Lezione 17 - Study of Different Types of Hydraulic Turbines.

We have looked at the analytical determination of the performance and optimization of the Pelton turbine.

We still need to look at how to change the operating condition, traditionally this is done by changing the geometry, in the case of the Pelton this is done by changing the shape of the nozzle.

The buckets have wholes to better allow the jet to flow when moving between buckets.

We can use a deflector while reducing the section to reduce the effect of water hammer.

The point of the nozzle is called a Dublole needles, which is moved back and forth to easily reduce the cross-section.

The Pelton turbine is easy to regulate, it doesn't suffer from cavitation (can work with H) and easy to startup, all while not loosing efficiency

since C_{ax} is highest at start

this isn't true for Francis and Kaplan since their C_{ax} depends on the velocity triangles, so at startup they act like pumps (*), so they require motors that can produce power as well as extract to help on startup.

(*) → since the triangles are so messed up on startup.

2x design velocity → dangerous.

If there is a blackout, the turbines go to escape velocity.

How do we stop the flow from causing damage?

1. Stop nozzle → problem: causes water hammer, causing immense damage, the flow doesn't know since we are no longer in steady state condition, the flow is gradually informed at the speed of sound, in the case of water the speed of sound is at least 10x the max speed we can reach. But no fluid is incompressible and the information needs to still propagate, in the time it takes to propagate, the water will still accumulate, this can either be done by destroying the penstock (if the penstock is perfectly

inelastic) or we increase (sometimes enormously) the pressure of the water (up to 100 bars)

This problem is called the water hammer problem.

To avoid this we can use a diverter to quickly reduce the effect of flow on the turbine, this can be done easily and quickly, this gives us time to reduce the size of the flow slowly avoiding water hammer.

For Francis and Kaplan we cannot use a deflector so we have to contend with reducing the nozzle area slowly accept the impact on our turbine, this means that for a bit our turbine will accelerate with $C_{nx}=0$, so we need to design it to consider this higher speed to reduce the damage caused.

Pelton turbine - design criteria:

$$\omega_{s,ot} = \frac{\omega Q^{1/2}}{(gH_m)^{3/4}} = \frac{d}{D}\sqrt{i}$$

i ↳ number of nozzles.

we can use u or v_1, since φ_{opt}, when $u = \frac{v_1}{2}$

→ relevant shape parameter of machine.

→ a bigger d means we have to consider the jet for a larger part of the motion, reducing efficiency as the triangles will not be optimal

When the d is very small there are parassitic losses which reduce efficiency.

d/D therefore is a parameter that needs to be optimized so we can reduce losses, and kept as stable as possible.

Design strategy for designing Pelton machine

Hm, Q are known.
↳ from L' target.

⇒ we have $\omega_{s,opt} \propto \omega$. and we know $H_m \propto U_{opt}^2 \propto \omega D^2$

⇒ $\omega_{s,opt}$ D has to be constant

Hydro-dynamics set d/D:

⇒ $\omega_{s,opt} \propto \sqrt{i}$ — to keep U constant.

Putting everything together. imposing the maximum value of i (6) ⇒ $\omega_{s,opt}$ increase ⇒ ω increases while D decreases ⇒ the constant decreases.

⇒ Small and fast machines since they are better for techno-economic optimization.
→ in general for hydraulic machines.

Reaction machines
↳ Centripetal / Mixed-Flow (Francis)
↳ Axial (Kaplan)

Reaction turbines are different from impulse turbines (Pelton) and can come in different types.
It's very rare to find a purely radial turbine

Kaplan machines are more useful at higher ω_s.
The higher the ω_s the more the machines get.

In high ω_s Francis turbines we can impose a change in cross section within the rotor since the blades already create a nozzle effect, so this increase in area just reduces the nozzle effect without causing diffusion.
We can increase the cross section very quickly without much negative effects, since draft tubes need a lot of space to increase the cross-section, they this helps us reduce the amount of space we take up.

Francis Turbines

↳ Basic optimisation rule, $V_2 = V_{2m}$, $V_{2t} = 0$

$$\Rightarrow l_{eff} = u_2 V_{2t} - u_1 V_{1t} = -u_1 V_{1t} = -u_1 V_1 \sin\alpha_1$$

We can define a k_p for Francis: $k_p = \frac{u_1}{V_1} \to l_{eff} = \frac{-u_1^2 \sin\alpha_1}{k_p}$

Reaction degree $\chi = 1 - \frac{v_1^2}{2gH_m}$
(for Francis)

$$\Rightarrow v_1^2 = 2gH_m(1-\chi) \Rightarrow \eta = \frac{|l_{ott}|}{gH_m} = 2k_p(1-\chi)\sin\alpha$$

$$\Rightarrow \chi = 1 - \frac{\eta}{2k_p \sin\alpha_1}$$

→ not very concrete, it doesn't really help us understand how to optimise.

→ Doesn't help at all to optimize

Typical design choices: → Of experienced designers and from data to see trends.

$\alpha_1 = 75-80^\circ$, $k_{p,ott} = \sin\alpha_1$

$\Rightarrow v_{1t} = u_1$ and $\chi = 0{,}5$, $l_{ott} = -u_1^2$

Comment: for a given motor head, the Francis needs higher u than the Pelton (for which $l_{opt} \approx -2u_1^2$)

→ Classic theoretical condition

→ We also need to consider cavitation, Francis needs to be underground.

Francis turbines can be used as pumps (when operated in reverse) and turbines, if we need it for a pumped hydro setup.

Kaplan Turbine

↳ Extreme (axial) Francis.

The distribution and stator are still radial but before it goes to the turbine it is made into being axial.

Features of a Kaplan turbine

Since H_m is very low, the machine is composed by few blades, mounted directly to the shaft

Blades have variable radii, due to their relatively high b/D ratio for the blades.

<u>Power control for Francis Turbines</u> → Common theory, comparison

Achieved by pivoting (or staggering) the stator/distributor blades ⇒ reduction of the throat between blades, so to reduce v_m.

The blades are not cambered, they are straight.

↳ This can have large effects on the velocity triangles. The geometric similarity is violated so we no longer consider similarity.

Changing the angle, causes the v_t after the rotor to no longer be null so we risk inducing cavitation.

↳ Still with cambered blades

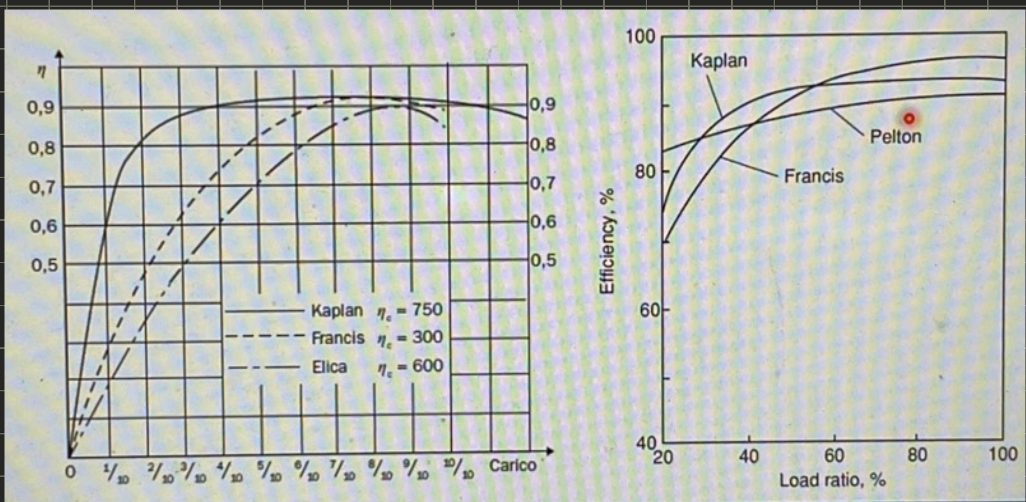
The change in the angle causes the reaction degree to change since w_{2t} changes a lot.

Because of how much everything changes, the ability to change L, is not for free, and there is a high cost for doing so, there is a severe penalty for off-design.

Kaplan turbine (in comparison to other ones)
↳ low stator/rotor blade numbers ⇒ both stator and rotor blades are pivotable. This is a way of compensating for the loss in efficiency that we see in Francis turbines.

Propeller-like rotors have less regulation than Francis.

The Pelton is the least efficient but it's the least penalised by a change in operating condition.



Impulse tend to have higher v, which means more losses so lower efficiency, which is why Pelton is low.