Determination of the Vacuum System for R2R by using a New Pumping Simulation Program

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## Agenda

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### Who we are and what we do

**Technologies**
- Oil-sealed & Dry Technology
- Mechanical & Magnetically Levitated Turbo Molecular Pumps
- Cryogenic
- Vacuum Accessories & Vacuum Systems

**Values**
- Higher productivity
- Improved use of resources
- Reduction of waste
- Energy efficiency
- High level application experience and full line vacuum technology

**Market & Applications**
- Process Industry (Metallurgy, Automotive)
- Construction, display and large area coating
- Food & Packaging
- Research & Development
- R&D/analytics

**Customers**
- Reliable partner for more than 55,000 customers
- Large global Sales and After Sales Network
- High consultancy and engineering capabilities

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Vacuum technologies are a key part of many modern industrial applications as they often rely on vacuum technologies.

**Leybold Vacuum** offers a broad range of advanced vacuum solutions for use in manufacturing and analytical processes, as well as for research purposes.

We focus on the development of application- and customer-specific systems for the creation of vacuums and extraction of processing gases.

Fields of application are coating technologies, thin films and data storage, analytical instruments and classic industrial processes.
## Agenda

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Which Parameters are important for the Vacuum System Selection?

### Important for the Customer
- Pump down load / unload lock time
- Process time
- Conditioning pressure
- Process pressure
- Investment costs

### Required Outcome
- Energy costs
- Costs of resources (cooling water, CDA, N2, ..)
- Maintenance/service interval
- Maintenance/service costs

### Set up Condition
- Chamber/s – Volume, surface material, temperature
- Pipework – Dimensions, components (e.g. valves, bends, orifices, filters)
- Mass flows – Process gas, leakage, purge
- Process conditions – (Gases,) Particles, dust, temperature, mechanical stress – vibration, electromagnetic stress – magnetic field, plasma
- Potential hazards condensation, chemical reactions, ATEX

### Parameters of the specific Pumping System
- Pumping speed
- Pressure (Process~, Base~, ultimate~)
- Power consumption
- Particle handling
- Protection against media (corrosive gases, particles)
# The Vacuum Components for Thin Film Coating

Fore-vacuum Pumps and Systems

## Wide Selection. Which are the best suitable ones for my process?

<table>
<thead>
<tr>
<th>Oil-sealed rotary-vane pumps</th>
<th>Oil Diffusion Pumps</th>
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<td>Dry compressing screw pumps</td>
<td>Turbomolecular Pumps</td>
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<td>Booster pumps</td>
<td>Cryo Pumps</td>
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<tr>
<td>Pump-systems</td>
<td>Accessories (valves, flange &amp; fittings, gauges, leak detectors)</td>
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The PASCAL Simulation Program
What does “vacuum simulation” mean?

Goal of the Simulation Program
- To determine the best suitable pumping system for achieving the required process conditions
- Note – Vacuum system design is not trivial

The working principle
- The program uses well-known equations of vacuum physics as well as proprietary models, covering the whole range from atmosphere to UHV
- Simulation of pumps and components bases on measured characteristics and/or appropriate calculation models

Main Calculation Tasks
- Operation point calculation – Maintaining a certain gas flow or pressure level
- Pump down calculation – How long does it take to..?
- Pumping speed calculation – How big is the influence of conductances?
The PASCAL Simulation Program
Something more in detail …

Model capabilities
- Each pump/component is modeled as an individual vacuum element
- Vacuum system layout can be fully 2-dimensional
- It is possible to use multiple chambers within a single system
- It is possible to calculate two or more independent vacuum systems at once
- Pumps/valves are switchable; switching is controlled either by pressure, time or by another vacuum element
- Certain boundary conditions (pressure or flow b.c.) can be applied at any place of the vacuum system

Physical effects taken into account
- Desorption (at this time within chambers only)
- Internal volume of each vacuum element
- Pressure- and time dependent change in gas temperature within the chamber/s (during pump down), due to thermodynamic effects
- Transient operation of mechanical boosters using FCs
The PASCAL Simulation Program
The general program’s composition

The back-end and the data base are hosted on a Cologne-based server
The front-end (user interface) runs within a web browser

Resultant advantages:

- Code and data are always up-to date
- No individual installation necessary
- Cross-platform user interface – Pascal runs on Windows, iOS, Android, ...
- Starting a calculation on a first device you can get the results either on the same or on a different one
- Projects can be shared easily just by submitting the project’s URL
- Good access control, via secure connection
The PASCAL Simulation Program
The graphical user interface

- Choose elements from central database, intelligent search available
- Drag & Drop
- Copy & Paste of one or more elements at once
- Double click on an element opens its configuration window
The PASCAL Simulation Program
Types of calculation results

Operating Point Calculation
- Detailed information on any point of the vacuum system about –
  Pressure, pressure difference, pumping speed, gas flow, mass flow, temperature, rotational speed, power consumption, conductance, compression ratio (where applicable)

Pumping Speed and Pump Down Calculation
- Diagrams (lin/log scalable, zoomable) and tables of –
  All properties mentioned above, vs. pressure resp. vs. time

Export of
- Diagrams and tables (see above): to Excel
- Report: to Word
  including vacuum layout, diagrams, project & software information, …
Calculation tasks Operating Point Calculation (1/2)

Main question
- What’s the pressure inside the system for a given gas flow?
- Can the system maintain a certain pressure level (process ~, base ~, ..)?

Other information, e.g.
- Are pumps in safe operation mode?

Please note:
- All calculations are quasi-stationary.
  *I.e., volume of elements, inertia effects, desorption flow etc. are disregarded!*
Calculation tasks Operating Point Calculation (2/2)

Example

- **Task** – Maintaining a chamber pressure of 3.5e-2 Torr

First attempt

- using a **single line** between Chamber and pumping system
  → **9+3+1** pumps needed

Improvement – Using **three lines in parallel**

- → Just **3+1+1** pumps left!
- → Chamber pressure is even lower
  - The procedure is an iterative optimization
  - The result depends on the experience of the operator

Give it more thought – save money 😊
Calculation tasks: Pump Down Calculation (1/2)

Main question:
- How long do I need to pump down my system to a certain pressure?

Please note:
- Transient effects are taken into account!
  - *thermodynamic and inertia effects, desorption*
- Each chamber resp. conductance element may start at a different pressure level
  - *we may use pre-evacuated elements to improve the pump down*
- Pipework dimensions have big influence on pump down time due to
  - *its conductance*
  - *its own volume (buffer for pressure equalization vs additional amount of gas to be pumped)*
- Roots pump settings depend on duty cycle
  - *the time span ratio between “on duty” and “idle” mode*
Example: Pipework diameter variation – comparing DN 320/200/100

Assumption: All elements start at atmosphere

1. Main influence – Pipework volume i.e., large DN $\rightarrow$ large Volume $\rightarrow$ slow(er) pump down
2. Main influence – Pipework conductance i.e., large DN $\rightarrow$ better conductance $\rightarrow$ fast(er) pump down

* Cut-in of booster pumps

Which one is the best diameter? $\rightarrow$ Depends on the pressure level you want to reach
Main question:
- What’s the pumping speed of the vacuum system after all (i.e., at the chamber port)?

Please note:
- Pumping speed calculations are quasi-stationary ones. No thermodynamics, no transient effects! (see: Operating point calculation)
- In 2dimensional systems calculating the pumping speed is problematic. Always ask yourself: Does this make sense?
- Knowing the effective pumping speed gives a clue about losses due to conductivity within the vacuum system.
- **But**, comparison just of pumping speeds may fool you if it comes to pump down!
There is an **important difference** between the pumping speed at the pump’s inlet and the “real” pumping speed at the chamber.

It is **not easy** to judge a system’s performance only by looking at the pumping speed curve.

E.g., during pump down the **Leybold System** has a better performance above 12mbar → so it’s faster in this time span. The higher Booster performance of **Competitor’s System** is available much later.

**Please note:**
- Even if it’s similar to a real project - this is just an example!
- Comparison results always depend on the system layout and the target values.
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### Customer’s input and request

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<th>Application</th>
<th>Name or description</th>
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<tr>
<td>Pumped gases</td>
<td>Type of gas, in case of complex gases, add CAS (Chemical Abstract Service) number</td>
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</table>
| Process pressure     | Pressure at given flows  
|                      | Base pressure  
|                      | Pump down requirements:  
|                      | Starting/Target pressure  
|                      | Pump down time |
| Chamber and pipes    | Vacuum chamber volume  
|                      | Surface of chamber/material  
|                      | Outgassing rate  
|                      | Length and diameter of piping |
| Customer’s expectation | Pump combination for achieving process pressure with process gas flow  
|                      | Reaching conditioning vacuum in 15 min  
|                      | Requirements for explosion protection (ATEX) |
Vacuum system for Web Coating
Example – The Modular R2R Coating System
GENESIS by Emerson & Renwick

The simulation approach for Process condition

- Breaking down the different zones into four chambers (winding zone and three process zones)
The simulation approach for Process condition

- Breaking down the different zones into four chambers (winding zone and three process zones)
- Separation of chambers by aperture elements (slits for foil)
The simulation approach for Process condition

- Breaking down the different zones into four chambers (winding zone and three process zones)
- Separation of chambers by aperture elements (slits for foil)
- Adding of piping and generic pumps
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The simulation approach for Process condition

- Breaking down the different zones into four chambers (winding zone and three process zones)
- Separation of chambers by aperture elements (slits for foil)
- Adding of piping and generic pumps
- Adding of surfaces with given outgassing rates
- Definition of process flows
Vacuum system for Web Coating
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The simulation approach for Process condition

- Breaking down the different zones into four chambers (winding zone and three process zones)
- Separation of chambers by aperture elements (slits for foil)
- Adding of piping
- Adding of surfaces with given outgassing rates
- Definition of process flows
- Selecting pumps to achieve the required process pressures
Target
- Maintaining 2e-3 .. 8e-3 mbar within chambers when flows are 300 sccm into each of zones 1..3

Solution
- Using Operating Point Calculation

Results
- Winding zone: 0.27e-3 mbar
- Zone 1: 3.6e-3 mbar
- Zone 2: 3.9e-3 mbar
- Zone 3: 3.6e-3 mbar
Vacuum system for Web Coating
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GENESIS by Emerson & Renwick

„Beauty test“:
- Pumping down chambers, no flows
- Down to: 1e-5 mbar
- Target = within: 15 min

Solution:
- Using Pump Down Calculation

Results of the calculation:
- Winding zone: 15 min
- Zone 1: <13 min
- Zone 2: <13 min
- Zone 3: <13 min

(w/o additional cryo pump or cold surface for removing water vapor, e.g. Polycold®)
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| Example for R2R coater |
| **Summary** |
Summary

- Designing a complex vacuum system, as for R2R coaters, is **not trivial**
- To achieve the expected vacuum related results, it is important to know the **exact process conditions**
- Piping, degassing, switching of valves etc. have a **big influence** of the **vacuum performance**
- The PASCAL simulation program is a **strong tool** and it **helps** to optimize the pumping system and so to save money
- But, finding an optimum solution, needs an **experienced person**, knowing how to operate the tool
- **Our experts will be happy to support you to make the best selection for your individual demand**
Thank You
Calculation tasks Pump Down Calculation (1/2)

Example: Pipework diameter variation – comparing DN 320/200/100

Assumption – Pipework starts pre-evacuated

1. Main influence – Pipework volume
2. Main influence – Pipework conductance
3. Pressure equalization for pre-evacuated pipework

Which one is the best diameter?
⇒ Depends on the pressure level you want to reach!

* Cut-in of booster pumps
Calculation tasks Pump Down Calculation (2/2)

Example: Desorption rate variation

1e-6 mbarl/s*cm²
- Stainless steel, non-treated, dirty, several sealings

1e-7 mbarl/s*cm²
- HighVac treated stainless steel, clean, dry, average number of sealings

1e-8 mbarl/s*cm²
- UltraHighVac treated stainless steel, very clean, dry, limited number of sealings

Please note:
- At high pressure (above 30..50mbar) desorption may be neglected.
- Desorption has largest influence especially on the early pump down process.
- After a “sufficiently long time” the systems ultimate pressure only depends on leak/process flows …
The PASCAL Simulation Program Additional modules – CoO - Cost of Ownership Calculator

- Calculation of Cost of Ownership for the pumping system
- Input
  - Investment cost
  - Utility cost like electrical energy, purge gas, cooling water
  - Service cost
- Output
- CoO in defined time frame
- Cost split by tables and diagrams