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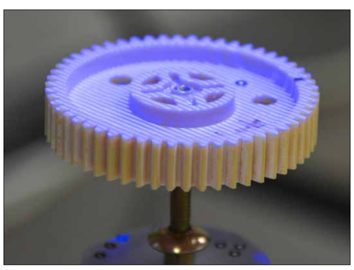

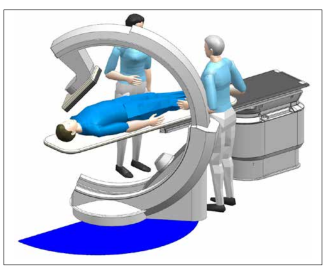

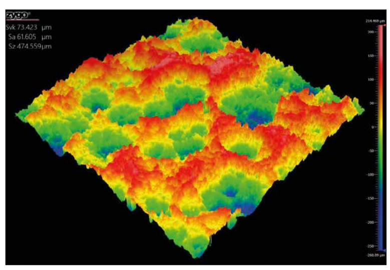

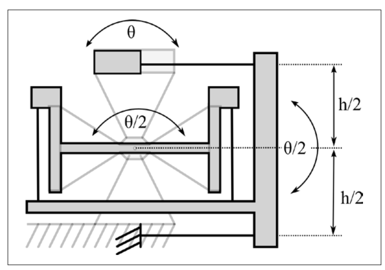

- THEME: ENERGY (MICRO & MACRO)
- NOVEL INTERVENTIONAL X-RAY SYSTEM ARCHITECTURES
- 2019 PRECISION FAIR IMPRESSIONS
- MULTIPLE-NOZZLE RECOATER

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The main cover photo (by Thomas Tolstrup, featuring solar collectors) is courtesy of Heliac.
Read the article on page 8 ff.

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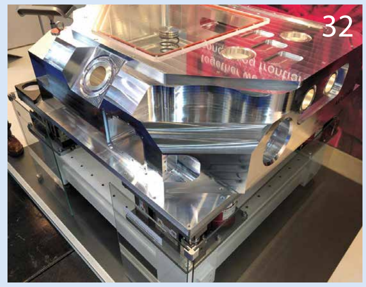

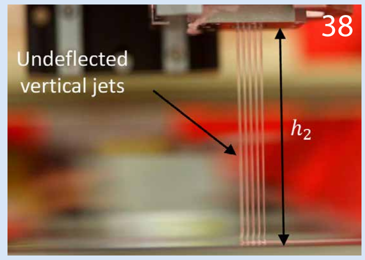

FEATURES

SAVING ENERGY, SECURING PRECISION

Precision engineering and today's energy challenges related to climate change and limited material resource availability appear to be unrelated. But think one level deeper. Over the last centuries, mankind has been able to generate valuable products in smaller and smaller dimensions. Large windmills and boats became steam engines and then petrol engines made with millimeter precision. Products made by craftsmen became mass-produced items. In these products, every component has to have accurate dimensions to be exchangeable with other components and to fit in any other part with micrometer precision. Today, we produce valuable products with nanometer precision. We are even able to process food using 3D printers with microlitre-precision dosing of ingredients, after eons of bulk production of food the size of decilitres on your daily plate.

The basic reason behind this trend is that on a general level the cost of a product is related to the amount of material required to build that product. If one writes off the design costs in three years and the manufacturing equipment costs in seven years, the only remaining costs are those of the material and the logistics of handling. If you make the products smaller and smaller, they will become cheaper. Once you make them smaller, however, precision aspects become more important.

We expect this trend to accelerate. Where the fourth industrial revolution is about digitalisation, the fifth will be about sustainability. CO_2 costs today are at a level of 30 euro/ton, i.e. 3 eurocent/kg. Realistic price levels will look more like 10 eurocent/kg, and it is possible that they will reach 300 euro/ton or 30 eurocent/kg. Petrol taxes today are already 1 euro/litre, so why should CO_2 waste costs be so low? If CO_2 costs increase to the level of 10 eurocent/kg or more, the use of new materials will become significantly more expensive, as mining and processing involve a lot of CO_2 emissions. The costs of these will add up to the cost price of materials. More refurbishment and recycling, etc., will be the first simple steps in avoiding these increasing costs, but shrinking the size of a product to a smaller dimension ultimately reduces the amount, and therefore the costs, of the materials required.

It can be expected that future products will be designed with minimal material usage. This might result, in motion systems for example, in less weight and less required energy. As stated above, however, think deeper: less material might result in less stiffness, whereas the same positioning precision will still be needed. A smarter digitalised solution might help, but one way or another precision engineering skills will be necessary for finding the proper solutions with fewer materials. Lastly, as an ultimate consequence, precision skills will remain important even during the coming years/decade when a fifth industrial revolution will change our industry once again.

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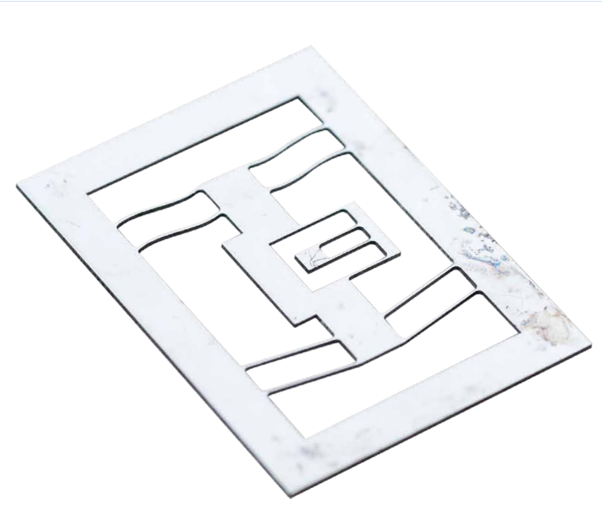
CLASSIFYING MINIATURISED GENERATORS

Although motion energy harvesting at the small scales has been a research topic for over 20 years, the implementation of such generators remains limited in practice. One of the most important contributing factors here is the poor performance of these devices under low-frequency excitation. In this research, a classification of miniaturised generators is proposed based on the dynamics of the nonlinear systems. This provides insight in the performance of different types of designs, which can be used to develop new designs with better efficiencies under realistic conditions.

THIJS BLAD AND NIMA TOLOU



Glossary

- Vibration energy harvester: Device that delivers an electrical output as a result of applied mechanical vibrations.
- Transducer: Part that converts energy from one form to another.
- Piezoelectricity: Electric charge that accumulates in certain solid materials in response to applied mechanical stress.
- Resonance: Phenomenon of amplification that occurs when the frequency of a periodically applied force is close to a natural frequency of a system.
- Bandwidth: Range of frequencies for which a satisfactory performance is obtained.
- Frequency up-converter: Device that incorporates a mechanism that takes a low-frequency input and delivers an output with increased frequency.

AUTHORS' NOTE

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Introduction

Small generators that harness ambient sources of energy can be attractive alternatives to batteries as wireless power supplies for low-power electronic devices. Of all ambient energy sources, kinetic energy in the form of motion or vibration is generally the most versatile and ubiquitous energy source available [1].

Generators that aim to use this source are grouped under the term vibration energy harvesters and have been investigated for over 20 years since the early work of Williams and Yates in 1996 [2], who investigated the piezo-electric, electromagnetic, and electrostatic transduction mechanisms for the purpose of vibration-to-electric energy conversion.

Generally, the power that can be harvested is in the range of micro- to milliwatts and may fluctuate greatly when the ambient motions are constantly changing. However, the expanding number of wireless devices and the great advances in their power consumption are continuously increasing the interest in the field of energy harvesting.

The most attractive applications are found in environments where battery replacement is expensive, inconvenient and/or prohibited by regulations. Examples of such applications are medical implants such as pacemakers, or wireless sensor networks composed of many small sensor nodes that can be used for the monitoring of structural health in buildings or for the tracking of goods.

In many of these applications it is reasonable to assume future power requirements in the order of a few microwatts. Given that a buffer is used to deal with fluctuations in generated power, this is certainly within reach for energy harvesters of modest sizes in many realistic vibration environments. In the case of the pacemaker, it was already demonstrated in vivo [3] that relevant amounts of energy can be harvested from the motion of the heart itself.

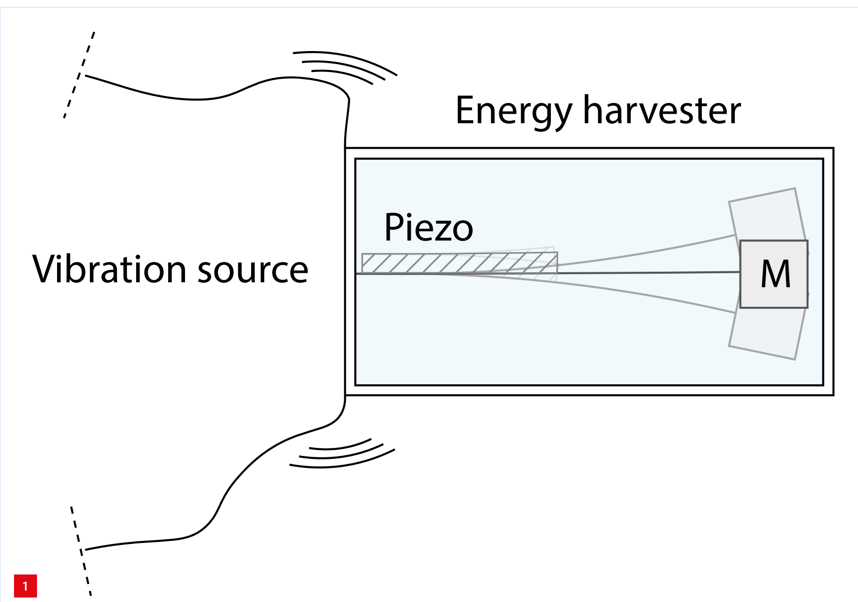
Working principles

Powering these devices requires the transformation of virtually useless energy from an ambient source into useful electric power. For this transformation two things are fundamentally required: an ambient source with a relevant amount of available energy and a device that can facilitate this transformation with a relevant efficiency.

The basic working principle of the vibration energy harvester shown in Figure 1 is as follows. The housing of the generator is mounted on a vibration source. Inside the generator is a suspended inertial element (proof mass) that moves relative to the housing as a result of the applied motion. This relative motion results in an electrical power output due to a transducer such as a piezoelectric material.

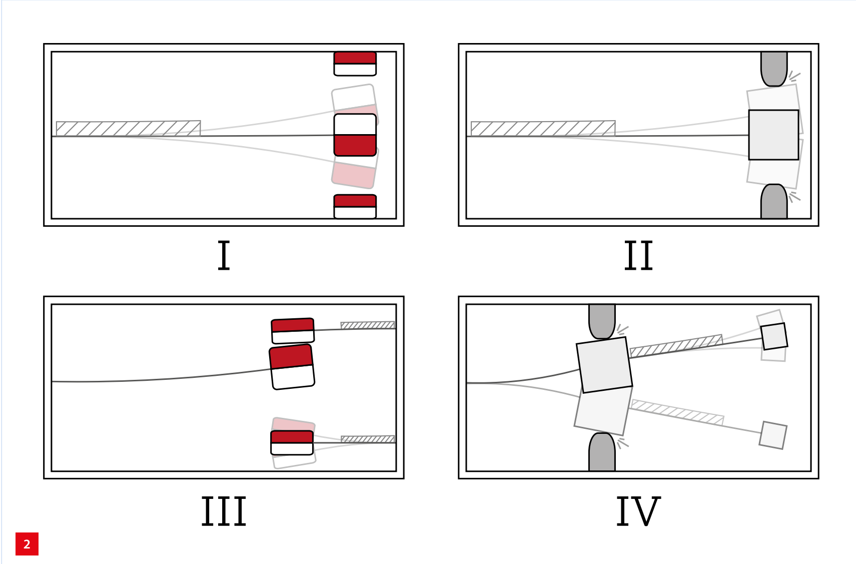
Relevant parameters for the maximum power output are the dimensions and mass of the generator as well as the frequencies and accelerations of the applied vibrations. Furthermore, the actual power output is greatly dependent on the dynamic response of the generator to the applied vibrations. In cases where a vibration is applied with a fixed frequency and acceleration, a generator can be designed based on linear models to operate at resonance such that satisfactory power output is ensured. Using this strategy, generators have been reported with efficiencies up to 30% of the theoretical maximum [4].

However, in practical applications the generators will be exposed to vibrations with frequencies and amplitudes that change over time. Although excellent performance was achieved through a resonance-based strategy, the bandwidth over which this performance was found was extremely narrow.



1

General concept of vibration energy harvesting using a piezoelectric transducer; the device is mounted on a vibrating source and generates output power as a result of internal motion.



2

Classification of miniaturised generators under low-frequency excitation.
Single-degree-of-freedom generator:
I) using soft stoppers;
II) using hard stoppers.
Frequency up-converter:
III) using plucking;
IV) using impact.

Therefore, in realistic cases these devices may not deliver the required performance. To overcome this problem, more complex mechanisms with nonlinear elements are being developed and investigated. These mechanisms open up a range of nonlinear dynamics and have the potential to demonstrate relevant power outputs under realistic conditions. However, the design of their dynamic response is vastly more complex compared to the linear case, and as a result, the efficiencies of these types of systems are typically much lower.

Overview

When the size of the energy harvester approaches the amplitude of the applied vibrations (as can be the case with miniaturised generators under low-frequency excitation), the internal motion must be limited. The implementation of the motion limiter is an important design aspect and affects the dynamics of the device. Based on the dynamics found in these systems, the miniaturised nonlinear generators can be classified in the groups shown in Figure 2.

Single-degree-of-freedom generators (I + II)

The first class of nonlinear energy harvesters contains the generators with a single degree of freedom (DoF), which is used directly for the energy conversion. In this class we find two groups of devices: I) those that use soft stoppers, and II) those that use hard stoppers, to limit the internal motion.

WIND, STORAGE, SOLAR, OFFSHORE AND BEYOND

The euspen Special Interest Group meeting on Precision Engineering for Sustainable Energy Systems took place at the University of Strathclyde, Glasgow, UK on 9-10 October 2019. Distinguished delegates from all over the world shared their experiences and ideas to identify areas of improvement for increased production and high-quality renewable energy systems with low costs.

After the welcome speech by euspen's President, Prof. Enrico Savio, University of Padua, Italy, the Principal and Vice-Chancellor of the University of Strathclyde, Prof. Sir Jim McDonald addressed the importance of precision engineering for renewable energy systems and expressed his desire to take the message from the SIG meeting to the Scottish and UK government in his role as President of the UK Royal Academy of Engineering and co-chair of the Scottish Government's Energy Advisory Board.
Dr. Marieke Beckmann from National Physical Laboratory, UK presented the urgent need for renewable energy systems to address social and economic challenges. She also highlighted the need for advanced metrology systems in the development of renewable energy systems across wind, solar, wave, etc.

Presentations

The two-day programme of six lecture sessions, a poster session and a commercial session provided a rich mix in four broad categories: Wind, Storage, Solar, Offshore and beyond. With growing concern about the necessity of green energy, the programme was strongly focused on the barriers, technological improvements and future challenges for these renewable energy systems.

Wind

The first session started with a discussion of trends by Prof. W.E. Leithead of the University of Strathclyde. Wind energy faces challenges including reliability, high cost, maintenance, etc. Despite these challenges, energy bodies over the world have set their future development goals in the wind sector. Prof. Alex Slocum, MIT, USA addressed the importance of total design for future wind energy systems.

A Competence Center for Wind energy (CCW) was presented by Prof. Frank Härtig, PTB, the National Metrology Institute of Germany. The centre comprises three major sections. It can accurately measure the 3D geometries of large components with diameters up to 4 m. The wind tunnel allows to generate homogeneous wind fields with speeds in the range of 1-30 m/s. Finally, the torque measuring unit can measure torques up to 5 MN·m and hopefully the range up can be extended to 20 MN·m in future. The talk highlighted the importance of applying digital technology based on measured big data for future wind energy systems, as well as the need of unifying the definition of digital twin in this field.

1

Heliac from Denmark has developed an extremely efficient solar collector based on the large-area precision manufacturing of light-guiding polymer Fresnel lenses on glass. (Photos: Thomas Tolstrup, Heliac)

EDITORIAL NOTE

This event report was contributed by euspen (European Society for Precision Engineering and Nanotechnology).

www.euspen.eu

Wind turbine hub precision manufacturing with a mobile CNC machine was presented by Alessandro Checchi of the Technical University of Denmark (DTU). The prototype of a mobile CNC machine with enhanced manufacturing capabilities was designed and implemented. The design models' validations show good agreement. Enhanced reliability of wind energy systems requires better quality assurance by traceable metrology for large drivetrain components. For this, Dr. Harald Bosse of PTB introduced some novel measurement standards.

Storage

In this session, several energy storage methods were introduced: pumped hydro, gravity and electrolyser. Prof. Maximilian Fleischer, chief key expert from Siemens, explained how power generation and consumption are mismatched today due to residual loads. Economical usage of this excess energy from renewables is important where the storage technologies can play an important role to solve this problem. A pumped hydro power plant can be an effective storage solution.

Cheng Cheng, from the Australian National University, focused on the potential of off-river pumped hydro systems with 100% renewable energy, which can be the lowest-cost energy storage system. About 616,000 possible off-river sites (between 60° North and 56° South latitude) over the world have already been identified.

On the other hand, chemical storage systems such as proton-exchange membrane (PEM) electrolysers can be alternative solutions because of their reduced size. Dr. Arend de Groot of TNO, the Netherlands discussed the supply chain development for PEM electrolysers. Finally, Miles Franklin of Gravitricity, UK presented a storage system based on gravity. They are developing this technology, which can be very effective for small-range application.

Solar

Solar is one of the important sources of renewable energy and the technology is now well developed and reliable. Prof. Tapas Mallick of the University of Exeter, UK discussed the challenges, opportunities and integration of solar energy technologies.

Dr. Henrik Pranov of Heliac, Denmark presented large-area precision manufacturing of light-guiding lenses for solar heat (Figure 1). These polymer Fresnel lenses on glass were tested at DTU and proved to constitute extremely efficient solar collectors. They deliver heat at the same cost as natural gas. Pranov also demonstrated a rock-based system to store solar or excess process heat where the charging and discharging takes place by condensation or evaporation, respectively.

Prof. Liam Blunt from the University of Huddersfield, UK presented the roll-to-roll production and in-process metrology for thin-film photovoltaics carried out in the EU-funded NanoMend project. He reported initial measurements taken on prototype films and the correlation of water vapour transmission with defect density, and also described an in-process, high-speed, environmentally robust optical interferometer instrument developed to detect defects on the polymer film during manufacture.

Offshore and beyond

Prof. Alex Slocum of MIT talked about energy harvesting and storage-system-stabilised offshore wind turbines. He presented a symbiotic energy harvesting idea to lower the cost where the offshore wind turbine structure supports the wave and hydro energy systems. The main challenge to this symbiotic system is the weight restriction. Dr. Zhiming Yuan of the University of Strathclyde presented several offshore renewable energy hybrid models. Integration can yield a platform that can serve multiple purposes including water breaking and aquaculture. His colleague Dr. David Butler discussed manufacturing challenges for lifetime extension of renewable energy systems, through refurbishing or remanufacturing of system parts. And Dr. Cameron Johnstone from the same university nicely wrapped up the meeting with an update of wave and tidal energy development.

Conclusion

The two-day programme generated a variety of discussions on the status, challenges and opportunities for renewable energy systems. They are becoming matured with a huge amount of ongoing research and developments. Overall, the SIG meeting was successful and inspiring. All the delegates felt the same as Prof. Alex Slocum (Figure 2) wished, "we are all responsible for the canvas of life – we can work together to create a beautiful future for the planet and all its lifeforms."

Prof. Alex Slocum, MIT: "We are all responsible for the canvas of life – we can work together to create a beautiful future for the planet and all its lifeforms."

ADVANCED METROLOGY FOR ENERGY EFFICIENCY

Lightweighting is a priority for automotive OEMs in their quest to adhere to exacting engine efficiency and emission guidelines. More and more, massive iron engines and components are replaced with aluminium and lightweight alloys that match the strength of iron without the negative weight implications. Cutting-edge optical metrology tools can facilitate the manufacture of lightweighted engine components.

MICHAEL SCHMIDT

There have been many initiatives in recent years aimed at reducing vehicle emissions and increasing overall efficiency. This has required the automotive sector to focus enormous resources on optimising engine performance. Be it due to concerns over climate change or insulating economies against the vagaries of fuel costs and possible fuel shortages; the race is on to make vehicles considerably more efficient while at the same time maintaining a level of required functionality and attractiveness to stimulate sales and profitability.

Thermal barrier coatings

Focusing on efficiency, automotive OEMs are looking to reduce weight and at the same time, enhance the efficiency of engine performance. One area of focus in line with these goals is the replacement of cast-iron cylinder liners used in aluminium cylinder blocks with more thermally efficient and lighter-weight materials. Various viable alternative materials and solutions exist that must be wear- and scuff-resistant as well as having a low friction coefficient, one such being thermal barrier coatings (TBCs).

TBCs are the choice for many automotive OEMs today, effectively, coating the cast aluminium block bores with a spray of wear-resistant, ceramic or composite material. This material will harden to form a much thinner surface – relative to a liner – in the aluminium cylinder. To date, the most commercially viable of these are being applied through the use of the plasma spray process, which yields superior wear resistance compared to iron, enabling aluminium alloy engines to utilise robust tribological materials within the harsh environments of combustion chambers.

However, there are also some inherent issues with the spray-coating process that require the implementation of rigorous quality management procedures and measuring protocols. For example, at the high velocity with which the coating is applied to the cylinder wall, a splatter morphology occurs, leading to possible inconsistent coating.

Surface metrology

Properties of the coating such as porosity, micro-hardness, thickness, adhesion, and strength are essential metrics in assessing its viability and provide important tools for evaluating which process parameters need to be changed to achieve an optimum coating [1].

The non-deterministic porosity distribution across the surface of the cylinder after spraying requires the use of a metrology technology that is able to reliably, repeatably and accurately measure the three phases required to produce a finished lined cylinder:
- mechanical activation;
- thermal spray application;
- post-spray finishing.

Any metrology solution used to assess the surface characteristics of a spray-lined cylinder must be able to make highly accurate measurements at all three of the phases of the process, each stage transitioning from extremely rough to very smooth. This dynamic range of surface textures requires a metrology solution such as the one developed by Zygo using its coherence scanning interferometry (CSI) technology (see the box). CSI can capture data pertaining to a vast array of surface heights and textures and is used in Zygo's range of 3D optical profilers.

3D optical profilers

CSI extends interferometric techniques to surfaces that are complex in terms of roughness, steps, discontinuities, and structure. Additional benefits include the equivalent of autofocus at every point in the field of view and suppression of spurious interference from scattered light.
CSI technology is at the heart of all Zygo's 3D optical

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CSI: coherence scanning interferometry explained

CSI uses the principle of optical interference to compare a part that needs to be measured to a 'perfect' reference surface; Figure 1 shows a typical set-up. Interferometry divides a light source into two paths and compares the light reflected from a test surface to light reflected from a reference surface. The two reflections combine at a detector where they interfere with each other, and a pattern of light and dark intensities is created. That interference pattern represents the surface topography of the test surface

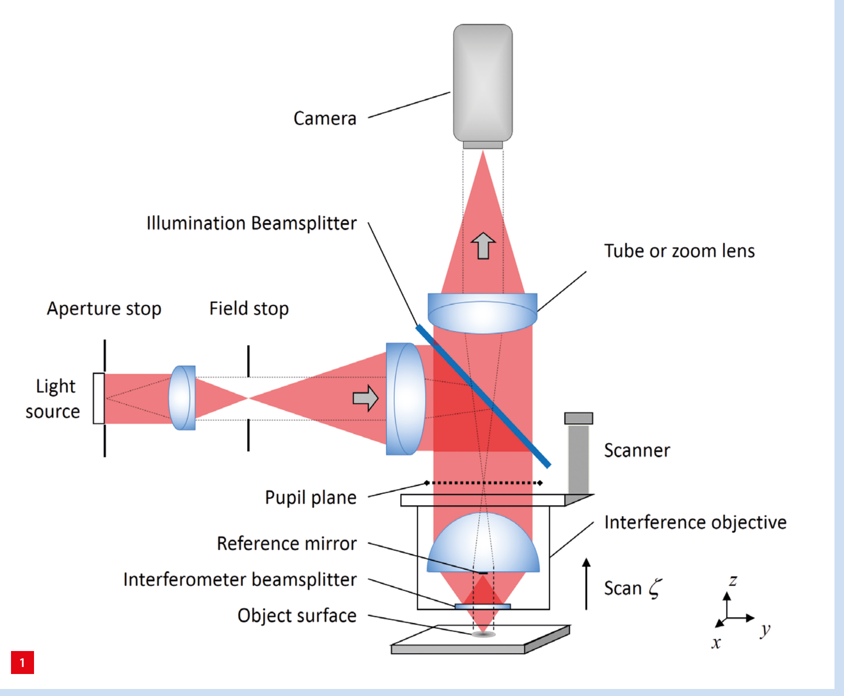
In the system, light comes from an illuminator based on white LEDs. That light travels through illumination optics to the objective. The objectives in Zygo's optical profilers not only provide magnification like a regular light microscope, but they also contain the reference surface. This makes them an interferometer, or an interferometric objective.

The objective has a beam splitter which divides the incoming light into two paths: a test path which goes to the part being measured, and a reference path which goes to the perfect mirror. When the distance between the beam splitter and the reference surface is the same as the distance between the beam splitter and the test surface, the light that is reflected off of these two surfaces will interfere, creating a series of alternating light and dark called an interference signal.

The interference signal only happens when the test and reference legs of the interferometer have the same length, so if one of those lengths is changed, complex topography can be explored. This is called scanning, and it is done by moving the entire objective perpendicular to the test part.

The interference signal is imaged onto a camera and each pixel processes the signal it sees to produce its own height value, and then all the heights for all the pixels are combined to create a map for the surface being tested.

Because CSI uses white light, the interference signal is localised, which means that it only happens when the test and reference legs are the same length. Because of this, surfaces that are rough or structured with steps or other discontinuities can be measured.



Typical set-up for coherence scanning interferometry; see the text for explanation.

As an all-optical technology, CSI is completely non-contact, and Zygo's CSI instruments can measure virtually any material and texture from rough to smooth, shaped to flat, and opaque to transparent. CSI is also very precise with nanometer or sub-nanometer height precision and a fast, consistent measurement speed (1.9 million pixels in just a few seconds) at all magnifications, unlike other techniques where the height precision and speed depend directly on the magnification.

Comparing confocal scanning microscopy with CSI, both have the ability to stitch multiple images, are characterised by high-magnification, high-resolution imaging, and are suitable for rough and steeply sloped surfaces. However, CSI can in addition be used on super-smooth or optically transparent surfaces, and with CSI measurement speed and instrument precision is independent of objective numerical aperture and magnification. Also, unlike confocal scanning microscopy, CSI is appropriate for low-magnification, large-field-of-view imaging (< 5x).

profilers, delivering sub-nanometer height precision at all magnifications, and analysis of a broader range of surfaces (from rough to super-smooth, including thin films, steep slopes, and large steps) quicker and more precisely than other commercially available technologies. This makes it ideally suited to applications such as the spray-lined cylinder application, which is detailed below.
Alternative technologies, such as fax film, rely on affixing a thin sheet of plastic to the cylinder surface and applying a solvent to soften and conform the sheet to the surface. When removed and sufficiently hardened, it is then manually inspected under a microscope. This method,