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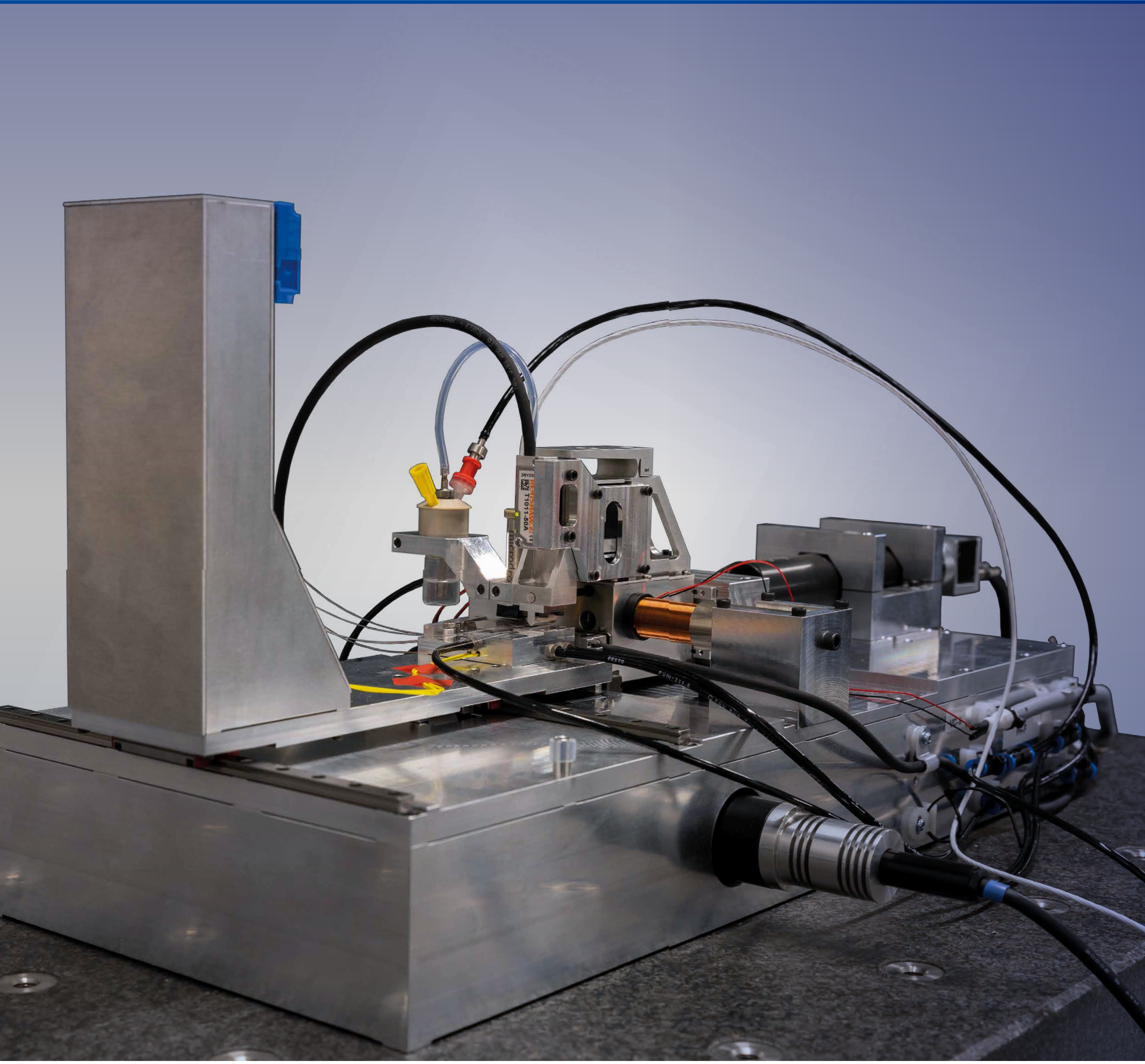

- THEME: PRECISION MECHATRONICS
- AUTOMATED SUB-MICRON-ACCURATE OPTICAL FIBRE ALIGNMENT
- DSPE CONFERENCE 2021 PREVIEW
- LIFELONG OPTICS LEARNING

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The cover image (featuring a fibre-array assembly machine) is courtesy of Matthijs van Gastel. Read the article on page 5 ff.

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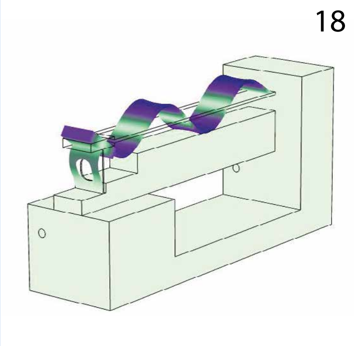

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SYSTEMS ENGINEERING AS THE DRIVER FOR CONTINUOUS GROWTH

The Brainport region continues its growth, also during a global pandemic. With around five big OEMs, a strong supply chain, and a successful start-up and scale-up climate, we're able to create new products and ventures, make the most complex systems, and pick up new challenges every day. This success is based on a strong fundament in systems engineering and a secret sauce, which I call social innovation.

One thing Brainport has learned, also from transitions in the past, is the ease with which we can find and strengthen each other. That's also something that makes us unique, that's part of our culture, and can't be copied. It's the grease in our systems engineering approach, by which we can make the most complex systems together. That's also why we call Brainport the Champions League of Technology and Innovation.

Nowadays, challenges need a systems engineering approach; they can't be solved alone anymore, we need to perform together, regionally as well as globally. Challenges like climate change, the need for new mobility and the Dutch nitrogen crisis require this systems engineering approach more than ever, and thus Brainport is the place to create the new future.

Although we are the champions in systems engineering, I strongly believe we continuously need to learn more, stay open for different views and keep building on our strengths. This is why we took the initiative in 2019 for a business trip to key centres in systems engineering in North America: Waterloo University, MIT and Stevens Institute of Technology. For this initiative, Brainport Development, HTSC, TU/e, VDL ETG, TNO-ESI and Holland Innovative joined forces.

Thanks to the strength of our network (Holland Innovative's scientific director Jeroen de Mast is also a professor at Waterloo University), the invitation was quickly organised and our main OEMs were connected to the initiative. This was crucial, as they have achieved the competitive systems engineering position of the region. We can build on their strong shoulders and become even stronger by the possibility to jointly work on the most complex challenges. You only can learn and develop if you get the opportunity to work and play in this champions league.

The initiative has already resulted in a stronger focus as well as the awareness that a systems engineering approach is necessary. We opened up the initiative to all stakeholders in the ecosystem, from educational institutions to the industry (with an important role for SMEs) and government agencies. In the long term, the results will also improve the competitive position of Brainport and the Netherlands.

The main focus is on strengthening our knowledge around systems engineering in a sustainable way in education as well as in lifelong learning. We focus on the educational process through challenge-based learning, sharing of cases, and talent development in general. This way, we expect to attract more new employees from abroad in order to not only fill the gap in the human capital need for our projects but also to achieve the diversity mix that is needed to solve all our complex challenges. We know we have to bring together knowledge from all over the world; this initiative is to organise the blind spots as well as our strengths and facilitate the career paths of talents.

As I said, social innovation is the grease that's needed to become agile and develop our leadership and social skills. That's why I'd like to invite everyone to work on this part: build your network, have a balance with activities besides your corporate projects, and use initiatives like our "Drinks, Pitches & Demos" to connect to others, practice your pitching capabilities, and share insights. It enriches you as a professional – and moreover, it's fun!

Hans Meeske
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PRECISION FOR PHOTONICS

The adoption of photonic chips is currently held back by the considerable cost involved in their production. In particular, optical fibre alignment and fixation have been a bottleneck in terms of product performance, cost and production volume. A new optical fibre array has been developed to couple multiple fibres to a photonic device with sub-micrometer accuracy. To assemble this fibre array in an automated manner, a fibre-array assembly machine has been designed and realised. This machine is able to assemble a 16-fibre array within four minutes with a 100 nm alignment accuracy, which is both significantly faster and more accurate than currently employed methods can achieve.

MATTHIJS VAN GASTEL

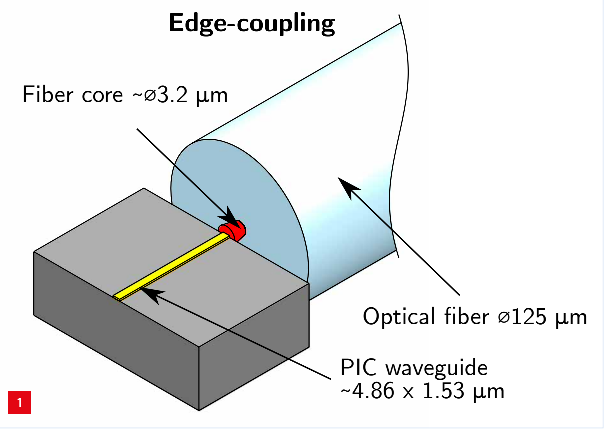
In today's society, the need for data transmission is growing exponentially. Photonic chips show great potential for energy-efficient data transmission with high bandwidth. These chips rely on information transfer based on light as opposed to electrons in the conventional electronic chips.

Photonic chips enable many new applications such as sensors for autonomous driving cars or new medical imaging techniques. An increasingly important issue for enabling large-scale adoption of photonic chips is their assembly and packaging. These processes are currently estimated to account for more than 50 percent of the total cost of a photonic device.

Especially the coupling of optical fibres, which are used to guide light in and out of the photonic device, is critical as they require sub-micrometer alignment. Current fibre alignment methods can either not cope with these alignment requirements or are not suitable for large-scale production. Furthermore, current methods are often labour-intensive and time-consuming.

Current methods

A typical optical fibre is composed of a very thin strand of silica glass with a diameter of 125 μm. The silica glass strand consists of two parts with a different refractive index to enable light guiding: the core and a surrounding cladding. A core as small as Ø 2-10 μm is embedded in the middle of the fibre. This core guides the light, and the surrounding cladding material with a slightly lower refractive index confines the light within this core. To couple light in and out of a photonic chip, the fibre core needs to be aligned with respect to the coupling channels or waveguides present on the chip's side. Figure 1 shows a schematic representation of a fibre-chip coupling. Since a typical photonic waveguide is small (~1-5 μm), a precise fibre alignment is required to ensure efficient operation of the optical components. Especially the alignment in a lateral direction is critical, with a desired alignment accuracy of typically < 200 nm.



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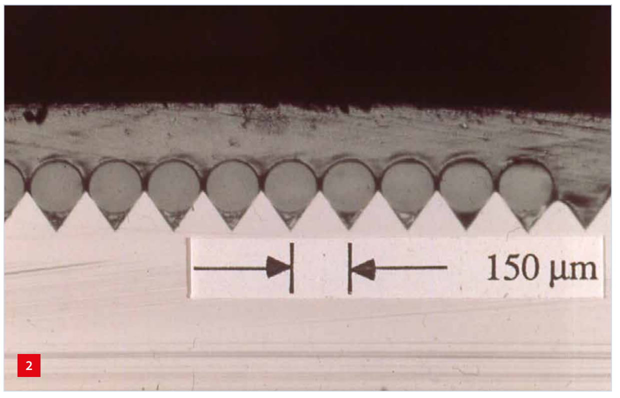
Schematic rendering of a fibre-to-waveguide-edge coupling.

Nowadays, V-groove fibre arrays are typically used for multi-fibre alignment. Figure 2 shows an example of such a V-groove array. For these arrays, multiple optical fibres are placed into V-grooves that determine the position of the fibres with respect to each other. After the assembly of a fibre array, it can be aligned with respect to the waveguides of a photonic device. A major downside of these arrays is the inability to compensate for the manufacturing tolerances of optical fibres and the V-groove array itself, typically resulting in lateral alignment errors of > 2 μm.



2

Passive alignment using a V-groove fibre array.

AUTHOR'S NOTE

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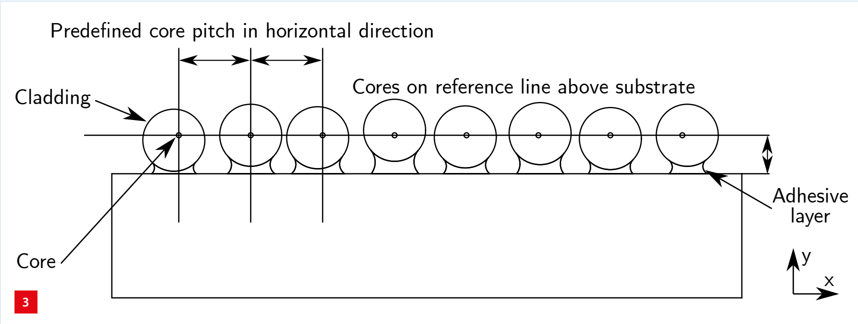


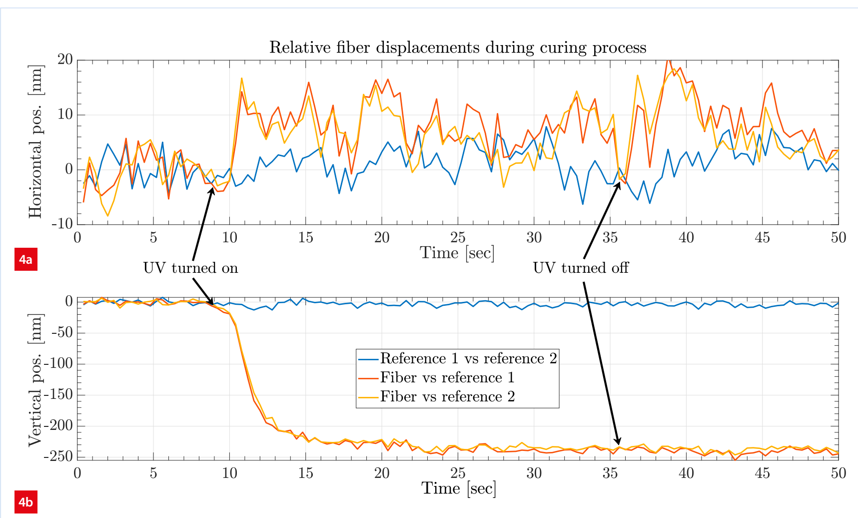
The proposed concept of the optical fibre array.

Active alignment methods that use optical feedback to optimise the waveguide alignment are able to compensate manufacturing tolerances of the fibre, enabling sub-micron-accurate alignment. Current active alignment methods, however, are time-consuming, with alignment times of multiple minutes per single fibre connection, and are therefore expensive and not suitable for volume production.

Optical fibre array concept

The main challenge to obtain a low-loss coupling for photonic devices is to overcome the accuracy bottleneck due to the manufacturing tolerances of the individual fibres. In the proposed concept the alignment is split up into two steps. First, a fibre array is assembled with a mutual lateral alignment accuracy of < 0.1 μm between the fibre cores. Later on, this fibre array is assembled in one step to the photonic chip. Since this step is not within the scope of this research, it will not be discussed further. A perfect alignment of the channels/waveguides on the photonic chip is assumed since these chips are made using a lithographic process. In reality, some small chip warpage is present due to the dicing process.

With our decoupled approach we eliminate the risk of having to discard an entire chip when a single fibre alignment has failed. Additionally, this allows for dedicated assembly equipment, resulting in faster and more economical production.



Measured fibre displacements during the adhesive curing process. The displacements are shown relative to fixated reference fibres.
(a) Horizontal (lateral) direction.
(b) Vertical direction.

The array, shown in Figure 3, consists of multiple fibres, which are fixated to a flat quartz carrier substrate using UV-curable adhesive. Each fibre is individually actively aligned with respect to the already fixated fibres using a high-precision manipulator before curing. The adhesive layers are used to overcome differences in manufacturing tolerances of the fibres. During the alignment process the cores of the fibres are positioned so that there is no variation in the vertical direction on a horizontal line above the substrate and with a predefined pitch in horizontal direction. By using an adhesive as fixation method, the achievable distance between the fibres can be kept to a minimum since the adhesive only needs to be present on a small portion of the fibre diameter. The usage of a simple flat carrier without the need for any electrical connections or mechanical adjustments results in a cost-effective solution, where the number and pitch of the fibres can easily be varied for specific chip designs.

Adhesive fixation

Adhesives are prone to shrinkage due to curing, which can disturb the fibre alignment. As a result, not the alignment process itself but rather the fixation process forms the bottleneck in reaching the required sub-micron alignment. Simulations and experiments have been performed to investigate the shrinkage-induced fibre displacement for multiple selected types of adhesives. Figure 4 shows the typical fibre displacement due to adhesive shrinkage during the curing process. This figure presents the displacement of the fibre to be cured relative to the two reference fibres that are already fixated. When the UV-curing head is turned on, a clear vertical displacement is observed while simultaneously negligible horizontal drift is observed.

Capillary action results in the formation of a symmetrical bond profile around the fibre when the fibre is brought into contact with the adhesive, which explains the negligible observed horizontal drift.

To measure the shrinkage of selected adhesives, the fibre-to-substrate distance (indicated in Figure 5a) was varied between 1 and 3 μm. This range is sufficient to overcome the most typical fibre tolerances. Larger adhesive layer thicknesses are unfavourable due to a lower bond stiffness and an increased sensitivity for temperature-induced displacements. Figure 5b shows the results of one of the selected adhesives. A negative linear trend can be observed for the shrinkage as a function of the fibre-substrate distance in the examined range of 1 to 3 μm.

FRAGILE AND COOL

A novel design of a retractable imaging device that is able to facilitate a fragile image sensor has been developed. Two major design challenges characterise this design project. Firstly, the designing of a statically determined support for the fragile image sensor that ensures a low thermal resistance to meet the strict cooling requirements. Secondly, designing a non-overdetermined linear retraction mechanism with appropriate pretension and without collision forces at the end of its stroke.

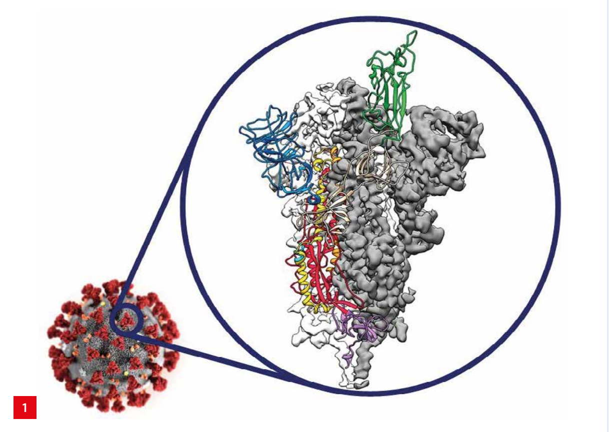
TEUN VAN DE SANDE

Imaging devices are used for capturing samples within, for example, structural biological or fundamental material research. Prodrive Technologies develops and manufactures such imaging devices. Figure 1 shows an example of the importance of the project described here. On the left, the Covid-19 virus is shown with its red crowns on top, depicting the S-proteins. On the right, a 3D reconstruction of an S-protein is shown, which was generated from approximately 3,000 images that were captured by such an imaging device.

The image sensor considered here is highly fragile, and should be able to withstand extreme temperature differences and thermal cycles while operating in a vacuum environment. Therefore, this sensor requires proper support. Furthermore, the imaging device should be able to insert and retract the image sensor with high repeatability.

Two major design challenges

A system decomposition resulted in two major design challenges to solve. Firstly, designing a statically determined support of the fragile sensor, including its strict requirements on cooling. Secondly, designing a high-precision linear retraction mechanism with a well-defined pretension and without end-of-stroke collision forces.



1

A 3D reconstruction of the S-protein of the Covid-19 virus, which was generated from approximately 3,000 images captured by an imaging device [1] [2].

For confidentiality reasons, no further details on the design challenge and the specifications can be provided.

Figure 2 shows a simplified schematic section view of the proposed imaging device. The outer dimensions of the device are 200 mm x 150 mm x 75 mm (*x*, *y*, *z*). The image sensor is attached to a carrier and located in a vacuum environment. A vacuum bellow is used to separate the vacuum from atmospheric pressure. One end of the bellow is connected to the interface flange, which is the fixed world. The other end is closed by the bellow flange. As a result, only a minimal number of components is located in the vacuum, which minimises potential outgassing inside the vacuum environment.

Stress-free support of the image sensor

Minimising deformation during thermal cycling is critical in enhancing the lifetime of the imaging sensor, as this sensor is highly fragile. The induced stress can be minimised by choosing the right material. The image sensor is attached to a carrier with a comparable coefficient of thermal expansion (CTE) value. As the CTE values of both materials are comparable, low relative thermal deformation between the sensor and its carrier will occur. Moreover, the sensor's printed circuit board assembly (PCBA) is thermally decoupled from this carrier.

The carrier is attached to a heatsink that absorbs the dissipated heat. The extreme temperature changes require a stress-free and statically determined mounting of the carrier to the heatsink. Having thermal interface material between the heatsink and carrier ensures low thermal resistance, while allowing stress-free movement of the sensor and carrier.

Figure 3 shows this attachment. Three slotted holes in the carrier construct a thermal centre at the centre of the image sensor, which minimises thermal stresses and pixel movement at the same time. The thermal centre is indicated by the crossing of the dashed lines. The sensor's PCBA contains a flexible part to prevent constraining any degree

AUTHOR'S NOTE

Teun van de Sande graduated in mechanical engineering from the Eindhoven University of Technology (NL). For his master thesis work, supervised by Nick Rosielle, he received the Wim van der Hoek Award 2020. Currently, he is working as a mechanical system architect at Prodrive Technologies in Son (NL). The author acknowledges the support of Ron Hendrix of Prodrive Technologies.

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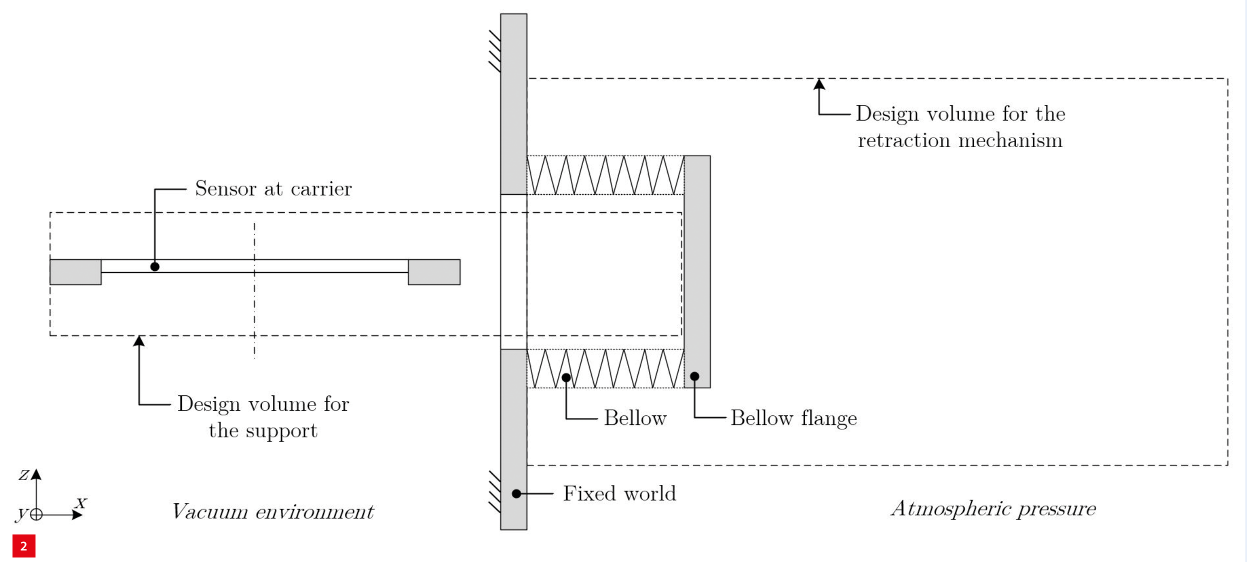


2

Schematic section view of the proposed imaging device, including the design volumes for the two major design challenges: sensor support and retraction mechanism.

of freedom (DoF) of the sensor assembly. In this way, the position of the sensor assembly is only defined by the support. Compared to, for example, a flexure mechanism for creating a thermal centre, this is a compact and robust design that eases assembly and manufacturability.

The support has a constant temperature during operation, which means that thermal deformation of the support can be considered negligible. Therefore, it is acceptable that the mechanical and thermal paths are not entirely uncoupled within this part.

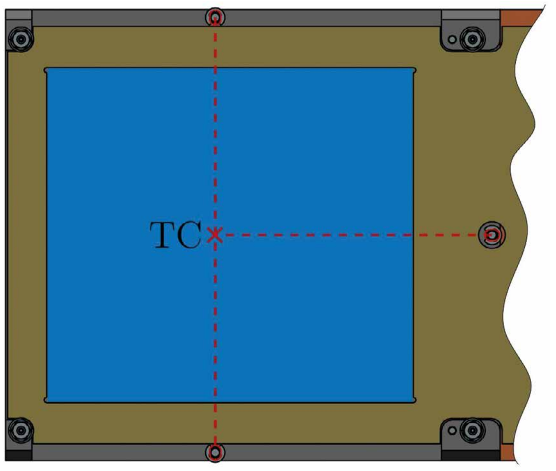
Statically determined linear guide

Preferably, the motion path is defined mechanically to ensure no collision will occur during the movement. The stroke in x-direction is approximately 100 mm. Moreover, the bellow flange should be supported close to the interface flange at the inserted position to acquire considerable stiffness and to achieve the required repeatability. Figure 4a shows a typical guidance concept based on two conventional linear bearings, preloaded using preload screws. However, this preloading method will establish a form-closed construction, in which misalignment or wear can affect the preloading. This could result in unpredictable preloading with variations over the stroke (or over time), which negatively affects the dynamic behaviour in the inserted position. Moreover, this preloading method could be disadvantageous for thermal behaviour, as the sideways alignment is defined at the left linear bearing instead of at the mid-plane.

The linear bearings are constraining five DoFs each, which is considerably over-constrained. The degree of over-constraint should be diminished by strict manufacturing tolerances. Moreover, this linear guide will over-constrain the bellow as well. The bellow constrains one DoF, namely the rotation R_x around the direction of motion.

Over-constraint is not preferred as it induces internal stresses, which could negatively affect repeatability and result in damage in the long term. The linear guide as proposed in Figure 4b does not have these drawbacks, since it only constrains four DoFs (y, z, R_y, R_z) by pointing crowned track rollers towards the centre of the bellow.

Figure 5 shows the proposed design of the linear guide in an isometric view. The sensor assembly is mounted to a carriage that is guided on the frame plates using two sets of steel rollers, which are mounted to the left and the right side of the carriage. A set of rollers consists of two main track rollers at the bottom and one preloading track roller at the top. The preloading track roller is – viewed from above, along the z-axis – centred between both main track rollers.



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Top view of the cooling assembly. The crossing of the dashed lines indicates the thermal centre.