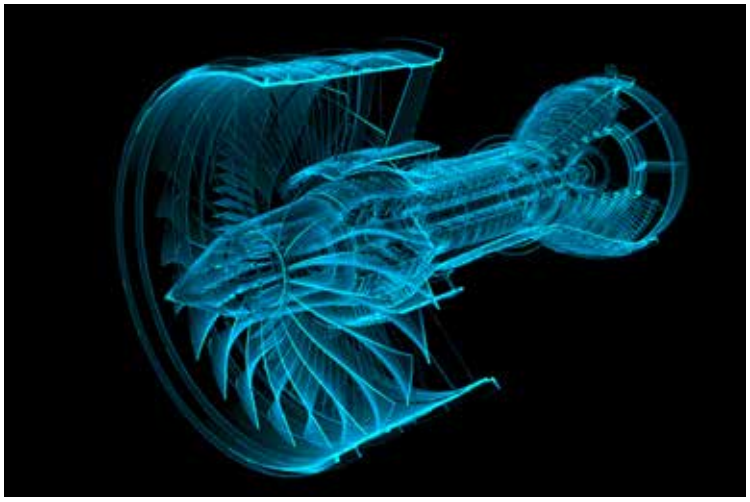
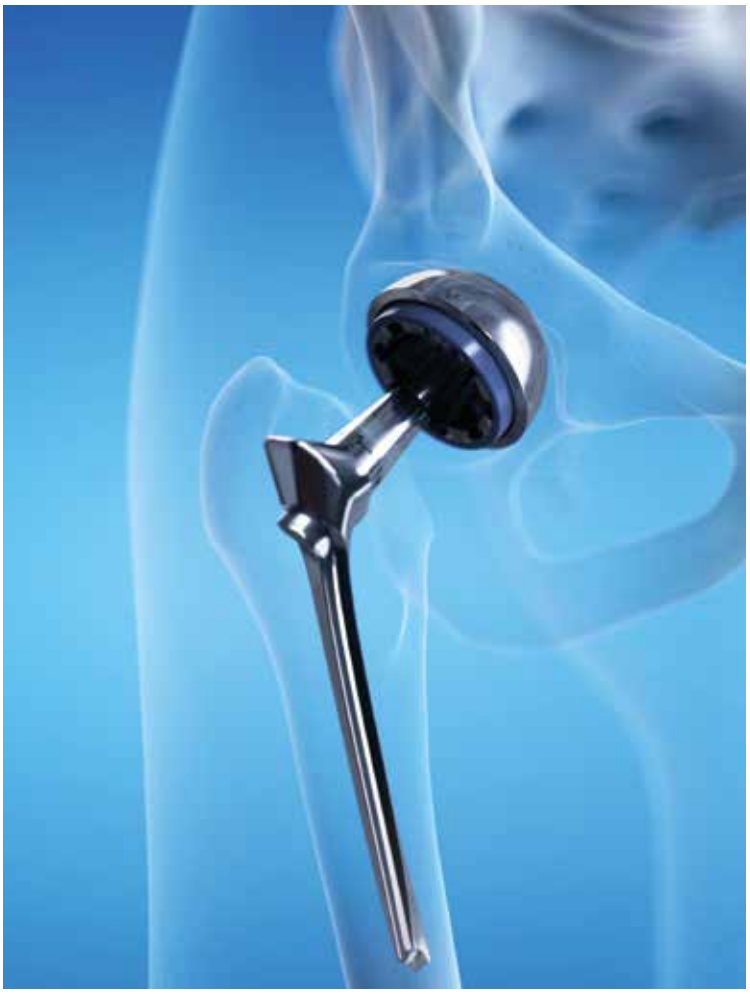




3D printing

Your partner for vacuum solutions in additive manufacturing processes

PFEIFFER VACUUM

3D printing

Additive manufacturing is revolutionizing the industry

What is 3D printing?

Classic 3D printing has been around since the 1980s, then known as rapid prototyping. Today, 3D printing (also known as „additive manufacturing“) is revolutionizing the entire industry. Printing spare parts at home is no longer just a vision, but has become reality. In the future, it will be possible to avoid supply chains, which will enable this technology to make a positive contribution to environmental development.

Classic 3D printing is often associated with the layer-by-layer application of plastic. In this process which is known as extrusion, plastic strands are melted and then applied layer by layer. However, this is only one of many processes now on the market. In industry in particular, other processes are frequently used that enable additive manufacturing with other materials. What they all have in common is that materials are applied layer by layer. This allows complex, three-dimensional shapes to be produced that would be difficult or impossible to manufacture with other machines. It is now also possible to make components from metal powders using an additive manufacturing process. This eliminates the otherwise laborious milling, turning, drilling or cutting of workpieces from metal blocks. The advantages are obvious: The process allows complicated parts to be produced that conventional metal processing is not technically or economically capable of. Last, but not least, this can be done in a drastically reduced time.

One particular method for producing 3D printed parts from metal powders is electron beam melting (EBM), where vacuum technology is indispensable.

Figure 1: EBM 3D printer Q10
© Courtesy of Arcam AB

3D printing

Electron beam melting

Electron beam melting (EBM) Electron beam melting (EBM) is an additive manufacturing technique in which the component is made from metal powders. The process is similar to selective laser melting (SLM). The main difference between the two melting processes is the energy source, which in this case is not a laser beam but an electron beam. This is one reason why the process is only possible under vacuum conditions.

The image shows the schematic structure of an Arcam EBM 3D printer. The EBM system essentially consists of an electron beam gun, an electron beam column and a building chamber in which the component is formed. The electron beam gun consists of a filament, usually a tungsten wire. The electron beam is generated here. The electron beam column consists of three lenses: the astigmatism lens, the focus lens and the deflection lens. The task of the electron beam column is to correct the beam shape and to adjust the beam focus. It also serves as a deflection unit. The building chamber is designed as a vacuum chamber due to the vacuum conditions that are required. It contains the storage containers for the metal powder, a rake and a building platform. Apart from the rake system, or vertically movable building platform, there are no moving parts in the building chamber.

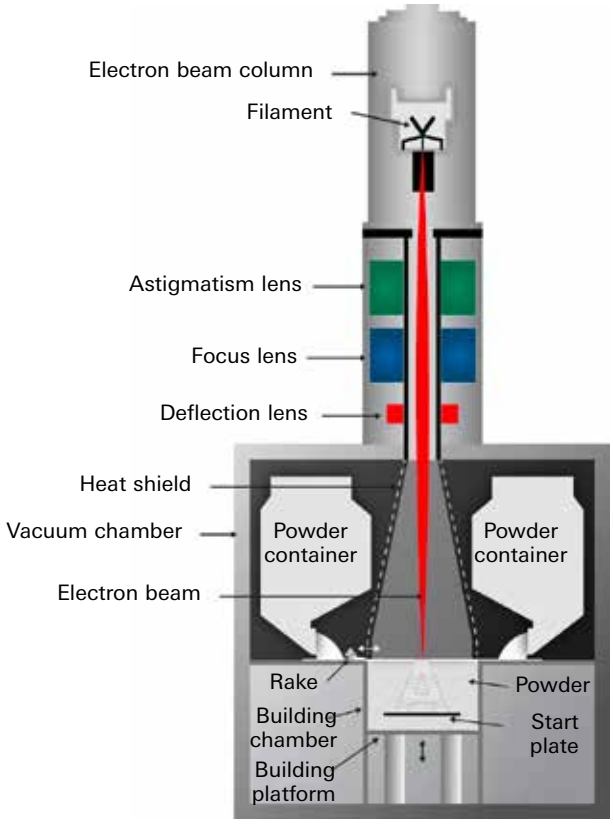


Figure 2: Arcam EBM system, schematic representation
© Courtesy of Arcam AB

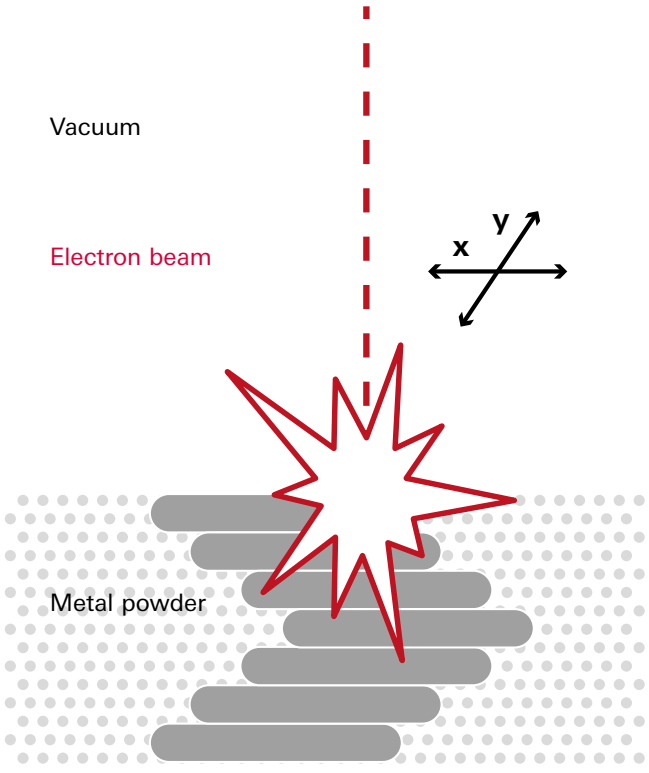


Figure 3: Melting of the metal powder layer by layer

3D printing

Electron beam melting

The process is as follows: Electrons are emitted by heating the tungsten wire to 2,500°C under vacuum. These are accelerated by electromagnets, then focused and projected onto the powder surface at half the speed of light. This causes the powder particles to heat up, thus selectively melting a thin layer of metal powder. After applying a layer, the building platform will lower one layer thickness at a time, and the powder bed is filled up with metal powder from the powder hoppers containers. Components are built up layer by layer in the powder bed. Once the printing process is finished, the part can be taken out of the machine and the excess powder removed. Complex shapes and overhangs require support structures so all components are anchored to the building platform. These supports must be removed when the printing process is completed. After this, it may be necessary to carry out surface treatment, such as polishing. In some cases, curing in an oven may also be required to relieve tensions that have arisen during the printing process. This heat treatment, in turn, sometimes takes place in vacuum furnaces, such as when hot isostatic pressing is used.

Properties of electron beam melting

The EBM process offers several advantages. One main advantage is the ability to realize highly complex geometries in materials with a higher melting point as well as highly reactive materials. For this reason, alloys of titanium and cobalt-chrome are generally used for EBM, but other alloys such as Ti6Al4V, ASTM F75 or alloy 718 are also used. As a result, identical or even better mechanical, dynamic and chemical properties are achieved than with original metals.

Figure 4: Metal powder for 3D printing; alloys of titanium and cobalt-chrome are often used

Printing with titanium, in particular, opens up new applications for additive manufacturing. In general, the EBM process is a „hot“ process. The powder is heated before the process, which reduces deformation of the component and the need for support structures.

In addition, printing the component under vacuum also prevents air bubbles from forming in the hot metal. This degassing effect results in a homogeneous metal layer on the printed component. Another positive effect of the vacuum, and thus the advantage of EBM, is the prevention of oxidation on the molten metal powder. As a result, the powder does not tarnish or rust when heated, with the result that a large part of the non-melted powder can be directly recycled at the end of the printing process. This process is therefore of great interest, especially in the aviation industry.

An advantage over the SLM process is the printing speed. By splitting the electron beam, the powder can be melted in several places at once, which accelerates the printing process. This is possible due to very high deflection rates of the electron beam (> 1,000 m/s). However, the component sizes that can be realized are smaller, with a maximum diameter of 250 mm and a height of 380 mm. Accuracy and precision are also lower than with the SLM process due to the slightly larger width of the electron beam compared to the laser beam. It should not be forgotten, however, that EBM enables the processing of highly reactive materials, which is not possible with SLM.

The characteristics of the EBM process are as follows:

- Maximum constructed size: 350 x 350 x 380 mm
- Smallest possible structure size: 0.1 mm
- Accuracy: +/- 0.2 mm (can be improved by subsequent finishing work)
- Smallest layer thickness: 0.05 mm
- Typical surface quality: 203 - 25.4 µm RA (can be improved by subsequent finishing work)
- Density: up to 99.9%

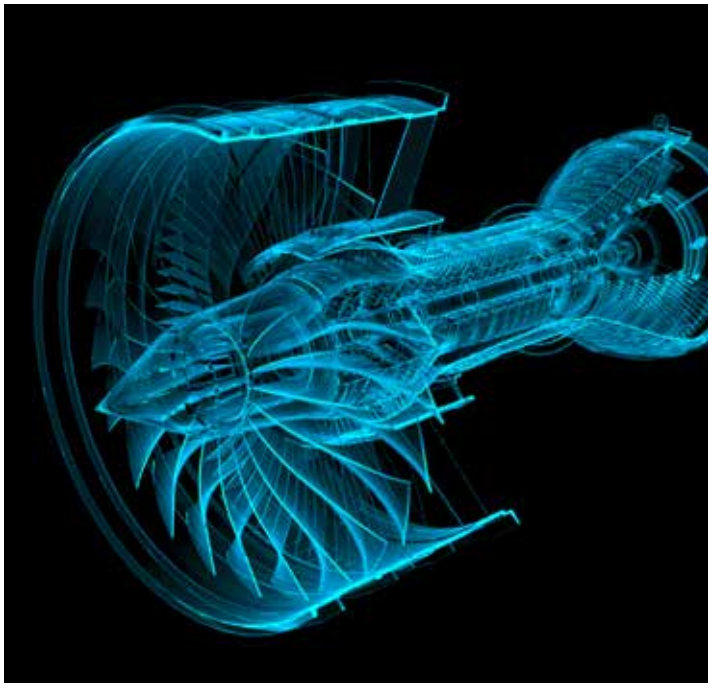


Figure 5: Graphic of a 3D-printed aircraft turbine made of metal powder

Figure 6: Example of an implant printed using EBM

3D printing

Electron beam melting

Technical requirements of the vacuum

The vacuum in the EBM process serves several purposes. First, it protects against oxidation and prevents air bubbles. On the other hand, it is necessary for generating the electron beam in the electron beam gun and for a precise melting process. The vacuum prevents the collision of the electron beam with gas particles, which would lead to a deflection of the beam. The decisive factor here is a high mean free path length which is proportional to the decreasing pressure. Thus, a low final pressure is required to achieve a high mean free path. For the EBM process, a high vacuum of less than $5 \cdot 10^{-5}$ mbar is therefore required. The fastest possible pump-down time is required to shorten the set-up times when changing a component. During the printing process, a partial pressure of $4 \cdot 10^{-3}$ mbar helium is introduced in part, which serves to ensure a clean and controlled environment. This is important in order to meet the chemical requirements for the component building material. In general, the vacuum equipment should be insensitive to dust and particles and have good heat resistance.

Fields of application of EBM

The EBM process is particularly important for printing with highly reactive materials, which also have to be brought into a complex geometry. One of these metal alloys is Ti6Al4V, which has gained immense value in aerospace engineering due to its dense strength ratio and good corrosion resistance. Due to its excellent biocompatibility, it is also increasingly used in medical technology in the form of prostheses and implants. In addition to other titanium alloys such as TiAl, CoCr is also used especially in medical technology for implants and as dental prostheses. CoCr is characterized by a high stiffness and wear resistance and is also biocompatible. By using 3D printing, the implants or prostheses can be adapted precisely to the particular requirements of the patient.

Figure 7: Acetabular cup, part of an artificial hip joint
© Courtesy of Arcam AB

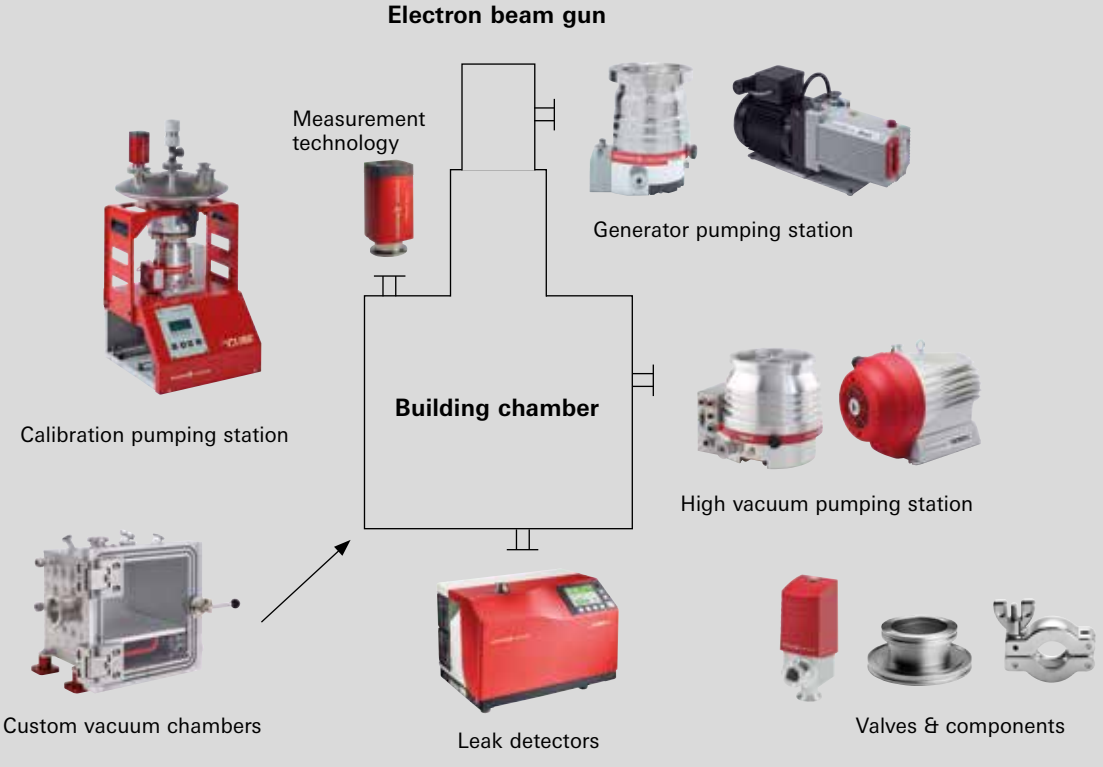
Comprehensive pump portfolio for electron beam melting

Pfeiffer Vacuum offers a comprehensive product portfolio for electron beam melting. This comprises backing pumps and high vacuum pumps for evacuating the building chamber and electron beam gun, pressure gauges for atmospheric to high vacuum pressure with the option of a calibration unit, custom vacuum chambers, valves and flange components for connecting the vacuum components and leak detectors for locating and leaks.

Design

Pfeiffer Vacuum supports its customers in designing a complete vacuum system for an EBM printer. This includes the dimensioning of all backing pumps and high vacuum pumps, including recommendations for any additional components required.

The design takes into account the specific pump characteristics, losses due to piping, leaks and desorption effects of the inner chamber surfaces. State-of-the-art calculation programs developed specifically for this purpose are used in the design process.



3D printing

Evacuation

Evacuation of the building chamber

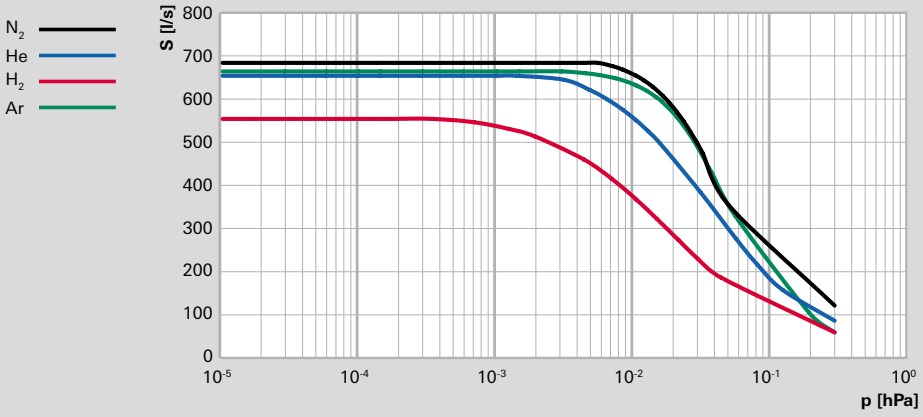
In the building chamber, a final pressure of less than $5 \cdot 10^{-5}$ mbar should be achieved before helium is admitted, and a constant process pressure of $4 \cdot 10^{-3}$ mbar should be set during the printing process. Different high vacuum and backing pump combinations are possible, depending on the volume of the building chamber. The desorption rate must also be taken into account when selecting high vacuum pumps. The reason: gas molecules (predominantly water) are bound to the inner surfaces of the building chamber as well as to the metal powder, which are gradually released under vacuum.

The desorption rate of the surfaces leads to an accumulation of gas, which decreases over time. The higher the final pressure to be achieved, the greater the impact of desorption. Desorption has a negative effect on the pump-down time and it is important to take this phenomenon into account in the design.

The turbomolecular pumps of the HiPace series have proven themselves as high-vacuum pumps for this purpose. The advantages of this pump series for the EBM process are:

- Compact sizes
- Minimal vibrations
- Good resistance to dust
- Low final pressure
- Reliable
- Long lifetime
- Low operating costs
- Superior performance
- Relatively high transfer pressure

Pfeiffer Vacuum turbopumps are available for pumping speeds between 10 and 2,700 liters per second. These pumps impress with their high level of economy and flexibility. Proven bearing systems offer optimum reliability, and are available in two different bearing systems options for Pfeiffer Vacuum turbopumps: Hybrid bearings, a combination of a ceramic ball bearing on the fore-vacuum side and a permanent-magnetic radial bearing on the high vacuum side, and complete, active magnetic bearings that enable the rotor to run completely free of contact and thus wear.



The sophisticated rotor design makes it possible to achieve extremely high pumping speeds, critical backing pressure and gas throughput values as well as very good compression values for light gases. The HiPace 700 with hybrid bearings, in particular, has proven itself for evacuating the building chamber.

In order to achieve a suitable forevacuum pressure for switching on the turbomolecular pump in the desired time, an appropriately dimensioned forevacuum pump is required. Pfeiffer Vacuum is available here for consultation and assists customers in selecting the correct backing pump. Typical backing pump requirements in the EBM process are:

- Worldwide voltage, ideally single-phase
- Low noise level for ideal working environment
- High pumping speeds for short cycle times when changing the component (usually 10 l/s)
- Low operating costs (cost of ownership)
  - Long to service intervals
  - Low power consumption (standby mode)

Pfeiffer Vacuum offers rotary vane pumps as backing pumps or, if carbon-free vacuum is required, scroll pumps.

Product overview

Fore-vacuum		High vacuum
Rotary vane pumps DuoLine	**Scroll pumps HiScroll**	**Turbopumps HiPace**
		
■ High operational safety thanks to integrated high-vacuum safety valve ■ Complete series from 1.25 to 300 m^3/h ■ Available optionally with wear-free magnetic coupling, thus extended maintenance intervals and no unplanned downtimes due to oil leaks ■ Pumping principle does not depend on the type of gas used	■ Dry backing pump: for the low to medium power requirement of 6-20m^3/h ■ Extremely quiet: <47dB[A], in stand-by mode even <42dB[A] ■ Intelligent: equipped with RS-485 (ProfiNet optional), condition monitoring and variable frequency for easy and individual integration into systems ■ Efficient and powerful: A drive that is up to 15% more efficient in its class ensures lower heat generation, wear and tear and operating costs ■ Very good final pressure: < $1 \cdot 10^{-2}$ hPa	■ Robustness against particle problems ■ Compact size ■ Minimal vibrations ■ Long service life and low operating costs ■ Complete series from 10 m^3/h to 2300 m^3/h ■ As a HiPace Plus version, even less influence on the magnetic field of the electron beam guns

3D printing

Evacuation

Evacuation of the electron beam gun

Turbomolecular pumps are normally used at the electron beam gun to generate and maintain pressure in the high vacuum range. Since the pump-down process at the electron beam gun is usually not time-critical, small to medium sized turbomolecular pumps (HiPace 80 or HiPace 300) are used. Small backing pumps such as rotary vane pumps, scroll pumps or multi-stage Roots pumps are also used here as backing pumps.

A critical point on the electron beam gun is the magnetic field. This can be negatively influenced by the hybrid bearing and the related one-sided magnetic bearing. To minimize this influence, a special version of the HiPace series can be used here. The HiPace Plus series is routinely used in electron microscopes and impresses with its reduced magnetic field and minimal vibrations. The magnetic field is limited due to improved magnetic bearings, internal shielding of the motor and a low stray magnetic field. The influence of the pump on sensitive equipment is reduced as a result. Furthermore, the series has a specially embedded bearing to minimize vibrations.

Figure 8: HiPace Plus

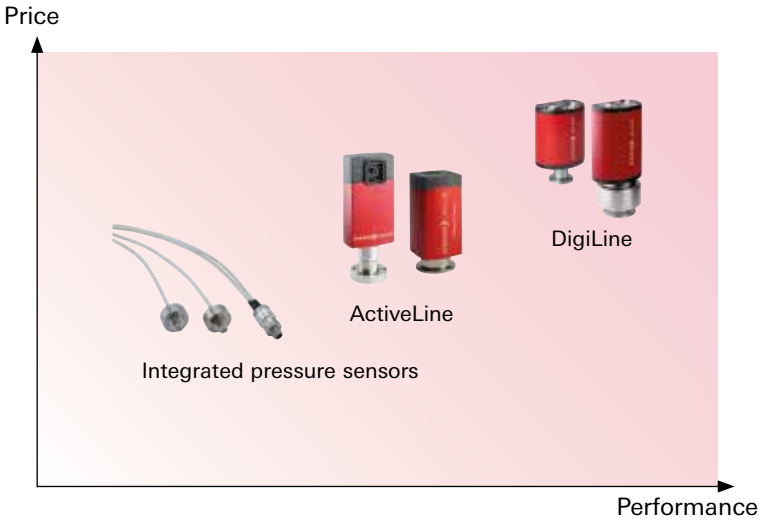
3D printing

Pressure measurement

Pressure measurement

For measuring the pressure at the building chamber and electron beam gun, sturdy and reliable combination vacuum gauges of type RPT 200 and HPT 200 (Piezo/Pirani transmitter and Pirani/ Bayard-Alpert transmitter) from the Pfeiffer Vacuum DigiLine range have proven themselves in practice. Digital signal conversion minimizes measurement errors and enables easy system integration. The electron beam is not disturbed by their magnetic field. Sturdy, compact Piezo/Pirani transmitters (Pfeiffer Vacuum RPT 200 DigiLine) are generally utilized to measure the fore-vacuum pressure of the high-vacuum pumps used.

For this application, vacuum gauges from the DigiLine series with a Profibus signal output are principally used. Alternatively, Pfeiffer Vacuum also offers a range of other pressure transmitters that can be matched to customers' needs regarding control signal requirements.



Product overview

HPT 200

- Combination of Pirani and Bayard-Alpert sensor
- Indicating range: $5 \cdot 10^{-10}$–1000 hPa
- High accuracy of up to ±10%
- High operating safety with two heating filaments

RPT 200

- For precise gas-type independent measurement of ventilation processes
- Measurement range $1 \cdot 10^{-4}$ to 1200 hPa
- Gas-type independent measurement for pressures >10 hPa

3D printing

Calibration

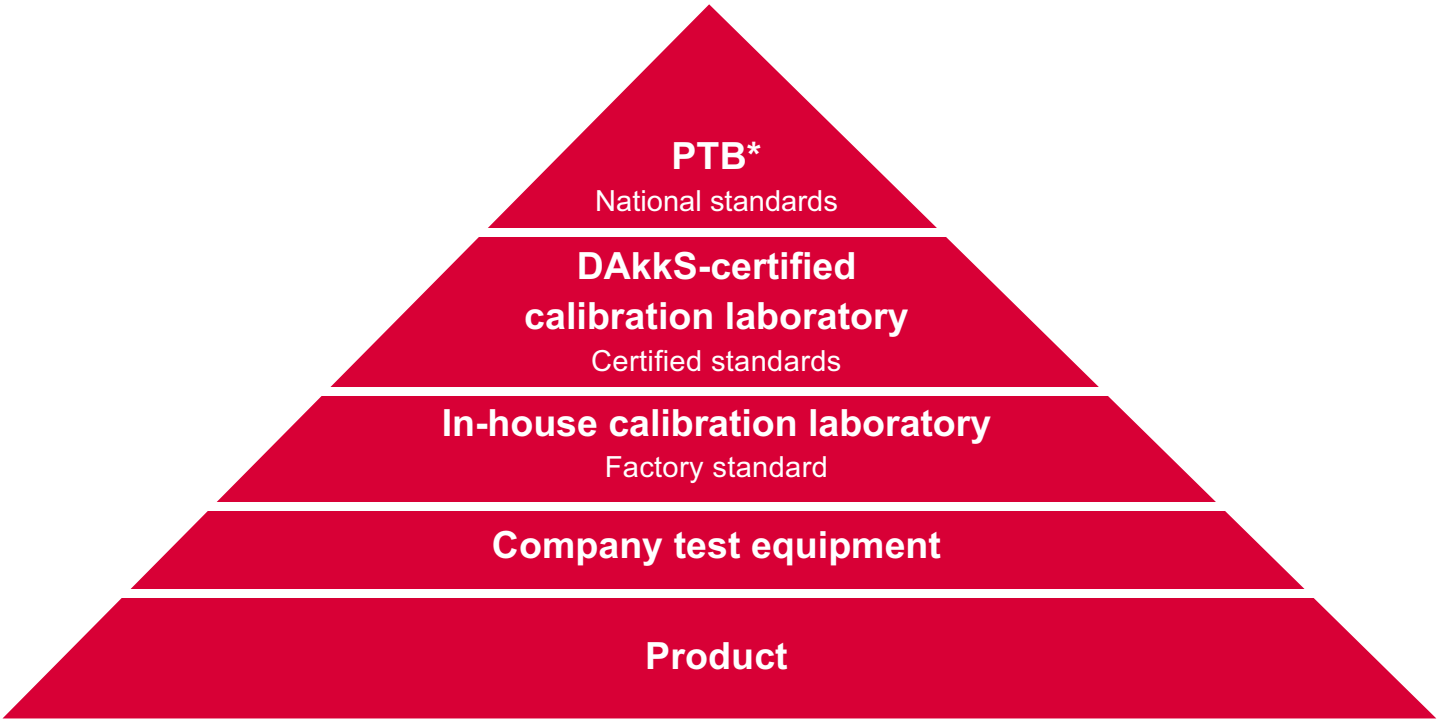
Calibration

In order to ensure the accuracy and repeatability of the pressure measurement and thus the process stability in the long term, it is essential to regularly calibrate the vacuum gauges. The measuring signals can shift due to the contamination of the sensors through particles or condensate as well as due to long-term aging. An integral part of quality assurance is therefore calibration, in which the measuring signals of the measuring instruments used are compared with a reference gauge. The reference vacuum gauge must have been calibrated by a certified laboratory (e.g., DAkks [Deutsche Akkreditierungsstelle GmbH = German accreditation agency] certified in Germany, NIST certified in the U.S.) and be traceable to a national standard.

Factory and DAkkS calibration

Pfeiffer Vacuum offers both factory and DAkkS calibration of vacuum gauges. The calibration is carried out according to high quality standards and in compliance with ISO 3567. The test conditions and discrepancies recorded are documented in the calibration certificate issued.

Hierarchy of the calibration chain (decreasing accuracy)



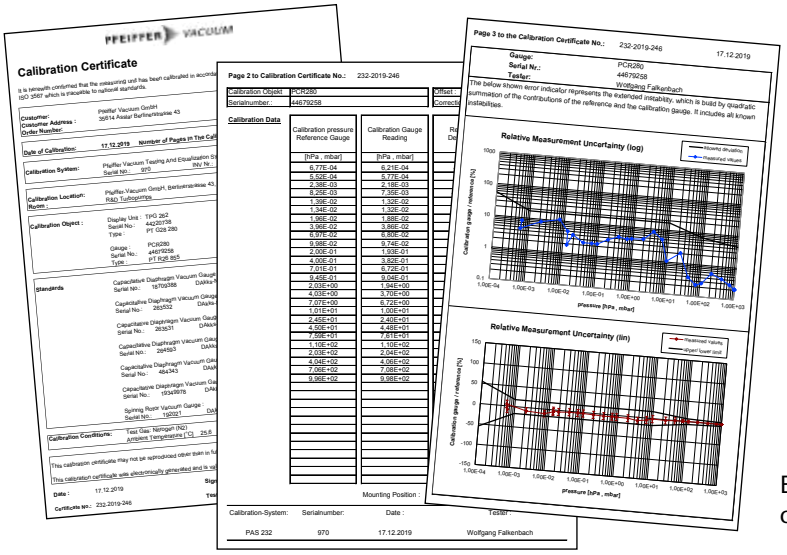
*Physikalisch-Technische Bundesanstalt
(National Metrology Institute of Germany)

3D printing

Calibration

Pfeiffer Vacuum calibration systems

When a large number of vacuum gauges are used, direct in-house calibration can be more cost-efficient than external calibration. With its Basic and Pro models, Pfeiffer Vacuum offers calibration pumping stations specially developed for this purpose. These systems incorporate an integrated turbopumping station to provide the pressure necessary for accurate zero adjustment. A vacuum chamber in accordance with ISO 3567 ensures homogeneous pressure distribution and a symmetrical arrangement of the vacuum gauges at the same height. Gas inlet and pump input are also located on an axis of symmetry. With the Pfeiffer Vacuum calibration systems and a corresponding reference vacuum gauge, the calibration can be carried out easily, particularly for the relevant pressure range.



Example of a calibration certificate

Product overview

Basic calibration system	Pro calibration system
	
■ Compact system with up to six flange connections for vacuum gauges	■ Mobile system with up to eight flange connections for vacuum gauges

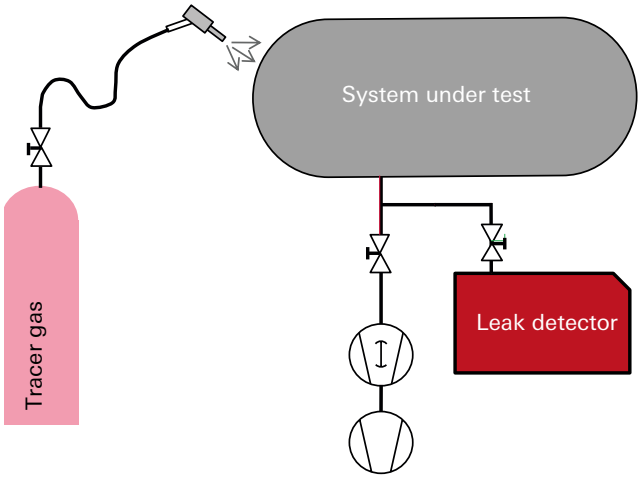
- Calibration range 1,013 – 10^{-4} hPa
- Easy to use
- Recipient according to ISO/TS 3567 standard
- For static and dynamic calibration
- Customized solutions available
- DAkkS reference vacuum gauges optionally available

3D printing

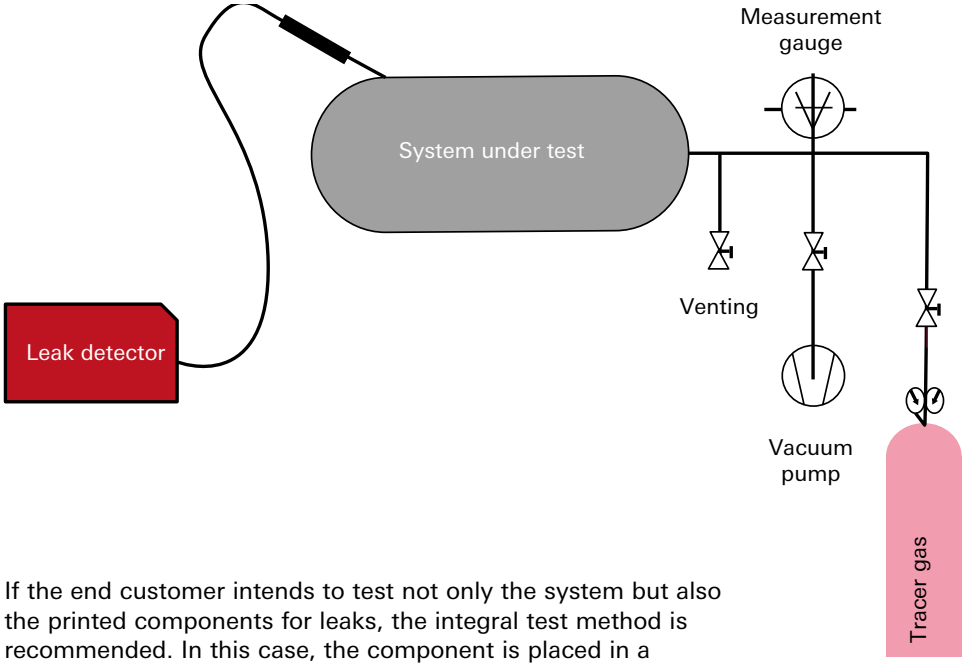
Leak detection

Leak detection

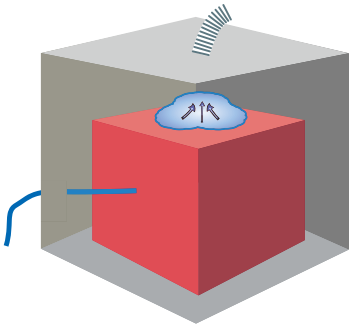
Good leak tightness in the EBM process is necessary to achieve the required final pressure and to guarantee purity during the process. Particularly in the high vacuum range, even a small leak can prevent the final pressure from being reached. For the EBM systems, an integral leakage rate of less than $1 \cdot 10^{-5}$ mbar is the minimum requirement so that system manufacturers can guarantee no errors due to system leakage and that none will occur subsequently at the customer's premises. Pfeiffer Vacuum offers helium leak detectors in various configurations for detecting the required leakage rate. Their high detection sensitivity, short testing time and easy operation make helium leak detectors ideal for localizing leaks. Testing can be performed in a variety of ways. One method is to evacuate the system and spray helium locally, from the outside, on sealing points, welds and other potential leaks using a spray gun. In the event of a leak, the helium flows into the evacuated vacuum chamber and is sucked in and detected by the leak detector. In order to realize short response times, the leak detector is used in large systems in partial flow to the existing vacuum system.



A further method is the sniffing test. Here, the system is pressurized with a tracer gas such as helium. A sniffer probe is then passed over the system. In the event of a leak, the leak detector discovers the escaping tracer gas and thereby localizes the leak. Since helium is usually added during the EBM process, anyways, this method can also be used to guarantee a helium supply.



If the end customer intends to test not only the system but also the printed components for leaks, the integral test method is recommended. In this case, the component is placed in a vacuum test chamber and filled with tracer gas. If there is a leak, the tracer gas will escape from the component into the test chamber and will be measured by the leak detector.



With the ASM 340, Pfeiffer Vacuum offers a powerful leak detector for universal use. The compact and portable ASM 310 is the first choice for mobile use, such as for service engineers.

Product overview

ASM 340	ASM 310
	
■ Fastest response time thanks to high helium pumping speed ■ Easy handling, intuitive menu navigation and large color touchscreen ■ Fastest operational readiness in its class ■ Cart available for ease of mobility	■ Dry pumping system, fore-vacuum pumping speed 1.7 m^3/h ■ Ultralight, only 21 kg and portable ■ Clever design with extensible handle ■ Removable control panel ■ SD card for data storage

Pfeiffer Vacuum Service

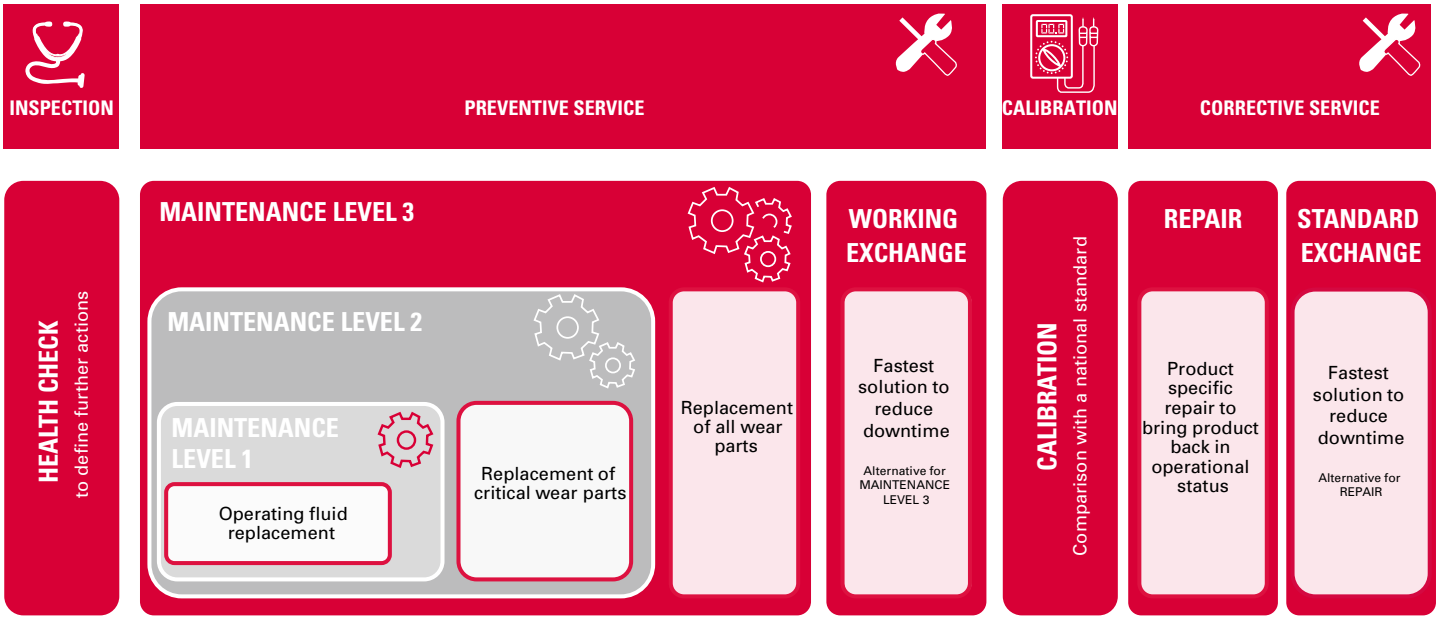
Our services – your advantages

Each customer places its own particular demands on its products, and these may also be influenced by application-specific parameters. Our flexible service concept, with a focus on preventive services, offers just the right solution for you.

Preventive maintenance – avoid downtimes

With our preventive service concept, we can recommend service intervals tailored to each product. The aim is to avoid failures and to carry out planned and predictable servicing.

Maintenance level 1 includes fluid changes and contributes significantly to the good working order of the product. **Maintenance level 2** also includes replacement of all wear and tear parts. In **maintenance level 3**, all wear and tear parts of the product are replaced and the product is overhauled. In order to keep downtimes to a minimum, we offer temporary replacements for many of our products for the duration of maintenance. We provide an equivalent **replacement product** that our customers can start using immediately.



Services at a glance

- User training and product training
- Pfeiffer Vacuum original spare parts and tools
- Troubleshooting and advice from our technical support team
- Comprehensive on-site service by our service technicians
- Maintenance and repair in our service centers worldwide
- Individual service agreements
- Replacement products
- Calibration service for measuring devices and helium test leaks

Spare parts – original parts increase life expectancy

Pfeiffer Vacuum's spare parts and tools are defined early in the product development stage to ensure their proper fit and quality.

Every improvement to our serial products is also transferred to our spare parts. This means products are brought up to state of the art status after undergoing maintenance level 3 or a repair.

Advice – to assist you with any questions you may have

In addition to our individual concepts and the quality of our replacement parts, it is our employees and personal contact that give our service its special touch.

Technical support – competent advice from the experts

Since not everything about our products is self-explanatory and questions can arise both before and after purchase, Pfeiffer Vacuum's Technical Support is available to assist our customers.

Each member of our team specializes in a specific area of our portfolio to enable them to assist our customers competently with technical questions relating to our products. Our team also works closely with our developers and application experts.

Field service technicians on site

From commissioning new vacuum components and systems to troubleshooting, and from maintenance to repairs, we offer our customers a comprehensive range of on-site services. Our service locations ensure customer proximity and short-term assistance in emergencies.

Service agreements – individually tailored to your project

We offer project-specific service agreements so that our customers can plan maintenance or service interventions over a long term. These agreements can be made at a later date or as early as during the project planning stage. In order to take our customers' differing needs into account, agreements may include all or just some of the services we offer.

Components and valves

The connection in your vacuum system

A vacuum system is made up of a variety of individual parts which are combined to form a single unit. Pfeiffer Vacuum offers standard solutions, but also component modifications or a customized solution to fit your needs perfectly.

Your advantages and benefits

- A direct contact for you and your projects
- Proactive support and competent advice
- Convenient ordering

- Short delivery times
- High delivery reliability
- High security of supply

- More than half a million parts in stock
- High uptime
- Cost saving- no keeping stock necessary

www.vacuum-shop.com

- Convenient online vacuum component ordering any time
- Information about your prices, delivery times and terms

Components

Valves

Feedthroughs

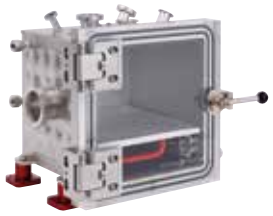
Manipulators

Custom vacuum chambers

Individually designed chambers for your vacuum applications

Due to our many years of experience, we can provide professorial quidance for system specifications, design and engineering.

Our physicists, designers, project managers and production specialists have extensive experience in many applications from all market segments. The tasks are based on your requirements: our starting point on the path to a finished product can range from a rough sketch to a complete set of blueprints.

High vacuum chambers	Advantages	Benefits
	■ Preconfigured design	■ Cost and time savings due to lower design expenses
	■ Proven, tough design	■ Reliable and safe
	■ Customized ports	■ Individual adaptation to your processes

Medium vacuum chambers	Advantages	Benefits
	■ Preconfigured design	■ Cost and time savings due to lower design expenses
	■ Proven, tough design	■ Reliable and safe
	■ Customized ports	■ Individual adaptation to your processes

Modular vacuum chambers	Advantages	Benefits
	■ Preconfigured design	■ Cost and time savings due to lower design expenses
	■ Modularly expandable	■ Maximum flexibility at all times
	■ Customized ports	■ Adaptable individually to your application

Custom vacuum chambers	Advantages	Benefits
	■ Individual design	■ Can be adapted optimally to your process
	■ High quality materials	■ Best quality and long life
	■ Robust design	■ Reliable and safe
	■ Project engineering and construction by qualified and experienced project managers	■ Time saving

VACUUM SOLUTIONS FROM A SINGLE SOURCE

Pfeiffer Vacuum stands for innovative and custom vacuum solutions worldwide, technological perfection, competent advice and reliable service.

COMPLETE RANGE OF PRODUCTS

From a single component to complex systems:
We are the only supplier of vacuum technology that provides a complete product portfolio.

COMPETENCE IN THEORY AND PRACTICE

Benefit from our know-how and our portfolio of training opportunities!
We support you with your plant layout and provide first-class on-site service worldwide.

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