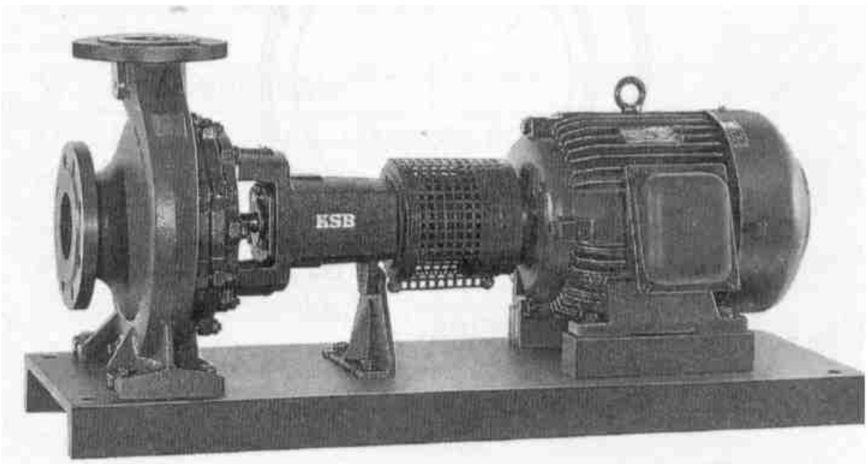
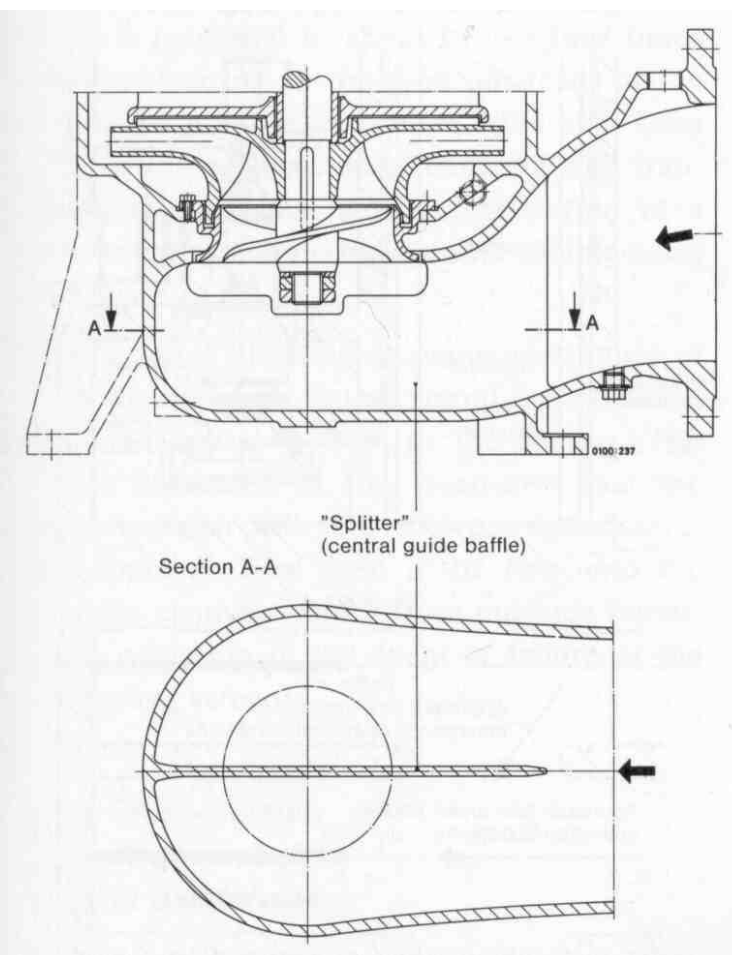
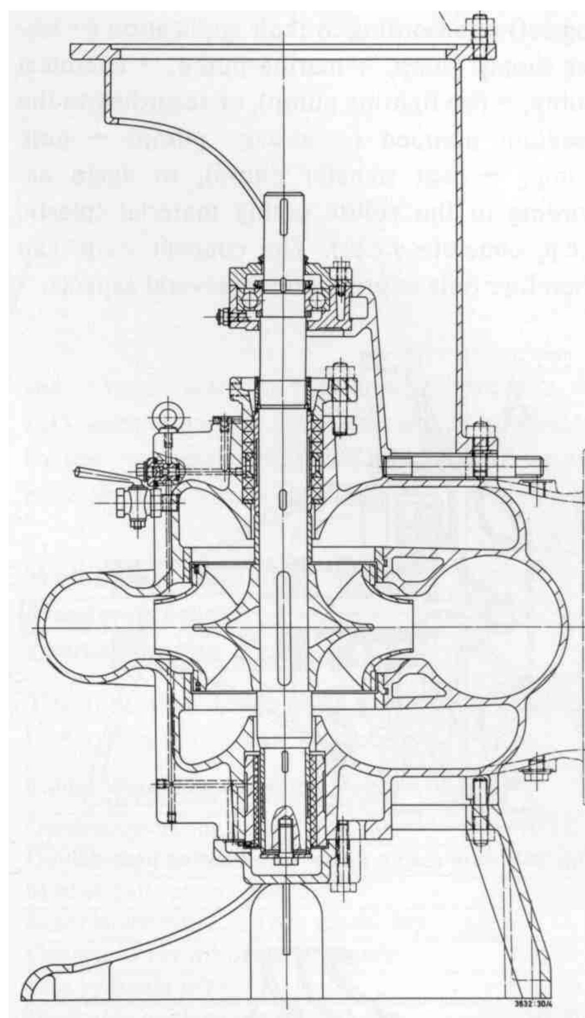
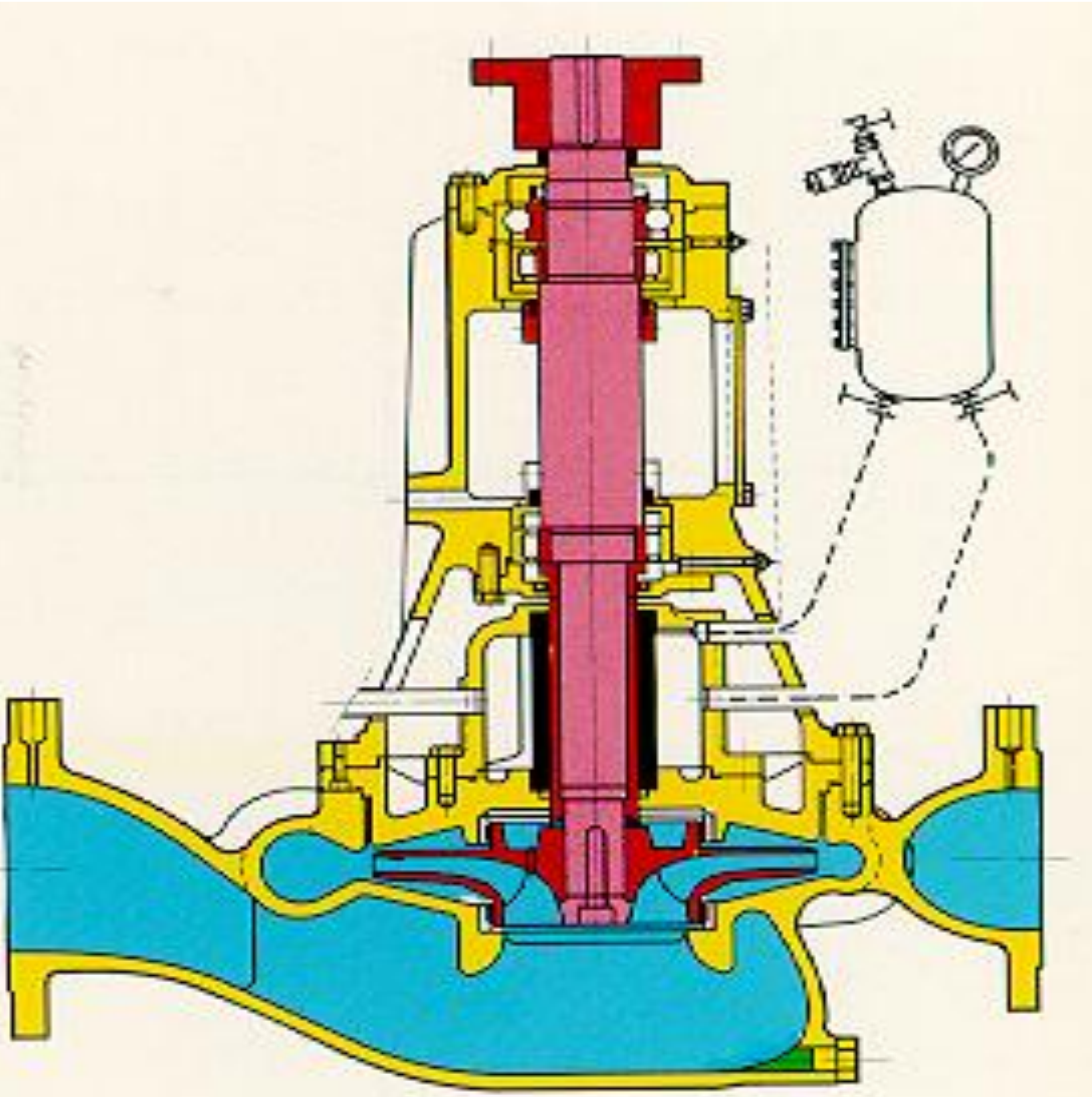
Centrifugal pumps

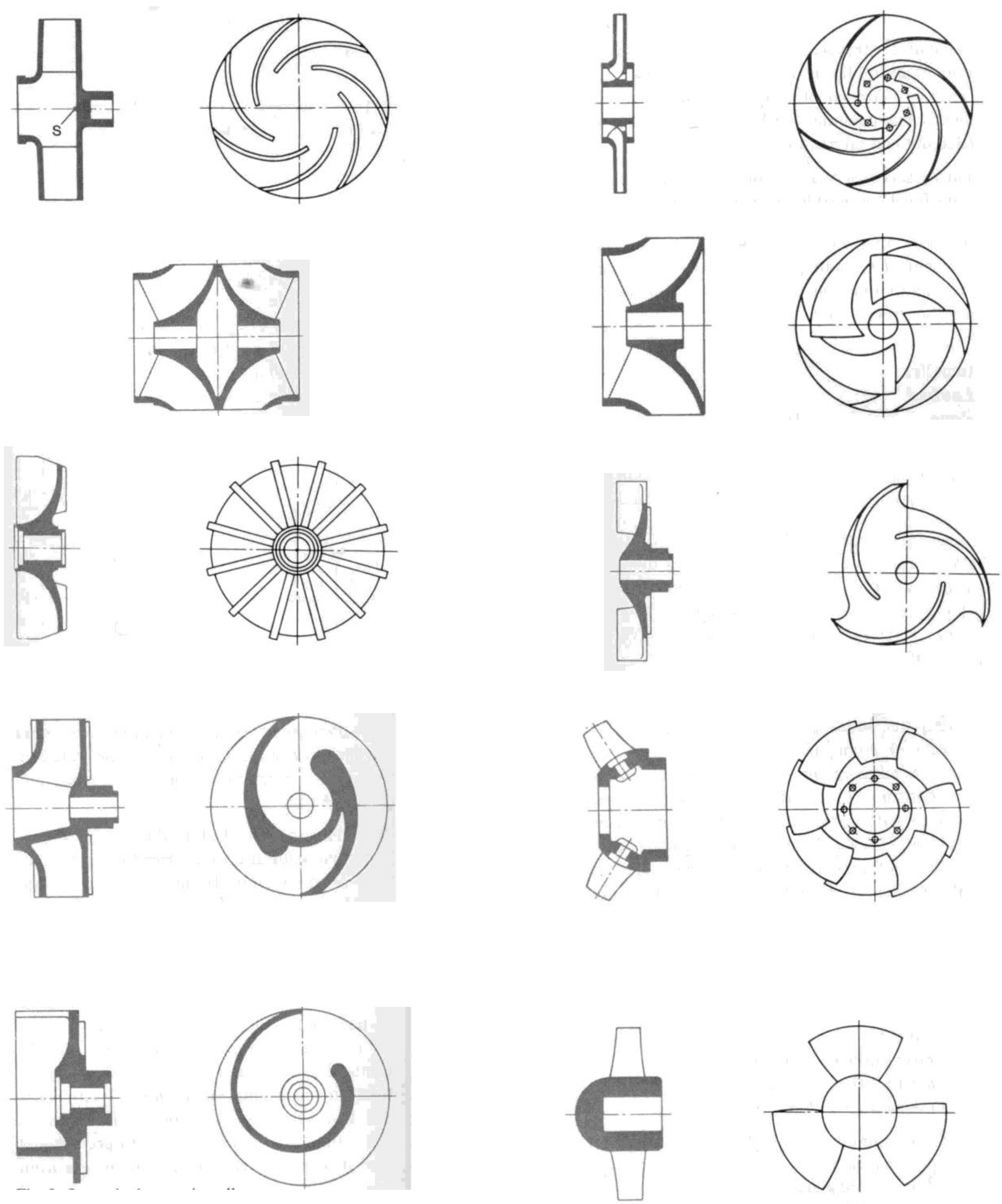




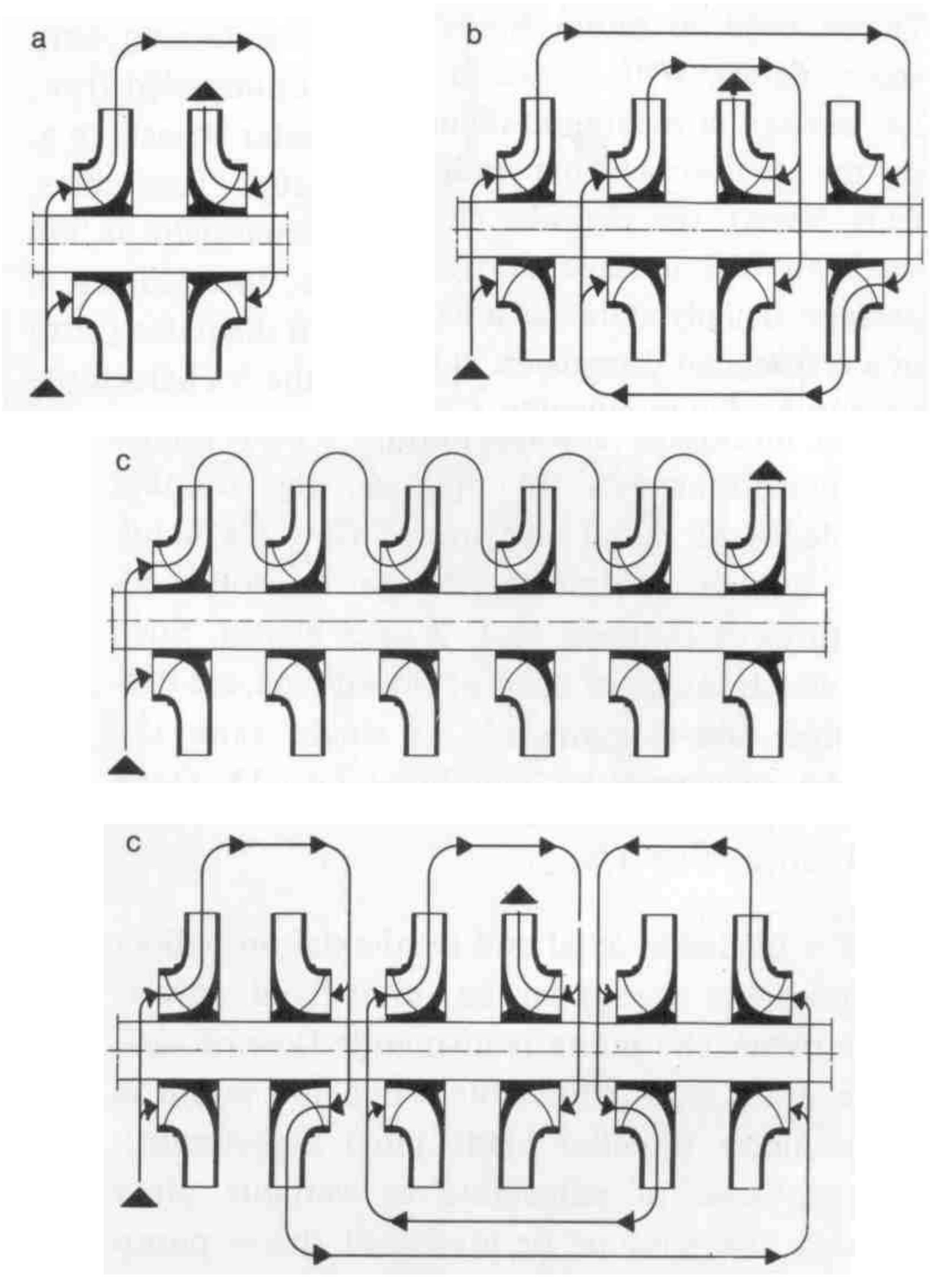




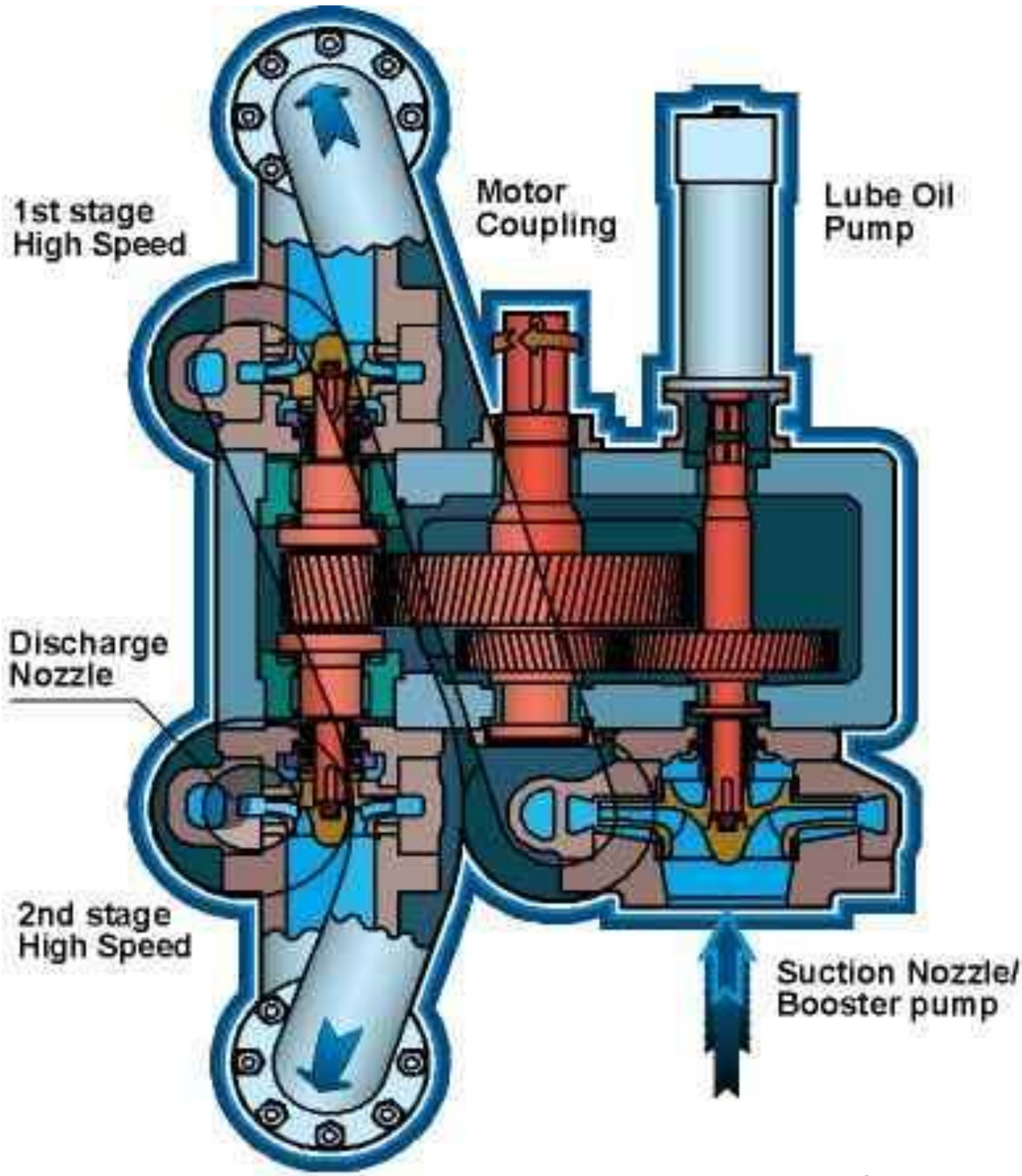
Impellers



Multistage impellers



Cross section of high speed water injection pump



Source: www.framo.no

Water injection unit
4 MW

Source: www.framo.no

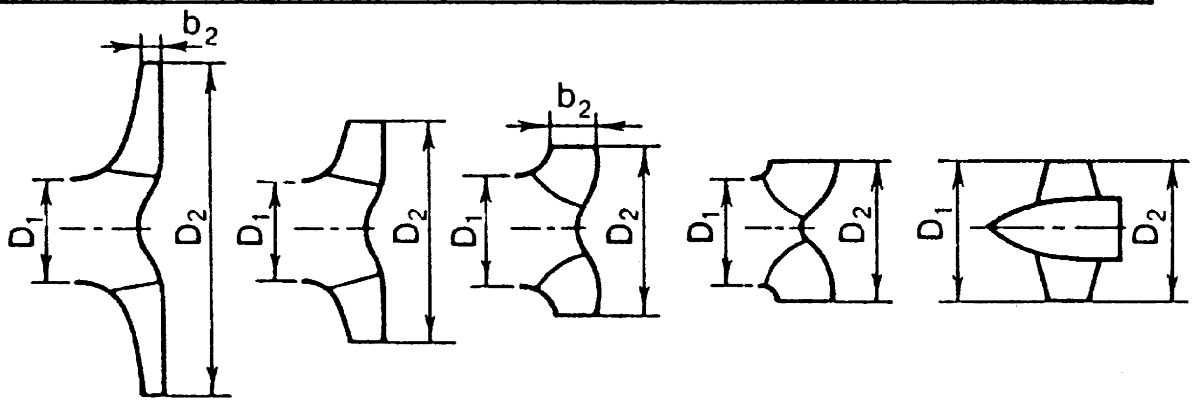
Specific speed that is used to classify pumps

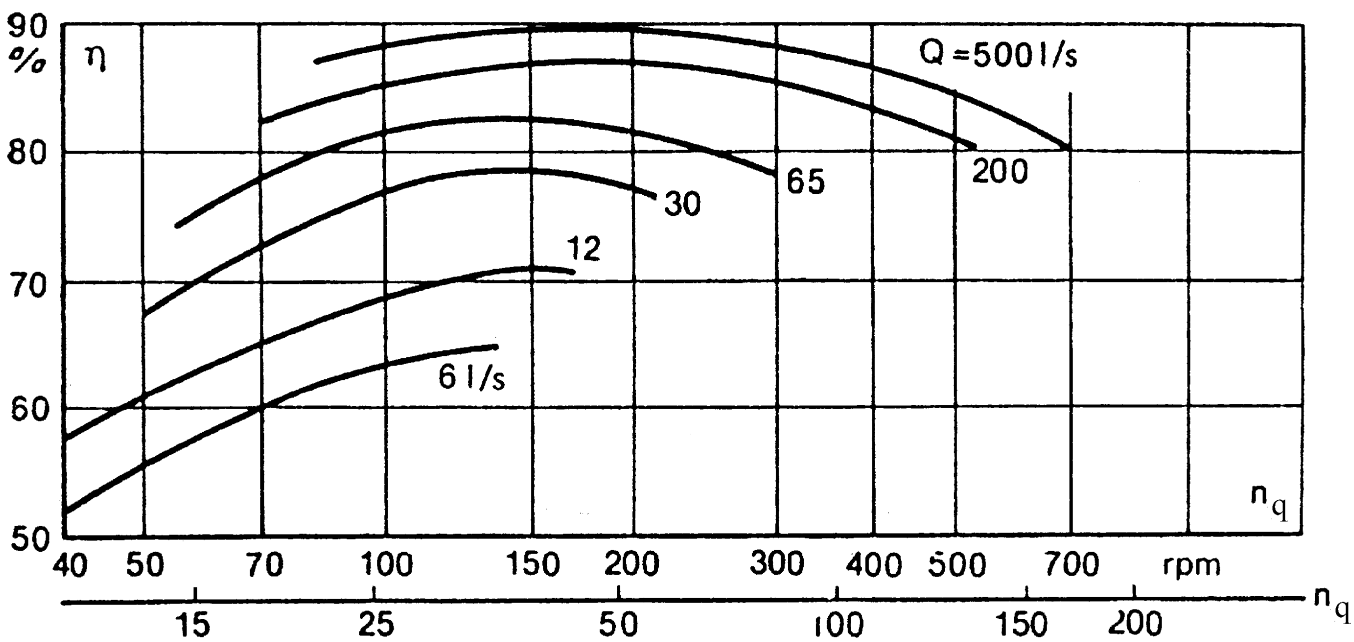
$$n_q = n \cdot \frac{\sqrt{Q}}{H^{3/4}}$$

n_q is the specific speed for a unit machine that is geometric similar to a machine with the head H_q = 1 m and flow rate Q = 1 m^3/s

$$n_s = 51{,}55 \cdot n_q$$

n_q	60 - 80	80 - 120	120 - 240	240 - 350	400 - 800
D_2/D_1	3.0 - 2.4	2.4 - 1.8	1.8 - 1.3	1.3 - 1.1	1.0





Affinity laws

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2}$$

$$\frac{H_1}{H_2} = \left(\frac{u_1}{u_2}\right)^2 = \left(\frac{n_1}{n_2}\right)^2$$

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

Assumptions:

Geometrical similarity

Velocity triangles are the same

Exercise

- Find the flow rate, head and power for a centrifugal pump that has increased its speed
- Given data:

η_h = 80 %
n_1 = 1000 rpm
n_2 = 1100 rpm

P_1 = 123 kW
H_1 = 100 m
Q_1 = 1 m^3/s

$$Q_2 = \frac{n_2}{n_1} \cdot Q_1 = \frac{1100}{1000} \cdot 1 = \underline{\underline{1{,}1\, m^3/s}}$$

$$H_2 = \left(\frac{n_2}{n_1}\right)^2 \cdot H_1 = \left(\frac{1100}{1000}\right)^2 \cdot 100 = \underline{\underline{121\, m}}$$

$$P_2 = \left(\frac{n_2}{n_1}\right)^3 \cdot P_1 = \left(\frac{1100}{1000}\right)^3 \cdot 123 = \underline{\underline{164\, kW}}$$

Exercise

- Find the flow rate, head and power for a centrifugal pump impeller that has reduced its diameter
- Given data:

$\eta_h = 80\ \%$

$D_1 = 0{,}5\ m$

$D_2 = 0{,}45\ m$

$P_1 = 123\ kW$

$H_1 = 100\ m$

$Q_1 = 1\ m^3/s$

$$\frac{Q_1}{Q_2} = \frac{\Pi \cdot D_1 \cdot B_1 \cdot c_{m1}}{\Pi \cdot D_2 \cdot B_2 \cdot c_{m2}} = \frac{D_1}{D_2} = \frac{n_1}{n_2}$$

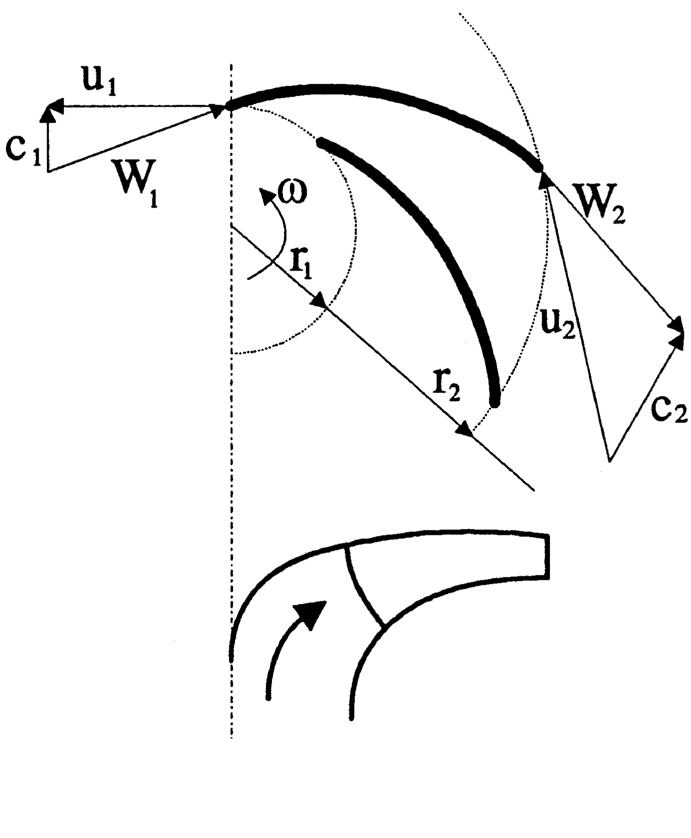
$$\Downarrow$$

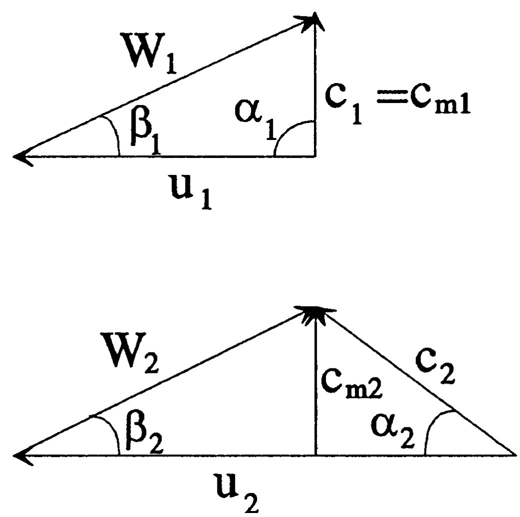
$$Q_2 = \frac{D_2}{D_1} \cdot Q_1 = \frac{0{,}45}{0{,}5} \cdot 1 = \underline{\underline{0{,}9\ m^3/s}}$$

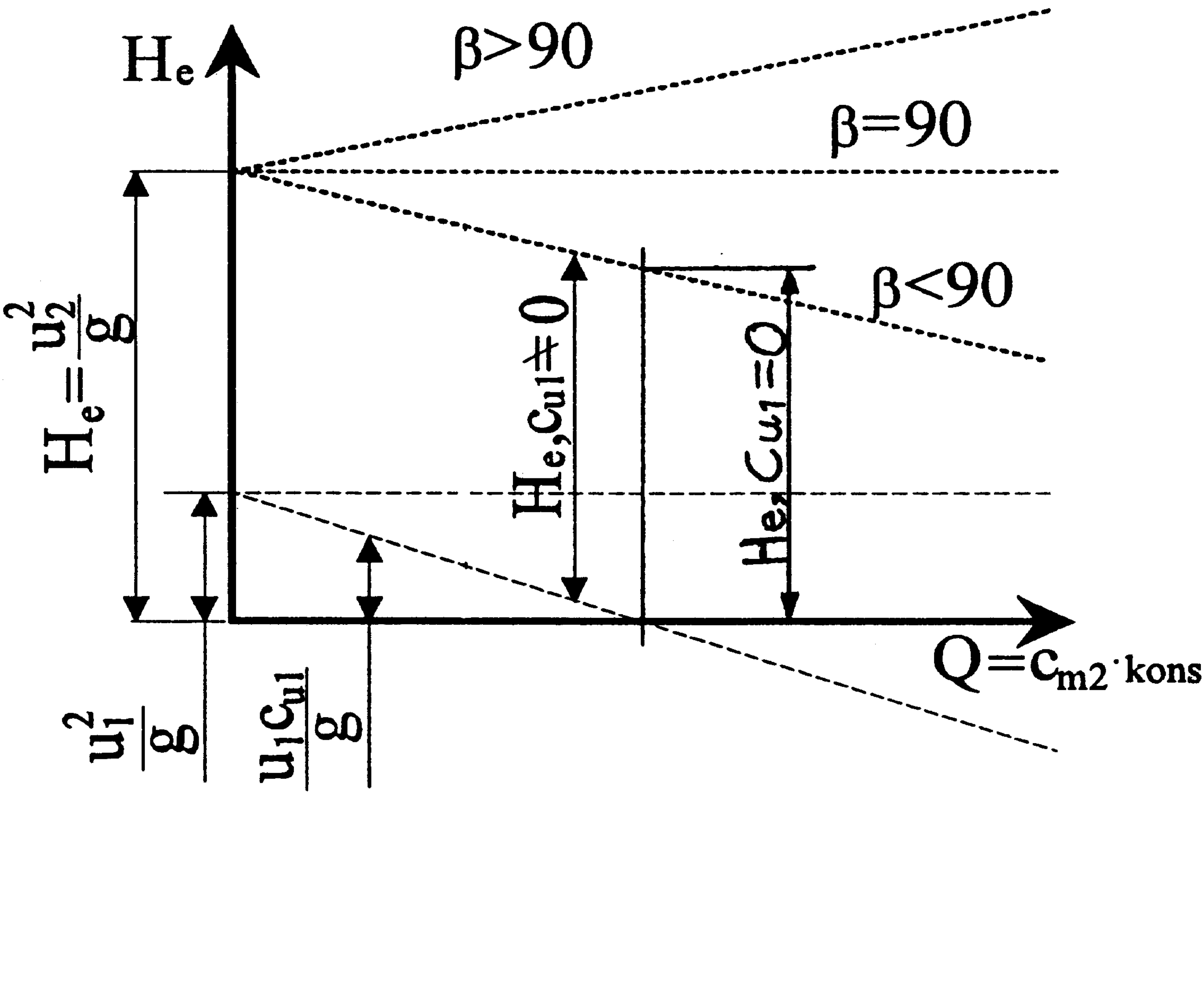
$$H_2 = \left(\frac{D_2}{D_1}\right)^2 \cdot H_1 = \left(\frac{0{,}45}{0{,}5}\right)^2 \cdot 100 = \underline{\underline{81\ m}}$$

$$P_2 = \left(\frac{D_2}{D_1}\right)^3 \cdot P_1 = \left(\frac{0{,}45}{0{,}5}\right)^3 \cdot 123 = \underline{\underline{90\ kW}}$$

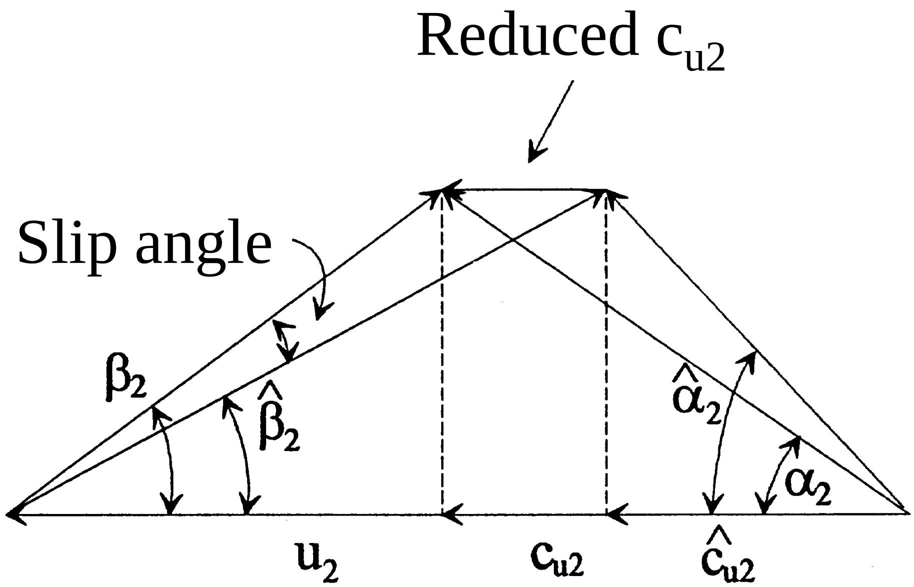
Velocity triangles

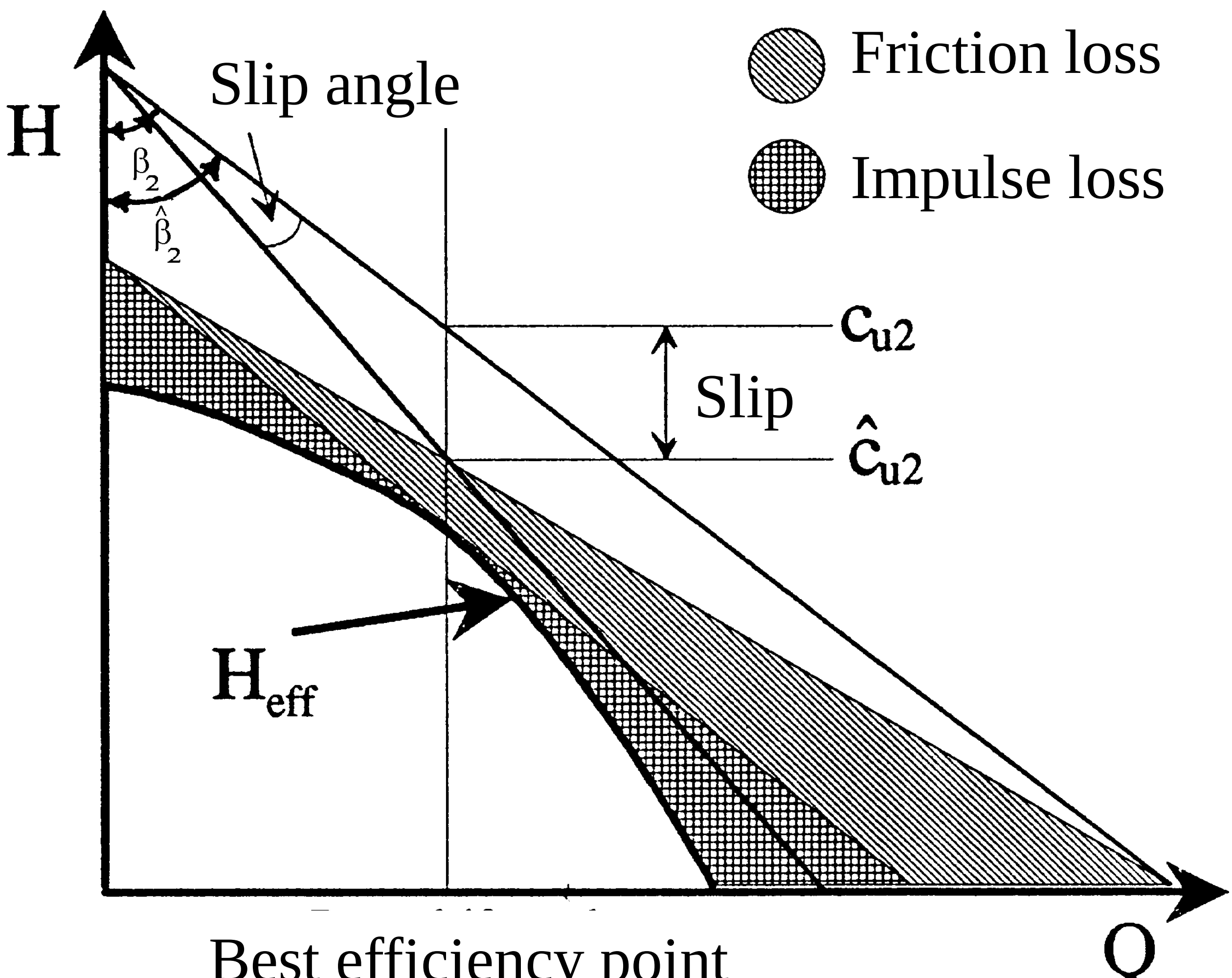






H_e
β>90
β=90
β<90
$H_e = \frac{u_2^2}{g}$
$H_{e,c_{u1}} \neq 0$
$H_{e,c_{u1}} = 0$
$\frac{u_1^2}{g}$
$\frac{u_1 c_{u1}}{g}$
$Q = c_{m2} \cdot kons$


Reduced c_{u2}
Slip angle
β_2
$\hat{\beta}_2$
$\hat{\alpha}_2$
α_2
u_2
c_{u2}
$\hat{c}_{u2}$


H
Slip angle
β_2
$\hat{\beta}_2$
Friction loss
Impulse loss
c_{u2}
Slip
$\hat{c}_{u2}$
H_{eff}
Q
Best efficiency point

Power

$$P = M \cdot \omega$$

Where:

M = torque [Nm]

ω = angular velocity [rad/s]

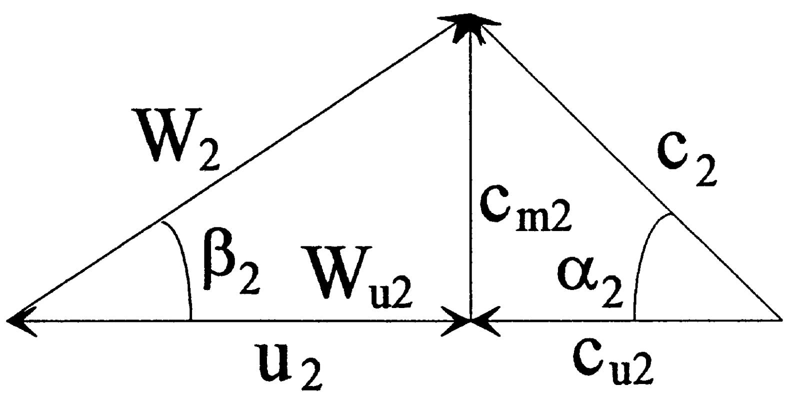
$$P = \rho \cdot Q \cdot \left(r_2 \cdot c_2 \cdot \cos\alpha_2 - r_1 \cdot c_1 \cdot \cos\alpha_1 \right) \cdot \omega$$

$$= \rho \cdot Q \cdot \left(u_2 \cdot c_{u2} - u_1 \cdot c_{u1} \right) \cdot \omega$$

$$= \rho \cdot Q \cdot g \cdot H_t$$

In order to get a better understanding of the different velocities that represent the head we rewrite the Euler's pump equation

$$H_t = \frac{u_2 \cdot c_{u2} - u_1 \cdot c_{u1}}{g}$$



$$w_1^2 = c_1^2 + u_1^2 - 2 \cdot u_1 \cdot c_1 \cdot \cos\alpha_1 = c_1^2 + u_1^2 - 2 \cdot u_1 \cdot c_{u1}$$

$$w_2^2 = c_2^2 + u_2^2 - 2 \cdot u_2 \cdot c_2 \cdot \cos\alpha_2 = c_2^2 + u_2^2 - 2 \cdot u_2 \cdot c_{u2}$$

$$H_t = \frac{u_2^2 - u_1^2}{2 \cdot g} + \frac{c_2^2 - c_1^2}{2 \cdot g} - \frac{w_2^2 - w_1^2}{2 \cdot g}$$

Euler's pump equation

$$H_t = \frac{u_2 \cdot c_{u2} - u_1 \cdot c_{u1}}{g}$$

$$H_t = \frac{u_2^2 - u_1^2}{2 \cdot g} + \frac{c_2^2 - c_1^2}{2 \cdot g} - \frac{w_2^2 - w_1^2}{2 \cdot g}$$

$\frac{u_2^2 - u_1^2}{2 \cdot g} =$ Pressure head due to change of peripheral velocity

$\frac{c_2^2 - c_1^2}{2 \cdot g} =$ Pressure head due to change of absolute velocity

$\frac{w_2^2 - w_1^2}{2 \cdot g} =$ Pressure head due to change of relative velocity

END