2.9.3 The balance piston

We have seen above that the Parsons turbine has a balance piston. We will now look into why this is necessary in a reaction turbine.

To this end, we will look at illustration 34. In this illustration the most important diameters have been indicated with the aid of bold arrows.

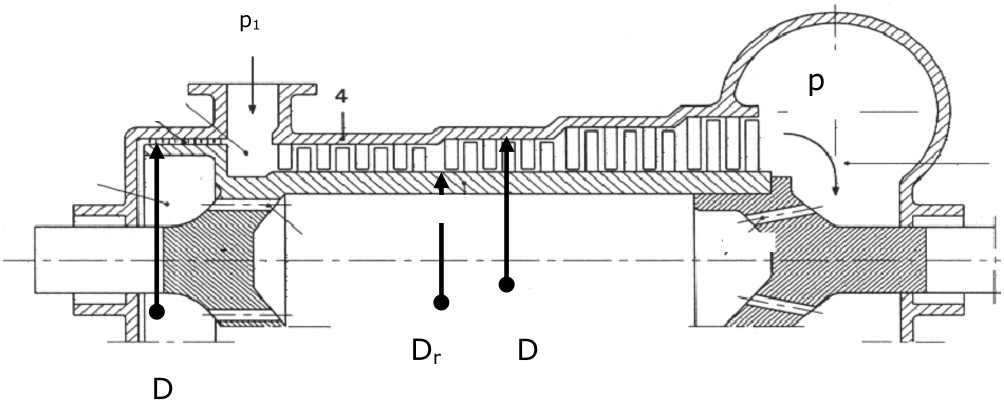

Illustration 34. Parsons turbine with balance piston.

Legend for illustration 34:

p_1	Initial pressure of the steam, entry pressure.
p_e	Terminal pressure of the steam.
D_e	Diameter of the balance piston.
D_r	Rotor diameter.
D_m	Average diameter measured at average blade height.
4	Casing.

Pressure difference

As we know, in the case of a reaction turbine the pressure drops in both the guide blades and the rotor blades. Normally speaking, the pressure difference that causes a force to the right would amount to $p_1 – p_2$. The pressure difference over the guide blades will however not exercise any force on the rotor, because the guide blades are mounted in the casing. The pressure .difference Δp which ensures that a force to the right is exercised on the rotor therefore amounts to:

$$\Delta p = \frac{p_1 - p_e}{2} \qquad [\mathrm{N/m^2}]$$

The pressure p_e is therefore also on the left of the balance piston via the equalizing vents.

The purpose of the balance piston is to cancel out the axial force towards the condenser and to take the load off the axial bearing, which is always required.

We are now going to use the following values in our calculations:

p_1	Initial pressure of the steam, entry pressure	N/m^2
p_e	Terminal pressure of the steam	N/m^2
D_e	Diameter of the balance piston	m
D_r	Rotor diameter	m
D_m	Average diameter measured at average blade height	m
F_r	The force to the right	N
F_l	The force to the left	N
F_{res}	The resulting force	N

Axial force

The axial force on the rotor towards the right, exit side, as a result of the pressure difference on the rotor blades.

$$F_r = \frac{\pi}{4} \cdot \left(D_m^2 - D_r^2\right) \cdot \frac{p_1 - p_e}{2} \qquad [N]$$

The axial force to the left on the balance piston:

$$F_l = \frac{\pi}{4} \cdot \left(D_e^2 - D_r^2\right) \cdot \left(p_1 - p_e\right) \qquad [N]$$

The resulting force will therefore amount to:

$$F_{res} = F_r - F_l \qquad [N]$$

Perfect balance

In the case of a perfect axial balance the following should however apply:

$$F_r = F_l$$

The outcome is then:

$$\frac{\pi}{4} \cdot \left(D_m^2 - D_r^2\right) \cdot \frac{p_1 - p_e}{2} = \frac{\pi}{4} \cdot \left(D_e^2 - D_r^2\right) \cdot \left(p_1 - p_e\right)$$

$$\left(D_e^2 - D_r^2\right) = \frac{\left(D_m^2 - D_r^2\right)}{2}$$

$$D_e^2 = \frac{\left(D_m^2 - D_r^2\right)}{2} + D_r^2$$

$$D_e^2 = \frac{\left(D_m^2 - D_r^2\right)}{2} + \frac{2D_r^2}{2}$$

Complete balance

We now find the diameter of the balance piston in the case of a *perfect* balance:

$$D_e = \sqrt{\frac{D_m^2 + D_r^2}{2}} \qquad [m]$$

2.9.4 Further theoretical considerations of the diameter of the balance piston

We refer to the average diameter as D_g and to the average blade height as h_g.

We can then argue that:

$$D_m = D_g + h_g$$
$$D_r = D_g - h_g$$

We now take the formula for the diameter of the balance piston:

$$D_e = \sqrt{\frac{D_m^2 + D_r^2}{2}}$$

This gives:

$$D_e = \sqrt{\frac{\left(D_g + h_g\right)^2 + \left(D_g - h_g\right)^2}{2}}$$

The outcome of this calculation is:

$$D_e = \sqrt{\frac{\left(D_g^2 + 2 \cdot D_g \cdot h_g + h_g^2 + D_g^2 - 2 \cdot D_g \cdot h_g + h_g^2\right)}{2}}$$

$$D_e = \sqrt{\frac{\left(2 \cdot D_g^2 + 2 \cdot h_g^2\right)}{2}}$$

$$D_e = \sqrt{D_g^2 + h_g^2}$$

In the case of the Parsons it is known that:

$$h_g \approx \frac{1}{10} \cdot D_g$$

This gives:

$$D_e = \sqrt{D_g^2 + \left(\frac{1}{10} \cdot D_g\right)^2}$$

Or:

$$D_e = \sqrt{D_g^2 + \frac{1}{100} \cdot D_g^2}$$

As the last term below the root is very small we find that:

$$D_e = D_g$$

We can now see that in the case of a perfect axial balance, the diameter of the balance piston is almost equal to the average diameter of the Parsons. However, if we replace several stages of the Parsons by a Curtis wheel, the diameter of the balance piston will increase because the Parsons gets shorter, as we will see later. If the Parsons turbine gets shorter, the average diameter will increase; the diameter of the balance piston must therefore also increase.

2.10 The Rateau turbine

The Rateau turbine is very similar to the Zoelly turbine. This turbine is often used as a control wheel in small installations.
The Rateau turbine is known for its exceptionally high efficiency. The distinctive difference between this turbine and the Zoelly turbine is solely the shape of the nozzle. Rateau type nozzles are not purely conically shaped but follow the shape of the steam flow.
Illustration 35 shows a nozzle made according to the Rateau principle.

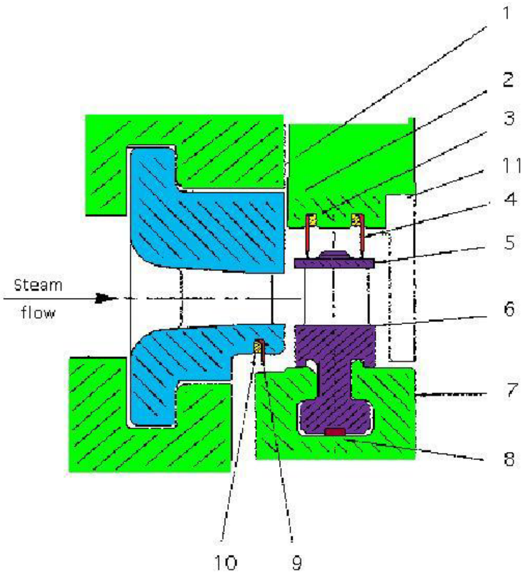

Illustration 35. Rateau nozzle with rotor wheel.

Legend for illustration 35:

1. Turbine casing
2. Nozzle segment
3. Locking strip for labyrinth
4. Labyrinth seal
5. Shrouding
6. Rotor blade
7. Rotor wheel
8. Shim
9. Labyrinth seal
10. Locking strip for labyrinth
11. Control wheel chamber

For purpose of comparison, a Zoelly-turbine nozzle is shown in illustration 36.

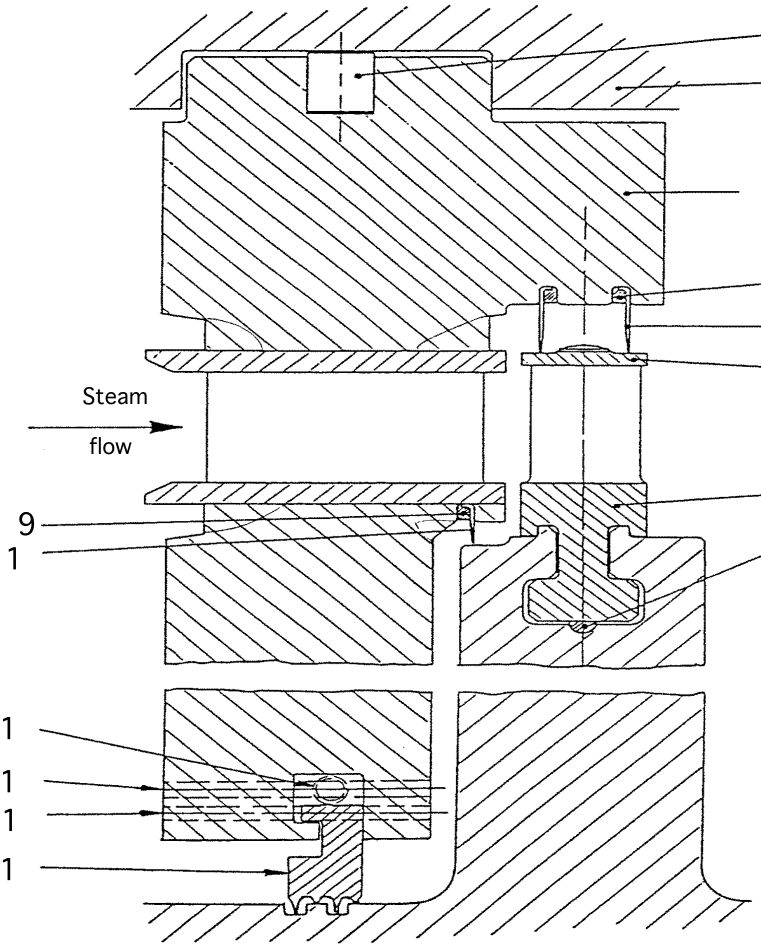

Illustration 36. A Zoelly-turbine nozzle.

Legend for illustration 36:

1. Shear pin
2. Turbine casing
3. Partition
4. Locking strip for the labyrinth
5. Labyrinth seal
6. Shrouding
7. Rotor blade
8. Shim
9. Locking strip for labyrinth
10. Labyrinth seal
11. Spring
12. Locking pin
13. Locking pin
14. Labyrinth seal

Illustration 37 shows a compound turbine. The first stage is a Rateau wheel followed by 15 Zoelly Stages and 3 Parsons Stages.

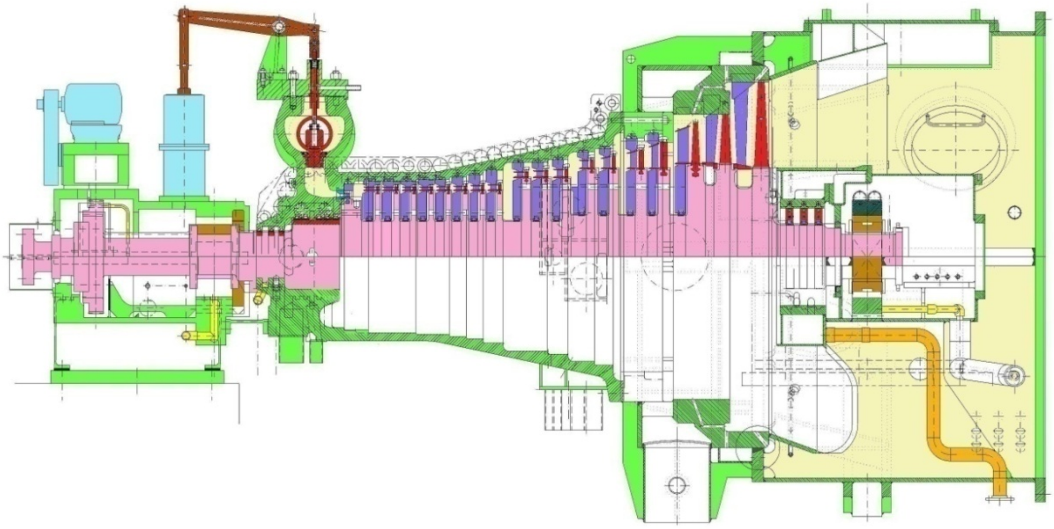

Illustration 37. Compound turbine.

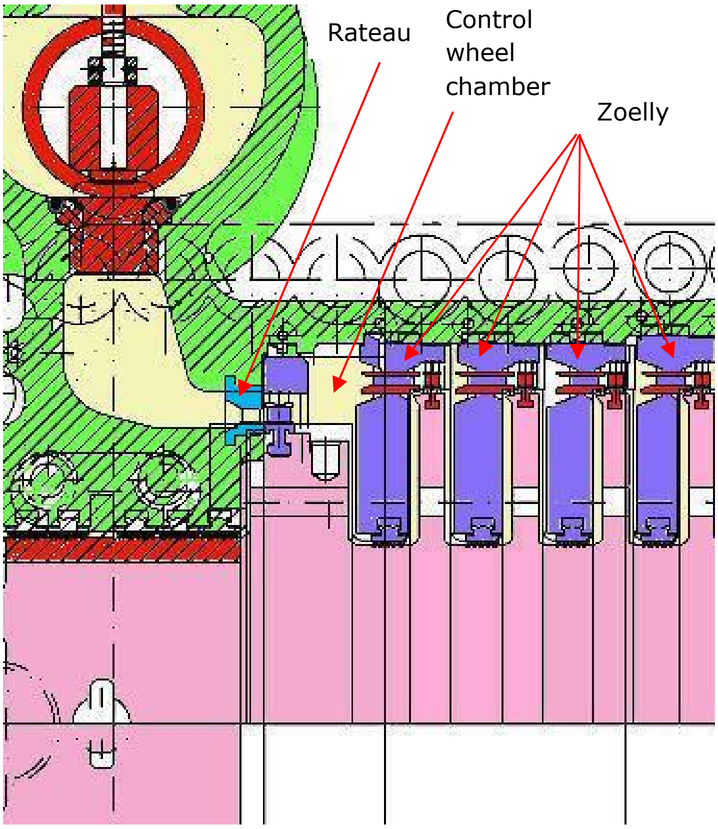

Illustration 38. Detail of the first stages.

2.11 Gland steam

Roughly speaking, there are two systems for supplying gland steam on the labyrinths, namely:

- A manually controlled system
- An automatically controlled system

2.11.1 The manually controlled system

Illustration 39 shows a manually controlled system.

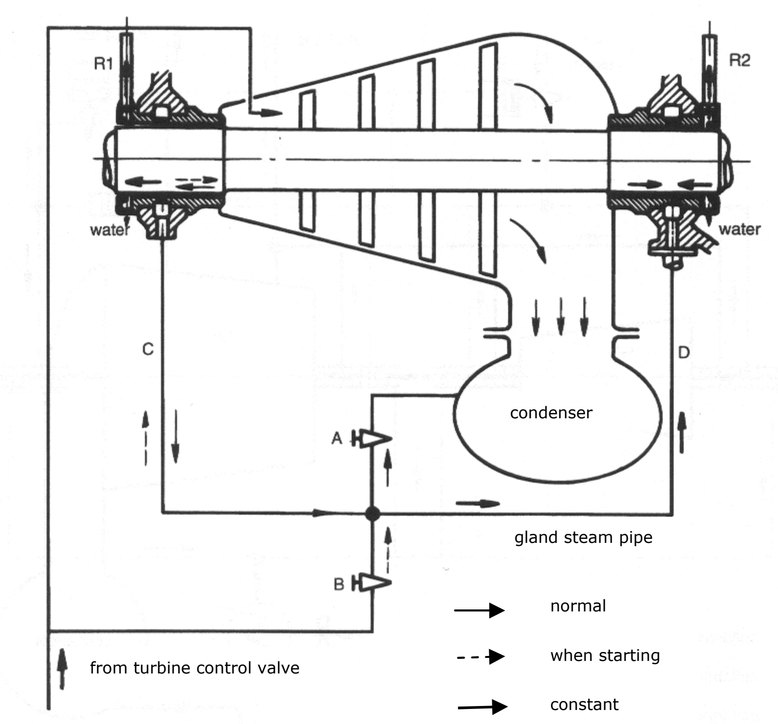

Illustration 39. Manually controlled gland steam system.

Steam is supplied to the system via control valve B. The pressure in the system is controlled with the aid of valve A, where steam is supplied to the condenser. When the turbine is switched on, steam is supplied to the glands via pipe C and D, as it is important to ensure that no air leaks in on both sides. The excess steam on the labyrinths is discharged via pipes R1 and R2. In the case of heavy loads, steam will flow from pipe C to pipe D, as the pressure in C is higher. In the case of low loads less steam will escape via pipe C.

It is obvious that in the case of changing loads, valve A will constantly need to be re-adjusted in order to keep the slight excess pressure in the gland steam system "constant".