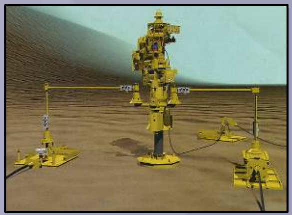
PRESENS

Pressure Sensor Technology

A differential pressure sensor for space with a silicon MEMS element

7th ESA Round Table on MNT for Space Applications

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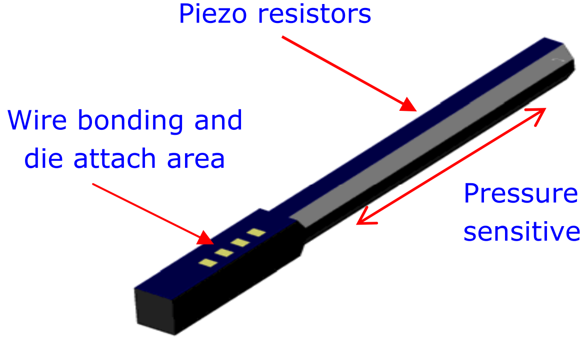
Truly different!

Background and motivation

- **Presens is a fabless MEMS company**
  - Complete control of design, test and performance
  - Subcontract processing
- **Our proprietary tubular silicon MEMS element is specially designed for high pressure applications**
  - Large volume of installations subsea
  - A new sensor for space applications are in development
  - Two contracts with ESA
- **Have seen a growing interest in a new high accuracy differential pressure sensor for flow applications**
  - Both subsea and space



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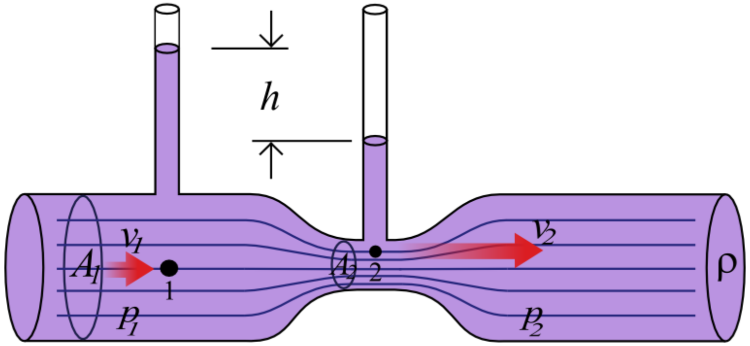
Background

- **Mechanical pressure sensors are differential**
  - The tubular element is not suitable for differential pressure
  - Have made new high accuracy element based on a diaphragm design
- **Differential pressure sensors are used for flow measurement or for tank level measurement**
  - The sensor measures a differential pressure created by media flow across a restriction. The flow is related to the differential pressure.
- **Typical requirements both for space and subsea**
  - Small dp range
  - High static pressure
  - High resolution
  - High accuracy
  - Long term stability
  - Long term reliability
    - Static pressure can become the differential pressure



Space vs. Subsea

Subsea

- **Advanced electronics**
  - 24 bit ADC
  - Microcontroller
- **Advanced bus interface**
  - CANopen
  - RS485
- **No weight constraint**
- **No size constraint**
- **No power constraint**
- **Operational environment**
  - Unlimited cooling
  - External pressure up to 700 bar

Space

- **Analogue electronics**
  - Operational amplifiers
  - Radiation hard
- **Simple interface**
  - 0 to 5 V analogue signal
  - 12 bit ADC
- **Light weight**
- **Small size**
- **Low power consumption**
- **Operational environment**
  - Restricted cooling
  - Vacuum of space
  - Almost zero gravity
  - Ionizing radiation

Application specifications

- **dp-pressure ranges**
  - 0 to 300 mbar
  - 0 to 1500 mbar

- **dp-pressure resolution**
  - Sub millibar resolution is required to achieve the accuracy of the application

- **Static pressure and maximum pressure**
  Two pressure ranges are of interest
  - 25 bar 100 bar
  - 300 bar 1200 bar
  - Consequently a system to protect the element against extreme pressures are required

- **Temperature range**
  - -40 °C to +85 °C
  - -60 °C to +85 °C

Design constraints

- **High resolution**
  - Requires high sensitivity of the sensing element
- **High accuracy**
  - Compensation for temperature and static pressure
  - Long term stability of the element and the system
- **Long term stability**
  - Isolated electrical bridge
  - Minimize hysteresis effects
  - Control of mounting stress
  - Separation diaphragms between media and sensing element
  - Long term stability and reliability of the dp-pressure seal
- **Shall tolerate high static pressures**
  - Requires mechanical overpressure protection of sensing element
- **Radiation tolerant**
  - Radiation improved design and process for the element
  - Radiation hard analogue electronics

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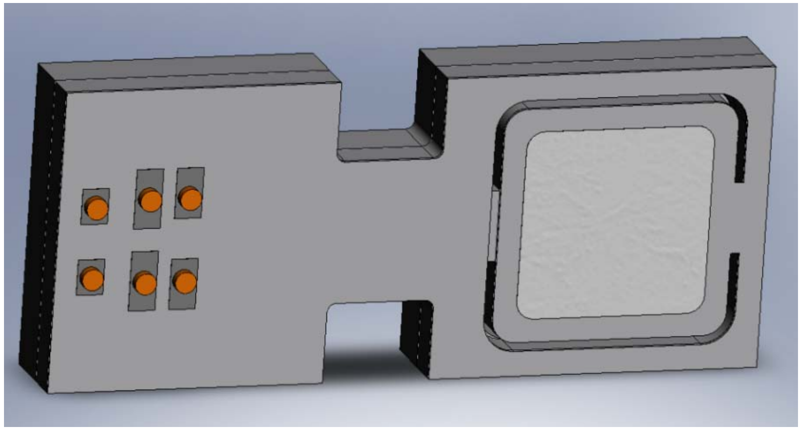
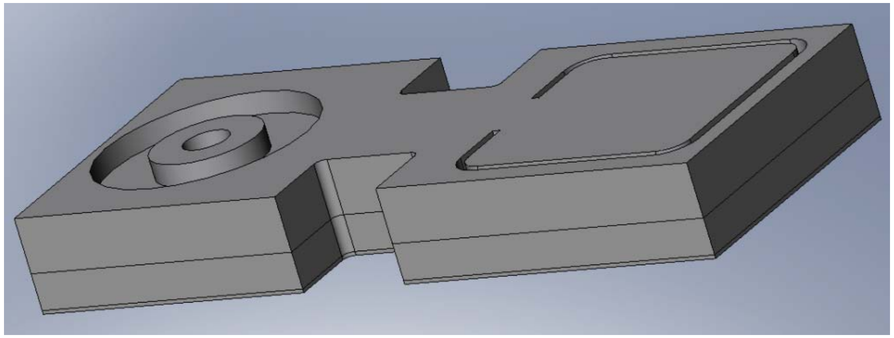
Design of the MEMS element

- **High sensitivity for the pressure signal**
  - Optimize diaphragm thickness and size
- **Rely on proven bridge design**
  - Wheatstone bridge is designed exactly like we use it on the high pressure elements
- **Isolate the Wheatstone bridge from electrical changes**
  - Use buried piezo resistors
- **Prevent stress from the metal and oxide to affect the diaphragm**
  - Route metal lines outside the diaphragm
- **Decouple mounting stress from the diaphragm**
- **Decouple thermal and mechanical stress from the diaphragm**
  - Designed for extension to very high pressures
  - Compression effects are decoupled from the diaphragm
  - Thermal stress is decoupled from the diaphragm

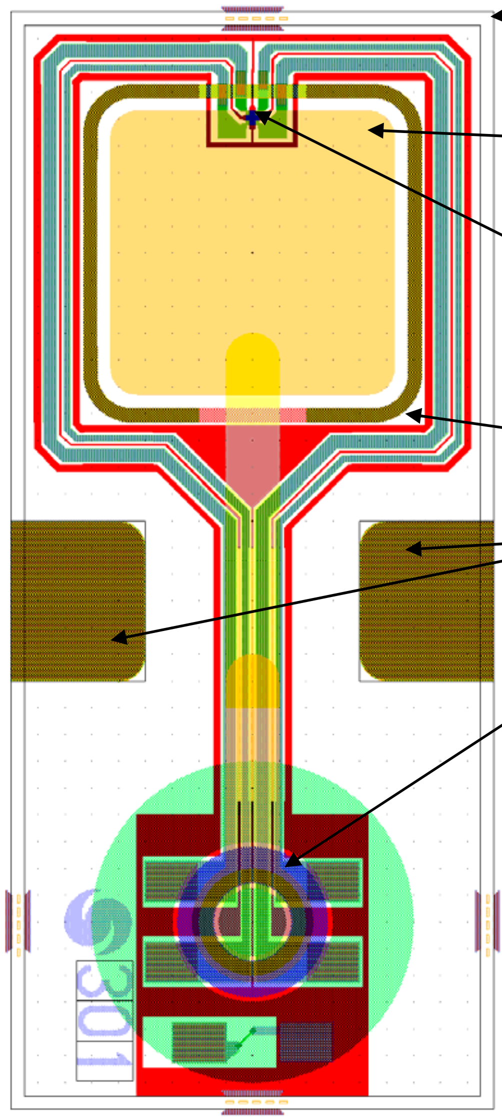
Element features

- **Diaphragm decoupled from mechanical stress**
  - Decoupled from the supporting frame
  - Decoupled from the assembly stress
- **Tubular pressure port**
  - Reduces effects of mounting stress
- **Hermetic sealing using gold to gold bonding**
  - Long term reliability without risking leaks through the seal





Δp-element chip outline



- **Chip Size**
  - Length: 4 mm (3 and 6 mm)
  - Width: 1.7 mm
- **Membrane size**
  - W&L:1.04 mm (0.34, 0.54, 0.78 mm)
  - Thickness: 20 μm
- **Wheatstone bridge configuration**
  - X-ducer (R_b≈1.5 kΩ)
  - X-ducer with hole (≈4 kΩ)
- **Decoupling of mechanical stress**
  - Mechanical decoupling of diaphragm
  - Beam length
  - Pressure inlet port with tube design
    - $Ø_{hole}$ = 0.25 mm
    - $Ø_{inner}$ = 0.6 mm
    - $Ø_{outer}$ = 1.2 mm
- **Die attach**
  - Gold ring for thermocompression bonding

Processing

- **The MEMS wafer is a complex three layer structure**

- **Three basic steps in the processing**
  - Building the MEMS wafer with mechanical shapes and inner structure
  - Processing electrical wafer
    - Buried piezo resistors
    - Thermal oxide and additional deposited passivation
  - Shaping the exterior of the MEMS element
    - Decouples stresses from the diaphragm
    - Prepare for die attach

- **Processed wafers finished and delivered**
  - Processing is possible
  - Yield is acceptable

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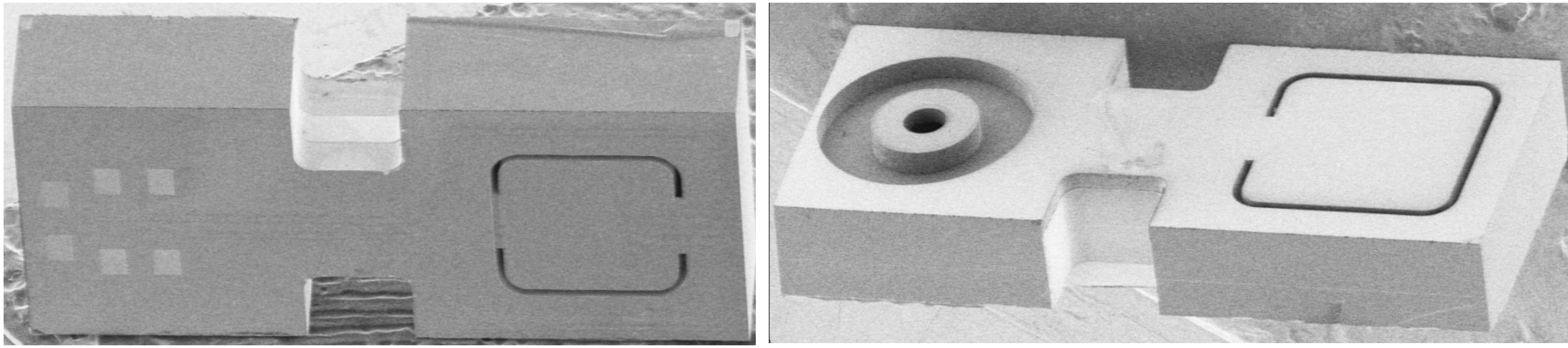
Process results



Scanning Electron Microscope pictures showing the sensing element

Process data

- **Sheet resistances**
  - Piezo resistors: 372 Ω/square
  - Surface conductor: 33 Ω/square
  - Field doping: 28 Ω/square

Element data

- **Bridge resistance**
  - X-ducer: 1.6 kΩ
  - X-ducer hole: 4.1 kΩ
- **Leakage current**
  - Typical 0.2 nA
- **Breakdown voltage**
  - Typical 22 V

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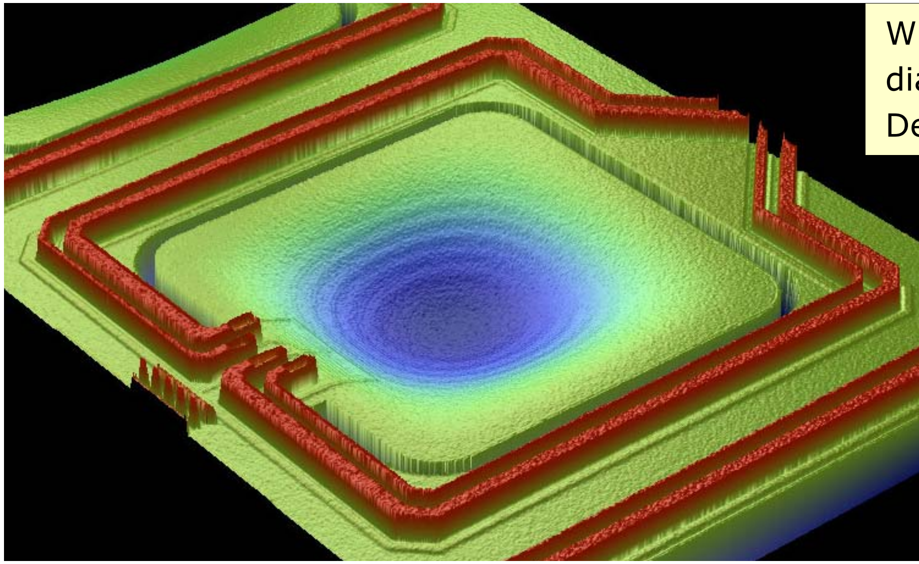
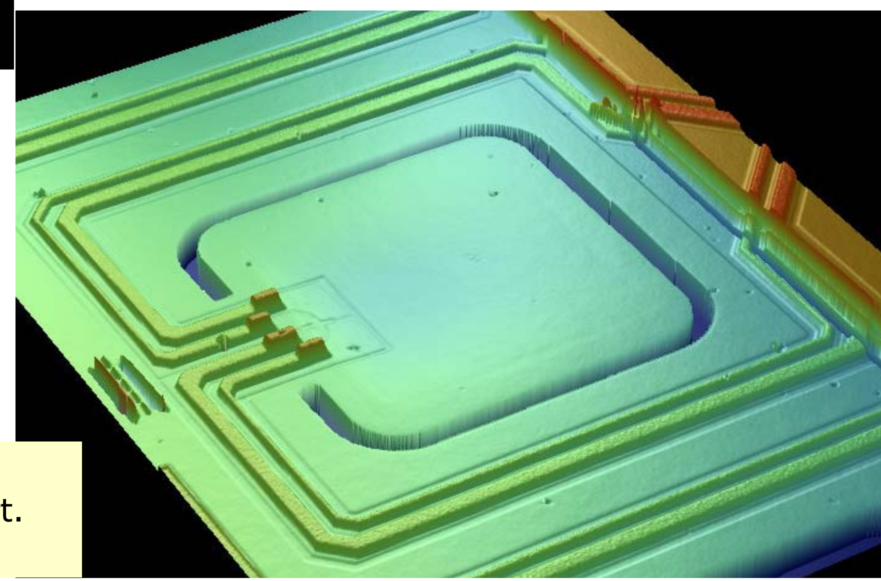
Pressure sensitive

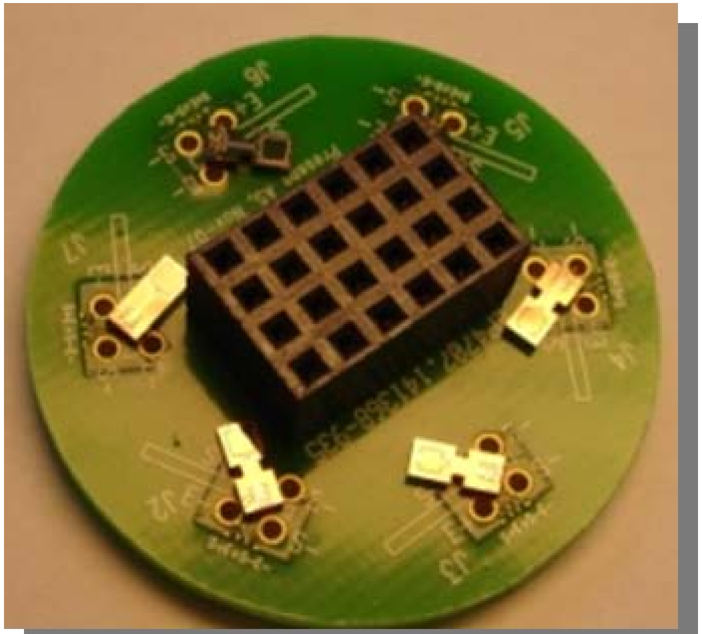


White light interferometric image showing the diaphragm deflection before opening the pressure port. Deflection equal to 1.2 µm.

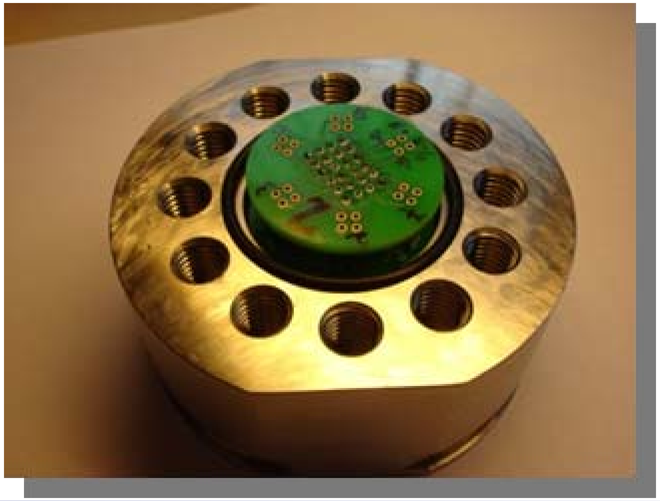


White light interferometric image showing the diaphragm deflection after opening the pressure port. Deflection equal to 0.05 µm.

First pressure testing



- **Mounting**
  - Elements glued to PCB
  - Wires bonded between element and PCB
- **Test jig**
  - PCB mounted within steel pressure chamber
  - Temperature control by mass
  - Glass feed through for electrical connection
- **Pressure application**
  - Applied pressure in 10 or 100 mbar steps
  - Applied pressures between 10 mbar and 18 bar

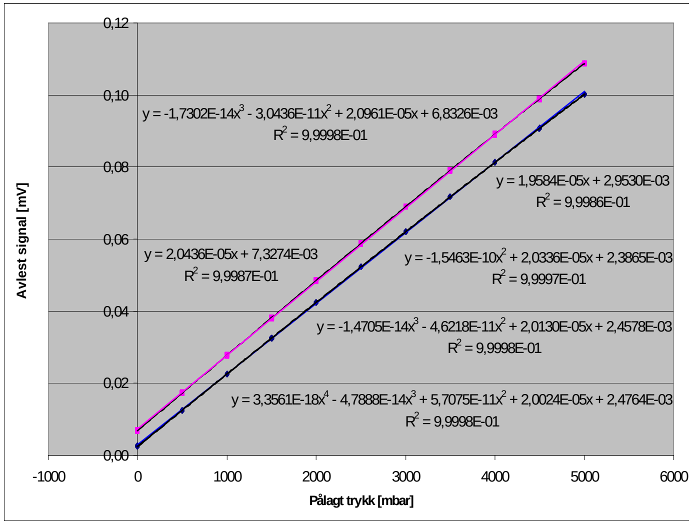


Set-up and equipment

- **Temperature control with water bath**
  - Neslab 17
- **Pressure applied with precision controller**
  - Druck DPI515
- **Pressure measured with**
  - GE Druck DPI-515
- **3 V bias voltage applied with**
  - Agilent voltage source
- **Bridge resistance and voltage measured with**
  - Agilent 34401A 6 ½ Digital Multimeter
  - Agilent 34970 Data Acquisition/Switch unit

Test results

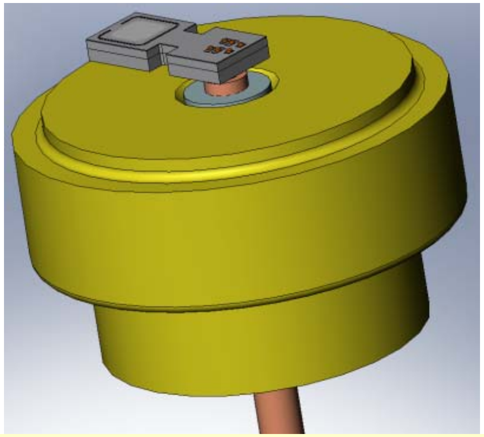
- **Signal Offset**
  - Values in the range -2 to 2 mV/V
  - Small and varying temperature effect
  - Negative temperature coefficient
- **Sensitivity**
  - Sensitivity varies with diaphragm size
  - Typical values are much lower than simulated
  - Positive temperature coefficient
- **Nonlinearity**
  - Intrinsic nonlinearity better than 1.2%
- **Burst pressure**
  - Burst pressure for the large diaphragm is > 18 bar



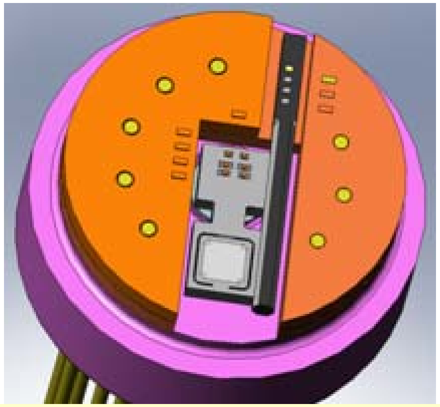
Design	Diaphragm	Sensitivity [mV/Vbar]	Nominal sensitivity	Offset [mV/V]	Nonlin [%]	Rb [Ω]
301	1060 µm	6,7	20	1,5	1,1%	1700
305	780 µm	3,1	10	-55,8	1,2	1650
307	540 µm	1,3	5	1,28	1,4%	1640
309	340 µm	0,38	2	0,68	3,2%	1661

Sensor assembly

- **Element mounted directly to the end of a tube**
  - Glassed-in tube
  - Pressure applied trough the tube
  - Electrical isolation
- **Gold to gold thermocompression bonding At 400 °C**
  - Die shear force of 1.1 kP
  - Not leak proof
- **Alternatives**
  - Tried epoxy adhesive
  - Considered Gold-Tin eutectic solder
  - Considered Lead-Tin eutectic solder
- **Requirements**
  - Leak proof: $2.5x10^{-8}$ mbarL/min
  - Mechanical strength: > 1.2 kg



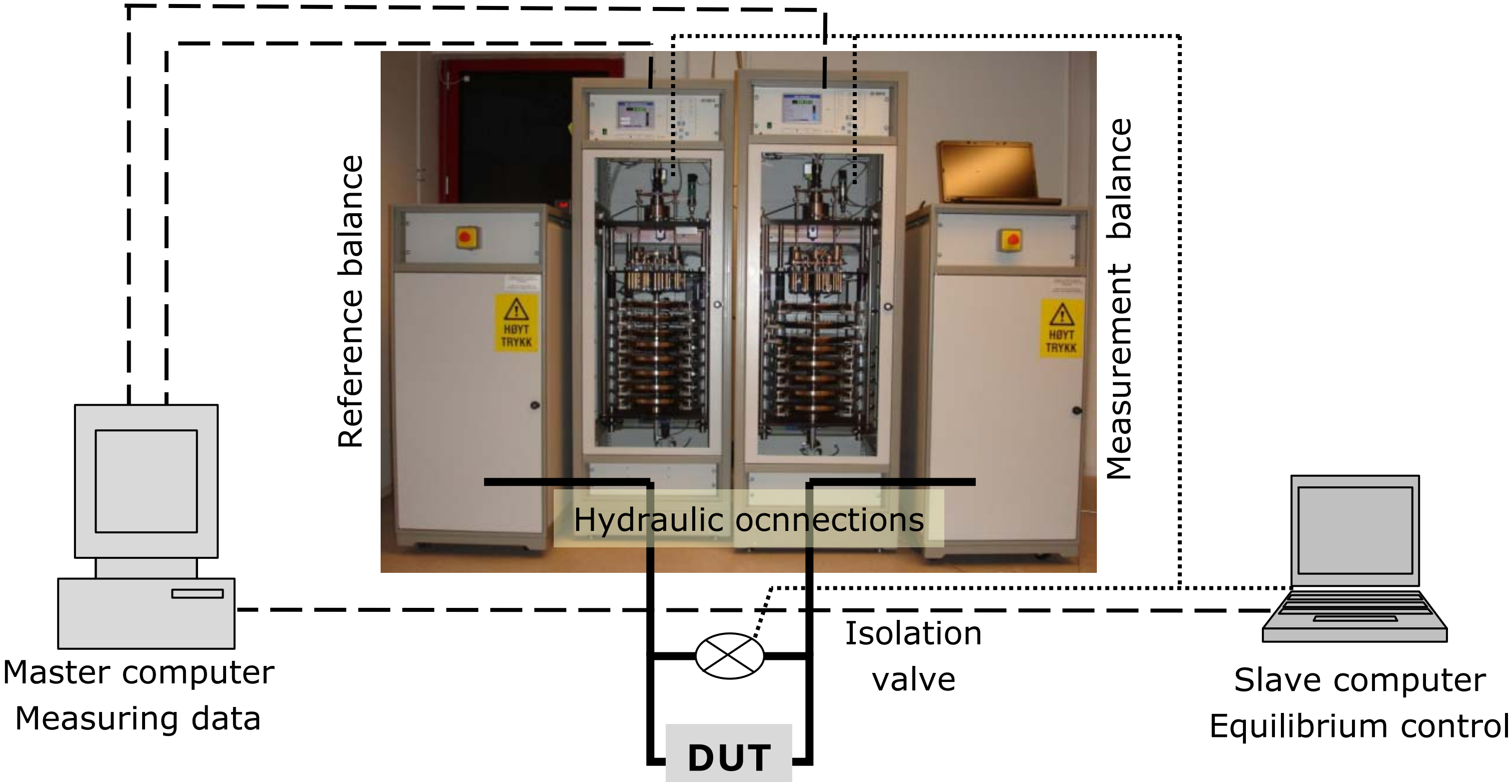
Bulhead for test purposes



Prototype bulk head with dp and absolute element

Pressure testing

Differential pressure with static pressures



- **A pair of DH Budenberg dead weight testers**
  - Can adjust line pressures from 1 bar to 1723 bar
  - Can apply dp-pressures up to the line pressure
    - Minimum resolution is 0.1 mbar

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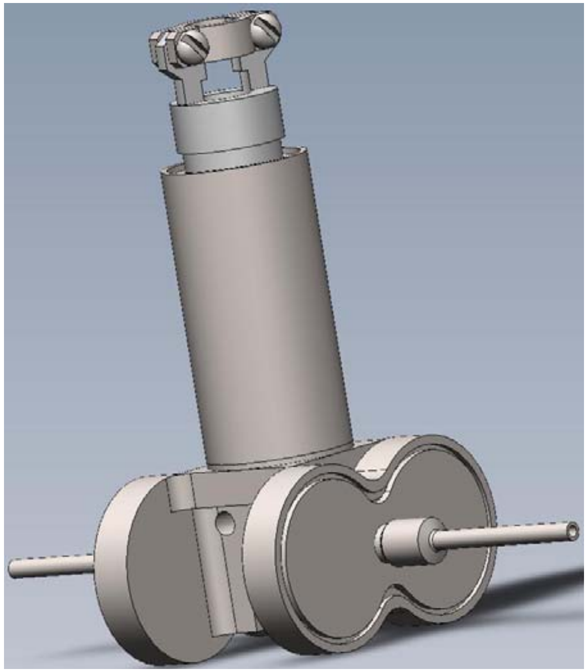
System specifications



- **Design goals**
  - Sub-mbar resolution
  - High accuracy, better than 0.1 %
  - Differential pressure range 0 to 300 mbar
- **Mechanical**
  - Low mass: 185 g (except oil filling and cables)
  - All parts made in titanium grade 5
  - Corrosive operation with separation diaphragms
- **Presens patented overpressure protection system**
  - Protects the element from high static pressures without reducing sensitivity or accuracy

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Special features

Electronics

- Analogue radiation hard
- Chopping amplifier to compensate for offset and sensitivity
- Reads pressure and temperature signal
- Look-up table for compensation of temperature and line pressure

Power consumption

- Constant bias for the sensing element
- Current limited start-up
- Maximum current 16 mA

Interface

- Flying leads, shielded twisted pairs
  - Power, pressure and temperature
- 0 V to 5 V (0.5 to 7 V full signal range)
- Shielded twisted pair for pressure and temperature

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Conclusions

- **A new silicon MEMS sensing element has been designed and tested**
- **Performance is according to expectations**
  - Sensitivity is lower than expected
  - Assembly of the element limits the testing
- **A concept for a new differential pressure sensor has been presented and is under development**

Acknowledgements
The Research Council of Norway
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