measurement sensor and data transmission technology innovation has reduced installation costs, simplified maintenance and enhanced plant performance

Measurement sensor technology is a key driver in the development of modern industrial processes. The technologies, to measure and transmit process parameters, such as flow, level, temperature and pressure, have developed significantly since the 1960's.

Impulse lines, used to connect instruments to the process, are found less frequently on new installations and are being replaced on existing ones. Where used, they require specialist knowledge during design, installation and maintenance for reliable measurement. Modern techniques have simplified maintenance and enhanced plant performance.

data transmission technology

Transmission technology development has allowed universal application of self-powered two wire 4-20 mA dc signals. This has eliminated power supply and special sensor cabling for magnetic flow meters, thermocouples and resistance bulbs, reducing cost and simplifying installation.

In the 1980's, microprocessors facilitated the transition from signal to information based process automation. Smart transmitters provided bi-directional digital communication and diagnostics capability with HART® (Highway Addressable Remote Transducer) protocol. The 4-20 mA and HART digital signals are transmitted over the same wiring, providing a centralised capability to configure, calibrate, characterise and diagnose devices in real time together with reporting capability. Data can be captured from multi-parameter devices without additional hardware, providing predictive maintenance capability.

Development in fieldbus digital communication allows field devices to be connected using a single cable bus structure, reducing cabling, installation time and cost. Fieldbus is a device level network that sacrifices speed for security. There are several protocols available with Modbus®, PROFIBUS PA and FOUNDATION™ being the most common. Modbus® was the earliest protocol and has connectivity with Ethernet and other fieldbus protocols. PROFIBUS PA was developed in Europe and with PROFINET has Ethernet connectivity. FOUNDATION™ fieldbus was developed in North America by ISA, suppliers and users.

Signal Transmission History Summary		
Transmission Method	Introduced	Common Use From
Pneumatic 3 - 15 psi	1940's	1940's
Electronic 4 - 20mA	1950's	1950's
Modbus®	1979(Modicon)	1980's
HART®	mid-1980's (Rosemount)	1990
Fieldbus PROFIBUS PA	1989 (Siemens)	1990's
FOUNDATION™ fieldbus	1988 (ISA S50-02)	2000

Fieldbus technology is more complex and costly, requiring suppliers to provide sensor options to meet the different standards. Fieldbus selection is guided by plant layout, sensor interface capabilities and data management infrastructure. An industry working group is currently developing the capabilities of Electronic Device Description (EDD) technology.

flow measurement technology

Accurate flow measurement is a key element in process productivity. Various types of flow meters are used, with the orifice plate and differential pressure transmitter predominant prior to 1965. New materials, manufacturing techniques and micro-electronics have resulted in significant developments.

Flow Measurement History Summary		
Method	Principle	Common Use From
Pitot tube	1732 (Pitot)	1750's
Head Meters	1738 (Bernoulli)	1800's
Positive Displacement	1815 (Clegg)	1850's
Turbine	1790 (Woltman)	1940's
Magnetic	1832 (Faraday)	1950's
Thermal	1914 (King)	1970's
Vortex	1878 (Strouhal)	1960's
Coriolis	1835 (Coriolis)	1970's
Ultrasonic	1842 (Doppler)	1970's

Measurement accuracy is quoted for a given turndown ratio (max/min reading) as % span (max–min reading), % full scale or % actual, with the latter being highest specification for same value. Accuracy is important for stock and custody monitoring, and reproducibility, the ability of the sensor to reproduce its reading, being important for control.

The positive displacement flowmeter, one of the earliest meters, is based on a fixed volume of fluid causing a known mechanical displacement to generate a calibrated pulse. Configurations based on vanes, gears, pistons, or diaphragms are available. Oval gear meters have reduced slippage, achieving accuracies of ±0.05% rate for μ = 0.2-5 cps and ±0.25% rate for μ > 5cps over 10:1 turndown. Advancements in accuracy from ±0.5% rate have been achieved by temperature compensation, multivariable flow computation and HART, making meters suitable for custody transfer. Fluid viscosity affects the pressure drop and presence of solids or entrained air can cause mechanical damage.

The axial turbine flowmeter consists of a rotor, driven at a rate proportional to the fluid velocity, to generate a calibrated pulse. Developments in materials have improved bearing design to extend the application and improve robustness, achieving accuracies of ±0.5% rate for μ = 0.8-2 cSt over a 15:1 turndown, depending on size and conditions. Installations require an upstream strainer and straight pipe section with custody transfer requiring upstream flow straighteners. Meter is suitable for bi-directional flow.

The magnetic flowmeter measures the voltage generated by an electrically conducting liquid flowing through a magnetic field, which is proportional to fluid velocity. Fluid contact electrodes can measure liquids with conductivities as low as 2 µS/cm and with non-contact capacitive signal pick-up electrodes down to 0.05 µS/cm. Meters can achieve accuracies of ±0.2% rate over a 10:1 turndown depending on size and conditions and contribute no additional pressure drop. Installation requires minimum 5D upstream straight pipe section and is suitable for bi-directional flow. Preferred method for conducting liquids, including corrosive liquids, slurries, sludges, liquids with abrasive solids.

The vortex shedding flowmeter measures the frequency of vortices formed by a fluid flowing across a bluff non-streamlined body, which is proportional to fluid velocity above the minimum flow condition at which vortex shedding ceases. Typical accuracies claimed for liquids are ±0.5% rate for Reynolds Number (Re) >20,000 and for steam/gases ±1.0 % rate for velocity < 35 m/s. Advancement in accuracies are being achieved by compensating for varying Re and process conditions, with reduced bore meters extending the measuring range. Installation requires a minimum 15D upstream and 5D downstream straight pipe section with pressure drop being ~2 velocity heads. Preferred method for steam and with integral temperature compensation gives mass flow of saturated steam.

The Coriolis flowmeter measures the twist created by fluid flowing through an oscillating single or dual tube assembly, which is proportional to mass flow and is independent of fluid viscosity and density. This is a “one for all” multi-variable meter and provides density and temperature measurement allowing derivation of other variables such as volume flow, solids content and concentration. Typical accuracies claimed for liquids are ±0.1% rate and for gases ±0.35 % rate over a 20:1 turndown, and is suitable custody metering. There are no special installation requirements but pressure drops can be significant. If capital cost is not an issue, this is preferred method for non-conducting liquids.

The ultrasonic “time of flight” flowmeter measures the time difference between the paths of two or more ultrasonic signals beamed in opposite directions. Meters can be clamp on or insertion type. The accuracy is enhanced by characterising the varying velocity profiles due to changes in Re and process conditions. Multi-path chordal insertion meters can achieve accuracies of ±0.25% rate over a 10:1 turndown whilst clamp on meters claim ±1.0% rate. Installation may require up to 20D upstream straight pipe without a flow conditioner and 3D downstream. The meters can be used on bi-directional flow and contribute no additional pressure drop. Ultrasonic meters are now gaining acceptance for liquid custody transfer. Time of flight ultrasonic flowmeters are not suitable for use on liquids containing entrained gases or solids.

The thermal dispersion flowmeter measures the cooling effect of a gas as it passes over a heated transducer, which is proportional to the mass flow, thermal and flow properties of the gas. Typical accuracies claimed are ±1.5% reading over a 10:1 turndown. Installation may require up to 20D upstream straight pipe and 5D downstream no additional pressure drop. This is preferred method for pure gases and constant composition gas mixtures.

The following gives an indication of comparitive costs with the lowest first:
turbine → magnetic → vortex → thermal → ultrasonic → positive displacement → Coriolis.

liquid level measurement technology

Liquid level measurement is key to reliable and safe process plant operation. Normally flows are held steady whilst levels are allowed to change within limits, requiring reproducibility. Accuracy is important for tanks used for stock and custody control.

Level Measurement History Summary		
Method	Principle	Common Use From
Hydrostatic	1738 (Bernoulli)	1800’s
Float Displacer	250bc (Archimedes)	1930’s
Conductivity	1834 (Faraday)	1930’s
Load Cell (Strain Gauge)	1856 (Kelvin)	1930’s
Load Cell (Piezoelectric)	1881 (Lippmann)	1950’s
Capacitance (RF)	1861 (Maxwell)	1960’s
Tuning Fork	1711 (Shore)	1960’s
Ultrasonic (Doppler)	1842 (Doppler)	1970’s
Nucleonic	1898 (Curie)	1970’s
Radar	1888 (Hertz)	1980’s

The hydrostatic continuous, indirect, level method measures the pressure due to liquid level and density plus over-pressure. The sensor measures the pressure difference between this pressure and a reference pressure, normally atmospheric, so is not preferred for vacuum and pressure service. Instruments can be flanged mounted or rod insertion type, the latter not being recommended for turbulent conditions. Typical accuracies claimed are ±0.2% reading, and is dependent on process fluid properties and conditions.

The displacer continuous or point level method measures the change in buoyancy via a torque tube or lever arrangement. The continuous measuring range is set by the displacer length immersed in the tank or external cage, which is preferable on noisy applications. The point method uses a float with the range being limited by the length of the float arm.

The nucleonic point or continuous, non-contact, level method measures the signal strength of a radioactive source beamed across a vessel. Independent of fluid properties and has typical ranges of 0.24 to 3.36m. Typical accuracies claimed are ±2% reading. This is the preferred method for controlling level in flash vessels and reboilers under all temperature and pressure conditions.

The radar point or continuous level method measures the travel time of an impulse transmitted and reflected from the liquid surface. Interference echoes resulting from tank internals and agitators are suppressed and signals characterised to give liquid volume. The sensor has no contact with the liquid but is exposed to head space conditions, which do not affect the measurement. Reflectivity requires the liquid dielectric constant(ε_R) to be $\geq$1.4 (hydrocarbons 1.9-4.0, organic solvents 4.0-10 and conductive liquids >10). The antenna and signal conditions are adjusted to suit the process, with guided radar being used for low ε_R and turbulent conditions. Method is suitable for custody transfer with accuracy ±0.5mm being claimed.

The capacitance point or continuous level method is suitable for liquids which can act as dielectrics. The measurement is more sensitive when the difference $\delta\varepsilon_R$ of the liquid and the vapor space or between the two liquids are higher. Special designs, involving coated and twin probes, are used when $\delta\varepsilon_R < 1.0$, conductivities > 100 μmho, coating effects or vessel material is non conducting. Typical accuracies claimed are ±0.25% span and is dependent on fluid properties so is not suitable for changing conditions. Maximum conditions 200°C at 100 bar and 400 °C at 10 bar.

The ultrasonic point or continuous level measurement is based on the time-of-flight principle. A sensor emits and detects ultrasonic pulses which are reflected from the surface of the liquid. The method is non-invasive, with some types being non-contact, and is not affected by ε_R, conductivity, density or humidity. Maximum conditions 150°C at 4 bar.

Load cells, based on strain gauge or piezoelectric, measure the weight of the process vessel plus contents. Individual load cell accuracy of 0.03% full scale is achievable but overall performance is dependent on correct installation practices preventing external forces, due to associated piping and equipment. For vessels with jackets, agitation and complex piping it is difficult to obtain an acceptable accuracy. When the container can be totally isolated, as in final dispensing and filling applications, precision weighing can be achieved.

The vibrating tuning fork principle is used to detect point liquid level but is unsuitable in viscous and fouling applications. Maximum conditions 280 °C at 100 bar.

The conductivity point level method requires a liquid conductivity > 0.1 μmho and is frequently used on utility and effluent pump control systems.

The following gives an indication of comparitive costs, with the lowest first: conductivity → capacitance → tuning fork → hydrostatic→ displacer → ultrasonic → load cell → radar → nucleonic.

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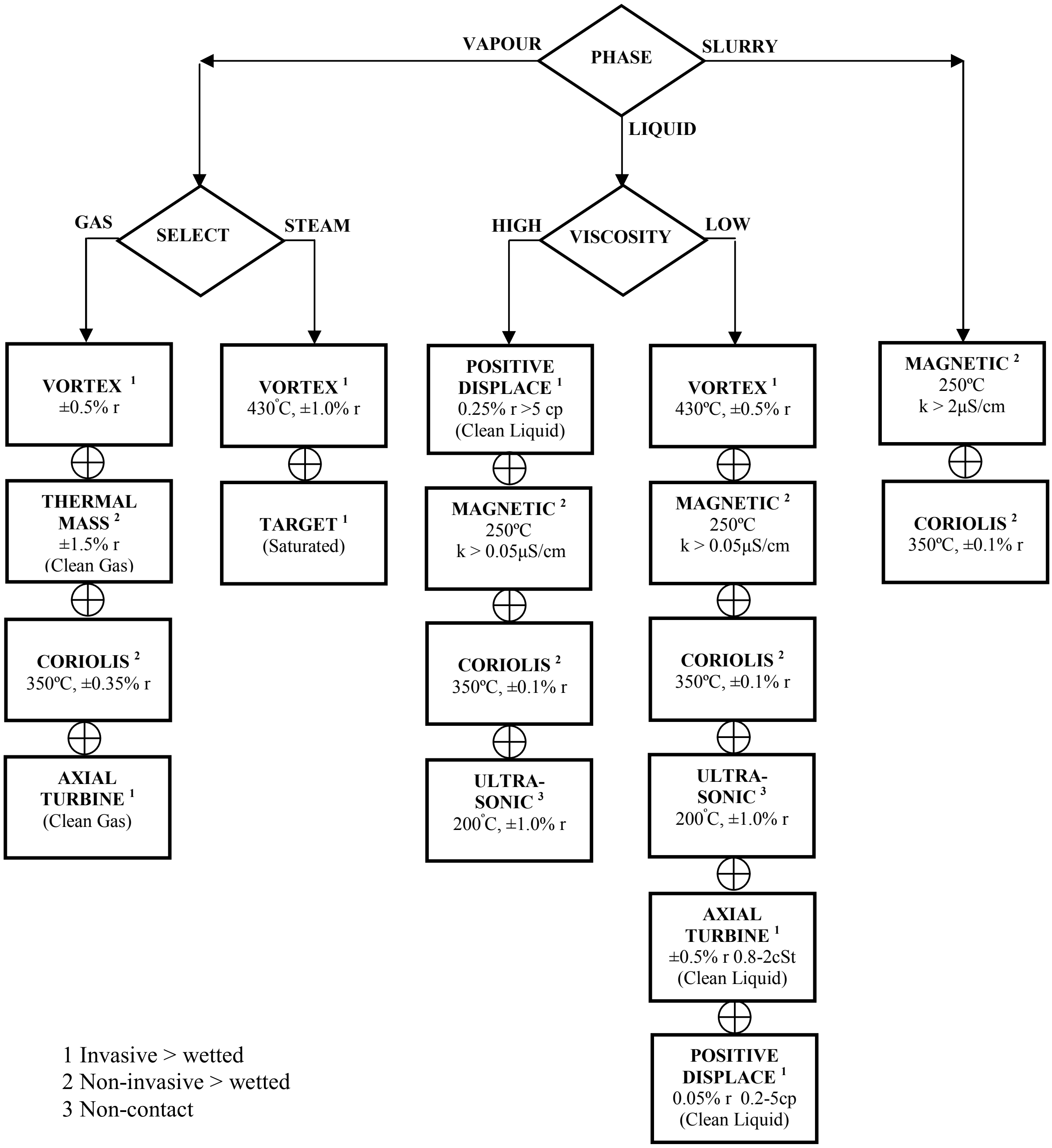
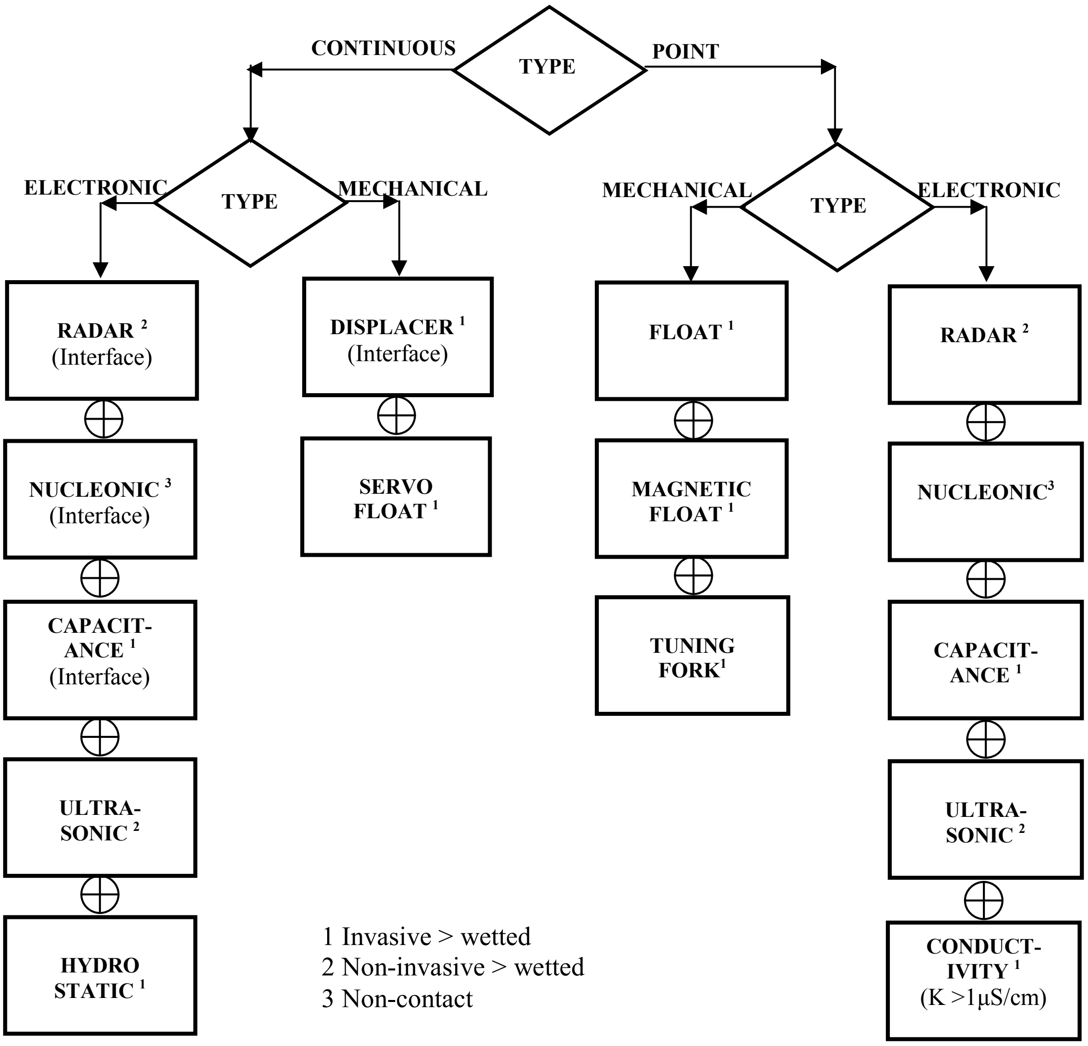
FLOW SENSOR TYPES & APPLICATION CHART

(Excludes head meters)



1 Invasive > wetted
2 Non-invasive > wetted
3 Non-contact

LIQUID LEVEL SENSOR METHODS
(No impulse lines)



CONTINUOUS LEVEL APPLICATION CHART

(No impulse lines)