Evaluating the 3D Sensitivity Function for a Capacitive Flowmeter

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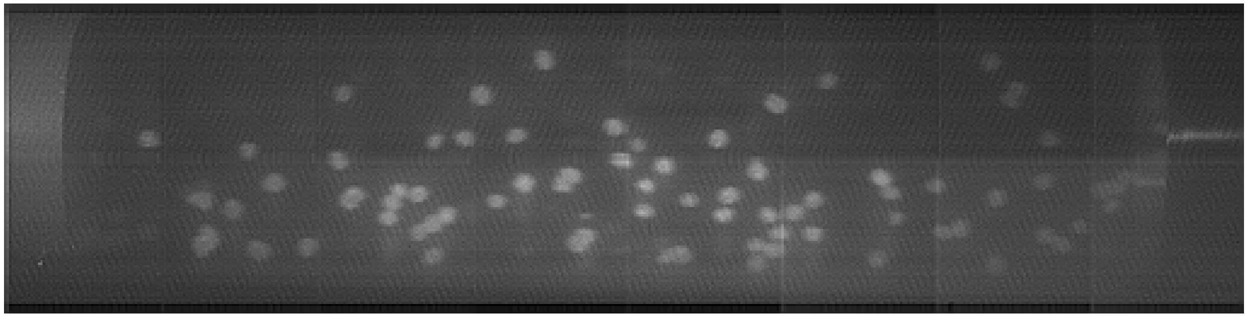
Agenda

- Introduction
- Correlative Flow Sensor
- Flow Meter Sensitivity
- Determination of Sensor Sensitivity
  - Finite Element Analysis
  - Metrological Determination
- Conclusion

Introduction

- Conveying of solid material in everyday life
- Variety of applications (industry, agriculture, …)
- Pneumatic conveying well-suited for granular and powdery material
- Gas-solids flow through closed conveyor pipe
- Aim: Particle velocity and particle concentration



Correlation Flow Meter (1/2)

- Pneumatically conveyed material flow shows fluctuations and disturbances
- Measurement in upstream and downstream layer

Signal model: $$x_2(t) = x_1(t + \Delta t) + m(t) + r(t) + n(t)$$

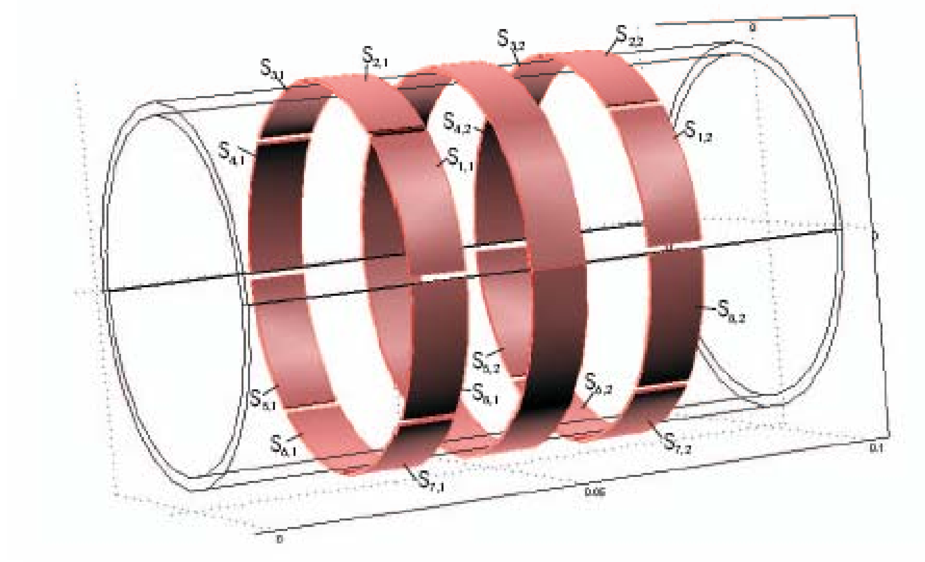
Velocity determination: $$\Phi_{12}(\tau) = \lim_{T \to \infty} \frac{1}{T} \cdot \int_0^T x_1(t) \cdot x_2(t - \tau) \cdot dt$$

$$\Delta t = \arg\max_{\tau} \left(\Phi_{12}(\tau) \right)$$

$$\overline{v}_{dist} = \frac{d_0}{\Delta t}$$

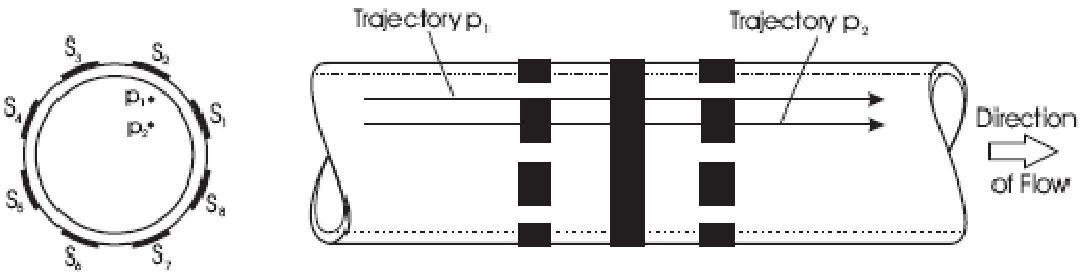
Correlation Flow Meter (2/2)

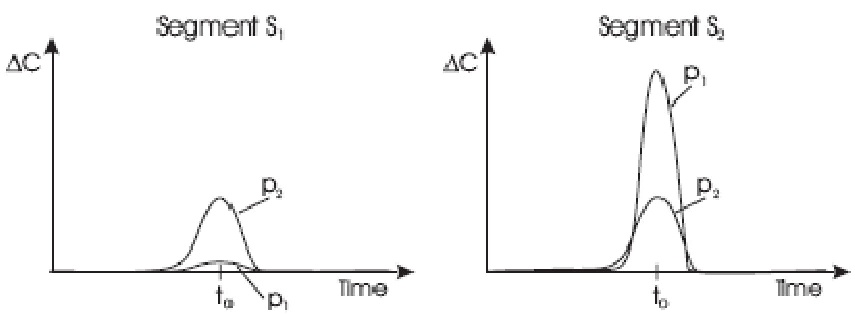
- Non-invasive capacitive flow sensor
- Two layers of transmitter electrodes (segmented)
- One common receiver ring
- Subsequent excitation of transmitters (TDMA)



Flow Meter Sensitivity

- Electric field lines are in large part parallel to direction of flow ⇨ minor "bulges" of the field
- Segment readout dependent on particle trajectory
- ⇨ Spatial resolving sensor





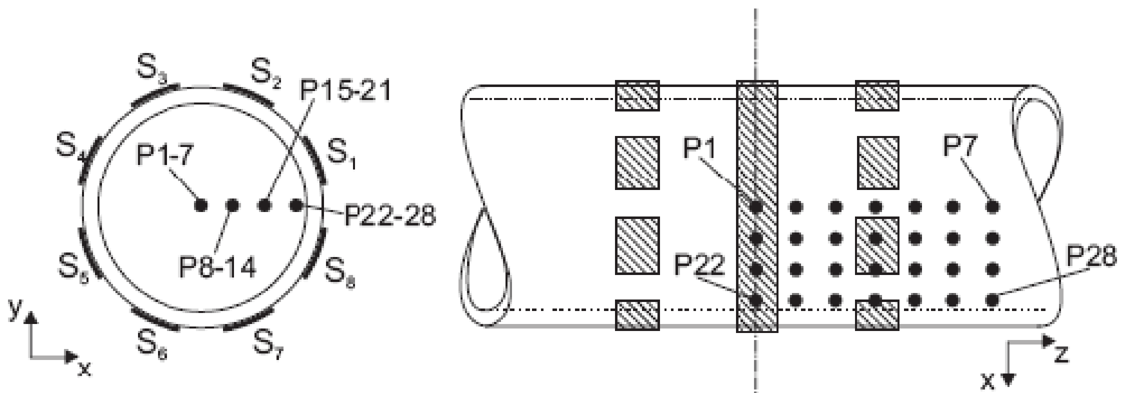
$$S = \lim_{V \to 0} \frac{1}{V} \cdot \frac{\partial Q}{\partial \varepsilon} = \lim_{V \to 0} \frac{1}{V} \cdot U \cdot \frac{\partial C}{\partial \varepsilon}$$

$$\Delta Q = \int_{\Omega} S \cdot \varepsilon \cdot d\Omega - \int_{\Omega} S \cdot d\Omega$$

Determination of Sensor Sensitivity

- Perturbation approach: spherical “disturbance” of deviating permittivity placed in volume of pipe
- Capacitance variation due to disturbance analyzed

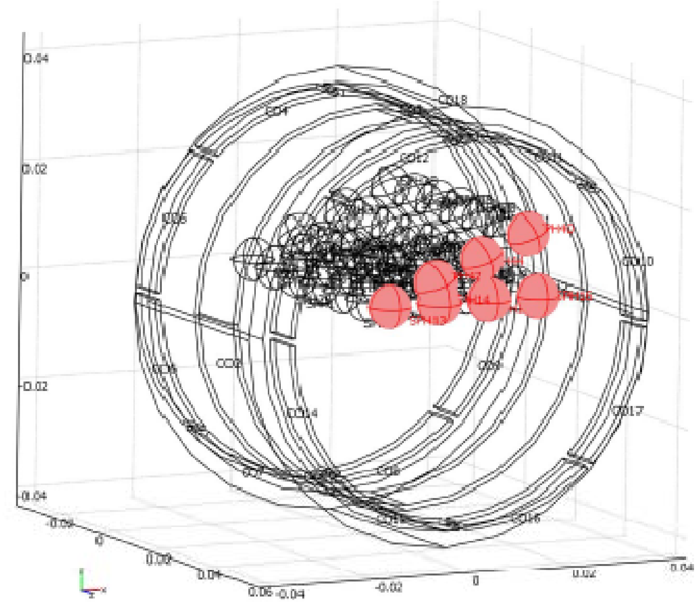
$$C = f\left(x, y, z, r_{par}, \varepsilon_{r,par}\right)$$



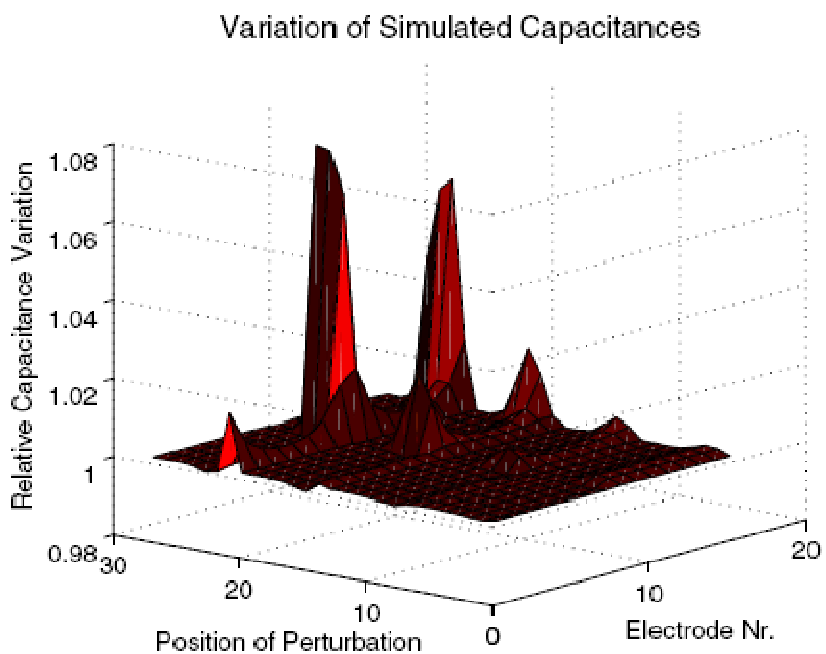
Finite Element Analysis (1/2)

- 3D geometry model of the setup (non-conductive pipe, two layers of transmitter electrodes, receiver ring)
- Spherical perturbation with diameter 8 mm, different positions in the pipe volume

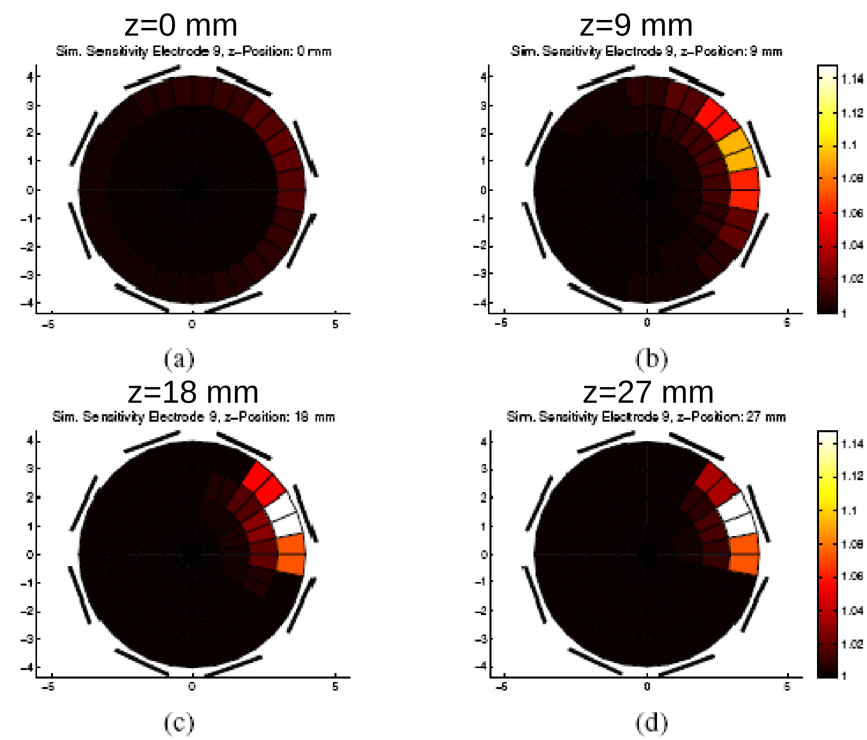
- Electrostatic problem formulation
- 105.000 elements
- Capacitance calculation based on charge integration of receiver electrode surface



Finite Element Analysis (2/2)



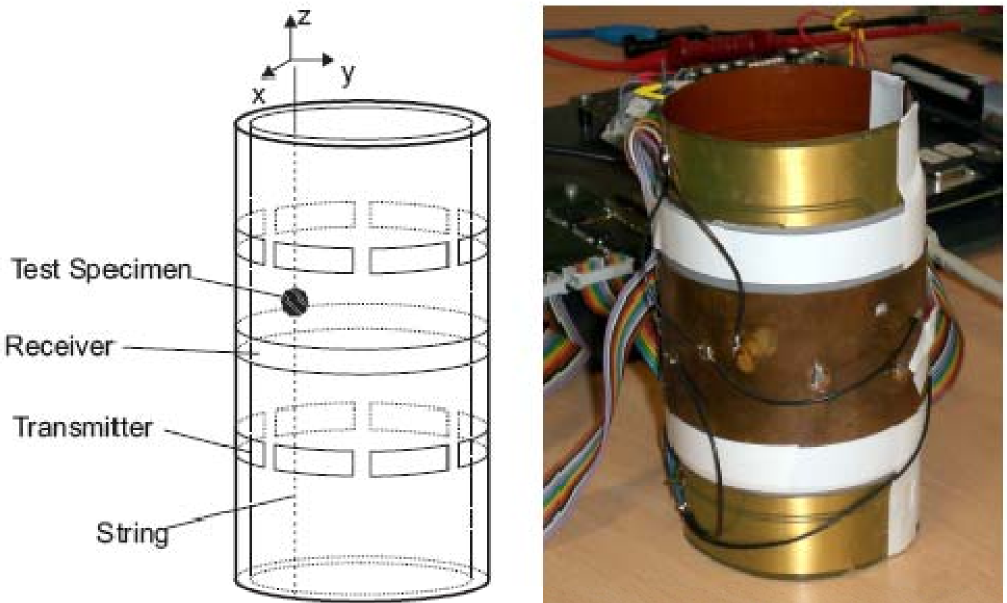
Relative variation of the simulated capacitances



Cross-sectional sensitivity maps

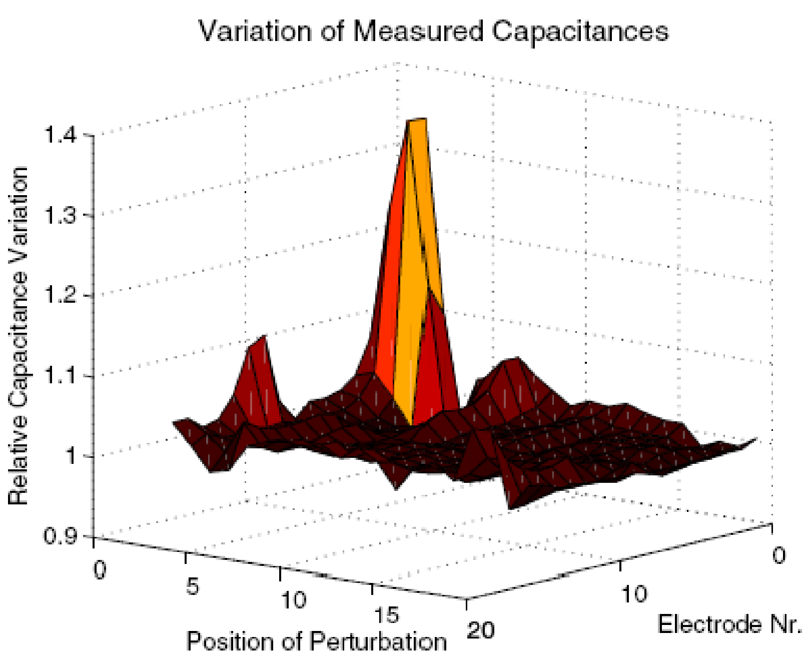
Metrological Determination (1/2)

- Thin-walled spherical latex shell with water mounted on plastic string used as disturbance
- Diameter 15 mm, can be moved in pipe volume



(a) (b)

Metrological Determination (2/2)



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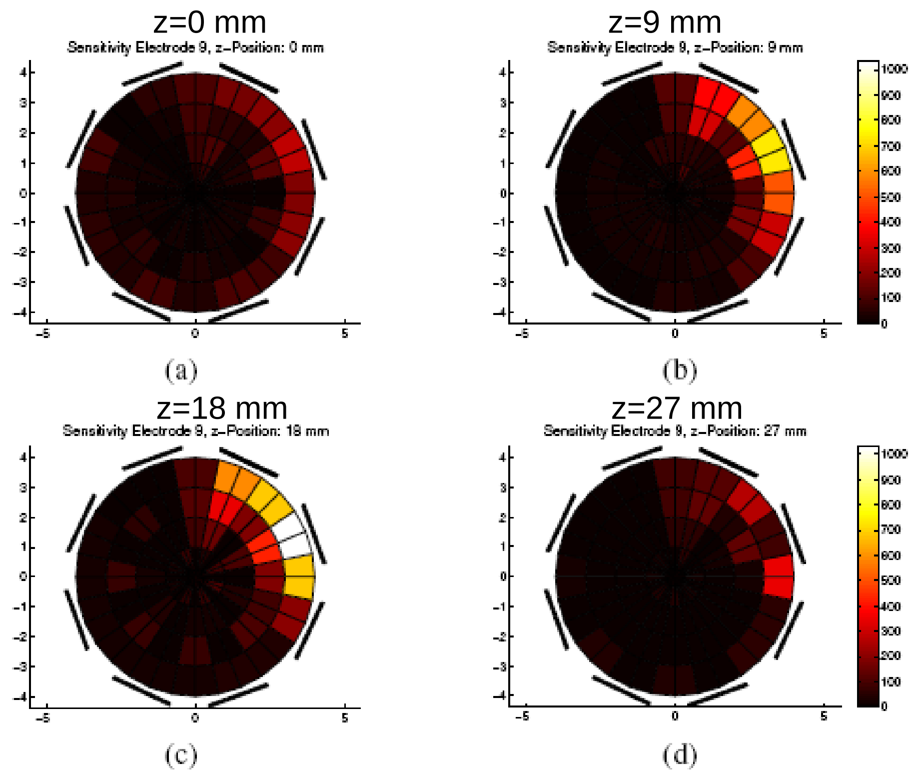

Cross-sectional sensitivity maps

Conclusion

- Two approaches on determination of 3D sensitivity function
- Perturbation placed at different positions of pipe volume
- Capacitance variations analyzed to obtain sensitivity map
- Finite Element Analysis and metrological determination
- Good accordance of model with measurement data even though simplifications for model have been made