Industrial Flow Measurement Practice

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Introduction

In the recent decades the market for the products of the industrial process industries has changed greatly. The manufacture of mass produced products has shifted to locations where raw materials are available economically. Competitive pressures have forced a swing to specialization as well as to an ability to adapt to customers desires. The systems are designed so that the economic data, such as raw material properties, raw material costs, batch sizes, are quickly integrated into the processes. An important consideration is the assurance and improvement of product quality.

The operation of such systems requires a high degree of automation. With the assistance of process technology the control of the procedures can be optimized and personnel requirements minimized. The process control technology assures that process cycles are documented so that the quality of the product is always traceable.

The most important prerequisite for automation is knowledge of the actual process parameters, which can be ascertained utilizing measurement instruments. If the actions dependent on the measurements are be realized then the specifications must naturally be qualitatively high. Therefore the measurement instrument requires:

- high accuracy
- overview functions
- easy operation and maintenance
- testability even without a test stand
- self monitoring
- error signals
- communication ability

The planner of an industrial process system assumes in advance that the measurement error limits will be satisfied. However, it is not always possible to divorce himself from the problems associated with the measurement site.

This publication is intended to be an aid in the selection of meters in the area of flow rate and total flow metering. It is dedicated to the friends of ABB Automation Products.

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List of Symbols

A	Area, cross-section (mm^2, m^2)
B	Magnetic flux density, induction (T)
b	Width (mm, m)
C	Flow discharge coefficient (1)
c	Resistance coefficient (1) (see Variable Area Flowmeter)
c	Sound velocity (m/s)
c	Specific heat (J/K · kg)
D, d	Diameter (mm, m)
E	Velocity of approach factor (1) (see Differential Pressure Measurement)
E	Energy (J, KWh)
e	Energy level (kinetic energy expressed as liquid level) (m)
F	Force (N, kg · m/s^2)
f	Frequency (s^{-1})
g	Acceleration due to gravity = 9.81 m/s^2
H	Energy level (kinetic energy expressed as liquid level) (m)
h	Height, elevation, level (mm, m)
J	Electrical current (A)
k	Surface roughness (mm)
l	Length (mm, m)
m	Mass (g, kg)
m	Area ratio (d^2/D^2) (1) (see Differential Pressure Measurement)
p	Pressure (Pa, bar), P_{dyn} = dynamic pressure
Δp	Differential pressure (Pa, bar)
q_m	Mass flowrate (g/s, kg/h)
q_Q	Heat flow (J/s)
q_v	Volume flowrate (l/s, m^3/h)
T	Temperature (K, °C)
T	Time constant (s)

t Time (s)

U Electrical voltage (V)

V Volume (mm^3, m^3, l)

v Velocity (m/s)

W Weighting factor (1) (see Electromagnetic Meters)

β Diameter ratio d/D ;1< (see Differential Pressure Measurement)

γ Thermal volume expansion coefficient (K^{-1})

Δ Difference, specifically differential pressure Δp

ε Expansion coefficient (1)

η Dynamic viscosity (Pa · s)

χ Electrical conductivity (S/cm)

λ Resistance coefficient, coefficient of friction (1) (see Free Surface Measurements)

μ Flow coefficient (1), (see Weir)

ν Kinematic viscosity (m^2/s)

ρ Density (kg/m^3, g/cm^3)

Φ Magnetic flux (Wb, Vs)

ω Angular velocity (s^{-1})

Fr Froude number (1)

Re Reynolds number (1)

St Strouhal number (1)

VUZ Viscosity Influence Number (1)

1 Introduction to the Physics of Flowrate and Total Flow Measurements

1.1 Measurement Values

Fluid mechanics provides the tools for optimizing production processes and fill and batch operations. In addition to pressure and temperature measurements the measurement of the flowrate is one of the most important variables. The quantitative determination of amount, volume, and flowrate allows the production processes to be influenced through control and regulation.

The most important basic values are mass and volume:

Mass with the symbol m measured in kg or g
Volume with the symbol V measured in m^3, dm^3 or cm^3

The ratio of mass to volume, the **Density**, defines the relationship between both values:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} : \rho = \frac{m}{V} \left[\frac{kg}{dm^3}, \frac{kg}{m^3}, \frac{g}{cm^3}\right]$$

Since the majority of production systems operate continuously, the measurement values must be representative of the instantaneous conditions or indicate the instantaneous values. Therefore a time dependent value is necessary, namely flowrate. Using the two basic units, mass and volume, one differentiates between **mass flowrate q_m** and **volume flowrate q_v**.

$$\text{Mass flowrate} = \frac{\text{Mass}}{\text{Time}} : q_m = \frac{m}{t} \left[\frac{kg}{s}, \frac{g}{s}, \frac{kg}{h}\right]$$

$$\left(\text{Volume flowrate} = \frac{\text{Volume}}{\text{Time}}\right)\text{""} : q_v = \frac{V}{t} \left[\frac{m^3}{s}, \frac{l}{s}, \frac{m^3}{h}\right]$$

Mass flowrate is the ideal measurement value because it is independent of pressure and temperature, although volume flowrate is usually technically more convenient to measure and therefore it is preferred.

The volumes of incompressible liquids are generally unaffected by the pressure in the ranges normally encountered. Temperature effects however may be significant and in some cases require correction measures.

The corrected volume V_2 is:

$$V_2 = V_1 \,(1 + \gamma \cdot \Delta T) \qquad (1.1)$$

γ [K^{-1}] : Thermal volume expansion coefficient (Specific fluid property)
T [K] : Temperature

Modern flowmeters incorporate amplifiers which can apply calculated corrections to the flowrate analogous to V_2. The effects of temperature and pressure are appreciably greater for gas measurements. It is for this reason that these measurements are usually based on normal conditions, namely p_n = 101325 Pa or 1.01325 bar and T_n = 273 K.

The **Normal volume** v_n is:

$$V_n = V \cdot \frac{273}{273 + T} \cdot \frac{1.013 + p}{1.013} \qquad (1.2)$$

V = volume at operating conditions in m³
T = operating temperature in °C
p = operating pressure in bar

Naturally the calculations required to convert the volume flowrate to **Normal conditions** can be carried out by computer components.

The flowrate, which is a time dependent value, furnishes information regarding the instantaneous conditions in the pipe line. It does not provide any information about the total mass or volume. In order to determine these values an integration is required:

$$V = \int_{t_1}^{t_2} q_v \cdot dt \qquad (1.3a)$$

or

$$m = \int_{t_1}^{t_2} q_m \cdot dt \qquad (1.3b)$$

The flowrate represents the present while the volume or mass represents the past.

1.2 Fluid Mechanics Concepts

1.2.1 Viscosity

The **Viscosity** or **Stickiness** of a fluid characterizes its ability to resist shape changes. This is a result of the internal friction in the fluid caused by the forces between the molecules. Since the mol ecular movement is related to the temperature, the viscosity is also a function of the temperature. The absolute viscosity in Pa.s is defined as follows: 1 Pascal-second is identical to the absolute viscosity of the laminar flow of a homogeneous fluid between two flat parallel plates spaced 1 meter apart with a velocity difference of 1 m/s in which a shear force of 1 Pascal exists.

The kinematic Viscosity ν is a density related viscosity and has units of m^2/s:

$$\nu = \frac{\eta}{\rho} \left[\frac{Pa \cdot s \cdot m^3}{kg} = \frac{m^2}{s}\right] \tag{1.4}$$

This fluid property, **viscosity**, also exists in gases. The values are appreciably smaller than for liquids and increase with temperature.

1.2.2 Reynolds Number

The Reynolds Number Re is a dimensionless number utilized in similarity techniques. With it, it is possible to project values measured with a particular flowing fluid to another fluid with different viscosity and density values, but with similar geometric relationships.

$$Re = \frac{d \cdot v}{\nu} \; [\,1\,] \tag{1.5}$$

d: pipe diameter in m
v: average flow velocity in m/s:
ν: kinematic viscosity in m^2/s

1.2.3 Flow Regimes

At low velocities and high viscosities the fluid flows in layers, that means, the fluid particles move in well ordered adjacent sliding layers. This is known as **laminar flow** in which the layers do not mix with one another.

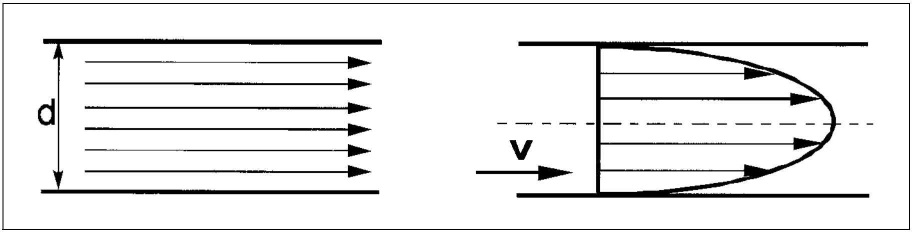


Fig 1-1: Laminar Flow Velocity Profile

The velocity distribution shows, that the frictional forces at the stationary pipe wall exert the highest retarding force and that from layer to layer the velocity increases to its maximum value, which occurs in the middle of the pipe.

If the velocity increases or the viscosity decreases an additional motion is superimposed on the axially oriented movement throughout the flow stream which moves in all directions in a random manner and affects the flow streamlines in such a way that a uniform velocity profile results. This is known as **turbulent flow**. A boundary layer is formed in the vicinity of the wall in which the velocity must accelerate from zero to v, because of its adhesion at the wall. Therefore the velocity profile is this outer region is not steady.

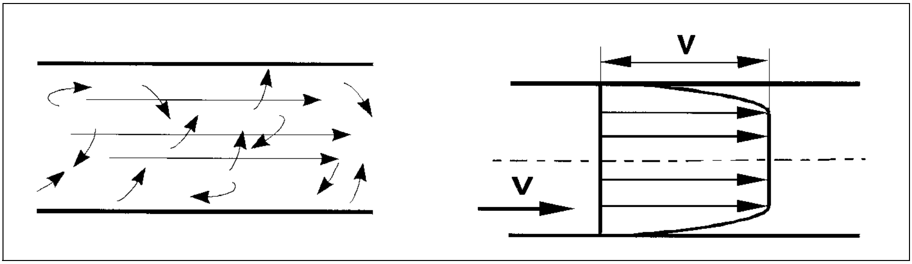


Fig 1-2: Turbulent Flow Velocity Profile

The determining criterion for the flow regime is the value of the Reynolds Number Re, since it takes into consideration the decisive factors v and ν.

The critical Reynolds number Re_{Cr} defines with reasonable accuracy the transition point:

$$Re_{Cr} \sim 2300$$

Flow Characteristics	Re < 2300	Re > 2300
Flow regime	laminar	turbulent
Pressure loss in pipe line, meter	small	appreciable
Velocity profile	parabolic	approx. rectangular
Relationship of the average value of the velocity to the maximum velocity at the center of the pipe	0.5	0.8...0.9

Tbl. 1-1: Flow Effects

Under ideal conditions the transition can occur at higher Reynolds numbers. This unstable condition changes immediately to the stable turbulent condition at the slightest stimulus, e.g. due to a flow disturbance.

Almost all meters for measuring flowrate operate at velocities in the turbulent range.

1.2.4 Flow Separation

As already mentioned, there exists at the wall of the flow conduit a boundary layer in which the flow velocity climbs from zero to v. A projecting restriction at the wall extends the length of the boundary layer and restrains the fluid even more in the vicinity of the wall so that downstream of the restriction a dead zone with a slightly negative pressure exists. The fluid flows from the region of higher velocity into this dead zone and creates vortices.

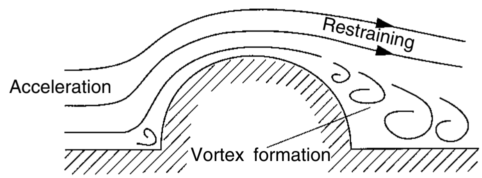


Fig 1-3: Dead Space with Vortex Formation

The flow separates from the surface of the wall. Examples are shown in Figs. 1-4 and 1-5. Vortices are undesirable for measurements because they consume energy which is removed from the flow stream resulting in pressure losses. Furthermore they change the velocity profile to such a degree that many measuring methods will not function.

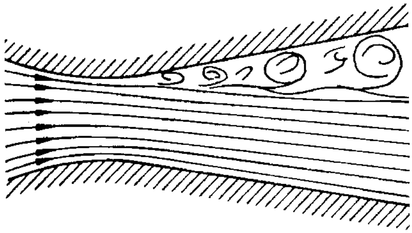


Fig 1-4: Flow Separation at an Expansion

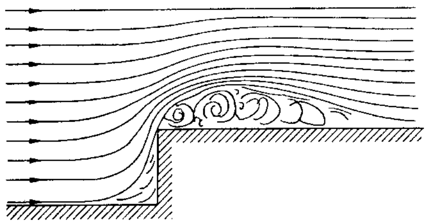


Fig 1-5: Flow Separation After a Sharp Edge

Figs. 1-6 and 1-7 show the flow profiles after flow disturbances.

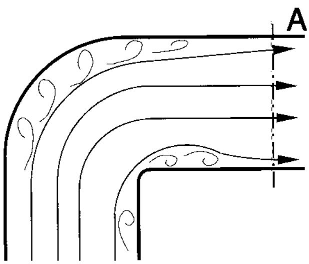
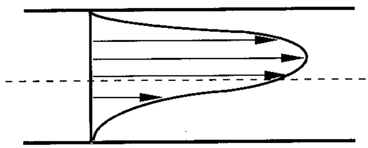


Fig 1-6: Flow Streamlines in an Elbow



Velocity Profile at Location A

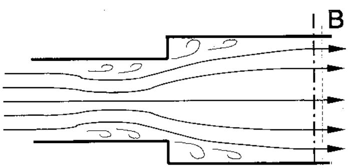
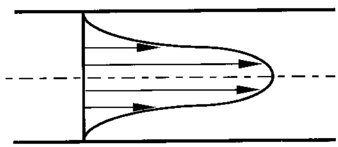


Fig 1-7: Flow Streamlines at a Step Expansion



Velocity Profile at Location B

When a body is placed in the middle of the flow stream, separation occurs and vortices are formed on both sides. It is interesting to note, that after a vortex has formed on one side a similar vortex forms on the other side which causes the first one to be shed.

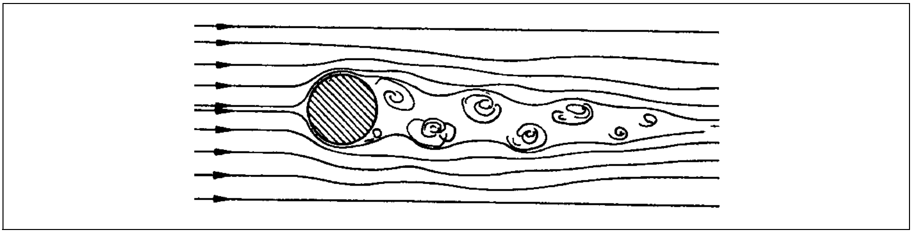


Fig 1-8: Karman Vortex Street

That periodic vortices are shed from each side alternately was discovered by Karman after whom the vortex street is named. These usually undesirable vortices are utilized as the basis for the measurement in the Vortex Meter.

1.2.5 Energy Equations and Flowrate

The following energy types exist In a flowing fluid (liquid or gas):

Potential energy { position energy, pressure energy }
Kinetic energy

(Additional forms of energy, e.g. electrical, chemical, are of no importance in this situation). There are

Position energy:	$m \cdot g \cdot h$	m = mass g = gravity h = height
Pressure energy:	$m \cdot \frac{p}{\rho}$	p = static pressure ρ = density
Kinetic energy:	$m \cdot \frac{v^2}{2}$	v = flow velocity

Their sum is:

$$E = m \cdot g \cdot h + m \cdot \frac{p}{\rho} + m \cdot \frac{v^2}{2} \quad (1.6)$$

The **Bernoulli** law of conservation of energy states that the sum of the energy at every location in the flow passage must remain constant (expansion must be considered for compressible gases), when energy is neither externally added nor removed. Based on the mass flow q_m this yields:

$$g \cdot h + \frac{p}{\rho} + \frac{v^2}{2} = \text{const} \quad (1.7)$$

This equation can be simplified because the position changes in a pipe line are minimal so that the potential energy can be neglected:

$$\frac{p}{\rho} + \frac{v^2}{2} = \text{const} \quad (1.8)$$

Or by comparing at two locations (Fig. 1-9):

$$\frac{p_1}{\rho} + \frac{v_1^2}{2} = \frac{p_2}{\rho} + \frac{v_2^2}{2} \quad (1.9)$$

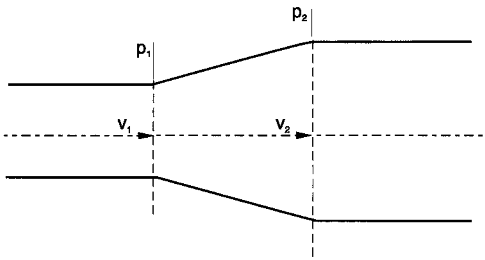


Fig 1-9: Pipeline Expansion

Rearranging equation (1.9), the basic equation for the pressure drop becomes:

$$\Delta p = p_1 - p_2 = \frac{\rho}{2}(v_2^2 - v_1^2) \quad (1.10)$$

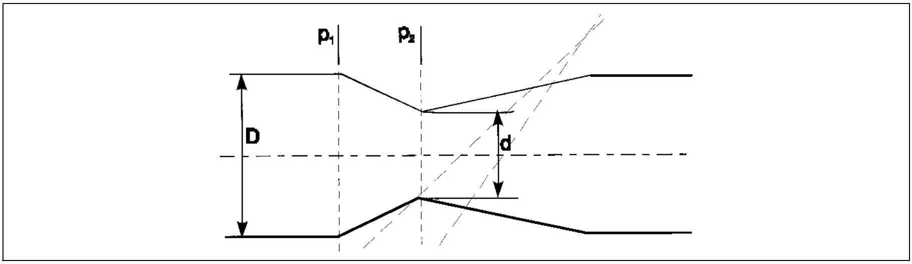


Fig 1-10: Pipeline Restriction

The pipe restriction shown in Fig. 1-10 presents two different cross sections, with diameters D an d, to the flow stream.

$$q_v = v \frac{D^2 \pi}{4} = v \cdot A \tag{1.11}$$

Based on the laws of continuity, the same mass of fluid flows through each cross section at the same time, for incompressible fluids that means the same flow rate:

$$\begin{gathered} q_v = v_1 \cdot A_1 = v_2 \cdot A_2 \\ q_v = v_1 \frac{D^2 \pi}{4} = v_2 \cdot \frac{d^2 \pi}{4} \\ \frac{v_1}{v_2} = \left(\frac{d}{D}\right)^2 \end{gathered} \tag{1.12}$$

Introducing a new variable, the area relationship m results in

$$m = \left(\frac{d}{D}\right)^2 \tag{1.13a}$$

$$\begin{gathered} m = \frac{v_1}{v_2} \\ v_1 = m \cdot v_2 \end{gathered} \tag{1.13b}$$

which when inserted in Equation (1.10):

$$\Delta p = \frac{\rho}{2}\left(v_2{}^2 - m^2 v_2{}^2\right) = \frac{\rho}{2} v_2{}^2 (1 - m^2) \tag{1.14}$$

replacing v_2 by

$$v_2 = \frac{q_v}{A_2} \qquad \text{from (1.11)}$$

$$\Delta p = \frac{q_v^2}{A_2^2} \cdot \frac{\rho}{2} (1 - m^2) \qquad (1.15)$$

yields the flow rate

$$q_v = A_2 \sqrt{\frac{2 \cdot \Delta p}{\rho(1 - m^2)}} \qquad (1.16)$$

A restriction in the cross sectional area for the flow results in an increase in the fluid velocity at that location resulting in a reduction of the static pressure due to the conversion of the kinetic energy. This pressure drop is the differential pressure Δp which is proportional to the square of the flow rate.

$$q_v^2 \sim \Delta p$$

$$q_v \sim \sqrt{\Delta p} \qquad (1.17)$$

When the flow velocity is reduced to zero at an obstruction, a pressure increase occurs at this location because the kinetic energy is converted to pressure.

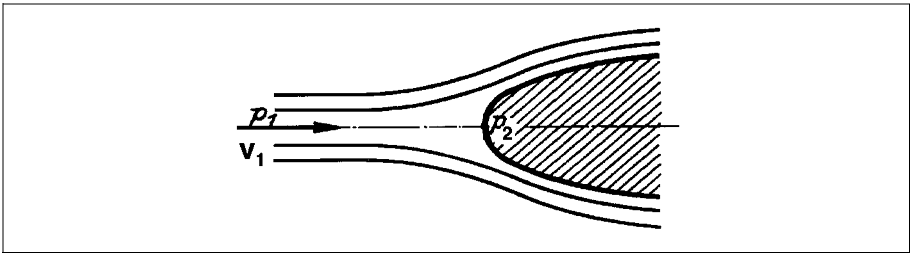


Fig 1-11: Flow Obstruction

At the center of the obstruction, at the **stagnation point** the velocity is :

$v_2 = 0$

It follows from Equation (1.9):

$$\frac{p_1}{\rho} + \frac{v1^2}{2} = \frac{p_2}{\rho} + \frac{0^2}{2}$$
$$p_2 = p_1 + \frac{\rho}{2} \cdot v_1^2 \tag{1.18}$$

The total pressure p_2, at the stagnation point is the sum of the static pressure p_1 and the converted dynamic pressure $P_{dyn} = \frac{\rho}{2} \cdot v_1^2$.

Therefore, if both of these pressure values are known, then the flow velocity can be calculated from:

$$v = \sqrt{\frac{2}{\rho}(p_2 - p_1)} \tag{1.19}$$

For **stagnation pressure measurements** this relationship is used to determine the flow velocity.

1.2.6 Channel Hydraulics

Flow in Open Channels

The elevation h, pressure p and velocity v energies are additive for a flow (Fig. 1-12) in the cross section A according to the energy relationships of Bernoulli for a uniform velocity distribution when the friction losses are neglected.

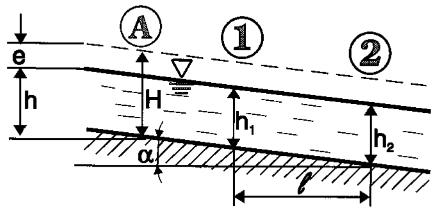


Fig 1-12: Sloped Open Channel

$$E = m \cdot g \cdot h + m \cdot \frac{p}{\rho} + m \cdot \frac{v^2}{2} \tag{1.6}$$

Neglecting the atmospheric pressure which is constant and does not influence this discussion and expressing the energy values as fluid heights the equation can be written as:

$$H = h + \frac{v^2}{2g} = h + e \tag{1.20}$$

The expression $e = \frac{v^2}{2g}$ symbolizes the conversion of the kinetic energy into potential energy expressed as a fluid elevation. The curve e is the energy line.

Based on the laws of continuity, the energy contents at points 1 and 2 must be the same:

$$h_1 + \frac{v_1^2}{2g} = h_2 + \frac{v_2^2}{2g} \tag{1.21}$$

To investigate the flow relationships for various slopes the elevation difference is included:

$$h_1 + l \cdot \tan\alpha + \frac{v_1^2}{2g} = h_2 + \frac{v_2^2}{2g} \tag{1.22a}$$

$$h_2 - h_1 - \frac{v_1^2 - v_2^2}{2g} = l \cdot \tan\alpha \tag{1.22b}$$

After simplification and algebraic rearrangement, the expression for the slope of the upper water surface for rectangular cross sections is:

$$\frac{h_2 - h_1}{l} \approx \frac{\tan\alpha}{1 - \frac{v^2}{g \cdot h}} \tag{1.23}$$

Substituting $v = \sqrt{g \cdot h}$ a noteworthy limiting velocity v_{gr} is reached, namely the wave velocity. It is identical to the propagation velocity of flat waves. In Equation 1.23 at v_{gr} the term

$$1 - \frac{v^2}{g \cdot h} = 0$$

For the slope

$$\frac{h_2 - h_1}{l} = \infty$$

which means that under ideal conditions (e.g. frictionless operation) the slope is infinite. The **Froude Number** Fr is the defining criterion.

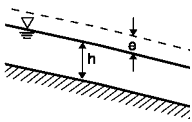
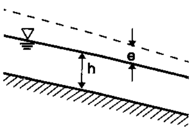
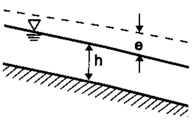
$$Fr = \frac{v}{\sqrt{g \cdot h}} \qquad (1.24)$$

(Fr symbolizes the relationship between inertial and gravitational forces, Equation 1.24 applies to a special case; a rectangular cross section).

The value of Fr for a **wave propagation velocity** v_{gr} is 1. In this condition a standing wave exists which cannot move either upstream or downstream.

If the velocity is smaller than v_{gr} the flow regime is known as **subcritical**. Waves can propagate upstream and obstructions in the flow stream can produce effects upstream of their location.

For velocities greater than v_{gr} the flow regime is known as **Supercritical**. Waves in this case can propagate downstream from a distribution. Waves cannot propagate upstream.

Flow Regime	$e = \frac{v^2}{2g}$	Discharge	Froude Number	Velocity	Kinetic Energy
Critical		uniform	Fr =1	$v = \sqrt{g \cdot h}$	$\frac{v^2}{2g} \Rightarrow$ constant
Subcritical		retarded	Fr < 1	$v < \sqrt{g \cdot h}$	$\frac{v^2}{2g} \Rightarrow$ decreasing
Supercritical		accelerated	Fr > 1	$v > \sqrt{g \cdot h}$	$\frac{v^2}{2g} \Rightarrow$ increasing

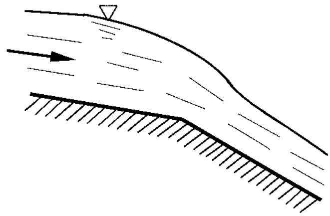
Tbl. 1-2: Flow Regimes and Slopes

Transition from Subcritical to Supercritical

When a subcritical flow is accelerated it may become super critical, a condition which is desirable in order to eliminated backflowing waves. This is the case in a Venturi flume for example.

Fig. 1-13 Shows two examples:

a.
The slope becomes steeper, the kinetic energy increases, flow goes from sub- to supercritical.



b.
A damming upstream of a gate increases the potential energy and the velocity downstream is so large that the flow becomes supercritical. This same effect is achieved by a restriction located at the side.

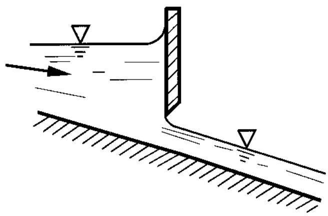


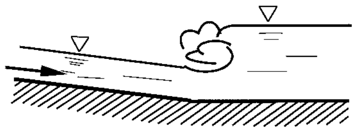
Fig 1-13: Accelerating Transition

Transition from Supercritical to Subcritical

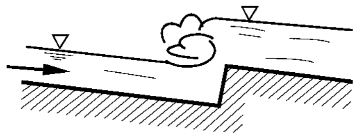
A large portion of the kinetic energy of a supercritical flow must be decreased if subcritical flow is to be achieved. The flow velocity decreases and the water level increases. In the subcritical flow regime a wave which moves upstream is produced which converts a great deal of energy into heat.

Finally, when the velocities of the supercritical flow and the wave propagation are the same, the wave moving at the propagation velocity stands. This is known as a **hydraulic Jump** which occurs often and becomes stabilized at a disturbance.

a)
When the slope decreases suddenly, the flow level rises and in the transition a hydraulic jump occurs with an energy absorbing rolling wave.



b)
A similar effect occurs when a positive step is encountered which in itself requires additional energy.



c)
A special case is the backflow after a gate when the level downstream is high. The wave is formed at an invisible hydraulic jump.

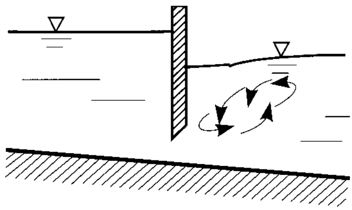


Fig 1-14: Hydraulic Jump

Discharge from Large Openings, Discharge from Rectangular Weir

According to Bernoulli the entire available energy is converted to kinetic energy for frictionless discharge from an open vessel.

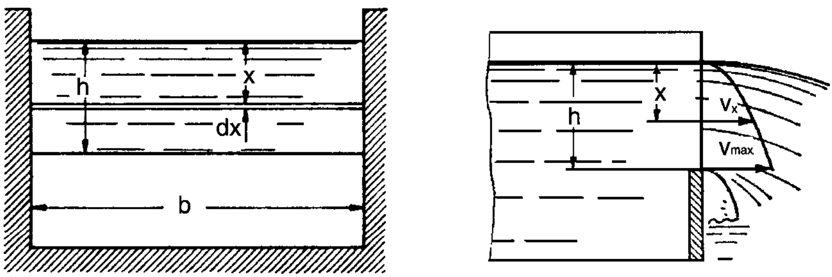


Fig 1-15: Rectangular Weir

There exists at a depth x the discharge velocity.

$$v_x = \sqrt{2g \cdot x}$$

There exists at a depth x a discharge flowrate

$q_{vx} = A_x \cdot v_x$ from:

$$q_{vx} = b \cdot dx \cdot \sqrt{2g \cdot x} \qquad (1.25)$$

and for the entire opening:

$$q_v = \int_0^h b \cdot \sqrt{2g \cdot x} \; dx \qquad (1.26a)$$

$$q_v = \frac{2}{3} \cdot b \cdot h \cdot \sqrt{2g \cdot h}$$

$$q_v = \frac{2}{3} \cdot b \cdot \sqrt{2g} \cdot h^{3/2} \qquad (1.26b)$$

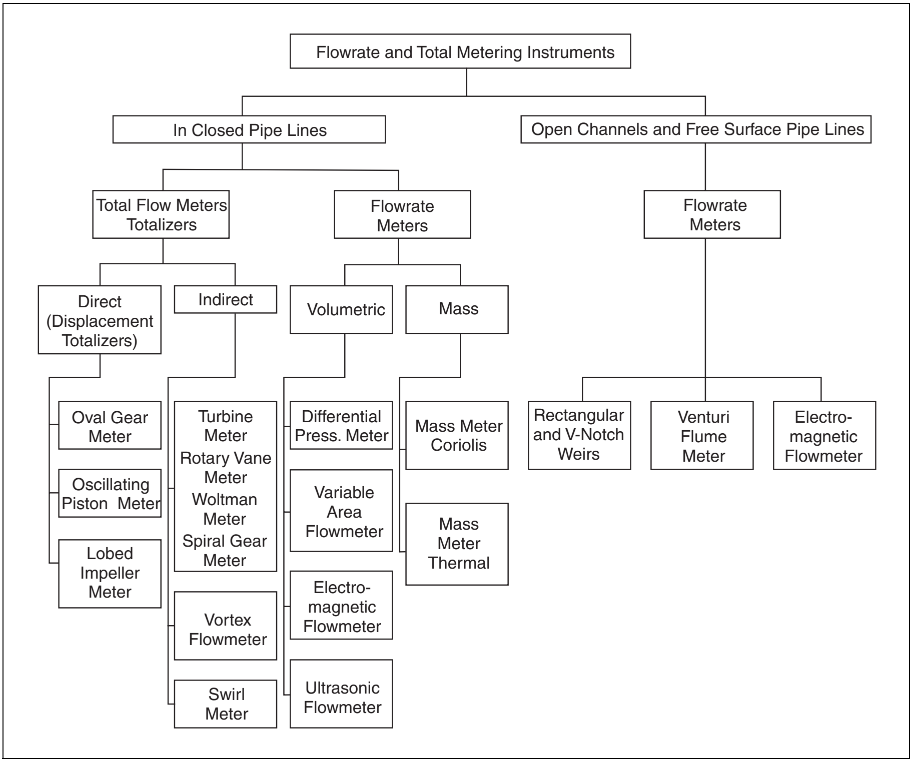
Losses actually occur in the discharge which are incorporated in the discharge coefficient:

$$q_v = \frac{2}{3} \mu \cdot b \cdot \sqrt{2g} \cdot h^{3/2} \qquad (1.27)$$

This equation forms the basis for the calculation requirements for metering in pipes and channels.

2 Flowrate and Total Flow Metering of Gases and Liquids

There are a wide variety of different methods available for metering flowrate and total flow. Each method has its own specific characteristics which are directed toward individual installation requirements. The most important principles existing in the market place are described and compared in the following chart:



Flowrate and Total Flow Meter Classifications

The chart differentiates between volume and mass flowmeters for pipeline measurements and the characteristics which define these two methods, Total flow meters, usually referred to as flow totalizers, are instruments in which a defined volume is filled and then integrated to determine the total flow quantity. The indirect flow totalizers operate with moving metering chambers, but whose volume is known (can be compared to a line of buckets). In these totalizers the enclosed chambers of the direct flow totalizers are missing and the measurements are made either mechanically utilizing vaned wheels through which defined volumes are transported or electrically, using quantity proportional pulses.

Some flowmeters utilize the fluid velocity or the kinetic energy of the flow stream for flowrate determination which is also an indirect method.

The user faces the difficult task of selecting the technically best and most cost effective meter for his application. The following instrument descriptions are designed to assist in that selection.

2.1 Volumetric Totalizers

Volumetric totalizers with moving chambers which are driven by the fluid are known as displacement meters. They can be used for liquids and gases. They are direct volumetric totalizers because they transport the fluid in measured chambers with defined geometrically bounded volumes.

Included in the indirect category are volume totalizers with metering vanes such as those in a turbine flowmeter and those which force flow stream changes. In these methods a pulse total is generated which represents a specific – not geometrically bounded – volume, for example, the flow quantity which produces one complete revolution of a rotary vane meter.

2.1.1 Oval Gear Meter

The metering element of this **volume totalizer** consists of two oval gears.

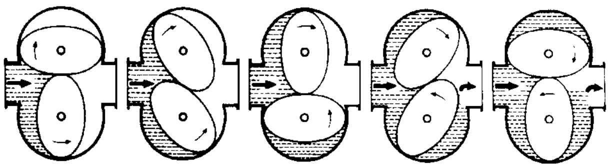


Fig. 2-1: Flowrate Operation of an Oval Gear Meter

The driving fluid produces the required torque, which varies as a function of the gear position, to rotate the gears.

Therefore the torques on the lower gear in the left side of Fig. 2-1 cancel each other while the torque on the upper gear is one sided and actually causes the rotation. Around the upper gear a bounded crescent like volume exists which is pushed towards the outlet of the meter. Each rotation of the pair of oval gears transports a defined fluid volume.

The number of rotations is therefore an exact measure of the quantity of fluid which has flowed through the meter. The precision teeth assure a good seal between the two gears. The play between the oval gears and the walls of the metering volume is so slight that the leakage flow is small.

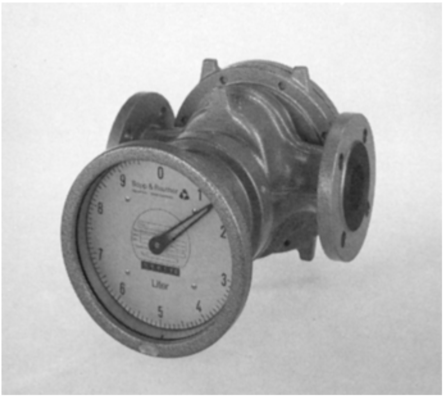


Fig. 2-2: Oval Gear Meter for Industrial Fluids, Design with Totalizer

The rotations of the pair of oval gears are transmitted without a stuffing box to an indicator either by a permanent magnet coupling or by a feedback free magnetic field controlled pulse transmitter.

The gears and bearings are subject to mechanical wear. Through selection of materials for the housing, oval gears, and bearings as well as by design consideration of expansions due to high temperatures, oval gear meters are suitable for almost all operating conditions.

The accuracy limits shown in Fig. 2-3 represent their relationship to the metering fluid, especially as a function of its viscosity. For low viscosities the flow range is appreciably less than that for higher viscosities.

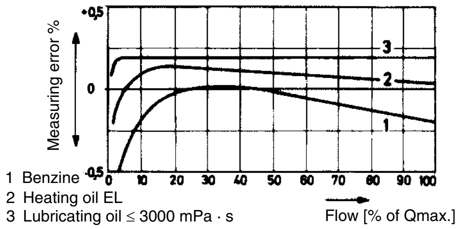


Fig. 2-3: Flowrate Error Curves in % of Rate

It is understandable that the pressure drop increases with increasing viscosity. The pressure drop curves (Fig. 2-4) include the meter size as an additional parameter.

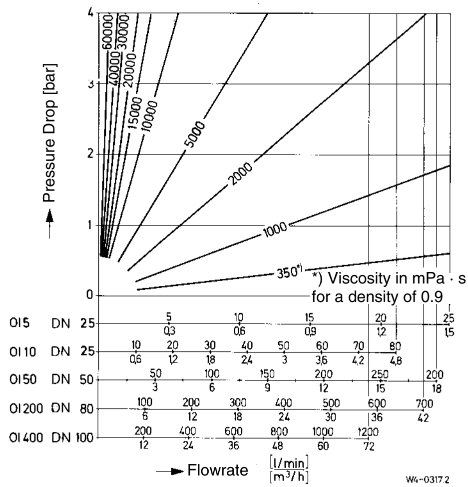


Fig. 2-4: Flowrate Pressure Drop

Specifications:

Meter size:	DN 6...DN 400 [1/4”...16”]
Max. possible flowrate:	1200 m^2/h
Viscosity:	0.3...1 · 10^5 mPa · s
Max. allowable pressure:	100 bar
Max. allowable temperature:	290 °C

Approved for certification

2.1.2 Oscillating Piston Meter

In a cylindrical housing a piston oscillates eccentrically in a hollow cylinder. In this manner it transports a defined volume. The method of operation is shown in Fig. 2-5.

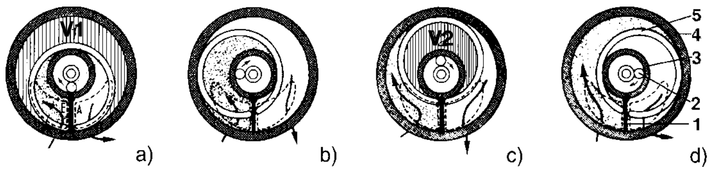


Fig. 2-5: Flowrate Oscillating Piston Meter Operation

The stationary outer cylinder (4) is also the housing, in which a dividing wall (1) and a guide ring (3) are mounted. The dividing wall on the bottom of the housing provides the boundary between the inlet (E) the outlet (A) openings. The bearing for the oscillating piston (5) is mounted in sleeve (2) and is guided along the dividing wall. Openings for filling and draining are located in its base. In positions a and b the piston volume V_2 is filled. At the same time the fluid forces the piston away so that the housing volume V_1 can be filled. At the same time the force from the piston causes the portion of the fluid volume V_1 in the right side to be discharged. When position (d) is reached the volume V_1 has been completely discharged once and refilled, the volume V_2 begins its discharge phase. One rotation of the piston encompasses both volumes, V_1 and V_2.

Fig. 2-6: Oscillating Piston Meter for Water - Type RONDO DIRECT in Various Meter Sizes

The movement of the piston bearing (2) is transmitted to an indicator using a magnet and follower arrangement. A magnetic coupling is not utilized in the Oscillating Piston Totalizer RONDO DIRECT. The rotary motion of the piston is transmitted directly from the piston to the counter.

Since the oscillating piston wears rapidly, proper material selection is very important. Various materials are available such as gray cast iron, bronze, hard rubber, carbon and plastics. For high temperature operation an intermediate spacer is used to provide additional separation between the totalizer and the meter.

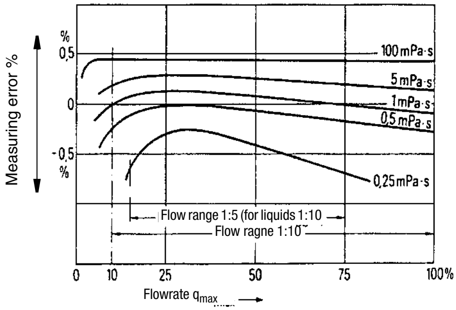


Fig. 2-7: Flowrate Viscosity Related Errors

The error curves in Fig. 2-7 indicate the high accuracy attainable at high viscosity due to a decrease in leakage losses. The oscillating piston meters are still operational at viscosities as high as 10,000 mPa·s.

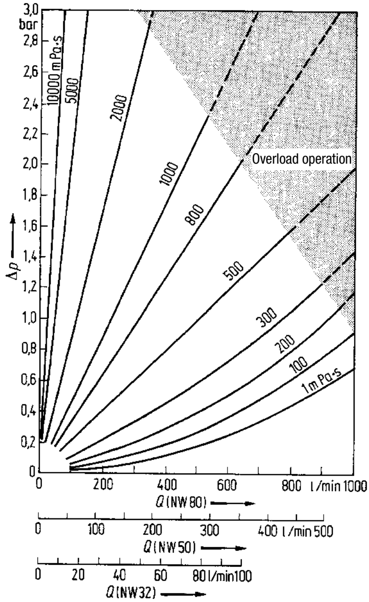


Fig. 2-8: Pressure Drop

That the pressure drop increases with increasing viscosity is shown in Fig. 2-8. For large differential pressures the material used for the oscillating piston must be checked for mechanical strength.

Specifications

Meter size	DN 15...DN 80 [1/2”...3”]
Max. possible flowrate	1000 m^3/h
Viscosity	$0.3...2 \cdot 10^4$ mPa·s
Max. allowable pressure	PN 100
Max. allowable temperature	300 °C
Approved for certification	

2.1.3 Lobed Impeller Gas Meter

Two rotating impellers, designed with a figure eight cross section, rotate in opposite directions due to the forces exerted by the gas being metered. The shape of the impellers prevents contact while the gap between them remains constant.

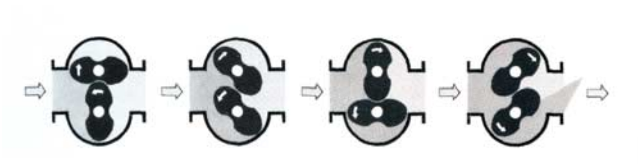


Fig. 2-9: Operation principles of the Lobed Impeller Meter

A gear drive external to the measuring chamber synchronizes the impellers. During each rotation four crescent shaped volumes are moved through the measuring chamber. The number of rotations is proportional to the total flow. The rotation is coupled using an adjustable fine tooth gear train to the totalizer.

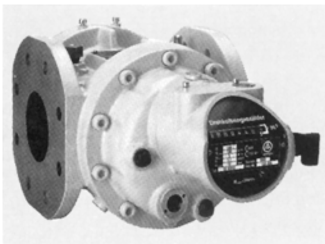
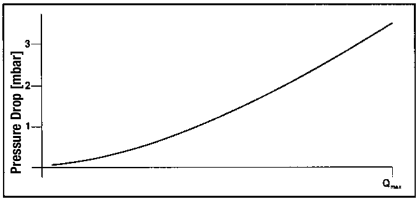


Fig. 2-10: Lobed Impeller Meter

An unmeasured flow, which is a function of the pressure drop, flows through the gaps. This negative error is compensated by an adjustment. The viscosity of gases increases at high pressures and reduces the losses in the gaps which compensates for the higher losses which would otherwise exist due to the higher pressure drops.

The pulsations in the gas discharge can cause the pipeline connected to the meter to vibrate. If resonance should occur, loud noises and sudden pressure drops can result. This condition should not be allowed to occur; if necessary noise and pulsation dampers should be utilized.



Pressure Drop

Fig. 2-11: Lobed Impeller Meter Pressure Drop

The pressure drop results from the mechanical and dynamic resistances in the meter. The dynamic portion increases appreciably with increasing flow.

Lobed impeller meters are very susceptible to contamination. Since contamination affects the pressure drop it must be monitored and the meter cleaned when required.

Specifications

Meter size:	DN 40...DN 3000 [1-1/2”...120”]
Flowrate:	between 3 m^3/h and 6500 m^3/h (gas at operating conditions)
Pressure rating:	max. PN 25
Operating temperature:	-10...+ 40 °C
Flow range:	to 1:50
Error limits:	within the allowable limits for the certification, i.e. less than 1 %.

Approved for certification

2.1.4 Turbine Flowmeter

Turbine flowmeters are indirect volumetric totalizers in which the flow stream causes a vaned rotor to revolve. The number of rotor revolutions is proportional to the total flow and the frequency of the revolutions to the flowrate.

The various designs are differentiated by the direction of the inflow and by the method utilized to measure the signal.

Rotary Vane Meter

The flow entry is tangential and causes the wheel to revolve in the rotary vane meter. A gear train is utilized to transmit the rotations of the wheel axle to the totalizer which, in wetted designs, is located in the fluid. Rotary vane meters are available as single jet (Fig. 2-12a) and as multijet designs (Fig. 2-12b).

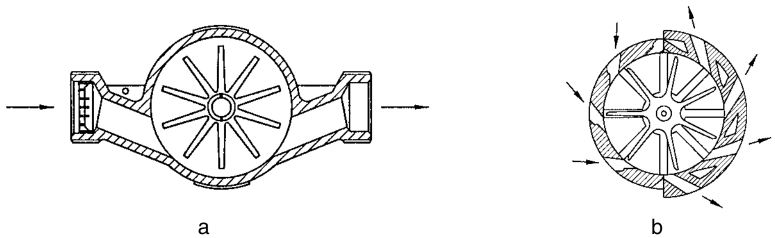


Fig. 2-12: Rotary Vane Meter

Seals separate the indicator area from the measurement area and transmit the rotation over a magnetic coupling. Rotary meters are used as domestic water meters, and are also used in hot water systems as the volume metering element for smaller heat quantity totalizers.

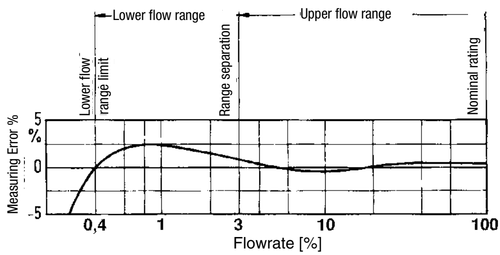


Fig. 2-13: Error Curve for a Multijet Rotary Vane Meter

Fig. 2-13 shows the error curve with reference to the certification limits which are ± 2 % (Cold Water)/ ± 3 % (Warm Water) in the upper and lower flow ranges.

Specifications:

Nominal sizes (based on the flowrate):	0.6...15 m^3/h
smallest possible flowrate:	12 l/h
largest possible flowrate:	30 m^3/h
Viscosity limit:	≤ 5 mPa·s
Approved for certification	

Fig. 2-14: Cross Section of a Single Jet Totalizer Type PICOFLUX

Fig. 2-15: Cross Section of a Multijet Totalizer Type OPTIMA ARTIST

Woltman Meter

The axle of a Woltman Meter rotor is parallel to the flow stream direction. The flow is also axial to the turbine wheel. A low friction gear train connects the axle to the totalizer.

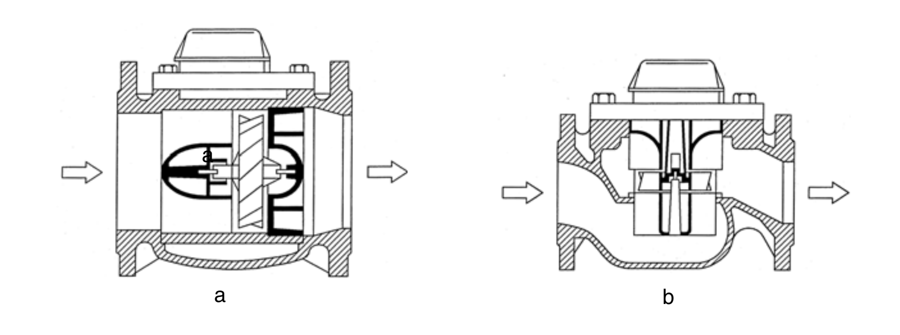


Fig. 2-16: Woltman Meter

There are two distinct designs, one with a horizontal turbine „WP“ (Fig. 2-16a) and one with a vertical turbine „WS“ (Fig. 2-16b). The vertical design offers the advantage of minimal bearing friction and therefore a higher sensitivity resulting in a larger flow range. The pressure drop however is appreciably higher because of the shape of the flow passage. The horizontal design allows the totalizer to be mounted in any orientation (e.g. vertical), a larger flow range and lower pressure drops.

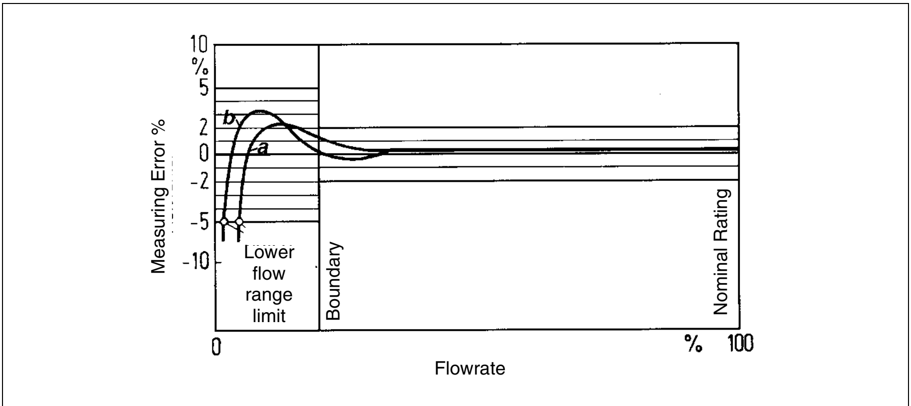


Fig. 2-17: Typical Flowrate Error Curve for a Woltman Meter DN 80 [3”]

The error curve shown in Fig. 2-17 indicates the certification error limits. The Woltman Meter is used primarily as a water meter, but similar to the Rotary Vane Meter is also used as the volume measurement element for heat quantity totalizers.

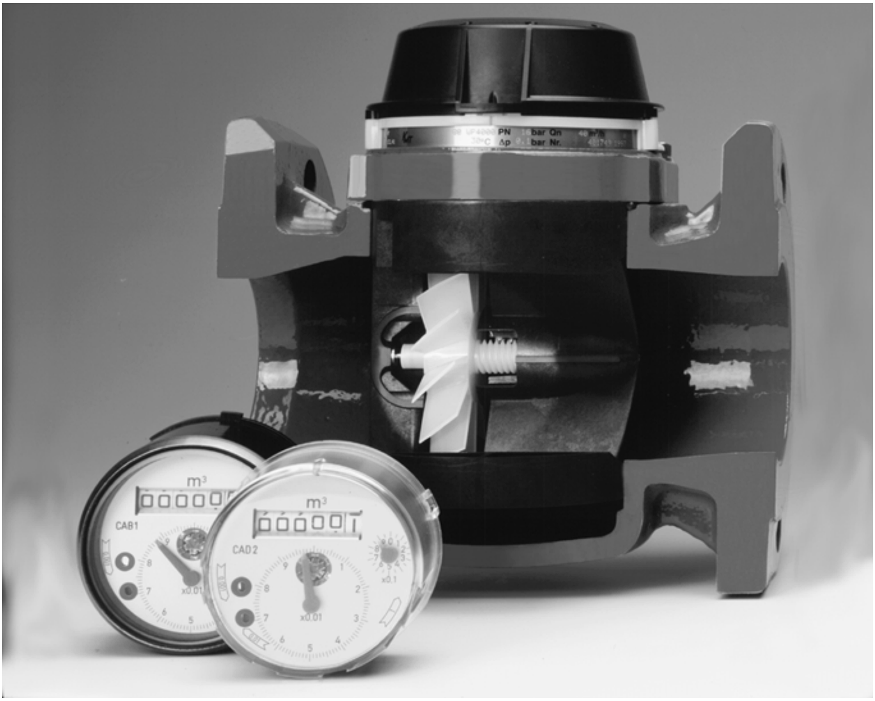


Fig. 2-18: Cross Section Woltman Meter WP Type HELIX

Fig. 2-19: Cross Section Woltman Meter WS Type VERTIX

The Combined Water Meter „WPV“ (Fig. 2-20) was designed for wider flow ranges. It is a combination of two totalizers, a large (main totalizer) and a smaller (secondary) one. An automatic pressure controlled spring loaded valve switches to the totalizer whose range is best suited for the flowrate.

Fig. 2-20: Combination Totalizer Type INLINE with Secondary Totalizer MODULMETER MO-N

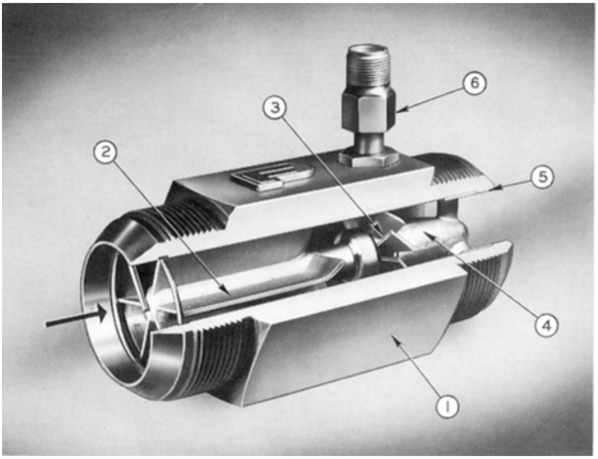
While the **Cold Water Meter** described above have an upper temperature limit of 40 °C (50 °C), the **Hot Water Meter** can be used up to 120 °C (130 °C). With appropriate material selections the Woltman Meter can also be used in industrial applications for deionized water.

Specifications:

Design:	WP	WS	WPV
Meter size:	DN 40...500 [1-1/2”...20”]	DN 50...150 [2”...6”]	DN 50...200 2”...8”]
Smallest possible flowrate	350 l/h	200 l/h	20 l/h
Largest possible flowrate	4500 m^3/h	350 m^3/h	600 m^3/h
Viscosity limit:	$\leq$ 3 mPa·s		
Approved for Certification			

Turbine Flowmeter

Turbine wheel meters, commonly known as turbine flowmeters, are similar in their basic design to the Woltman Meters with the one essential difference – the measurement of the rotation is made electrically with almost no feedback on the rotor. The turbine rotors are light in weight producing minimal friction in the bearings.



1 Housing
2 Guide body
3 Rotor
4 Bearing mount
5 Outlet
6 Electr. connections

Fig. 2-21: Turbine Flowmeter

As a result, the flow ranges can be expanded because the system responds with greater sensitivity. Smaller sizes are possible. The turbine flowmeter measures gases and liquids with elevated viscosities.

A coil in the housing opposite the vanes of the rotor measures the signal by various methods:

1. A magnet in the one vane induces a voltage pulse in the coil during every revolution.
2. The coil encloses a magnet and the vanes are made of permeable material. As the vanes pass the magnet, the field is distorted inducing a voltage pulse.
3. A high frequency AC voltage (10 kHz) is fed to the coil. The permeable vanes vary the amplitude of the supply voltage resulting in a secondary frequency superimposed on the carrier frequency.

In all three cases, a frequency signal is generated which is proportional to the number of revolutions and therefore to the flowrate. The signal is fed to a preamplifier in the connected converter. In this manner the totalizer, each of whose individual pulses represent a defined volume, becomes a flowmeter as a result of the time based frequency which is generated.

Interesting is the fact that this instrument can meter at higher viscosities, with the restriction, however, that the start of the linear range is displaced (Fig. 2-22).

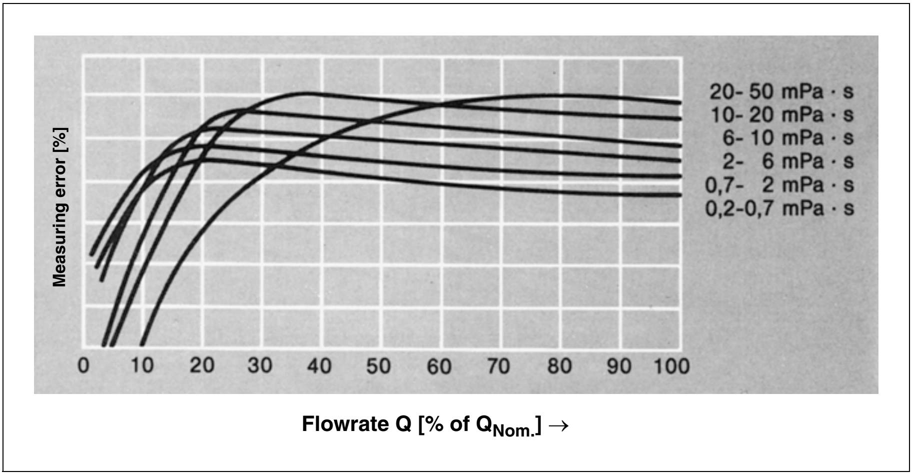


Fig. 2-22: Viscosity Effect on the Error Curves

The flow range is reduced as the viscosity increases. It is for this reason that for higher viscosities a calibration curve, which is not linear, must be prepared.

Specifications:

Meter size:	DN 5...DN 600 [3/16”...24”]
Minimum possible flowrate:	5 l/h (water)
Maximum possible flowrate:	10,000 m^3/h (water)
Flow range max.:	1:100
Viscosity limits:	700 mPa·s
Temperature:	-200 °C (cryogenic liquids) to +250 °C (600 °C)
Pressure rating:	to 100 bar (1000 bar)
Error limits:	+0.25 % of rate ...+1 % of rate

A special turbine flowmeter variation is the **Turbine Gas Totalizer** for metering large gas flows. The gas flow velocity is increased by a reducer at the inlet with a ring shaped cross section and guided over the freely turning rotor. The revolutions which are measured are mechanically transmitted to the totalizer using a gear train.

This instrument is often used for the custody transfer of natural gas for which it has received certification approval.

Specifications:

Meter size:	DN 50...DN 600 [2"...24"]
Minimum possible flowrate:	2.5 m^3/h (at operating conditions)
Maximum possible flowrate:	25,000 m^3/h
Flow range:	1:20
Certified design error limits:	+1 % of rate (span 1:5)
Temperature limits:	-10...+50 °C

2.1.5 Vortex Flowmeter

Why does the flag flap in the breeze? Why does a taut line (power line) sing in the wind? There are numerous examples of the effects of vortex formation at bodies around which there is flow. What is actually happening?

As already mentioned in Chapter 1.2.4 a flow obstruction causes vortices. On a free standing body vortices are formed on both sides which are alternately shed resulting in the formation of a Karman Vortex Street. The flag mentioned above reacts to the progress of the vortex street, the taut wire vibrates at the **vortex shedding frequency**.

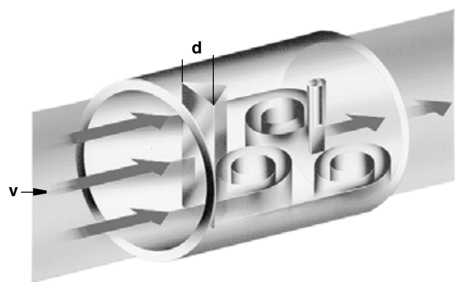


Fig. 2-23: Principle of Operation Vortex Flowmeter

If the geometric distance l between two consecutive vortices and the time interval is t when viewed from a fixed position, then the vortex frequency f is:

$$f \sim \frac{l}{t}$$

Strouhal discovered a relationship between geometry and velocity

$$f \sim \frac{v}{d}$$

where d is the diameter of a shedder body. The **Strouhal Number** St, a dimensionless constant, is:

$$f = St \frac{v}{d}$$

The requirement for the shedder (body) is that the geometry of the vortex generation does not change with flowrate and that the Strouhal Number remain constant over a wide Reynolds Number range. The shape and the opening ratio in the pipe define the manner of vortex shedding and the constancy of the Strouhal Number. Another system requirement assigned by the flow engineer, namely, that the vortex intensity be strong. Finally, the pressure drop should not be too large.

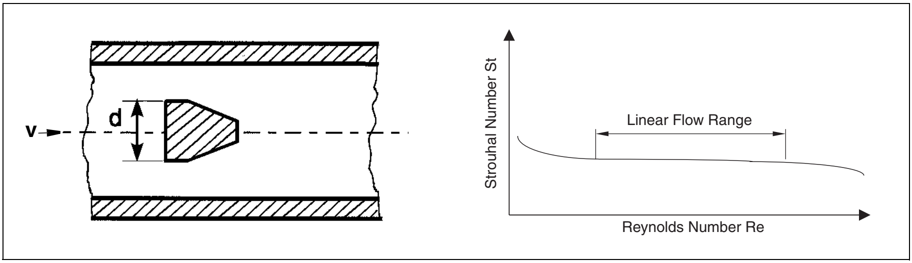


Fig. 2-24: Delta-Shedder and the Dependence of the Strouhal No. on the Reynolds No.

The optimum shape of the shedder has been determined empirically and through calculations; **ABB** has selected the delta shape.

The minimum Reynolds Number value Re_{min} (Fig. 2-24) defines the low end of the flow range, this means that the flow range decreases with increasing viscosity. The upper Re limit is so high that it is meaningless for selecting the range end value.

The methods for vortex determination vary. The vortices generate periodic pressure and velocity variations which provide a corollary means for the measurement. **ABB** mounts the sensor either behind the shedder or in the shedder in such a manner that it can vibrate freely (the location is determined by the meter size and the type of connections). Its tongue is forced to vibrate at the shedding frequency by the pressure differences.

Piezo elements inside the sensor convert the resulting pressure forces into electrical pulse signals which can be amplified. An arrangement of four Piezo sensors has been selected to cancel pipeline vibrations.

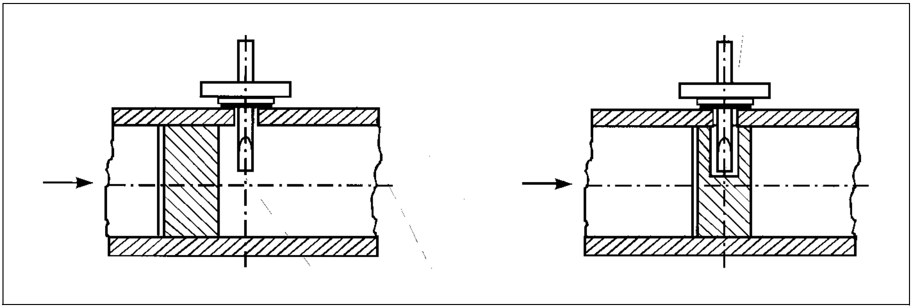


Fig. 2-25: Vortex Flowmeter Sensors mounted in the primary

If the fluid velocity profile is distorted (swirl, vortices) as it flows into the metering section, then the vortices cannot form properly. Therefore it is necessary to install conditioning straight sections upstream of the meter whose length is dependent on the type of distortion.

Steam, gases and liquids can be metered with a Vortex Flowmeter.

The Compact Design **FV4000-VT4** (Fig. 2-28) combines the flowmeter primary and the converter into a single entity and includes a local display of the flowrate and totalized flow value. The converter is based on a Digital Signal Processor (DSP) and generates a 4...20 mA-Signal as the analog output. As a 2-wire instrument it requires a supply voltage of 14 V...46 V DC, which can be fed over the 2-wire analog output cable.

A binary output is available in addition to the analog output. This output can be configured as a pulse output or as a contact output. The measurement display for gases and liquids is made in direct reading engineering units.

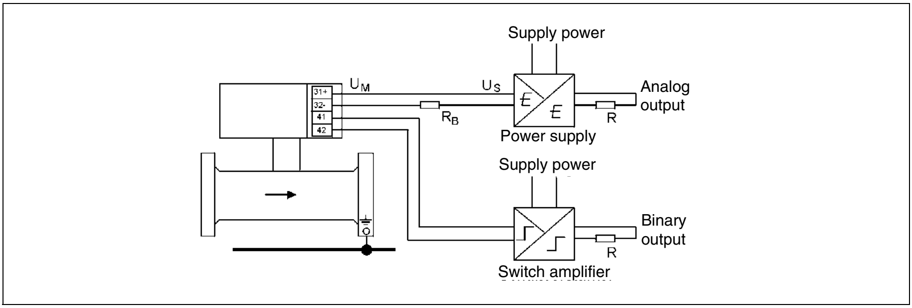


Fig. 2-26: 2-Wire Interconnection Diagram

Utilizing an integrated Pt 100 in the flow sensor, a saturated steam measurement or temperature monitor option can be incorporated without any additional costs.

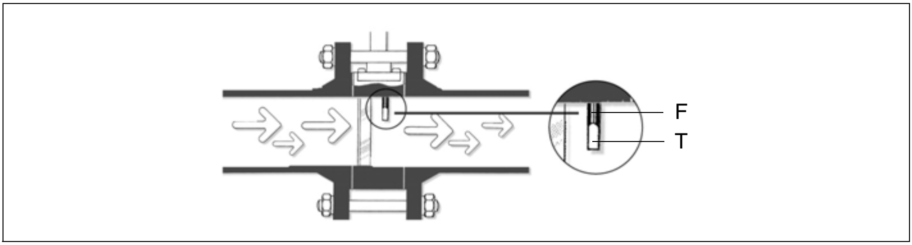


Fig. 2-27: Sensor for Flowrate (F) and Temperature (T) Measurements

Fig. 2-28: Compact Design: FV4000-VT4 (shown: flanged instrument)

Fig. 2-29: Remote Mounted: FV4000-VR (shown: Wafer Design instrument)

The converter can also mounted remotely at a distance from the flowmeter primary if a special cable with a max. length of 10 m (Fig. 2-29) is used. It can be wall or pipe mounted.

2- Wire Technology with a Fieldbus Data Link

The converter is designed in 2-wire technology, i.e. the voltage supply and the digital communication from the Fieldbus data link utilize the same cable. In parallel, a contact output is available which can be used as an pulse output, alarm or system monitoring output. All stored data is saved during a power outage.

A Device Management Tool DSV4xx (SMART VISION) can be used for operating and configuring intelligent field instruments, utilizing FDT/DTM-Technology. A data exchange with a complete palette of field instruments can be accomplished over various communication paths. The main goal of the data set is a parameter display, configuration, diagnostics, records and data management for all intelligent field instruments, which themselves satisfy the communication requirements.

Common Specifications

Allowable supply power:	9 V...32 V (no Ex-Protection)
Current use:	Normal operation: 10 mA
	FDE (Fault Disconnection Electronic): 13 mA
Ex-Design:	II 2 G EEx ia IIC T4

Communication PROFIBUS PA
The converter is suitable for connection to the Segment Coupler DP/PA.

PROFIBUS PA-Protocol
Output signal per EN 50170 Volume 2, PROFIBUS
Transmission technology IEC 1158-2/EN 61158-2
Transmission speed: 31.25 KByte/s

PROFIBUS Profile-Version 3.0

Ident-No.: 05DC hex

Function blocks:	**2 x AI, 1 x TOT**
GSD-Files:	-PA139700 (1 x AI)
	-PA139740 (1 x AI, 1 x TOT)
	-ABB_05DC (2 x AI, 1 x TOT + manufacturer specific)

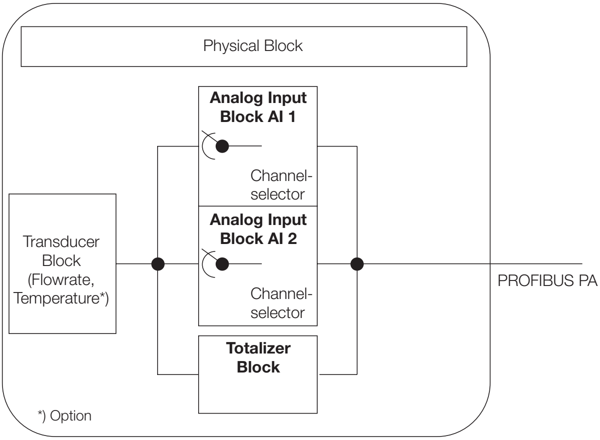


Fig. 2-30: Block Structure of the FV4000 with PROFIBUS PA

The output values (volume, normal, mass flowrate or temperature) can be selected over the Channel selector.

Communication FOUNDATION Fieldbus
The converter is suitable for connection the special supply instruments or a Linking Device.

FOUNDATION Fieldbus-Protocol
Output signals per FOUNDATION Fieldbus-Protocol
Specification 1.4 / ITK 4.01 for the H1-Bus
Transmission technology IEC 1158-2/EN 61158-2
Transmission speed: 31.25 KByte/s

Manufacturer ID:	0x000320
Device ID:	0x0015
Reg-Number:	IT013600

Function blocks: 2 x AI / FV4000 has LAS-Functionality

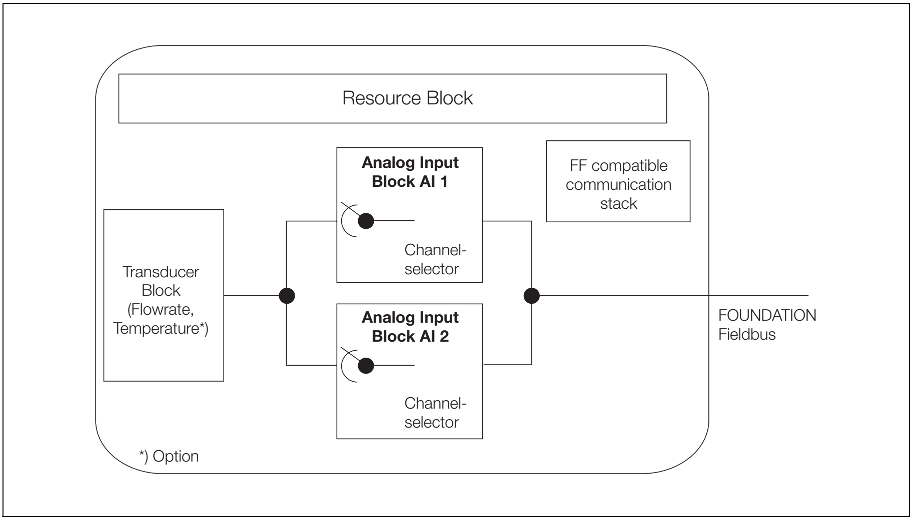


Fig. 2-31: Block Structure of the FV4000 with FOUNDATION Fieldbus

The output values (volume, normal, mass flowrate or temperature) can be selected over the Channel Selector.

Instrument Selection

The Vortex Flowmeter are available in sizes DN 15 to DN 300 [1/2" to 12"].

ABB provides at no cost, resource material to help in the selection and sizing of instruments suitable for a particular measurement task, as well as order support.

Water $\rho = 1000\ kg/m^3$ $\nu = 1 \cdot 10^6 m^2/s$				Gas $\rho = 1{,}2\ kg/m^3$ $\eta = 18{,}2 \cdot 10^6\ Pa \cdot s$	
DN	inch	Flow range [m^3/h]	Re_{min}	Flow range [m^3/h]	Re_{min}
15	½	0.5... 6	20,000	4... 24	20,000
25	1	0.8... 18	20,000	14... 150	20,000
40	1½	2.4... 48	20,000	30... 390	20,000
50	2	3.0... 70	20,000	40... 500	20,000
80	3	8.0... 170	40,000	90... 1200	25,000
100	4	10.0... 270	40,000	150... 1900	40,000
150	6	30.0... 630	70,000	300... 4500	40,000
200	8	70.0...1100	70,000	250... 8000	40,000
250	10	60.0...1700	70,000	800...14000	40,000
300	12	95.0...2400	70,000	1400...20000	40,000

Tbl. 2-1: Vortex Flowmeter FV4000, Flow Ranges

The flow ranges listed in Tbl. 2-1 for water must checked using the curves in (Fig. 2-32) when fluids with a higher viscosity are to be measured.

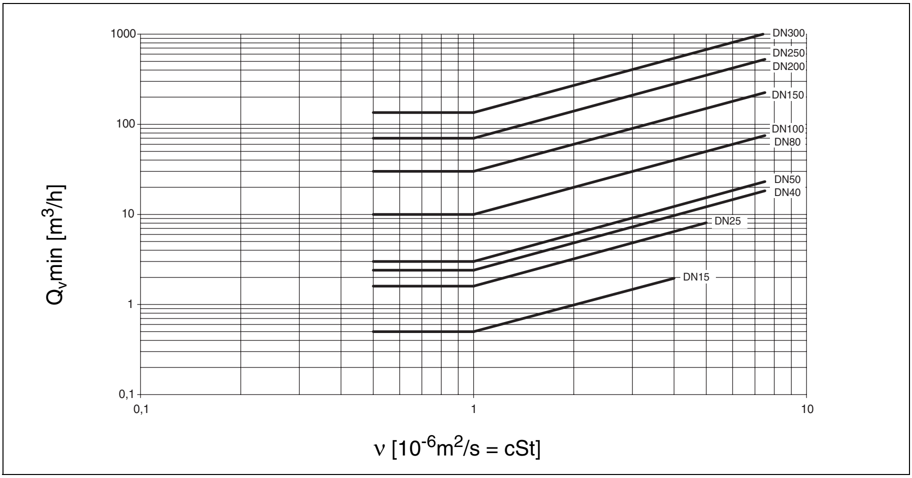


Fig. 2-32: Minimum Flowrates for Liquids as a Function of the Kinematic Viscosity

To avoid cavitation, a positive pressure must be maintained in the measuring section which can be calculated as follows:

$$p_2 \geq 1{,}3 \cdot p_D + 2{,}6 \cdot \Delta p$$

p_2 = Static pressure downstream from instrument
p_D = Fluid vapor pressure at operating temperature
Δp = Pressure drop (curves Fig. 2-34)

When selecting meters for gas or steam metering, please note that the values in the table refer to air and that the Vortex Flowmeter measures in units at operating conditions. The operating density must be first calculated (ρ_N = density at normal conditions)

$$\rho = \rho_N \frac{1{,}013 + p}{1{,}013} \cdot \frac{273}{273 + T} \tag{2.2}$$

and then the flowrate in units at operating conditions

$$q_v = \frac{1}{\rho} \cdot q_m \text{ or } q_v = q_n \frac{\rho_N}{\rho} \tag{2.3}$$

q_m = Mass flowrate in kg/h
q_n = Normal flowrate in m³/h

The flowrate q_v is the value in the table listed for the meter size. The operating density is essential for determining the minimum flowrate which can be metered, see Fig. 2-33.

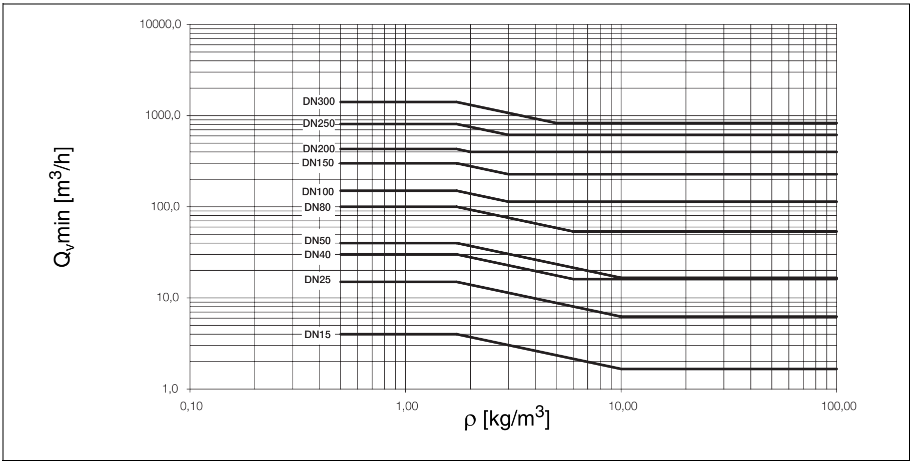


Fig. 2-33: Minimum Flowrate, Gas/Steam as a Function of the Fluid Density, DIN-Design (280 °C)

Based on the fact that the a shedder body exists in the inside of a vortex meter, a pressure drop occurs which is a function of the flowrate (Fig. 2-34).

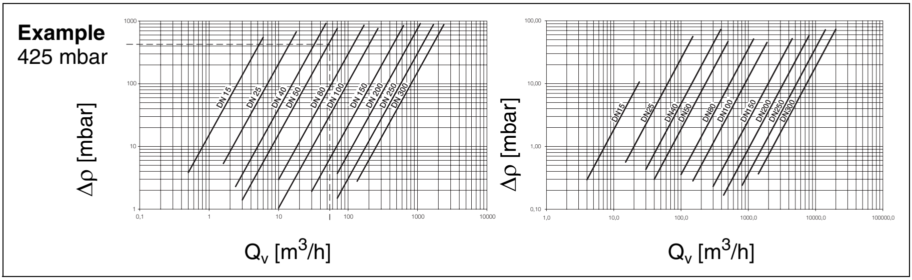


Fig. 2-34: Pressure Drop for Water (left) and for Air (right) at 20 ºC, 1.013 bar, DIN-Design

For saturated steam metering a special program is integrated. A separate menu is incorporated which contains the saturated steam tables utilized for correction calculations. With the integrated temperature measurement the corrections can be made with minimum effort. The mass flowrate signal is available directly at the analog output.

Specifications (Installation Lengths)

		Flanged Connections		Wafer Design	
DN	inch	DIN	ANSI	DIN	ANSI
15	½	200	200	65	112.5
25	1	200	200	65	112.5
40	1¼	200	200	65	113
50	2	200	200	65	112.5
80	3	200	200	65	111
100	4	250	250	65	116
150	6	300	300	65	137
200	8	350	350	–	–
250	10	450	450	–	–
300	12	500	500	–	–

Tbl. 2-2: Installation Lengths in mm

Specifications

Temperature limits:	-55...+400 °C (fluid temperature) -55...+70 °C (ambient temperature)
Max. possible pressure:	160 bar
Accuracy:	≤ 1 % of rate for gases, steam ≤ 0.75 of rate for liquids
Fluid wetted materials:	1.4571 [316Ti], Option Hastelloy-C
Ex-Protection:	II 2 G EEx ib II C T4 II 2 G EEx d II C T6 II 2D T 85 °C...T_{fluid} IP 67 FM Class I Div1, Group A, B, C, D

Installation of the Flowmeter

The following installation recommendations for the flowmeter should be observed.

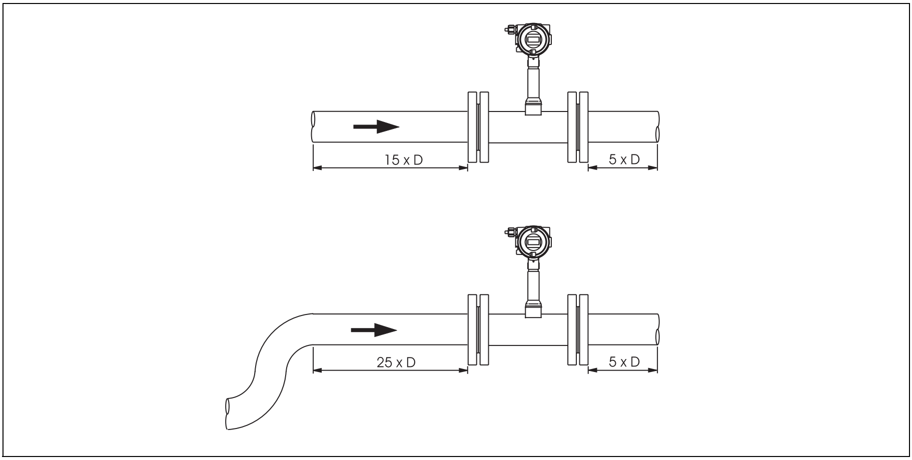


Fig. 2-35: Up- and Downstream Straight Sections

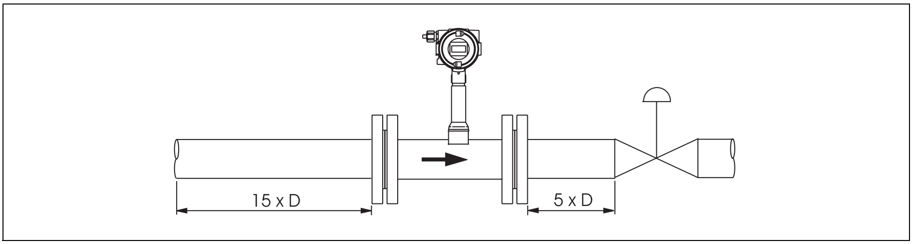


Fig. 2-36: Control Valve Location

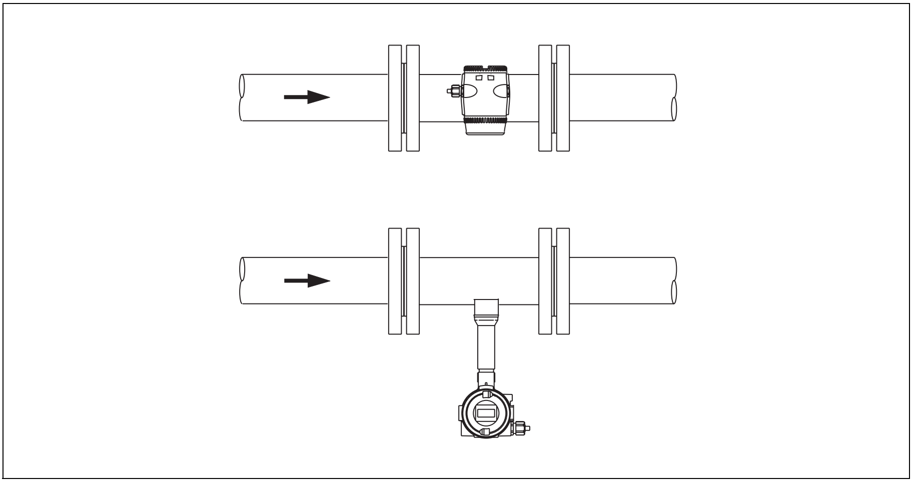


Fig. 2-37: Installation Orientation for Higher Temperatures, Fluid Temperature > 150 °C

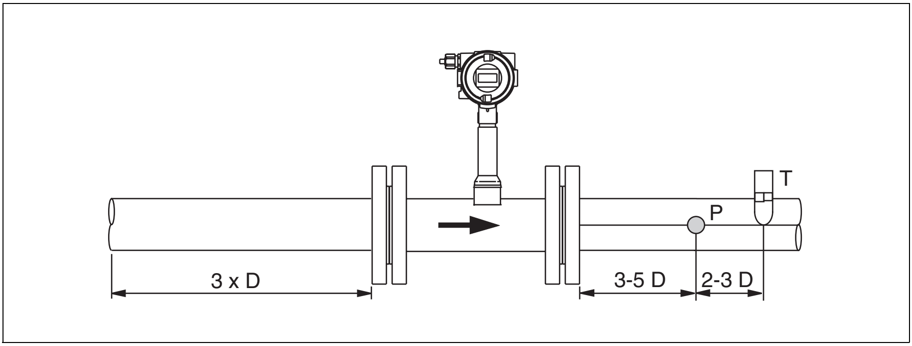


Fig. 2-38: Pressure (p) and Temperature (T) Measurement Locations for compensation

2.1.6 Swirl Flowmeter

A stationary guide body is located in the inlet of the meter, whose shape is similar to a turbine rotor, which forces the fluid to rotate. The flow flows through the meter pipe of the Swirl Flowmeter in a thread like rotation.

Fig. 2-39: Cross Section of a Swirl Flowmeter

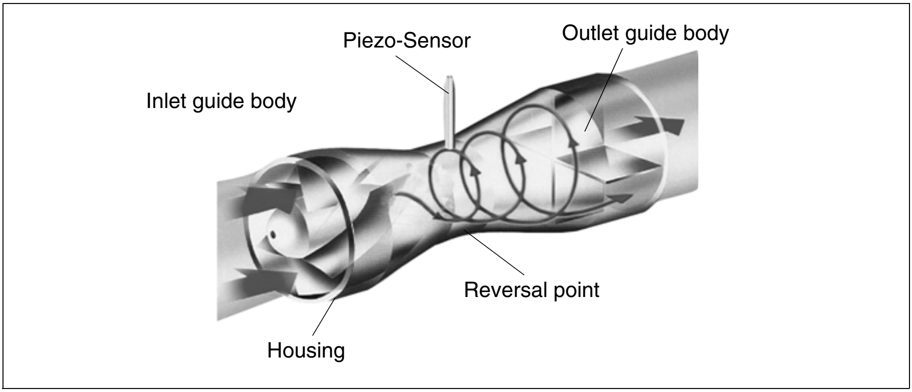


Fig. 2-40: Flow Stream in a Swirl Flowmeter

The flow stabilizes in the cylindrical cross section. A consideration of the cross sections in this region shows that the rotational velocity at the wall is relatively small and increases toward the pipe center until a stable vortex core is formed at the center. During the transition of the flow into the expanding section of the pipe the vortex core is displaced because a backflow occurs in the expander section.

The vortex core forms a spiral like secondary rotation whose frequency is proportional to the flowrate over a wide range. This secondary rotation is measured with a Piezo sensor. The Piezo sensor utilizes the resultant pressure differences for its pulse measurements.

The same sensors are used in both the Swirl and Vortex flowmeters. The rotation frequency is between 10 and 1500 Hz; the higher frequencies indicating higher flowrates.

In the converter the signals are processed into usable outputs. The same converters as described for the Vortex and Swirl flowmeters are used.

Fig. 2-41: Compact Design: FS4000-ST4

Fig. 2-42: Remote Design: FS4000-SR4

The flowrate of liquids, gases and steam can be measured with the Swirl flowmeter.

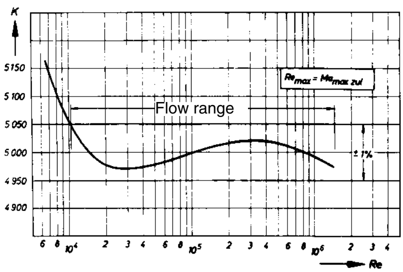


Fig. 2-43: Calibration Curve for a Swirl Flowmeter

Fig. 2-43 shows a typical calibration curve of a Swirl Flowmeter. On the ordinate is plotted the K-Factor in pulses per volumetric unit versus the Reynolds number on the abscissa. A semi-dimensionless presentation is practical because the fluid related values can be expressed by the Reynolds number. This demonstrates for example, that the minimum flowrate for higher viscosities increases and thereby reduces the linear range. Of course it is possible to meter in the nonlinear range. Viscosities up to 30 mPa·s can be metered dependent on the meter size.

Each instrument has its own calibration curve which is a constant attribute of the meter; it will only change when the shape of the metering section is mechanically deformed. By using the reduced flow ranges resulting from application conditions, a better accuracy can be realized for the entire range of ± 0.5 % of rate.

A linearization of the calibration curve can be made using a DSP-controlled converter. Using the data from the actual 5 point calibration an accuracy of 0.5 % or rate can be achieved for liquids, gases and steam.

A definite advantage of the Swirl flowmeter over other systems is the fact that conditioning sections up- and downstream of the meter are not required. To assure that the accuracy specifications can be achieved straight sections with a length of 3D/1D are recommended.

Water $\rho = 1000\ kg/m^3$ $\nu = 1 \cdot 10^6 m^2/s$			Gas $\rho = 1{,}2\ kg/m^3$ $\eta = 18{,}2 \cdot 10^6\ Pa \cdot s$
DN	Inch	Flow Range [m^3/h]	Flow Range [m^3/h]
15	½	0.1... 1.6	2.5... 16
20	¾	0.2... 2	2.5... 25
25	1	0.4... 6	5 ... 50
32	1¼	0.8... 10	7 ... 130
40	1¼	1.6... 16	12 ... 200
50	2	2.5... 25	18 ... 350
80	3	3.5... 100	60 ... 850
100	4	5.0... 150	65 ... 1500
150	6	15.0... 370	150 ... 3600
200	8	25 ... 500	200 ... 5000
300	12	100 ...1000	400 ...10000
400	16	180 ...1800	1000 ...20000

Tbl. 2-3: Swirl Flowmeter Flow Ranges in m^3/h (q_v)

Instrument Selection

Swirl flowmeters are available in sizes from DN 15...DN 400 [1/2”...12"]. The flow ranges are listed in Tbl. 2-3. For liquid measurements the maximum flow velocity is 6 m/s, for gases maximum 50 m/s.

ABB provides at no cost resource material to help in the selection and sizing instruments suitable for a particular measurement task, as well as order support.

It is important to avoid cavitation when metering liquids. Sufficient static pressure must exist in the metering section. To assure satisfactory operation the following check should be made:

$$p_2 \geq 1,3 \cdot p_D + 2,6 \cdot \Delta p$$

p_2 = static pressure downstream from meter
p_D = vapor pressure of the liquid at operating temperature
Δp = pressure drop (curve)

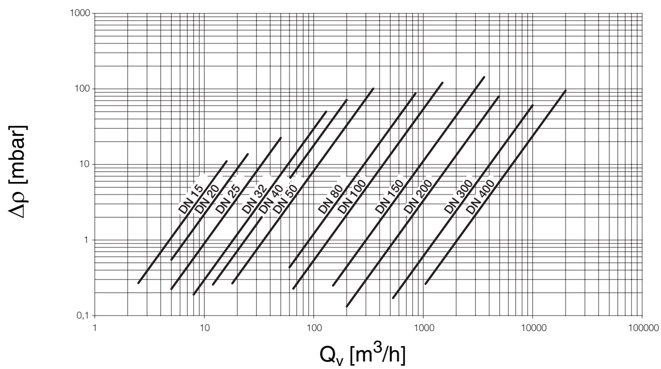


Fig. 2-44: Pressure Drop for Air (22 °C; 1013 mbar, ρ = 1.205 kg/m³)

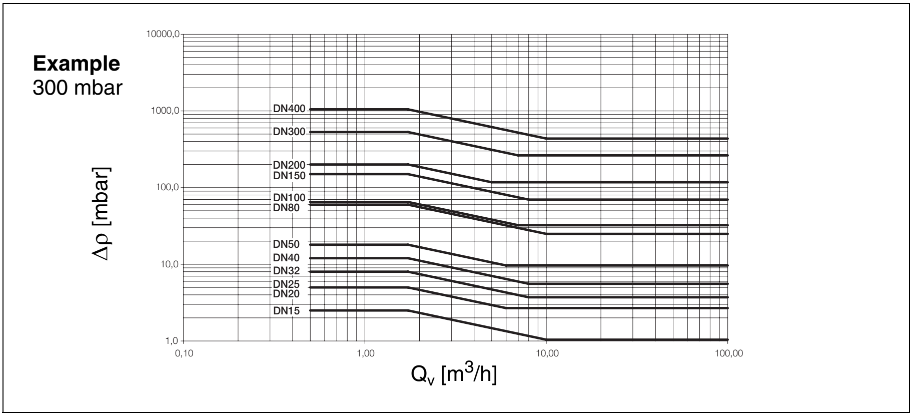


Fig. 2-45: Pressure Drop for Water (20 °C, 1013 mbar, ρ = 998 kg/m^3)

When making a flowmeter selection to meter gases, a conversion to operating conditions is necessary.

$$\rho = \rho_N \frac{1{,}013 + p}{1{,}013} \cdot \frac{273}{273 + T} \tag{2.4}$$

ρ = operating density (kg/m^3)
ρ_N = normal density (kg/m^3)
p = operating pressure (bar)
T = operating temperature (°C)
q_v = operating flowrate (m^3/h)
q_N = normal flowrate (m^3/h)

$$q_v = q_N \frac{\rho_N}{\rho} \tag{2.5}$$

This calculation can be made automatically in the converter.

Converter

The converter for the Swirl flowmeter is the same as the one described for the Vortex flowmeter.

Specifications:

Temperature limits:	-55 °C...+280 °C (fluid temperature) -55 °C...+ 70 °C (ambient temperature)
Max. possible pressure:	40 bar
Accuracy:	0.5 % of rate
Fluid wetted materials:	1.4571[316Ti] (Hastelloy C)
Ex-Protection:	II 2 G EEx ib II C T4 II 2 G EEx d II C T6 II 2D T 85 °C...T_{fluid} IP 67 FM Class I Div1, Group A, B, C, D

Installation of the Flowmeter

The following recommendations should be observed when installing the flowmeter in the pipeline.

Up- and downstream straight sections are not required if the radius of curvature for single or double elbows is greater than 1.8 x D.

Additional straight in- or outlet sections are not required for flanged reducers per DIN 28545 ($\alpha/2 = 8°$) installed at the outlet. Fig. 2-46 shows recommended in- and outlet straight sections for different pipeline configurations at the installation location.

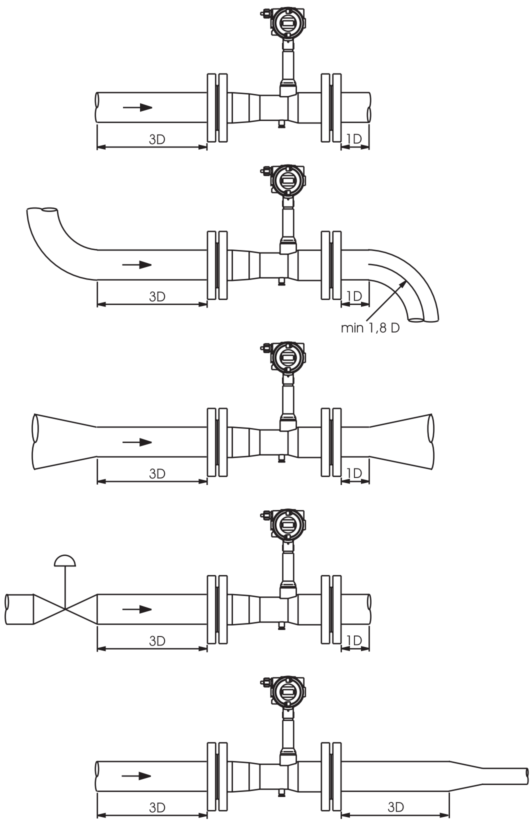


Fig. 2-46: In- and Outlet Straight Sections

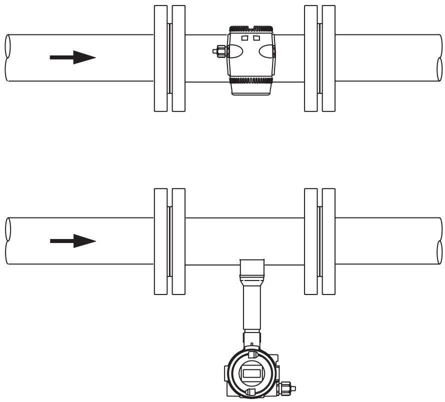


Fig. 2-47: Installation Orientation for Higher Fluid Temperatures > 150 °C

Multivariable Instruments

Instruments which measure more that one physical variable are referred to as Multivariable Instruments. They may have as an option a Pt 100 integrated directly in the sensor for temperature measurements.

To convert the flow measurements to normal or mass units in many instances an additional temperature measurement is all that is required, e.g. for saturated steam or for gas measurements when the pressure remains constant.

Compensation of Process Effects

Integrated Temperature Measurement

There are appreciable advantages to measuring the temperature and flowrate at the same location:

- High accuracy through optimal positioning of the temperature sensor
- No cabling
- Faster response time

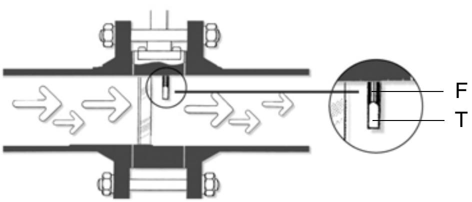
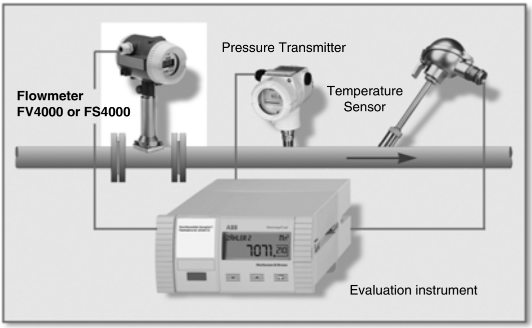


Fig. 2-48: Sensor for Flowrate (F) and Temperature (T) Measurements

Pressure and Temperature Compensation

If the process conditions are such that pressure variations occur or the fluid is superheated steam, then an integrated temperature measurement alone is not sufficient to convert the gas flow volume measurements to mass, normal or steam mass values. For these applications a flow computer is predestined for use with Vortex and Swirl flowmeters. The supply power is provided by the evaluation instrument – appreciably reducing wiring expenses.

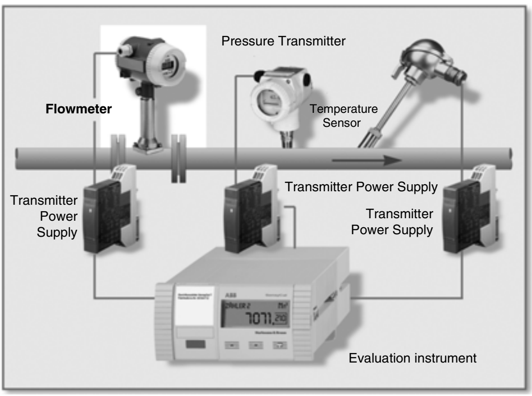


Components Required

- **Flowmeter** (Vortex or Swirl)
- **Pressure transmitter** for absolute pressure
- **Resistance thermometer,** optional with integrated sensor head transmitter
- **Evaluation instrument**

Measurements in the Ex-Area

The signals must be made intrinsically safe using a transmitter power supply.

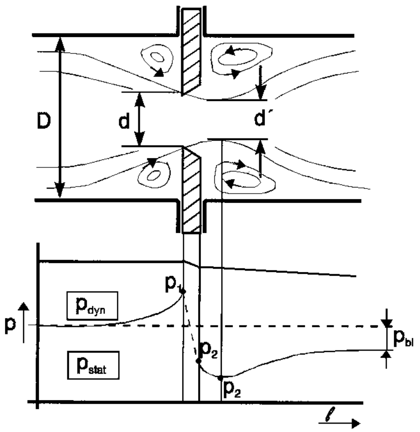


2.2 Flowmeters

2.2.1 Differential Pressure Flowmeters

In Chapter 1.2.5 the relationship between the pressure drop Δp due to a restricted pipe section and the volume flowrate q_v was presented.

This physical phenomenon is the basis for the differential pressure measurements, for devices with restrictions in a full flowing pipeline which generate a pressure drop.



p_1 pressure before the orifice restriction
p_2 pressure in orifice opening
$p_{2'}$ lowest static pressure
p_{bl} permanent pressure drop

Fig. 2-49: Pressure Curve in a Differential Pressure Meter

Fig. 2-49 shows the conversion forms of the energy. In the restricted section the kinetic energy (dynamic pressure p_{dyn}) increases due to the increase in velocity and the potential energy (static pressure p_{Stat}) decreases. The pressure differential results from the difference between the static pressures upstream and the pressure at or immediately downstream of the restriction. A recovery of the energy occurs downstream of the restriction due to the reduction of the velocity reduced by the permanent pressure drop p_{bl} .

The differential pressure process is a universally utilized metering principle for flowrate metering. Differential pressure meters are used for liquid and gas metering at extremely high temperatures and pressures. The meters have been optimized by extensive research activities over decades and the results published as standards. Governing is the ISO Standard 5167 and the German version DIN 1952 with whose assistance exact calculations can be made. The mass and volumetric flowrate equations may be found in these documents:

$$q_m = C \cdot E \cdot \varepsilon \cdot \frac{\pi}{4} d^2 \sqrt{2 \cdot \Delta p \cdot \rho} \tag{2.6}$$

$$q_v = C \cdot E \cdot \varepsilon \cdot \frac{\pi}{4} d^2 \sqrt{\frac{2 \cdot \Delta p}{\rho}} \tag{2.7}$$

Three new concepts are introduced, they are the velocity of approach factor E, the discharge coefficient C and the gas expansion factor ε.

Velocity of approach factor E

$$E = \frac{1}{\sqrt{1 - \beta^4}} = \frac{D^2}{\sqrt{D^4 - d^4}} \tag{2.8}$$

takes into consideration the effects of the diameter ratio $\beta = \frac{d}{D} = \sqrt{m}$

The factor E provides the means to relate the discharge coefficient C to the former discharge coefficient α, which was replaced by C in the ISO Standard.

The discharge coefficient C is a function of the diameter ratio β, the Reynolds number Re, the design of the restriction, the location of the pressure taps and finally the friction due to pipe roughness. The empirically determined values are presented in curves and tables. The gas expansion factor ε takes into account the changes in the density of gases and steam due to the pressure reduction in the restriction. Tables and curves have also been published for ε. The VDI/VDE-Guideline 2040 supplements the referenced calculation documents.

Differential Pressure Meter Designs

Various designs provide for an optimum adaptation to the operating conditions and requirements of the user. An important consideration is, for example, the pressure drop, which as a rule should be small, or the lengths of the inlet and outlet straight sections which for a Venturi tube can be short. Certainly costs are also important considerations.

Meters with the following designs are included in the standards.

Orifices	**Orifice** with corner taps
	Orifice with D and D/2 taps
	Orifice with flange taps
Nozzles	ISA-1932-**Nozzle**
	Long radius nozzle
Venturis	Classical **Venturi tube**
	Venturi nozzle

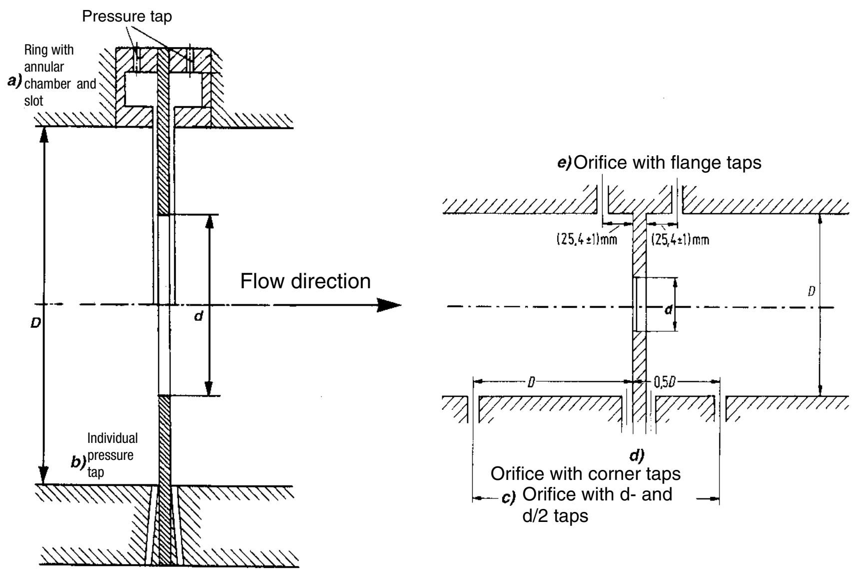


Fig. 2-50: Orifices

The most cost effective design is the orifice plate. Fig. 2-50 shows corner tap arrangements in (b/d) as individual taps and in (a) using an annular groove. The D and D/2 tap arrangement is shown at (c). The pressure connections for the flange tap arrangement, with standard 25.4 mm [1"] spacing, are made by drilling through the flanges. They are often combined with an annular chamber arrangement (a).

Nozzles have lower pressure drops, require however, more precise manufacture. Fig. 2-51 (b) shows an ISA 1932 Nozzle and its installation with corner taps ((a) lower) and with an annular chamber (upper). Long radius nozzles (c/d) are available for large and small diameters. Their installation is shown in (a).

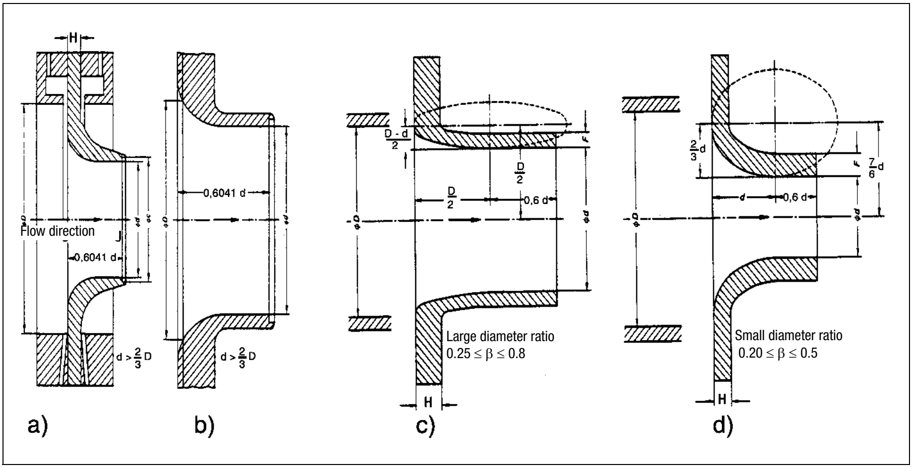


Fig. 2-51: Nozzles

Venturi tubes and Venturi nozzles are characterized by very small pressure drops. Both are also available in shortened versions. The fact that the pressure drop is an important factor in evaluating the various designs is shown by the curves (Fig. 2-53).

Pressure drop means energy loss and increased pumping requirements.

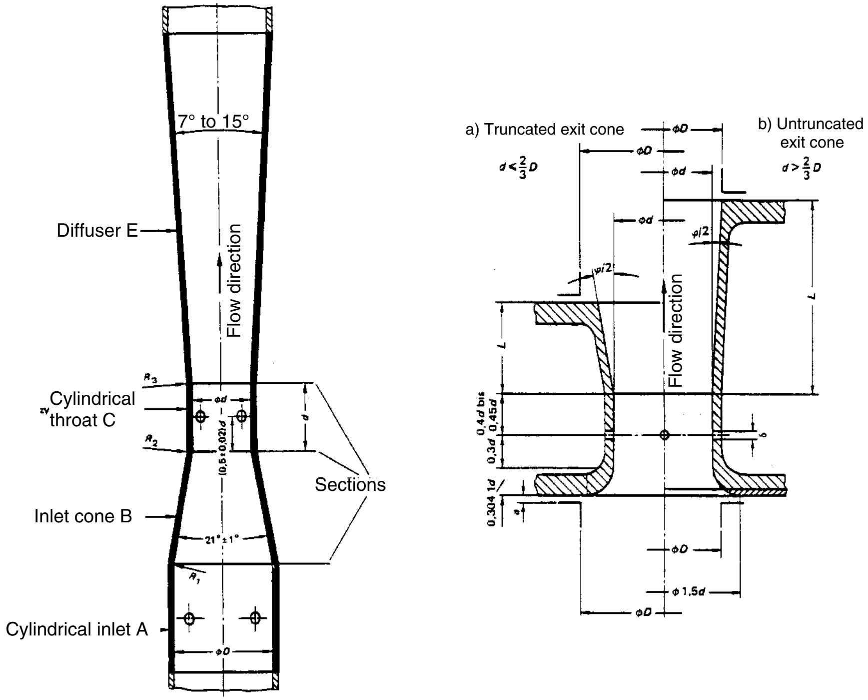


Fig. 2-52: Classical Venturi Tube and Venturi Nozzle

Comparing the range of possible installations shown in Tbl. 2-4 it is apparent that orifices have the basic disadvantage of high pressure drop. It is important that the edges of the orifice remain sharp. This causes the orifice to be sensitive to contamination and abrasion.

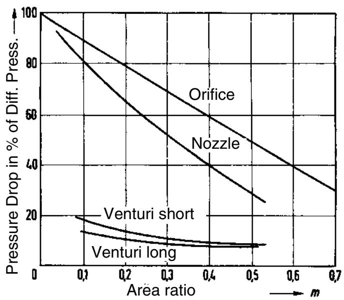


Fig. 2-53: Permanent Pressure Drop for Various Differential Pressure Meters

	Orifices			Nozzles		Venturis	
	Corner Pressure Taps	Flanged Pressure Taps	D and D/2-Pressure Taps	ISA 1932	Long Radius	Venturi Tube	Venturi Nozzle
d_{min} [mm]	12.5	12.5	12.5	15	10	20	50
D_{min} [mm]	50	50	50	50	50	50	65
D_{max} [mm]	1000	760	760	500	630	1200	500
β_{min}	0.23	0.20	0.20	0.3	0.2	0.3	0.32
β_{max}	0.80	0.75	0.75	0.8	0.8	0.75	0.78
$Re_{D, min}$	$5 \cdot 10^3$ ...$20 \cdot 10^3$	$2.5 \cdot 10^3$ ...$540 \cdot 10^3$	$2.5 \cdot 10^3$ ...$540 \cdot 10^3$	$2 \cdot 10^4$	10^4	$2 \cdot 10^5$	$1.5 \cdot 10^5$
$Re_{D, max}$	10^8	10^8	10^8	10^7	$2 \cdot 10^7$	10^6	$2 \cdot 10^6$

Tbl. 2-4: Application Limits for Differential Pressure Meters

One can imagine that meters as thoroughly researched as differential pressure meters can satisfy many special requirements. Therefore for fluids containing solids, segmental orifices are utilized in which the metering region is restricted only at the top. For fluids with high viscosities the Venturi nozzle can be used to Reynolds numbers as low as 50. Nozzles with a throat diameter of 0.6 mm can be used to meter flowrates as low as 2 l/h. These nozzles together with the differential pressure transmitter are generally incorporated in a single assembly. And naturally the table values can be extended to size 2000 [78"] and beyond.

Installation Requirements

Differential pressure meters can be used without problems only under specific flow conditions. Non-uniform flow streams after disturbances prevent an axisymmetric velocity profile from forming in the throat and thereby alter the differential pressure values. That is why the differential pressure producer must be installed between two straight cylindrical pipe sections in which no disturbances or diameter changes may exist. Along these sections the required velocity profile for metering can form. Tbl. 2-5 lists the recommendations per DIN 1952 for the required straight pipe sections.

	Orifices, Nozzles, Venturi Nozzles				Classical Venturi Tube		
	Diameter Ratio β				Diameter Ratio β		
	0.2	0.4	0.6	0.8	0.3	0.5	0.75
Single 90° elbow or tee	10	14	18	46	0.5	1.5	4.5
2 or more 90° elbows in different planes	(34)	(36)	48	80	0.5	(8.5)	(29.5)[1)]
Diffuser from 0.5 D to D with a length of 1...2 D	16	16	22	54			
Diffuser from 0.75 D to D with a length of 1 D					1.5	2.5	6.5
Fully opened gate	12	12	14	30	1.5	3.5	5.5
Outlet	4	6	7	8	4	4	4
[1)] This type of disturbance can still have an affect after 40 x D, therefore the values are enclosed in parenthesis.							

Tbl. 2-5: Required Disturbance Free Straight Sections, Lengths Listed in Multiples of D

A particularly difficult flow condition is swirl, in which the fluid moves from side to side in the pipeline. The recommended straight sections are not sufficient by any means for conditioning such a flow profile. Therefore a flow straightener must be installed. A flow straightener can also be used to shorten the recommended straight lengths for the other types of disturbances.

Installation Arrangements

The complete flow metering installation consists of the following elements:

a) Differential pressure producer
b) Fittings for the differential pressure producer and protective devices
c) Pressure tap lines
d) Differential pressure connections
e) Differential pressure transmitter
f) Condensate chamber
g) Power supply instrument for supply voltage

The arrangement and design of the installation is a function of the application. The minimum requirements for each metering location are pressure tap lines between the differential pressure producer and the differential pressure transmitter. Shut off vales (b) are installed in both pressure tap lines. For protection of the differential pressure transmitter (e) a combination of valves (d), three to five valves, are installed ahead of the transmitter converter to isolate and protect it by preventing the application of the pressure from one line only.

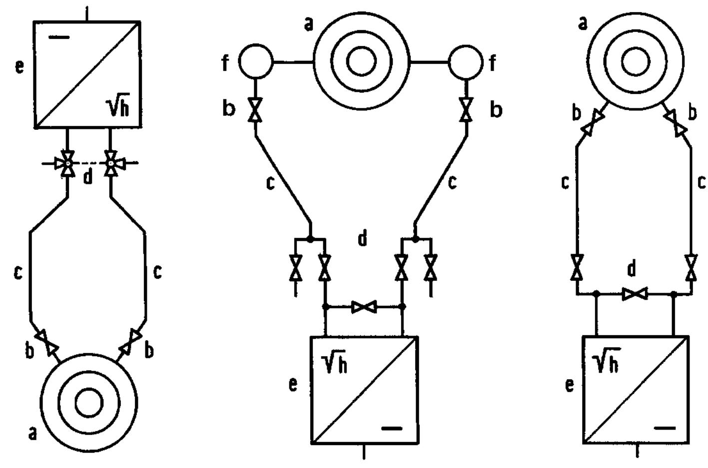


Fig. 2-54: Differential Pressure Metering Set-up

If the differential pressure producer is to be used for gas metering it should always be installed above the differential pressure producer to prevent any condensate from entering the pressure tap lines. Conversely gas bubbles should not enter the pressure tap lines when metering liquids. Therefore in those applications the converter should be installed below the differential pressure producer. For steam metering the pressure tap lines are filled with condensate from the condensate chambers (f).

There are a number of meter arrangements for extraordinary installation situations. There are isolation chambers for aggressive fluids to prevent their entry into the transmitter. The VDE/VDI Guideline 3512 provides information for such special situations.

Differential Pressure Transmitter

The **differential pressure transmitter** must satisfy the following requirements:

a) It should withstand the high static pressure which exists in the pipeline.

b) It should be very sensitive for operation at the lowest differential pressures because at high differentials the unrecovered pressure losses is high.

c) It should be made of materials which provide corrosion resistance to aggressive fluids.

d) It should convert the differential pressure into an electrical or analog output signal

e) It should be able to extract the square root in order to achieve a direct linear output proportional to the flowrate.

f) It should be easy to operate and include self monitoring functions.

g) Additionally, it should be communication capable including SMART or Fieldbus technologies (PROFIBUS PA, FOUNDATION Fieldbus).

h) It should be interference resistant (EMC) and be available in an Ex-proof design.

Within the Series 2600T, ABB provides instruments which satisfy all of the above requirements.

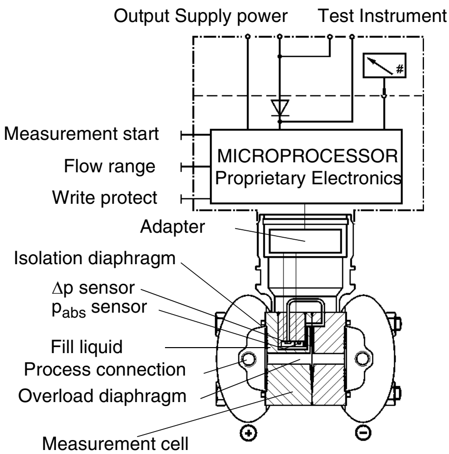


Fig. 2-55: Functional Schematic

The Transmitter 265DS is a modular designed instrument and consists of the measurement element and an integrated adapter and operator electronics.

This transmitter is a Multisensor instrument for measuring the differential and absolute pressures. The completed welded measurement cell is a two chamber system with an internal overload diaphragm and an internal silicone absolute pressure sensor . The absolute pressure sensor, on the plus side only, measures the process pressure and provides information for an almost complete static pressure effect compensation. The differential pressure sensor is connected to the minus side of the measurement cell by a capillary tube. The existing differential pressure (Δp)/absolute pressure (p_{abs}) is transmitted to the measurement diaphragm of the silicone sensor over an isolation diaphragm and the fill liquid.

A minimal deflection of the silicone diaphragm changes the output voltage of the measurement system. This pressure proportional signal is linearized, temperature compensated and converted by the adapter electronics and other electronic circuits into an electrical signal 4...20 mA/HART, PROFIBUS PA or FOUNDATION Fieldbus.

To prevent damage to the measurement system due to an overload on one side up to the total nominal pressure, an overload diaphragm is incorporated. For differential pressures with the specification limits the overload diaphragm has no effect on the measurements. After the limits are exceeded the overload diaphragm shifts from its middle position until it contacts the isolation diaphragm. In this way the pressure acting on the sensor is limited.

A local operator option is available for „local" operation, containing two keys for setting the range start and end values and a write protect switch. In conjunction with the integrated LCD-display, the transmitter, independent of the communication protocol selected, can be completely configured externally using the „local operator option". The smallest range end value is 0.5 mbar, the largest 100 bar. The basic accuracy is under 0.04 % of the range setting. The fluid wetted parts are selected to be suitable for the chemical characteristics of the fluids to be metered.

Fig. 2-56: Differential Pressure Transmitter 265DS

When using a differential pressure flow measurement system the density of the fluid varies with pressure and temperature changes, it is recommended that, as a minimum when metering gases or steam, additional measurements be made of the process temperature and pressure and to calculate the state and condition of the fluid. This will assure a reliable measurement of the normal or mass flowrates even under varying conditions.

Even for such complex challenges, which in the past had to be satisfied by using individual differential pressure, absolute pressure and temperature transmitters and an additional computation element, can now be solved using the Multivariable Transmitters 267CS or 269CS, which directly measure all the variables plus calculate and apply the corrections required when the state of the fluid changes all in a single instrument.

The measurement cell is used for both the differential and static pressure measurements, as already described for the 265DS, only the electronics was expanded to include a measurement of the process temperature using an external temperature sensor.

Not only is density calculated based on the actual process conditions for the fluid state corrections but the flow coefficient is also calculated based on the Reynolds Number and the diameter ratio for the differential pressure meter type and the expansion coefficient and the real gas factor for the prevailing process conditions. This is in effect a dynamic fluid state correction assuring the highest degree of accuracy.

Fig. 2-57: Multivariable Transmitter 269CS

2.2.2 Variable Area Flowmeter

The flowrate of gases and liquids can be determined simply, yet relatively accurately with Variable Area flowmeters. The fluid flows upward through a vertical conical tube whose diameter increases in the upward direction. The upward flowing fluid lifts a float located in the tube to a height so that the annulus has an area which results in an equilibrium of the forces acting on the float.

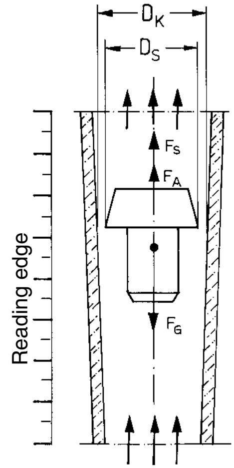


Fig. 2-58: Principle of Variable Area Flowmeters

Three forces act on the float (Fig. 2-58. Downward the gravitational force F_G.

$$F_G = V_s \cdot \rho_s \cdot g \qquad (2.8)$$

There are two forces acting in an upward direction:
The buoyancy force F_A and the fluid pressure force F_S:

$$F_A = V_s \cdot \rho_m \cdot g \qquad (2.9)$$

$$F_s = c_w \cdot A_s \cdot \frac{\rho_m \cdot v^2}{2} \qquad (2.10)$$

V_s: Volume of the float
m_s: Mass of the float
ρ_s: Density of the float
ρ_m: Density of the fluid
c_w: Resistance coefficient
A_s: Cross sectional area the float at the reading edge
v: Flow velocity of the fluid
D_k: Inside diameter of cone at the reading edge
D_s: Diameter of the float at the reading edge

At equilibrium or at the float position:

$$F_G = F_A + F_S \quad (2.11)$$

The flowrate is:

$$q_v = v \cdot A = v \frac{\pi}{4} (D_k^2 - D_s^2) \quad (2.12)$$

The resistance coefficient c_w is converted to the flow coefficient.

$$\alpha = \sqrt{\frac{1}{c_w}} \quad (2.13)$$

α is a function of the geometric shape of the meter tube and the float and above all, of the diameter ratio. α also includes the friction effects. These empirically determined values define curves which are incorporated into the basic equations.

The general Variable Area meter equation can be formulated taking into account all the aforementioned equations.

Volume flowrate:

$$q_v = \frac{\alpha}{\rho_m} D_s \sqrt{g \cdot m_s \cdot \rho_m \left(1 - \frac{\rho_m}{\rho_s}\right)} \quad (2.14$$

Mass flowrate:

$$q_m = \alpha \cdot D_s \sqrt{g \cdot m_s \cdot \rho_m \left(1 - \frac{\rho_m}{\rho_s}\right)} \quad (2.15)$$

The annular area available for the flow changes as a result of the conical form of the metering pipe with the elevation of the float. Thus the float location provides information regarding the flowrate. When a glass metering pipe is used the flowrate can be read directly from a scale located adjacent to or on the metering pipe.

In comparison to the differential pressure meter a physical analogy exists which is evident from the similarity of the basic equations. The essential difference is mechanical, because the flow area remains constant in a differential producer the pressure difference varies with flowrate while in the Variable Area meter the flow area varies to suit the flowrate and the pressure difference remains constant.

Floats

An important requirement for metering is the exact centering of the float in the metering tube. Three methods have found acceptance:

1. Through slots on the float head the flowing fluid forces the float to rotate and center itself. This principle cannot be utilized with all float shapes. Additionally there is a strong dependence on the fluid viscosity.

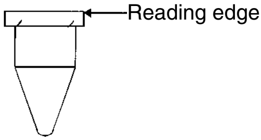
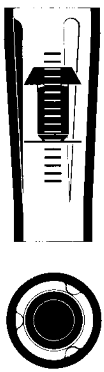


Fig. 2-59: Rotating Float

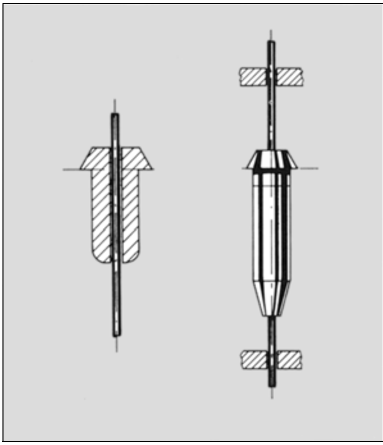
2. The float is guided by three ribs or three flats (ball floats) which differ from the metering tube cone in that they are parallel to the tube axis.



Advantages:
A variety of float shapes are possible. Even for cloudy, opaque fluids the reading edge remains visible.

Fig. 2-60: Float Guides with 3 Ribs or 3 Flats

3. A guide rod in the middle of the meter tube is used to guide the float.



This method is used primarily in flowmeters with metal meter tubes.

Fig. 2-61: Float with Guide Rod

A wide variety of float shapes are available. The weight, shape and materials are adapted to the individual installations.

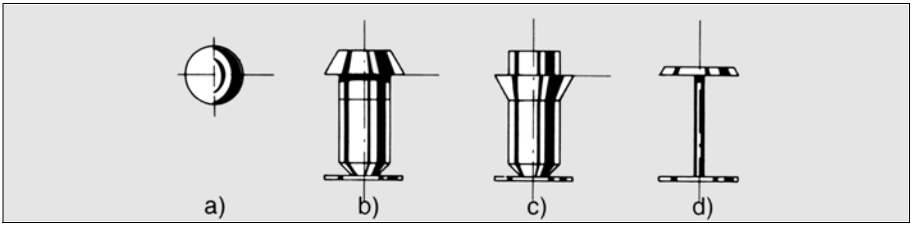


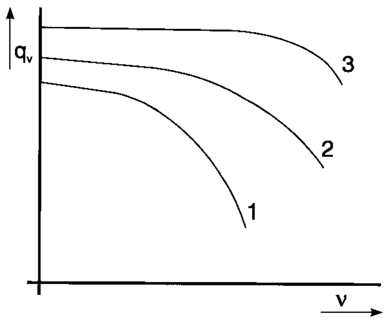
Fig. 2-62: Float Shapes

a) Ball float
b) Viscosity immune float
c) Viscosity non-immune float
d) Float for low pressure drop

Fig. 2-62 shows the most common used float shapes.

The ball float is the metering element for the small flowmeters. Its weight can be determined by selecting from a variety of materials. Shape changes are not possible.

Therefore the flow coefficient is defined. The ball shape is responsible for the [increased] viscosity effect.



1. Ball float
2. Float body with a downward oriented cone
3. Viscosity immune float

Fig. 2-63: Viscosity Effects for the Various Float Shapes

Fig. 2-63 shows the effect of viscosity on the flowrate indication. The curve for the ball float (1) stands out in particular because there is no linear region. That means that every change in viscosity results in indication changes. Remember, that for many fluids small changes in temperature can result in viscosity changes.

The floats with the conical bottom, (Fig. 2-59 and Fig. 2-62c) are used less in the small size meters and more in the larger size meters. The linear region of the curve in Fig. 2-63/2 is relatively short. This confirms the statements made about the rotating floats. Appreciably more insensitive is the float shape shown in Fig. 2-62b. The corresponding curve Fig. 2-63/3 has a longer linear region. Such an instrument is unaffected by relatively large changes in viscosity, however, for the same size meter, 25% less flowrate can be metered than for the previously described float. The larger portion of Variable Area meters manufactured by **ABB** include a viscosity immune float.

Finally there are the very light floats (Fig. 2-62d) with relatively low pressure drops. This design requires minimum upstream pressures and is usually preferred for gas flowrate metering.

Pressure Drop

The pressure drop occurs primarily at the float because the energy required to produce the metering effect is derived from the pressure drop of the flowing fluid and to a lesser degree in the meter fittings (connection and mounting devices).

The pressure drop at the float is dependent on its largest outside diameter and its weight and therefore is independent of its elevation in the meter tube, i.e. it is constant. The pressure drop through the fittings, however, increases as the square of the flow-rate.

The resultant pressure drop is the reason for the requirement of a minimum upstream pressure.

Sizing Procedures

There are tables for all Variable Area meters with flowrate values listed for water and air in which the empirically determined α-values have already been incorporated. Therefore complicated calculations are not necessary. For fluids other than water or air only a conversion calculation to the equivalent table values is required. The following applies for liquids in smooth conical (metal metering pipes) and glass metering tubes with three rib guides

$$q_{vwater} = q_{v1}\sqrt{\frac{(\rho_s - 1)\cdot\rho_1}{(\rho_{s1} - \rho_1)\cdot 1}} \qquad (2.16)$$

q_{v1} = Volumetric flowrate
q_{m1} = Mass flowrate
ρ_s = Float density (usually 8.02 g/cm^3 for stainless steel)
ρ_{s1} = Float density of the actual float material used
ρ_{s1} = Only for special cases

ρ_n = Density of the fluid
ρ_1 = Density of water, here = 1 g/cm^3

$$q_{vwater} = q_{m1}\sqrt{\frac{\rho_s - 1}{\rho_1\cdot 1(\rho_{s1} - \rho_1)}} \qquad (2.17)$$

Similar sizing procedures are available for glass tube meters with three flats and ball floats.

Example:

Fluid	**Ammonia, liquid**
Mass flowrate qm	1500 kg/h
Density ρ	0.68 kg/l
Dyn. viscosity η	0.23 mPa·s
Operating pressure	15 bar
Operating temperature	20 °C

from equation (2.17):

$$q_{vwater} = 1500 \sqrt{\frac{8.02 - 1}{0,68 \cdot 1(8,02 - 0,68)}}$$

$$q_{vwater} = 1779 \ \text{l/h}$$

This water equivalent value is used in the tables for the selected instrument type to establish the **meter size**.

It is necessary to calculate the gas density ρ_B relative to air before converting to equivalent table values for air:

$$\rho_{n air} = 1,293 \ \text{kg/m}^3$$

$$\rho_B = \frac{\rho_n}{1,293} \cdot \frac{T_n}{T_n + T} \cdot \frac{p_n + p}{p_n} \qquad (2.18)$$

ρ_n = Density of the gas at normal conditions
T_n = 273.15 K
T = [°C]
p_n = 1.013 bar
p = [bar]
ρ_1 = Density of the gas at operating conditions

Equation 2.16 can be simplified for gases ($\rho_s << \rho_w$; $\rho_{s1} << \rho_1$) to:

$$(q_v)_n = q_{v1} \sqrt{\frac{\rho_s \cdot \rho_1}{\rho_{s1} \cdot \rho_n}} \qquad (2.19)$$

Use this equation and the dimensionless ratio to calculate the ρ_s for the air table values:

$$(q_v)_{nair} = q_{v1} \sqrt{\frac{\rho_s \cdot \rho_B}{\rho_{s1}}} \tag{2.20}$$

or for mass flowrate qm:

$$(q_v)_{nair} = \frac{q_{m1}}{1{,}293} \cdot \sqrt{\frac{\rho_s}{\rho_{s1} \cdot \rho_B}} \tag{2.21}$$

Example:

Fluid	**Ammonia, gaseous**
Flowrate q_m	1500 kg/l
Density ρ_n	0.7714 kg/m^3
Pressure p	5 bar
Temperature T	100 °C

from equations (2.18) and (2.19):

$$\rho_B = \frac{0{,}7714}{1{,}293} \cdot \frac{273}{373} \cdot \frac{6{,}013}{1{,}013} = 2{,}592$$

$$q_{vnair} = \frac{1500}{1{,}293} \cdot \sqrt{\frac{8{,}02}{8{,}02 \cdot 2{,}592}} = 720{,}6 \text{ m}^3\text{/h}$$

Viscosity Effects

After selection of the flow meter size the viscosity effects should be checked using the **Viscosity Influence Number VUZ**.

$$VUZ = \eta\sqrt{\frac{\rho_s - \rho_w}{(\rho_{s1} - \rho_1)\rho_1 \cdot \rho_w}} = \eta\sqrt{\frac{\rho_1 - 1}{(\rho_{s1} - \rho_1)\rho_1}} \qquad (2.22)$$

η = actual fluid viscosity

The VUZ value calculated must be smaller than the value listed in the flowrate tables. The flowrates are unaffected by viscosities less than the calculated value even when the viscosity changes. If the calculated VUZ value exceeds the listed values then the instrument must be calibrated using the actual viscosity.

Example:

Fluid	**Ammonia, liquid**
Dyn. viscosity η	0.23 m · Pas
Density ρ	0.68 kg/l
Float density $\rho_s = \rho_{s1}$	8.02 (stn. stl.)

$$VUZ = 0.23\sqrt{\frac{8{,}02 - 1}{(8{,}02 - 0{,}68) \cdot 0{,}68}} = 0{,}27$$

The VUZ-Table value of **28** is much greater than the calculated value. There is no viscosity effect.

Variable Area Flowmeters can be selected and exactly calculated in a much simpler way using the ABB-Calculation Program „flow calc“.

Instrument Descriptions Purgemaster (Small flowmeter)

The Purgemaster flowmeters are built small and designed for small flowrates with local indication. All are designed so that the metering tubes can be exchanged and include a needle valve to set the flowrate. The flow range is always 1:10 or 1:12.5 for scale lengths between 38 and 250 mm. A ball is used for the float. The accuracy is a function of the meter tube material and the scale length.

For water, or the equivalent flowrates calculated for other fluids, the flow range end values lie between 0.03 l/h and 140 l/h; for air and gases between 2.88 and 4330 l/h.

Purgemaster „SNAP-IN“ Series FAG6100

"SNAP-IN", is an elegant method for exchanging meter tubes. The meter tube adapters and seals in the lower fitting are spring loaded so that the meter tube can be pushed down and pulled out from the top. A polycarbonate protection cap locks the meter tube in place. An integrated check valve prevents backflow. A DVGW certificate has been granted.

Fig. 2-64: Series FAG6100

Materials

Housing:	Stainless steel
Meter tube holder:	1.4401[316] brass
Meter tube:	Borosilicate glass, Trogamid
Float:	Glass, Sapphire, Tantalum
	1.4401[316], Carboloy
O-Rings:	Buna-N, Viton-A, Ethylene-Propylene
Protection cap:	Polycarbonate

Specifications

Type	Scale Length (mm)	Housing Length (mm)	Flow Range for Water
10A6134/44	38	120	3...48 cm^3/h to 3...132 l/h
10A6131/41	70	151	24...264 cm^3/h to 10...105 l/h
10A6132/42	130	264	2.6...32 cm^3/h to 11.2...140 l/h

The flowrate value set with a needle valve varies when the pressure changes. A differential pressure regulator is an available accessory which maintains a constant flowrate independent of pressure changes.

Ring sensor initiators are used as alarm signal transmitters.

Principle of Operation

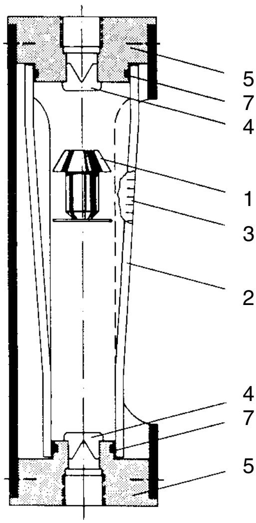
The ring sensor has a bistable operation which engages the relay in the switch amplifier when the switch point is reached by the ball float. The relay remains engaged even if the float continues its travel beyond the switch point. The relay is released as soon as the float passes back through the switch point in the opposite direction into the acceptable range. The instantaneous position, either above or below the switch point, is unambiguously indicated. Use in an Ex-proof area is possible because the ring initiators used are intrinsically safe sensors with intrinsically safe circuits. Because of the relatively short meter tube length the Model 10A6131/41 is only suitable for either a min. or max. alarm transmitter; for both minimal and maximum alarm signals the model Model 10A6132/42 is more suitable.

Glass Tube Flowmeter Series FAG1190

The most used flowmeter is this rugged and simply designed process meter. Flanges, female pipe threads or for the food industry, the preferred round threads (DIN 11851) provide connections to the process. Glass tube flowmeters are suitable for flowrate measurements in many industries, e.g. oven manufacture. The standard housing material is stainless steel.

The metering tube is sealed and positioned with O-rings to eliminate mechanical stresses.

A supplementary protection shield is provided for gas metering which protects the meter tube from contact or mechanical damage. Personnel safety is assured. A DVGW certificate has been granted.



1 Float
2 Meter tube
3 Scale
4 Float stop, inlet/outlet
5 Inlet/outlet fittings
6 Housing
7 O-Rings

Fig. 2-65: Basic Construction

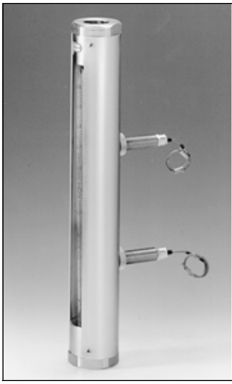
Materials:

Meter tube:	Borosilicate glass
Float:	Glass, Sapphire, Tantalum, 1.4301, 1.4571, PVDF and others
Fittings:	PVC, PVDF and others
O-Rings:	Buna-N, Viton-A, Ethylene-Propylene
Housing:	Stainless steel 1.4301
Connections	FAG1190-97: Internal threads
	FAG1190-98: Flanged connections
	FAG1190-87: Pipe couplings

Fig. 2-66: Series FAG1190

Specifications:

Housing Size	Meter Tube Size	Scale Length	Flow Range End Value (Water) [l/h]	Flow Range End Value (Air) [m^3/h]	Max. Allow. Pressure [bar]	Accuracy Class
1/4	1/16	100	0.03... 1.1	0.003... 0.04	38	6
1/4	1/18	130	0.37... 10	0.022... 0.33	33	1.6
1/4	1/4	130	4.7 ... 132	0.223... 4.03	30	1.6
1/2	1/2	250	43 ... 418	1.3 ... 12.3	21	1.6
3/4	3/4	250	144 ... 1300	4.3 ... 38.7	17	1.6
1	1	250	310 ... 2800	9.2 ... 83.0	14	1.6
1 1/2	1 1/2	250	560 ... 4800	17.3 ...142.5	9	1.6
1	1	250	1420 ...17000	42.6 ...510	7	1.6



Proximity Switches activate the contacts of the alarm transmitter e.g. min. and max. alarms. The adjustable inert gas switches have a bistable operation, i.e., once activated, the self holding contact will only be released by the float moving in the opposite direction.

Fig. 2-67: Alarm Signal Transmitter 55AX1000

Metal Pipe Variable Area Flowmeter

The all metal armored Variable Area flowmeter can be used more universally than the glass tube meter. The operating pressure can be as high as 250 bar and the maximum allowable temperature (dependent on the ambient temperature) is 400 °C.

The transmission of the float position to the indicator is accomplished by a magnetic coupling system consisting of a permanent magnet located in or on the float and a permanent magnet follower on the indicator axis. The follower system does not lose its coupling even when the float takes a sudden jump due to a flowrate change. The guide rod of the float remains within the metering pipe even for extreme float excursions.

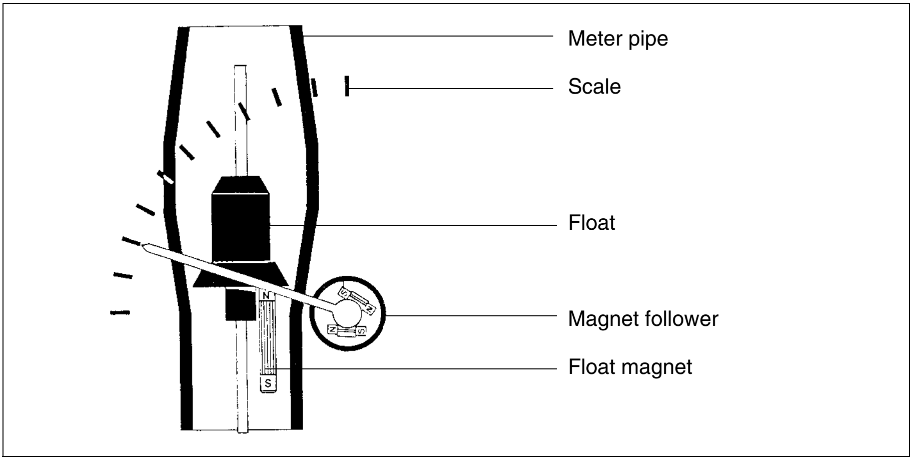


Fig. 2-68: Basic Design of a Metal Pipe Variable Area Flowmeter

Metal Pipe Armored Variable Area flowmeter Series FAM5400

The metal pipe flowmeter is a meter that not only has a local indicator but there are plug-in units which can be retrofitted with one or two alarm transmitters, electric converter with an analog output 4...20 mA as well as a digital display for local indications and totalized flow values. After correct selection of fluid wetted materials, chemically aggressive as well as opaque fluids can be metered. Loose flanges assure a advantageous orientation of the indicator. A damping fixture reduces oscillation of the measurement values. A double jacket is used when heating is required. Two limit alarms and an electrical or pneumatic transmitter can be installed in the indicator. The retrofitting can be accomplished without interrupting the process. Use of suitable materials for the fluid wetted parts allow chemically aggressive (also opaque) liquids, gases and steam to be metered. In combination with the application proven multi-function float this flowmeter opens new application horizons for this traditional flow measurement technology.

A suitable damping system impedes compression oscillations in gas and steam measurements. A double jacket is available to heat the meter tube with steam or hot water when heat is required for difficult applications.

Multi-Function Float

The multi-function float consists of a basic body whose geometry can be varied by adding various elements. The total weight can also be changed by adding additional weights to achieve an optimal configuration.

Materials:

Meter tube: 1.4404[316L] or PTFE lined
Float: 1.4571[316Ti], Hastelloy C, PTFE
Flanges: 1.4404[316L]
Indicator housing: Aluminium

Flow Ranges

Meter Size		Length	Flow Range End Value	
			Water	Air
DN	Inch	[mm]	[m^3/h]	[m^3/h]
15	1/2	250	0.03... 0.85	0.1... 25
25	1	250	0.28... 6.1	8.4... 180
50	2	250	4.2 ... 24	125 ... 720
80	3	250	7 ... 54	210 ...1550
100	4	250	25 ...120	760 ...3600

Specifications

Scale length: 100 mm
Max. possible pressure: 450 bar
Max. possible temperature: 400 °C (for ambient temperature 50 °C)
Accuracy Class: 1.6
Contact output: 1 or 2 alarm contacts using slot initiators
Analog output: 4...20 mA; supply voltage 14...28 V DC
intrinsically safe supply II 2G EEx ib IIC T4
non-intrinsically safe supply II 2G EEx d IIC T6
Communication: HART-Protocol

Electronic Converter

All metal pipe flowmeters with converters are arranged so that the mechanical indicator will continue to operate even if the converter fails. This means that the flowrate value can always be read at the meter location even if the transmission of the electrical signals has been interrupted.

The μP based converter is designed as a 2-wire instrument. Only a single 2 wire cable is required for both the supply power and the current output using the HART-Protocol. This intelligent SMART-Converter allows access to all the parameters so they can be changed if required.

The converter monitors itself and includes automatic error diagnostics. The programming switches are accessible when the cover is removed. The converter can be configured without opening the cover (Ex-Design) using a Magnet Stick. A high contrast two line display is included for viewing the flow values and parameters.

FAM5400 with
4...20 mA Current and Display

FAM5400 with
Alarm Contacts

Fig. 2-69: Armored All Metal Flowmeter Series FAM5400

Armored Purgemeter Series FAG3200

With small Variable Area flowmeters in an all metal design it is possible to readily meter gases and liquids under extreme operating conditions. Cloudy fluids, which are common in the chemical, petrochemical and pharmaceutical industries, present no problems to this flowmeter.

Even in the laboratory, for gas analyzers and wherever the prevailing conditions exclude the use of a glass tube meter, the advantages of the small Armored Purgemeter come to the fore.

Materials:

Fluid wetted parts:	1.4571, PVDF
O-Rings:	Viton-A, Buna-N
Indicator housing:	Aluminium, Stainless steel
Cap:	Polycarbonate, Trogamid, Stainless steel with glass window

Specifications:

Minimum flow range:	0.1...1.0 l/h water 0.008...0.048 m^3/h air
Max. flow range:	300...3000 l/h water 8...90 m^3/h air
Scale Length:	60mm
Max. allow. pressure:	100 bar
Max. allow. temperature:	150 °C
Accuracy Class:	6
Analog output:	4...20 mA
Contact output:	1 or 2 alarm contacts using slot initiators

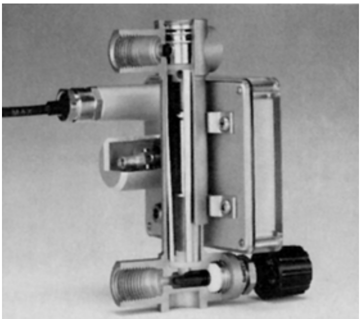


Fig. 2-70: Cross Section Armored Purgemeter

Fig. 2-71: Armored Purgemeter

2.2.3 Electromagnetic Flowmeters

If an electrical conductor is moved in a magnetic field which is perpendicular to the direction of motion and to the conductor, an electrical voltage is induced in the conductor whose magnitude is proportional to the magnetic field strength and the velocity of the movement. This characterization of the laws of induction also applies to the movement of a conductive fluid in a pipe through a magnetic field.

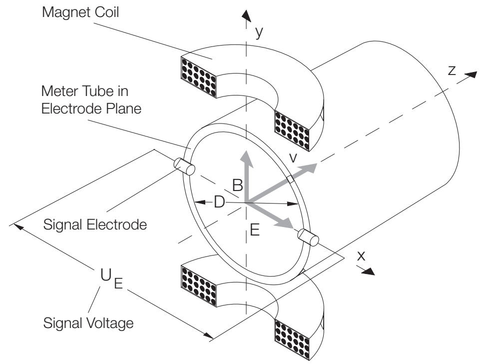


Fig. 2-72: Electromagnetic Flowmeter Principle

For the Electromagnetic flowmeter (EMF) the following equation applies:

$$U_o \sim B \cdot v \cdot D \qquad (2.23)$$

with the induction B, the flow velocity v and the conductor length (pipe diameter) D.

The flowrate q_v through the cross section A under consideration is

$$q_v = A \cdot v = \frac{D^2\pi}{4} \cdot v \qquad (2.24)$$

Combining the two equations results in the defining relationship for the metering system:

$$U_o \sim q_v$$

To utilize the principle shown in Fig. 2-72 requires that a magnetic field exist within the pipe and that the induced voltages can be measured without any interference. Two coils generate the magnetic field that extends through the pipe only when if it is not shunted by permeable pipe materials. Austenitic steel does not hinder the **magnetic field**; therefore it is the most commonly used material for the meter pipe in the EMF. To prevent shorting out the induced signal voltage U the metering pipe must have an electrically insulating inner surface. The signal voltage U_E is measured at two electrodes which are in galvanic contact with the fluid.

An additional requirement for the operation has already been mentioned, namely the fact that the fluid must be an electrical conductor. Therefore a minimum conductivity is required, 20; 5; 0.05 µS/cm dependent on flowmeter type.

Magnetic Field Design

The signal U_E measured at the electrodes is the sum of all the elemental voltages induced in the entire area of the magnetic field within the metering pipe. The following consideration ignores the three dimensional nature of the field and is limited to the cross sectional area in the plane of the electrodes. It turns out that the magnitude of the elemental voltages at the electrodes, i.e. the ratio of the partial voltage due to each element to the total voltage U_E at the electrodes is a function of the geometric location of that element.

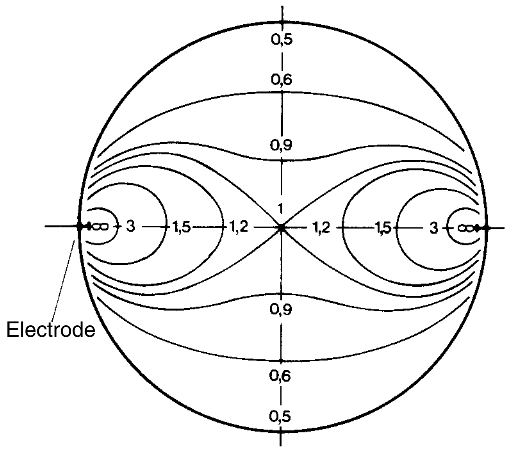


Fig. 2-73: Weighting Factor Distribution in the Electrode Plane

Fig. 2-73 shows the distribution of the weighting factor of the elemental voltages based on an assumed value of 1 at the center. It is obvious that the elemental voltages induced in the vicinity of the electrodes have a greater effect than those induced in the regions near the poles. The **Weighting Factor W** concept is used to define the location related magnitude. In a homogeneous magnetic field, in which the field strength B is the same throughout, the elemental voltages measured at their sources are all the same when the fluid flow velocity is constant throughout.

For a nonsymmetrical velocity profile, for example after an elbow (Fig. 1-7a), the various regions in the metering pipe cross section have differing velocity values so that the total signal is no longer the average of all the elemental voltages and no longer represents the flowrate.

With a magnetic field design in which the field strength is inversely proportional to the weighting factor a method of compensation was discovered. The magnetic field strength is increased in the low weighting factor areas and conversely decreased in the high weighting factor areas, so that the product of the weighting factor W and the field strength B is constant of the entire cross section under consideration:

$$W \cdot B = \text{const} \tag{2.25}$$

Now the magnitude of all the elemental voltages is the same and a nonsymmetrical velocity profile causes no error.

The practical implementation of a weighting factor inverse magnetic field can only be approached in practical designs. This fact is the basis for the recommendation that short straight conditioning sections, 3 to 5 times the pipe diameter in length, be installed upstream of the Electromagnetic flowmeter. This length is sufficient to effectively eliminate the effects of upstream flow disturbances.

Noise Voltages

The signal voltage U_E is smaller than 0.5 mV per 1 m/s of flow velocity. The magnitude of the noise voltages superimposed on the signal voltage may sometimes be appreciably larger. The connected converter has the function to reject the influences of the noise signals and to convert and amplify the measurement signal so that other connected instruments such as indicators, recorders, or controllers can be operated.

What noise voltages exist?

First there is an electrochemical potential. It exists in a galvanic system at the interface between the electron conductive metal electrodes and the ion conductive fluid. These "polarization voltages" are a function of a variety of ambient conditions such as temperature, pressure and fluid composition.

Their values are not reproducible and are different at each electrode so that their effects can not be predicted.

The magnet coils are capacitively coupled to the signal leads and to the electrodes inside the Electromagnetic flowmeter. This coupled „capacitive noise“ voltage is a function of the excitation voltage and of the internal impedance of the metering section and is therefore also a function of the conductivity of the metered fluid. Careful shielding measures, especially when the conductivity is low, can prevent stray capacitance influences.

The signal leads in the instrument are the connection elements coming from the electrodes and are brought together at the top of the metering pipe and together with the fluid form a single turn loop in which the excitation circuit induces a „transformer voltage“.

Precise mechanical assembly and orderly placement of the leads minimizes this voltage. Liquid filled flowmeters, particularly in the larger sizes, are good conductors of ground currents from a nonsymmetrical distribution system.

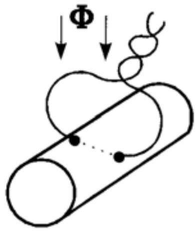


Fig. 2-74: Conductive Loop in a Transformer

The voltage differential existing between the electrodes due to these currents induces an additional „external” noise voltage, which can be prevented by shunting the ground current around the meter through a parallel connected low resistance grounded conductor (large copper wire).

To reduce the noise voltages various means are employed which are a function of the different types of magnet excitation to either prevent their generation or their effects. Direct current voltages, e.g. polarization voltages, can be blocked by capacitively coupling to the converter.

Magnetic Field Excitation

The geometric design of the magnetic field has already been described. How do the time relationships affect the noise voltages?

Simplest would be to use permanent magnets for the field generation. All alternating current induced noise voltages would be eliminated. Unfortunately the polarization voltages, whose magnitude cannot be predicted, would be so large that they would swamp the measurement signal. Is a 50/60 Hz alternating current excitation the answer? This system must cope with the noise voltages generated by the alternating current field, but there are still reasons for its existence.

A magnetic field excitation means which combines the advantages of both of the aforementioned systems and reduces their disadvantages is the pulsed DC field.

The Pulsed DC Field

At time t_0 a DC voltage is applied to the magnet coils. Because of the inductance of the coils the excitation current **I** increases slowly to its final value.

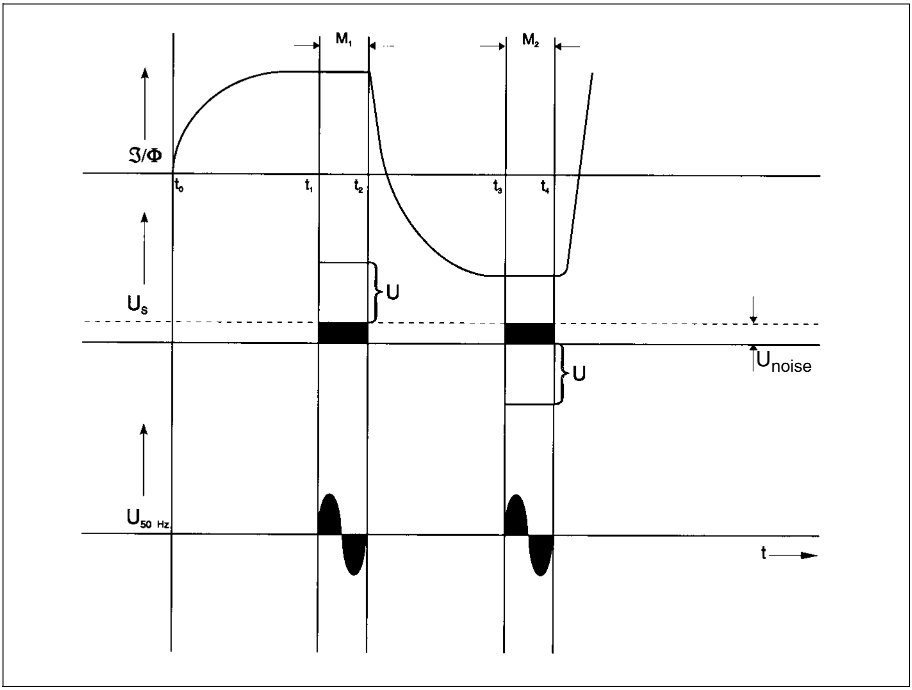


Fig. 2-75: Magnetic Field with Pulsed DC Excitation

After the decay of the transients which occur as a result of the excitation reversal the excitation current I and the magnetic flux remain constant so that the time differential of the flux is zero:

$$\frac{d\Phi}{dt} = 0$$

The transformer noise disappears and to a great extent the capacitive noise also.

Only when this condition has been reached after 60 ms, is the converter turned on at time t_1 and during the next 20 ms time interval measures the electrode signal $U_s \cdot$ 20 ms is one period of a 50 Hz system (for other frequencies there are corresponding time intervals). The 50 Hz noise signals, which are primarily due to external influences, are automatically eliminated.

The electrode signal U_s includes the desired measurement signal U and the remaining uncompensated noise U_{noise}. During the measurement interval M_1 the following applies:

$$U_{s1} = U + U_{noise} \tag{2.26a}$$

This value is stored.

At t_2 the polarity of the DC voltage is reversed and therefore also the measurement signal U. The polarity of U_{noise} does not reverse so that during the measurement interval M_2 the following applies:

$$U_{s2} = -U + U_{noise} \tag{2.26b}$$

The converter subtracts this value from the value of the previous measurement interval.

$$U + U_{noise} - (-U + U_{noise}) = 2U \tag{2.26c}$$

The result is a measurement signal proportional to the volumetric flowrate free of noise signals. This is called a system with automatic zero adjustment since at 6 1/4 Hz its value is calculated six and one quarter times a second.

A higher accuracy can be achieved because of the stable zero even at fluid conductivities at the lower limit of 5 µS/cm.

AC Magnetic Field Excitation

The pulsed DC field has some limitations when a fast measurement is required and the 160 ms measurement cycle is too long.

An example occurs in a filling system in which extremely short measurement intervals are coupled with exact valve closure characteristics. Another application is the metering of two phase fluids, that is hydraulic transport of solids e.g. paper pulp or dredged material. With direct current excitation these fluids create a noise voltage which is superimposed on the measurement signal and results in errors. These noise voltages do not occur with alternating current excitation.

The field excitation is provided directly from the line voltage (50/60 Hz) or from a driver circuit in the converter. Because of the high inductance of the magnet coils the flux f lags the excitation current I by almost 90°.

The measurement signal U is in phase Φ and is a sinusoidal voltage at line frequency whose amplitude is proportional to the flowrate. The various noise voltages are fed together with the signal voltages to the converter which must sort them out.

The DC noise voltages (polarization voltages) are capacitively decoupled. The AC noise voltages (transformer and capacitive voltages) are not in phase with the measurement signal U; their effects are automatically eliminated using phase selective circuits.

The external AC noise voltages unfortunately can neither be predicted in amplitude or phase. All components which are not in phase with the measurement signal U are automatically compensated. Only the in phase components affect the measurement signal resulting in an unstable zero. This noise component is eliminated by compensating the signals that exist at zero flow.

The zero adjustment can be automated when during a measurement the flow is at zero. This is the case in fill systems for example. When the shut off valve sends a signal that the flow is at „zero“ the converter commences an automatic zero adjustment procedure. AC field excitation is available down to a conductivity of 20 µS/cm. This conductivity limit can be reduced to 0.5 µS/cm if a preamplifier is installed. Continued development of this technology has resulted in a driver circuit which will provide an excitation current at a frequency considerably higher than the normal line frequency of 50/60 Hz. Using this technology, line frequency induced noise components can be automatically compensated and the zero stability is almost as accurate as when a pulsed DC excitation is used.

Signal Measurement

The discussions up to this point all assumed that the electrodes were in galvanic contact with the metered fluid. This is the normal situation. There are installation conditions where this is unsatisfactory, for example, extremely low conductivities or for fluids which deposit an insulating coating in the flowmeter. This coating interrupts the signal current circuit.

A smooth flow passage is formed by the outer surface of the standard electrode together with the inner surface of the liner. A degree of self cleaning for readily removable deposits can be achieved with pointed electrodes which extend into the higher velocity regions of the flow stream. For difficult applications, e.g. for thick grease layers, a mechanical cleaning through a clean out flange or a removal of the meter from the line is necessary.

This relatively large effort seldom assures satisfactory long term operation. It can be achieved with **capacitive electrodes** (Fig. 2-76).

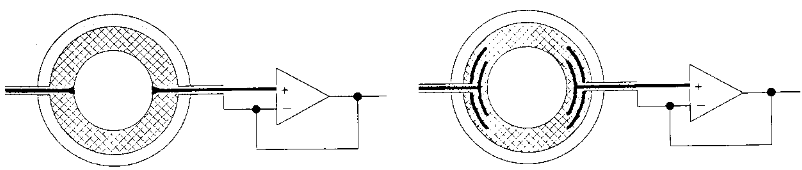


Fig. 2-76: Signal Measurement, Left Galvanic, Right Capacitive

Two metallic area electrodes are located behind the meter liner. They form two capacitors together with the fluid wetted inner wall whose dielectric is the liner.

The signal generation occurs as previously described with a pulsed DC or an AC magnetic field. The resulting signal loads the capacitors so that on the outer side a proportional flow signal can be measured. Since the capacitance must be least 20 pF, minimum area dimension limits exist which cannot be met by meters smaller than DN 25 [1"].

Shield electrodes between the measurement electrode and the metering pipe prevent a capacitive loss to the outside. The Driven-Shield technique eliminates the capacitance between the signal leads and the shield. The signal voltage amplitude is coupled back to the shield so that the voltage differential between the conductor and the shield is zero.

The minimum **conductivity** which can be metered with capacitive electrodes is 0.05 µS/cm.

Flowmeter Primary

The Electromagnetic flowmeter consists of a primary and a converter. Determining factors for the primary are material selections and the type of process connections. The liner and electrodes are located in the interior of the primary and contact the fluid. They must be made of materials which are chemically resistant to the metered fluid, which in some cases may be extremely aggressive. The most commonly used liner materials are hard rubber, soft rubber, PTFE, PFA, ceramic and common electrode materials are stainless steels 1.4571 [316], 1.4539, Hastelloy, Tantalum and Platinum.

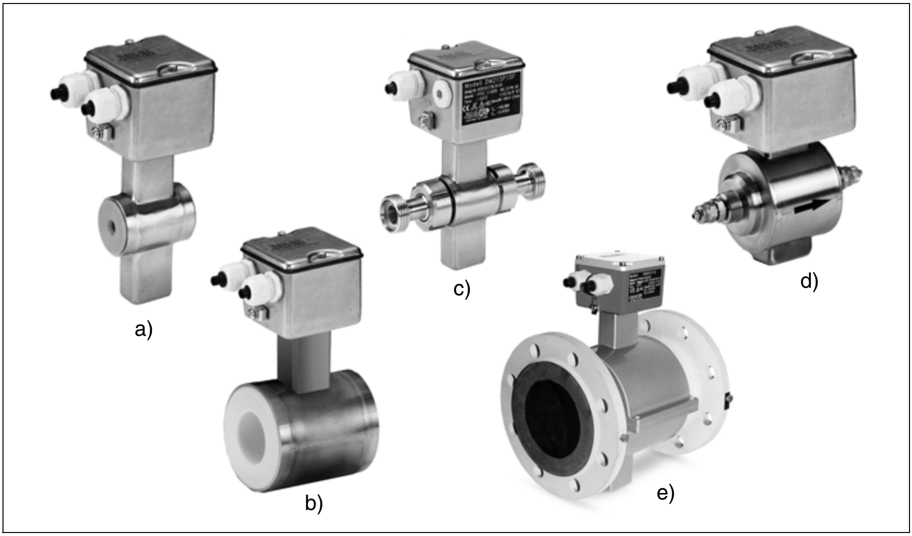


Fig. 2-77: EMF-Flowmeter Primary Designs

a) Flowmeter primary, Wafer Design
b) Flowmeter primary, Wafer Design
c) Flowmeter primary, Food industry fittings DIN 11851
d) Flowmeter primary, sanitary connections
e) Flowmeter primary with a flange for the process connections

A housing, metering pipe and pipe connections form the exterior of the primary. Here also the specific installation conditions, i.e. the ambient conditions, determine the materials. The metering pipe material for technical reasons must be austenitic stainless steel. The pipeline connections are generally steel or stainless steel while the housing is usually either painted cast aluminum or stainless steel.

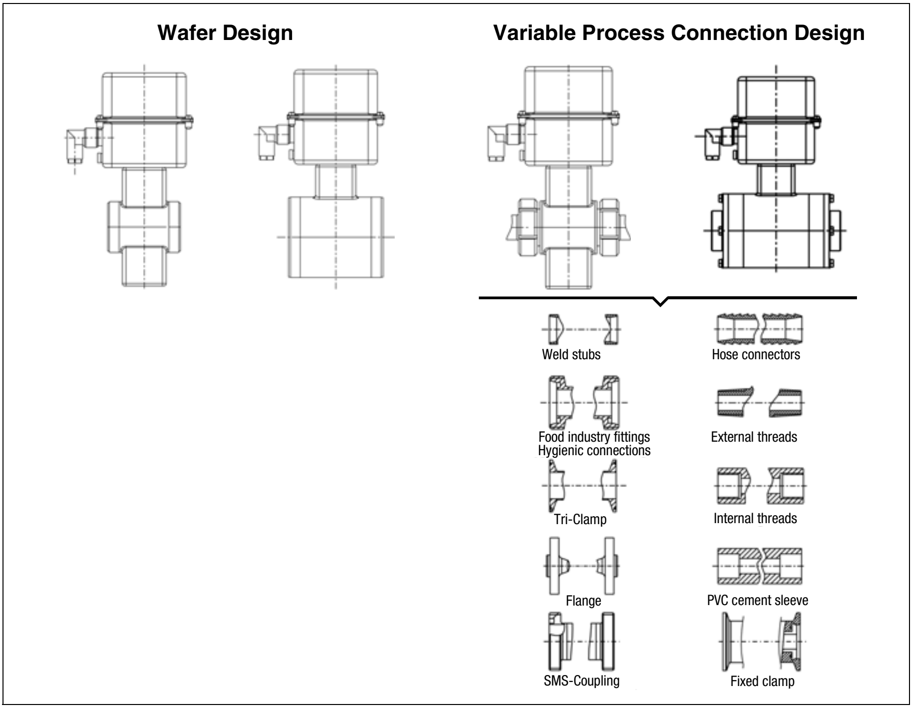


Fig. 2-78: EMF Flowmeter Primary in Stainless Steel with Vacuum Tight PFA Liner and Variable Process Connections

Magnetic Field Stabilization

According to equation (2.23) the measurement signal U_0 is proportional to three variables, the flux density B, the diameter D and the flow velocity v. A direct proportionality to only one of the variables requires that the other two be constant. If the measurement signal U_0 is to be proportional only to the flow velocity v then the flux density B and the diameter D must remain constant. While D, a mechanical value is constant, the flux density B varies with the excitation current I. A reference voltage U_{Ref} which is proportional to the flux density, is generated in the flowmeter primary/converter and maintained constant.

Electromagnetic flowmeters are basically flow calibrated, usually at ambient temperatures of 20 °C. If the instrument is later used at different temperatures the ohmic resistance of the coils changes and with it the excitation current I and the flux density B and therefore also the measurement signal U_0.

The excitation voltage, which influences the current, is line related and can also vary.

These effects can be prevented through utilization of constant current devices, a costly solution. An more elegant procedure is the compensation circuit.

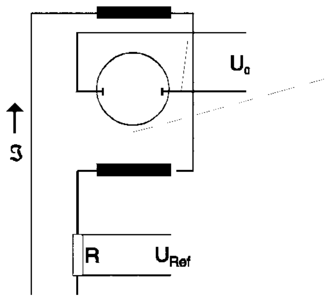


Fig. 2-79: Generation of a Compensation Voltage

A voltage drop U_{Ref} occurs across a resistor R connected in series with the magnet coils which is proportional to the excitation current I and therefore the flux density B. The flow signal U_o is also proportional the flux density B. When these ratio of these two values U_o/U_{Ref} is calculated, the influence of B is cancelled. From the basic equations (2.23) and (2.24)

$$q_v = \frac{A}{D} \cdot \frac{U_0}{B} \qquad (2.27)$$

and replacing B by U_{Ref}

$$q_v = K \cdot \frac{U_0}{U_{Ref}} \qquad (2.28)$$

This equation with K as the **Calibration Factor** forms the basis for the calibration of the electromagnetic flowmeters from **ABB**. The calibration factor K is replaced by the calibrations factors C_Z (zero value) and C_S (span value) for each excitation frequency for instruments with pulsed DC excitation. These values are stored in a memory module (EEPROM/FRAM) together additional parameters e.g. meter size, flow range, pulse factor, in- and output selections.

The converter continuously operates with these values and thereby controls the excitation current and the reference voltage. Thus the continuous monitoring of these vales assures that the excitation current remains under control. Since the calibration values and parameter settings are stored digitally in an EEPROM/FRAM, it is possible to exchange a converter for each and every flowmeter primary. The same converter module can be universally used with all the flowmeter primaries.

Converter

The task of the converter is to amplify the relatively small signal voltages, free them from noise voltages and to convert them into usable signals and to indicate their values.

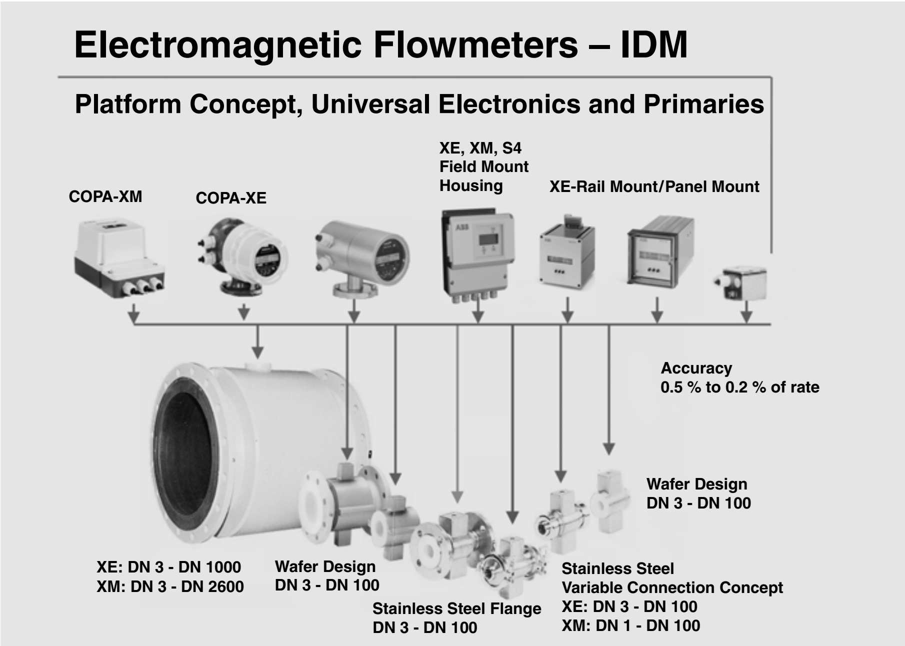


Fig. 2-80: Platform Concept, Universal Electronic Modules and Flowmeter Primaries

Different designs of the converter in conjunction with the flowmeter primaries satisfy the specific requirements for a particular EMF-System.

Converter XE

The converter XE is a microprocessor controlled converter with a local flowrate indicator and totalizer. The converter can be configured without opening the housing using a Magnet Stick or with the housing opened, using three buttons. The local display can be plugged in three different orientations to assure best readability. All meter location parameters are automatically monitored and errors signalled. The standard version includes a programmable current output (0...5; 0/2...10; 0/4...20mA) and a pulse output (optocoupler, passive or active), contact in- and outputs and empty pipe recognition. The System XE has an accuracy of ± 0.5 % of rate. An option for communication using HART-Protocol, PROFIBUS DP, PROFIBUS PA, FOUNDATION Fieldbus is available.

Converter XM

The converter XM is a complete self monitoring and user friendly instrument with a local flowrate indicator and totalizer. Beyond the three buttons no additional operator instrument is required. All meter location parameters are automatically monitored and errors signalled. In addition, all parameters can be accessed using the keypad and their settings changed. Communication with HART-Protocol or PROFIBUS DP is possible.

Fig. 2-81: Converter Module XM with Keypad and Display

The background lighted (LCD) assures high reading resolution using the dot matrix display, so that all messages and descriptions can be displayed unabbreviated in any of nine selectable national languages.

→F 98.14 %
←R 516.000 m^3

upper: →F = Forward, flowrate indication shown in %
lower: ←R = totalized flow in the Reverse flow direction

Prog.prot.
off

Program protection prevents access or operation by unauthorized personnel. A four digit code number for technician access.

Low flow cut-off
1.0000 %

Low flow cut-off eliminates inaccurate totalization e. g. under 1 % of flow range end value and suppresses totalization when hydraulic oscillations exist at zero flow.

Fig. 2-82: Typical Indicator Display

Density

2.54300 g/cm^3

A preset density value can be entered to display the flowrate and totals in mass units.

Submenu

Detector e. pipe

When the meter pipe empties, the measurement is halted and an alarm contact is actuated.

UREF too large

→ F 12.000 m^3

Error message for reference voltage U_{Ref} error. Magnetic field excitation current is too large. Error messages signalled over contact output. All errors are stored in an error register.

These limited examples (Fig. 2-82) show the variety of viewing and programming possibilities. Of course operation is possible while on line, i.e. the measurement values continue to be processed while parameter changes are being made. During supply power interruptions all data is stored for a 10 year period. The accuracy of the XM-System is ± 0.4 % of rate and optionally ± 0.2 % of rate.

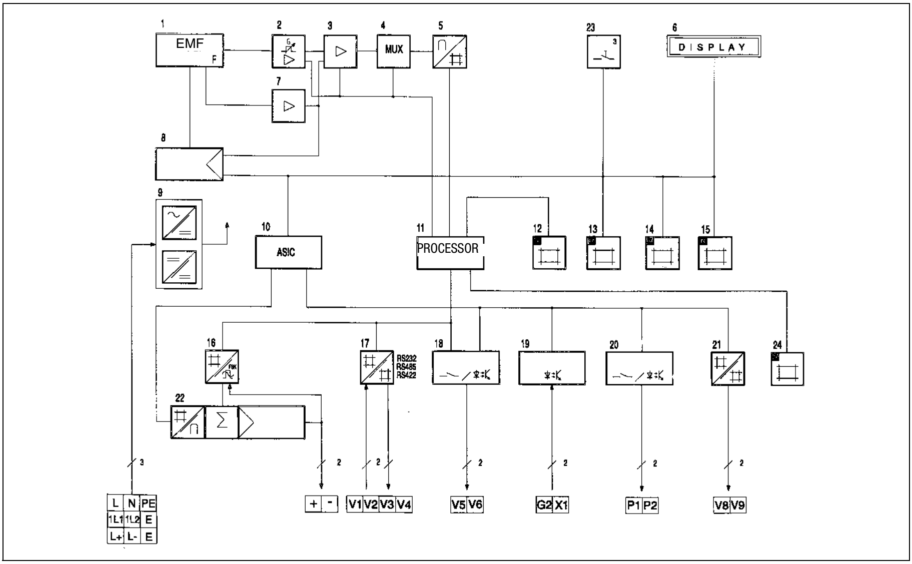


Fig. 2-83: Block Diagram EMF-System XM

Converter FSM4000

This converter is a memeber of the AC field excited EMF-Systems with a new increased driver frequency. Therefore after start-up a zero adjustment is rarely required and the measurement system has a system accuracy of ± 0.5 % of rate, the same as a pulsed DC instrument. The flowmeter primaries incorporate expanded flowmeter primary diagnostics with which the user can obtain additional information for a possible upcoming measurement system verification requirement. Communication using HART, PROFIBUS PA and FOUNDATION Fieldbus is possible.

Mounting the Converter

Based on the requirements of the user the arrangement of the EMF-System may vary. The different variants of the flowmeter primary have already be described. The converter variants are defined the housing arrangements. There are two distinctly different mounting options: a converter mounted remote from the flowmeter primary and the other, a converter mounted directly on the flowmeter primary, a compact design.

Fig. 2-84: EMF-Flowmeter Primary and Converter in a Wall Mount Housing

The **Compact Design COPA-XE** or **COPA-XM** unites the flowmeter primary and the converter in a single housing, in which local operating or display possibilities are available. The big advantage of this variant is the elimination of the interconnection cabling.

Fig. 2-85: COPA-XE in a Compact Design

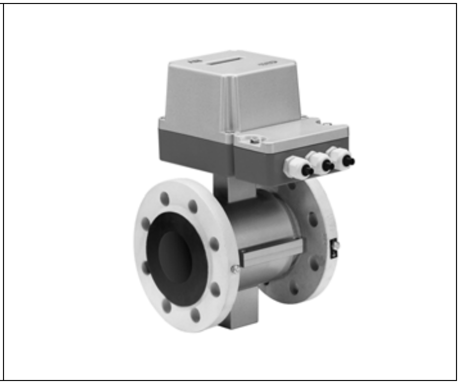


Fig. 2-86: COPA-XM in a Compact Design

An interesting variant is the Compact Design instrument **COPA-XE „d"**, for Ex-Zone 1. The signal in- and outputs for these instruments are available as intrinsically safe „i" (per NAMUR) or as nonintrinsically safe „e" (per PELV) designs, which can be switched at the meter site.

Fig. 2-87: COPA-XE „d", Compact EMF with Converter in Pressure Tight Encapsulated Housing

Easy converter data entry from the outside in Ex-Zone 1 using a Magnet Stick, this means applicability in the Ex-Area without any restrictions. Naturally, operation and indication is possible under all operating conditions as well as communication using HART or PROFIBUS PA or FOUNDATION Fieldbus.

COPA-XT – The First 2-Wire EMF for Industrial Applications

There are already a number of 2-wire instruments available in the established measurement systems, e.g. pressure transmitters, Vortex flowmeters, Variable Area flowmeters and other measurement instruments. The supply power for these systems operate with an intrinsically safe 4...20 mA standard signal. The HART-Protocol provides an industrial proven digital communication ability for field instruments using existing 4...20 mA installations. This protocol can be utilized to transmit measurement and instrument data and beyond that, comprehensive system integration using process control systems.

The 2-wire-EMF from ABB Automation Products is a measurement system with a supply voltage similar to other instruments designed in 2-wire technology, i.e., the instrument is supplied exclusively from the 4...20 mA standard signal. With the accuracy of 0.5 % of rate and a size range from DN 10 to DN 100 this flowmeter line can be used in many applications. With this new technology, the installation costs can be trustically reduced.

The energy in this innovative magnetic field generation is stored in the special driver circuit using well known DC field technology, in which, it is in essence supplemented by a flowrate proportional excitation frequency. Because of the stored energy the EMF cannot be configured as an intrinsically safe instrument, but through a combination of other Ignition Types (II 2G EEx emd [ib] IIC T3...T6) the Ex-Protection for use in Category 2G (Zone 1) can be achieved. In addition, the 2-wire EMF includes a local display and a binary output using a switch amplifier. The configurable binary output can be used for pulse totalization, alarm contact, max. min. alarm etc.

Fig. 2-88: COPA-XT Ex-Design

Fig. 2-89: COPA-XT Standard Design

The 2-wire technology reduces the installation costs per meter location, reduces the energy costs because the EMF requires only max. 0.5 Watt and simplifies stocking due to standardization.

Miniflow and COPA-XL – The New Alternative for Simple Flowrate Measurements

Alternatives to the instruments described so far are the electromagnetic flowmeters **Miniflow** and **COPA-XL**. They were developed for simple flowrate measurements which have no special requirements.

The meter size range extends from DN 10 [3/8”] (1/2“ threaded connections) to DN 50 (2“-threaded connections) for the Miniflow and for the COPA-XL from DN 10...DN 300 [3/8”...12”]. The converter is mounted directly on the meter pipe in both designs. The complete unit is very compact, has low weight and can be quickly installed in the pipeline using the threaded connections. The electrical connections to the instrument are made with a plug. In addition to the two line display, which indicates the actual flowrate and the total flow value, both designs incorporate flowrate proportional 20 mA and pulse outputs. The instruments can be configured using the clear text display in conjunction with the foil keypad.

Fig. 2-90: Miniflow

Fig. 2-91: COPA-XL

Fill-MAG – The Intelligent Fill and Batch System

Exact filling and volume injections with high reproducibility often present difficulties when filling small as well as large containers. These problems have been addressed and solved by **ABB** with the Electromagnetic Fill-MAG-System or COPA-XF.

Dependent on the individual application requirements (fluid, fill and injection time, boundary conditions, etc.) Mass, Vortex and Swirl flowmeters can be used for batch processes. The control technology for the Mass flowmeter offers the same comfort as a Fill-MAG-System (detailed information relative to these instruments may be found in the appropriate instrument descriptions).

The Fill-MAG provides a very compact and intelligent electromagnetic flowmeter system whose major features are fast response times and specialized software adapted to batch and fill processes coupled with an ability to CIP/SIP clean the abrasion resistant primary. This specialized software is suitable for fill and injection processes with cycle times ≥ 500 ms and assures a reproducibility ≤ 0.2% of rate. In a fill system the automatic measurement and correction of the second stage flow, which is a function of the valve characteristics, is of great importance. Good measurement results can only be achieved with systems such as the Fill-MAG, which can compensate for these effects and is suitable for wide variety of diverse boundary conditions.

Flowmeter Technology

The Fill-MAG is designed using remote technology. The converter is available in a 19"-Version or can be installed in a field mounted housing. The process connection options for the stainless steel primary include all the usual commercially available connections.

The Fill-MAG System operates with programmable in- and output contacts (Fig. 2-92). Four different fill and preset volumes can be set directly at the converter or selected by an external fill volume selector switch or from a PC, SPC or Process Control System.

The fill cycle is initiated by a start signal which opens the valve. After the anticipatory or end contact volumes have been reached the converter directly controls the fill valve. Utilization of an RS 485 data link permits up to 32 converters to be connected and configured from a single operator station, SPC or Converter Dialog Unit (MDE). The connection of additional components such as control loops, control elements (weigh scale) as well as printers is possible.

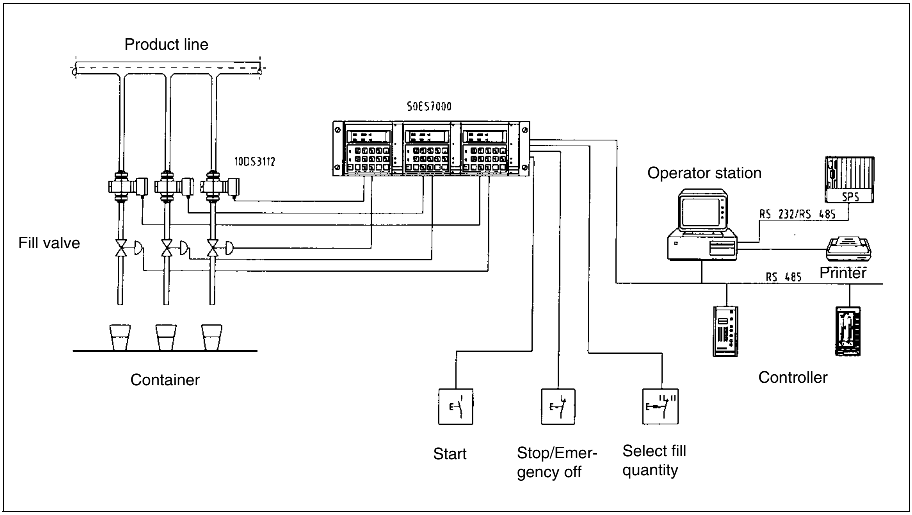


Fig. 2-92: Schematic of a Fill System with Supervisory Recipe Control and Integration in a Process Control System

Special features of the Fill-MAG System include:

- Suitable for fast as well as continuous fill and batch processes from the smallest amounts to large containers.
- Meter sizes from DN 1 mm to DN 400 mm [1/25” to 16”].
- Accurate, reproducible fill cycles reducing the amount of safety overfill quantities.
- Monitoring the adherence to the user programmable over- and underfill limits after each fill operation.
- Automatic emergency shutoff if the max. fill time is exceeded or an error is detected by the system monitor in the converter.

Single or Two Stage Fill Cycles

To achieve a high degree of reproducibility of the fill or injection cycles, in addition to the flowmeter, components such as valves, good level and pressure control as well as the system concept are of critical importance.

One of the most important factors is the quality of the fill valve (fast response time, reproducible closing characteristics). The second stage flow occurs during the closing cycle of the valve based on the valve closing time. This flow quantity is measured by the flowmeter and a correction made by a specially developed algorithm in the converter to assure that the desired fill quantity has been reached when the valve, whose closing cycle is initiated by an end contact signal from the converter, is finally closed.

The second stage flow measurement is used to adjust the end contact activation for the following fill cycle. In this manner continuously changing second stage quantities are recognized and automatically corrected in comparison to fill systems which use a preset totalizer value to correct for the second stage flow. The control of the second stage flow is ultimately decisive for the reproducibility of the fills. Use of an anticipatory contact (two stage fill cycle Fig. 2-93) which reduces the flowrate prior to the valve closure decreases the second stage quantity and thereby increases the repeatability. A prerequisite is a similarity fo fill curve, which is a function of the valve, the upstream pressure, the system concept and lastly of the product itself.

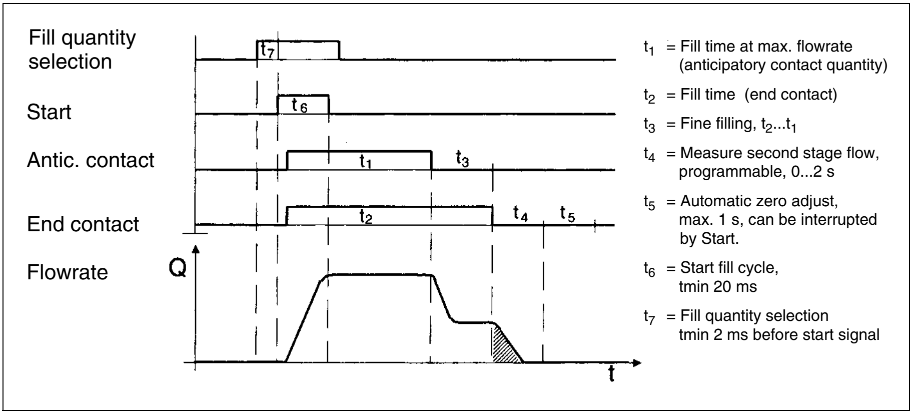


Fig. 2-93: Two Stage Fill Cycle

For very short fill and injection times (approx. 3 s) it is recommended that the valve be controlled directly by the end contact (single stage fill cycle Fig. 2-94). Anticipatory and end contacts are user programmable.

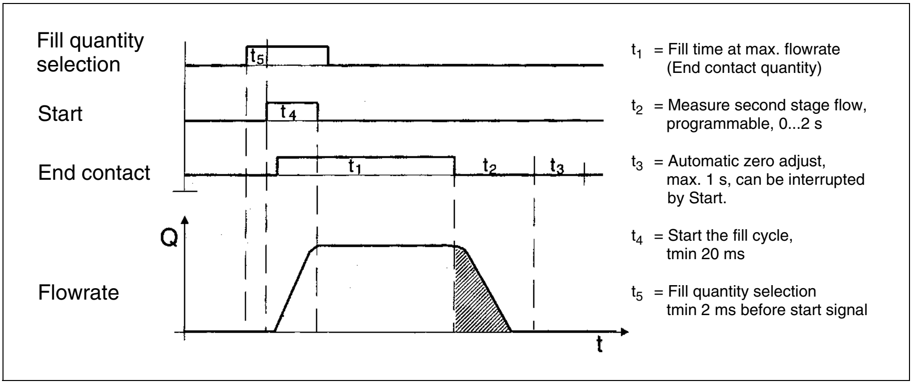


Fig. 2-94: Single Stage Fill Cycle

Certifiability

The measurement system has been approved PTB (German National Institute of Technology and Science) in Braunschweig, Germany for certified applications. Approvals for a variety of fluids has been received for the Fill-MAG. Specialized application areas for this EMF type are KEG-filling, as well as the measurement of chemical products. Regular recording of the process fill cycles, centralized data acquisition and recording parameter settings for a certification report are possible. Dependent on the printer protocol selected (4 different reports) various data sets can be printed and used for statistical analysis.

The above described Fill-MAG-System offers a number of possibilities for automating a wide variety of processes. Fast amortization of the investments by reducing the actual fill quantity due to a reduction of the safety overfills and thereby the product cost, improvement of the product quality, increase in productivity and profit optimization plus reduction of the operating, maintenance and service costs.

Electromagnetic flowmeters offer convincing advantages over the existing mechanical fill and injection systems using fill pistons or pumps, intermediate or prefill container, rotary vane or turbine flowmeters and weigh systems.

Additional advantages include:

- Wear free and low maintenance
- CIP/SIP-capability of the flowmeter reducing the cleaning and sterilization time.
- Shortest fill times for a variety of fill quantities possible because of the wide flow range.
- Higher product output through optimal utilization of the system, because suction phase and tare determination required by mechanical systems are eliminated.
- Communication possible with the measurement system including integrated statistical functions.

COPA-XF, the Flowrate Sensor

The COPA-XF (Fig. 2-95) is a compact instrument in which the converter is mounted directly on the flowmeter primary. The flowmeter primary, process connections together with the converter housing are all made of stainless steel. Due its small dimensions it is ideal for cluster mounting in round and series filling machines. It is also suitable for continuous flow metering, when only a pulse or current output is required and display is **not** required for indication. The reproducibility of the instrument is 0.2 % of rate for fill cycles longer than 2...4 seconds.

The meter sizes available are DN 3 mm...DN 100 mm [1/10”... 4”]. All the usual commercial process connections are available. Special customer specified connection designs can be accommodated. A 24 V DC power supply is required. For harsh operating conditions the COPA-XF includes an instrument air connection for creating a protective air stream. The instrument is also available in a tropicalized design with coated circuit boards.

The second generation COPA-XF instruments incorporate **3 different operating modes**. In addition to the **operating mode „Batch“** for fill and injection processes it can function as flowrate proportional flowrate sensor with 1, 2, 5 KHz or scaled pulse output. In the **operating mode „Conti“** for continuous metering an additional 0/4...20 mA current output available. The **operating mode „Filler“** functions as a stand-alone fill system based on the main features or functions of the proven Fill-MAG technology.

In contrast to the intelligent Fill-MAG-System or the operating mode „Filler“ in the **COPA-XF**, the COPA-XF with the **operating modes „Batch“** or **„conti“** can be considered a pure flowrate sensor.

Hereunder one understands an EMF that has either a frequency or a current output and a scaled pulse output. To utilize this instrument type in a fill or injection application additional soft- and hardware would be required to provide the higher level evaluation and control functions. Considering the technology or the reproducibility for longer fill times (>2...4 s) it is in no way inferior to the Fill-MAG-System. Its output is simply a flowrate proportional frequency signal. The scaled pulses must be calculated and processed in a preset counter, PC, SPC or PCS.

Fill quantity preselection, utilization of single or two stage fill system, Start/Stop function, second stage flow measurement and correction, control and/or monitoring functions as well as valve actuation are all functions which must be carried out by other evaluation instruments connected to the flowrate sensor. The performance of these instruments or software together with the flowrate sensor are responsible for the quality of a fill and injection system as well as for the reproducibility of the fills. A schematic of such a flow system is shown in Fig. 2-97.

Fig. 2-95: Flowrate Sensor COPA-XF, Standard

Fig. 2-96: COPA-XF in Compact Design with Communication Capabilities (here using MDE 55 HT 4000)

Decisive for the development of such a Flowrate Sensor were the market demands for an economical, small and effective compact EMF in a stainless steel design for multi-valve fillers with up to 168 fill valves.

Due the impressive number of fill valves per system and the possibility to develop and configure the required software in-house, this system concept became interesting from technical and economic viewpoints.

One time developed software together with know-how can be transferred to many other systems. Each system type can utilize the economical Standard Flowrate Sensor and apply the in-house developed software with different user interfaces and system specific components.

Since central computers already exist for other control tasks for the fill machines, they can take also be used for the signal processing, the fill quantity presets and the required corrections as well as the valve control functions.

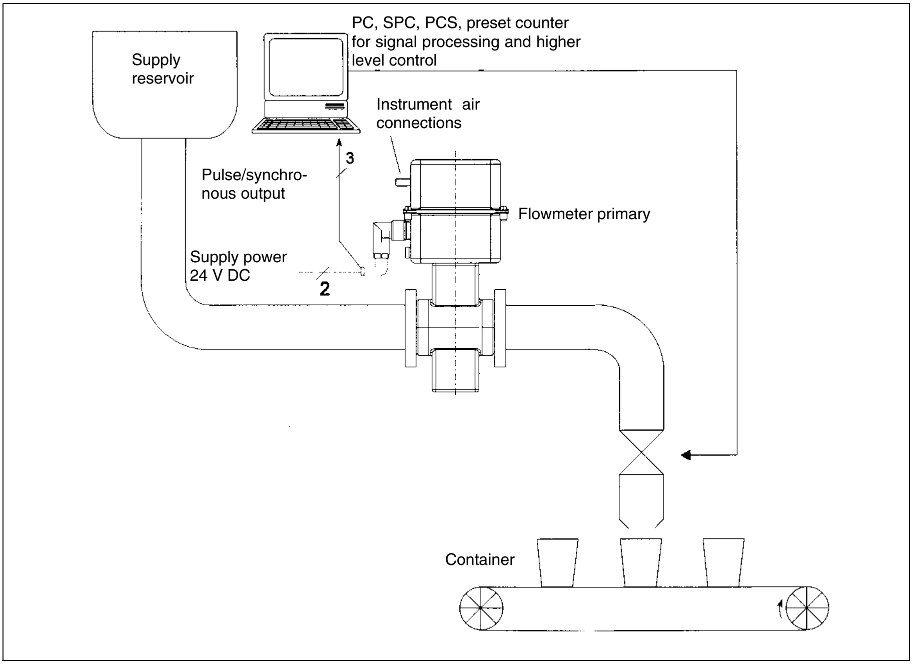


Fig. 2-97: Schematic of a Fill System with the Electromagnetic Flowmeter COPA-XF

Communication Capabilities

For the configuration and control of the COPA-XF two possibilities are available. After opening the housing cover the Converter Operator Unit 55BE1000 with display can be plugged into the converter for service purposes.

If parameter changes for the process or information about the present status of the process is required the implementation of a RS 485 data link in the instrument offers many possibilities.

The ASCII-Protocol, or in the future PROFIBUS DP, can be used for communication with a process control system, a stored programmable controller or a PC and the individual software. The connection is made using a separate communication plug.

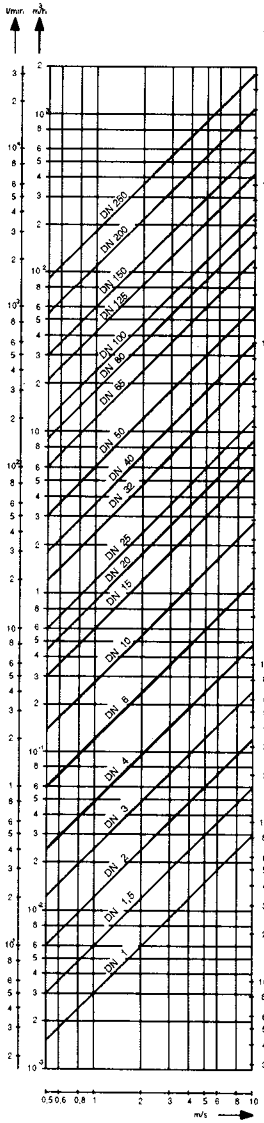
A total solution for monitoring the COPA-XF and for changing the parameters, without removing the housing cover is provided by the Dialog Unit 55HT4000 with display.

It is simply plugged in the communication jack. In the operating mode „Dialog unit“ the possibility exists for a 1:1 communication with a specific instrument. The operating mode „Central setting“ offers parallel communication with a maximum of 4 converters.

This new generation of volumetric operating fill machines with electromagnetic flow measurements instead of fill systems with intermediate or preset fill containers (limitations for fluid varieties and fill time) or weigh systems, takes advantage of the many benefits which an EMF-System offers. The CIP/SIP-cleanability, wear free and low maintenance technology, viscosity insensitivity coupled with the wide flow ranges of the EMF with a simple and fast change over to other fill quantities results in quality improvements, product savings by reducing overfills, productivity improvement and cost reductions.

EMF Sizing

The user provides the meter size of the EMF primary when he indicates the size of the process connections. A check calculation using the actual flowrate values should however be made which should indicate the same size. Otherwise the pipe size must be adjusted.



The basis for the calculation is the flow velocity, a standardized size independent value

A few examples from actual situations (the values refer to the flow range end values):

Slurries, pulps, pastes	0.5 … 1 m/s
Liquid food stuffs	1 … 2 m/s
Liquids in chem. processes	1 … 3 m/s
Potable water	3 … 6 m/s
Water to transport solids to	15 m/s

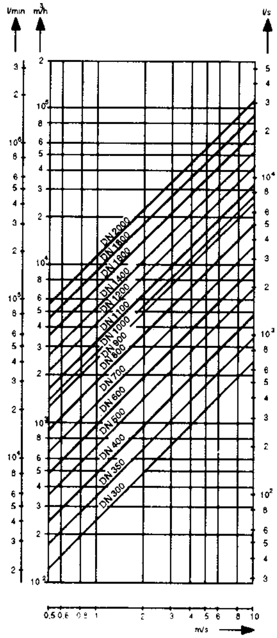


Fig. 2-98: Flowrates as a Function of the Flowmeter Size

Using the nomograph Fig. 2-98 the desired flowmeter size can be determined. When the values in the nomograph are used to determine the pipe size, differences between the calculated value and the actual pipe diameter may exist. This is due to the differing liner thicknesses and is compensated for during the calibration.

Occasionally differences exist between the calculated EMF meter size and the actual pipe size with the EMF size usually the smaller. A transition using conical sections is possible when cone angles are less than 8°.

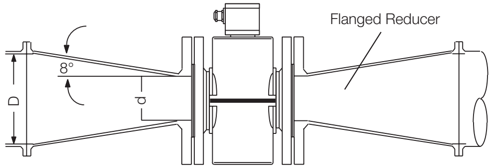


Fig. 2-99: Reductions at the Metering Location

The pressure drop resulting from the 8° reduction can be calculated using the nomograph Fig. 2-100. The diameter ratio d/D must be calculated and the curve for the actual flow velocity v selected from the family of curves. The pressure drop Δp can be read at the intersection between these two values.

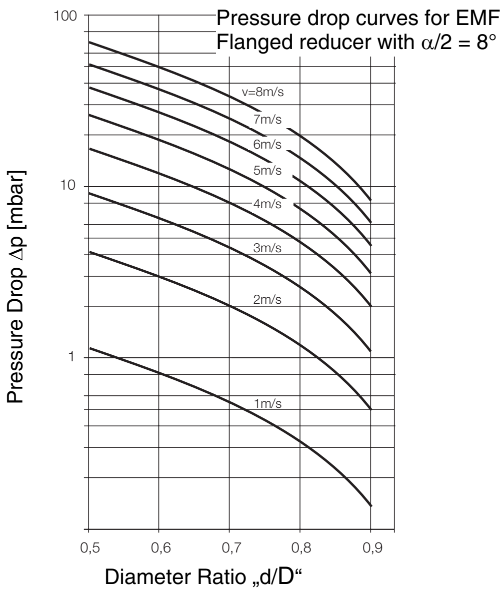


Fig. 2-100: Pressure Drop with Reducers

Specifications

Signal Measurement	Galvanic		
Magnet Field Excit.	EMF with Pulsed DC Excitation		
Model	**COPA-XE** **MAG-XE**	**COPA-XM** **MAG-XM**	**COPA-XF**
Liner Material	DN Inch PN	DN Inch PN	DN Inch PN
Hard rubber	15-1000 ½-40 10-40	15-2000 ½-78 6-40	
Soft rubber	65-1000 2½-40 10-40	50-2000 2-78 6-40	
PTFE	10- 800 3/8-32 10-40	10- 800 3/8-32 10-40	
PFA	3- 100 1/10-4 10-40	3- 100 1/10-4 10-40	3-100 1/10-4 10-40
Peek	– – –	1- 2 1/25-1/12 10-40	
Torlon	– – –	1- 2 1/25-1/12 10-40	
Electrode Material	For hard/soft rubber liner: Std. SS No.1.4571[316Ti], Option Hastelloy C or B; For PTFE/PFA liner: Std. Hastelloy C, Option Hastelloy B, Ti, Ta, Pt-Ir		
Excitation frequency	6 1/4 Hz, 12 1/2 Hz or 25 Hz		12.5/25 Hz
Min. conductivity	5 µS/cm		5 µS/cm
Max. pressure rating	PN 250		PN 40
Max. temperature	130 °C	180 °C	130 °C
Electrode design	Standard, pointed electrode, removable electrode as an option for meter size ≥ DN 350[14”] and for hard rubber liner		
Process connection	Flanged: DN15-2000 [1/2”-78”] hard/soft rubber, DN10-600[3/8”-24”]PTFE, DN3-100[1/10”-4”] PFA. Wafer Design: DN3-100[1/10”-4”] PTFE, PFA. Aseptic connection.: DN3-100[1/10”-4”] PFA. Tri-Clamp: DN3-65[1/10”-2½”] PFA 1/8" Sanitary conn. DN1-2 [1/17”-1/12”] Peek, Torlon		var. process connections DN3-100 PFA [1/10”-4”]
Flow range end value	0.5...10 m/s	0.5...15 m/s	0.5...10 m/s
Max. measurement deviation	0.5 % of rate opt. 0.25 % of rate	0.4 % of rate opt. 0.2 % of rate	0.5 % of rate ≤ 0.2 % reproduc-ibility
Current output	0...5 mA, 0/2...10 mA, 0/4...20 mA, 0...10...20 mA, 4...12...20 mA selectable		
Load	0...600 Ω	0...1000 Ω	0...600 Ω
Pulse output	optocoupler, active	optocoupler, active optional relay	Opto, active
Pulse width	pulse width selectable from 0.1 ms...2000 ms		1.25
Supply power	power supply 85...253 V AC 16.8...26.4 V AC 16.8...31.2 V DC	24, 115, 230 V 24 V DC 50/60 Hz 24 V DC	16.8...31.2 V DC
Auto. empty pipe det.	yes ≥ DN 10[3/8”]	yes ≥ DN 10[3/8”]	Operating Mode
Max./min. alarm	yes	yes	• continuous
2 flow ranges	no	yes	• Batch
Preset totalizer	no	yes	• Filler

Tbl. 2-6: Overview: Flowmeter Primary and Converter Designs

Specifications

Signal Measurement	Capacitive	Galvanic	
Magnet Field Excitation	EMF with Pulsed DC Field Excitation	EMF with AC Field Excitation	
Model	**MAG-CM COPA-CM**	**Fill-MAG**	**FSM4000**
Liner Material	DN PN	DN PN	DN PN
Hard rubber	no	15...400 10...40	15...1000 10...40
Soft rubber	no	no	50...1000 10...40
ETFE	25...300 10...40	10...300 10...40	10... 300 10...40
PTFE	no	10...400 10...40	10... 600 10...40
PFA	no	3...100 10...40	3... 100 10...40
Peek	no	1... 2 10	1... 2 10
Torlon	no	1... 2 10	1... 2 10
Electrode Material	Capacitive signal measurement	For hard/soft rubber liner: SS No.1.4571[316Ti], For PTFE/PFA liner: Hastelloy C, For Aseptic food industry fittings: 1.4539	
Excitation frequency	12 1/2 Hz/15Hz/ 25 Hz DC	50/60 Hz AC	50/60/70 Hz AC
Min. conductivity	0.05 µS/cm	20 µS/cm, Option: 5 µS/cm or 0.5 µS/cm	
Max. pressure rating	PN 40	PN 250	PN 250
Max. temperature	100 °C	150 °C	180 °C
Electrode design	Capacitive electrode behind liner	Standard, pointed	
Process connections	Flanged	Flanged, Wafer Design, Aseptic food industry fittings, Tri-Clamp, others upon request	
Flow range end value	0.5...15 m/s	0.5...10 m/s	0.5...10 m/s
Max. measurement deviation	1 % of rate	1 % of rate 0.2 % reproducibility	0.5 % of rate 0.2 % reproducibility
Current output	0/4...20 mA; 0/2...10 mA; 0...5 mA selectable		0/4...20 mA; 0/2...10 mA
Load	0...1000 Ω	0...550 Ω	
Pulse output	active, passive	active, passive	
Supply power	24, 115, 230 V 50/60 Hz 24 V DC	24, 115, 230 V 50/60 Hz	20.4..26.4 V AC; 20.4...31.2 V DC 100...230 V AC
Auto. empty pipe detector	no	yes (except for preamplifier)	
Max.-Min.-Alarm 2 Flow ranges Preset totalizer	yes yes yes	no no yes	yes no no

Tbl. 2-7: Overview: Flowmeter Primary and Converter Designs

Aquaprobe – The Flowrate Sensor

The Flowrate Sensor **Aquaprobe** is a special application of the electromagnetic flowmeter technology. In comparison to the Electromagnetic flowmeters previously described, the flowrate probe is installed from the outside through a bushing without opening the pipeline. This minimizes the installation costs.

The flowmeter can be installed in a pressurized operating pipeline. The magnetic field in the Aquaprobe does not extend over the entire pipe cross section as it does in an EMF. The flow velocity is measured at a representative point in pipe cross section and the flowrate calculated in the converter. The Aquaprobe is suitable for permanent installations as well as for portable use. Special application areas are flowrate measurements in municipal water distribution networks. In this application the Aquaprobe can measure the flowrate and the flow direction at specific sections of the pipe network. Even at very low flowrates the accuracy remains 2 % of rate. In this way the Aquaprobe can be used to detect leaks in the water distribution network.

A pressure transmitter can be installed in the ½“ connection in the Aquaprobe. Therefore, in addition to the flowrate measurement, a pressure measurement can also be made. In the water distribution network both measurements (pressure and flowrate) can be utilized to draw conclusions about encrustations/deposits in the pipeline. Encrustations/deposits have negative effects, e. g. in the event of a fire the max. water flow from the pipeline may be not be sufficient.

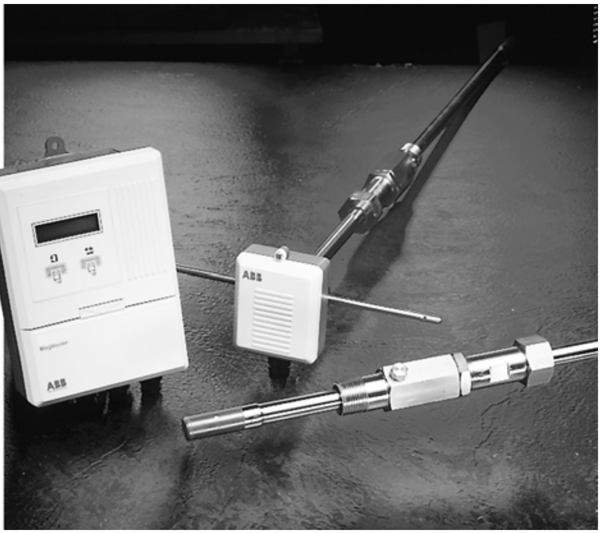


Fig. 2-101: Aquaprobe

2.2.4 Ultrasonic Flowmeter

The **sound velocity** c which is a material property value is the propagation velocity of a sound wave in a fluid. It changes with the density of the fluid. Therefore it is temperature dependent in liquids and pressure and temperature dependent in gases. When a sound impulse is transmitted from location A it arrives at a second location B with the velocity of sound at time:

$$t = \frac{l}{c}$$

The time changes when the sound carrier is also in motion, in fact, it is the sum of the sound velocity in the fluid and the fluid velocity. This effect is utilized in an ultrasonic flowmeter.

There are two basic methods for ultrasonic flow measurements:

1. Transit time method
2. Doppler method

Transit Time Method

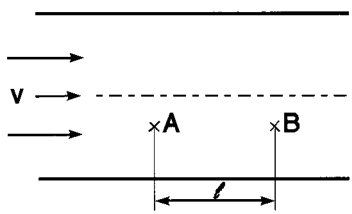


Fig. 2-102: Sound Path in a Liquid Stream

A sound impulse transmitted from a fixed point A travels with a velocity c + v and arrives at point B after a time interval t_1:

$$t_1 = \frac{l}{c + v} \quad (2.29a)$$

The time required for an impulse to travel from B to A is t_2:

$$t_2 = \frac{l}{c - v} \quad (2.29b)$$

Since the measurement of t_2 is made immediately after t_1 it is assumed that during this time interval the sound velocity c in the fluid is constant. Then from

$$c = \frac{l}{t_1} - v \qquad c = \frac{l}{t_2} + v$$

the flow velocity in the fluid can be extracted using

$$v = \frac{l}{2}\left(\frac{1}{t_1} - \frac{1}{t_2}\right) \tag{2.30}$$

This measurement value is independent of the sound velocity, the pressure, the temperature and the density of the fluid.

In a practical meter design a sound impulse is sent diagonally across the pipe. Then the flow velocity of the fluid in the pipeline becomes

$$v = \frac{l}{2 \cdot \cos\alpha}\left(\frac{1}{t_1} - \frac{1}{t_2}\right)$$

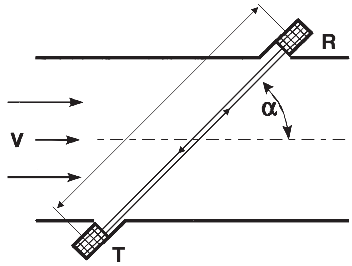


Fig. 2-103: Schematic of Transit Time: R = Receiver, T =Transmitter

An essential requirement for the transit time measurement is the acoustic transparency of the fluid. There should be few solid particles or air bubbles in the fluid.

Doppler Method

For ultrasonic flowrate measurements using the Doppler-Effect there must be inhomegenieties or impurities (dispersers) in the fluid being metered so that a portion of the sound energy can be reflected.

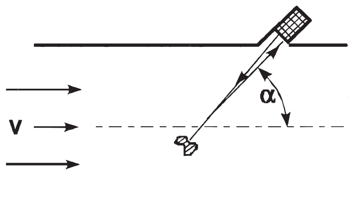


Fig. 2-104: Schematic of the Doppler Principle

The sound wave with a transmitter frequency f_1 impinges on a particle in the liquid (solid particle or gas bubble) and is reflected. Therefore every particle acts as a moving transmitter with the transmitter frequency f_1. The frequency shift Δf of the reflected signal received is a function of the flow and sound velocities:

$$\Delta f = 2 \cdot f_0 \cos(\alpha) \cdot \frac{v}{c}$$

Since the sound velocity is a function of the temperature, pressure and composition of the fluid, even small changes in these variables affect the Doppler shift and an appropriate compensation must be provided. The solution is to include a defined upstream section, e.g. made of resin, in which Piezo transmitter is cast.

Applying the refractive equation of Snellius

$$\frac{\cos(\alpha)}{c} = \frac{\cos(\beta)}{c_v}$$

from which

$$\Delta f = 2 \cdot f_0 \cos(\beta) \cdot \frac{v}{c}$$

and therefore

$$v = \frac{c_v}{2 \cdot f_0 \cdot \cos(\beta)} \cdot \Delta f = \text{const} \cdot \Delta f$$

The factor $c_v/\cos(\beta)$ can be determined. The Doppler shift is therefore essentially independent of the sound velocity in the fluid. Only sound velocity changes in the acoustic upstream section change the Doppler frequency. This change can be determined beforehand and compensated.

Limits

For the ultrasonic flow measurement the flow velocity is measured within the narrow band of the sound beam. The calculated flowrate through the entire flow area is only valid for axisymmetric flow profiles. In order to assure that these conditions exist flow conditioning sections with a length up to 10 D are required. It is possible to reduce the effects of nonsymmetrical flow by using two or more sound beams for additional profile samples.

Installation

Ultrasonic flowmeter instruments are designed in two types. There is the **Inline System** and the **Clamp-on System**. In the Inline design the ultrasonic transducers are mounted rigidly in the pipe wall and are in contact with the fluid. These measurement systems can be calibrated and achieve an accuracy of ± 0.5 % of rate and better.

Different is the Clamp-on technology. The ultrasonic transducers are mounted on the outside of the pipe. The sound impulse must traverse the pipe wall and any coatings which may be present with differing sound velocities twice. During installation the laws of refraction and reflection must be considered. Although the determination of the flow velocity is straightforward, the exact pipe geometry must be known if the flowrate in the pipeline is to be calculated.

These measurement systems can only be dry calibrated and achieve an accuracy better than ± 2.0 % of rate. If an on-site calibration can be conducted then accuracies up to ± 0.5 % of rate are possible.

Specifications

Meter size	DN 25...DN 3000 [1”...120”] Above meter size DN 600 [24”] the Clamp-on system is preferred
Flow velocity	1...10 m/s
Accuracy	+ 0.5 % of rate for Inline + 2.0 % of rate for Clamp-on
Max. fluid temperature	°C...260 °C with special designs up to 500 °C and higher

2.2.5 Coriolis Mass Flowmeter

Principle of Operation

For cost and material balance calculations mass flow information is preferred in technical processes because it is independent of physical influences when compared to volume flow information. Pressure, density, temperature, viscosity do not change the mass. Therefore the mass flowrate is preferred. Mass can only be measured indirectly, e.g. with the help of Newtons second law which states that force times acceleration equals mass. When weighing the acceleration is due to gravity and this law is applicable.

How can the mass of a fluid be determined using this relationship? One must accelerate the fluid in a rotating system and measure the inertia effects. A physical effect named after the French mathematician Coriolis is utilized.

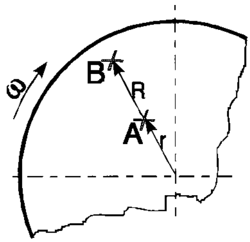


Fig. 2-105: Rotating Disc

A mass m located at point A at an average distance r from the center on a plate with an angular velocity ω which is to be moved towards B at a radius R, that is to a location with a higher torque and a higher energy content.

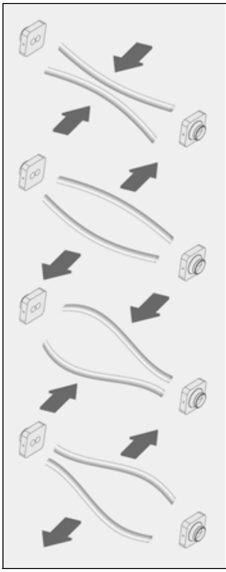
If no energy is added to the system the mass will not arrive at point B or a different variable must change, namely ω. The torque which opposes the change is the Coriolis force F_c:

$$\vec{F_c} = -2\ m\ (\vec{\omega} \times \vec{v}) \tag{2.35}$$

v is the velocity of the mass on the way from A to B. These principles are transferred to a fluid filled pipe.

Principle of operation: When a mass flows through a vibrating pipe Coriolis forces exist which bend or twist the pipe. These very small meter pipe distortions are measured by optimally located sensors and evaluated electronically. Since the measured phase shift between the sensor signals is proportional to the mass flowrate the mass flowrate through the Coriolis Mass flowmeter can be determined directly.

This measurement principle is independent of density, temperature, viscosity, pressure and conductivity. The meter pipes always vibrated at resonance. The resonant frequency which exists is a function of the meter pipe geometry, the material properties and the vibrating fluid mass in the meter pipe. It provides exact information about the density of the fluid. In summary, it can be stated that the Coriolis-Mass flowmeter can be used to simultaneously measure the mass flowrate, density and temperature of a fluid.



Movement of the pipe inward
no flowrate

Movement of the pipe outward
no flowrate

Direction of the Coriolis force **with flowrate** and movement of the pipe inward

Direction of the Coriolis force **with flowrate** and movement of the pipe outward

Fig. 2-106: Simplified Presentation of the Coriolis Forces

Advantages and Disadvantages

Advantages:

- Universal metering system for flowrate, density and temperature, independent of
  - conductivity
  - in- and outlet pipe sections
  - velocity profile
  - fluid density and therefore pressure and temperature
- Direct mass flowrate measurement
- Very high accuracy (typically ± 0.15 % of rate)
- Multi-variable measurement principle, simultaneous measurement of
  - mass flowrate
  - volume flowrate
  - density
  - temperature
- No moving parts, therefore wear free

Disadvantages:

- Relatively high acquisition cost (for an accuracy of 0.15 % of rate)
- Installation limitations for multiphase fluids or high gas content.
- Deposits or abrasion can lead to errors, especially in the density measurement
- Limited material selections for fluid wetted parts, corrosion resistance must be checked

Double Pipe Measurement System

The overwhelming majority of Coriolis instruments today are based on the double pipe principle with a flow splitter and two bent meter pipes. The advantage of this design, e. g. the FCM2000-MC2, is temperature stability and in particular, the decoupling of the meter pipe vibrations from external vibrations. The amplitudes of the vibrations which are required for determining the phase shift, are measured between the two meter pipes and not relative to the housing. Possible vibrations of the housing therefore have no effect on the measurements.

Based on the appreciably more stable and defined signals this system provides the most accurate measurements coupled with insensitivity to outside influences. A well designed double pipe meter requires minimum energy to start and keep the system resonating and generates measurement signals even for the smallest flowrates. The double pipe design is used in approx. 80 to 90 % of present applications.

Fig. 2-107: Bent Single Pipe Design

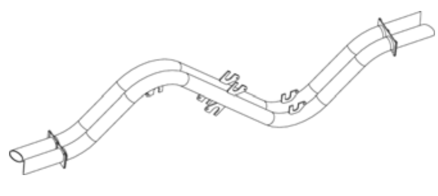


Fig. 2-108: Double Pipe Design FCM2000-MC2

Single Pipe Measurement System

In addition to the double pipe design there is a single pipe design, e.g. the ABB-Model FCM2000-MS2. In order to maintain the insensitivity to external vibrations, the meter pipes in this design are bent into loops. The amplitudes of the vibrations, and thereby the phase shift, are measured between the pipe loops and not relative to the housing. This principle offers distinct advantages for the smaller size meters because a flow splitter in not required.

The **Straight Single Pipe** design has advantages in that it can be more easily cleaned, has a reduced pressure drop and is less harsh on the fluid itself. These advantages come with a lower accuracy and a higher sensitivity to external vibrations. Because of the straight meter pipe, the amplitude differences must be measured relative to the housing. If the housing is also vibrating, the effects are difficult to compensate. Plus the measured signals are appreciable smaller which also contributes to the reduced accuracy mentioned earlier, especially for the density measurement.

It is difficult to start and keep a single pipe resonating. The elasticity of a pipe is directly related to its wall thickness. Therefore vibrating straight pipes must be constructed thin and are available only for limited meter sizes. For abrasive or corrosive fluids the thin wall sections of the meter pipe can add additional safety concerns.

Application Areas

Based on the advantages mentioned above it is not difficult to understand that this Coriolis measurement principle is being preferred by more and more industries over other measurement principles. Of particular interest if the direct mass measurement, because many recipes or processes are based on the mass of the materials being used. Previous dependence on density variations and therefore temperature or pressure changes are concerns of the past. If in the past a volume measurement had to be converted to mass, the Coriolis technology eliminates this step.

Since this principle is independent of the properties of the fluid, such as conductivity, velocity profile, density, viscosity etc. almost all materials can be measured: e.g. oils and fuels, cleaning and solvent fluids, fats, silicone oil, alcohol, methane, fruit mixtures, starch, dyes, biozide, vinegar, catsup, mayonnaise, beer, milk, sugar solution, gases, liquefied gases, etc.

As a result of the simultaneous measurement of the density and temperature of the fluid a real time quality analysis of the fluid can be made. If the density of the fluid changes from the set point value, quality problems in the process are identified. Also the presence of air inclusions or similar effects can be monitored from the density signal.

In the food and beverage industry a deciding factor is the good cleanability of the instruments, even a double pipe system, as the EHEDG-Certified flowmeter primary design from ABB has demonstrated. Furthermore the highly accurate mass and density measurements of the materials are a great advantage. Compositions can be monitored online. The concentrations of two phase fluids can be determined from the density measurement using special software. Thus for the sugar concentration in a liquid the °BRIX is readily available. Up to 3 different density-concentration curves can be entered in the converter of the FCM2000, so that every type of concentration can be measured.

In the chemical industry of particular importance are very exact mass measurements. The variable EEx-Concept (EEx „e“ and „i“ defined by the user connections) including isolation and not least, the additional security of a pressure tight housing enclosing the meter pipes are also advantages. ATEX-Approvals up to Group 1 (Zone 0) have been received. The high reproducibility (typically 0.1 % of rate) in particular is essential for control or fill processes.

In the petrochemical field the additional material compatibility per NACE and the rugged design are of importance, especially where extreme ambient conditions exist. They are used in oil fields at -50 °C or in offshore applications where a highly corrosive salt water environment is present. For this last application, ABB offers a special protective coating for North Sea applications.

In the paper industry the Coriolis Mass flowmeters were predestined for use in the coating and color kitchens. Problems always occurred due to the varying density of viscosity values, there e.g., the FCM2000 which extremely stable and highly accurate measures the mass directly. Also the conversions from volume to mass units has become unnecessary.

Due to the multivariability, flexibility, high accuracy, wear free and ruggedness, the Coriolis Mass flowmeter technology continues to conquer new application fields. Although at first it may appear that the initial acquisition costs are higher they often become negligible when compared to the later savings due to more accurate and simpler fills. In comparison to the traditional instruments the accuracy remains constant for a long time period at a minimum maintenance cost.

Often Asked Questions with Answers

What must I consider during the installation of the instruments?

These instruments in comparison to the other flowmeters are relatively easy to install. They can be installed horizontally or vertically. Specific distances from elbows or valves, etc. are unimportant because the measurements are unaffected by flow profile effects. The instruments should be supported close to the in- and outlet flanges, but not the housing.

What effect do gas or air bubbles in the fluid have on the measurement?

First gas bubbles tend to dampen the vibration of the pipes, which is compensated by a higher excitation current. If the gas content is not too large and has an essentially uniform distribution, the mass flow measurement is hardly affected. The density measurement however can be impaired. This can be explained by the measurement principle. The resonant frequency of the vibrations is proportional the instantaneous vibrating mass, consisting of the fluid and the meter pipes. Assuming that the pipes are completely filled, the density can be calculated from the equation:

$$m = \rho \cdot V$$

If the pipes are not completely filled or contain a gas or air components then an error will occur because V in the equation is incorrect.

How do solids affect the measurement?

As long as the solids vibrate exactly the same as the meter pipe and thereby add a contribution to the flowrate signal, there are no problems with the measurement. Decisive is the relationship between the particle size (inertia) and the viscous forces (acceleration forces). I.e., the lower the viscosity the smaller the particle size should be. Generally, a self draining design is preferred, to prevent particles being deposited in the pipe bends, especially when there is no flow.

What is affected if the back pressure is too low?

When the back pressure is low the fullness of the meter pipes cannot be guaranteed, and also the danger that cavitation may occur exists when the vapor pressure is less than the system pressure. In many instances where problems with a Coriolis Mass flowmeter have been reported the problems can be traced to either low back pressure or gas content in the fluid.

What happens if the meter pipes are not completely filled?

In this case the meter pipes cannot reach a stable vibrating condition and a measurement in no longer possible. This condition can be recognized by an unstable, too low a density signal and also by a large increase in the driver current.

Fig. 2-109: Flowmeter FCM2000-MS2

Fig. 2-110: Flowmeter FCM2000-MC2

The flowmeter primary FCM2000 is characterized by two one piece bent pipes mounted in parallel. A twist and bend free structure which joins the in- and outlet is designed to absorb the external moments and forces. The meter pipes are welded to flow splitters at their in- and outlet ends. Thus there is no direct coupling to the process connections. This design to a large extent minimizes the effects of external vibrations.

The elimination of welds at the highest stressed locations as well as hard soldering in a vacuum the pipe, driver and sensors brackets assures long term durability. An exceptional long term stability is achieved by vacuum annealing the meter pipes.

Fig. 2-111: Flowmeter Certified for the Food and Beverage Industries

The optimized flowmeter primary design together with meter pipe material 1.4435/316L allows unrestricted use in hygienic application. The entire design consisting of meter pipe, flow splitter and process connections have been tested and approved by EHEDG. The CIP and SIP processes can be carried out at temperatures up to 180 °C.

The converter FCM2000 for the compact and remote designs incorporates a digital signal processor (DSP), with which the flowrate and density measurements can be made at the highest precision. An exceptional long term stability and reliability are the results of the new DSP-converter. Self diagnostics for the flowmeter primary and converter and absolute zero stability are additional advantages.

Specifications FCM2000

Accuracy, Mass Flowrate

± 0.4 % of rate ± 0.02 % of Q_{max}
± 0.25 % of rate ± 0.02 % of Q_{max}
± 0.15 % of rate ± 0.01 % of Q_{max}

Flow Range, Flowrate

	Flowmeter Primary DN	Inch	Max. Flow Range [kg/min]	Max. Flow Range [kg/h]
MS2	„S“ 1.5	1/17	0... 1.08	0... 65
	„T“ 3	1/10	0... 4.17	0... 250
	„U“ 6	1/4	0... 16.7	0... 1000
MC2	„E“ 20	3/4	0... 100	0... 6000
	„F“ 25	1	0... 160	0... 9600
	„G“ 40	1-1/4	0... 475	0... 28500
	„H“ 50	2	0... 920	0... 55200
	„I“ 65	2-1/2	0... 1890	0...113000
	„J“ 80	3	0... 2460	0...148000
	„K“ 100	4	0... 4160	0...250000
	„L“ 150	6	0...11000	0...660000

Flow Range, Density

0.5 kg/dm^3...3.5 kg/dm^3

Accuracy. Density

Standard calibration: ± 0.005 kg/dm^3
High acc'y calibration ± 0.001 kg/dm^3
Reproducibility ± 0.0001 kg/dm^3

Process Connections

Flanges (DIN/ANSI)
Tri-Clamp (DN 20...DN 100)
Food industry fittings DIN 11851
Other connections upon request

Pressure Rating

DIN PN 16, PN 40, PN 100
ANSI CL 150, CL 300, CL 600

Materials

Fluid wetted parts
Stainless steel 1.4571/316 Ti
Stainless steel 1.4435/316 L
Hastelloy C4 2.4610
Housing: Stainless steel 1.4301

Temperatures

Fluid: -50...+180 °C
-20...+180 °C (ATEX and FM)
-40...+180 °C (opt. ATEX & FM)
Ambient: -20...+60 °C
-20...+60 °C (ATEX & FM)
-40...+60 °C (opt. ATEX & FM)

Ex-Approval

II 2D T 115 °C ... T_{fluid} IP 67
II 2G EEx me [ib] IIC T6 ≤ DN 40
II 1/2G EEx me [ib] IIC T6 ≥ DN 50
TÜV 99 ATEX 1443 X
FM Class I, Div. 2; Div. 1
EEx „d“
Outputs in Ex „e“ or Ex „ib“

Current output 1/active

0/4...20 mA, selectable
User configurable in software

Current output 2/passive

4...20 mA
User configurable in software

Scaled pulse output

Scaled pulse output max. 5 kHz, galvanically isolated from current output

Contact in-/outputs for:

Automatic system monitoring
Forward and reverse flow signal
Max./Min. contact
External zero return
External totalizer reset

Communication

- HART-Protocol
- PROFIBUS PA
- FOUNDATION Fieldbus
- RS 485 – ASCII-Protocol
  (with 50MM2 converter)
- PROFIBUS DP
  (with 50MM2 converter)

Supply Power

High voltage 85 V...253 V
Low voltage 24 V AC/DC

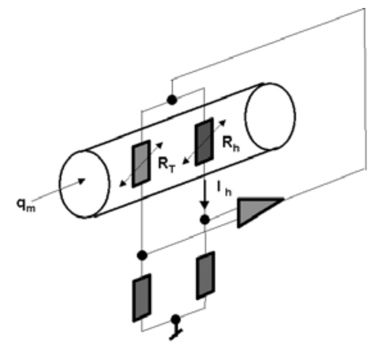
2.2.6 Thermal Mass Flowmeters for Gases

The most used flowmeters for gases measure the actual volume. This requires additional measurements of pressure and temperature to calculate the mass flowrate. These corrective measures add cost and increase the complexity of the measurements; in addition they decrease the measurement system accuracy. The Thermal Mass flowmeters provide mass flowrate in kg/h directly without any additional measurements or calculations. Using the normal density of the gas the normal volume flowrate can be calculated e. g. in Nm^3/h.

There are two industrial methods used for thermal gas mass flowrate metering, Hot Film Anemometers and Calorimetric or Capillary meters.

Hot Film Anemometer Sensyflow

This method uses the flowrate dependent heat transfer of a heated body in the fluid. This flowrate dependent cooling is not a function of the pressure and temperature, but of type and number of particles which impact the heated surface. The method determines the mass flowrate of the fluid directly.



R_h: Thin film resistor – heated

R_T: Thin film resistor – fluid temperature

q_m: Mass flowrate

I_h: Heat flow

V: Control circuit

Fig. 2-112: Operating Principle, Hot Film Anemometer

The sensor consists of two resistors which are part of a bridge circuit. One resistor is at the temperature of the flowing gas, the other is electrically heated and simultaneously cooled by the flow. A control circuit applies heat to the resistor so that a constant temperature difference exists between the resistors. The power P, in then a measure of the mass flowrate of the gas. With the instrument and gas dependent constants $K_{1...3}$ this relationship can be represented by the King's equation:

$$P = \Delta T \cdot K_1 + K_2 \cdot (qm)^{K_3}) \quad (2.36a)$$

The procedure provides a flowrate value directly in units of kg/h or Norm-m^3/h, the density correction of the flowrate otherwise required is no longer necessary. The compact design of the measurement sensor assures a minimum pressure drop of typically 1 mbar. The response time for sensors designed in thin film technology is in the ms range (e. g. Sensyflow P and eco2). Rugged instruments for industrial applications (Sensyflow iG and VT) still achieve response times of 0.5 s. Vibration insensitivity and an extremely wide flow ranges at accuracies up to 1 % of rate are the rule for instruments of this type.

Hot Film Anemometer Sensyflow iG in Digital Technology

For digital instruments, the measurement principle described above was further developed to include a gas temperature measurement and appreciably increased diagnostic functions. The flow range could be expanded to 1:150 because of the improved signal quality. The separate measurement of the gas temperature can be used to compensate for the temperature dependence of the gas constants. The diagnostic functions can be used as a preventative maintenance tool to evaluate the operating time, temperature spikes and system loads.

Technical Designs

Different instrument concepts were developed for pneumatic, test stand, machinery manufacture, sterile and chemical process applications. Their primary difference is the construction of the sensors, dependent on whether speed, flexibility or chemical resistance is required.

Instruments for Processes

Rugged, universal instrument designs for process applications are available with Sensyflow VT-S and iG. All designs are installed in the process using special pipe fittings, which assure a defined and reproducible installation condition.

- Sensyflow VT-S is a compact instrument, which directly provides a flowrate proportional 0/4…20 mA-Signal from the sensor head.
- The digital Sensyflow iG is available with PROFIBUS DPV1 or Analog/HART-Communication. Up to 4 curves the different gases or pipe diameters can be entered.

In the hygienic branches (food and beverage industries) special materials and a matched sensor design make the instrument CIP- and SIP capable.

Typical Applications

- Gas flow measurements in the chemical and process industries
- Compressed air balancing
- Gas burner control
- Digester gas and aeration measurements in sewage treatment plants
- Gas measurements in an air separation system
- Hydrogen measurements in processes
- Carbonization in breweries and soft drink production

Fig. 2-113: Instrument Designs for the Different Industries

Specifications (Sensyflow IG and VT-Series):

Diameter:	From DN 25 [1”], also for non-round pipes
Flow Range:	to 1...150
Temperature range:	-25...+300 °C
Pressure range:	0.5...40 bar absolute
Accuracy:	≤ 1 % of rate
Typical; pressure drop:	1 mbar
Response time:	0.5 s
Output signal:	0/4...20 mA; pulse; frequency; binary
Communication:	HART, PROFIBUS DPV1
Supply power:	230; 110; 24 V AC; 24 V DC
Materials:	Stainless steel; Hastelloy; Ceramic
Ex-Protection:	Zone 0

Instruments for Flowrate Test Stands

For test stand applications, e. g. intake air measurements for combustion motors, include a high accuracy requirement over a wide flow range with a fast response time being essential. Only then can the dynamic processes be depicted correctly with sufficient resolution. Sensyflow P has been designed specifically for such applications.

Fig. 2-114: Thermal Mass Flowmeter for Test Stands –Sensyflow P

Specifications (Sensyflow P):

Diameter:	DN 25…DN 200 [1”...8”]
Flow Range:	1:40
Temperature range:	-25...80 °C
Pressure range:	2.5 bar absolute
Accuracy:	≤ 1% of rate
Typical pressure drop:	10 mbar
Response time:	T_{63} ~ 12 ms
Output signal:	0/4...20 mA; 0...10 V; RS 232, ASAM-GDI
Supply power:	230/110 V AC

Compressed Air Regulation

In paint robots the ratio of paint to atomization air for color application control must be controlled with a very fast response time. The Sensyflow eco2 conceived for such applications is a compact unit incorporating a complete electronic package. It as also suitable for all compressed air applications to DN 25 [1”] as a result of its universal connection concept.

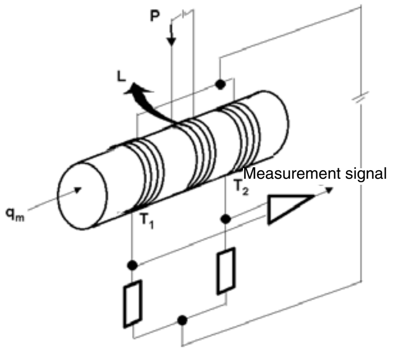
Fig. 2-115: Thermal Mass flowmeter for Compressed Air – Sensyflow eco 2

Specifications (Sensyflow eco 2):

Diameter:	to DN 25 [1”]
Connections:	small flange, G 3/8"...1", Legris, Transair
Flow Range:	1:100
Temperature range:	0...50 °C
Pressure range:	10 (16) bar absolute
Accuracy:	≤ 3 % of rate
Typical pressure drop:	10 mbar
Response time:	T_{63} ~ 25 ms
Output signal:	0/4...20 mA; 0...5/10 V; pulse, digital, frequency, RS 232
Supply power:	24 V DC

Calorimetric or Capillary Methods

For very small pipe diameters or extremely small flowrates, which primarily exist in the gas analyses sector and in laboratories, the Calorimetric method can be used. The gas flows through a capillary which is heated with a constant power P.



q_m: Mass flowrate

P: Constant electric heating power

L: Thermal dissipation power

Fig. 2-116: Heating or Capillary Method, Operating Principle

$$q_m = \frac{(P - L) \cdot C}{c_p \cdot (T_2 - T_1)}$$

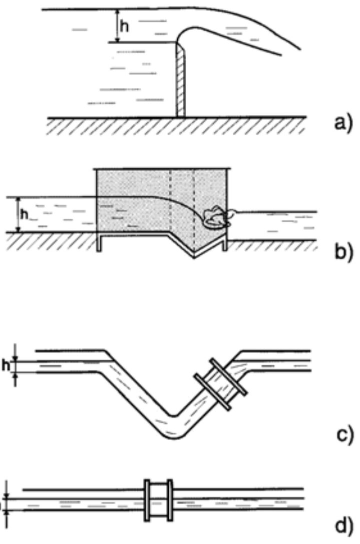
The mass flowrate can be calculated from the resultant temperature difference, the heat loss of the system and an instrument constant C.

Specifications	
Diameter:	to DN 25 [1”]
Flow range:	1...50
Max. allow. temperature:	70 °C
Max. allow. pressure:	100 bar
Accuracy:	< 1 % of rate
Response time:	1...5 s
Output signal:	0/4...20; 0...10 V; digital
Supply power:	24 V DC
Materials:	Aluminium, stainless steel; plastic

2.3 Flow in Open Channels and Free Surface Pipelines

2.3.1 Flow Metering in Open Channels

Open channels are found extensively in the water and waste water industries. They are characterized by one surface bounded by the atmosphere. The same applies for free surface flows in pipelines which are often found in the process industries.



Two methods are most often used:

1) An indirect method using a height measurement with a metering weir (a)

and a Venturi flume (b).

2) A velocity measurement in a free surface flowrate with an electromagnetic meter either as a full meter in an invert (c) or as a

flowmeter for partial full pipelines (d).

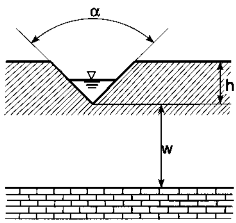
Fig. 2-117: Flowrate Measurement Methods

Metering Weir

For large flows and small slopes flow overflow are suitable for metering when the water can be dammed and when the flow stream is completely ventilated. Ventilation means that air has free access under the overflow so that the stream will separate and fall freely. Metering weirs consist of thin wall plates with sharp edges placed perpendicular to the flow stream. Various shapes are used as a function of the application conditions. For smaller flowrates a **V-notch weir** is used.

Based on Equation (1.27) the flow through a **V-notch weir** is

$$q_v = \frac{8}{15} \cdot \mu \cdot \tan\frac{\alpha}{2}\sqrt{g \cdot h} \cdot h^{5/2} \qquad (2.37)$$



The discharge coefficient μ is a function of the ratio of the overflow height h to the weir height w.

The value can be determined using a complicated calculation procedure. Fig. 2-119 shows the μ values in curve form.

Fig. 2-118: Thomson V-Notch Weir

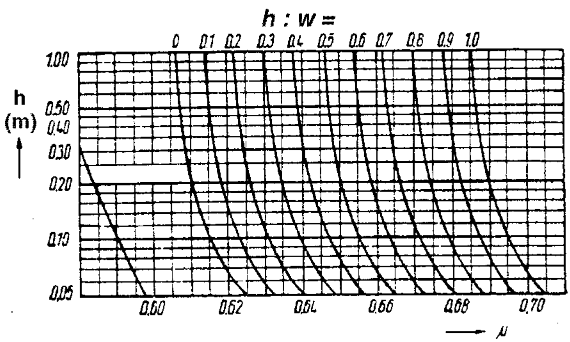


Fig. 2-119: Discharge Coefficient μ for a V-Notch Weir per Rehbock and Thomson

V-notch weirs are suitable for flowrates between 2 and 100 l/s. By paralleling a number of V-notch weirs a reasonable arrangement can be designed for higher flowrates.

The flow range for good edge conditions is 1 : 100.

For very large flowrates the **Rectangular weir** is used with the disadvantage of its limited accuracy in the lower flow ranges.

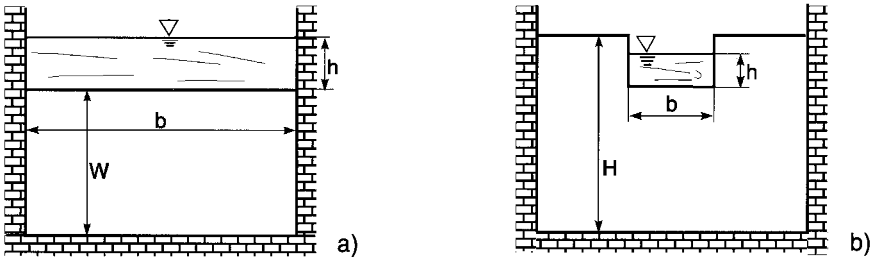


Fig. 2-120: Rectangular Weir without (a) and with (b) Side Contraction

The basis for the calculations is Equation (1.27). For rectangular weirs without side contractions (Fig. 2-120a) applies:

$$q_V = \frac{2}{3}\mu \cdot b \cdot \sqrt{2g} \cdot h^{3/2} \qquad (2.38)$$

where the discharge coefficient is μ and $h_e = h + 0.0011$ (m)

$$\mu = 0{,}602 + 0{,}083 \cdot \frac{h}{w}$$

for

$$w \geq 0{,}3 \text{ m}$$

$$\frac{h}{w} \leq 1$$

$$0{,}025 \leq h \leq 0{,}8 \text{ m}$$

Because of the side containment of the overflow stream in a rectangular weir without contractions the air supply can become restricted. Therefore ventilation must be assured.

For side contractions the basic equation is applied

$$q_v = \frac{2}{3}\mu \cdot b \cdot \sqrt{2g} \cdot h^{3/2}$$

for a coefficient

$$\mu = 0{,}6161 - \left(0{,}1 \cdot \frac{h}{b}\right)$$

for $0{,}075 \leq h \leq 0{,}6\,m$

$$b \leq 2 \cdot h_{max} \leq 0{,}3\ m$$

The flow range for the rectangular weir is about 1 : 20. The measurement of the height h is made approximately 4 x h upstream of the weir. The water velocity should not exceed 6 cm/s upstream of the weir. And naturally the water level after the weir must be low enough to permit an overflow; therefore the height between the lower edge of the opening must be at least 5 cm above the lower water level.

Venturi Flume Meter

For flow metering with metering weirs the water must be dammed which may cause changes in the inflow region under certain conditions. These restrictions do not apply to a Venturi flume meter.

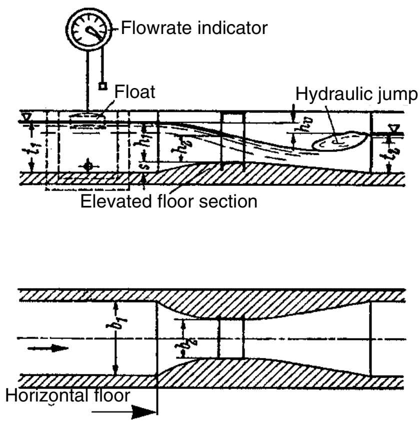


Fig. 2-121: Venturi Flume

Therefore it can react to the smallest flowrates. As with the Venturi nozzle the constriction of the flow cross sectional area results in an energy conversion, which accelerates the fluid in the region of the constriction. The constrictions are usually at the sides; there are some however with elevated floor sections.

Calculations for the rectangular Venturi flume using Equation (1.27):

$$q_v = \frac{2}{3}\mu \cdot b_2 \cdot \sqrt{2g} \cdot h^{3/2}$$

The water level upstream of the flume inlet (headwater) is quiet, the water is in the subcritical regime. This occurs automatically because the water is dammed causing the flow velocity v to decrease resulting in subcritical flow conditions.

The acceleration of the water in the constricted region must bring the water to a supercritical state, so that the tailwater conditions do not have an effect on the flow level ahead of the constriction. Only when this condition is assured will a unique relationship exist between the level of the headwater and the flowrate. Subsequently, a subcritical flow state may be reached again after the channel expansion characterized by a hydraulic jump and a standing wave. A backflow must be avoided, because it influences the operation of the measurement system.

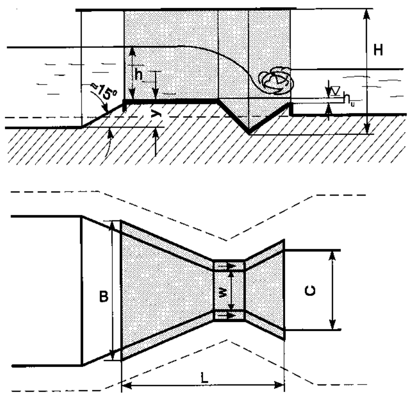


Fig. 2-122: Parshall Venturi Flume

Parshall Venturi Flume

The Venturi flume supplied by **ABB** follows the design of Parshall with the added feature that, in addition to the side restrictions, a step in the bottom assures the transition from subcritical to supercritical flow. The channel, made of glass fiber reinforced polyester, is available in standardized sizes. The user need only to install it in the existing channel.

Because of the shape of this Venturi flume, the exponent of h is changed slightly in Equation (1.27); the simplified equation is:

$$q_v = k \cdot h^n \qquad (2.39)$$

The geometric design and determination of the flow ranges have been established using the dimensionless values k and n so that checks of the fixed prescribed flow ranges are unnecessary.

Type	Constriction [mm]	Flowrate max., [m^3/h]	Dammed Hgt. max., [mm]	Dimensions [mm]		
				Length L	Height H	Width B
W 45	45	50	260	480	450	280
W 75	75	190	457	915	667	390
W 150	150	395	457	1524	724	527
W 225	225	900	609	1625	875	705
W 300	300	1640	762	2867	1143	974
W 450	450	2510	762	2943	1143	1155
W 600	600	3380	762	3020	1143	1336
W 900	900	5140	762	3170	1143	1701
W 1200	1200	6920	762	3318	1143	2067
W 1500	1500	8730	762	3464	1154	2432
W 1800	1800	10550	762	3617	1154	2797
W 2100	2100	12374	762	3765	1154	3162
W 2400	2400	13990	762	3915	1154	3514

Tbl. 2-8: Flow Ranges and Dimensions for the Parshall Venturi Flume

The meter should be located in a section where the cross sections and the slopes are constant and where the slope preferably should be between 1‰ and 2‰. The disturbance free conditioning section ahead of the Venturi flume should have a length of 10 to 20 times the flume width B (at least 2 m) and a downstream length 10 x B (at least 1 m). The height measurement is made at a location approx. 3 x h upstream of the beginning of the Venturi flume. Backflow from the tailwater is tolerated to a limited degree in a Parshall Venturi flume, and the ratio of the tailwater height h_u to the headwater height h is between 0.6 and 0.7, dependent on the height of the Venturi flume.

Meter Primary for Channel Meters

After the metering weirs and Venturi flumes have been installed, which provide defined relations between the measurable values and the flowrate, a device is still needed with which the liquid level can be measured and converted to flowrate proportional values. The headwater level h can be measured directly or indirectly.

Direct measurements can be made using
a float measurement,

Indirect measurements can be made using
a pressure converter to measure the hydrostatic pressure
an echo sounder to measure the level without contact
a bubbler to measure the hydrostatic pressure.

Float Measurement

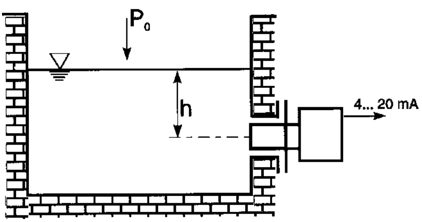
The water level is sampled by a float whose elevation is mechanically transmitted to a nonlinear scale or is electrically linearized and converted to a standardized output signal. Contamination, fouling, mechanical abrasion, and frost can affect the float and transmitting element, and since these affect the flow profile they are responsible for errors. Possibly the float will have to be installed in a separate float chamber. This results in increased maintenance expenditures.

These are the reasons that a float measurement is seldom used in these applications.

Hydrostatic Pressure Measurement

The hydrostatic pressure is the force exerted by a column of water above a reference point. The measured pressure is proportional to the height.

$$p = h \cdot \rho \cdot g + p_0 \quad (2.40)$$



The reference point must lie below the height of minimum water level.

Fig. 2-123: Pressure Measurement

In a Venturi flume it is possible to integrate the measurement location in the floor of the flume. Fig. 2-123 shows a specially designed electrical converter for installation in a side wall.

The converter (Fig. 2-124) includes a tube with a membrane which is firmly attached to the channel wall. An oil fill is used to transmit the pressure at the membrane to a capacitive metering cell where a 0/4 … 20 mA current output signal is produced.

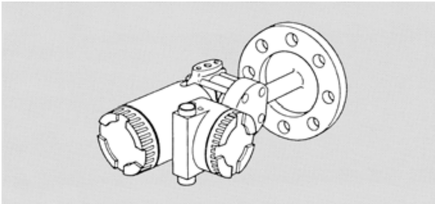


Fig. 2-124: Electrical Converter for Fluid Levels Type DHE

The metering cell operates as a differential pressure meter in the sense that the minus side is open to atmospheric pressure p_o. This pressure p_o is applied to both sides of the membrane and is therefore self cancelling. The zero for converters installed in the side wall can be set for the beginning flow measurement range based on the flume floor. Naturally, communication between this instrument and modern control systems can be made over a data link or a Fieldbus. The measurement ranges lie between 32 … 3200 mbar and 5 … 50 bar.

The membrane attached to the inner wall of the flume is unaffected by deposits or contamination.

Bubbler Method

A probe is inserted into the fluid either from the side or from the bottom and air or an inert gas is injected into the flume; the air bubbles to the top, thus the name bubbler method.

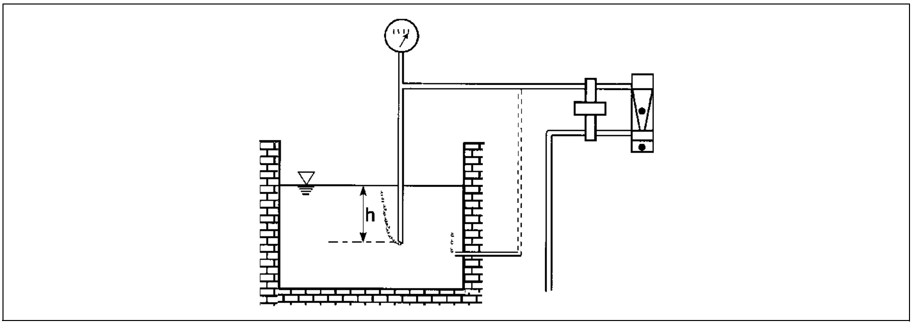


Fig. 2-125: Bubbler Method

For injecting the gas a Purgemeter type 10A6100 with needle valve and differential pressure regulator is used. Beyond the regulator, which acts as a restriction, a pressure exists in the probe which is the same as the hydrostatic pressure at the end of the probe. The needle valve is used to set the bubble rate and the differential pressure regulator to maintain a constant flowrate. A pressure meter or pressure converter processes the level proportional pressure signal.

The advantage of the bubbler method lies in the fact that the sensitive measurement elements are not in contact with the fluid and are therefore not subjected to chemical or mechanical attack. Additionally, the cost for providing explosion proof protection is minimal.

Echolot

The most successful water level measurement method is the noncontacting echo technique. A sound signal is transmitted from a sound generator located above the water level which, after it is reflected from the water surface, is received. The distance between the transmitter/receiver and the water level is calculated from transit time of the sound wave . The sound velocity however is a function of the composition of the elements in the sound path, including temperature and humidity which can vary. A reference path, which is precisely defined mechanically, can be used to compensate for these disturbance factors.

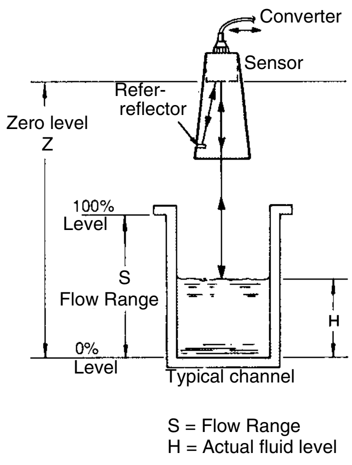


Fig. 2-126: Echolot Principle

A cone is installed at the sensor to protect against external influences, e.g. snow fall and to shield against undesirable wall reflections.

The converter (Model 50US3100) which is used includes a microprocessor which includes stored curves for different flume meters which are used to calculate the flow-rate proportional 0/4 ... 20 mA output signal. Naturally such converters include self monitoring functions, alarm contacts and flow totalizers.

2.3.2 Flowrate Measurements in Free Surface Pipelines

There are closed pipeline systems which are not continuously filled with fluid but run partially full because their size had to be selected to accommodate sporadic high flows. The most important example is in the waste water lines, in which the flow at night is small, somewhat more during the day, but is extremely high after a rain storm. A metering instrument is required which provides accurate measurement values under all these conditions.

The solids containing waste water prevents the installation of devices projecting into the pipeline. Therefore the ideal metering instrument is the Electromagnetic flowmeter. With one minor disadvantage: the measurement signal is the fluid velocity. Only after multiplying by the cross sectional area A is the desired flowrate available $q_v = v \cdot A$. Since A, as noted above, is constantly changing the are two possible solutions for the measurement; either arrange the pipeline so that it always runs full or install the Parti-MAG Electromagnetic flowmeter specifically designed for these applications.

Electromagnetic Flowmeter in an Invert

An invert can be used (Fig. 2-127) to assure that the pipe always runs full and a correct measurement can be made. An argument against the invert is the danger that solids will be deposited especially in waste water applications.

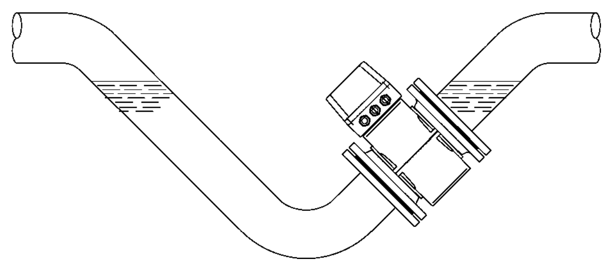


Fig. 2-127: Electromagnetic Flowmeter in an Invert

The friction force of flowing water (drag), which increases with increasing flowrate, is often underestimated. Deposits are flushed from the invert when the flow is high, and it can be speculated, that the water may sometimes be dammed ahead of the invert for short periods of time at the lower flowrates. Another possibility is to install a separate line for flushing.

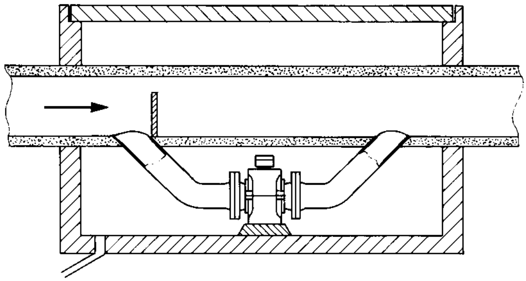


Fig. 2-128: Invert with a High Water Bypass Line

Higher velocities in the invert prevent deposits. The pipeline is designed with a cross sectional area that during periods of high water – rain storm – is actually undersized.

A solution to this problem is to install a bypass invert and install a weir in the main pipeline (Fig. 2-120) which has the disadvantage, that during high water flows, some of the water will not be metered. In contrast to the **Parti-MAG II** Electromagnetic flowmeter, the invert method has the advantage that more accurate meters can be used for partially full conditions. The cost advantage of smaller meters is usually offset by the higher construction costs.

Parti-MAG II Electromagnetic Flowmeters for Partially Full Pipelines

It is known that the Electromagnetic flowmeters described in Chapter 2.2.3 provide a flow velocity v proportional signal so that the flowrate q_v can be calculated by multiplying this value by the constant cross sectional area A. The instrument requires that in the metering section, the pipe cross section remain full. This requirement cannot be fulfilled for free surface flows. Therefore the standard Electromagnetic flowmeter cannot meter accurately under conditions where the fill level must be included in the calculation. This is the fundamental idea behind the design of the **PARTI-MAG II**.

For the determination of two unknown values the laws of algebra state that two independent equations, or in this case, two measurement values are required.

This is accomplished in the PARTI-MAG II as follows:

The flow to be measured flow through meter pipe insulated with a liner. Using externally mounted magnet coils at the top and bottom, a magnetic field is generated in the meter pipe cross section (Fig. 2-129).

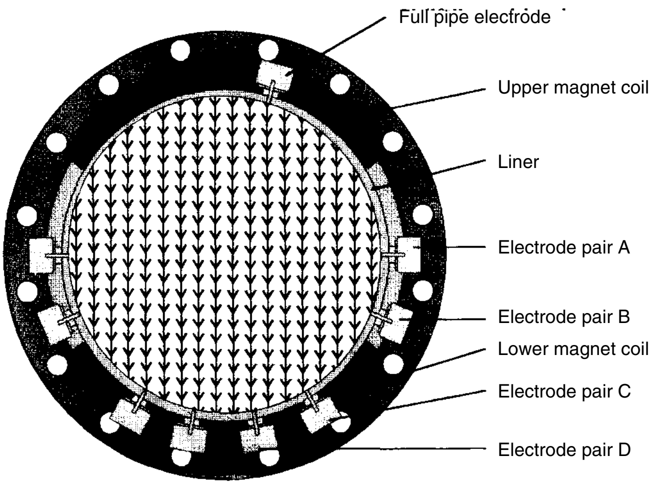


Fig. 2-129: Design of the Flowmeter Primary

As shown in Fig. 2-129, the PARTI-MAG II Electromagnetic flowmeter contains four pairs of electrodes, installed at different „levels". To measure the voltage induced in the flowing fluid the optimally placed electrode pair A, B or C, based on the fill level, is used. In this way flowrates from a fill level of 10 % all the way up to a full pipe condition can be measured. This corresponds to 5 % of the cross sectional flow area.

The electrodes are installed perpendicular to the flow direction and to the magnetic field. The induced voltages are measured at these electrodes. When the pipe is full this voltage, as in the usual EMF, is a „direct measure" for the average flow velocity.

In contrast, in a partially full pipeline the voltage measured at the electrodes must be corrected using a factor. It is selected from a curve stored in the converter.

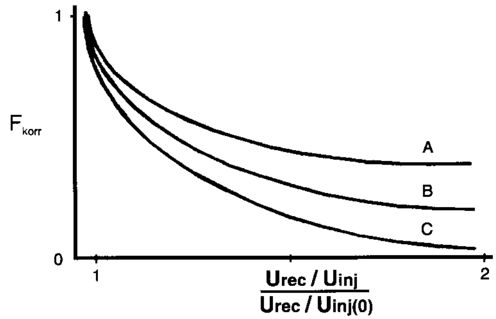


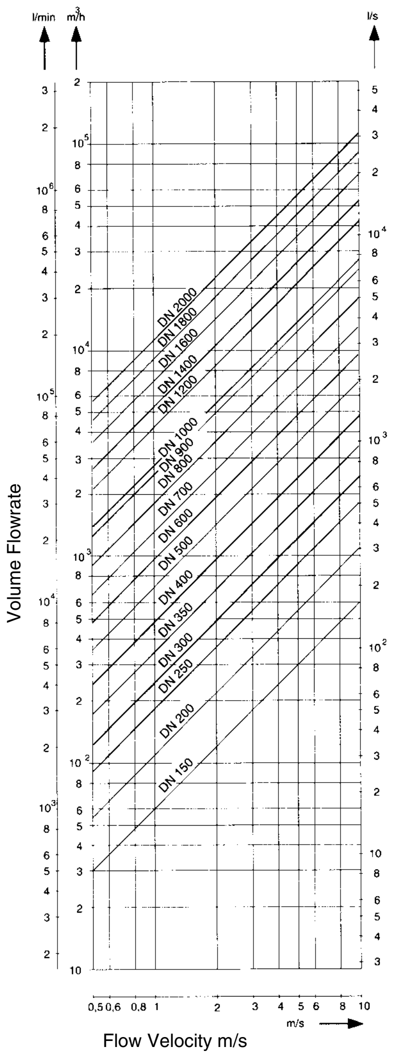
Fig. 2-130: Correction Curves for Flow Velocity Proportional Voltages Measured at Electrode Pairs A, B, C

The correction curves depicted in Fig. 2-130 show the relationship between two voltages U_{rec}/ U_{inj}.

With the Parti-MAG Electromagnetic flowmeter an instrument has been designed that combines the advantages of the system described earlier and eliminates the disadvantages when the pipeline is partially full. There are no additional pressure drops, costly constructions are eliminated, and the smallest flowrates at low levels or large flowrates when the pipeline is full can be metered.

Fig. 2-131: PARTI-MAG II Electromagnetic Flowmeter Primary and Converter

The quality of the measurement is a function of the velocity profile in the filled state. An accuracy at a full pipeline condition is ± 1.0% of rate; at partially full conditions an accuracy of 3 to 5 % of rate can be achieved down to a minimum fill level of 10 % D.



Sizing

The flowmeter size can be determined using the Nomograph Fig. 2-132 based on the maximum flowrate under a full meter pipe condition utilizing the actual flow velocity.

Fig. 2-132: Flowrate as a Function of the Meter Size

A special case is the sizing for sloped water and waste water pipelines. In this case the flow velocity is determined from the friction and the slope of the pipeline. The velocity can be calculated by using the friction coefficient. According to **Nikuradse** the following applies for a rough wall pipe with turbulent flow

$$v = \sqrt{\frac{h_v}{l} \cdot \frac{2g \cdot d}{\lambda}} \qquad (2.42)$$

with the pipe diameter d in mm and the roughness k in mm. For steel or cast iron pipes an approximation can be calculated using k = 1. To calculate the flow velocity the **Darcy-Weisbach** equation is used and after conversion becomes:

$$\lambda = \frac{1}{\left(2 \lg\frac{d}{k} + 1{,}14\right)^2} \qquad (2.41)$$

with the ratio h_v/l for the slope. The value v determined for the full pipe can be used for comparison with the flowrate in the nomograph (Fig. 2-117). As already mentioned, the accuracy is a function of the uniformity of the flow profile, especially when the pipe is partially full.

This condition can only be satisfied in a long pipeline with constant roughness when flow profile disturbances in the pipeline, inlet and outlet connections, deposits, and other wave and vortex producing influences are located sufficiently far from the metering section. An ideal situation is one in which uniform flow exists. This fact is the basis for the recommendation that conditioning sections be installed with a length of 5 x D upstream and 3 x DN downstream of the metering section.

Specifications:

Model:	MAG-XP
Magnetic field excitation:	pulse DC magnetic field
Signal measurement:	galvanic
Minimum conductivity:	50 μS/cm

Sizes

Liner Material	Electrode Material
Hard, soft rubber	SS No. 1.4571/316Ti Hastelloy C or B
PTFE/PFA	Hastelloy C Hastelloy B, Ti, Ta, Pt-Ir

Electrode Materials

Liner Material	DN	PN
Hard rubber	150...2000 [6”...78”]	6...40
Soft rubber	150...2000 [6”...78”]	6...40
PTFE	150... 800 [6”...32”]	10...40
PFA	150... 250 [6”...10”]	10...40

Specifications:

Process connections	Flanges	
Ex-Protection	Zone 1	
Flow range end value	0.5...10 m/s	
Max. accuracy	Full:	1 % of rate
	Partially full:	3 to 5 % of rate
Output	0/4...20 mA, load < 1000 Ω	
	0/2...10 mA, load < 2000 Ω	
Pulse output	active 24 V DC	
	passive (optocoupler) 5...25 V, 5...200 mA	
Data link	RS 232, RS 485	
Supply power	24 V, 115 V, 230 V, 50/60 Hz	

3 Regulations and Requirements for Quality and Safety

3.1 Quality Assurance

In order for a company to be financially viable it must operate in a correct market oriented manner. Therefore its highest goal must be to fulfill the requirements of it's customers. Optimal functionality and product longevity at competitive prices are expected. Product liability requires an error free manufacture and adherence to the applicable safety standards, safety regulations and the recognized rules of the technology.

In every company there were and are organizational and procedural systems with whose assistance these tasks are to be fulfilled. With the advent of the Quality Assurance System per DIN EN ISO 9000 an apparatus has been provided which is based on international regulations and which provides for constant monitoring by independent organizations.

The ABB Automation Products GmbH Factory in Göttingen, Germany received the Certification based on the Standard DIN EN ISO 9001 in 1993. A yearly audit by TÜV-CERT certifies the validity and application of these standard has been confirmed. Our Quality Assurance Manual (abbreviated QMA) which is available to everyone describes the goals, responsibilities, areas of applicability and procedures within the ABB Automation Products GmbH Factory in Göttingen Germany. There are instructions and specifications for all areas which define the interactions in order to assure a trouble free course from the initiation of a product idea all the way to delivery to customer

For the customer and company partners, the QA Certificate per DIN EN ISO 9001 denotes a high quality for our products. Under quality, we do not only understand the operation according to the specifications, service and on time shipments but also good cooperation between our customers and all our employees.

This is further attested to by being classified as qualified in accordance with Regulation KTA 1401 for the system and product based **Quality Assurance** for planning and manufacture of flowmeters for nuclear facilities by the VBG-Working Group.

The TÜV-CERT certifies the Quality Assurance per DIN ISO 9001at **ABB Automation Products**.

TÜV CERT

ZERTIFIKAT

Die TÜV CERT-Zertifizierungsstelle der TÜV NORD
Zertifizierungs- und Umweltgutachter Gesellschaft mbH
bescheinigt gemäß
TÜV CERT-Verfahren, dass das Unternehmen

ABB Automation Products GmbH
D - 37079 Göttingen

für den Geltungsbereich

Instrumententechnik in Vertrieb,
Produktion, Entwicklung und Verwaltung

ein Qualitätsmanagementsystem eingeführt hat und anwendet.

Durch ein Audit, Bericht-Nr. 937142-03
wurde der Nachweis erbracht, dass die Forderungen der

DIN EN ISO 9001 : 1994

erfüllt sind.

Dieses Zertifikat ist gültig bis Dezember 2001

Zertifikat-Registrier-Nr. QA 413

Hannover, den 7. März 2000

ZERTIFIZIERUNGS- UND
UMWELTGUTACHTER GESELLSCHAFT

TÜV CERT

CERTIFICATE

The TÜV CERT Certification Body of TÜV NORD
Zertifizierungs- und Umweltgutachter Gesellschaft mbH
certifies in accordance with TÜV CERT
procedures that

ABB Automation Products GmbH
D - 37079 Göttingen

has established and applies a quality system for

Instrumentation in Sales, Production,
Development and Administration.

An audit was performed, Report No. 937142-03

Proof has been furnished that the requirements according to

DIN EN ISO 9001 : 1994

are fulfilled.

The certificate is valid until December 2001

Certificate Registration No. QA 413

Hanover, March 7, 2000

ZERTIFIZIERUNGS- UND
UMWELTGUTACHTER GESELLSCHAFT

3.2 Protection Types per EN 60529 (Excerpts from the Standard)

The standard EN 60529 classifies the protection of electrical equipment by housings, enclosures, or the like. It defines **Protection Types** with varying degrees of protection.

The standard EN 60529 includes:

a) Protection of personnel against electric shock from parts that are energized during operation or from approach to such parts as well as protection against physical contact with moving parts within the equipment (housings) and protection of the equipment against entry of solid objects (physical contact and foreign object protection).

b) Protection of equipment against damaging entry of water (water protection)

Identification

The protection classes are designated by an abbreviated symbol, consisting of two fixed code letters IP (International Protection) followed by two code numbers which define the protection grade:

The first number indicates protection grade for the physical contact and foreign object protection grade. The second number indicates the damaging water entry protection grade.

For designating the complete abbreviated symbol (code letters and protection grade characteristic numerals) the term "Protection Class" is used.

Protection Class EN 60529- IP 4 4

Name — Protection Class
EN-Number — EN 60529-
Code letter — IP
First code number (see Tbl. 3-9) — 4
Second code number (see Tbl. 3-10) — 4

A housing with this designation is protected against penetration of foreign objects with a diameter over 1 mm and of water spray.

When the protection class of a part of the equipment, e.g. connection terminals, deviates from that of the main part, then a separate abbreviated symbol is to be provided. The lower class is to be noted first

Example: Terminals IP 00 – Housing IP 54

Protection Grades for Electric Shock and Foreign Body Protection

First Code Number	Protection Grade (Electric Shock and Foreign Body Protection)
0	No special protection
1	Protection against entry of solid objects exceeding 50 mm in size (large objects)[1]. No protection against deliberate access, e.g. by hand, but for contact with large surfaces.
2	Protection against entry of solid objects exceeding 12 mm in size (medium size objects)[1]. Protection against contact by fingers or similar objects.
3	Protection against entry of solid objects exceeding 2.5 mm in size (small objects)[1] [2]. Protection against tools, wires etc. diameter or thickness greater than 2.5 mm.
4	Protection against entry of solid objects exceeding 1.0 mm in size (granular objects)[1] [2]. Protection against tools, wires etc. diameter or thickness greater than 1.0 mm.
5	Protection against ingress of damaging dust. The entry of dust is not totally prevented but dust cannot enter in sufficient quantity to interfere with satisfactory operation. (Dust protected)[3]. Complete electric shock protection.
6	No ingress of dust (dust-tight). Complete electric shock protection

1) The ingress, of regular or irregular shaped solid objects whose dimensions in three perpendicular planes are larger than the specified diameter, is prevented for equipment in protection classes 1 to 4.

2) For protection classes 3 and 4 the application of this table falls under the jurisdiction of the responsible technical committee when drain or vent holes exist in the equipment.

3) For protection class 5 the application of this table falls under the jurisdiction of the responsible technical committee when drain or vent holes exist in the equipment.

Tbl. 3-9: Protection Grades for the First Code Number

Protection Grades for Water Protection

Second Code Number	Protection Grade (Water Protection)
0	No special protection
1	Protection against dripping water, vertically falling. It shall have no harmful effect (dripping water).
2	Protection against dripping water, vertically falling. Vertically dripping water shall have no harmful effect when the enclosure is tilted at any angle up to 15º from its normal position (slanted falling water).
3	Protection against water falling as a spray at any angle up to 60º shall have no harmful effect (spraying water).
4	Protection against water splashed against the equipment (enclosure) from any angle. It shall have no harmful effect (spraying water).
5	Protection against water projected by a nozzle against the equipment (enclosure) from any direction. It shall have no harmful effect (water jet).
6	Protection against water from heavy seas or water projected by powerful jets. Water shall not enter the equipment (enclosure) in harmful quantities (flooding).
7	Protection against water when the equipment (enclosure) is immersed in water under the defined conditions of pressure and time. Ingress of water in a harmful quantity shall not be possible (immersion).
8	The equipment (enclosure) is suitable for continuous submergence in water under conditions which shall be specified by the manufacturer (submersion).
1) Normally this protection grade will mean that the equipment is hermetically sealed. However with certain types of equipment it can mean that water can enter but only in such a manner that it produces no harmful effect.	

Tbl. 3-10: Protection Grades for the Second Code Number

3.3 Requirements for Noise Compatibility (EMC)

The metering instruments and their electronic amplifiers and computing devices are constantly becoming more efficient and more sensitive. The µ-electronics has with its digital data processing has opened up new avenues. The expanded installation spectrum unfortunately includes a gray side. Greater sensitivity also means greater susceptibility to disturbing influences.

With the advent of the European Union (EU) the various regulations in the different countries were dropped. This means that all instruments used in commerce within the union must be compliant with the valid regulations, i.e., this means that the requirements of the valid regulations are sufficient. To certify that the instruments conform they must be identified by a CE-symbol.

For the flowmeters from **ABB** at the present time EMC-Regulation 89/336/EWG is applicable. Based on this regulation, all instruments which fall thereunder are to be identified with a CE-Mark beginning as of 01 Jan. 1996. The CE-Mark in combination with a Certificate of Compliance means that the valid EN-Standards (Basic Standards EN 50081 and EN 50082) at the time are satisfied.

These basic standards in the future will be based on additional product standards, and will then have to be satisfied by the various instruments. In addition to the requirements of the EMC-Regulation there are special requirements for the chemical industry, which are defined in the NAMUR-Recommendations. Our instruments are tested in accord with the NAMUR-Recommendations, whose requirements include or exceed the basic standards.

The causes of interference are:

- variations in the supply voltage
- interruption of the supply voltage
- discharge of static electricity
- electromagnetic fields
- transient overvoltages in the form of pulse groups (bursts) on the supply lines
- transient overvoltages in the form of pulse groups (bursts) on the data, I/O. and signal lines
- transient overvoltages in the form of individual high energy pulses on the supply lines

Examples of the causes of interference signals are: electrical and electronic switches, relays, circuit breakers, frequency converters, magnetic valves, as well as atmospheric interferences such as lightning.

The interference response is evaluated by the reaction of the instrument to an interference according to three criteria:

a. No reduction in functionality
   The primary requirement for digital instruments is that they should not be affected in any manner and the primary requirement for analog instruments is that they should not be affected beyond their error limits.

b. Reduction in Functionality
   Evaluated is the effect outside of the error limits during the interference period however with self restoration, i.e. subsequent reestablishment to its original status.

c. Loss of Functionality
   Evaluated is primarily the functional failure at the onset of an interference until an automatic or manual restart occurs.

The NAMUR-Recommendation (5/93) lists the limits for the individual interference effects. The most important requirements are:

1. Line supply tolerances

AC	U_N	+10 % - 15 %
DC	U_N	+20 % - 15 %
Frequency tolerance	f_N	± 2 %

When the values are above or below the tolerance limits the instruments / systems must ensure an automatic restart or the ability to be switched to a safe setting.

2. Mains interruption

Evaluated for at least 10 interruptions

Starting Conditions	Interruption Interval	Repeat Rate	
AC (0.85 · U_N) DC (0.85 · U_N)	0...20 ms	1 s	no change in functionality
AC (0.85 · U_N) DC (0.85 · U_N)	> 20 ms	> 1 s	automatic restart or the ability to be switched to a safe setting

3. Start-up current limitation

The maximum possible amplitude of the peak start-up current spike and its transient response are to be indicated. The peak amplitude of the start up current spike shall not exceed 15 times the nominal peak current value.

4. Transient overvoltages at the instrument from the supply lines (unipolar voltage spikes)

	Supply Power	
	Not isolated from other general equipment (e.g. 230/400 V Grid) û	Isolated from other general equipment (e.g. 24-V Grid) û
Between each line	1 kV	0.5 kV
Between each line and ground	2 kV	1 kV

5. Transient overvoltages at the instrument from the supply line (pulse groups [bursts])

	û
Between each connection of the supply power and the protective ground connection	2 kV

6. Transient overvoltages at the instrument from the supply line (pulse groups [bursts])

	û
Decoupling using a capacitively coupled section	1 kV

7. Discharging static electricity

		û Contact Discharge	û Air Discharge
Direct discharge	Closed housing for all touchable parts	6 kV	8 kV
Indirect discharge	Vertical/horizontal coupling plate	6 kV	

8. Electromagnetic fields

	Voltage	Test Method
9 kHz ... 26 MHz	10 V	Circuit controlled over coupling devices to all lines
26 MHz... 80 MHz	10 V	
80 MHz...230 MHz	[10 V]	

	Field Strength	Test Method
26 MHz... 80 MHz	[10 V/m]	Antenna radiation
80 MHz...230 MHz	10 V/m	
230 MHz...500 MHz	10 V/m	
500 MHz... 1 GHz	3 V/m	

For special installations the manufacturer and user can agree to specifically adjusted requirements, usually higher requirements. Tests on instruments for these requirements in-house or by a neutral agency.

The test reports or certificates are a component of the instrument or the instrument type. An optimal insensitivity to interferences is assured to the user.

3.4 Explosion Protection

Among the many products and intermediate products in the chemical and process industries there are many which can form explosive mixtures with other products or with the oxygen in the air. Metering and control instruments which come in contact with such mixtures cannot be the source of an explosion, but must still operate effectively.

In order for an explosion to occur a number of events must occur simultaneously:

a) A sufficient degree of dispersion (degree of scattering) for mists or dust require particle sizes between 0.1 and 0.001 mm. For gases this degree is provided by nature.

b) Only when the concentration of a flammable substance in air exceeds a minimum value does the danger of an explosion exist. On the other hand there is a maximum value (a rich mixture) above which an explosion can no longer take place.

c) Naturally a sufficient amount of the mixture must be present. As little as 10 liters of an explosive mixture are considered to be dangerous.

d) An ignition source must provide sufficient energy in order to initiate the explosion.

Considering these criteria some measures to prevent an explosion inevitably come to mind:

Explosive mixtures are to be avoided, volumes are to be limited, ignition must be prevented and in an extreme situation the effects are to be confined.

These measures are considered during the design of the instruments, for example, the space in which an explosive mixture can accumulate is kept very small or in which the energy content of a possible spark source is minimized or in which the explosion is restricted to a small space.

Classification of Explosion Hazard Areas

Explosion hazard areas are divided into zones based on the probability of the existence of a hazardous atmosphere.

1. Explosion hazard areas with combustible gases, vapors or mists.

Zone 0 includes areas in which it is expected that hazardous atmospheres will exist continuously or exist for long time periods.

Zone 1 includes areas in which it is expected that hazardous atmospheres can occasionally exist.

Zone 2 includes areas in which it is expected that hazardous atmospheres will exist infrequently and then only for a short time interval.

Zone	0	1	2	Safe Area
Hazardous Explosive Atmospheres	Continuously and long term	Occasionally	Seldom and short term	Practically never

2. Explosion hazardous areas with combustible dust.

Zone 10 includes areas in which, due to dust, it is expected that hazardous atmospheres will exist continuously or exist for long time periods.

Zone 11 includes areas in which it is expected that occasionally through swirling of accumulated dust a hazardous explosive atmosphere can exist for short time intervals.

Comparison of the Installation Areas Based on Zones and Categories

	Category 1 Very High Degree of Safety		Category 2 High Degree of Safety		Category 3 Normal Degree of Safety	
Adequate Safety	Use of 2 protective measures for 2 error conditions		For frequent instrument disturbances for 1 error condition		For disturbance free operation	
Installed in	Zone 0	Zone 10 (VDE) Zone 20 (IEC)	Zone 1	Zone 21 (IEC)	Zone 2	Zone 11 (VDE) Zone 22 (IEC)
Atmospheres G = Gas; D = Dust	G	D	G	D	G	D

Temperature Classes

To evaluate the danger from combustible materials there exists a classification according to their ignition temperatures and according to their ignition penetration characteristics. The **ignition temperature** is the lowest temperature at which a heated probe will initiate ignition in a combustible mixture (ignition sources are e.g. hot surfaces, flames, electrically or mechanically induced sparks, light rays, shock waves, chemical reactions).

Therefore gases / vapors are divided into temperature classes and the equipment (in this case the metering instruments) designed accordingly. The maximum surface temperature of the equipment must always remain below the ignition temperature of the hazardous mixture.

Ignition Temperature (°C)	Temperature Class
> 450	T1
> 300	T2
> 200	T3
> 135	T4
> 100	T5
> 85	T6

Explosion Groups

The ability to ignite and the ignition penetration characteristics of a hazardous mixture are material properties. The details are particularly important for the design of the equipment. For intrinsically safe electrical equipment the ignition energy is the criterion for ignitability. The smaller the required ignition energy the more hazardous the mixture. The penetration capability provides information relative to the design of the flame path widths in pressure tight encapsulated equipment.

Explosion Group	Ignition Energy (EN 50020)	Test Gas	Range
I	< 260μ J	Methane	Mining protection
II A	< 160μ J	Propane	
II B	< 60μ J	Ethylene	Explosion protection
II C	< 20μ J	Hydrogen	

Gases and vapors are classified according to these criteria. The following table lists the classification of various materials. The equipment used for these materials must be certified accordingly.

	T1	T2	T3	T4	T5	T6
I	Methane					
II A	Acetic acid Acetone Ammonia Carbon dioxide Ethane Ethyl acetate Gasoline (pure) Methanol Propane Toluene	Ethyl alcohol i-Amylacetate n-butane n-butyl	Aircraft Fuel Diesel fuel Gasoline Heating oil Jet fuel n-Hexane	Acetalhyd. Ethyl- ether		
II B	City gas (Illuminating-gas)	Ethylene				
II C	Hydrogen	Acetylene				Carbon-disulfide Ethyl nitrate

Ignition Types

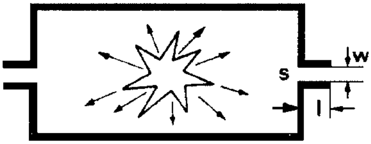
The explosion protection of electrical equipment can be achieved through use of the following defined **Ignition Types**.

Ignition Types Pressure Tight Encapsulation d (EN50018)

Basic Principle:

Parts which can ignite an explosive mixture are contained in an enclosure which itself will contain the pressure of an explosion of a hazardous mixture occurring in its interior and prevent the explosion from reaching the atmosphere surrounding the enclosure.

Schematic representation



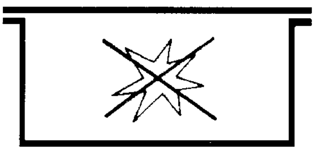
Applications:
Switch gear devices, command and indicator instruments, controllers, motors, transformers, lamps and other spark producing parts.

Ignition Types Increased Safety e (EN50019)

Basic Principle:

In this case measures are incorporated to increase the degree of safety of an instrument by preventing prohibited higher temperatures and the generation of sparks and arcs inside or outside of the electrical equipment which during normal operation will not occur.

Schematic representation



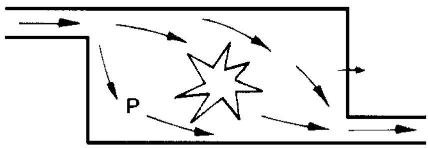
Applications:
Terminals and connection boxes, control housings for installation of Ex-elements (which are protected under another **Ignition Class**), squirrel cage motors, lamps.

Ignition Types Pressurized Encapsulation p (EN50016)

Basic Principle:

The entry of a explosive atmosphere into the housing of electrical equipment is prevented by filling the interior of the housing with an ignition protecting gas (air, inert or other appropriate gas) under a pressure greater than that of the surrounding atmosphere. The over pressure is maintained with or without a gas supply.

Schematic representation



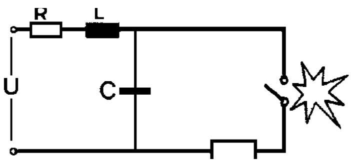
Applications:
As above, especially for large instruments or entire rooms.

Ignition Types Intrinsic Safety i (EN50020)

Basic Principle:

The equipment installed in the hazardous area contains only intrinsically safe circuits. A circuit is intrinsically safe when sparks or thermal effects cannot occur under defined test conditions (which include normal operation and certain malfunctions) which could ignite a particular explosive atmosphere.

Schematic representation



Applications:
Measurement and control technology, communication technology

There are different intrinsically safe classifications, namely ia and ib.

ia is for use in Zone 0.
The instrument must be so designed that in the event of a failure or under every possible combination of two failure modes an ignition is not possible.

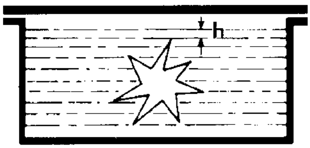
ib is for use in Zone 1.
The instrument must be so designed that in the event of a failure an ignition is not possible.

Ignition Types Oil Filled O (EN50015)

Basic Principle:

Electrical equipment or parts of electrical equipment are made safe by surrounding them with oil so that an explosive atmosphere on the surface or outside of the housing will not be ignited.

Schematic representation



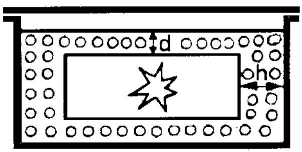
Applications:
Transformers (used very seldom)

Ignition Types Sand Encapsulation q (EN50017)

Basic Principle:

The housing of electrical equipment is filled with sand or some other fine grained material so that under the designated operating conditions an arc occurring within the housing will not ignite an explosive atmosphere external to it. Ignition may not occur either by a flame or by an increased temperature on the surface of the housing.

Schematic representation



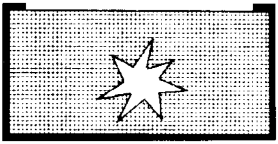
Applications:
Transformers, condensers, heater wire connection boxes

Ignition Types Potted Encapsulation m (EN50028)

Basic Principle:

Parts which could ignite an explosive atmosphere are encapsulated in a casting material which is sufficiently resistant to the environment so that the explosive atmosphere cannot be ignited by sparks or heating within the encapsulation.

Schematic representation



Applications:
Low power switch gear devices, command and annunciator instruments, indicating instruments, sensors.

Explosion Protected Instruments in Free Commerce

A prerequisite for commerce within the European Union is controlled by the EU-Directives. The Directive 94/9/EG (ATEX 100a) has been in effect since 1996.

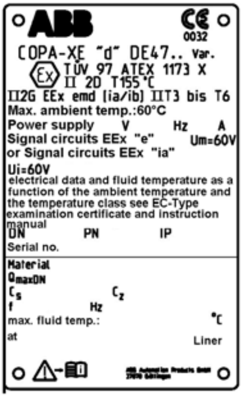
The basis for the harmonized standards EN 50014...EN 50020 and EN 50028 is the Directive 76/117/EWG which will be replaced by the latest revisions through use of ATEX 100a. Additionally, ATEX 100a requires a conformity evaluation of the Quality Assurance of the manufacturer, which includes special requirements for explosion protected equipment during development, design and manufacturing.

Instruments, which are tested in accordance with ATEX 100a and submitted for an EU-Type Examination Certificate, will be also identified by a CE-Mark. The Identification Number of the agency which conducted the Quality Assurance evaluation will be included.

Comparison of the Differences Between the Old and New Ex-Directives

Directive	**Directive NEW: 94/9/EWG ATEX100a**
Valid and usable until 30.06.2003 i.e., all issued approvals will become invalid (instruments can continue to be operated).	Valid and usable since 01. 03. 1996
Appointed agencies in Germany PTB, DMT	Appointed agencies in Germany e.g. PTB, DMT, TÜV-Hannover, BAM-Berlin
Test center issues Certificate of Compliance	Test center issues EU-Type Examination Certificate Manufacturer issues Certificate of Compliance
Test Certificate No.: E.g., PTB No. Ex-95.D.2154 X Identification:	Test Certificate No.: E.g., TÜV 97 ATEX 1153 Identification: with no. of the appointed agency that evaluated the QA-system (0032 for TÜV-Hannover)
Standards: EN 50014 following, old issues	Standards: EN 50014 ff, old issues
Group I —> Mining Mine gas Zone 0 and Dust Zone 10 Mine gas Zone 1 and Dust Zone 11	Instrument Group I —> Mining Category M1 Category M2
Group II —> expl. area Gas Zone 0 Gas Zone 1 Gas Zone 2 Dust Zone 10 Dust Zone 11	Group II —> expl. area Category 1 and G for Gas, vapors, mists Category 2 and G for Gas, vapors, mists Category 3 and G for Gas, vapors, mists Category 1 and D for Dust Category 2 and D for Dust
Example: EEx ib IIC T4 (for use in Zone 1)	Example: II 2G EEx ib IIC T4 Specification and safety relevant sections in the Operation Manual must also be available in the language of the user.

Example of an Ex-Protection Classification and Identifications



Test Agency — Year of approval — Directive 94/9 EWG — running number — special conditions

T Ü V 9 7 A T E X 1 1 7 3 X
(Test Certificate No. from TÜV)

II 2 G EEx emd [ib] II C T3 to T6

- T3 to T6: Temperature Class
- II C: Explosion Group
- emd [ib]: **Ignition Types**
  - d: Pressure Tight Encapsulation
  - e: Increased Safety
  - m: Potted Encapsulation
  - ib: Intrinsic Safety, also when an error is corrected
- EEx: CENELEC Identification for the Ex-Protection

II = Explosion Group
2 = Category 2
G = Gas, vapors, mists

3.5 Corrosion

Corrosion is defined as the destruction of materials through chemical reactions. Generally the concept is limited to a change of the structure of a metal due to an aqueous solution. This is electrolytic corrosion for which the generation of rust is a prime example.

Metals with their free electrons are good electrical conductors. The conductivity of corrosive aqueous solutions is small, the current transport is ionic. During corrosion a positive current flows in the liquid. This causes the positively charged metallic ions to migrate into the liquid. The intensity of this process is a function of the ionic mobility and it increases with increasing temperature and decreases with concentration increases. Also voltage differentials augment the corrosion. That is why the non-noble metals, such as aluminum and iron, which are grouped at the negative end of the electromotive series, are severely attacked. Corrosion problems can be avoided by utilizing noble metals.

Organic chemicals, plastics also show destructive characteristics when they come in contact with aqueous solutions. In this case it is primarily substitution processes which alter the material. Substitution is the replacement of an atom or atomic group by another atom or atomic group. A material with new chemical and physical characteristics is produced. The resistance to the solution can worsen. In order to evaluate the majority of organic materials it is necessary to rely on the experiences of the producers which are summarized in corrosion resistance tables.

The behavior of the materials used by **ABB** is listed in the Corrosion Resistance table (see Chapter 7) for the most important chemical products.

3.6 Data Transmission

The primary task of the converter connected to a primary is to produce an output signal which is proportional to the measured value and which can be used by other secondary instruments connected to the converter (indicators, recorders, controllers). Standardized output signals are essential because secondary instruments are universally installed.

With the advent of the so-called intelligent converter, electrical data systems have forged to the forefront. Analog information transmission is still preferred but with the increasing number of signals transmitted the costs per signal is increasing.

Digital technology offers appreciable advantages, e.g.:

a. the number of electrical interconnections decreases dramatically because every output does not require is own leads.

b. communication is not limited to the transmission of measurement signals. The data exchange occurs in both directions which means that the access and setting of parameters can be effected from the outside. An error diagnosis is possible at any time.

c. the digitally operating process computers do not require an A/D converter, which can cause transmission errors.

d. the complete system can be expanded without great effort.

e. insensitive to external interferences on the communication lines.

3.6.1 Standardized Pneumatic Signal

Instruments and systems using an air supply are not used very often anymore. The reason for their decline is their limited capabilities when compared to modern digital technology coupled with the large expenses incurred in providing the air supply and costly installations. The standardized signal is the pressure range between 0.2 and 1 bar.

3.6.2 Standardized Electrical Analog Signal

The most common standardized electrical signal is a direct current of 0 … 20 mA or 4 … 20 mA. It is called an impressed direct current because it is independent of the electrical resistance up to a specific maximum load. The maximum load for flowrate converters is 750 or 1000 ohms, which means that the total resistance in the secondary circuit can lie between 0 and 1000 ohms. The 0 … 10 or 2 … 10 mA signals are used less frequently.

3.6.3 Contact Outputs

There are two types of output contacts. The continuous contact is used for status signals with which an alarm or limit condition can be indicated.

The alarm contact should be activated when dangerous conditions exist, e.g. during instrument failure or for critical measurement values. The limit contact is of interest in a control sense since its status could indicate possible changes in the process trends. Examples are the empty pipe detector contact, the signal for flow direction and the max- min- conditions.

The pulse output has a completely different function. Short term pulses transmit data, in fact, volume proportional signals which can be integrated by a totalizer. In this manner a volume signal is generated from the flowrate. The totalizer indicates the total amount that has flowed through the meter during a specific time interval.

Electrically there are a number of methods to design an output contact. Passive methods are a relay or optocoupler contact. Current and voltage pulses are known as active outputs.

3.6.4 Data Link

The data communication with a process computer is in digital form. The data link has the task to convert all the signals so that a faultless communication is possible. All command characters and values are transmitted as data words. Their structure and timing are determined by a transmission protocol which is formatted by the manufacturer.

ABB Automation Products utilizes the ASCII Code. A communication is always initiated from a personal computer (PC), a stored programmable controller (SPC) or from the lead computer set up as the master, which means that the metering instrument only transmits data upon request.

The serial **data link RS 232 C** and **data link V.24** operate at a signal level of ± 15 V rectangular.

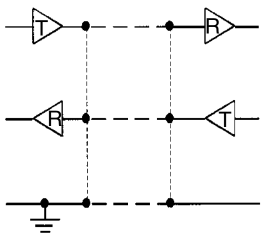


Fig. 3-133: RS 232C: R = Receiver T = Transmitter

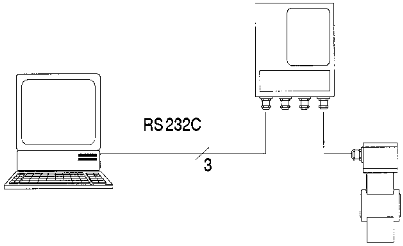


Fig. 3-134: Installation with Data Link RS 232 C

The data link with three connecting leads functions only in a direct connection with a PC or other device. The cable length is limited to 15 m because of the asymmetrical square wave and its sensitivity to interferences.

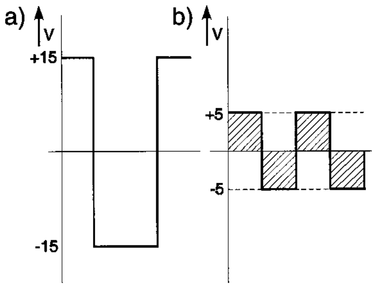


Fig. 3-135: Signal Form RS 232 (a) and RS 485 (b)
(RS 485 always transmits plus and minus levels on one of the two leads)

With a similar but symmetrical square wave signal transmitted on two leads the **RS 485** operates with considerably less sensitivity to interferences. Therefore the cable length can be as long as 1200 m. **ABB Automation Products** installs four conductors instead of the usual two and forgoes the cross cabling.

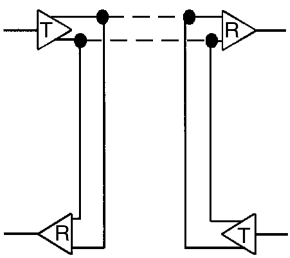


Fig. 3-136: RS 485: R = Receiver T = Transmitter

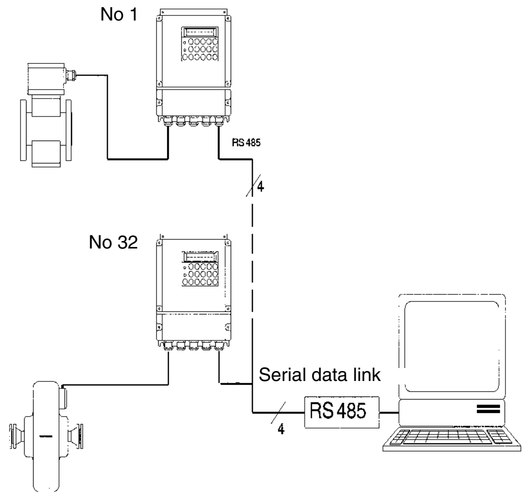


Fig. 3-137: Installation with Data Link RS 485

A bus system can be utilized with the RS 485 data link with up to 32 instrument participants. This means that up to 32 instruments can be connected in parallel on a single cable. They are only activated when they are addressed by the master.

3.6.5 HART-Protocol

The world wide standardized signal in the measurement industry is the 4 ... 20 mA current. Since this analog signal can only transmit one parameter a system has been developed with which additional information can be transmitted using an alternating current signal superimposed on this current. With the HART-Protocol (Highway Addressable Remote Transducer) a standardization using the Bell 202-Standard was achieved. The smart converters are HART compatible. The HART-Protocol processes the various parameters from a variety of manufacturers. The FSK (Frequency-Shift-Keying) procedure is the basis for the Bell 202-Standard with which both digital values, logic 0 and logic 1, are expressed as frequencies of 1200 Hz and 2200 Hz.

Because the average value of the frequency is zero the digital communication does not affect the analog signals.

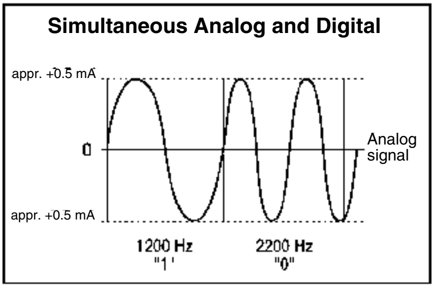


Fig. 3-138: FSK-Procedure

The modulation of the communication signals is provided by a Bell 202 modem as the link between the PC or master computer and the 4 … 20 mA line. It can be interconnected at any arbitrary location along the current line (Fig. 3-139).

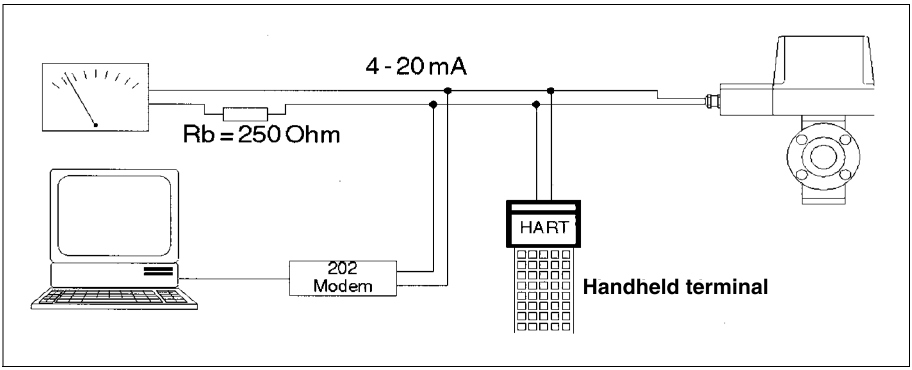


Fig. 3-139: HART Installation

Another communication means is with a handheld terminal which contains a modem as well as a PC. It is certainly an elegant and problem free procedure when a handheld terminal is connected at any location on the signal line to access or change the instrument parameters. And for a variety of instruments, one after the other. The HART-Protocol allows operation from two master instruments.

When a multiplexer is installed from **ABB** utilizing the HART-Protocol up to 1024 field instruments can be monitored and programmed centrally (Fig. 3-140).

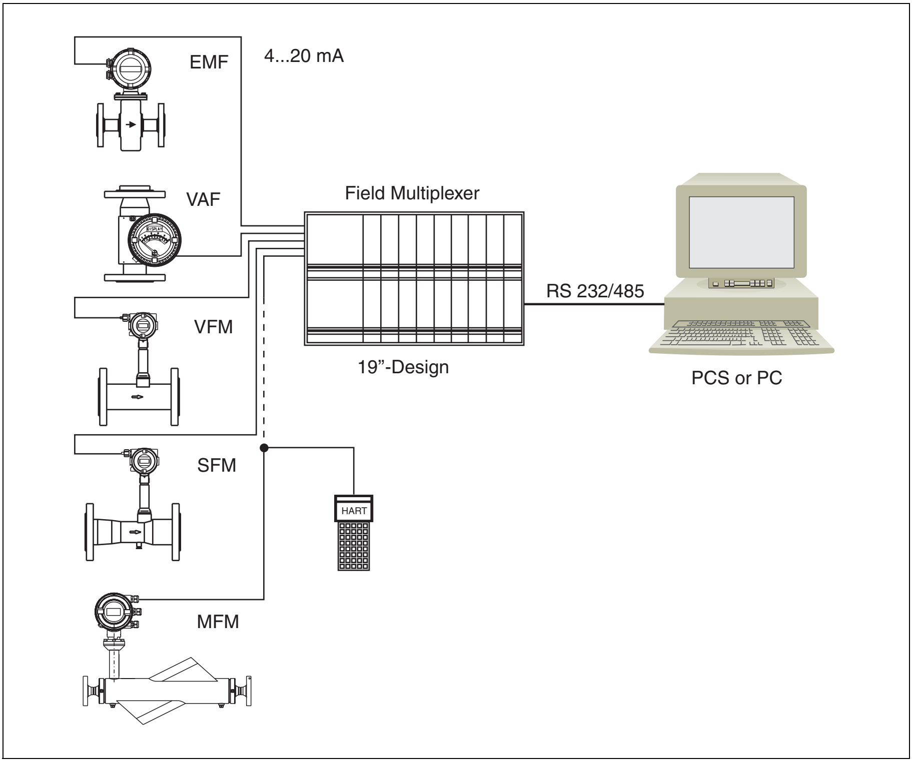


Fig. 3-140: HART-Protocol Installation with Multiplexer

3.6.6 Fieldbus in Process Automation

Fieldbus systems are a communication medium for serial communication between decentralized instruments in the field level and the input entry level in the process level. For process data acquisition in the field level not only intelligent sensors and actuators with direct connections to the fieldbus are used but also intelligent „Remote I/0's" as Interface-Systems for convention field instruments.

Over only two wires all the relevant signals such as in- and output values, parameters, diagnostic information, configuration scheme and for an additional application area, the operating energy, can be transmitted If a field instrument has a higher energy requirement, then this instrument can be supplied from a source other than the „Signal bus".

The use of a unique definition for the communication protocol allows the protocol to be open to all field instrument suppliers. In this manner it was possible to achieve interchangeability and also use the standard 4...20 mA signal for field instrument technology.

This, in addition to other requirements, is the prerequisite for the use of fieldbus systems and for the user to realize their significant potential.

The PROFIBUS-Family

PROFIBUS is a manufacturer independent, open fieldbus standard for applications in production, process and factory automation systems. PROFIBUS-Technology is defined in the German Standard DIN 19245 and in the international standard EN 50170. Thereby every product supplier has the PROFIBUS-Standard available for his use.

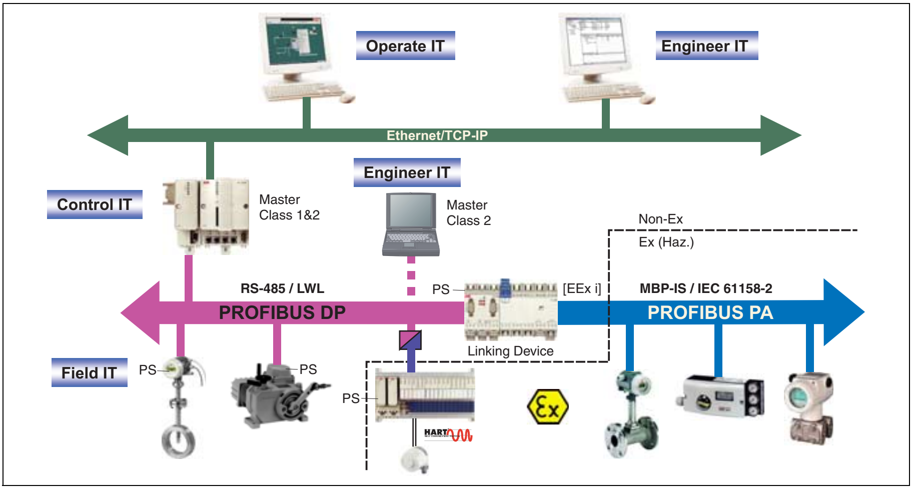


Fig. 3-141: Automation Structure-Hierarchy, I/O Fieldbus

The PROFIBUS-Family consists of three protocol types, which are used according the the requirements of the application. Naturally, all three protocol types can communicate with one another in a complex system over a PROFIBUS-Network. The basis for this is the compatibility of all the protocol types.

The three protocol types are:

PROFIBUS DP	Decentralized Periphery
PROFIBUS PA	Process Automation
PROFIBUS FMS	Field Message Specification

PROFIBUS DP: The Bus for Decentralized Periphery

Both the PROFIBUS DP and PA protocols are of importance for process automation. The PROFIBUS variant DP provides the communication between the process near components (PNK) and a process control system and decentralized peripherals in the field. PROFIBUS DP is especially suitable for high transmission speeds and is therefore often used in decentralized peripheral groups or externally supplied field instruments such as positioners or flowmeters. PROFIBUS DP/V1 allows acyclical communication.

PROFIBUS PA: Expansions for Process Automation

PROFIBUS PA was developed for process system technology. Properties and supply for the field instruments over a 2-wire bus is possible and corresponds to the IEC 1158-2 Standard. This variant is used for communication with 2-wire supplied sensors and actuators in the field. PROFIBUS PA uses an expanded DP-Protocol. The instrument properties and their behavior are described by the so-called Profile and defined in the standard. Using coupler assemblies (segment couplers, gateways) all the buses are combined in a PROFIBUS DP-Network. This assures that all information in the entire PROFIBUS-System (DP + PA) is available in a continuous network.

PROFIBUS FMS

Today PROFIBUS FMS has little meaning in the field level. Existing instruments can be operated together with DP-Instruments on the same bus.

3.6.7 FOUNDATION Fieldbus

The organization Fieldbus Foundation was originated in the year 1994 and grew out of the ISP (Interoperable Systems Project) and the WorldFIP (North American Section). Members of the Fieldbus Foundation are manufacturers of components and systems as well as users, particularly from North America. The goal of this organization is the development and implementation of a standard fieldbus for automation with the designation FOUNDATION Fieldbus (FF). This goal is expressed in the motto of the organization: „Fieldbus Foundation – dedicated to a single international Fieldbus“. For this reason, the organization has striven for about 10 years to disseminate its IEC-Fieldbus standard. Even though the FOUNDATION Fieldbus is an organization specific bus, it is especially noteworthy, because it mimics the stand of the fieldbus technology in the USA.

Make note that the FOUNDATION Fieldbus is in no way identical to the long standing IEC-Fieldbus standard. In fact, the two are moving further apart, because the FOUNDATION Fieldbus, in addition to a low-speed-variant (31.25 kbit/s, IEC 1158-2) as the higher level bus, has also introduced a high-speed-variant with 100 Mbit/s based on a Fast ETHERNET with fiber optic cables. The IEC-Fieldbus standard which in the meantime is almost completed, includes as before, a higher level with a bus at 1...2.5 Mbit/s.

3.7 Calibration and Certification

3.7.1 Why Calibrate?

In the company the requirement for rigorous traceability of the test equipment to national standards by calibrations to assure that everyone uses the „same measurement stick“, is essential both for suppliers who manufacture the products and for users who install these parts with other parts, due to increasing national and international division of work and the resultant requirement for interchangeability.

In addition to the technical reasons, there are also legal viewpoints. Relevant directives must also be observed together with contractual obligations with the purchaser of the products (assurance of the quality of the product) and the responsibility to only bring products to the market place whose safety for regulated usage is not compromised by faults. As far as contractual responsibilities for accuracy of measurement instruments which are agreed upon, a nonfulfillment of these requirements is a failure of a guaranteed property.

Proof of the selection of adequate test equipment and its proper operation within the scope of product liability is of great importance, because a systematic and completely documented test equipment monitoring in combination with continuous proof of the adequacy of the test equipment for the task is essential for a possible exoneration.

3.7.2 Definitions per DIN 1319, Part 1

Measuring
Measuring is the experimental process by which a special value of a physical property is determined as a multiple of a unit or a reference value.

Calibration (Measurement)
Calibration within the framework of measurement technology means to ascertain the measurement deviation on the completed instrument.

Certification
The certification of a measurement instrument (also a material measurement) includes use of the inspection tests prescribed by the applicable inspection agency accompanied by a stamp. The test is to establish whether the instrument meets the certification requirements, i.e. if it in its condition and measurement characteristics satisfied the prescribed requirements, in particular, assurance that the measurement deviations do not exceed the error limits. The stamp certifies that the instrument at the time of the test satisfied these requirements and based on its design can be expected, if used in accordance with the rules for the technology, will in the time after the certification remain „correct".

Adjusting
Adjusting within the realm of measurement technology means to set or adjust an instrument (also a material measurement) so the measurement deviations are minimized, or that the values of the deviations do not exceed the error limits. Adjusting usually means that a permanent change has been made to the instrument or the material measurement.

3.7.3 Flowrate Calibration Methods per (VDE/VDI 2641, DIN EN 24006)

The common measurement methods are:

Volumetric Method
Procedure to measure the volume flowrate of a liquid using a calibrated volume tank and measuring the fill time.

Gravimetric Method
This method is comparable to the volumetric method. However instead the volume of the fluid is measured by weighing, taking into account the density and the weight of displaced air.

Comment:
The calibrations can be conducted using either a standing START-STOP operation (opening and closed a shutoff device) or a flying START-STOP operation (operation of a diverter device). Furthermore, a distinction is made between a static and a dynamic method, whereby the later does not require a diverter device.

Comparison Method
The liquid flows through the instrument being calibrated and a second flowrate measurement instrument which was previously calibrated.

Pipe Test Section Method
Volumetric measurement instrument consisting of pipe section with a constant cross section and known volume. The flowrate is derived from the time required for a plug, either driven mechanically or by the fluid, to traverse the pipe section.

In test stands with the highest accuracy requirements, a static weigh method is used almost exclusively in conjunction with a diverter using the flying START-STOP operation. At ABB Automation Products GmbH Factory in Göttingen, Germany the static and comparison methods are used exclusively for gas calibrations.

3.7.4 Boundary Conditions, Measurement Fixtures

During the design of a calibration test stand, e.g. using a gravimetric method, a series of requirements per DIN EN 29104 must be met:

1. Flow must be stationary.
2. The flow in the obstruction free inlet section must be axisymmetric and free of swirl and pulsation.
3. The reference flowmeter or the calibrated test section for measuring the flowrate or flow must satisfy the requirements of ISO 4185 and ISO 8316.
4. The flow range of the reference flowmeter of the calibration standard must of the same range as the range of the instrument being tested. The error limits of the reference standard must no be larger than one third of the error limits for the instrument being tested.
5. The measuring system and the reference standard must be described in detail, including the traceability of the reference standard and the uncertainty of the measuring system. The calculation of the uncertainty of the flowrate measurement must be in accord with ISO 5168, ISO 7066-1 and ISO 7066-2.

6. The flowmeter primary must be installed between a straight, unobstructed inlet section at least 10 x D long and an unobstructed outlet section at least 5 x D long. If swirl free velocity profiles are required, a flow straightener must be installed.
7. During the calibration the flowmeter primary must be completely filled with fluid.

In addition the physical characteristics of the measurement fluid, for example, density and viscosity, must also be considered. Analogy calculations can be made using the Reynolds number which takes into account flow velocity conditions. Naturally, the other equipment on the test stand also have accuracies, which must be so good that they only have minimal impact on the flowrate measurement results.

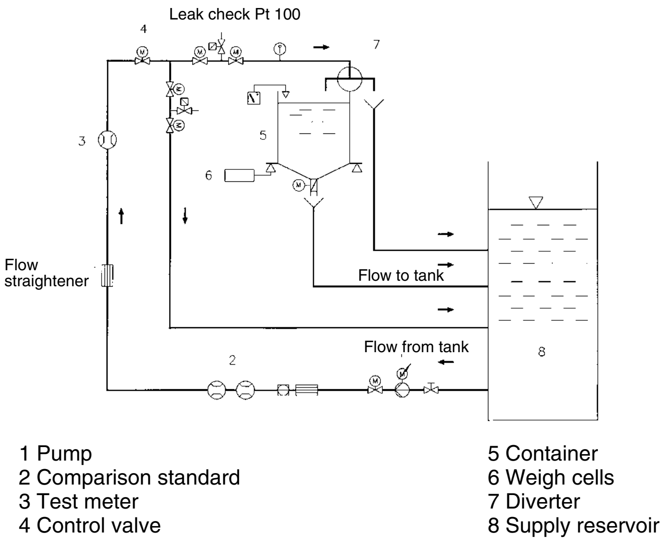


Fig. 3-142: Test Stand for Gravimetric Calibration and Comparison Calibration Methods

For the test stand schematic shown in Fig. 3-142 the water flows through two comparison standards (2), which cross check each other. The flowmeter being calibrated (3) is installed in a long, undisturbed pipe section. The control valve (4) and the pump (1) determine the flowrate. The water can then either be returned directly to the supply reservoir (8) or by actuating the diverter (7) into the tank (5), where its mass can be measured. The scale arrangement (6) itself is checked in periodic intervals with weights by the Certification Agency.

3.7.5 Approval of the Test Stands and the Products

DKD-Accreditation [DKD = German Calibration Service]

ABB Automation Products GmbH has two DKD-Calibration laboratories in Germany for flowrate measurements: at the Göttingen Factory DKD-K-18101 and at the Alzenau Factory DKD-K-05701. The calibration laboratories are accredited and monitored by PTB [German National Institute of Technology and Science). The DKD-Calibration Certificates received are proof of the traceability to the national standards as required in standards DIN EN ISO 9001 and DIN EN ISO/IEC 17025. Calibrations in DKD-Laboratories provide the user assurance of the reliability of the measurement results, increase the confidence of the customer and provide competitiveness in the national and international markets and are the technological basis for the measurement and test equipment monitoring within the framework of the Quality Assurance measures.

The collaboration of DKD in the European co-operation for Accreditation (EA) assures that Calibration Certificates issued by DKD and other (national) calibration services are equivalent to each other. In a multilateral agreement these calibration services have pledged reciprocal recognition of each others calibration certificates. The signatories in the calibration services sector at the present are the Accreditation Agencies in Belgium (BKO/OBE), Denmark (DANAK), Germany (DKD), Finland (FINAS), France (COFRAC), Ireland (NAB), Italy (SIT), Netherlands (RvA), Norway (NA), Austria (BMwA), Portugal (IPQ), Sweden (SWEDAC), Switzerland (SAS), Slovakia (SNAS), Spain (ENAC), Czech Republic (CAI) and the United Kingdom (UKAS). In addition corresponding agreements have been reached with the Accreditation Agencies in Australia (NATA), Brazil (INMETRO), Hong Kong (HKAS), New Zealand (IANZ), Singapore (SAC), South Africa (SANAS) and one Accreditation Agency in the USA (A2LA).

Testing of Measurement Instruments for the Volume Measurement of Flowing Fluids (Certification Approval)

Various test stands at the ABB Automation Products Factory in Göttingen have received from PTB [German National Institute of Technology and Science) the approval to calibrate approved certified instruments (see next section) as well as technical tests in the presence of Certification Official. The Certification Certificates issued (does not contain any measurement specifications per the Certification Regulation) or Test Certificates MEN (with measurement specifications) are proof of the traceability to national standards, as required by the standards DIN EN ISO 9001 and DIN EN ISO/IEC 17025.

Type Examination Approval for Intrastate Certified Calibrations (Germany)

In order to certify an instrument it is not enough to have an approved test stand. The flowmeter instruments themselves must also be approved by PTB for intrastate use in order to certify that the requirements of the Calibration Regulations can be satisfied. The Calibration Regulation EO 5 differentiates by fluid and evaluates them individually. Therefore the approval includes not only the instrument type but also the meter size, the flowrate range and the fluid. ABB has received the following approvals:

Approvals	Mark	Instr. Type	Application	Meter Size Range
Cold water/waste water	6.221	EMF	Flowrate	DN 25...2000 [1”...78”]
Liquids other than water e.g.: • Brine • Beer • Beer wort • Beverage conc. • Chem. liquids	5.721	EMF	Flowrate Filling & injections Filling & injections	DN 25...150 [1”...6”] DN 100...150 [4”...6”] DN 25... 80 [1’...3”] DN 25... 80 [1”...3”] DN 25 [1”] DN 25...150 [1”...6”]

Approved and Certified instruments can be identified by the special Type plates:

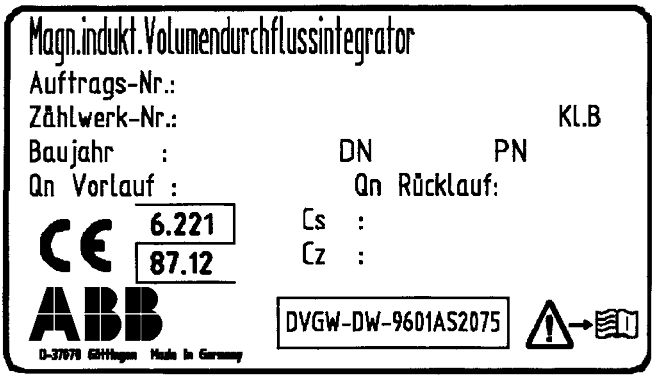


Fig. 3-143: Type Plate for Instruments with Approval for Certified Calibration of Water/Waste Water (only for Germany)

3.7.6 Calibration Possibilities at ABB

Factory Calibrations

Measured value:	**Volume flowrate**	
Fluid:	Water	
Meter size range:	DN 1...DN 2400 [1/25”...96”]	
Flow range:[1)]	q_v = 0.2 l/min...6,000 m^3/h	
Measurement inputs:	Current	(0/4...20) mA
	Frequency	(0...10) kHz
	Data link	only with ABB Automation Products instruments

Measured value:	**Volume flowrate**
Fluid:	Atmospheric air
Meter size range:	DN 15...DN 300 [1/2”...12”]
Flow range:[1)]	q_v = (2...5,400) m^3/h
Measurement inputs:	Frequency

Measured value:	**Mass flowrate**
Fluid:	Atmospheric air, various gases
Meter size range:	DN 25...DN 1000 [1”...40”]
Flow range:	q_m = 1 kg/h...9,000 kg/h
Measurement inputs:	Current (0/4...20 mA)
	Frequency

Certified/Special Calibrations MEN

Measured value:	**Volume flowrate**	
Fluid:	Water	
Meter size range:	DN 10...DN 2400 [3/8”...96”]	
Flow range:[1)]	q_v to max. 6,000 m^3/h	
Measurement inputs:	Current	(0/4...20) mA
	Frequency	(0...10) kHz

1) specified is the maximum range over all meter sizes;
the ranges for individual sizes must be requested separately.

DKD-German Calibration Service

Measured value:	**Volume / mass flowrate**
	Volume / mass of flowing fluids
Fluid:	Water
Meter size range:	DN 50...DN 600, DN 800 [2”...24”, 32”]
Flow range:[1)]	q_v = (5...3000) m^3/h V = (1500...50,000) Liter
	q_v = (5...3000) m^3/h m = (1500...50,000) kg
Accuracy:	± 0.10 % of rate
Measurement inputs:	Current (0/4...20) mA
	Frequency (0...10) kHz

Measured value:	**Mass flowrate**
Fluid:	Atmospheric air
Meter size range:	DN 25...DN 1000 [1”...40”]
Flow range:	q_m = 1 kg/h...9,000 kg/h
Accuracy:	0.3/0.4 % of rate
Measurement inputs:	Current (0/4...20 mA)
	Frequency

1) specified is the maximum range over all meter sizes;
the ranges for individual sizes must be requested separately.

4 Selection Criteria

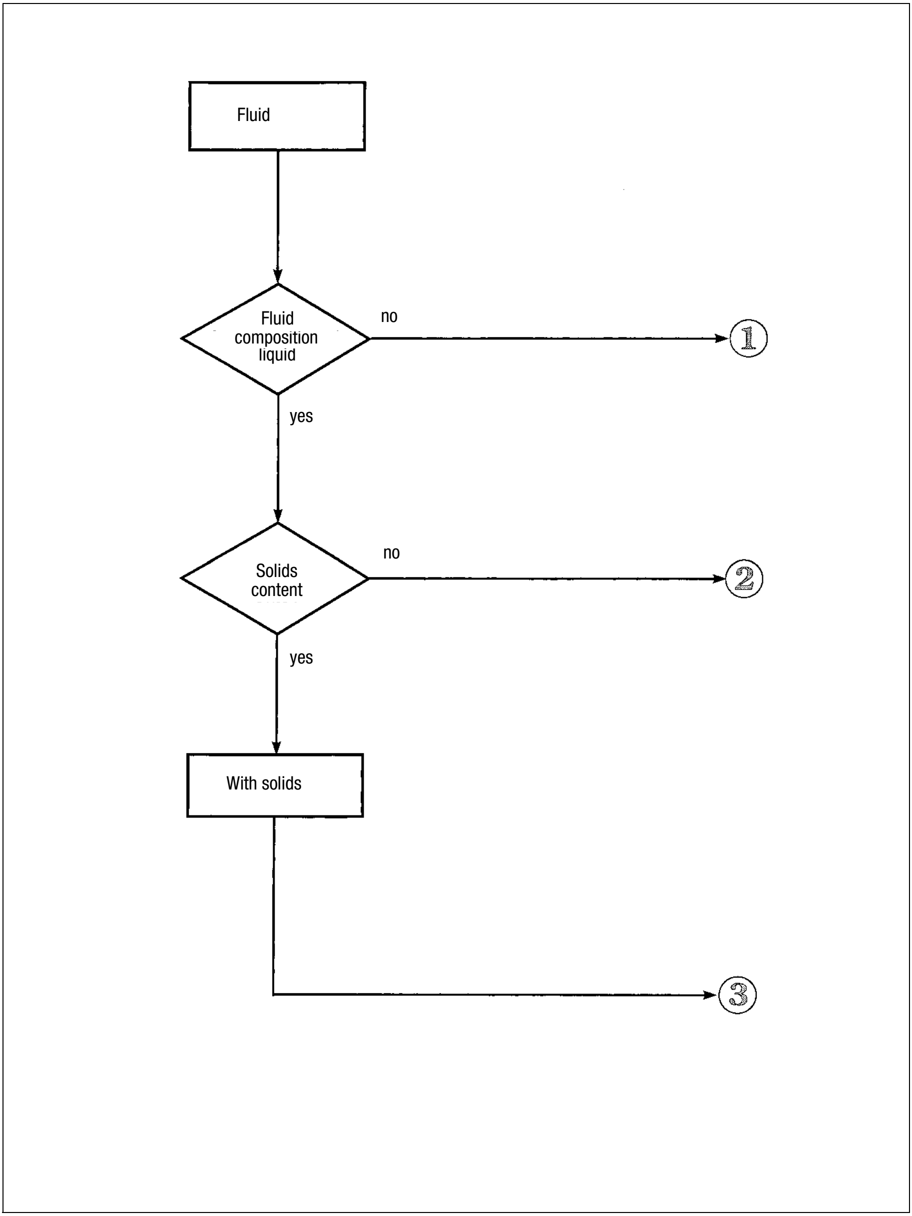
By listing opposite to each other the decisive characteristics of volume meters and flowmeters an attempt is made to compile the most interesting view points for instrument selection in order to provide a guide for the user. The various criteria are assembled in the tables so that the applicability may be readily ascertained for a particular situation.

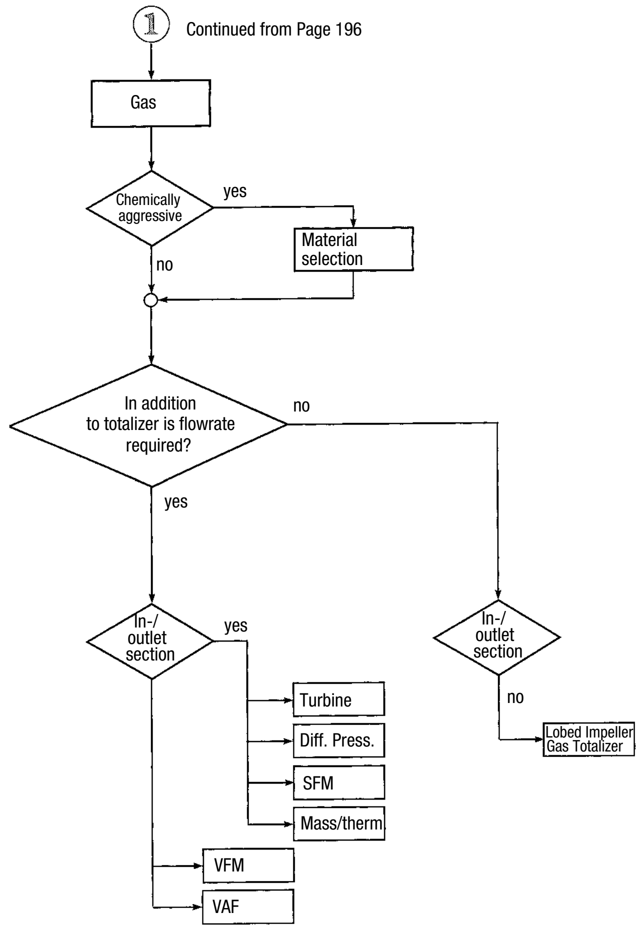
Naturally it is not possible within the framework of this publication to be all encompassing. There are always special designs for individual applications and the sizes and values listed will certainly require overhauling as technology continues to evolve.

Unfortunately the price often decides over design and construction of a metering instrument. Preparation of the installation site, assembly and maintenance are additional costs which are often forgotten. Additionally perhaps, considerations regarding accuracy and long term use play an important role in instrument selection. The following comparisons should provide assistance in this regard.

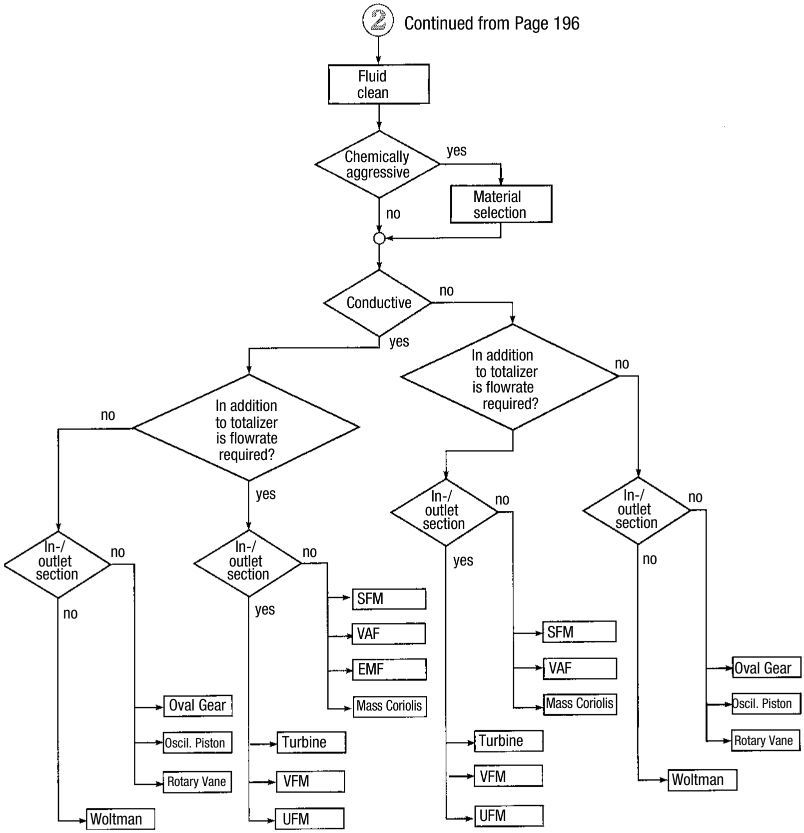
4.1 Instruments for Closed Pipelines

Flow chart for instrument selection with a number of important selection criteria:

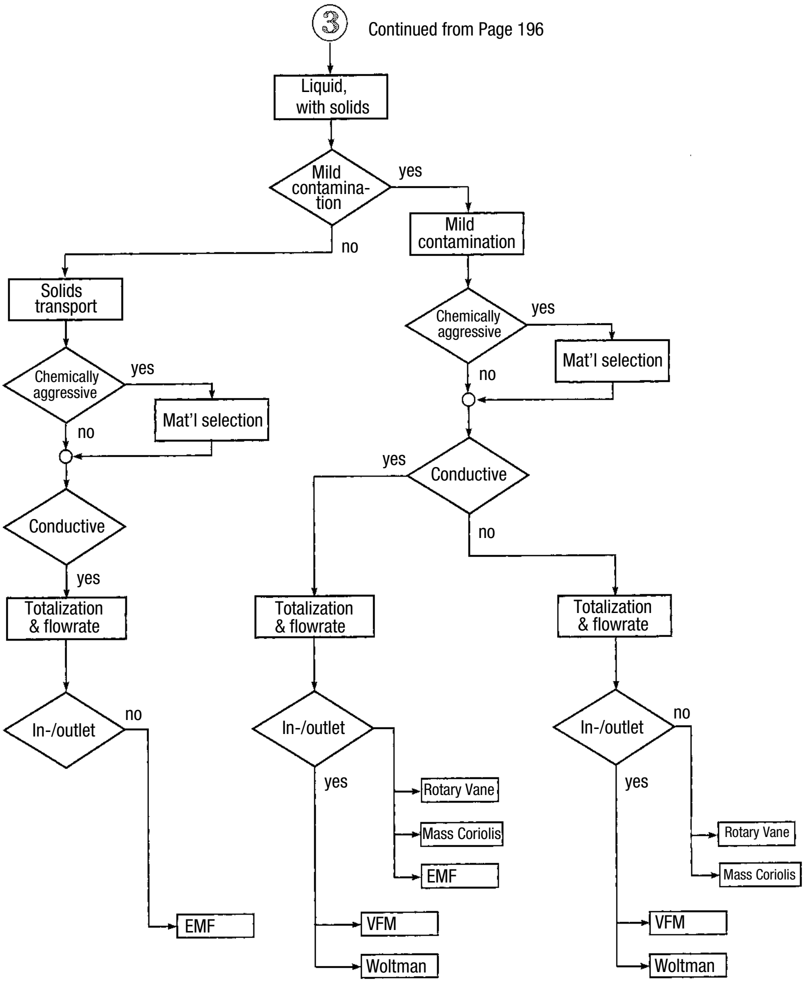




SFM = Swirl Flowmeter
VAF = Variable Area Flowmeter
VFM = Vortex Flowmeter



SFM = Swirl Flowmeter
EMF = Electromagnetic Flowmeters
VAF = Variable Area Flowmeter
UFM = Ultrasonic Flowmeter
VFM = Vortex Flowmeter



3
Continued from Page 196
Liquid, with solids
Mild contamina-tion
yes
no
Mild contamination
Solids transport
Chemically aggressive
yes
no
Mat'l selection
Chemically aggressive
yes
no
Mat'l selection
Conductive
yes
Conductive
yes
no
Totalization & flowrate
Totalization & flowrate
Totalization & flowrate
In-/outlet
no
EMF
In-/outlet
yes
Rotary Vane
Mass Coriolis
EMF
VFM
Woltman
In-/outlet
no
yes
Rotary Vane
Mass Coriolis
VFM
Woltman

4.1.1 Influences of Metered Fluid Properties

In first place is the fluid itself. Its flowrate and its volume are to be determined. Before an instrument type can be selected the type of metered fluid must be analyzed together with its characteristics. This represents an appreciable portion of the meter sizing effort.

<table>
<tr><th rowspan="2" colspan="2"></th><th rowspan="2">Fluid</th><th rowspan="2">Fluid State</th><th rowspan="2">Upper Viscosity Limit [mPa·s]</th><th colspan="2">Solids in Fluid</th><th rowspan="2">Electrical Conductivity</th><th rowspan="2">Gas Content in Liquid</th><th rowspan="2">Pressure Density Temperature Changes</th><th rowspan="2">Chemically Aggressive Fluid, Corrosion Danger</th></tr>
<tr><th>Mild Contamination</th><th>Solids Transport</th></tr>
<tr><td rowspan="6">volume totalizer</td><td rowspan="3">Direct</td><td>Oval Gear Totalizer</td><td>F</td><td>$1 \cdot 10^5$</td><td rowspan="5">increased wear,

blockage danger</td><td>u</td><td>n</td><td>error</td><td rowspan="6">Minimal Error</td><td>SS housing
SS wheels
Carb. bearing</td></tr>
<tr><td>Lobed Impeller Totalizer</td><td>F</td><td>$2 \cdot 10^4$</td><td>u</td><td>n</td><td>error</td><td>SS housing
PTFE piston
Carb. bearing
PTFE bearing</td></tr>
<tr><td>Oscil. Piston Totalizer</td><td>G</td><td>no effect</td><td>u</td><td>n</td><td>–</td><td>Cast steel housing
cast Alum,
Steel piston
Oil seal</td></tr>
<tr><td rowspan="3">Indirect</td><td>Rotary Vane Totalizer</td><td>F</td><td>5</td><td>u</td><td>n</td><td>error</td><td>Plastic parts,
Brass housing</td></tr>
<tr><td>Woltman Totalizer</td><td>F</td><td>3</td><td>u</td><td>n</td><td>error</td><td>Cast housing,
Plastic-Rotary Vane,
SS parts</td></tr>
<tr><td>Turbine Totalizer</td><td>F (G)</td><td>700</td><td>u</td><td>u</td><td>n</td><td>over speed danger</td><td>Nickel rotor,
SS housing,
other parts SS</td></tr>
<tr><td colspan="11">n = no effect
u = unsuitable
F = liquid
G = gas
D = steam</td></tr>
</table>

Tbl. 4-11: Effect of Fluid Properties

	Fluid	Fluid State	Upper Viscosity Limit [mPa·s]	Solids in Fluid		Electrical Conduct-ivity	Gas Content in Liquid	Pressure Density Tempera-ture Changes	Chemically Aggressive Fluid, Corrosion Danger
				Mild Contamination	Solids Transport				
Flowmeters	Vortex Flowmeter	F, G, S	10	essentially insensitive to contamination	u	n	cavitation effects possible	effects for gas metering, none for liquids	SS
	Swirl Flowmeter	F, G, S	30		u	n			SS (Hastelloy, PTFE)
	Differential Pressure Meter	F, G, S	see Table 2.4	damage to metering edge, plugging of pressure tap connections	u	n	error	effects on Δp	SS
	Variable Area Flowmeter	F, G, S	100 (700)	damage to metering edge	u	n	error	density changes buoyancy	SS, Hastelloy, PTFE, Glass
	Electro-magnetic Flowmeter	F	no effect	n	n	≥ 0.5 µs/cm	error	n	PTFE, PFA, Platinum
	Ultrasonic Flowmeter	F (G)	Re-effect	only for Doppler types. damping for transit time	u	n	error for Doppler, damping for transit time	sound velocity changes for Doppler	SS, PTFE
	Mass Flowmeter, Coriolis	F (G)	no effect	with restrictions	u	n	error	Density is measured	SS, Hastelloy
	Mass Flowmeter, Thermal	G	no effect	essentially insensitive to contamination	u	n	–	n	SS, Hastelloy, Ceramic

n = no effect
u = unsuitable
F = liquid
G = gas
S = steam

Tbl. 4-12: Effect of Fluid Properties

Viscosity Effects

The viscosity is a fluid property. Through use of the Reynolds number it is possible to coordinate the viscosity effects and the sizing. For Re < 2300 laminar flow exists with a large viscosity effect. The transition region exists between approximately 2300 < Re > 3000 above which turbulence exists. In the turbulent region there are no limitations due to viscosity. Small Re-values have varying effects dependent upon the metering method.

For gas totalization or flow metering the viscosity effect is hardly noticeable. Only for small Variable Area flowmeters does the effect increase slightly in the lower flow ranges.

The situation for liquids is quite different. Completely viscosity independent are the Electromagnetic flowmeters and the Mass flowmeters although the pressure drop in the latter is affected as a function of the length of the flow path. Ultrasonic flowmeters have difficulties in the transition region from laminar to turbulent flow.

In the Vortex, Swirl and Turbine flowmeters an increasing viscosity moves the minimum flow measurement to a higher value thus reducing the flow range.

Oval Gear and Oscillating Piston meters are ideal instruments for high viscosities. At higher viscosity they become more accurate because of the decrease in leakage losses.

A special Variable Area flowmeter float design decreases the effects of viscosity in this flowmeter.

Solids in the Fluid

Solids in the fluid means various things. First there is the usually undesirable **contamination**, then there are mixtures such as pastes and slurries, and finally there is the hydraulic transport of solids. Contamination is undesirable because its amount and effects are difficult to predict. Gases can convey liquid or dust particles. Solid particles in a gas are dangerous because the gas flow velocities are high and therefore the kinetic energy of the particles can be appreciable, so that they may become destructive or cause solid **deposits**.

The Oscillating Piston meter assumes that the gas will be filtered. A screen with 0.1 to 0.2 mm openings is recommended before the inlet. Additionally a flushing arrangement can be used to remove dirt. For Differential Pressure and Variable Area flowmeters the dust particles damage the sensitive sharp metering edges.

Unclean fluids effect Lobed Impeller meters by causing increased wear. In the worst case the rotating parts become stuck. Vortex and Swirl flowmeters flush light contamination through the meter.

If a nonconducting coating (oil, grease) in an Electromagnetic flowmeter interrupts the electrical contact between the electrodes and the fluid then a meter with capacitively coupled electrodes must be installed. A conductive coating, e.g. from magnetite, only results in an error when the fluid (in this case water) has a conductivity of less than 100 µS/cm. Otherwise the Electromagnetic flowmeter is the least affected meter.

A special case is the Ultrasonic flowmeter, because the Doppler principle requires foreign bodies as reflectors while the transit time principle can only tolerate a minute amount of particles and will not operate if gas bubbles are present. Deposits affect the sound path and cause errors.

A prerequisite for proper functioning of the mass meter is that the solid particles follow the vibrations, which again is a function of the fluid viscosity. Therefore with an increasing mass and inertia of the particle the danger of incorrect measurements increases.

Hydraulic Solids Transport, e.g. coal or dredging slurries require a piping system without constrictions or obstructions. Increased abrasion is also always present. The flowrate measurement in these lines is only possible with Electromagnetic flowmeters. The abrasion effects can be minimized by proper material selections for the liner (polyurethane, soft rubber) and for the electrodes (Hastelloy C). The mass rate of the moving solids is generally the variable which is desired. Therefore a density meter (radioactive density meter) and a volumetric flow meter are combined and the mass flowrate calculated from the product of the two values.

Undesirable deposits in the pipeline are removed with scrapers. The effectiveness of the scraper requires, among other things, a constant diameter along the entire length of the pipeline. The flowmeter installed in the pipeline is of course subjected to the same requirements, i.e., matching of the diameters without steps. Only Electromagnetic and Ultrasonic flowmeters can be individually adapted. The Mass flowmeter with its constant diameter single tube design can be scraped, but its diameter cannot be adapted. Multipipe Mass meters cannot be scraped.

Gas Content in a Liquid

The instruments used to meter liquids are volumetric meters which cannot differentiate between gas and liquid. Therefore gaseous components in a liquid cause errors whose magnitude is equal to the proportion of gas in the mixture. A correct measurement should be expected from the Coriolis Mass flowmeter. But here also errors occur because of the damping characteristics of the gases.

Beyond these there are side effects which must also be considered. For Turbine flowmeters it might happen that larger gas bubbles could cause over speeding. Cavitation is readily generated at higher flow velocities particularly in Vortex and Swirl flowmeters. In the Ultrasonic flowmeters using the transit time principle both the transit time and the damping are changed so that even small gas bubbles can cause an effect. Errors are noted with as little as a 0.2% volume of gas.

Corrosion Risks with Aggressive Fluids

The effects of **corrosion** can only be avoided by proper material selection. A slight inattention, for example, in selecting the material for a gasket can result in an inoperative instrument.

The complicated elements of volumetric totalizers are disadvantaged when it comes to material selections. Therefore these meters are not preferred in corrosive applications. Rotary Vane and Woltman meters are preferred for water measurements.

The flowmeters offer a variety material choices. For Differential Pressure flowmeters it is important not only to consider that the orifice or nozzle must be corrosion resistant but also the pressure lines and fittings. In certain installations the injection of an isolating fluid or gas is used to prevent the entry of dangerous fluids.

Variable Area flowmeters made of special materials are expensive and are seldom installed, the same holds true for the Mass flowmeters.

Suitable solutions to the problems are offered only by the Electromagnetic and Ultrasonic flowmeters. The smooth metering pipe can be lined with a corrosion resistant liner such as PTFE for example. Transducers in the Ultrasonic flowmeters and electrodes in the Electromagnetic flowmeters are in direct contact with the fluid, i.e. extend through the pipe or the liner. The ultrasonic transducers can be provided with stainless steel or Hastelloy protectors. There are better alternatives available in the Electromagnetic flowmeters. A wide variety of electrode materials are available from stainless steel to Monel, Titanium, Hastelloy, Platinum and even Carbon.

4.1.2 Flow Regime Effects

The fluid flowing through the pipeline has characteristics which effect the flow regimes, particularly in combination with the pipeline configuration. They influence the flow metering instruments with their limited ability to process these effects without errors. In other words, there are limitations which are characterized by the **velocity profile** and the Reynolds number.

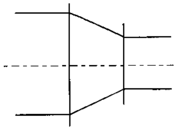
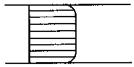
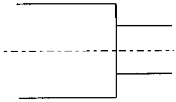
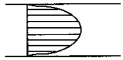
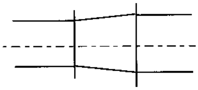
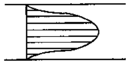
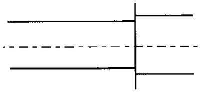
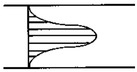
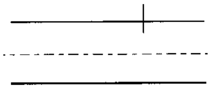
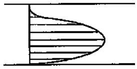
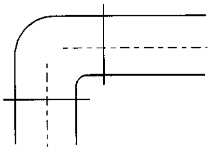
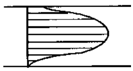
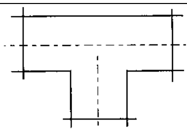
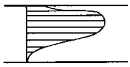
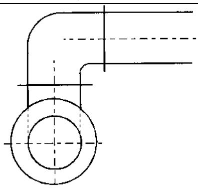
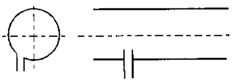
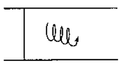
The ideal condition is flow with a turbulent **axisymmetric velocity profile**, (the two dimensional profile shown in Fig. 1-2 should be visualized in three dimensions). All instruments operate correctly. Similarly most instruments operate correctly with axisymmetric laminar flow profiles with the restriction that the flow ranges of the indirect volumetric totalizer, the Differential Pressure and Variable Area flowmeters decrease with increasing viscosity.

The least affected by flow profile irregularities are the direct volumetric totalizers. And for fluids with lower Reynolds numbers they are the most accurate.

	Instrument Type	Flow Regime			Conditioning Section		
		Laminar	Transi-tion	Turbulent	Upstream	Down-stream	Shock Type Operation
Direct	Oval Gear Meter	n	n	n	n	n	wear
	Oscil. Piston Meter	n	n	n	n	n	wear
	Lobed Impeller Meter	n	n	n	n	n	resonance danger
Indirect volume totalizer	Rotary Vane Meter	n	n	n	n	n	n
	Woltman Meter	n	n	n	5 x D	3 x D	n
	Turbine Flowmeter	n	n	n	15 x D	5 x D	over speed wear
	Vortex Flowmeter	u	u	n	15...25 x D	5 x D	n
	Swirl Flowmeter	u	u	n	3 x D	n	n
	Diff. Pressure Flowmeter	n	n	n	Tbl. 2.5	Tbl. 2.5	error
Flowmeters	Variable Area Flowmeter	n	n	n	n	n	error
	Electromagnetic Flowmeters	n	n	n	3 x D	2 x D	n
	Ultrasonic Flowmeters	n	u	n	Same as orifices Tbl. 2.5	5 x D	n
	Mass Flowmeters Coriolis	n	n	n	n	n	error
	Mass Flowmeters Thermal	n	n	n	15 x D	5 x D	n

n = no effect;
u = unsuitable
1 x D = conditioning section 1xD in length

Tbl. 4-13: Flow Regime Effects

Type of Disturbance		Velocity Profile	
Concentric reducer			Axisymmetric
Concentric square edge reducer			
Concentric expander			
Concentric square edge, expander			
Eccentric gate			Non-Axi symmetric
90°-elbow			
Tee			
Two 90°-elbows in different planes			Super imposed unstable velocity profile
Eccentric side entry			Swirl

Tbl. 4-14: Velocity Profiles in Pipes 1 … 2 x D After the Disturbance with Turbulent Flow

Disturbed velocity profiles in turbulent flow must be considered independent of the meter type. Tbl. 4-14 shows a number of examples of disturbances and their influence on the velocity profile cross sections. The direct volumetric totalizers have no difficulty with such changes. The same holds true for Variable Area and Coriolis Mass flowmeters as well as for Swirl flowmeters.

The Differential Pressure flowmeters are very sensitive to disturbances. Long disturbance free straight sections provide for uniformity (Tbl. 2-5). The Ultrasonic flowmeter is affected when its very narrow sound beam does not sense all the velocity differences, which is very seldom the case. Therefore requirements similar to those for the Differential Pressure flowmeters are necessary. The two or more beam Ultrasonic flowmeters are better suited for such conditions.

The axisymmetric flow profiles are well-behaved disturbances who lose their effects after even short conditioning sections. The step changes can carry wall vortices along. The indirect totalizers, Electromagnetic and Mass flowmeters have no difficulty.

It is different with non symmetric profiles. The indirect volumetric totalizers require conditioning sections 10 to 15 x D long (conditioning sections are straight sections with the same diameter as the meter; flow straighteners provide a means for shortening the required lengths), while the Electromagnetic flowmeters demand only 3 to 5 x D. Swirl and transverse vortices persist in straight sections over long distances. Since their effects on the measurement are appreciable, flow straighteners must be used to eliminate their effects.

The conditioning sections listed in Tbl. 4-13 should be installed upstream of the meters. Additional straight sections downstream are installed to prevent feedback from downstream disturbances. The lengths lie between 3 x D and 10 x D.

4.1.3 Installation Spectrum, Meter Site Limits

The installation site is included in the selection of the meter because the ambient conditions can only be adjusted to a limited degree to the requirements of the particular instruments.

When solids are being transported hydraulically the Oscillating Piston meter cannot be installed or if gas measurements are to made an Electromagnetic flowmeter cannot be used, the required electrical conductivity is not present.

Tbl. 4-15 lists a number of criteria which may be a function of the meter site. The specifications in the tables are taken from manufacturer's publications. There are certainly instrument variations available whose installation specifications exceed those listed in the table.

<table>
<tr><th></th><th></th><th></th><th>Meter Size DN Inch</th><th>Installation Length</th><th>Max. Allow. Fluid Temp.</th><th>Highest Pressure Rating PN</th><th>Vibra-tion</th><th>Pulsation</th><th>Response to Reverse Flow</th><th>Supply Power</th></tr>
<tr><td rowspan="8">volume totalizer</td><td rowspan="3">Direct</td><td>Oval Gear Totalizer</td><td>6... 400
1/4...16</td><td>horizontal</td><td>300 °C</td><td>100</td><td rowspan="6">increased wear</td><td rowspan="2">minimal effect</td><td rowspan="5">reverse counting</td><td rowspan="5">not required, only for converter and output</td></tr>
<tr><td>Lobed Impeller Totalizer</td><td>15... 800
1/2...32</td><td>arbitrary</td><td>300 °C</td><td>100</td></tr>
<tr><td>Oscil. Piston Totalizer</td><td>40... 300
1½...12</td><td>horizontal</td><td>40 °C</td><td>25</td><td>strong effect</td></tr>
<tr><td rowspan="5">Indirect</td><td>Rotary Vane Totalizer</td><td>15... 50
½...2</td><td>horizontal (vertical)</td><td>130 °C</td><td>16</td><td rowspan="3">effect</td></tr>
<tr><td>Woltman-Totalizer</td><td>40... 400
1½...16</td><td>horizontal; vertical</td><td>130 °C</td><td>40</td></tr>
<tr><td>Turbine Totalizer</td><td>5... 600
3/16...24</td><td>horizontal (vertical)</td><td>250 °C</td><td>100</td><td rowspan="5">no direct measurement</td><td rowspan="4">to supply the converter</td></tr>
<tr><td>Vortex Flowmeter</td><td>25... 250
1...10</td><td>arbitrary</td><td>400 °C</td><td>100</td><td>effect*)</td><td rowspan="2">little effect</td></tr>
<tr><td>Swirl Flowmeter</td><td>15... 400
½...16</td><td>arbitrary</td><td>280 °C</td><td>100</td><td>effect*)</td></tr>
<tr><td rowspan="6" colspan="2">Flowmeters</td><td>Diff. Pressure Flowmeter</td><td><50...2000
2...78</td><td>arbitrary</td><td>1000 °C</td><td>630</td><td>little effect</td><td>little effect</td></tr>
<tr><td>Variable Area Flowmeter</td><td>3... 100
1/10...4</td><td>arbitrary</td><td>360 °C</td><td>250</td><td>strong effect</td><td>strong effect</td><td>same as totalizers</td></tr>
<tr><td>Electromagnetic Flowmeter</td><td>1...3000
1/25...120</td><td>arbitrary</td><td>180 °C</td><td>250</td><td rowspan="2">no effect</td><td>no effect</td><td>meters reverse flow</td><td rowspan="4">required</td></tr>
<tr><td>Ultrasonic Flowmeter</td><td>10...3000
3/8...120</td><td>arbitrary</td><td>200 °C</td><td>100</td><td>minimal effect</td><td>metering possible</td></tr>
<tr><td>Mass Flowmeter, Coriolis</td><td>1.5... 150
1/17...6</td><td>arbitrary</td><td>180 °C</td><td>100</td><td>no effect</td><td>insignifi-cant effect</td><td>meters reverse flow</td></tr>
<tr><td>Mass Flowmeter Thermal</td><td>25...3000
1...120</td><td>arbitrary</td><td>300 °C</td><td>40</td><td>no effect</td><td>little effect</td><td>metering possible</td></tr>
<tr><td colspan="11">*) Compensation for Vortex</td></tr>
</table>

Tbl. 4-15: Installation Spectrum

Pressure and Temperature

Housing strength due to its wall thickness and material selection, mechanical tolerances for temperature expansion, gasket type and material, sensors limits and the effects on the transmitting element; these are some of the considerations that effect instrument selection at high temperatures and pressures. For Variable Area flowmeters differentiation must be made between glass and metal pipe meters. The pressure and temperature limitations for glass tube meters naturally lie far below those for metal pipe meters.

Differential Pressure flowmeter selection includes the fittings, pressure lines, and converter. These parts must be designed appropriately. The limiting values for the converter usually are controlling for the entire system. The upper temperature limit for the converters is usually around 120 ºC, higher temperatures must be reduced by isolators in the pressure lines.

Vibration

Pipeline vibrations primarily cause wear on the moving parts and bearings in the volumetric totalizers. In the oscillating elements in the Vortex and Mass flowmeters the vibration frequencies are superimposed on the measurement frequencies causing errors. If resonance occurs parts may fracture. The Vortex flowmeter from **ABB** is substantially insensitive to vibrations because of the separation of the sensor from the shedder and the oscillation compensation in the converter.

The differential signals are essentially decoupled from external vibrations in the Mass flowmeter FCM2000 because of its S-shaped double pipe system. Additionally, the digital filter technology assures wide insensitivity to external vibrations. Should the vibrations be the same as the excitation frequency, then the measurements could be affected.

The relatively large mass of the variable area float makes it sensitive to vibrations. Vibration dampeners and wall mounting should be utilized.

Pulsation

Pulsation effects are a function of the inertia of the metering system. Only when the metering element can follow the pulsations without lag will the measurement be unaffected.

Meters which contain moving parts are therefore subjected to increased wear. It is essential that a damping device be provided. Oval Gear meters and Oscillating Piston meters have so much inertia that they provide a degree of self damping sufficient for averaging purposes. The metering error will increase somewhat.

In Chapter 2.1.3 the dangers of pulsation for Lobed Impeller meters was noted. Turbine, Vortex, and Swirl flowmeters measure the flow essentially without inertia, include however, in the connected converters, time constant elements. Again the average is obtained with slightly larger errors. Gas Turbine flowmeters are in danger when the rotational speed increases too quickly resulting in more bearing wear should over speeding occur.

As a result of the nonlinear relationship between flowrate and differential pressure the error in Differential Pressure flowmeters is also affected by pulsations. Therefore a damping device is definitely recommended, preferably using storage volumes or expansion tanks in the fluid line. The Hodgson number can be used to calculate the required volumes. The damping elements in the differential pressure transmitter accommodate small pulsations.

The variable area float tends to dance when pulsations are present. Therefore damping elements must also be used here. Metal pipe flowmeters can have damping elements installed as an option.

Reverse Flow Metering

An extreme form of pulsation can lead to reverse flow. Additionally many pipelines are specifically designed for bidirectional flow. Are there meters which can also measure reverse flow?

The direct volumetric totalizers can naturally reverse their direction and totalize backwards when the secondaries include appropriate provisions. The best solutions are provided by the Electromagnetic and Mass flowmeters which provide all measurements for both flow directions and can switch automatically.

Supply Power

Measurement and control technology operates with measurement signals which must be transmitted over long distances. Therefore all totalizers and flowrate meters provide appropriate output signals whose generation requires electrical power. The flowmeters additionally require supply power for their operation.

When only local indication is required, electrical lines are not required for the totalizers and the Variable Area flowmeters.

In very few instances these days is the standard 0.2 … 1 bar pneumatic signal used. These meters must be designed with appropriate transmitters whose power is provided by a pressurized air supply of 1.4 bar. Pneumatic transmitters are available for Differential Pressure and Variable Area flowmeters.

Grounding the Electromagnetic Flowmeters

Grounding per VDE 0100 is not only required because of safety considerations but also to assure proper operation of the flowmeter primary. The signals measured at the electrodes are only a few millivolts in amplitude and can be affected by stray ground currents which may flow through the flowmeter. The grounding screws on the flowmeter primary are to be connected protective earth (for EX-Designs per VDE 0165 to Potential Equalization, PA) in accord with VDE 0100, Part 540. For measurement reasons the ground and signal potentials should be identical, if possible. An additional ground connection to the terminals (supply power) in the connection box is not required. For plastic or insulated pipelines **one** grounding plate or grounding electrodes are required for connections to earth. When pipeline section is not free of stray currents, it is recommended that a grounding plate be installed **up- and downstream** from the flowmeter.

Grounding electrodes are used when price considerations are important and when stray currents are not present. **Attention**, not all instrument designs can be specified with grounding electrodes.

One grounding plate is installed when plastic or insulated pipeline are used and for instrument designs, which do not include grounding electrodes.

Two grounding plates are installed for insulated pipelines when stray potentials may exist in the pipeline. Also when cathodic protection is used, and the flowmeter primary is to be installed electrically insulated in the pipeline so that the cathodic potential can be shunted around the flowmeter primary.

4.1.4 Operating Characteristics of the Meters

The operating characteristics of the instruments are listed inTbl. 4-16:

	Instrument Type	Flow Range	Error Limits in % of rate	Dynamic Behavior, Time Constant [s]	Pressure Drop at q_{vmax} [bar]
Direct volume totalizer	Oval Gear Meter	1:2...1:10	0.1...0.3		4
	Oscil. Piston Meter	1:5...1:250	0.2...2		3
	Lobed Impeller Meter	1:20 (1:50)	1		0.03
Indirect volume totalizer	Rotary Vane Meter	1:100...1:350	2...3		0.25...0.75
	Woltman Meter	1:100...1:12500	2...3		0.005...0.5
	Turbine Flowmeter	1:5...1:20	0.5 (liquid) 1 (gas)		0.5...1
	Vortex Flowmeter	1:15...1:20	0.75 (liquid) 1 (gas)	0.2	0.7 (water) 0.07 (air)
	Swirl Flowmeter	1:15...1:25	0.5	0.2	0.3 (water) 0.05 (v)
Flowmeters	Diff. Pressure Flowmeter	1:5 (1:10)	2		0.005...1 func. of Diff. Pressure and opening ratio
	Variable Area Flowmeter	1:12	Class 1.6/2.5		0.005...0.2
	Electromagnetic Flowmeter	1:50	0.25	0.2	same as pipeline
	Ultrasonic Flowmeter	1:10	1	1	same as pipeline
	Mass Flowmeter Coriolis	1:100	0.15	0.2	0.5...1
	Mass Flowmeter Thermal	1:40...1:150	1	0.012	0.002

Tbl. 4-16: Operating Characteristics

	Instrument Type	Moving Parts	Wear, Wear Parts	Material Selection for Fluid Wetted Parts	Cleaning Sterilization
Direct volume totalizer	Oval Gear Meter	oval gears, gear train	bearings, gear teeth	oval gears and housing of gray cast iron, SS, Bronze, bearings of hard carbon, SS	–
	Oscil. Piston Meter	piston, gear train	bearings, piston	housing & metering chamber of gray cast iron, SS, Bronze, Duroplast, piston of gray cast iron, hard rubber, carbon, PCTFE, Tantalum, plastic	+
	Lobed Impeller Meter	impeller, gear train	bearings, impeller	Piston and housing of Alum.-alloy or gray cast iron, bearings of SS	–
Indirect volume totalizer	Rotary Vane Meter	rotary vane, gear train	bearings	housing of Brass, Metering insert of plastic, Axles of SS	–
	Woltman Meter	rotary vane, gear train	bearings	housing of gray or ductile cast, rotary vane and metring insert of plastic, Brass, SS	–
	Turbine Flowmeter	rotor	bearings	rotor and housing of SS, bearings of Sapphire, tungsten carbide	–
	Vortex Flowmeter	none	insignificant wear	SS (1.4571[316Ti])	+
	Swirl Flowmeter	none		housing of SS (1.4571[316Ti]); guide bodies of 1.4571[316Ti], Hastelloy C; sensor prot. of 1.4571[316Ti], Hastelloy C	+
Flowmeters	Diff. Pressure Flowmeter	none	metering edges	SS (1.4571[316Ti])	
	Variable Area Flowmeter	float	metering edges	SS (1.4571[316Ti]), Hastelloy C, PTFE, PVDF, Glass	+
	Electromagnetic Flowmeter	none	insignificant wear	liner of hard/soft rubber, PFA, PTFE, electrodes of 1.4571[316Ti], Hastelloy, Tantalum, Platinum, Carbon	++
	Ultrasonic Flowmeter	none		SS (1.4571[316Ti]), Hastelloy C	++
	Mass Flowmeter Coriolis	none		SS (1.4571[316Ti]), Hastelloy C, 1.4435	++
	Mass Flowmeter Thermal	none		SS, Hastelloy C, Ceramic	++

Tbl. 4-17: Continuation of Operating Characteristics

Instrument Type		Measurement Indication and Measurement Transmission								
		Local Indica-tor	Alarm Con-tact	Cur-rent Output	2-wire De-sign	Pul-se	Data Link	HART	Ex-Prot.	Certifica-tion Ap-proval
Direct volume totalizer	Oval Gear Meter	yes	yes	n	n	yes	n	n	not req'd	liquids
	Oscil. Piston Meter	yes	n	n	n	yes (Ex)	n	n	not req'd	liquids
	Lobed Impeller Meter	yes	yes	n	n	yes	n	n	not req'd	gases
Indirect volume totalizer	Rotary Vane Meter	yes	n	n	n	yes	n	n	not req'd	water
	Woltman Meter	yes	n	n	n	yes	n	n	not req'd	water
	Turbine Flowmeter	n	n	n	n	yes	n	n	yes	liquids gases
	Vortex Flowmeter	yes	yes	yes	yes	yes	yes	yes	yes	n
	Swirl Flowmeter	yes	yes	yes	yes	yes	yes	yes	yes	n
Flowmeters	Diff. Pressure Flowmeter	yes	n	yes	yes	n	yes	yes	yes	n
	Variable Area Flowmeter	yes	yes	yes	yes	yes	n	yes	yes	n
	Electromagnetic Flowmeter	yes	yes	yes	yes	yes	yes	yes	yes	water, food, chemicals
	Ultrasonic Flowmeter	yes	n	yes	yes	yes	yes	yes	yes	hot water
	Mass Flowmeter Coriolis	yes	yes	yes	n	yes	yes	yes	yes	yes
	Mass Flowmeter Thermal	yes	yes	yes	n	yes	yes	yes	yes	n

Tbl. 4-18: Continuation of Operating Characteristics

Flow Ranges

The flow ranges for the Oval Gear and Oscillating Piston meters are a function of the viscosity of the fluid. They are 1 : 10 for viscosities up to approx. 300 mPa·s and increase to 1 : 20 for viscosities of $1 \cdot 10^4$ mPa·s. The conditions are exactly the opposite for indirect totalizers and flowmeters. With increasing viscosity the start of the linear range increases and the flow ranges are reduced.

Because of the square root relationship which exists in the Differential Pressure flowmeters between the flowrate and the differential pressure the flow range is a function of the required accuracy. A flow range of 1 : 3 promises very high accuracy.

Electromagnetic and Ultrasonic flowmeters represent a special situation in that their range end values can be set and thereby optimized. Thermal Mass flowmeters achieve flow ranges up to 1:150.

Error Limits

The error limits represent controversial specifications, because they are values published by the manufacturers for ideal boundary conditions. In practice deviations from the ideal conditions are common, so that additional stipulations must be made for the instrument accuracies. It is important to realize that the accuracy may be based on the measured value (% of rate) or on the range end value (% of max). In the VDI/VDE Directive 2600 (4) the types of errors, reference values, and error conditions are defined.

Through special calibrations better accuracies can be achieved, which are generally valid only for a specific time period. Exactly how the error limits can be affected by contamination, wear and physical changes is not always known

The values listed in the table are based on the measured values [% of rate]. Based on these values a classification system for the Variable Area flowmeters was established, VDI/VDE 3513 Sheet 2 which represents a combination of error values based on both the measured and range end values. 75% of the of the error values for an accuracy class are percent of rate values and the other 25% are percent of max. values.

The sum of the two values yields the Accuracy Class **1 - 2.6 - 2.5 - 4 - 6 - 10.**

Dynamic Response

The term time response defines the output vs. time relationships which exist after a step change in the metered value has occurred (step response). The characteristic value is the time constant T (also τ) and the time T_a required to reach the actual value. After a step change the indication reaches 63% of the actual value after time T. After 5 T, which corresponds to T_a, the indication is essentially equal to the actual value.

For totalizers, information regarding their time response is seldom given because both the moving masses and the viscosities of the fluids vary. For the Variable Area flowmeters the same comments apply while for the Differential Pressure flowmeters the pressure lines with their various fittings influence the time response.

Wear

Long term meter life is understandably an important requirement of the users. Therefore the mechanical wear must be kept to a minimum.

Wear is caused primarily by abrasion of the metering elements (by the fluid) and by the bearing friction of the moving parts. The Electromagnetic flowmeter can be considered to be ideal because the smooth inside wall only shows wear when highly abrasive fluids are metered such as lime slurries, sand - water mixtures, or coal - water mixtures in solids transport. If the walls are lined with polyurethane or soft rubber then even these fluids rarely cause difficulties.

Even though Vortex and Swirl flowmeters have no moving parts, they do have parts which extend into the flow stream. A specific size, hardness and edge sharpness of solid particles in the fluid cannot be exceeded. Small dust components in gases and plastic suspensions are permissible.

The metering edge in orifices must remain sharp because even small changes cause erroneous measurements. In extreme cases a nozzle should be used for small particle concentrations in the fluid. Even then the pressure connections can create problems because they may become plugged. The metering edge of the Variable Area flowmeter floats is also precisely machined. It may not be damaged.

Bearing wear in the totalizers and their rotating meter bodies can be added to the difficulties mentioned above. A small quantity of hard particles in the fluid can destroy these meters. Ideal are metered fluids which have a tendency to lubricate.

Materials

Material selection always requires information about corrosion problems. Some fluids are chemically harmless, but can become corrosive when small amounts of other materials are present, perhaps only contamination. Therefore care must be exercised. The variety of possible materials is especially restricted where complicated and difficult to manufacture parts are required. This is particularly true in the volumetric totalizers and to a certain extent in the Swirl, Mass and Thermal Mass flowmeters.

At first glance the Differential Pressure flowmeters would seem to present no problems. But not only must the orifice plate or the nozzle be manufactured of resistant metals but also the pressure lines, fittings and the pressure transmitter must also be made of suitable materials. Sometimes constant flushing of the pressure lines is used to help.

Now it becomes a question of cost. This is the case when Variable Area flowmeters are made of resistant materials. They are only installed when supply power is unavailable at the metering location. The material selection problem is solved almost ideally for Electromagnetic flowmeters because the PTFE liner material can be used for almost all fluids. Platinum is exceptionally good as an electrode material. It may be possible to solve the electrode material problem by using the capacitive electrode design.

The Ultrasonic flowmeter requires the proper protection tube material for the sound transducers (transmitter / receiver).

Cleaning, Sterilization

Why must a closed pipeline be cleaned? There are various answers: deposits due to sedimentation or adhesion reduce the cross sections, crystal formations block the flow, residue can contaminate the product. The ability to clean is a determining factor for meter selection.

Where deposits are to be expected meters with moving parts are seldom installed. Also in installations of Swirl, Vortex and Thermal Mass flowmeters difficulties can be encountered. In the Ultrasonic flowmeter the sound path is altered so that erroneous measurements may occur. Nonconducting deposits affect the Electromagnetic flowmeters unless the same meter type with capacitive electrodes is installed. Electrically conductive deposits short out the signal and cause erroneous measurements.

Deposits are removed by flushing, dissolving, or by mechanical cleaning using a brush or scraper. A prerequisite for using a scraper is a pipeline with a defined diameter without internal projections. This requirement can only be met by an Electromagnetic flowmeter, and perhaps by the Ultrasonic flowmeter. Among the residues remaining in the pipeline are bacteria in the food industry which can spoil the product. Thorough cleaning and sterilization using steam, liquid cleaning agents, acids and bases cannot be avoided. This is usually accomplished using **CIP**- (Clean In Place) and **SIP-**(Sterilize In Place) procedures in which all elements in the system remain in place. The CIP capability is determined by testing. Certificates have been granted for Variable Area, Electromagnetic, Thermal and Coriolis Mass flowmeters. The Oscillating Piston meter must be disassembled for cleaning.

4.1.5 Installation and Maintenance

The user of measurement information expects a problem free installation of the meter and thereafter only wants to see exact measurement values, the meter itself is no longer of interest. Even though modern technology comes close to fulfilling these expectations, regular monitoring can prevent failures. Therefore included in the selection of a meter is the question regarding the capabilities of the maintenance personnel.

The meter is installed in the pipeline relatively straightforward manner using flanged or threaded connections while giving consideration to the conditioning sections e.g. Swirl and Thermal Mass flowmeters. At this point the requirement for stress free installation must be stressed because very often the meters are installed in existing pipelines with existing stresses. Wafer designs (sandwich) require exact centering. There are Ultrasonic flowmeters for which the transducers (transmitter / receiver) must be welded into the pipeline wall. This method produces error free measurements only when an on-site calibration is conducted which takes into account the actual pipeline geometry.

The work is essentially completed when totalizers and Variable Area flowmeters which operate without supply power are installed. When supply power is required for the meters it must be made available and connected. Primaries with remote mounted converters communicate with each other with low level disturbance sensitive signals. Therefore special shielded cables are used. Compact meters avoid this expense.

An appreciable expense is required for Differential Pressure flowmeter installations. Pressure lines and various fittings must be mounted and installed. The differential pressure transmitter requires supply power.

All meters are designed nowadays so that maintenance personnel can monitor the proper functional operation of a meter through simple tests. A number of instruments are self monitoring and announce error conditions.

The wear in bearings and metering elements in the rotating totalizers can usually be best determined by a visual examination. That is why these meters are constructed so that they can be opened at the metering site.

The EMF must be installed axisymmetrically. The EMF must always be completely filled with the fluid being metered and may not drain. An exception is the PARTI-MAG II. This EMF is designed for partially full pipeline metering. If it is not possible to assure that the flowmeter primary will not drain, then for sizes DN 10[3/8”] and above with cable lengths up to 50 m (for the remote design) the output signals can be turned off from an external contact or automatically using the „Detector empty pipe“ module. This eliminates errors in the system when the flowmeter drains.

In most installations it is sufficient to install a straight pipe section with a length of 3 x D upstream of the flowmeter and on 2 x D long downstream. These are requirements for the user. According to the reference conditions in EN 29104, certified designs or DVGW-Directives other straight section lengths are specified which must be maintained.

The EMF must be installed so the meter pipe is always filled with fluid (exception PARTI-MAG II). Valves or other shut off devices should be installed in the outlet section. A slight slope of approx. 3 % is advantageous for degassing. Assure that the imaginary line which connects the two electrodes is horizontal if possible or no more than 45° from the horizontal, so that any air or gas bubbles cannot affect the measurement voltage.

Note:

Because of the different accuracy specifications as well as meter size dependent up- and downstream lengths incorporated within the instrument itself, (In-/outlet from flange to electrodes) shorter up- and downstream sections may be used. For further information please contact **ABB**.

The monitoring and test system for the electromagnetic meters is optimally structured. In addition to internal test functions, simulators are available with whose use practically all parameters can be checked.

		Installation Tasks	Pipeline Upstream from Meter	Maintenance During Operation	Self Monitoring	Service
Direct volume totalizer	Oval Gear Meter	connect flanges	filter	mainte- nance free	not possible	local dis- assembly possible
	Oscil. Piston Meter	connect flanges or threads	filter recom- mended, no condition- ing section	mainte- nance free	not possible	
	Lobed Impeller Meter	connect flanges	filter	monitor lubrication	not possible	
Indirect volume totalizer	Rotary Vane Meter	connect flanges or threads	no conditioning section	mainte- nance free	not possible	meter insert exchange possible
	Woltman Meter	connect flanges	no conditioning section	mainte- nance free	not possible	
	Turbine Flowmeter	connect flanges, electrical connections	no conditioning section	mainte- nance free, monitor pos- sible foreign lubrication	not possible	exchange primary
	Vortex Flowmeter	connect flanges or install wafer design, electrical connections	Long conditioning section	mainte- nance free	continu- ous plau- sibility and error monitor- ing with error mes- sages	electronic control function and test values, sensor can be ex- changed
	Swirl Flowmeter	connect flanges, electrical connections	no conditioning section	mainte- nance free		

Tbl. 4-19: Maintenance Efforts

		Installation Tasks	Pipeline Upstream from Meter	Maintenance During Operation	Self Monitoring	Service
Flowmeters	Diff. Pressure Flowmeter	center meter in flanges, connect press. tap lines, fittings, transmitter, supply power	long conditioning section	regular inspection recommended	not possible	Direct measurements at transmitter
	Variable Area Flowmeter	connect flanges or threads	no requirements	maintenance free	continuous plausibility and error monitoring with error messages	Glass flowmeter with „SNAP-IN“ design
	Electromagnetic Flowmeter	connect flanges, electrical connections	short conditioning section	maintenance free		electronic control function and test values, simulator
	Ultrasonic Flowmeter	connect flanges or weld stubs, electrical connections	long conditioning section	maintenance free	indicate signal losses	
	Mass Flowmeter Coriolis	connect flanges, wall mount, electrical connections	none requirements	maintenance free	continuous plausibility and error monitoring with error messages	electronic control function and test values
	Mass Flowmeter Thermal	connect flanges or install wafer design and insert sensor	conditioning section	maintenance free	Error messages	sensor can be exchanged

Tbl. 4-20: Continuation Maintenance Efforts

4.2 Instruments for Channels and Free Surface Pipelines

The comparison(Tbl. 4-21) is not as extensive as those for meters in closed pipelines because a large number of parameters refer exclusively to closed pipelines and because the installation spectrum is being limited for these meters only. Channels and free surface pipelines are installed primarily in water and waste water applications so that only these fluids will be considered. Waste water often includes a variety of non-water components which must be considered when making comparisons. Chemically aggressive components play an important role in material selection. Solid components can cause errors or hamper measurements. Therefore it is important that the sweeping forces of the water are sufficient to carry the solids further.

		Meter Sizes	Max. Flowrate	Flow Range	Error Limits	Flowrate Indication and Transmission	Solids in Fluid	Air in Fluid	Flow Regime Effects
Open Channels	Weir Meter	practically unlimited	unlimited	1:20 (1:100)	> 3 %	by appropriate selection of converter all types are possible from local indication to HART-Protocol	danger of deposit build up before the weir and on the overflow edge	ventilation required so the stream separates at the edge	none
	Venturi Flume	width in mm 220...3514	13,990 m^3/h	1:10 to 1:20	(design type calibration) ± 6 % of rate		no deposits when minimum velocity is maintained	air removed in entry sections	entry section of 20xW straight smooth and rectangular
Free Surface Pipelines	EMF in Invert	all sizes up to DN 2500 [100”]	267,000 m^3/h	1:50	± 0.25 % of rate	EMF meters offer all possibilities from local indication to data links & HART-Protocol + PROFIBUS + FF	danger of deposits at low velocities and heavy solids	reduce air otherwise errors	3 x D upstream section
	Parti-MAG	DN 150 to DN 2000 [6” to 78”]	171,000 m^3/h	1:100	± 1.5 % of max.		no sedimentation	air removed in entry sections	Conditioning sections 10xD up- & 5xD downstream

Tbl. 4-21: Meters for Open Channels and Free Surface Pipelines

4.2.1 Solids in the Fluid

When the flow velocity in the dammed area ahead of a weir decreases the particles carried along with the fluid settle. The deposits change the geometric conditions and cause metering errors. Floating particles change the geometry even more and may even plug the meter overflow.

The Venturi flume accelerates the fluid in its constricted areas and drives the solids through. The floating particles may have a negative impact of the level measurements. Foam build up causes metering errors which are a function of the type of converter used.

In pipe inverts extremely low velocities can be present leading to the formation of deposits which have little or no effect on the measurements. When the velocity increases the invert is flushed (sand deposits in straight pipelines are carried along at velocities > 0.25 m/s).

Installing a Parti-MAG II solves these problems automatically.

4.2.2 Gas Components

Gas components are usually entrained air. Since all the instruments discussed in this chapter measure the volumetric flow, the air in the water is considered as fluid and causes an error as large as the volume of entrained air.

The weir requires ventilation, air entry at its sides so that the overflow stream can separate from the metering edge and not attach to the outer side of the weir due to the presence of a vacuum. Air resulting from this ventilation causes no errors because the level measurement is made approx. 4 x h ahead of the weir. Basically open channel measurements are rarely affected by entrained air.

The Parti-MAG II also allows the fluid to deaerate in its entry section, The possibility exists however, when the pipe runs full that entrained air can no longer be separated in the entry section. Errors result.

In inverts however air can be sucked in due to vortices in the inlet. Through an increase of the level ahead of the invert (inlet shaft) this effect can be prevented. When the incoming fluid falls into the inlet shaft as a free stream the same air injection effects occur.

4.2.3 Flow Stream Effects

The flow stream effects in closed pipelines were described in Chapter 4.1.2. Those conditions also apply in this situation, especially for the Electromagnetic flowmeter in an invert. An additional parameter complicates the measurements in open channels and that is the nature of the upper surface of the liquid because wave motion in the metering section will be included in the measurements. The metering weir is not as affected as the Venturi flume.

The Venturi flume dams the flow in the water entry section and thereby quiets the surface when subcritical flow is present. The entry section should be straight with a constant cross sectional area without any unevenness. The location of any hydraulic jump should be at least 20 x w (flume width) upstream of the Venturi flume. On the exit side there is a requirement that in no case may backflow be present in the Venturi flume which could produce a level at the metering location which corresponds to a higher flowrate. The Parshall flume accommodates a slight backflow.

This backflow can be ideally handled in the Parti-MAG II Electromagnetic flowmeter for partially full pipelines because this meter measures the combined dynamic effects of velocity and the utilized cross sectional area. This means that at zero flow no metering signal exists. The Parti-MAG II can measure flow in both directions. It can also meter the backflow.

The velocity distribution within the flow cross sectional area in the Parti-MAG II should be approximately uniform. Therefore subcritical flow is preferred so that the irregularities that might exist in the vicinity of a hydraulic jump can be avoided. Below are shown some practical piping installations:

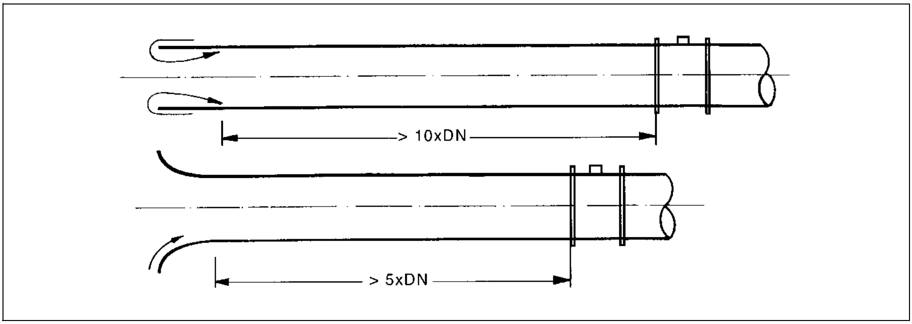


Fig. 4-144: Pipe Inlet

When the flow into the pipe occurs at a blunt entry (Fig. 4-144) evidences of separation at the wall near the inlet appear coupled with vortex formation. Dependent on the pipe roughness, inlet sections 15 x D (pipeline size) or longer are required so that the flow is uniform in the metering section. A more effective flow stream entry with a trumpet shape can be used to reduce the length of the inlet section.

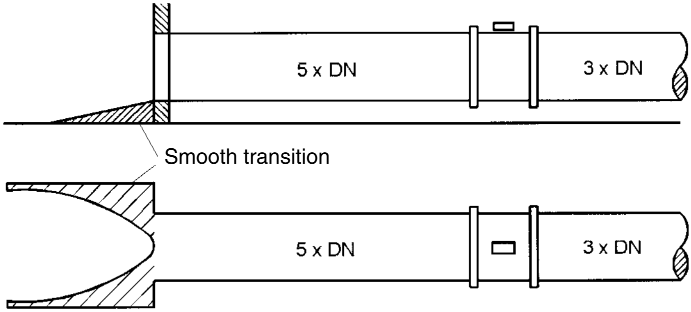


Fig. 4-145: Transition from Rectangular to Circular Cross sections

A meter as interesting as the Parti-MAG II reduces construction expenditures and can therefore be installed in many locations. The transition to a circular cross section is very important because waves and vortices can occur at these locations. An example of a transition from a rectangular to a circular cross section is shown in Fig. 4-145. Smooth transitions are preferred with an important consideration that the bottom elevation extend right through the Parti-MAG.

A constant bottom elevation should be maintained for installation in rounded channels whenever possible. The more the channel approaches an egg shape the more readily can a Parti-MAG II be fitted. An effective flow stream transition (Fig. 4-146) should also be provided in these situations.

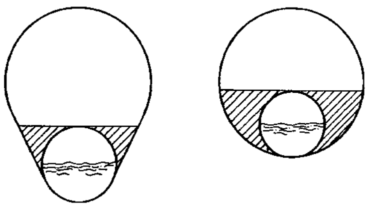


Fig. 4-146: Transition to a Round Cross Section

Extremely important are the considerations of the conduit conditions far from the metering location. A perpendicular inflow from the side generates vortices which will persist even after a 15 x D long straight section (Fig. 4-147). An overflow weir in the entry assures a satisfactory flow stream.

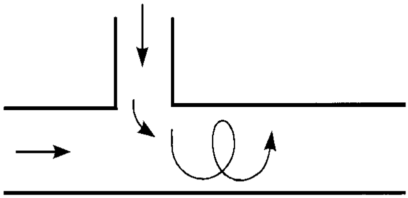
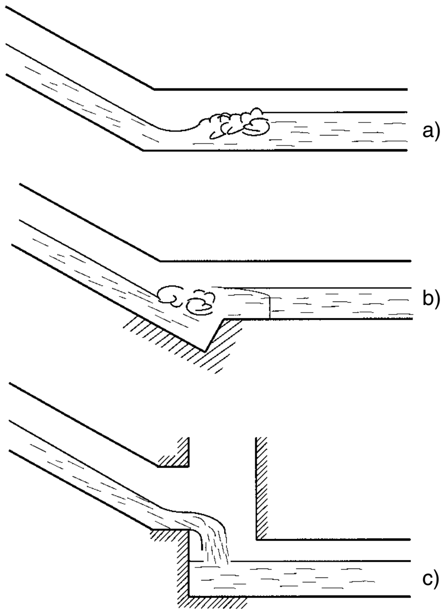


Fig. 4-147: Partially Full Channel with Perpendicular Side Inflow (Top View)

Supercritical inflow must be transformed to subcritical. The hydraulic jump shown in Fig. 4-148a moves in position as a function of the energy content of the inflow.



This uncertain flow stream condition requires either a very long conditioning section before the metering location or a local elimination of the hydraulic jump through installation of a stilling basin (Fig. 4-148b) which converts the kinetic energy into thermal energy.

Another variation is the transition shaft shown in Fig. 4-148c. In the shape shown there is a danger of entrained air existing in the outflow section during full flow conditions. Therefore air eliminators are required.

Fig. 4-148: Supercritical Inflow

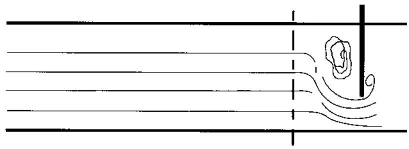


Fig. 4-149: Flat Gate in Outflow

The gate in the line (Fig. 4-149) generates unsteady flow stream conditions. The hydraulic influences upstream however are small. Therefore the meter location should be situated 1 to 3 x D ahead of the gate.

The upstream effects of disturbances downstream of the Parti-MAG II are relatively small so that generally a short outlet section is sufficient. An example is the free fall exit (Fig. 4-150).

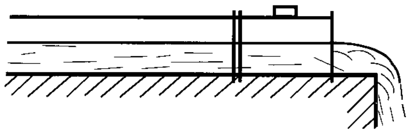


Fig. 4-150: Free Flow After a Meter Site

The meter location must far enough away so that the fluid surface level drop off does not begin inside the meter. A distance of 3 x D is usually sufficient.

Occasionally a measurement must be made after a channel bend which may include sloped bottom(Fig. 4-151). The centrifugal forces produce a sloped surface with a perpendicular secondary flow. The local conditions determine possible measurement errors.

Fig. 4-151: Cross Section Through a Channel Bend

5 Overview of the Outstanding Meter Features

5.1 Oval Gear Meters, Oscillating Piston Meters

Advantages:

- High accuracy
- Suitable for fluids with high viscosity
- Operates in both flow directions (forward and reverse)
- No flow profile effects, therefore no conditioning sections
- No supply power
- Certification approvals

Limitations:

- Volumetric totalizer
- Only for liquids
- High pressure drop
- Moving parts, wear
- Accuracy decrease for lower viscosities due to leakage losses
- Sensitive to contamination, filter required
- Flow blockage at zero flow through soilage
- Sensitive to overloading
- Monitoring and maintenance

5.2 Lobed Impeller Meters

Advantages:

- Exceptional accuracy for gas measurements
- No conditioning sections
- No supply power
- Certification approvals

Limitations:

- Volumetric totalizer
- Only for gases
- Moving parts, wear
- Flow blockage at no flow due to contamination
- Sluggish toward quick changes
- Also affected by quick changes at high pressure differentials, danger of over speeding
- Monitoring

5.3 Turbine Meters

Advantages:

– No supply power for Rotating Vane and Woltman meters
– Rotating Vane and Woltman meters certified for water
– Turbine flowmeters suitable for cryogenic fluids
– Turbine flowmeters usable at extreme temperatures and pressures
– Turbine flowmeters certified for gas

Limitations:

– Limited material selection
– Only for low viscosities
– Moving parts, wear
– Sensitive to contamination
– Axial flow totalizers flow profile sensitive
– Conditioning sections
– Affected by overloading and fast changes at high differential pressures, danger of over speeding
– Vibration sensitive

5.4 Vortex Flowmeters

Advantages:

– No moving parts
– Rugged construction
– Suitable for liquids, gases and steam
– Easily sterilized
– Unaffected by pressure, temperature and density changes
– Linear relationship between flow rate and measurement signal

Limitations:

– Conditioning sections
– Minimum Reynolds Number required

5.5 Swirl Flowmeter

Advantages:

- No moving parts
- No conditioning section → 3xD/1xD
- Suitable for liquids, gases and steam
- Exceptional repeatability
- Unaffected by pressure, temperature and density changes

Limitations:

- Pressure drop
- Minimum Reynolds Number required

5.6 Differential Pressure Flowmeter

Advantages:

- Universally suitable for liquids, gases and steam
- Also in extreme situations, e.g. viscosity, suitable because of the variety of versions
- Calculations possible for unusual situations
- Suitable for extreme temperatures and pressures
- Range changes possible
- Low pressure drop for nozzles

Limitations:

- Square root relationship between flow rate and differential pressure, therefore shorter range
- Affected by pressure and density changes
- Pressure drop for orifice plates
- Edge sharpness for orifice plates must be assured therefore no solids or contamination
- Very long conditioning sections
- Expensive installation requiring pressure lines, fittings and transmitter
- Installation and maintenance experience advantageous
- Maintenance intensive

5.7 Variable Area Flowmeter

Advantages:

- Inexpensive
- No supply power for local indication
- Suitable for liquids, gases and steam
- No conditioning sections
- Simple meter construction, therefore installation and maintenance friendly
- Indication with opaque fluids
- Metal meter pipe with converter
- Metal pipe meter can be sterilized, CIP tested

Limitations:

- Vertical installation
- Constant pressure drop
- Affected by density, temperature and viscosity changes
- Solids damage metering edge, otherwise slight contamination allowed
- Affected by pulsation and vibration
- Expensive when exotic materials are required

5.8 Electromagnetic Flowmeter

Advantages:

- Unobstructed flow passage
- No moving parts
- No additional pressure drop
- Essentially flow profile insensitive therefore no conditioning sections
- Unaffected by changes in temperature, density, viscosity, concentration, electrical conductivity
- Favorable material selections for chemically aggressive and abrasive fluids
- Unaffected by contamination and deposits
- Especially suitable for hydraulic solids transport
- Can be sterilized, CIP tested
- Linear relationship between flow rate and measurement signal
- Meters in both flow directions (forward and reverse)
- Flow range setting can be optimized
- Minimum maintenance, but still maintenance friendly
- Certification approvals

Limitations:

- For liquids only
- Lower conductivity limit 0.05 µS/cm
- Gas inclusions cause errors

5.9 Ultrasonic Flowmeter

Advantages:

- Unobstructed flow passage
- No moving parts
- No additional pressure drop
- Favorable material selections for chemically aggressive fluids
- Linear relationship between flow rate and meter signal
- Minimum maintenance
- Meters in both flow directions (forward and reverse)
- For transit time meters unaffected by temperature, density and concentration
- Installation of transducers in existing pipelines possible, with on site calibrations

Limitations:

- For liquids, gas still problematical
- Sound beam must traverse a representative cross section therefore flow profile dependent, long conditioning sections required
- Errors due to deposits
- Transit time meters require clean liquids
- Doppler meters only for slight contamination and few gas bubbles
- Doppler meters affected by sound velocity changes due to temperature, density and concentration changes
- Unsuitable for heavily contaminated liquids
- Gas bubbles cause errors

5.10 Mass Meters, Coriolis Principle

Advantages:

– True mass metering
– Additional temperature and density measurements
– High accuracy
– Unaffected by pressure, temperature and viscosity
– No conditioning sections
– Meters in both flow directions (forward, reverse)
– Can be sterilized, CIP-tested, EHEDG certified
– Flow range settings can be optimized for flowrate and for density
– Self draining

Limitations:

– For liquids only
– Affected by gas inclusions
– Vibration sensitive when improperly installed
– Material selections limited
– Large size limitations

5.11 Mass Meters, Thermal

Advantages:

– True gas mass metering
– No pressure and temperature corrections
– Very small pressure drop
– High accuracy
– Wide flow range
– No moving parts
– Rugged design
– Fast response time
– Easily sterilized

Limitations:

– Only for gases
– Conditioning sections

5.12 Metering Weirs

Advantages:

- Simple design
- Minimum space requirements at meter site
- Minimum construction costs

Limitations:

- Damming, therefore space requirements ahead of the meter site
- Danger of deposit build up before the weir, not suitable for waste water
- Stream separation through ventilation must be assured
- Affected by large floating items

5.13 Venturi Flume

Advantages:

- No potential energy differences compared to the weir
- Low pressure drop
- Suitable for unclean waste water
- Easy maintenance

Limitations:

- Nonlinear flow characteristic
- Channel constriction, therefore damming of the headwater and deposit build up danger due to velocity decrease
- Plugging danger due to spurious floating items
- Measurement impossible when backflow exits in tail water (exception Parshall Flume)
- Quality and reliability of the metering a function of the connected converter
- Installation expense

5.14 Electromagnetic Flowmeters in Inverts

Advantages:

- All the advantages of the electromagnetic meters listed in Item 5.8
- Smaller sizes more economical than the PartiMAG II
- More accurate than the PartiMAG II

Limitations:

- Construction required
- Higher pressure drop than PartiMAG II
- Deposit danger for low velocities

5.15 PartiMAG II Electromagnetic Meter for Partially Full Pipelines

Advantages:

- Unobstructed flow passage
- No additional pressure drop
- No deposit build up danger
- All the advantages of the electromagnetic meters listed in Item 5.8
- Easy cleaning
- Backflow may be present

Limitations:

- Conditioning sections

6 Keywords for the Operating Conditions and Requirements at the Metering Site

When a metering site is being planned certain requirements must be satisfied in order for the desired metering functions to be realized. Shall the meter provide information by itself (local indication) or support other functions (e.g. provide the set point value for a controller). The planner begins his preparations for the meter selection by considering the operating conditions. He raises questions regarding the fluid, the local conditions and the data presentation requirements. The following keyword summary is presented as a selection aid:

Fluid Properties:

- Gases, steam: dry, wet
- Liquids: gas and solids content, crystallizing component deposits, dust in gas
- Density
- Temperature, temperature variations, time relationships
- Viscosity
- Electrical conductivity of the fluid, of a coating
- Chemical aggressiveness, material selection
- Abrasion danger

Operating Conditions:

- Pipeline size
- Design of a channel, slopes, damming
- Pressure rating
- Flow rate, smallest, largest value: type of flow changes (step changes)
- Flow stream conditions: uniform, turbulent flow velocity distribution, swirl, pulsation
- Bidirectional (forward and reverse)
- Static pressure, pressure shock, pressure drop allowed

Ambient Conditions:

- Ambient temperature
- Humidity effects, Protection Class
- Dust entry, Protection Class
- Vibration
- Pipeline construction before and after the meter
- Explosion protection
- Supply power, cabling
- Electrical radiation disturbances
- Mounting possibilities

Data Presentation:

- Accuracy
- Fixed, adjustable flow range internal, external
- Internal, external monitoring capabilities
- Local indication
- Totalization, integration
- Alarm signals
- Standardized analog output, what value?
- Pulse output for remote totalization
- Data link, which type?
- PROFIBUS
- HART-Protocol
- Explosion protection
- Certification

7 Materials, Corrosion Resistance Tables

Included among the criteria for meter selection are the materials to be utilized. Of primary interest are those materials which come in contact with the fluid. Also the ambient conditions must not be neglected where it is most important that humidity be considered.

Generally the user knows his fluids so well that he can readily indicate suitable materials. The following tables are provided for assistance. The listed information is taken from manufacturer's publications. A guarantee for the completeness and correctness cannot be given.

The following list includes the parts in the individual meters which come in contact with the fluid

Vortex Flowmeter:

Meter pipe:	1.4571/316Ti; 1.4435/316L; Hastelloy C
Sensor:	1.4571/316Ti; 1.4435/316L; Hastelloy C
Shedder:	1.4571/316Ti; 1.4435/316L; Hastelloy C
Gasket:	Graphite, PTFE, Viton A, Kalrez

Swirl Flowmeter:

Meter pipe:	1.4571/316Ti, 1.4435/316L, Hastelloy C
Sensor:	1.4571/316Ti, 1.4435/316L, Hastelloy C
Guide bodies:	1.4571/316Ti, 1.4435/316L, Hastelloy C
Gasket:	Graphite, PTFE, Viton A, Kalrez

Electromagnetic Flowmeter:

Liner	Hard rubber; Soft rubber; PFA; PTFE; Torlon, PEEK, PVDF
Electrodes	1. 4571; Hastelloy B; Hastelloy C; 1.4539; Titanium; Tantalum; Platinum/Iridium

Mass Flowmeter:

Meter pipe	1.4571/316Ti; 1.4435/316L; Hastelloy C

Thermal Mass Flowmeter

Meter pipe	1.4571/316Ti; Hastelloy
Sensor	1.4571/316Ti; Hastelloy:, Ceramic Al_2O_3
Gasket	Viton; Kalrez

Variable Area Flowmeter:

Meter pipe	Glass; Hastelloy C; PTFE; 1.4404/316L
Float	Glass; 1.4571/316Ti; Hastelloy C; PVDF; PTFE
Fittings	1.4301/304; PVC; Hastelloy C
O-Rings	Buna N; Viton A; Ethylene/Propylene = EPDM

The following symbols are used in the resistance tables:

+ indicates usable material
- indicates unsuitable material
  open fields indicate unknown resistance

Even though the tables may indicate that a metal is satisfactory, it may be possible that an attack could occur due to electrochemical reactions in the flowmeter.

					Metals									Non Metals										
	Gaseous/Liquid	Electrical Conductivity	Concentration (%)	Temperature (°C)	1.4301/304	1.4539	1.4541/321	1.4571/316Ti	Hastelloy B	Hastelloy C	Titanium	Tantalum	Platinum	Hard Rubber	Soft Rubber	PFA	PTFE	EPDM	Buna N	Viton A	PVDF	PVC	Glass	Al_2O_3
Acetic acid	F	+	50	80	+	+	+	+	+	+	+	+	+	-	-	+	+	+			+	-	+	+
Acetic anhydride	F	+	100	20	+	+	+	+	+	+	+	+	+			+	+					+	+	+
Acetone	F	-	100	40	+	+	+	+	+	+	+	+	+	-	-	+	+	+	-	-	-	-	+	+
Acetylene	G	-	100	20	+	+	+	+	+	+	+	+	+	+	+		+	+	+				+	+
Alum.chloride solution	F	+	30	70	-	-	-	-	+	-	-	+	+	+	+		+			+		+	+	+
Alum.chloride solution	F	+	80	70	-	-	-	-	+	-	-	+	+				+			+		+	+	+
Alum.sulfate solution	F	+	20	50	-	-	-	+	-	+	+	+	+	+	+		+			+			+	+
Alum.sulfate solution	F	+	50	50	-	-	-	+	-	+	+	+	+	-	-		+			+			+	+
Ammonia	G	-	100	50	+	+	+	+	+	+	+	-	+	-	-	+	+	+	+	-	-	-	+	+
Ammonia solution	F	+	25	50	+	+	+	+	+	+	+	-	+	-	-	+	+	+	+		+	+	+	+
Aniline	F	-	100	25	+	+	+	+	-	+	+	+	+	-	-		+			+		-	+	+
Argon	G	-	100	100	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Beer	F	+		10	+	+	+	+	+	+	+	+	+			+	+	+		+		+	+	+
Benzene	F	-	100	50	+	+	+	+	+	+	+	+	+	-	-	+	+	-		-	-	-	+	+
Blood	F	+			+	+	+	+	+	+	+	+	+			+	+	+		+	+	+	+	+
Brine	F	+		20	-	-	-	-	-	+	-	+	+			+	+	+	-	+		+	+	+
Bromine	F	-	100	20	-	-	-	-	-	+	-	+	+			+	+			+		-	+	+
Butane	G	-	100	50	+	+	+	+	+	+	+	+	+			+	+	-	+	+	-	-	+	+
Butyl acetate	F		100	50	+	+	+	+	+	+	+	+	+			+	+	+		-	+	-	+	+
Butyl alcohol	F	-	100	20	+	+	+	+	+	+	+	+	+			+	+		+	+		+	+	+
Butylene	G	-	100	20	+	+	+	+	+	+	+	+	+			+	+	+	+	+		+	+	+
Calcium chloride solution	F	+	100	20	+		+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+
Calcium chloride solution	F	+	30	20	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Calcium hydroxide solín.	F	+	50	20	+	+	+	+	+	+	-	-	+			+	+	+		-	+	+	+	+
Calcium hydroxide solín.	F	+	50	50	+	+	+	+	+	+			+	-	-	+	+	+	+	+	+	+	+	+
Calcium hypochlor. sín	F	+	20	50	-	-	-	-	-	+	+	+	+			+	+	+		+			+	+
Calcium permanganate s	F	+	50	20	+	+	+	+		+		+	+	-	-	+	+		+	+	+	-	+	
Calcium sulfate solution	F	+	20	50	+	+	+	+	+		+	+	+			+	+	+	+	+	+	+	+	+
Caprolactam	F	-	50	50				+	+	+			+	+	-								+	+
Carbolic acid	F	-	90	50	-	+	+	+	+	+	+	+	+	-	-	+	+	-	-	-	+	-	+	+
Carbolic acid, diluted	F	-		50			+	+	+	+	+	+	+			+	+				+	-	+	+
Carbon dioxide	G	-	100	50	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Carbon tetrachloride	F	-	100	50	+	+	+	+	+	+	+	+		-	-	+	+	+	-	+	+	-	+	+

	Gaseous/Liquid	Electrical Conductivity	Concentration (%)	Temperature (°C)	Metals									Non Metals										
					1.4301/304	1.4539	1.4541/321	1.4571/316Ti	Hastelloy B	Hastelloy C	Titanium	Tantalum	Platinum	Hard Rubber	Soft Rubber	PFA	PTFE	EPDM	Buna N	Viton A	PVDF	PVC	Glass	Al_2O_3
Carbonic acid	F	+		50	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+
Chlorinated water	F	+	100	20	-	-	-			+		+		-	-	+	+	+		+	+	-	+	+
Chlorine dioxide, dry	G	-	100	20	+					+		+	+	-	-	+	+				+		+	+
Chlorine, dry	G	-	100	20	+	+	+	+	-	+		+		+	-	+	+	-		+	+	+	+	+
Chlorine, dry	F	-	100	20	+	+	+	+	-	+		+	+	-	-	+	+	-		+	+	-	+	+
Chlorine, wet	G	-	100	20	-	+	-	-	-	+		+		-	-	+	+	-		+	+	+	+	+
Citric acid	F	+	60	50				+	+	+	-	+	+		-	+	+	+		+	+	-	+	+
Copper chloride solution	F	+	50	20	-	-	-	+	-	+	+	+	+	+	+	+	+		+		+	+	+	+
Copper sulfate solution	F	+	50	80	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	-	+	+
Copper sulfate solution	F	+	100	80	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	-	+	+
Deionized water	F	-			+	+	+	+	+	+	+	+	+	-	-	+	+	+	+	+	+	+	+	+
Diesel fuel	F	-	100	50	+	+	+	+	+	+	+	+	+	-	-	+	+	-	+		+	-	+	+
Ethane	G	-	100	50	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+		-	-	+	+
Ethanol	F	-	96	50	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-		+	
Ethyl acetate	F	-	100	50	+	+	+	+	+	+	+	+	+	-	-	+	+	-	-	+	-		+	+
Ethyl alcohol	F	-	100	78	+	+	+	+	+	+	+	+	+	+	+		+		+			-	+	+
Ethyl ether	F	-	100	20	+	+	+	+	+	+	+	+	+	-	-	+	+	-	+		+	-	+	+
Ethylene	G	-	100	50	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+		+	+	+	+
Ethylene chloride	F	-	100	50	-	+	-	+	+	+	+	+	+	-	-	+	+	-	+		-	-	+	+
Ethylene glycol	F	+	100	50	+	+	+	+	+	+	+	+	+			+	+	+			-	-	+	+
Fatty acid	F	-	100	50	+	+	+	+	+	+	+	+	+	-	-	+	+			+		+	+	+
Ferric chloride solín	F	+	3	20	-	+	-	-	-	+	+	+	+			+	+	+	+	+	+	+	+	+
Ferric chloride solín	F	+	10	20	-	-	-	-	-	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+
Ferric sulfate solín	F	+	10	20	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+
Fluorine	G	-	100	20	+	+	+	+	-	+		-				+	+	-			+	+	-	-
Formaldehyde solution	F	+	40	50	+	+	+	+	+	+	+	+	+	-	-	+	+	-		+	+	+	+	+
Formic acid	F	+	100	80	-	+	-	+	-	+	-	+	+	-	-	+	+	-	+		+	-	+	+
Gasoline	F	-	100	20	+	+	+	+	+	+	+	+	+	-	-	+	+	-		+	+	-	+	+
Gelantine	F	+		50	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Glycerine	F	-	100	100	+	+	+	+		+	+	+	+	+	-	+	+	-		+	-	-	+	+
Glycol	F	-	100	50				+	+	+	+	+	+			+	+			+	+		+	+
Heating oil	F	-	100	80	+	+	+	+		+						+	+	-	+		+		+	+

					Metals									Non Metals										
	Gaseous/Liquid	Electrical Conductivity	Concentration (%)	Temperature (°C)	1.4301/304	1.4539	1.4541/321	1.4571/316Ti	Hastelloy B	Hastelloy C	Titanium	Tantalum	Platinum	Hard Rubber	Soft Rubber	PFA	PTFE	EPDM	Buna N	Viton A	PVDF	PVC	Glass	Al_2O_3
Helium	G	-	100	80	+	+	+	+	+	+	+	+			+	+	+	+			+	-	+	+
Heptane	F	-	100	50	+	+	+	+	+	+		+	+	-	-	+	+	-	-	+	+	-	+	+
Hexane	F	-	100	50	+	+	+	+	+	+		+	+			+	+	-		+	+	-	+	+
Hydrazine solution	F	+	25	20	+	-	+	-					+	-	-	+	+	+	-		+	+	-	-
Hydrobromic acid	F	+	48	50	-	-	-	-	+	-	-	+	+	+	+	+	+	-		+		+	+	+
Hydrochloric acid	F	+	10	50	-	-	-	-	+	-	+	+	+	+	-	+	+	-	-	+	+	+	+	+
Hydrochloric acid	F	+	37	20	-	-	-	-	+	+	-	+	+	+	-	+	+	-	-	+	+	+	+	+
Hydrochlorin acid	G	-	100	20	-	+	+	+	+	+		+	+	-	-	+	+	+	+		+		+	+
Hydrocyanic acid	F	+	100	20	+	+	+	+	+	+	+	+	+	-	-	+	+			+		+	+	+
Hydrofluoric acid	F	+	40	20	-	-	-	-	-	+	-	-	+	+	-	+	+	-	-	-	+	+	-	-
Hydrofluoric acid	F	+	70	20	-	-	-	-	-	+	-	-	+	-	-	+	+	-	-	-	+	-	-	-
Hydrogen	G	-	100	50	+	+	+	+	+	+		+	+			+	+	+	+	+	+	+	+	+
Hydrogen peroxide solín	F	+	40	20	+	+	+	+		+	-	+	-	-	-	+	+	+		+	+	-	+	
Hydrogen sulfide, dry	G	-	100	20	+	+	+	+	-	+	+	+	+	+	+	+	+	+		+	+	-	+	+
Kerosine	F	-	100	20	+			+								+	+		+	+			+	
Krypton	G	-	100	50	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+		-	-	+	+
Magnesium chloride s.	F	+	50	20	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Magnesium sulfat. solin.	F	+	20	50	+	+	+	+	+	-		+	+	+	+	+	+	+	+	+	+	+	+	+
Malic acid	F	+	50	50	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+
Methane	G	-	100	50	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	-	-	+	+
Methanol = Methyl alc.	F	-	100	50	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	-	+	+
Methyl benzol = Toluene	F	-	100	50	+	+	+	+	+	+				-	-	+	+	-	-	+	+	-	+	+
Methylene chlorid	G	-	100	20	+	+	+	+	+	+	+	+	+	-	-	+	+	-	-	-	-	-	+	+
Monochloracetic acid	F	+	70	50				+	+	+	+	+	+	-	-	+	+	+	-	-		-	+	+
Natural gas, dry	G	-	100	40	+	+	+	+	+	+	+	+	+	-	-	+	+	-	+		+	+	+	+
Neon	G	-	100	100	+	+	+	+	+	+	+	+	+			+	+		+				+	+
Nitric acid	F	+	20	40	+	+	+	+	-	+	+	+	+	-	-	+	+	-	-	-	+	+	+	+
Nitrogen	G	-	100	50	+	+	+	+	+	+	+	+	+			+	+	+	+	+	-	-	+	+
Oleum	F	+	10	50	-	-	-	-	+	-	-	-	+	-	-		+	-	-	+	-	-	+	+
Oleum	F	+	20	20	-	-	-	-	+	-	-	+	+	-	-		+	-	-	+	-	-	+	+
Olive oil	F	-		50	+	+	+	+	+	+	+	+	+	+	-	+	+		+	+	+	-	+	+
Oxalic acid solution	F	+	10	50	-	+	-	+	+	+	-	+	+	+	-	+	+	+		+	+	-	+	+

	Gaseous/Liquid	Electrical Conductivity	Concentration (%)	Temperature (°C)	Metals									Non Metals										
					1.4301/304	1.4539	1.4541/321	1.4571/316Ti	Hastelloy B	Hastelloy C	Titanium	Tantalum	Platinum	Hard Rubber	Soft Rubber	PFA	PTFE	EPDM	Buna N	Viton A	PVDF	PVC	Glass	Al_2O_3
Oxygen	G	-	100	50	+	+	+	+	+	+		+	+			+	+	+		+	-	-	+	+
Ozone	G	-	10	20	+	+	+	+		+	+	+	+	-	-	+	+	+	-	+	+	+	+	
Perchlorethylene	F	-	100	50	+	+	+	+	+	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+
Petroleum	F	-	100	20	+	+	+	+	+	+		+	+	-	-	+	+	-	+	+	+	+	+	+
Phenol	F	-	90	50	-	+	+	+	+	+	+	+	+	-	-	+	+	-	-	-	+	-	+	+
Phosgene	F	-	100	20	+	+	+	+	+	+	+	+	+	-	-	+	+	+	-			-	+	+
Phosphoric acid	F	+	30	50	-	+	-	+	+	+	-	+	+	-	-	+	+	+	-	+	+	-	+	+
Phosphoric acid	F	+	80	20	-	+	-	+	+	+	-	+	+	+	+	+	+	-	-	+	+	+	+	+
Photographic emulsion	F	+		20	+	+	+	+		+			+			+	+						+	+
Phthalic anhydride	F	-		20	-	-	-	-	+	+	+	+	+	+	-	+	+		-	+	+	+	+	+
Propane	G	-	100	50	+	+	+	+	+	+				-	-	+	+	-	-	+	-	-	+	+
SalpNitric acid	F	+	70	50	-	+	+	+	-	-	+	+	+	-	-	+	+	-	-	-	+	-	+	+
Sea water	F	+		50	-	+	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+
Sodium bicarbonate s.	F	+	20	50			+	+	+	+	+		+	+		+	+		+	+	+		+	+
Sodium bisulfate solut.	F	+	10	50	-	-	-	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+
Sodium bisulfate solut.	F	+	50	50	+	+	+	+		+	+	+	+	+		+	+		+		+	+	+	+
Sodium carbonate solín	F	+	50	50	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+
Sodium chloride solution	F	+	10	20	-	+	-	-	-	+	+	+	+	-	-	+	+	+	+	+	+	+	+	+
Sodium chloride solution	F	+	20	20	-	-	-	-	-	+	+	+	+	-	-	+	+	+	+	+	+	+	+	+
Sodium hydroxide solín	F	+	20	50	+	+	+	+	+	+	+	-		+	-	+	+	+	-	-	+	+	-	+
Sodium hydroxide solín	F	+	50	50	+	+	+	+	+	+	-	-		+	+	+	+	-	-	-	+	+	-	-
Sodium hypochloride s.	F	+	20	50	-	-	-	-		+	+	-	+	-	-	+	+	+		+	+	-	+	+
Sodium nitrate solution	F	+	30	50	+	+	+	+		+	+	+	+	+	+	+	+	+		+	+	-	+	+
Sodium silicate solution	F	+	30	50	+	+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	+	+
Sodium sulfate solution	F	+	20	50	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	-	+	+
Sodium vanadate solín	F	+	10	50	+	+	+	+	+	+						+	+	+	+	+	+		+	+
Spinning bath solution	F	+		50				+	+	-	-	+		-	-	+	+	-		+		-	+	+
Sulfur dioxide dry	G	-	100	50	+	+	+	+	-	+	+	+	+	+		+	+	+		+	+	-	+	+
Sulfuric acid	F	+	10	50	-	+	-	-	+	+	-	+	+	+	+	+	+	+		+	+	+	+	+
Sulfuric acid	F	+	50	20	-	+	-	-	+	+	-	+	+	+	+	+	+	-		+	+	-	+	+
Sulfuric acid	F	+	96	20	-	+	-	+	+	+	-	+	+	-	-	+	+	-		+	+	-	+	+
Sulfurous acid	F	+	10	20	+	+	-	+	-	+		+		+	-	+	+	+		+	+	+		
Tannic acid	F	+	50	50			+	+		+				+	+	+	+	-			-		+	+

	Gaseous/Liquid	Electrical Conductivity	Concentration (%)	Temperature (°C)	**Metals**									**Non Metals**										
					1.4301/304	1.4539	1.4541/321	1.4571/316Ti	Hastelloy B	Hastelloy C	Titanium	Tantalum	Platinum	Hard Rubber	Soft Rubber	PFA	PTFE	EPDM	Buna N	Viton A	PVDF	PVC	Glass	Al_2O_3
Tartaric acid	F	+	20	50	-	-	-	-	+	+	+	+		+	+	+	+			+		+	+	+
Toluene	F	-	100	50	+	+	+	+	+	+				-	-	+	+	-	-	+	+	-	+	+
Trichlorethylen	F	-	100	50	+	+	+	+	+	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+
Tricresyl phosphate	F		100	50	+	+	+	+	+	+				-	-	+	+		+	-	-	-	+	+
Urea	F	+	30	50			+			+		+	+	+	+	+	+	+	+	+	+	-	+	+
Vinyl acetate	F		100	20	+			+	-	+				-	-	+	+	+		+	+	+	+	
Vinyl chloride	F		100	20		+		+	+	+		+	+	-	-	+	+		-	+			+	
Wort	F	+		5	+	+	+	+	+	+	+	+	+			+	+	+		+		+	+	+
Xylene	F	-	100	50	+	+	+	+	+	+				-	-	+	+	-		-	+	-	+	+
Yeast	F	+		20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+
Zinc chloride solution	F	+	60	20	-	-	-	-	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+

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Dechema-Material Table: Dechema Frankfurt/Main

9 Keyword Index

The features and characteristics of the most important methods for measuring the flowrate and quantities of flowing fluids are described and compared.

Numerous practical details provide the user with valuable information about flow metering in industrial applications.

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