CHAPTER 8

Kaplan Turbines

Introduction

Kaplan turbines have been developed to be the most employed type of turbines for low heads and comparatively large discharges when the speed number $^{*}\underline{\Omega} > 1.0$. The Kaplan turbines are fairly suitable for the purpose of three main reasons:

- relatively small dimensions combined with high rotational speed
- a favourable progress of the efficiency curve
- large overloading capacity

The runner has only a few blades radial oriented on the hub and without an outer rim. The water flows axially through. The runner blades have a slight curvature and cause relatively low flow losses. This allows for higher flow velocities without great loss of efficiency. Accordingly the runner diameter becomes relatively small and the rotational speed more than two times higher than for a Francis turbine for the corresponding head and discharge. In this way the generator dimensions as well become comparatively smaller and cheaper. The comparatively high efficiencies at partial loads and the ability of overloading is obtained by a co-ordinated regulation of the guide vanes and the runner blades to obtain optimal efficiency for all operations.

8.1 Kaplan turbine construction

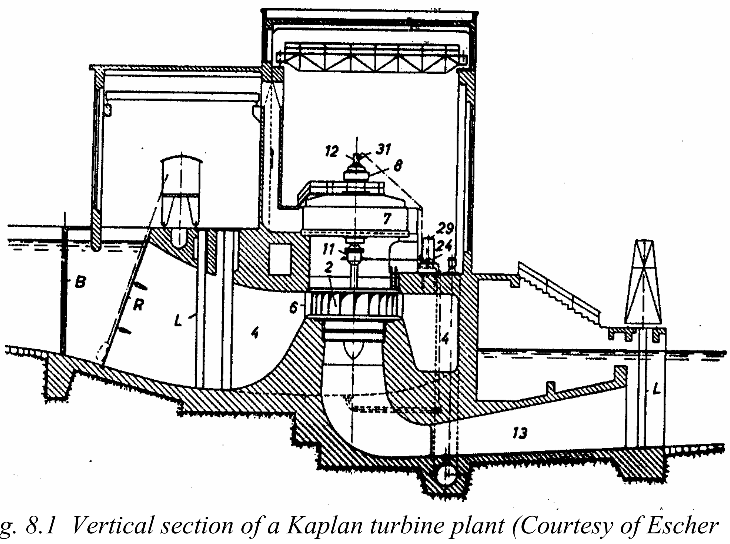

Fig. 8.1 Vertical section of a Kaplan turbine plant (Courtesy of Escher Wyss)

8.1.1 Arrangement

A vertical section through a Kaplan unit is shown on Fig. 8.1. From the upstream basin the water flows into the scroll casing (4). The water flows from the scroll casing through the stay ring (6), the guide apparatus (2), the runner and the draft tube (13) into the tail water basin.

The generator (7) is arranged above the turbine, and in most cases above the highest level of the tail water. The axial thrust bearing (8) is loaded with axial forces from all the rotating parts. In many cases this bearing is arranged upon the upper turbine cover, which then have to carry all the axial forces.

8.1.2 Kaplan turbine construction

A vertical section through a Kaplan turbine unit is shown on Fig. 8.2. The name of the main components are numbered and listed beside and below the figure.

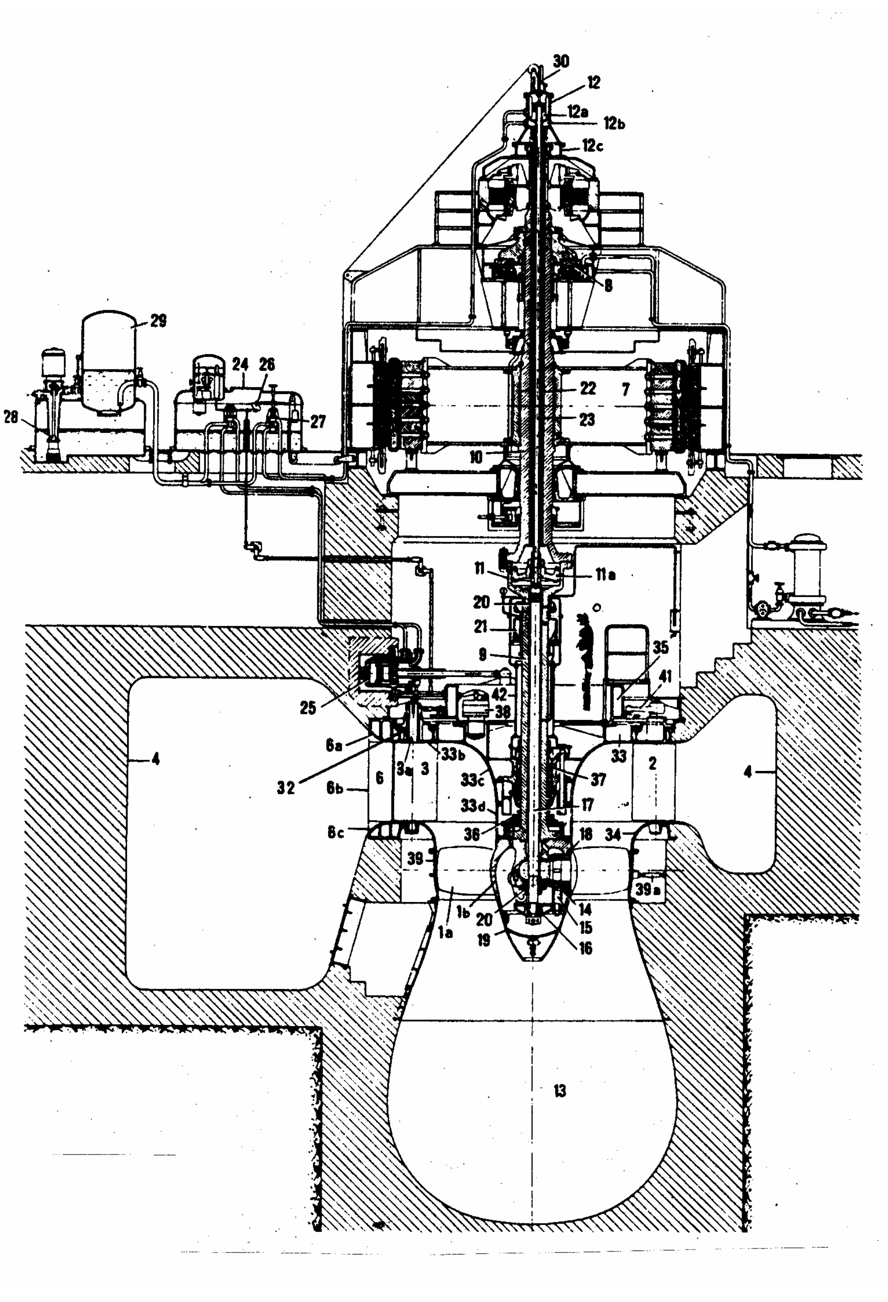

Fig. 8.2 Vertical section of a Kaplan turbine unit (Courtesy of Escher Wyss)

1a. Runner vanes
1b. Crown
2. Guide vane cascade
3. Guide vanes
4. Scroll casing
6a. Upper ring
6b. Stay vanes
6c. Lower ring
7. Generator
8. Axial-thrust bearing
9. Turbine shaft
10. Generator shaft
11. Runner vane servo.
11a. Servomotor piston
12. Oil inlet
12a. and 12b. oil chambers
12c. Oil collector
13. Draft tube
14. Regulating ring for runner vanes
15. Links from (14) to (15)
16. Lever spider for force transfer from (17)
17. Rod for force transfer from (11a)
19. Crown cover
20. Conveying of rod (17)
21. Rotating oil collector
22. and 23. Coaxial pipes
24. Turbine govrnor
25. Servomotor for guide vane cascade
26. Cam
27. Reg. valve for high pressure oil to runner servomotor
28. Oil pump
29. Accumulator
30. Lining for for feed back lever
31. Feed back lever
32. Turbine cover
33b. Outer cover
33c. Inner cover

33d. Base ring for bearin foot
35. Regulating ring
36. Shaft sealing box
37. Radial bearing
38. Outer shroud
39a. Horizontal supports
41. Guide vane lever
42. Stationary cover lining of turbine shaft

8.2 Main components and their functions

The Kaplan turbines have the following main components:

- scroll casing and stay ring
- guide apparatus
- covers
- runner
- runner blade servomotor
- regulating mechanism of the runner blades
- co-operation of regulating the runner blades and guide vanes
- turbine shaft
- turbine bearing
- shaft sleeve and seal box
- runner chamber
- draft tube

8.2.1 Scroll casing

The scroll casings for lower heads 25 - 30 meters are made of concrete. To make these type of scroll casings with the required accuracy, wooden models are used against which the concrete is poured. The manufacturer of the turbine determines the shape and makes the drawings of these models. The quality of a water tight and even surfaces of the scroll casings is required to be the same as for draft tube bends of concrete.

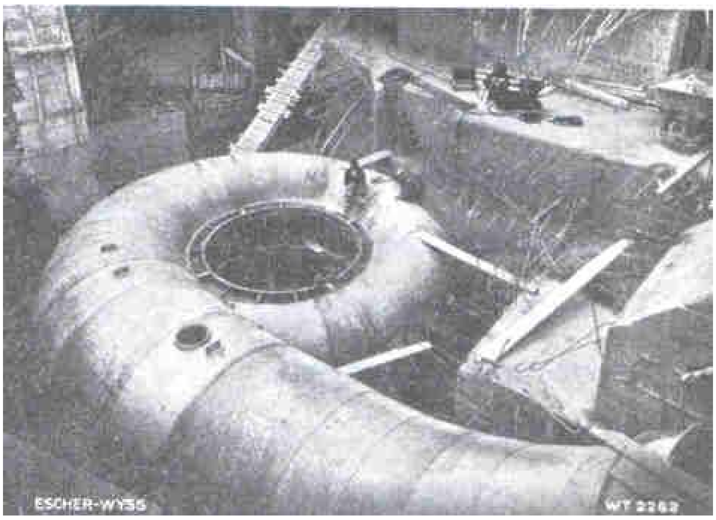

Fig. 8.3 Kaplan scroll casing of steel plates

For higher heads the hydraulic pressure may be too high for the concrete to withstand the load. In such cases scroll casings of steel plates are designed in a way analogous to that of Francis turbines as shown on Fig. 8.3. The cross sections of the scroll casing are normally of circular shape, and the steel plate shells are welded to the stay ring.

The vanes in the stay ring conduct the water towards the guide vanes. In addition the hydraulic forces are transferred through the stay ring and the stay vanes which are anchored to the concrete with large prestressed stay bolts. The stay vanes are normally made of welded steel plates and filled with concrete.

Fig. 8.4 shows a picture of the phase of installation of the stay ring. The lower part of the concrete scroll casing is completed.The upper stay bolts are installed and will be embedded together with the rest of the scroll casing.

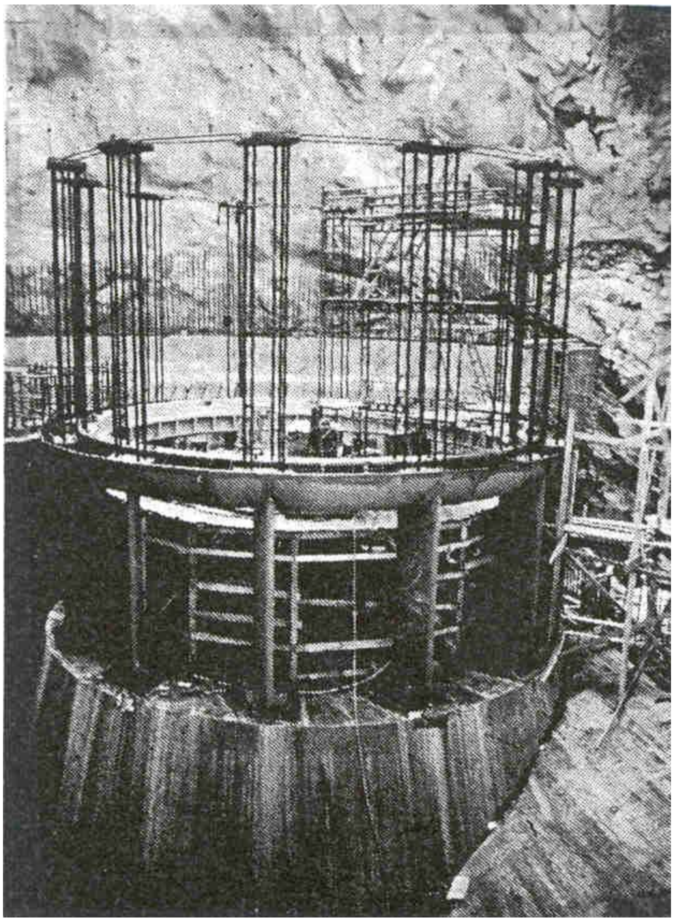

Fig. 8.4 Erection of a stay ring /1/

8.2.2 The guide vane cascade

The guide vane cascade of Kaplan turbines are constructed in the same way as for Francis turbines. In the sense of operation a regulating ring rotates the guide vanes through the same angles simultaneously when adjustments follow changes of the turbine load. The vanes are manufactured of steel plate material and the trunnions are welded to them. The vane design is purposely to obtain optimal hydraulic flow conditions, and they are given a smooth surface finish.

8.2.3 Covers

The Kaplan turbines are usually provided with an inner cover in addition to an upper and a lower cover. The inner cover is bolted to the upper cover and forms a shield from upper flow conducting surface and downwards to the runner. Furthermore this serves as a support for the guide vane mechanism with the regulating ring, the turbine bearing and the shaft seal box with standstill seal.

The lower turbine cover is combined with the runner chamber by a flanged connection.

8.2.4 Runner

The runner in a Kaplan turbine is a very challenging part to design. The details for adjusting the blades can be designed in different ways. Increasing blade number for increasing head may create problems because of lack of space and consequently high stresses in some details of the construction. It is not however, only the head that determines the number of blades. The blade length and shape as well as the specific blade loading and location in relation to the downstream water level, are factors which must be considered. As a general guideline four blades can be used up to heads of 25 - 30 meters, five blades up to 40 meters, six blades up to 50 meters and seven blades up to heads of 60 - 70 meters. Kaplan turbines have also been designed with 8 blades for heads even higher than 70 meters. This increases the hub diameter and the shape of the hub becomes more complicated, and the efficiency may suffer.

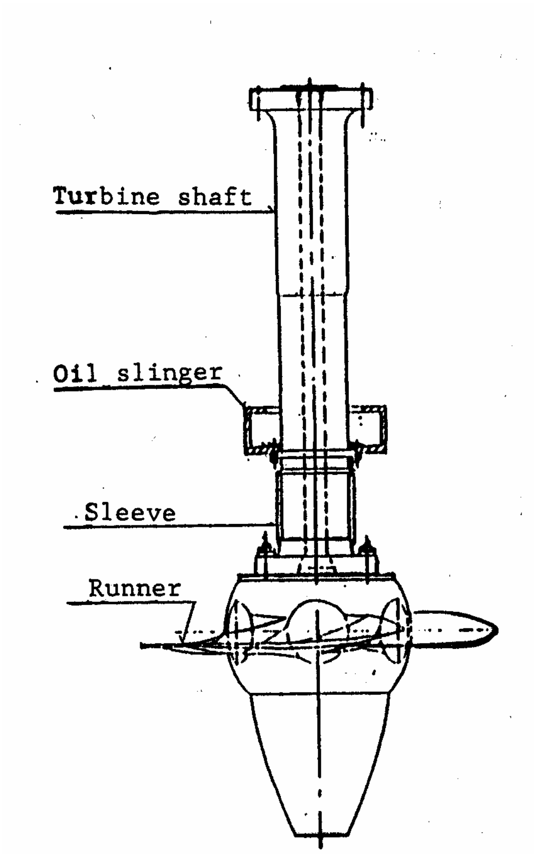

Fig. 8.5 Rotating parts of a Kaplan turbine /1/

The outside of the hub is spherically shaped[/1/] as shown on Fig. 8.5. This is done to keep a small clearance gap between the adjustable blade ends and the hub for all operating conditions. With increasing head the hub diameter is increasing from approximately 40% to 65 - 70 % of the runner diameter.

The torque of the runner is transferred to the turbine shaft through either a pure friction joint connection or through a combined shear bolt and friction joint. The bolts joining the turbine shaft flange and the runner are prestressed by means of heat for the largest bolt dimensions.

8.2.5 Runner blade servomotor

The servomotor for the rotary motion of the runner blades is either a construction part of the turbine shaft or located inside the hub. An example of the former type is shown schematically on Fig. 8.6, which is a concept from Escher Wyss.

There are however, good reasons for localising the servomotor inside the hub, and the details of a such construction are dealt with in the chapter of bulb turbines. This servomotor may consist of a moving cylinder and a fixed piston integrated with the hub. The conversion from axial piston movement to rotating blade movement is carried out by a link and lever construction.

The hub is completely filled with oil to provide reliable lubrication of moving parts. The oil pressure inside the hub is kept higher than the outside water pressure to prevent water penetration into the oil.

8.2.6 Regulating mechanism of the runner blades

An example of the regulating system of the runner blade slope is shown on Fig. 8.6. The slope of the runner blades (1a) are adjusted by the rotary motion activated by the force from the piston (11a) through the rod (17). The cylindrical extension of the upper end of the turbine shaft (9) serves as a servomotor cylinder (11) whereas the lower flange of the generator shaft serves as cover. The rod (17) moves in the two bearings (20).

The oil supply to the servomotor (11) is entered at the upper end of the generator shaft (10). The oil is conveyed to the respective sides of the servomotor through two coaxial pipes (22 and 23) inside the hollow generator shaft. The inner tube (22) conveys oil to and from the lower side of the piston (11a), whereas the annular opening between the pipes (22) and (23) conveys oil to and from the piston top side. The oil is supplied through the entrance arrangement (12) with the two chambers (12a) and (12b) at the top of the unit.

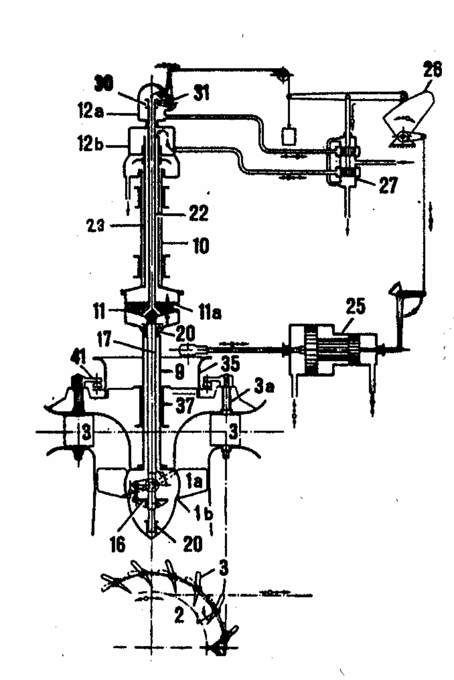

Fig. 8.6 Regulating mechanism

8.2.6 Cooperation of regulating the guide vanes and the runner blades

The turbine governor operates directly on servomotor (25) which executes the movement of the guide vanes (3) shown on Fig. 8.6. The movement of the servomotor thriggs and controls the slope adjustment of the runner vanes. This is carried out by a rod and lever transfer from the servomotor (25) to the cam (26) which is turned according to the movement of the servomotor piston (25). In this way the spool valve (27) is moved out of the neutral position and the servomotor piston (11a) is then put to movement by the oil pressure supply.

The spool valve (27) receives pressure oil either directly from the oil pump or from the accumulator which is energised by an oil pump.

8.2.8 Runner chamber

The clearance gap between the outer blade ends and the chamber wall is essential to keep as small as possible for all blade inclinations. Therefore the runner chamber is made spherical below the rotation centre line of the blade trunnions.

Ideally the spherical shape should have been maintained above the blade rotation centre as well However, on account of installation and dismantling aspects, this part is being made cylindrical as shown on fig.8.7, which is a concept of Escher Wyss. The gap between the runner blade ends and the runner chamber wall is approximately 0.1% of the runner diameter.

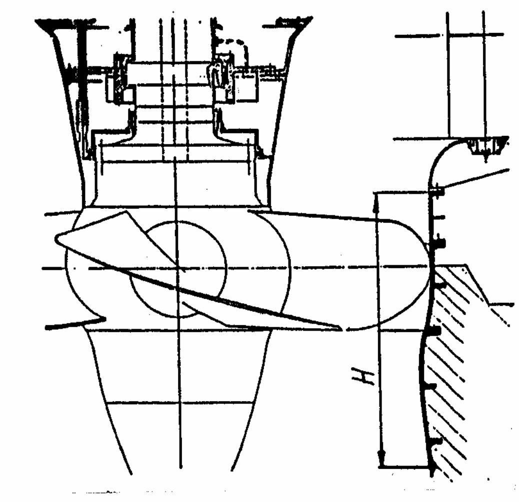

Fig. 8.7 Runner chamber

On fig. 8.7 the length of the runner chamber is indicated by H. At the lower end this chamber is welded to the draft tube via an extruded steel profile.

Cavitation erosion on the runner chamber may occur during the running time of the turbine. To reduce the magnitude of such erosion attacks and to ease the subsequent repair, the runner chamber is normally made of cast or welded stainless chromium nickel steel with higher cavitation resistance than carbon steel. Existing erosions may then be repaired by welding on site. The runner chamber is reinforced by external ribs.

The runner chamber is normally completely or partly embedded in concrete. The turbine shown on fig. 8.7 has an access tunnel around the complete circumference, providing access to the lower guide vane bearings. In combination with this tunnel there is a manhole access to the runner chamber for inspection of the runner blades.

In the lower part of the runner chamber there is a tap for connection of a vacuum meter. In the lower part holes are plugged by means of removable stainless steel plugs.

8.2.9 Turbine shaft

The turbine shaft Fig. 8.5, is made of Siemens Martin steel and is provided with integrally forged flanges in both ends[/1/].

In the area of the shaft seal box, a wear sleeve made of stainless material is clamped around the shaft. The rotating oil reservoir is bolted to the turbine shaft.

8.2.10 Turbine bearing

The bearing design is shown on Fig. 8.8 and the function is described in the chapter of Francis turbines[/1/].

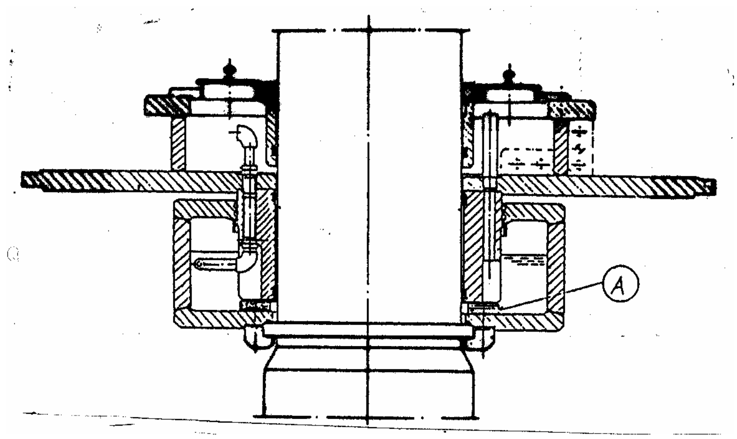

Fig. 8.8 Turbine bearing /1/

The only detail that deviates from the normal Francis turbine bearing is the back thrust slide ring A, which is bolted to the bottom of the rotating oil reservoir. By load rejections the turbine is subject to a vertical force acting upwards and this may cause a lifting of the unit. The back thrust ring then hit the underside of the bearing pads which transfer the vertical force to the base of the bearing.

The back thrust ring is made of bronze and is provided with lubrication grooves ensuring a good distribution of oil, and a load carrying oil film is then attained.

Low head Kaplan turbines are more exposed to lifting than high head Kaplan turbines. These turbines also have a comparatively higher speed increase at load rejections. With the guide vanes closed, the runner is pumping the water against the downstream water pressure. In this way a vertical upward force is created because the pressure above the runner becomes lower compared with the pressure below it. This effect increases with increasing speed.

8.2.11 Shaft seal box

A commonly applied seal box for Kaplan turbines is the carbon ring box of a type as shown on Fig. 8.9. The seal elements against the turbine shaft consist of specially made split carbon rings which are pressed against the shaft by means of spiral springs. The seal box is exposed to a fluctuating pressure from the turbine waterside and the rings must be located with this in mind. The turbine shaft is exposed to certain wear by the seal rings. The shaft which is passing through the seal box is therefore provided with a wear sleeve of stainless steel.

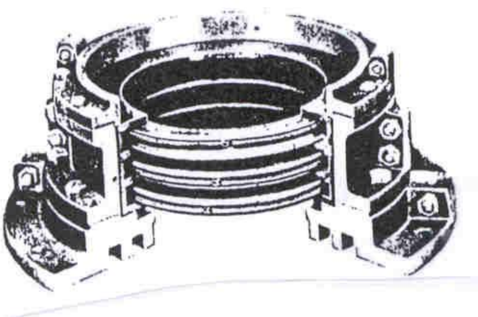

Fig. 8.9 Carbon ring seal box

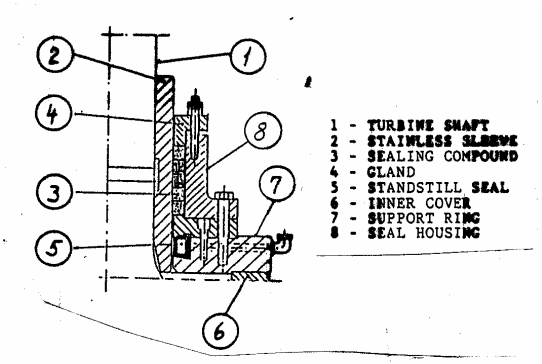

Fig. 8.10 Compound seal box /1/

A simpler seal box design[/1/] is shown on Fig. 8.10. This shaft seal is used for small and middle size turbines with moderate circumferential shaft speed.

The shaft seal box is mounted on the inner turbine cover (6). It consists of the support ring (7), seal housing (8), gland (4) and sealing compound (3). The sealing compound seals against a stainless sleeve (2) which is clamped to the turbine shaft (1).

By means of a gland (4) the sealing compound may be compressed, and a good sealing effect is obtained. Too hard compression may cause heating between the shaft sleeve and the sealing compound. To monitor this a temperature sensor is mounted in the seal housing. The sensor is connected to an alarm in the control room.

The inflatable rubber seal ring (5) which is used as a standstill seal, is described in the chapter of Francis turbines.

Leakage from the seal box is collected in a sump in the inner cover and is pumped to the station sump by float controlled pumps.

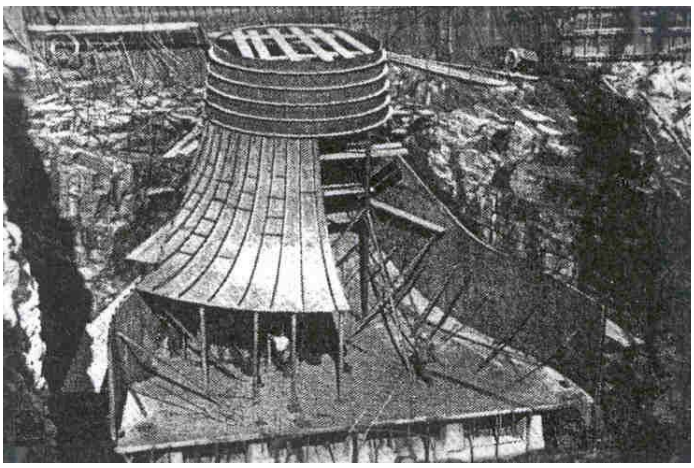

Fig. 8.11 Draft tube erection /1/

8.2.12 Draft tube

The draft tube consists of a draft tube cone and a draft tube plate lining through the bend.

The water has a relatively large velocity when it leaves the runner. This kinetic energy must be converted to pressure energy in the draft tube. To obtain this with a minimum of losses, the outlet velocity at the draft tube outlet should be as uniform as possible. Because the kinetic energy represents a high fraction of the total energy, the shape of the draft tube is of great importance for the hydraulic efficiency.

The draft tube of a Kaplan turbine has a somewhat special shape. The units have comparatively large dimensions and the civil works are expensive. It is therefore a requirement to make the draft tube as shallow as possible. The cone, the upper part and the inner curve surface are always lined with steel plates. The rest is normally made of unlined concrete. The formwork and the pouring of concrete are made as simple as possible by making the walls straight with single curved surfaces only.

The draft tube shown on Fig. 8.11, is welded from steel plate through the bend.

8.3 Drainage and filling arrangement

A normal drainage and filling arrangement is shown in chapter 7 about Francis turbines. A similar arrangement usually exists for a Kaplan turbine plant as well. Because of low head and large dimensions, it is normally not a main inlet valve upstream of the turbine. Instead an intake gate is installed at the top of the penstock. Drainage of inlet pipe and scroll casing is carried out by means of a common drainage pipe after the intake gate is closed. The inlet pipe may however be drained through the turbine down to draft tube level.

8.4 Condition control

The general principles for condition control are the same as for Francis turbines. Further considerations are therefore connected only to a few specific details.

8.4.1 Runner

The runner should be inspected both from above and below. Particular attention should be given to possible cavitation erosion and scratches on the blades as well as leaks around the blade flange against the hub.

8.4.2 Runner chamber

The narrow gap between runner and the runner chamber should be checked if foreign objects may have passed the gap and made scratches in the chamber.

8.4.3 Guide vane mechanism

For guide vane mechanism with individual vane servomotors on bulb turbines it should be checked that the vanes have an identical movement.

8.4.4 Shaft seal box

For bulb turbines at standstill it should be checked that the water does not flow out of the box along the shaft into the turbine bearing.

8.5 Monitoring instruments

The instrumentation consists mainly of the same components as for Francis turbines and is described in Chapter 7.

8.6 Assembly and dismantling

The cone and the runner chamber of a Kaplan turbine are normally completely or partly embedded in concrete. Therefore these parts can not be dismantled. Consequently all dismantling of the turbine therefore must be done upwards through the stator of the generator after removal of the generator rotor.

The parts in question for dismantling are first and foremost the inner cover and the runner. The inner cover is bolted to the outer cover. The smallest diameter of the outer cover is dimensioned to allow the runner to be lifted after dismantling of the inner cover.

Dismantling of the guide vanes may take place after the outer cover is lifted above the longest upper trunnion of the guide vanes.

By assembly or dismantling the runner may hang either by means of the brackets bolted to the runner chamber below the runner or by means of brackets bolted to the lower cover[/1/] as shown on Fig. 8.12.

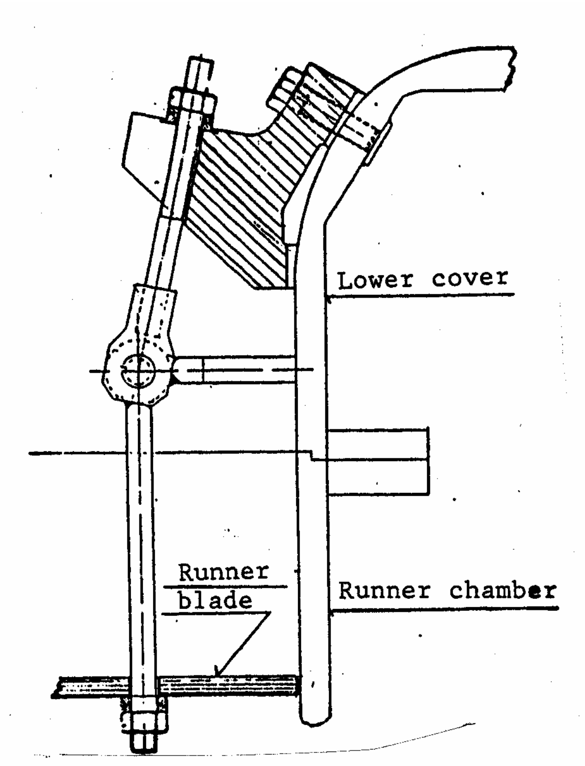

Fig. 8.12 Runner hanging device /1/

To replace a runner blade, it must be possible to dismantle a part of the runner chamber. This part is cut loose from the concrete and is pulled back. The blade may then be dismantled, pulled out and may be taken out through the draft tube.

References

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), Universitetsforlaget , Oslo, Norway 1980.
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 1989.
5. Wislicenus, G. F.: Fluid Mechanics of Turbomachinery, Volume 1 and 2, Dover Publication, New york, USA, 1965.