8. SPECIALISED FLOWMETERS

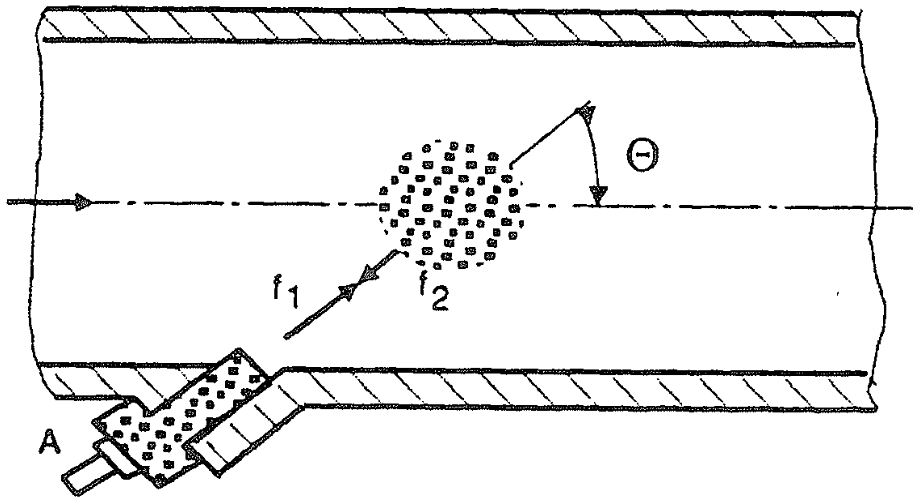
8.1. Ultrasonic flowmeters

8.1.1. Application example: gas well

8.1.2. Principles

$$f_1 - f_2 = 2\,\bar{v}\,f_1 \frac{\cos\theta}{a}$$

$$\frac{f_1 - f_2}{f_1} << 1$$



Doppler principle

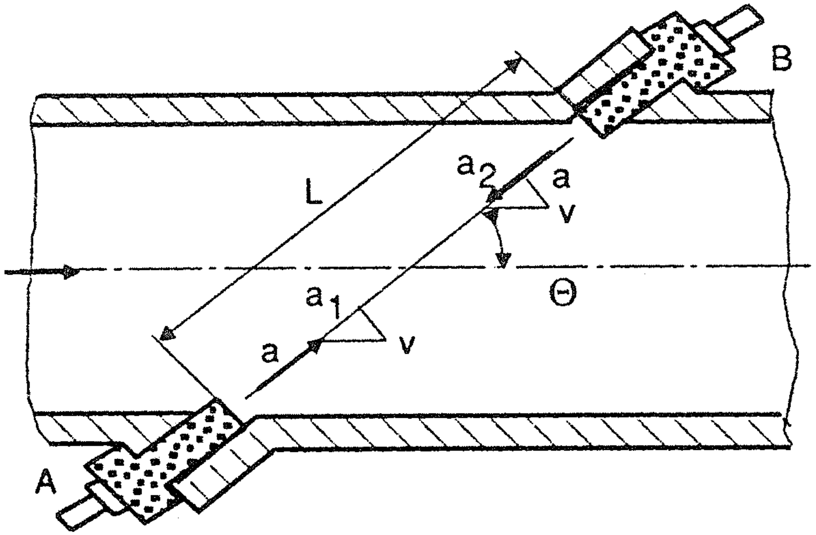
$$a_A = a + v\cos\theta$$

$$a_B = a - v\cos\theta$$

$$\bar{v} = \frac{1}{L}\int_L v\, dL$$

$$\bar{a}_A = a + \bar{v}\cos\theta = \frac{L}{t_A}$$

$$\bar{a}_B = a - \bar{v}\cos\theta = \frac{L}{t_B}$$



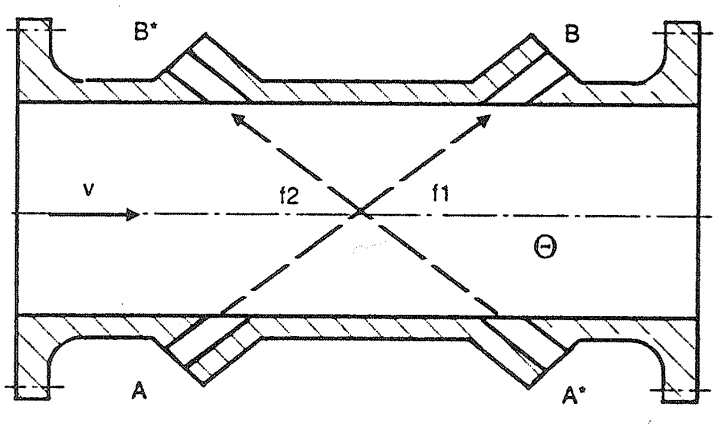
Transit time difference principle

$$\bar{v} = \frac{L}{2\cos\theta}\left(\frac{1}{t_A} - \frac{1}{t_B}\right) = \frac{L}{2\cos\theta}\left(\frac{t_B - t_A}{t_A t_B}\right) = (t_B - t_A)\frac{1}{2\cos\theta}\frac{1}{L}\frac{L}{t_A}\frac{L}{t_B} =$$

$$= (t_B - t_A)\frac{1}{L 2\cos\theta}\bar{a}_A \bar{a}_B \approx (t_B - t_A)\frac{a^2}{L 2\cos\theta}$$

$$q_V = \bar{v} A$$

$$\bar{v} = \frac{L}{2\cos\theta}\left(\frac{1}{t_A} - \frac{1}{t_A*}\right) = \frac{L}{2\cos\theta}\left(f_A - f_A*\right)$$

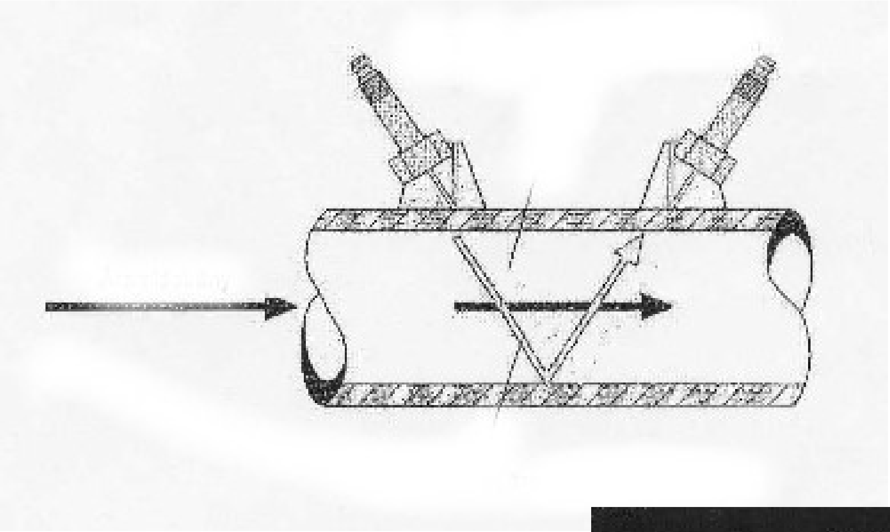


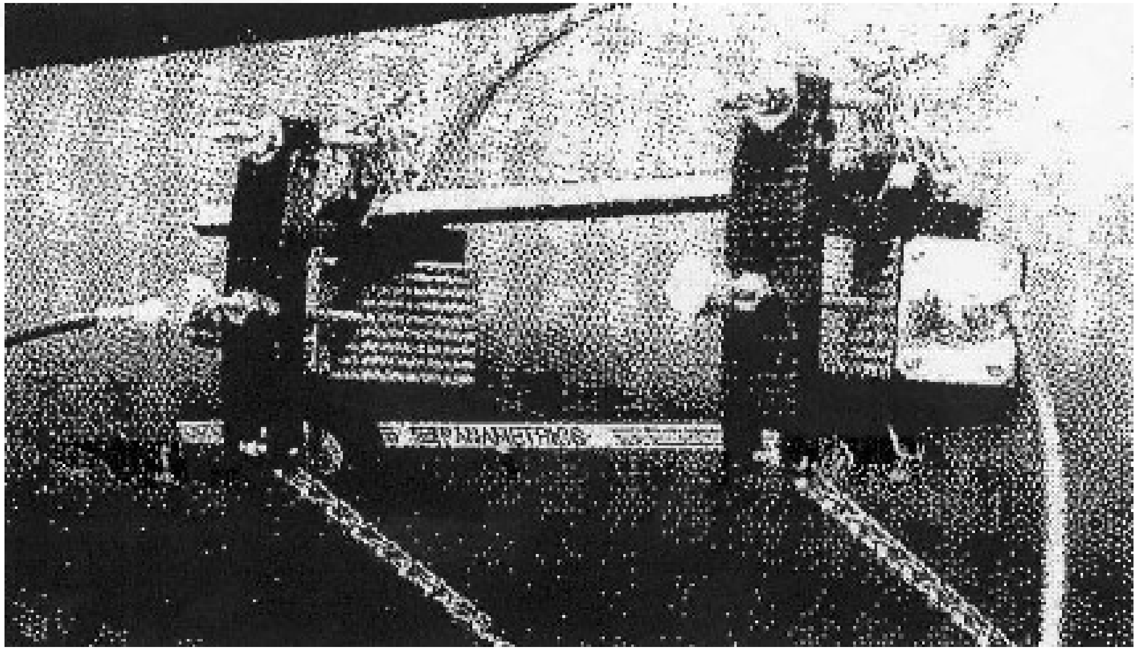
Frequency tracking ("Sing around") principle

US300PM (main unit)

Left: Transducer for large pipes
Middle: Transducer for small- and medium-sized pipes
Right: Wall thickness probe (for general temperature)

Steel industry application (contaminated cooling water)





ADVANTAGES:

- Non-intrusiveness
- No pressure drop
- Long life cycle
- Subsequently mountable
- The measurement principle is independent from the fluid density

•**LIMITATIONS / DISADVANTAGES:**

•The relative measurement error is in the order of magnitude of 1 – 2 % or even higher

•Contacting with fluid of high temperature (say above 200 °C), the pieso-electric elements usually do not operate properly

•Acoustic transparency of the fluid is necessary

•Temperature dependence of the measurement results ⇔ “Sing around” concept

•In multiphase flows, the acoustic signal may be absorbed ⇒ increased noise

•The contamination of the fluid determines the technique to be applied. Highly contaminated fluids cannot be measured.

•Sensitivity to the adjustment of geometry, i.e. L and θ

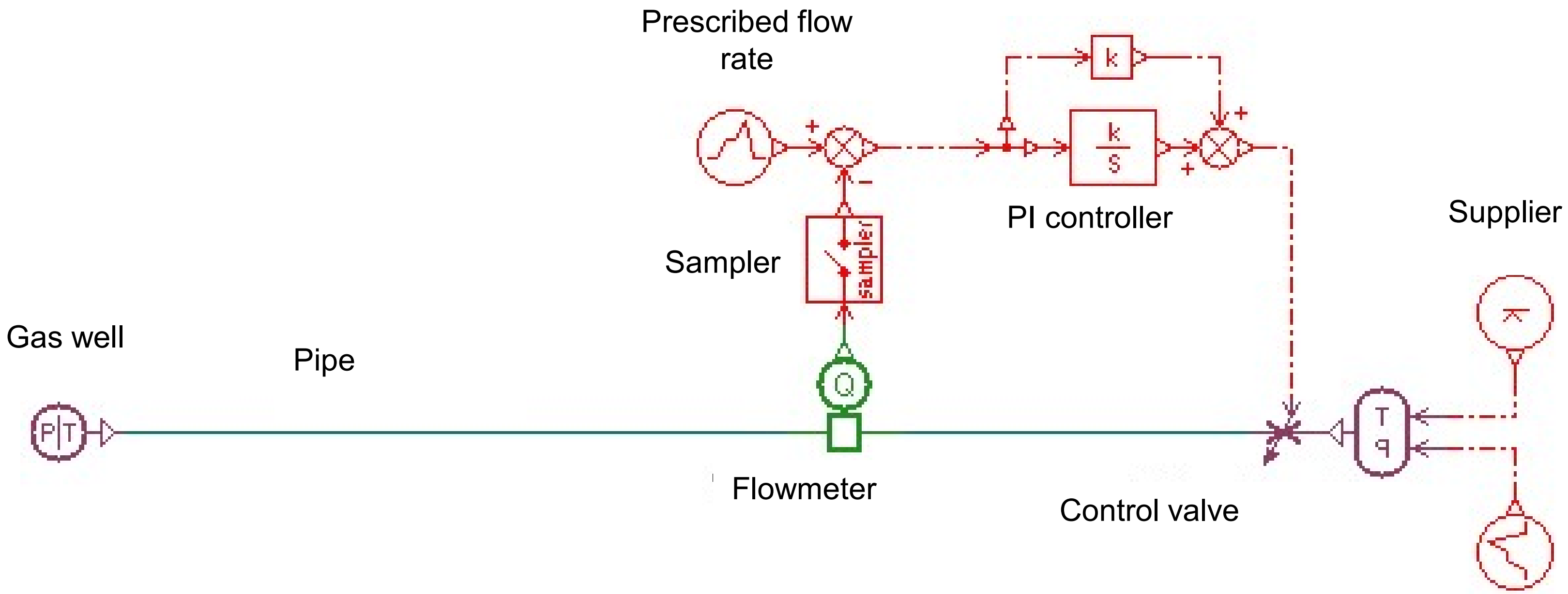
•The mean velocity is determined not in the entire cross-section but along a linear path ⇒ increased measurement uncertainty, sensitivity to the velocity profile, i.e. no reliable measurement can be carried out in strongly disturbed flow e.g. close downstream of elbows or valves

•Deposit on the sensors ⇒ increased signal-to-noise ratio

•The errors are increased if the cross-section is not filled fully with the liquid (no measurement for free surface fluids)

CASE STUDY – Natural gas well

AMESim model:



„Hydrate corks" (solidified minerals) passing through the measurement section in the pipeline: measurement technical problems

Faster PI control: inability to follow the ordering signal when the measurement is disturbed

Setting the PI control to slower mode: increased reaction time but less sensitivity to measurement anomalies

8.2. Magneto-inductive flowmeters (magneto-hydrodynamic, MHD)

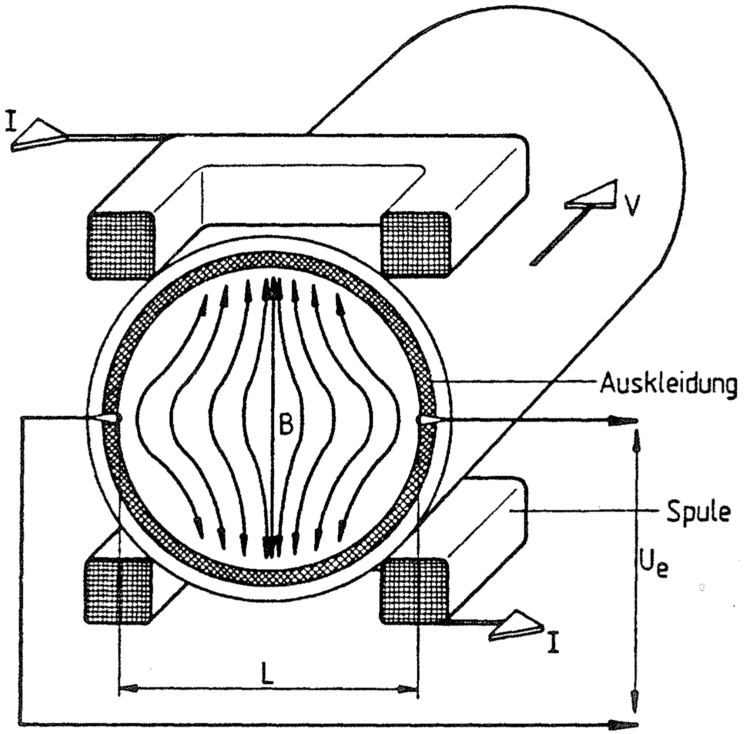
8.2.1. Application examples: slurry, paper pulp

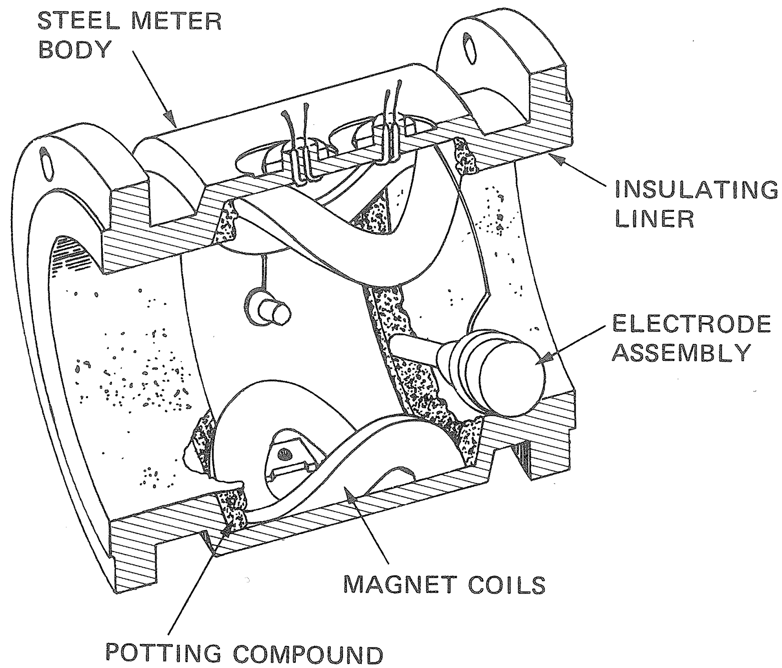
8.2.2. Principle and layout

$$u = B\,L\,v$$

Faraday effect

$$q_V = \frac{uD\pi}{4B}$$





•2 main units: transducer, data processor
•Withstand to mechanical and chemical load
•Flanged and sandwich layouts
•Water-proof layout possible

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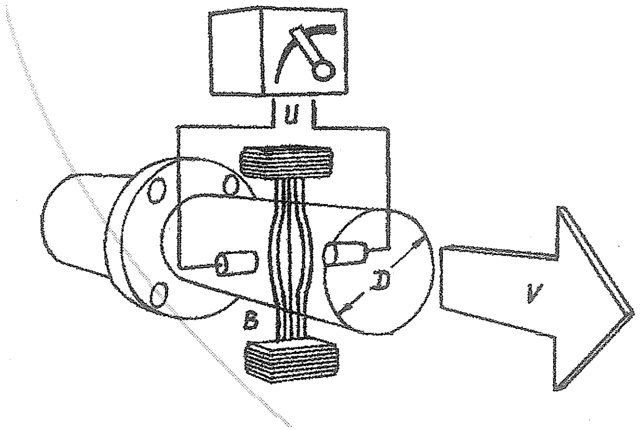
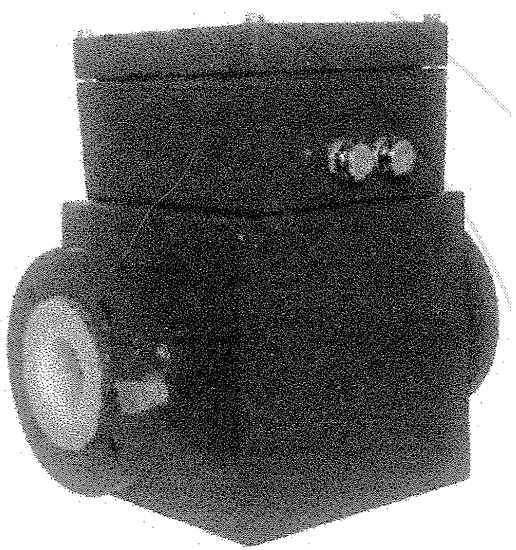
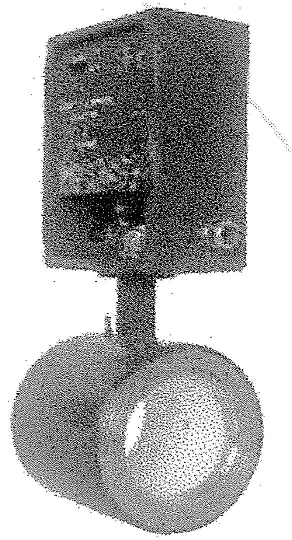
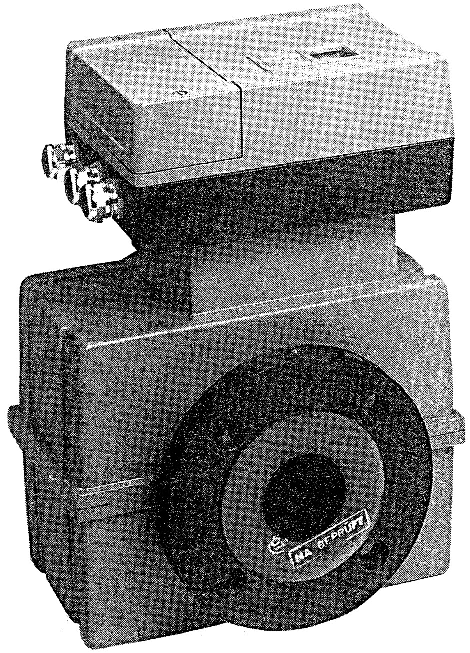








Integral Flowmeter

Remote Flowtube

ADVANTAGES:

- Above a conductivity limit: the principle is independent from conductivity
- Unsteady flow measurements
- Measurements are independent from fluid pressure, density, temperature, kinematic viscosity
- Minimum dependence on the velocity profile $\Rightarrow$ strongly disturbed flows can also be measured
- Limited space demand, arbitrary location of measurements. 3 to 5 pipe diameter undisturbed upstream and downstream sections are to be guaranteed in order to limit the measurement error, but this requirement is still loose compared e.g. to a throughflow orifice meter.
- Liquid with solid impurities can be measured
- No pressure drop, non-intrusiveness
- High, certified, guaranteed accuracy (relative error 0.2 to 1 %)
- High linearity, also for dynamic effects
- Stable internal parameters, no calibration required
- Low maintenance costs (cleaning etc.)

•**LIMITATIONS / DISADVANTAGES:**

•Electric conductivity of the fluid is necessary ⇒ only liquids, but even among liquids, no measurement is possible for petrochemical products (oil, gasoline, petrol, etc.)

•Deposit (contamination) on the pipe wall ⇒ reduced voltage signal ⇒ reduced signal-to-noise ratio

•If air or other gases are present in the liquid in X % volume fraction ⇒ the measurement error increases by approx. X %.

•If the flow cross-section is not filled at X area percentage ⇒ the problem is as above, the measurement error increases by approx. X %.

•The life cycle of the electrodes is limited according to the fluid temperature and pressure.

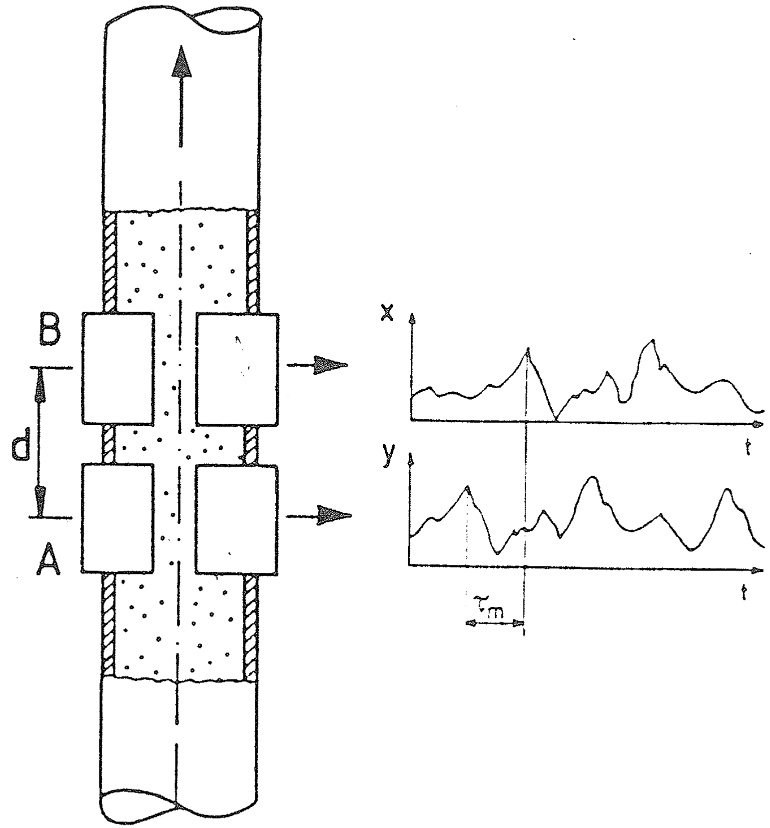
•Increased zero-point error

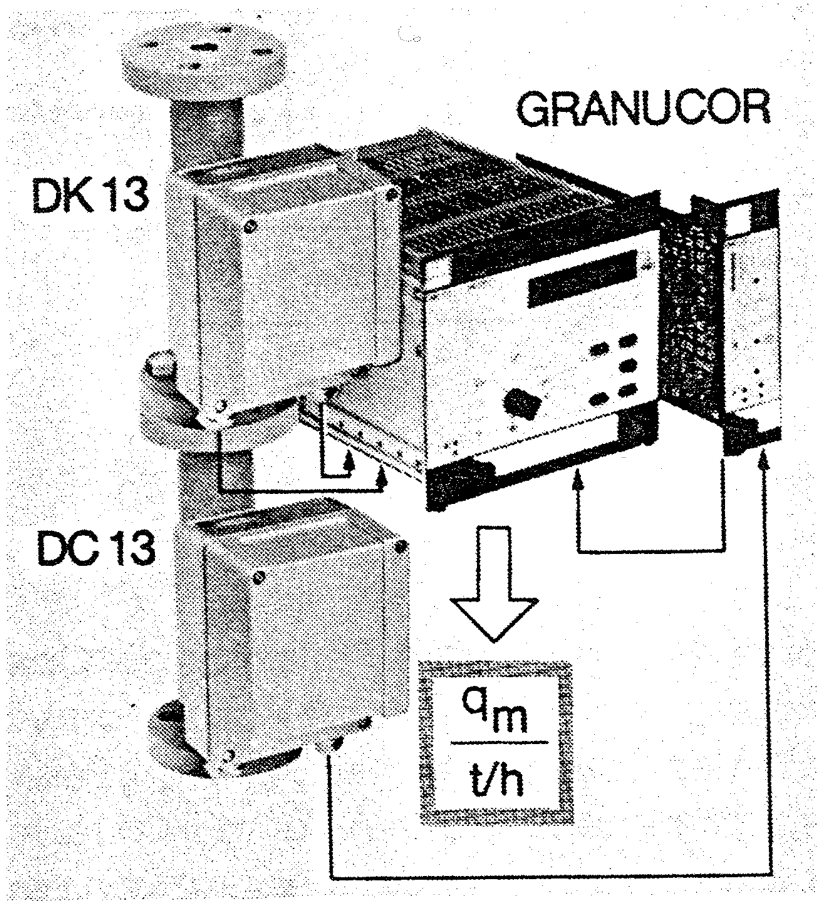
8.3. Capacitive cross-correlation technique

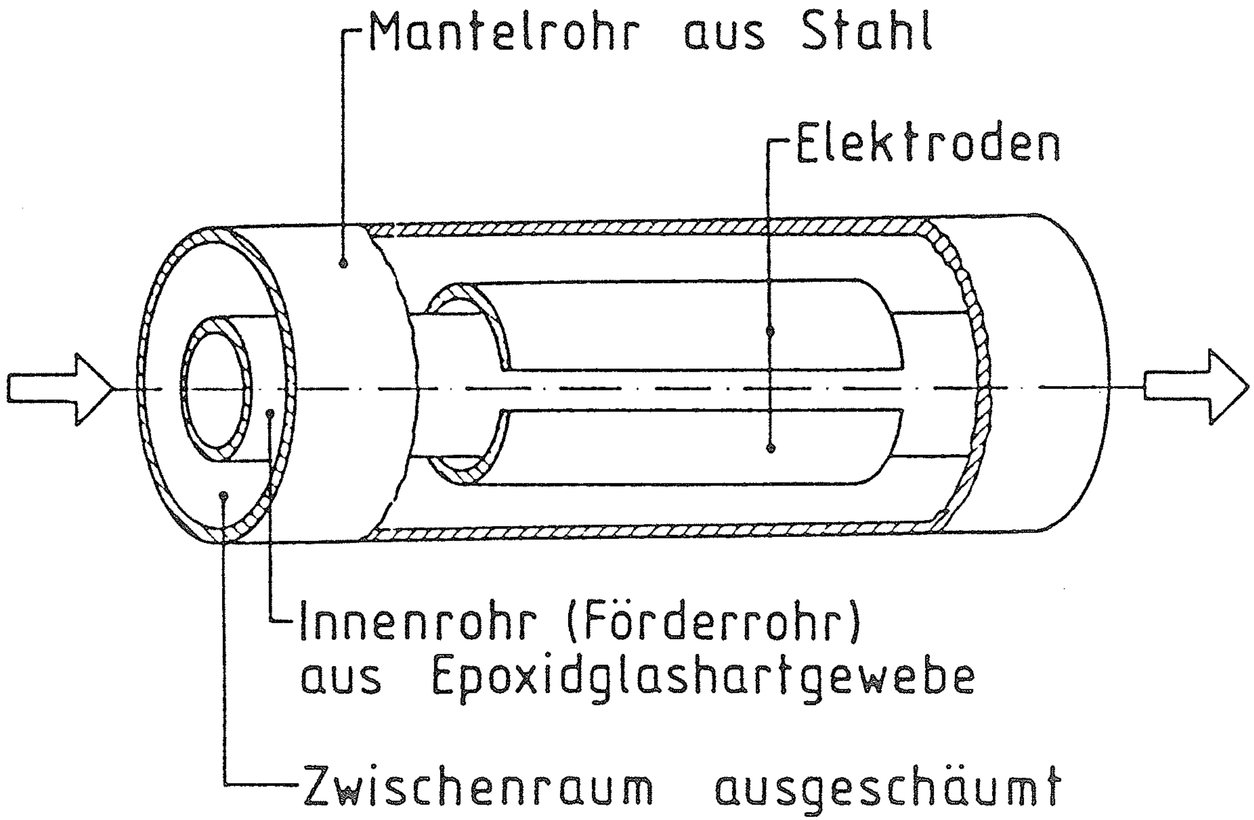
8.3.1. Application examples: plastic granulates

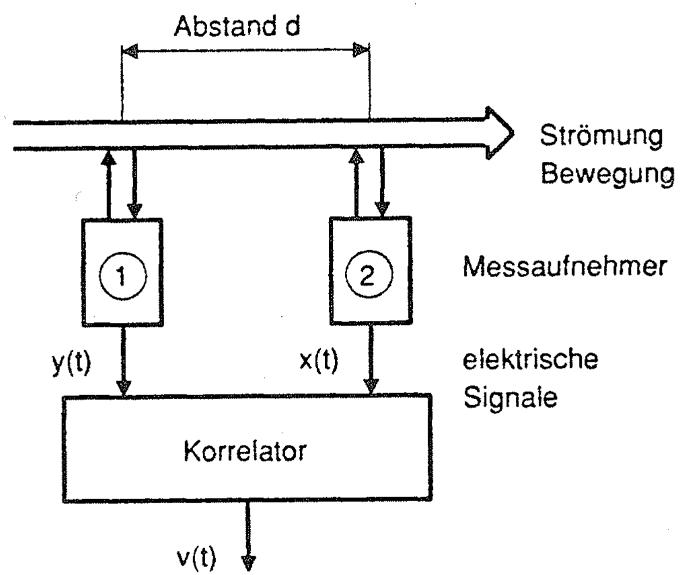
8.3.2. Principle and layout

$$v = \frac{d}{\tau_m}$$

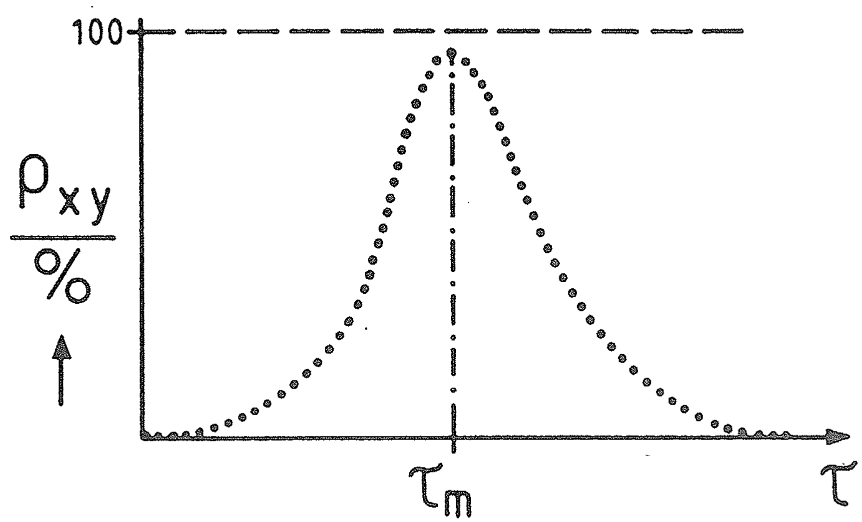





Mantelrohr aus Stahl
Elektroden
Innenrohr (Förderrohr)
aus Epoxidglashartgewebe
Zwischenraum ausgeschäumt



Abstand d
Strömung
Bewegung
1
2
Messaufnehmer
y(t)
x(t)
elektrische
Signale
Korrelator
v(t)



100
ρ_{xy}
%
τ_m
τ

ADVANTAGES:

- Statistic method, enabling the limitation of measurement errors
- Two-phase flows can be measured
- No temperature dependence
- Non-intrusive measurement

LIMITATIONS / DISADVANTAGES:

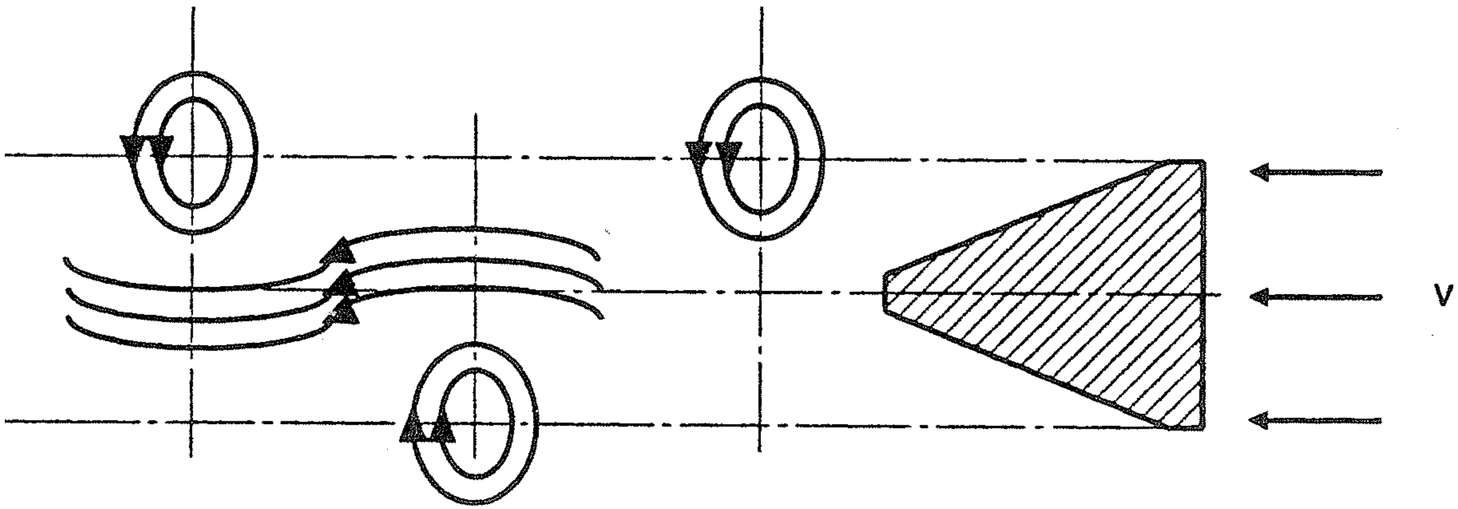
- Increased space demand. The minimum displacement between two electrodes is governed by the sensor size, particle size, maximum sampling frequency, and the required accuracy.
- The work experiences are still limited
- High investment costs
- No measurements are possible close to the zero point of flow rate

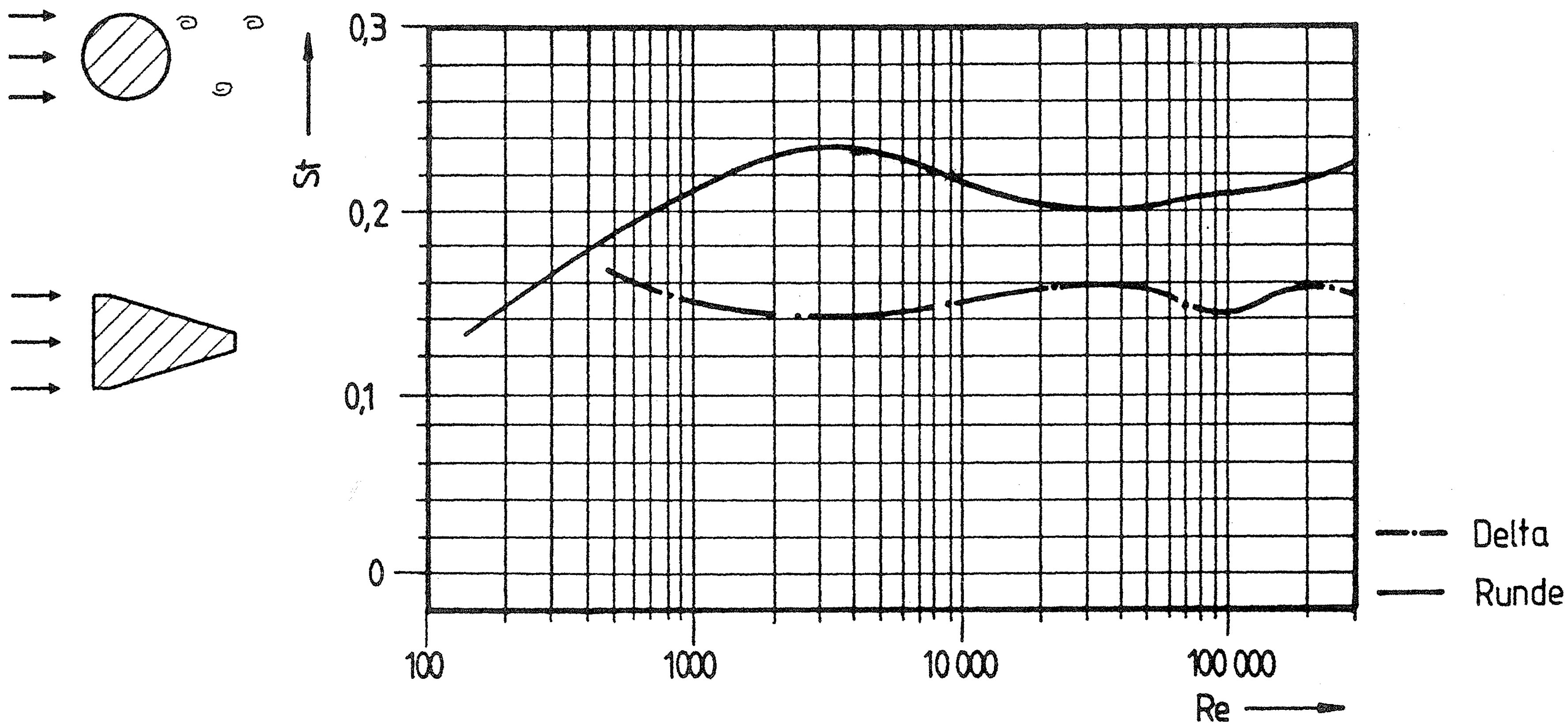
8.4. Vortex shedding flowmeters

8.4.1. Application examples: clean gases, steam

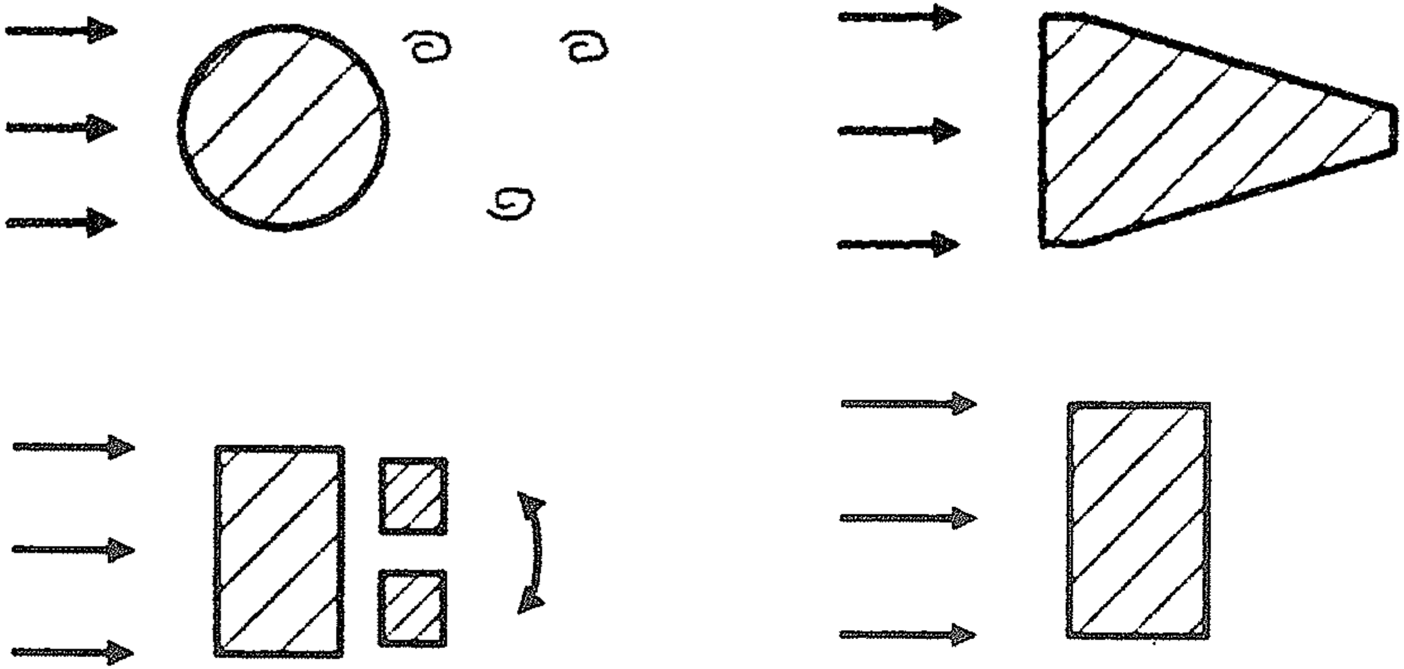
8.4.2. Principle

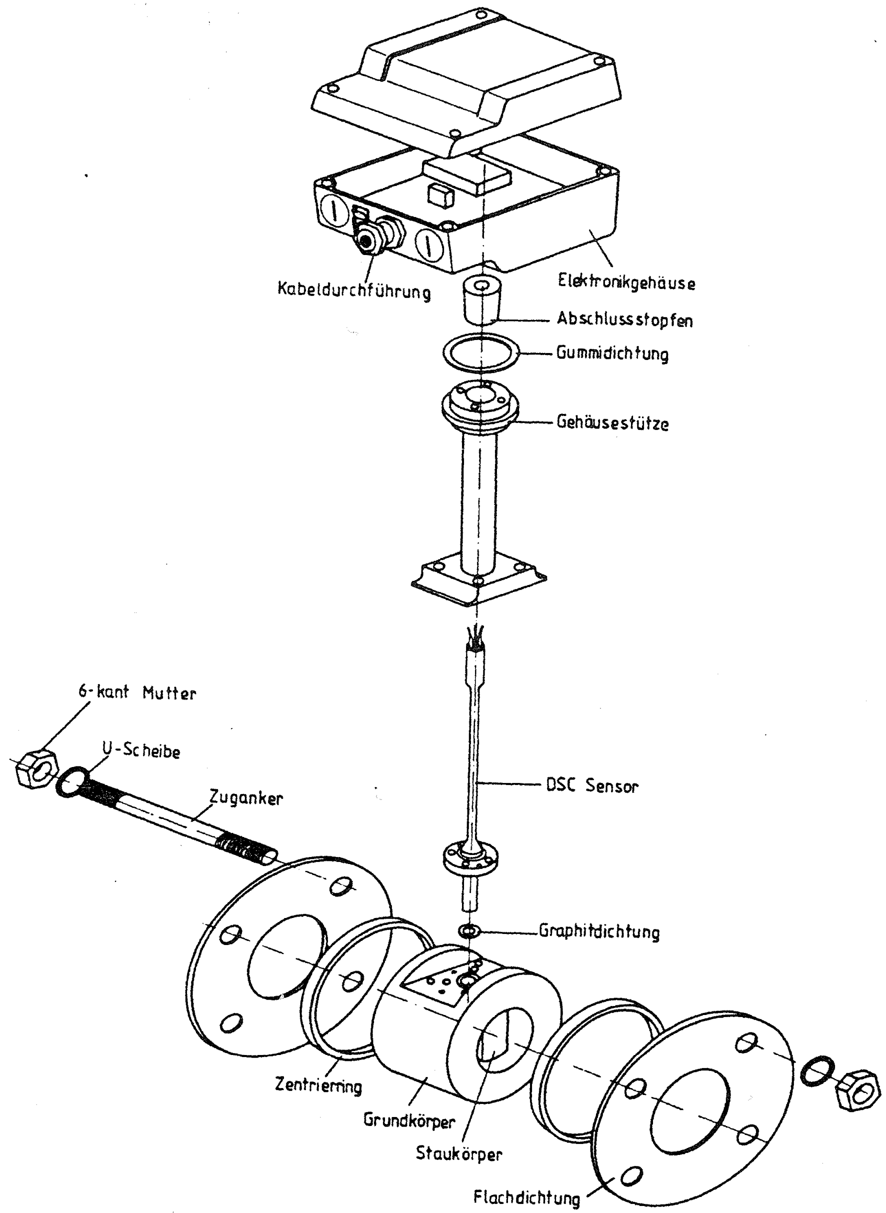
$$Str = \frac{f \cdot d}{v} \qquad v = \frac{d}{Str} \cdot f \qquad \mathrm{Re} = \frac{v \cdot d}{\nu}$$



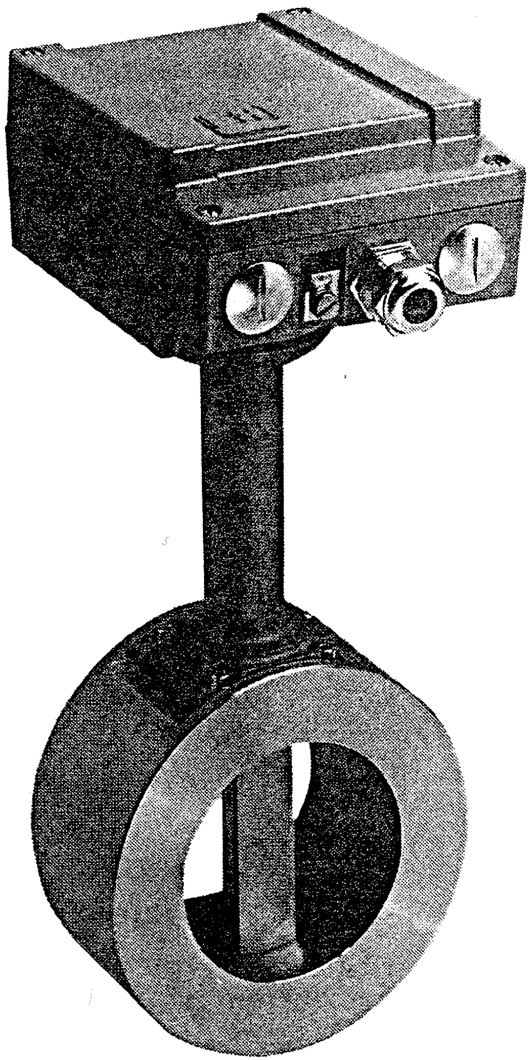


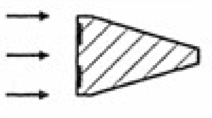
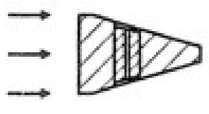
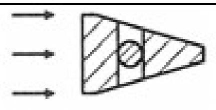
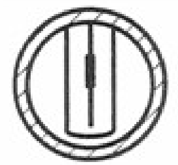
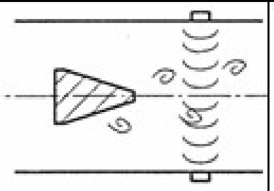
0,3
0,2
0,1
0
St
100
1000
10 000
100 000
Re
Delta
Runde





Kabeldurchführung
Elektronikgehäuse
Abschlussstopfen
Gummidichtung
Gehäusestütze
6-kant Mutter
U-Scheibe
Zuganker
DSC Sensor
Graphitdichtung
Zentrierring
Grundkörper
Staukörper
Flachdichtung



Principle	Figure	Comments	Applications	Limits
Thermistors		The thermistors are heated with constant current. The alteration in temperature due to vortex shedding, and as a result, in the thermistor resistance, is detected by means of a Wheatstone bridge comprising the thermistors.	- Clean gases - Clean liquids	- Sensitivity to contamination - No resistance to temperature shocks
Pressure sensors		Flexible membranes comprised in capacitance elements ⇒ pressure fluctuation ⇒ membrane deformation ⇒ modulated capacitance	- Liquids - Gases - Low pressure steam	- Below 150 °C - Time-dependent characteristics of membranes - High pressure fluctuation necessary
Mechanical sensors		The pressure fluctuation results in the periodic displacement of the sphere or disk in the o. m. of 0.1 mm ⇒ actuating a microswitch	- Warm water - Steam - Low temperature liquids	- Sensitive to contamination - The condensed water may block the microswitch - Temperature shock may result in blockage or rupture due to thermal dilatation
Strain gauges		Elastic mounting of the strut ⇒ deformation due to cross-stream oscillation ⇒ 10 μm o.m deformation measured	- Gases - Liquids	Up to cca. 100 °C
Ultrasound sensors		Ultrasound modulated by the vortex street	- Gases - Liquids	- Sensitive to external acoustic and vibration effects

ADVANTAGES:

- No effect of density and kinematic viscosity in liquids
- Broad-scale approximate linearity, independently from fluid density, kinematic viscosity, and pressure
- Moderate installation costs
- High dynamic response
- Limited error (below 1 %)
- Temporal stability of parameters
- Low pressure drop
- The vortex shedding principle is independent from the temperature. The temperature is limited „only” by the sensors. The range of -200 to 400 °C can be usually measured. E.g. high temperature gas and steam measured.

LIMITATIONS / DISADVANTAGES:

- Reynolds number limit to ensure moderate errors: cca. 20 000 to $2 \cdot 10^6$
- No measurements are possible if no vortices are shed
- Single phase flow is recommended. Multiphase: problems with contamination, vortex formation and abrasion of the strut.
- No measurement is possible if the measurement cross-section is not fully filled with the fluid
- Increased errors if no undisturbed upstream and downstream pipe sections are guaranteed
- Dependence on the velocity profile $\Rightarrow$ application of upstream straighteners (e.g. honeycombs) is recommended for uniformisation of the velocity profile
- Risk of cavitation erosion of the strut $\Rightarrow$ increased upstream pressure may be needed
- Not applicable for high viscosity fluids (lack of vortex shedding)
- Not applicable for pulsing flow