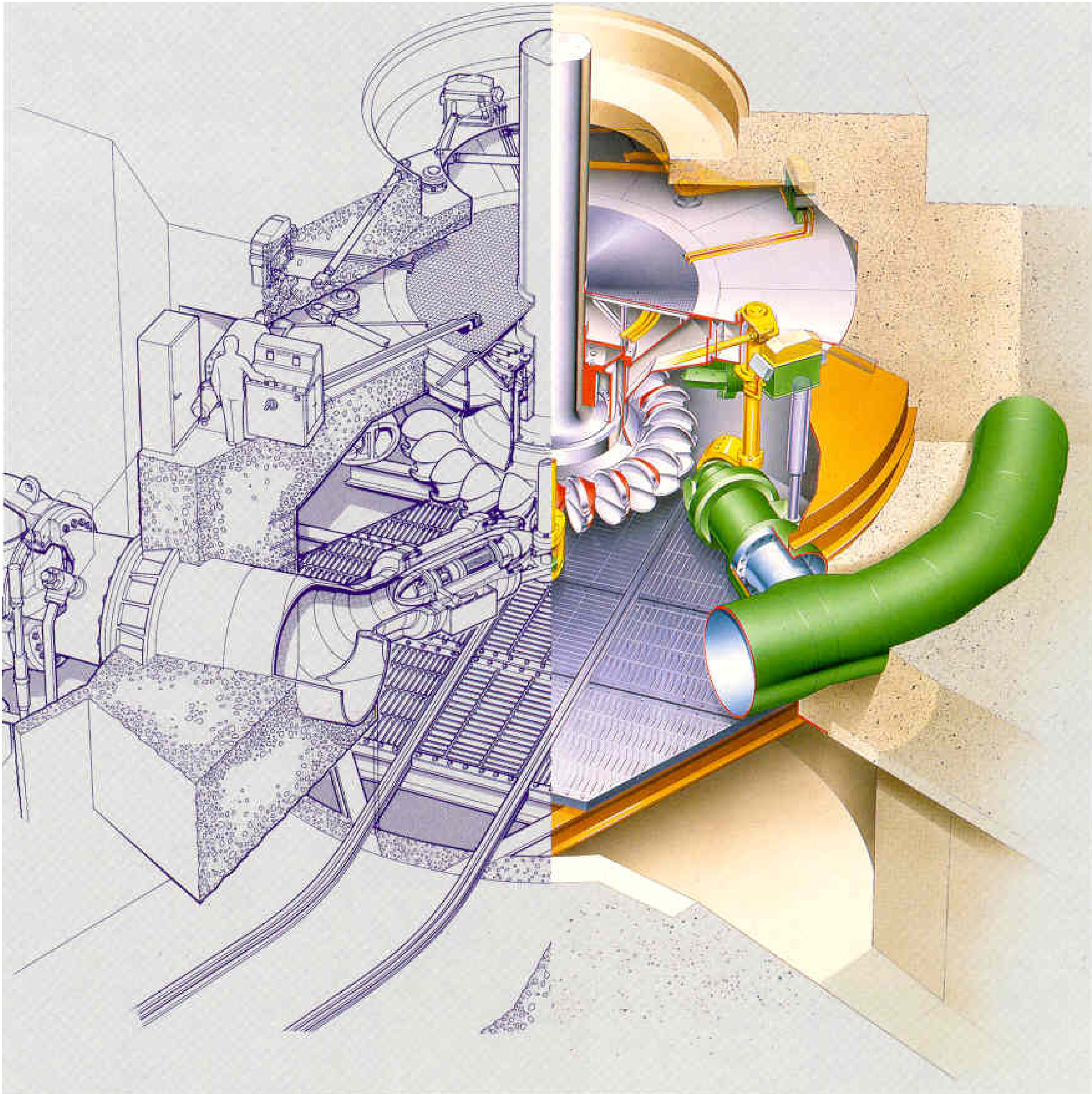
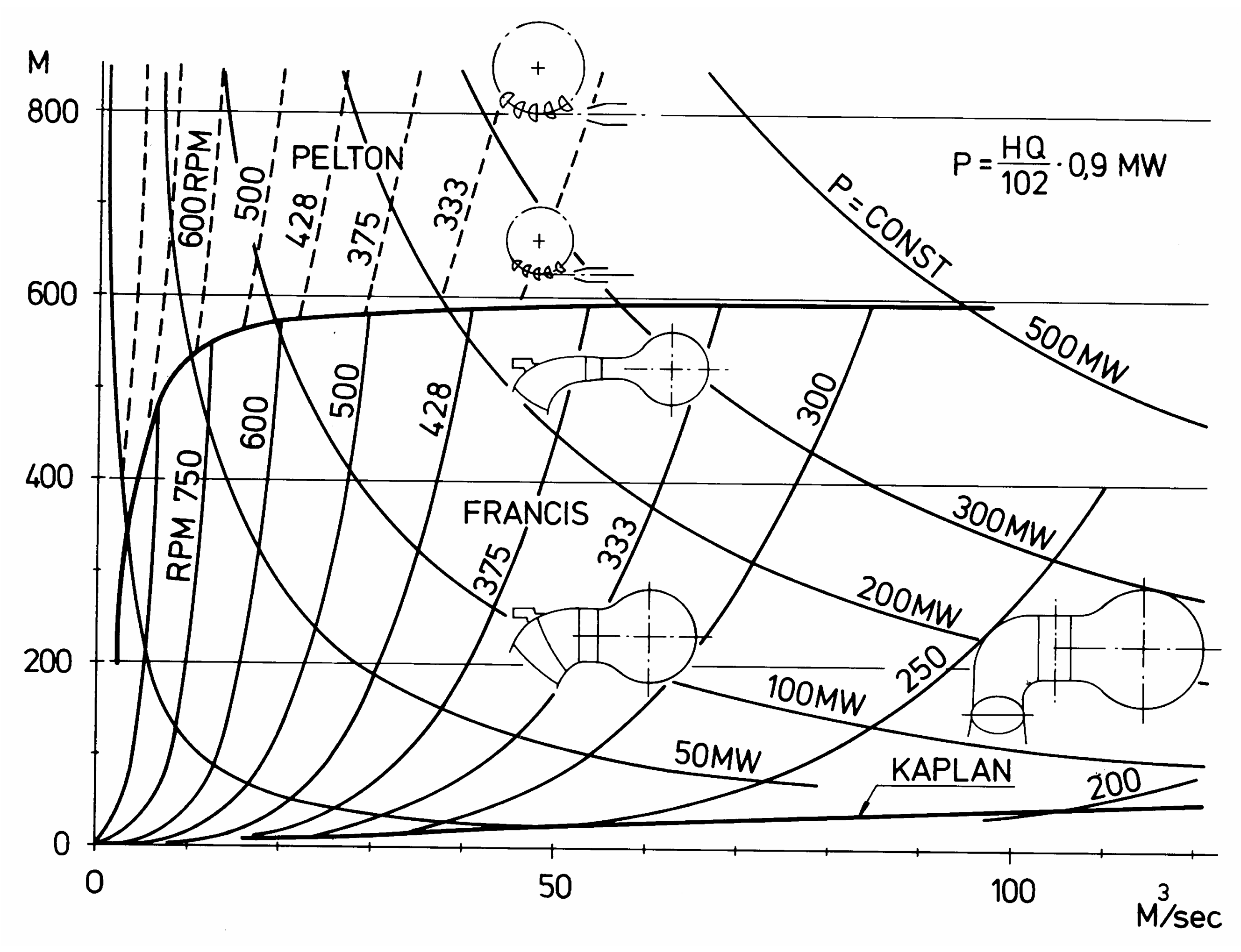
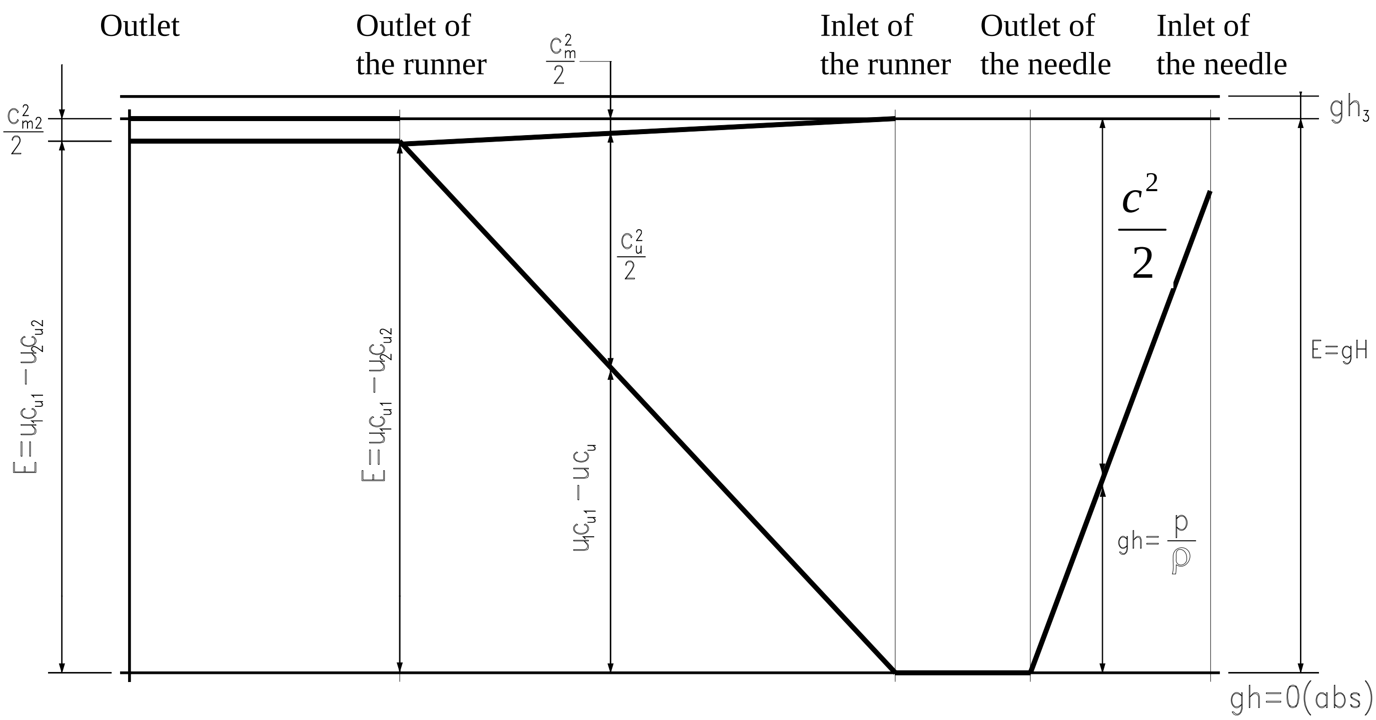
Design of Pelton turbines



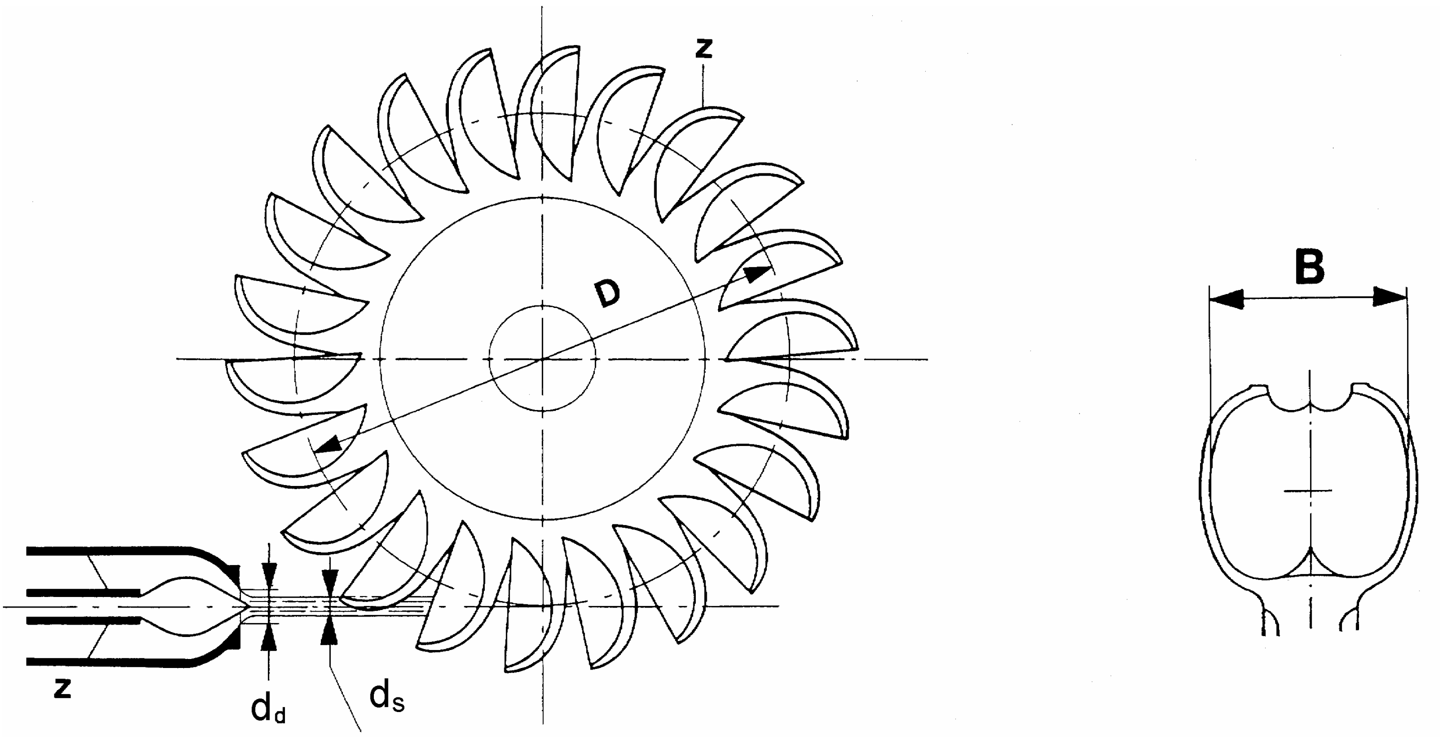
When to use a Pelton turbine

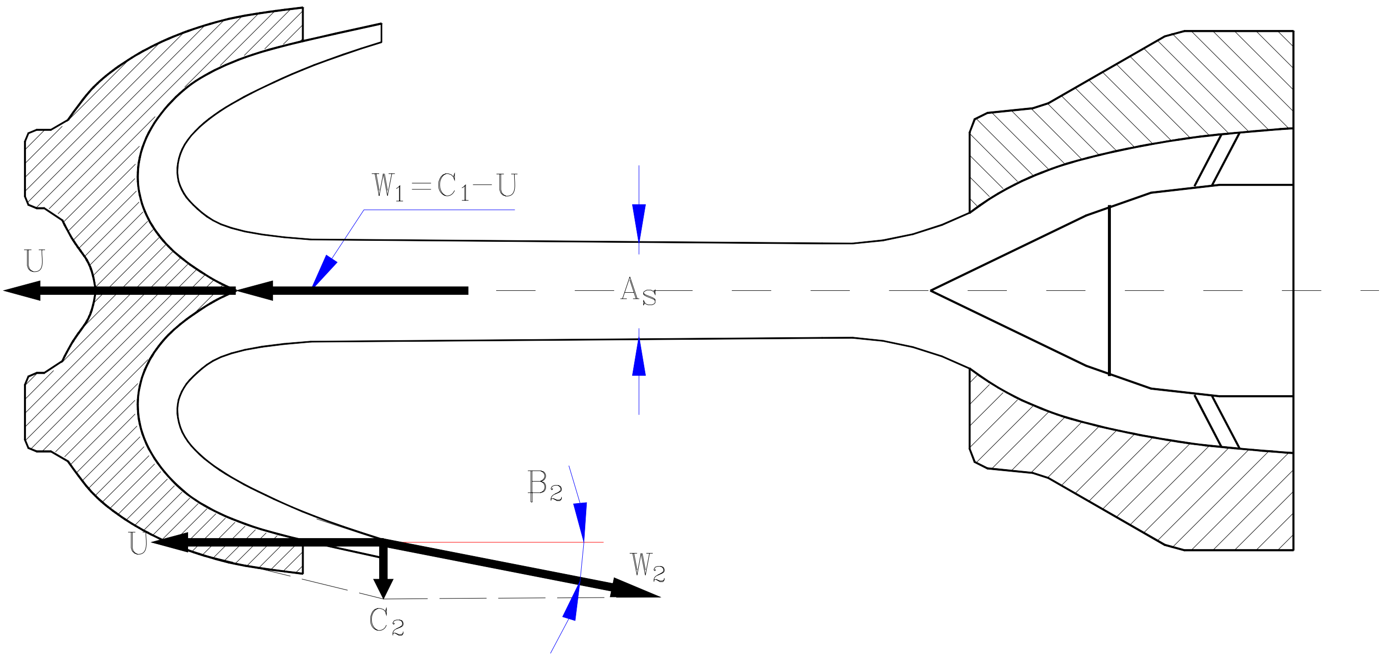


Energy conversion in a Pelton turbine

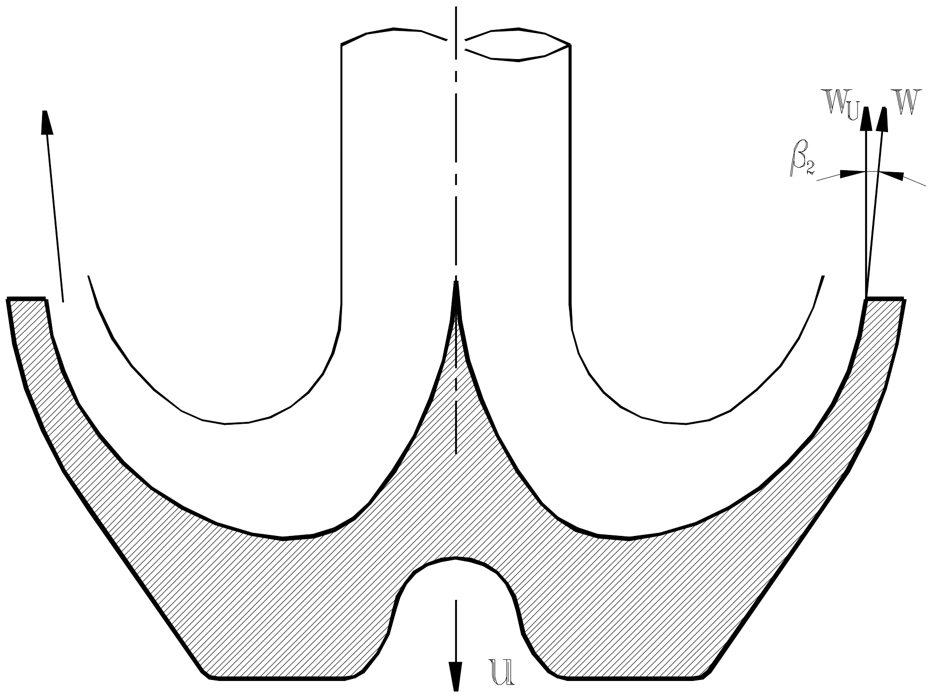


Main dimensions for the Pelton runner





W1=C1−U
U
As
β2
U
W2
C2



Wu
W
β2
u

The ideal Pelton runner

Absolute velocity from nozzle:

$$c_1 = \sqrt{2 \cdot g \cdot H_n} \qquad \underline{c}_1 = \frac{c_1}{\sqrt{2 \cdot g \cdot H_n}} = 1$$

Circumferential speed:

$$u_1 = \frac{c_{1u}}{2} = \frac{1}{2} \cdot \sqrt{2 \cdot g \cdot H_n} \qquad \underline{u}_1 = 0.5$$

Euler`s turbine equation:

$$\eta_h = 2(\underline{u}_1 \cdot \underline{c}_{1u} - \underline{u}_2 \cdot c_{2u})$$

$$\underline{c}_{1u} = 1 \qquad \underline{c}_{u2} = 0$$

$$\eta_h = 2 \cdot (\underline{u}_1 \cdot \underline{c}_{1u} - \underline{u}_2 \cdot \underline{c}_{2u}) = 2 \cdot (0{,}5 \cdot 1.0 - 0{,}5 \cdot 0) = 1$$

The real Pelton runner

- For a real Pelton runner there will always be loss

We will therefore set the hydraulic efficiency to:

$$\eta_h = 0.96$$

The absolute velocity from the nozzle will be:

$$0.99 \leq \underline{c}_{1u} < 0.995$$

C_{1u} can be set to 1,0 when dimensioning the turbine.
This gives us:

$$\eta_h = 2(\underline{u}_1 \cdot \underline{c}_{1u} - \underline{u}_2 \cdot \underline{c}_{2u})$$

$$\Downarrow$$

$$\underline{u}_1 = \frac{\eta_n}{2 \cdot \underline{c}_{1u}} = \frac{0,96}{2 \cdot 1,0} = 0,48$$

From continuity equation:

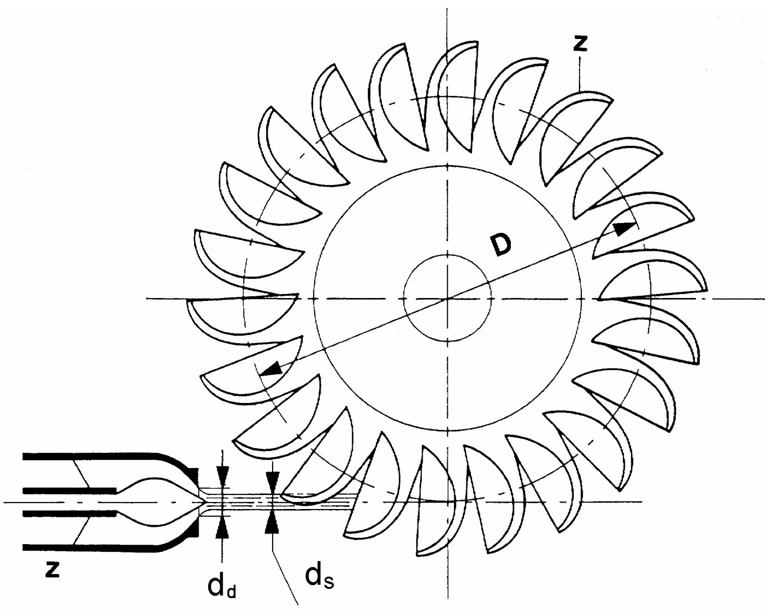
$$Q = z \cdot \frac{\pi \cdot d_s^2}{4} \cdot c_{1u}$$

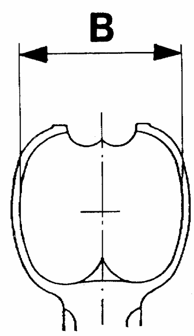
$$\Downarrow$$

$$d_s = \sqrt{\frac{4 \cdot Q}{z \cdot \pi \cdot c_{1u}}}$$

Where:

Z	=	number of nozzles
Q	=	flow rate
C_{1u}	=	$\sqrt{2 \cdot g \cdot H_n}$



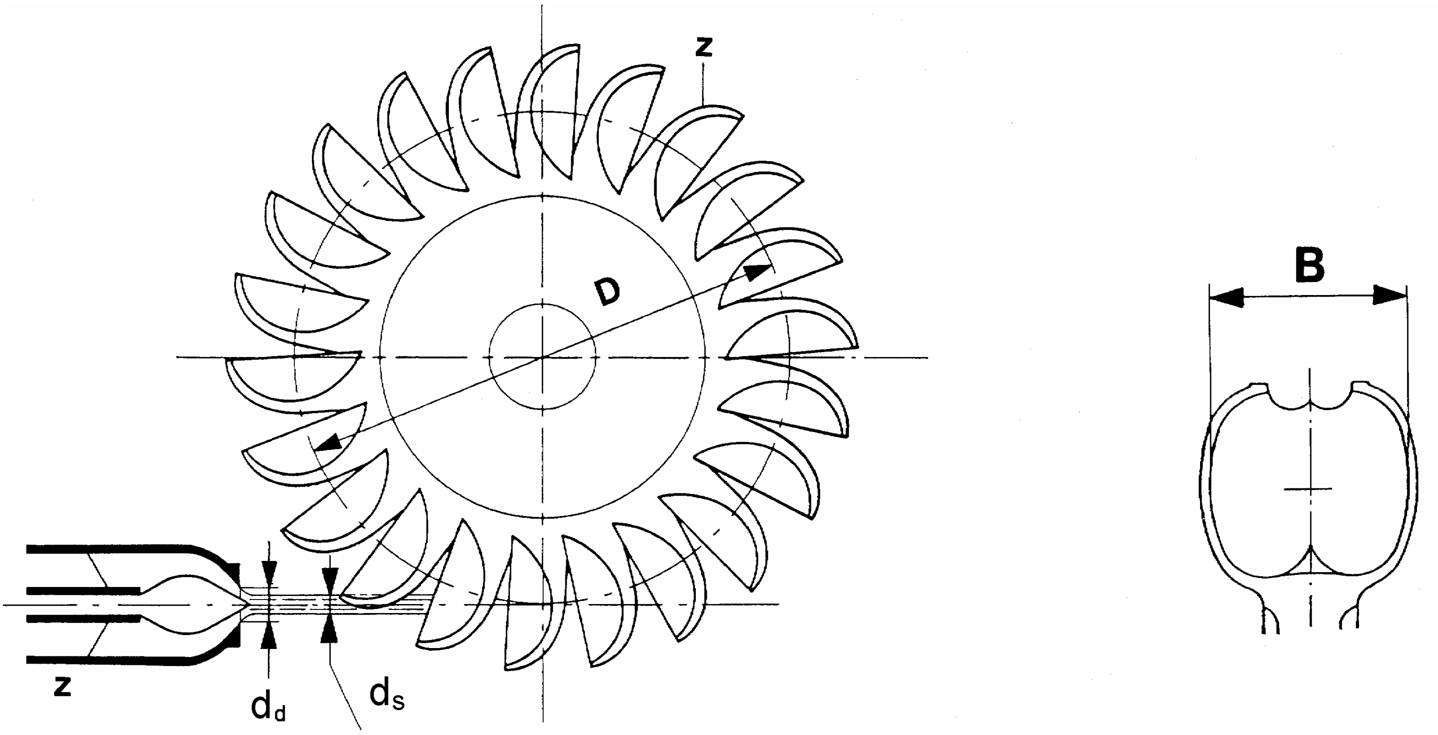


The size of the bucket and number of nozzles

$$3.1 > \frac{B}{d_s} \geq 3.4$$

Rules of thumb:

$B = 3{,}1 \cdot d_s$ 1 nozzle
$B = 3{,}2 \cdot d_s$ 2 nozzles
$B = 3{,}3 \cdot d_s$ 4-5 nozzles
$B > 3{,}3 \cdot d_s$ 6 nozzles

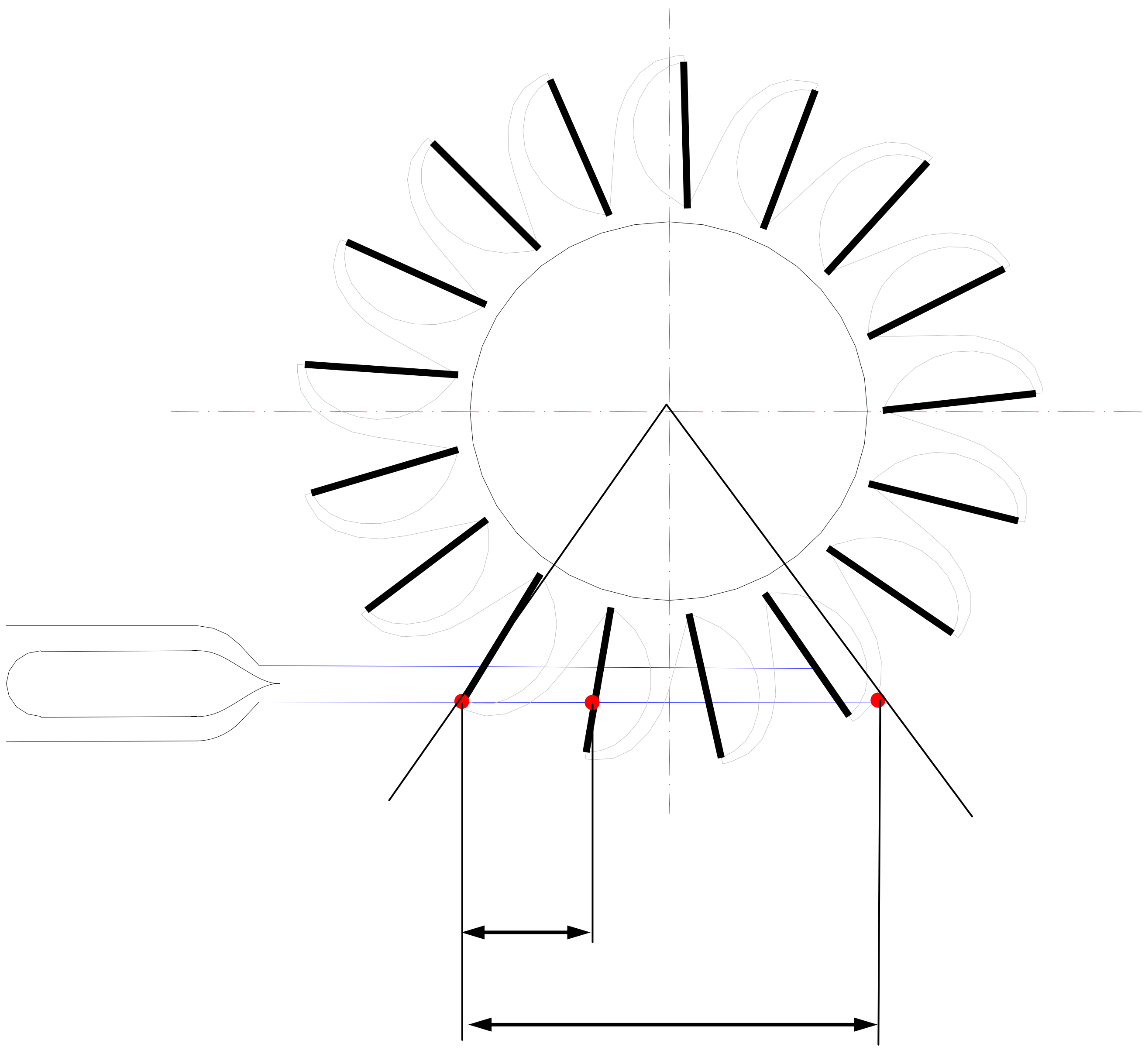


Number of buckets

$$z \geq 17$$

empirical

Number of buckets



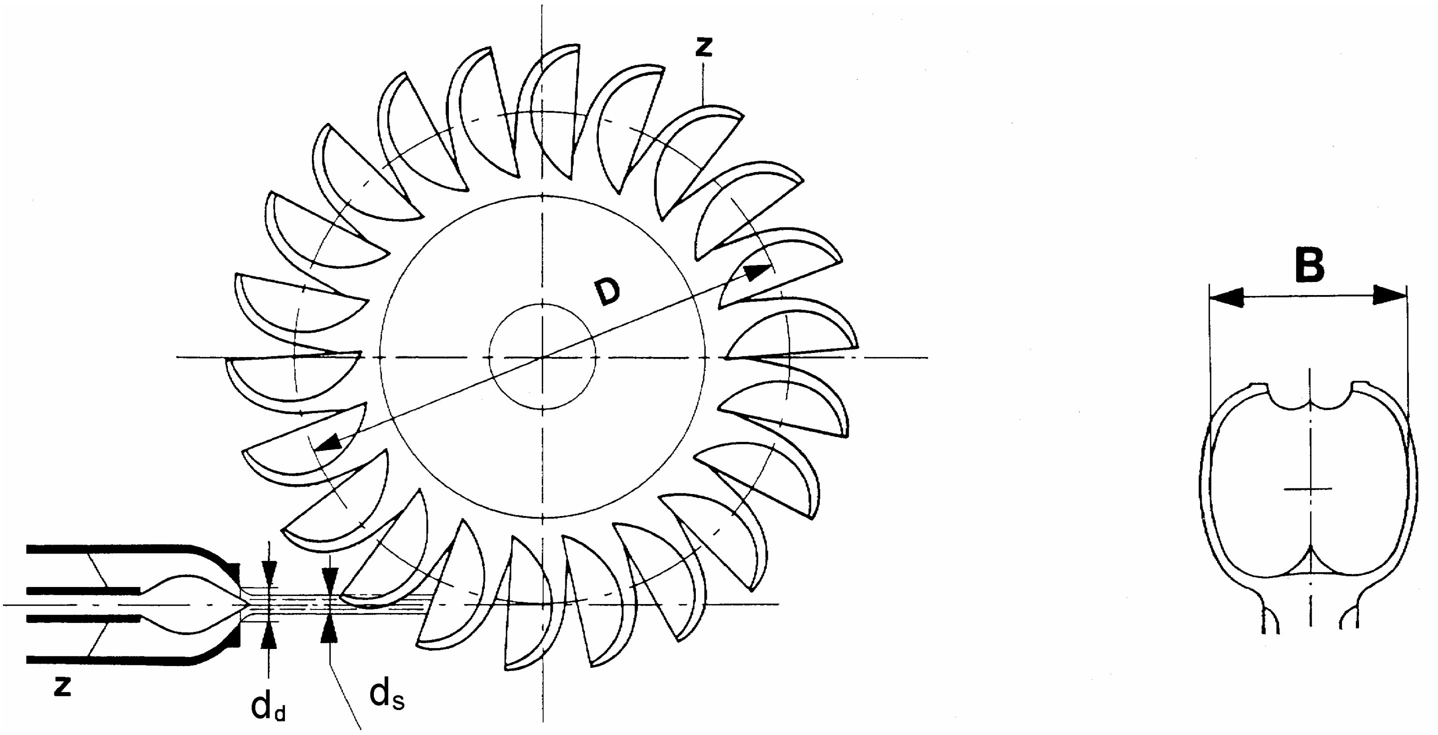
Runner diameter

Rules of thumb:

$D = 10 \cdot d_s$	$H_n \leq 500$ m
$D = 15 \cdot d_s$	$H_n = 1300$ m

$D < 9{,}5 \cdot d_s$ must be avoided because water will be lost

$D > 15 \cdot d_s$ is for very high head Pelton



Speed number

$$\Omega = \underline{\omega}\sqrt{\underline{Q} \cdot z}$$

$$\underline{c}_{1u} = 1{,}0$$

$$\underline{u}_1 = 0{,}5$$

$$\underline{Q} = \frac{\pi \cdot d_s^2}{4} \cdot \underline{c}_{1u} = \frac{\pi \cdot d_s^2}{4}$$

$$\underline{\omega} = \frac{\omega}{\sqrt{2 \cdot g \cdot H_n}} = \frac{2 \cdot u_1}{D \cdot \sqrt{2 \cdot g \cdot H_n}} = \frac{\sqrt{2 \cdot g \cdot H_n}}{D \cdot \sqrt{2 \cdot g \cdot H_n}} = \frac{1}{D}$$

$$\underline{\Omega} = \underline{\omega} \cdot \sqrt{\underline{Q} \cdot z} = \frac{1}{D} \cdot \sqrt{\frac{\pi \cdot d_s^2 \cdot z}{4}}$$

$$\boxed{\underline{\Omega} = \frac{d_s}{D}\sqrt{\frac{\pi \cdot z}{4}}}$$

For the diameter: $D = 10 \cdot d_s$
and one nozzle: $z = 1$

$$\underline{\Omega} = \frac{d_s}{D}\sqrt{\frac{\pi \cdot z}{4}} = \frac{1}{10}\sqrt{\frac{\pi \cdot 1}{4}} = 0{,}09$$

The maximum speed number for a Pelton turbine with one nozzle is $\Omega = 0{,}09$

For the diameter: $D = 10 \cdot d_s$
and six nozzle: $z = 6$

$$\underline{\Omega} = \frac{d_s}{D}\sqrt{\frac{\pi \cdot z}{4}} = \frac{1}{10}\sqrt{\frac{\pi \cdot 6}{4}} = 0{,}22$$

The maximum speed number for a Pelton turbine today is $\Omega = 0{,}22$

Dimensioning of a Pelton turbine

1. The flow rate and head are given

   *H = 1130 m

   *Q = 28,5 m^3/s

   *P = 288 MW

2. Choose reduced values

   $\underline{c}_{1u} = 1 \quad \Rightarrow \quad c_{1u} = 149$ m/s

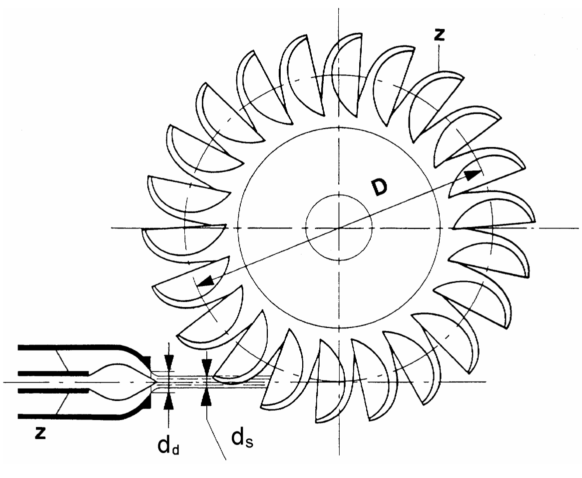
   $\underline{u}_1 = 0{,}48 \quad \Rightarrow \quad u_1 = 71$ m/s

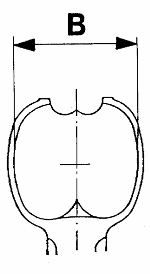
3. Choose the number of nozzles

   z = 5

4. Calculate d_s from continuity for one nozzle

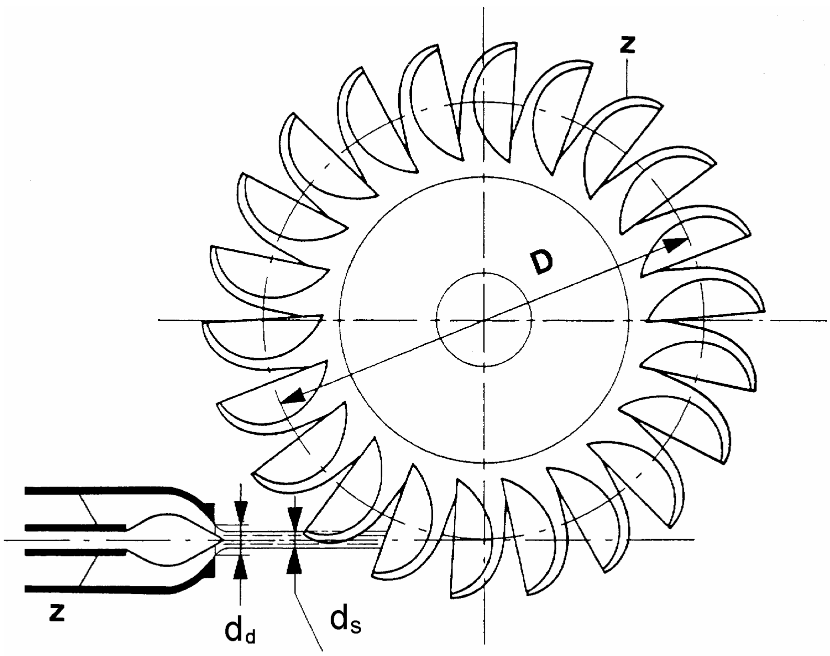
$$d_s = \sqrt{\frac{4 \cdot Q}{z \cdot \pi \cdot c_{1u}}} = 0{,}22 \text{ m}$$

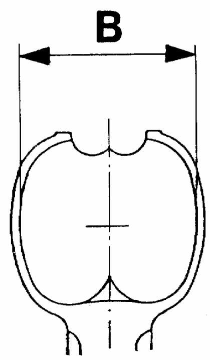




5. Choose the bucket width

$$B = 3{,}3 \cdot d_s = 0{,}73 \text{ m}$$



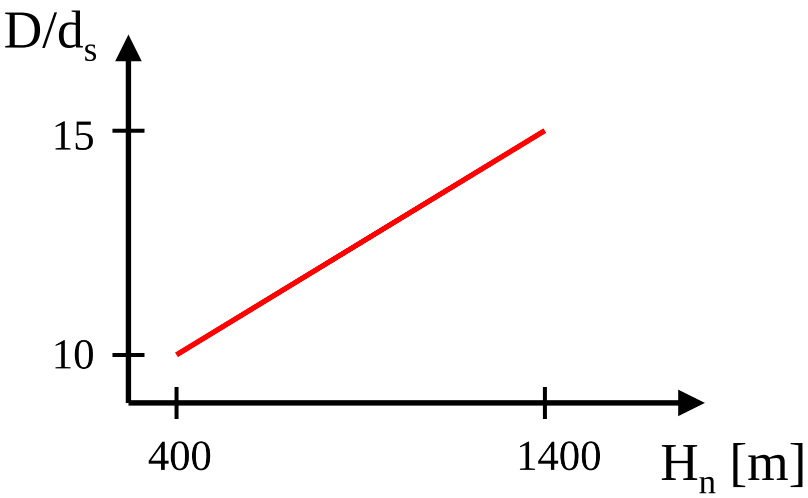


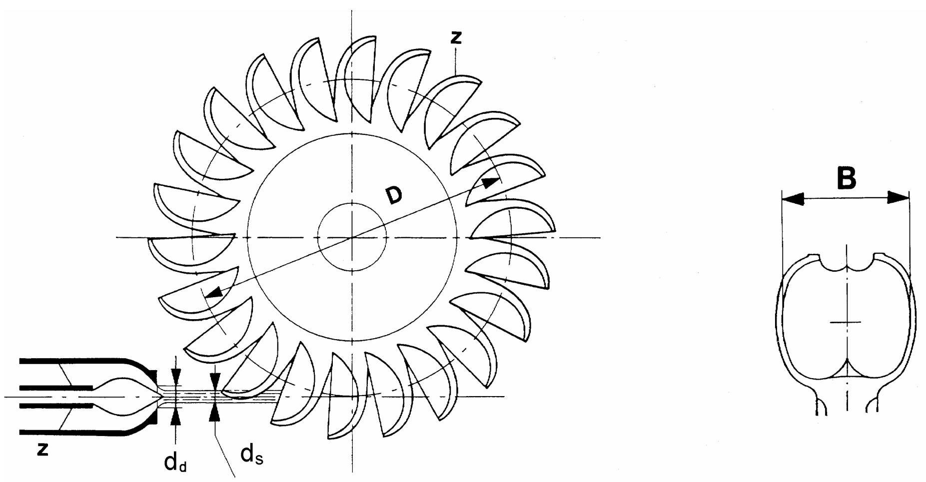
6. Find the diameter by interpolation

$$\frac{D}{d_s} = 0{,}005 \cdot H_n + 8 = 13{,}65$$

$$\Downarrow$$

$$D = 13{,}65 \cdot d_s = 3{,}0 \text{ m}$$





7. Calculate the speed:

$$u_1 = \omega \cdot \frac{D}{2} = \frac{2 \cdot \Pi \cdot n}{60} \cdot \frac{D}{2}$$

$$\Downarrow$$

$$n = \frac{u_1 \cdot 60}{\Pi \cdot D} = 452 \text{ rpm}$$

8. Choose the number of poles on the generator:

The speed of the runner is given by the generator and the net frequency:

$$n = \frac{3000}{Z_p} \quad [\text{rpm}]$$

where Z_p=number of poles on the generator

The number of poles will be:

$$Z_p = \frac{3000}{n} = 6{,}64 = 7$$

9. Recalculate the speed:

$$n = \frac{3000}{Z_p} = 428{,}6 \quad [\text{rpm}]$$

10. Recalculate the diameter:

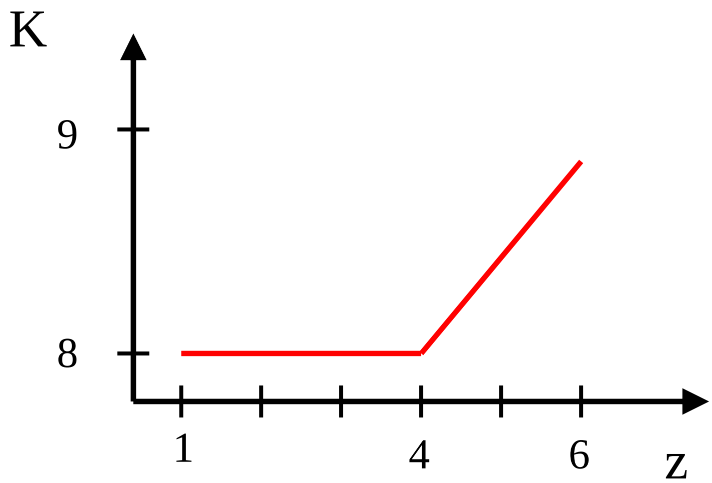
$$u_1 = \omega \cdot \frac{D}{2} = \frac{2 \cdot \Pi \cdot n}{60} \cdot \frac{D}{2} \quad \Rightarrow \quad D = \frac{u_1 \cdot 60}{\Pi \cdot n} = 3{,}16 \text{ m}$$

11. Choose the number of buckets

z = 22

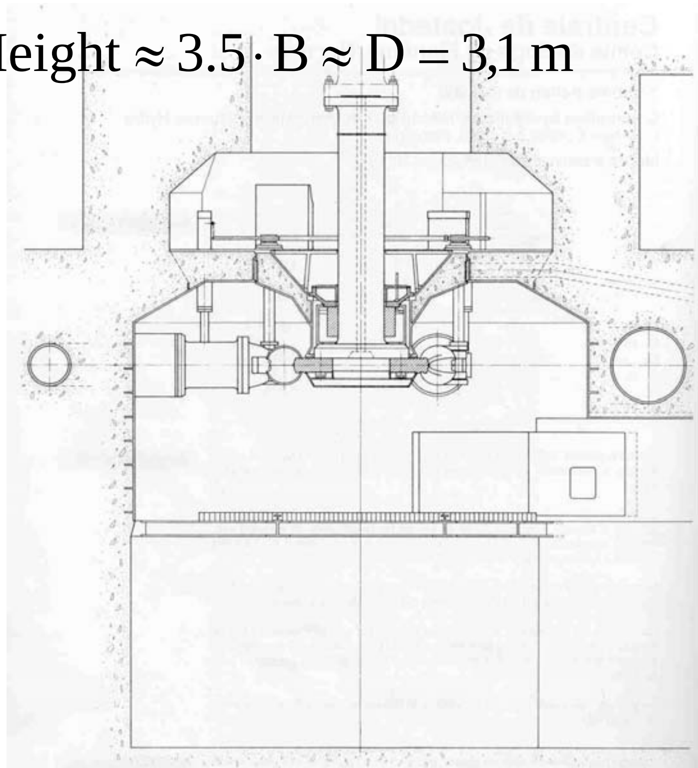
12. Diameter of the turbine housing (for vertical turbines)

$$D_{Housing} = D + K \cdot B = 9{,}4\ m$$

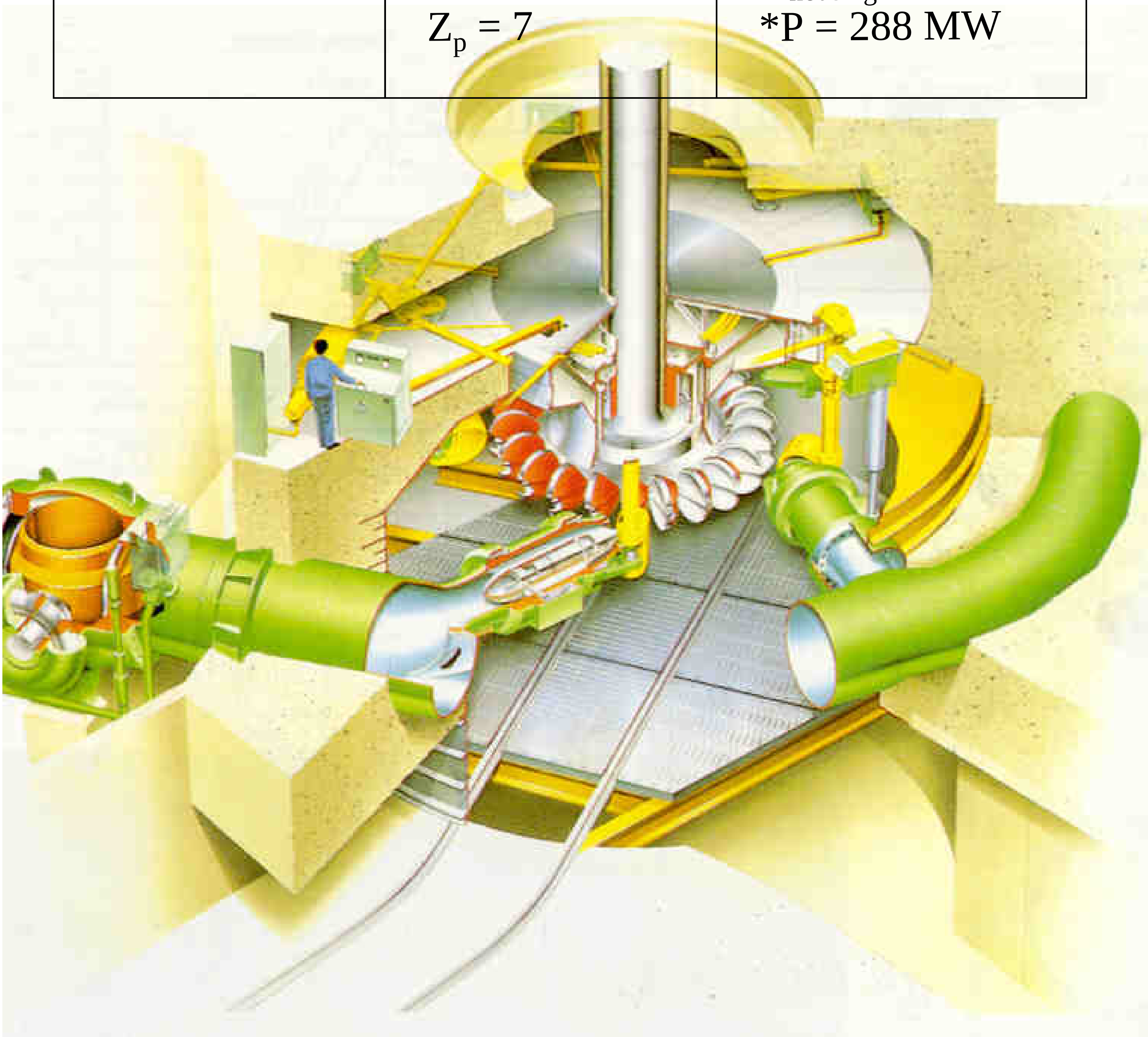


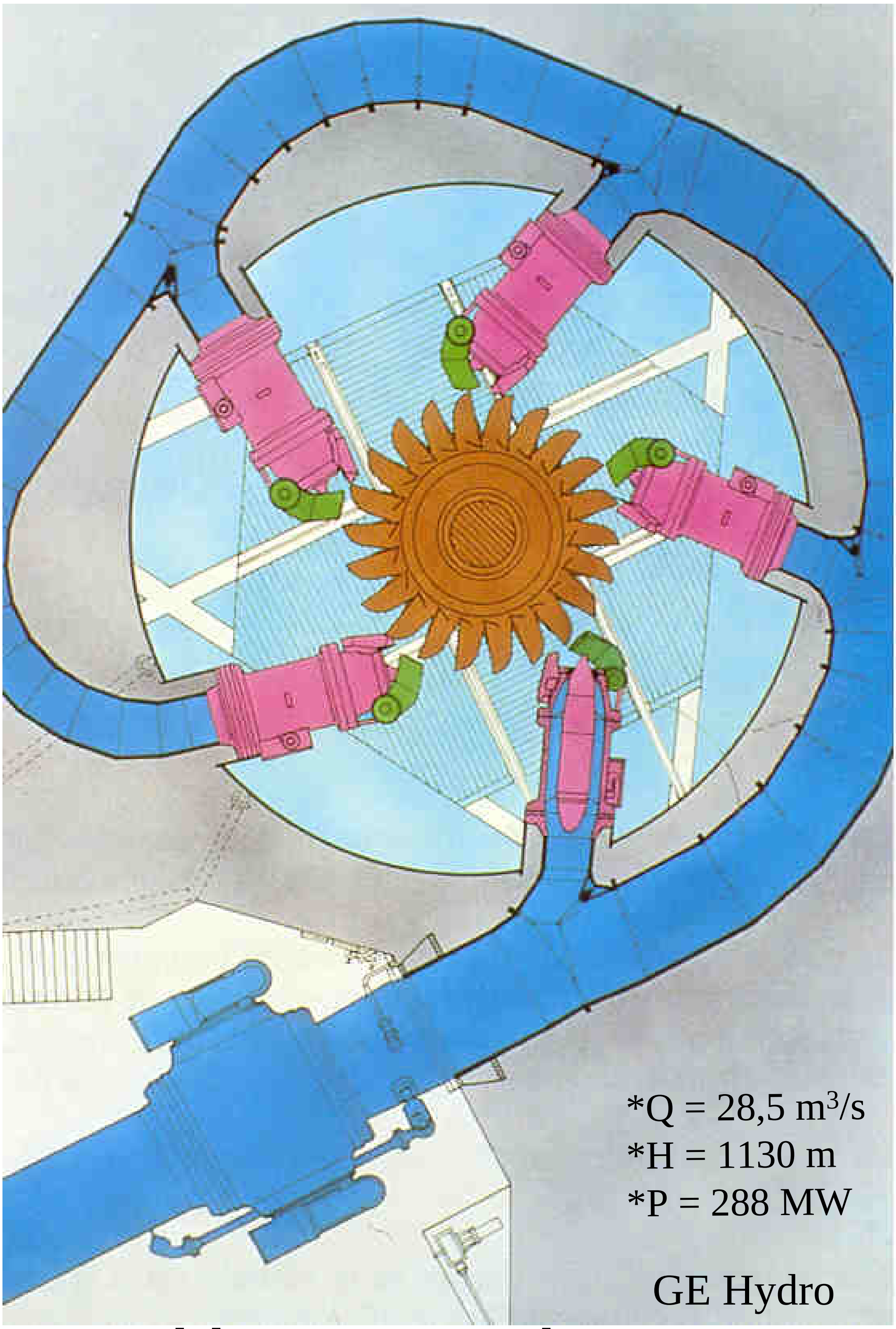
13. Calculate the height from the runner to the water level at the outlet (for vertical turbines)

$$Height \approx 3.5 \cdot B \approx D = 3{,}1\ m$$

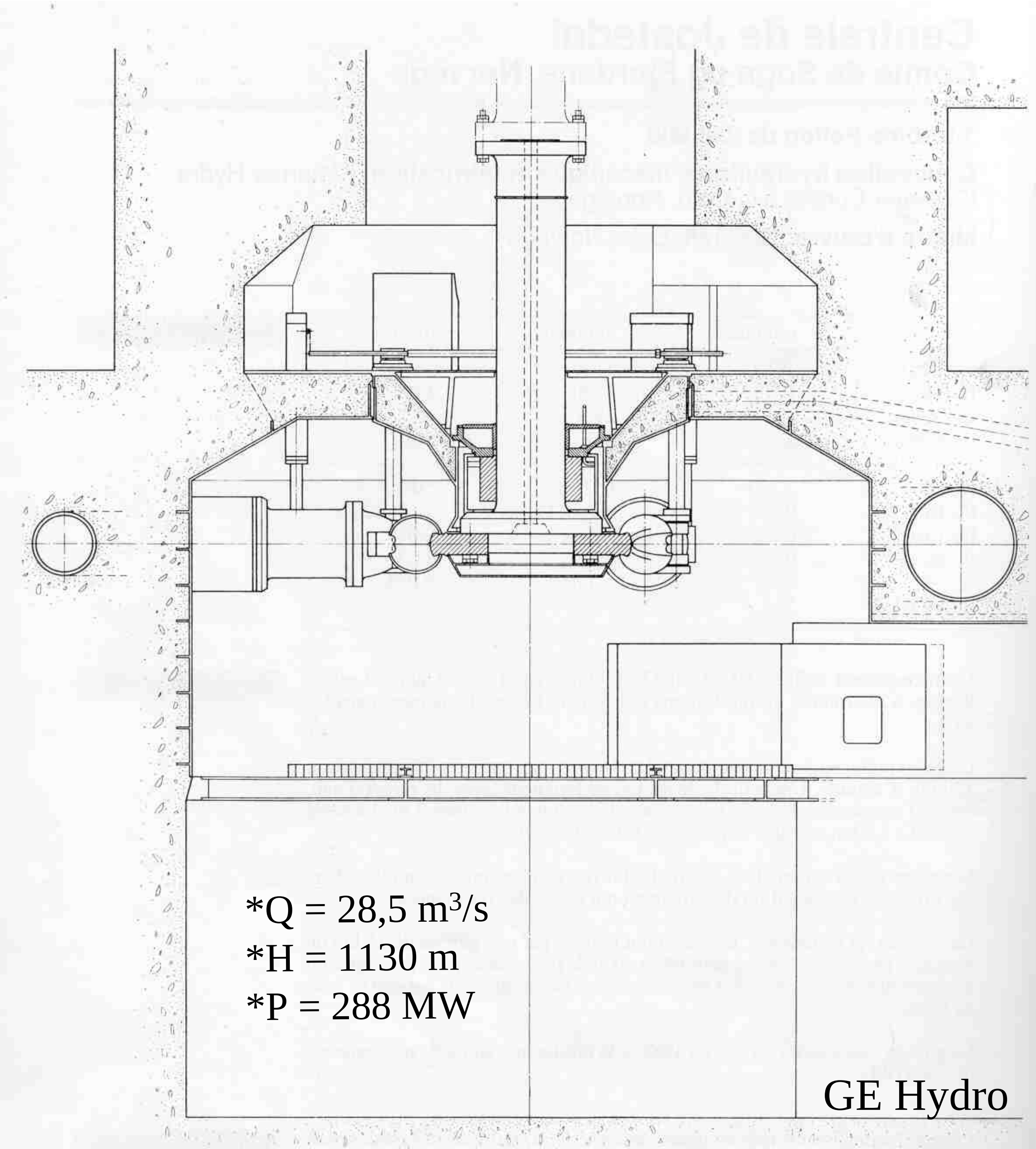


Given values:	Chosen values:	Calculated values:
*Q = 28,5 m^3/s	$\underline{c}_{1u} = 1$	$d_s = 0{,}22$ m
*H = 1130 m	$\underline{u}_1 = 0{,}48$	n = 428,6 rpm
	z = 5	D = 3, 16 m
	B = 0,73 m	Height = 3,1 m
	z = 22	$D_{housing} = 9{,}4$ m
	$Z_p = 7$	*P = 288 MW





Jostedal, Sogn og Fjordane



Jostedal, Sogn og Fjordane

Example

Khimti Power Plant

1. The flow rate and head are given

   *H = 660 m

   *Q = 2,15 m^3/s

   *P = 12 MW

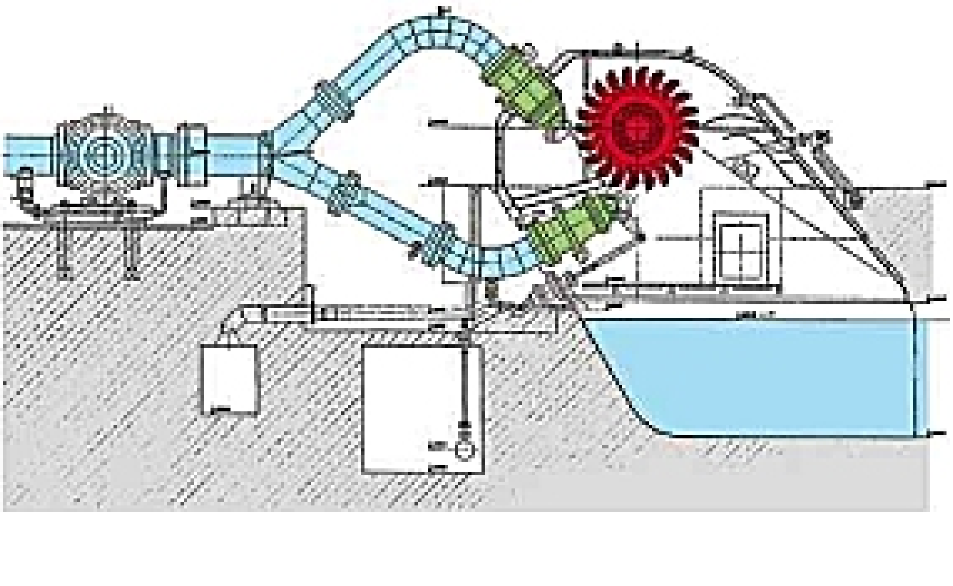
2. Choose reduced values

   $\underline{c}_{1u} = 1 \quad \Rightarrow \quad c_{1u} = 114$ m/s

   $\underline{u}_1 = 0{,}48 \quad \Rightarrow \quad u_1 = 54{,}6$ m/s

3. Choose the number of nozzles

   z = 1



Example

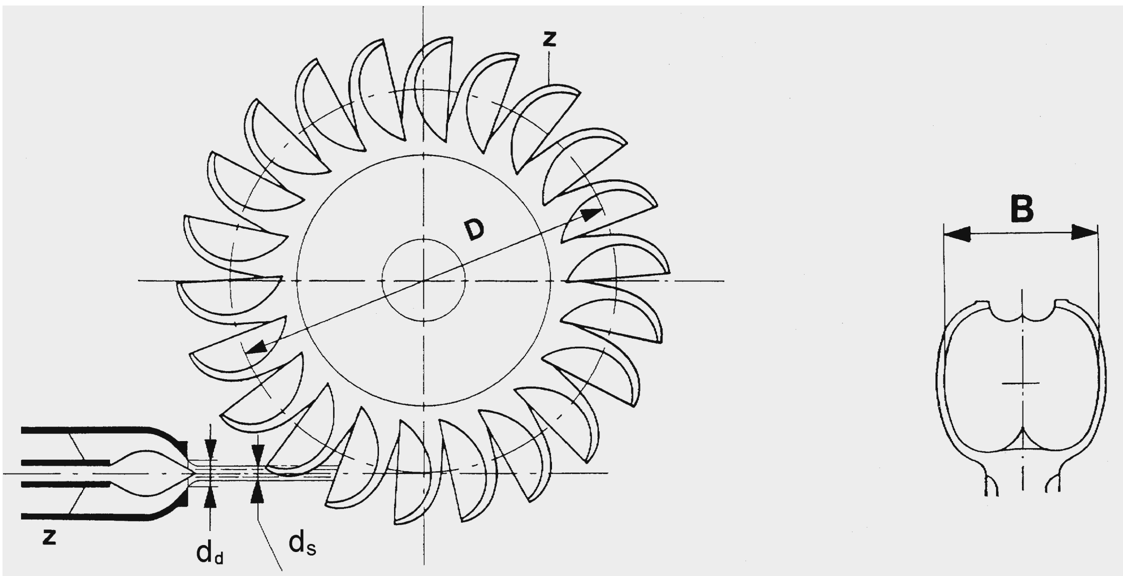
Khimti Power Plant

4. Calculate d_s from continuity for one nozzle

$$d_s = \sqrt{\frac{4 \cdot Q}{z \cdot \pi \cdot c_{1u}}} = 0{,}15\, m$$

5. Choose the bucket width

$B = 3{,}2 \cdot d_s = 0{,}5$ m

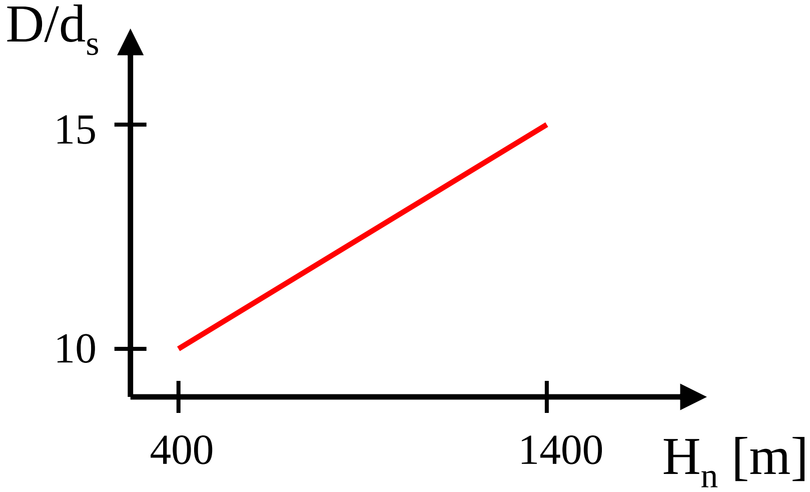


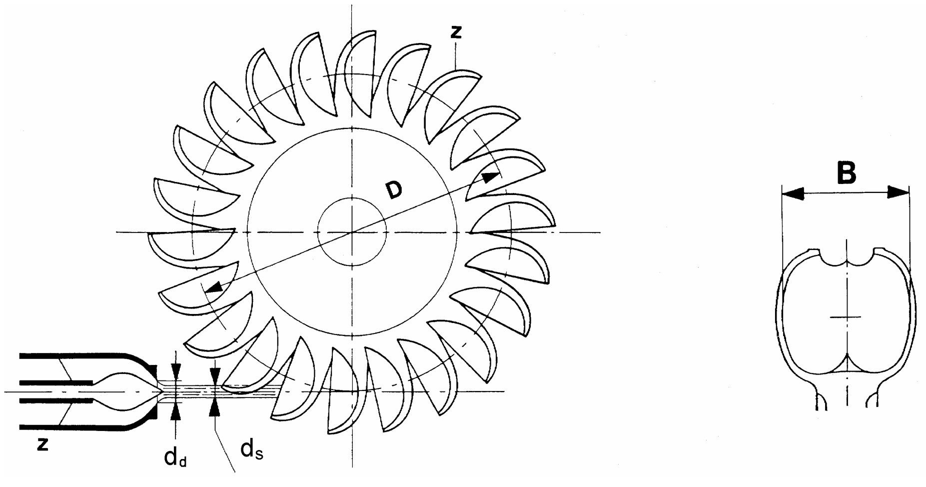
6. Find the diameter by interpolation

$$\frac{D}{d_s} = 0{,}005 \cdot H_n + 8 = 11{,}3$$

$$\Downarrow$$

$$D = 11{,}3 \cdot d_s = 1{,}7\ m$$





7. Calculate the speed:

$$u_1 = \omega \cdot \frac{D}{2} = \frac{2 \cdot \Pi \cdot n}{60} \cdot \frac{D}{2}$$

$$\Downarrow$$

$$n = \frac{u_1 \cdot 60}{\Pi \cdot D} = 613\, rpm$$

8. Choose the number of poles on the generator:

The speed of the runner is given by the generator and the net frequency:

$$\mathrm{n} = \frac{3000}{\mathrm{Z_p}} \quad [\mathrm{rpm}]$$

where Z_p=number of poles on the generator

The number of poles will be:

$$Z_p = \frac{3000}{n} = 4{,}9 = 5$$

9. Recalculate the speed:

$$n = \frac{3000}{Z_p} = 600 \quad [rpm]$$

10. Recalculate the diameter:

$$u_1 = \omega \cdot \frac{D}{2} = \frac{2 \cdot \Pi \cdot n}{60} \cdot \frac{D}{2} \quad \Rightarrow \quad D = \frac{u_1 \cdot 60}{\Pi \cdot n} = 1{,}74\ m$$

11. Choose the number of buckets

z = 22