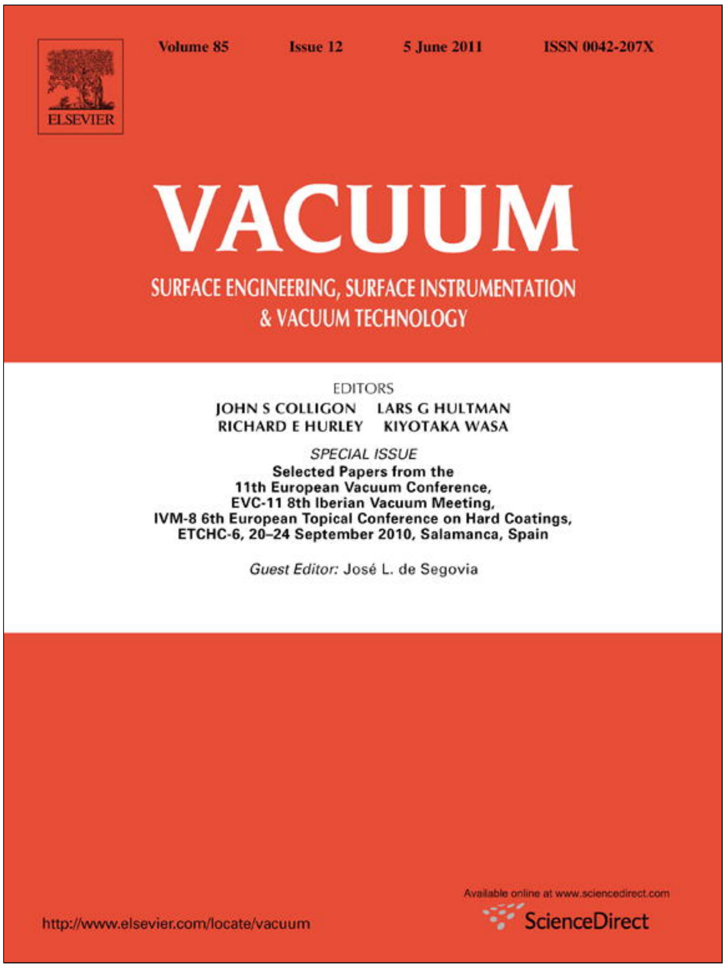

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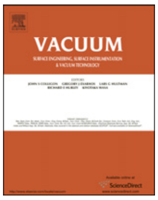

Developments in nEXT turbomolecular pumps based on compact metal spring damping

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ABSTRACT

A new range of turbomolecular pumps based on a Compact Metal Spring Damper (CMSD) system is described. The CMSD is essentially a support mechanism for the lower mechanical bearing which takes the form of a three-armed radial leaf spring. The result is that the design allows for small radial movement but has very high axial stiffness. The impact the CMSD has on the design of a new drag stage is described as is the constant very low vibration signature. Pumps fitted with a CMSD achieve such low vibration without the need for high-speed balancing and are fully end-user serviceable.

1. Introduction

The development of the first turbomolecular pump is attributed to Becker in 1957 and became commercially available in 1958 [1]. Kruger and Shapiro [2] published work in 1960, describing the blading geometry of axial-flow molecular turbines in molecular flow. This led (from the mid-1960s) to the open, thin-bladed axial-flow designs typical of modern turbomolecular pumps. Hybrid or compound turbomolecular pumps were developed from the mid-1980s in which Gaede, Holweck or Siegbahn molecular drag stages were added to the blade stacks to increase compression ratios and to allow the operation of the pumps at higher backing pressures [3–5].

In early turbomolecular pumps the bearing mechanism for the high-speed rotor relied on oil (and later sometimes grease) lubricated steel bearings. Latterly high-precision ceramic bearings have been employed. These high-precision ceramic bearings can be tuned to a turbomolecular pump's rotor at comparable radial and axial loads. Ceramic ball bearings exert lower centrifugal forces and stress on the bearing races than steel bearings. They are also harder and more thermally stable which means their spherical profile is maintained and wears on the ball and races are minimised. Their smooth surface leads to lower friction and matching of materials (ceramic balls and stainless steel races) is made to avoid pitting. These factors give the ceramic bearings a longer lifetime than older bearing designs; even at very high rotational speeds (>1000 Hz). The bearing lubricant (oil) has to be able to cool the bearings, have good lubrication properties at high speed and a very low vapour pressure.

The development of ceramic bearings allowed higher rotational speeds thus permitting higher pumping speeds for a given rotor diameter of a turbomolecular pump. Balancing of turbomolecular pumps is typically done dynamically in various planes with the objective to match the rotational axis with the principle axis of inertia. Balancing minimises vibration and noise and maximises bearing life.

Many contemporary pumps have a passive, permanent magnet bearing at the high vacuum side of the rotor in combination with a lubricated mechanical lower bearing (See Fig. 1). Fully magnetic suspension pumps ("Maglev") are available where the position of the rotor is sensed and actively corrected to give a contact-less suspension, though these are significantly more expensive.

Turbomolecular pumps are extensively used in scientific instrument applications – notably mass spectrometry and electron microscopy. For the most part these systems use smaller pumps (50–500 l/s), usually with ball bearings, or hybrid systems comprising one ball bearing and one passive magnetic bearing (Fig. 1). Most of the factors which decide the use of active magnetic bearings in the industrial (semiconductor) processes apply equally in these scientific instrument applications, but the adoption of magnetic bearings has been limited, and confined mainly to larger and more costly instruments. Many of these instruments are used for inspection and editing of semiconductor wafers.

The reasons for slow adoption of active magnetic bearings in scientific instruments include:

- Cost – capital cost of most scientific instruments is much lower than the semiconductor process tools
- Size – semiconductor process pumps are in the range 1000–4000 l/s whereas pumps used in scientific instruments

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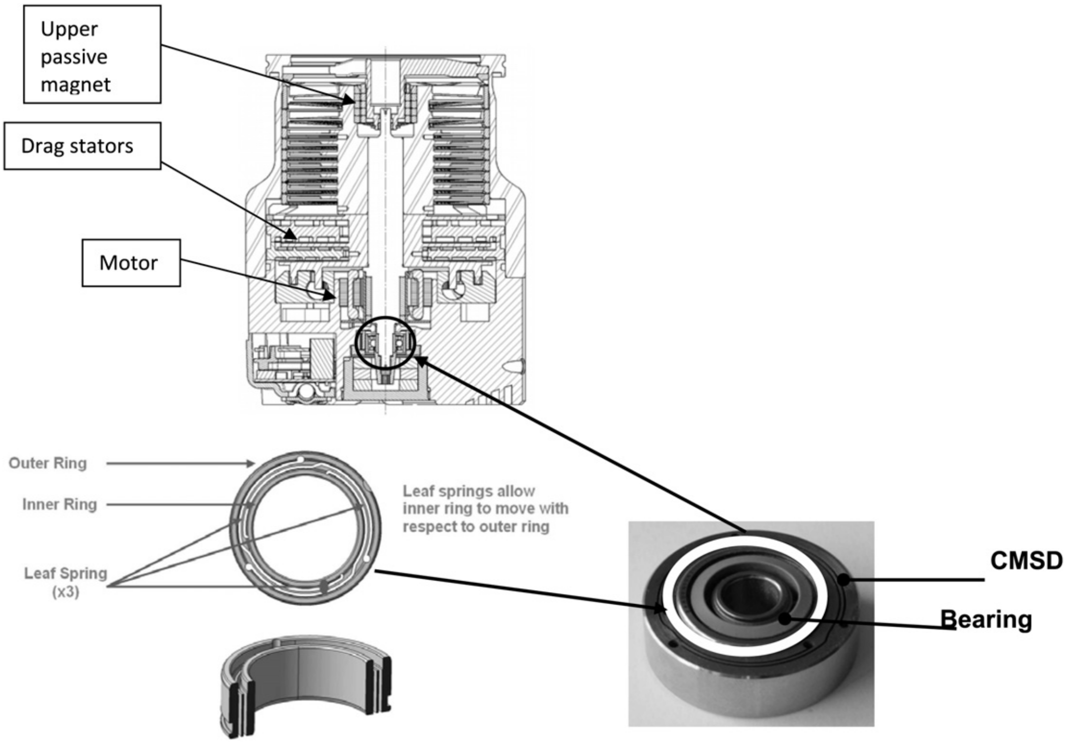

Fig. 1. nEXT turbomolecular pumps bearing arrangement: CMSD.

are generally in the range 50–500 l/s. Fully active magnetic bearings do not economically scale down to these smaller sizes.

- Configuration – pumps used in Mass Spectrometry are frequently specialist, multi-inlet "split-flow" configurations. These split-flow designs need long slender rotors carrying several different molecular and viscous pumping stages customised to pump the various chambers of the spectrometer. These constructions do not naturally lend themselves to the normal Maglev spindle configuration used in semiconductor process turbomolecular pumps.

In this paper we will discuss a new mechanical bearing suspension system with many of the desirable characteristics of fully active magnetic bearing pumps, in the new Edwards nEXT range of pumps. The nEXT range includes discrete and split-flow (multi-inlet) versions in 'Duplex' (Turbo blades with Siegbahn drag stages) or 'Triplex' form (turbo blades with Siegbahn and regenerative drag stages) [6–9].

2. Compact metal spring damper

The most important innovation in the nEXT pump is the patented [10–14]. Compact Metal Spring Damper (CMSD) which supports the oil-lubricated ceramic lower bearing of the pump in combination with a permanent magnet upper bearing. The CMSD is a wire-eroded 3 arm radial leaf spring component which supports the lower mechanical ceramic bearing and is shown in Fig. 1. The CMSD allows the ceramic bearing (and thus the impellor) to have small movement in the radial direction and to 'absorb' any rotor imbalance. It also minimises the transmission of vibration from the rotor to the pump body. The nEXT uses a Siegbahn drag configuration which requires accurate positioning in the axial direction. The CMSD is very stiff in the axial direction, facilitating this control. The 'freed' space in the pump, previously occupied by Holweck mechanisms may be used to add regenerative drag stages which are discussed in a separate paper [15]. Traditionally damping elastomer rings are used in conventional bearings to provide damping of the vibration both axially and radially. Over time these elastomers change characteristics/properties due to temperature and exposure to oil. They can wear, swell and soften with oil which causes deformation/compression set and rotor imbalance (drift) and thence increased vibrations transmitted to the body of the pump. The CMSD eliminates the need for these elastomers thereby vibration drift is significantly reduced if not eliminated.

The CMSD gives a stable and low vibration profile (with low power) without the need for high speed balancing. Traditionally pumps were balanced at low speed (<2000 rpm) at atmospheric pressure to correct for any course unbalance of the motor and at high speed (45000–60000 rpm) under vacuum for fine balancing using a variety of small weights.

An illustration of the (calculated) vibration/displacement characteristics is shown in Figs. 3 and 4. These are for a nominal case of 3 μm unbalance in both upper and lower planes of a nEXT200/

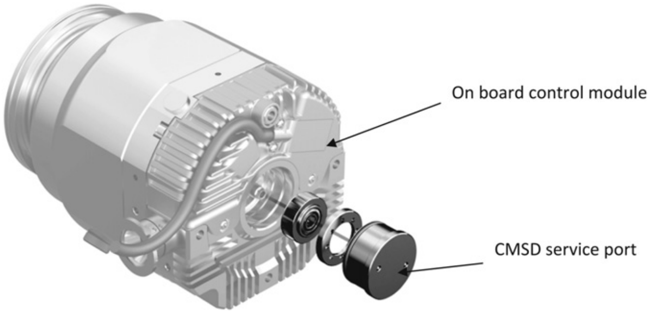

Fig. 2. nEXT turbomolecular pump service port.

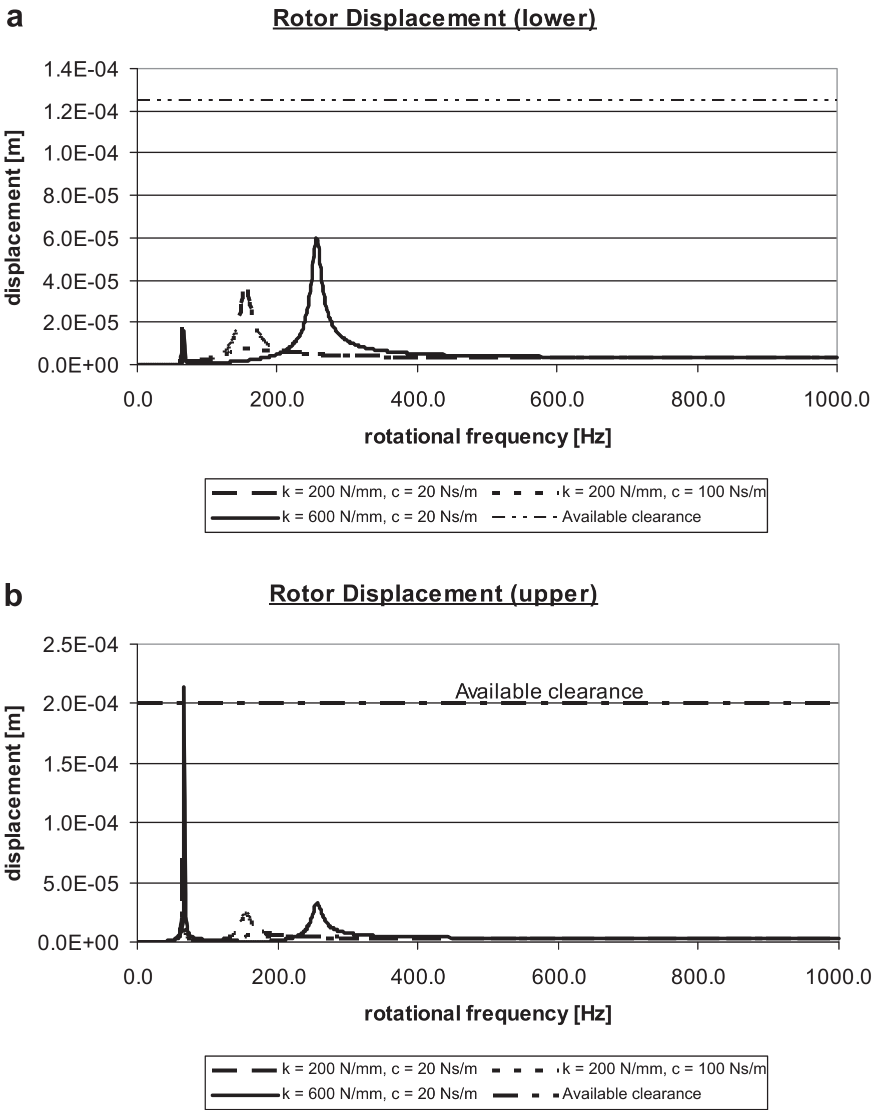

Fig. 3. Rotor displacement (a) Lower (b) Upper (k = stiffness and c = damping factor).

200D – this means the inertial axis of the rotor is displaced (due to unbalance) by 3 μm from the geometric axis (defined by the bearing centres). The graphs of lower (3a) and upper (3b) rotor displacement both exhibit a flat region over the range 500–1000 Hz. This is because when above the critical (lower) speeds, the rotor is effectively rotating around its inertial axis, virtually without any influence from the bearings. The nominal case is typical of the nEXT and CMSD (k = stiffness 200 N/mm, c = damping factor 20 N/m). With an increase in stiffness (a factor of 3 increase to 600 N/mm) and damping factor still 20 N/m the magnitude and frequency of the second critical speed increases significantly and the transmitted vibration to the pump body increases almost 3-fold. The increased damping case (stiffness of 200 N/mm and damping factor increased to 100 N/m) shows that the increase in damping improves control of the second critical speed, but at the cost of increasing transmissibility (acceleration). The “ski jump” effect is seen on the body acceleration as it approaches nominal rotational speed.

The CMSD allows the design of the radial stiffness and damping of the lower bearing support independently of one another, so as to arrive at the best compromise between control of the second critical speed (higher damping) and transmissibility at full speed (lower damping).

For the special case of electron microscopy (SEM, TEM, STEM, etc), individual microscope manufacturers have stages which themselves have resonant frequencies which make them susceptible to particular axial and radial vibration frequencies in a turbopump. The CMSD relies on arc-shaped spring members which are rectangular section beams, and the aspect ratio of these rectangular beams may be selected to independently tune the axial and radial stiffness and hence place the axial and radial natural frequencies of the pump well away from the resonant frequencies of the stage. By the appropriate choice of material parameters, they can also be tuned to avoid particular excitation frequencies present in the pump, for example, the cage frequency or ball–train frequency (which in a pump rotating at 1000 Hz, is typically around 360–370 Hz).

When a pump is serviced in the field – it is important that the unbalance vibration does not increase significantly. Achieving this depends on achieving a reproducible fit of the inner ring on the shaft and reproducible run-out. Selective assembly can improve the reproducibility of bearing fit, and reduced tolerances of shaft and bearing can be achieved at a cost, but with the right selection of radial stiffness and damping, acceptable vibration can be achieved even with unbalance values of ∼3 μm. Also, small movements in

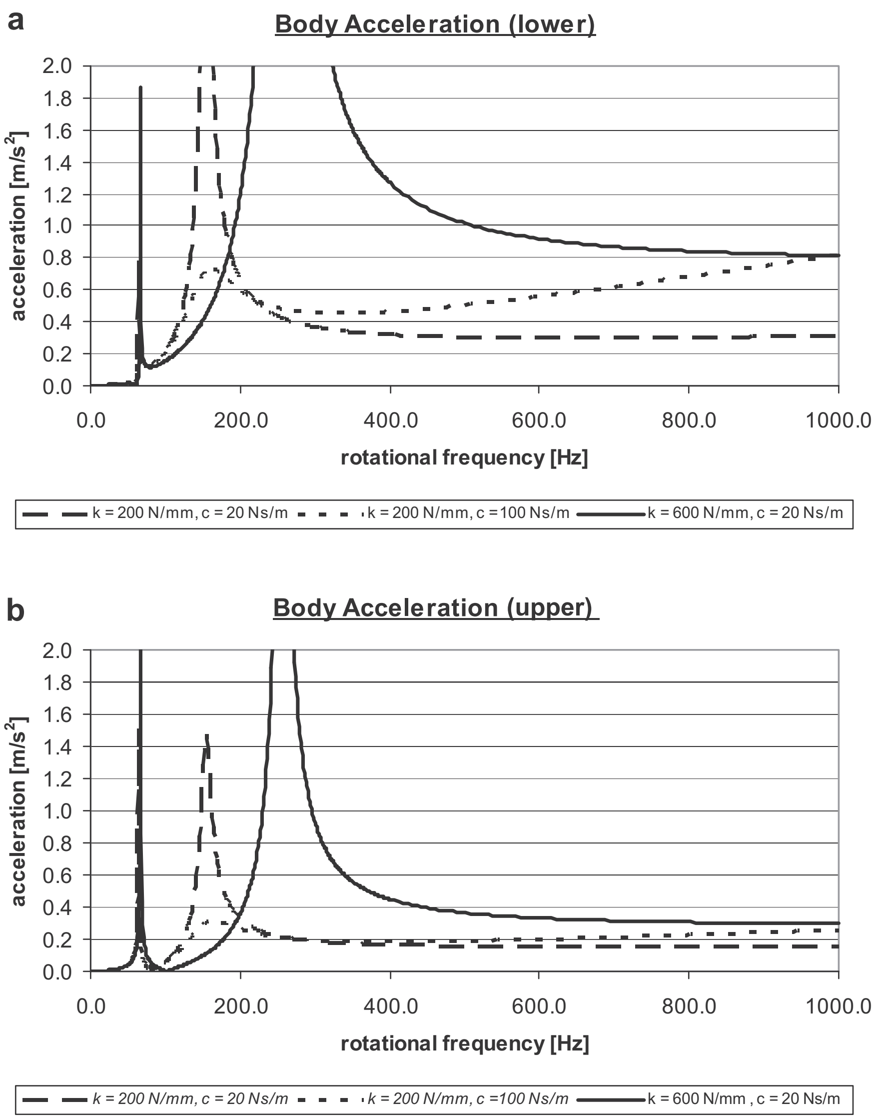

Fig. 4. Body acceleration (a) Lower (b) Upper (k = stiffness and c = damping factor).

the rotor inertial axis caused by thermal effects and relaxation of internal stress can be accommodated.

The CMSD is so effective at reducing transmitted vibrations that it means that nEXT pumps do not need to be high-speed balanced during manufacture and therefore do not need to be balanced during service. This gives nEXT a major advantage over its EXT predecessor (and many of its competitors) in that the pumps can now be serviced in the field and often in situ. The service procedure takes place through the service port on the base of the pump (Fig. 2). Access to the rest of the pump is not necessary. Servicing of the pump can be accomplished with two inexpensive specialist tools plus a minimum of standard workshop tools.

3. Innovations for optimized service procedure

There are two levels of service intervention: an oil reservoir lubrication service and a bearing assembly (plus oil reservoir) service. The former takes place typically after 2 years, the latter after 4 years. During an oil reservoir lubrication service, the oil cartridge is simply removed and replaced with a new cartridge, which is pre-charged with the appropriate amount of oil. The time required to perform the above interventions is typically <5 min for the oil cartridge and ~ 10 min for the bearing change.

It is also possible, through serial communications, to enquire what time period is remaining to the next service intervention, thus scheduled/preventative maintenance visits or interventions can be planned in advance. Ultimately the CMSD eliminates the need to remove the next product from the field for the projected life of >10 years.

4. General

As mentioned above, the CMSD is very stiff in the axial direction which allows the accurate positioning of a Siegbahn drag configuration. A patented [13] outer diameter o-ring seal maximises light gas compression across the Siegbahn stages. In the Triplex nEXT model regenerative stages are added which allows the pump to exhaust to higher pressures (>20 mbar) and gives the opportunity for vacuum system rationalisation with additional pumping port. The nEXT range comprises Triplex (T) and Duplex (D) versions: nEXT240D, nEXT240T, nEXT300D, nEXT300T, nEXT400D and nEXT400T and also Split-flow versions.

5. Summary

Innovations for a new generation of turbomolecular pumps have been developed. A patented Compact Metal Spring Damper allows the lower ceramic bearing movement in the radial direction and to ‘absorb’ any rotor imbalance. The CMSD is very stiff in the axial direction (as shown in Figs. 3 and 4) which allows the precise positioning of Siegbahn drag stages. The use of the CMSD avoids the need for balancing the pump during manufacture and rebalancing the pump after bearing change and hence servicing is a fully end-user task. A unique combination of Siegbahn and regenerative drag stages in combination with the molecular bladed stages, permit operation at backing pressures up to 20 mbar. This means that a backing pump with a relatively smaller capacity can be used.

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