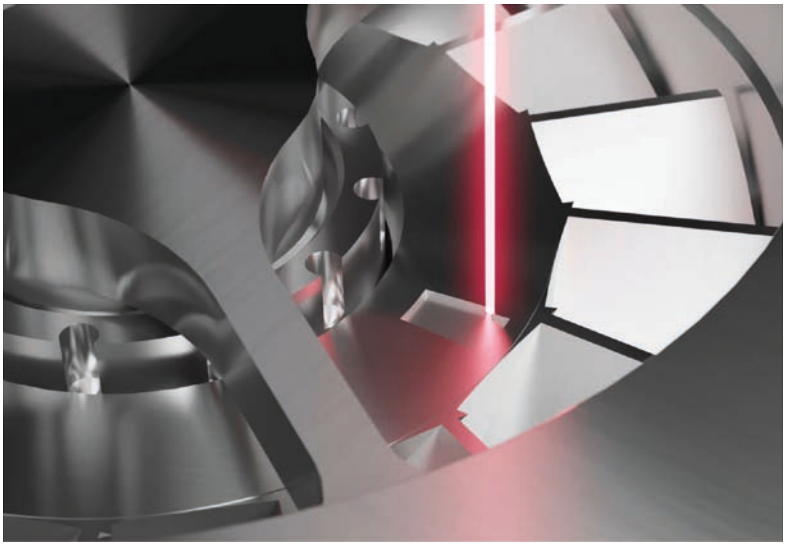
Revolution in Balancing Technology

Laser Balancing makes the operation of turbopumps even more efficient.

Turbopumps play an important role in vacuum technology for generating clean high and ultra-high vacuum. Inside the hybrid-bearing turbopump, a rotor is supported by a combination of permanent magnet bearings and roller bearings and driven at very high speeds.



HiPace 80 Neo – the world's first laser-balanced turbopump in its class

The balancing of these hybrid-bearing rotors has been a core competence of Pfeiffer Vacuum for many years, enabling the supply of technologically advanced turbopumps with a very low vibration level. With the launch of the new advanced HiPace 80 Neo, the Laser Balancing developed by Pfeiffer Vacuum is introduced – an innovation that provides improved durability and lower vibration as well as noise emissions.

But from the beginning: Why do rotors need to be balanced at all? What is the difference between conventional practice and balancing with the Laser Balancing method? And what advantages does it offer?

Structure of the turbopump

To this day, the turbopump remains essential for generating oil-free high and ultra-high vacuum. Immediately after its invention, it gradually replaced existing pumping principles for vacuum generation. In the 1960s, the demand for high vacuum began to increase more and more, quickly establishing the turbopump as the standard for high and ultra-high vacuum generation in a wide variety of applications. Without its use, many process steps in semiconductor manufacturing or coating would not be possible.

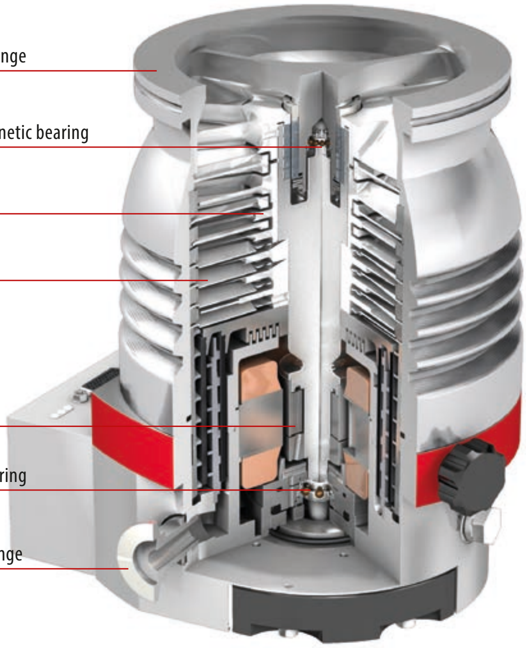


Fig. 1 Sectional model of a hybrid-bearing turbopump showing the rotor shaft bearing arrangement with a permanent magnetic bearing and a ball bearing.

The design of the turbopump is similar to that of a turbine. Inside the pump, several rotor disks are mounted on a shaft (**Fig. 1**). Between them are stator disks whose blade orientation is mirror-inverted to that of the rotor blades. As a result, the gas molecules to be pumped are conveyed from the high-vacuum flange along the individual turbo stages to the fore-vacuum flange. The rotor of the turbopump is driven by a brushless three-phase synchronous motor.

This enables very high rotational frequencies of up to 1500 Hz. The rotor shaft bearing, in turn, consists of a permanent magnetic bearing on the high vacuum side and a high performance ball bearing on the fore vacuum side. Although the ball bearing is minimally lubricated, the pump generates an oil-free vacuum.

This hybrid bearing, which is rarely found in mechanical engineering, represents a special feature to the bearing and thus balancing technology and differs from usual bearing technologies. In combination with the very high speeds, balancing the turbopump rotors in particular is a technological challenge. This is because the balancing quality in particular has a major influence on the service life and performance of the turbopump.

Why are rotors balanced?

The process of balancing is most likely familiar from the automotive sector. There, new car tires must also be balanced. Even bodies that appear symmetrical on the outside actually have slight inequalities in their mass distribution. This can be due to the manufacturing process of the component or an inhomogeneity in the density of the raw material. This uneven mass distribution is described by the term unbalance. When an unbalanced body is set in rotation, vibrations occur. The resulting forces depend on the rotational speed as well as the amount of unbalance. They can quickly increase sharply and cause damage to other components of the vehicle. For this reason, the unbalance of rotating objects is reduced by balancing.

While the speed of automotive tires is optimally 1500 to 2500 rpm, rotors of turbopumps reach speeds of up to 90 000 rpm, or 1500 Hz. The demands on the balance quality are therefore extremely high. The slightest unbalance in the range of a few milligrams can strongly influence the operation of the pump. A high balance quality is therefore relevant both for the smooth running of the rotor and for years of damage-free operation of the turbopump. It also ensures minimization of vibrations that are transmitted to the vacuum chamber and the customer application.

Conventional balancing

The conventional balancing technology has been one of Pfeiffer Vacuum's core competencies for many years. It enables vibration-reduced operation of hybrid-bearing turbopumps. By adding additional mass, for example through balancing weights, uneven mass distribution is reduced. Mass balancing is widely used with the aid of machining processes. This includes, for example, grinding and the removal of material by drilling holes.

In conventional balancing, the radial deflection of the rotor is measured in two measuring levels near the bearing (**Fig. 2**). With the aid of a special algorithm, the unbalance of the rotor is determined from this. To reduce the total unbalance, the rotor is divided along the axis of rotation into several balancing levels with corresponding holes. Balancing weights are manually screwed in along the circumference of the individual balancing levels. This reduces the uneven mass distribution and the remaining unbalance of the rotor is reduced below the necessary limit value. The unbalance is determined at several speeds and gradually compensated for.

Fig. 2 Illustration of a turbopump rotor showing the position of the balancing levels.

Laser balancing

The requirements for turbopumps are divided into primary and secondary properties. While the primary properties concern pump performance, the application requirements for turbopumps have also been increasing in the area of secondary properties in the last decade. The high-speed rotors are therefore subject to further development. This includes the service life of the rotor, vibroacoustic emissions and cleanliness with regard to the outgassing behavior of the components and surfaces. Vibroacoustic emissions are sound and vibrations emitted by the pump at the housing. The main cause of increased vibroacoustic emissions is rotor imbalance. The novel laser balancing system remedies this problem and enables turbopump rotors to be balanced even more efficiently. The conventional balancing process is optimized by dispensing with balancing holes and weights. The complete automation of the balancing process also plays a key role here.

To begin with, the rotor to be balanced is mounted in the automated laser balancing system. Inside this, the laser is encapsulated in a special chamber to avoid the danger of laser radiation to the environment. Mass balancing as well as the individual steps for measuring and determining the unbalance are carried out iteratively at different speeds. This makes it possible to obtain a precisely and effectively balanced rotor in all speed ranges. As in conventional balancing, the radial deflections of the turbopump rotors are measured using distance measuring

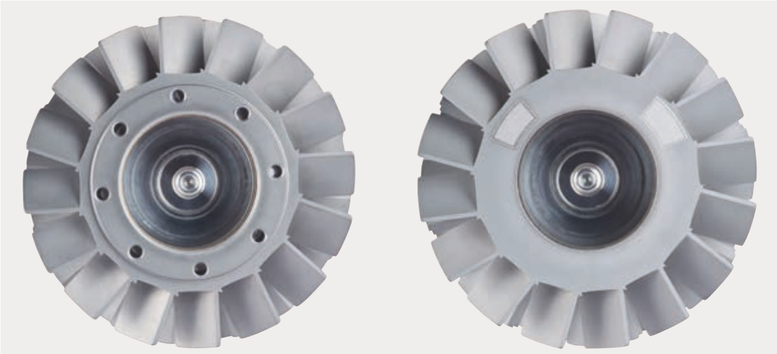


Fig. 3 Comparison of a balancing level of conventional balancing (left) with balancing holes and of laser balancing (right) with laser ablation segments

sensors in two measuring planes near the bearings. After the unbalance has been determined by the advanced balancing algorithm, the mass balance is reversed. Material is removed by a laser at the same angular position of the unbalance vector. The unequal mass distribution is thus corrected. A high-energy pulsed laser beam heats the rotor material in the balancing planes locally to such an extent that a melt emission with vaporization and/or sublimation occurs. In this process, the material can be removed in the form of a defined segment geometry at any point along the circumference (**Fig. 3**).

Compared to conventional balancing, in which graduated balancing weights are screwed in or masses are milled or drilled away, laser ablation works much more precisely. As a result, a significantly lower residual unbalance can be achieved. The material properties are not affected. In combination with a mirror system that can be moved relative to the laser, even a single processing laser reaches the different balancing planes. This results in greater flexibility in the design of new rotors and the definition and alignment of the balancing planes.

The absence of geometrically defined balancing holes and the precision of the laser allow any position of the ablation segment in the first balancing step.

This corrects the uneven mass distribution exactly in the necessary angular position of the individual balancing planes. Within the subsequent balancing steps, the algorithm of the balancing system takes into account the ablation segments already processed and places additional segments accordingly.

As soon as the residual unbalance over the entire speed range has been corrected in accordance with the tolerances, the rotor is removed from the automated system.

Advantages of laser balancing

In many devices and applications with integrated turbopumps, low vibrations and/or quiet running of the rotors are a prerequisite for their operation. Laser balanced rotors therefore represent a major advance for their areas of application. In combination with the underlying calculation algorithms, they ensure more efficient correction of residual unbalance in a modern, automated balancing system: If the residual unbalance is reduced, this affects the balancing quality class of the rotors. In this context, a well-balanced rotor with a high balance quality means a low amount of balance quality class $G = U_{\text{Rest}} \cdot \frac{\omega}{m}$ where ω is the speed of the rotor in Hz and m is the mass of the rotor in kg.

Based on the unbalance tolerances, this reduces the residual unbalance and therefore the balance grade by about 50 %. Centrifugal forces induced by unbalance are minimized. The rotor material and the bearings are thus subjected to less stress. For this reason, turbopumps with laser-balanced rotors have a longer service life.

In addition, lower vibrations are transmitted to the pump housing via the bearing. During operation, this has a positive effect on the noise emission of the pump and sensitive components or processes mechanically coupled to the turbopump. Particles generated during laser ablation are already extracted and filtered during the process. Furthermore, the subsequent cleaning of the laser-balanced rotor guarantees maximum surface cleanliness.

Application examples are ion mobility spectrometers, which are used as benchtop devices on laboratory workstations. In this context, low-noise operation of the integrated turbopump is required. Another example are electron microscopes, which enable sharp high-resolution images only through a vibration-optimized rotor and low vibroacoustic emissions.

The described advantages of innovative laser balancing illustrate the technological progress of laser-balanced rotors compared to conventionally balanced rotors. With extended rotor life and reduced vibration and noise emissions from the turbopump, the process represents another milestone in vacuum technology and offers greater flexibility for the design of new turbopump rotors.

Contact

Pfeiffer Vacuum GmbH,
Berliner Str. 43, 35614 Asslar, Germany,
phone: +49 6441 802-0
www.pfeiffer-vacuum.com