Lecture on

Pelton Turbine

by

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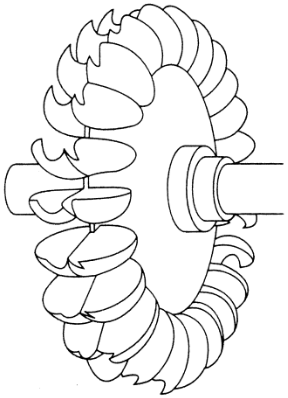
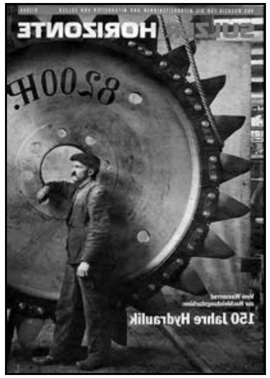
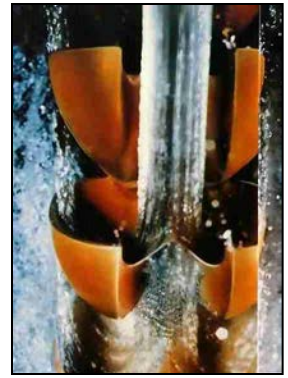
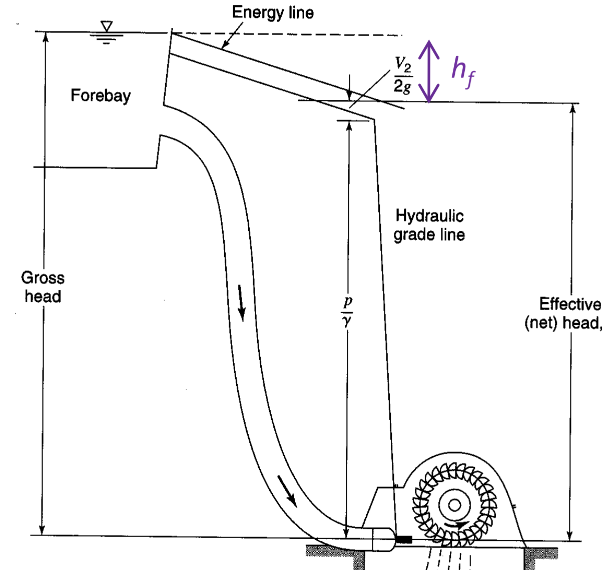
   



Turbines:
Pelton wheel
(1889)

Available power is γ(Q)H

Available power is γ(Q-q)H

Bucket power is γ(Q-q)Hr

Shaft Power

Flow Q

Head H

Turbine

Q_a=Q-q, H

Q-q, H_r=H- Δh

Leakage q

Head losses in runner Δh

Mechanical losses , friction

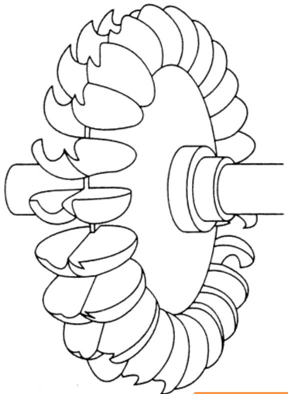
$\eta_v = Q_a/Q$ ≈ 0.97-0.99

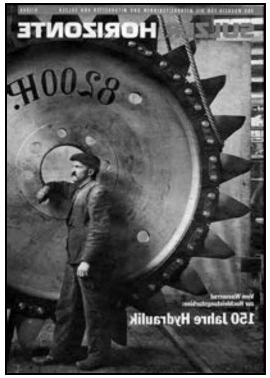
$\eta_h = H_r/H = \rho Q_a(V_{w1}+V_{w2})/(\gamma Q_a H)$

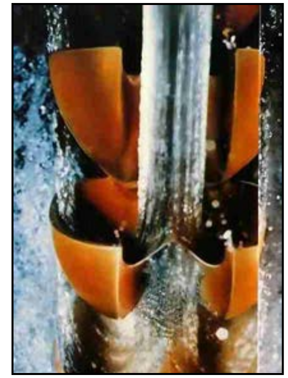
$\eta_m = P/(\gamma Q_a H_r)$

$$\eta_v = \frac{\text{volume of water actually striking the runner}}{\text{volume of water supplied to the turbine}} \quad \eta_h = \frac{\text{power delivered to runner}}{\text{power supplied at inlet}} \quad \eta_m = \frac{\text{power at shaft of turbine}}{\text{power delivered to runner}}$$

$$\eta o = \frac{\text{volume available at the shaft of the turbine}}{\text{power supplied at the inlet of the turbine}} = \eta_v \times \eta_h \times \eta_m = \frac{Q_a}{Q} \times \frac{H_r}{H} \times \frac{P}{\rho g Q_a H_r} = \frac{P}{\rho g Q H}$$







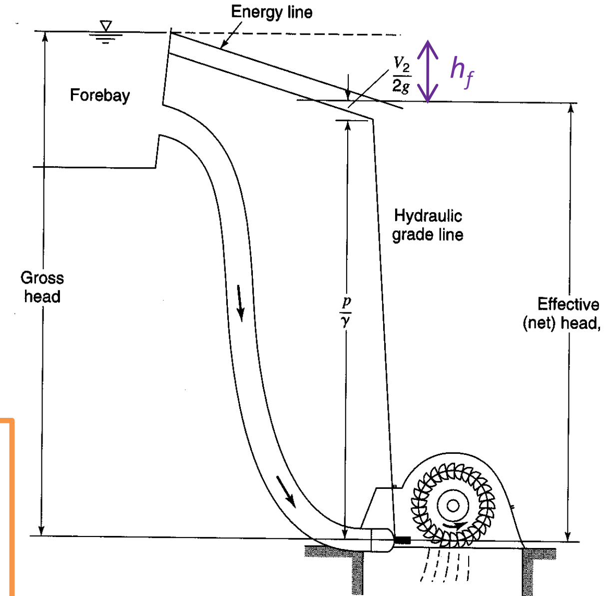
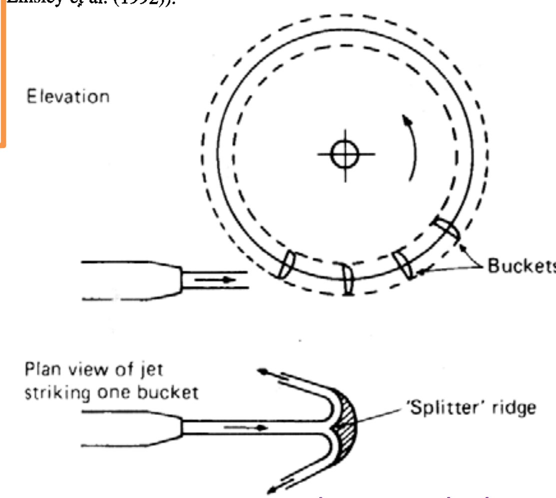
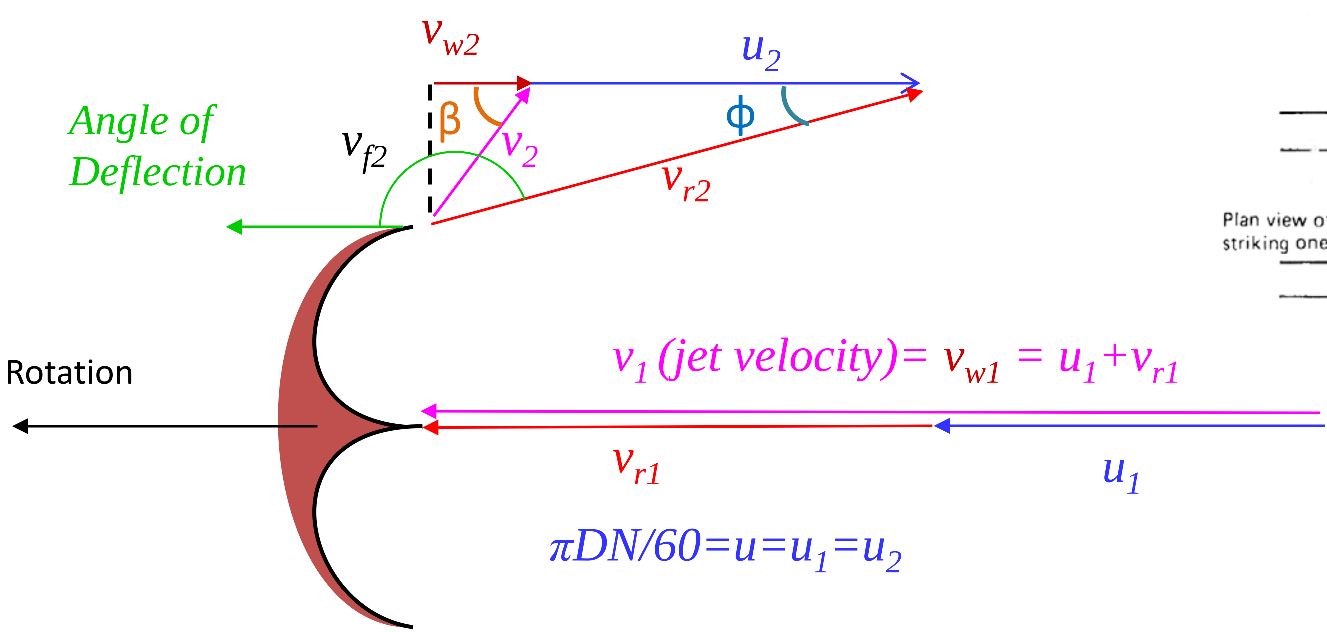


Figure 13.2.4 Definition sketch for impulse-turbine installation (from Linsley et al. (1992)).

Turbines: Pelton wheel (1889)

v_1 = velocity of jet at inlet
u_1 = velocity of the vane/bucket at inlet
v_{r1} = relative velocity of jet at inlet
α = angle between the direction of the jet and the direction of motion of the vane, guide blade angle (Here in this figure it is zero)
θ = angle made by v_{r1} with direction of motion of vane at inlet, vane angle at inlet (=0)
v_{w2} = velocity of whirl at outlet
v_{f2} = velocity of flow at outlet
β = angle between v_2 with the direction of motion of vane at outlet
ϕ = angle made by v_{r2} with direction of motion of vane at outlet, vane angle at outlet





Net Head $H = H_g - h_f - h_p$
$h_f = 4fLV^2/(d^* \times 2g)$
Height of nozzle above tail race level is h_p
d^* = diameter of penstock
D = diameter of wheel

See force on curve plate when plate is moving in the direction of jet

Let V = Absolute velocity of jet,

a = Area of jet,

u = Velocity of the plate in the direction of the jet.

V_r= Relative velocity of the jet of water or the velocity with which jet strikes the curved plate = $(V - u)$.

If plate is smooth and the loss of energy due to impact of jet is zero, then the velocity with which the jet will be leaving the curved vane = $(V - u)$.

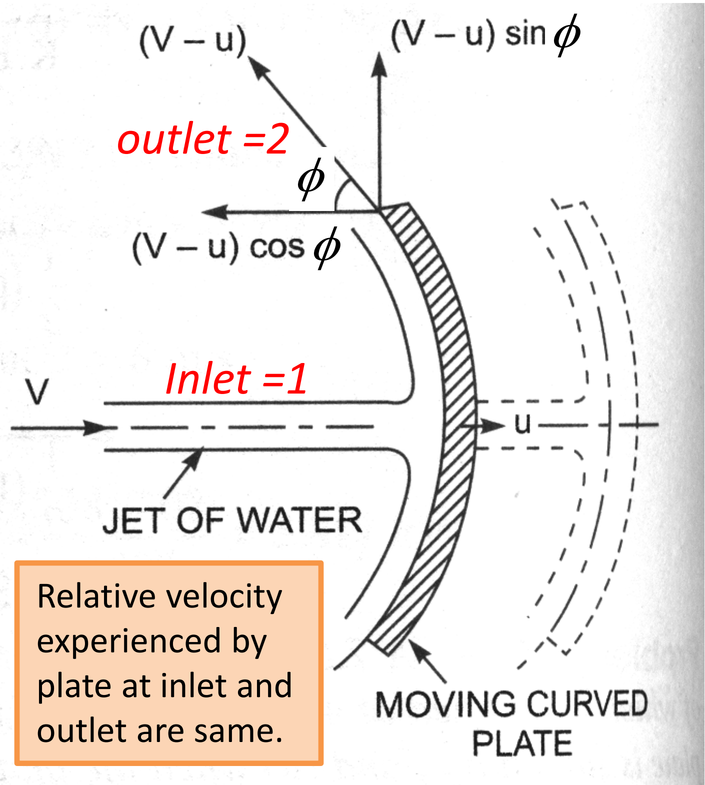
This velocity can be resolved into two components, one in the direction of the jet and other perpendicular to the direction of the jet.

Component of the velocity in the direction of jet

$$= -(V - u)\cos\phi$$

(–ve sign is taken as at the outlet, the component is in the opposite direction of the jet).

Component of the velocity in the direction perpendicular to the direction of the jet = $(V - u)\sin\phi$.



Jet striking a curved moving plate.

for pelton wheel... *

$$F_x = \rho a V\left[(V-u) + (V-u)\cos\phi\right] = \rho a V (V-u)\left[1+\cos\phi\right]$$

Turbines: Power conversion

$$P = \eta_o Q \rho g h \quad \Rightarrow \quad P = T\omega \quad \Leftarrow \quad T = Fr \quad \Leftarrow \quad F = \Delta M = \dot{m}\Delta v = \rho Q \Delta v$$

See force on curve plate when plate is moving in the direction of jet

per sec…

Mass of the water striking the plate = $\rho \times a \times$ Velocity with which jet strikes the plate $\quad \dot{M} = \rho Q$

$= \rho a(V - u)$ For general case, but for pelton wheel… *

$\therefore$ Force exerted by the jet of water on the curved plate in the direction of the jet,

F_x = Mass striking per sec × [Initial velocity with which jet strikes the plate in the direction of jet − Final velocity]

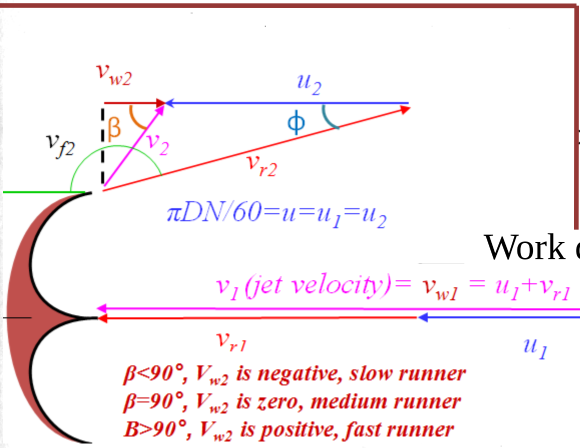
$$= \rho a(V-u)\,[(V-u) - (-(V-u)\cos\phi)]$$

$$= \rho a(V-u)\,[(V-u) + (V-u)\cos\phi]$$

$$= \rho a(V-u)^2\,[1+\cos\phi]$$

For pelton wheel

$$Fx = \rho a(V)_1\left[(V-u)_1 + (V-u)_2\cos\phi\right]$$



Work done by the jet on plate per second

$= F_x \times$ Distance travelled per second in the direction of x

$$= F_x \times u = \rho a(V-u)^2\,[1+\cos\phi] \times u$$

$$= \rho a(V-u)^2 \times u\,[1+\cos\phi]$$

In connection to the fig of pelton bucket and velocity triangle,

$V_1 - u_1 = V_{r1}$, $\quad Vw_2 = Vr_2\cos\phi - u_2$

v_1 (jet velocity)= $v_{w1} = u_1 + v_{r1}$

* Where water coming out of the nozzle is always in contact with the blade/bucket/plate, if all plates are considered. Hence mass of water striking the plate is **ρaV**.

$$Fx = \rho a V_1\left[(V-u)_1 + (V-u)_2\cos\phi\right] = \rho a V_1\left[Vr_1 + Vr_2\cos\phi\right] = \rho a V_1\left[(Vw_1 - u_1) + (Vw_2 + u_2)\right]$$

$$Fx = \rho a V_1\left[(Vw_1 + Vw_2)\right]$$ As $u_1 = u_2$

From velocity triangle: $Vw_2 = Vr_2 \cos\phi - u_2$

Force exerted by water by the jet of water in the direction of motion: $Fx = \rho a V_1 (Vw_1 + Vw_2)$

(since β is acute angle, + sign), a=area of jet

Work done by the jet on the runner per second = $Fx \times u = \rho a V_1 (Vw_1 + Vw_2) u$ Nm/s

Power given by the jet = $Fx \times u = \rho a v_1 (Vw_1 + Vw_2) u / 1000$ kW

Work done per unit weight of water striking = $\dfrac{\rho a V_1 (Vw_1 + Vw_2) u}{\rho a V_1 g} = \dfrac{1}{g}(Vw_1 + Vw_2) u$

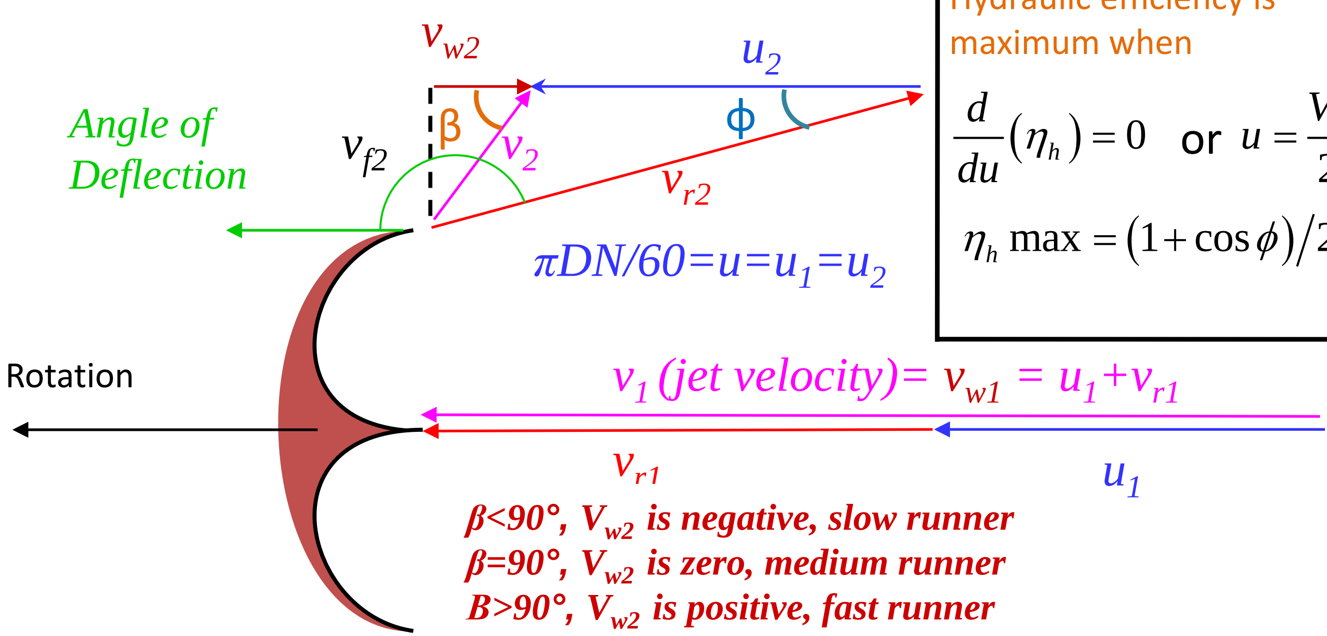
Energy supplied by the jet at inlet in the form of K.E. = *1/2mV²*

Friction factor K = Vr_2/Vr_1

$$\eta_h = 2(\rho' - \rho'^2)(1 + K\cos\phi)$$

K.E. of jet per second = $\dfrac{1}{2}(\rho a V_1) V_1^2 = \dfrac{1}{2}(\rho Q) V_1^2$

Hydraulic efficiency = $\eta_h = \dfrac{\rho a V_1 (Vw_1 + Vw_2) u}{1/2(\rho Q) V_1^2} = \dfrac{2(Vw_1 + Vw_2) u}{V_1^2} = \dfrac{2(V_1 - u)[1 + \cos\phi] u}{V_1^2}$

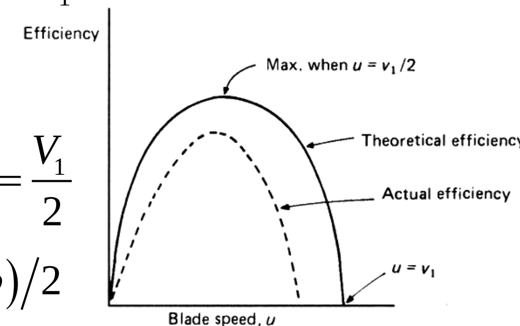


β<90°, V_{w2} is negative, slow runner
β=90°, V_{w2} is zero, medium runner
B>90°, V_{w2} is positive, fast runner

Hydraulic efficiency is maximum when

$$\frac{d}{du}(\eta_h) = 0 \quad \text{or} \quad u = \frac{V_1}{2}$$

$$\eta_h \max = (1 + \cos\phi)/2$$

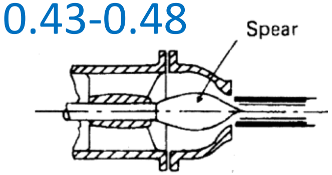


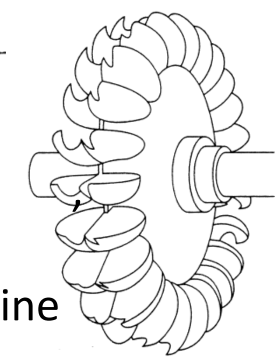
$\rho' = u/V_1$

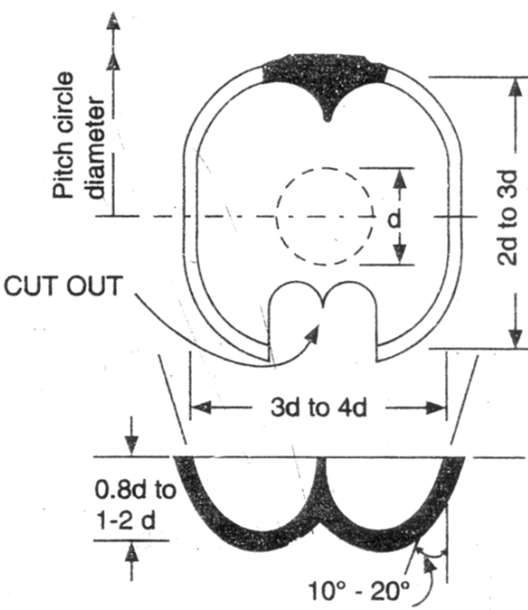
Net Head H = Hg-h_f
h_f=4fLV²/(d*×2g)
d* = diameter of penstock
D = diameter of wheel

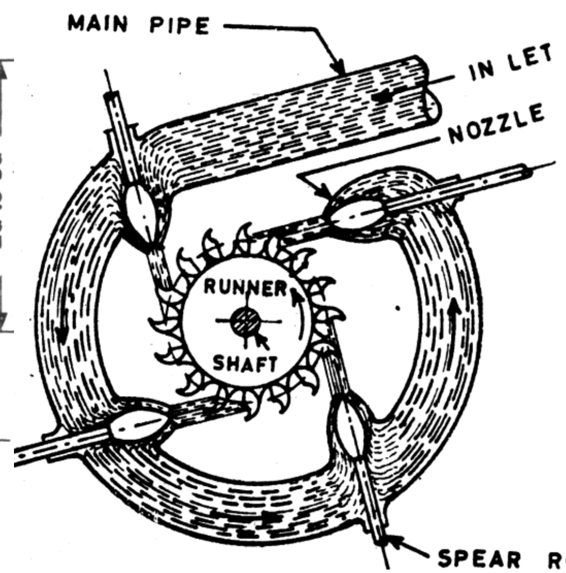
Design of Pelton Wheel

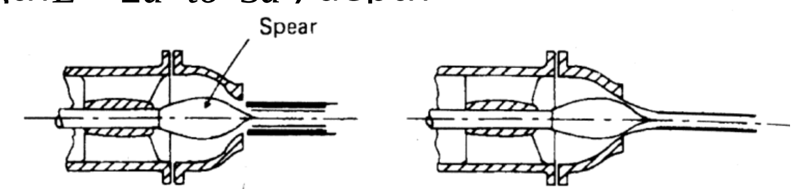
1. **Velocity of jet** at inlet $V_1 = C_v\sqrt{2gH}$ where Cv = coefficient of velocity = 0.98-0.99
2. **Velocity of wheel** $u = \phi\sqrt{2gH}$ where ϕ is the speed ratio = 0.43-0.48
3. **Angle of deflection** is 165° unless mentioned.
4. **Pitch or mean diameter** D can be expressed by $u = \pi DN/60$
5. **Jet ratio** $m = D/d$ (12 in most cases/calculate), d = nozzle diameter
6. **Number of bucket** on a runner $Z = 15 + D/2d$ (Tygun formula) or $Z = 5.4\sqrt{m}$
   m=6 to 35
7. **Number of Jets** = obtained by dividing the total rate of flow through the turbine by the rate of flow through single jet
8. **Size of Bucket**: Axial Width $B = 3d \ \ to \ \ 4d$, radial length $L = 2d \ \ to \ \ 3d$, depth $T = 0.8d \ \ to \ \ 1.2d$



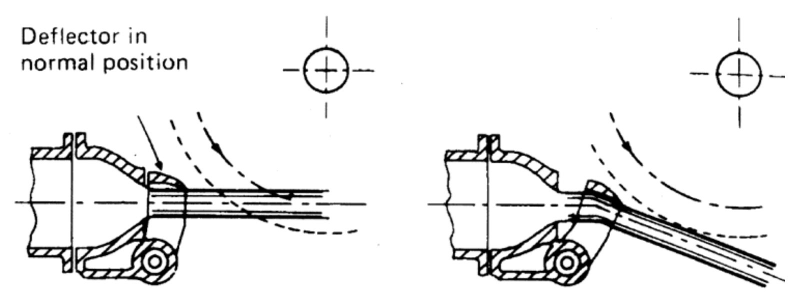






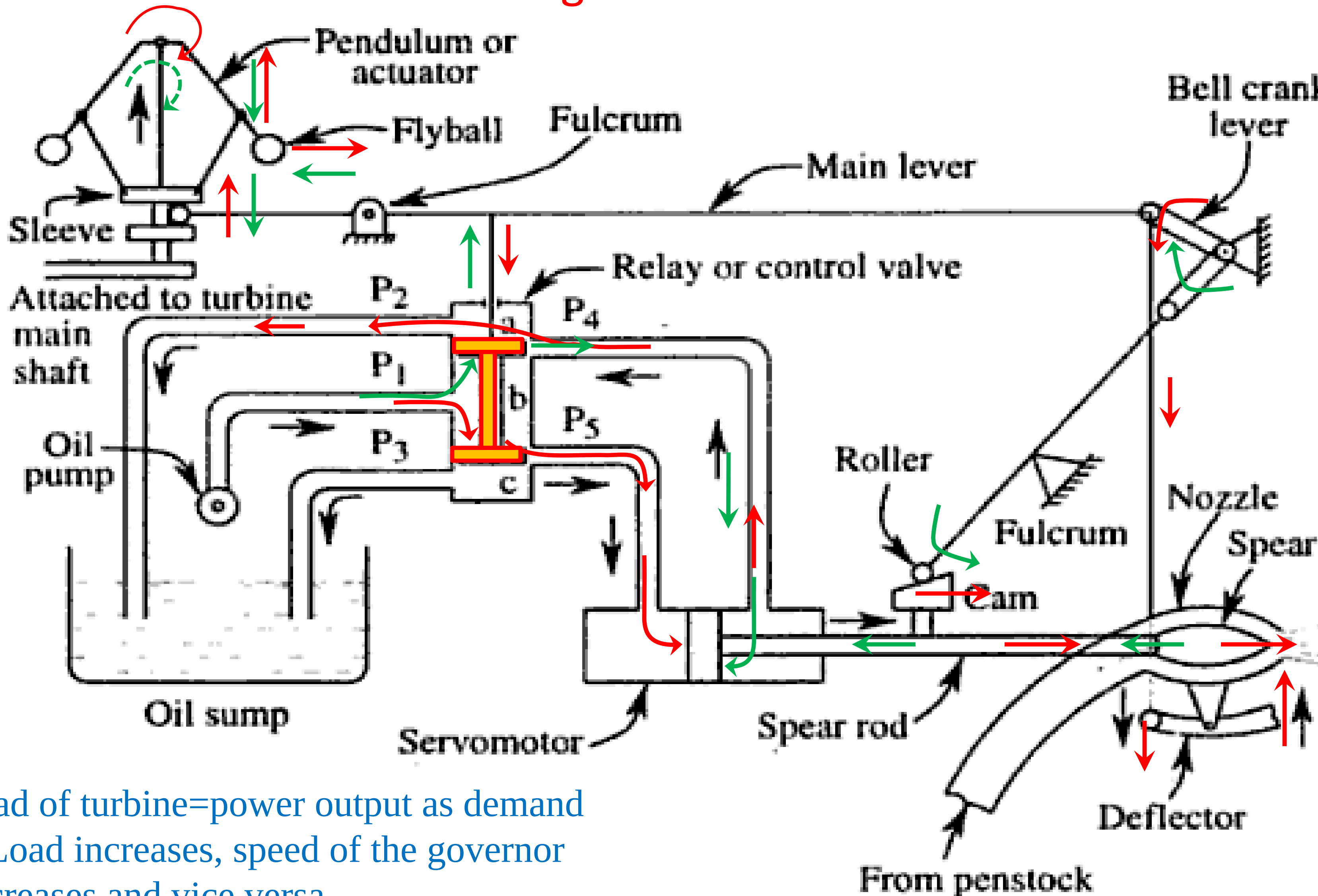


(a) Spear valve to alter jet diameter



(b) Jet deflected from buckets

Governing of Pelton Turbine



Load of turbine=power output as demand
If Load increases, speed of the governor decreases and vice versa