Infrastructure Commission (INFCOM)

Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT)

Expert Team on Quality, Traceability and Calibration (ET-QTC)

Calibration of Wind Instruments

Part-2: Methods of Measurement

Holger Doerschel (DWD)
Zafer Turgay Dag (TSMS)

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Content

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Methods of measurement

nowadays at **weather-stations** there are in principle only anemometers with rotating and with non-rotating parts in use

- with rotating-parts:
  - cup anemometers (only wind speed)
  - wind vanes (only wind direction)
  - propeller anemometers (wind speed and wind direction in one instrument)
  - combined cup anemometers and wind-vanes

- without moving parts:
  - ultrasonic anemometers (wind speed and wind direction)

Methods of measurement

remote sensing instruments with a more scientific background or special applications

- light detection and ranging (LIDAR)
- sound/sonic detecting and ranging (SODAR)
- radio detecting and ranging (RADAR) for the detecting of low level wake turbulence (LLWAS, Low Level Wind Shear Alert System)

Methods of measurement

reference anemometers used in wind tunnels

- static pressure sensors / static pitot tube
- laser doppler anemometry (LDA) also called laser doppler velocimetry (LDV)
- hot-wire anemometers / hot-film anemometers

Methods of measurement

some factors influence the rotational speed

- turbulence produced by the anemometer
- the shape of the cups influences the drag coefficient
- friction of the mount point (bearings)
- mounting / holders
- for some ultrasonic anemometers the ambient noise

Methods of measurement

cup anemometer (wind speed)

- today three cups are widely used
- the shape of the cups are usually half-sphere or cone
- for a wide range of speeds measured in m/s or knots
- air flow pass cups in any horizontal direction and turned the shaft at a rate that is in degree “proportional” to the wind speed

  - influences: ball bearings, wind resistance through the cups, holders

- counting the turns of the shaft over a defined period or other methods like a dynamo produces a value proportional to the average wind speed

Methods of measurement

cup anemometer (wind speed)

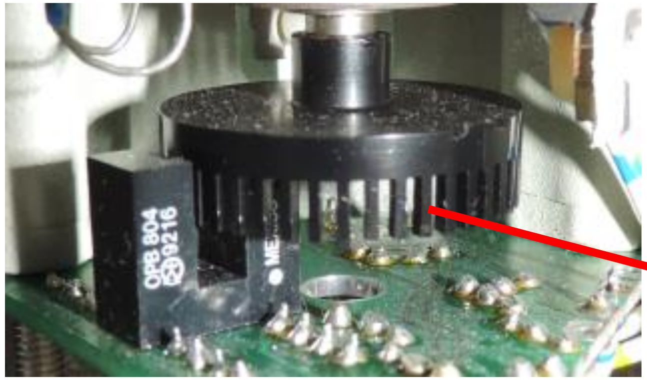
- many output formats e.g.
  - voltage 0 … 10 V $\Rightarrow$ 0 … 75 m/s
  - frequency 0 … 1000 Hz $\Rightarrow$ 0 … 50 m/s
  - current 0 … 20 mA or 4 … 20 mA $\Rightarrow$ 0 … 50 m/s

- digital protocol via
  - ethernet, EIA-232/422/485
  - Wifi, Bluetooth, LoRaWAN
  - …

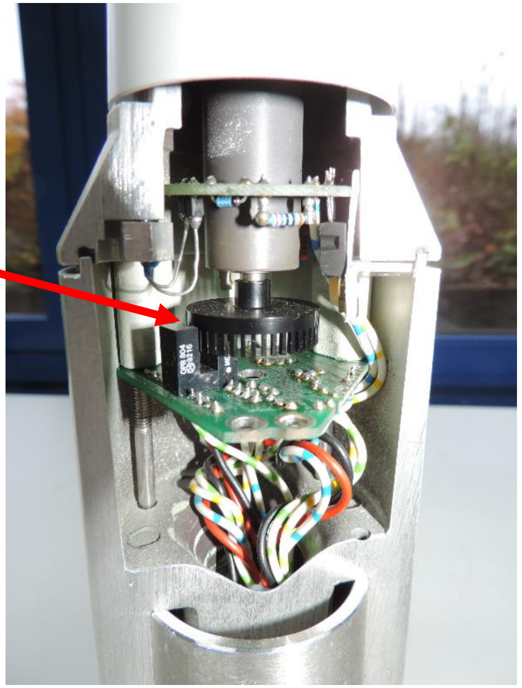
Methods of measurement

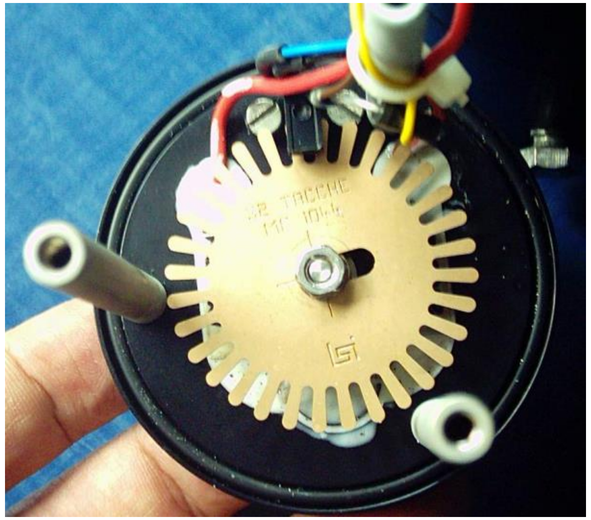
cup anemometer (wind speed)

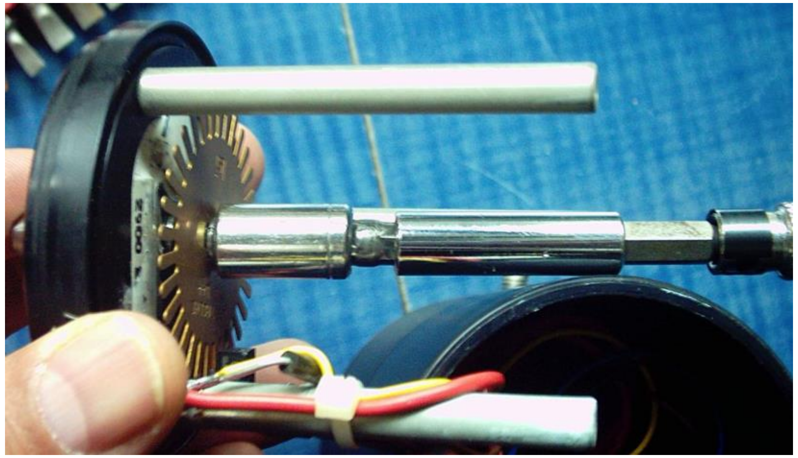
- example of a technical solution using a light barrier
- each revolution produces the pulse signal



light barrier







Methods of measurement

cup anemometer (wind speed)

- frequency output

Wind tunnel speed in ms^{-1}	Output of DUT in Hertz
0,51	6,57
1,04	16,61
2,54	43,97
5,09	93,37
7,52	142,38
10,07	196,32
12,58	249,82
15,06	302,98
19,90	408,75
30,10	629,59
40,17	855,11
49,85	1062,00

Methods of measurement

cup anemometer (wind speed)

- Note: Manufacturer's fit is linear and not always the best choice!

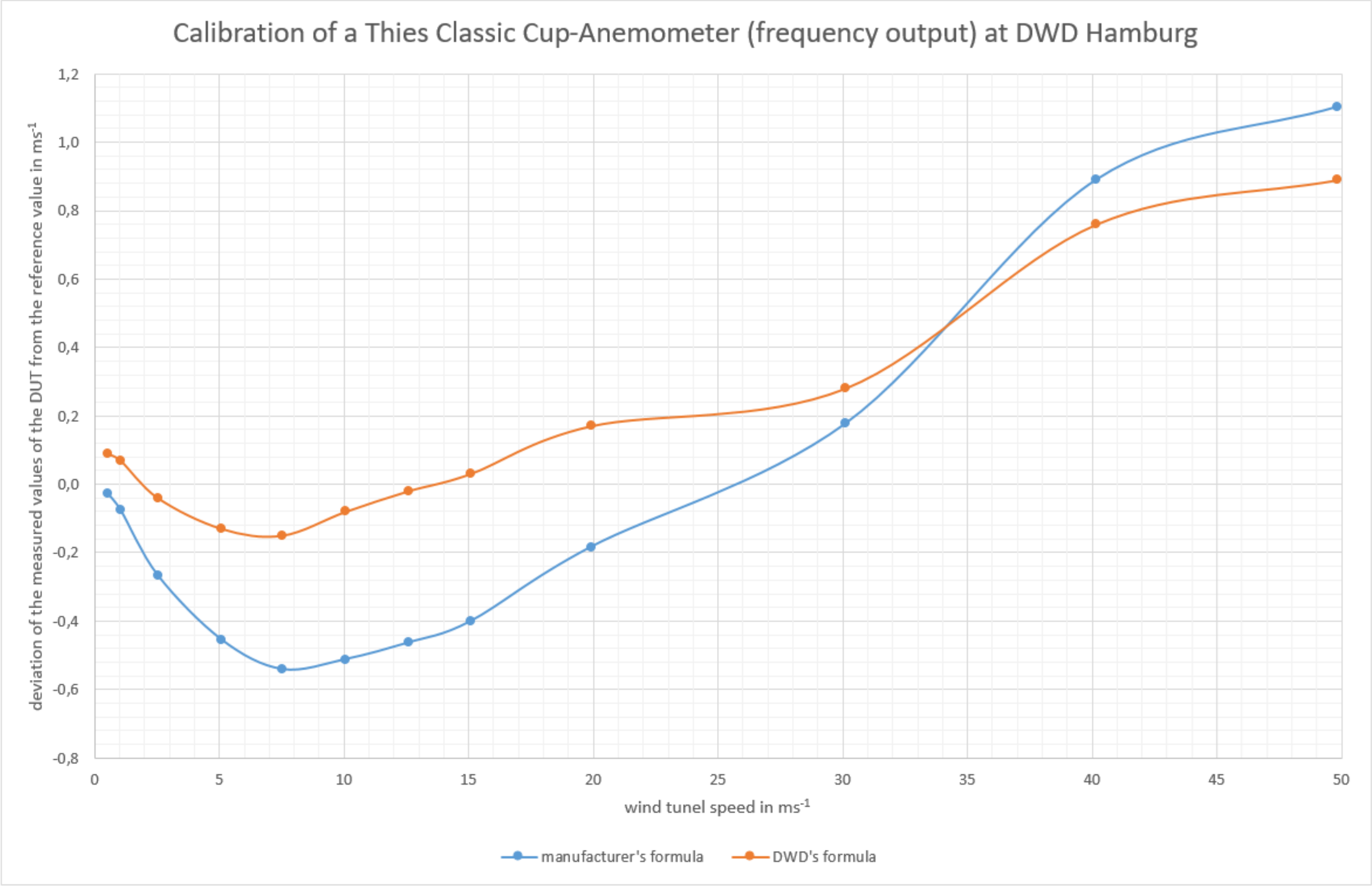
- In general, it is best to determine an individual characteristic curve for each type of cup anemometer.
  - To do this, a larger number of units are analysed and an average characteristic curve is then determined.

- However, the characteristic curve will change during operation due to contamination and wear of the bearings!

Methods of measurement

cup anemometer (wind speed)

- Manufacturer’s fit against DWD’s individual fit



Methods of measurement

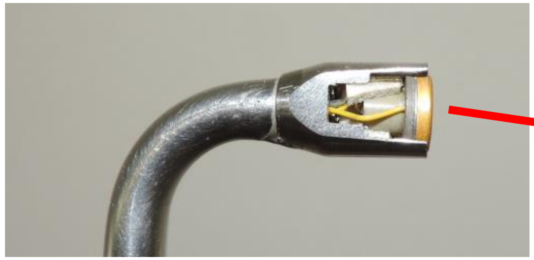
propeller anemometer (wind speed and wind direction)

- combination of anemometer and wind vane
  same axis
- the wind speed sensor has a shape of a four blade helicoid propeller
- the propeller is always turned into the wind
- the wind direction sensor is arranged as a vane directly behind the propeller
- many output formats 0...5V DC, NMEA, RS485

Methods of measurement

ultrasonic anemometer (wind speed and wind direction)

- three to six ultrasonic transducers
- they act as a microphone and a loudspeaker

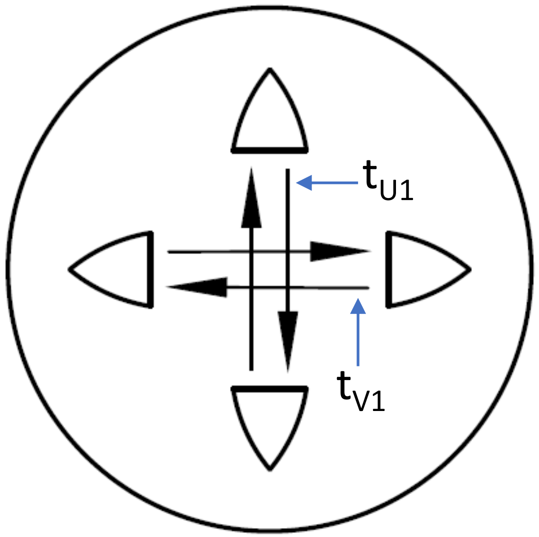


- measures the time required to transmit an acoustic signal across a fixed path to determine the wind velocity component along that path

Methods of measurement

ultrasonic anemometer (wind speed and wind direction)

- an ultrasonic anemometer with four transducers makes four measurements:
  - the traveling times are measured
  - from the north to the south and from the south to the north $\Rightarrow t_{U1}, t_{U2}$
  - from the west to the east and from the east to the west $\Rightarrow t_{V1}, t_{V2}$



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Methods of measurement

ultrasonic anemometer (wind speed and wind direction)

- distance *d* is known for example 20 cm
- speed of sound *c* (depends on the temperature)

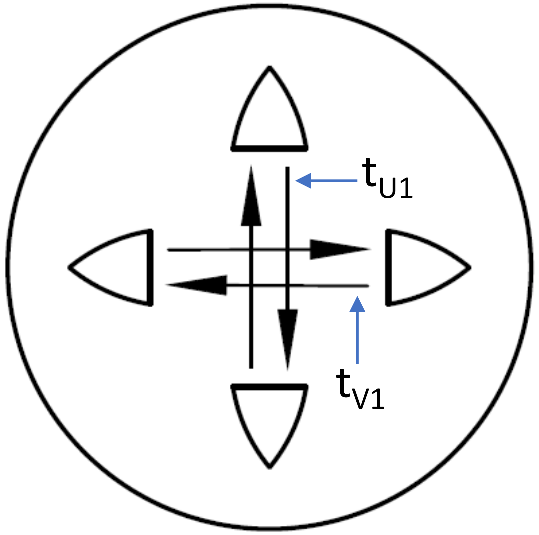
traveling times:

$$t_{U1} = \frac{d}{c+U} \qquad (1)$$

$$t_{U2} = \frac{d}{c-U} \qquad (2)$$

$$t_{V1} = \frac{d}{c+V} \qquad (3)$$

$$t_{V2} = \frac{d}{c-V} \qquad (4)$$



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Methods of measurement

ultrasonic anemometer (wind speed and wind direction)

- elimination of the speed of sound c

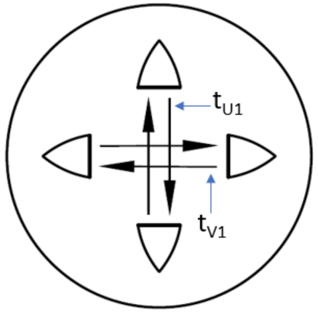
$$U = \frac{d}{2} * \left(\frac{1}{t_{U1}} - \frac{1}{t_{U2}}\right) \qquad (5)$$

$$V = \frac{d}{2} * \left(\frac{1}{t_{V1}} - \frac{1}{t_{V2}}\right) \qquad (6)$$

Methods of measurement

ultrasonic anemometer (wind speed and wind direction)

- (simple) example with a distance d = 0.2 m, t_{U1}= 0.01 s and $t_{U2} = t_{V1} = t_{V2} = 0.02$ s



$$U = \frac{0.2\,m}{2} * \left(\frac{1}{0.01\,s} - \frac{1}{0.02\,s}\right) = \frac{0.1\,m}{1} * \left(\frac{2}{0.02\,s} - \frac{1}{0.02\,s}\right) = \frac{0.1\,m}{0.02\,s} = 5\,\frac{m}{s} \quad (7)$$

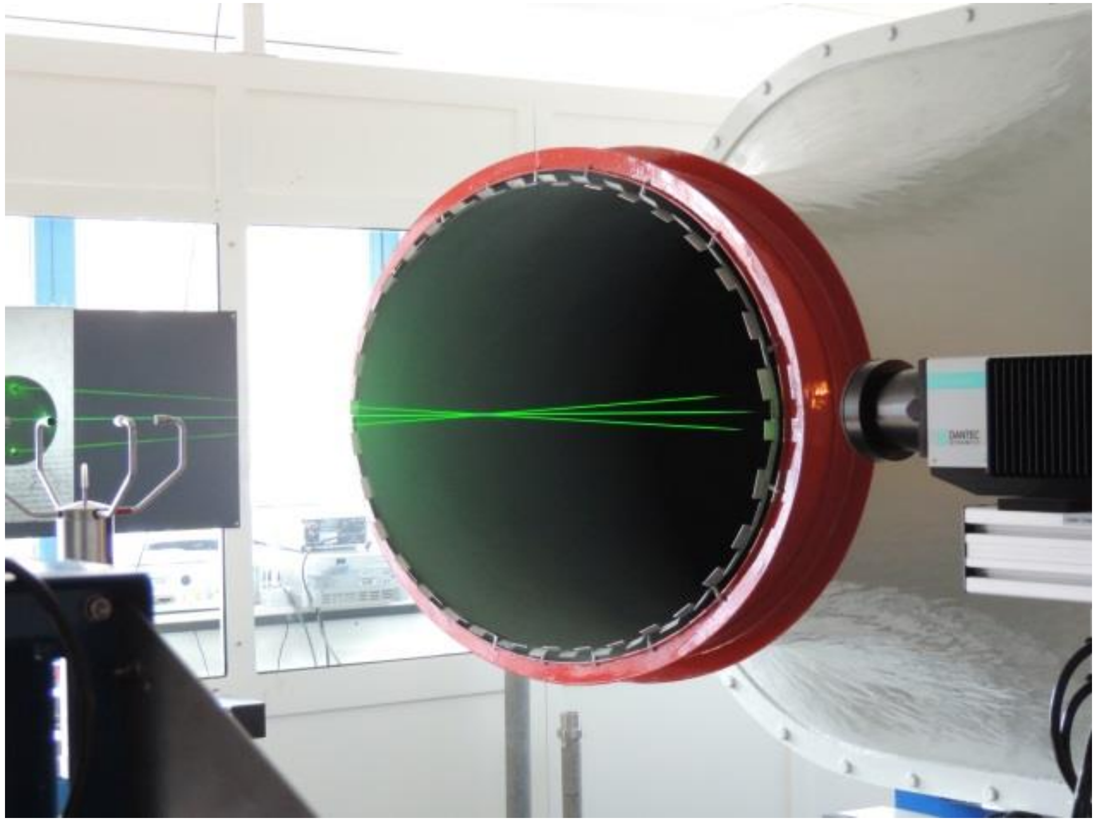
$$V = \frac{0.2\,m}{2} * \left(\frac{1}{0.02\,s} - \frac{1}{0.02\,s}\right) = \frac{0.1\,m}{1} * \left(\frac{0}{s}\right) = 0\,\frac{m}{s} \quad (8)$$

→ wind speed is $5\,\frac{m}{s}$ with a wind direction is 360° (north)

Methods of measurement

laser doppler anemometer (LDA)

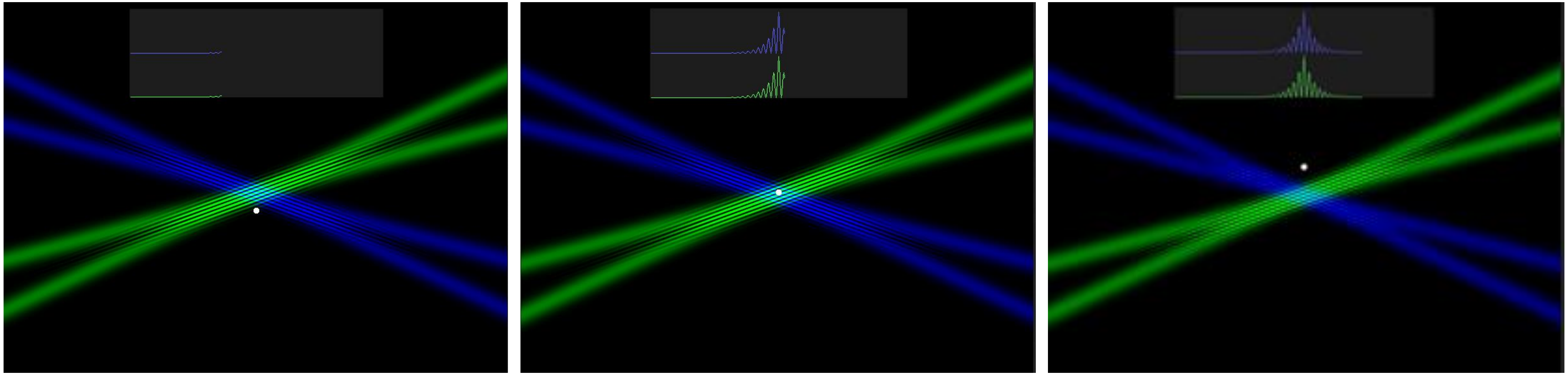
- calculates the velocity of tracer particles (~ wind speed)
- very fine fog is blown into the wind tunnel with a fog machine



Methods of measurement

laser doppler anemometer (LDA)

- two (four, six) laser beams are used to generate an interference fringe model with light and dark fringes
- particles such as fine fog reflect the laser light and a double doppler-shifted signal is received

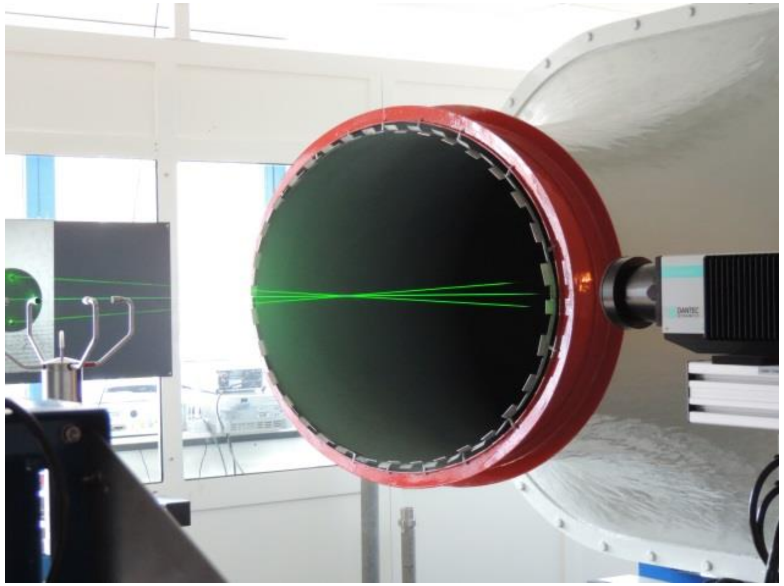


https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_1/1.4_gase/1.41/4beams_moving_particle.gif

Methods of measurement

laser doppler anemometer (LDA)

- expensive!
- seeding particles are needed ⇒ pollution of the wind tunnel (screens and honeycomb)
- traceable to SI (length, time)



- practically no influence to the flow
- high resolution
- low uncertainties < 0,2 % of measured velocity speed are possible

Methods of measurement

pitot tube anemometer

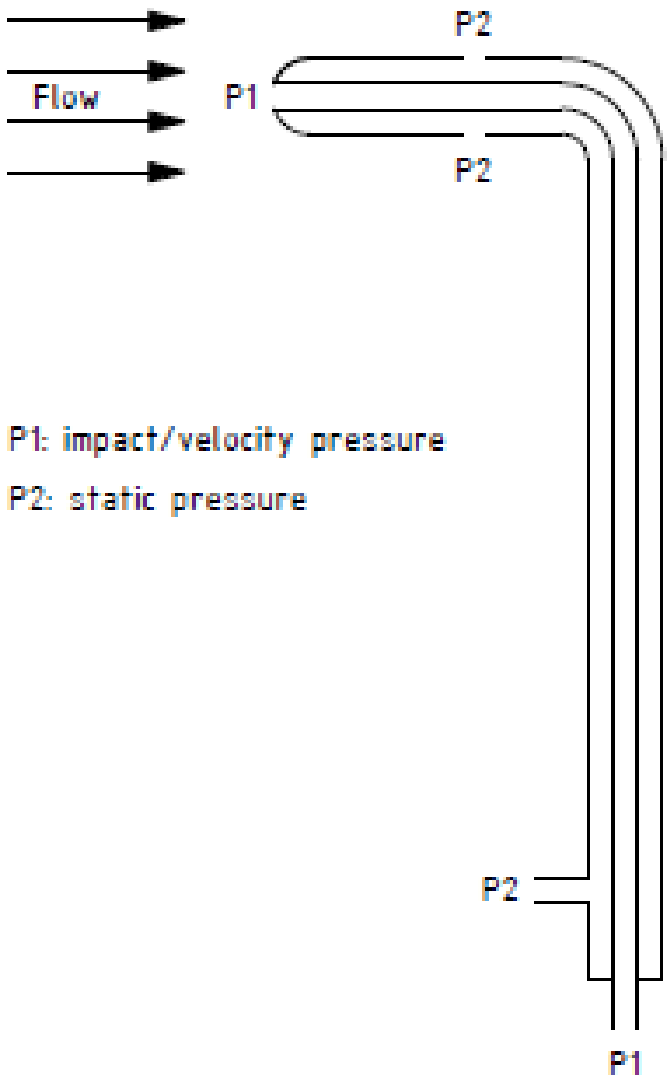
- less expensive!
- L type ones are the most widespread
- a very high-resolution differential pressure measurement is required

Methods of measurement

pitot tube anemometer

- P1 detects the overall pressure
- P2 detects via holes on the outer pipe (static pressure)
- the differential pressure Δp between P1 and P2 is measured, whereby P1 is considered representative of the pressure of the flow
- the density of the air (ρ) needs to be calculated from the measurements of temperature, humidity and air pressure

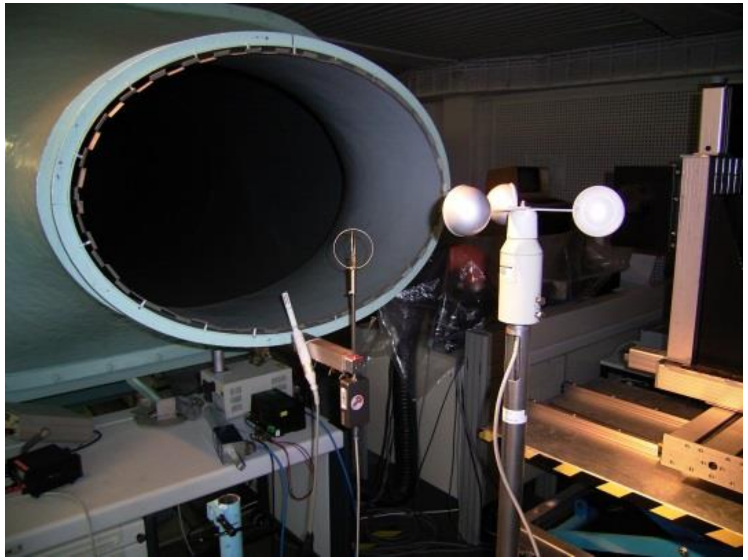
$$V = \sqrt{\frac{2\,(P1\ - P2)}{\rho}}$$

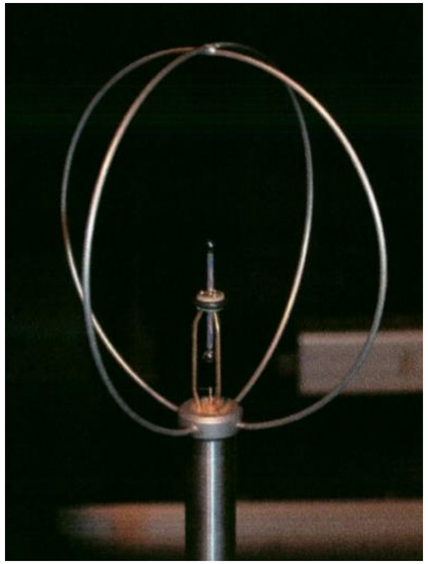


Methods of measurement

hot-wire anemometer and hot film anemometer

- for lower speed measuring
- uncertainties about 1 %
- traceable to SI (temperature)





Calibration of Wind Instruments
End of Part 2

Thank you.

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