Theory of turbocompressors

A course of lectures. 3 semester.

Group 63238/10

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Theory of turbocompressors. *Lecture 6.*

CONTENT

Turbocompressor's stage theory basics

- **The "head" losses schematization when different working modes of the stage by consumption on the example of the impeller: canal losses and inlet losses (shock loss).**
- **Equation of the sudden expansion losses usage (Bord-Karno equation) for the shock loss calculation.**
- **Useful "head" characterization.**
- **Efficiency characterization. Surge limit term. Maximum, critical, optimized and calculated consumptions.**
- **Degree of reaction. Theoretical "head" coefficient and consumption coefficient dependence when different outlet blade angle. Influence of the blade number finitude.**
- **Diffusive flow character. The turbine stage comparison.**

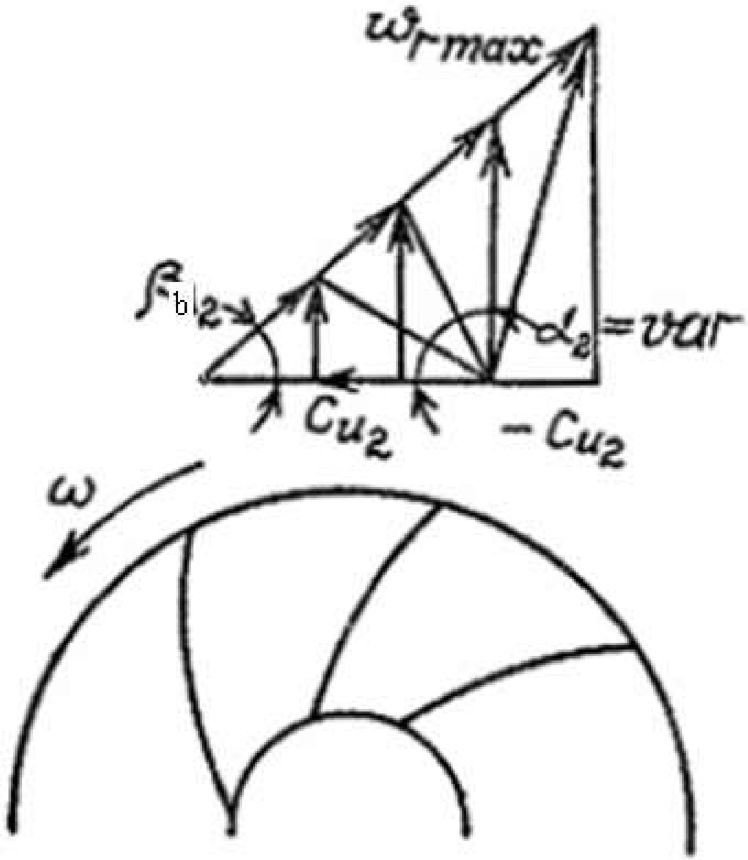
From the outlet velocity triangles in hypothetic impeller with infinite number of blades

$$c_{u2} = u_2 - w_{u2}$$

$$w_{u2}/w_{r2} = \mathrm{ctg}\beta_{b2}$$

$$\psi_T = c_{u2}/u_2 = 1 - \varphi_2 \mathrm{ctg}\beta_{b2}$$

1. β_{b2} < 90° ("sweepback blades")



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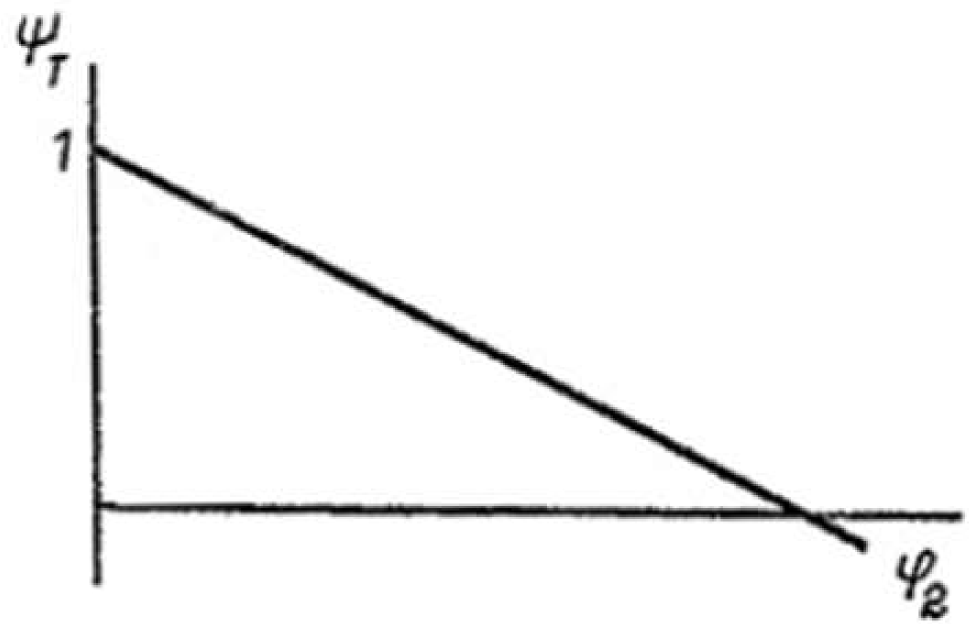


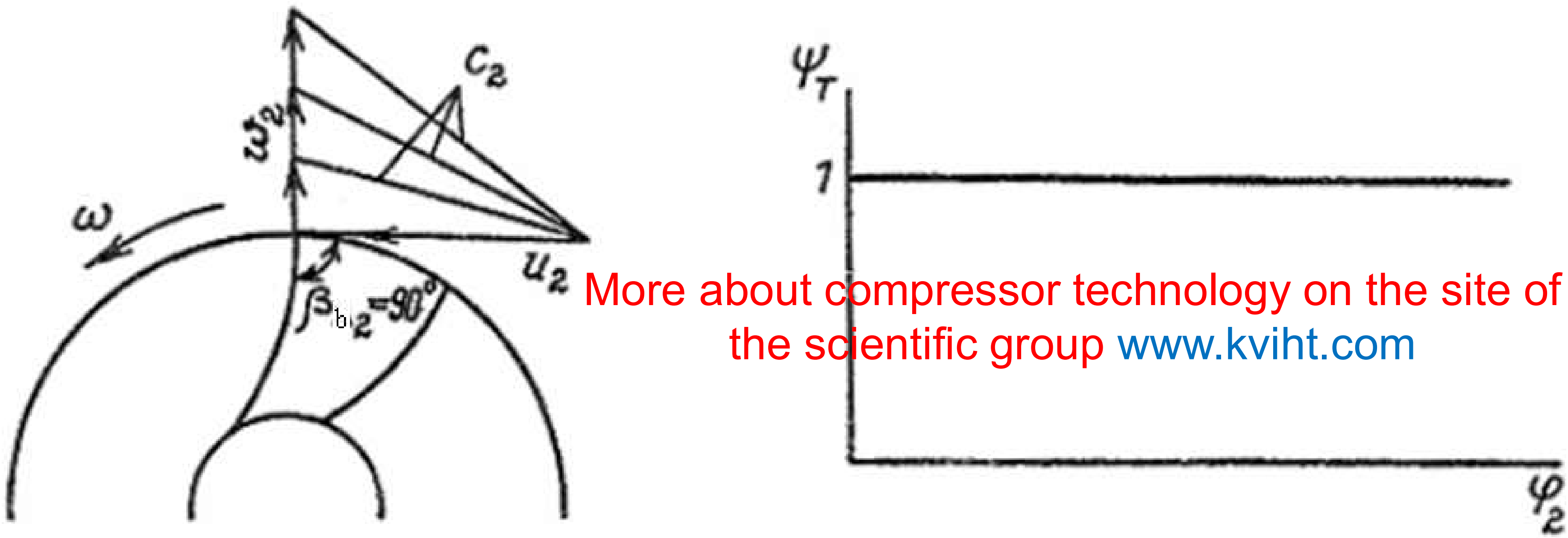
Outlet velocity triangles and "head" characterization of the ideal impeller when infinite blades number c_{u1}=0, β_{b2}<90° ("sweepback blades")

Case when flow with $\varphi_2 > \varphi_{2max}$ is also practicable. If the characteristics goes from the first to the fourth quadrant, the "head" is negative. Centrifugal compressor is changed to centrifugal turbine, gas is something like "run for" the impeller, "bear against" blade's back and by "pushing away" from it gets negative swirl.

2. β_{b2}=90° (“radial ending blades”)

At this case cotangent of blade’s outlet is equal to zero and “head” coefficient doesn’t depend on consumption

$$\psi_T = f(\varphi_2) = const = 1$$

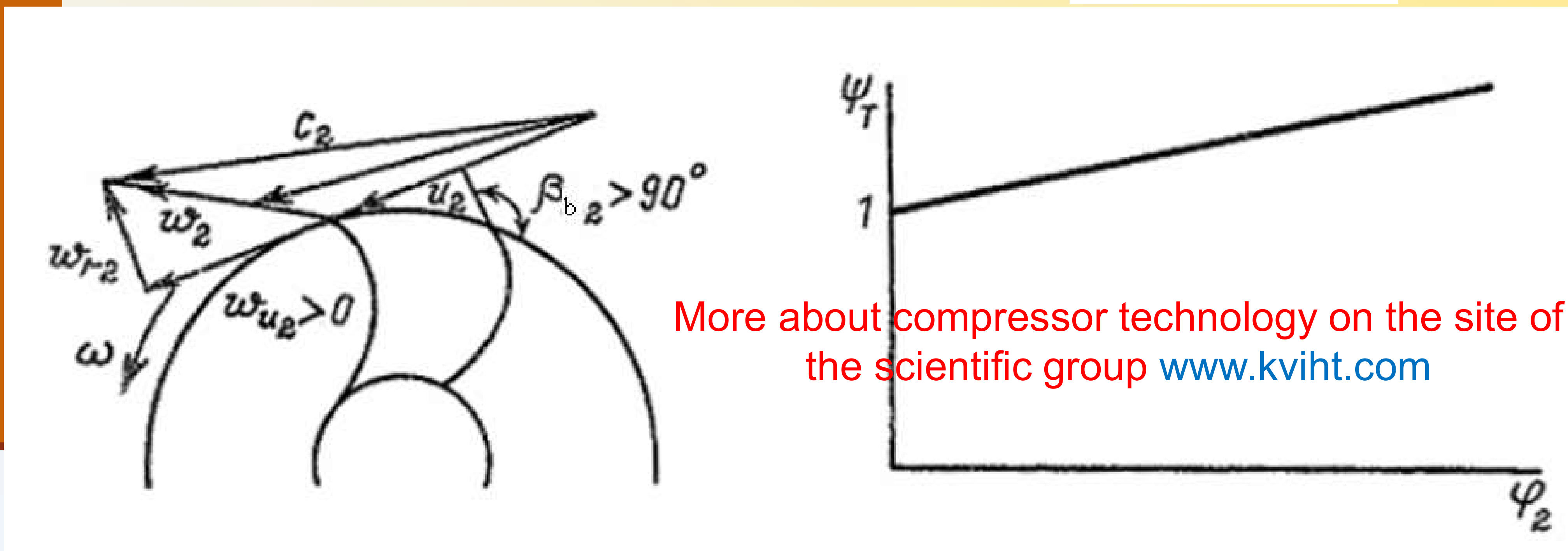


Outlet velocity triangles and “head” characteristics of the ideal impeller when infinite number of blades, c_{u1}=0, β_{b2}=90° (“radial ending blades”)

3. βb2>90° ("sweep forward blades")

At this case cotangent of outlet blade angle changes it's sign on the opposite:

$$\psi_T = 1 + \varphi_2 |ctg\beta_{b2}| \quad \text{when} \quad \beta_{b2} > 90°$$



Outlet velocity triangle and "head" characteristics of the ideal impeller when infinite number of blades, cu1=0, βb2>90° ("sweep forward blades")

Degree of reaction Ω – is a ratio between the whole input work in the impeller and it's part which was used on the gas compression in the impeller. Degree of reaction Ω determines the part of kinetic energy on the impeller outlet.

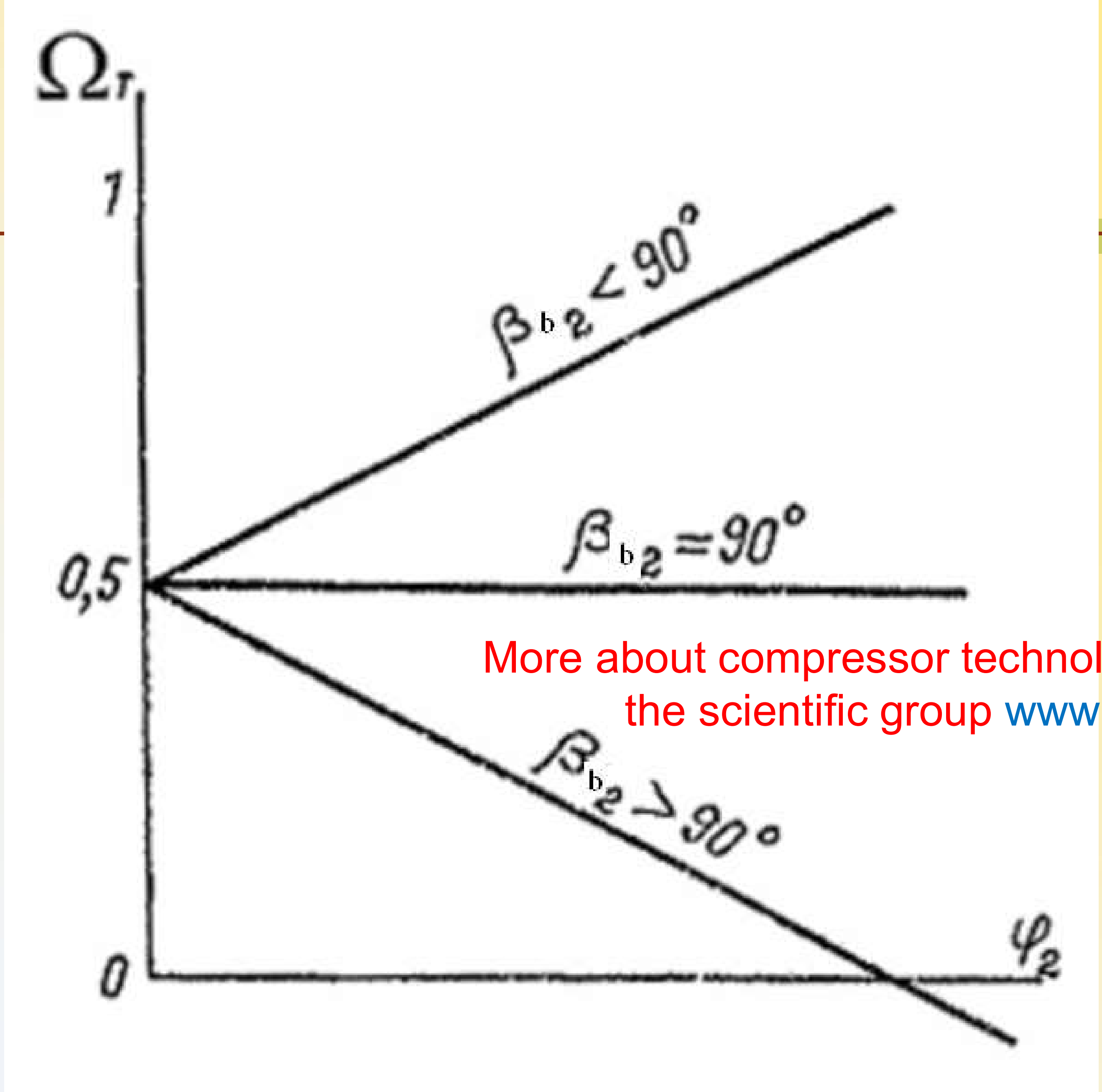
For the ideal impeller with $h_r=0$, $z=\infty$ (when $\beta_2=\beta_{b2}$), $c_{u1}=0$ and when additional condition simplification $c_{r1}=c_{r2}$.

$$\Omega_{\text{т}} = \frac{h_{\text{p}}}{h_{\text{т}}} = \frac{h_{\text{т}} - h_{\text{d}}}{h_{\text{т}}} = 1 - \frac{h_{\text{d}}}{h_{\text{т}}} =$$

$$= 1 - 0,5\frac{c_2^2 - c_1^2}{c_{u2}u_2} = 1 - 0,5\frac{c_{u2}^2 + c_{r2}^2 - c_{r1}^2}{c_{u2}u_2}$$

When $\Omega_T = 1 - 0{,}5\psi_T$ and $\psi_T = 1 - \varphi_2 ctg\beta_{b2}$:

$$\Omega_T = 0{,}5(1 + \varphi_2 ctg\beta_{b2})$$



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Dependence $\Omega=f(\varphi_2)$ when impeller is with $\beta_{b2}><90°(z=\infty)$

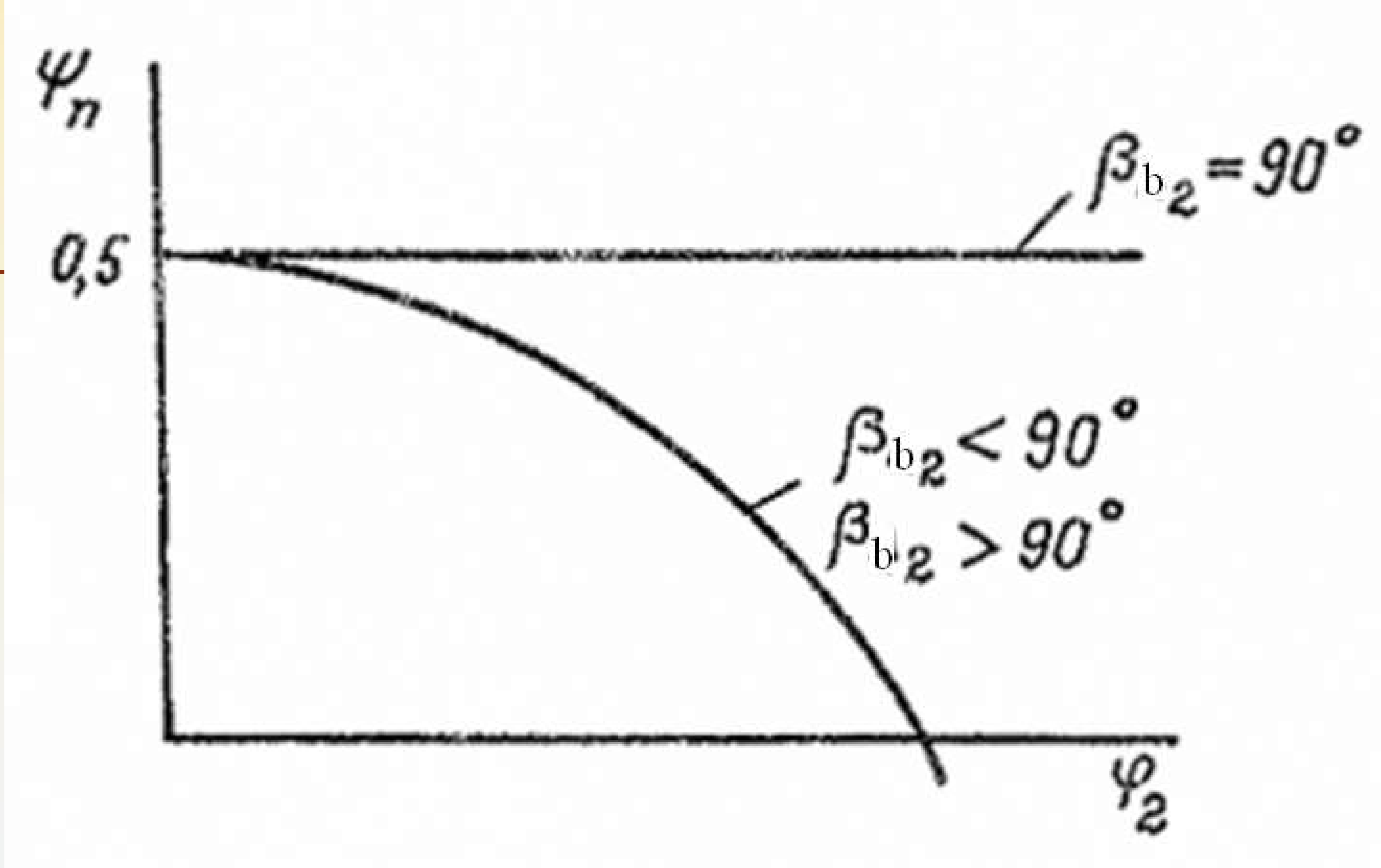
Pay attention once more that when $c_1 = c_{r1} = c_{r2}$ the ratio is:

$$\Omega_T = 1 - 0{,}5\psi_T,$$

So, **the increase of pressure coefficient could be acheaved only by decreasing of reaction degree.**

$$h_{\text{П}} = \Omega_{\text{Т}} h_{\text{Т}} \qquad \psi_{\text{П}} = \Omega_{\text{Т}} \psi_{\text{Т}}$$

$$\psi_{\text{П}} = 0{,}5[1 - (\varphi_2 \text{ctg} \beta_{b\,2})^2]$$



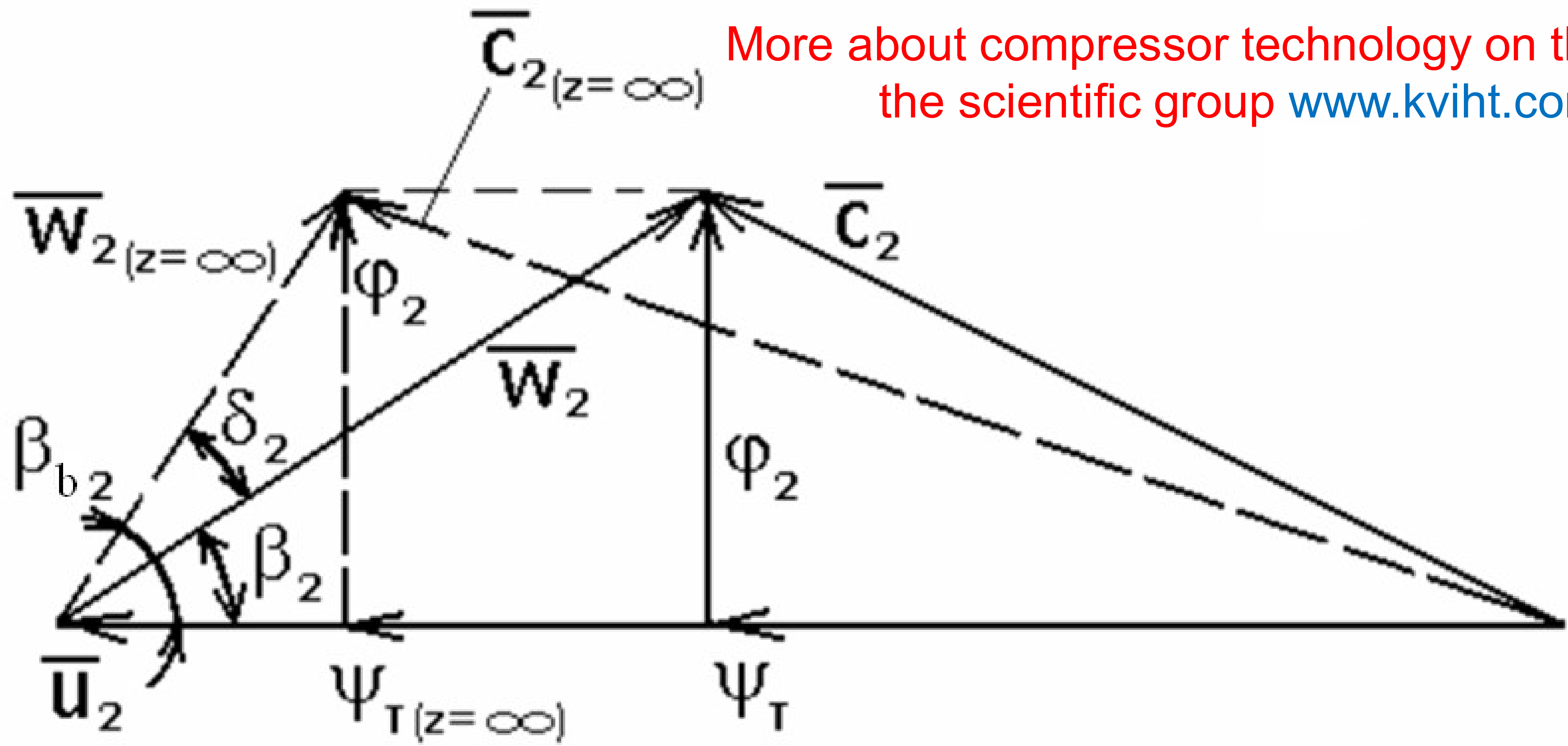
Static "head" of the impeller and consumption coefficient dependence when different β_{b2}><90°

The influence of the finite number of blades on the “head” characteristics of the impeller

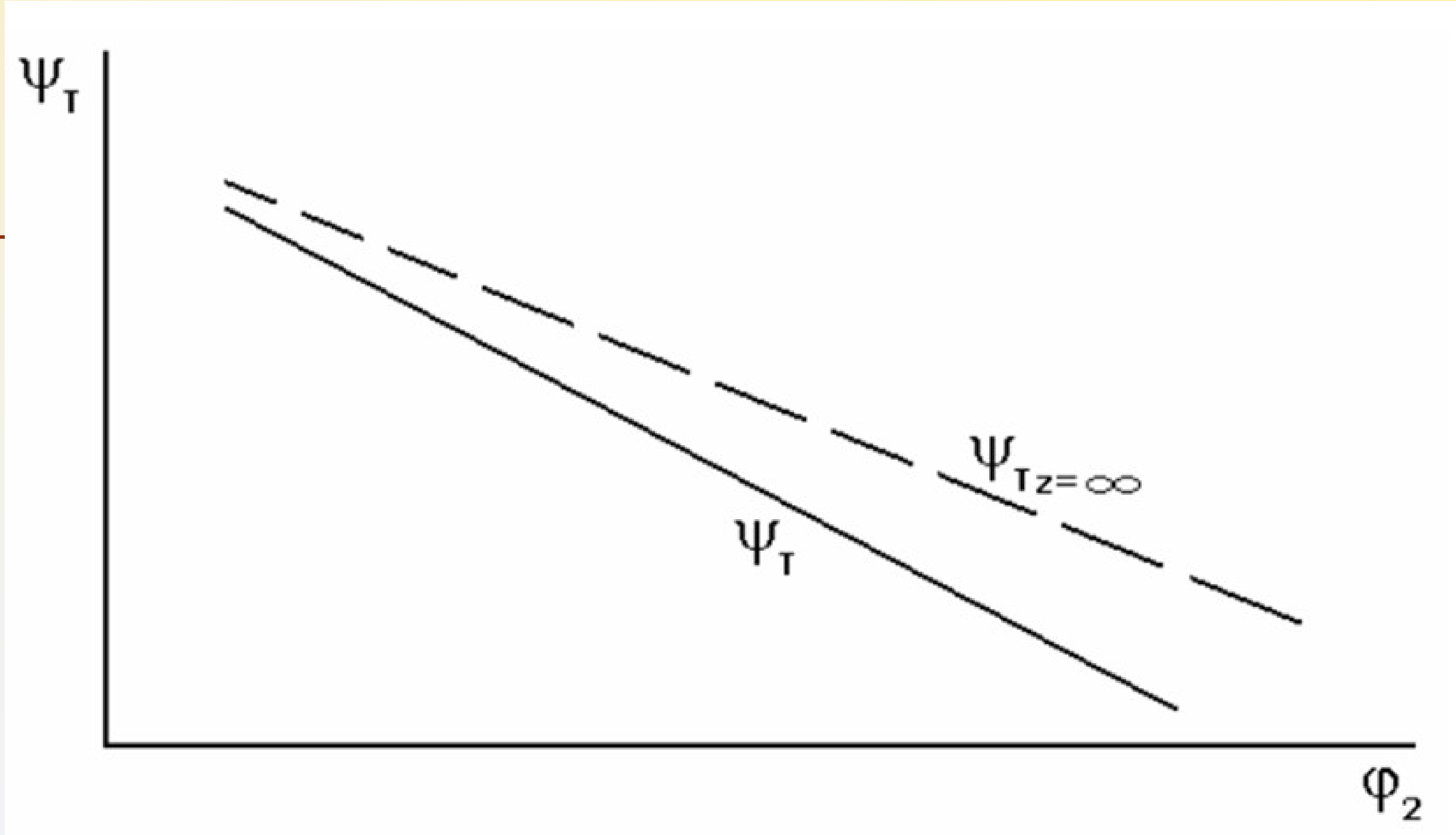
$$\psi_{T\,(z=\infty)} = 1 - \varphi_2 \mathrm{ctg}\beta_{b2}$$

$$\psi_T = 1 - \varphi_2 \mathrm{ctg}\beta_2 = 1 - \varphi_2 \mathrm{ctg}(\beta_{b2} - \delta_2)$$

The influence of the finite number of blades on the "head" characteristics of the impeller



Velocity triangles for the impeller of centrifugal compressor with infinite blades number (dotted line) and real impeller (solid line)



"Head" characteristics of the impeller of centrifugal compressor with infinite blades number (dotted line) and real impeller (solid line)

Centrifugal impeller efficiency:

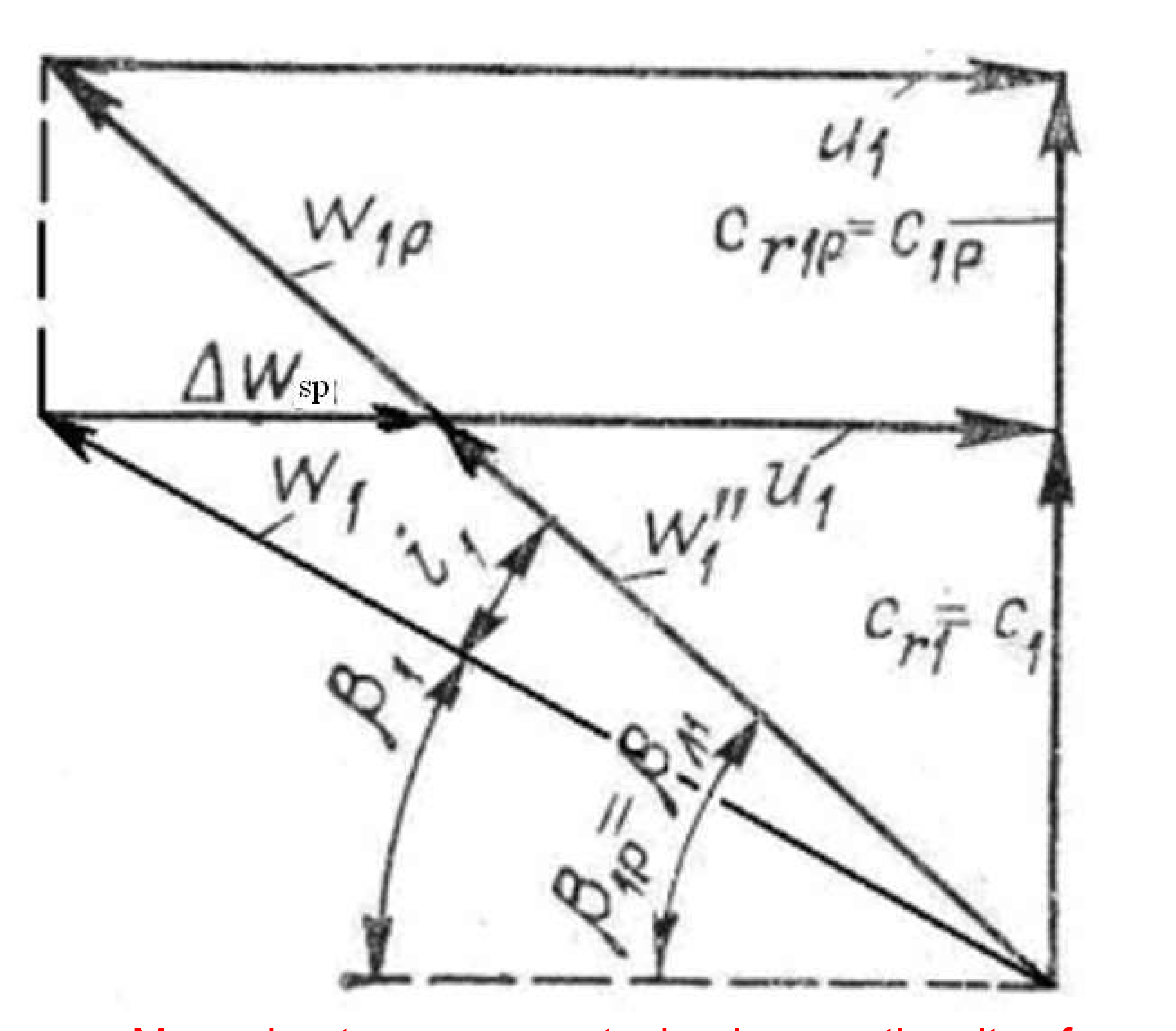
$$\eta^* = \frac{h_p + h_d}{h_T} = \frac{h_T - h_r}{h_T}$$

In the first approximation all the losses in the flow passage of the impeller are divided on two groups:

$$h_r = h_{r\ sp} + h_{r\ fr}$$

The first group of losses – **shock loss $h_{r\ sp}$** – take into account losses which are connected with angle of attack on the blade system inlet in the calculated modes.

The second group of losses $\mathbf{h_{r\ fr}}$ take into account **friction losses** in between blades canals.



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Velocity triangle on the impeller inlet

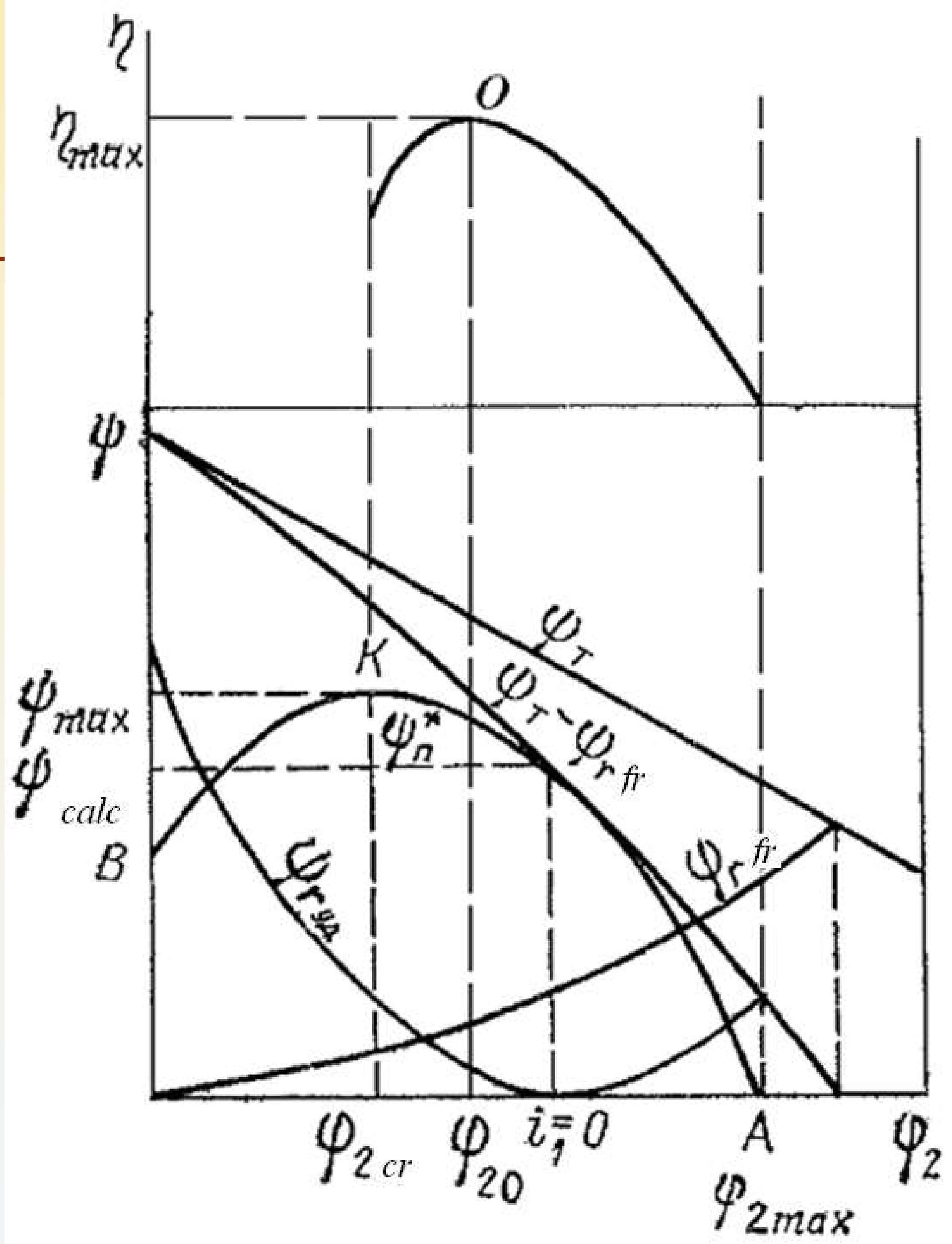
Friction losses in between the blades canal is calculated with the help of the formula:

$$h_{r\ \mathrm{fr}} = \zeta_{\mathrm{fr}} \frac{w_{1p}^2}{2}, \qquad h_{r\ \mathrm{fr}} = \zeta_{\mathrm{fr}} \frac{w''^2_1}{2}.$$

ζ_{fr} - friction losses coefficient

Shock losses on not calculated mode will be different from zero. For the shock losses calculation we use **Bord-Karno equation** (the same as sudden expansion losses)

$$h_{r_{sp}} = \frac{\Delta w_{sp}^2}{2}$$



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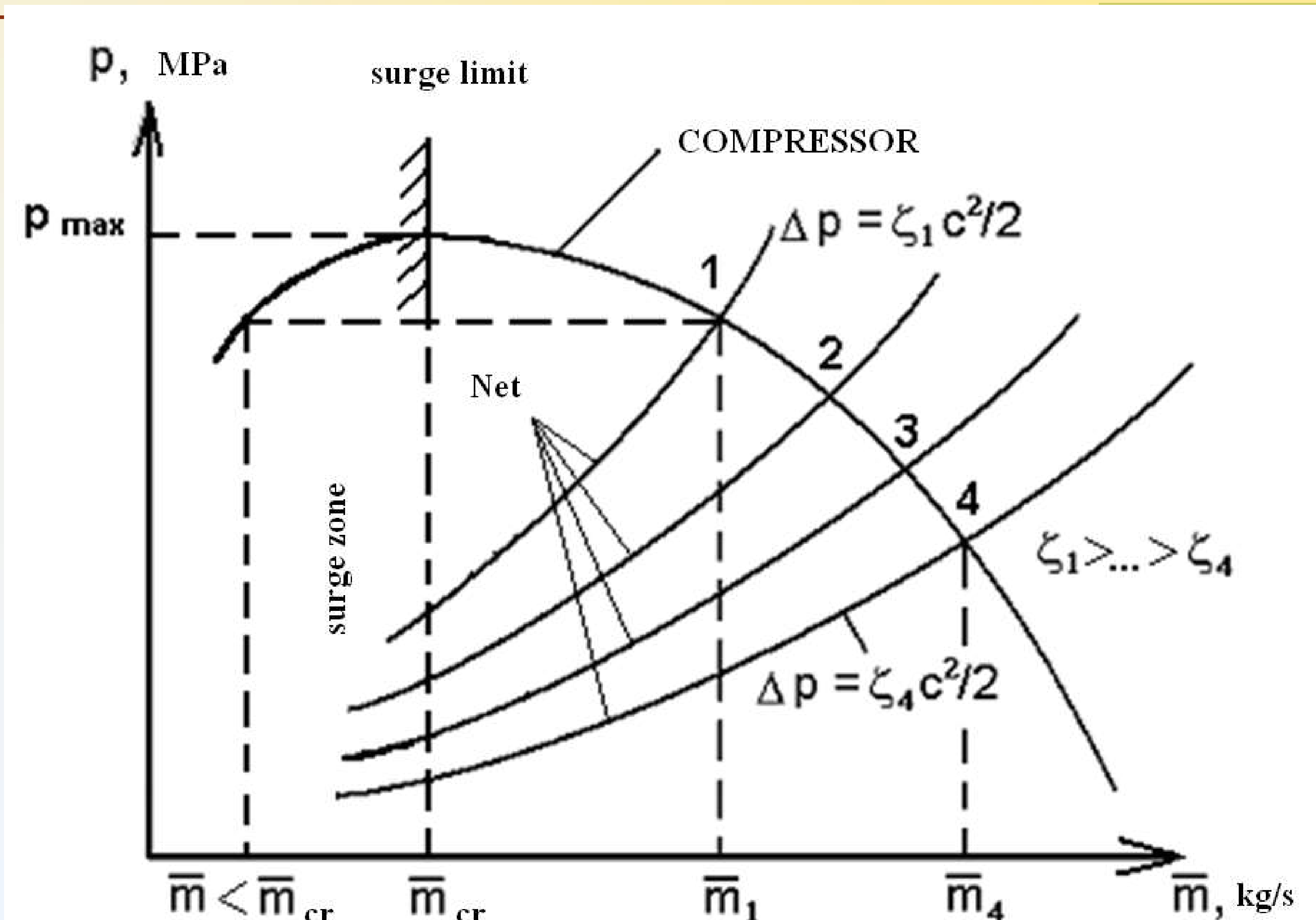
- **Maximum consumption**, when compressor doesn't create the pressure difference – φ_{2max} (dot A).
- **Optimal consumption** φ_{20} corresponds to the efficiency maximum (dot 0).
- **Critical consumption** corresponds to the maximum of useful "head".
- **Calculated consumption** determined by technical task on the design period, as it is the most time-consuming modes of exploitation.

Sergey Kartashov, Yuru Kozhukhov **Turbocompressors theory.**
Lecture 6.
Surge. Surge limit. Work prohibition on the surge mode



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Surge – is unsteady low frequency process (one period in some seconds), when compressed gas is going to the network and occasionally breaks from network to the inlet

THANK YOU FOR YOUR ATTENTION

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