T400-Series Technical Note

The Challenge of Flow Measurement

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We are sometimes asked why top quality Flowsensors have an absolute accuracy of 10-15% when even disposable pressure transducers have accuracy specifications of 1% or better. The answer lies in a brief review of fluid mechanics.

PRESSURE

Pressure is a scalar quality associated with the potential energy of a fluid. It is expressed in units of force per area. It does not have direction. Since it is an energy measurement, pressure equilibrates and varies only slightly across a vessel's cross section. These characteristics permit adequate blood pressure measurements with a point Sensor.

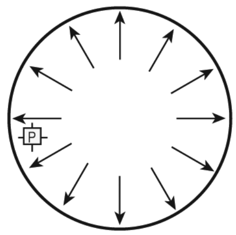

Fig. 1: Pressure

VELOCITY

Velocity is a vector quantity associated with movement. It is expressed in units of distance per time (m/min, cm/sec). Velocity has direction. Measurement of velocity is very sensitive to the alignment between the vessel and the Sensor. In hemodynamic applications, measuring the average velocity is complicated by variations in velocity across a vessel. In most vessels, blood velocity increases as its distance from the vessel wall increases to create a parabolic laminar flow profile (Fig. 2).

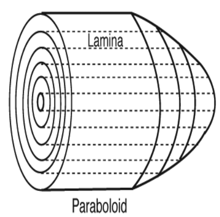

Fig. 2: Laminar Flow Profile

To accurately measure average flow from flow velocity requires a Sensor that can integrate the velocities over the entire area of the vessel (Fig. 3). In practice, many velocity Sensors only measure the maximum velocity at the center of the vessel and assume a parabolic laminar profile (Fig. 4). Other Sensors measure the local velocity at several points and assume a rotationally symmetrical profile (Fig. 5).

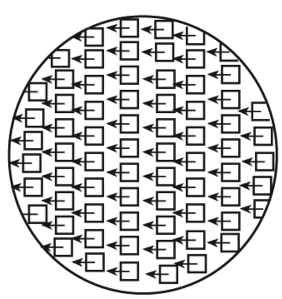
Fig. 3: Integration over entire area of vessel

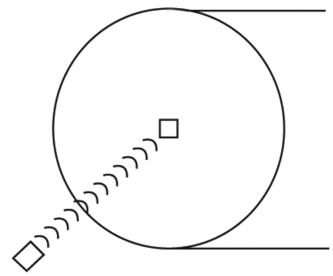
Fig. 4: Continuous Doppler: peak velocity measurement.

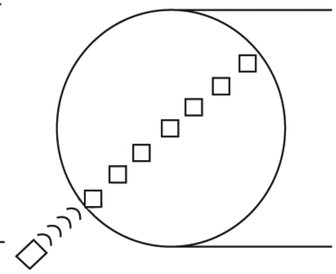
Fig. 5: Pulse Doppler: measures local velocity at several ranges.

FLOW

Flow is a vector quantity associated with the movement of mass. It is expressed in units of "mass flow" or "volume flow". Flow, like velocity, has direction.

Volume flow can also be expressed as a product of average velocity and area. Since both terms are vectors, the velocity term must actually be the component of velocity perpendicular to the plane of the area.

In hemodynamic applications, both the area and the velocity are continually changing. This complicates measurement. Volume Flowsensors are usually integrating devices that are sensitive to changes in local velocity over the entire area of the vessel. A perfect Flowsensor is uniformly sensitive to changes in velocity over the entire cross-sectional area of the vessel. It is also fully insensitive to changes in cross sectional area of the vessel.

Both electromagnetic and ultrasonic transit time Flowsensors are integrating volume Flowsensors. Both devices respond to local changes in blood velocity anywhere within the vessel. However, neither device is "perfect" as it is currently impossible to build Flowsensors with a truly uniform sensing field.

The Challenge of Flow Measurement Cont.

ELECTROMAGNETIC FLOWSENSORS

With an electromagnetic Flowsensor, flow sensitivity is greatest in the area of the vessel closest to the electrode. This flow sensitivity is also affected the conductive properties of the vessel wall and electrical couplant. Consequently, electromagnetic Flowsensors require a tight fit around the vessel.

ULTRASONIC TRANSIT-TIME FLOWSENSORS

In contrast, transit-time Flowsensors can be used with a loose, non-constrictive fit around a vessel, since vessel-wall and acoustic couplant are integrated into the volume flow measurement. Ultrasonic transit-time Flowsensor measurements show a variation in field sensitivity in only one dimension. This approximates the contour of a loaf of bread. The flow sensitivity pattern and insensitivity to wall effects allow the transit-time Flowsensors to measure flow over a range of vessel sizes.

However, since the ultrasonic illumination is not completely uniform, an error range in absolute accuracy exists. This is demonstrated by Fig. 6 where an ideal calibration line has the equation Y = X. In practice, there are small deviations from perfection in the slope and offset. The actual equation is Y = A + BX, where A is the offset and B is the slope.

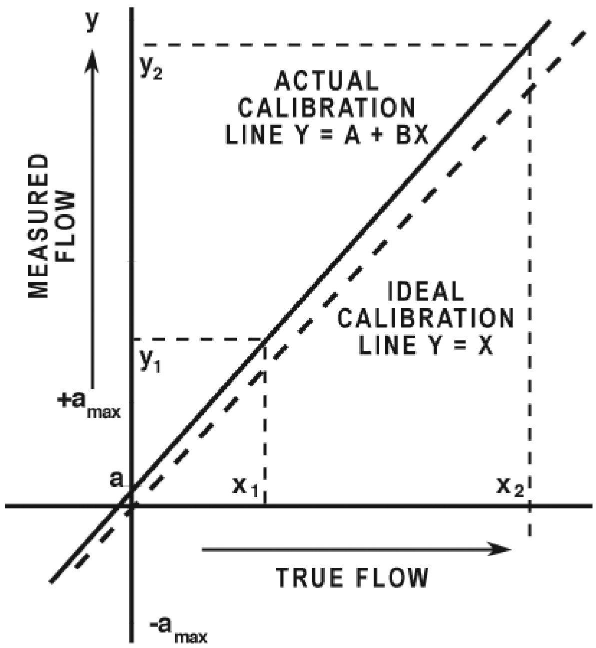

Fig. 6: Absolute accuracy graph showing discrepancy between ideal calibration line and small deviations in slope and offset that result in the actual calibration line.

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