

Sounding Out the Flow

How Ultrasonic Flowmeters Work



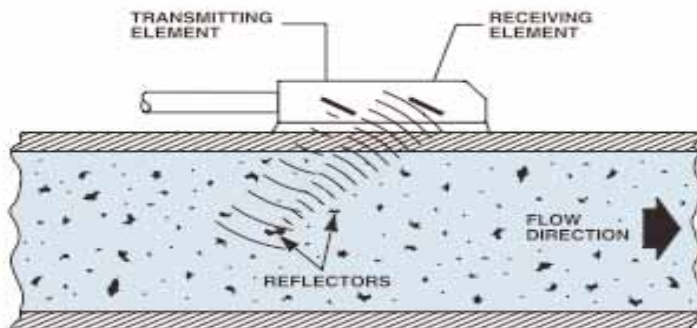
In 1842, Christian Doppler discovered that a stationary observer perceives a sound to have shorter wavelengths as its source approaches, longer wavelengths as its source recedes. The Doppler effect explains why one hears rising pitch in the blowing horn of an approaching car. When the car zooms away, the pitch seems to drop. Ultrasonic Doppler flowmeters put this frequency shift to work in so-called dirty liquids containing acoustical discontinuities—suspended particles, entrained gas bubbles or turbulence vortexes.

When transmitted into a pipe that contains flowing liquid with such discontinuities, an ultrasonic pulse or beam reflects from them with a change in frequency that is directly proportional to the liquid's flow rate. Thus, the ultrasonic Doppler flowmeter calculates flow rate from the velocity of the discontinuities, rather than from the velocity of the liquid. It suits liquids such as certain wastewaters, slurries, sludges, crude oils, phosphates and pulp stocks. Although the Doppler flowmeter generally works well with mining slurries, high-density polyethylene (HDPE) pipes may cause inaccuracies because their flexure changes the diameter of the measurement area. If flexure is great enough, it may break the coupling between an exterior-mounted transducer and the pipe's outside surface.

Proper signal reflection typically requires suspended solids or bubbles of 100 microns or larger in a concentration of 100 parts per million or higher. Doppler-shift measurement doesn't work in liquids with particulate concentrations exceeding 45 percent by weight or with high concentrations of very fine bubbles. Discontinuities at these extremes attenuate the reflected signal until it is indistinguishable from pipe background noise. Acoustically absorbent slurries, such as lime and kaolin, may also attenuate the signal below usable strength.

A 100 micron/100 parts per million liquid equates to a 1 MHz transducer frequency. For every foot per second of velocity, the reflected signal shifts about 6 Hz from the transmitted signal, making ultrasonic metering impractical for flow velocities significantly less than one-half foot per second. As for the upper limit of detectable flow velocity, it has yet to be established, though it surely surpasses 50 feet per second, since successful installations at that velocity are well documented.

Typically, an ultrasonic Doppler flowmeter consists of a transmitter/indicator/totalizer and a transducer. The user selects a configuration appropriate to the application, taking into account the liquid, the size and concentration of solids or bubbles, the pipe dimensions and the pipe lining. The transmitter's signal threshold usually adjusts to filter out mechanical and electrical noise.



Ultrasonic Doppler Flow Sensor

A high-frequency oscillator in the transmitter drives the transducer, which, in the popular clamp-on design, mounts on the pipe exterior. The transducer generates an ultrasonic signal that passes through the pipe wall into the flowing liquid; the transmitter converts the difference between its output and input frequencies to electronic pulses. Processed, scaled and totalized, the pulses provide a measurement of flow.

Ultrasonic Doppler flowmeters that clamp onto the outside of a pipe operate non-invasively, without moving parts. They cause no pressure drop, risk no damage from the process liquid and entail little maintenance. If properly calibrated, they can have $\pm 1\%$ accuracy, however, the pipe wall and any air space between the wall and the liquid can generate signal interference. Moreover, a stainless steel pipe wall might conduct the transmitted signal to the extent that the reflected signal will seem to undergo a major shift.

With concrete-lined, plastic-lined and fiberglass-reinforced pipes, the problem is built-in acoustical discontinuities that can scatter the transmitted signal or seriously attenuate the reflected signal. Many clamp-on meters simply won't operate with lined pipes. Those that will may have an accuracy of $\pm 20\%$ at best.

In-line, or wetted, transducers using Doppler-shift or transit-time (also known as "time of flight") signaling circumvent the limitations that pipe walls and linings impose. An ultrasonic cousin of the Doppler flowmeter, the transit-time flowmeter measures a signal traveling between two transducers, one upstream and one downstream. The difference in elapsed time between the signal going with and against the flow determines liquid velocity, compensating for the liquid's density and temperature, which influence the speed of sound, or sonic velocity, within the liquid. If the sonic velocity causes a great enough shift in the signal's refraction angle, the signal can miss the downstream transducer altogether, a failure known as walk-away.

Transit-time flowmeters come in single-path and multi-path designs, the former using one transducer pair to measure a small section of fairly uniform flow; the latter using multiple pairs to measure non-uniform flow along a length of large-diameter pipe or conduit of the type commonly found in utility applications. Multi-path designs are used in raw wastewater and storm water applications, and to measure stack gas flows in power plant scrubbers.



**FDT100 Series In-Line
Ultrasonic Flowmeter**

The new in-line, single-path FDT100 Series from Omega Engineering has many of the features that make transit-time flowmeters the preferred ultrasonic design for use with so-called clean liquids (clean in the sense that they lack acoustical discontinuities). Intended for consumable and industrial water applications, FDT100 models run on batteries, have no moving parts, boast a wide measurement range, require no filtration, come in two flange styles (150-pound ANSI and DIN) and in various sizes, and offer a choice of integral or remote electronics that display flow rate or totalized flow at the push of a button.

There are transit-time flowmeters that can handle very hot (e.g., liquid sulfur and molten metals), very cold (e.g., liquid nitrogen and other cryogenic liquids as cold as -300°C [-508°F]) or low-flow applications. Axial and coaxial transit-time flowmeters, for in-line use with pipes as small as 0.5 inches, offer extra low-flow sensitivity because they can measure flow sections significantly longer than the pipe's diameter. Transit-time flowmeters also work well with viscous liquids if the Reynolds number at minimum flow is under 4,000 (laminar flow) or over 10,000 (turbulent flow). Serious non-linearities preclude their use in the transitional flow region. (A Reynolds number expresses the velocity profile of a flowing liquid as a single, dimensionless ratio of inertial and viscous force.)

A third ultrasonic flowmeter employs cross-correlation between upstream and downstream transducer pairs to compute flow. Some flowmeters of this design use microprocessors to switch automatically between "clean" and "dirty" modes based on correlation factors. A single cross-correlation hybrid flowmeter could, for example, monitor flow of either activated or digested sludge. Carefully engineered applications using such flowmeters have had reported installed accuracy within 0.5% of reading.

Until recently, clean liquids and Doppler flowmeters were incompatible. A user working with, say, drinking water, could have gotten around the problem only by aerating the flow, which adds acoustical discontinuities in the form of bubbles. Still, a Doppler flowmeter would be useless in such an application if the bubbles measured smaller than 30 microns or if their concentration fell below 25 parts per million.

With a new breed of multi-liquid Doppler flowmeter, users can dispense with improvised aeration. Omega's FD-7000, for example, handles emulsions and slurries by mounting on a straight run of pipe and operating like typical Doppler flowmeters. When used with clean liquids, however, it senses ultrasonic waves reflecting off turbulent swirls. A flow analyzer in the transmitter/indicator/totalizer tells a user which of the two metering modes to employ.

In applications containing insufficient particle or bubble reflectors for conventional Doppler measurement, the FD-7000's mating-flow transducers should be mounted on the pipe at a point where non-symmetrical hydraulic turbulence exists, the best position being one to three pipe diameters downstream from a 90° elbow. A digital filtering system and signal recognition circuitry transform the turbulence reflections to linear data. Operating in this mode, the FD-7000 is one of the few flowmeters that do not require a straight upstream pipe run.



**FD7000 Series
Ultrasonic Flowmeter**

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