub and ring. In most cases the runner is made of stainless steel.

As examples of runners Fig. 7.5 shows a photograph of a low head turbine and Fig. 7.6 shows a photograph of a high head turbine.

Fig. 7.5 Low head Francis turbine

Fig. 7.6 High head Francis turbine

The manufacture however, may be different from one manufacturer to the other and depends on the size and speed number.

The water flow through the labyrinth seals is a leakage flow and is not utilised by the runner. This flow is depending on the seal clearances. In a new turbine the seal clearances are small and the leakage flow losses lower than 0.5 %. However, during turbine operation the seals are worn, the leakage increases and the turbine efficiency decreases. Sand laden water causes a fast seal wear, and for high head turbines an increase of leakage losses of 2 - 5% has occurred after a relatively short running time.

On high head turbines the leakage water is normally utilised as cooling water for the generator, transformers and bearings. The runner is provided with a pump ring which is indicated on Fig. 7.7. This ring is pumping sufficient power for the cooling water system and prevents water to reach the labyrinth shaft seal. Through outlets in the upper cover filtered water is then provided.

Low head turbines cannot be provided with a similar pumping device because of low rotational speed. Instead the seal water normally runs through holes in the hub and directly into the draft tube.

The runner torque is transferred to the turbine shaft through a bolted friction joint or a combined friction and shear joint as shown on Fig. 7.7. For large dimensions the bolts of this joint are prestressed by means of heat. The bolts are made from high tensile strength steel and provided with a centre bore for measurements of elongation during prestressing.

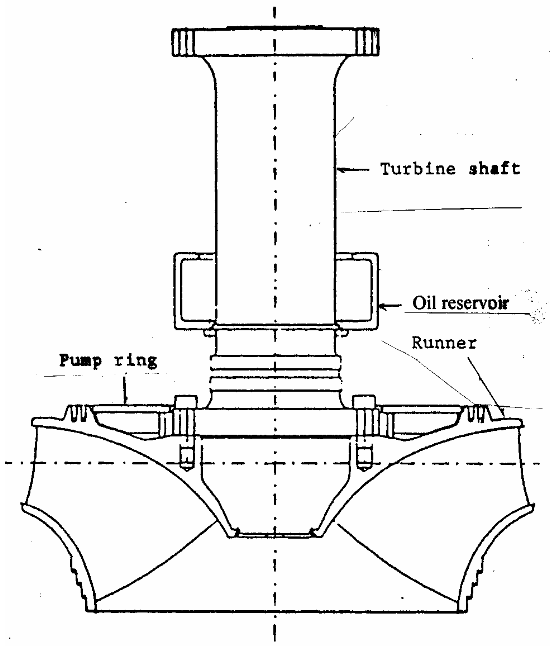


Fig 7.7 Rotating parts of a Francis turbine /1/

7.3.5 Turbine shaft and bearing

The turbine shaft Fig. 7.7, is manufactured from Siemens Martin steel and has forged flanges in both ends/1/. The turbine and generator shafts are connected by a flanged joint. This joint may be a bolted reamed or friction coupling where the torque is transferred by means of shear or friction.

An oil reservoir is bolted to the turbine shaft as shown on Fig. 7.7. On Fig. 7.8 this oil reservoir (2) is shown together with the construction of the bearing system.

This bearing is a rather simple and commonly used design and has a simple way of working and a minimal requirement of maintenance. The bearing house (1) Fig. 7.8, is split in two halves and mounted on the upper flange of the upper cover.

The bearing pad support ring (3) consists of two segments bolted together and mounted to the under side of the bearing house. The pad support ring has four babbit metal bearing surfaces with correctly shaped leading ramps ensuring stable centring of the turbine shaft. In the pad support ring there are also four oil pockets. The upper part of the housing has a cover (5) split in two halves with inspection openings.

The cover is provided with a cylindrical extension sleeve around the shaft reaching to the bottom of the housing, but leaving a slit for the oil to access the bearing pads. The extension prevents the oil in the housing from rotating with the shaft. The bearing pad support ring is surrounded by the oil reservoir. A riser pipe connected to an oil scoop passes through the bottom of the stationary bearing house and bearing pad support ring.

Under rotation the centrifugal forces keep the oil as a layer along the vertical cylindrical wall of the reservoir. The stagnation pressure from the rotating oil at the inlet end of the scoop, forces oil through the riser and cooler to the stationary upper oil reservoir.

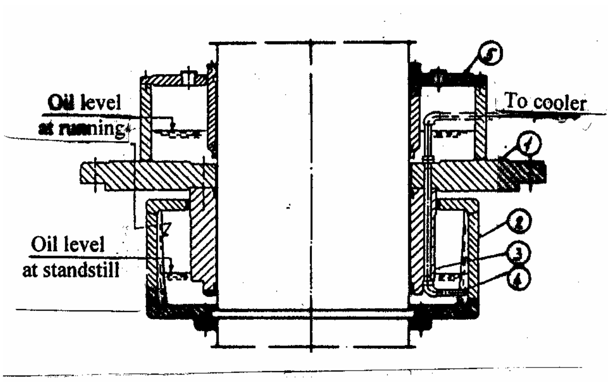


Fig. 7.8 Radial bearing of a vertical Francis turbine /1/

From the upper reservoir cooled oil flows to the pockets in the pad support ring. From these pockets the oil film follows the shaft rotation, enters the bearing segments and establishes the load carrying film in the bearing pads. Finally the oil comes back to the rotating reservoir from where a new circulation round starts.

The oil volume in the rotating reservoir is regulated by positioning the oil scoop at a certain distance from the reservoir wall.

7.3.6 Shaft seal

The location of the shaft seal is shown at pos.(13) on Fig. 7.4. An example of some details of a certain seal design/1/ is shown on Fig. 7.9. This shaft seal is split in two halves and mounted on the upper cover.

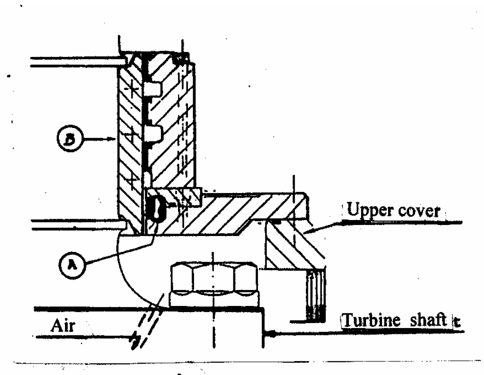


Fig.7.9 Shaft seal of a vertical Francis turbine /1/

The seal surfaces are lined with babbit metal, and depending on speed and size there are as small radial clearances as 0.2 - 0.4 mm between the surfaces of the shaft seal and the sleeve (B). The sleeve is made of corrosion resistant material and fixed to the shaft.

With the special pumping ring system mentioned above, the clearances in the seal box will run without water when the turbine is running. This is why the seal box can be given a design without contact between the babbit lined labyrinth and the shaft sleeve. A labyrinth seal of this type is suitable for operation in sand laden water because no sand will reach the seal while the turbine is running at normal speed.

At stand still a submerged turbine with open draft tube gate, is exposed to a downstream water pressure. A water leakage flow may then penetrate through the upper labyrinths and the seal box. This leakage water is removed from the box by a siphon pipe to the power house drainage pump sump.

For very deep submergence of the turbine an inflatable rubber seal ring (A) is installed in the labyrinth seal box. This ring is inflated during stand still in order to prevent leakage. During operation the air pressure inside the rubber seal is released and the rubber is not in contact with the shaft.

By means of the inflatable rubber seal it is possible to perform the dismantling of the shaft seal box without emptying the draft tube. At standstill the seal is activated by means of air pressure to compress the seal against the rotating sleeve (B) for establishing a droptight seal.

At certain loads unstable flow may occur in the draft tube downstream of the runner. In some cases this can be stabilised by air supply. This air may be supplied through a separate air supply pipe connected to the shaft seal box.

Instead of the design described above, the shaft seal box may also be designed with carbon rings. These are without clearance to the rotating parts and therefore subject to certain wear. Water cooling is necessary to a carbon seal and it cannot run dry without damage.

7.3.7 Regulating mechanism

The regulating mechanism is located by pos. (15) in Fig. 7.4. The design of the mechanism[/1/] is shown in more detail on fig. 7.10.

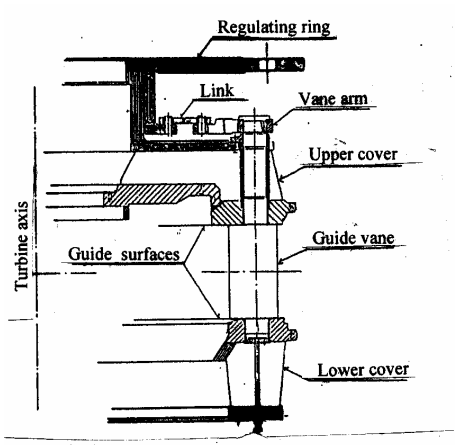


Fig. 7.10 Regulating mechanism of a Francis turbine /1/

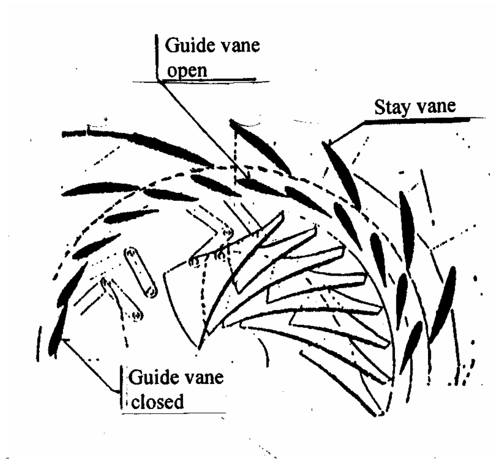


Fig. 7.11 Guide vane regulating system of a vertical Francis turbine /1/

The guide vane mechanism provides the regulation of the turbine output. Together with the governor it is able to maintain a stable speed of the unit and the frequency in the electrical distribution grid.

The turbine governor controls the servomotor which transfers its force through a rod to the regulating ring. This ring transfers the movement to the guide vanes through a rod, lever and link construction. A section through a part of the guide vane cascade, the stay vanes and the runner is shown on Fig. 7.11. The guide vane exit area in flow direction is varied by an equal rotation of each of the guide vanes.

The vane levers are mounted on the upper trunnion and fixed by a wedge, shear pins or pure friction joint.

The guide vane lever and regulating ring are connected through links. These links are connected through selflubricated spherical bearings on trunnions on the regulating ring and the lever respectively.

The trunions are positioned on the guide vanes for achieving minimal regulating forces from the hydraulic forces acting on them.

7.3.8 Draft tube

The draft tube (34) on Fig. 7.3, forms the water conduit from the runner to the draft tube outlet. Fig. 7.12 shows a draft tube in more detail[/1/]. It consists of the draft tube cone and the draft tube steel plate lining.

The aim of the draft tube is also to convert the main part of the kinetic energy at the runner outlet to pressure energy at the draft tube outlet. This is achieved by increasing the cross section area of the draft tube in the flow direction. In an intermediate part of the bend however, the draft tube cross sections are decreased instead of increased in the flow direction to prevent separation and loss of efficiency.

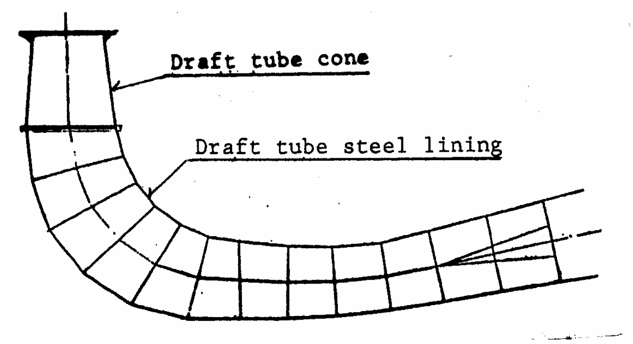


Fig. 7.12 Draft tube of a vertical Francis turbine /1/

The draft tube cone is a welded steel plate design and consists normally of two parts, the upper and lower cone. The inlet part of the upper cone is made of stainless steel. It is normally provided with two manholes for inspection of the runner from below. The lower part is designed as a dismantling piece and is mounted to a flange on the draft tube bend top. This design is always used for units where the runner is dismantled downwards.

For units being dismantled upwards the draft tube cone is made in one piece.

The draft tube lining is completely embedded in concrete.

7.4 Drainage and filling arrangements

A normal drainage and filling arrangement[/1/] is shown in Fig. 7.13.

The penstock cone and the scroll casing of a submerged turbine can be drained to a level corresponding to the tail water level through the draft tube. The draft tube is normally filled tube gate.

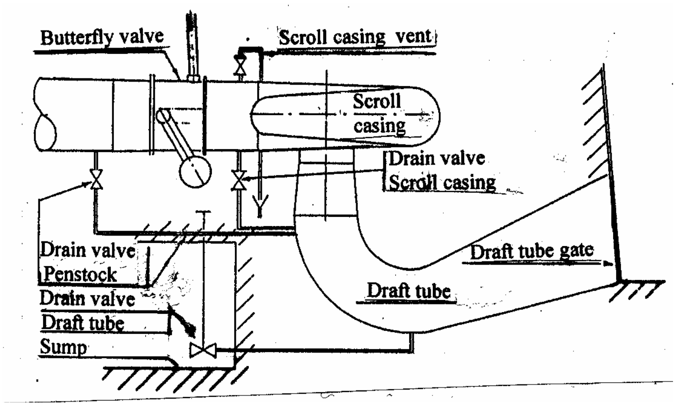


Fig. 7.13 Draining and filling system of a Francis turbine /1/

A turbine that is not submerged, the draft tube and the scroll casing are filled from the penstock.

7.5 Condition control

Routine inspections

Routine inspections means visual inspection of the complete turbine:

- look for possible leakages
- inspect bolted connections
- drain pumps should be inspected and level switches tested.

RPM shutdown curve

The activity is to record the RPM with 30 seconds intervals from the moment of closed guide vanes to standstill of the unit. The RPM shutdown curve should be drawn from nominal RPM to standstill.

Leakage control of guide vanes

The activity is to record the RPM with the spherical valve open and the guide vanes closed.

Shaft alignment

The activity is to record the shaft misalignment by means of a micrometer dial instrument against the shaft at the turbine bearing top. The misalignment should be recorded at different loads on the unit.

Labyrinth seal water flow

The assessment of wear and control of the labyrinth rings is possible by measuring the labyrinth water flow.

Runner

Visual inspection of the runner is required to record possible cavitation and erosion damages as well as cracks in vanes. The inspection of the inlet is done from the scroll casing. Three of the guide vane arms should be dismantled and the guide vanes rotated by hand to open position. The unit should be rotated manually to enable inspection of the complete runner circumference. The outlet side of the runner should be inspected from the draft tube cone.

Scroll casing and draft tube

The activity is to carry out inspection of painting for possible corrosion and ensure that all manometer connection openings are open and that the manhole cover is drop tight after completed inspection.

Guide vane mechanism

The guide surfaces of the covers should be inspected from the scroll casing and possible wear recorded.

Visual inspection of the surfaces of the guide vanes. The clearances between the guide vanes and the cover surfaces and the clearance between guide vanes should be checked.

Look for possible leakages in the guide vane bearings. Look for slacks in the bearings of the guide vane arms and links.

Check the connection between regulating ring and the servomotor.

Shaft seal box

During operation water will normally not flow over the shaft seal box. It may however happen during start and stop. If water runs into the upper cover it is removed by a drain pump.

Turbine bearing

The same activities as for Pelton turbines.

7.6 Monitoring instruments

The turbine is provided with instruments usually as presented in the following list:

- A manometer connected to the scroll casing
- A manometer connected to the penstock upstream of the main valve
- A pressure switch with two minimum settings connected to the penstock upstream of the main valve
- A mano-vacuum meter directly mounted to the draft tube cone
- A manometer connected to the leakage pipe
- A limit switch for signal of stand still seal on

The bearing is provided with:

- A contact thermometer in for high and critical high temperature control
- A remote thermometer for oil temperature measurements in the bearing housing
- A level switch for high and low oil level warning. This hangs together with cooling water leakage

7.7 Assembly and dismantling

The assembly and dismantling is important part of the design of the turbines and the arrangement of the installation. The objective is to make those duties as convenient and easy as possible. Wear will occur sooner or later in the guide vane mechanism as well as in the upper and lower runner labyrinths depending on the water quality and the operating head.

Medium and high head Francis turbines with free access to the draft tube cone provide good opportunities for fast dismantling and assembly of vital parts.

A widely used method is to dismantle the main parts downwards and then lift them up on the floor in the machine hall by using the main crane in the power station. The parts in question are the runner, lower cover and the labyrinth rings. Furthermore the turbine bearing should be easily removable. Dismantling of the upper cover is seldom required. Possible damage to the surface adjacent to the guide vanes is easily repaired on site.

Assembly or dismantling downwards requires a comparatively large opening below the scroll casing. This may be difficult to achieve with low head turbines with large dimensions because the load carrying concrete around the scroll casing occupies space needed for access. These turbines however, are not so much exposed to wear in the labyrinths and other components. The draft tube cone is often embedded in concrete, and the complete turbine must be dismantled upwards after prior removal of the generator rotor.

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