Technology Focus – Turbine Flow Meters

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GOING ROUND IN CIRCLES: WORKING PRINCIPLES AND DESIGN FEATURES OF TURBINE FLOW METERS

This **technical paper** combines Part 1 and Part 2 of our turbine series where Titan Enterprises explains the working principles of the Pelton Wheel and other turbine flowmeters and discusses five critical design features.

Turbine flow design has changed little since their invention in the eighteenth and nineteenth centuries due to the simplicity and power of these devices to extract energy from the movement of a flowing water source.

Turbine flow meters are one of the most commonly used and simplest methods of measuring liquid flow, from water and beer to aggressive chemicals, including ultra-pure water. The variety of turbine flowmeters are based on the mechanics – the physical orientation of the turbine in relation to the fluid flow.

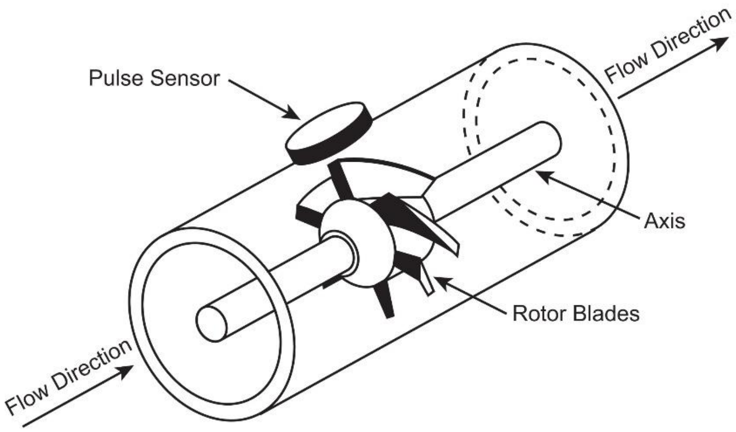
Part 1: Working Principles of the Pelton Wheel and other Turbine Flowmeters

Turbine flowmeters work in two primary ways:

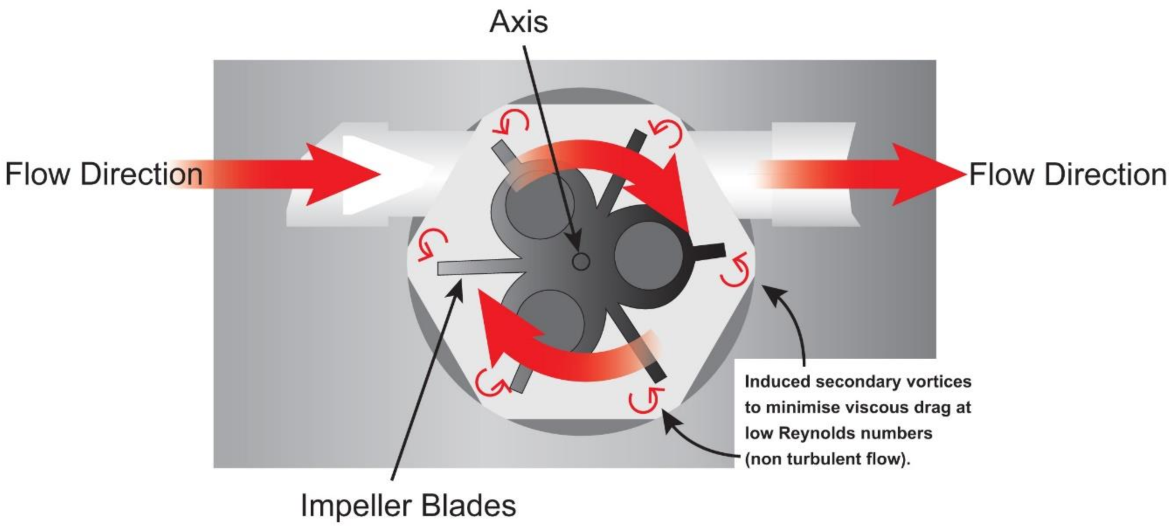
1. Analogous to a propellor or windmill – Axial turbine
2. Analogous to a water wheel – Radial turbine

Turbine flowmeters measure the flow rate of a fluid within a pipe or process line by utilising a rotor or turbine that rotates on an axis as the fluid moves across its blades. As the turbine rotates, each blade of the turbine passes a sensor which outputs a pulse signal. The speed at which the turbine rotates is directly proportional to the volumetric flow rate and the number of pulses the total volume passed.

In an axial turbine, the fluid flows along the rotation axis where the fluid enters and exits in the same direction, the fluid striking the angled turbine blades:



In contrast, fluid flowing through a radial turbine strikes the plain blade in the direction of the tangent or 90° to the rotational axis (hence also referred to as tangential flow):



Titan Enterprises released its first flowmeter sensor in 1981, a turbine device based on the Pelton Wheel design and working principles of the radial turbine.

The Pelton wheel, conceived by Lester Pelton in the 1870's, is an energy extraction device. Its working principle and design are simple: characterised by a series of distinctive reaction cups, to extract as much energy as possible from the moving liquid, typically to generate electricity. These cups or buckets efficiently capture the momentum of high-velocity water jets, inducing an impulsive force. This force makes the turbine rotate and the rotating shaft runs a generator to produce electricity. As the energy available is only kinetic energy, the Pelton wheel is an example of an impulse turbine.

Claimed to be the world's largest electricity generating Pelton Wheel, this example is installed at the Eiriksdal Hydropower Plant in Norway and generates up to 30MW of power.

(Trevor Forster, MD of Titan Enterprises)

Such impulse turbines do not require an enclosed case, whereas Radial flow turbines have very different requirements. They must operate in an enclosed pressure chamber and have a linear velocity to flow rate characteristics. Early flowmeters were designed using radial flow onto blades (without reaction cups) with single or multi-jets of liquid. In the last seventy years or so, as accurate measurement of lower flow became a requirement, smaller meters were produced and became known as the generic Pelton wheel flow meter we know today where a single jet impinges a flat blade in an enclosed chamber. There are many design variations of these devices to ensure the best overall performance is attained. The most common system is to simply point a jet radially at a turbine and place the outlet directly opposite the inlet. The turbine has multiple flat blades, from 3 to many more. Titan has utilised up to 12 blades in order to increase the resolution on custom-designed OEM turbine flowmeters, thus improving the accuracy of low volume dispense.

Titan's mini turbine flowmeter range use the radial flow principle based on the Pelton wheel technique. This well proven method is the ideal way of measuring low rates of flow of low viscosity liquids. For these mini flowmeters, a jet of fluid is directed at a turbine that is mounted on robust low friction sapphire spindle and bearings. The geometry of the turbine and the fluid chamber ensures that the rotational speed of the rotor is proportional to the flow rate through the device. The use of this radial arrangement allows more energy to be imparted into the turbine, so the bearing drag is far less important. Furthermore, because more energy is available the bearings themselves can be a lot stronger, increasing the life of the flowmeter. For larger flows, some of the liquid can bypass the turbine chamber, which then behaves as a "shunt" to the metered fluid. Accuracy is still maintained and the output remains linear.

Axial flow turbines are typically larger and have a higher flow throughput. Generally more efficient at moving large volumes of air or fluid at lower pressures, they are more suitable for large-scale, high-speed applications where high flow rates and low pressure drops are of prime importance. As such conventional axial turbines are commonly used in thermal power plants, propulsion aircraft engines, wind turbines, and cooling fans for electronics and HVAC systems. Complex designs, manufacture and maintenance of axial turbines can be costly and challenging, becoming increasingly difficult to manufacture as size is reduced and bearing drag becomes more significant.

On the other hand, radial turbine flowmeters are better suited for applications requiring low flow rates, typically seen in medical applications and laboratory work.

Whilst offering many advantages and ideally suited to handling clean fluids, the turbine flowmeter has one Achilles' heel: it is very sensitive to changes in liquid Reynolds Number; a product of viscosity and density, therefore temperature and, for gas fluids, pressure. Turbine flow devices perform most efficiently with turbulent flow of liquid through the meter. Laminar flow and viscous drag can disrupt the dynamic behaviour of this type of flowmeter which ultimately affect the accuracy of flow measurements. To mitigate this effect, Titan use a hexagon-shaped chamber which permits the formation of vortices that reduce the drag and assist the linearity into the laminar flow region.

Titan's range of turbine flow meters offers numerous advantages for industry application:

- Low cost compared to other flow measuring technologies
- Fast response time with high repeatability
- Easy to install and maintain
- Provide direct volumetric flow measurement
- Long life of bearings
- Many can be coupled with display instruments (such as Titan's Pulsite® Solo or Pulsite® Link)
- Acceptable pressure-drop
- Can be used as flow switches

Part 2: 5 Critical Design Features for Pelton Wheel Turbine Flowmeters

The design challenge for turbine flowmeters based on the working principles of this type of radial turbine is primarily straightforward: simple electronics versus complex precision engineering.

In developing a cost-efficient and reliable Pelton wheel turbine flowmeter, Titan Enterprises considers five critical design elements:

1. Excellent linearity and repeatability
2. Long operational life
3. In-line meter connections
4. Good chemical resistance of materials
5. Ease of manufacture

1. Linearity and repeatability

Good linearity and excellent repeatability are essential in any turbine flowmeter, and one of the more subtle critical design areas is that of the radial clearance of the turbine in the housing. If the radial clearance is too small there is a constant drag with the chamber wall that causes problems with linearity and changes in fluid properties. Too large a clearance and the chamber volume becomes unacceptable and the entrainment of gasses becomes problematic. The same is true with the side clearances. There are a series of solutions to turbine drag as the chamber velocities start to become laminar.

Titan use a hexagonal chamber that permits the formation of vortices which reduce the drag and assists the linearity into the laminar flow region. Other turbine designs use square chambers or square chambers with posts in the four corners, effectively generating the space for eight vortices.

With known fluid properties and careful calibration techniques, variations affecting linearity and repeatability can be ‘calibrated out’. Designing-out some of these issues to give good flowmeter performance ensures the resulting solution doesn’t become overly expensive.

2. Long operational life

The linearity and repeatability are also linked to the design of the bearings. Here, special care must be taken in both bearing design and choice of materials to ensure long, reliable operational life. The most common fluids used in these devices are water-based and many bearing materials would not be suitable for long term use due to the poor lubricating qualities of water, increasing wear. Add to that the requirement of aggressive chemicals and the bearing material options are further reduced.

With low flow rates and the energy available from the fluid minimal, the bearings must also be of low friction and able to maintain the original level of friction for the operational life of the meter. For a domestic coffee machine for example, this may only be four hundred hours of use so a simple metal spindle in plastic housing would be sufficient. Whereas the operational life of flowmeters used in medical equipment is more likely to be 4 years plus, so a more durable bearing material like sapphire or ruby would be more suitable.

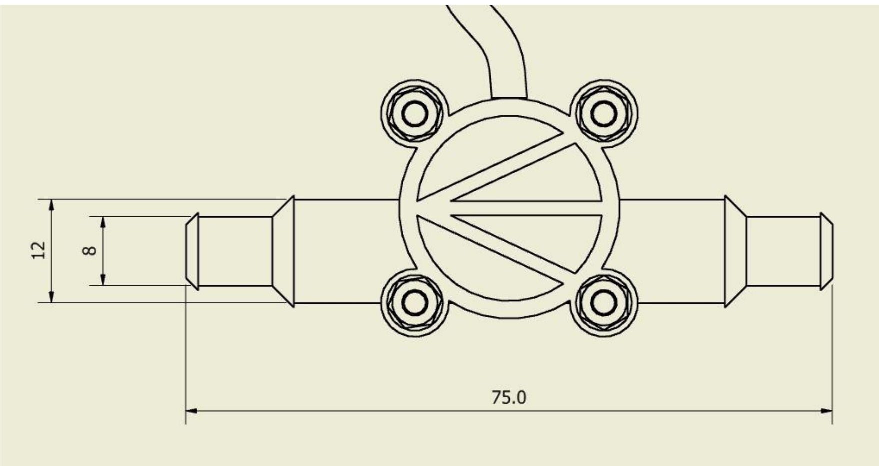
The loads on the bearings can be quite high so there is a trade-off to consider between bearing life, low friction and the meter's lifespan. A ball and cup bearing would give low friction and excellent low-end performance when new, but the wear on the extremely small contact area would soon result in turbine precession affecting linearity and repeatability.

Titan utilise a sapphire spindle and bearing arrangement, and together with their recommended installation, this ensures the flow devices continue to operate within specification for years.

3. In-line meter connections

With a rotating turbine, the lower density gasses tend move towards the spindle and can stay there under certain conditions effecting the meter linearity and life of the bearings. One solution is to extract the fluid axially on the centre line of the turbine's rotation, leaving the inlet and outlet connections at 90° to each other. This 90-degree inlet to outlet orientation is not always acceptable and can cause problems for installation. However, this can be solved with a complicated housing but this will result in a retained fluid volume increase, as well as compromising the bearing arrangement.

Some flowmeter manufacturers run the incoming stream at an angle so that it wraps its way around a wider than normal blade and exits at a corresponding angle to the inlet jet, one whole revolution later. Two hundred and seventy degrees of wrap-around is also quite common but this tends to leave the inlet and outlet on the same 'face' of the device or requires the incorporation of a manifold system.



Titan's In-line Radial Turbine Design

Titan chose the in-line radial design, i.e. the inlet and outlet are opposite each other, for 3 key reasons:

- Ease of installation for the customer
- Lower manufacturing costs which result in a cost-effective meter
- To minimise the pressure drop within the customer's piping system

4. Good chemical resistance of materials

The turbine itself seems like a simple element but it must also be carefully considered. Low mass is important, so a polymer is often used in turbine manufacture, and occasionally the turbine's density is matched to the fluid to fractionally reduce bearing load at start-up. A potential issue here is that the turbine's rotation must be detected somehow. Optical detection allows for no extra mass increase to the turbine, but liquid measurement is restricted to optically clear fluids and any build-up of deposits on the optical path can stop detection.

Some manufacturers use curved or tapered blades on the turbine. If magnetic or inductive detection is required, a suitable magnetic material insert is necessary, and this should be over-moulded to protect it from aggressive chemicals.

Titan produce the majority of their turbine devices in NSF-approved PVDF (suitable for food and medical applications), and overmould the magnets to ensure long-life in the most corrosive chemical environments.

5. Ease of manufacture

To ensure ease of manufacture, the design should integrate the latest innovations in moulding and machining technologies, accommodating various flow ranges and simplifying production. From the outset, components should be designed for easy interchangeability and made from high-grade materials to enhance durability and streamline assembly. This approach not only optimises manufacturing efficiency but also ensures consistent quality and performance.

To conclude, a Pelton wheel turbine is not just the simple paddle in a chamber. It is the perfect device for cost effective low-flow measurement and the choice available is extremely wide from the $1 meter for your coffee machine, through to a device costing tens of thousands for demanding industrial use.

As with all flowmeters, it is essential to ensure you are choosing the correct sensor for your application. When specifying a flowmeter, Titan Enterprises recommends the following considerations:

- Is the flow range, pressure, temperature and chemical resistance acceptable for your application?
- Is the flowmeter cost-effective over the lifetime of the installation?
- Does it have the performance required for the application and will it maintain that performance over the operational window?
- Are the suppliers/manufacturers knowledgeable in their technical capabilities and honest in their specifications?

Visit Titan Enterprises' website for full technical information on Titan's turbine flowmeters. To discuss your specific OEM application, please contact Titan Enterprises on +44 (0)1935 812790 or email sales@flowmeters.co.uk.