Basics & Design for Ultra Clean Vacuum

Why use vacuum?
- Generate force
  - Suction cup
  - Clamping
- Prevent heat conduction/convection
  - Thermos
- Evaporate metals
  - Coating
- Avoid contamination
  - Loss of reflection of mirrors (EUV)
  - Contaminating samples (TEM/SEM)
- Avoid absorption of energy
  - EUV
  - Electron-/ion beams / X-rays

Vacuum specification:
- 0.3 – 1 mbar
- $10^{-3} – 10^{-6}$ mbar

Examples of spectra 2
Residual gas spectra of a non-baked vacuum system

$P_{\text{min}} = \frac{Q}{S_{\text{eff}}}$

$Q$ (mbar ltr/sec)
$S_{\text{eff}}$ (ltr/sec)

Sources of gas:
- $Q_{\text{desorption}}$
- $Q_{\text{permeation}}$
- $Q_{\text{virt. leak}}$
- $Q_{\text{leak}}$

leakage:
- $Q_{\text{leak}} = P_{\text{min}} / S_{\text{eff}}$

Exercise 1, question
A Load-Lock is connected to a Main Vacuum Chamber.
2 valves with $d_{\text{max}} = 40$ cm and a flange thickness $= 30$ mm are in contact.
The enclosed gas volume $= 10^5$ Pa in between the 2 valves expands into the main chamber.

What is the pressure in the main chamber after opening the indicated valve?
Contents

- Mechatronics Training Curriculum
- Details of Course *Basics & Design for Ultra Clean Vacuum*
Mechatronics Training Curriculum

Premium
- Advanced Motion Control - 5 days
- Advanced Feedforward & Learning Control - 3 days
- Passive Damping for High Tech Systems - 3 days
- Masterclass Design Principles - On request
- Basics and Design for Ultra Clean Vacuum - 4 days
- Experimental Techniques in Mechatronics - 3 days
- Metrology & Calibration of Mechatronic Systems - 3 days
- Actuation and Power Electronics - 3 days
- Machine Vision for Mechatronic Systems - 2 days
- Thermal Effects in Mechatronic Systems - 3 days
- Workshop Mechatronics System Design - On request

Advanced
- Advanced Mechatronic System Design - 6 days

Standard
- Motion Control Tuning - 5 days
- Dynamics and Modelling - 3 days
- Design Principles for Precision Eng. - 5 days
- Basics and Design for Ultra Clean Vacuum - 4 days
- Experimental Techniques in Mechatronics - 3 days
- Metrology & Calibration of Mechatronic Systems - 3 days
- Actuation and Power Electronics - 3 days
- Machine Vision for Mechatronic Systems - 2 days
- Thermal Effects in Mechatronic Systems - 3 days

Basic
- Mechatronics System Design – part 1 - 5 days
- Mechatronics System Design – part 2 - 5 days

www.mechatronics-academy.nl

Relevant partner trainings:
- Applied Optics
- Electronics for non-electrical engineers
- System Architecture
- Soft skills for technology professionals...

Basics & Design for Ultra Clean Vacuum – overview
In the past, many trainings were developed within Philips to train own staff, but the training center CTT stopped.

**Mechatronics Academy B.V.** has been setup to provide continuity of the existing trainings and develop new trainings in the field of precision mechatronics. It is founded and run by:

- Prof. Maarten Steinbuch
- Prof. Jan van Eijk
- Dr. Adrian Rankers

We cooperate in the **High Tech Institute** consortium that provides sales, marketing and back office functions.
Basics & Design for Ultra Clean Vacuum
Course Director(s) / Trainers

Trainers

• Dr. Dick van Langeveld (NEVAC)
• Ing. Theo Mulder (NEVAC)
• David Schijve (NEVAC & VacTec)
• Ing. Mark Meuwese (Settels Savenije van Amelsvoort)
• Ir. Sven Pekelder (Settels Savenije van Amelsvoort)

Course Director(s)

• Ing. Mark Meuwese (Settels Savenije van Amelsvoort)
• Dr.ir A.M. Rankers (Mechatronics Academy)
## Program

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<tr>
<th>Day</th>
<th>Topic</th>
<th>Presenter</th>
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| 1   | 09.00 Fundamentals | Dick van Langeveld  
11.30 Flow of gases | Dick van Langeveld  
12.30 Lunch | Theo Mulder  
13.30 Total & Partial Pressure |  
17.00 End of day |
| 2   | 09.00 Pumps / Applied RGA | David Schijve  
12.30 Lunch |  
13.30 Leak Tightness (Theory & Practice) | David Schijve  
17.00 End of day |
| 3   | 09.00 Engineering Aspects | Dick van Langeveld  
12.30 Lunch |  
13.30 Design for Qualification | Sven Pekelder / Mark Meuwese  
17.00 End of day |
| 4   | 09.00 Mechatronic Aspects | Mark Meuwese  
12.30 Lunch |  
13.30 Vacuum Budgetting | Sven Pekelder  
17.00 End of day |
Day 1 (morning)

Sources of gases to take care of
- Vapor pressure of the material
- Diffusion (disorption of water vapor & contaminants)
- Permeability
- Adsorption

Determined in the design phase (material selection), key-role storage and assembly.

Air is a mixture of gases

<table>
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<th>%</th>
<th>gas</th>
<th>Symbol</th>
<th>AMU</th>
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<td>neon</td>
<td>Ne</td>
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<tr>
<td>5.9x10⁻⁵</td>
<td>hydrogen</td>
<td>H&lt;sub&gt;2&lt;/sub&gt;</td>
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The mean free path, λ, of molecules

Transport properties of a gas depend on the length of λ as related to the characteristic dimension of the part through which the gas flows.

This ratio is known as the Knudsen number, Kn = AM

One can discriminate different regimes:
- Kn << 1: 'high' p, high density, viscous flow
- Kn >> 1: 'low' p, low density (dilute gases), molecular flow

Consequences:
We need to use different physical models to describe the flow of gases in the different regimes.

Exercise 1, question
A Load-Lock is connected to a Main Vacuum Chamber.
2 valves with dia<sub>av</sub> = 40 cm and a flange thickness = 30 mm are in contact.
The enclosed gas volume @ 10<sup>⁵</sup> Pa in between the 2 valves expands into the main chamber.

What is the pressure in the main chamber after opening the indicated valve?

A few basic things about sorption

Number of colliding molecules N<sub>c</sub> on a surface A

\[ \Delta N_c/A = 0.25 \times (N/V) \times A \times \bar{v} \]

Agas molecule loses its original impulse and temperature upon contact with the surface of a solid and adopts the temperature of the surface instantaneously.

When desorbing, the molecule preferentially leaves the surface perpendicular to it.

Condensation

Condensation only occurs at sufficiently low T, when the cohesion between the layers is stronger than the thermal energy.

Example: water on window in summer, ice in the freezer.
Flow of gases

Flow of gas through a system

Summary conductances

Vacuum regimes

Piezoelectric pressure gauge

Examples of spectra 2
Residual gas spectra of a non-baked vacuum system
Basics & Design for Ultra Clean Vacuum – overview

Day 2 (morning)

Overview Vacuumpumps

Types of compression

- Isothermal compression: Heat of compression is dissipated by the pump and its pumped medium.
\[ T_{\text{gas in}} = T_{\text{gas out}} \]
\[ p_1 \times V_1 = p_2 \times V_2 \] (Boyle’s law)

With \( p_1 = 10 \text{ mbar} \), \( V_1 = 100 \text{ cm}^3 \) and \( V_2 = 1 \text{ cm}^3 \) it follows
\[ p_2 = 1000 \text{ mbar} \]

- Adiabatic compression: Heat of compression is fully transferred to the gas.
\[ T_{\text{gas out}} > T_{\text{gas in}} \]
\[ p_1 \times (V_1)^{1.4} = p_2 \times (V_2)^{1.4} \]

With \( p_1 = 10 \text{ mbar} \), \( V_1 = 100 \text{ cm}^3 \) and \( V_2 = 1 \text{ cm}^3 \) it follows
\[ p_2 = 6309 \text{ mbar} \]

Molecular flow

Incoming molecule with thermal velocity

Hybrid Molecular Pump Siegbahn principle

Summary turbomolecular pump

- A TMP needs always a backing pump
- Critical backing pressure of 10 Pa (\(10^{-5} \text{ mbar}\))
- Compression ratio increases with increasing molecular mass
- As long as the oil- or grease lubricated TMP is in operation: no backstreaming of hydrocarbons
- If an oil- or grease lubricated TMP is not in operation: TMP should always be vented
Day 2 (afternoon)

Ultimate pressure (U)HV system

\[ P_{\text{min}} = \frac{Q}{S_{\text{eff}}} \]

**Q (mbar ltr/sec)**

**S_{\text{eff}} (ltr/sec)**

Sources of gas:
- \( Q_{\text{desorption}} \)
- \( Q_{\text{permeation}} \)
- \( Q_{\text{virt.leak}} \)
- \( Q_{\text{leak}} \)

leakage:
- \( Q_{\text{leak}} = P_{\text{min}}/S_{\text{eff}} \)

Leak testing

Why?
- R&D: (U)HV systems
- Industry: Quality certification!

Example:
Gas cylinder Airbag need 10 yrs operation
Qualification: pressure drop less < 0.5 mbar

\[ Q_{\text{leak}} = \frac{V \cdot \Delta p}{\Delta t} \]

\[ = 0.2 \text{ ltr} \times 500 / 10^{-5} \times 365 \times 24 \times 3.6 \]

\[ = 3.2 \times 10^{-7} \text{ mbar ltr/sec} \]

Leak calculation

Leaks generate gas flow \( Q \):

Round hole:
- Assume molecular or laminar flow
- \( C = 123 \frac{d^2}{D} \)
- \( \text{Flow:} \ D = 0.05 \text{mm} \)
- \( \text{Wall thickness} 5 \text{mm} \)

\[ C_{\text{mol, w}} = 123 \cdot \left( \frac{5}{6} \right)^{3 / 2} \cdot 3.1 \times 10^{-9} \text{ m^3/ps} \]

\[ C_{\text{am, w}} = 1303 \cdot \left( \frac{100}{1000} \right)^2 \cdot \left( \frac{5}{6} \right)^{3 / 2} \cdot 8.4 \times 10^{-8} \]

\[ Q_{\text{mol, w}} = C_{\text{mol, w}} \cdot \Delta p \cdot 1 \times 5 \times 3.1 \times 10^{-4} \text{ Pam/} \sec \]

\[ = 3.1 \times 10^{-3} \text{ mbar/s} \]

\[ Q_{\text{am, w}} = C_{\text{am, w}} \cdot \Delta p \cdot 1 \times 5 \times 3.1 \times 10^{-4} \text{ Pam/} \sec \]

\[ = 8.4 \times 10^{-2} \text{ mbar/s} \]
Day 3 (morning)

**Why use vacuum?**
- Generate force
  - Suckling cup
  - Clamping
- Prevent heat conduction/convection
  - Thermos
- Evaporate metals
  - Coating
- Avoid contamination
  - Loss of reflection of mirrors (EUV)
  - Contaminating samples (TEM/SEM)
- Avoid absorption of energy
  - UV
  - Electron-/ion beams / X-rays

**Pumping speed**
- What will be the effective pumping speed at the entrance of the chamber?
- What will be the end pressure, when Q=10^-3 mbar L/s?
- What will be the pump-down time to reach 10^-4 mbar?

**Theoretical pump down curve**

**Gasloads**
1. Leaks
   a. Real leaks
   b. Virtual leaks
2. Desorption/Outgassing
3. Diffusion
4. Permeation
5. Evaporation
6. Backstreaming pump

**O-ring seal**
- Why here?

**Cleaning procedures, removing oil & grease with water & soap**

1 mbar
1.10^-3 mbar

- washing machine with soap
- ultrasonic with soap

- Pre-cleaning with tap water
- Cleaning step
- neutralize
- rinse with semi-water
- Dry
- Bake out @ 120 - 200°C in vacuum
Day 3 (afternoon)

Qualification

- Medium RGA qualification system Philips AppTech
- Typical application: (sub)assemblies
- Background ≈1% of product specification
  - $p_{\text{H}_2\text{O}} \approx 10^{-10}\text{ mbar}$

Checks

- Check $0.5 < \frac{P_{\text{vacuum}}}{P_{\text{external}}} < 2$
- Typical ratios
  - $\frac{Q_{\text{H}_2\text{O}}}{Q_{\text{C}}}$
  - $\frac{Q_{\text{H}_2\text{O}}}{Q_{\text{H}_2\text{O}}}$
- Compare with estimations for outgassing rates [mbar·s·cm$^2$]

Case: feedthrough flange

- Complex feedthrough flange → test separately → 2 additional test parts
- Stacked couplings → more complex test-flange
- Finding a leak very complex and time consuming
Day 4 (morning)
Day 4 (afternoon)

Overview vacuum system

- Qualification-chamber for materials testing
- Loadlock for entering and exiting samples
- Sample size 30x30x30 mm max
- Sample chamber $10^{-3} - 10^{-7}$ mbar depending on sample
- Required end pressure in loadlock $10^{-5}$ mbar
- Measuring device to be kept on $10^{-7}$ mbar
- Operating temperature 20 °C

Main chamber

- Beam diameter 0.1 mm
- Lower chamber $10^{-3} - 10^{-7}$ mbar depending on gasload sample
- Upper chamber, above aperture, to be kept on $10^{-4}$ to protect probe electronics
- Pump lower chamber 200 l/s
- Outgassing of probe: $Q_{\text{probe}} = 5 \times 10^{6}$ mbar.l/s
- Determine required pump at aperture diameter of 2 mm
- (neglect probe attachment and pump attachment)

Loadlock: O-rings

- O-ring diameter 3.53 mm, Viton
- Calculate permeation for one type based on following assumption: Permeation length is the length of the O-ring groove.
- For other O-rings compensate for different length (all diameters taken equal for simplicity)

Loadlock: What determines the gasload?

- YAF series 12 12146-944

Inner valve

- Does it work?
- Determine force required to compress the O-ring
- Would the compression be enough to limit leaktight at initial pumpdown of main chamber?
- What would be better solutions for the valve-construction?
Sign-up for this training

Via the website of our partner
High Tech Institute