# Hydraulic Power Plants and Turbines

*Master Degree in Innovative Technologies in Energy Efficient Buildings for Russian & Armenian Universities and Stakeholders*

# Specific work and power of hydraulic plants

- Hydraulic energy power generation (hydropower) has been used since ancient times to grind flour and perform other tasks. Today hydropower is the most widely used form of renewable energy accounting for about 16 percent of global electricity generation. Modern hydraulic power plants use the potential energy of water to operate turbines driving electric generators.
- If 1 and 2 designate the extremity inlet (upper) and outlet (lower) sections of the plant layout, the work exchange (per unit mass) in the open system is:

$$W_{12} = (h_1 - h_2) + (c_1^2/2 - c_2^2/2) + g\,(z_1 - z_2)$$

- Since enthalpy (h) and kinetic energy ($c^2/2$) variations are generally negligible, the work can be written:

$$W_{12} = W = g\,(z_1 - z_2) = g\,H'$$

where H' is the geodetic head, i.e., the difference in height between the source and the water outflow

- Actual power P is given by:

$$P = M \cdot W \cdot \eta = \rho \cdot Q \cdot g \cdot H' \cdot \eta$$

where:

$\rho$ = water density = 1000 kg/m$^3$

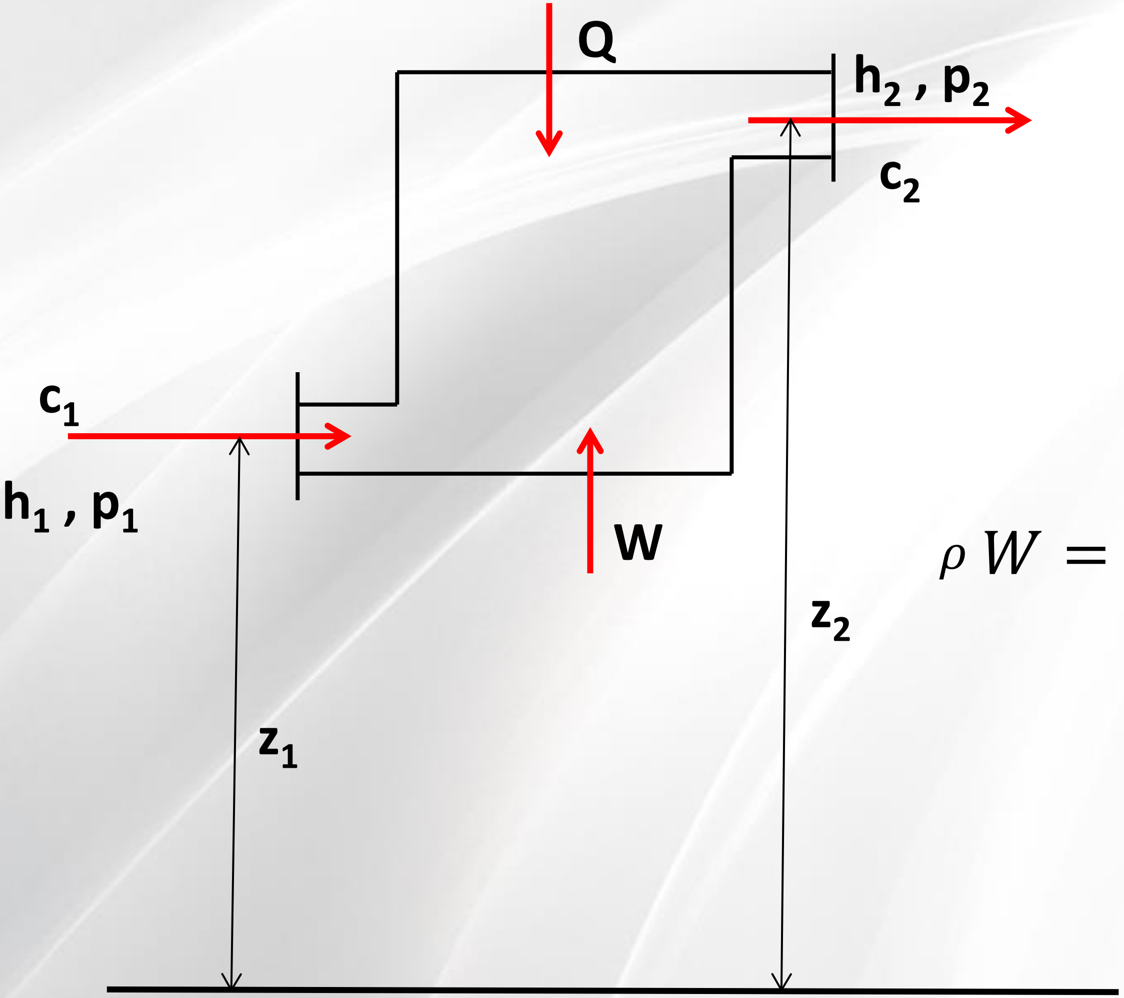
Q = volume flow rate

$\eta$ = overall efficiency (taking account of circuit pipes and turbine losses)

# Types of hydraulic plants and turbines

- There are three main types of hydropower facilities:
  - **reservoir (impoundment) plants**: they mainly use the position energy of the water collected (naturally or by a dam) in a basin or lake, at high elevation in the mountains.
  - **water flowing (run-of-river) plants**: they channels a portion of a river through a canal or penstock. They may not require the use of a dam. The water coming from upstream must be used for generation at that moment, or must be allowed to bypass the plant.
  - **pumped-storage plants**: they are similar in structure to reservoir plants and move water between reservoirs at different elevations. At times of low electrical demand, the excess generation capacity of the grid is used to pump water from a lower reservoir to an upper reservoir. During periods of high electrical demand, the water is released back to the lower reservoir and turns a turbine, generating electricity. Pumped-storage schemes currently provide the most commercially important means of large-scale grid energy storage.
- The hydraulic turbines are power generating fluid machines that convert the energy of water supplied by a hydraulic plant into mechanical work.
- Hydraulic turbines may be classified into:
  - **impulse turbines** (Pelton), where the pressure of the fluid along the rotor channels is constant
  - **reaction turbines** (Francis, Kaplan), where the pressure of the fluid drops along the rotor channels

# The energy equations for open systems




$$dW = c\,dc + \frac{dp}{\rho} + dw_f + g\,dz$$

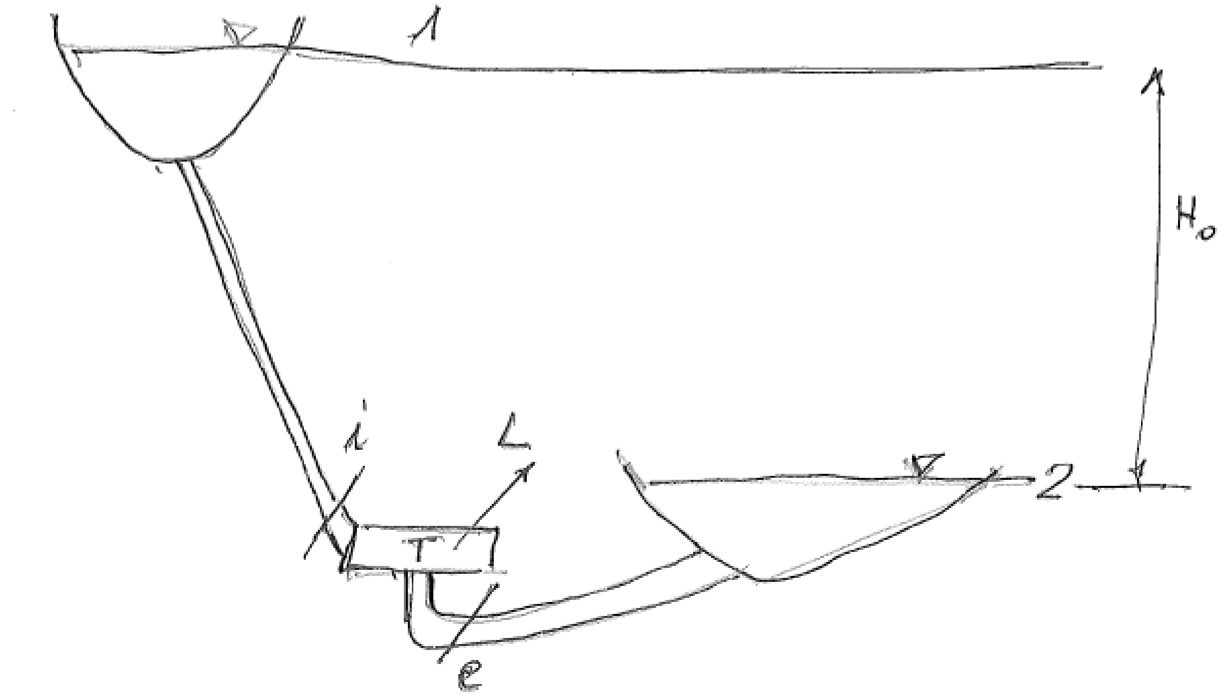
**Mechanical form**

If ρ = cost:

$$\rho\, W = \left(p_2 + \frac{1}{2}\rho {c_2}^2 + \rho g z_2\right) - \left(p_1 + \frac{1}{2}\rho {c_1}^2 + \rho g z_1\right) + \rho w_f$$

$$p + \frac{1}{2}\rho c^2 + gz = p_t$$ **Total pressure**

APPLICATION OF ENERGY EQUATION TO THE HYDRAULIC POWER PLANT




(1) E

ENERGY EQUATION

Applied between section 1 and 2

$$\frac{p_1}{\rho} + \frac{c_1^2}{2} + g z_1 = \frac{p_2}{\rho} + \frac{c_2^2}{2} + g z_2 + \left(L_T + g h_{pu} + g h_{pd} + g h_{pT}\right)$$

$$p_1 = p_2 = p_a \qquad c_1 = c_2 = 0$$

$$L_T = g\,\overbrace{(z_1 - z_2)}^{H_o} - g h_{pu} - g h_{pd} - g h_{pT}$$

$$L_T = g H_o - g h_{pc} - g h_{pT}$$

$$H = H_0 - h_{pc} \qquad H = \text{net head}$$

$$\eta_c = \frac{H_0 - h_{pc}}{H_0} = \frac{H}{H_0}$$

$$L_T = g H - g h_{pT}$$

$$\eta_T = \frac{gH - g h_{pt}}{gH} = \frac{L_T}{gH}$$

$$L_T = g H \eta_T \qquad \eta_T = \eta_v \cdot \eta_i \cdot \eta_m$$

$$\boxed{P_T = \rho Q g H \eta_T}$$

ENERGY EQUATION APPLIED TO UPSTREAM AND DOWNSTREAM PARTS OF THE HYDRAULIC PLANT

③E

UPSTREAM:

$$\frac{p_a}{\rho} + \frac{c_1^2}{2} + \rho z_1 = \frac{p_i}{\rho} + \frac{c_i^2}{2} + \rho z_i + \rho h_{pup}$$

$$\frac{p_e}{\rho} + \frac{c_e^2}{2} + \rho z_e = \frac{p_a}{\rho} + \frac{c_2^2}{2} + \rho z_2 + \rho h_{pd}$$

SUMMING

$$\frac{p_e}{\rho} + \frac{c_e^2}{2} + \rho z_e + \rho z_1 = \frac{p_i}{\rho} + \frac{c_i^2}{2} + \rho z_i + \rho z_2 + \rho(h_{pup} + h_{pd})$$

$$g(z_1 - z_2) - \rho(h_{pup} + h_{pd}) = \frac{p_i}{\rho} + \frac{c_i^2}{2} - \frac{p_e}{\rho} - \frac{c_e^2}{2} + \rho(z_i - z_e)$$

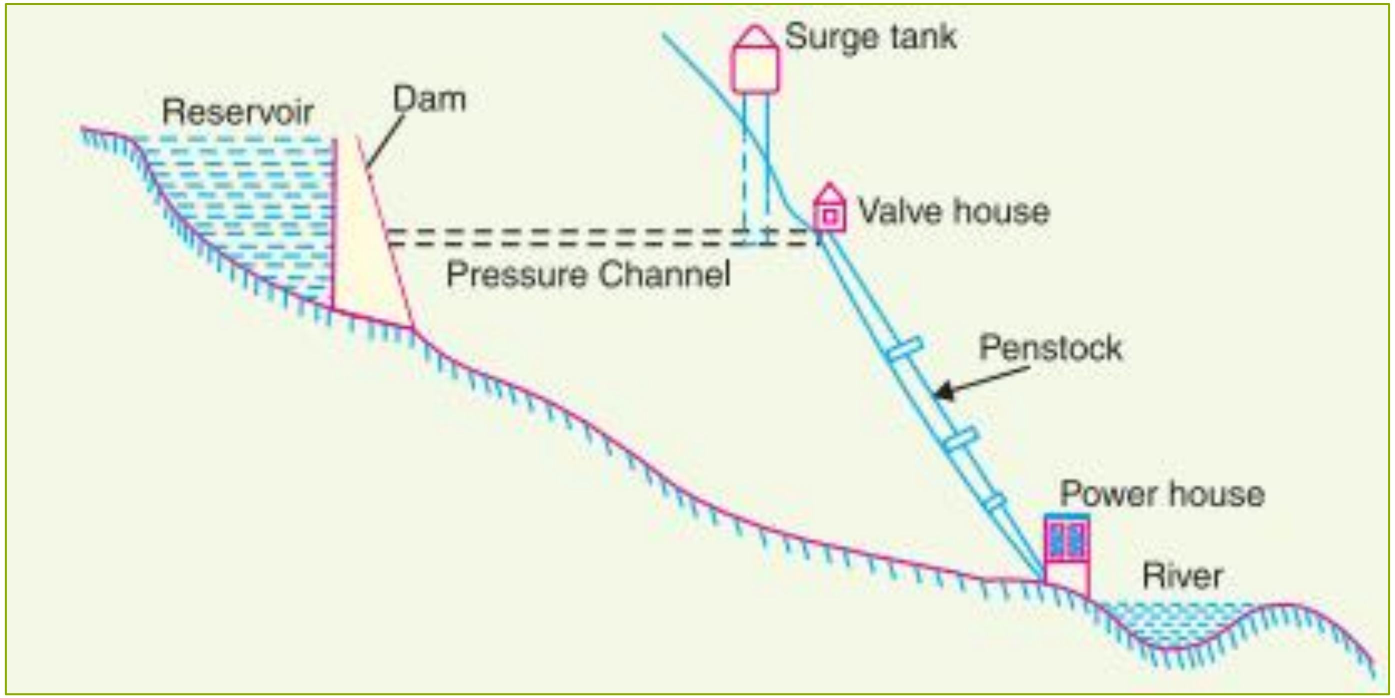
$$\rho H = \left(\frac{p_i - p_e}{\rho}\right) + \frac{c_i^2 - c_e^2}{2} + \rho(z_i - z_e)$$

$$gH = L_T + g h_{pT}$$

$$L_T = \left[\left(\frac{p_i - p_e}{\rho}\right) + \frac{c_i^2 - c_e^2}{2} + \rho(z_i - z_e)\right] - g h_{pT}$$

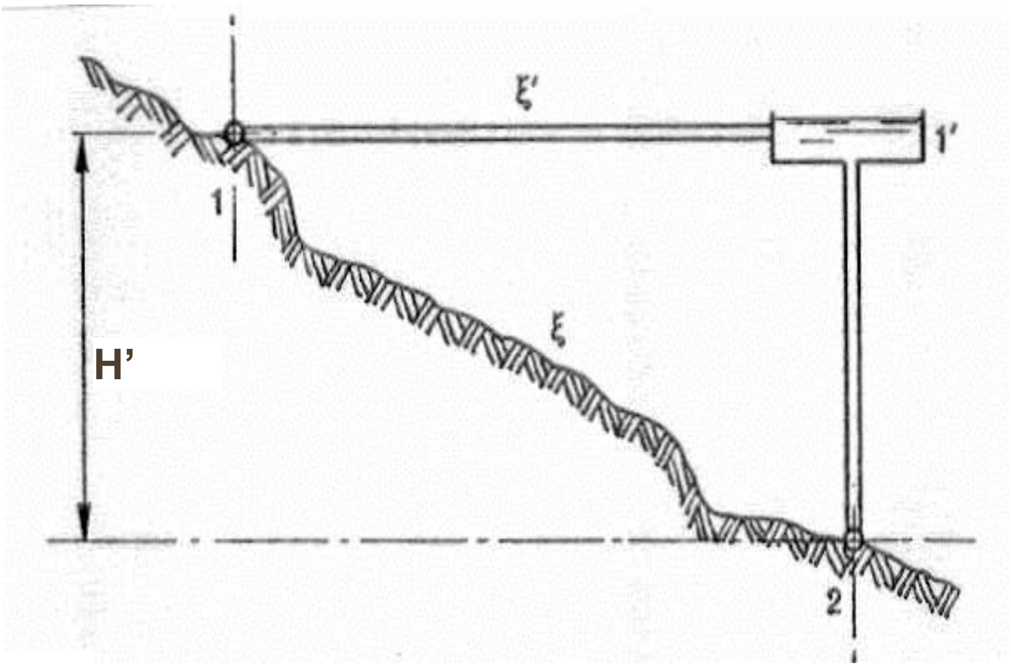
# Reservoir plants

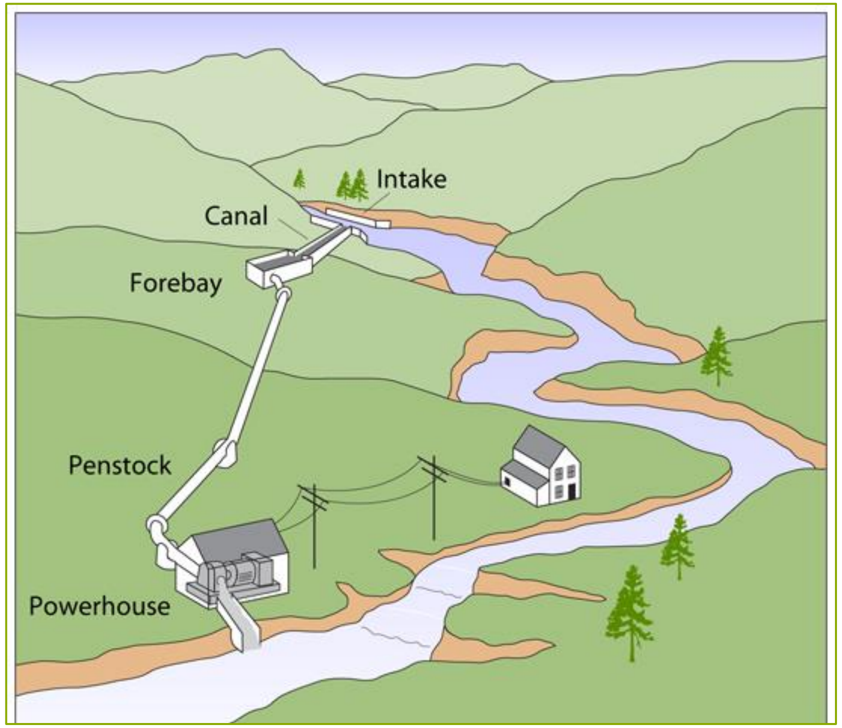
- The level differentials available are normally high (H’ = 500-1500 m), while the water volume flow rates are usually quite low (Q = 0.5-50 $m^3/s$).
- Pelton and Francis type hydraulic turbines are generally used in this type of plant.



# Water flowing (run-of-river) plants

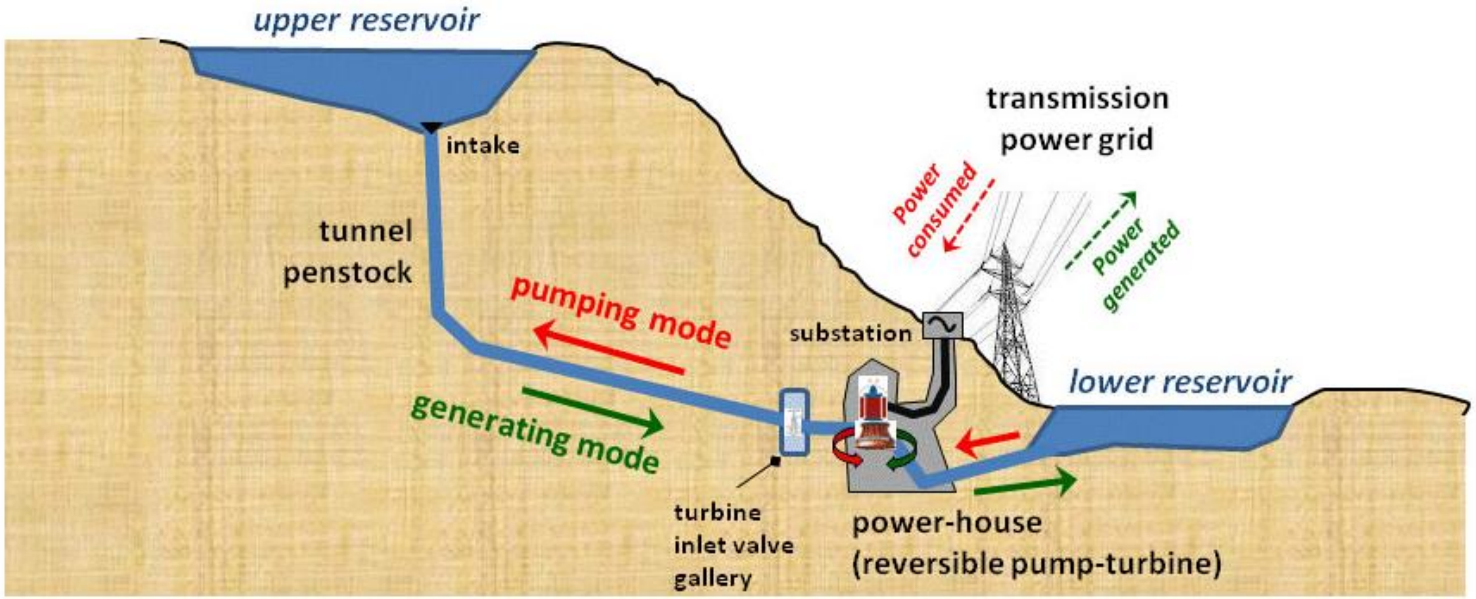
- In this case the geodetic heads are normally low (H' = 5-50 m) while the water flow rate range is extensive (Q = 5-500 $m^3/s$).
- Different hydraulic turbines can be used, mainly depending on the water flow rate.
- A portion of the river flow rate is diverted to an artificial canal with lower loss coefficient (ξ') than the natural one (ξ).



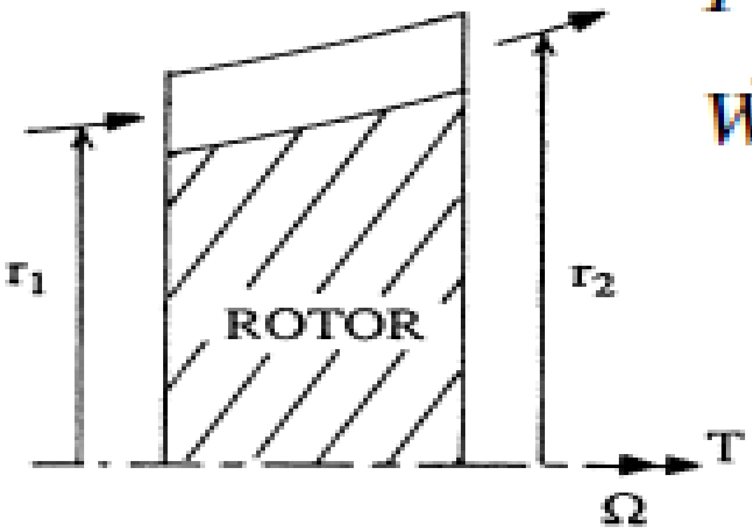



# Pumped-storage plants

- Pumped-storage plants store energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines to produce electric power.
- Although the losses of the pumping process make the plant a net consumer of energy overall, the system is economically profitable since it allows to sell more electricity during periods of peak demand, when electricity prices are highest.



# THE EULER WORK EQUATION




$$T = \dot{m}(r_2 V_{\theta 2} - r_1 V_{\theta 1})$$

$$\dot{W} = T\,\Omega = \dot{m}\;\Omega(r_2 V_{\theta 2} - r_1 V_{\theta 1})$$

$$= \dot{m}(U_2 V_{\theta 2} - U_1 V_{\theta 1})$$

$$\Delta h_0 = U_2 V_{\theta 2} - U_1 V_{\theta 1}$$

A hypothetical rotor for which flow enters at radius $r_1$ and leaves at radius $r_2$. The torque created is $T$ and the rotor rotates at $\Omega$ radian/s.

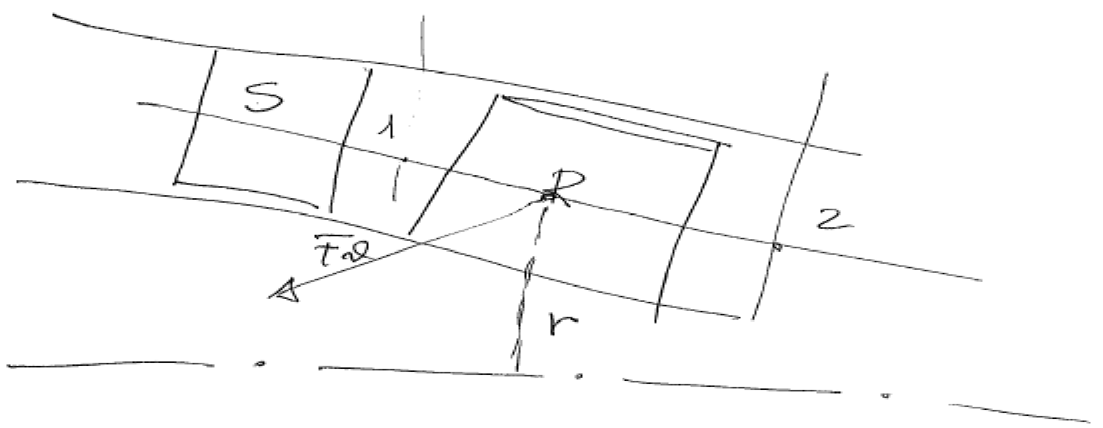
the torque is equal to the rate of change of moment of momentum

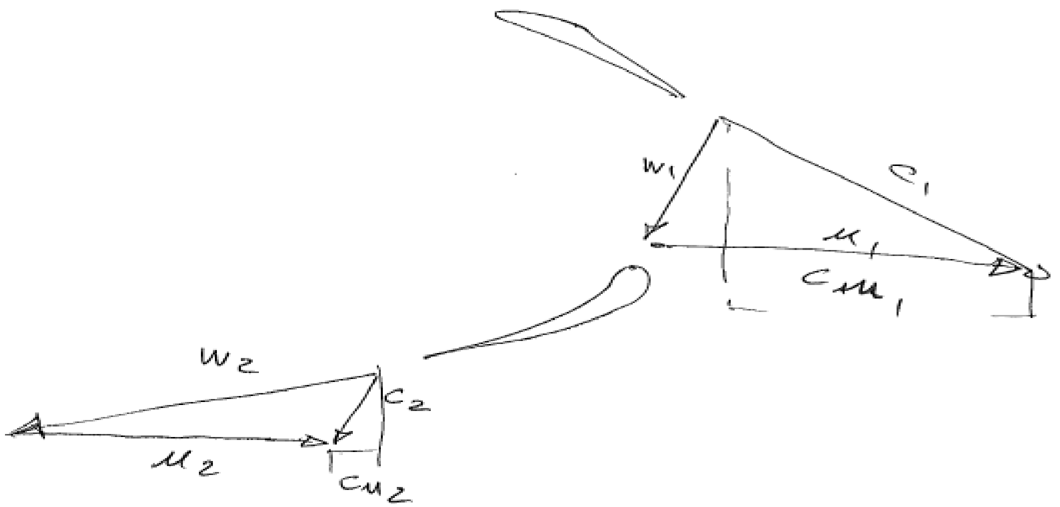
$$\Delta h_0 = U\,(V_{\theta 2} - V_{\theta 1}), \qquad \Delta h_0/U^2 = V_{\theta 2}/U - V_{\theta 1}/U$$

# EULER EQUATION FOR TURBINE

(MOMENT OF MOMENTUM EQUATION)

4E



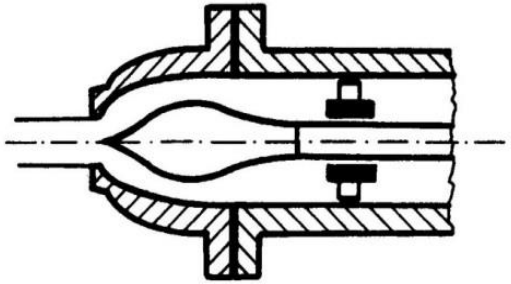



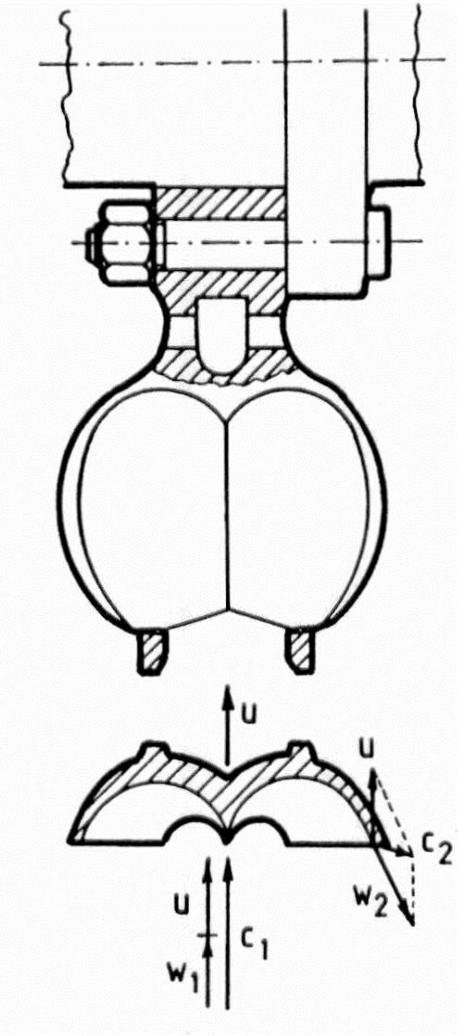

$$L = (u_1 c_{u_1} - u_2 c_{u_2}) \qquad L = \dot{m} P$$

$$P = \dot{m} \, (u_1 c_{u_1} - u_2 c_{u_2})$$

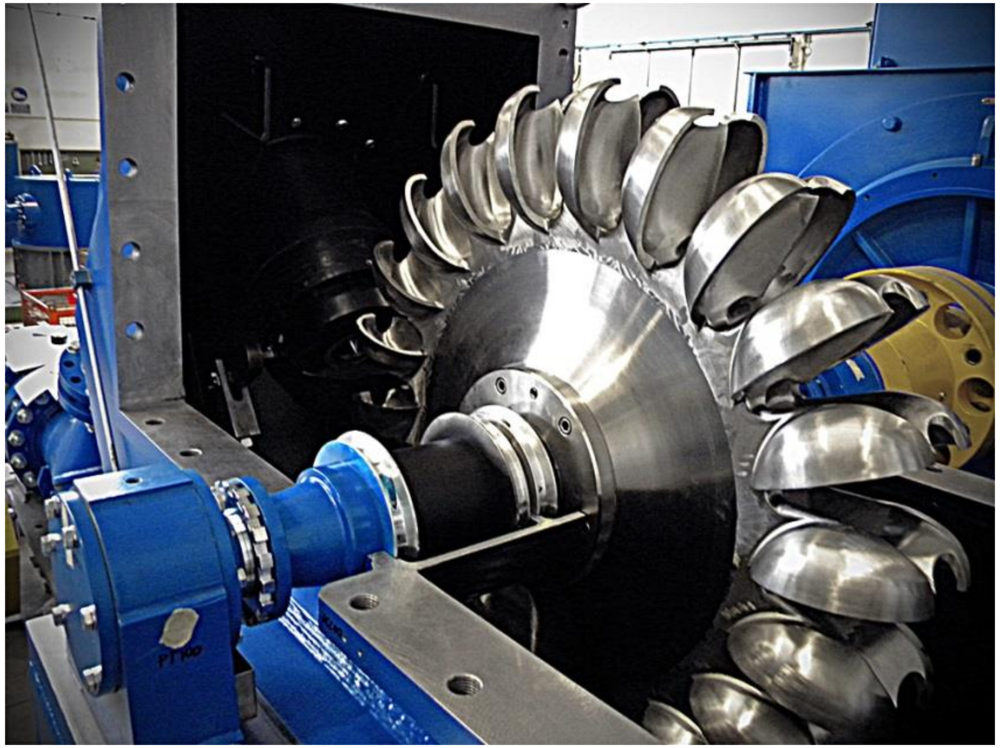
$$P = \omega \, C = \omega r F_\theta = u F_\theta = u \, \dot{m} \, \Delta c_u$$

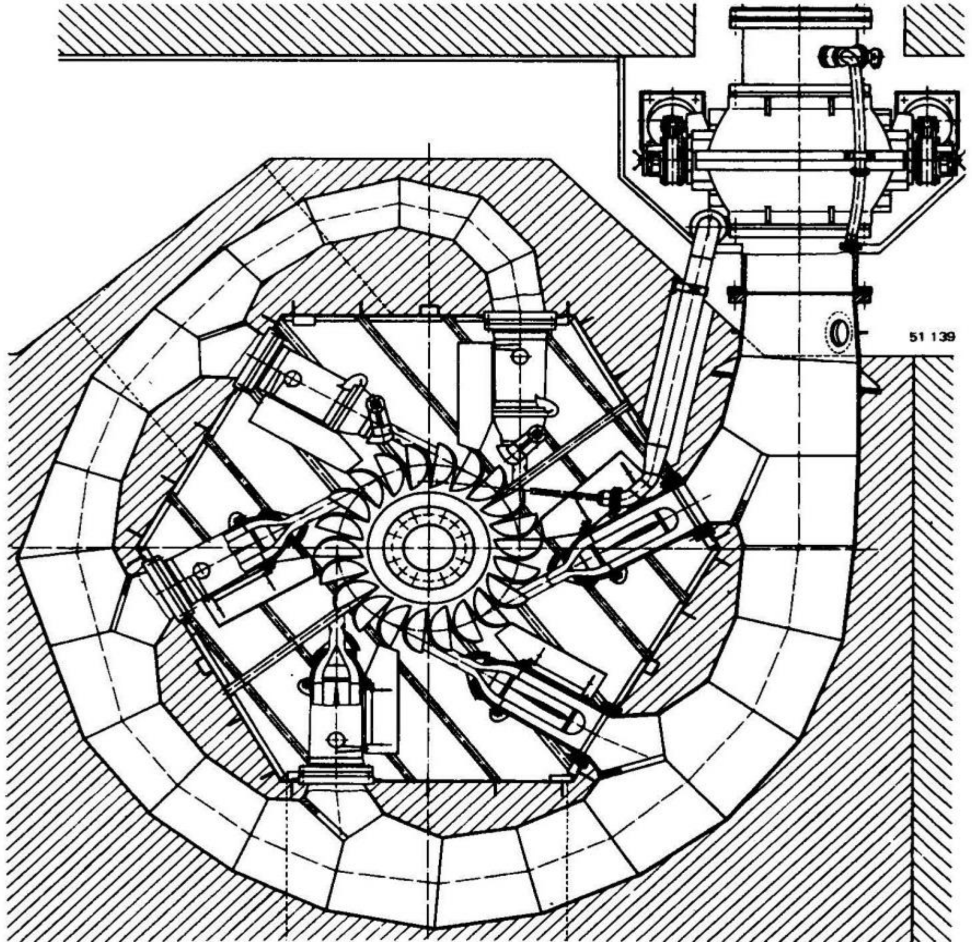
- The Pelton is an impulse type turbine. The Pelton wheel consists of a rotor, with double-spoon buckets mounted at its periphery.
- The water is transferred from a high head source through penstock pipes.
- Each branch duct from the penstock pipe ends in a nozzle, through which the water flows, controlled by a moving needle.
- All the available energy is converted into kinetic energy in the nozzle.
- The water kinetic energy is converted into mechanical work in the rotor





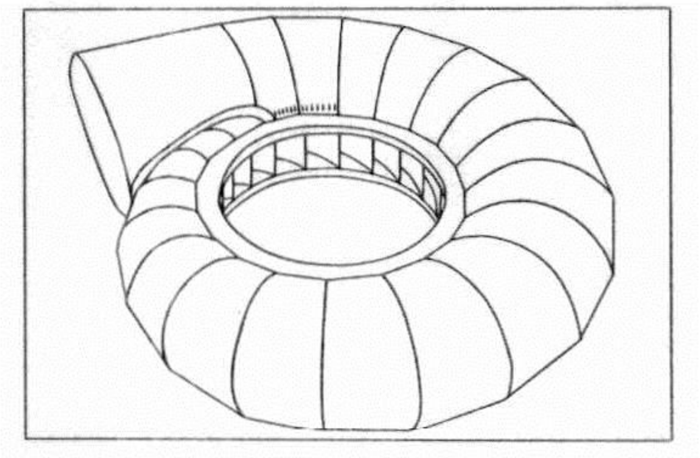
# Pelton turbine (2/2)

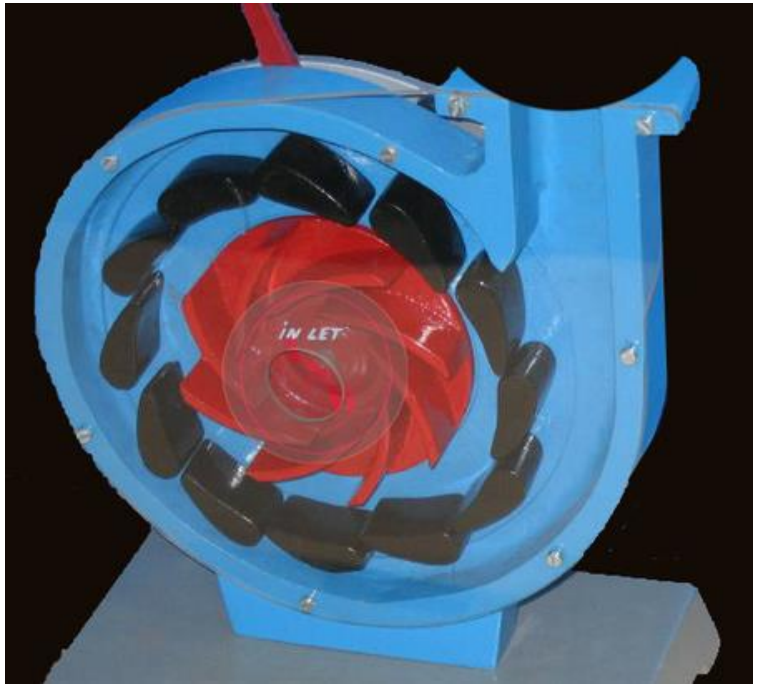


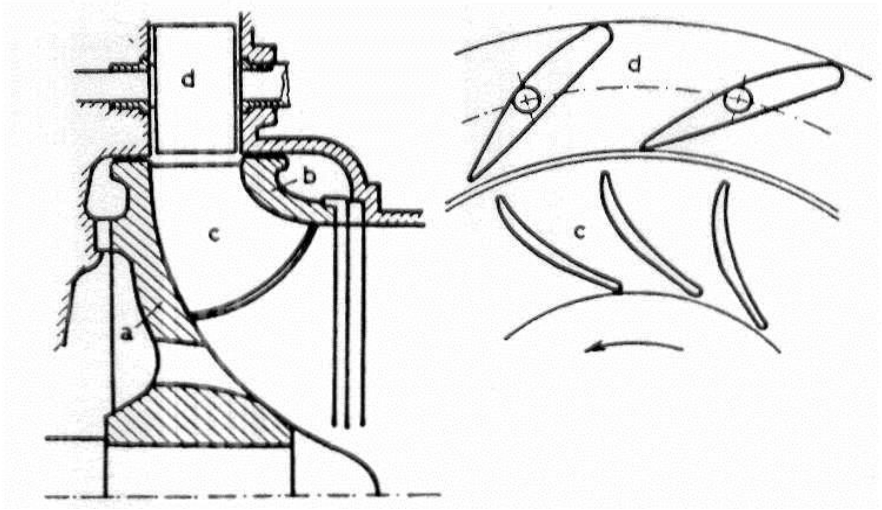


# Francis turbine (1/2)

- Reaction turbines (mainly Francis and Kaplan) are used when the geodetic heads are relatively low (H' < 150-300 m) and the water flow rates are high (Q > 10-30 $m^3/s$).
- The Francis turbine is a radial inflow turbine in which a spiral casing provides a uniform distribution of water around the distributor (stator) circumference. The water, from the spiral casing, is guided into the runner (turbine rotor) by a number of distributor blades.

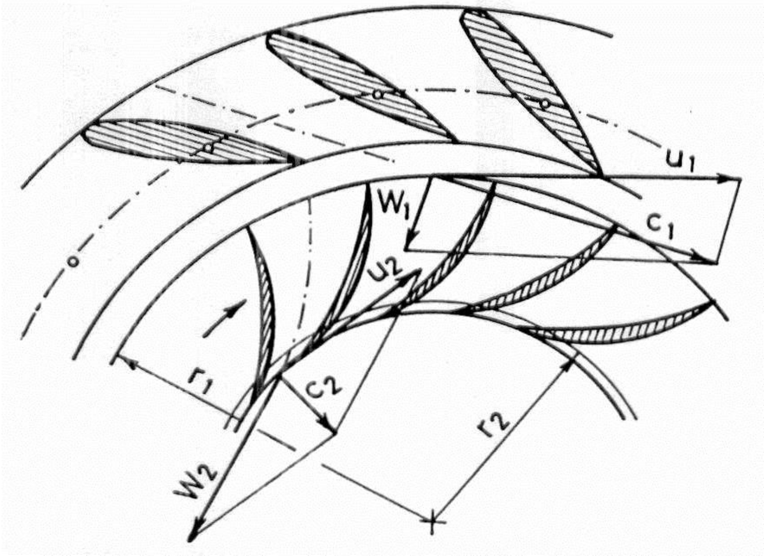




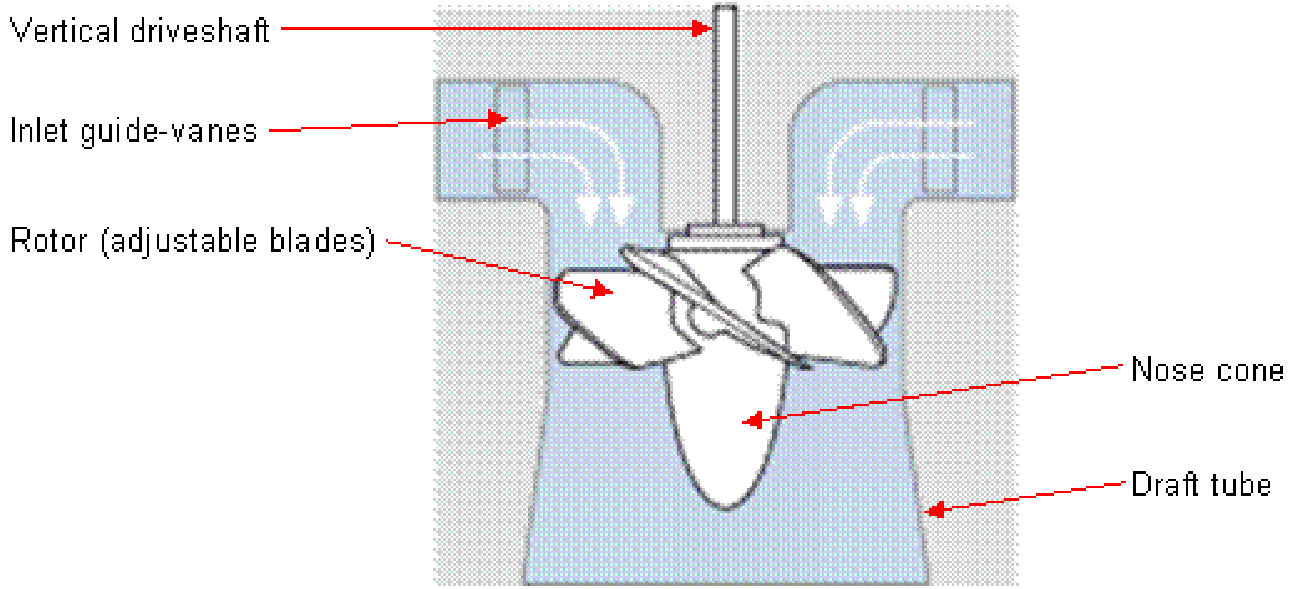
# Francis turbine (2/2)

- Flowing through the distributor vanes, the water is accelerated transforming part of its pressure energy in kinetic energy and reaching a correct velocity directed tangentially to the rotor blades.
- The distributor blades can be rotated about fixed pivots by a servo-mechanism, so that the volume flow rate can be controlled. At any load, the distributor blades are turned at the best angle, so that the flow enters the runner without any impact.



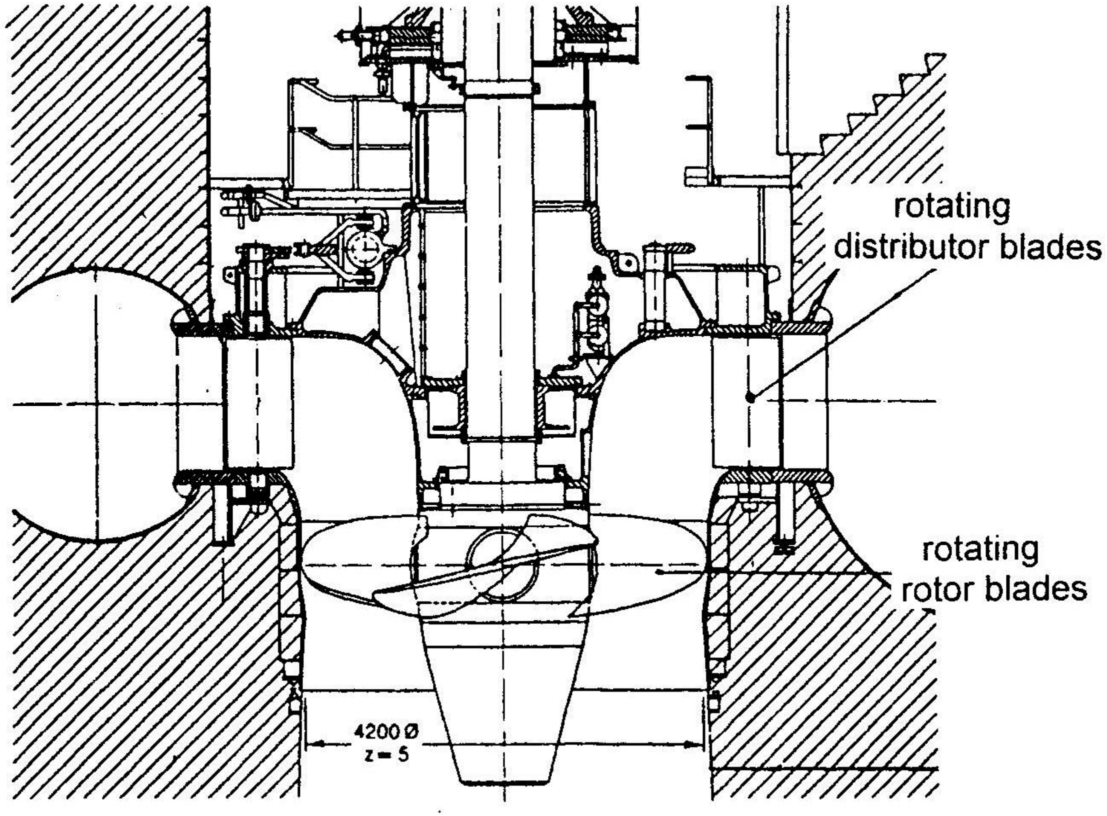

# Kaplan turbine (1/2)

- Increasing the volume flow rate and decreasing the geodetic head, the shape of Francis turbine rotor changes: the radial development of the rotor blades decreases while their axial extent increases, in order to handle higher flow rates.
- For the highest water flow rates, Kaplan reaction turbines are used. In this case, not only the distributor blades are rotating , but also the rotor blades are adjustable and can be turned about pivots fixed to the runner, so that the triangles of fluid velocity are optimised at any turbine load.

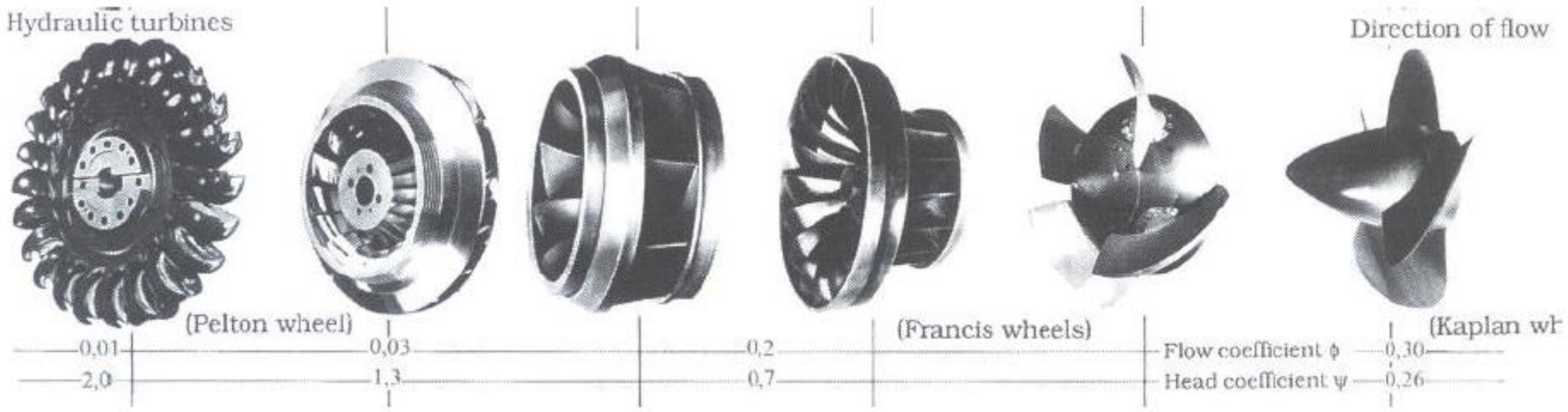


# Kaplan turbine (2/2)

- Kaplan turbines are used for small geodetic heads (H' = 5-40 m) and very high water flow rates (up to 50 $m^3/s$). Power output ranges from 5 to 200 MW.



# Classificazione: Turbina Pelton, Francis, Kaplan



HYDRAULIC TURBINE SIMILARITY

(1)S

1. Geometrical similarity

All dimensions are in proportion

$$L_1 / L_2 = \lambda$$

2. Time similarity

Characteristic times are in proportion

$$T_1 / T_2 = \tau$$

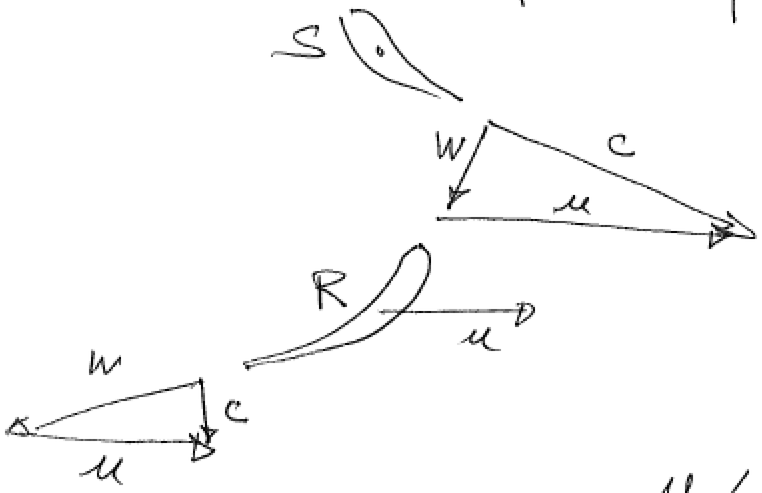
3. As a consequence Kinematic Similarity

$$\lambda \tau^{-1} = \text{const.}$$

3. As a Consequence Kinematic Similarity

$$\lambda \, \tau^{-1} = const.$$

Similarity of velocity triangles




$$u_1/c_1 = const = u_2/c_2$$

1 Turbine 1
2 Turbine 2

(2) 5

4. For Hydraulic Plant

net head H is proportional to the velocity

$c = \sqrt{2gH} \cdot K \qquad K = 1$ for Pelton

$c^2 \propto H$ or $c \propto \sqrt{H}$

5. Consider the Turbines Power

$$\frac{P_1}{P_2} \propto \frac{H_1 Q_1 \rho_1 g_1 \eta_1}{H_2 Q_2 \rho_2 g_2 \eta_2} = \frac{H_1 Q_1}{H_2 Q_2}$$

$$Q \propto c \cdot D^2$$

$$H \propto c^2$$

$$\frac{P_1}{P_2} = \frac{c_1^3 D_1^2}{c_2^3 D_2^2} \cdot \frac{n_1^2}{n_2^2} \cdot \frac{n_2^2}{n_1^2}$$

$$\frac{P_1}{P_2} = \frac{c_1^5}{c_2^5} \frac{n_2^2}{n_1^2} \Rightarrow$$

$$\frac{n_1^2 P_1}{c_1^5} = \frac{n_2^2 P_2}{c_2^5} \Rightarrow \frac{n_1 \sqrt{P_1}}{H_1^{5/4}} = \frac{n_2 \sqrt{P_2}}{H_2^{5/4}}$$

(3)s

Therefore

$$\frac{n\sqrt{P}}{H^{5/4}}$$ is constant and characteristic $= n_s$

for hydraulic turbines in geometrical and kinematic (operation) similarity.

Considering $P \propto Q\,H$

also

$$\frac{n\sqrt{Q}\,\sqrt{H}}{H^{5/4}} = \frac{n\sqrt{Q}}{H^{3/4}} = n_q$$ is characteristic

$$n_s = n_q \times 3{,}13$$

From $n_q$ the geometry of the turbine can be determined via statistical relationships.

# Classificazione: Turbina Pelton

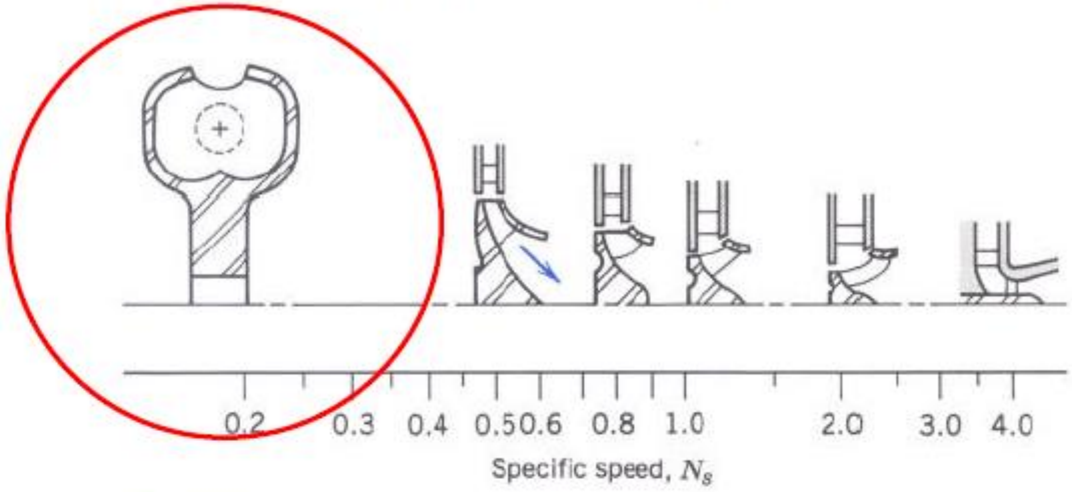



**Fig. 11.16** Typical geometric proportions of commercial hydraulic turbines as they vary with dimensionless specific speed [12].

La turbina **Pelton**:

- Copre il campo dei **bassi valori di** $n_s$.
- È una turbina ad **azione pura**.
- È adatta a essere utilizzata con **elevati salti** $H$ e **basse portate** $Q$.

# Classificazione: Turbina Francis

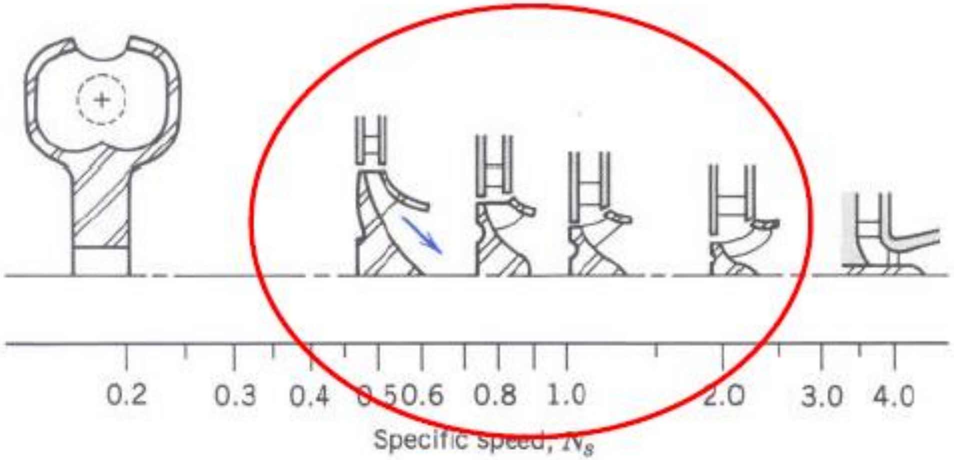



**Fig. 11.16** Typical geometric proportions of commercial hydraulic turbines as they vary with dimensionless specific speed [12].

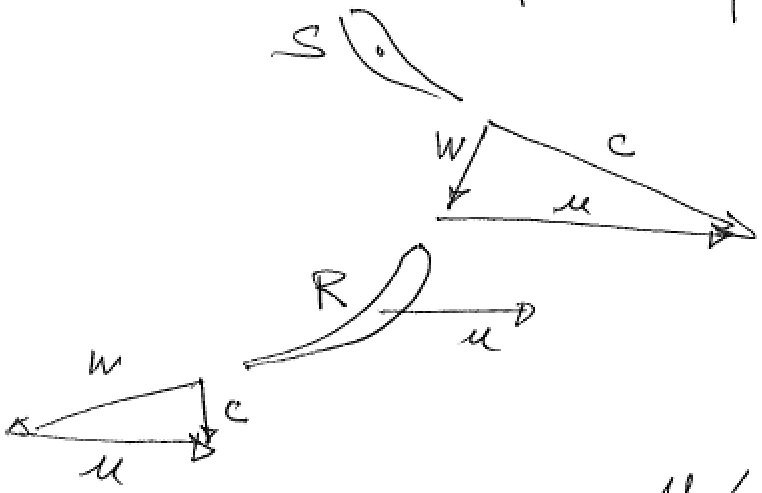
La turbina **Francis**:

- Copre il campo dei **medi valori di** $n_s$.
- È una turbina con valori **medi di grado di reazione**.
- È adatta a essere utilizzata con **medi salti** $H$ e **medi valori per la portata** $Q$.

3. As a Consequence **Kinematic Similarity**

$$\lambda \, \tau^{-1} = \text{const.}$$

Similarity of velocity triangles

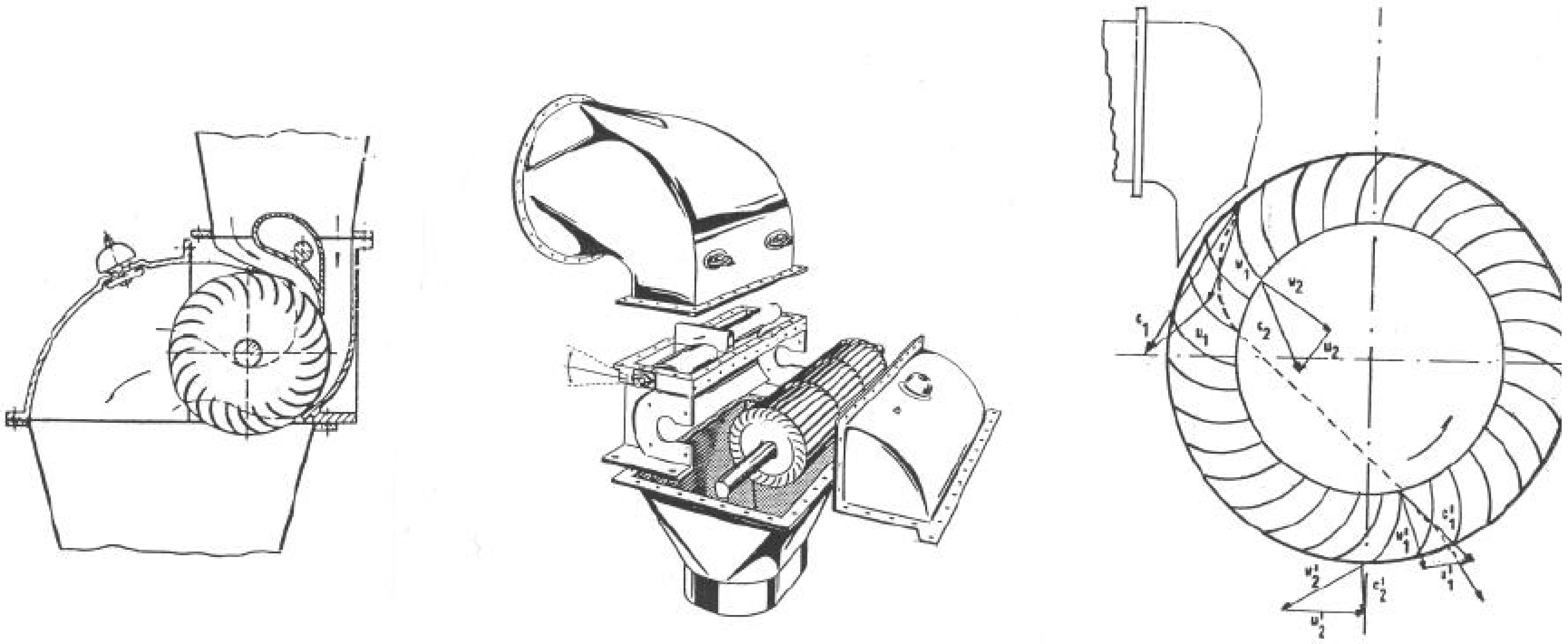



$$u_1/c_1 = \text{const} = u_2/c_2$$

1 Turbine 1
2 Turbine 2

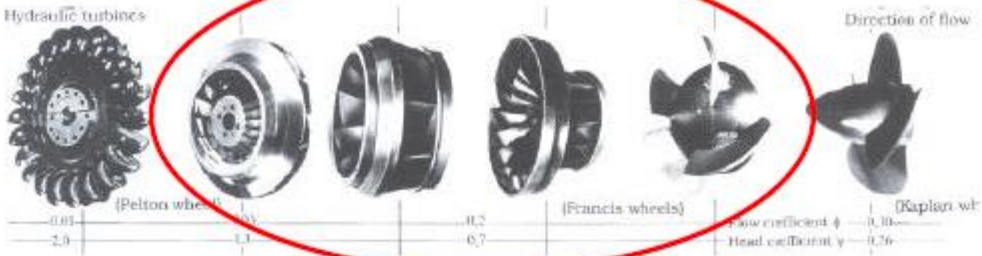
# Turbine Pelton: ruota

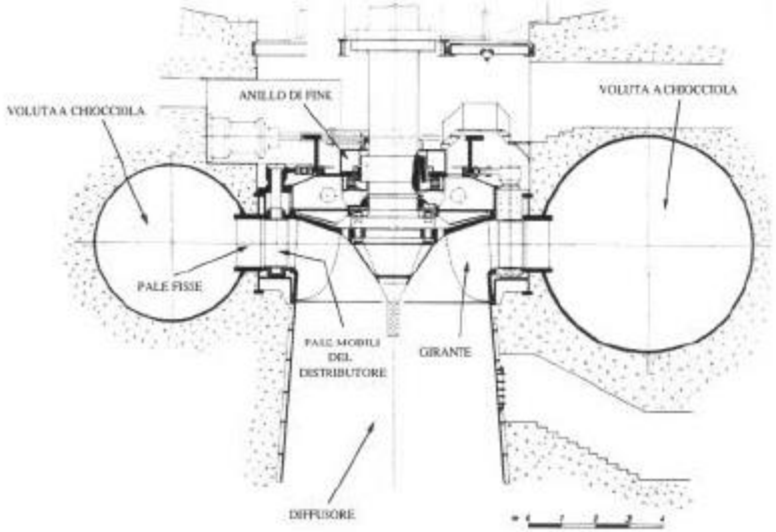
# Turbine Cross-Flow (Banki-Mitchell)

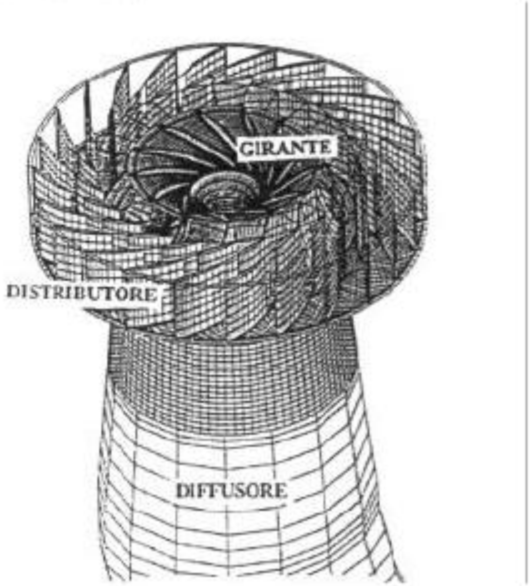


Sono macchine molto semplici e poco costose.  Non necessitano di particolare manutenzione e sono adatte ad impieghi per piccole potenze.

# Turbine Francis



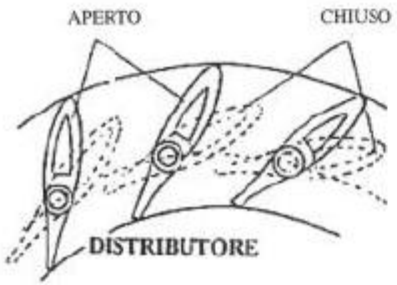

Sono turbine molto diffuse per dislivelli fino a circa 500 m.

Il grado di reazione e quindi il loro sviluppo asso-radiale varia con $n_s$.

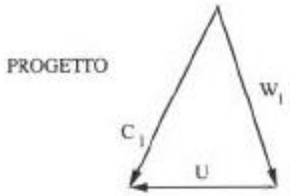
# Turbine Francis: Regolazione

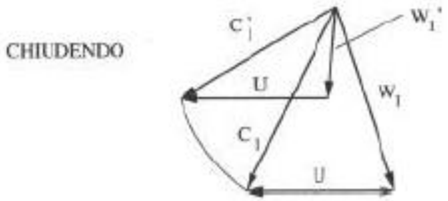
- per la regolazione si usa l'ANELLO DI FINK
- in sostanza si varia la sezione di "gola"

Fig. 11.1.5 - Anello di Fink

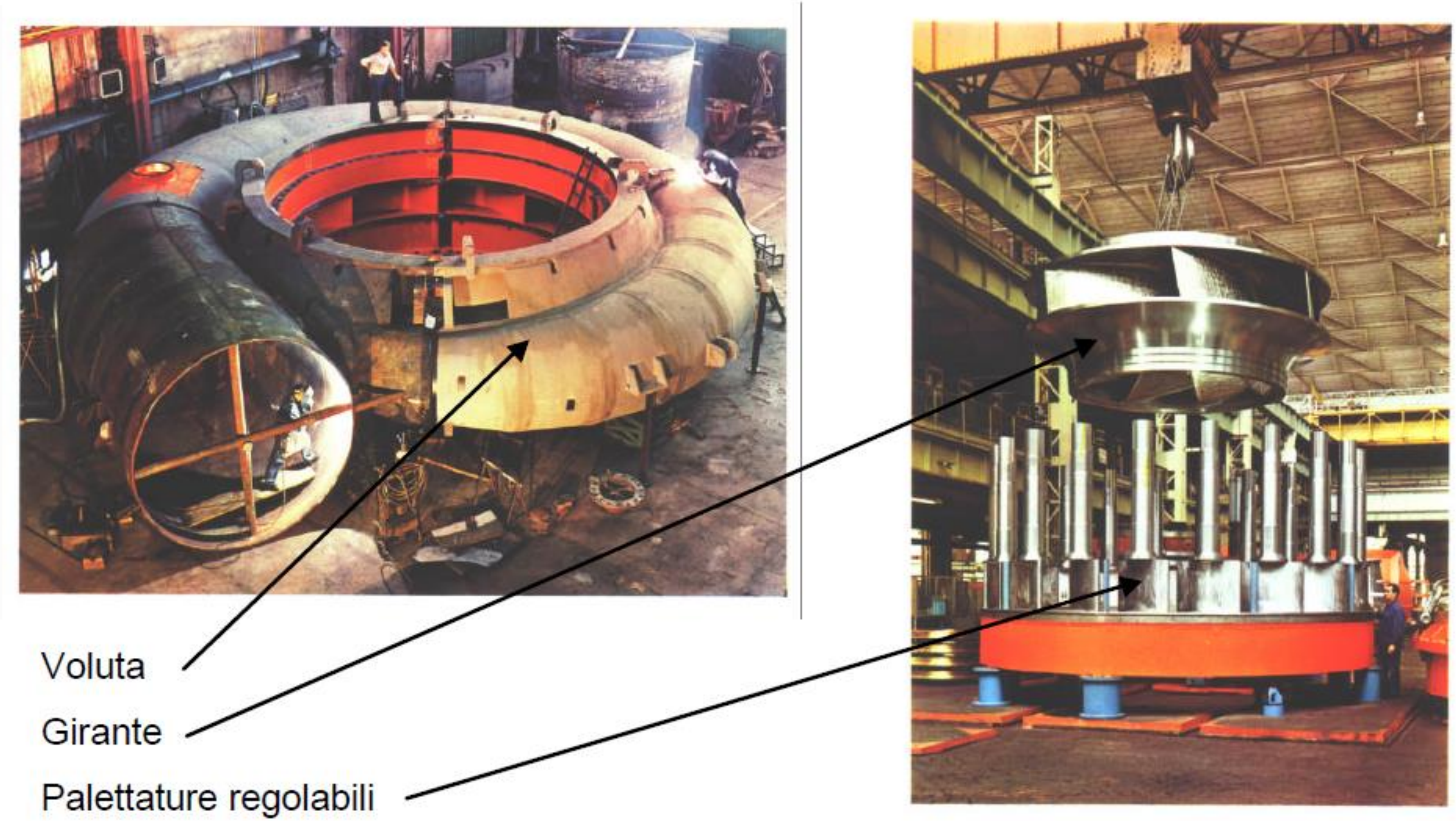




- chiudendo il distributore $w_1'$ tende verso le incidenze maggiori $\Longrightarrow$ cresce il carico sulla macchina!



# Turbine Francis



# Turbine Francis: Girante

E' una girante centripeta.

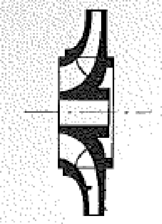
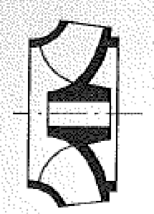
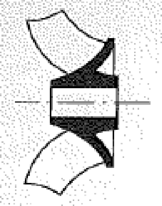
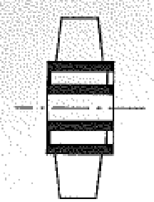
Il numero di pale varia da 8 a 20.

All'aumentare del numero di giri specifico si nota;

- diminuzione numero di pale
- riduzione sviluppo radiale
- aumento distanza tra statore e rotore

*Tabella 11.4*

**Caratteristiche principali di diversi tipi di giranti al variare della velocità specifica $\omega_s$**

| *Forma girante* | | *Caratteristiche* | $\omega_s$ |
|---|---|---|---|
| I<br>lenta<br>(*flusso radiale*) |  | Basse velocità di rotazione $n$ e/o<br>Basse portate $V$ e/o<br>Lavoro massico $l$ elevato | 0,2 ÷ 0,6 |
| II<br>media<br>(*flusso radiale*) |  | Medie velocità di rotazione $n$ e/o<br>Medie portate $V$ e/o<br>Lavoro massico $l$ medio | 0,6 ÷ 1,2 |
| III<br>veloce<br>(*flusso misto*) |  | Alte velocità di rotazione $n$ e/o<br>Portate $V$ elevate e/o<br>Piccolo lavoro massico $l$ | 1,0 ÷ 3,0 |
| IV<br>ultraveloce<br>(*flusso assiale*) |  | Altissime velocità di rotazione $n$ e/o<br>Altissime portate $V$ e/o<br>Piccolo lavoro massico $l$ | 2,0 ÷ 10 |

Kalan

1976

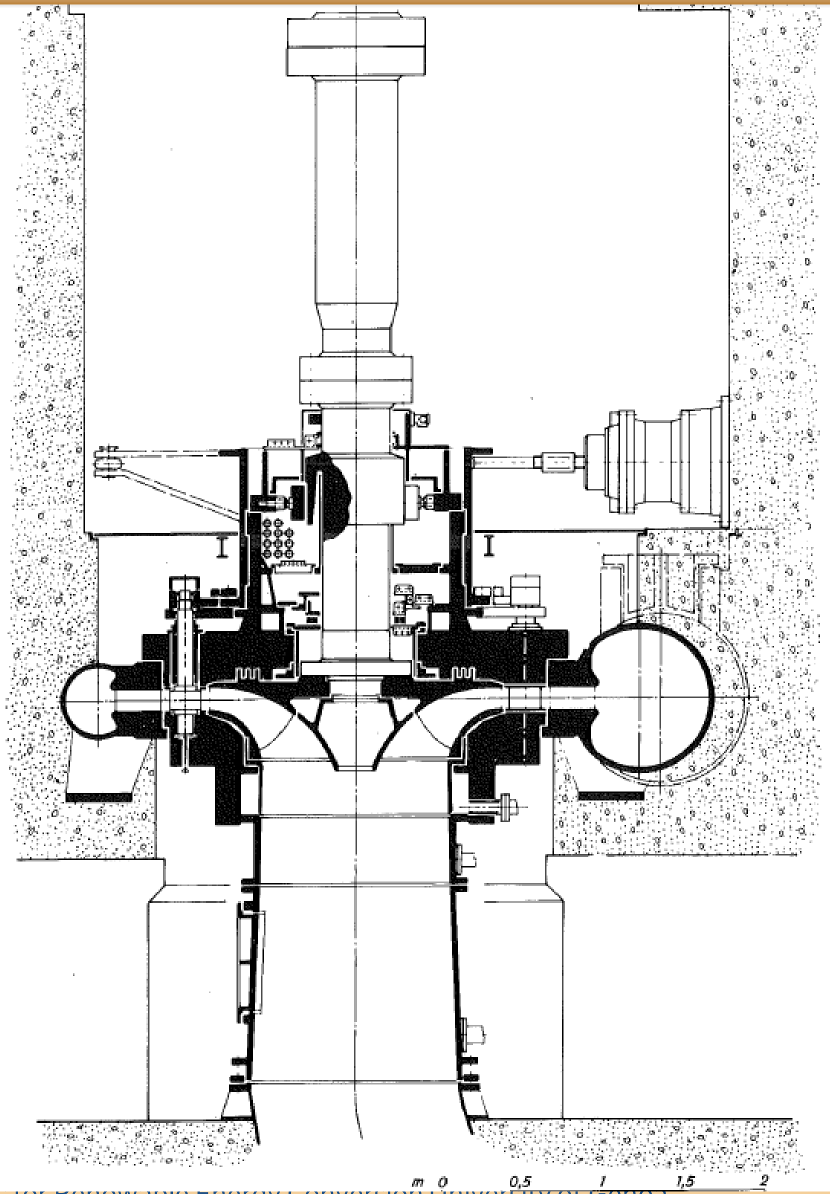
F r a n c i s  3 × 40.000 kW

ANSALDO - RIVA CALZONI - FRANCO TOSI

| | | | | | |
|---|---|---|---|---|---|
| $H_n$ | = | 477,5 | 449,-- | 415,- | m |
| Q | = | 9,25 | 9,25 | 9,25 | $m^3/s$ |
| $P_r$ | = | 40.000 | 37.725 | 34.868 | kW |
| n | = | | 750 | | rev/min |

Turbina ad asse verticale. Camera spirale in lamiera saldata, imbocco ∅ 900 mm. Girante in acciaio fuso inox Cr-Ni 13/4, ∅1785 mm, smontabile dall'alto. Scarico sincrono. Supporto di spinta da 175 t, combinato con il supporto di guida conglobato nella crociera superiore dell'alternatore. Valvola rotativa ∅ 900 mm. Pressione di prova 86.5 $kg/cm^2$.
Regolatore meccanico tachiaccelerometrico tipo TA 605. Gruppo di pneumatizzazione per il funzionamento del gruppo come compensatore sincrono.

Vertical shaft turbine. Welded steel plate spiral case, inlet dia. 900 mm. Cr-Ni 13/4 cast stainless steel runner, dia. 1785 mm, removable from above. Relief valve. 175 ton thrust bearing, combined with the guide bearing, located in the upper generator spider.
Spherical valve, dia. 900 mm. Test pressure 86.5 $kg/cm^2$.
Tachoaccelerometric governor, type TA 605.
Blow-down equipment for the operation of the unit as synchronous condenser.



ITAUBA

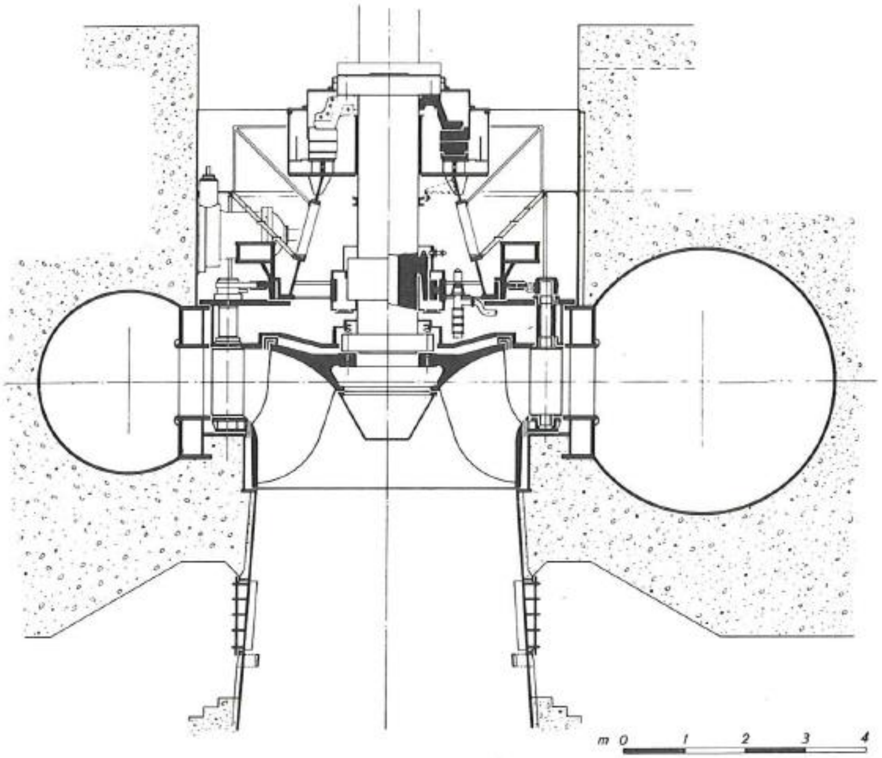
**Francis 4 × 128.000 kW**

**ANSALDO** (in collaborazione con G.I.E., Co. Em. S.A., Voith)

| | | | | |
|---|---|---|---|---|
| $H_n$ | = | 87,6 | 76,-- | m |
| Q | = | 160,-- | 147,2 | $m^3/s$ |
| $P_r$ | = | 127.980 | 102.460 | kW |
| n | = | 150 | | rev/min |

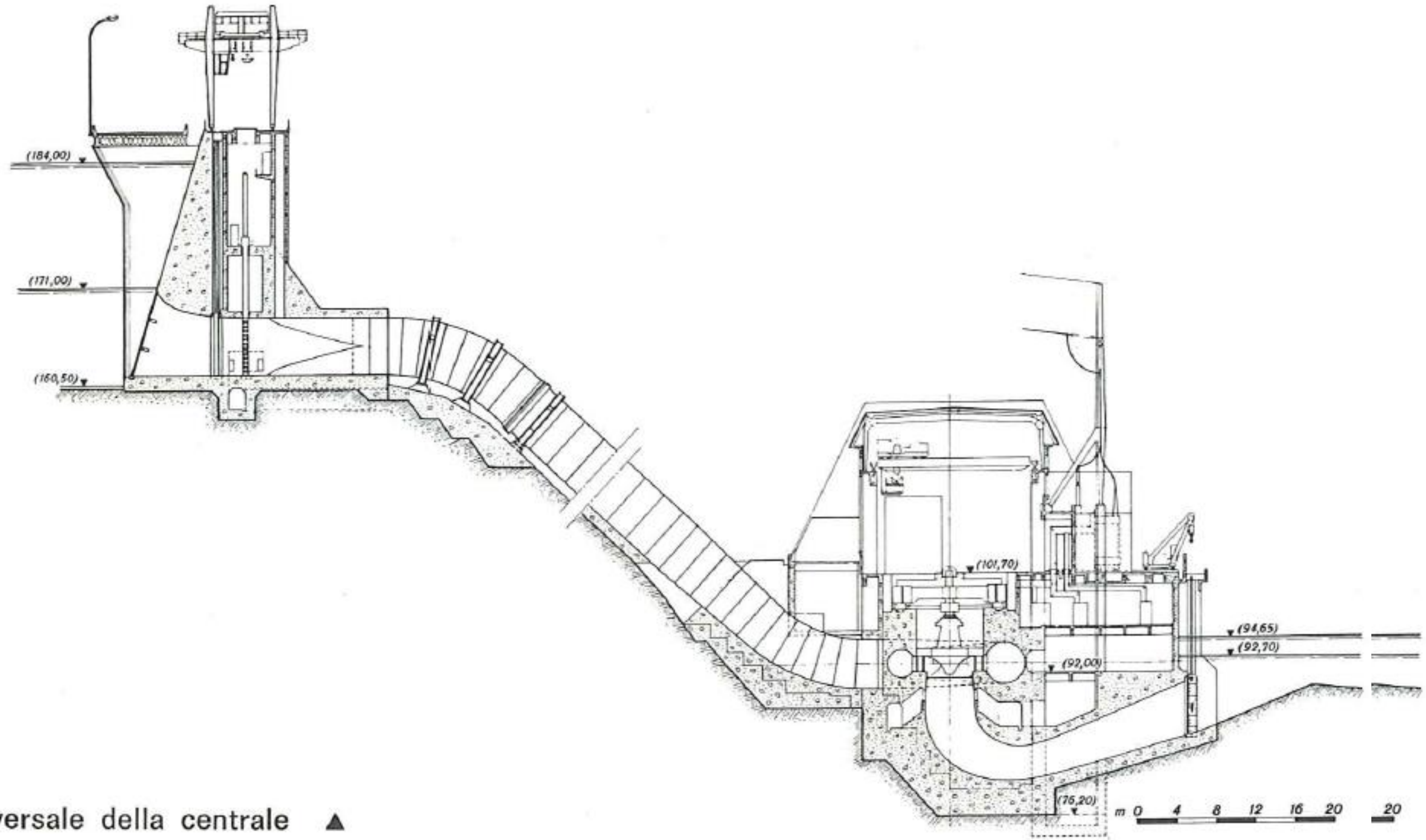
Turbina ad asse verticale. Camera spirale in lamiera saldata composta sull'impianto, imbocco Ø 5100 mm. Girante fusa di pezzo in acciaio al C, Ø 4600 mm, peso 45 t. Supporto di spinta da 760 t con iniezione d'olio ad alta pressione, montato su sostegno tronco-conico poggiante sul coperchio superiore della turbina.

Vertical shaft turbine. Welded steel plate spiral casing composed on site. Inlet dia. 5100 mm. Integrally cast runner of carbon steel, dia. 4600 mm, weight 45 tons. 760 ton thrust bearing with high pressure oil injection, fitted on a supporting cone resting on the turbine head cover.



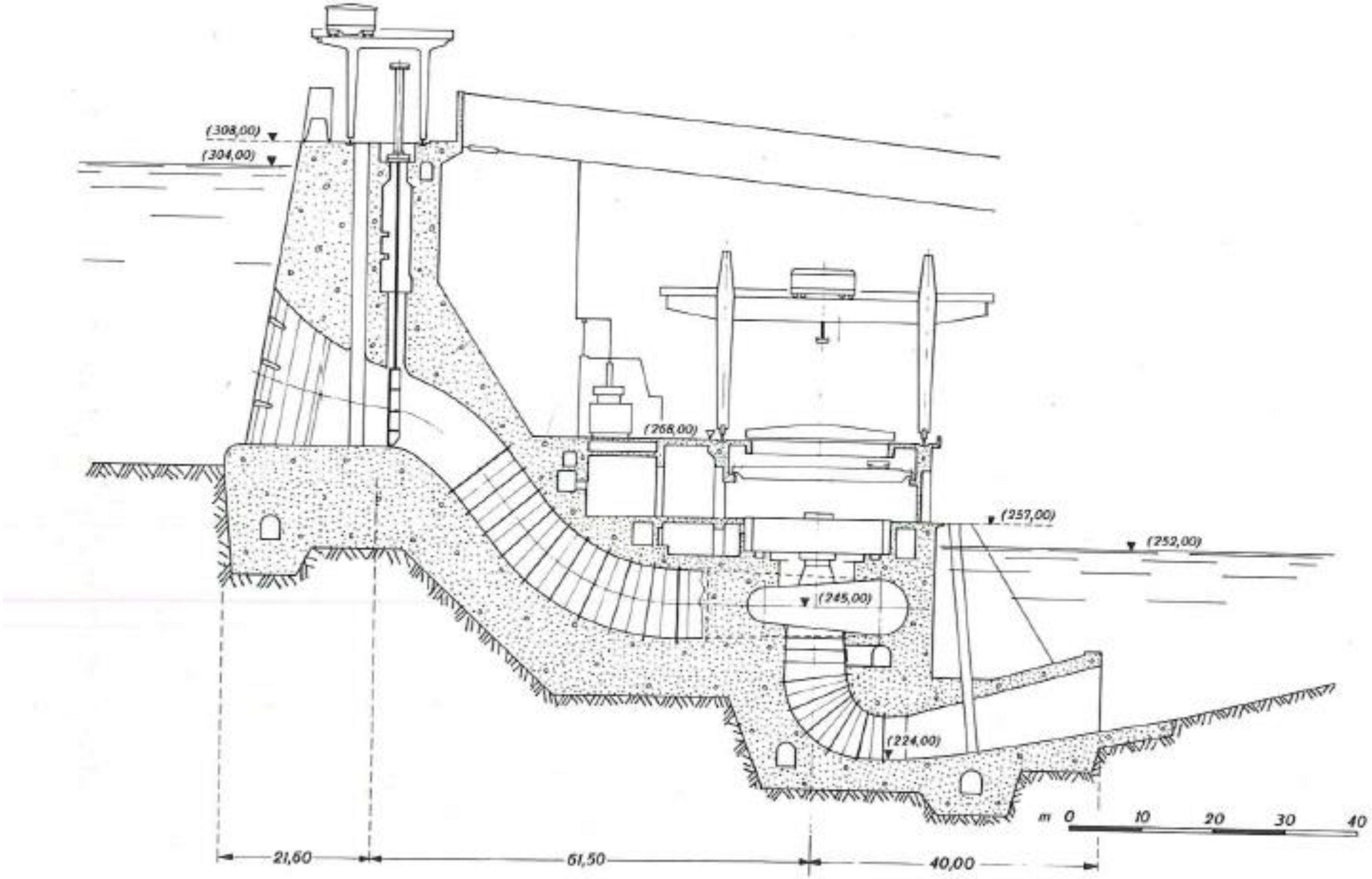

Sezione verticale della turbina ▶
Turbine vertical section

## ITAUBA




Sezione trasversale della centrale ▲
Power house cross section

# ITAPARICA



(308,00)
(304,00)
(268,00)
(257,00)
(252,00)
(245,00)
(224,00)
m 0 10 20 30 40
21,60
61,50
40,00

ITAPARICA

1978

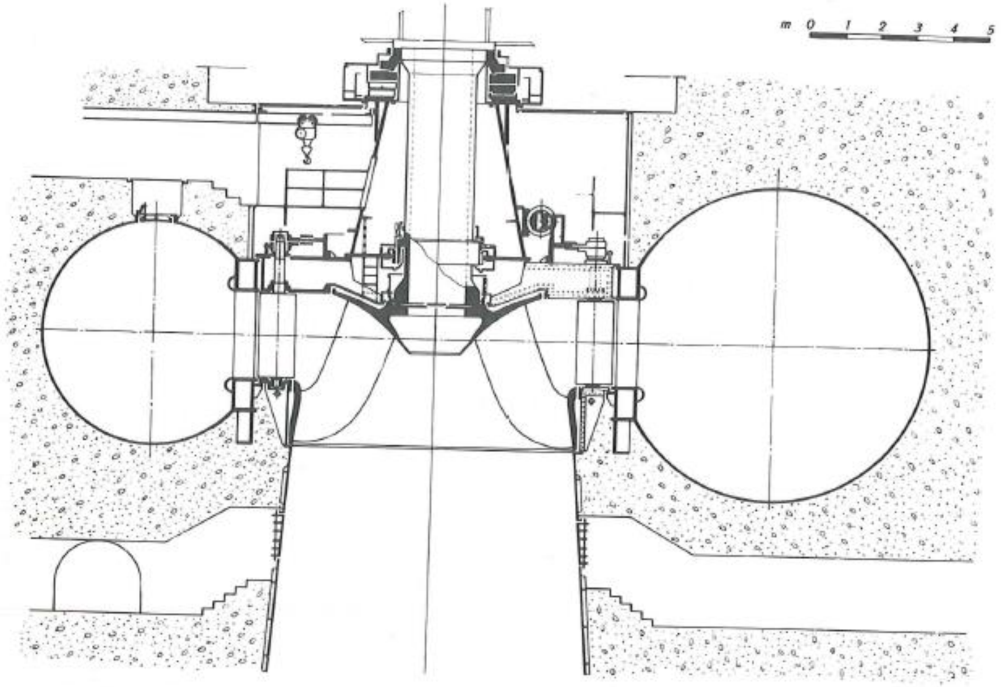
Francis 3 × 264.000 kW

| | | | | |
|---|---|---|---|---|
| $H_n$ = | 53,2 | 50,8 | 46,3 | m |
| Q = | 542,5 | 539,-- | 510,-- | m³/s |
| $P_r$ = | 264.000 | 250.000 | 216.000 | kW |
| n = | | 81,8 | | rev/min |

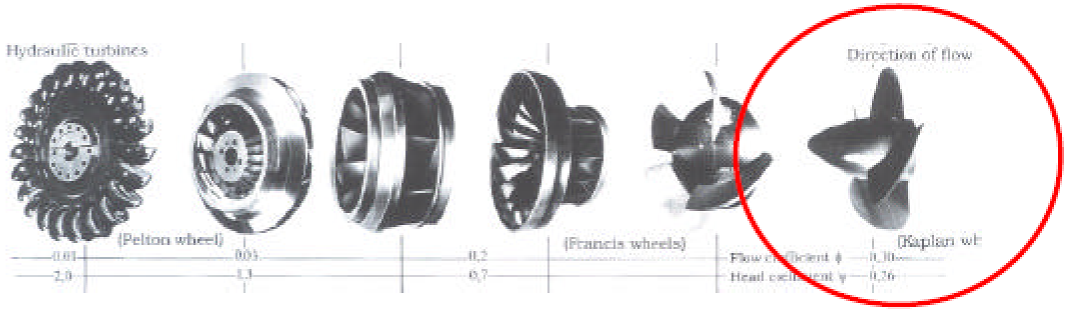
ANSALDO - RIVA CALZONI - FRANCO TOSI (in collaborazione con G.I.E., Co. Em. S.A.)

Turbina ad asse verticale. Camera spirale in lamiera saldata composta sull'impianto, imbocco Ø 9500 mm. Girante composta a mezzo saldatura con pale ricavate separatamente in acciaio al C, Ø 7925 mm, peso 220 t. Supporto di spinta da 1960 t con iniezione d'olio ad alta pressione, montato su sostegno tronco-conico poggiante sul coperchio superiore della turbina.

Vertical shaft turbine. Spiral casing of welded steel plates to be composed by welding on site. Inlet dia. 9500 mm. Runner composed by welding with separate carbonium steel blades, dia. 7925 mm, weight 220 tons. 1960 ton located on a supporting cone resting on the turbine head cover.



# Turbine Kaplan

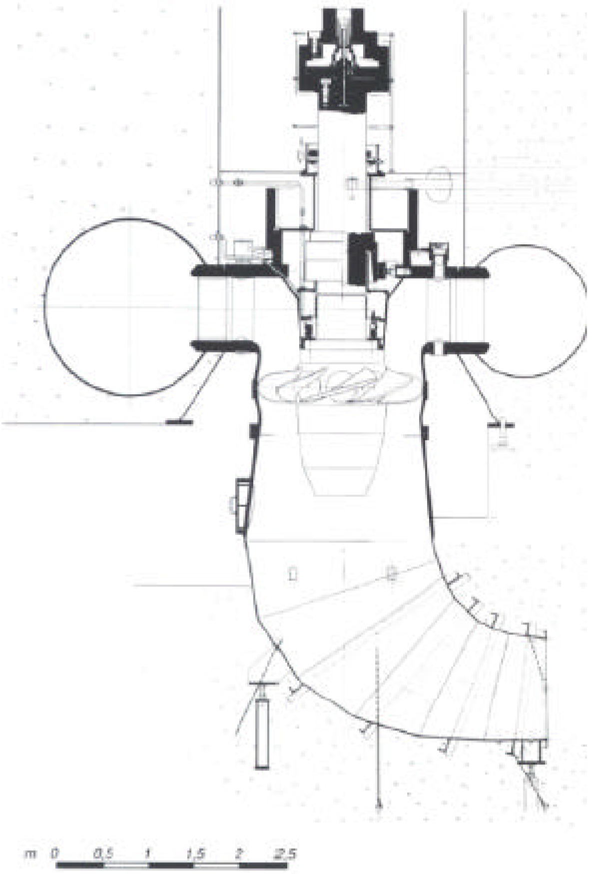



Il grado di reazione è piuttosto elevato ($R \sim 0.7$).

Il numero di pale della girante è compreso tra 3 e 7.

Le pale del distributore sono in genere orientabili.

Le pale della girante possono essere dotate di meccanismi per la regolazione del calettamento (passo variabile, Kaplan)




Sezione verticale della turbina
Turbine vertical section

# Turbine Kaplan

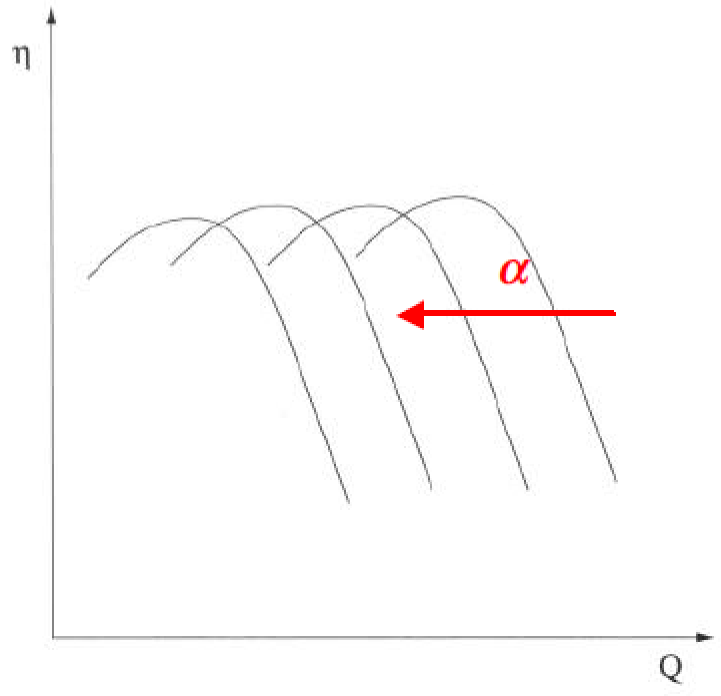
Girante Kaplan con palettature a calettamento variabile

# Turbine Kaplan: Regolazione

Le turbine Kaplan sono costruite con palettature a calettamento variabile sia per le parti statoriche che per le parti rotoriche.

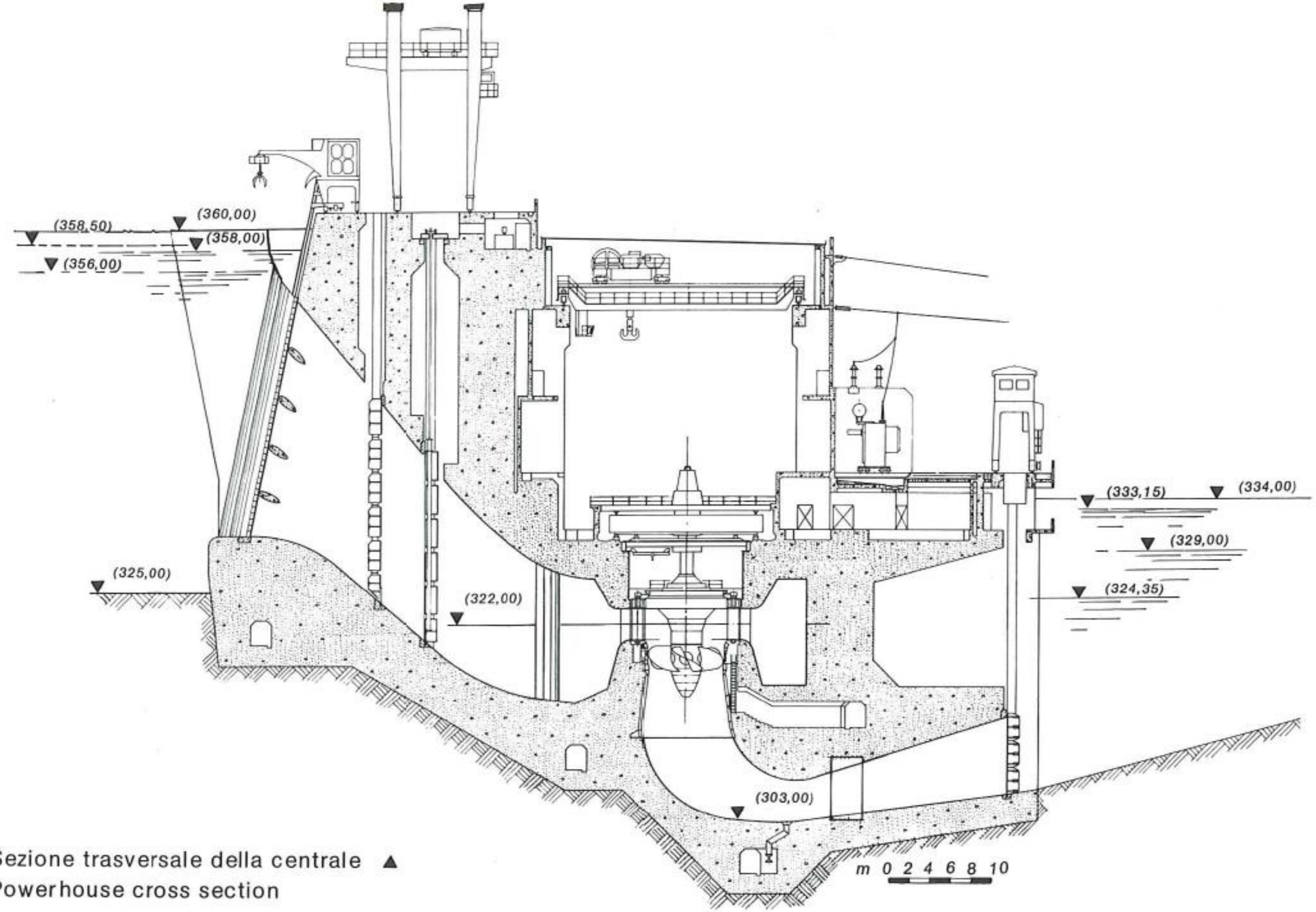
Per piccoli impianti si utilizza il calettamento variabile o sul rotore o sullo statore.

Per potenze impegnative si preferisce il calettamento variabile sia del distributore che delle pale della girante.




Curva di funzionamento al variare del calettamento

Nova
Avanhandava



Sezione trasversale della centrale
Powerhouse cross section

# Nova Avanhandava

1979

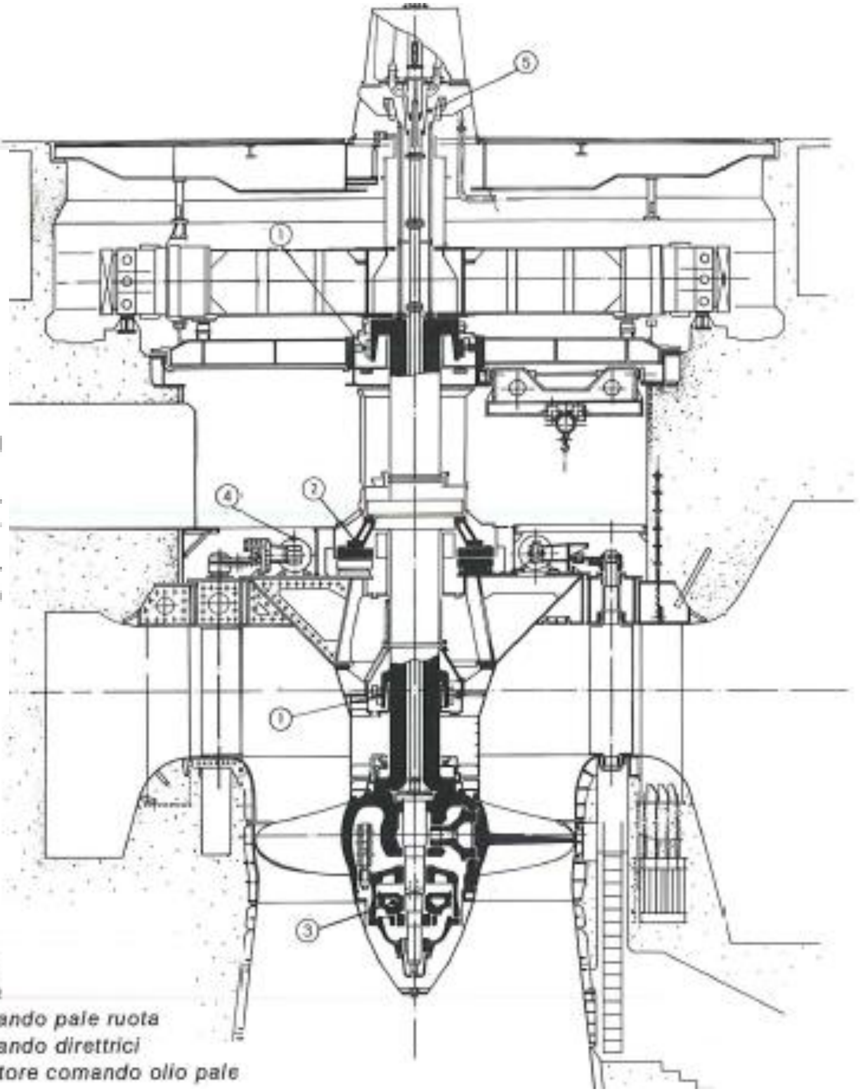
Kaplan 3 x 112.000 kW

| | | | | |
|---|---|---|---|---|
| $H_n$ = | 26,50 | 30,-- | 33,15 | m |
| Q = | 470,-- | 400,-- | 280,-- | $m^3/s$ |
| $P_r$ = | 112.000 | 110.500 | 87.000 | kW |
| n = | | 94,74 | | rev/min |

RIVA CALZONI - FRANCO TOSI, in collaborazione con Co.Em.S.A.

Turbina ad asse verticale con camera semispirale in cemento e aspiratore a gomito con rivestimento metallico parziale.
Girante a 5 pale fuse in acciaio inox Cr-Ni 13/4, Ø 7.400 mm con servomotore posto nell'ogiva; peso 164 t.
Supporto di spinta da 1.850 t posto sul coperchio turbina, dotato di refrigeranti esterni e iniezione d'olio ad alta pressione.
Supporto di guida autorefrigerante.
Regolatore elettronico tipo RE 100/A/PR.

Vertical shaft turbine with concrete spiral casing and draft tube of the elbow type with partial metal lining.
Runner with 5 blades cast of 13/4 Cr-Ni stainless steel, dia. 7400 mm. Servomotor placed in the runner hub nose. Weight 184 tons.
1850 ton thrust bearing placed on the turbine head cover, with external coolers and high pressure oil injection system.
Self cooling guide bearing.
Electronic speed governor type RE 100/A/PR.



1. Supporto di guida
2. Supporto di spinta
3. Servomotore comando pale ruota
4. Servomotore comando direttrici
5. Colonetta distributore comando olio pale

## Bersia

1980

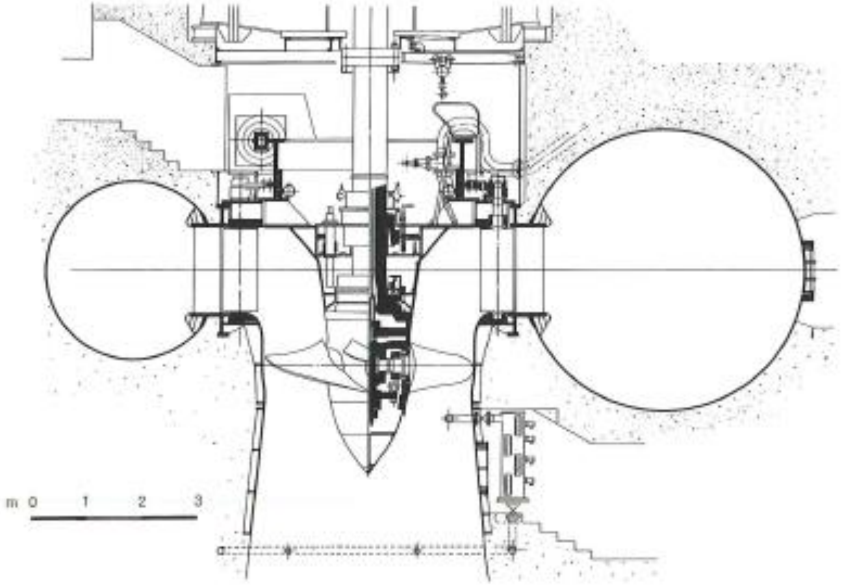
Kaplan 3 x 26.000 kW

ANSALDO

| | | | | | |
|---|---|---|---|---|---|
| $H_n$ = | 27,2 | 26,5 | 24,8 | 19,7 | m |
| Q = | | 104,103 | | | m³/s |
| $P_t$ = | 25.685 | 24.997 | 23.343 | 18.263 | kW |
| n = | | 187,5 | | | rev/min |

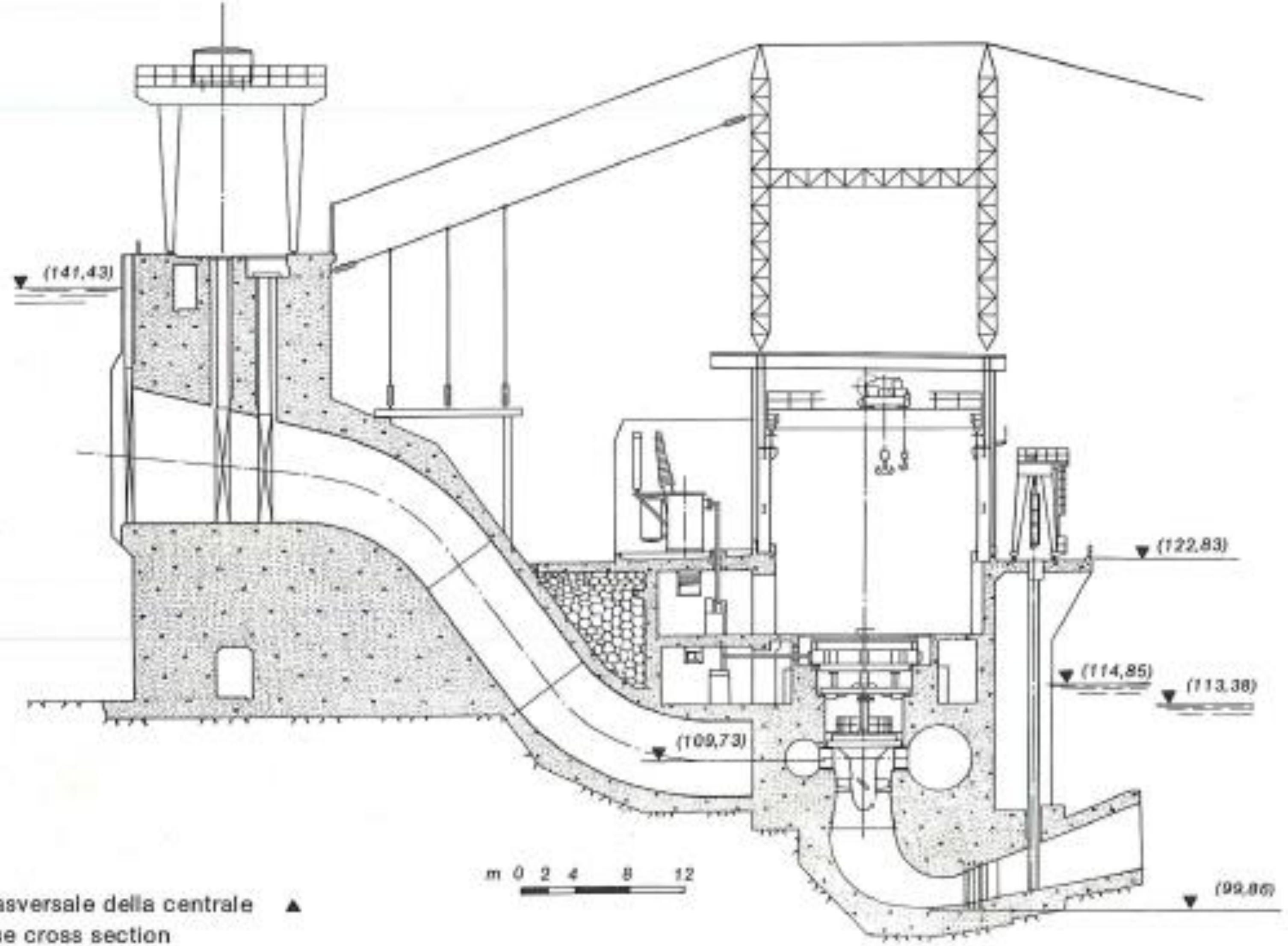
Turbina ad asse verticale. Camera spirale in lamiera saldata sul posto con imbocco Ø 5.100 mm.
Girante Ø 3.700 mm con 5 pale in acciaio inox Cr-Ni 13/4.
Servomotore di comando pale nel mozzo della girante.
Distributore con tenuta ausiliaria.
Regolatore elettronico RIVA CALZONI tipo RE 100/A/PR completo di generatore di segnale tachimetrico.
Tutti i gruppi sono predisposti per funzionare come compensatore sincrono.

Vertical shaft turbine. Spiral casing of steel plate, welded on the field. Inlet dia. 5100 mm.
Runner dia. 3700 mm, with 5 blades of 13/4 Cr-Ni stainles steel.
Runner blade control servomotor placed in the runner hub.
Wicket-gate with auxiliary seals.
RIVA CALZONI electronic speed governor type RE 100/A/PR complete with speed signal generator.
All the units can work as synchronous condensers.



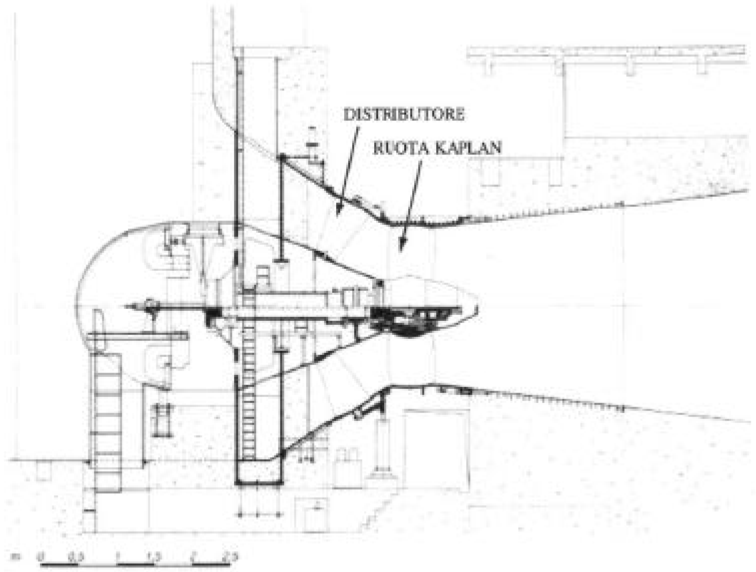

◄ Sezione verticale della turbina
Turbine vertical section

## Bersia




Sezione trasversale della centrale
Powerhouse cross section

# Turbine a Bulbo



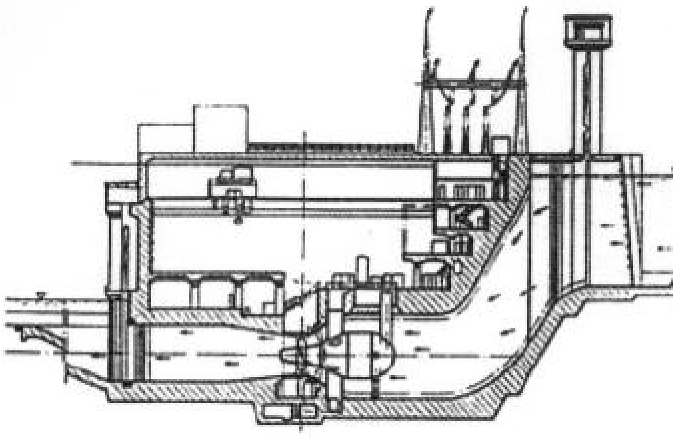



Fig. 12.3.2 - Rappresentazione schematica dell'installazione

Sono macchine molto diffuse per **dislivelli inferiori ad i 10 m**.

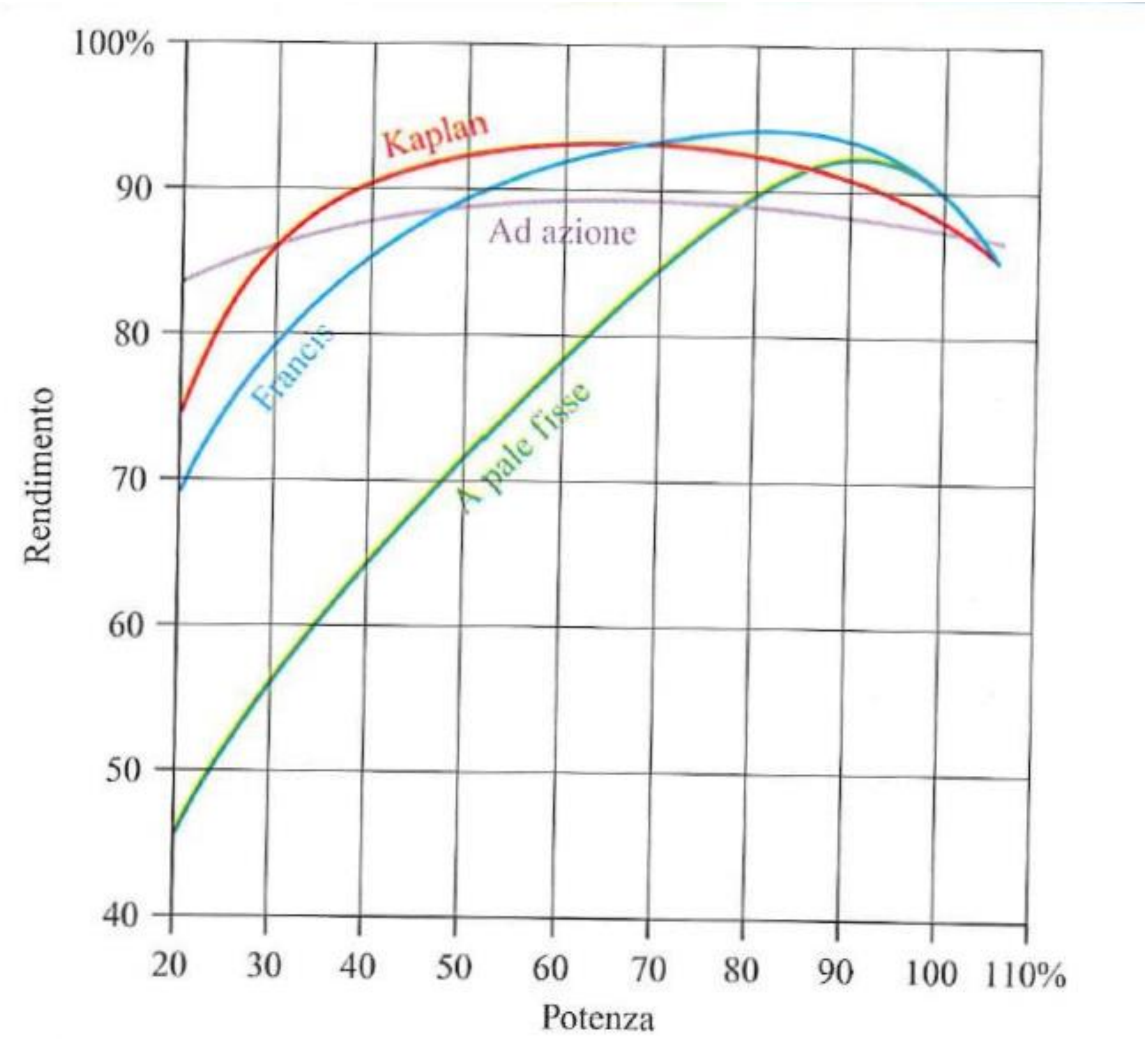
L'alternatore è contenuto in un **"bulbo"** completamente immerso in acqua.

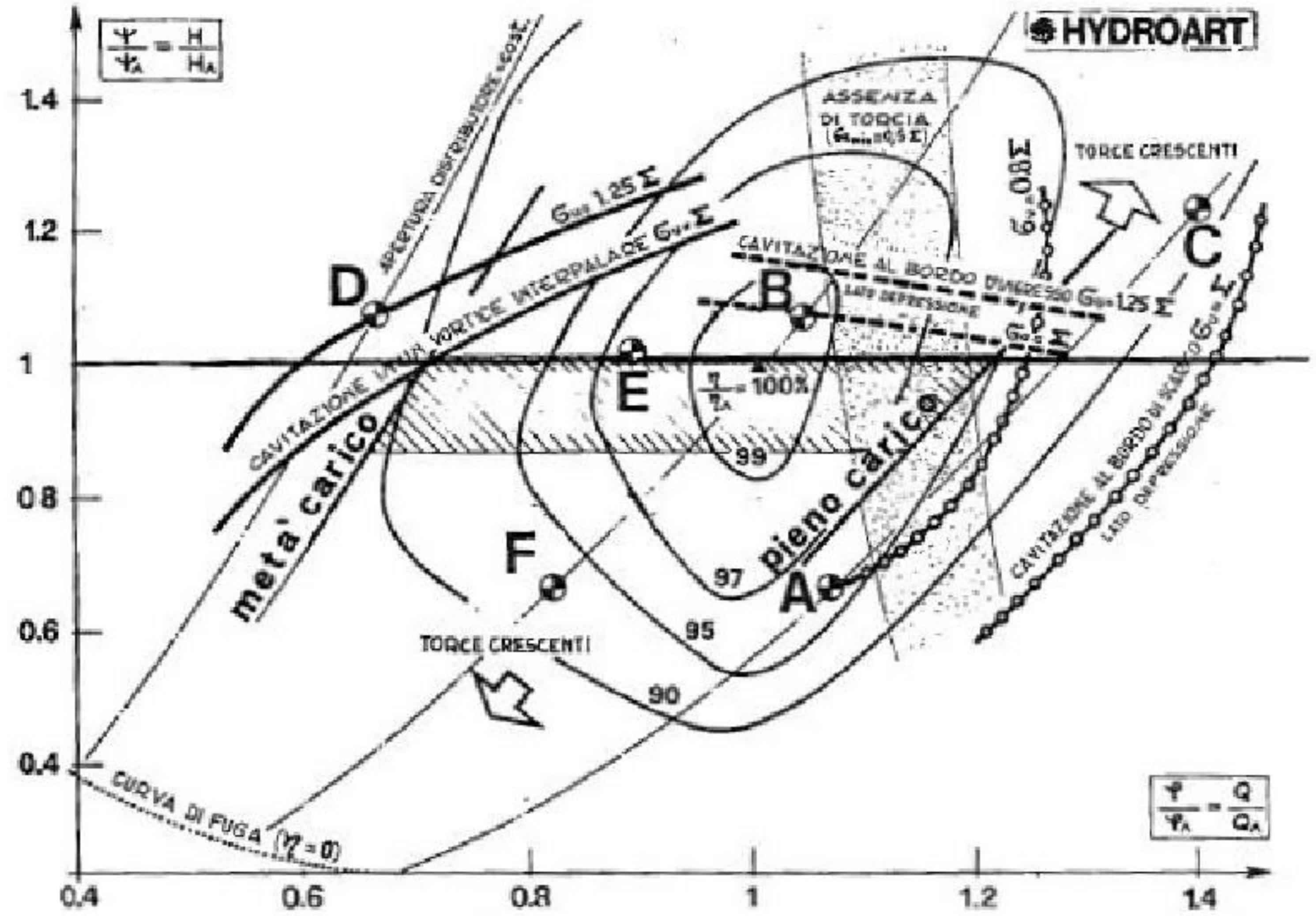
In questo tipo di macchina il tubo diffusore ha un ruolo di fondamentale importanza.

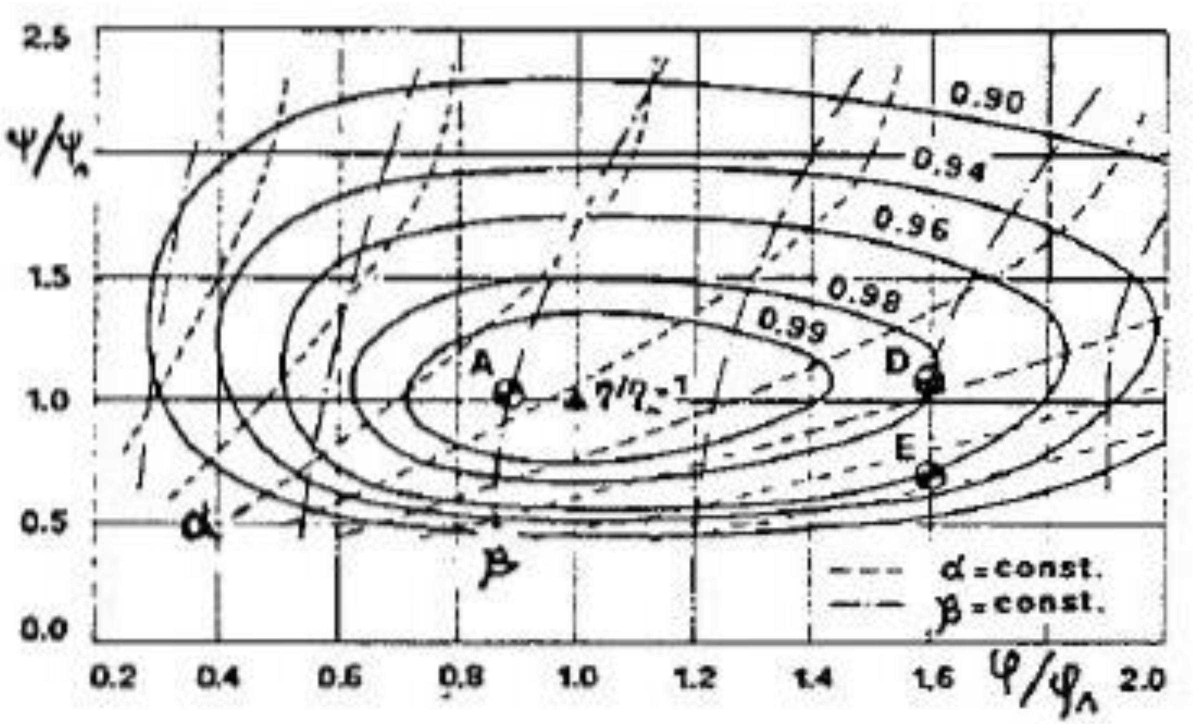
# *Turbine a Bulbo*

Distributore

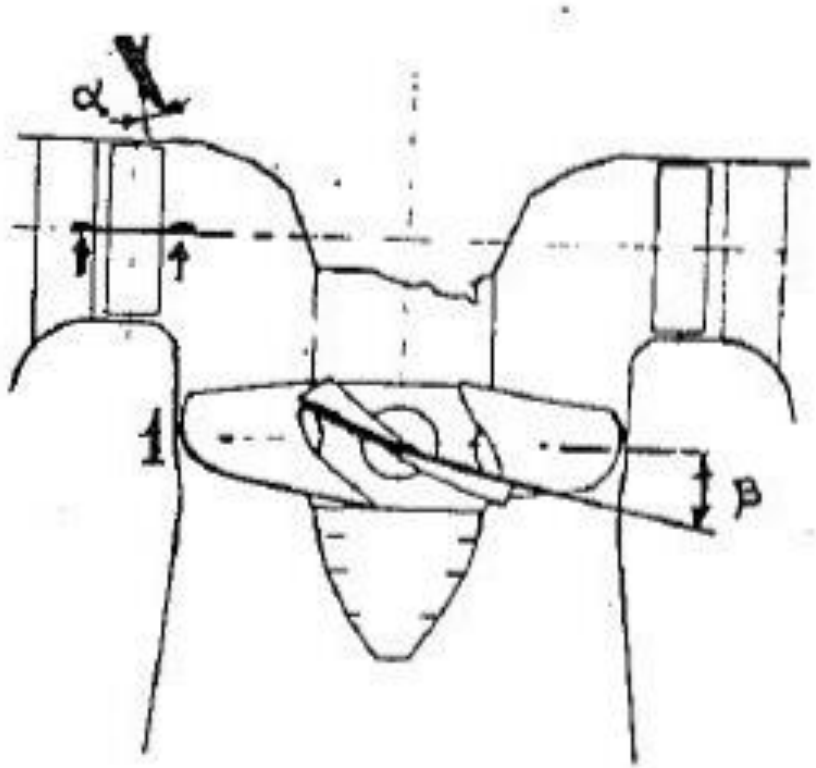
girante


100%
90
80
70
60
50
40
Rendimento
Kaplan
Francis
Ad azione
A pale fisse
20
30
40
50
60
70
80
90
100
110%
Potenza


HYDROART
1.4
1.2
1
0.8
0.6
0.4
ASSENZA DI TORCIA
TORCE CRESCENTI
D
B
C
E
F
A
99
97
95
90
meta' carico
pieno carico
CAVITAZIONE AL BORDO D'INGRESSO
LATO DEPRESSIONE
CAVITAZIONE AL BORDO DI SCARICO
LATO DEPRESSIONE
APERTURA DISTRIBUTORE = COST.
CURVA DI FUGA
TORCE CRESCENTI
0.4
0.6
0.8
1
1.2
1.4



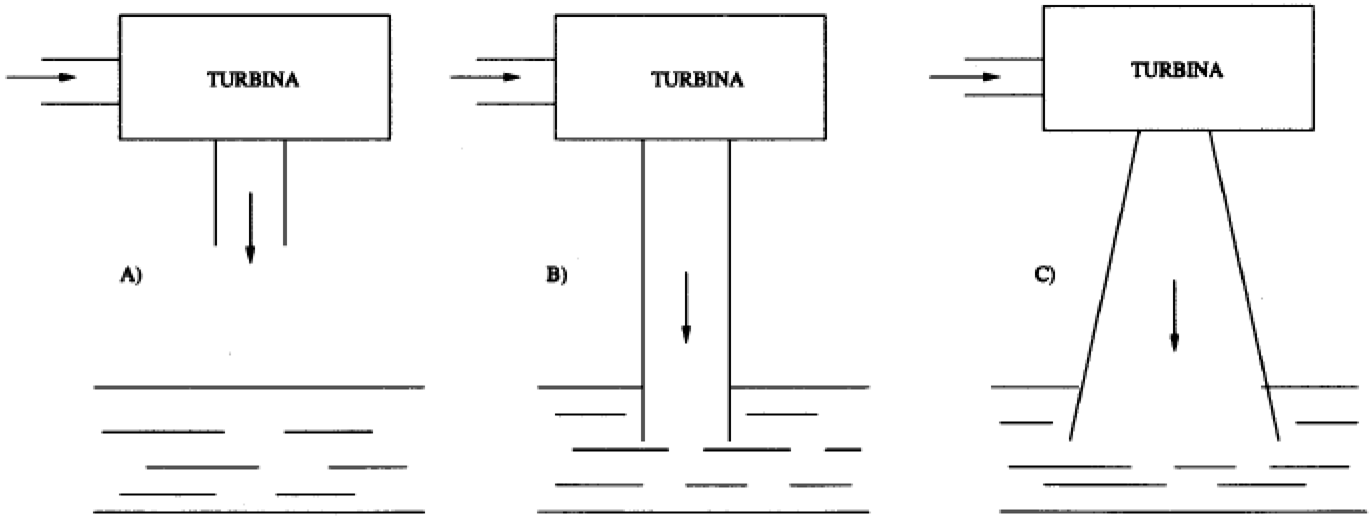
2.5
1.5
1.0
0.5
0.0
ψ/ψ
0.90
0.94
0.96
0.98
0.99
A
D
E
α
β
α = const.
β = const.
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
φ/φ
2.0

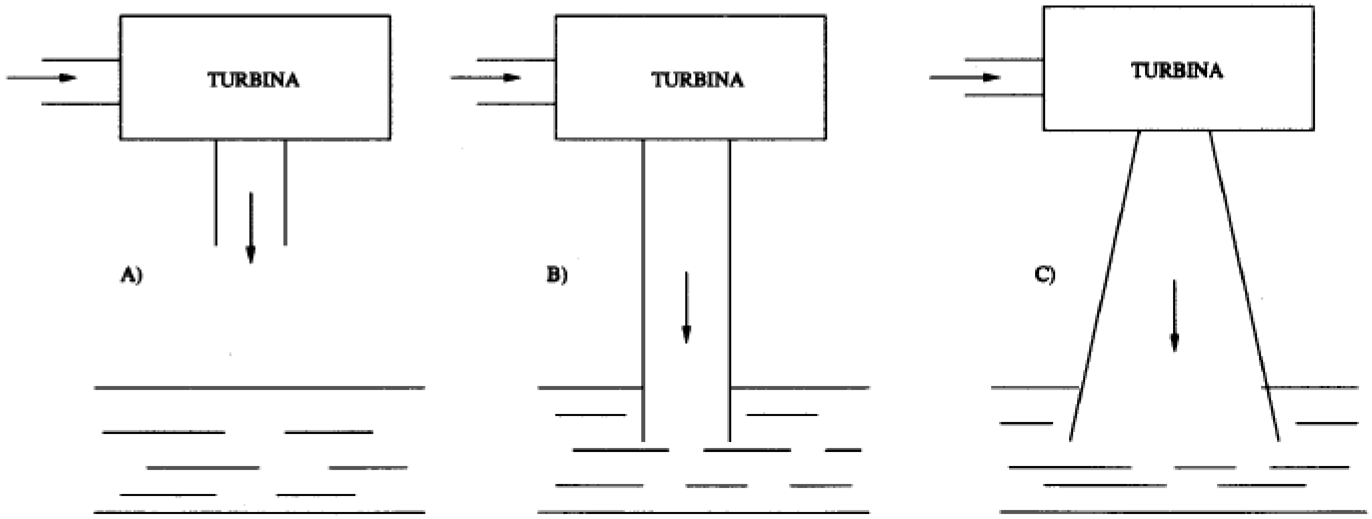
α
β

# Diffusore di scarico

Nelle turbine con grado di reazione $R$ non nullo, si usa inserire un diffusore allo scarico della macchina al fine di recuperare energia cinetica allo scarico nonché di utilizzare l'intero salto geodetico utile.



# Diffusore di scarico



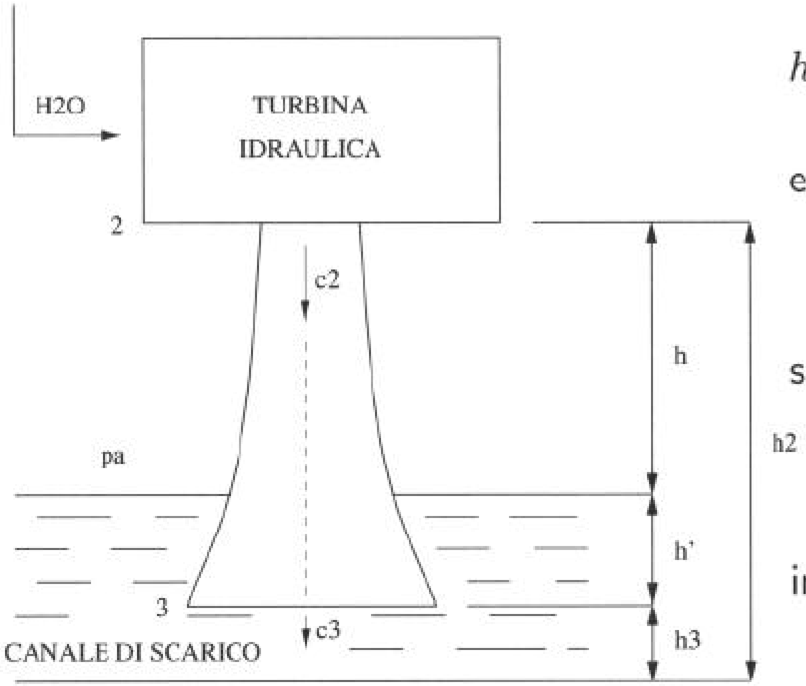

Caso **A**: viene persa l'energia cinetica allo scarico nonché il dislivello scarico pelo libero

Caso **B**: viene persa l'energia cinetica allo scarico

Caso **C**: viene ridotta la perdita di energia cinetica con un diffusore

# Diffusore di scarico

## DIFFUSORI




➢ risulta:

$$h_2 - h_3 + \frac{p_2}{\gamma} + \frac{c_2^2 - c_3^2}{2g} - \frac{p_a}{\gamma} - h' - Y = 0$$

ed essendo

$$h = h_2 - h_3 - h'$$

si ottiene

$$h + \frac{p_2}{\gamma} + \frac{c_2^2 - c_3^2}{2g} - \frac{p_a}{\gamma} - Y = 0$$

infine:

$$\frac{p_2}{\gamma} = \frac{p_a}{\gamma} - h - \frac{c_2^2 - c_3^2}{2g} + Y$$

➢ $p_2 < p_a$ deve essere valutata tenendo conto dei problemi di cavitazione altrimenti deve essere abbassato il corpo di turbina (ridotto h)

(3)s

Therefore

$$\frac{n\sqrt{P}}{H^{5/4}}$$ is constant and characteristic $= n_s$

for hydraulic turbines in geometrical and kinematic (operation) symilarity.

Considering $P \propto Q\,H$

also

$$\frac{n\sqrt{Q}\,\sqrt{H}}{H^{5/4}} = \frac{n\sqrt{Q}}{H^{3/4}} = n_q$$ is characteristic

$$n_s = n_q \times 3{,}13$$

From $n_q$ the geometry of the turbine can be determined via statistical relationships.

TURBINE DIMENSIONING (4

**Head coefficient : $\psi$**

$$\psi = \frac{gH}{u^2} = \frac{K_1 H}{D^2 n^2}$$

**Flow coefficient : $\varphi$**

$$\varphi = \frac{Q}{u \cdot \frac{\pi D^2}{4}} = \frac{K_2 Q}{D^3 \cdot n}$$

$$n_q = \frac{n\sqrt{Q}}{H^{3/4}} = \frac{n\sqrt{\varphi}\ \sqrt{D^3 \cdot n}}{\psi^{3/4}\ (D^2 n^2)^{3/4}} K$$

$$n_q = K \frac{n^{3/2} \cdot D^{3/2}}{n^{3/2}\ D^{3/2}} \frac{\sqrt{\varphi}}{\psi^{3/4}} = K \frac{\sqrt{\varphi}}{\psi^{3/4}}$$

$\sigma$ (THOMA coefficients of cavitation) related to $n_q$

Suction head $h_s$ depends on $\sigma$ time $H$

therefore $n_q$ must be chosen in function of net head $H$

(5)

1. Given H is given $n_q$ and therefore n (but $n \cdot z_p = 3000 = 50 \times 60$)

$z_p$ is number of couples of poles

2. $\varphi$ and $\psi$ are statistically related therefore given $n_q$ $\varphi$ or $\psi$ are known and D can be determined

3. From $n_q$ the geometry of the turbine can be determined via statistical relationships

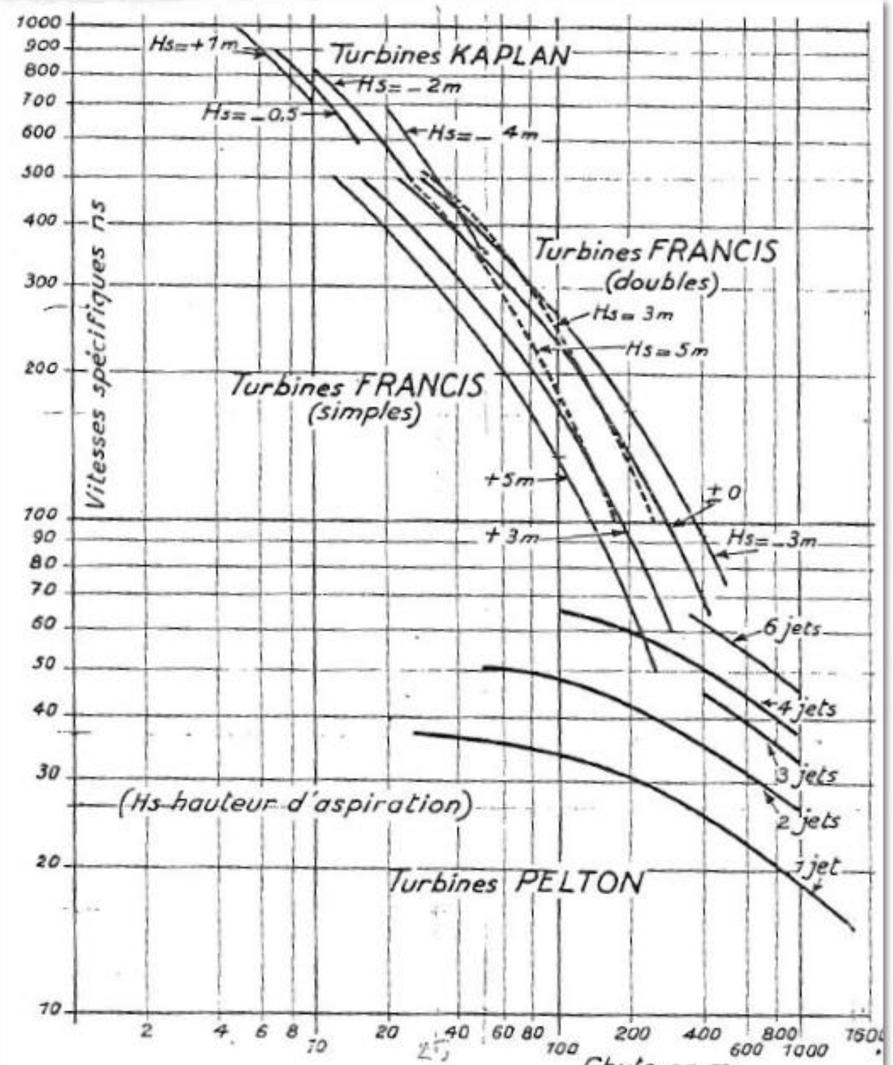



Fig. 2.33. — Limites des vitesses spécifiques en fonction de la chute (d'après Th. Bell. Kriens-Lucerne Suisse).

## FRANCIS

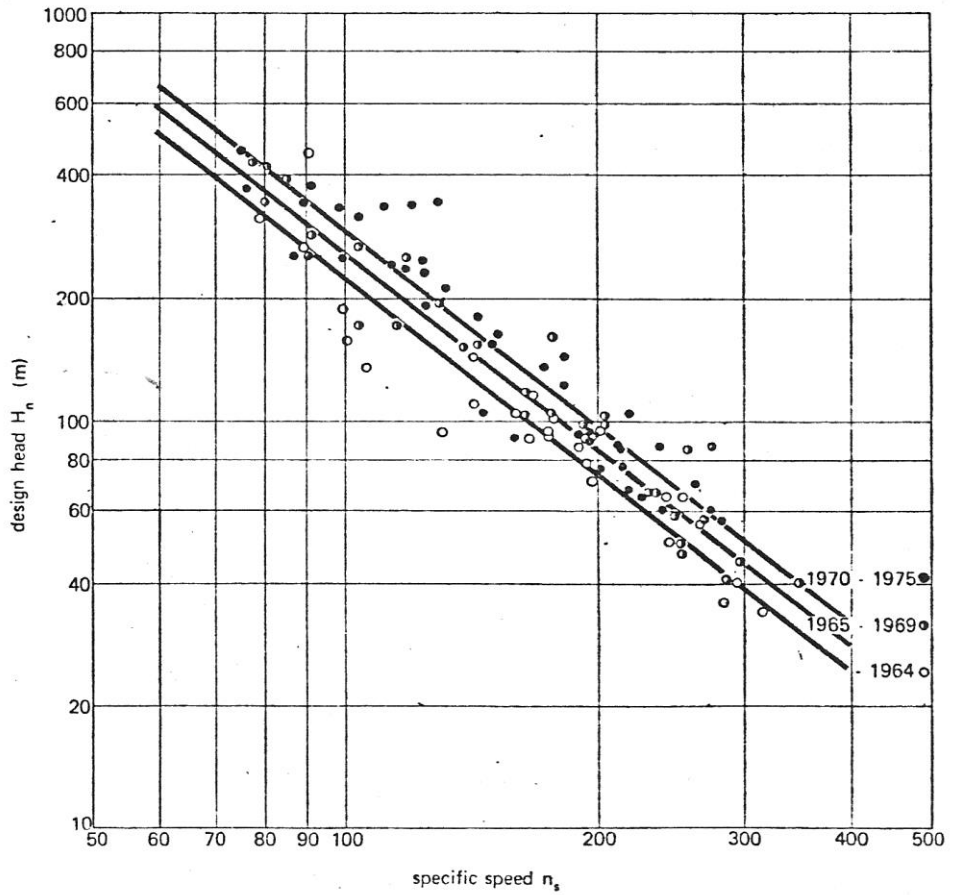
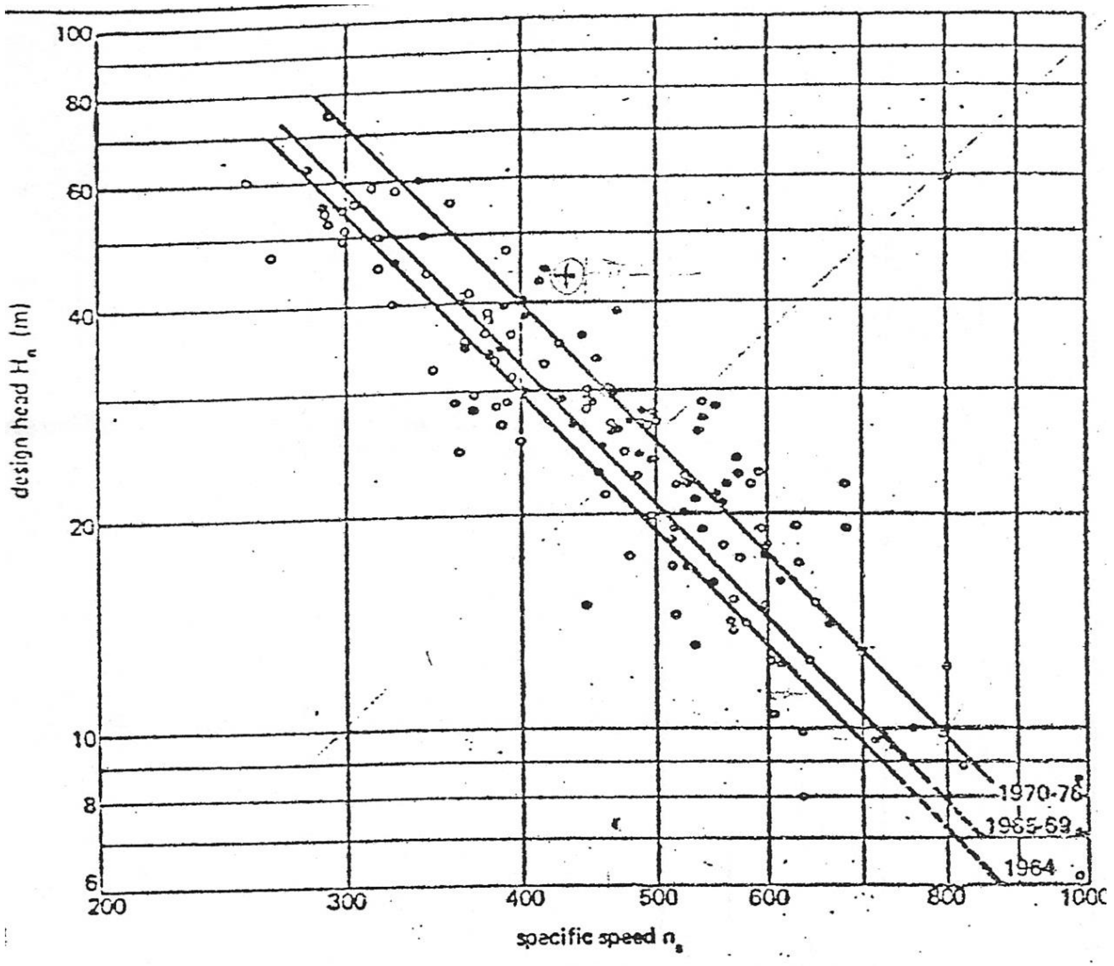



*Fig. 1. Specific speed versus design head. The curves indicate that over a period extending from some time before 1964 to the present there has been a trend to increase the value of the specific speed for a given head.*

## KAPLAN



100
80
60
40
20
10
8
6
design head $H_n$ (m)
200
300
400
500
600
800
1000
specific speed $n_s$
1970-76
1965-69
1964

Teacher’s contact:

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Production and Transportations (DIME)
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