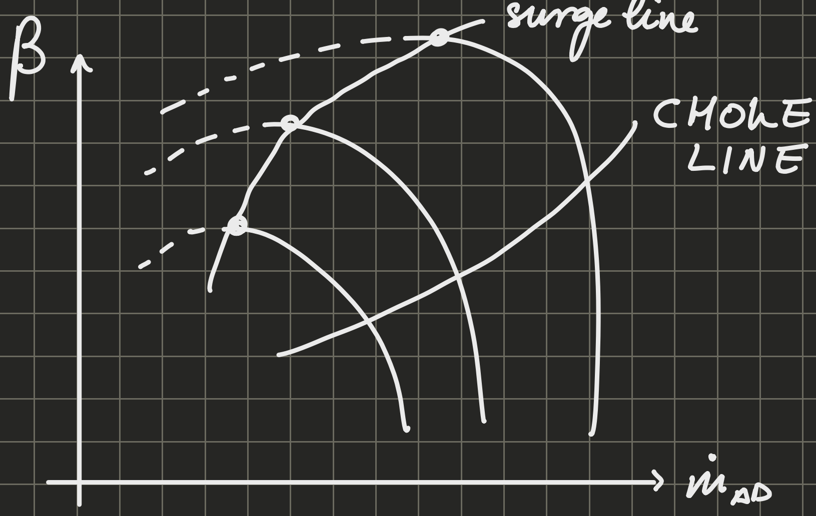
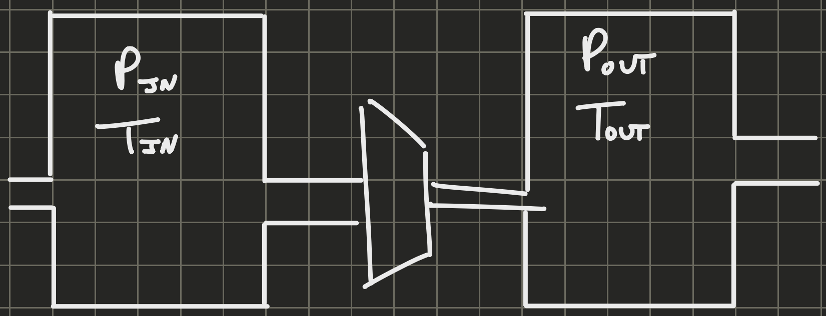
Lezione 25 - Axial Turbines

Surge Instability in Axial Compressors

If a compressor is tested alone, we can reconstruct the machine behaviour and reconstruct the curve.



The curve to the right can be measured, on the left it cannot be measured due to large noise.



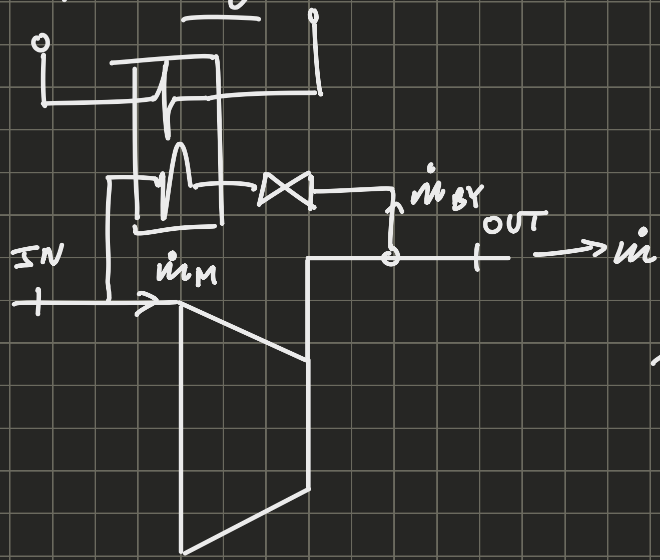
8 : 38

The compressor keeps the β. One we move to the left due to instability, there is mild ___, this is a perturbation. As this increases the flow rate goes back, causing the fluid to go back.

The velocity triangles are completely changed and so are the forces, slowly destroying the machine.

This backflow increases P_{IN} and decreases P_{OUT}, at some point $P_{IN} > P_{OUT}$, because it's an elastic system, the fluid the when P_{IN} is even bigger than P_{OUT} initial the flow will go back, and the flow continues to go back and forth, and at some point the machine explodes.

Bypass System → One method of avoiding surge



$\dot{m}_M > \dot{m}$

$\dot{m}_M = \dot{m}_{BY} + \dot{m}$

Theory: If we talk about turbocompressors, we first have to discuss about dimensionless quantities, then talk about curves, then talk about surge.

Uses for Axial-Flow Turbines → used mainly in energy generation.

There are many typical applications:
- Rankine Cycle → constructed around the water state diagram
  - → $\dot{m} = 500$ kg/s
  - → $\dot{L}$ can be up to 1 GW.

This cycle has a crucial role for superheater/turbine technologies on cycle optimization.
Any amount of efficiency we can extract is huge.

$Q_{OUT} / Q_{IN} \sim 100$

→ the cross section has to change by two orders of magnitude to dispose the same massflow rate at inlet and outlet of the turbine (constant V_m).

Limitations are in the maximum pressure ratio achievable with a single stage, and in the maximum flow rate passing through a feasible annular cascade.

$\boxed{9:00}$ A multi-stage axial configuration allows to combine the extreme flow rate with high pressure ratios.

There are different possible configurations

The machine has to operate at $n = 3000$ rpm, because no gearbox that works in those conditions do not exist, so since we need to produce electricity we need to spin at that specific speed.

The steam-cycle is not studied here.

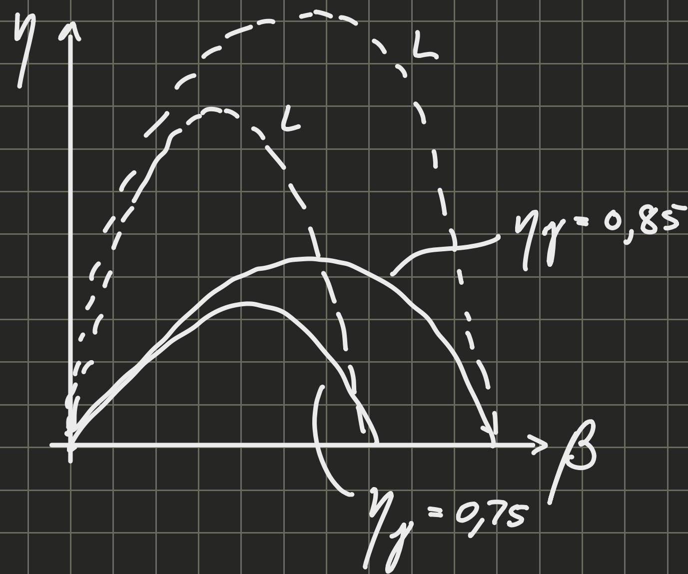
Second Application:
↳ Turbogas cycle
↳ Realization of the Joule-Brayton cycle with two nearly isentropic and one almost isobaric transformations.

$\dot{m} \sim 200\,kg/s$ $\beta \simeq 15 \div 45$

$\dot{L}$ can exceed easily 100 MW.

Turbomachine performance and technology are crucial for optimization.

We need T_3 to be very high, ~ 2000 K, which exceed material sustainability, but we can actively cool the blades.

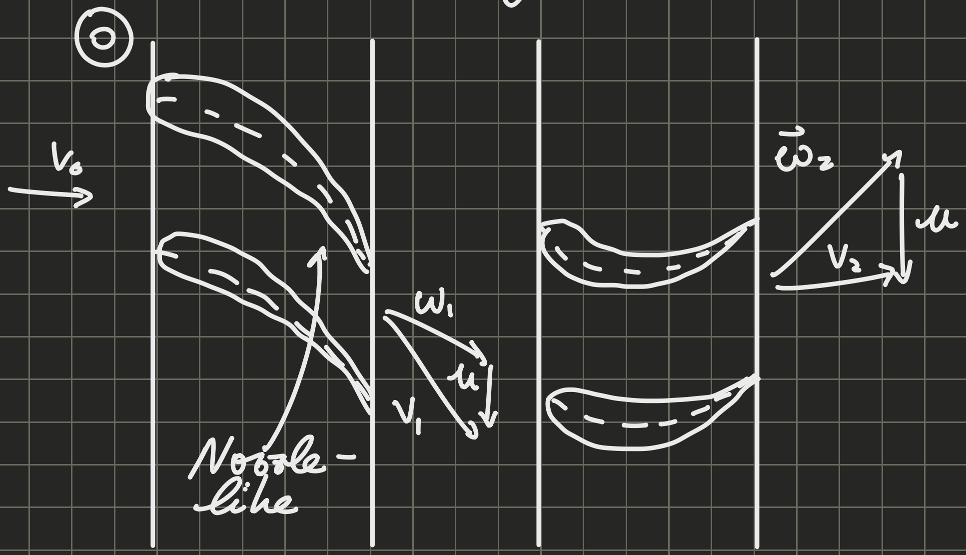


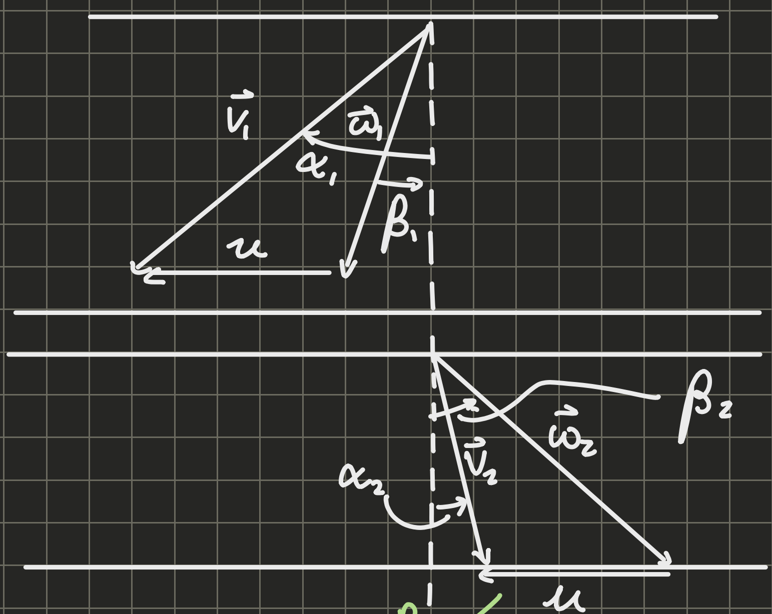
We use multi-stage compressors and turbines. The machine can operate on different shafts at different speeds.

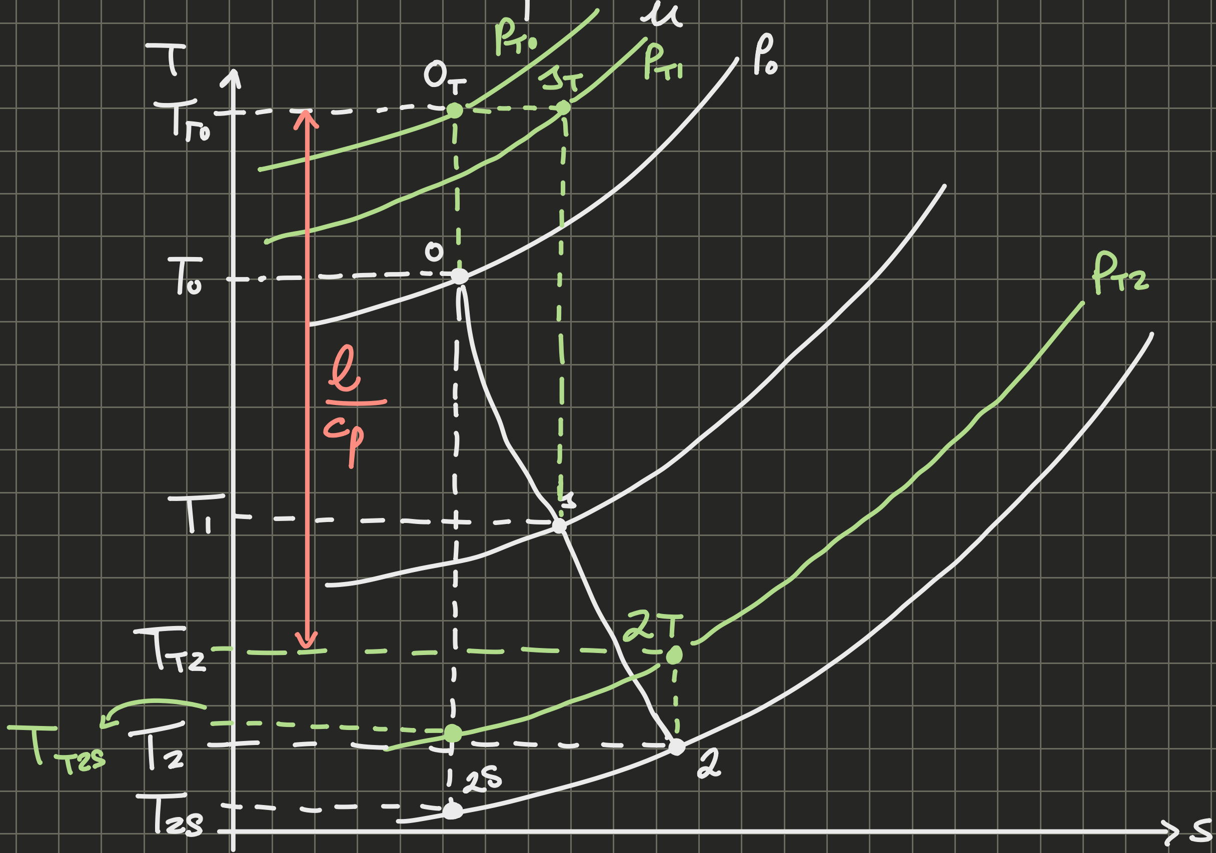
We use 2 compressors and 2 turbine, each operating at different pressures.

<u>Turbine-Stage</u>

Thermo-fluiddynamic diagram







$l + q = \Delta h_T$

STATOR: $l = 0,\ q = 0 \Rightarrow \Delta h_T = 0 \Rightarrow h_{T1} = h_{T0} \Rightarrow T_{T1} = T_{T0}$

ROTOR: $l \neq 0,\ q = 0 \quad \Delta h_T = l \Rightarrow l = c_p(T_{T2} - T_{T1}) = c_p(T_{T2} - T_{T0})$

$$\eta_{TS} = \frac{|l|}{h_{T0} - h_{2S}}$$

Total to Static efficiency

$$\eta_{TT} = \frac{|l|}{h_{T0} - \underbrace{\left(h_{2S} + \frac{v_2^2}{2}\right)}_{h_{T2S}}}$$

Should be v_{2S}

the calculate velocity if the transformation had been isoentropic.

$\eta_{TT} > \eta_{TS}$

Because η_{TS} consider also the loss due to discharged flow.

$$\chi = \frac{\Delta h_R}{l} = \frac{w_2^2 - w_1^2}{v_1^2 - v_2^2 + w_2^2 - w_1^2}$$

same definition, without sign, as compressor

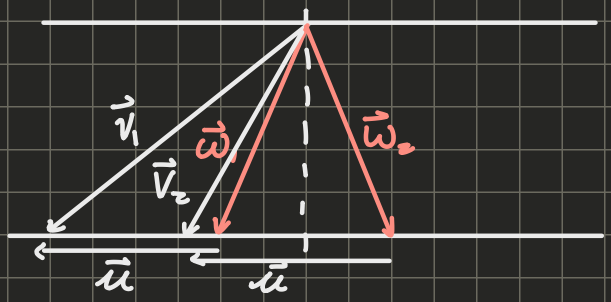
Stage-styles in axial turbines

↳ In turbines we have more creative liberty for designs.

Impulse Stage $v_m = \text{const}$

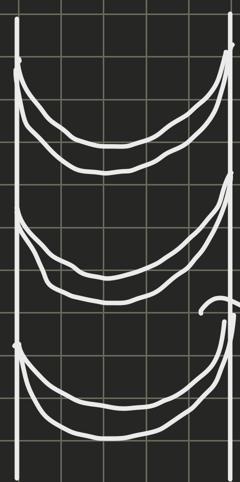
$\chi = 0 \Rightarrow \Delta h_R = 0 \Rightarrow |\vec{\omega}_2| = |\vec{\omega}_1|$

↳ like Pelton.

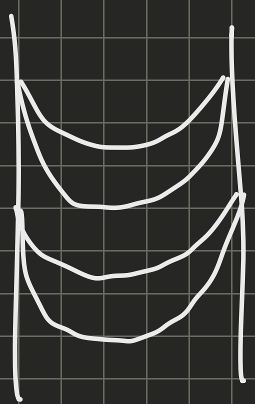


$|\beta_1| = |\beta_2|$

↳ Drew different to separate $\vec{v}_2$, but it is the same



This is a divergent, then convergent which will create adverse pressure gradients.

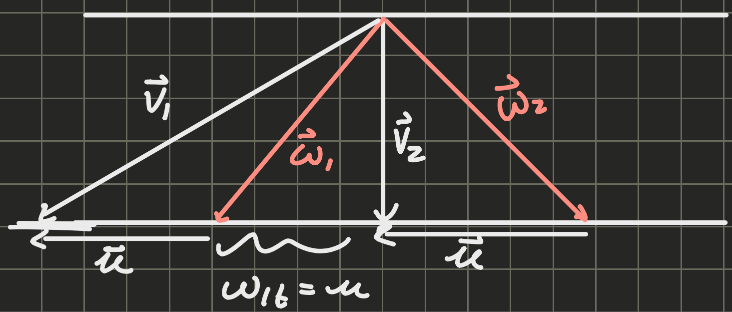


So we design around the channel instead of the blade (creative liberty) as to keep the channel in constant dimension.

9:56 → internet kept disconnecting.

Stage optimized if $v_{2t} = 0$!

To design we can start from the bottom instead of the top:



$$v_{1t} = v_1 \sin\alpha_1 = 2u$$

$$k_p = \frac{u}{v_1} \Rightarrow k_{p,opt} = \frac{\sin\alpha_1}{2}$$

$$l_{opt} = u(v_{2t} - v_{1t}) = -2u^2$$

In first approximation

ρ = const, D_m = const, v_m = const $\Rightarrow$ b = const

↳ Across the rotor, the b will change for the stator.