EUROPEAN SCOPE

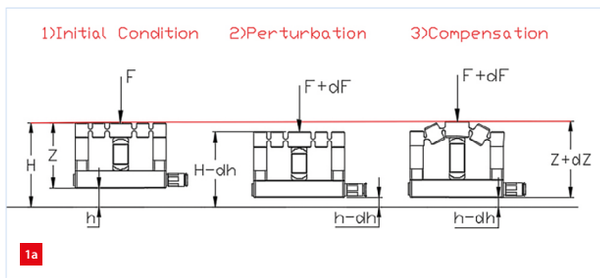
The first two Gas Bearing Workshops, in 2015 and 2017, were mainly visited by interested people from Germany, Belgium and the Netherlands. This year in the third edition, however, much attention was paid to developments in France, Italy and the UK. Accordingly, the number of attendees went up, from 40 to 60, well distributed over the participating countries. This turned out to be a fitting number in terms of quality of discussion during and between the presentations.

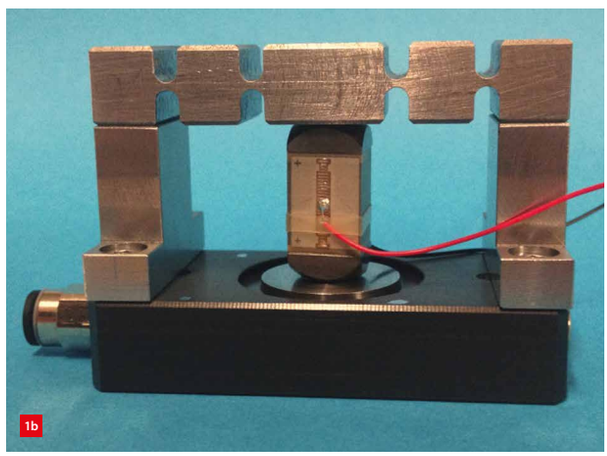
JOS GUNSING

In his opening remarks to the Gas Bearing Workshop 2019 in Düsseldorf, Germany, Patrick Janssen from the Dutch Consulate on-site expressed his pleasure with the continuation of the initiative. He said he sincerely hoped that the organising partners VDE-GMM (*VDE-Gesellschaft Mikroelektronik, Mikrosystem und Feinwerktechnik*) and DSPE would continue to co-operate and innovate.

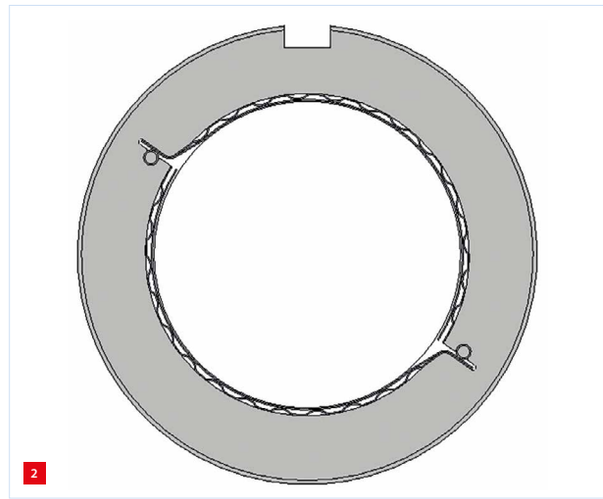
Next, Terenzo Raparelli, Mihaï Arghir and Duc Ha started with a joint keynote speech presenting the latest developments in Italy, France and the UK, respectively.

In Italy, research is concentrated at the Politecnico di Torino, primarily aimed at air-bearing feeding with subjects like supply hole discharge coefficients, behaviour of porous and metal (woven) mesh and, of course, numerical modelling. Applications are mainly found in the fields of textile industry and milling, i.e. high-speed spindles. Special attention should be paid to the research on active thrust pads with PZT/piezo technology (Figure 1) for increasing the dynamic load behaviour. A company worth mentioning is MAGER Air Bearings, which develops and builds a range of air-bearing applications.





Active thrust pad bearings with PZT/piezo technology. (Courtesy of Politecnico di Torino)
(a) Working principle.
(b) Physical realisation.



Radial air foil bearing. (Courtesy of Omega Dot)

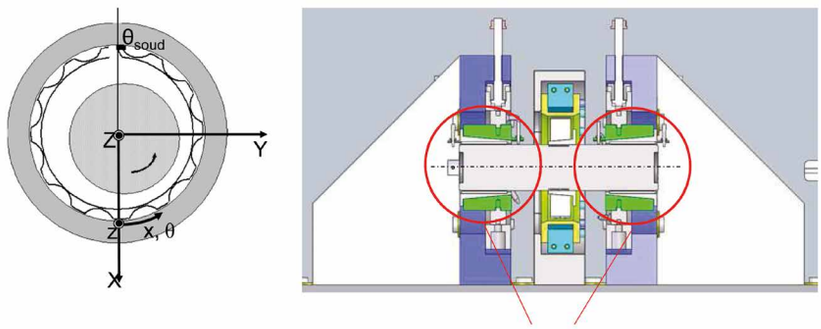
In France, research started in the early 1960s with gyroscope air bearings. With space turbo pumps (rocket fuel pumps, Safran Group) and microturbo applications being relevant for industry, foil bearings in journal (radial) and thrust (axial) versions are important research topics. Also, refrigerant pump bearings (for Liebherr) with two-phase flow (gas-liquid) present an interesting research subject. INSA Lyon and Université de Poitiers are the places to be in France.

In the UK, several universities/institutes (Birmingham, Manchester, Leicester, Huddersfield, Cambridge, Queen's University (Belfast), Brunel University and Cranfield) contribute to gas-bearing research. Besides fundamental topics, there are applications predominantly in the field

AUTHOR'S NOTE

Jos Gunsing is founder/owner of MaromeTech, a technology & innovation support provider, based in Nijmegen (NL).

jos.gunsing@marometech.nl



Test rig for aerodynamic foil bearings. (Source: Balducchi, F., Arghir, M., and Gaudillère, F., "Experimental Analysis of The Unbalance Response of Rigid Rotors Supported on Aerodynamic Foil Bearings", GT2014-25552, ASME Turbo Expo 2014)

of turbo machinery, dealing with hybrid air bearings (a combination of aerodynamic and aerostatic bearings), foil bearings (Figure 2) and squeeze-film bearings.

Research topics and applications

Andreas Lange (Technische Universität Kaiserslautern, Germany) and Federico Colombo (Politecnico di Torino) focused their lectures on, respectively, simulation-driven design, including stability analysis and lumped-parameter models for gas bearings. They both provided useful contributions that can accelerate the design of gas-bearing applications and help to make it (close to) right first time.

Duc Ha (Omega Dot, Worcester Park, UK) is deeply involved with air foil bearings, especially in applications for turbo machinery. He presented the advantages of foil bearings (in fact aerodynamic bearings) as compared to high-speed roller bearings or hydrodynamic bearings:

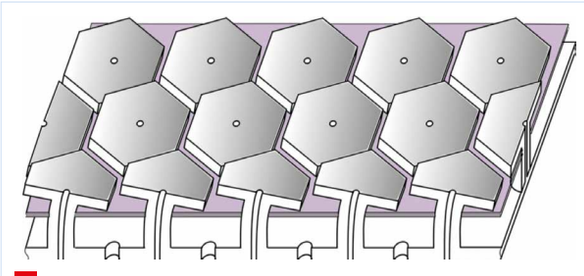
- Oil-free.
- Lower friction and operational cost.
- Low noise and vibration.
- Low maintenance.
- Zero wear.
- Self-acting (i.e., starting without an extra air supply), no extra lubrication required.
- Compliancy adaptable.

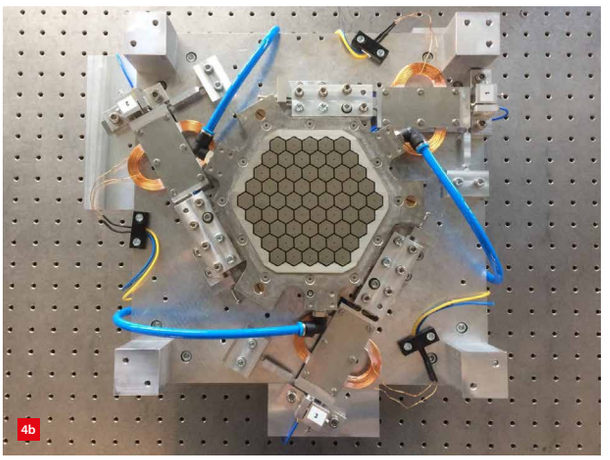
Foil bearings are particularly interesting for turbo compressors, turbo alternators (i.e. generators) and airplane air conditioner drives. Foil bearings can be applied both as journal and thrust bearings at speeds up to 200 m/s and temperatures up to 700 °C. The compliant foils accommodate for thermal expansion, e.g. shaft thermal growth. The main research topics for air foil bearings include cost reduction (as evidenced by patent literature) and recently also condition monitoring aimed at improving reliability, or reducing machine downtime.

Mihaï Arghir (Université de Poitiers) showed an interesting case of a rocket fuel pump (15MW pumping power in a cryogenic environment) with hybrid bearings. In hybrid bearings the static load is also carried on a gas film (aerostatically) and with increasing speed, the aerodynamic effect takes over and also contributes to the stability of the bearing-shaft combination. Arghir also investigates foil bearings, specifically the unbalance response during coast-down (gradually revving down). Nonlinear models of the compliant bump stiffness/damping and the impact on bearing start-up behaviour, bearing stability plus the impact of manufacturing errors, are his specialty. This research is ongoing (Figure 3).

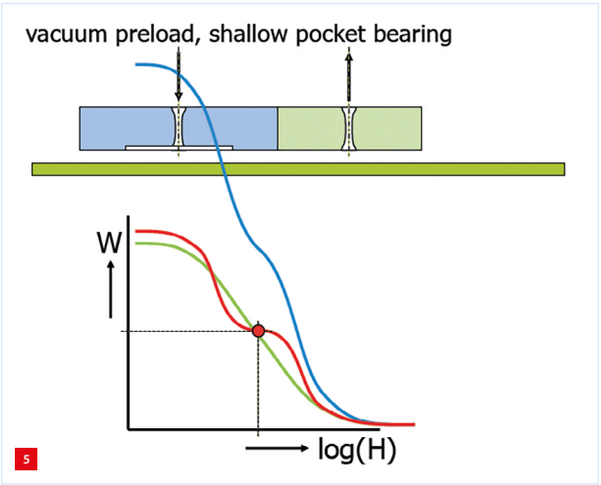
Peculiar twist

Ron van Ostayen, Delft University of Technology (TU Delft, NL), gave a peculiar twist to air-bearing design conventions when he stated that he was looking for, among other things, more friction in air bearings. Elaborating on this, he showed the latest results for the 'flowerbed' research aimed at transporting/positioning wafers with the help of air flow, where friction is indeed required (Figure 4). The flowerbed consists of air-bearing pads that can be actively tilted This air-bearing tilt not only will result in a lifting force, but will also create drag in a specific direction, thus achieving a movement of the air-lifted substrate. This motion, as well as position or speed, can be controlled. It presents an interesting concept for very fragile substrates and also avoids the need for applying separate wafer carriers.





Flowerbed with actively tilting air-bearing pads. (Courtesy of TU Delft)
(a) Schematic of principle.
(b) Research set-up.



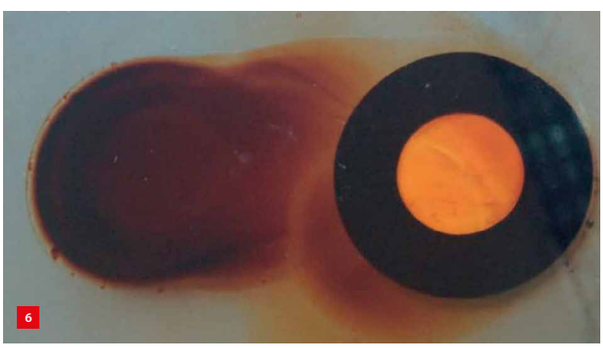
Zero stiffness: combination of vacuum preload and a shallow pocket air bearing (W = resultant force, H = air gap height). At the red dot, stiffness is approximately zero. (Courtesy of TU Delft)

Van Ostayen's next statement was that he was looking for low stiffness; preferably zero stiffness. This feature can be applied very successfully in air mounts for machine frames in order to have a perfect vibration isolation. In fact, it is a smart combination of vacuum preload and a shallow pocket air bearing acting in the same direction (Figure 5). By applying the right settings, a small area with low/zero stiffness can be created.

The last example of an apparently impossible air-bearing feature presented by Van Ostayen was a bearing without an air supply. This bearing consists of a ferrofluid ring between glass plates that encapsulates an air bubble (Figure 6), making any air supply obsolete.

Conclusions

Firstly, the Gas Bearing Workshop provided an excellent opportunity to network in an informal setting with people from at least six countries: as well as the 'newcomers' France, Italy and the UK, this naturally included Germany, Belgium and the Netherlands. The presentations gave a good overview of air-bearing research in these countries. In two years' time, in early spring 2021, the 4th Gas Bearing Workshop will be planned and the organisers hope to welcome a lot of interested people by then. Regarding the 2019 edition, they can look back on an exciting and open-minded Gas Bearing Workshop, where creative ideas were raised and flowed frictionlessly during the day.



Air bubble trapped with ferrofluid ring (shaped by a magnet) between glass plates acting as air bearing without air supply. Moving the glass plate over the bearing results in a trail of ferrofluid. (Courtesy of TU Delft)

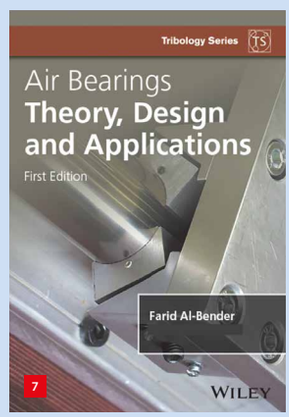
INFORMATION
WWW.GAS-BEARING-WORKSHOP.COM

New standard work on air-bearings

Farid Al-Bender, retired professor of mechanical engineering at KU Leuven, Belgium, gave a general presentation on air bearings. It could be considered a sneak preview of his new book, "Air Bearings – Theory, Design and Applications", which will appear at the end of this year.
Al-Bender is a long-time expert in air-bearing technology. He obtained his Ph.D. in 1992 in Leuven, where he was appointed professor and was the co-founder of Leuven Air Bearings. KU Leuven has been an expertise centre for air-bearing technology since the 1970s. When Al-Bender realised that no new air-bearing textbook had been published since the 1960s, he decided to write one himself, for beginners and experts in the field (Figure 7).

Table of Contents (600 pages)

1. Intro
2. General formulation and modelling
3. Flow into the bearing gap
4. Reynolds Equation: derivation, forms and interpretation
5. Modelling of flow in externally pressurised bearings
6. Basic characteristics of circular centrally fed aerostatic bearings
7. Dynamic characteristics of circular centrally fed aerostatic bearing films
8. Aerodynamic action of self-acting and hybrid bearings
9. Journal bearings
10. Dynamic whirling behaviour and the rotordynamic stability
11. Tilting pad air bearings
12. Foil bearings
13. Porous bearings
14. Hanging bearings
15. Actively compensated gas bearings
16. Design of an active aerostatic slide
17. Thermal characteristics of the film flow



Farid Al-Bender, "Air Bearings – Theory, Design and Applications", Wiley, 2019.