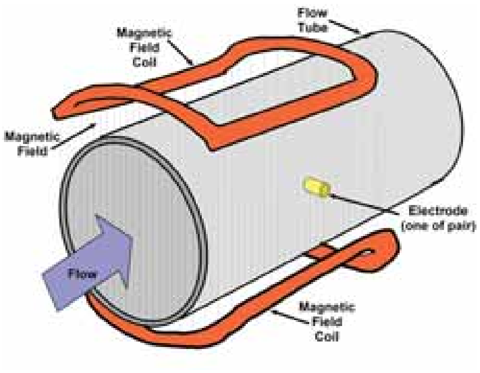
by Jesse Yoder, Ph.D.

Pioneers of Flow Measurement

Founding the Technologies of Today

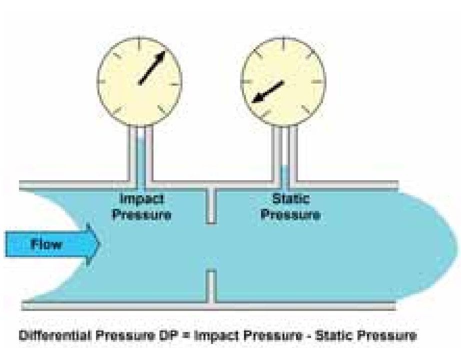
It is easy to forget in today's fast-paced world the importance of the many thinkers and pioneers who have made modern-day technologies possible. This is as true in the area of flow measurement as it is in other technology segments. The following looks at some of the pioneers of flow measurement, who formulated many of the principles that underlie the sophisticated flow instruments of today.

Michael Faraday (1791–1867) is one of the key players in the development of magnetic flowmeters. He is known for formulating Faraday's Law of Electromagnetic Induction. According to this principle, a voltage is generated when a conductor moves through a magnetic field. This voltage is proportional to the velocity of the conductive fluid moving through the field. This is the principle that underlies the operation of magnetic flowmeters today.



Electromagnetic flowmeters utilize Faraday's law for conductive fluids.

Though Faraday died in 1867, it was not until 1952 that the first commercial magnetic flowmeter was introduced in Holland. Today, revenues from magnetic flowmeters worldwide are second only to the combined differential-pressure market, including transmitters and primary elements. Magnetic flowmeters are the leader in measuring liquid flows, especially for waster and wastewater. While magnetic flowmeters can measure most types of liquids, they cannot measure the flow of hydrocarbon-based liquids, and they cannot measure gas or steam flow.



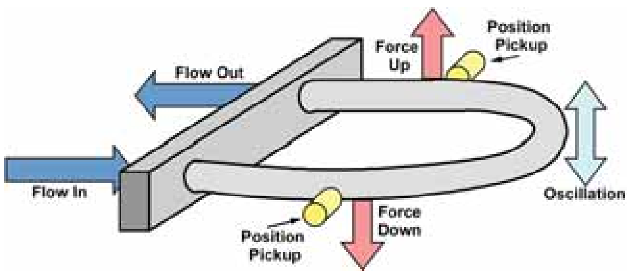
Bernoulli's theory is the basis of differential-pressure flowmetering technology, which relies on the presence of a constriction in the flowstream, such as an orifice plate. Orifice plates create a pressure drop that is a function of flow velocity.

Daniel Bernoulli (1700 – 1782) is most closely associated with differential-pressure (DP) flow measurement. He formulated what is known as Bernoulli's theorem. According to this principle, in a flowing stream, the sum of a fluid's static energy, kinetic energy, and potential energy is conserved across a constriction in the pipe. This constriction is called a primary element, and it introduces a difference in downstream pressure compared to the pressure upstream from the constriction. A DP flow transmitter is used to measure the pressure differential, and it uses this information to compute flowrate. Alternatively, this information is fed to a flow computer, which performs the computations.

DP flow is the most studied and best understood type of flow measurement. One aspect of DP flow measurement that is sometimes overlooked is the difference in types of primary elements. While orifice plates are the most commonly used type, Venturis, flow nozzles, and averaging Pitot tubes are also widely used. Venturis are sometimes used for measuring flow in large water pipes, and flow nozzles are used for high speed flows, including steam flow measurement. Pitot tubes are used for both liquids and gases, including air flow measurement.

One disadvantage of DP flow transmitters is that they introduce a pressure drop in the line. This is especially true of orifice plates, but it also applies to the other types of primary elements. Primary elements are also subject to wear over time, and this can degrade the flow measurement. DP flowmeters are being displaced in some applications by new-technology flowmeters, such as ultrasonic, magnetic, and vortex. However, the large installed base of DP flowmeters gives them an advantage that will help them maintain market share for many applications.

Gaspard-Gustave de Coriolis (1792-1843) is well known for his work on what is now called the Coriolis effect. In 1835, Coriolis showed that an inertial force has to be taken into account when describing the motion of bodies from a rotating frame of reference. The Coriolis effect forms the basis for the operation of today's Coriolis flowmeters. Coriolis flowmeters compute mass flow based on measuring the amount of deflection in vibrating tubes as fluid passes through them.



The principles of the Coriolis effect show that induced Coriolis forces twist a flow tube an amount proportional to the mass flowrate.

While Coriolis died in 1843, the first Coriolis flowmeters were not introduced until the 1970s. Since this time, the Coriolis flowmeter market has become one of the fastest growing flowmeter markets. Coriolis flowmeters are prized for their high accuracy and reliability, although their purchase price is typically higher than most other types of flowmeters. While the primary use of Coriolis flowmeters is for liquid applications, their use for gas flow measurement is growing. Some are even being used for steam applications, though this use is still very limited.

Traditionally, Coriolis flowmeters have mainly been used in line sizes of two inches and less. While this is still true, in the past several years, several companies have brought out Coriolis flowmeters for line sizes above six inches.

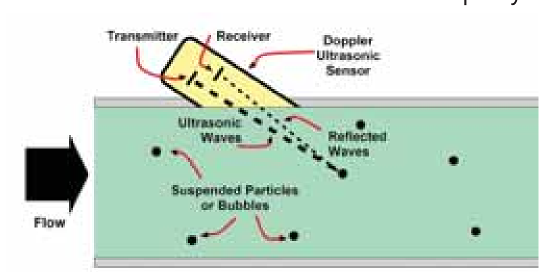
Theodore von Kármán (1881-1963) is most closely associated with vortex flowmeters. He made early studies in 1912 on the use of bluff bodies and vortex swirls. This series of vortex swirls is now called the von Kármán vortex street. Von Kármán lived from 1881–1963.

The principle of operation of vortex flowmeters is called the von Kármán effect. According to this principle, flow alternately generates vortices when a bluff body is present in the flowstream. A bluff body is a piece of material with a broad, flat front, mounted at right angles to the flowstream. The velocity of flow is proportional to the frequency of the vortices

The first commercial vortex flowmeters were introduced in 1969. Since then, other suppliers have entered the vortex flowmeter market, making this technology widely available in North America, Europe, and Asia. Vortex flowmeters are among the most versatile of flowmeters in that they can reliably be used to measure liquid, gas, and steam flow. For many years, growth in the vortex flowmeter market was slowed by the lack of industry standards for their use. This changed in January 2007, when the American Petroleum Institute (API, www.api.org) approved a draft standard for the use of vortex flowmeters for custody transfer of liquid, gas, and steam.

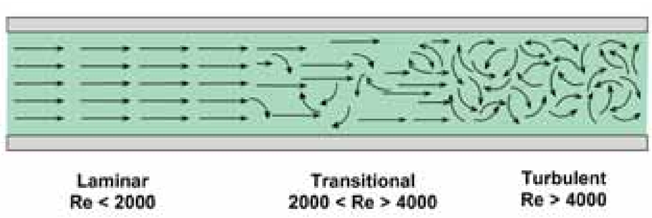
Christian Doppler (1803 – 1853) is known for proposing what is today called the Doppler effect. The principles behind the Doppler effect have to do with the apparent change in wavelength and frequency of a wave perceived by the observer to be moving relative to the wave source. The Doppler effect is the principle that underlies the operation of today's Doppler flowmeters.

Doppler flowmeters are a type of ultrasonic flowmeter that can handle dirty liquids. The other main type of ultrasonic flowmeter is called transit time, and they operate on a different principle. Transit-time ultrasonic flowmeters send an ultrasonic pulse across the flowstream and measure the length of time it takes the signal to cross the flowstream and back. They base the flowrate computation on the difference between the two transit times of the signal — one across and one back. The signal travels faster when it is traveling with the flow.



The Doppler frequency difference between source and reflected beams is a measure of flow velocity.

Ultrasonic flowmeters were first introduced for commercial use in 1963. While Doppler flowmeters are still used to handle dirty fluids, technological improvements in transit-time flowmeters have made them better suited for some dirty liquids. As a result, the growth in the transit-time ultrasonic flowmeter market has outpaced the growth in the Doppler market.



Bluff obstacle in vortex flowmeters creates eddies in the wake separated by a constant distance. So the frequency of eddies generated is a function of flow velocity.

Multipath ultrasonic flowmeters are also used for custody transfer of natural gas, and this has been a fast-growth area for ultrasonic flowmeters.

Osborne Reynolds (1842 -1912) is known for his formulation of the Reynolds number. This number reflects how turbulent or laminar flow is in a flowstream. The Reynolds number states the relation between the inertial forces and the viscous forces in a flowstream.

The Reynolds number is not associated so much with a particular flow technology; instead, it is important across the range of different flow technologies. In laminar flow, the viscous forces near the pipe wall slow down the flow. In turbulent flow, with the fluid flowing faster, the effects of the pipe wall are less pronounced. These effects can be important in calculating flowrate.

In addition to the pioneers of flow measurement mentioned here, there are many other great scientists who have contributed to our flow technology. In addition, new flow technologies, such as sonar and optical, are being developed today. This leaves plenty of room for more pioneers of flow to appear in the future. FC

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The material for this article is based on Flow Research's "Pioneers of Instrumentation" 2009 calendar. To request a FREE "Pioneers of Instrumentation" calendar, contact Jesse Yoder, president of Flow Research, at jesse@flowresearch.com or 781 245-3200. To preview the calendar, visit www.flowcalendar.com.