***Chapter Three***

***IMPULSE TURBINES***

***3-1.Introduction:***

A special case of axial flow turbine is the so called impulse turbine. This type of turbine has no change in pressure across the rotor and thus has zero reaction. Impulse turbines are chosen when the head available exceeds about ***300 m.***

The impulse turbine is very easy to understand. A nozzle transforms water under a high head into powerful jet. The momentum of this jet is destroyed by striking the runner, which absorbs the resulting force. If the velocity of the water leaving the runner is nearly zero, all of the kinetic energy of the jet has been transformed into mechanical energy, so the efficiency high.

A practical impulse turbine was invented by ***Lester A. Pelton*** ***(1829-1908)*** in California around ***1870***. There were high-pressure jets there used in placer mining, and a primitive turbine called the hurdy-gurdy, a mere rotating platform with vanes, had been used since the ***'60's***, driven by such jets. Pelton also invented the split bucket, now universally used, in ***1880***. Pelton is a trade name for the products of the company he originated, but the term is now used generically for all similar impulse turbines.

***3-2. Basic Equations:***

If the water is not slowed down as it passes over the bucket surface, it follows that there is no change in the relative velocity across the rotor. Thus the rotor blades will be shaped such that ***W1=W2***. In reality friction slows it down slightly and we define a blade friction coefficient as:





***(a) (b)***

***Figure (3-1):Pelton Wheel Runner.***

An impulse turbine, as the name indicates, is a turbine which runs by the impulse of water. In an impulse turbine, the water from a dam is made to flow through a pipeline, and then through guide mechanism and finally through the nozzle. In such a process, the entire available energy of the water is converted into kinetic energy, by passing it through nozzles; which are kept close to the runner. The water enters the running wheel in the form of a jet which impinges on the buckets, fixed to the outer periphery of wheel. The jet of water impinges on the buckets with a high velocity and after flowing over the vanes, leaves with a low velocity, thus imparting energy to the runner. The commonest example of an impulsive turbine is Pelton wheel which is shown in ***Figure (3-1)***.

The buckets are doubling hemispherical with a splitter in the center as shown in ***Figure (3-1b)***. The outer edge of the buckets deflects the flow back at an angle of ***β*** to the incoming jet to develop an equation for the shaft power of impulse turbine, select a control volume which encloses the buckets and the wheel, since the incoming jet is in the tangential direction



The incoming relative velocity is





***(a) (b)***

***Figure (3-2):Pelton Wheel Velocity Triangles at***

***a) Inlet, and b) Outlet***

The inlet velocity is shown in ***Figure (3-2a)***. The bucket speed entering and leaving the control volume is the same:



Because the pressure is atmospheric throughout the flow, ***P1=P2***. Since the degree of reaction of the ***Pelton Wheel*** is ***0***, it is an impulse turbomachine. Then by Bernoulli's ***equation (1-21)*** ***W1=W2***; that is, the magnitude of the relative velocity entering and leaving the control volume is unchanged. The direction of the leaving relative velocity vector is nearly tangential to the direction of the outer edge of the bucket. The outlet velocity triangle is shown in ***Figure (3-2b)***. Note the decrease in ***νθ2*** from ***νθ1*** by comparing the inlet and outlet velocity triangle. Then:

|  |  |
| --- | --- |
|  | …(3-1) |

The shaft power becomes:

|  |  |
| --- | --- |
|  | …(3-2) |

If there is friction then the diagram power becomes as:

|  |  |
| --- | --- |
|  | …(3-3) |

Since the Pelton Wheel is a turbine, the shaft power must be negative ***Vjet > Ω R*** when ***Ω=0*** or ***Ω=Vjet/R***, the shaft power is zero. There must be a certain value of ***Ω*** between there two values for which the power is a maximum, to find this value we use:

|  |  |
| --- | --- |
|  | …(3-4) |

The maximum power occurs when

|  |  |
| --- | --- |
|  | …(3-5) |

Or the bucket speed is half the jet speed. The maximum power is

|  |  |
| --- | --- |
|  | …(3-6) |

The power also depends on the bucket angle ***β*** and is greatest when ***β=0o***. However, ***β=0o*** is not a practical possibility because of interference of the leaving flow with the incoming jet. In actual Pelton wheels ***β*** is usually about ***15o***.

The theoretical velocity issuing from the nozzle is given by:

|  |  |
| --- | --- |
|  | …(3-7) |

Allowing for friction in the nozzle this becomes

|  |  |
| --- | --- |
|  | …(3-8) |

Where

***H-*** is the gauge pressure head behind the nozzle.

***p-*** the gauge pressure.

***Cv-*** coefficient of velocity and this is usually close to unity.

The mass flow rate from the nozzle is:

|  |  |
| --- | --- |
|  | …(3-9) |

Where

***Cc-*** is the coefficient of contraction (normally unity because the nozzles are designed not to have a contraction).

***Cd***-is the coefficient of discharge and ***Cd=CcCv***

***3-3.Efficiencies of an Impulse Turbine***

In general, the term efficiency may be defined as the ratio of work done to the energy supplied. An impulse turbine has the following three types of efficiencies.

1- Hydraulic efficiency.

2- Mechanical Efficiency.

3- Overall Efficiency.

***3-3-1.-Hydraulic Efficiency***

It is the ratio of work done on the wheel to the energy of the jet.

|  |  |
| --- | --- |
|  | …(3-10) |

And the maximum hydraulic efficiency

|  |  |
| --- | --- |
|  | …(3-11) |

***3-3-2.Mechanical Efficiency:***

It was observed that all the energy supplied to the wheel does not come out as useful, but a part of it is dissipated in overcoming friction of bearings and other moving parts. Thus the mechanical efficiency is the ratio of the actual work available at the turbine to the energy imparted to the wheel.

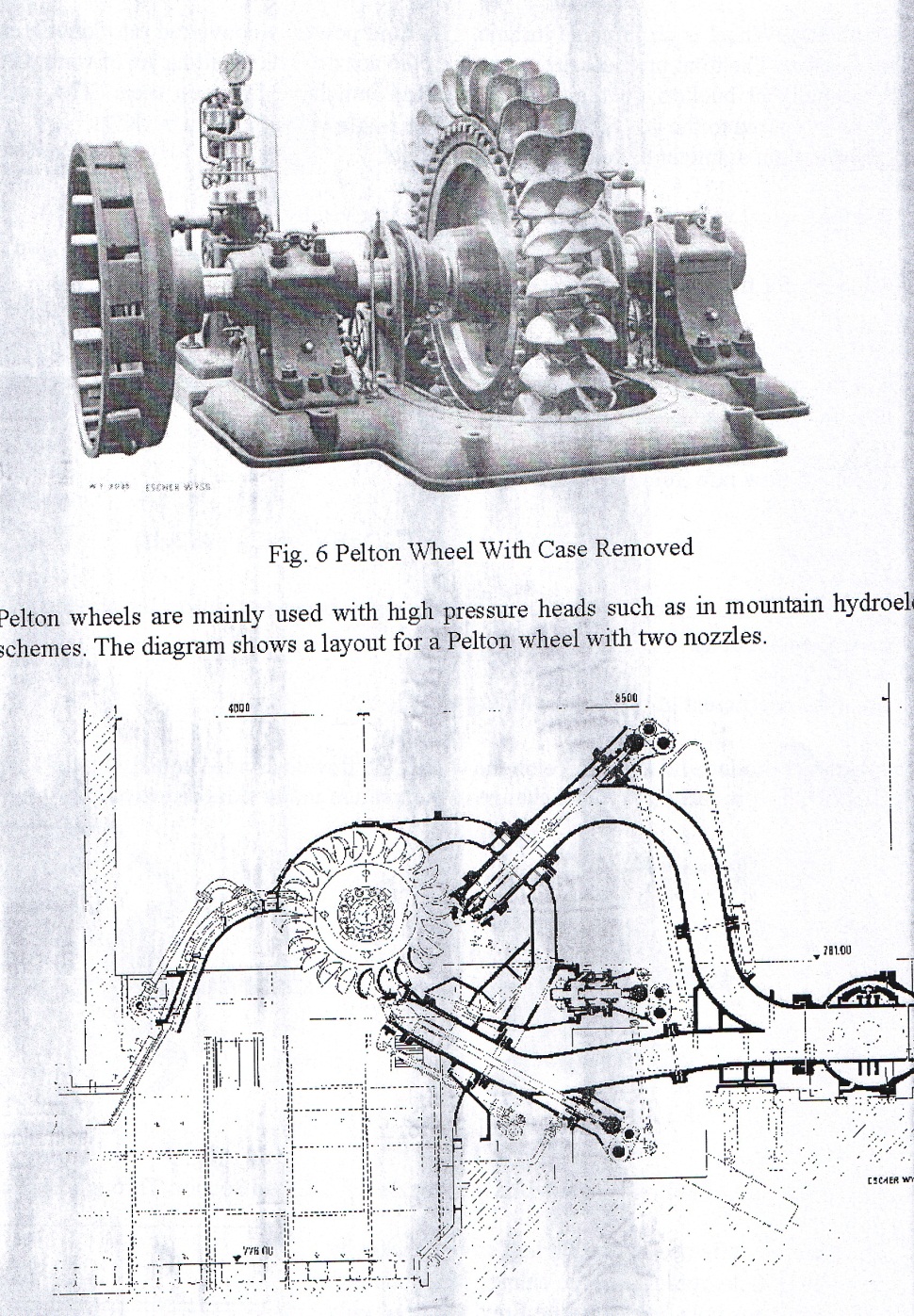
***3-3-3.Overall Efficiency:***

It is a measure of the performance of a turbine, and is the ratio of the actual power produced by the turbine to the energy actually supplied by the turbine, i.e.:

|  |  |
| --- | --- |
|  | …(3-12) |

***3-4.Number of Jets of Pelton Wheel:***

A Pelton turbine, generally, has a single jet only, but whenever a single jet cannot develop the required power, we may have to employ more than one jet. In ***Figure (3-3)*** is shown an arrangement of two jets for a Pelton wheel.



***Figure (3-3): Arrangement of Two Jets for Pelton Wheel.***

In general, the maximum number of jets provided to a Pelton wheel is six. Sometimes, instead of providing number of jets to wheel, two or three wheels are mounted on a common shaft. Such a system is known as overhung wheels.

Total discharge of the wheel, must be equal to the discharge through the jets:

|  |  |
| --- | --- |
|  | …(3-13) |

Where

***n-*** Number of jet

***A-***Area of nozzle =(π/4)\*d2

***d-***jet diameter.

***Vjet-***velocity of jet***.***

***3-5.Size of Buckets of a Pelton Wheel:***

In general, the buckets of a Pelton wheel have the following dimensions

***Width of the buckets=5d,*** and

***Depth of the bucket=1.2 d***

***3-6. Number of Buckets on The Periphery of a Pelton Wheel:***

The number of buckets, on the periphery of a Pelton wheel, is decided mainly on the following two principles,

1. The number of buckets should be as few as possible, so that there may be as little loss, due to friction, as possible.
2. The jet of water must be fully utilized, so that no water from the jet should go waste.



***Figure (3-4): Number of Buckets on the Periphery.***

***Let: R- Radius of the Mean Bucket Circle.***

***d- Diameter of the Jet, and***

***α-Angle Subtended by the Two Adjacent***

***Buckets at the Center of the Wheel.***

Now consider a jet of water impinging on the buckets of a Pelton wheel with center as ***O***. At one instant let ***a, b,*** and ***c*** be the position of three adjacent buckets as shown in ***Figure (3-4)***. It can be shown from the Figure that:

|  |  |
| --- | --- |
|  | …(3-14) |

Then, the number of buckets may be found out by the relation:

|  |  |
| --- | --- |
|  | …(3-15) |

***Note:*** ***equation (3-15)*** it is a theoretical relation, derived for the number of buckets required for a Pelton wheel, but for actual practice, the number of buckets are half the number of bucket obtained from the above equation. This unsatisfactory result which led to use a many of empirical formula, one of such formula that is widely used is:

|  |  |
| --- | --- |
|  | …(3-16) |

Where:

***D***-mean buckets diameters=diameter of wheel.

***d***- Diameter of the jet.

***Example (3-1):***

A Pelton Wheel develops ***4500 hp*** under a head of ***100 m***, and with an overall efficiency of ***85%***, fined the diameter of the nozzle, if the coefficient of velocity for the nozzle is ***1***.

***Solution:***

We know that the velocity of jet is



By using the overall efficiency:



***Example (3-2):***

A Pelton Wheel having semi-circular buckets and working under a head of ***140 m*** is running at ***600 rpm***. The discharge through the nozzle is ***50 L/sec***, and diameter of the wheel is ***60 cm***, find:

A- Power available at the nozzle, and

B- Hydraulic efficiency of the wheel, if the coefficient of the velocity is ***0.98***.

***Solution:***

Because of semi-circular, angle of blade ***β=0o*** and ***1L=10-3 m3***



***Example (3-3):***

The buckets of a Pelton Wheel revolve on a mean diameter of ***1.5 m*** at ***1500 rev/min***. the jet velocity is ***1.8*** times the bucket velocity. Calculate the water flow rate required to produce a power output of ***2 MW***. The mechanical efficiency is ***80%*** and the blade friction coefficient is ***0.97***. The deflection angle is ***165o.***

***Solution:***

According to the mechanical efficiency, the diagram power will be find from:





Since there is a mechanical efficiency so we used diagram power with friction:





***Problems:***

***Q3-1;***

An Impulse turbine of Pelton types delivers maximum horsepower of ***19000***, when working under a head of ***900 m*** and running at ***600 r.p.m.***, find the least diameter of the jet, and the mean diameter of the wheel. Take overall efficiency of the turbine as ***89.2%.***

Note: in actual case, maximum efficiency takes place when the velocity of the wheel is ***0.46*** times the velocity of the jet.

***Q3-2:***

A Pelton wheel has a tangential velocity of buckets of ***15 m/sec***. The water is being supplied under a head of ***36 m*** at the rate of ***20*** ***L/sec***. The buckets deflects the jet through an angle of ***160o***, if the coefficient velocity for the nozzle is ***0.98***, find the diagram power produced by the wheel.

***Q3-3:***

Consider the impulse turbine installation shown in the ***Figure below*** Analyze the flow in the penstock to develop an expression for the velocity of the jet as function of the head ***(H)*** and ratio of jet diameter ***(Dj)*** to penstock diameter ***(D)***.

Reservoir Surface

H

Vj

L

Turbine Wheel

Penstock

D

***Q3-4:***

Calculate the diagram power for a Pelton Wheel ***2m*** mean diameter revolving at ***3000 rev/min***with a deflection angle of***170o*** under the action of two nozzles, each supplying ***10 kg/s*** of water with a velocity twice the bucket velocity. The blade friction coefficient is ***0.98.***

If the coefficient of velocity is ***0.97,*** calculate the pressure behind the nozzles.

***Q3-5:***

A Pelton wheel is ***1.7 m*** mean diameter and runs at maximum power. It is supplied from two nozzles. The gauge pressure head behind each nozzle is ***180 m*** of water. Other data for the wheel is:

Coefficient of discharge ***Cd=0.99.***

Coefficient of velocity **Cv=0.995.**

Deflection angle***=165o.***

Blade friction coefficient***=0.98.***

Mechanical efficiency*=****87%****.*

Nozzle diameter***=30 mm.***

***Calculate the following***

1- The jet velocity

2- The mass flow rate.

3- The water power.

4- The diagram power.

5- The diagram efficiency.

6- The overall efficiency.

7- The wheel speed in rev/min.

***Q3-6:***

A Pelton wheel is supplied with ***1.2 kg/sec*** of water at ***20 m/sec***. the buckets rotates on a mean diameter of ***250 mm*** at ***800rev/min***. The deflection angle is ***165o*** and friction is negligible. Determine the diagram power. Draw the vector diagram to scale and determine ***Δνθ*** .