Statics

Chapter Four

Impulse turbines-Pelton wheel

By

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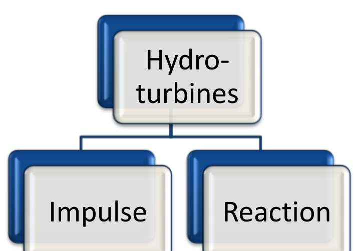
Impulse turbines-Pelton wheel

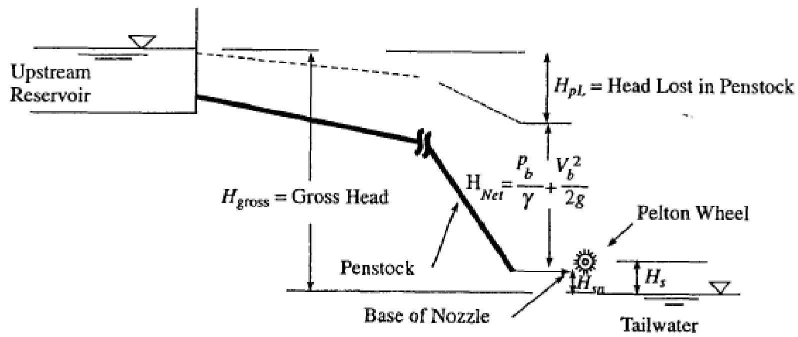


- Energy extracted at the atmospheric pressure
- Pelton wheel is an example.

- Energy extracted due to diffrence in pressure
- Frances turbine is an example.

Impulse turbines-Pelton wheel

System description



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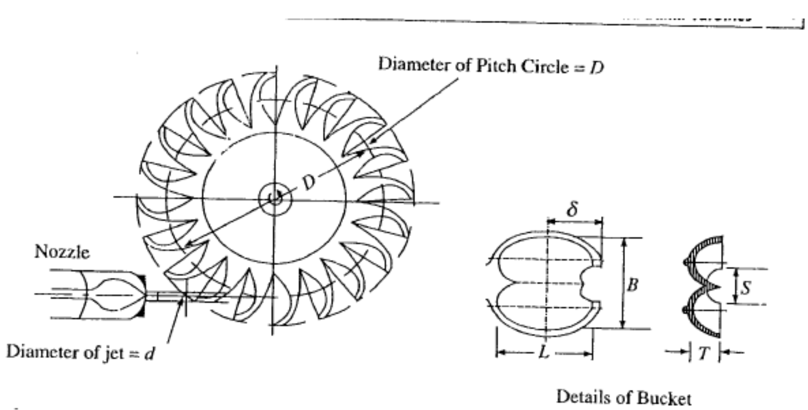
System description



Impulse turbines-Pelton wheel

Theoretical analysis

net head $= H = H_{\text{gross}} - H_{\text{pL}} - H_{\text{sn}}$

where H_{gross} = Gross head = Difference in water surface elevation of upstream reservoir and tailwater level.

H_{pL} = Head loss in the penstock

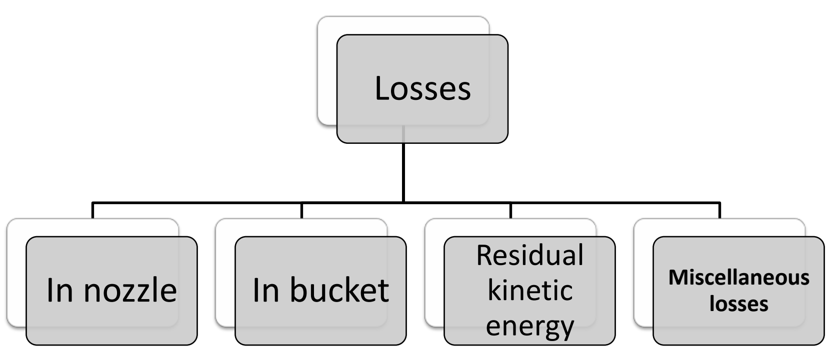
H_{sn} = Height of the lowest nozzle above the tailwater level

Also, $$H = \frac{p_b}{\gamma} + \frac{V_b^2}{2g}$$

where $\frac{p_b}{\gamma}$ = Pressure head at the base of the nozzle and $\frac{V_b^2}{2g}$ = Velocity head at the base of the nozzle.

Impulse turbines-Pelton wheel

Kinetic energy of jet



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Losses in nozzle

$$H_{Ln} = \left(\frac{1}{C_v^2} - 1\right)\left(1 - \left(\frac{A_1}{A_b}\right)^2\right)\frac{V_1^2}{2g}$$

where A_b = Cross-sectional area at the base of the nozzle, and

A_1 = Cross-sectional area of the jet.

C_v is the velocity coefficient of the nozzle

Losses in bucket

$$H_{Lb} = \frac{v_{r1}^2}{2g} - \frac{v_{r2}^2}{2g} = (1 - K^2)\frac{v_{r1}^2}{2g}$$

$K = \frac{v_{r2}}{v_{r1}}$. *bucket friction coefficient*

Impulse turbines-Pelton wheel

Residual kinetic energy losses, H_{Le}

$$H_{Le} = \frac{V_2^2}{2g}$$

V_2 is the absolute velocity of water leaving the bucket.

Net head, H

Net head (H) = Energy transmitted to the turbine (H_e) + Losses in [nozzle (H_{Ln})+ buckets (H_{Lb})] + Energy going waste to tailwater (H_{Le})

$$H = H_e + [H_{Ln} + H_{Lb} + H_{Le}]$$

$$= H_e + H_{Lke}$$

where H_{Lke} = Total loss of kinetic energy in the nozzle - bucket system

Impulse turbines-Pelton wheel

Overall power,P

The *shaft power P* developed by the interaction of a jet with the buckets in the Pelton wheel is given by

$$P = \eta_0 \gamma Q H$$

where η_0 is the overall efficiency, H = Net head, and Q = Discharge through the nozzle.

Impulse turbines-Pelton wheel

Speed Ratio, Ku

$$\text{Speed ratio} = K_u = \frac{u}{\sqrt{2gH}}$$

0.43 < Ku< 0.47

Specific speed,Ns

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

- N: Peripheral speed of the wheel in rpm
- P: Brake power in kW developed per jet
- H: Net head in metres

8< Ns< 30

Impulse turbines-Pelton wheel

Specific speed,Ns

Table 4.1 *Specific speeds of different kinds of turbines*

Type of turbine	Specific-speed range (N_s in kW- rpm-m units)
Pelton (Single jet or for each jet in a multijet unit; maximum of six jets)	8–30 (on power per jet basis)
Francis	40–450
Kaplan	300–900

Rotational speed,N

$$u = \frac{\pi DN}{60} \text{ and hence}$$

$$N = \frac{60u}{\pi D} = \frac{60 \times K_u \sqrt{2gH}}{\pi} \times \frac{1}{D}$$

Impulse turbines-Pelton wheel

Specific Speed in Terms of Defined Ratios

Specific speed $N_s = \frac{N\sqrt{P}}{H^{5/4}}$ where P is the power per jet.

Speed of rotation $N = \frac{60 \times u}{\pi D} = \frac{60 \times K_u \sqrt{2gH}}{\pi D}$ (4.15)

Considering the power per jet, $P = \eta_0\, \gamma\, QH = \eta_0\, \gamma \times \left(\frac{\pi d^2}{4}\right) \times V_1 H$

$$= \eta_0\, \gamma \times \left(\frac{\pi d^2}{4}\right) \times H \times C_v \sqrt{2gH} \quad (4.16)$$

Substituting Eq. (4.15) and Eq.(4.16) in the expression for the specific speed,

$$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{1}{H^{5/4}} \times \frac{60 \times K_u \sqrt{2gH}}{\pi D} \times \sqrt{\left[\eta_0 \gamma \left(\frac{\pi}{4}\right) d^2 \times H \times C_v \sqrt{2gH}\right]}$$

$$N_s = \frac{60 \times (\gamma)^{1/2} \left(\frac{\pi}{4}\right)^{1/2}}{\pi} \times K_u \sqrt{C_v} \times \left(\frac{d}{D}\right) \times (2g)^{3/4} \times (\eta_0)^{1/2}$$

$$N_s = \frac{60}{\sqrt{\pi}} \times \frac{1}{2} \times (\gamma)^{1/2} (\eta_0)^{1/2} (2g)^{3/4} K_u \sqrt{C_v} \times \left(\frac{d}{D}\right) \quad (4.17)$$

Substituting $\gamma = 9.79$ m^3/s and $g = 9.81$ m/s^2,

$$N_s = 493.7 K_u \left(\frac{d}{D}\right) \sqrt{\eta_0 C_v}$$ This could be written as $N_s = \frac{K_1}{\left(\frac{D}{d}\right)}$

Impulse turbines-Pelton wheel

Coefficient of Velocity of the Nozzle, Cv

$$C_v = \frac{V_1}{\sqrt{2gH}}$$

$$V_1 = C_v\sqrt{2gH}$$

$$Q = \left(\frac{\pi}{4}d^2\right)V_1 = \left(\frac{\pi}{4}d^2\right)C_v\sqrt{2gH}$$

0.98< Cv< 0.99

Also

$$\frac{K_u}{C_v} = \frac{u}{V_1}$$

Jet Ratio, m

$$\text{Jet ratio} = m = \frac{D}{d}$$

D: pitch diameter of the runner

d: diameter of the jet

7< m< 26

Impulse turbines-Pelton wheel

4.2.2Basic theory of Pelton Wheel

1. Notations

The following notations are used in the derivation of the basic equations for power and efficiency of a Pelton turbine. Some of the notations are explained once again, for purpose of clarity, in the course of the derivations that follow.

u = Peripheral velocity of the wheel

V_1 = Jet velocity = absolute velocity of jet entering the bucket

v_{r1} = Relative velocity of jet at the inlet = $(V_1 - u)$

D = Pitch diameter of the wheel

d = Diameter of the free jet

β = Bucket angle = Deflection angle of the relative velocity of the jet

β' = $(180 - \beta)$ = Supplementary angle of bucket angle β.

K = Bucket friction coefficient

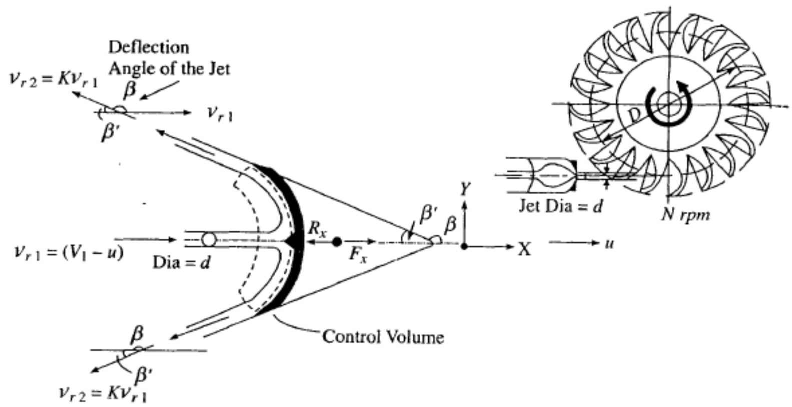
N = Speed of rotation

Q = Discharge carried by the jet

H = Net head on the turbine

Impulse turbines-Pelton wheel

4.2.2Basic theory of Pelton Wheel



Impulse turbines-Pelton wheel

Velocity triangles

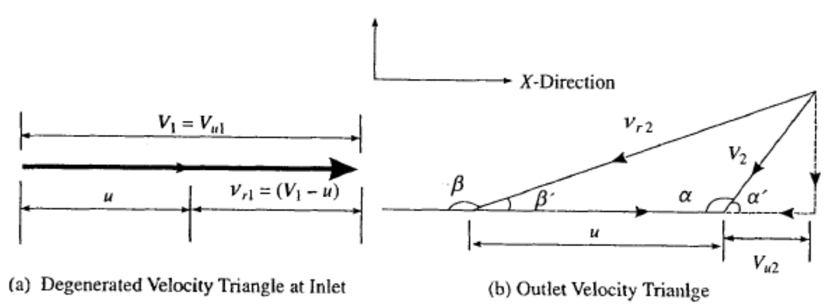


Fig. 4.4 *Velocity triangle at the inlet and outlet of a Pelton turbine*

Impulse turbines-Pelton wheel

Governing equations

Force

$$F_x = \rho Q [(v_{r1}) - (-K v_{r1} \cos \beta')]$$

$$F_x = \rho Q [(V_1 - u)(1 + K \cos \beta')]$$

Torque

$$T = F_x \frac{D}{2} = \rho Q[(V_1 - u)(1 + K \cos \beta')]\frac{D}{2}$$

Power

$$P = F_x u = \rho Q u [(V_1 - u)(1 + K \cos \beta')]$$

Head

$$H_e = \frac{P}{\gamma H} = \frac{1}{g} u [(V_1 - u)(1 + K \cos \beta')]$$

Hydraulic efficiency

$$\eta_h = \frac{H_e}{H} = \frac{u[(V_1 - u)(1 + K \cos \beta')]}{gH}$$

Impulse turbines-Pelton wheel

Other equations

$$H_e = \frac{(V_{u1} + V_{u2})u}{g} = \frac{[V_1 + K(V_1 - u)\cos \beta' - u]u}{g}$$

$$H_e = \frac{u[(V_1 - u)(1 + K \cos \beta')]}{g}$$

$$\eta_h = \frac{H_e}{H} = \frac{u[(V_1 - u)(1 + K \cos \beta')]}{gH}$$

Impulse turbines-Pelton wheel

Analysis of Power, Torque and Efficiency

1. Power

If η_0, η_h, η_m *and* η_v are the overall, hydraulic, mechanical and volumetric efficiencies of the turbine then they are related as

$$\eta_0 = \eta_h \, \eta_m \, \eta_v = \frac{P}{\gamma Q H}$$

$$\eta_0 = \frac{u\left[(V_1 - u)(1 + K\cos\beta')\right]}{gH} = \frac{\eta_0}{\eta_m \eta_v} = \frac{P}{\eta_m \eta_v \gamma Q H}$$

$$P = \eta_m \, \eta_v \, \rho \, Q \, u \, (V_1 - u)(1 + K\cos\beta')$$

$$P = C_1 \, u \, (V_1 - u) = P = C_2 \, \frac{u}{V_1}\left(1 - \frac{u}{V_1}\right)$$

C_1 and C_2 are constants for a given turbine unit

Impulse turbines-Pelton wheel

$\varepsilon = u/V_1$. The power is given by

$$P = C_2 \, \varepsilon \, (1 - \varepsilon)$$

maximum power $\frac{dP}{d\varepsilon} = 0$ $\qquad \frac{dP}{d\varepsilon} = C_2 \, (1 - \varepsilon) = 0$

This gives the condition for maximum power as $\varepsilon = 0.5$, that is $u = \frac{V_1}{2}$.

Substituting $u = K_u \sqrt{2gH}$ and $V_1 = C_v \sqrt{2gH}$, the condition of maximum power reduces to

$$K_u = \frac{C_v}{2} \qquad (4.28)$$

Impulse turbines-Pelton wheel

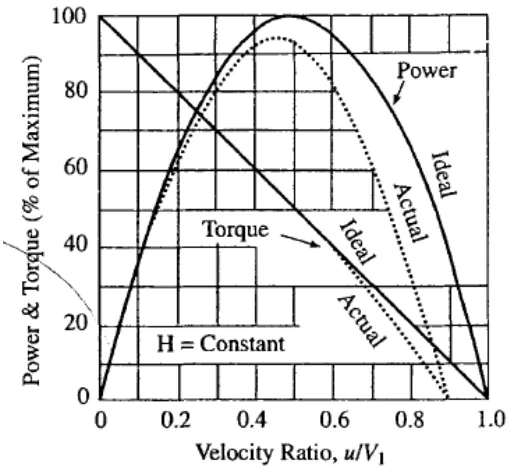


Fig. 4.5 *Variation of power and torque with speed ratio*

Impulse turbines-Pelton wheel

2. Torque

$$T = \frac{P}{\omega}$$

Since $u = \frac{\pi DN}{60}$ and angular velocity $\omega = \frac{2\pi N}{60}$ radians/second, $u = \frac{\omega D}{2}$.

$$P = \eta_m \, \eta_v \, \rho \, Q \, u \, (V_1 - u)(1 + K \cos \beta')$$

$$T = \frac{P}{\omega} = \frac{\eta_m \eta_v \, \rho \, Q \, D}{2} (V_1 - u)(1 + K \cos \beta')$$

Also, in terms of H_e,

$$T = \frac{\gamma Q H_e}{\omega} = \gamma Q H_e \left(\frac{D}{2u}\right)$$

$$= C_4 (V_1 - u)$$

Impulse turbines-Pelton wheel

Runaway Speed

$$P = \eta_m \eta_v \rho Q u (V_1 - u)(1 + K \cos \beta')$$

the power $P = 0$ when $u = 0$ and when $u = V_1$

$u = V_1$, the wheel is running at maximum velocity of $u = \frac{\pi DN}{60} = V_1$

normal wheel velocity be u_0

Under normal conditions $u_0 = K_u \sqrt{2gH}$ and $V_1 = C_v \sqrt{2gH}$.

Under runaway conditions, the theoretical runaway speed is

$$u_R = V_1 = C_v \sqrt{2gH} = \left(\frac{C_v}{K_u}\right) u_0$$

Impulse turbines-Pelton wheel

Since $u \propto N$, theoretical runaway speed in rpm is

$$N_R = \left(\frac{C_v}{K_u}\right) N_0$$

where N_0 = Normal operative speed.

3. Wheel Efficiency, η_w

$$\text{Wheel efficiency} = \eta_w = \frac{\text{Power transmitted to the wheel by the water jet}}{\text{Power input to the wheel as kinetic energy}}$$

$$\eta_w = \frac{\rho Q u \left[(V_1 - u)(1 + K \cos \beta')\right]}{\rho Q \frac{V_1^2}{2}} = 2\left(\frac{u}{V_1}\right)\left(1 - \frac{u}{V_1}\right)(1 + K \cos \beta')$$

Impulse turbines-Pelton wheel

the wheel efficiency does not include the losses in the nozzle

$$\eta_w = \frac{\eta_h}{(C_v^2)}$$

Substituting $u = \frac{V_1}{2}$ in the expression for η_w given by Eq. 4.33, the value of maximum wheel efficiency is obtained as

$$\eta_{wmax} = 2 \times \frac{1}{2} \times \frac{1}{2} \times (1 + K \cos \beta')$$

$$\eta_{wmax} = \frac{1}{2} (1 + K \cos \beta') \qquad (4.34)$$

Impulse turbines-Pelton wheel

Nozzle Efficiency

$$\text{Nozzle efficiency} = \eta_n = \frac{\text{Energy at nozzle outlet}}{\text{Energy at nozzle inlet}}$$

$$\eta_n = \frac{\left(\frac{V_1^2}{2g}\right)}{H} = \frac{V_1^2}{2gH} = \frac{(C_v^2 \times 2gH)}{2gH} = C_v^2$$

$$\eta_h = \eta_w \cdot \eta_n$$

Impulse turbines-Pelton wheel

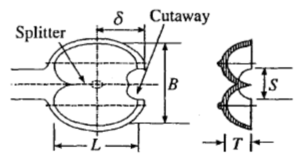
COMPONENTS OF PELTON TURBINE

1. *Wheel*

2. ***Buckets***

$$Z = \frac{m}{2} + 15$$

Table 4.2 *Basic geometrical dimensions of the Pelton bucket*



Radial length = L	Axial width = B	Depth of bucket = T	Axial width of cutaway = S	Radial length of cutaway = δ	Inlet bucket angle = β_1	Outlet bucket angle = β_2
L/d	B/d	T/d	S/d	δ/d	β_1	β_2
2.0 to 3.0	3.0 to 5.0	0.8 to 1.2	1.1 to 1.2	0.18 to 0.20	5° to 8°	165° to 170°

Impulse turbines-Pelton wheel

COMPONENTS OF PELTON TURBINE

Nozzle with Control Arrangement

1. Nozzle

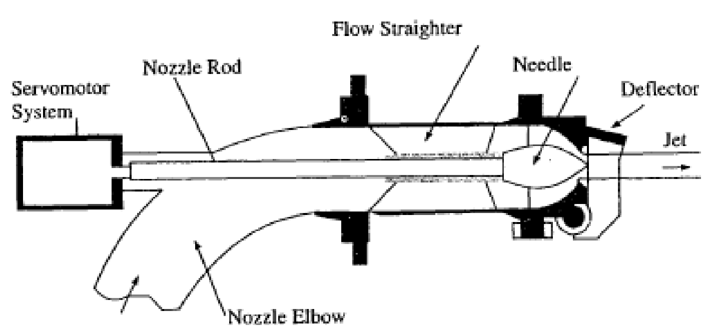


Fig. 4.6 *Typical nozzle assembly of a Pelton turbine*

Impulse turbines-Pelton wheel

COMPONENTS OF PELTON TURBINE

Nozzle with Control Arrangement

2. Deflectors

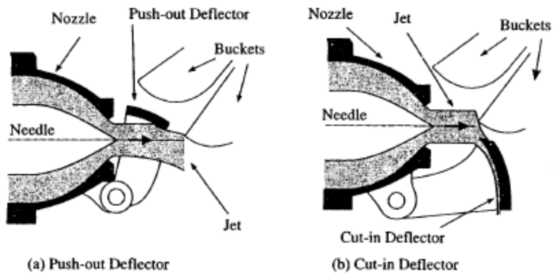


Fig. 4.7 *Deflectors: (a) Push-out deflector (b) Cut-in deflector*

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COMPONENTS OF PELTON TURBINE

Manifold, Braking Jet and Auxiliary Jet

1. Manifold

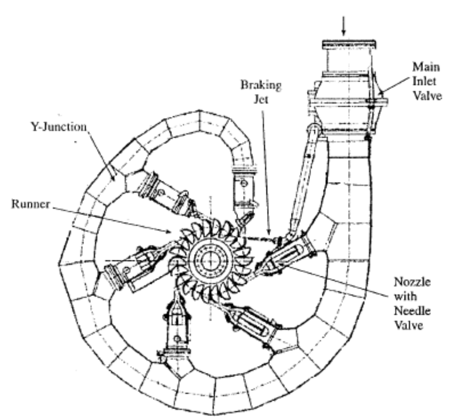

Fig. 4.8 *Schematic sketch of the manifold and jet arrangements in a six-jet Pelton turbine*

Impulse turbines-Pelton wheel

COMPONENTS OF PELTON TURBINE

Manifold, Braking Jet and Auxiliary Jet

2. ***Braking Jet***

3. ***Auxiliary Nozzle (Relief Nozzle)***

Enclosing Chamber (Casing)

Impulse turbines-Pelton wheel

Working Proportions of Pelton Turbine

Table 4.3 *Salient working proportions and ranges of important parameters of a Pelton turbine*

S.No	Item	Range	Normal value
1	Head, H	100–1870 m	
2	Speed	75–1000 rpm	
3	Maximum capacity	420 MW	
4	Speed ratio, K_u	0.43–0. 47	0.46
5	Coefficient of velocity, $C_v = \frac{V_1}{\sqrt{2gH}}$	0.98 to 0.99 for full valve opening	0.985
6	Jet ratio $= m = \frac{D}{d}$	$N_s = 209\left(\frac{d}{D}\right)$	7 to 26
7	Runaway speed, N_R	1.85 N – 1.90 N	1.87 N
8	Bucket angle, β_2	170–165°	165°
9	Number of buckets	$Z = \frac{m}{2} + 15$	
10	Specific Speed, N_s	Single jet: N_s = 8–30 Also per jet in multijet Pelton. (Max. of 6 jets)	

Impulse turbines-Pelton wheel

4.4 PERFORMANCE CHARACTERISTICS OF PELTON TURBINES

1. Variation of Discharge

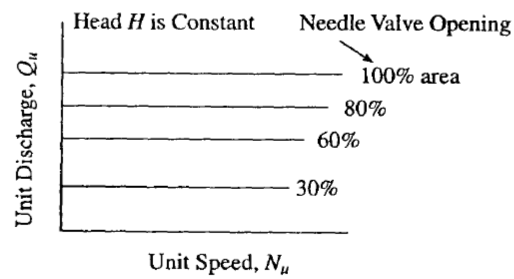

Fig. 4.9 *Variation of discharge with speed in a Pelton turbine*

Impulse turbines-Pelton wheel

2. Variation of Power

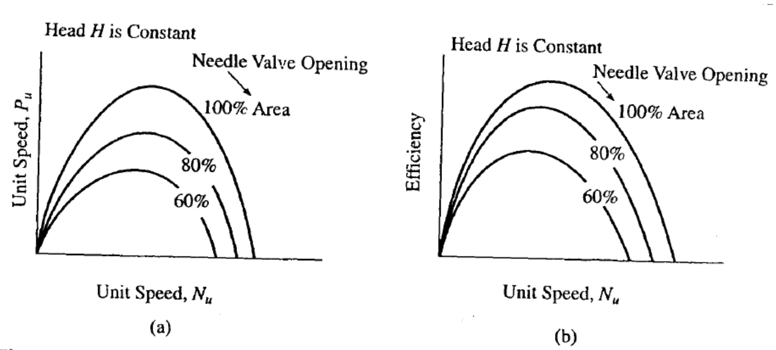

Fig. 4.10 *Variation of (a) power, and (b) efficiency with speed in a Pelton turbine*

Impulse turbines-Pelton wheel

3. Variation of Efficiency

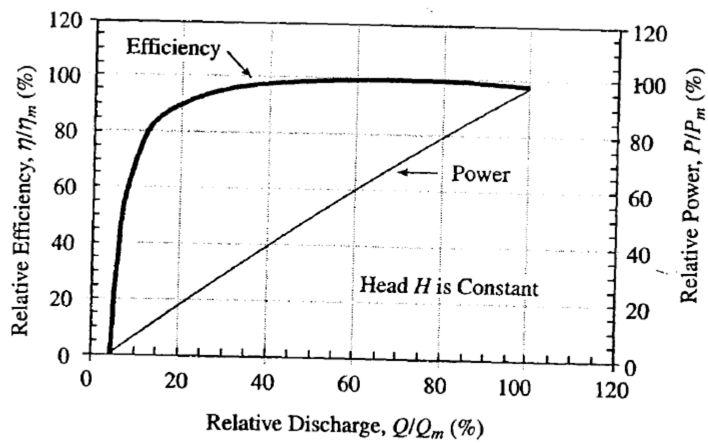

Fig. 4.11 *Variation of power and efficiency with discharge in a Pelton turbine*

Impulse turbines-Pelton wheel

4.9 SELECTION OF TURBINE TYPE

(a) Gross Head and Net Head Magnitude and variation in a water year

(b) Available Discharge Average daily/ weekly magnitude and probabilities of occurrence in a water year

(c) Power Potential Daily/weekly over a year

Impulse turbines-Pelton wheel

4.9 SELECTION OF TURBINE TYPE

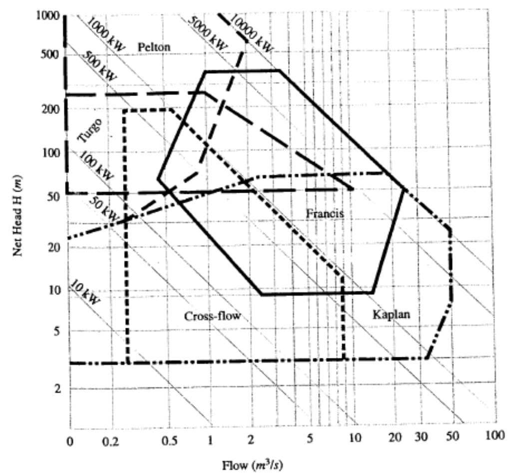

Fig. 4.16 *Turbine selection chart for small hydro projects (SHP)*

Impulse turbines-Pelton wheel

4.9 SELECTION OF TURBINE TYPE

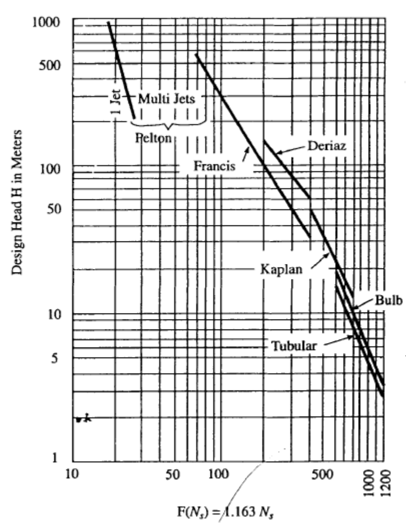

Fig. 4.17 *Chart for selection of turbine based on specific speed*

Impulse turbines-Pelton wheel

*EXAMPLE 4.1

The water jet in a Pelton wheel is 8 cm in diameter and has a velocity of 93 m/s. The rotational speed of the wheel is 600 rpm and the deflection angle of the jet at the bucket is 170°. If the ratio of bucket velocity to jet velocity is 0.47, determine the (a) diameter of the wheel, and (b) power transferred to the wheel by the jet. Take bucket friction coefficient K = 0.96.

Solution

Given: $d = 0.08$ m, $V_1 = 93$ m/s, $N = 600$ rpm, $\beta_2 = 170°$, $\frac{u}{V_1} = 0.47$, $K = 0.96$

Since, $u/V_1 = 0.47$,

$$u = 0.47 \times 93 = 43.71 \text{ m/s}$$

(a) $u = \frac{\pi DN}{60}$

Diameter of the wheel $D = \frac{60 \times u}{\pi N} = \frac{60 \times 43.71}{\pi \times 600} = 1.391$ m

$\beta'_2 = 180 - 170 = 10°$

Discharge $Q = \frac{\pi}{4}(0.08)^2 \times 93 = 0.4675 \text{ m}^3/\text{s}$

(b) Power transmitted to the runner by the jet = Theoretical power =

$P = \rho Qu (V_1 - u)(1 + K\cos\beta'_2)$

$P = 0.998 \times 0.4675 \times 43.71 \times (93 - 43.71)(1 + 0.96 \times \cos 10°)$

$P = 1955$ kW

Impulse turbines-Pelton wheel

*EXAMPLE 4.3

The following data pertains to a Pelton turbine:

Speed ratio = 0.46	*Coefficient of velocity of the nozzle = 0.97*
Mechanical efficiency = 0.92	*Speed = 300 rpm*
Pitch diameter of runner = 2.0 m	*Bucket friction coefficient K = 0.97*
Jet deflection angle at bucket = 170°	*Discharge = 0.5 m^3/s*

Calculate the (a) power transmitted by the jet to the wheel, and (b) net head.

Solution

Power transmitted by the jet to the wheel (Euler power) is given by

$$P = \rho Qu (V_1 - u)(1 + K\cos\beta'_2)$$

$$u = \frac{\pi DN}{60} = \frac{\pi \times 2.0 \times 300}{60} = 31.423 \text{ m/s}$$

$$\frac{u}{V_1} = \frac{K_u}{C_v} \text{ and hence } V_1 = \frac{uC_v}{K_u} = \frac{31.426 \times 0.97}{0.46} = 66.26 \text{ m/s}$$

$$P = 0.998 \times 0.5 \times 31.423 \times (66.26 - 31.423)(1 + 0.97\cos 10°)$$

$$= 15.68 \times 34.84 \times 1.9553 = 1068 \text{ kW}$$

Since, $u = K_u\sqrt{2gH}$

Net head $H = \frac{u^2}{2gK_u^2} = \frac{(31.423)^2}{2 \times 9.81 \times (0.46)^2} = 237.8$ m

Impulse turbines-Pelton wheel

****EXAMPLE 4.7**

A Pelton wheel of 2.5 m diameter operates under the following conditions:

Net available head = 300 m	*Jet deflection angle in the bucket = 165°*
Coefficient velocity of the jet = 0.98	*Diameter of jet = 20 cm*
Bucket friction coefficient = 0.95	*Mechanical efficiency = 0.95*
Speed = 300 rpm	

Determine (a) the shaft power (b) hydraulic efficiency, and (c) specific speed.

Solution

$$\beta_2' = 180 - 165 = 15°$$

Velocity of jet $V_1 = C_v \sqrt{2gH} = 0.98 \times \sqrt{2 \times 9.81 \times 300} = 75.186$ m/s

Discharge $Q = A_1 V_1 = \frac{\pi}{4}(0.2)^2 \times 75.186 = 2.362\ \text{m}^3/\text{s}$

$$u = \frac{\pi DN}{60} = \frac{\pi \times 2.5 \times 300}{60} = 39.27\ \text{m/s}$$

Impulse turbines-Pelton wheel

Euler head $H_e = \frac{1}{g} u(V_1 - u)(1 + K \cos \beta_2')$

$$= \frac{1}{9.81} \times 39.27\,(75.186 - 39.27)\,(1 + 0.95 \cos 15°)$$

$$= 275.7\ \text{m}$$

Hydraulic efficiency $\eta_0 = \frac{H_e}{H} = \frac{275.7}{300} = 0.919$

Overall efficiency $\eta_0 = (\eta_m \eta_h) = 0.919 \times 0.95 = 0.873$

Shaft power $P = \eta_0\, \gamma QH = 0.873 \times 9.79 \times 2.362 \times 300 = 6057$ kW

Specific speed $N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{300\sqrt{6057}}{(300)^{5/4}} = 18.7$

Impulse turbines-Pelton wheel

**EXAMPLE 4.10

A Pelton turbine has jet velocity of 90 m/s and peripheral velocity of 40 m/s. If the deflection angle of the jet in the bucket is 160°, find the (a) head loss due to bucket friction, and (b) kinetic energy head of exit discharge from the buckets. Take bucket friction coefficient K = 0.9.

Solution

Given: $V_1 = 90$ m/s, $u = 40$ m/s, $\beta_2 = 160°$, $K = 0.9$

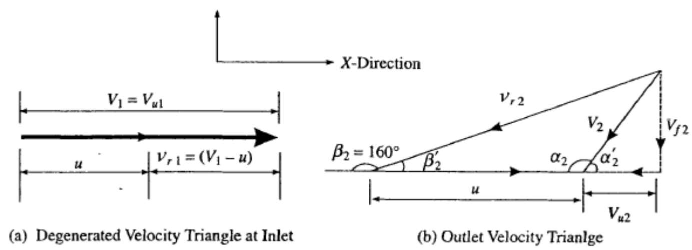

Fig. 4.20 *Velocity triangles, Example 4.10*

Impulse turbines-Pelton wheel

Figure 4.20 shows the inlet and outlet velocity triangles. $\beta_2' = 180 - 160 = 20°$

Since $K = 0.9$, relative velocity $v_{r2} = 0.9 v_{r1} = 0.9\,(V_1 - u)$.

$$v_{r2} = 0.9 \times (90 - 40) = 45 \text{ m/s}$$

Let α_2' be the direction of the absolute velocity V_2 with the peripheral velocity.

$$V_{f2} = V_2 \sin \alpha_2' = v_{r2} \sin \beta_2'$$

$$V_{f2} = 45 \sin 20° = 15.39 \text{ m/s}$$

$$V_{u2} = V_2 \cos \alpha_2' = v_{r2} \cos \beta_2' - u$$

$$V_{u2} = 45 \cos 20° - 40 = 2.29 \text{ m/s}$$

$$\tan \alpha_2' = \frac{V_{f2}}{V_{u2}} = \frac{15.39}{2.29} = 6.72$$

Angle $\alpha_2' = 81.537°$

$$V_2 = \frac{V_{f2}}{\sin \alpha_2'} = \frac{15.39}{\sin 81.537°} = 15.56 \text{ m/s}$$

(a) Energy loss at the bucket $= \dfrac{v_{r1}^2}{2g} - \dfrac{v_{r2}^2}{2g} = \dfrac{(50)^2 - (45)^2}{2 \times 9.81} = 24.2\,\text{m}$

(b) Kinetic energy head of exit discharge from the buckets $= \dfrac{V_2^2}{2g} = \dfrac{(15.56)^2}{2 \times 9.81} = 12.34\,\text{m}$

**EXAMPLE 4.19

The following data pertains to a single-jet Pelton turbine:

Jet diameter = 10 cm	*Jet ratio = 12*
Coefficient of velocity of the nozzle = 0.98	*Speed ratio = 0.46*
Bucket friction coefficient = 0.95	*Jet deflection angle at the bucket = 165°*
Net head = 150 m	

Calculate the torque (a) at the start, and (b) at normal speed.

Solution

$D/d = 12$. Hence, $D = 12\,d = 12 \times 0.10 = 1.20$ m

Area of jet $A_1 = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times (0.10)^2 = 0.007854\ \text{m}^2$

Velocity of jet $= V_1 = C_v \sqrt{2gH} = 0.98 \times \sqrt{2 \times 9.81 \times 150} = 53.16$ m/s

Discharge $Q = A_1 V_1 = 0.007857 \times 53.16 = 0.4176\ \text{m}^3/\text{s}$

By Eq. (4.22),

Torque $T = \frac{\rho Q D}{2}(V_1 - u)(1 + K\cos\beta_2')$

$\beta_2' = (180 - \beta_2) = 180 - 165 = 15°$

$T = \frac{0.998 \times 0.4176 \times 1.2}{2}(53.164 - u)\ [1 + (0.95)(\cos 15°)]$

$T = 0.4794(53.164 - u)$

At start, $u = 0$ and hence

Torque $T = 0.4794\ (53.164 - 0) = 25.49$ kNm

Impulse turbines-Pelton wheel

**EXAMPLE 4.26

For a Pelton turbine the bucket friction coefficient K = 0.95, coefficient of velocity C_v = 0.93 and the speed ratio K_u = 0.46. Find the deflection angle β_2 of the relative velocity of the jet at the exit that would cause zero velocity of whirl at the exit of the bucket.

Solution

Condition for zero velocity of whirl at the exit of the bucket is $\alpha_2 = 90°$.

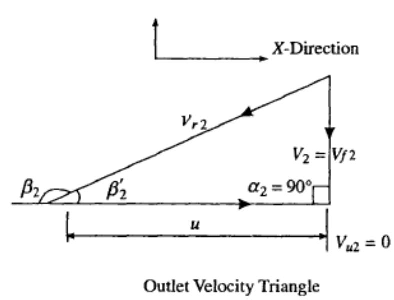

Fig. 4.24 *Velocity triangle, Example 4.26*

Impulse turbines-Pelton wheel

At this condition, $v_{r2} \cos \beta_2' = u$ where $v_{r2} = K(V_1 - u)$ = Relative velocity at the exit of the bucket, (See Fig. 4.24). In this, β_2 = Bucket angle = Deflection angle of the relative velocity of jet at the exit of bucket and $\beta_2' = 180° - \beta_2$.

Hence, $K(V_1 - u) \cos \beta_2' = u$

$$\cos \beta_2' = \frac{u}{v_{r2}} = \frac{u}{K(V_1 - u)} = \frac{1}{K\left(\frac{V_1}{u} - 1\right)}$$

$$= \frac{1}{K\left(\frac{C_v}{K_u} - 1\right)} = \frac{1}{0.95\left(\frac{0.98}{0.46} - 1\right)} = 0.93162$$

$$\cos \beta_2' = 21.31°$$

$$\beta_2 = 180 - \beta_2' = 158.69°$$