SAARC ENERGY CENTRE
Energy for Peace & Prosperity

Online training of SAARC Professionals on Small, Mini and Micro Hydro Power Generation (Sept 13 - 17, 2021)

Mechanical and Electrical Engineering Aspects of Designing SMMHP Plants

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CONTENTS

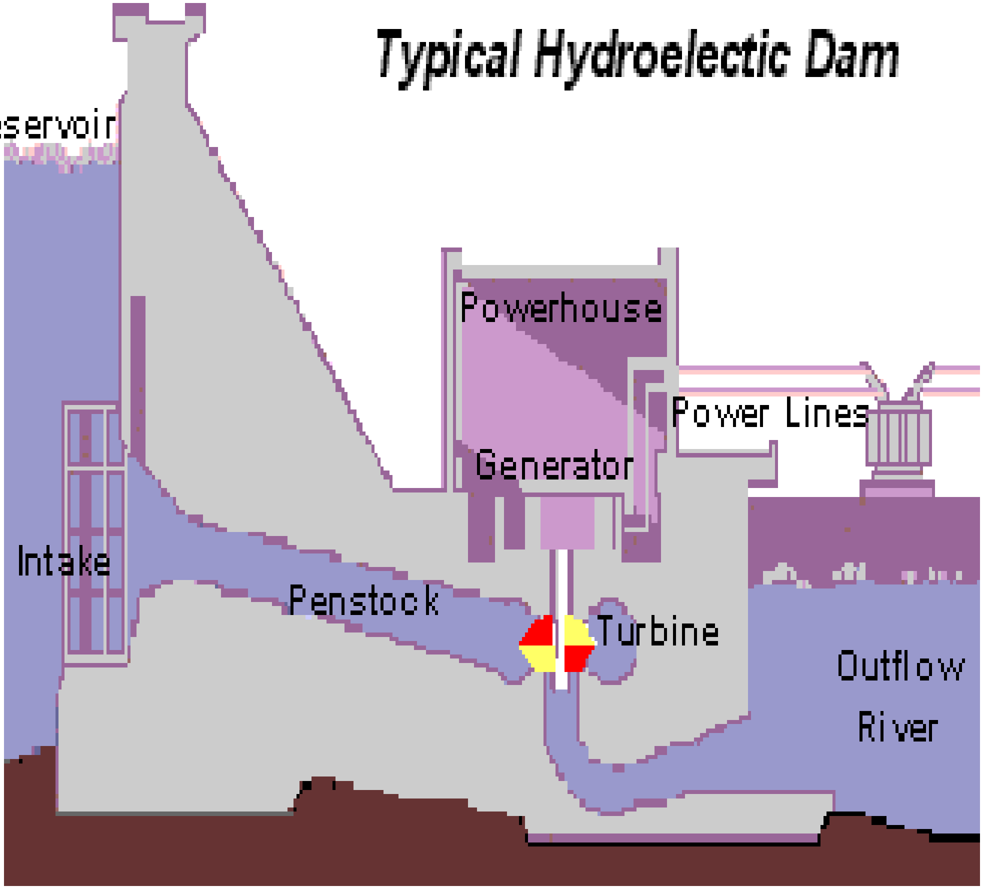
1. Basic components of SMMHP generation
2. Discussion on Electro-mechanical equipment
3. Design aspects of hydro turbines and generators
4. Selection of mechanical and electrical equipment

LEARNING OBJECTIVES

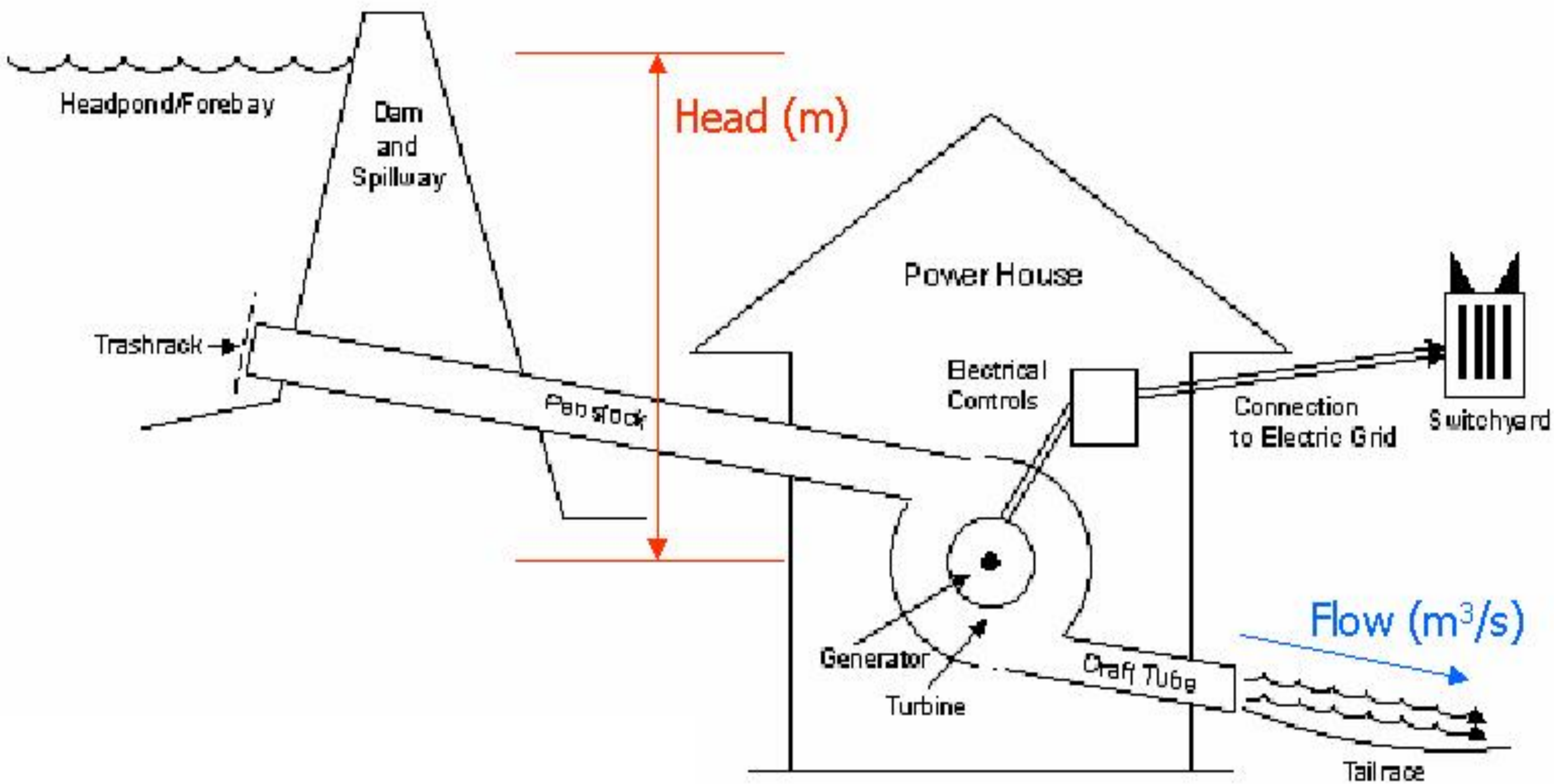
To understand the selection and design aspects of mechanical and electrical works.

HYDROPOWER

- Water from the reservoir flows due to gravity to drive the turbine.
- Turbine is connected to a generator.
- Power generated is transmitted over power lines.



BASIC EQUATION FOR HYDROPOWER



Power in kW = 9.81 x Flow x Head x Efficiency

TYPES OF SHP SCHEMES

- Run-of-river (Hill based)
- Canal fall based
- Dam Toe base

CLASSIFICATION

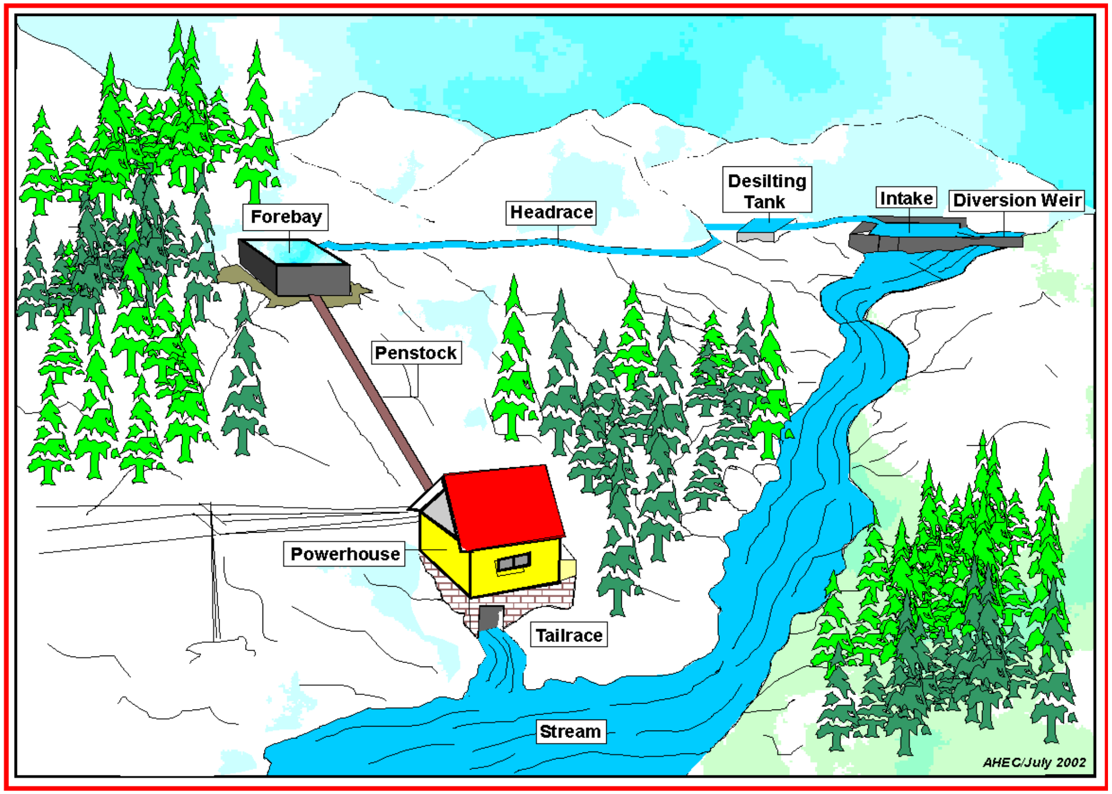
Based on Installed Capacity

Micro	:	Upto 100 kW
Mini	:	101 kW to 2000 kW
Small	:	2001 kW to 25000 kW

Unit size :1001 kW to 5000 kW

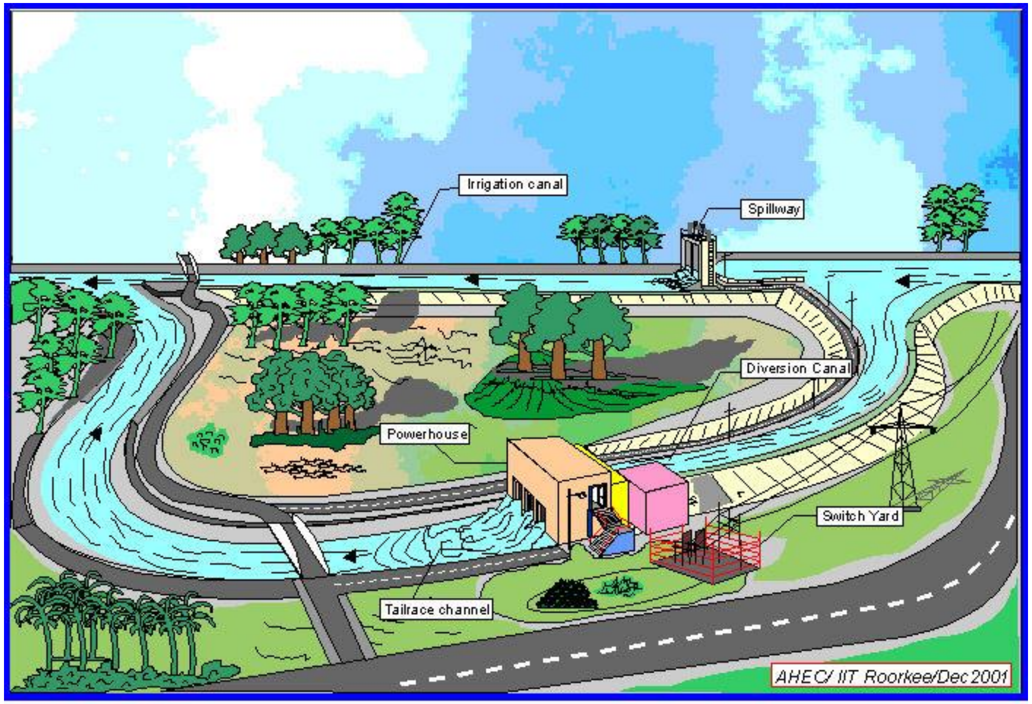
Based on Head

Ultra low head	:	Below 3
Low head	:	3 m to 40 m
Medium/High head	:	above 40 m

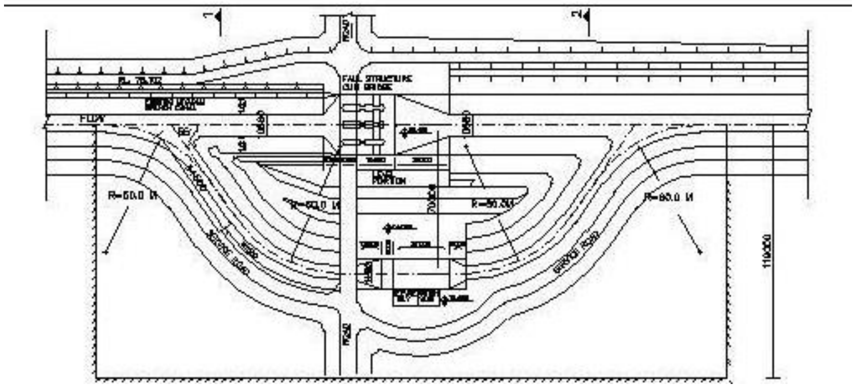


Typical Arrangement of Small Hydro Power Station

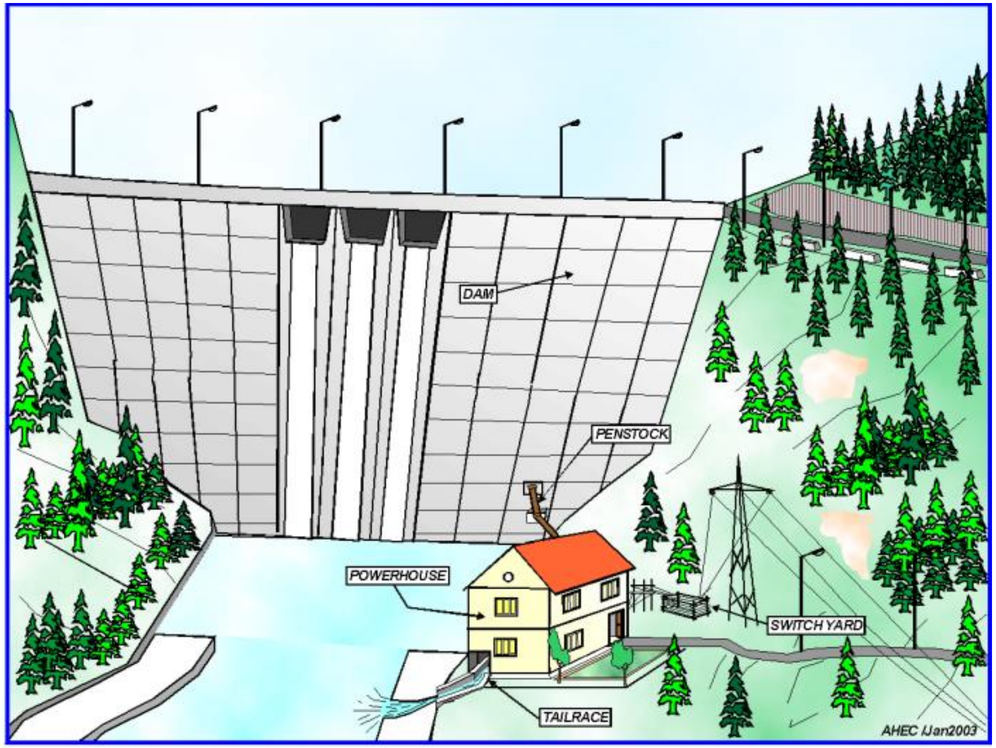
TYPICAL RUN OF RIVER SHP LAYOUT



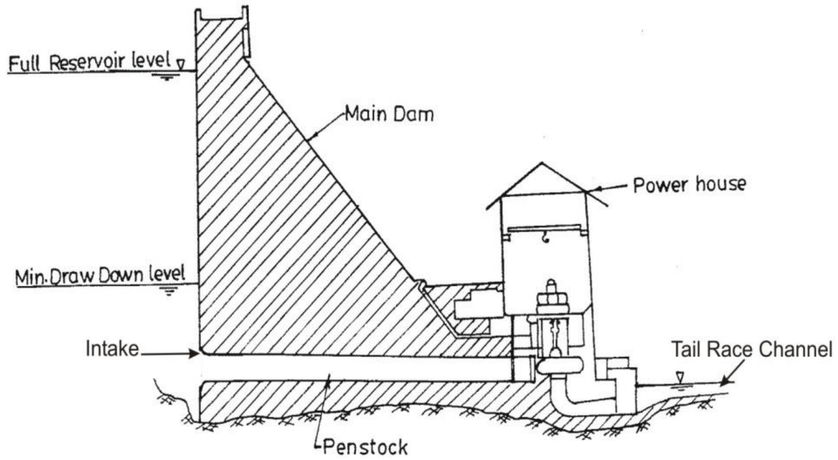
Typical Arrangement of Canal Fall Small Hydro Power Station



TYPICAL CANAL BASED SHP LAYOUT



Typical Arrangement of Dam toe Small Hydro Power Station



TYPICAL LAYOUT OF DAM TOE SHP SCHEME

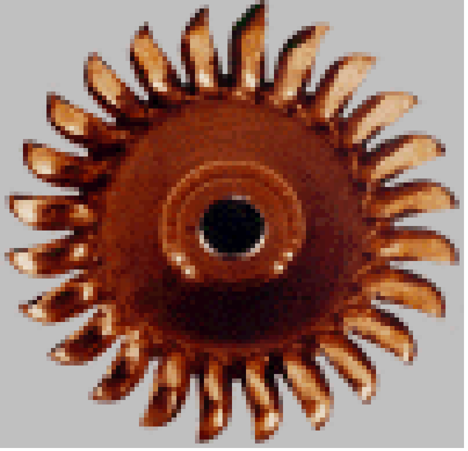
BASIC COMPONENTS OF SHP

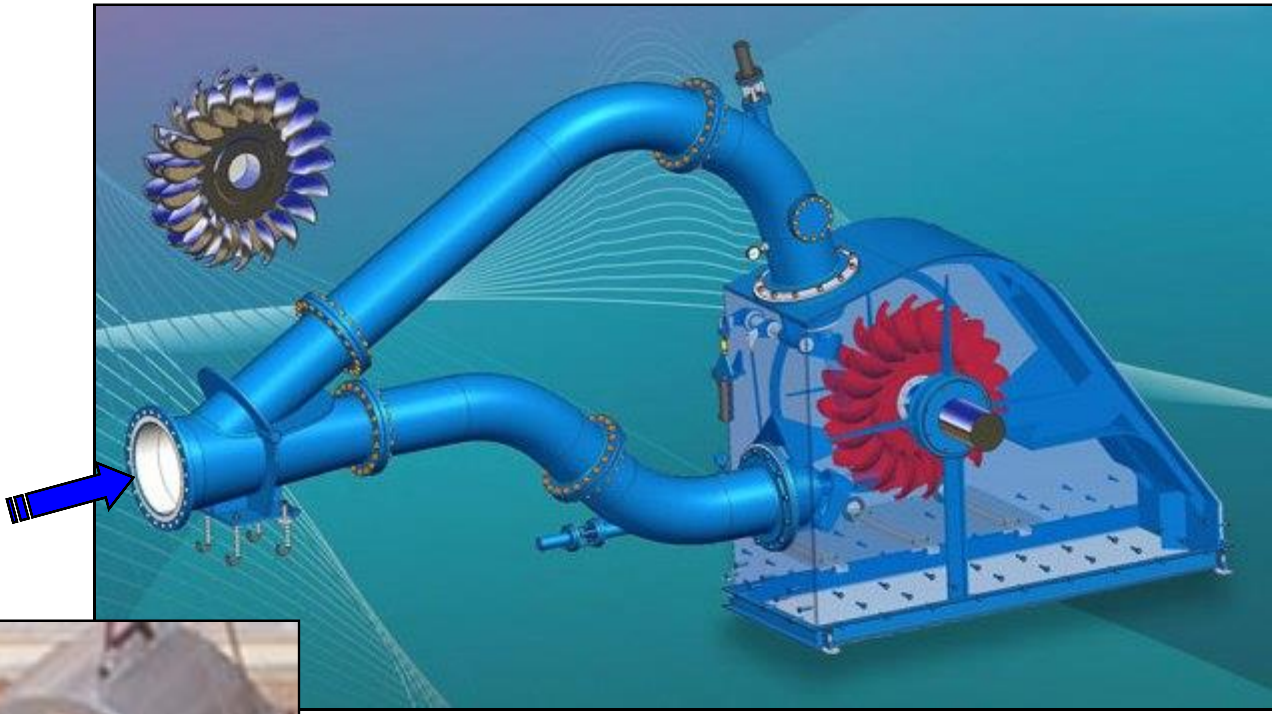
* **Civil Works**
  - Intake/Diversion Weir.
  - Power Channel.
  - Desilting Tank.
  - Forebay Tank.
  - Penstock.
  - Power House Building.
  - Tail Race.
* **Equipment**
  - Turbine.
  - Generator & Controls.

CLASSIFICATION OF TURBINES

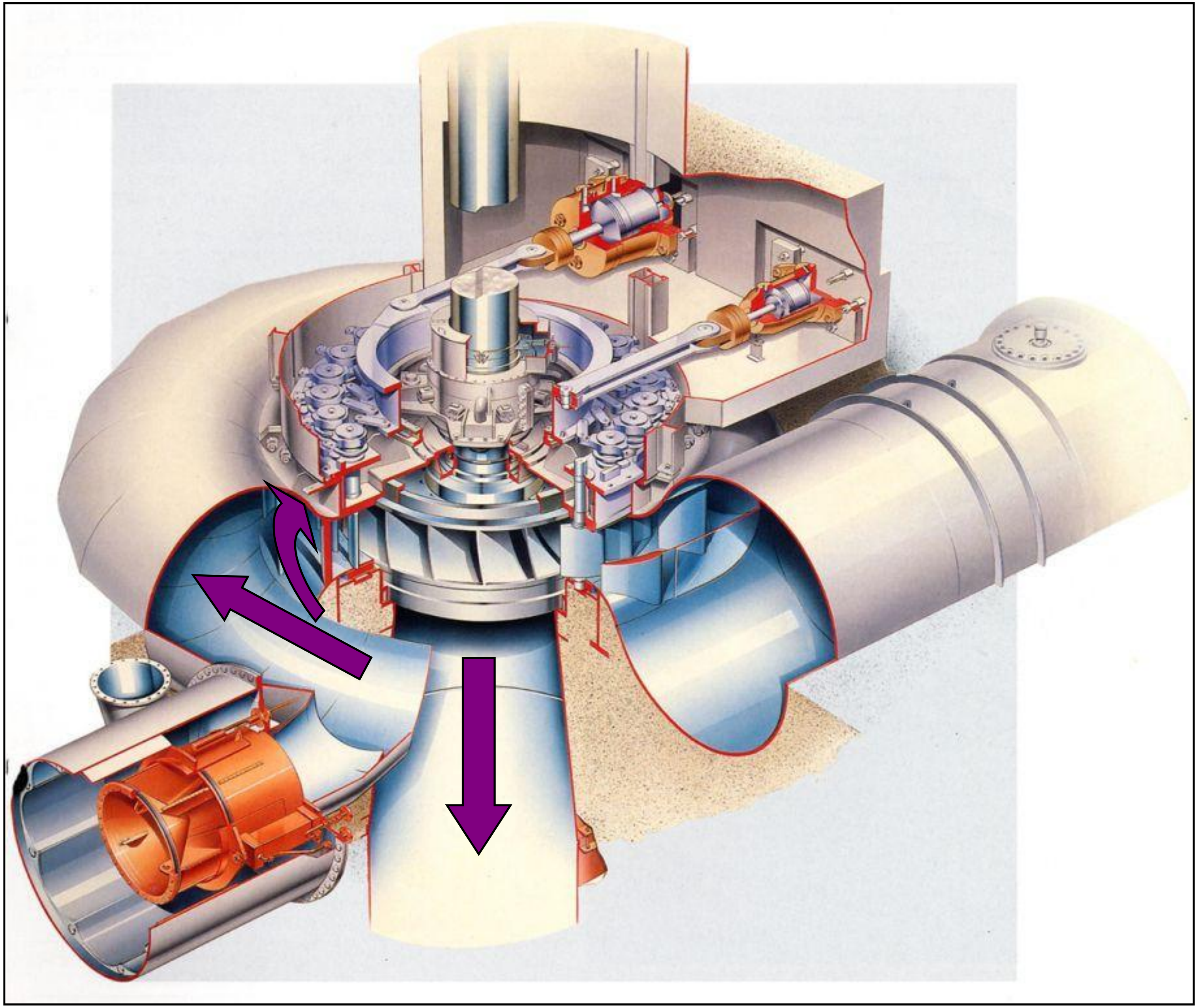
- **Impulse**
  - **Pelton, Turgo Wheel, Cross Flow**
- **Reaction**
  - **Francis**
  - **Axial Flow**
    - **Propeller, Semi Kaplan, Kaplan**

PELTON TURBINE

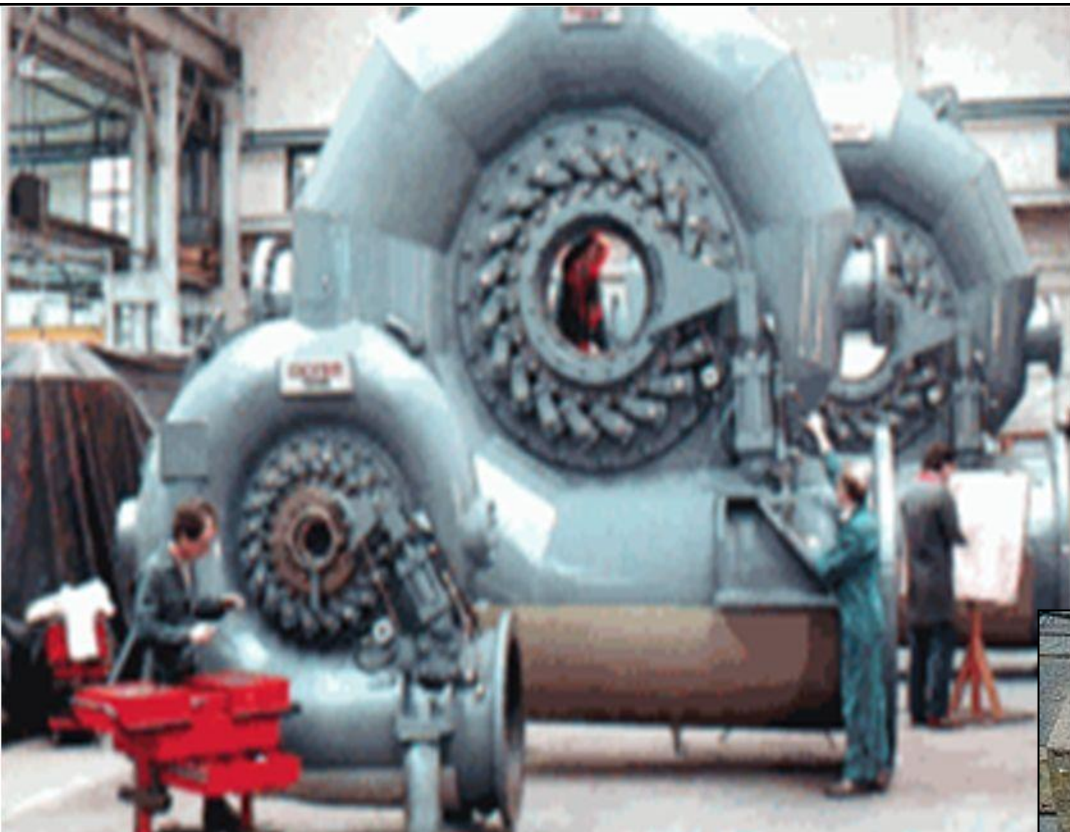




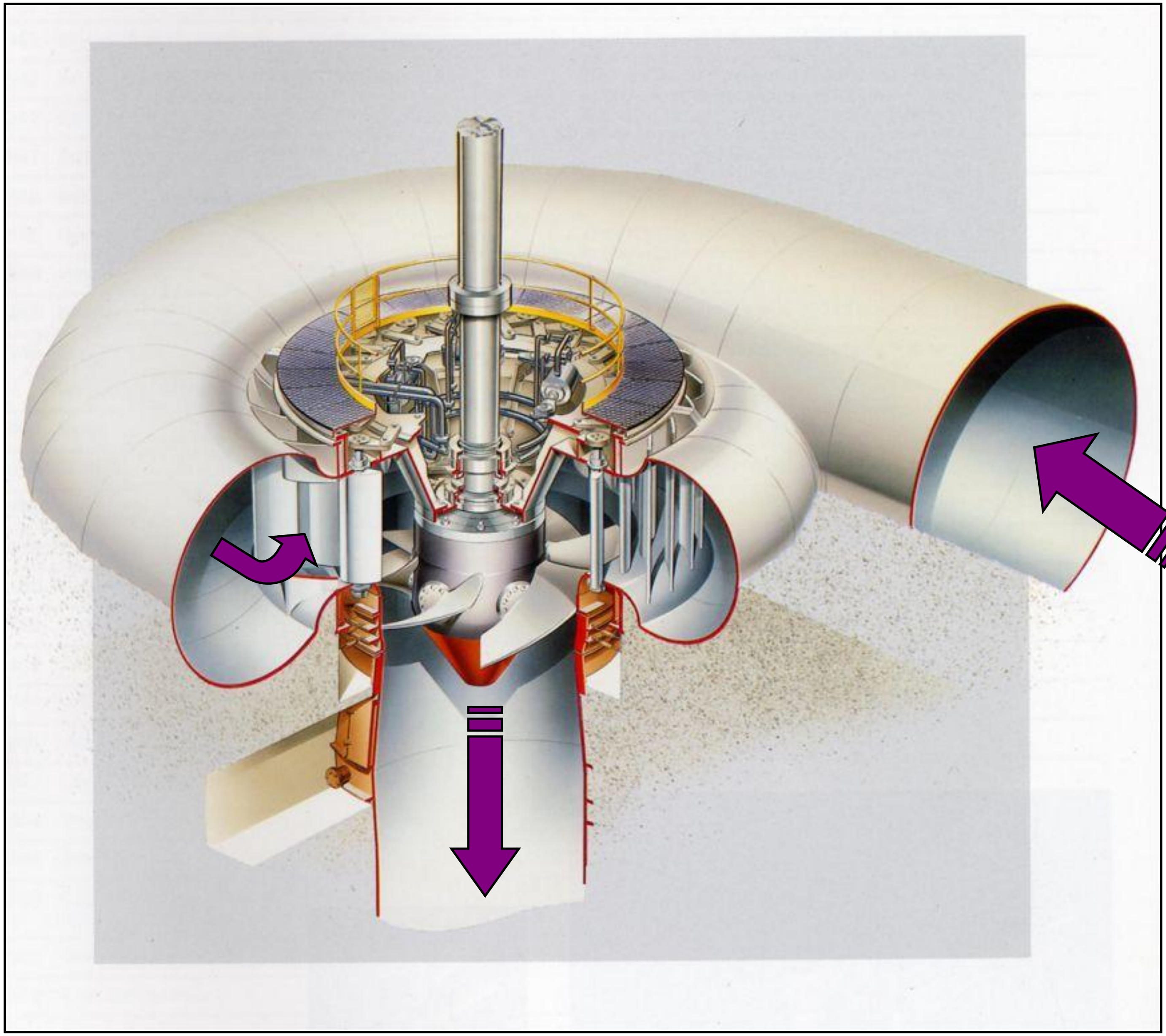
FRANCIS TURBINE



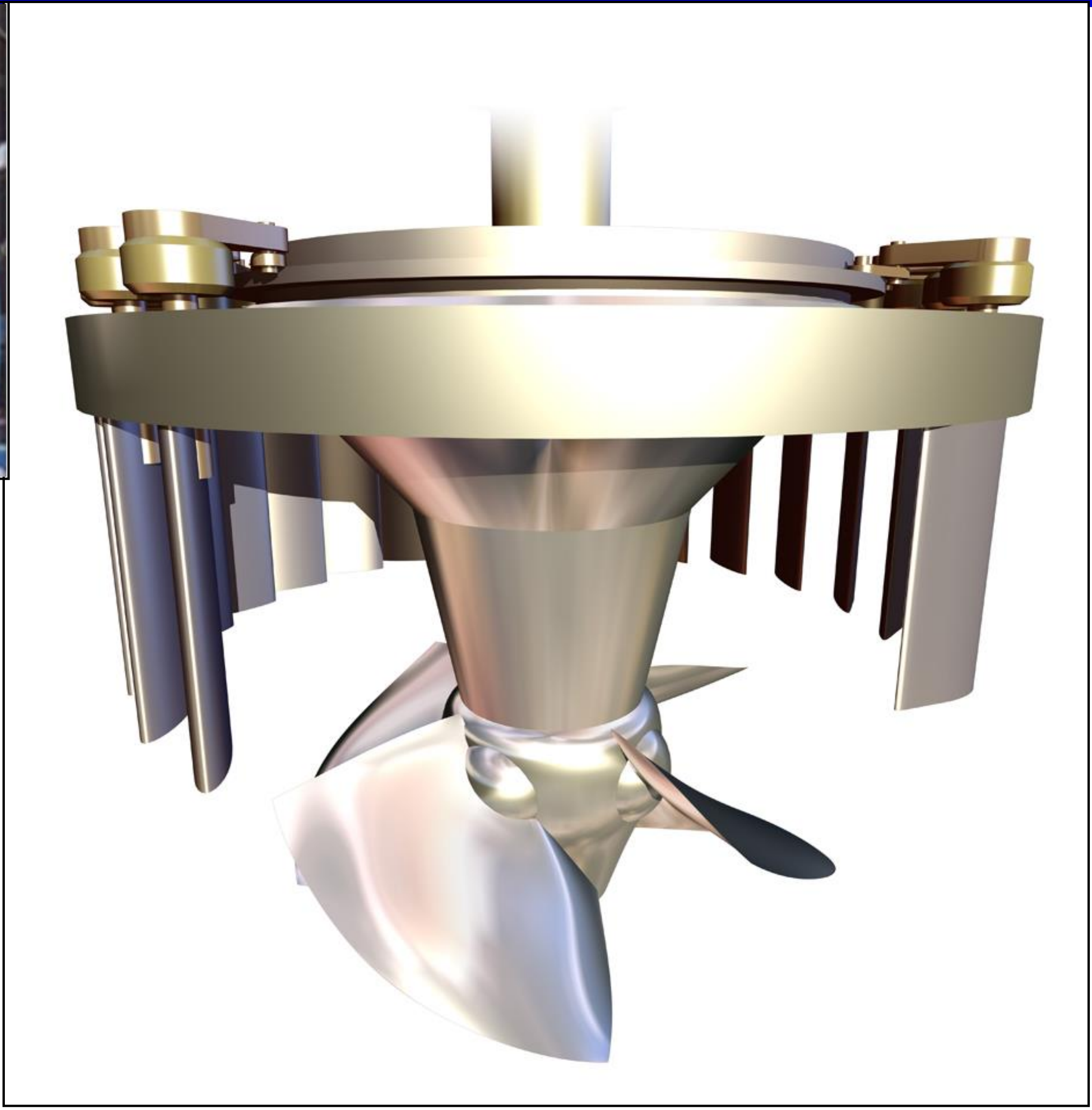
FRANCIS TURBINE



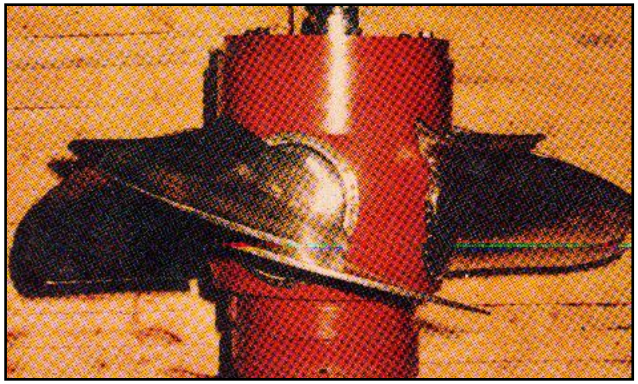
KAPLAN TURBINE

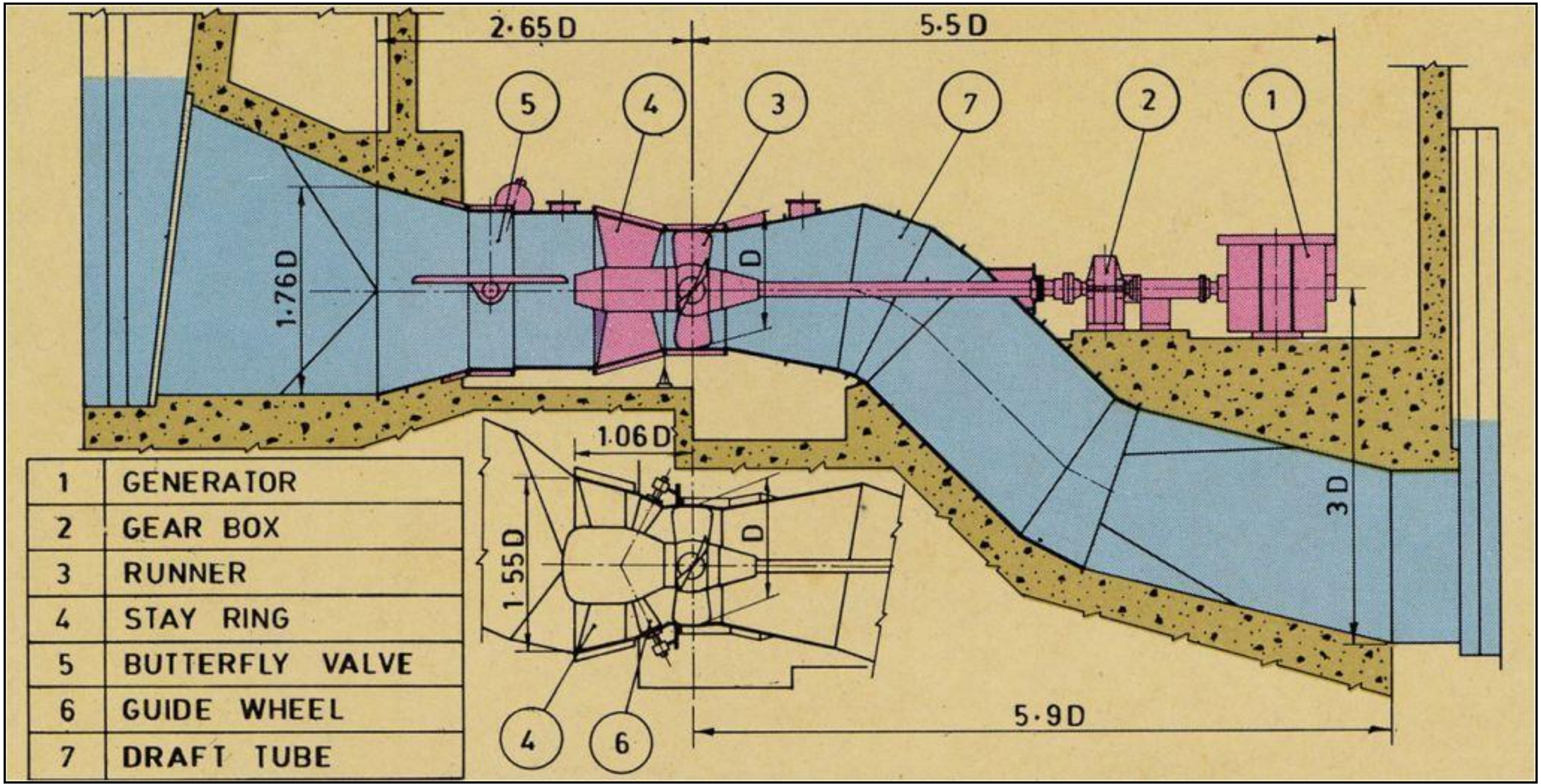


KAPLAN TURBINE

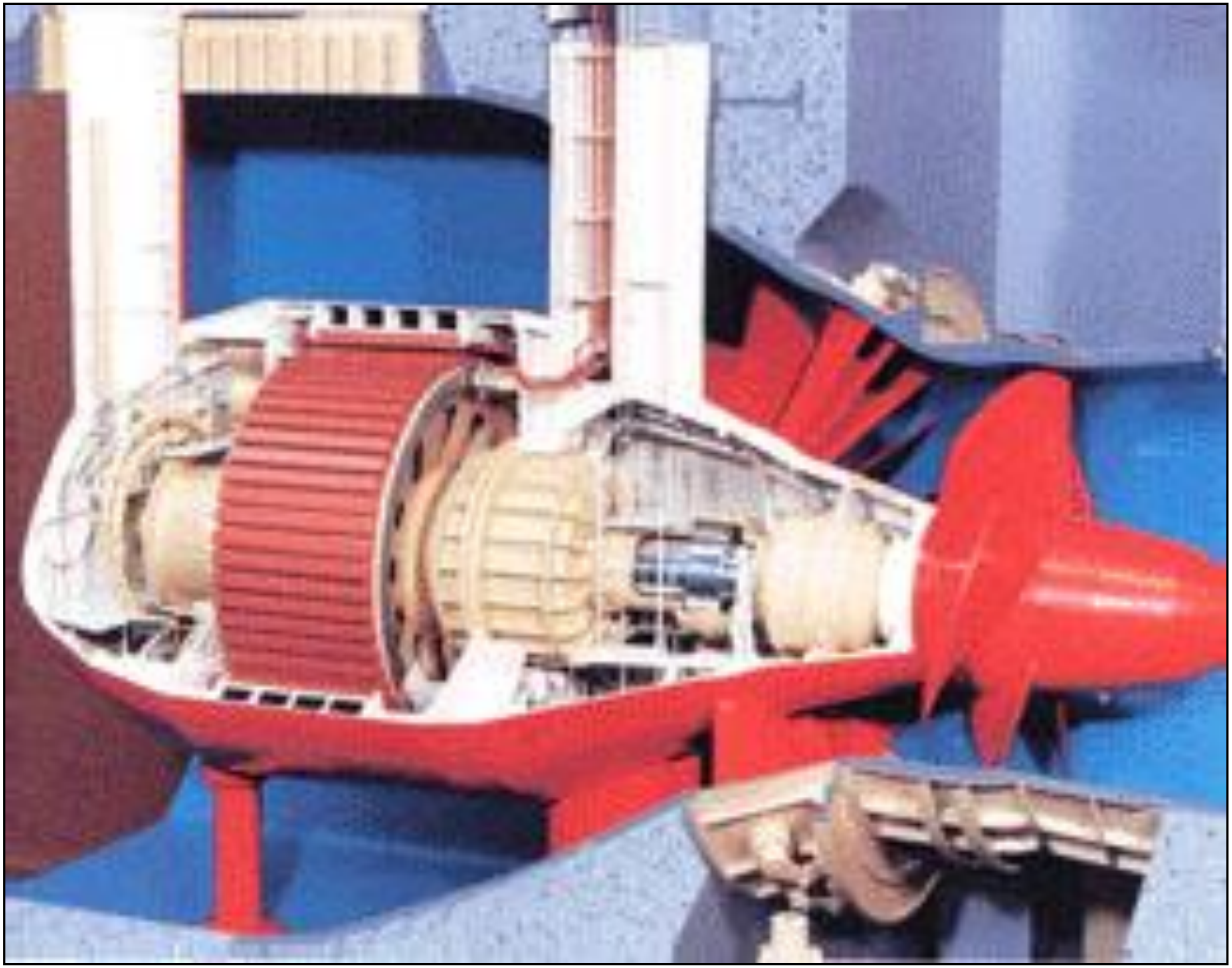


S – TYPE TUBE TURBINE



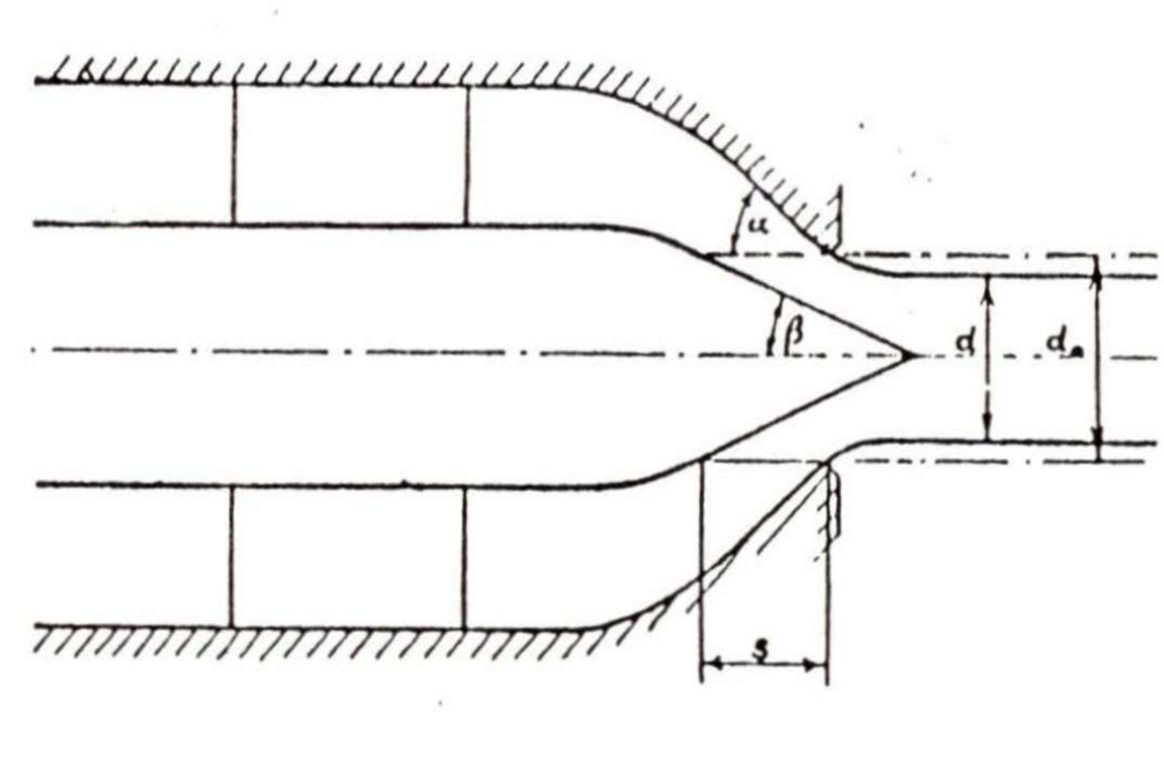


BULB TURBINE



DESIGN ASPECTS OF HYDRO TURBINES

Nozzle

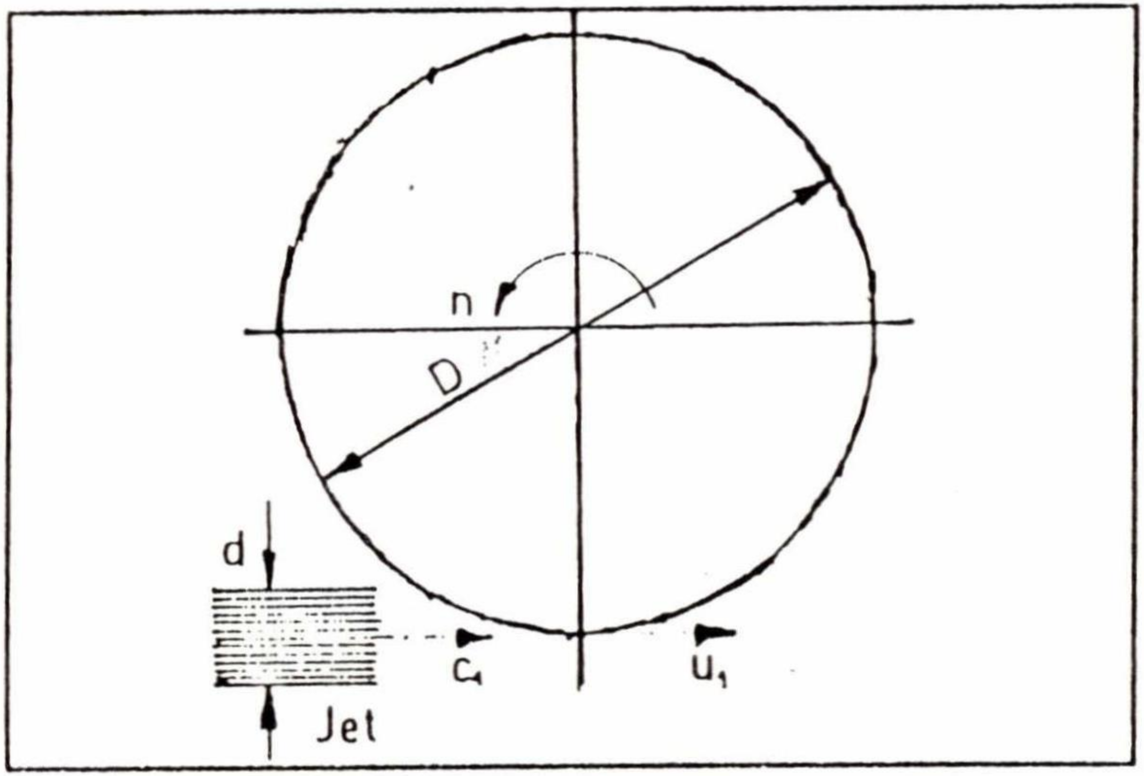


$$d = \frac{0.54\sqrt{Q/n_j}}{H^{1/4}}$$

$$\alpha = 22\frac{1}{2}^{o}$$

$$\beta = 28\frac{1}{2}^{o}$$

Runner

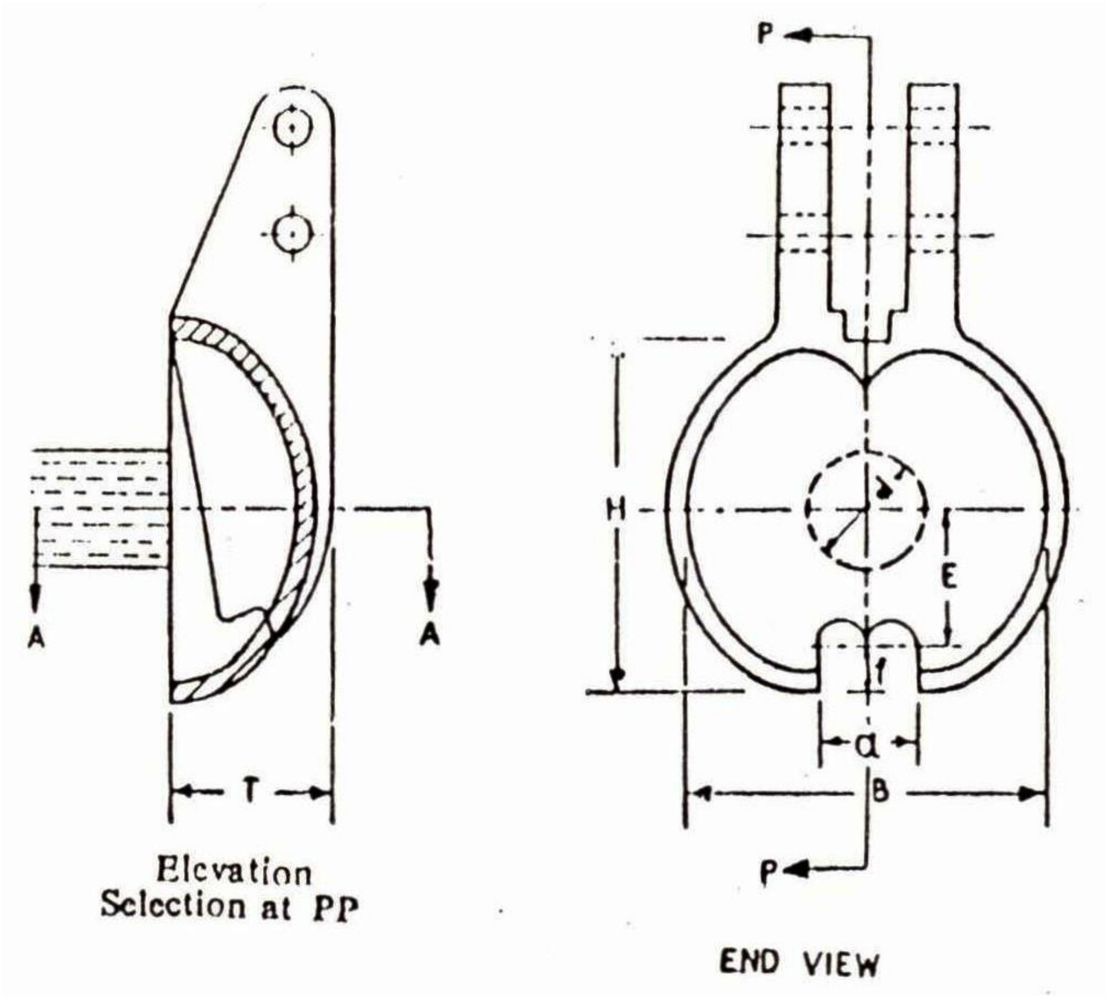


$$\mathrm{DN} = \mathrm{K}\sqrt{H}$$

$$\mathrm{K} = \frac{60}{\pi} Ku\sqrt{2g}$$

$$\mathrm{D} = \frac{38.9\sqrt{H}}{N}$$

Buckets



$Z = 0.5M + 15$

$M = D/d$

$B = (2.8 – 3.2)d$

$H = (2.2 – 2.8)d$

$T = (0.6 – 0.9)d$

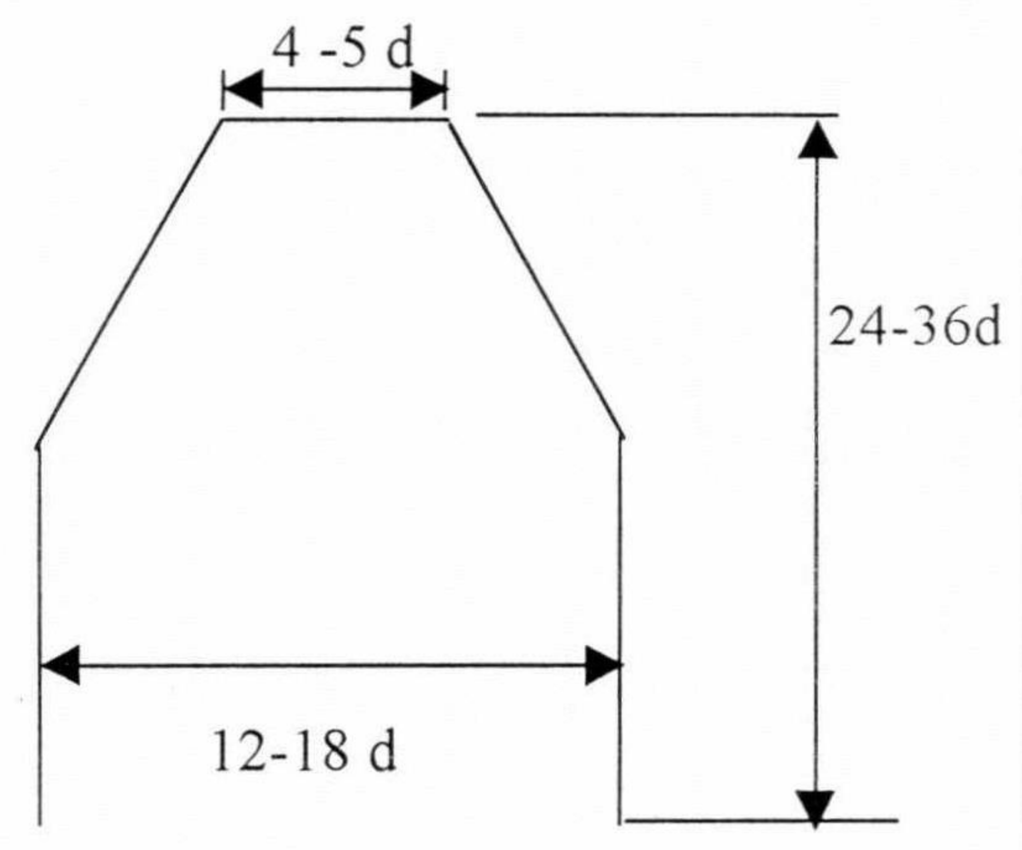
$a = 1.1d$

$f = 1.1d$

$\beta_1 = 5^o – 8^o$

$\beta_2 = 10^o - 20^o$

Casing

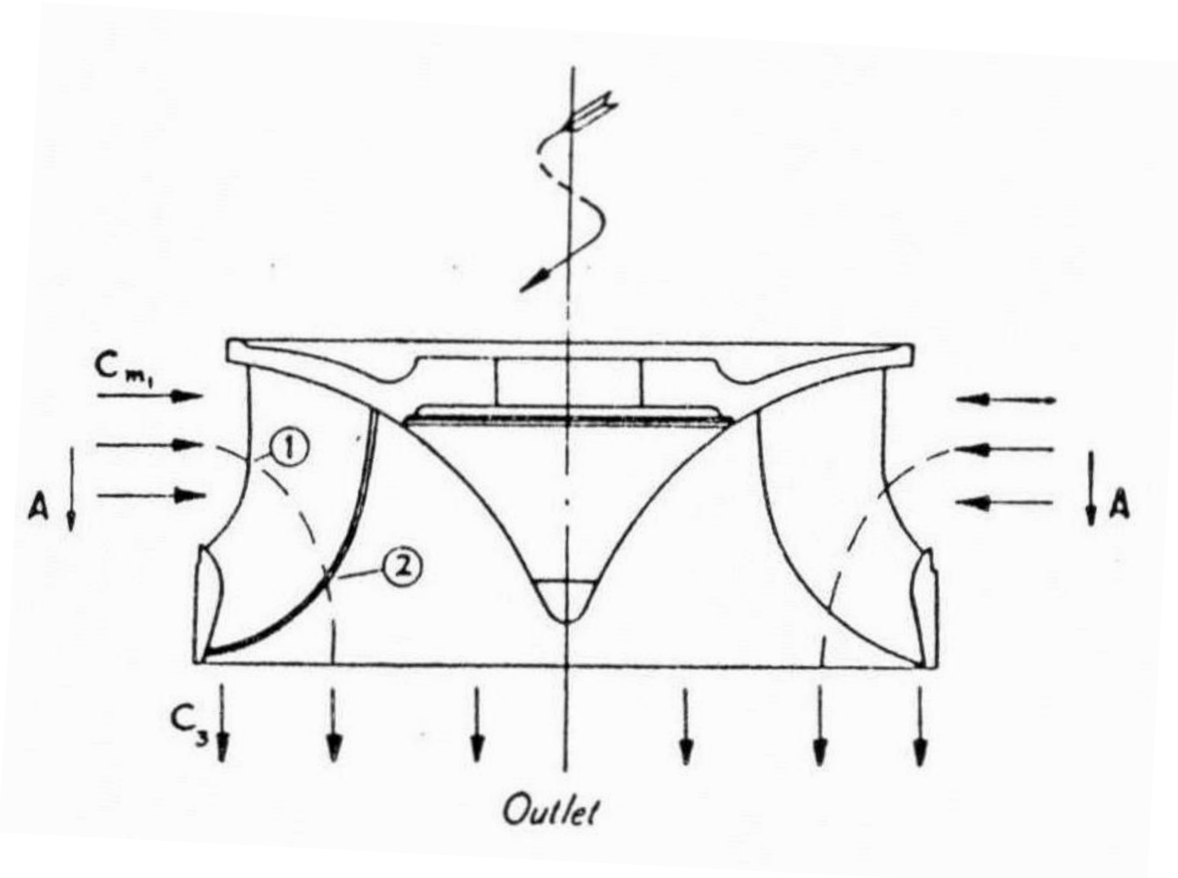


W at jet = (12 – 18)d

W at upper cover = (4 - 5)d

Height H = (24 – 36)d

Runner



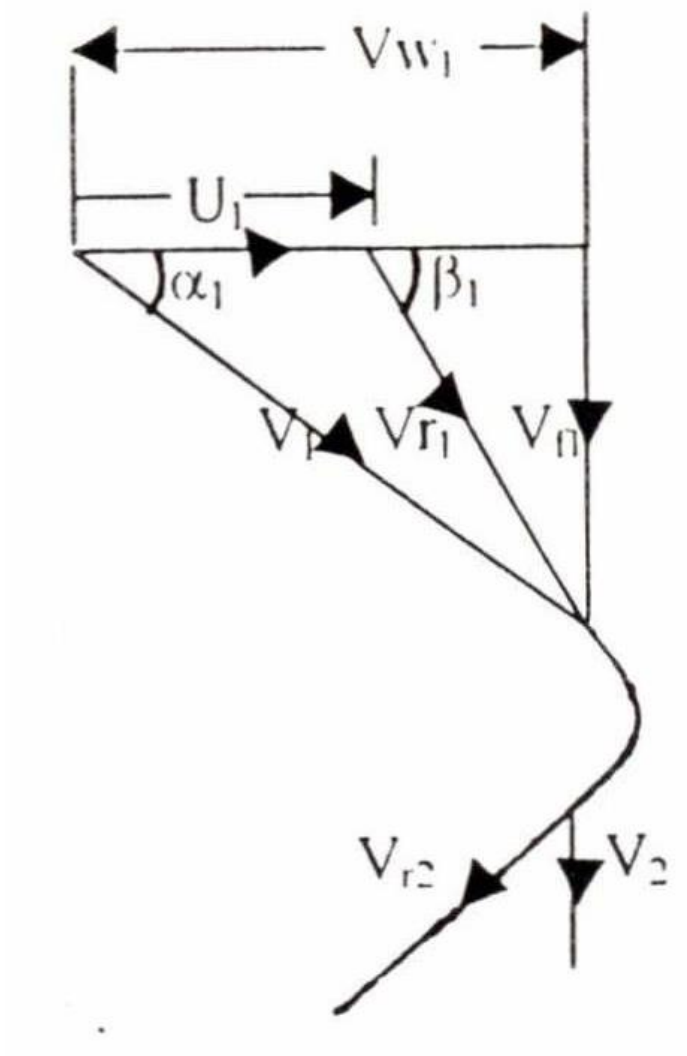
$$D_1 = \frac{84.6\,K_{u1}\sqrt{H}}{N}$$

$$D_2 = {D_1}/{2}$$

$$B = B_o = \frac{0.072\,Q}{D_o\,k_f\,\sqrt{H}}$$

$$Z = Z_o + 1$$

DESIGN OF FRANCIS TURBINE



BLADE ANGLES

Slow Runner

α_1 = 10 – 20

β_1 = 60 – 90

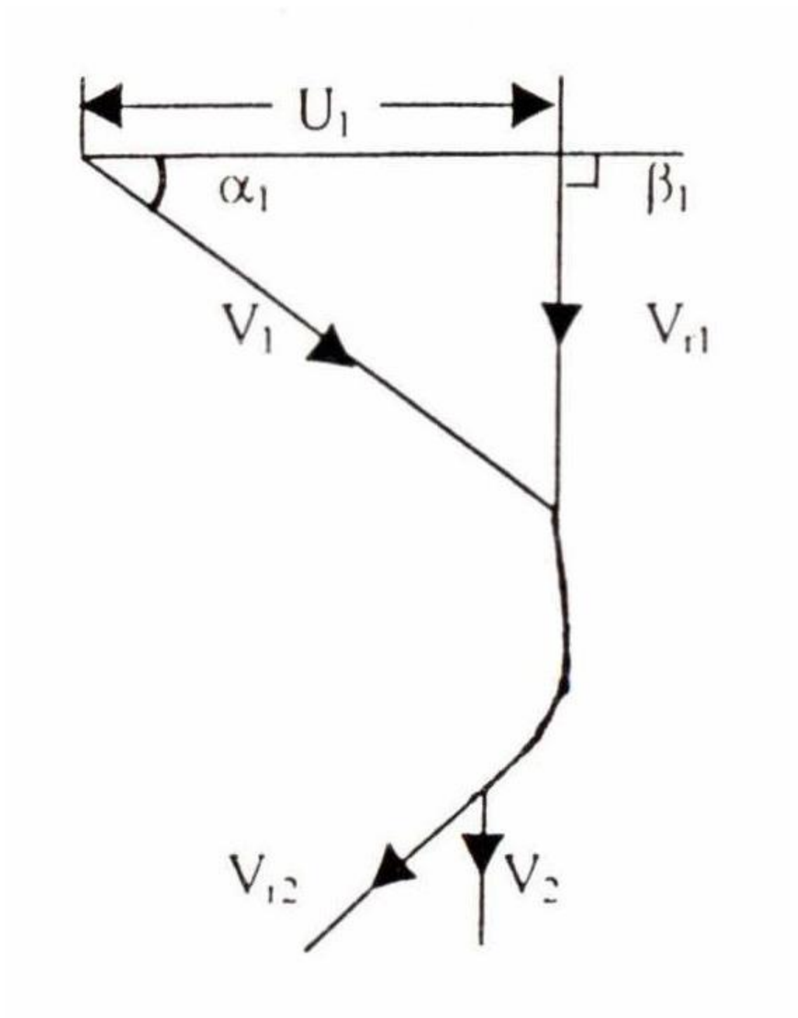
β_2 = 15

α_2 = 90

k_{u1} = 0.6 - 0.7

k_f = 0.1

DESIGN OF FRANCIS TURBINE



Medium Runner

$\alpha_1 = 20 – 30$

$\beta_1 = 90$

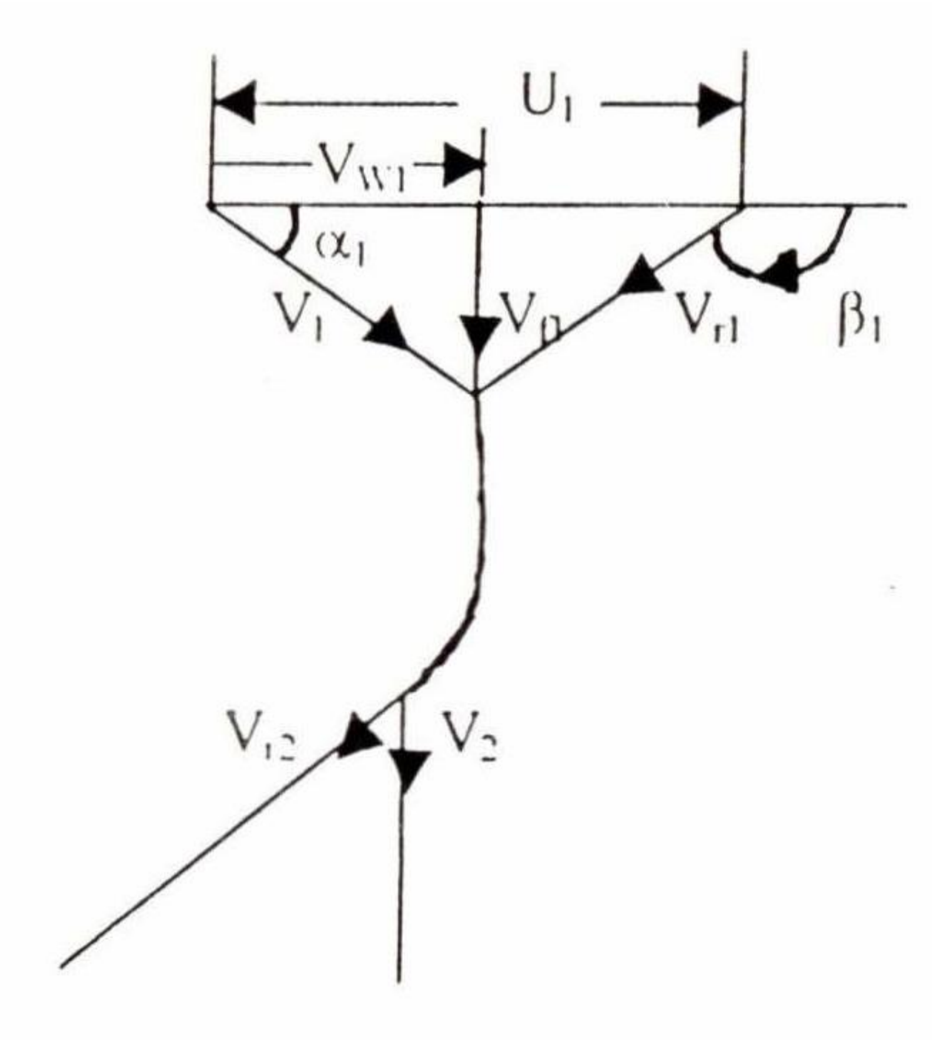
$\beta_2 = 15$

$\alpha_2 = 90$

$k_{u1} = 0.7 - 0.76$

$k_f = 0.15 - 0.3$

DESIGN OF FRANCIS TURBINE



Fast Runner

α_1 = 30 – 40

β_1 = 90 – 135

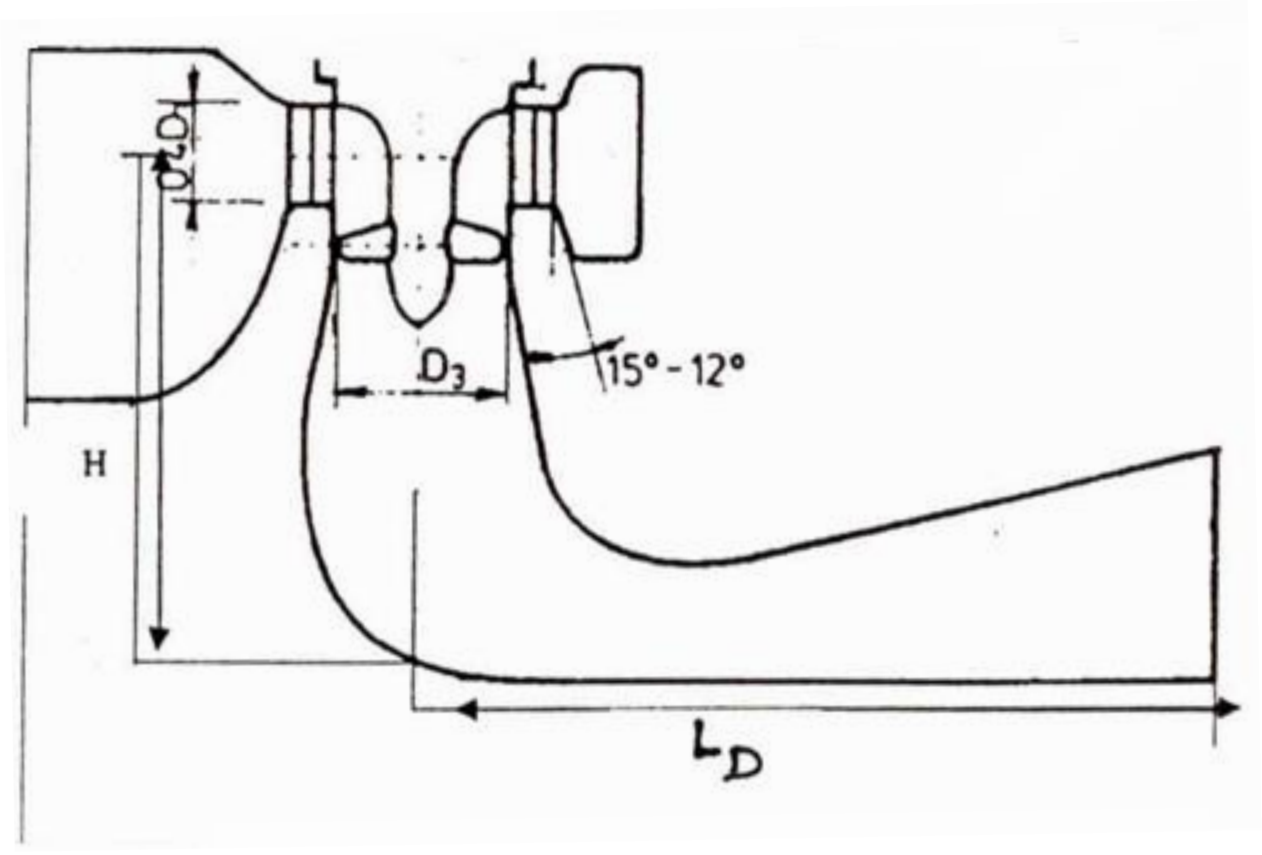
β_2 = 15

α_2 = 90

k_{u1} = 0.76 - 0.9

k_f = 0.25 - 0.35

Draft Tube



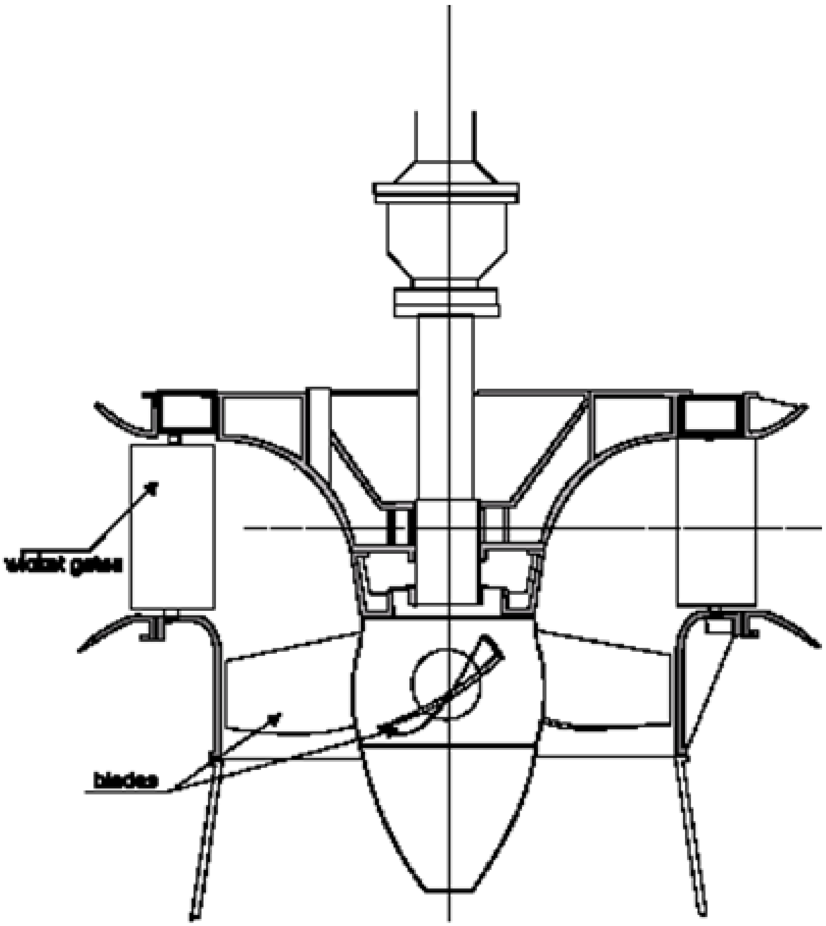
$$D_{di} = D_2$$

$$\alpha = 4 - 8^o$$

$$L_D = D_2\left(5 - \frac{N_s}{200}\right)$$

$$H = D_2\left(3.4 - \frac{N_s}{400}\right)$$

Runner



$$D_r = \frac{0.536}{H^{1/4}}\sqrt{\frac{Q}{(1-\nu^2)\,k_f}}$$

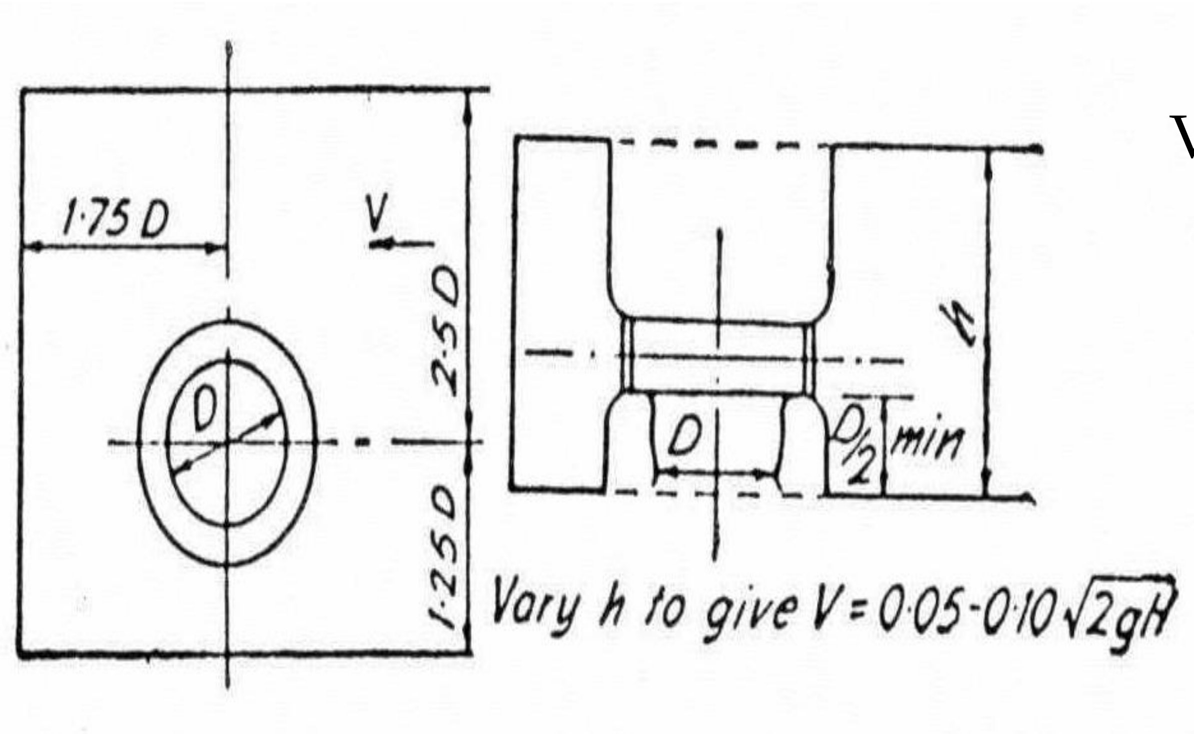
$$\nu = \frac{D_h}{D_r} = 0.38 + \frac{H}{220}$$

$$D_h = D_r \times \nu$$

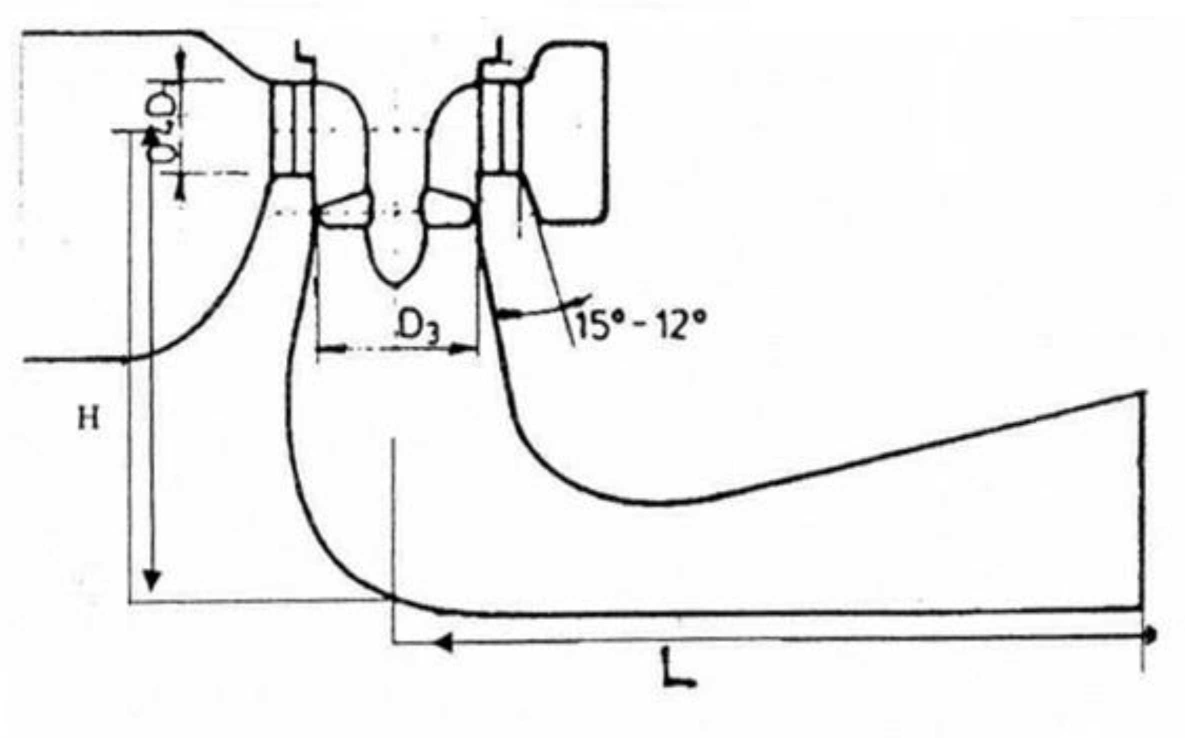
Casing

$$h_c = \frac{Q}{2.5 \times V_{fc}}$$

$$V_{fc} = 0.05 - 0.10\sqrt{2gH}$$



Draft Tube



$$D_{Di} = D_2$$

$$\alpha = 4 - 8^o$$

$$L_D = D_2\left(5 - \frac{N_s}{200}\right)$$

$$H = D_2\left(3.4 - \frac{N_s}{400}\right)$$

PERFORMANCE CHARACTERISTICS CURVES

INTRODUCTION

- Designed conditions of turbine:
- Hydraulic Turbines gives their best performance when they are operated at certain conditions of head, discharge, speed and output power.
- Model turbines are tested under different conditions of head, discharge, speed, power, efficiency. Results are plotted in the form of curves and are known as performance characteristic curves.
- For convenience, curves are plotted in terms of unit quantities.

TYPES OF PC CURVES

- Main Characteristics curves/Constant head curves.
- Operating characteristics curves/Constant Speed curves.
- Constant efficiency curves (Muschel Curves)

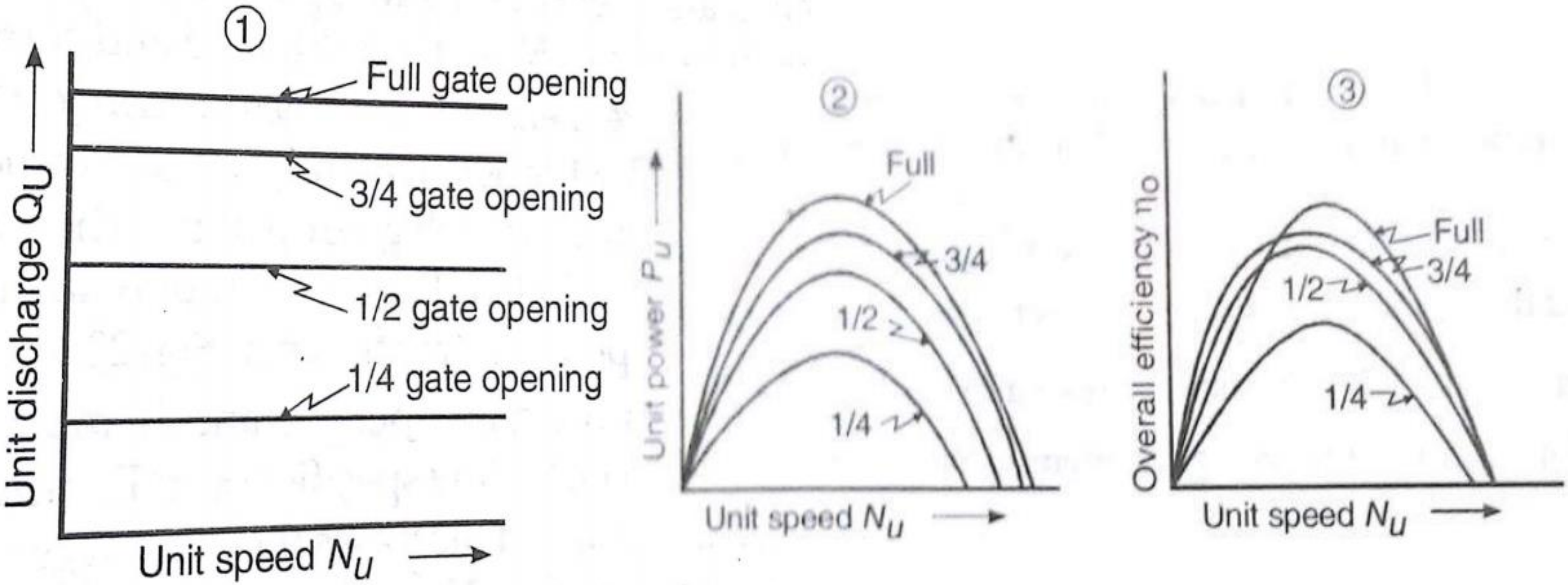
Main Characteristics Curves / Constant Head Curves

- Curves are drawn by conducting experiment at constant head.
- Head and gate openings are kept constant and speed is varied by varying load on the turbine.
- For each value of speed, corresponding values of power and discharge are obtained.

Operating Characteristics Curves / Const. Speed Curves

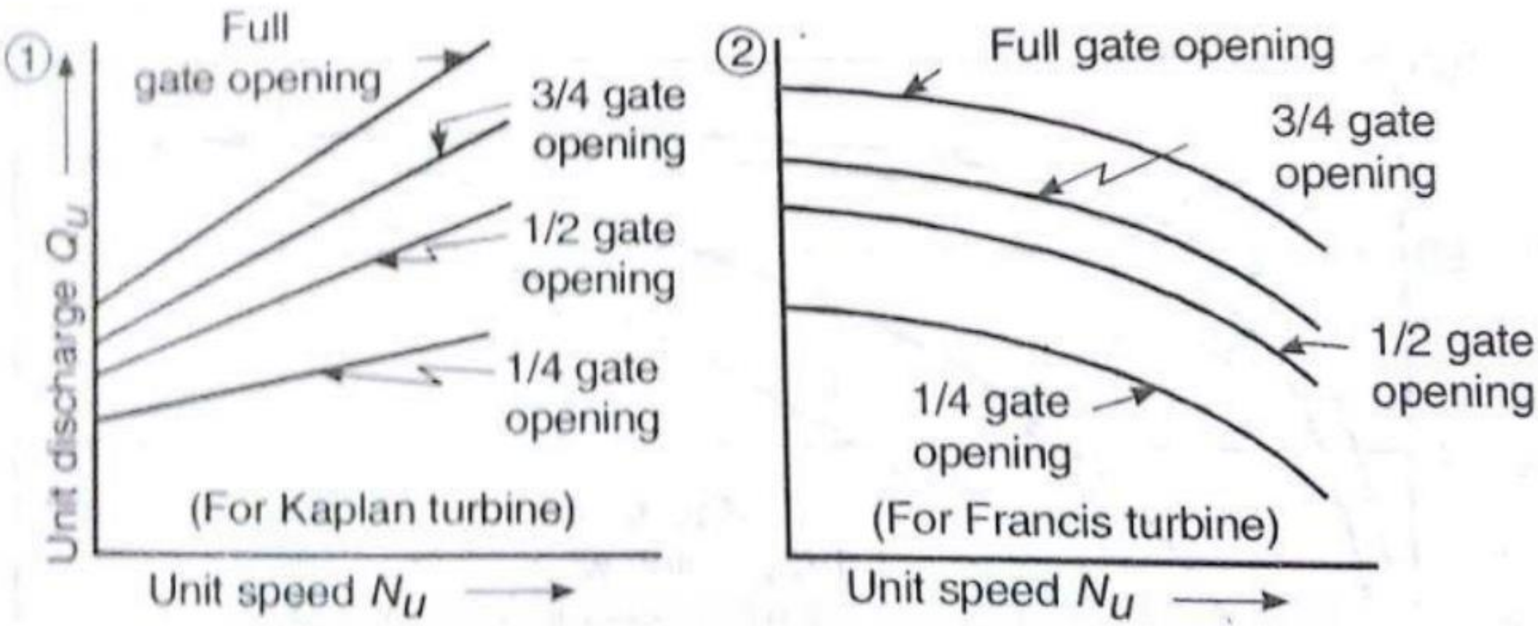
- Tests are performed at constant speed.
- Const. speed is attained by regulating the gate opening thereby varying the discharge flowing through the turbine as the load varies.
- Head may or may not kept constant.

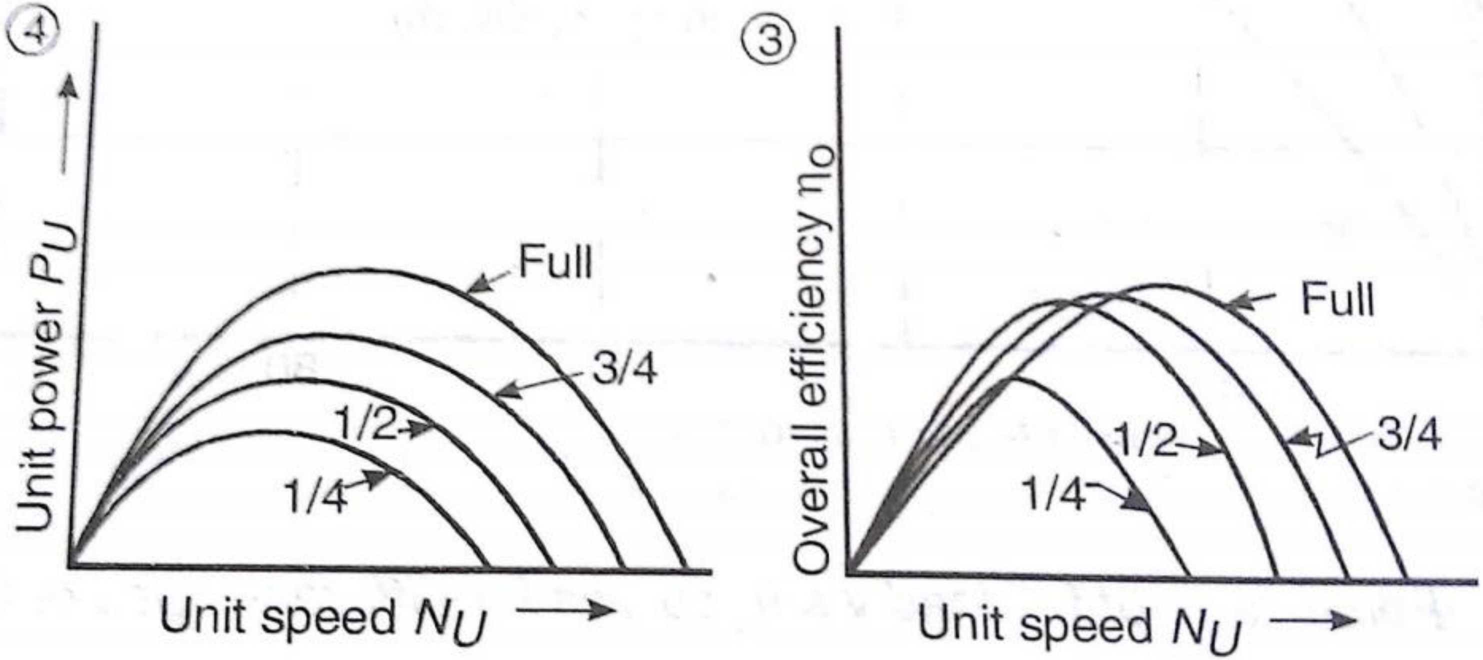
For Pelton wheel



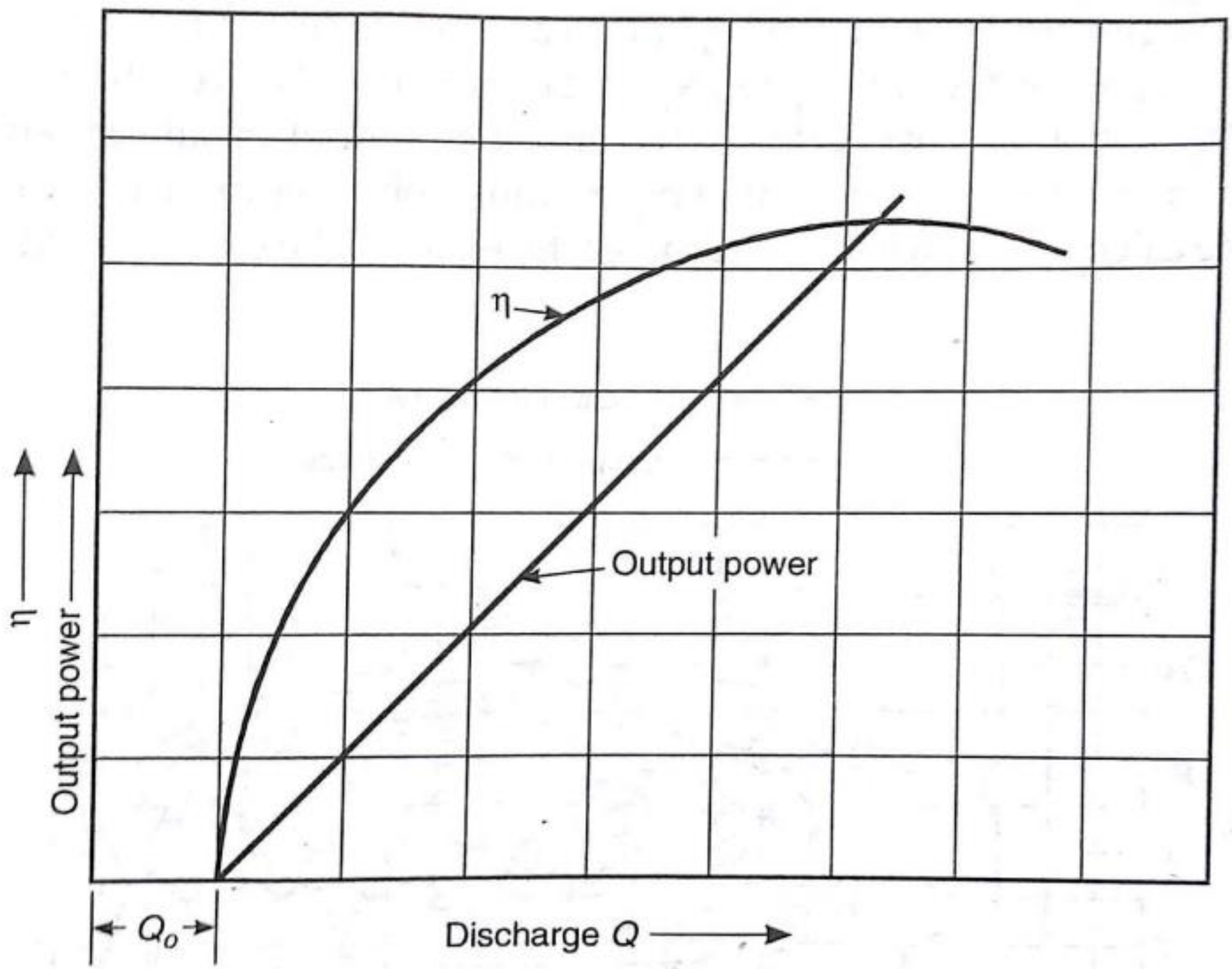
(a) For pelton wheel

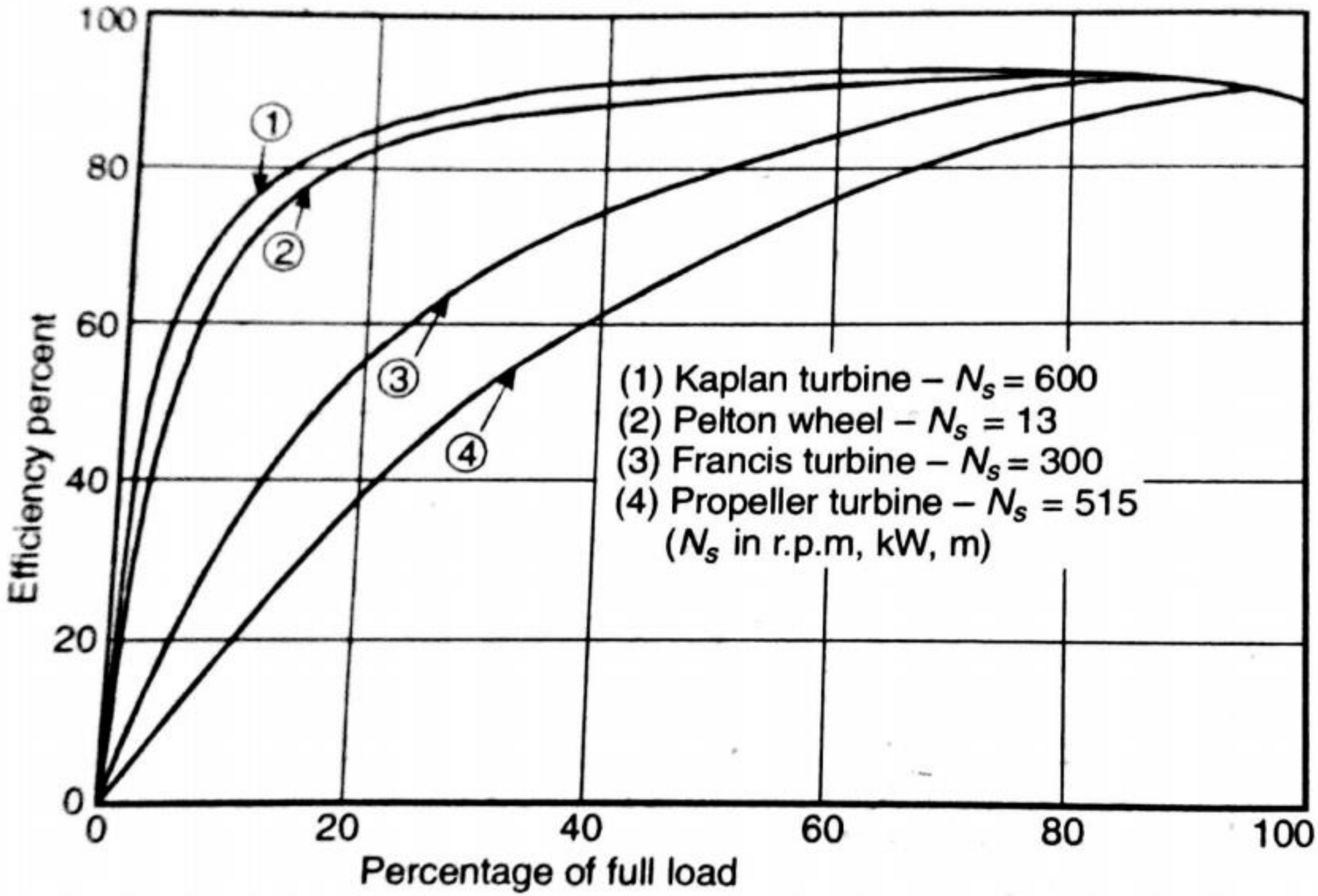
For Reaction turbines



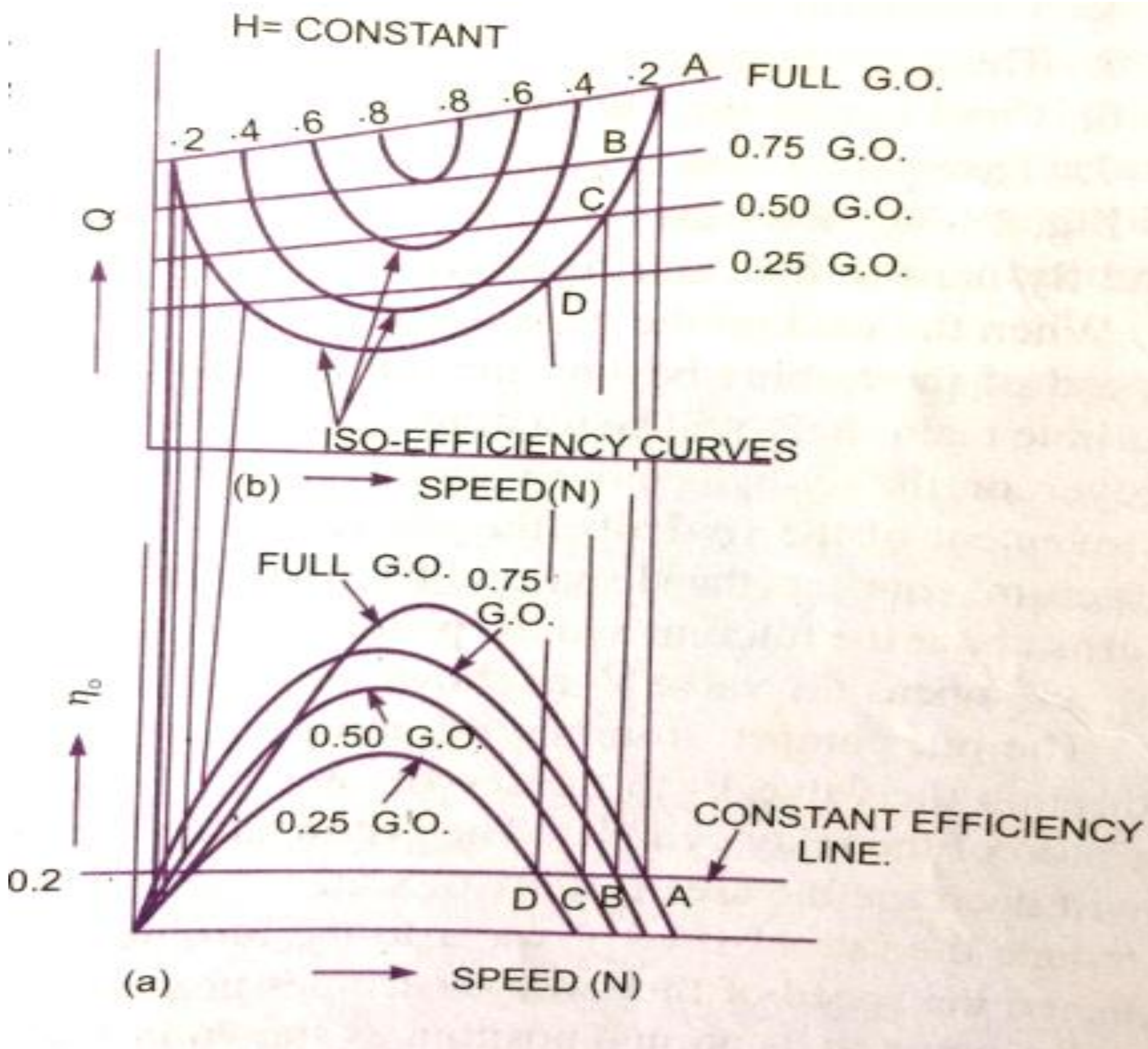


(b) For reaction turbine


η
Output power
η
Output power
Q_o
Discharge Q


100
80
60
40
20
0
Efficiency percent
0
20
40
60
80
100
Percentage of full load
1
2
3
4
(1) Kaplan turbine – N_s = 600
(2) Pelton wheel – N_s = 13
(3) Francis turbine – N_s = 300
(4) Propeller turbine – N_s = 515
(N_s in r.p.m, kW, m)

Constant Efficiency Curves



SIMILARITY LAW OF TURBINES

- In order to verify the design and the performance of hydro turbine it is required to be tested, under variable operating conditions.
- It is very difficult to test the performance of hydro turbine prototype in laboratory, so the concept of model testing i.e. of reduced sized machine is applied.
- Under this concept the results of performance available can be applied to know or to determine the performance of other machine (prototype). The mathematics applied is called the geometrical analysis by considering the law of similarly.
- According to law of similarity results for performance of a tested machine (model) can be applied or can be considered similar for machine (prototype), provided the machines are geometrically similar, kinematically similar and dynamically similar.

GEOMETRICAL SIMILARITY

- It implies that the model must be similar to the prototype turbine i.e. all the linear dimensions of two machines compared are proportional and angles between the corresponding elements are equal.

- Taking runner exit and entrance diameters to be proportional, the geometrical similarity implies,

$$\left(\frac{D_2}{D_1}\right)_m = \left(\frac{D_2}{D_1}\right)_p$$

KINEMATIC SIMILARITY

$$\frac{V_m}{U_m} = \frac{V_p}{U_p} = \text{constant}$$

For Pelton turbine it is modified as given below

$$Q = \frac{\pi}{4} d^2 v \qquad m = \frac{D}{d}, \qquad d^2 = \frac{D^2}{m^2}$$

$$Q = \frac{\pi}{4} \cdot \frac{D^2}{m^2} v$$

$$Q \,\alpha\, D^2 v$$

$$v \,\alpha\, \frac{Q}{D^2}$$

$$U = \frac{\pi D N}{60}$$

$$U \,\alpha\, ND$$

From (2.1) and (2.2)

$$\boxed{\frac{Q_m}{N_m D_m^3} = \frac{Q_p}{N_p D_p^3} = \text{constant}}$$

For Francis turbine;

$$Q = \pi D B v \qquad \left(\frac{B}{D} = k, \; B = kD \right)$$

$$Q = \pi k D^2 v$$

$$Q \,\alpha D^2 v$$

from (2.2) and (2.3)

$$\boxed{\frac{Q_m}{N_m D_m^3} = \frac{Q_p}{N_p D_p^3} = \text{constant}}$$

Similarly for Axial flow turbine it is represented as;

$$Q = \frac{\pi}{4}\left(D^2 - d^2\right)v \qquad \left(k = \frac{d}{D}\right)$$

$$Q = \frac{\pi}{4} D^2\left(1 - k^2\right)v$$

$$Q \;\alpha\; D^2 v$$

from (2.2) and (2.6)

$$\boxed{\frac{Q_m}{N_m D_m^3} = \frac{Q_p}{N_p D_p^3} = \text{constant}}$$

where, D is Outer runner diameter and

DYNAMIC SIMILARITY

It means the proportionality of forces acting on the streamlined elements of turbine passage. Mathematically we can derive the conditions as follows:

$$F \alpha \rho u^2 A \tag{2.8}$$

$$F \alpha p A \tag{2.9}$$

where,

P is pressure (ρgH)

ρ is the density and

h is the head

from (2.8) by (2.9)

$$\boxed{\frac{H_m}{D_m^2 \; N_m^2} = \frac{H_p}{D_p^2 \; N_p^2} = \text{constant}}$$

SELECTION OF HYDRO TURBINES

SPECIFIC SPEED FOR VARIOUS TYPES OF TURBINES

Types of Runner	N_s
Pelton	12 – 30
Turgo	20 – 70
Crossflow	20 – 80
Francis	80 – 400
Propeller and Kaplan	340 – 1000

Specific speed, $$\boxed{N_s = \frac{N\sqrt{P}}{H^{1.25}}}$$

Where, N – Turbine, RPM

P – Rated Power, kW

H – Head, m

FACTORS TO BE CONSIDERED IN SELECTION

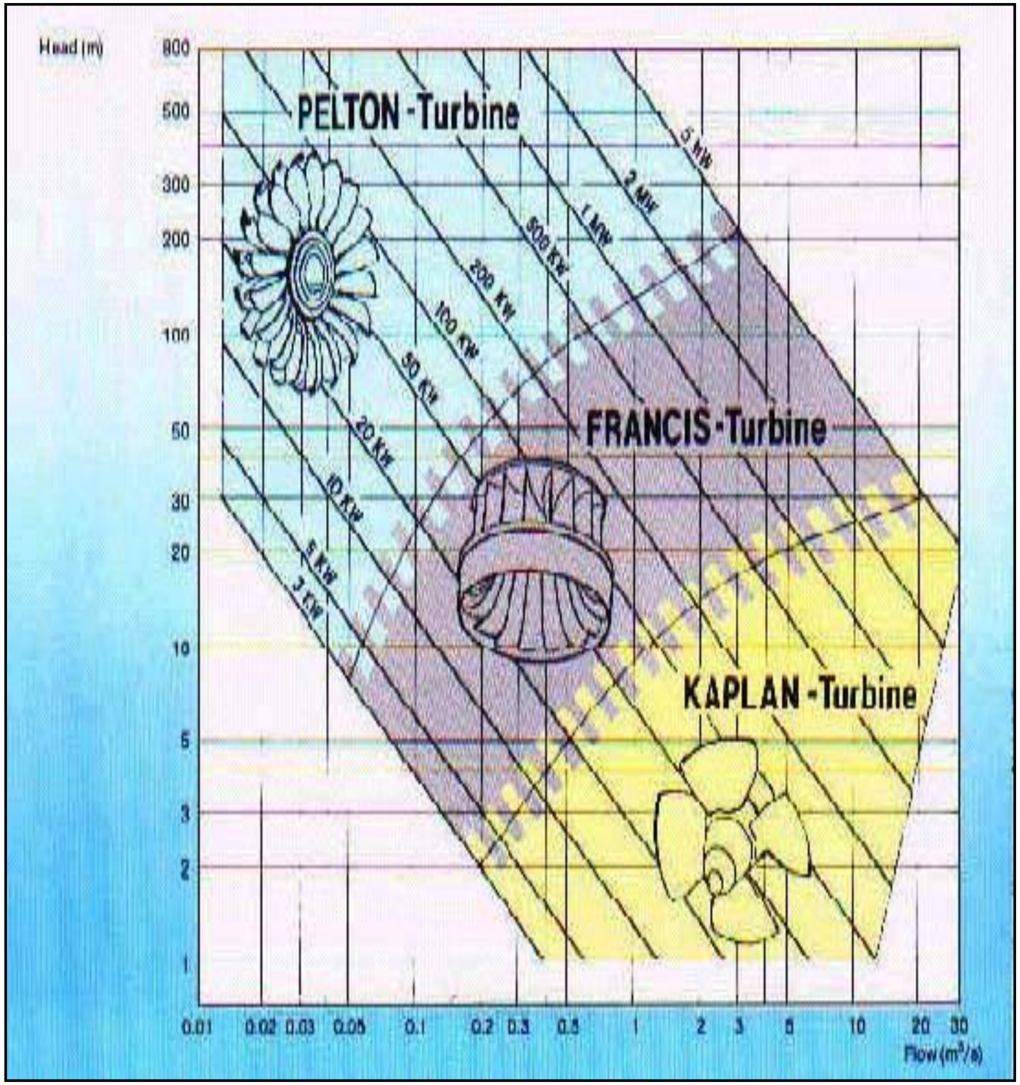
- The size of machine and hence its cost increases with increase in specific speed.
- The runner with high specific speed are more prone to cavitation and hence excavation cost for cavitation prevention will increase with specific speed.
- The part load efficiency of a turbine decreases with increase in specific speed. However, when double regulation of speed (as is done in case of Kaplan turbines), part load efficiency is nearby as good as that of Pelton wheel. This improvement in part load efficiency is obviously costly.

FACTORS GOVERNING THE SELECTION OF TURBINE

i. Head and discharge
ii. Specific speed
iii. Variation of head
iv. Maximum efficiency
v. Part load efficiency
vi. Initial cost of civil works
vii No. of units
viii. Running and maintenance cost
ix. Cavitation characteristics
x. Transporting limitations

Head & Discharge

- ***Head and discharge***
- *Specific speed*
- *Variation of head*
- *Maximum efficiency*
- *Part load efficiency*
- *Initial cost of civil work*
- *Number of units*
- *Cavitation characteristics*
- *Running & maintenance cost*
- *Transportation limitation*



HYDRO GENERATORS

TYPES OF GENERATOR

- Induction Generator
  - Grid Dependent
  - Low Cost
  - Lower Efficiency
  - Simpler Controls
- Synchronous Generator
  - Universal Application,
  - Stand alone
  - Higher efficiency
  - Higher Cost

SYNCHRONOUS MACHINES

- *Synchronous generators* or *alternators* are mostly used to convert mechanical power derived from hydraulic-turbine to ac electric power

CONSTRUCTION

- Basic parts of a synchronous generator:

- Rotor - dc excited winding
- Stator - 3-phase winding in which the ac emf is generated

- The manner in which the active parts of a synchronous machine are cooled determines its overall physical size and structure

OPERATION PRINCIPLE

The rotor of the generator is driven by a prime-mover

↓

A dc current is flowing in the rotor winding which produces a rotating magnetic field within the machine

↓

The rotating magnetic field induces a three-phase voltage in the stator winding of the generator

ELECTRICAL FREQUENCY

Electrical frequency produced is locked or synchronized to the mechanical speed of rotation of a synchronous generator:

$$f_e = \frac{P\,n_m}{120}$$

where f_e = electrical frequency in Hz

P = number of poles

n_m= mechanical speed of the rotor, in r/min

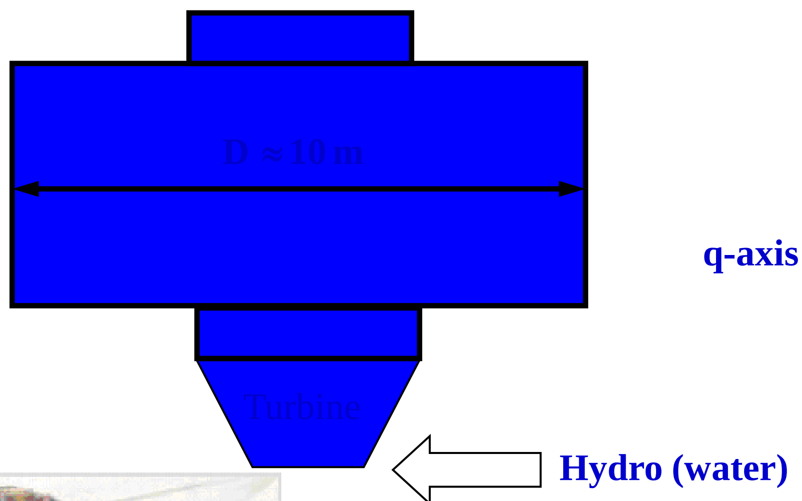
VARIOUS TYPES

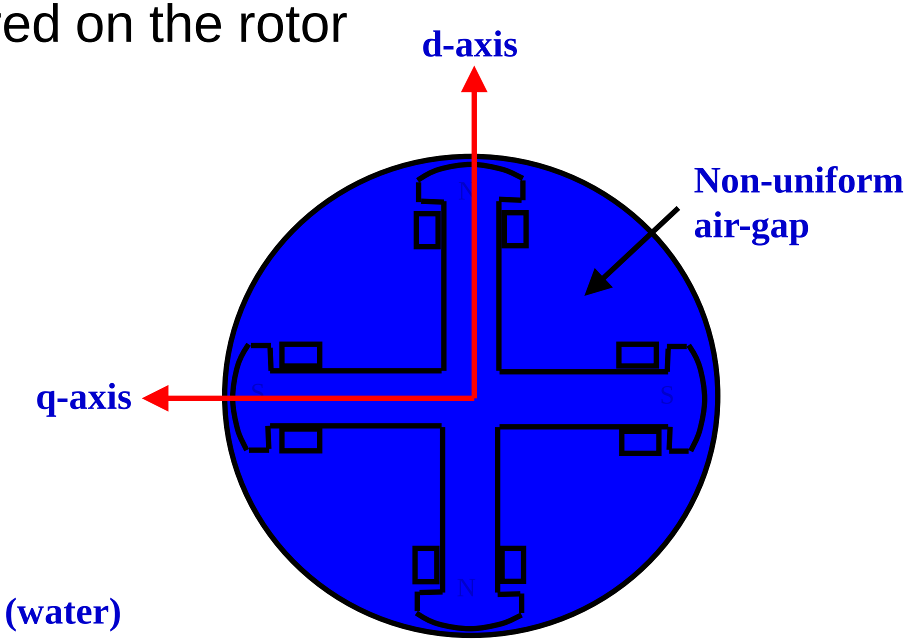
- Salient-pole synchronous machine
- Cylindrical or round-rotor synchronous machine

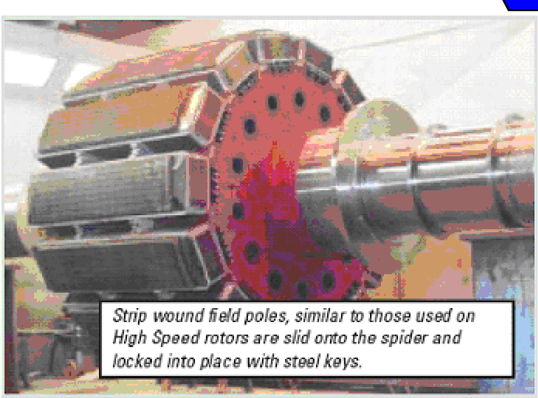
SALIENT-POLE SYNCHRONOUS GENERATOR

1. Most hydraulic turbines have to turn at low speeds (between 50 and 300 r/min)

2. A large number of poles are required on the rotor

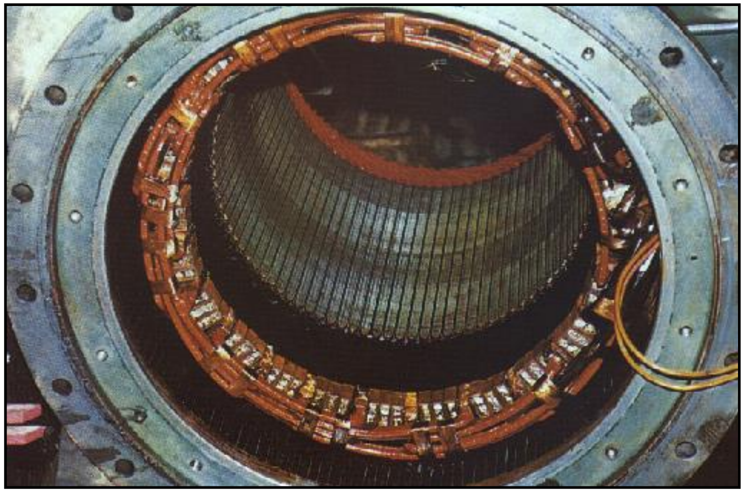




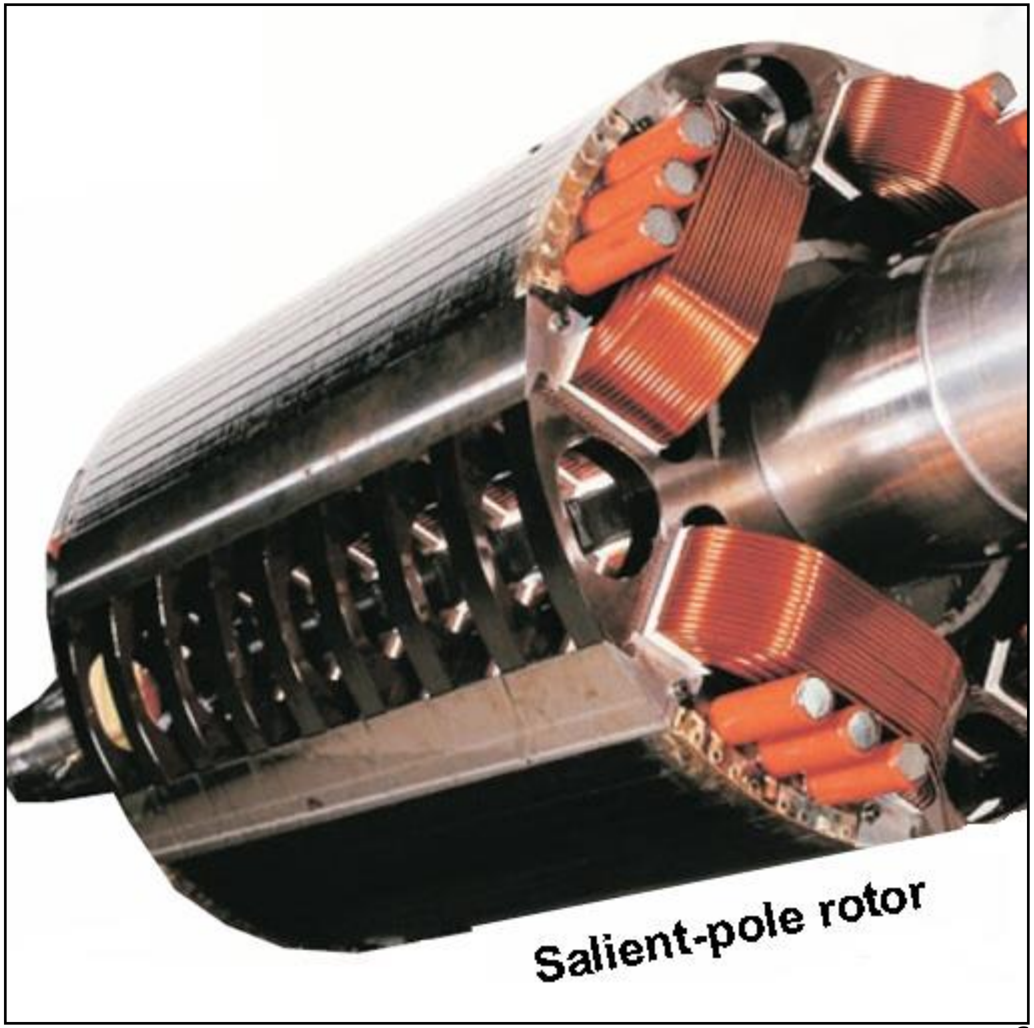


Hydro generator

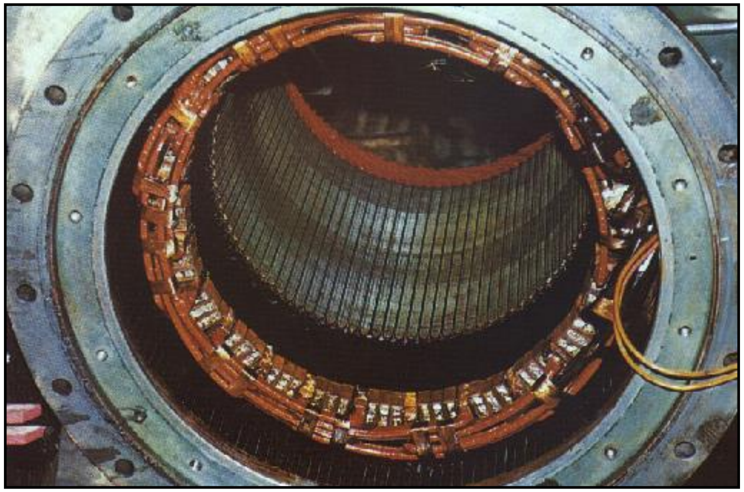
SALIENT-POLE SYNCHRONOUS GENERATOR



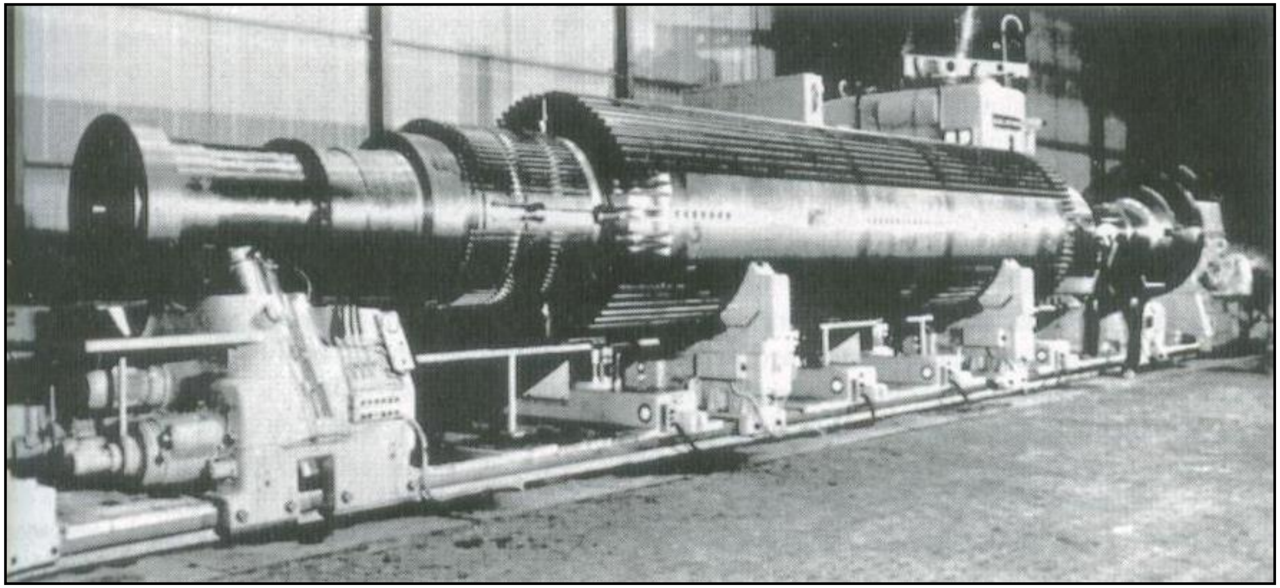
Stator



CYLINDRICAL-ROTOR SYNCHRONOUS GENERATOR



Stator



Cylindrical rotor

SAARC ENERGY CENTRE
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Online training of SAARC Professionals on Small, Mini and Micro Hydro Power Generation (Sept 13 - 17, 2021)

Thank you