H19

Pelton Turbine

User Guide

TecQuipment has taken care to make the contents of this manual accurate and up to date. However, if you find any errors, please let us know so we can rectify the problem.

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EM/DB/0115

TecQuipment

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Introduction

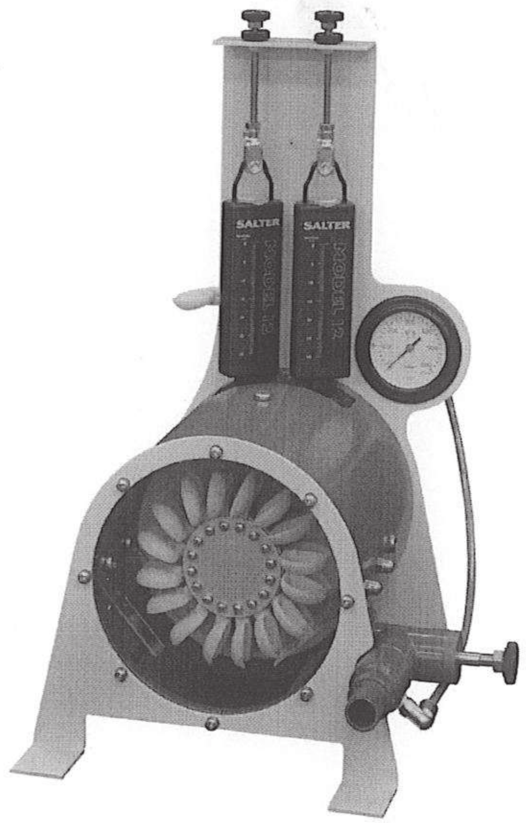


Figure 1 The Pelton Turbine (H19)

The Pelton Turbine is a hydraulic 'impulse' turbine, in which one or more water jets hit 'buckets' on a wheel. The force produced by the jet impact at right angles to the buckets creates a torque. This torque causes the wheel to rotate, producing power. The name 'Pelton' comes from L.A. Pelton, an American engineer who researched the best shape of the buckets needed for the turbine.

Although the concept is very simple, some very large machines of high efficiency have been developed, with power outputs of more than 100 MW and efficiencies of around 95%. On a small laboratory model, however, the output may be only a few Watts. The efficiency will then be much smaller, because losses in bearings and by air friction are proportionally higher than in a large, powerful turbine.

TecQuipment's Pelton Turbine (H19) is a laboratory scale, vertically-mounted turbine with a band-brake dynamometer that measures torque. It allows students to do tests of performance so they can understand how a Pelton turbine works. It works with TecQuipment's Hydraulic Bench (H1d). The bench provides a flow measurement and a recirculating water supply. Refer to the User Guide of the Hydraulic Bench for more details.

Description

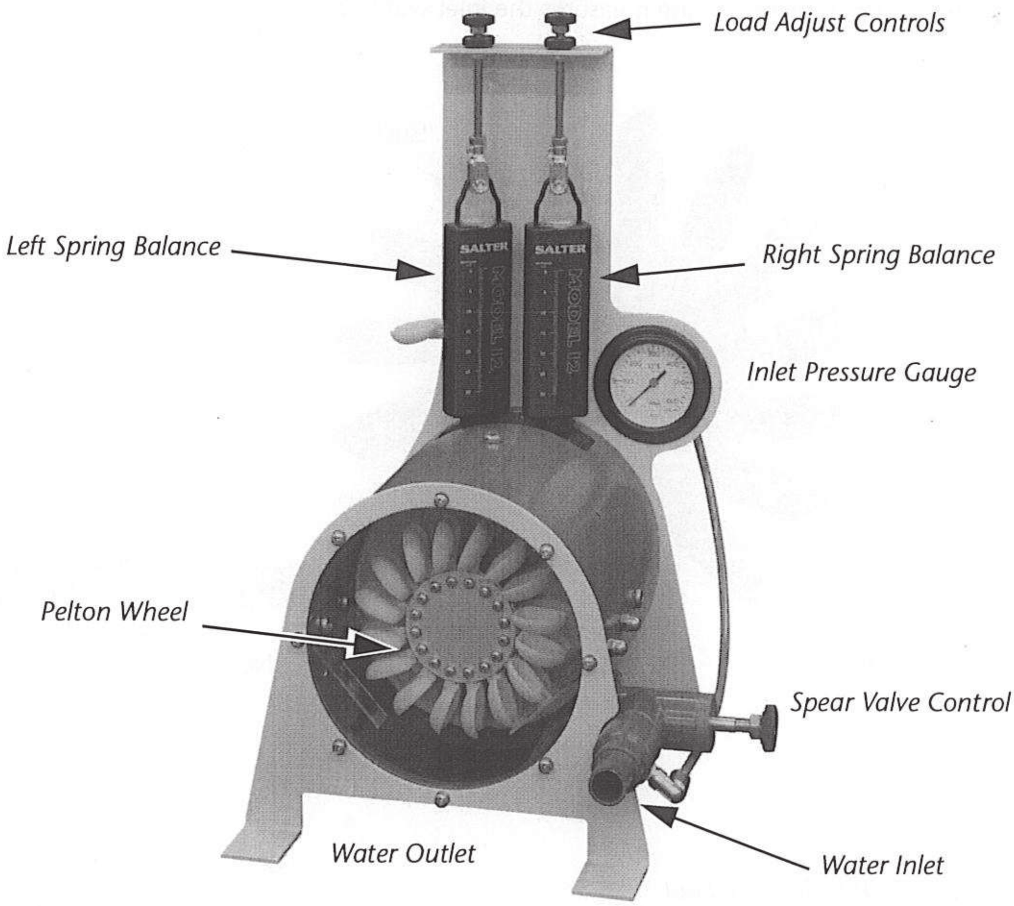


Figure 2 The Pelton Turbine (H19)

TecQuipment's Pelton Turbine is a metal frame that holds a Pelton wheel vertically, so students can see it working. It has an outlet under the wheel to allow water to fall directly into the measuring system of TecQuipment's Hydraulic Bench (H1D).

See Figure 3. The turbine is a wheel with 'buckets' around its circumference. Water passes through a Spear Valve that controls and directs the inlet flow through a nozzle and onto the buckets, pushing the wheel around. The water falls away and directly downwards from the buckets due to gravity. Determined by the date of manufacture, the unit may have an extra 'bucket' screwed to the frame so that students can see their shape and design without needing to take the equipment apart.

The turbine includes a transparent front so students can easily see the water flowing through the turbine. When used with an optional stroboscope, this also helps students to 'freeze' the image of the water flow to see it more clearly.

NOTE *You may need to darken the lighting around the test area to use the stroboscope effectively.*

See Figure 4. At the back of the wheel is a 'brake' drum that works with a cord and two spring balances to measure the torque in the turbine. The drum has a reflector and a clear cover to work with an optional tachometer (such as TecQuipment's OT1) to measure the speed of the turbine. To adjust the load, students adjust the threaded thumb-nuts above the spring balances.

A mechanical pressure gauge measures the inlet water pressure.

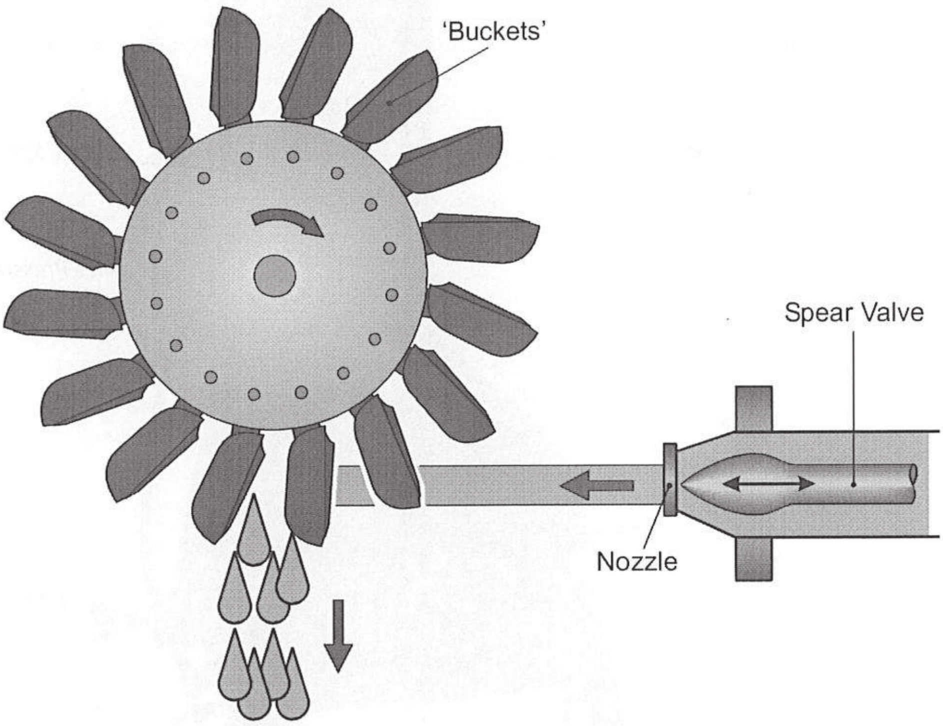


Figure 3 The Pelton Wheel

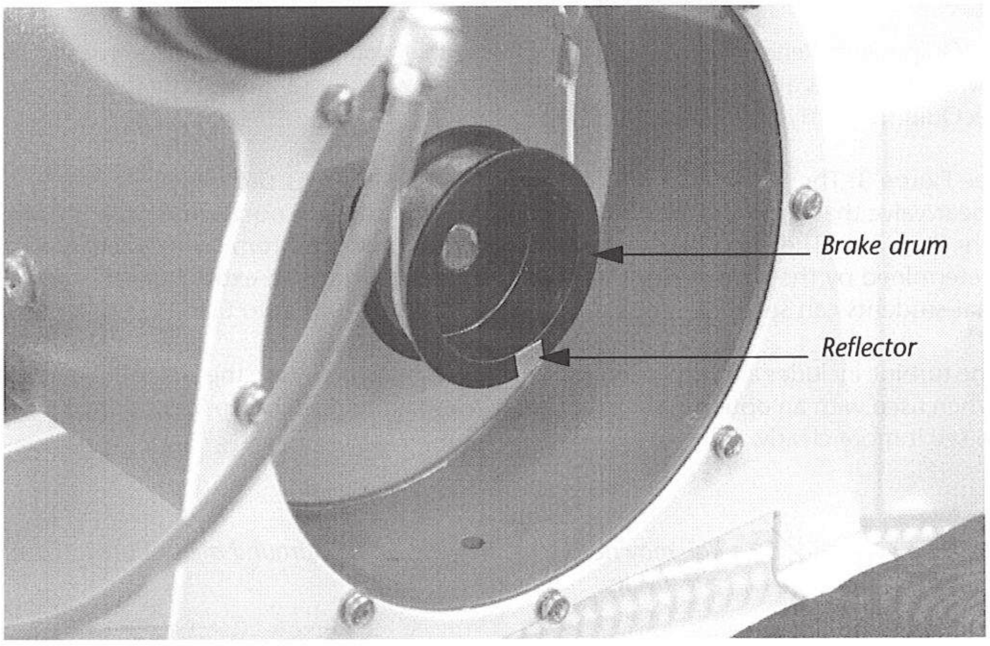


Figure 4 View of Back

Technical Details

Item	Details
Dimensions	470 mm high x 300 mm wide x 330 mm front to back
Nett Weight	5.5 kg (including a length of pipe)
Turbine Type	Pelton
Brake (drum) radius	25 mm (0.025 m)
Effective turbine radius	46 mm (0.046 m)
Nominal power output	3.5 Watts at 500 $rev.min^{-1}$ (when supplied by a Hydraulic bench)
Maximum speed	Approximately 1000 $rev.min^{-1}$ (when supplied by a Hydraulic bench)
Nominal Spear Travel range	6 to 7 mm*
Spear Outlet Nozzle Diameter	10 mm

Spear Valve Positions

Position of spear valve	mm travel
Shut	0
½ turn	0.75 mm
1 turn	1.50 mm
1½ turn	2.25 mm
2 turn	3.00 mm
2½ turn	3.75 mm
3 turn	4.50 mm
3½ turn	5.25 mm
4 turns	6.00 mm
4½ turns	6.75 mm

Table 1 Spear Valve Positions

NOTE **The actual amount of turns or spear travel range will vary due to manufacturing tolerances and amount of use of the spear valve.*

To Assemble and Fit the Pelton Turbine

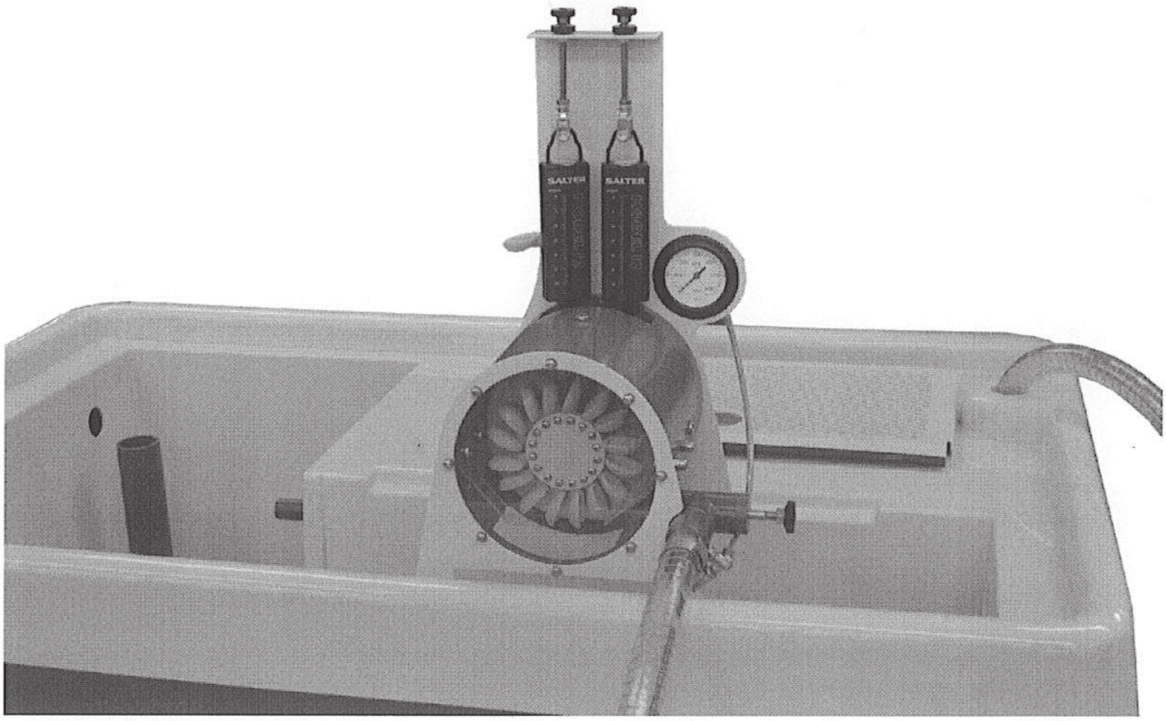


Figure 5 Put the Turbine onto the Top of the H1D Hydraulic Bench

1. Put the turbine onto the top of a Hydraulic Bench (H1d) so that its outlet is over the shallow reservoir part of the bench (see Figure 5).

2. Connect the outlet pipe of the bench to the inlet of the turbine.

Theory

Notation

Symbol	Description	Units
N	Rotational speed of the turbine	rev.min^{-1}
ω	Rotational speed of the turbine	rad.s^{-1}
P_{in} and P_w	Inlet (water) Power and Turbine Wheel (mechanical) Power	W
v	Velocity	m.s^{-1}
η_h	Hydraulic Efficiency	%
T	Torque	Nm
p	Pressure	Pa (Pascals)
Q_v	Volume Flow	m^3.s^{-1} or L.s^{-1} where shown
$\dot{m}$	Mass flow rate	kg.s^{-1}
R_d	Radius of the brake drum	m
D_w	Diameter of the turbine wheel	m
d	Diameter of water jet	m
R_w	Radius of the turbine wheel	m
A and B	Left and right spring balance reading	N (Newton)
F_d and F_w	Force at brake drum and force at wheel	N (Newton)

Conversions

Flow

The hydraulic bench measures volume flow in Litres per minute (L/min). To convert into the SI unit of m^3.s^{-1}, you must divide by 60000. This is a division by 60 to obtain Litres per second, then a division by 1000 to give m^3.s^{-1}.

$$1 \text{ L/min} = 0.0166 \text{ L/sec} = 0.0000166 \text{ m}^3.\text{s}^{-1}$$

Pressure

The pressure gauge may measure pressure in bar, but the SI unit is Pascals, where:

$$1 \text{ bar} = 100000 \text{ Pa}$$

Useful Equations

Turbine Power

This is the power absorbed by the turbine wheel, taken from the water.

$$P_w = \frac{2\pi NT}{60} \text{ or } P_w = \omega T \qquad (1)$$

Torque (*T*)

This is the torque measured by the two spring balances. The balances measure the turning force on the drum at the back of the turbine (see Figure 6).

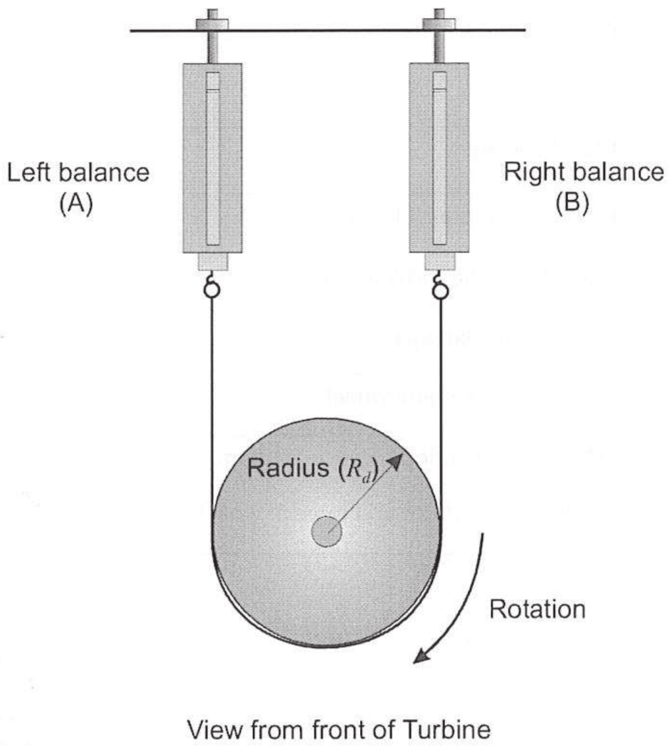


Figure 6 Torque Measurement

The total force is the difference between the readings. Due to the direction of rotation, the right hand balance will give a larger reading than the left hand balance, so for simplicity:

$$F_d = B - A$$

The torque is the radius of the drum multiplied by the force:

$$T = R_d \times F_d \qquad (2)$$

The Pelton Wheel

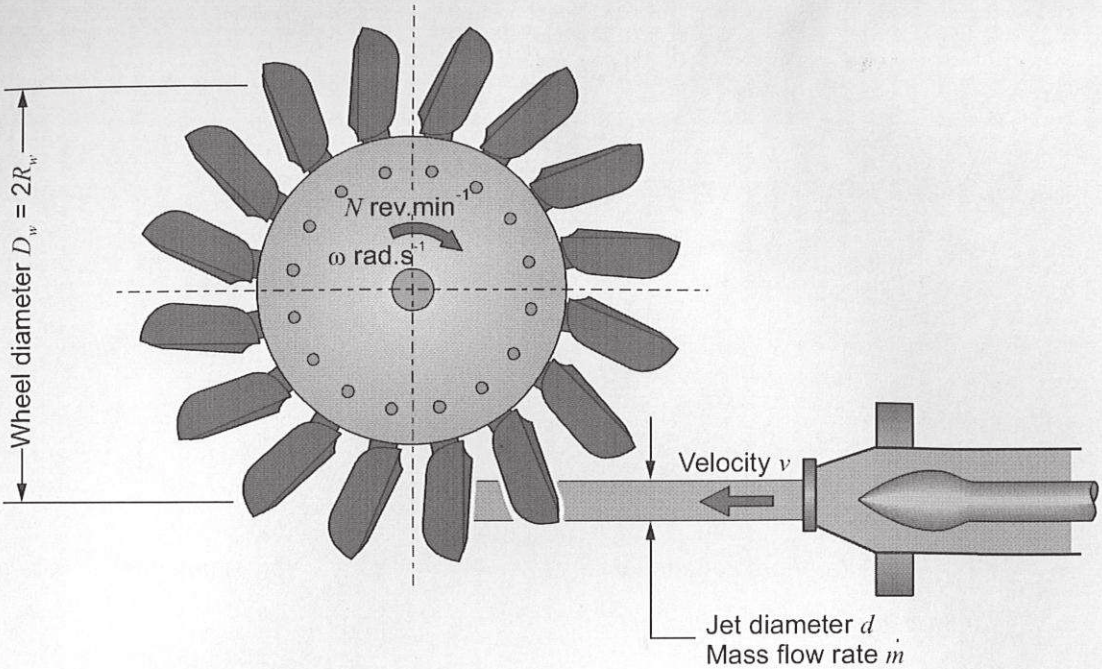


Figure 7 Pelton Wheel layout

The Pelton Wheel needs a source of water in order to run. If the head of water is known, along with the flow rate, then it is possible to find the best size of wheel to use, how fast it should rotate to obtain the maximum efficiency, and what power it is likely to develop.

The velocity in the jet can be estimated by using the known fixed head. The diameter of the jet can then be found from the known flow rate. A suitable wheel diameter can be chosen in relation to the jet size; typically the wheel would have a diameter of 10 times that of the jet. The best speed of rotation may then be selected, such that the speed of the buckets is approximately half that of the jet speed.

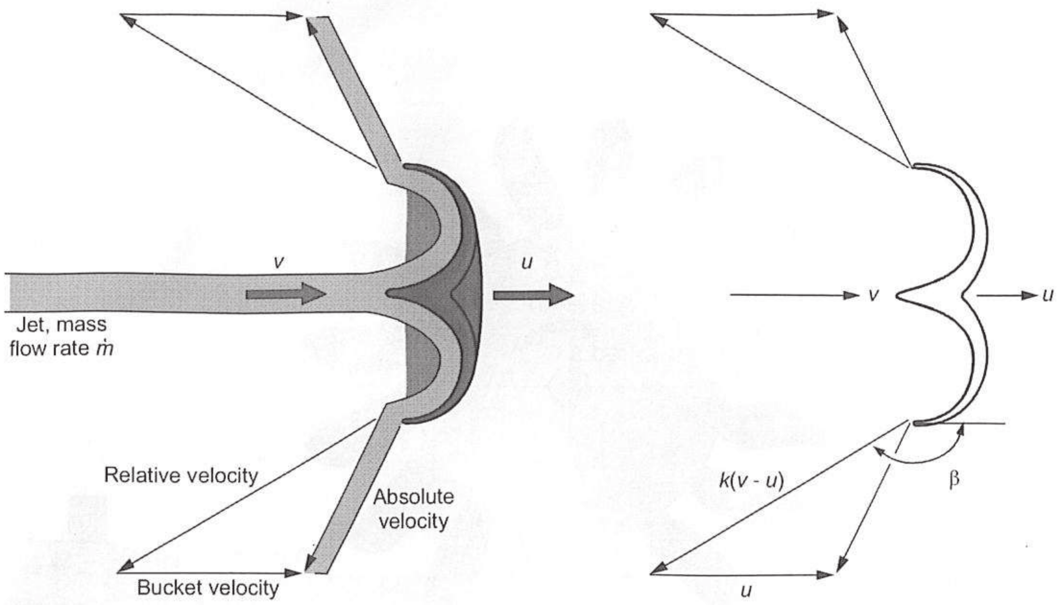
The power delivered in the jet can be calculated from the speed and cross-sectional area of the jet. The power developed by the Pelton wheel will be less than this, in the ratio of the wheel's efficiency, which may be estimated by reference to the known performance of existing machines of comparable size and output.

Depending on the head and flow rate available, the size and speed of the Pelton wheel obtained in this way may prove to be impracticable or uneconomic. Fortunately, other types of water turbine are available to suit a wide variety of circumstances.

The Pelton wheel is usually chosen when the available head is high, but the flow rate is comparatively low.

Force Exerted by a Jet

Figure 8a shows a water jet emerging at speed v from a nozzle, and striking one of the buckets of the wheel, which itself is moving at speed u. The mass flow rate is $\dot{m}$ and it is assumed that all of the water emerging from the nozzle strikes one or other of the set of buckets arranged around the periphery of the wheel, although, for simplicity, just one bucket is shown in the diagram.



(a) Force exerted by a jet *(b) Momentum change diagram*

Figure 8 Water Jet Striking Bucket

The relative velocity at which the jet impacts on the bucket is $k(v - u)$. The flow over the bucket is decelerated slightly by frictional resistance at the surface. Suppose that the relative velocity, as the water leaves the bucket, is $k(v - u)$, where k is a velocity reduction factor with a value somewhat less than unity.

The relative velocity is inclined at the bucket exit angle β to the jet's direction. The absolute velocity of the water at exit is the vector sum of the relative velocity and the bucket velocity u, as shown.

The force F_w generated on the bucket may be found by considering the momentum change, as shown in Figure 8b. The incoming rate of momentum flow in the direction of motion of the bucket is $\dot{m}v$, and the outgoing rate is:

$$\dot{m}[u + k(v - u)\cos\beta]$$

Note the positive sign before the relative velocity at exit, indicating addition of the relative and bucket velocities. Note also that β is greater than 90°, therefore cosβ will be negative.

Torque Exerted on the Wheel

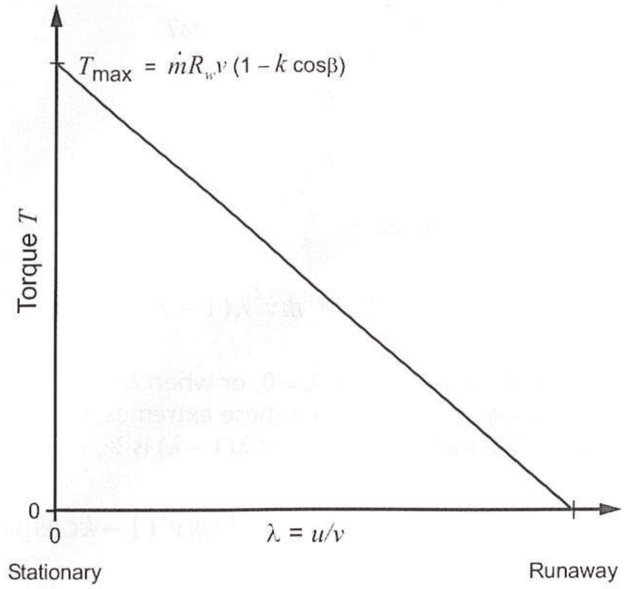


Figure 9 Variation of torque T with speed ratio λ

The force F_w produced on the bucket by the difference between these rates of momentum flows is:

$$F_w = \dot{m}v - \dot{m}[u + k(v - u)\cos\beta]$$

or

$$F_w = \dot{m}(v - u)(1 - k\cos\beta)$$

It is helpful to express the ratio of bucket speed u to jet speed v as λ:

$$\lambda = \frac{u}{v}$$

so that

$$F_w = \dot{m}v(1 - \lambda)(1 - k\cos\beta)$$

The torque T exerted on the wheel is therefore:

$$T = \dot{m}R_w v(1 - \lambda)(1 - k\cos\beta)$$

We see that for a particular wheel, supplied with water at some fixed flow rate (so that both $\dot{m}$ and v are also fixed), torque T varies as $(1 - \lambda)$. The torque therefore falls linearly from a maximum when $\lambda = 0$ (i.e. when the wheel is stationary) to zero when $\lambda = 1$ (i.e. when the bucket moves at the same speed as the jet). This is referred to as the runaway condition.

Power and Efficiency

The power output P_w developed at the wheel is given by:

$$P_w = \omega T$$

and noting that:

$$u = \omega R_w$$

The power output may be written as:

$$P_w = \dot{m}v^2\lambda(1-\lambda)(1-k\cos\beta)$$

This varies as $\lambda(1 - \lambda)$, so P_w is zero when $\lambda = 0$, or when $\lambda = 1$, i.e. when the wheel is either stationary or when turning at runaway speed. Between these extremes, the power varies parabolically, with a maximum when $\lambda = ½$. The maximum value of $\lambda(1 - \lambda)$ is ¼, so the maximum power output is:

$$P_{wmax} = \tfrac{1}{4}\dot{m}v^2(1-k\cos\beta)$$

Hydraulic Efficiency

The power input P_{in}, in the form of kinetic energy in the jet, is:

$$P_{in} = \tfrac{1}{2}\dot{m}v^2$$

However, the velocity calculation needs an accurate jet area, which is difficult to measure. You can predict the area at the exit to the spear, but the jet narrows slightly downstream from the spear to a 'vena contracta', of an unknown diameter. For further proof of this, TecQuipment manufacture equipment that allows you to measure the diameter of water jets emitting from nozzles and orifices.

Without an accurate figure for the jet diameter, the inlet pressure (shown on a small gauge) and water flow (measured by the hydraulic bench) give a good approximation of the inlet power from:

$$P_{in} = Q_v p$$

Where Q_v is in $m^3.s^{-1}$ and the pressure is in Pascals.

The hydraulic efficiency η_h, defined as the ratio of output power to input power is:

$$\eta_h = \frac{P_w}{P_{in}} = 2\lambda(1-\lambda)(1-k\cos\beta)$$

with a maximum value:

$$\eta_{max} = \tfrac{1}{2}(1-k\cos\beta)$$

In terms of percentage:

$$\eta_h = \frac{P_w}{P_{in}} \times 100$$

In the absence of friction, the relative speed is not reduced by passage over the bucket surface, so the value of k would then be unity. Moreover, the lowest conceivable value of $\cos\beta$ is -1, corresponding to $\beta = 180°$. So the factor $(1 - k\cos\beta)$ could ideally just reach the value 2. The maximum ideal efficiency, η_{max}, would then just reach 100%, all the kinetic energy in the jet being transformed into useful power output, with the water falling from the buckets with zero absolute velocity. In practice, however, surface friction over the bucket is always present, and β cannot reasonably exceed a value of about 165°, so you can never reach 100% efficiency.

It must be emphasised that the hydraulic efficiency used here gives the ratio of hydraulic power generated by the wheel to the power in the jet. The overall efficiency of the turbine will fall short of this hydraulic efficiency due to some loss of head in the nozzle, air resistance to the rotating turbine, and losses at the bearings.

As shown in Figure 10, you can reasonably expect a maximum efficiency of around 60% for this small turbine. Your results should show that the turbine may not be most efficient at its maximum power position and that the spear valve position affects maximum speed, torque, power and efficiency.

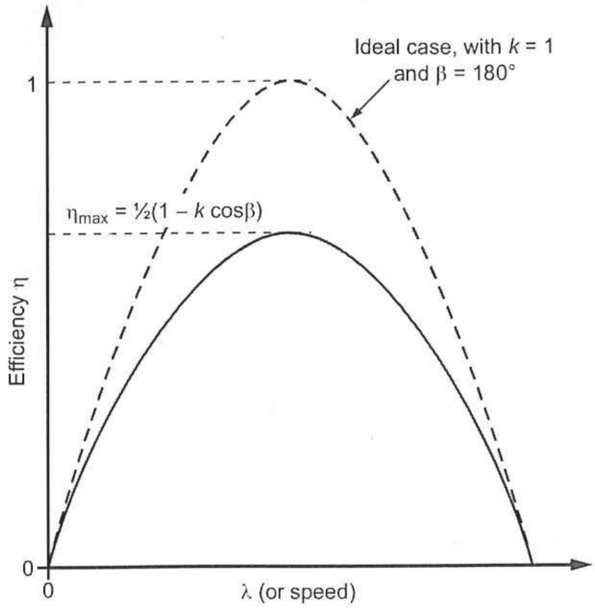


Figure 10 Theoretical Variation of Efficiency with Speed

Experiments

Useful Notes

Load Control

To change the load, you may adjust just one load adjustment screw, but you may find better load control if you adjust both load adjustment screws at the same time.

Assistance

During these experiments, you must record lots of readings. This is much easier if you have an assistant or if you work in small groups.

'Running in' the Turbine

The turbine uses seals to prevent water entering its bearings. When the seals are new or the turbine has not been used for some time, the friction caused by the seals can be higher than normal. Therefore, you must run the turbine for a few minutes before you do any tests. This is important because the turbine is small, so friction has a large effect on its performance.

Water Level

You must have the correct water level in your hydraulic bench, if it is too low, your results will be low.

Drain Hole

Occasionally a small amount of water may pass through the turbine seals and enter the bearings towards the brake drum. A small drain hole under the brake drum allows this water to drain away. Normally this will be just a few drops of water. If it becomes a constant stream of water, contact TecQuipment.

Experiment

Aims

To test the Pelton Turbine at different loads and spear valve settings and produce curves that show the turbine performance and the effect of different spear valve settings.

Procedure

1. Create three blank results table, similar to Table 1.

Initial Flow: **Spear Valve Setting:** **Inlet Pressure:** **Inlet Power:**					
Speed (rev.min^{-1})	**Left Balance (N)**	**Right Balance (N)**	**Load (Torque) (Nm)**	**Power (W)**	**Efficiency (%)**

Table 1 Blank Results Table

2. Adjust the spring balances to give no load and make sure that they show 0 (zero).
3. Fully shut the spear valve (turn it fully clockwise).
4. Start the hydraulic bench and slowly open its control valve while opening the H19 spear valve (turn it anticlockwise) until the bench flow is at maximum and the spear valve is fully open.
5. Use the Hydraulic Bench to measure the initial flow for reference. Note the inlet pressure.
6. Use the optical tachometer to measure the maximum (no-load) speed of the turbine. To do this, put the tachometer against the clear window at the back of the turbine and use it to detect the reflective sticker on the drum.

7. Slowly increase the load in steps to give at least six sets of results. At each step, record the turbine speed and the reading of each spring balance. Stop when the speed becomes unstable or the turbine stops rotating.

8. Repeat the test with the spear valve approximately half (50%) open and approximately quarter (25%) open. The exact amount of spear valve opening is not important, as long as long they are different from each other to compare the effect.

Results Analysis

For each table of results:

- Use the inlet pressure and flow to calculate the inlet power.
- Use your results and Equations 1 and 2 given in the theory section to calculate torque and mechanical power.
- Divide the mechanical power at the turbine by the fluid inlet power to find the turbine efficiency.
- Produce charts of torque and mechanical power at the turbine (vertical axis) against speed (horizontal axis) for each spear valve opening.
- Produce charts of efficiency against speed.

Compare your results. How does the spear valve position (opening) affect performance? How does the power in the turbine change with speed? What conditions give the best power, speed and efficiency?

Typical Results

These results are typical, using a brand new hydraulic bench and turbine. They are for guidance only. Your results may be slightly different, determined by the water level in your hydraulic bench, the age of your equipment and the water temperature.

Typical Calculation

Speed = 620 rev.min^{-1}

Left balance = 2 N, right balance = 4.25 N, Torque = 0.05625 Nm

Mechanical power at turbine = (2 x 3.142 x 620 x 0.05625)/60 = 3.65 Watts

Pressure at inlet gauge = 250 mbar = 25000 Pa

Water flow = 35 Litres in 82 seconds = 0.427 Litres per second

Power at inlet = 25000 x (0.427/1000) = 10.675 Watts

Efficiency = 3.65/10.675 = 0.34 = 34%

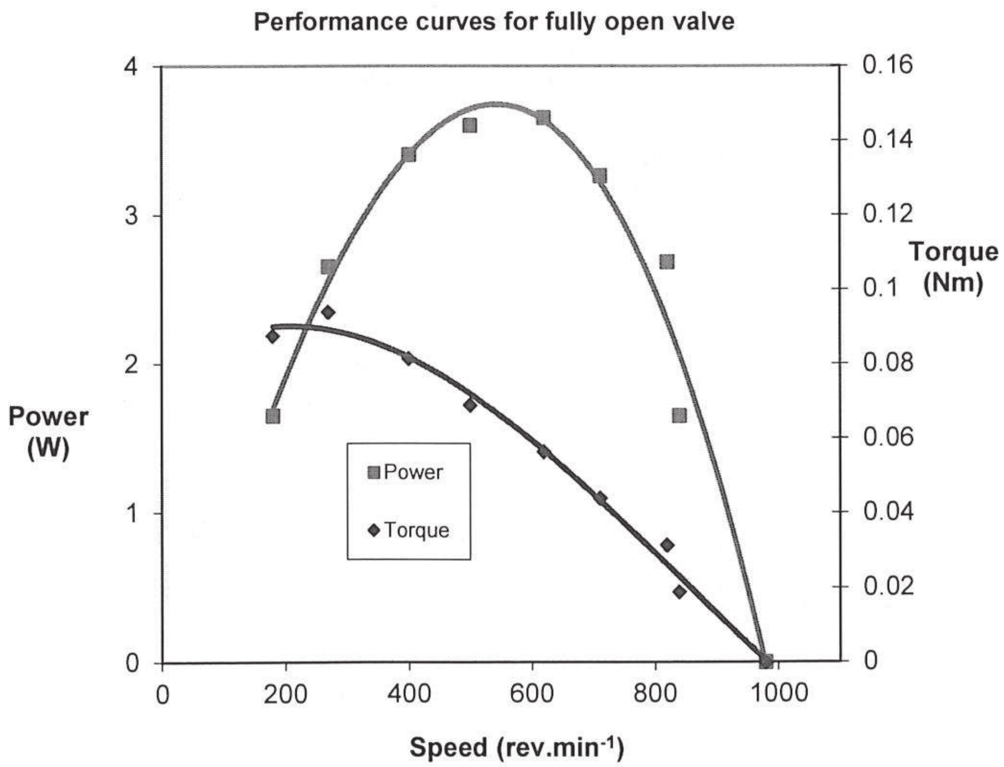


Figure 11 Fully Open Valve

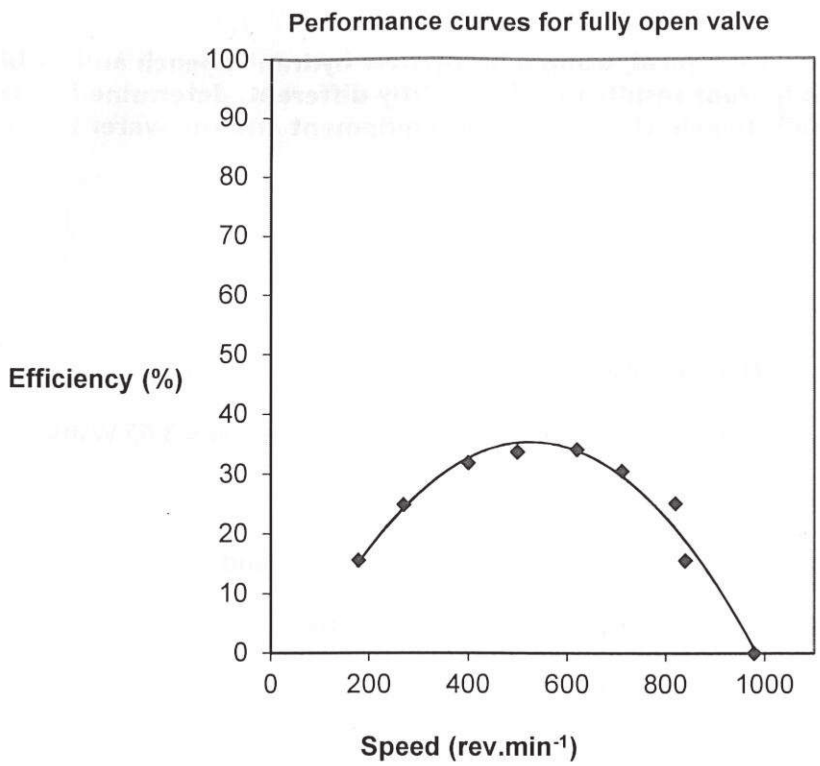


Figure 12 Fully Open Valve

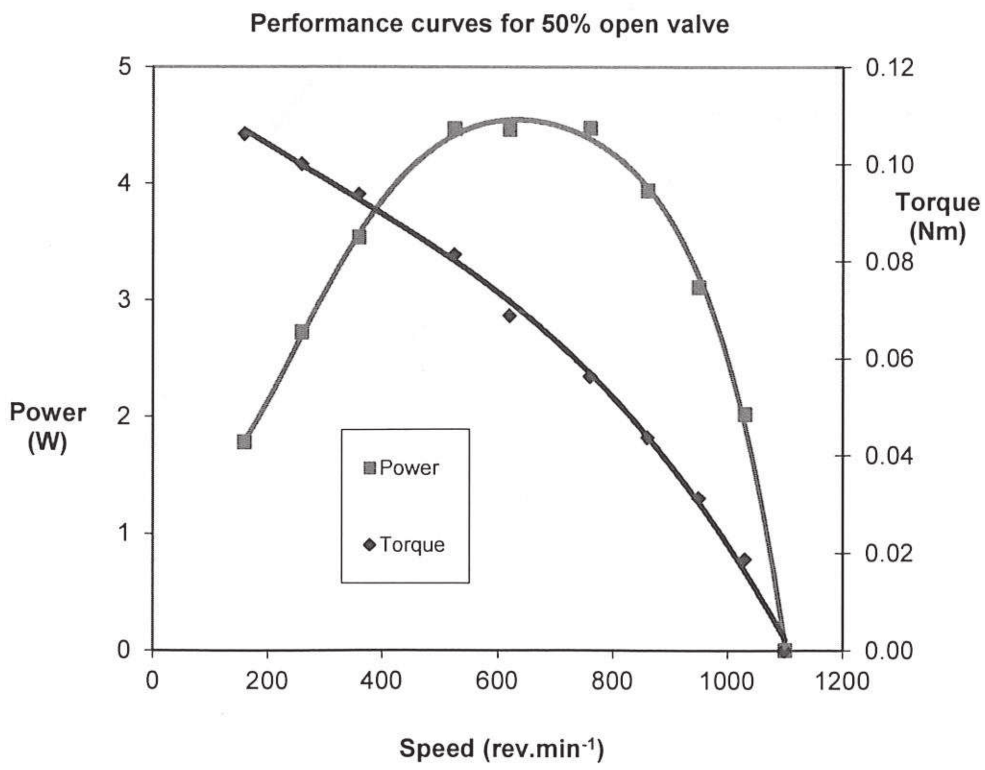


Figure 13 50% Open Valve

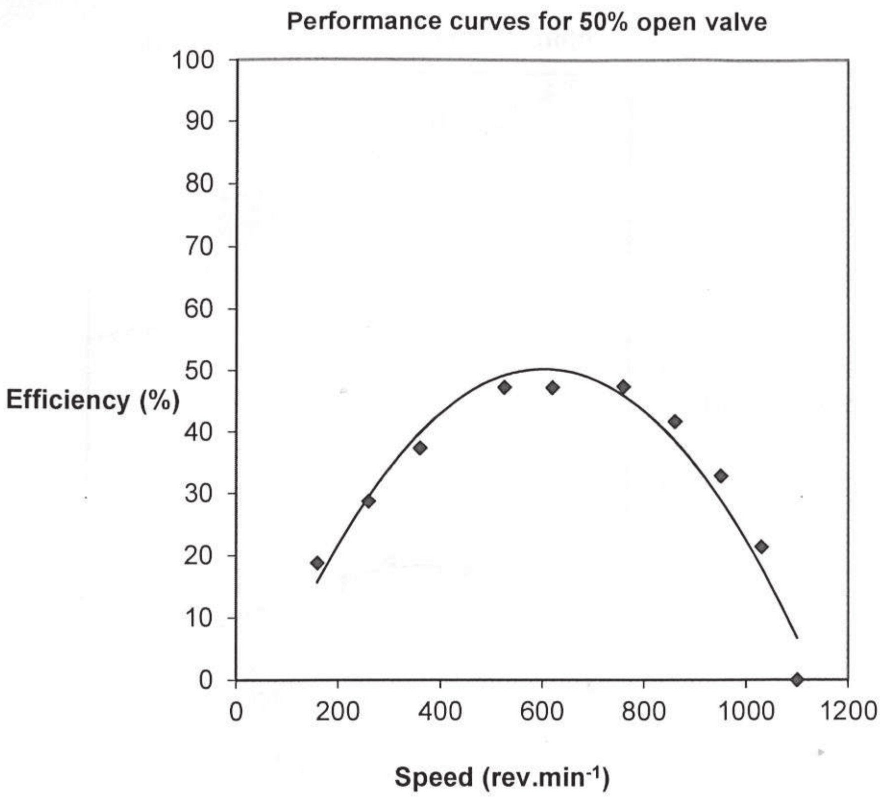


Figure 14 50% Open Valve

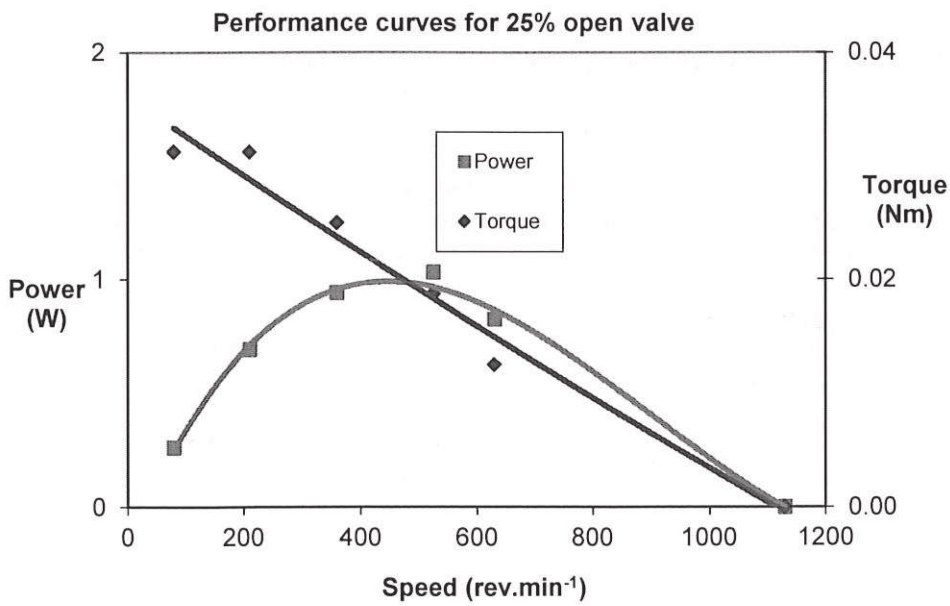


Figure 15 25% Open Valve

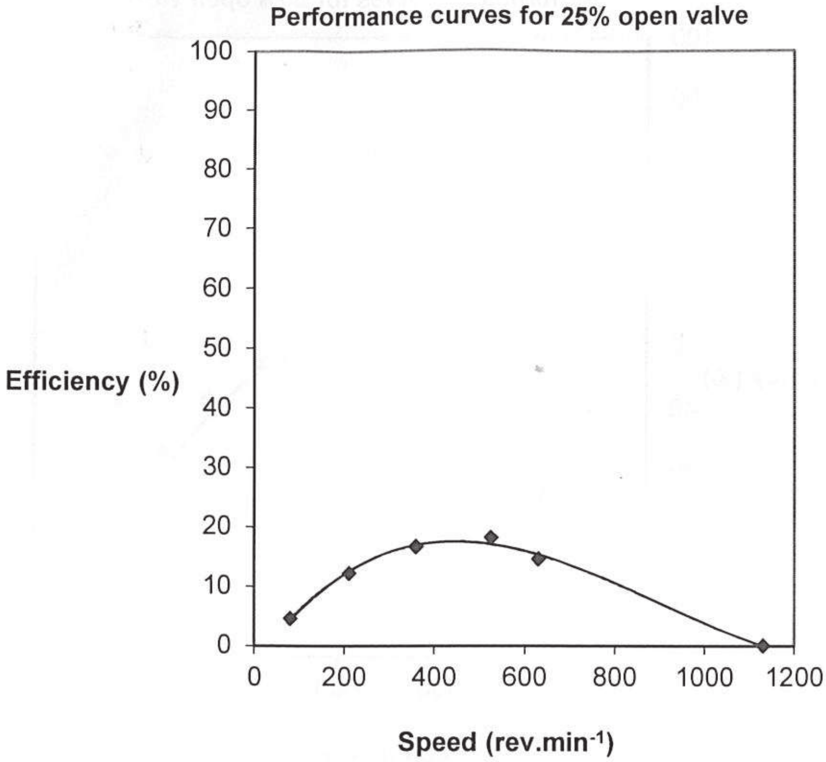


Figure 16 25% Open Valve

Conclusions

Note that the turbine is relatively small by normal standards, so you cannot expect high efficiencies and highly accurate results, due to the relatively high losses in the bearings and other moving parts compared with the size of the turbine.

The results should show that the turbine does not necessarily produce its maximum power when the spear valve is fully open. The turbine tested gave maximum power and efficiency with the spear valve fully open. Note that the fully open results give a slightly lower maximum speed.

These results suggest that the buckets catch the energy in the water more efficiently when the spear valve is half open, and generate more power. Also note that the peak power with a fully open valve is at a slightly lower speed than that for the half open valve.

Each power curve should show a trend of increasing up to a maximum at around half maximum speed, then decreasing. Note that the torque results produce almost straight lines, decreasing with speed.

The 25% open valve results should generally show all round poor performance, but the exact jet size is very unpredictable at this setting, so expect a wide variation of results.

The results suggest that the spear valve affects each variable in different ways, so assuming a constant load, the valve can allow you to fix a given torque, speed, power or best efficiency for the turbine.

Maintenance, Spare Parts and Customer Care

After use, disconnect and drain any water from the turbine and dry it down with a clean cloth. Make sure that the spring balances are loose (no load). Store the turbine in a dry and dust free area, suitably covered.

To clean the apparatus, wipe clean with a damp cloth - do not use abrasive cleaners.

Spare Parts

Check the Packing Contents List to see what spare parts we send with the apparatus.

If you need technical help or spares, please contact your local TecQuipment agent, or contact TecQuipment direct.

When you ask for spares, please tell us:

- Your name
- The full name and address of your college, company or institution
- Your email address
- The TecQuipment product name and product reference
- The TecQuipment part number (if you know it)
- The serial number
- The year it was bought (if you know it)

Please give us as much detail as possible about the parts you need and check the details carefully before you contact us.

If the product is out of warranty, TecQuipment will let you know the price of the spare parts.

Customer Care

We hope you like our products and manuals. If you have any questions, please contact our Customer Care department:

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