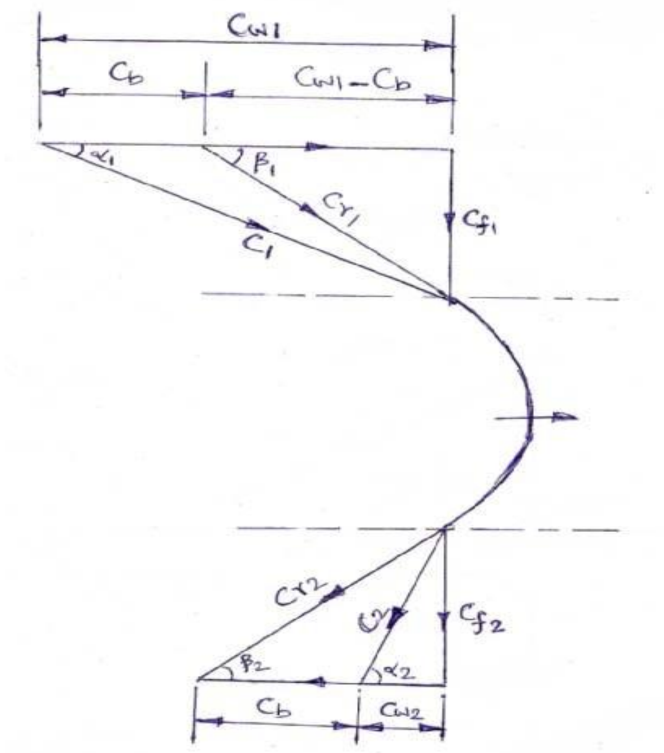
MODULE –II

STEAM TURBINE PROBLEMS

Velocity diagram for moving blades of impulse turbine



Let

α_1–Anglewithwhichthesteamentersthemovingblade(Nozzleangle)

α_2–Anglewithwhichthesteamleavesthemovingblade

β_1–Bladeangleatinlet

β_2–Bladeangleatoutlet

C_1–AbsolutevelocityofsteamatinletofthebladeC$_2$–
Absolutevelocity ofsteamleavingthe blade

C_{w1}–Tangentialcomponentofabsolutevelocityatinlet(Whirlvelocity)C_{w2}–
Tangentialcomponent of absolutevelocity at outlet

C_{f1} – Axial component of absolute velocity at inlet (Flow velocity)C_{f2}– Axial component ofabsolute velocity at exit

C_{r1} – Relative velocity of steam at inletC_{r2} – Relative velocity of steam at exitC_b– Blade velocity

The steam jet issuing from the nozzle at a velocity of C_1 impinges on the blade atanangleα$_1$.Thetangentialcomponentofthisjet(C_{w1})performsworkontheblades.Theaxialcomponentdoesnowork,butcausesthesteamtoflowthroughtheturbine.

The relative velocity at outlet (C_{r2}) is same as the relative velocity at inlet (C_{r1}) ifthereis no frictionallossat the blade.

Workdoneonthe blade

Workdone =ForcexDistance traveled

Work done per second = Force x distance traveled per second Force =mass acceleration

=massx rateofchangeofvelocity

=massflowratexchangeofvelocity

$$= \overset{*}{m}_s (C_{w1} - (-C_{w2})) = \overset{*}{m}_s (C_{w1} + C_{w2})$$

Distancetraveledpersecond=C_b

$$W = \overset{*}{m}_s (C_{w1} + C_{w2}) C_b$$

1 A steam at 4.9 bar and 160^{0}C is supplied to the single stage impulse turbine at a mass flow rate of 30 kg/min, from where it is exhausted to a condenser at a pressure of 19.6 kpa. the blade speed is 300 m/s. The nozzles are inclined as 25^0 to the plane of wheel and the outlet blade angle is 35$^{0.}$

Neglecting friction losses, determine i) theoretical power developed by the turbine. ii) diagram efficiency, and iii) stage efficiency.

We know that for dry saturated steam (or when n= 1.135), critical pressure ratio,

$$\frac{p_2}{p_1} = 0.577$$

$\therefore$ p_2=0.577p1=0.577x 8 = 4.616 bar

Now complete the Mollier diagram for the expansion of steam through the nozzle.

From Mollier diagram, we find that

h_1 = 2775kJ/kg; h_2 = 2650kJ/kg; h_3 = 2465 kJ/kg; x_2 = 0.965; and x_3 = 0.902

From steam tables, we also find that the specific volume of steam at throat corresponding to 4.616 bar,

$$\upsilon_{g^2} = 0.405 m^3/kg$$

and specific volume of steam at exit corresponding to 1.5 bar,

$$\upsilon_{g^3} = 1.159 m^3/kg$$

2. In a stage of impulse reaction turbine operating with 50% degree of reaction, the blades are identical in shape. The outlet angle of the moving blade is 19^0 and the absolute discharge velocity of steam is 100m/s in the direction70^0Cto the motion of blades. If the rate of flow through the turbine is 15000 kg/hr, calculate the power developed by the turbine

We know that heat drop lost in friction

= 10% = 01.

$\therefore$ Nozzle coefficient or nozzle efficiency

K = 1 – 01 = 0.9

We know that final velocity of the steam,

$$V_2 = 44.72\sqrt{Kh_d} = 44.72\sqrt{0.9\times 96.5} = 416.8 m/s$$

$\therefore$ Percentage reduction in final velocity

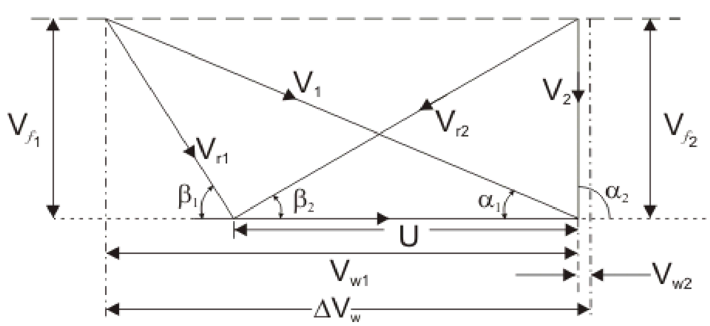
$$= \frac{439.3-416.8}{439.3} = 0.051 \; or \; 5.1\%$$

3.The Velocity of steam, leaving the nozzles of an impulse turbine, is 1200m/s and the nozzle angle is 20°. The blade velocity is 375 m/s and the blade velocity coefficient is 0.75. Assuming no loss due to shock at inlet, calculate for a mass flow of 0.5kg/s and symmetrical blading: (a) blade inlet angle; (b) driving force on the wheel; (c) axial thrust on the wheel; and (d) power developed by the turbine.

Given :

V=1200m/s; $\alpha = 20^o; V_b = 375 m/s; K = V_{r1}/V_r = 0.75; m = 0.5 kg/s;$

$\theta = \phi$, for symmetrical blading.



Solution:

Now draw the combined velocity triangle, as shown in fig.22.7, as discussed below:

1. First of all, draw a horizontal line, and cut *AB* equal to 375 m/s to some suitable scale representing the velocity of blade (V_b).
2. Now at *B*, draw a line *BC* at an angle of 20° (Nozzle angle, α) and cut off *BC* equal to 1200m/s to the scale to represent the velocity of stream jet entering the blade (V_b).
3. Join *CA*, which represents the relative velocity at inlet (V_r). By measurements, we find that *CA* = V_r = 860 m/s. Now cut off *AX* equal to 860 x 0.75 = 645 m/s to the scale to represent the relative velocity at exit (V_{r1}).

4. At *A*, draw a line *AD* at an angle equal to the angle ϕ equal to the θ, for symmetrical blading. Now with *A* as centre, and radius equal to *AX*, draw an are meeting the line through *A* at *D*, such that $AD = V_{r1}$.
5. Join *BD*, which represents the velocity of steam jet at exit (V_1).
6. From *C* and*D*, draw perpendiculars meeting the line *AB* produced at *E* and *F* respectively. CE and DF represents the velocity of flow at inlet (V_f) and outlet (V_{f1}) respectively.

   The following values are *measured from the velocity diagram :

   $\theta = 29^o; V_w = BE = 1130 m/s; V_{w1} = BF = 190 m/s$

   $V_f = CE = 410 m/s$ and $V_f = DF = 310$ m/s

   (a) Blade inlet angle

   By measurement from the velocity diagram, we find that the blade angle at inlet,

   $\theta = 29^0$ **Ans.**

   (b) During force on the wheel

   We know that driving force on the wheel,

   $F_x = m(V_w + V_{w1}) = 0.5\ (1130 + 190) = 660$ N **Ans.**

   (c) Arial thrust on the wheel

   We know that axial thrust on the wheel,

   $F_\gamma = m(V_f - V_{f1}) = 0.5(410 - 310) = 50 N$ **Ans.**

   (d) Power development by the turbine

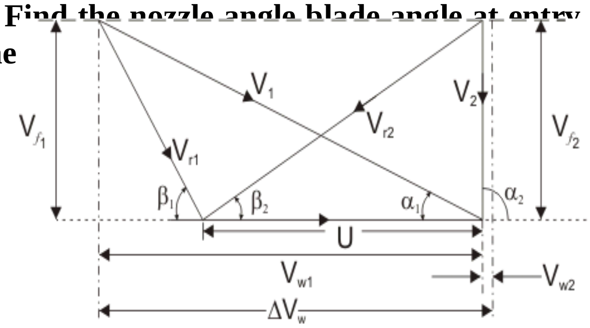
   We know that power development by the turbine,

   $P = m(V_w + V_{w1})\ V_b$

   $= 0.5(1130 + 190)\ 375 = 247\ 500\ W$

   $= 247.5\ kW$ **Ans.**

4.The steam supply to an impulse turbine with a single row of moving blades is 2 kg/s. The turbine develops 130 kW, the blade velocity being 175 m/s. The steam flows from a nozzle with a velocity of 400 m/s and the velocity coefficient of blades is 0.9. Find the nozzle angle blade angle at entry and exit, if the steam flows axially after passing over the



Given :

$m = 2$ kg/s; $P = 130 kW = 130 \times 10^3 W$;

$V_b = 175$ m/s; $V = 400$ m/s; $K = 0.9$

Solution:

Let

We know that power development (*P*),

$130 \times 10^3 = m \times V_w \times V_b = 2 \times V_w \times 175 = 350\ V_w$

$\therefore$ $V_w = 371.4$m/s

By measurement, we find that $\alpha = 19^0$; $\theta = 33^o$ and $\phi = 36^o$ **Ans.**

Explain the procedure to draw Velocity Diagram for Two Stage Impulse Turbine.

First of all, draw a horizontal line and cut off AB equal blade velocity (V_h) to

1. Now draw the inlet velocity triangle ABC for the first moving ring on the base AB with the help of nozzle angle of the first moving ring (α) and verily of steam entering the turbine (v)
2. Now cut off CX equal to the friction of the bladed on the first moving ring. The length AX will give the value of relative velocity at exit of the first moving ring (V1)
3. Now draw the outlet velocity triangle ABD for first moving ring on the same base AB with the help of exit blade angle for the first moving ring and relative velocity at the first ring (V1)
4. Now cut off DY equal to the friction of the blades of the fixed ring. The length BY will give the exit velocity of steam from the fixed ring. It will also be equal to the velocity of steam entering the second moving ring (V1)
5. Now draw the inlet velocity triangle ABC 'for the second moving ring on the same base AB with the help of nozzle angle of the second moving ring (α) and velocity of steam entering the second moving ring (V')
6. Now cut off C'Z equal to the friction of blades on the second moving ring. The length AZ will give the value of relative velocity at exit of the seconding moving ring (V'r).
7. Now draw the outlet velocity triangle ABC' for the second moving ring on the same base AB with the help of exit blade angle for the seconding moving ring(Φ) and exit velocity of the second moving ring (V2).

We know that power developed by a two stage impulse turbine,

$$P=m(EF+E'F)V_h \text{ Watts.}$$

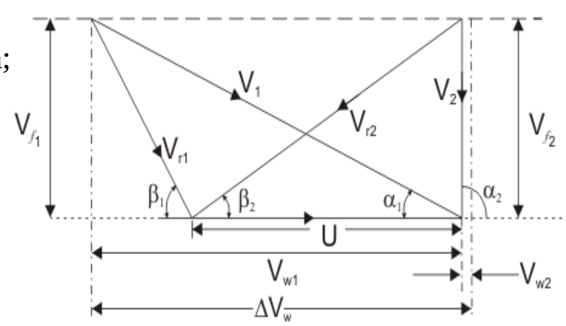
Where m is the mass of steam supplied in kg/s.

5.In a reaction turbine, the blade tips are inclined at 35º and 20º in direction of motion. The guide blades are of the same shape as the moving blades, but reversed in direction. At a certain place in the turbine, the drum diameter is I meter and the blades are 100 mm high. At this place, steam has a pressure of 1.7 bar and dryness 0.935. If the speed of the turbine is 250 r.p.m and the steam passes through the blades without shock, find the mass of steam flow and the power developed in the ring of the moving blades.

Given :

$\theta = \beta = 35^o$; $\phi = \alpha = 20^o$; d = 1m; h=100mm = 0.1m;

p = 1.7 bar; x = 0.935; N = 250 r.p.m



Solution:

We know that blade speed,

$$V_b = \frac{\pi(d+h)N}{60} = \frac{\pi(1+0.1)250}{60} = 14.4 m/s$$

Now let us draw the combined velocity triangle, as shown in Fig.23.9, as discusses below;

1. First of all, draw a horizontal line and cut off AB equal to 14.4 m/s to some suitable scale to represent velocity of blade (V_b)

2. Now draw velocity triangle ABC on the same base AB with $\alpha = 20^o$ and $\theta = 35^o$.

3. Similarly draw outlet velocity triangle ABD on the same base AB with ;$\phi = 20^o$ and $\beta = 35^o$.

4. From C and D draw perpendiculars to meet the line AB produced at E and F.
   By measurement from velocity triangle, we find that
   Change in the velocity of whirl, $(V_w + V_{w1})$ = EF = 42.5 m/s
and velocity of flow at outlet, V_{f1} = DF = 10 m/s

Mass of steam flow

From steam tables, corresponding to a pressure of 1.7 bar, we find that the specific volume of steam, $\upsilon = 1.031 m^3/kg$.

We know that mass of steam flow,

$$m = \frac{\pi(d+h)hV_{f1}}{x\upsilon_g} = \frac{\pi(1+0.1)0.1\times10}{0.935\times1.031} = 3.58 kg/s$$ **Ans.**

Power developed in the ring of the moving blades

We know that power developed in the ring of the moving blades,

$P = m(V_w + V_{w1})V_b = 3.58 \times 42.5 \times 14.4 = 2191$ W

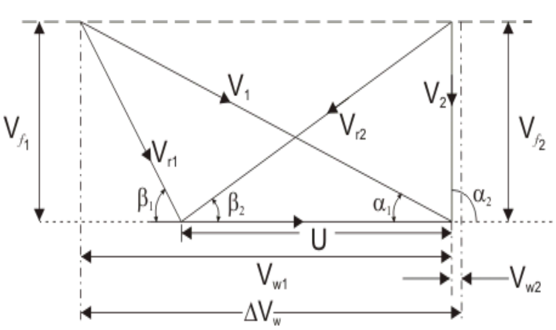
= 2.191 kW **Ans.**

6.A reaction turbine runs at 300 r.p.m. and its steam consumption is 15 400 kg/h. The pressure of steam at a certain pair is 1.9 bar; its dryness 0.93 and power developed by the pairs is 3.5 kW. The discharging blade tip angle is 20º for both fixed and moving blades and theaxial velocity of flow is 0.72 of the blade velocity. Find the drum diameter and blade height. Take the tip leakage steam as 8%, but neglect blade thickness

Given :

$N = 300$ r.p.m. ; $m_1 = 15\,400$ kg/h = 4.28 kg/s ;
$p = 1.9$bar ;$x = 0.93$;
$P = 3.5$kW = 3.5×10^3W; $\alpha = \phi = 20^o$;$V_f = 0.72\, V_b$

Solution :



Since the tip leakage steam is 8 %,
therefore actual mass of steam flowing over the blades,

$m = 4.28 - (4.28 \times 0.08) = 3.94$ kg/s

Blade height

h = Blade height, and

d_m = Mean

We know that blade velocity,

$$V_b = \frac{\pi d_m N}{60} = \frac{\pi d_m \times 300}{60} = 15.71 d_m m/s$$

∴ $V_f = 0.72 \times 15.71\ d_m = 11.3 d_m 11.3 d_m$ m/s

Now let us draw the combined velocity triangle, as shown in Fig.23.10, as discussed below

1. First of all, draw a horizontal line and cut off AB equal to 15.71 d_m to some suitable scale to represent the blade velocity (V_b)

2. Now draw velocity triangle ABC on the base AB with α = 20° and BC = V_f/sin 20°= 11.3d_m /0.342 = *33*$d_m$to the scale.

3. Similarly draw outlet velocity triangle on the same base AB with ;ϕ = 20° and Vr1 = V_{f1}/sin20° = 11.3d_m/0.342 = 33d_m, to the scale.

4. From C and D draw perpendiculars to meet the line AB produced at E and F.

By measurement from velocity triangle, we find that change in the velocity of whirl,

$(V_w + W_{w1}) = 46 d_m$ m/s

We know that power developed (*P*),

$3.5 \times 10^3 = m(V_w + V_{w1})V_b = 3.94 \times 46\ d_m \times 15.71 d_m = 2845\ d_m^2$

∴ $d_m^2 = 1.23$ *or* $d_m = 1.11$ m

and $V_{f1} = V_f = 11.3\ d_m = 11.3 \times 1.11 = 12.54$ m/s

From steam tables, corresponding to a pressure of 1.9 bar, we find specific volume of steam,

$\upsilon_g = 0.929 m^3 / kg$

We know that mass of steam flow (*m*),

$$3.94 = \frac{\pi d_m h V_{f1}}{x \upsilon_g} = \frac{\pi \times 1.11 \times h \times 12.54}{0.9. \times 0.929} = 50.6h$$

∴ $h = 0.078$ m = 78 mm Ans.

Drum dialeter

We know that drum diameter,

d = *d*$_m$ – *h* = *1.11 -0.78* = ***1.032 m*** **Ans.**

7. Ina single stage impulse turbine the blade angles are equal and nozzles angle is 20^0. The velocity coefficient for the blade is 0.83. Find the maximum blades efficiency possible. If the actual blade efficiency is 90% of maximum blade efficiency, find the possible ratio of blade speed to steam speed.

(e) Blade inlet angle

By measurement from the velocity diagram, we find that the blade angle at inlet,

$\theta = 29^0$

(f) During force on the wheel

We know that driving force on the wheel,

$F_x = m(V_w + V_{w1}) = 0.5\ (1130 + 190) = 660$ N

(g) Arial thrust on the wheel

We know that axial thrust on the wheel,

$$F_\gamma = m(V_f - V_{f1}) = 0.5(410 - 310) = 50N$$

8. A 50 % reaction turbine(with symmetrical velocity triangles running at 400 rpm has the exit angle of the blades as 20^0 and the velocity of steam relative to the blades at the exit is 1.35 times the mean blade speed. The steam flow rate is 8.33 kg/ s and at a particular stage the specific volume is 1.381 m^3/kg. Calculate for this stage: a suitable blade height , assuming the rotor mean diameter to be 12 times the blade height.

Blade inlet angle

By measurement from the velocity diagram, we find that the blade angle at inlet,

$\theta = 29^0$

During force on the wheel

We know that driving force on the wheel,

$F_x = m(V_w + V_{w1}) = 0.5\ (1130 + 190) = 660$ N

Arial thrust on the wheel

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Power development by the turbine

We know that power development by the turbine,

$P = m(V_w + V_{w1})\ V_b$

$= 0.5(1130 + 190)\ 375 = 247\ 500$ W

$= 247.5$ kW

8. In a test on a steam nozzle the issuing steam jet impinges on stationary flat plate which is perpendicular to the direction of flow and the force on the plate is measured. With convergent divergent nozzle supplied with steam at 10 bar dry saturated and discharging at 1 bar: the force is experimentally measured to be 600N. the area of the nozzle at throat measures 5cm^2 and the exit area is such that complete expansion is achieved under these conditions. Determine the flow rate of the steam and the efficiency of the nozzle assuming that all losses occur after the throat. Assume n = 1.135 for isentropic expansion.

Heat drop between entrance and exit,

$$h_{d3} = h_1 - h_3 = 2775 - 2465 = 310\text{kJ/kg}$$

∴ Velocity of steam at throat,

$$V_3 = 44.72\sqrt{h_{d3}} = 44.72\sqrt{310} = 787.4m/s$$

and $$m = \frac{A_2 V_2}{x_2 \upsilon_{g2}}$$

or $$A_3 = \frac{m x_3 \upsilon_{g3}}{V_3} = \frac{m \times 0.902 \times 1.159}{787.4} = 0.001.33m$$

$\therefore$ Ratio of cross-sectional area at exit and throat,

$$\frac{A_3}{A_2} = \frac{0.00133m}{0.000786m} = 1.7$$

9. A 50 % reaction turbine(with symmetrical velocity triangles running at 400 rpm has the exit angle of the blades as 20^0 and the velocity of steam relative to the blades at the exit is 1.35 times the mean blade speed. The steam flow rate is 8.33 kg/ s and at a particular stage the specific volume is 1.381 m^3/kg. Calculate for this stage: a suitable blade height , assuming the rotor mean diameter to be 12 times the blade height.

Blade inlet angle

By measurement from the velocity diagram, we find that the blade angle at inlet,

$$\theta = 29^0$$

During force on the wheel

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We know that power development by the turbine,

$$P = m(V_w + V_{w1})\ V_b$$
$$= 0.5(1130 + 190)\ 375 = 247\ 500\ W$$
$$= 247.5\ kW$$

10. A convergent nozzle required to discharge 2kg of steam per second. The nozzle is supplied with steam at 7 bar and 180^0C and discharge takes place against a back pressure of 1 bar. The expansion up to throat is isentropic and the frictional resistance between the throat and exit is equivalent to 63 kJ/kg of steam. Take approach velocity of 75 m/s and throat pressure 4 bar, estimate

i) suitable areas for the throat and exit, and

ii) Overall efficiency of the nozzle based on enthalpy drop between the actual inlet pressure and temperature and the exit pressure.

Final velocity of the steam

From steam tables, corresponding to a pressure of 15 bar, we find that enthalpy of dry saturated steam,

$$h_1 = 2789.9\ kJ/Kg$$

and corresponding to a pressure of 1.5 bar, enthalpy of dry saturated steam,

h_2 = 2693.4 kJ/Kg

∴ Heat drop, $h_d = h_1 - h_2$=2789.9 – 2693.4 = 96.5 kJ/Kg

We know that final velocity of the steam,

$$V_2 = 44.72\sqrt{h_d} = 44.72\sqrt{96.5} = 439.3 m/s$$

11. In a stage of impulse reaction turbine operating with 50% degree of reaction, the blades are identical in shape. The outlet angle of the moving blade is 19^0 and the absolute discharge velocity of steam is 100m/s in the direction70^{0}Cto the motion of blades. If the rate of flow through the turbine is 15000 kg/hr, calculate the power developed by the turbine.

We know that heat drop lost in friction

= 10% = 01.

∴ Nozzle coefficient or nozzle efficiency

K = 1 – 01 = 0.9

We know that final velocity of the steam,

$$V_2 = 44.72\sqrt{Kh_d} = 44.72\sqrt{0.9 \times 96.5} = 416.8 m/s$$

∴ Percentage reduction in final velocity

$$= \frac{439.3 - 416.8}{439.3} = 0.051 \text{ or } 5.1\%$$

12. In a De Lavel turbine steam issues from the nozzle with a velocity of 1200m/s. The nozzle angle is 20^0, the mean velocity is 400m/s and the inlet and outlet angles of blades are equal. The mass of steamflowing through the turbine per hour is 1000kg. Calculate:

i) Blade angles

ii) Relative velocity of steam entering the blades

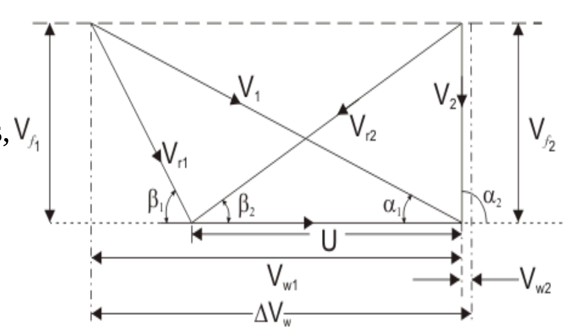
iii) Tangential force on the blades

iv) Power developed

v) Blade efficiency. Take blade velocity coefficient as 0.8

Solution :

Since the tip leakage steam is 8 %,
therefore actual mass of steam flowing over the blades,



m = 4.28 – (4.28 x 0.08) = 3.94 kg/s

Blade height

h = Blade height, and

d_m = Mean

We know that blade velocity,

$$V_b = \frac{\pi d_m N}{60} = \frac{\pi d_m \times 300}{60} = 15.71 d_m m/s$$

$\therefore$ V_f = 0.72 x 15.71 d_m = 11.3d_m11.3d_m m/s