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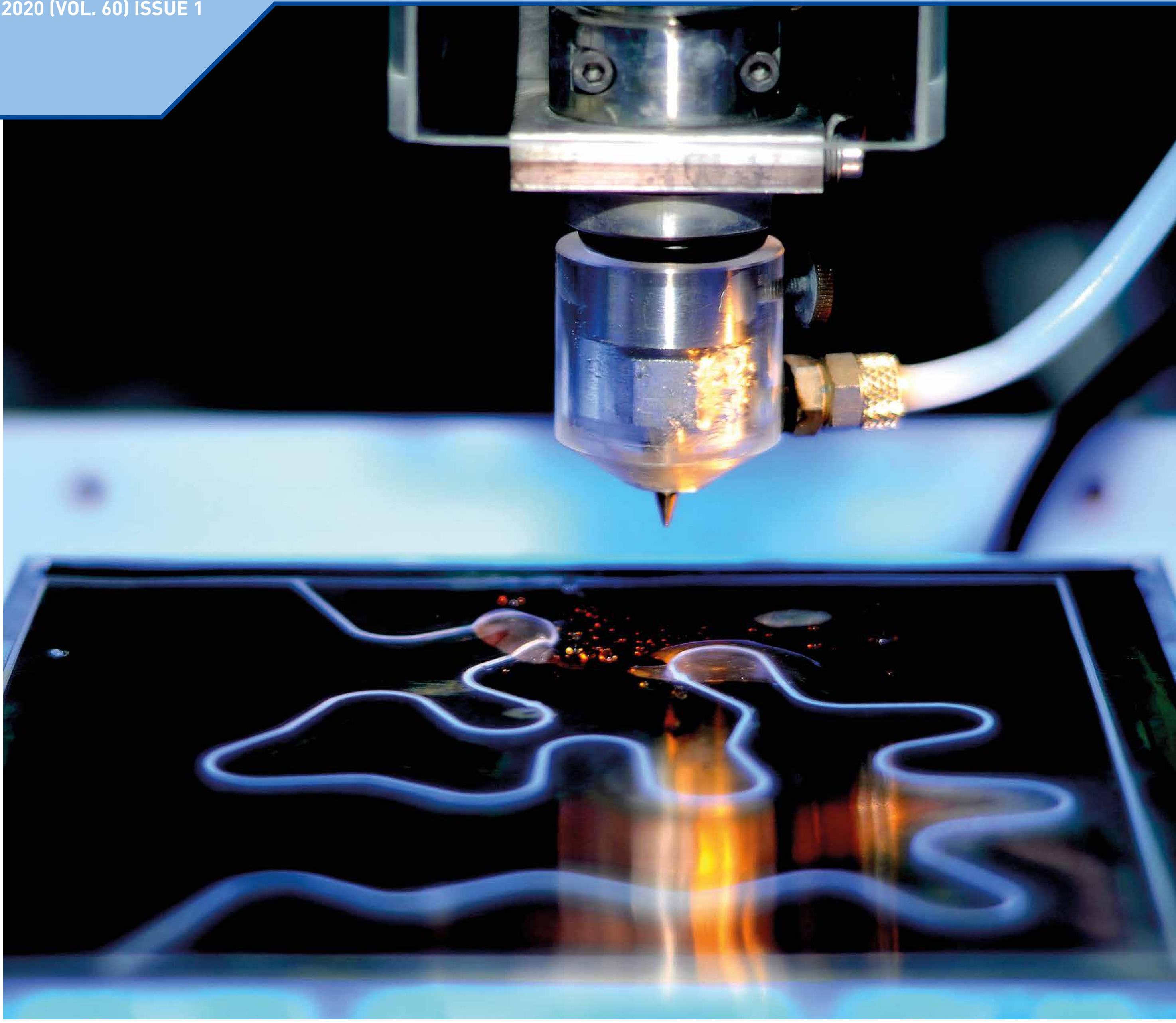

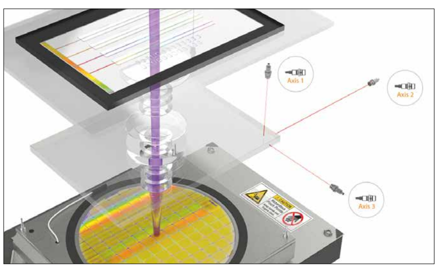

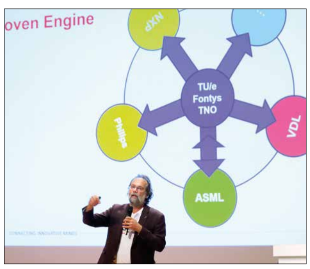

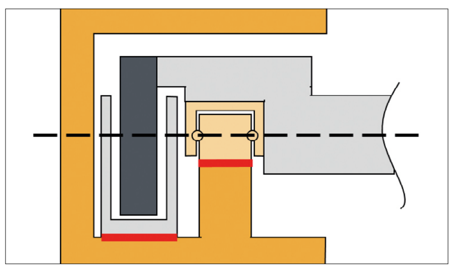

- HIGH-TECH SYSTEMS
- DESIGN OF HIGH-THROUGHPUT WAFER INSPECTION STAGE
- 2019 RIEN KOSTER AWARD WINNER; HANS VAN DE RIJDT
- EINDHOVEN ENGINE UPDATE

DSPE

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The main cover photo (featuring a free-jet electrochemical machining set-up) is courtesy of TU Chemnitz. Read the article on page 19 ff.

IN THIS ISSUE

FEATURES

EINDHOVEN ENGINE: NATLAB+ TO BE?

In 1891, the newly established company Philips decided to base itself in Eindhoven (NL), as its owners were able to purchase a factory there, including machinery (this factory is now the Philips Museum in the centre of Eindhoven). The initial growth of the company was facilitated by the automation of cigar making by cam-driven machines, which meant that Philips had access to a larger workforce. A second boost came from applying the experience of the cigar making automation to light-bulb manufacturing automation. Following light bulbs, radio tubes were made, which helped radios conquer the world. Televisions were the next breakthrough, followed by solid-state transistors, which enabled the development of consumer products. Philips had become a big company.

In the decades after the Second World War, Philips drove innovation through the NatLab (*Natuurkundig Laboratorium*, Philips Research) and CFT (*Centrum voor Fabricage Technologie*, Philips Centre of Manufacturing Technology). One could say that the NatLab did the fundamental research and CFT did the applied science.
High-tech companies like ASML, Thermo Fisher, Philips Healthcare, VDL ETG, NTS, Frencken, Prodrive, Neways, Raith and others started to flourish based on the ideas and competences developed by Philips Research and CFT. Communication between precision engineers within Philips (*Ontwikkeling en Bedrijfsmechanisatie*, Research and Factory Automation) was not limited by NDAs or confidentiality agreements. This knowledge sharing was essential for innovation and there are many examples where companies collaboratively built up experience and used their shared experience.

Nowadays, the arena has changed and it is filled with independent companies, where IP departments frustrate collaboration, which is not good at all. One good thing, however, is that researchers and engineers from different companies still like to share knowledge. DSPE strives to support this knowledge sharing, as you know. Recently, I spoke with some people in our community. The high-tech systems' supply chain is strong, we agreed, and the equivalent competence of the former CFT is developing in the relevant supply chain companies. Within two years they will have reached a level above that of the former CFT.

But what has been missing is the NatLab part, i.e. the capability of our region to do research on new technologies, new products and new business ideas, in a typical NatLab fashion: open doors, co-location of all disciplines, outside-the-box thinking, and a high refresh rate of talent and projects.

Marc Hendrikse, CEO of NTS-Group and executive chairman of Holland High Tech, recently requested my help in this matter. He asked me, as a professor at Fontys University of Applied Sciences, to become an ambassador of High Tech Systems & Materials. We agreed to ask the new generation (students) to participate in thinking outside the box. I told him this is a great idea, as students are not yet in a box, so by nature they think outside the box.
It is not easy to come up with ideas for starting new OEMs that can grow big, or to obtain funding for great high-tech ideas. Hence, it is not easy to create a successful new OEM. But history teaches us that we need perseverance to create a new high-tech future for our region.

At the Eindhoven University of Technology (TU/e), the initiative has been taken to create Eindhoven Engine: "connecting innovative minds". Eindhoven Engine aims to accelerate innovation in the Brainport Region through challenge-based research in its public-private research facility at the TU/e campus. Teams of our region's most talented researchers from industry and the knowledge institutes TU/e, Fontys and TNO will collaborate with students in Eindhoven Engine research programmes to deliver breakthrough technological solutions.

Will the Eindhoven Engine be our new NatLab, or even NatLab+, the + deriving from the involvement of students and of other knowledge institutes and high-tech supply chain partners? Hope so.
To be continued.

Hans Krikhaar
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VEGA MOTION PLATFORM DESIGN OVERVIEW

PM, a company well known for its precision linear bearings, has also gained experience in the development and production of custom motion systems. Recently, PM launched a stage that was completely developed and assembled in-house. The motion platform – designated as 'Vega' – was developed to set new standards for optical wafer inspection speed and accuracy. The central design concept was to position all driving dynamics in one plane, in order to prevent undesired reaction torques on the sensitive parts of the system.

MATHYS TE WIERIK AND JAN WILLEM RIDDERINKHOF

For more than 50 years, PM has been developing and producing very precise linear and rotating bearings. The Dutch family company focuses on bearings for the precision industry, where strict requirements are set for straightness, smoothness and stiffness. As well as these bearings, PM also develops high-end mechatronic motion solutions.

The development and production of these motion stages is often not the core competency of PM's customers and therefore it is something that they prefer to outsource. Typically, these customers are responsible for realising complex production process steps in the semiconductor, medical, optical or analytical industry. For PM, developing motion systems is a perfect addition to its bearing business, as the knowledge of making precision bearings can conveniently be used for developing stages, and vice versa.

PM normally builds motion platforms that are dedicated for customer projects. A year and a half ago, however, the company started to develop its own motion platform. PM engineers visited a number of customers to see what developments are taking place in their markets and what products they need to be competitive in five years' time. From all these discussions, PM derived a set of requirements that a next-generation motion system would need to meet.

The Vega motion platform had to be a fast, accurate stage, focused on back-end wafer inspection. This represents a particularly demanding market. Once having proven its competitiveness in that market, PM should be able to extend platform application to, for example, the medical market.

High throughput required

The bar was set high with the following critical performance requirements:

- Over a stroke of more than 300 mm, the mechanical accuracy in the X- and Y-direction must be better than 1 μm.
- Motion profiles include accelerations of 2 g and speeds of up to 2 m/s in the horizontal plane.
- Vibrations in the horizontal plane must remain below 25 nm, assuming the machine is operated on a cleanroom floor that vibrates at a VC-C specification.
- Vibrations in the vertical direction – the direction used to move the wafer into the optics' focal point – may not even exceed 10 nm.

Achieving high accelerations and short settling times are crucial in a wafer inspection application, where a high wafer throughput is key. Along with the technical demands, the timing of the project was also challenging: the complete design and production phase of the project needed to be performed within 12 months. Moreover, the stage had to be cost effective and robust, which was achieved by minimising the use of exotic materials and by manufacturing almost all components in-house at PM.

The starting point for the design was that all of the driving dynamics need to be in one plane. As a result, the motors do not cause any undesired reaction torques on the sensitive parts of the system. This was achieved by properly aligning the centres of mass for all moving bodies, the position of the motor forces and the position of the bearings. An additional advantage of keeping all the dynamics in one plane is that the out-of-plane loads on the bearings will also remain minimal – a lower bearing load adds to a longer lifespan with less wear and thus fewer bearing-induced inaccuracies.

Designing all of the dynamic components in one plane is relatively easy for a single-axis system. Normally, a second axis would be put on top of the first to realise the movement orthogonal to the first direction. Also, if needed, a third axis could be stacked on top. By stacking axes like this, however,

AUTHORS' NOTE

Mathys te Wierik (lead system engineer) and Jan Willem Ridderinkhof (manager R&D and engineering) both work at PM in Dedemsvaart (NL). This article is based in part on PM's presentation at the Precision Fair 2019, held last November in Veldhoven (NL).

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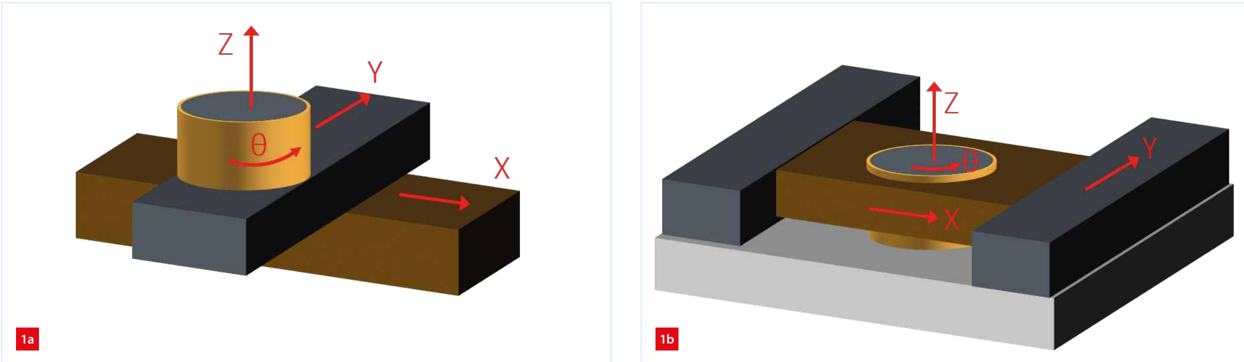


XYZθ-architecture alternatives
(a) Conventional low-speed.
(b) High-throughput-optimised, with all COGs in one single plane.

the centre of gravity (COG) of the moving mass is no longer ideal for each of the axes and, as a result, reaction torques occur when accelerating or decelerating the axes. These reaction torques create yaw, pitch and roll errors.

PM found a different solution, as can be seen in Figure 1. The construction consists of a horizontal box frame supported by a linear bearing on each side. In this square frame, the second axis is mounted, coplanar with the first axis. Then, the Zθ-module is integrated in this second axis, which is responsible for rotations and vertical movements. Only short-stroke vertical movements are made, so the centres of mass and actuation remain mostly in one plane. This means that the moving masses cannot exhibit lever arm behaviour, resulting in a much better positioning accuracy. Recirculating ball bearings were found to be accurate enough for optical wafer inspection when they are mounted correctly and the proper design principles have been applied.

Topology optimisation

After establishing the global layout, PM entered the detailed engineering phase. The dynamic requirements for such a wafer inspection stage meant that the box frame should be given a high structural stiffness at a minimum of moving mass. For accomplishing this, aluminium is an obvious material of choice. To shape the aluminium frame, PM developed its own topology optimisation program in Matlab.

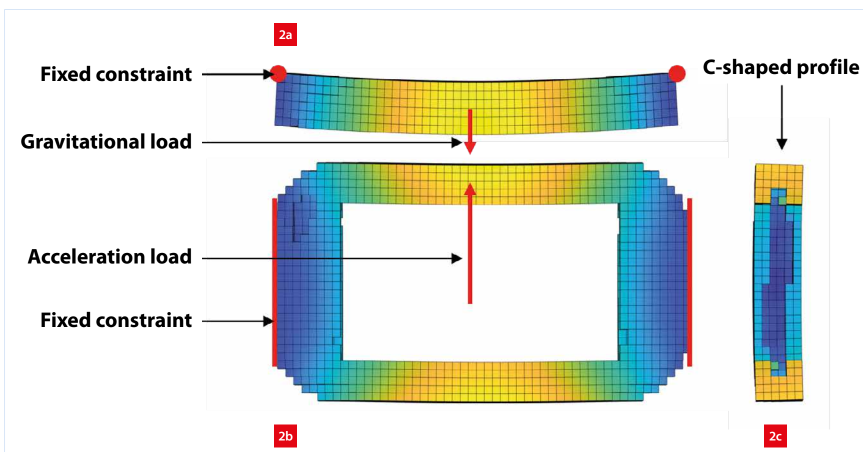
In the topology (shape) optimisation study, manufacturability was also considered. One of the constraints was having a constant material thickness for the cross members, allowing cost-effective and accurate manufacturing. The software eventually iterated to produce relatively large C-shaped profiles for the main cross members (see Figure 2). The C-shaped profile offers a good stiffness-to-weight value as well as a good base for installing bearings.

Actuators

The next question was how the motion platform should be driven. Various concepts were discussed and evaluated (Figure 3). The concepts in Figure 3a and 3b do not make optimal use of the bearing stiffness and require expensive grinding tolerances on two separate components (indicated in red), whereas the concept in Figure 3c only requires tight grinding tolerances on a single component.
Eventually, PM selected this third concept (Figure 3c); a solution based on an ironless motor with moving coils. This choice resulted in a somewhat complex construction, but this way the motor, the bearing and the encoder can all be mounted on the lower part of the C-profile. This choice helped to minimise the number of surfaces that needed very tight grinding tolerances to reach the accuracy requirements. Therefore, this design is cost effective, as it minimises manufacturing cost.

Settling-time simulations

To get a good understanding of what kind of settling times can be achieved, the frequency response functions of the



The optimum topology for the X-axis cross members has C-shaped cross sections placed near the outside of the box. The colour coding indicates displacement under gravitational and acceleration loading, from small (blue) to large (yellow) displacements.
(a) Side view.
(b) Top view.
(c) Cross section (the middle part showing a box frame member in the background).

VALIDATING INTERFEROMETER PERFORMANCE

Keeping up with Moore's law requires ultraprecise interferometry in semiconductor production and measurement. Attocube's IDS3010 (Interferometric Displacement Sensor) has the capability of measuring any kind of displacements and vibrations with nanometer accuracy, even under extreme environmental conditions. The validation that the IDS' displacement measurement performs in accordance to the International Length Standard is physically rooted in its technical design and certified by National Metrology Institutes participating in the CIPM-MRA (CIPM Mutual Recognition Arrangement).

FELIX SCHEINKÖNIG

Introduction

Based on Moore's law, the capability of technology should every year increase at least two times. As this evolution fast-forwarded itself with better materials and developments in their application, it presented the challenge of achieving greater precision in any kind of measurement. As the abilities of semiconductor technologies increased, this progress pushed the development of new production technologies. Based on sensitive materials and exactness at precision, production and measurements demand idealistic environmental conditions such as ultrahigh vacuum (UHV), cleanroom conditions, and high temperatures. Modern production processes and devices need to keep pace with these demands and deliver the highest precision, without compromising quality and output.

Attocube's IDS3010 (Interferometric Displacement Sensor), an ultraprecise interferometer, has the capability of measuring any kind of displacements and vibrations with nanometer accuracy, even under extreme environmental conditions. The IDS has three inputs and its modular design makes it easy to select different fibres and/or sensor heads for each of the three measurement axes, tailored to the specific application. With its compact size, the IDS3010 (Figure 1) can be directly integrated into machines and – for even more confined applications – its sensor heads can be remotely operated and interconnected via glass fibres. Therefore, the IDS is the product of choice for sophisticated precision engineering, space, synchrotron and semiconductor applications.

1
The IDS3010 laser interferometer.

AUTHOR'S NOTE

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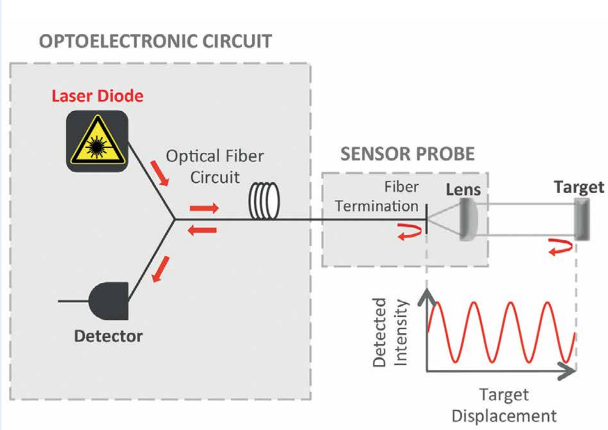
Work principle

Interferometers work by merging two or more sources of light to create an interference pattern, which can be measured and analysed. The interference patterns generated by interferometers contain information about the object or phenomenon being studied. They are often used to make the most accurate measurements that are not achievable any other way. This is why they are so powerful for the detection of, for example, gravitational waves.

The measuring principle of the IDS is also based on interferometry; see Figure 2. To measure displacements of a target, the IDS emits a laser beam of a certain wavelength. This laser beam gets coupled into an optical fibre and reaches a sensor head, in which the ferrule of the fibre ends. At the end of the ferrule, a small share of the beam is reflected back into the fibre. The remaining light travels to a reflective target and is also coupled back into the fibre where both beams interfere. The displacement of the target only influences the emitted beam. Therefore, the movement of the target causes a phase shift between the interfering signals that have been created, which leads to changes in the intensity of the interference signal.



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Working principle of the IDS3010.

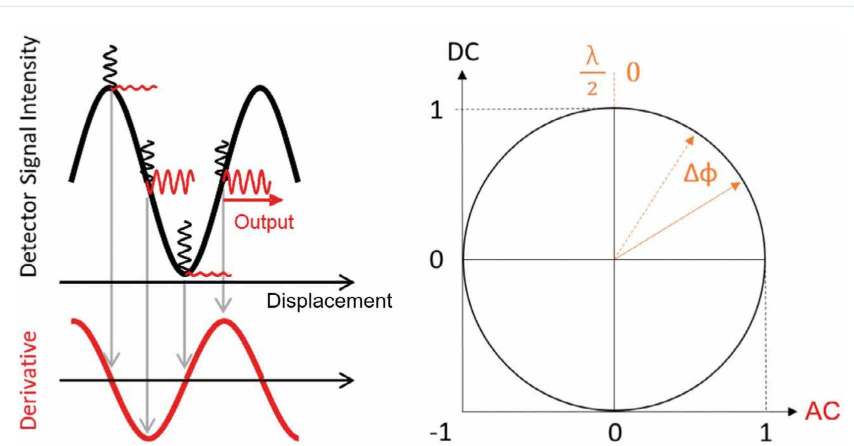
The interference signal is detected and processed by the IDS. Based on theory, it should contain all required information regarding the amount of displacement.
Two issues still remain, however:

1. The direction of the displacement cannot be determined.
2. At the peaks and lows of the signal, higher displacement is required to cause a detectable change in intensity

To overcome these challenges, the laser is modulated to create a second, 90°-phase-shifted, interference signal. The signals can be represented in a Lissajous figure (Figure 3), in which a full 360° shift is equal to a displacement of $0.5 \cdot \lambda$. The target displacement Δx is measured by analysing the phase change $\Delta\phi$ of the Lissajous figure, which is proportional to the laser wavelength λ:

$$\Delta x = \lambda / 4\pi \cdot \Delta\phi$$

The direction of movement can be determined based on the sign of $\Delta\phi$.



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The normalised Lissajous figure, which is based on two 90°-phase-shifted sinusoidal interference signals (AC and DC).

Environmental compensation unit

If an accurate interferometric measurement is performed in ambient conditions, the refractive index n of the medium must be taken into account. The refractive index of air depends on environmental parameters. A variation in the refractive index causes a phase shift of the laser light and leads to a systematic error in the displacement measurement. To ensure the accurate measurement of the displacement under ambient conditions, attocube offers an environmental compensation unit (ECU) as an additional device for the IDS3010. The ECU precisely measures the key parameters of the air and calculates the refractive index based on the Ciddor equation [1].

The refractive index at T = 20 °C, p = 1,013 mbar, 50% relative humidity and a CO_2 content of 400 ppm for a wavelength of 1,530 nm is n = 1.000268091. The dependence of the refractive index on temperature, pressure, wavelength, humidity and CO_2 content around these conditions is defined in Table 1.

CO_2 content can be neglected, as its influence is extremely small. Therefore, by measuring parameters such as temperature, pressure, and humidity, the ECU provides measurement accuracy of 1 ppm, even at ambient conditions.

Metrology aspects

In applications with the highest demand for accuracy, the measuring device must be compared to and traced in line with international standards (Figure 4). The validation that the IDS displacement measurement performs in accordance with the International Length Standard is physically rooted in its technical design and certified by National Metrology Institutes participating in the CIPM-MRA (International Committee for Weights and Measures (CIPM) - Mutual Recognition Arrangement [2]). Furthermore, performance is quality-checked during the production process. This provides assurance that the specification of a customer system is validated with full traceability.

Table 1
Dependence of the refractive index n of air on temperature T, pressure p, humidity h, CO_2 content x_c, and wavelength λ, around T = 20 °C, p = 101.325 kPa, h = 50%, x_c = 400 ppm, and λ = 1,530 nm.

Temperature T	dn/dT (K^{-1})	$-9.32 \cdot 10^{-7}$
Pressure p	dn/dp (mbar^{-1})	$2.70 \cdot 10^{-7}$
Humidity h	dn/dh (%$^{-1}$)	$-8.72 \cdot 10^{-9}$
CO_2 content x_c	dn/dx_c (ppm^{-1})	$1.42 \cdot 10^{-10}$
Wavelength λ	$dn/d\lambda$ (nm^{-1})	$-8.59 \cdot 10^{-10}$