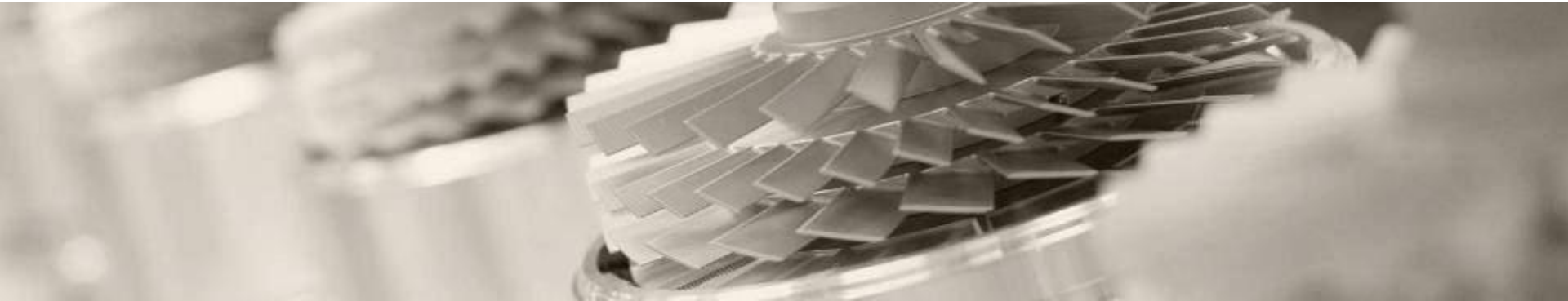
Turbomolecular Pump Systems

Development Methodology & Capabilities

Dieter Müller



Designing a World Class Turbomolecular Pump System

What is Required in General?

What is required for customer specific projects?

oerlikon leybold vacuum

Design Capabilities

Analytical Capabilities

Test Capabilities

Facilities, Personnel & Procedures

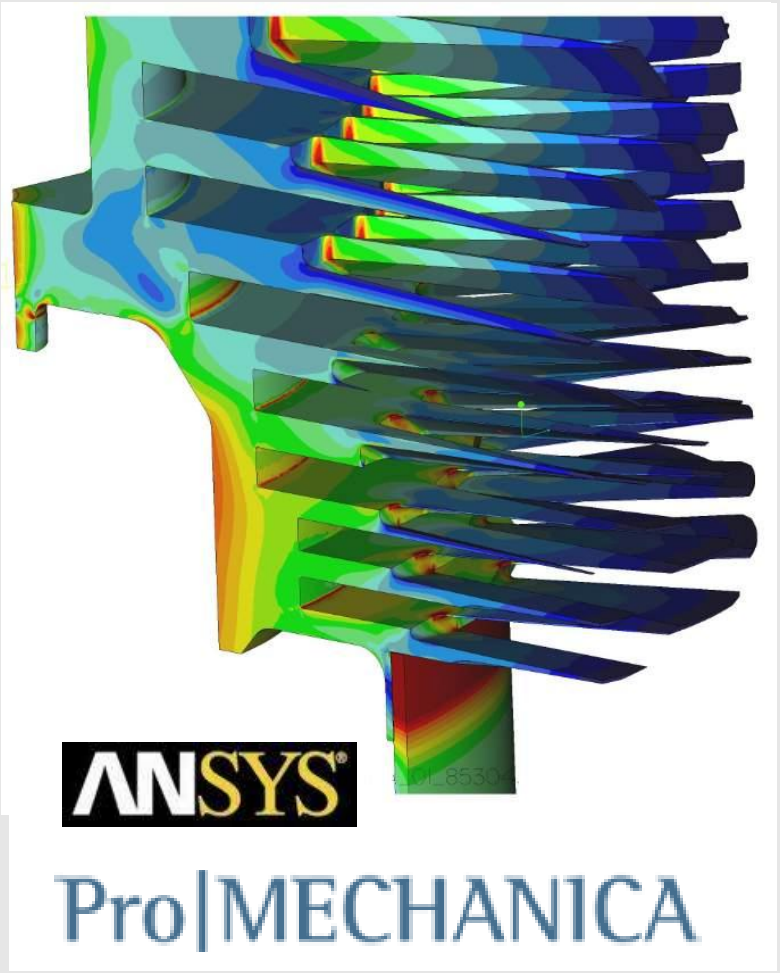
Design Capabilities
Design Software Packages & Design Controls

- Oerlikon Leybold Vacuum uses the Pro/Engineer Computer Aided Design (CAD) software package to design the complex geometries of a Turbomolecular Pump.
- Having a complete 3-Dimensional virtual model of the pump ensures the design is right first time.
- Coupled to this the SAP business management software tool is used to control the design process and design change process at each phase of the project.

Pro|ENGINEER®

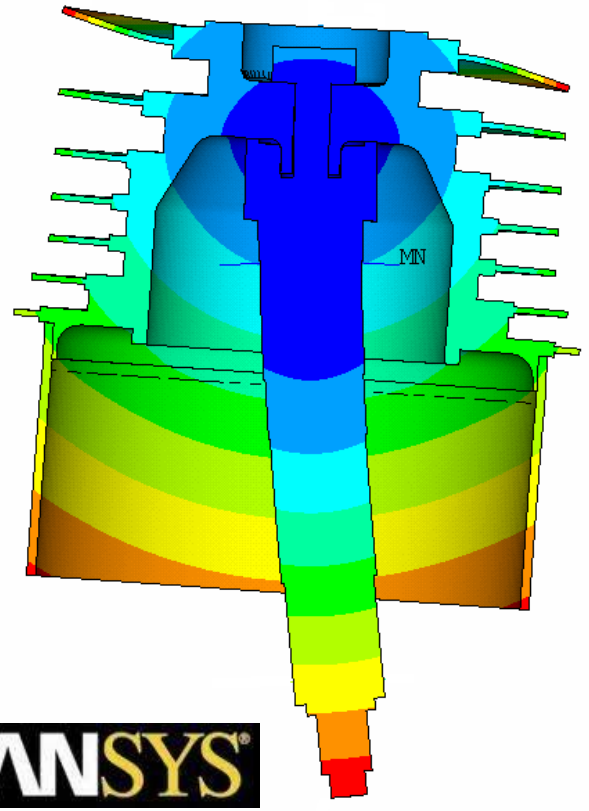
Analytical Capabilities
Stress Analysis

- High accuracy rotor stress analysis is critical when defining the maximum running speed and performance of a Turbomolecular Pump.
- Oerlikon Leybold Vacuum utilises state-of-the-art 3-Dimensional Finite Element Analysis (FEA) software packages to identify the stress characteristics within a Turbomolecular pump rotor.
- This detailed understanding of rotor stress ensures that maximum performance is achieved with a high level of reliability.



Analytical Capabilities
Rotordynamic Analysis

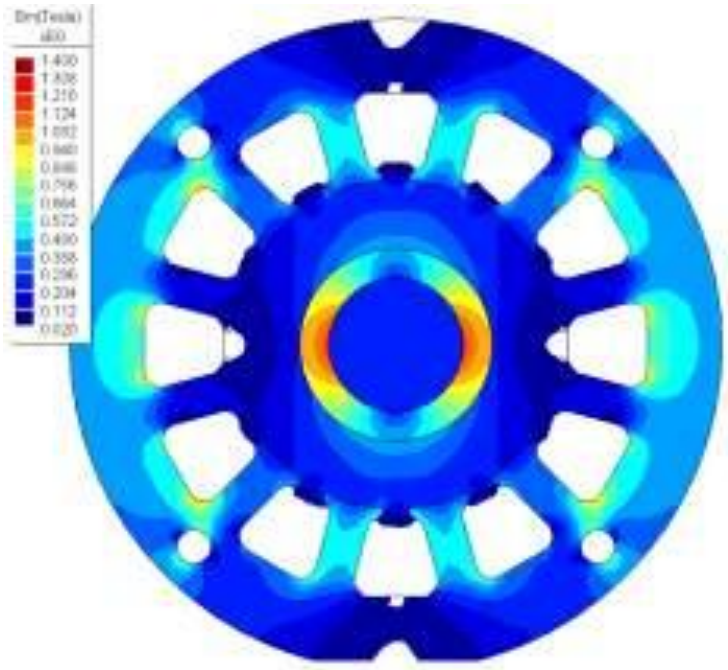
- To ensure a Turbomolecular Pump has a very low noise and vibration signature a detailed understanding of the pump Rotordynamics is required.
- Using highly sophisticated 3-Dimensional Rotordynamics software packages the full Rotordynamic characteristics of the pump can be simulated.
- With this capability the Turbomolecular Pump's natural frequencies, stiffness and damping can be optimised to give the lowest possible noise and vibration level.



MADYN 2000

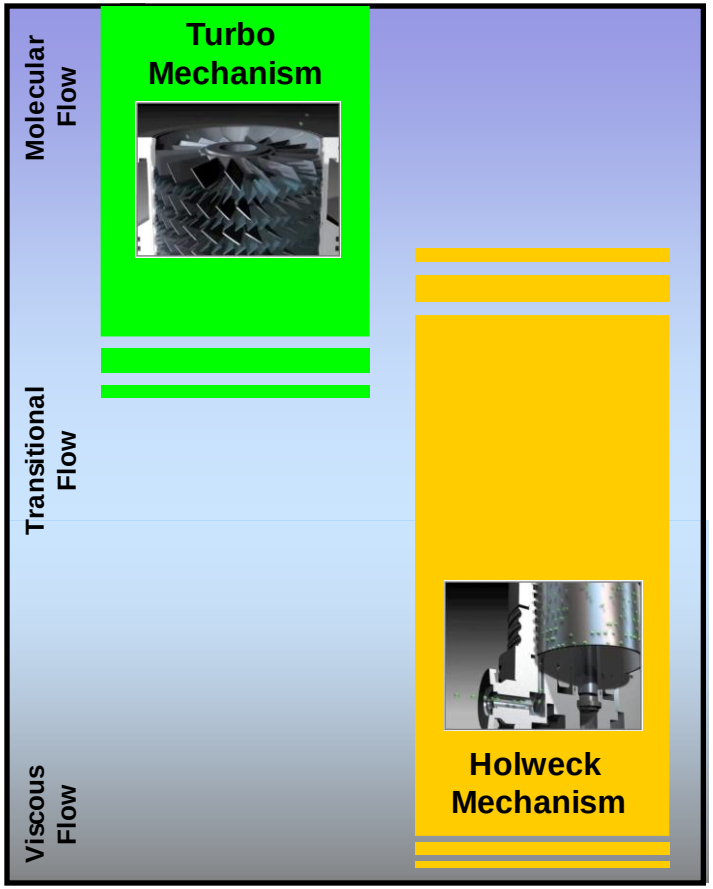
Analytical Capabilities
Magnetic Field Analysis

- Detailed Magnetic Field Analysis is critical to providing Turbomolecular Pumps.
  - With high motor efficiency and sufficient mechanical power.
  - With sufficient magnetic bearing stiffness and damping.
  - Which are suitable for running within magnetic fields.
- Advanced 3-Dimensional FEA software packages are used to identify the magnetic field behaviour within the Turbomolecular Pump.



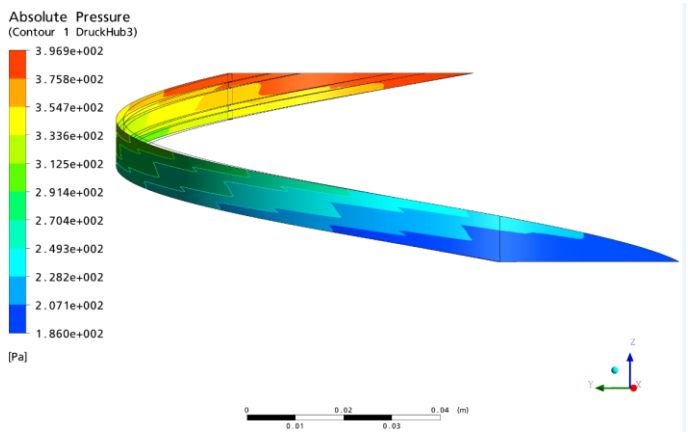
Analytical Capabilities
Vacuum Performance Simulation

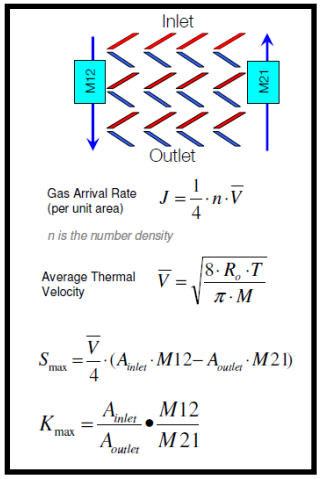
- Oerlikon Leybold Vacuum is at the forefront of vacuum modelling and over the years has developed a number of pump performance modelling tools.
- These modelling tools are used to optimise the pumping mechanism design of the Turbomolecular pump to ensure world class pumping performance.
- Various own modelling tools have been developed to calculate pumping performance across all pressure regimes for both Turbo and Holweck pumping mechanisms.

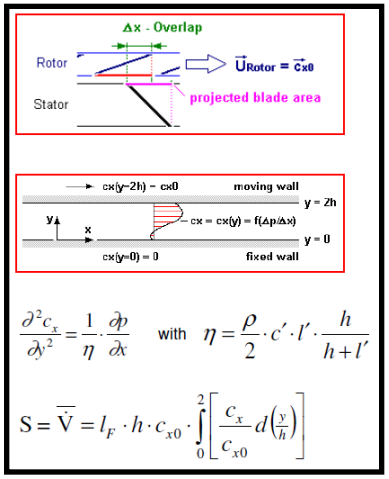


Analytical Capabilities
Vacuum Performance Simulation

- Pump Performance Models utilised by Oerlikon Leybold use the following principles or methods.
  - **Test Particle Method (Monte Carlo)** for modelling performance in the Molecular Flow Regime.
  - **Empirical gas flow equations** for modelling performance in the Viscous Flow Regime.
  - **Computational Fluid Dynamic (CFD)** for identifying the gas flow profile across complex shapes.



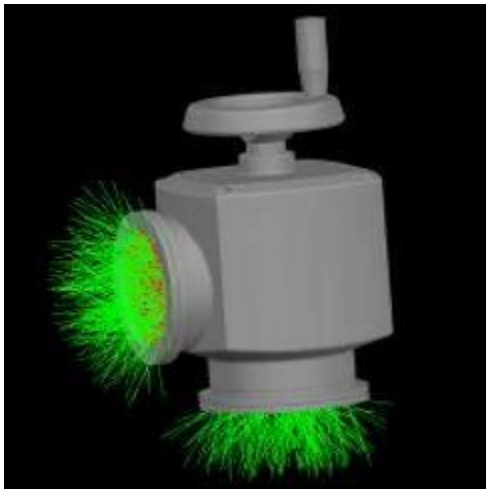


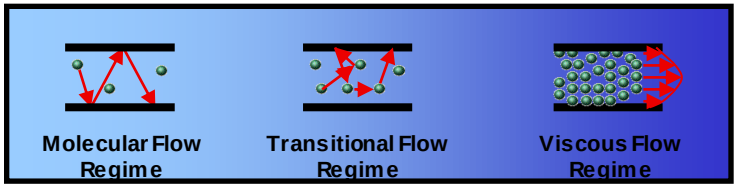


Analytical Capabilities
Conductance Simulation

- The conductance or restriction of pump housings, pipes and valves is critical to understanding the vacuum performance of an entire system.
- Oerlikon Leybold Vacuum has developed various conductance modelling tools to model pipes, valves, restrictions and vacuum housings in all three flow regimes.
- Dimension transfer automatically from our CAD system
- Conductance Models utilise the following methods.
  - 3-Dimensional Test particle method.
  - Empirical gas dynamic equations.

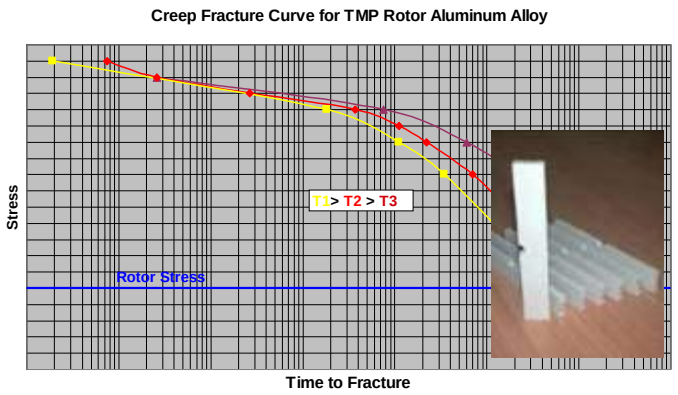
$$Speed = \frac{1}{\frac{1}{S_{Pump}} + \frac{1}{C_{Pipe}}}$$

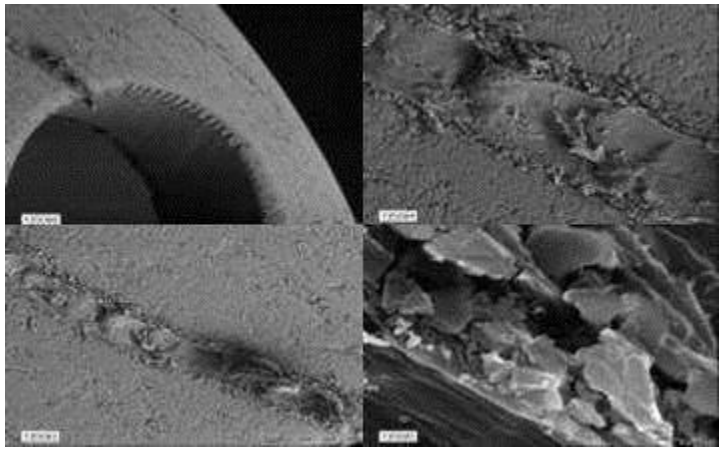




Analytical Capabilities
Material Analysis

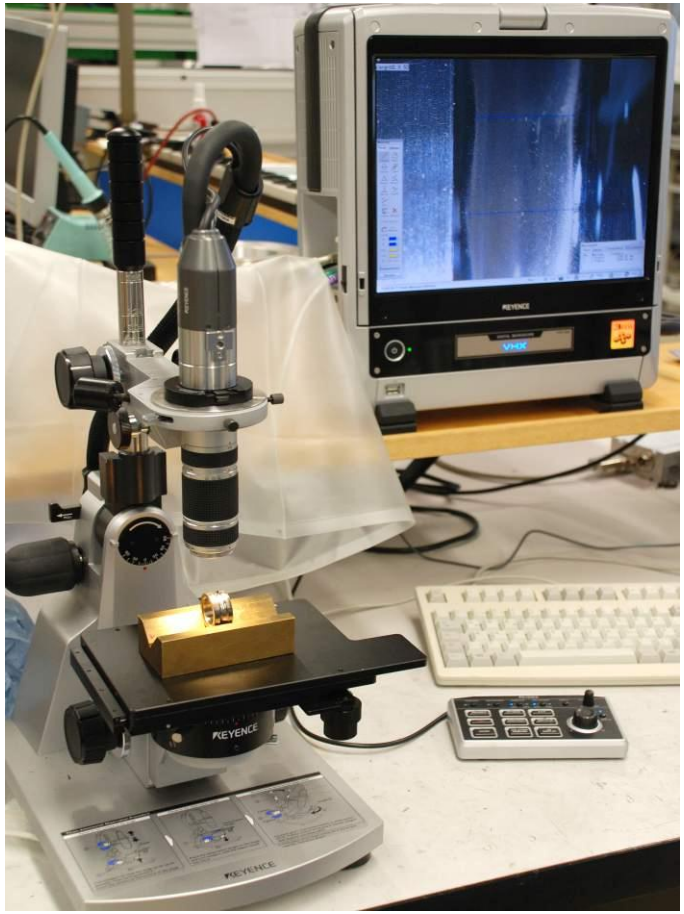
- Turbomolecular Pump rotors operate at high rotational speeds under high stress & temperature and in some cases pumping corrosive gases.
- A detailed understanding of materials technology is essential to ensure high performance products with long term reliability.
- Oerlikon Leybold Vacuum is continuously looking to new technologies to further improve the performance and reliability of products.
- Material properties are assessed using the following methods & tools.
  - Hardness, Fatigue & Tensile Testing
  - Thermal Creep Testing
  - Corrosion Testing
  - Scanning Electron Microscopes (SEM)
  - Energy Dispersive Spectroscopy (EDS)
  - Wavelength Dispersive Spectroscopy (WDS)
  - FTIR and RGA analysis for oils/greases





Analytical Capabilities
Bearing Analysis

- A detailed understanding of mechanical bearings is critical to ensuring long term pump reliability.
- This is especially true of high speed products like Turbomolecular Pumps with mechanical bearings as primary or back-up bearings.
- Oerlikon Leybold Vacuum conducts a large amount of bearing reliability testing in order to assess bearing reliability with a high level of confidence.
- Bearing Specialists within R&D use high powered digital microscopes to evaluate bearings after reliability testing.
- Occasionally external Tribology or evaluation work is also conducted with world leading experts to gain a more detailed understanding.



Test Capabilities
Vacuum Performance Testing

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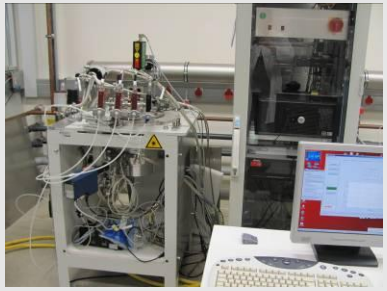
Automated Pumping Performance Measurement

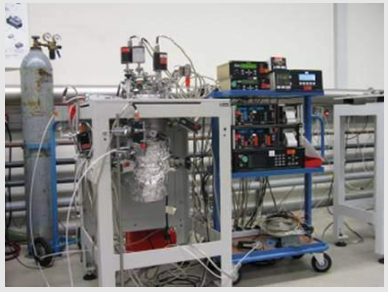


- Fully automated test facility capable of running 24 hours a day 7 days a week.
- Developed by Oerlikon Leybold Vacuum, the test facility generates 3 dimensional performance curves of flow vs. inlet pressure vs. backing pressure for various gas types.
- The test facility uses state-of-the-art measurement and control equipment with own DKD-calibration.

Ultra High Vacuum Performance Measurement

- Manual measurement of performance in the Ultra High Vacuum (UHV) Range < 1x 10^{-10}mbar.
- The test facility uses state-of-the-art measurement equipment and techniques.

Application Specific Performance Measurement



- Multiple performance test facilities available to run customer specific applications.
- Test facilities are flexible and can be configured to run various customer specific scenarios with or without customer equipment.
- All test facilities use state-of-the-art measurement and control equipment.

Test Capabilities
Vacuum Performance Testing

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Material Out-Gassing Rate Measurement

- The test facility uses Mass Spectrometry equipment to measure the out-gassing rate of any material in vacuum.
- All materials used in the construction of a Turbo-molecular Pump are assessed.
- Customer specific material can also be measured if required.

Hydrogen Test Facility

- TÜV Certified
- One of very few facilities in Germany
- Able to run performance tests with Hydrogen at high flow rates up to atmospheric pressures.

Conductance Measurement

- Critical when designing customer specific vacuum pump housings as conductance directly influences overall pumping performance.
- The test facility is able to measure conductance values for different pipes, housings and restrictions.

Test Capabilities
Thermal Testing

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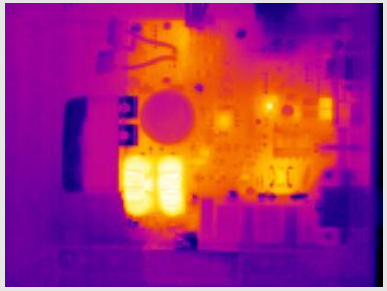
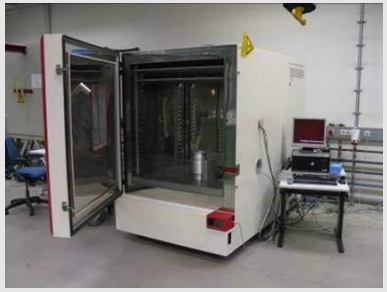
Thermal Performance Measurement



- The test facility uses thermocouples and infrared thermal sensors to measure the thermal characteristics of a pump at various operation conditions.
- Developed by Oerlikon Leybold Vacuum the test facility is fully automated, capable of running 24 hours a day, 7 days a week.
- Pump temperature is critical when identifying the performance limits of the pump.

Environmental Testing



- Environmental test facility is used to evaluate pump performance at various ambient temperatures and humidities.

Surface Radiation Measurement

- Test facility to measure the thermal radiation properties (emissivity) of various materials and coatings.
- Critical to ensure low temperature components in high vacuum applications where heat transfer through radiation is dominant.

Test Capabilities
Rotordynamics Testing

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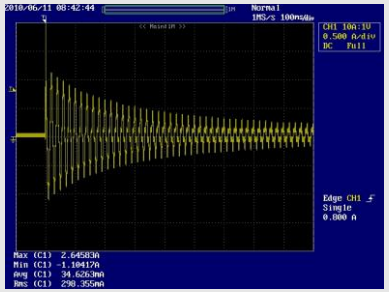
Noise & Vibration Measurement

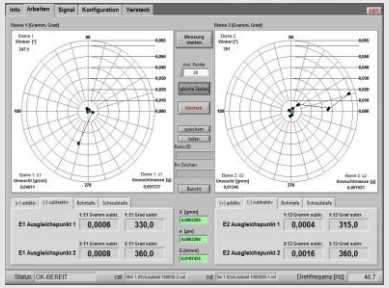
- Pumps tested on a floating anti-vibration table using the latest Fast Fourier Transform (FFT) equipment & techniques.
- Used to identify natural frequencies and noise & vibration response under all running conditions across a wide frequency range.
- Critical to Electro Microscope applications.

Static Natural Frequency Measurement



- FFT hammer test equipment is used to identify the static natural frequency of components.
- All natural frequencies within a Turbo Molecular pump need to be identified in order to ensure they are not excited during operation.

Rotor Balancing



- Low & high speed rotor balancing facility for 2 plane or single plane rotor balancing.
- Critical for ensuring low overall pump vibration at full speed.
- Test method and setup developed by Oerlikon Leybold Vacuum and used for all production products.

Test Capabilities
Robustness Testing

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Reliability Testing

- Extensive reliability test conducted on all products in a large reliability test facility.
- Developed by Oerlikon Leybold Vacuum, the test facility is fully automated and monitors all key reliability indicators on each pump.

Abuse / Misuse Testing

- Various test facilities available to ensure reliable and safe operation in the event of misuse.
  - Extreme venting
  - Extreme external mechanical shock
  - Sudden loss of power
  - ‘Gorilla’ Testing

Destructive Testing

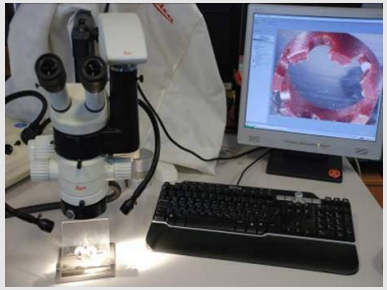
- Test facility to ensure safe operation in the event of catastrophic failure due to misuse.
  - Crash Test
  - Burst Test

Test Capabilities

Electronics Testing

- Wide range of electronic equipment used to verify and validate the electronic control systems used on Turbomolecular Pumps.

Component Inspection



- Two high powered digital microscopes are available to closely examine components.
- Critical for bearing inspection and analysis of high stressed components.

Component Measurement

- A wide range of high precision measurement equipment is available to measure all critical pump components.
- This includes Coordinate Measurement Machines (CMM) all the way to handheld micrometers.

Facilities, Personnel & Procedures

- High and Fore Vacuum R&D Departments are located in Köln Germany plus Valence.
- 25% of all employees have academic degree
- The multistory state-of-the-art facility houses both the R&D department, HV laboratory and production facility. FV laboratory in separate building and Valence
- Prototype machining and assembly facilities are available on-site thereby reducing development time significantly.
- The R&D department consists of 91 highly motivated, multi-disciplined scientists and engineers with a combined vacuum experience of > 1500 years.
- A well-controlled project phase gate system is used to monitor and control the New Product Development Process.

Facilities, Personnel & Procedures

- Lower skilled design tasks are done by externally hired engineers. Key technology developments by own staff.
- Cooperation with external institutes like KIT Karlsruhe, RWTH Aachen, FH Frankfurt,…
- Replacement of scientists which will retire up to 2 years prior to retirement to ensure technology transfer to next generation
- 7 additional hires 2010 and 2011 in fields of electronics, software, laboratory, solutions (systems and controls), especially for TMP and dry forevacuum

Facilities, Personnel & Procedures

Customer specific projects
(example: mass spectrometer)

- done by core staff (today: 8)
- Project team with project leader and team (engineering, laboratory, manufacturing, product management, service)
- Procedure according to our phase gate development process
- Targeted time from customer specification to
  - final, approved CAD design (3 weeks)
  - delivery of prototypes: 6 weeks 'PG 2 Alpha' (cost: 200%)
  - pre-series (from block material) 3 – 6 weeks 'PG 3 Beta' (cost: 150%)
  - in parallel to pre-series: TÜV documentation (min.6 weeks)
  - series from cast: 3 months 'PG 3 CR' (cost 100%)

Today: using existing TMP rotors from the shelf

Future (ZEUS): including modeling of optimized rotor
(+ 3 weeks max.)

Thank you.