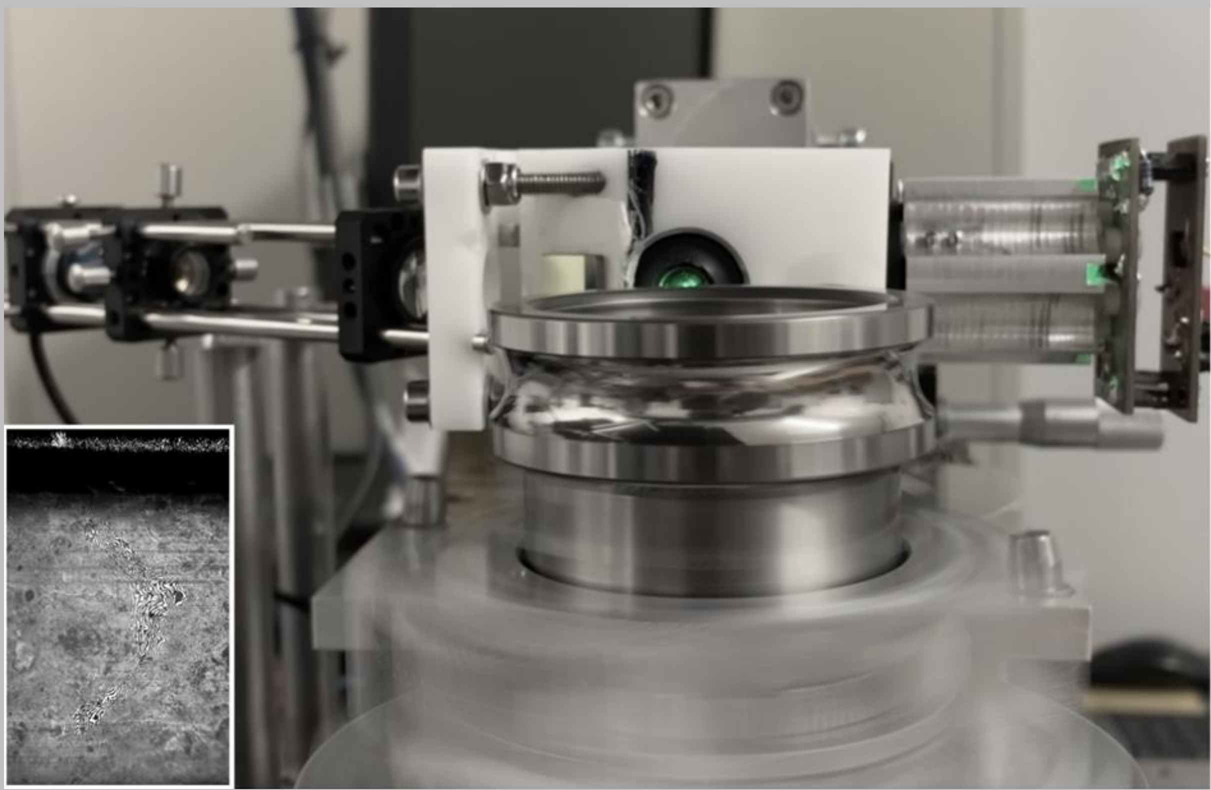
Annual Report

2021/2022



Lateral scanning white light interferometer
recording the topography of a rotating inner ring of a ball bearing

BIMAQ

Bremer Institut für
Messtechnik, Automatisierung
und Qualitätswissenschaft

Content

Content

Preface

Dear friends and partners of the institute!

The Bremen Institute for Metrology, Automation and Quality Science (BIMAQ) of the University of Bremen has successfully continued in mastering the constraints in teaching and research due to the pandemic situation. As in the last year, we provided 100 % of our normal teaching schedule, which means no loss for the students neither in quantity nor in quality. I am extremely thankful for the team behind me for making this possible.

I am also thankful for the continuing support of Deutsche WindGuard GmbH, who donated for the 5th time a student award for young talents. My congratulations to the two awardees in 2021.

The institute is strongly involved in two of the scientific core clusters of the university and the scientific agenda of the federal state, in BEST – Bremen Research Center for Energy Systems, and in MAPEX – Center for Materials and Processes.

As a member in MAPEX, we work on enabling in-process measurements by means of optical measurement principles. In the final third phase of the transregional collaborative research center 'process signatures' digital speckle photography is applied to decipher the material loading condition for different manufacturing processes. As a further example, particle image velocity is used to measure the cooling liquid flow field during grinding, i.e. in a turbulent two-phase flow. The new insights in in-process flow phenomena will contribute to our understanding of cooling, which is crucial for a sustainable manufacturing of parts with no compromises in quality. Last but not least a lateral scanning white-light interferometer was developed for the surface quality inspection on fast rotating objects with sub-micrometer resolution. The achievements will be presented at the general assembly of the well-known International Academy for Production Engineering (CIRP), which is the 4th year in series that a research work from the BIMAQ was selected for presentation at CIRP.

A special highlight for me is the awarding with an ERC Consolidator Grant. Here, I am looking forward to break new grounds with our concept of indirect optical geometry measurement.

And there is so much more to explore in the present annual report about our past and ongoing activities. Before you start to read, let me express my particular thanks to our seminar guests Prof. Rembe from TU Clausthal (laser vibrometry) and Dr. Stemmler from RWTH Aachen (virtual sensors for quality and process controls) for their inspiring talks, and of course all BIMAQ students, colleagues as well as research and industrial partners for their continuous support.

Bremen, June 2022

Andreas Fischer

Prof. Dr.-Ing. habil. Andreas Fischer

BIMAQ - the institute

Vision, topics and infrastructure

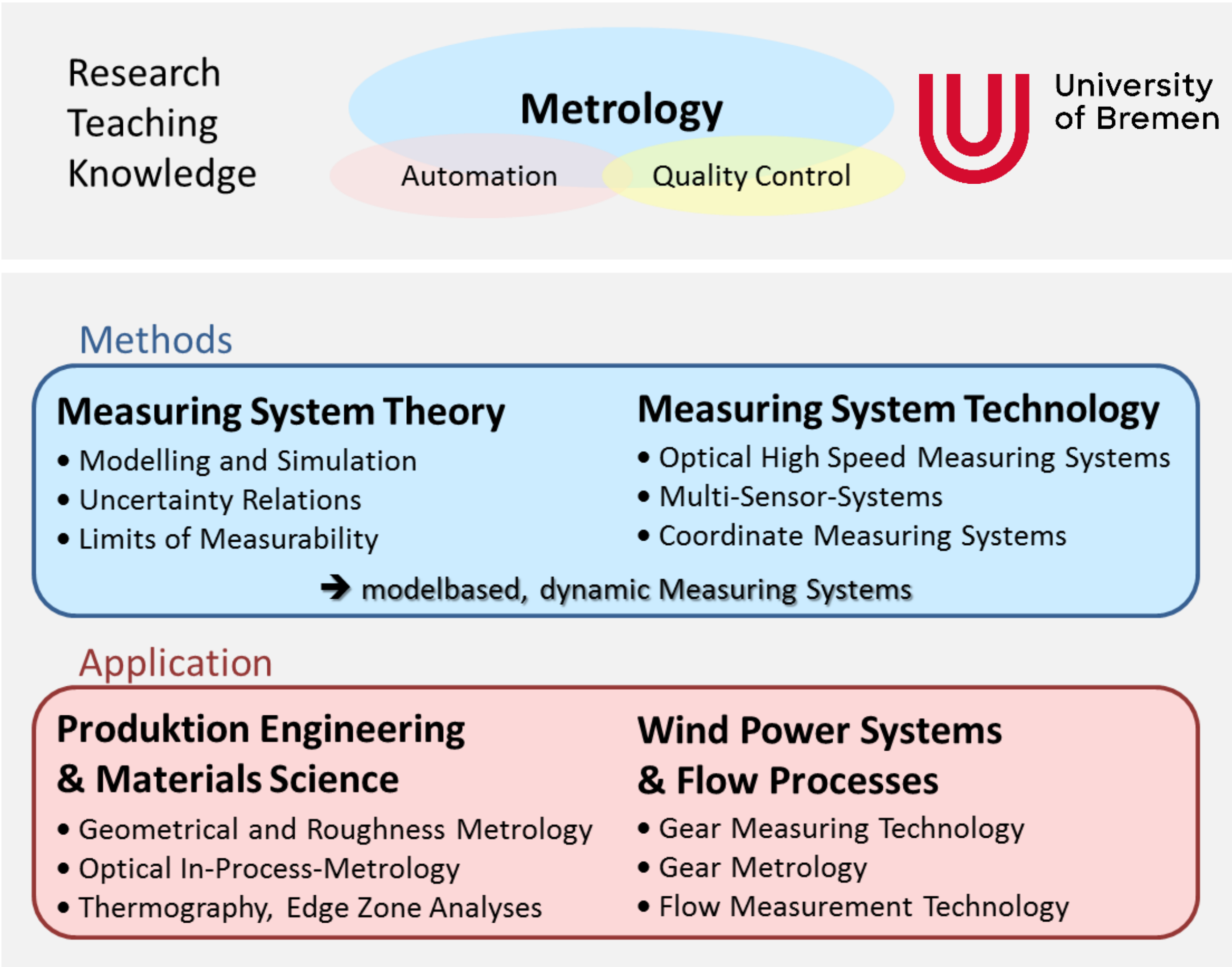
The research focus of the Bremen Institute for Metrology, Automation and Quality Science (BIMAQ) is the holistic investigation of optical measurement systems, which includes the design, realization, modelling, characterization and, finally, the application of novel measurement techniques. By applying a rigorous system-based analysis of the measurement systems, the limits of measurability and the respective uncertainty principles are investigated in order to determine and to surpass the limits of state-of-the-art approaches. Beyond pure measurement tasks, automation aspects and the application of quality controls are investigated as well. However, the core competence of BIMAQ is measurement system engineering, which is a key discipline for solving technical and overall social challenges.

A key challenge is to obtain information in situ or in-process from highly unsteady or complex technical processes. For this purpose, model-based, dynamic measurement systems are a key topic of the BIMAQ research, which includes interdisciplinary fundamental and application-oriented research on the measurement methods and their applications. Current research topics cover tasks from production engineering, materials science, wind energy systems and fluid mechanics.

In addition to methodical innovations for instance based on multi-sensor-system approaches, one highlight at the BIMAQ is a unique laboratory for large gear metrology with a coordinate measurement device for gears up to a few meters. This illustrates the unique BIMAQ expertise regarding the metrology of large gears and geometrical measurements with a high dynamical range. Further laboratories and equipment exist in the BIMAQ main building and the BIMAQ technical center, for instance for the analysis of the surface topography and strain down to the nanometre scale, for thermographic flow analyses from long distances of several hundred meters and for laser-based flow measurements in optically non-cooperative fluids.

BIMAQ

Bremen Institute for Metrology, Automation and Quality Science



BIMAQ competences

BIMAQ - the institute

Staff

Director

Prof. Dr.-Ing. habil. Andreas ***Fischer***

Emeritus

Prof. Dr.-Ing. Gert ***Goch***

Administration

Eva ***Schultze***

Anja ***Jacoby***

Research Scientists

M. Sc. Gert ***Behrends***

M. Sc. Björn ***Espenhahn***

Dr.-Ing. Axel von ***Freyberg***

M. Sc. Daniel ***Gleichauf***

Dipl.-Ing. Paula ***Helming***

M. Sc. Friederike ***Jensen***

Dr.-Ing. Merlin ***Mikulewitsch***

Dipl.-Ing. Felix ***Oehme***

M. Sc. Ann-Marie ***Parrey***

M. Sc. Marc ***Pillarz***

M. Sc. Yannik ***Schädler***

M. Sc. León ***Schweickhardt***

Dipl.-Ing. Michael ***Sorg***

Dr.-Ing. Dirk ***Stöbener***

Dr.-Ing. Andreas ***Tausendfreund***

M. Sc. Marina ***Terlau***

Dr.-Ing. Christoph ***Vanselow***

Student Research Assistant

Lars ***Bekov***
Felix ***Burgert***
Jacob ***Friedrich***
Julian ***Gebken***
Feline ***Jerg***
Puneet ***Kundra***
Florian ***Lüers***
Henrik ***Mahnke***
Henning ***Paul***
Ahmed ***Salman***
Leonard ***Schröder***
Altin ***Shala***
Maninderpal ***Singh***
Philipp ***Thomaneck***
Jan Lukas ***Tiefensee***

Technical Assistants

Dipl.-Ing. Werner ***Behrendt***

Dipl.-Ing. Frank ***Horn***

Uwe ***Reinhard***

Alumni

Dipl.-Phys. Gabriela ***Alexe***

M. Sc. Matthias ***Auerswald***

Dr.-Ing. Christoph ***Dollinger***

Dr.-Ing. Dennis ***Kruse***

Dr.-Ing. Marc ***Lemmel***

Dr.-Ing. Karsten ***Lübke***

Dr.-Ing. Jan ***Osmers***

Dr.-Ing. Stefan ***Patzelt***

Dr.-Ing. Helmut ***Prekel***

M. Sc. Volker ***Renken***

M. Sc. Johannes ***Stempin***

Dr.-Ing. Gerald ***Ströbel***

Dr.-Ing. Philipp ***Thiemann***

Dipl.-Ing. Jan ***Westerkamp***

Dr.-Ing Peiran ***Zhang***

Participation in scientific committees and associations

Member	Short Name	Scientific Committee / Association
BIMAQ	AUKOM	AUKOM Ausbildung Koordinatenmesstechnik e. V.
Andreas **Fischer**	DGaO	Deutsche Gesellschaft für angewandte Optik
Andreas **Fischer**	AHMT	Arbeitskreis der Hochschullehrer für Messtechnik e. V.
Andreas **Fischer**	ForWind	ForWind – Zentrum für Windenergieforschung
Andreas **Fischer**	MAPEX	Center for Materials and Processes
Andreas **Fischer**	SPIE	The International Society for Optics and Photonic
Andreas **Fischer**	EOS	European Optical Society
Andreas **Fischer**	Optica	The Optical Society
Andreas **Fischer**	IEEE	Institute of Electrical and Electronics Engineers
Andreas **Fischer**	VDI	Verein Deutscher Ingenieure
Andreas **Fischer**	GALA	Deutsche Gesellschaft für Laser-Anemometrie
Andreas **Fischer**	DHV	Deutscher Hochschulverband
Andreas **Fischer**		Regelungstechnisches Kolloquium in Boppard
Andreas **Fischer**	SFB TRR/136	Sonderforschungsbereich TRR 136 Prozesssignaturen
Andreas **Fischer**	BEST	Bremer Forschungszentrum für Energiesysteme
Gert **Goch**	WGP	Wissenschaftliche Gesellschaft für Produktionstechnik
Michael **Sorg**	DFMRS	Deutsche Forschungsvereinigung für Meß-, Regelungs- und Systemtechnik e. V.
Michael **Sorg**		BMWi-Forschungsnetzwerke Energie: Systemanalyse, Stromnetze, Erneuerbare Energien
Dirk **Stöbener**	MAPEX	Center for Materials and Processes
Dirk **Stöbener**	SFB TRR/136	Sonderforschungsbereich TRR 136 Prozesssignaturen
Dirk **Stöbener**	VDI	Verein Deutscher Ingenieure
Dirk **Stöbener**	VDI FA 3.61	VDI Fachausschuss 3.61 Messen an Zahnrädern und Getrieben
Axel **von Freyberg**	FVA	Forschungsvereinigung Antriebstechnik e. V., Arbeitskreis Messtechnik
Axel **von Freyberg**	DFMRS	Deutsche Forschungsvereinigung für Meß-, Regelungs- und Systemtechnik e. V.

Laboratories

LAB

Laboratory for dimensional metrology

BIMAQ's infrastructure features a variety of modern high-precision measurement systems. The equipment ranges from tactile coordinate, gearing and roughness measuring devices to optical systems like stripe pattern projection and laser triangulation as well as thermal, magnetic and acoustic probe systems and sensors for non-destructive analyses. The equipment is used for the calibration and validation of newly developed measurement and sensor systems, but it is also the basis for measurements within research projects and for the regional industry.

BIMAQ conducts form, size and location tests on very small to very large components, i.e. dimensions of a few millimetres up to 3 meters.

We offer standardized measurement and evaluation procedures as well as customer-specific solutions, such as the evaluation of advanced features or the digitization of a component.

Services

- development of measurement and evaluation strategies
- acquisition and analysis of dimensional deviations - tactile and optical measurements
- characterization of the surface quality - tactile and optical measurements
- gear inspection
- surface integrity analysis - non-destructive and non-contact
- order/reference measurements

Contact: a.freyberg@bimaq.de

Tactile measurement of a 5-axis milled gear segment

LAB Laboratory for large gears (in BIMAQ-Technikum)

To calibrate large gears currently no appropriate standards exist, that allow the traceability of the test processes to the SI unit 'meter' with sufficient accuracy. In close cooperation with the National Metrology Institute of Germany (PTB), BIMAQ therefore is involved in developing large gear standards with a diameter of 2000 mm and more.

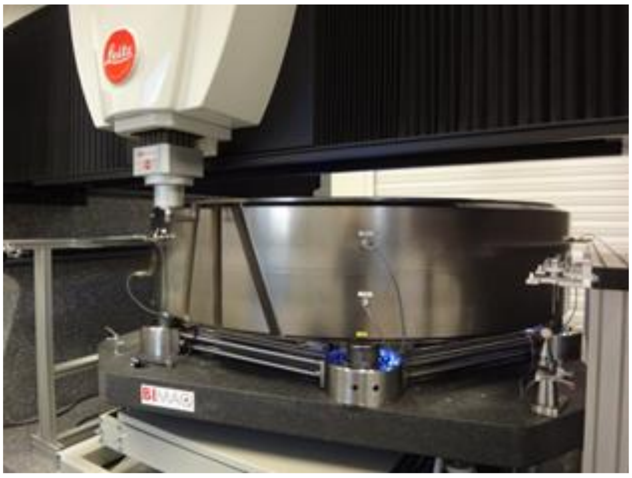
Furthermore, BIMAQ analyses the cause-effect relationships between gear manufacturing, geometric deviations and occurring gearbox damages. In the field of quality inspection of gears, algorithms are developed in order to evaluate dimensional measurement data.

Technical specifications

Portal coordinate measuring machine Leitz PMM-F 30.20.7:

- measuring volume:
  $3.0 \times 2.0 \times 0.7\ m^3$
- measuring uncertainty:
  $MPE_E = (1.3 + (L \text{ in mm})/400)\ \mu m$

Tactile measurement of large cylindrical gearing



Measurement on a 2 m gear standard with BIMAQ's large CMM

- workpiece mass:
  max. 6,000 kg
- rotary table:
  for rotation-symmetric components up to 3.0 m diameter
- air conditioning:
  maximum temperature gradients
  0.4 K/h, 0.8 K/d, 0.2 K/m

Services

- order/reference measurements
- analysis and evaluation of geometric deviations
- development of measurement and evaluation strategies
- software development

Contact: a.freyberg@bimaq.de

Laboratories

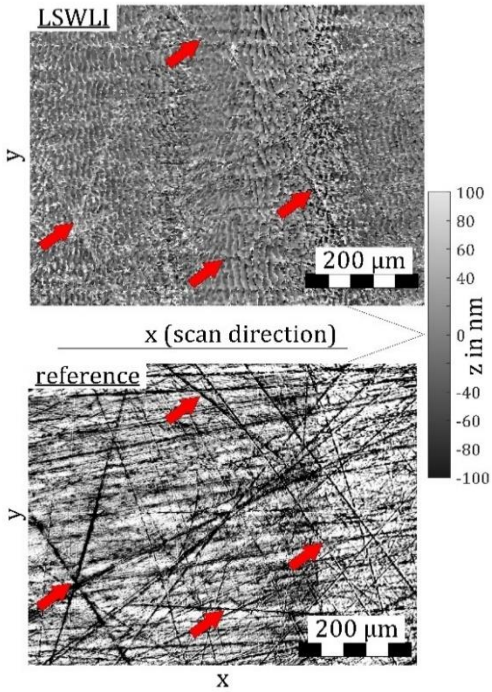
LAB

Laboratory for optical metrology

The laboratory for optical metrology focuses on two main research fields: in-process measuring methods and surface integrity evaluation.

The investigation of in-process measurement methods concentrates on the surface assessment with scattered light and other optical methods as well as the determination of thermo mechanical workpiece loads during manufacture.

The used light scattering methods allow a fast, in-process determination of statistical surface characteristics, sometimes without detecting the actual topography of the component. Such procedures are applied to investigate fast moving component surfaces in the manufacturing process. In addition to assessing the mean roughness in the observed measurement spot, statements about structure heights and widths as well as individual defect classes of components are possible. These evaluations are applied not only for structure sizes above the optical wavelength, but also for structure sizes below the optical wavelength in the nanometre range using the rigorous scattering theory based on Maxwell's equations. The measurement methods are investigated with simulative and experimental approaches to understand and surpass current limits regarding measurement resolution and uncertainty as well as to open up new application fields.



Enabling white-light interferometry for fast moving surfaces: new lateral scanning at a moving surface (top), slow vertical scanning at rest as reference (bottom) [Behrends at al., CIRP Annals, 2022].

Services

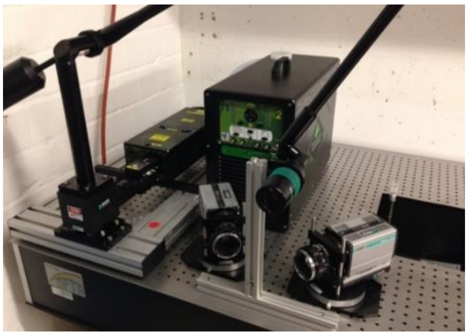
- basic research for new measurement methods
- feasibility studies on the near-process application of measurement principles, particularly in manufacturing and heat treatment processes
- development of measuring methods for industrial applications
- simulation and measurement of light scattering on micro- and nano-structured workpieces to assess the structural quality
- non-destructive surface integrity/topography checking and material characterization

Contact: d.stoebener@bimaq.de

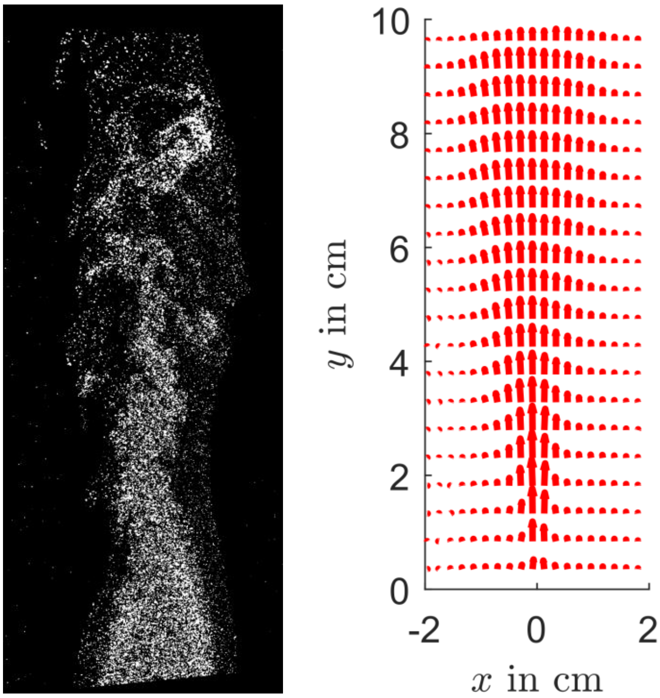
LAB

Laboratory for flow metrology

The three velocity components of a flow field can be determined in a measurement plane with a stereoscopic particle image velocimetry (PIV) system, which is the centerpiece of the laboratory for laser-based flow metrology. The particle-based measurement technique is applied in challenging conditions, e. g., hot jet flows, flame flows or two-phase flows. The main research topic is to quantify the measurement uncertainty caused by the influence of inhomogeneous refractive index fields. These fields lead to varying image distortions and, thus, measurement deviations of the particle position. The uncertainty budget for the determined velocity fields are obtained from model-based error propagations of the simulative and experimentally investigated refractive index field. The analysis of the measurement uncertainty budget is a key topic to identify and finally overcome fundamental limits of measurability.



Stereoscopic PIV system



PIV raw image (left) and mean velocity field (right) of a flame flow

Technical data

Dual-head PIV-Laser (Quantel Evergreen):

- pulse energy: 2 × 200 mJ
- wavelength: 532 nm
- pulse rate: 15 Hz
- pulse length: <10 ns
- light guide arm: 2.1 m

2 × sCMOS cameras (Andor Zyla):

- resolution: 5.5 Mpixel
- pixel width: 6.5 µm
- dynamic: 16 bit

Contact: c.vanselow@bimaq.de

BIMAQ - the institute

Laboratories

LAB

Laboratory for thermography

Boundary layer flow visualization on wind turbine rotor blades in operation

The boundary layer flow influences the temperature distribution on the surface of a rotor blade, which can be detected by a high speed thermographic imaging system. BIMAQ offers thermographic measurements of rotor blades on wind turbines in operation. Measurements are conducted in cooperation with the Deutsche WindGuard Engineering GmbH in Bremerhaven. Measurements can be performed from a distance between 60 m and 500 m.

Technical data

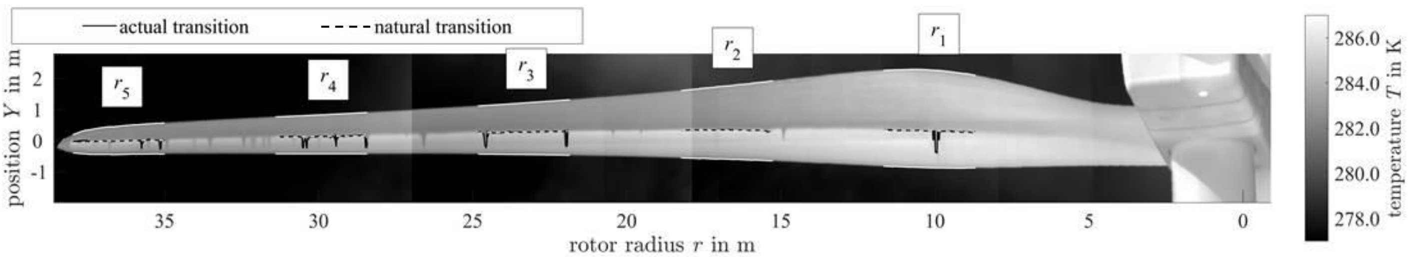
ImageIR thermographic imaging system:

- high speed IR imaging system
- thermal resolution: 0.025 K
- spectral range: 2 – 5 µm
- detector format: 640 x 512 pixel
- focal length incl. telephoto lens: 200 mm
- integration times between 1 µs and 1600 µs

ImageIR thermographic imaging system

Services

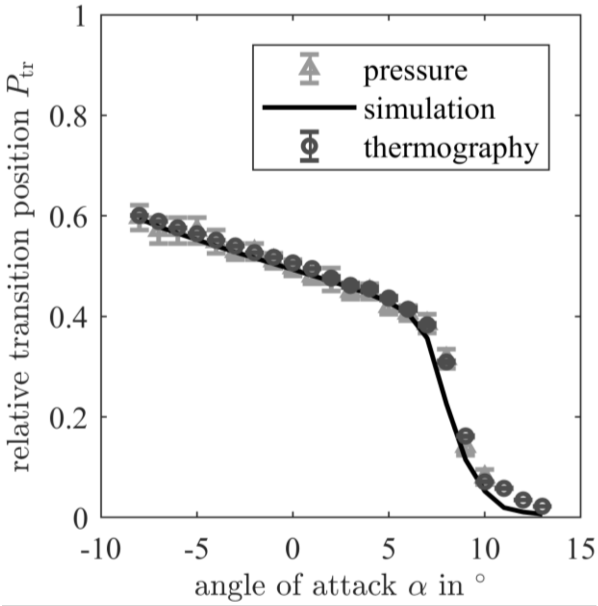
- determination of the laminar/turbulent transition location
- detection of early laminar-turbulent transition due to leading edge contamination, erosion, manufacturing irregularities or the effects of leading edge protection
- analysis of impact of leading edge protection on the boundary layer flow
- inspection of vortex generators, zig-zag tapes and other flow control devices
- investigation of the feasibility of anti-icing and de-icing systems



Evaluated thermographic image of the rotor blade of an 1.5 MW wind turbine with a 77 m rotor diameter

Boundary layer flow visualization in wind tunnel experiments

In order to investigate the boundary layer flow phenomena on airfoils, thermographic measurement approaches are developed and applied. The research focus are new image evaluation techniques based on the flow dynamics. The flow experiments with two different IR imaging systems are performed at the Deutsche WindGuard's aeroacoustic wind tunnel in Bremerhaven, where laminar air flows at speeds of up to 360 km/h and chord-Reynolds numbers of up to 6 million can be generated.



Relative position P_{tr} of the laminar-turbulent transition on the chord as a function of the angle of attack α

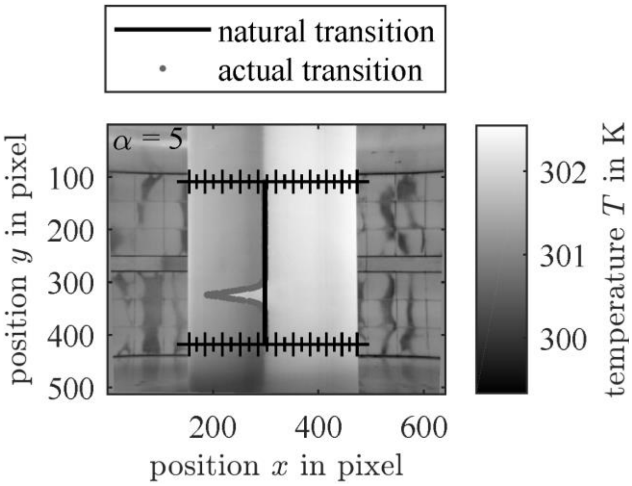
Technical data

VarioCam hr:

- detector format: 640 x 480 pixel
- thermal resolution: 0.030 K
- spectral range: 7.5 - 14 µm
- focal lengths: 12.5 mm and 30 mm

ImageIR:

- detector format: 640 x 512 pixel
- thermal resolution: 0.025 K
- spectral range: 2 - 5 µm
- focal lengths: 12 mm, 25 mm, 100 mm and 200 mm



Thermographic flow visualization on an airfoil in the wind tunnel

Services

- localization of the laminar-turbulent transition with a measurement uncertainty < 0.5 % chord length
- visualization of flow separations
- automated evaluation of wind tunnel campaigns
- comparison with reference measurements and simulation data

Contact: d.gleichauf@bimaq.de

Laboratories

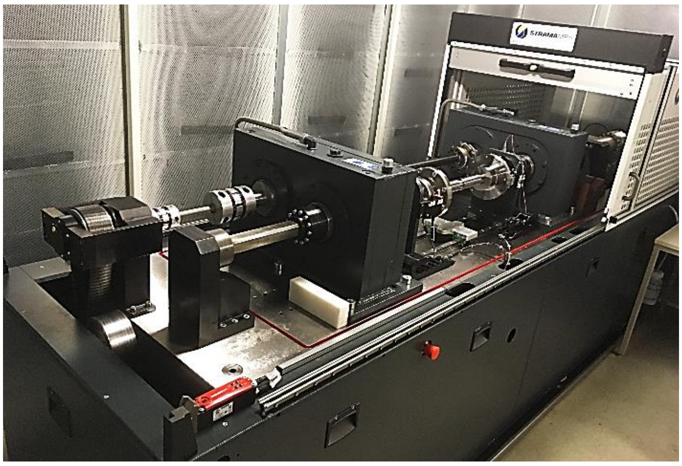
LAB

Laboratory for wind turbine sensors (in BIMAQ-Technikum)

Wind turbine generators (WTG) are dynamically highly stressed, which can lead to bearing and gear damages. For targeted improvements in design, production and choice of material meaningful metrics are missing. The individual trans-mission components (gears, bearings, shafts) are metrologically not accessible during operation, so far. A few states can be observed from the outside, e. g., temperature changes on the housing or noises or vibrations. But, the causes of problems are mostly inside the gear housing. These include mechanical stresses which may lead to undue distortion of the individual teeth and subsequently to wear of the tooth flanks.

Drivetrain inside the hub of a wind energy system

For testing new sensor concepts for WTG drivelines, the dynamic behaviour of WTG drivelines can be simulated experimentally in the BIMAQ-Technikum using a torque test rig. In addition, a WTG drive train and a 3.4 MW research WTG are available for sensor tests.



Torque test rig

Technical test rig specifications

- torque: ± 1 000 Nm
- speed: ± 3 000 min^{-1}
- axial force: 0 - 10 000 N

Services

- development of sensing prototypes
- order and reference measurement
- development of new measurement and evaluation strategies
- software development

Wind turbine drive train for sensor tests

Contact: m.sorg@bimaq.de

LAB

BIMAQ-Technikum and Mechanical workshop

BIMAQ maintains a 400 m² Technikum to support the research work.

The Technikum contains:

- laboratory for large gears
- torque test rig
- experimental field
- mechanical workshop

Mechanical workshop

For the production of test rigs, test stands and prototypes, the mechanical workshop is equipped, for example, with a

- CNC milling machine
  Travel distance:
  400 mm x 400 mm x 400 mm
- 3D printer
  Space:
  203 mm x 203 mm x 152 mm
- milling drill plotter
  maximum material size:
  229 mm x 305 mm x 35 mm

Services

- item and small-batch production
- additive and cutting machining

Contact: a.freyberg@bimaq.de

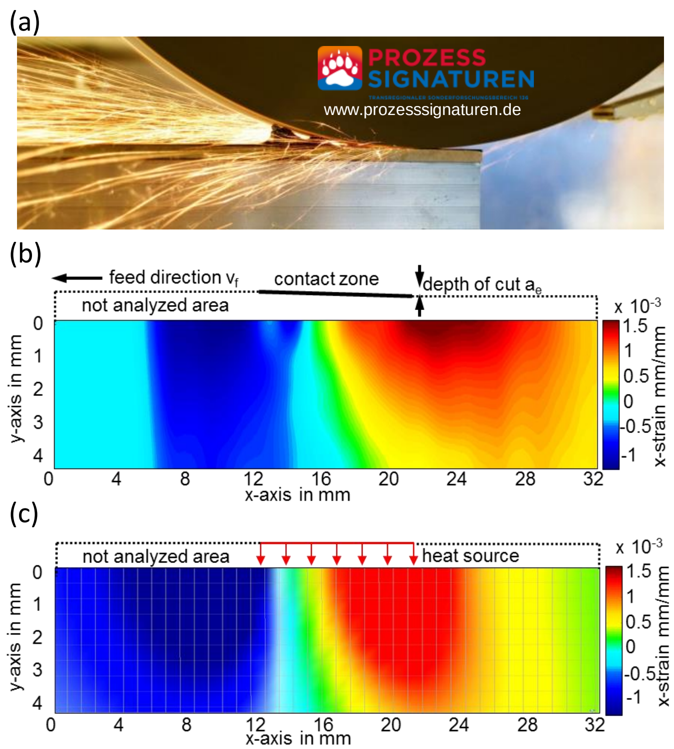
SFB/TRR 136 Process Signatures – Subproject C06

Surface-based optical measurements of mechanical material stresses

Funding organization: DFG/SFB
Funding ID: SFB Transregio 136
Duration: 1 Jan 2018 - 31 Dec 2022
Project scientist: Andreas Tausendfreund

In the SFB, the suitability of speckle photography for in-process measurements in highly dynamic manufacturing processes was demonstrated. Specially adapted evaluation algorithms and measuring systems were developed for this purpose, so that the use of speckle photography could also be realized on fast-rotating systems such as single-tooth peripheral milling, grinding under strong flying sparks, deep rolling or laser hardening [2]. Furthermore, a novel approach for in-process measurements based on an analysis of the shape-modified speckle correlation function is introduced to enable three-dimensional deformation measurements [3].

In addition to the three-dimensional reconstruction of the deformation fields, a central aim of the project is to determine parameters for establishing process signatures from the time-resolved stress fields measured in highly dynamic manufacturing processes. In this connection a quantification of the measurement uncertainty budget and a reduction of measurement uncertainty contributions are investigated. In addition, the data analysis is accelerated, for example by parallelization approaches. This reduces long evaluation times and enables in-process control in the future.



(a) Dry grinding process with strong flying sparks, (b) measured loads in form of strains agreeing with (c) finite element simulation of a moving heat source model [1].

[1] A. Tausendfreund, F. Borchers, E. Kohls, S. Kuschel, D. Stöbener, C. Heinzel, A. Fischer: Investigations on material loads during grinding by speckle photography. Journal of Manufacturing and Materials Processing 2(4):71 (12 pp.), 2018.

[2] A. Tausendfreund, D. Stöbener, A. Fischer: In-process workpiece displacement measurements under the rough environments of manufacturing technology. Procedia CIRP 87:409-414, 2020.

[3] A. Tausendfreund, D. Stöbener, A. Fischer: In-process measurement of three-dimensional deformations based on speckle photography. Applied Sciences 11(11):4981 (11 pp.), 2021.

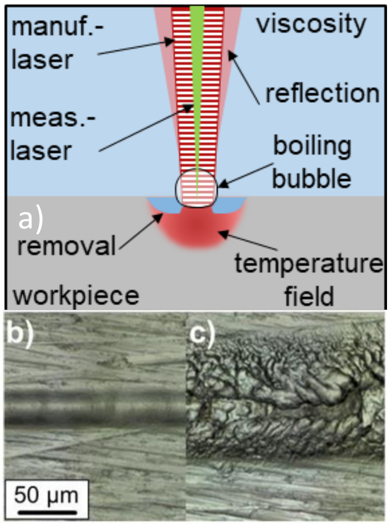
Near-process characterization of temperature field and material ablation changes during laser chemical machining

Funding organization: DFG
Funding ID: 451385285
Duration: 1 May 2021 – 30 Apr 2024
Project scientists: Merlin Mikulewitsch

Compared to other micromachining processes like micro milling, laser chemical machining (LCM) can achieve a higher removal quality with respect to shape accuracy at acute edge angles and small edge radii [1]. However, the production speed of LCM is lower, in particular because the removal rate is limited to avoid obstructive boiling bubbles, see Figure.

The research project aims to increase the process understanding of LCM in order to use fluidic irradiation variations to minimize the influence of boiling bubbles on the removal quality. For the first time, the process modeling will take the bubble influence into account, in particular with the aid of near-process measurements of the workpiece surface temperature, the boiling bubbles and the workpiece geometry in the removal zone. Indeed, an in-process capable measurement technique is essential for an improved process understanding and modeling, due to the complexity of laser chemical machining.

Confocal fluorescence microscopy was shown to be suitable for microgeometry measurements in liquids if a model-based signal processing approach is used [2]. However, the laser-induced surface temperature, which fundamentally affects the material removal result, is not measurable in situ to date. In order to facilitate an enhanced process modeling, we will combine the confocal geometric measurement using a fluorescent liquid with a fluorescence-based temperature measurement. The measurement approach is based on the determination of the fluorescence lifetime, which depends on the temperature of the fluorophore. As a result of our work, not only the material removal but also the spatial temperature distribution will be assessable during manufacturing.



a) Schematic representation of the LCM process and different manufacturing qualities for b) slow machining without boiling bubbles and c) fast machining with disturbances due to boiling bubbles.

[1] H. Messaoudi, M. Mikulewitsch, D. Brand, A. von Freyberg, A. Fischer: Removal behavior and output quality for laser chemical machining of tool steels. Manufacturing Review 6:13 (11 pp), 2019.

[2] A. Fischer, M. Mikulewitsch, D. Stöbener: Indirect fluorescence-based in situ geometry measurement for laser chemical machining. CIRP Annals - Manufacturing Technology 69(1):481-484, 2020.

ProstKühl

Near-process flow measurements of the cooling lubricant supply in grinding processes

Funding organization: DFG
Funding ID: 415003387
Duration: 1 Sept 2019 – 31 Aug 2022
Project scientists: Björn Espenhahn
Christoph Vanselow

Grinding is an essential manufacturing process to produce high quality surfaces. To prevent surface damages from grinding burn, a liquid cooling is used. However, the key flow mechanisms for an efficient coolant supply are not yet understood and only indirect optimisations of the coolant flow were performed so far. To identify the flow mechanisms, which are responsible for an efficient cooling of the grinding process, in-process flow field measurements of the coolant flow are necessary.

For this reason, the applicability of particle image velocimetry (PIV) as well as a shadowgraphy-based measurement system in a grinding machine are used to determine the coolant flow velocity field. A big challenge is to achieve valid flow velocity field measurements due to the fluctuating surface of the two-phase flow of cooling lubricant and air, which causes disturbing light refractions. Therefore, the studied approach is to determine the flow field by a statistical evaluation of multiple measurements. Furthermore, systematic and random measurement deviations due to light refraction are determined by an experimental technique, which measures the resulting light deflections inside the coolant flow.

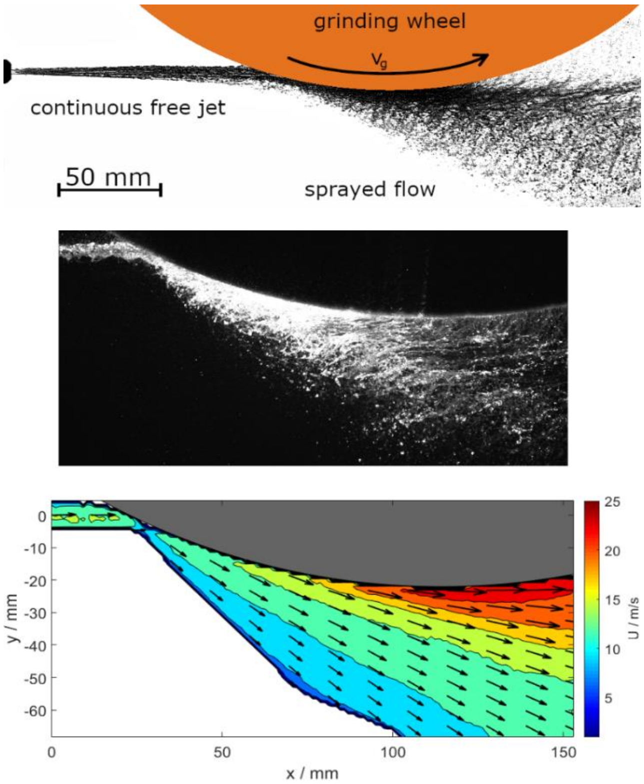


Illustration of the cooling process (top), visualization with laser sheet illumination (middle) and calculated average velocity flow field obtained with PIV (bottom).

[1] L. Schumski, N. Guba, B. Espenhahn, D. Stöbener, A. Fischer, D. Meyer: Characterization of the Interaction of Metalworking Fluids with Grinding Wheels. Journal of Manufacturing and Materials Processing 6(3):51 (18 pp.), 2022.

[2] C. Vanselow, B. Espenhahn, L. Schumski, D. Stöbener, D. Meyer, A. Fischer: Strömungsfeldmessung der Kühlschmierstoffzufuhr an der Schleifscheibe. tm - Technisches Messen 88(12):785-794, 2021.

[3] B. Espenhahn, L. Schumski, C. Vanselow, D. Stöbener, D. Meyer, A. Fischer: Feasibility of optical flow field measurements of the coolant in a grinding machine. Applied Sciences 11(24):11615 (18 pp.), 2021.

ThermoStall

Contactless in-process measurement of separated flow on non-scaled rotor blades of wind turbines

Funding organization: DFG

Funding ID: 420278089

Duration: 16 Dec 2019 – 15 Dec 2022

Project scientist: Felix Oehme

Because of the efficiency lowering effect, boundary layer flow separation is an unwanted phenomenon on rotor blades of wind turbines. The separated flow also induces unsteady loads, reducing the lifespan of the structural material and causing sound emission.

To achieve a better understanding of the boundary layer flow separation, a fast, non-invasive and contactless method for flow visualization is demanded to cope with the challenging requirements of in-process measurements on real wind turbines.

The aim of this project is thus to advance the existing thermographic flow visualization metrology for the detection of flow separation on wind turbines in operation. Compared to state-of-the-art methods with an invasive preparation of the blade surface, thermographic flow visualization uses the effect of different surface temperatures due to different heat transfer coefficients in the flow boundary layer to differentiate between different flow regimes without any contact and from a long working distance [1].

Thermographic flow visualization on wind turbine in operation with an infrared camera

While the principle potential of thermography for detecting flow separation was already verified in wind tunnel applications [2], the application to in-process measurements has yet to be made. Different spatiotemporal image processing methods are studied to increase the contrast between the flow separation and other flow states, while one open research question is how to record and evaluate image series on a moving rotor with unsteady inflow conditions. Additional tasks are to cope with a low spatial resolution due to high measuring distances and the overall non-reproducible, non-laboratory environmental circumstances. As a result of the project findings, the in-process flow visualization on wind turbines in operation will be fundamentally enhanced by the stall detection capability.

[1] F. Oehme, J. Suhr, N. Balaresque, D. Gleichauf, M. Sorg, A. Fischer: Thermographic stall detection by model-inspired evaluation of the dynamic temperature behaviour. Applied Sciences 11:8442 (18 pp.), 2021.

[2] F. Oehme, J. Suhr, N. Balaresque, D. Gleichauf, M. Sorg, A. Fischer: Thermographic detection of turbulent flow separation on rotor blades of wind turbines in operation. Journal of Wind Engineering and Industrial Aerodynamics 226:105025 (12 pp.), 2022.

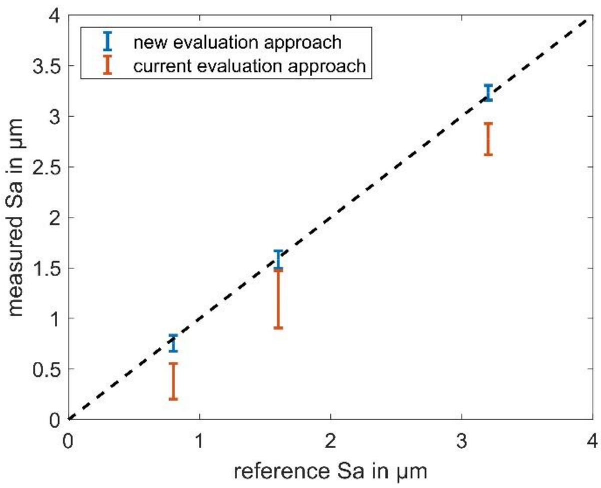
IQZeProd

Inline quality control for zero-error-products

Funding organization: AiF
Funding ID: 232 EGB
Duration: 1 Oct 2018 – 31 Jul 2021
Project scientist: Johannes Stempin

Quality control in manufacturing is usually realized at the end of the process chain. At this point, considerable costs and energy have already been invested into the components throughout the previous manufacturing steps. According to the state of the art, significant potentials of productivity and quality cannot be realized due to the late or unreliable detection of failures. In order to make the manufacturing process more robust and sustainable, the project *IQZeProd* investigates new inline monitoring solutions for the surface inspection.

Since one surface quality parameter is the surface roughness, polychromatic speckle correlation is studied that allows fast and precise roughness measurements over a wide measurement range. Since the current method is sensitive with respect to the tilt of the surface to be measured in relation to the sensor axis, a time-consuming alignment of the sensor is required that hinders inline use. To tackle this challenge, the surface tilt is measured by localizing the speckle pattern center. Finally, the speckle evaluation is enhanced to eliminate the cross-sensitivity with respect to the surface tilt. The successful reduction of the measurement uncertainty for a varying surface tilt is verified by theoretical considerations and validated by experiments, see figure below. The current accepted range of surface tilt amounts to ±1.25°, whose increasement with a novel model-based speckle evaluation and a robotor-assisted autonomous sensor adjustment is one promising issue of ongoing research.



Measured roughness Sa over the reference Sa for different roughness values on randomly, tilted surfaces with the double standard deviation of the mean value. As a result, systematic and random errors are reduced.

[1] J. Stempin, A. Tausendfreund, D. Stöbener, A. Fischer: Roughness measurements with polychromatic speckles on tilted surfaces. Nanomanufacturing and Metrology 4(4):237-246, 2021.

[2] S. Patzelt, D. Stöbener, A. Fischer: Laser light source limited uncertainty of speckle-based roughness measurements. Applied optics 58(23):6436-6445, 2019.

[3] A. Fischer, D. Stöbener: In-process roughness quality inspection for metal sheet rolling. CIRP Annals 68(1):523-526, 2019.

[4] D. Stöbener, A. Fischer: Optical roughness measurement with robot-assisted part inclination compensation. 22nd International euspen Conference & Exhibition, Geneva, 30.5.-3.6.2022, pp. 357-360.

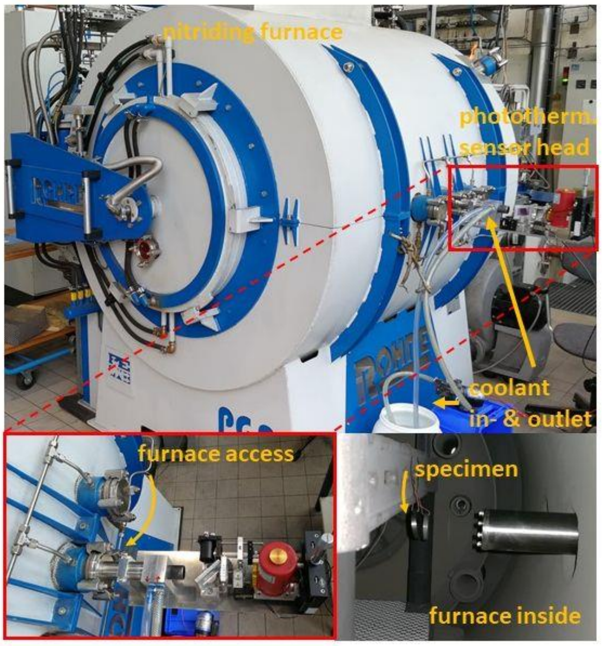
PhoMeNi

Photothermal measurement technique for non-contact in-process detection of nitriding layer formation during gas nitriding for industrial nitriding furnaces

Funding organization: AiF
Funding ID: 20501 N
Duration: 01 Feb 2019 – 31 Jul 2021
Project scientist: Merlin Mikulewitsch

For many decades, gas nitriding has been one of the most important thermochemical surface layer treatment processes for steels in order to improve surface hardness and wear resistance. The resulting nitriding layer consists of the outer compound layer and the underlying diffusion layer. Gas nitriding can often lead to incorrect nitriding results such as soft spots, a nitriding layer that is too thin or highly porous. Currently, the nitriding process lacks a direct measuring method to observe the boundary layer development in process, i.e. in an industrial nitriding furnace.

While X-ray diffractometry enables an in-situ characterization of the nitride phase formation, it cannot be used in industrial nitriding furnaces. The project *PhoMeNi* thus employs photothermal radiometry, an alternative measurement technique that allows in-process, contact-free and non-destructive boundary layer examination. Since photothermal signals depend on the thermal properties of the surface, modifications to the boundary layer (e.g. compound layer or near-surface pores) can be potentially observed during their formation and growth. As a result of *PhoMeNi,* a photothermal sensor for the use in industrial furnaces was developed. It enables in-process measurements of nitriding layer formation, which are required for understanding the nitriding kinetics. Using a physical signal model to evaluate the photothermal data, the thickness and thermal conductivity of the nitriding layer are directly quantified, even during the challenging process conditions at T = 550 °C.



Setup for the photothermal in-process measurements in an industrial nitriding furnace. A continuously cooled pipe (bottom left) enables optical access for the photothermal sensor head into the furnace to measure a specimen during nitriding (bottom right).

[1] J. Dong, H. Prekel, M. Dethlefs, J. Epp, A. Fischer: In-situ-Untersuchung von Randschichten während des Gas-nitrierens mittels Röntgendiffraktometrie und photo-thermischer Radiometrie. HTM Journal of Heat Treatment and Materials 72(3):154-167, 2017.

SUrfErCut

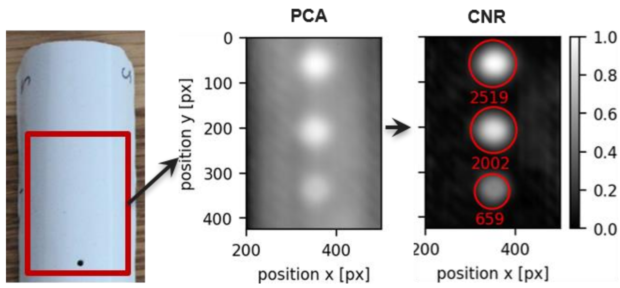
Systematic investigation of the causes of erosion damage to wind turbines

Funding organization: AiF
Funding ID: 40401106
Duration: 1 Sep 2019 – 31 Mar 2022
Project scientist: Friederike Jensen

The leading edge of a rotor blade is particularly exposed to mechanical and environmental stresses such as during rain, where the drops hit the blade with an impact speed of over 300 km/h. The impact of rain drops gradually removes the coated surface as well as parts of the underlying glass-fiber composite material. The condition of the leading edge of a wind turbine blade significantly influences the aerodynamic properties of the rotor blade and thus the performance of the wind turbine. Damage caused primarily by erosion limits the lifetime of wind turbines and leads to high maintenance and repair costs. Studies suggest that initial subsurface defects such as pores in the border area between coating and glass-fiber reinforced composite can lead to a premature erosion.

The aim of the project *SUrfErCut* is to investigate these initial subsurface defects and its effect on the course of damage when exposed to rain. By means of a thermographic measurement and a corresponding damage correlation map, the initial defects and the resultant erosion damages are detected in order to initiate early action measures such as a repair.

To establish the correlation damage map, test samples similar to rotor blades are examined and documented by thermographic measurements in the laboratory in their initial state and at various points in time of the damage process, which is caused by the loading of the sample in an erosion test rig.



Left: photograph of the test specimen, middle: PCA-processed thermogram, right: filtered thermogram with defect detection and CNR-calculation.

The first experiments show that sub-surface defects in different depths and with different diameters can be visualized and detected automatically, despite a coated and curved surface of the test sample [1]. Further investigations including computer tomography reference measurements have been carried out to determine the influence of these detected inhomogeneities on premature rain erosion. Finally, in-situ measurements and damage analyses are conducted on the leading edge of a real-scale wind turbine blade.

[1] F. Jensen, M. Terlau, M. Sorg, A. Fischer: Active thermography for the detection of sub-surface defects on a curved and coated GFRP-structure. Applied Sciences 11(20):9545 (19 pp.), 2021.

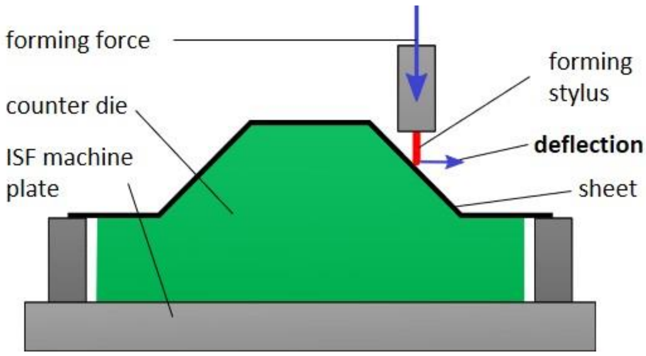
Rapid prototyping of sheet metal parts using intelligent 3D-printed dies

Funding organization: AiF
Funding ID: 290 EBG
Duration: 1 Jan 2021 – 31 Dec 2022
Project scientist: Marina Terlau

Economic manufacturing of customized sheet metal parts in small lot sizes is a challenge in industrial production. As conventional deep drawing requires expensive tools, incremental sheet metal forming (ISF) is a suitable alternative. Thereby, a forming stylus forms the sheet metal over a counter die. Instead of a counter die milled with a separate machine tool, the project *RapidSheet* proposes to combine an additive manufacturing of the counter die with the ISF process in a single machine tool. To increase not only the speed but also the accuracy of ISF, the geometrical deviation due to the deflection of the forming stylus must be corrected. For this purpose, an in-process tool deflection measurement is investigated.

To measure the tool deflection optically with a low uncertainty in a large machining volume, a novel multi-sensor-system is created, where each sensor consists of a camera chip and a mask. An LED attached to the tool tip casts a shadow on the camera so that the tool tip position is evaluated from the image of the shadow. Experimental results show that a lateral position measurement uncertainty of a single sensor of less than 15 µm in an angle-of-view of ±4,3° and a distance range between 100 mm and 500 mm is achievable. This already meets the sensing requirements. However, the measurement uncertainty of the axial position component with a single sensor is proven to be insufficient for the tool deflection measurement. Therefore, the axial component must be determined by triangulation with data from the neighbouring sensors.

Now, the multi-sensor-system will be realized with the goal of a three-dimensional position measurement with a sufficient uncertainty in the entire machining volume. Furthermore, a commercial acceleration sensor will be included which measures the high-frequency deflections. Finally, the combined measurement system will be validated during an in-situ measurement of the tool deflection in ISF.



Incremental sheet metal forming using a forming stylus, which is deflected due to forming forces.

[1] M. Terlau, A. von Freyberg, D. Stöbener, A. Fischer: In-Prozess-Messung der Werkzeugablenkung beim inkrementellen Blechumformen. 21. GMA/ITG-Fachtagung "Sensoren und Messsysteme 2022", Nürnberg, 10.-11.5.2022, pp. 90-96.

Research

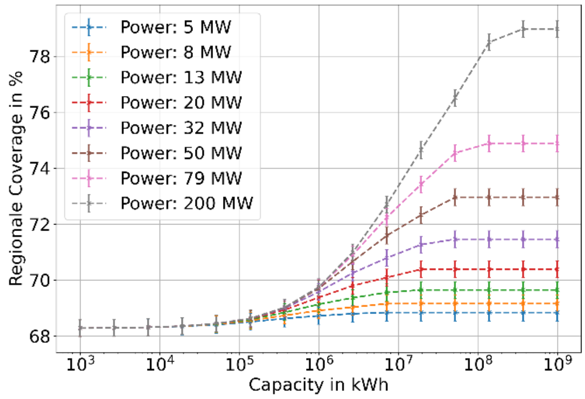
Geowisol2

Analysis of the geographical distribution of wind and solar power and their effect on the energy system in Germany

Funding organization: BMWK
Funding ID: 40401065
Duration: 1 Jan 2019 – 31 Mar 2022
Project scientist: Yannik Schädler

The expansion of renewable energies for an alternative energy system is one of the main goals for energy system transformation and for the reduction of climate-damaging greenhouse gases. Due to the fluctuation of wind and solar power, the challenges for the German power grid are increasing with its share in power generation. In order to optimally cover the increasing demand, it is necessary to have a precise knowledge of both the feed-in and demand quantities, resolved in terms of time and place. Such a comprehensive database is currently only available for parts of Germany or with limited spatiotemporal resolution.

For this reason, a database was developed which provides renewable and conventional power feed-in as well as energy demand time series, each as 15-minute average values and with a local resolution of 2-digit ZIP code regions. The determined geographical distribution have been mapped to the existing power lines. On this basis, the transmission volumes in the current expansion state and those of future expansion scenarios are analysed and evaluated over time [1]. In particular, the grid expansion and the integration of storage systems are considered as both aspects are becoming increasingly important. As a result, a tool is created to support and evaluate future energy infrastructure projects.



Example of the storage modelling for ZIP code 27: The highest regional coverage is achieved with the most powerful storage system. The uncertainty estimation is accomplished with a Monte-Carlo simulation.

[1] Y. Schädler, V. Renken, M. Sorg, L. Gerdes, G. Gerdes, A. Fischer: Power transport needs for the german power grid for a major demand coverage by wind and solar power. Energy Strategy Reviews 34:100626 (9 pp.), 2021.

[2] Y. Schädler, M. Sorg, A. Fischer: Measurement data-driven investigation of the actual power grid resilience with increasing renewable energy feed-in. Energy Science & Engineering 10(1):145-154, 2022.

[3] Y. Schädler, M. Sorg, A. Fischer: Data-based energy coverage measurements to discover the potentials of regional energy storage. tm - Technisches Messen 89(5):301-309, 2022.

FlexGear

Establishment of lightweight design concepts for gearboxes of wind turbines

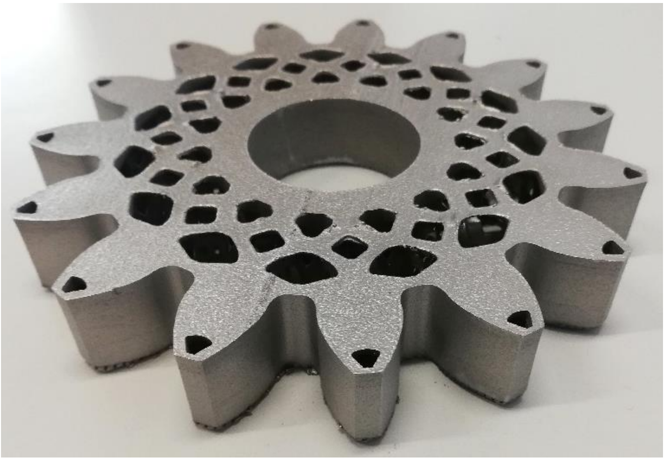
Funding organization: BMWK
Funding ID: 03LB1000A
Duration: 1 Dez 2020 – 30 Nov 2023
Project scientist: Marc Pillarz

In order to meet climate protection targets, there is a trend in industry towards conserving resources and saving energy through lightweight construction. Coupled with the objective of expanding the wind energy sector and installing larger wind turbines (WTG) with a power ≥ 5 MW, lightweight construction is also becoming important for gear technology.

If the output of WTGs increases, the mass and material consumption of WTG components will rise, because gearboxes must also be dimensioned larger. In order to save resources and energy, the material consumption in the design and manufacture of the gearboxes must be minimized by lightweight construction. Due to the high dynamic loads to which WTG gearboxes are subjected, lightweight gears have not been used in WTG gearboxes to date. Previous lightweight construction concepts only consider the structural optimization of the gearwheel body when designing gears. The gear rim is currently not considered, which shows potential for new lightweight design concepts.

The joint project *FlexGear* aims to develop design guidelines for holistic lightweight gears with integrated load monitoring for WTG gearboxes. The realization of lightweight demonstrators, of a test rig for measuring the geometry of the demonstrators under static load, and of a test rig for investigating dynamic load peaks will validate the design.

The holistic approach is to be manufactured additively and allows the integration of an inside sensing and telemetry system to record force curves and deformations, which contributes to the validation of the design. In addition, the integration of flexible structures within the gearing, e.g. by solid state joints and a condition monitoring system, coupled with the inside sensing system, will proactively compensate for peak loads. The holistic lightweight design approach thus enables direct and indirect potential for weight and material savings.



First demonstrator of an additively manufactured lightweight gear. Compared to a solid gear, the weight is reduced by 55 %. Fine machining and experimental load tests are the next steps.

PreciWind

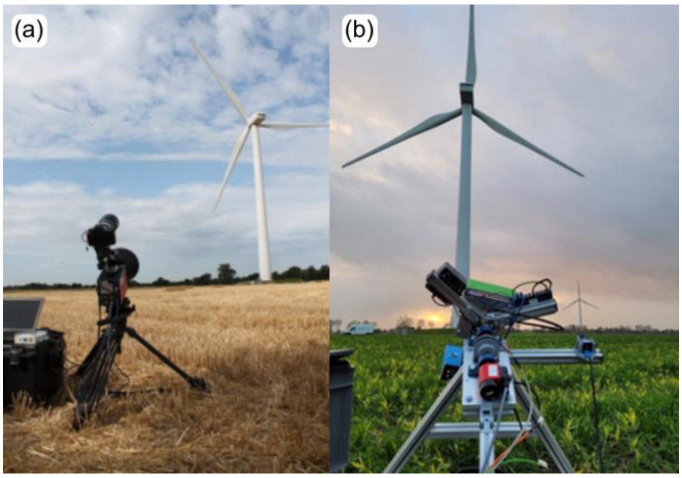
Precise measuring system for non-contact acquisition and analysis of the dynamic flow behaviour of wind turbine rotor blades

Funding organization: BMWK
Funding ID: 03EE3013D
Duration: 1 Jan 2020 – 31 Dec 2022
Project scientists: Daniel Gleichauf,
Paula Helming
Ann-Marie Parrey

The boundary layer flow of aerodynamic profiles on wind turbine rotor blades is unsteady. This is due to unsteady flow conditions since the wind speed, the turbulence level and the angle of attack vary, e.g., depending on the position of the rotor blade during one revolution of the rotor. This dynamic behaviour influences the aerodynamic properties of the profile and hence the efficiency of the energy production of the entire wind turbine.

The state of the art metrology for a non-invasive measurement of the boundary layer flow on rotor blades of wind turbines in operation is thermographic flow visualization. Compared to state-of-the-art methods that use invasive preparations of the blade surface, thermographic flow visualization uses the effect of different surface temperatures due to different heat transfer coefficients in the boundary layer for a contactless differentiation between the flow regimes [1]. So far, the measurement system only visualizes static flow phenomena by taking single snap-shots of the rotor blade during operation and does not consider dynamic deformations. [2]. Therefore, an advancement of the existing metrology is necessary that enables studying dynamic flow behaviour including deformations.

Therefore, the aim of project *PreciWind* is to develop a co-rotating measurement system that allows the camera system to follow the rotor blade movement. This way, each radial section of the rotor blade is observed continuously during one revolution of the rotor. This allows measurement of the dynamic flow in conjunction with dynamic structural behavior due to changing flow conditions.



(a) Thermographic flow visualization on a wind turbine in operation with an infrared camera. (b) Co-rotating measurement table with laser and optical sensors.

[1] D. Gleichauf, M. Sorg, A. Fischer: Contactless localization of premature laminar-turbulent flow transitions on wind turbine rotor blades in operation. Applied Sciences 10(18):6552 (21 pp.), 2020.

[2] P. Helming, A. von Freyberg, M. Sorg, A. Fischer: Wind turbine tower deformation measurement using terrestrial laser scanning on a 3.4 MW wind turbine. Energies 14(11):3255 (14 pp.), 2021.

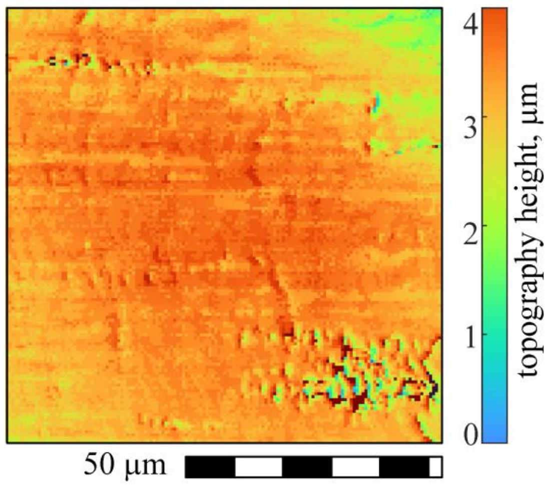
SiToH

Fast, interferometric, in-process topography measurement of moving surfaces applying high-performance hardware

Funding organization: BMBF
Funding ID: 100363507
Duration: 1 Aug 2018 – 3 Mar 2022
Project scientist: Gert Behrends

Rising demands regarding the quality of smooth surfaces of consumer goods and intermediate products necessitate metrology systems, which are able to quantify the topography of these surfaces in a quick and accurate manner.

One suitable technique is vertical scanning white light interferometry (VSWLI), as specified in DIN EN ISO 25178. State of the art VSWLI is able to accurately record surface topographies with a height resolution < 1 nm. Drawbacks of this method are its limitation to stationary surfaces and extensive post-processing when measuring large areas. The project *SiToH* overcomes these limitations by applying lateral scanning white light interferometry (LSWLI), as first described by Olszak [1]. LSWLI combines vertical and horizontal scanning into a single motion, enabling continuous measurements on moving surfaces without interruption.



LSWLI topography measurement of a sheet metal strip, mounted on a rotating cylinder with 22.6 mm diameter.

In order to record topographies with LSWLI with a low height measurement uncertainty, the recording positions on the surface must be tracked with sub-pixel accuracy for every moment of the scan. Tracking of the lateral position was realised by integrating an IR-illuminated, digital speckle correlation system into the LSWLI setup. The position measurement accuracy was validated in the laboratory to be 0.02 pixels (11 nm) in [2]. The system not only allowed tracking of the lateral scan, but also of lateral vibrations and shocks, which enabled LSWLI to be used in rough industrial environments. First tests of LSWLI under harsh industrial conditions were successful and will be presented at the next general assembly of the international academy of production engineering [3].

[1] G. Behrends, D. Stöbener, A. Fischer: Lateral scanning white-light interferometry on rotating objects. Surface Topography: Metrology and Properties 8(3):035006 (13 pp.), 2020.

[2] G. Behrends, D. Stöbener, A. Fischer: Integrated, speckle-based displacement measurement for lateral scanning white light interferometry. Sensors 21(7):2486 (17 pp.), 2021.

[3] A. Fischer, D. Stöbener, G. Behrends: A lateral-scanning white-light interferometer for topography measurements on rotating objects in process environments. CIRP Annals, 2022. (accepted)

LoGAZ

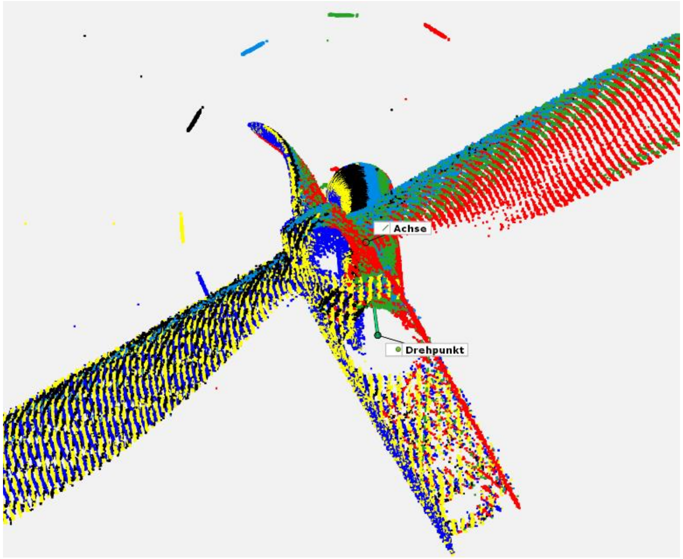
Laser optical measurement method for the state analysis of wind turbines

Funding organization: BAB
Funding ID: AUF0007A
Duration: 1 May 2020 – 3 Aug 2021
Project scientists: León Schweickhardt,
Axel von Freyberg

In order to be able to evaluate the aerodynamic condition of wind turbines, for example with regard to pitch adjustments, and to plan and prepare necessary maintenance work, non-contact measurements of the rotor blade geometry are required during turbine operation from large working distances (100 m – 300 m). As a promising solution approach, a commercial LIDAR system (light detection and ranging) from the project partner LASE is tested to measure the surface.

As a result, pitch deviations are measurable with an uncertainty between 0.15° (with provided nominal rotor blade geometry) and 0.92° (without a priori knowledge). In addition, further geometric features of the wind turbine like tower clearance or cone angle can be measured during the operation of the turbine.

As particularly promising outlook, the LIDAR system was shown to enable measurements of the mean 3D surface geometry of all blades while the turbine is rotating, if a proper geometrical calibration is provided as well as a synchronous video measurement to determine the speed and direction of rotation. This feature will be studied in further projects, as it provides an easy measurement setup for analyzing load-dependent deformations with no need to access the turbine control system.



Merged measurements of a wind turbine from different angles

[1]. A. von Freyberg, P. Helming, J. Friedrich, D. Stöbener, A. Fischer: Berührungslose Messung von Pitchwinkelabweichungen an Windenergieanlagen aus 150 m Entfernung. tm – Technisches Messen 88(11):686-695, 2021.

OptiProp

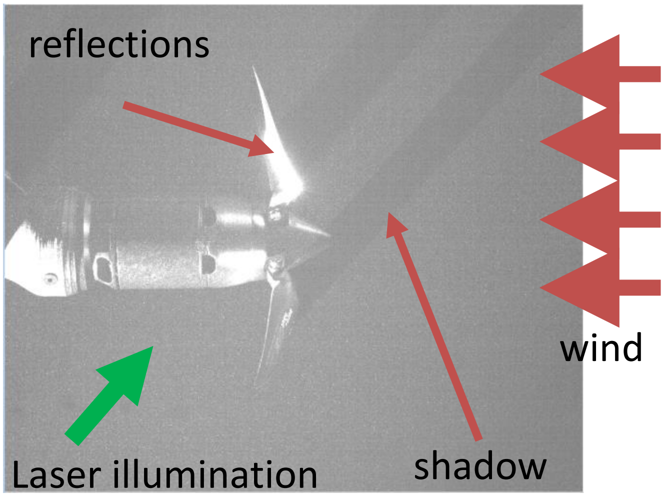
Development and commissioning of a test stand for the optimization of propellers

Funding organization: BiS
Funding ID: 989/PFAU-FUE-V-14-2/2021-ZB
Duration: 1 Jul 2021 – 30 Jun 2022
Project scientists: Gert Behrends
Christoph Vanselow

Within the project *OptiProp*, Deutsche Windguard Engineering GmbH and the University of Bremen, BIMAQ, develop and manufacture two test rigs for propeller drive units of different power classes (2.5 kW and 20 kW, respectively). A switchable stereo particle image velocimetry (PIV) measurement system is integrated into the existing measurement system of the aeroacoustic wind tunnel of the Windguard Engineering GmbH in Bremerhaven. Of particular interest regarding the integration of the PIV flow measurement system is a fast and, thus, cost-efficient operational readiness of the system for different measurement tasks in the wind tunnel. With the help of the extensive optical and acoustic sensor technology, the wind tunnel will be used to research design and optimization strategies for pioneering propulsion concepts for electric flight, such as Distributed Electric Propulsion (DEP).

The main advantage of these electric propulsion systems is reduced energy consumption, no emission of CO_2 and nitrogen oxides (NO_X) during operation, and reduced acoustic emissions. They also enable redesign of flight systems with more favorable load distributions or reduced need for control and high-lift elements. To establish electric propulsion in aviation, the following key challenges must be solved in combination: Weight savings with increased electrical system energy storage capacity, thermal management, flight control, safety, and certification. Wind tunnel testing makes a critical contribution to the development, optimization, and ultimately certification of new aerospace propulsion systems.

An automated propeller test rig in combination with unified procedures is currently not commercially available in Europe for the planned power classes in the required design.



PIV raw image of the propeller test rig in the wind tunnel. Measurement challenges are the strong reflections and the shadowing.

Measurement services for the industry

Measurement services

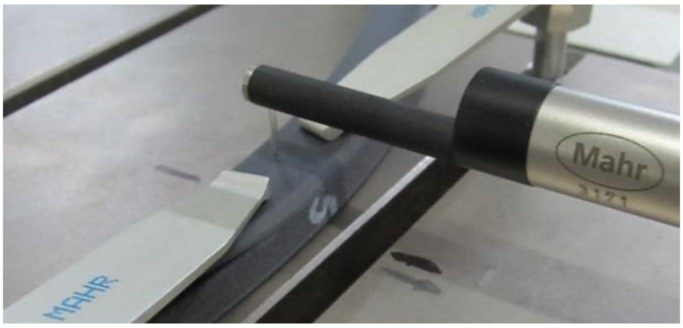
Dimensional measurements

Duration: continuously
Contact: a.freyberg@bimaq.de

With its extensive measurement equipment, BIMAQ offers measurement services for the local industry.

The measurement tasks range from dimensional measurements on metallic and fibre composite materials for the automotive, energy, aerospace and space industry to roughness measurements on flexible sealing elements. Depending on the application, geometrical features are acquired on coordinate measuring machines with tactile or optical probes and dimensional, shape and position deviations are evaluated. Other applications require the optical acquisition of free-form surfaces by means of stripe pattern projection systems.

Roughness measurements are performed either with a stationary measuring device or with a mobile device, e. g. on bearing rings with diameters up to 2 m.



Roughness measurement on a flexible sealing element

Thermographic flow visualization

Duration: continuously
Contact: d.gleichauf@bimaq.de

In a close cooperation with the Deutsche WindGuard Engineering GmbH, measurement services for flow visualizations in wind tunnel experiments and on rotor blades of wind turbines in operation are performed. The thermographic method for flow visualization is non-invasive and provides the location of different flow regimes as well as a localization of the laminar turbulent transition. The flow regimes can be distinguished by different surface temperatures and fluctuations in time. In wind tunnel experiments the acquisition, the automated processing and the evaluation of the results are part of the offered services. Combined with a telephoto lens, the high performance IR-camera is capable to detect small temperature differences on the rotor blade surface for a visualization of the flow conditions on wind turbines in operation. The information can be determined without the expensive instrumentation of conventional methods. The measurements are carried out at a distance of several hundred meters and enable an overall evaluation of the flow conditions on the rotor blade as well as the study of influences on the flow by contamination and erosion of the leading edge.

Teaching

Teaching activities, student projects, graduation works

Teaching activities

Lecture	PT	SE	WING	BB	Sem. BSc	Sem. MSc	CP	Students WiSe 21/22 and SoSe 2022
Messtechnik	●	●	○	○	3rd		3	91
Übung Messtechnik	●		○	○	3rd		1	82
Labor Messtechnik	●		○	○	3rd		1	17
Regelungstechnik	●		○		5th		3	38
Übung Regelungstechnik	●		○		5th		1	37
Labor Regelungstechnik	●		○		5th		1	26
Grundlagen der Qualitätswissenschaft	●	●	●		5th	1st	3	138
Regenerative Energien	●	○	○	○	4th 6th	1st	3	11
Prozessnahe und In-Prozess-Messtechnik	●	●	●		4th 6th	1st 2nd 3rd	3	12
Geometrische Messtechnik mit Labor* AUKOM	●	●	○		5th	1st	3	35
Methoden der Messtechnik - Signal- und Bildverarbeitung	●	●	●		5th	1st 2nd	3	14
Einführung in die Automatisierungstechnik mit Labor	●	●	○		5th	1st 2nd	3	46
Produktion von Verzahnungen (held by several chairs)	●	○				1st 2nd	6	9
Labor Produktion von Verzahnungen (held by several chairs)	●	○				1st 2nd	3	5
Grundlagenlabor Produktionstechnik		●			4th		2	25
Messtechnisches Seminar	●	●	●		4th	1st 2nd	3	14

Legend:

● - Pflicht-/Wahlpflicht-/Wahlfach, ○ - fakultativ

PT - Produktionstechnik, **SE** - Systems Engineering, **WING -** Wirtschaftsingenieurwesen Produktionstechnik, **BB** - Berufliche Bildung

* - AUKOM Certificate: AUKOM is a manufacturer-independent association for training in the field of geometric measurement technology. AUKOM offers the students to earn the level 1 basic certificate at cost.

Teaching activities, student projects, graduation works

Student projects

Kind of project	Title	Semester	Course of studies*
Informatikprojekt	Ansteuerung eines 3D-Laserscanners (Bilderfassung und -auswertung in Python	SoSe 2022	BSc PT BSc WING
Bachelorprojekt	Entwicklung eines Autofokussystems für die lateral scannende Weißlichtinterferometrie	WiSe 2021 / 2022	BSc PT BSc WING
Bachelorprojekt	Messdatenbasierte Optimierung von Energietransport und Speicherung im deutschen Energiesystem	WiSe 2021 / 2022	BSc PT BSc WING

*SE - Systems Engineering, PT - Produktionstechnik, WING - Wirtschaftsingenieurwesen - Produktionstechnik

Graduation works

Bachelor theses

- Chris Ole ***Ohlrogge***:
  Messung von quasi-stationären Strömungszuständen an Windenergieanlagen in Betrieb.
  Colloquium: 14 Dec 2021
- Nicola ***Brennenstuhl***:
  Sensorfusion zur Auswertung von Geometriedaten von Windenergieanlagen-Rotorblättern.
  Colloquium: 20 Jan 2022
- Hergen ***Kruse***:
  Automatisierte Defektdetektion in thermografischen Datensätzen.
  Colloquium: 2 Febr 2022
- Maninderpal ***Singh:***
  Thermografische Strömungsvisualisierung an Windenergieanlagen auf Grundlage von Wärmedissipation innerhalb der Grenzschichtströmung.
  Colloquium: 29 Mar 2022
- Kamil ***Hammoud***:
  Charakterisierung und Optimierung eines schattenbasierten Angulationssensors unter in-situ Bedingungen.
  Colloquium: 12 Apr 2022

Master theses

- Melad ***Lodin***:
  Einfluss eines heterogenen Brechzahlfeldes bei Particle-Image-Velocimetry-Messungen an einem Freistrahl.
  Colloquium: 2 Sep 2021
- Jendrik ***Blanke:***
  Untersuchung statisch belasteter Verzahnungen anhand geometrischer Merkmale.
  Colloquium: 17 Jan 2022
- Alex Peer ***Intemann***:
  Laserbasierte Schwingungs- und Deformationsmessungen an Windenergieanlagen.
  Colloquium: 5 Apr 2022

Publications and qualification of young academics

Publications

Books

- A. ***Fischer***, D. Stöbener, C. Vanselow, B. Ruck, A. Leder (Hrsg.):
  Experimentelle Strömungsmechanik - 28. Fachtagung, Deutsche Gesellschaft für Laser-Anemometrie - German Association for Laser Anemometry GALA e.V., Karlsruhe, 2021.
- A. ***Fischer*** (Ed.):
  Optical In-Process Measurement Systems. In: Applied Sciences, MDPI, Basel, 2022.
- A. ***Fischer*** (Ed.):
  Non-invasive measurement techniques for micro- and large-scale flows. In: tm - Technisches Messen 89(3), De Gruyter, Berlin, 2022.
- A. ***Fischer***, R. Bergmann (Eds.):
  Multi-dimensional optical measurement techniques. In: tm - Technisches Messen 89(6), De Gruyter, Berlin, 2022.
- C. ***Vanselow***:
  Einfluss von inhomogenen Brechungsindexfeldern auf die Particle Image Velocimetry. In: Forschungsberichte des Bremer Instituts für Messtechnik, Automatisierung und Qualitätswissenschaft (Hrsg.: A. Fischer). Vol. 5, Shaker, Düren, 2022.
- A. von ***Freyberg***:
  Automatische Partitionierung komplexer kombinierter Geometrien durch Ganzheitliche Approximation. In: Forschungsberichte des Bremer Instituts für Messtechnik, Automatisierung und Qualitätswissenschaft (Hrsg.: A. Fischer). Vol. 4, Shaker, Düren, 2021.

Journals

- G. ***Behrends***, D. Stöbener, A. Fischer:
  Integrated, speckle-based displacement measurement for lateral scanning white light interferometry.
  Sensors 21(7):2486 (17 pp.), 2021.
- B. ***Espenhahn***, L. Schumski, C. Vanselow, D. Stöbener, D. Meyer, A. Fischer:
  Feasibility of optical flow field measurements of the coolant in a grinding machine.
  Applied Sciences 11(24):11615 (18 pp.), 2021.
- L. Schumski, N. Guba, B. ***Espenhahn***, D. Stöbener, A. Fischer, D. Meyer:
  Characterization of the interactions of metalworking fluids with grinding wheels.
  Journal of Manufacturing and Materials Processing 6(3):51 (18 pp.), 2022.

- D. Meyer, L. Schumski, N. Guba, B. ***Espenhahn***, T. Hüsemann:
  Relevance of the region of interaction between the tool and the metalworking fluid for the cooling effect in grinding.
  CIRP Annals - Manufacturing Technology, 2022. (accepted)

- A. ***Fischer***, A. von Freyberg, D. Stöbener:
  Tooth flank approximation with root point iteration - potentials and limits in gear metrology.
  CIRP Annals - Manufacturing Technology 70(1):427-430, 2021.

- A. ***Fischer***:
  Fundamental flow measurement capabilities of optical Doppler and time-of-flight principles.
  Experiments in Fluids 62(2):37 (19 pp.), 2021.

- H. Li, A. ***Fischer***, M. Avila, D. Xu:
  Measurement error of tracer-based velocimetry in single-phase turbulent flows with inhomogeneous refractive indices.
  Experimental Thermal and Fluid Science 136:110681 (12 pp.), 2022.

- A. ***Fischer***, D. Stöbener, G. Behrends:
  A lateral-scanning white-light interferometer for topography measurements on rotating objects in process environments.
  CIRP Annals - Manufacturing Technology, 2022. (accepted)

- D. ***Gleichauf***, F. Oehme, M. Sorg, A. Fischer:
  Laminar-turbulent transition localization in thermographic flow visualization by means of principal component analysis.
  Applied Sciences 11(12):5471 (22 pp.), 2021.

- P. ***Helming***, A. von Freyberg, M. Sorg, A. Fischer:
  Wind turbine tower deformation measurement using terrestrial laser scanning on a 3.4 MW wind turbine.
  Energies 14(11):3255 (14 pp.), 2021.

- F. ***Jensen***, M. Terlau, M. Sorg, A. Fischer:
  Active thermography for the detection of subsurface defects on a curved and coated GFRP-structure.
  Applied Sciences 11(20):9545 (19 pp.), 2021.

- F. ***Oehme***, J. Suhr, N. Balaresque, D. Gleichauf, M. Sorg, A. Fischer:
  Thermographic stall detection by model-inspired evaluation of the dynamic temperature behaviour.
  Applied Sciences 11(18):8442 (18. pp.), 2021.

- F. ***Oehme***, J. Suhr, N. Balaresque, D. Gleichauf, M. Sorg, A. Fischer:
  Thermographic detection of turbulent flow separation on rotor blades of wind turbines in operation.
  Journal of Wind Engineering and Industrial Aerodynamics 226:105025 (12 pp.), 2022.

Publications and qualification of young academics

Publications

- J. ***Osmers***, N. Kaiser, M. Sorg, A. Fischer:
  Adaptive finite element eye model for the compensation of biometric influences on acoustic tonometry.
  Computer Methods and Programs in Biomedicine 200:105930 (10 pp.), 2021.
- A.-M. ***Parrey***, D. Gleichauf, M. Sorg, A. Fischer:
  Automated detection of premature flow transitions on wind turbine blades using model-based algorithms.
  Applied Sciences 11(18):8700 (23 pp.), 2021.
- M. ***Pillarz***, A. von Freyberg, D. Stöbener, A. Fischer:
  Gear Shape Measurement Potential of Laser Triangulation and Confocal-Chromatic Distance Sensors.
  Sensors 21(3):937 (22 pp.), 2021.
- L. ***Schweickhardt***, A. Tausendfreund, D. Stöbener, A. Fischer:
  Noise reduction in high-resolution speckle displacement measurements through ensemble averaging.
  Applied Optics 60(7):1871-1880, 2021.
  (highlighted article with excellent scientific quality, Editor's Pick)
- L. ***Schweickhardt***, A. Tausendfreund, D. Stöbener, A. Fischer:
  Parametric characterization of ground surfaces with laser speckles.
  Optics Express 30(8):12615-12629, 2022.
- Y. ***Schädler***, V. Renken, M. Sorg, L. Gerdes, G. Gerdes, A. Fischer:
  Power transport needs for the German power grid for a major demand coverage by wind and solar power.
  Energy Strategy Reviews 34:100626 (9 pp.), 2021.
- Y. ***Schädler***, M. Sorg, A. Fischer:
  Measurement data-driven investigation of the actual power grid resilience with increasing renewable energy feed-in.
  Energy Science & Engineering 10(1):145-154, 2022.
- Y. ***Schädler***, M. Sorg, A. Fischer:
  Data-based energy coverage measurements to discover the potentials of regional energy storage.
  tm - Technisches Messen 89(5):301-309, 2022.
- J. ***Stempin***, A. Tausendfreund, D. Stöbener, A. Fischer:
  Roughness measurements with polychromatic speckles on tilted surfaces.
  Nanomanufacturing and Metrology 4(4):237-246, 2021.
- A. ***Tausendfreund***, D. Stöbener, A. Fischer:
  In-process measurement of three-dimensional deformations based on speckle photography.
  Applied Sciences 11(11):4981 (11 pp.), 2021.

- C. ***Vanselow***, O. Hoppe, D. Stöbener, A. Fischer:
  Stereoscopic particle image velocimetry in inhomogeneous refractive index fields of combustion flows.
  Applied Optics 60(28):8716 (11 pp.), 2021.
- C. ***Vanselow***, B. Espenhahn, L. Schumski, D. Stöbener, D. Meyer, A. Fischer:
  Strömungsfeldmessung der Kühlschmierstoffzufuhr an der Schleifscheibe.
  tm - Technisches Messen 88(12):785-794, 2021.
- A. von ***Freyberg***, P. Helming, J. Friedrich, D. Stöbener, A. Fischer:
  Berührungslose Messung von Pitchwinkelabweichungen an Windenergieanlagen aus 150 m Entfernung.
  tm - Technisches Messen 88(11):686-695, 2021.

Conference contributions

- G. ***Behrends***, D. Stöbener, A. Fischer:
  Digitale Speckle-Korrelation zur Vorschubbestimmung bei der lateral scannenden Weißlichtinterferometrie.
  122. Jahrestagung der Deutschen Gesellschaft für angewandte Optik e. V. (DGaO), Bremen, 21.-23.9.2021, No. A8.
- B. ***Espenhahn***, L. Schumski, C. Vanselow, D. Meyer, D. Stöbener, A. Fischer:
  Methoden zur Strömungsfeldmessung der Kühlmittelzufuhr beim Schleifen.
  28. GALA-Fachtagung "Experimentelle Strömungsmechanik", Bremen, 7.-9.9.2021, No. 16 (8 pp.).
- A. ***Fischer***, A. von Freyberg, D. Stöbener:
  Tooth flank approximation with root point iteration – potentials and limits in gear metrology.
  70th CIRP General Assembly, E-conference, 22.-29.8.2021, No. P05.
- R. Sato, H. Matsukuma, Y. Shimizu, A***. Fischer***:
  Investigation of measurement range of a differential chromatic confocal probe employing a mode-locked femtosecond laser.
  10^{th} th International Conference on Leading Edge Manufacturing in 21^{st} Century (LEM21), E-conference, 14.28.11.2021, No. I11 (4 pp.).

Publications and qualification of young academics

Publications

- D. ***Gleichauf***, M. Sorg, A. Fischer:
  Lokalisierung der laminar-turbulenten Transition mittels thermografischer Strömungsvisualisierung und Hauptkomponentenanalyse.
  28. GALA-Fachtagung "Experimentelle Strömungsmechanik", Bremen, 7.-9.9.2021, No. 50 (10 pp.).

- D. ***Gleichauf***, M. Sorg, A. Fischer:
  Contrast enhancement in thermographic flow visualization on wind turbines in operation.
  TORQUE 2022 - The Science of Making Torque from Wind, Delft, 1.-3.6.2022.
  Journal of Physics: Conference Series 2265:022092 (8 pp.).

- P. ***Helming***, N. Poeck, A. v. Freyberg, M. Sorg, A. Fischer:
  Dynamic optical deformation measurements on wind turbines.
  TORQUE 2022 - The Science of Making Torque from Wind, Delft, 1.-3.6.2022.
  Journal of Physics: Conference Series 2265:022100 (9 pp.).

- M. ***Mikulewitsch***, J. Dong, D. Stöbener, J. Epp, A. Fischer:
  Oberflächeneinflüsse auf quantitative Nitrierschichtdickenmessungen mittels modellbasierter photothermischer Radiometrie.
  77 Härtereikolloquium (HK 2021), E-conference, 27.-28.10.2021, No. 8.

- F. ***Oehme***, M. Sorg, A. Fischer:
  Instationäre thermografische Strömungsvisualisierung zur Detektion von Strömungsablösung an Windenergieanlagen.
  28. GALA-Fachtagung "Experimentelle Strömungsmechanik", Bremen, 7.-9.9.2021, No. 49 (8 pp.).

- F. ***Oehme***, M. Sorg, A. Fischer:
  Detektion and localization of flow separation on operating wind turbines by means of unsteady thermographic flow visualization.
  TORQUE 2022 - The Science of Making Torque from Wind, Delft, 1.6.-3.6.2022.
  Journal of Physics: Conference Series 2265:022101 (9 pp.).

- A.-M. ***Parrey***, M. Sorg, A. Fischer:
  Automatisierte Detektion von verfrühten Transitionen an Rotorblättern mittels modellbasierter Algorithmen.
  28. GALA-Fachtagung "Experimentelle Strömungsmechanik", Bremen, 7.-9.9.2021, No. 14 (8 pp.).

- M. ***Pillarz***, A. von Freyberg, D. Stöbener, A. Fischer:
  Optische Messung zahnindividueller Formparameter am Beispiel von Geradverzahnungen.
  XXXV. Messtechnisches Symposium des AHMT, Kassel, 22.-23.9.2021.
  tm - Technisches Messen 88(S1):S53-S58, 2021.

- L. ***Schweickhardt***, A. Tausendfreund, D. Stöbener, A. Fischer:
  Speckle-Oberflächenmesstechnik unter Einsatz adaptiver Optiken.
  122. Jahrestagung der Deutschen Gesellschaft für angewandte Optik e. V. (DGaO), Bremen, 21.-23.9.2021, No. A5.
- L. ***Schweickhardt***, A. Tausendfreund, D. Stöbener, A. Fischer:
  Speckle pattern modulation for high-resolution displacement measurements.
  SPIE Optical Metrology, E-conference, 21.-26.6.2021, Vol.11782, No.117820D (7 pp.).
- D. ***Stöbener***, A. Fischer:
  Optical roughness measurements with robot-assisted part inclination compensation.
  22th International Conference & Exhibition of the European Society for Precision Engineering and Nanotechnology (euspen), Genf, 30.5.-3.6. 2022, pp. 357-360.
- A. ***Tausendfreund***, D. Stöbener, A. Fischer:
  Speckle photographic in-process measurement of three-dimensional deformations in running manufacturing processes.
  SPIE Optical Metrology, E-conference, 21.-26.6.2021, Vol.11782, No.1178205 (11 pp.).
- F. Frerichs, A. ***Tausendfreund***, T. Lübben:
  Comparison of temperature and displacement measurements with load simulations for the determination of Process Signatures.
  CIRP CSI 2022, Lyon, 8.-10.6.2022.
  Procedia CIRP 108(2):335-340.
- A. ***Tausendfreund***, F. Frerichs, D. Stöbener, A. Fischer:
  Experimental validation of workpiece deformation simulations by means of rigorous boundary condition analysis.
  CIRP CSI 2022, Lyon, 8.-10.06.2022.
  Procedia CIRP 108(2):341-345.
- M. ***Terlau***, A. von Freyberg, D. Stöbener, A. Fischer:
  In-Prozess-Messung der Werkzeugablenkung beim inkrementellen Blechumformen.
  21. GMA/ITG-Fachtagung "Sensoren und Messsysteme 2022", Nürnberg, 10.-11.5.2022, pp. 90-96.
- C. ***Vanselow***, D. Stöbener, A. Fischer:
  Systematischer Einfluss von inhomogenen Brechungsindexfeldern auf stereo- und tomo-PIV in Flammen.
  28. GALA-Fachtagung "Experimentelle Strömungsmechanik", Bremen, 7.-9.9.2021, No. 9 (8 pp.).

Publications and qualification of young academics

PhD theses

Influence of inhomegenous refractive index fields on Particle-Image-Velocimetry

Dr.-Ing. Christoph Vanselow

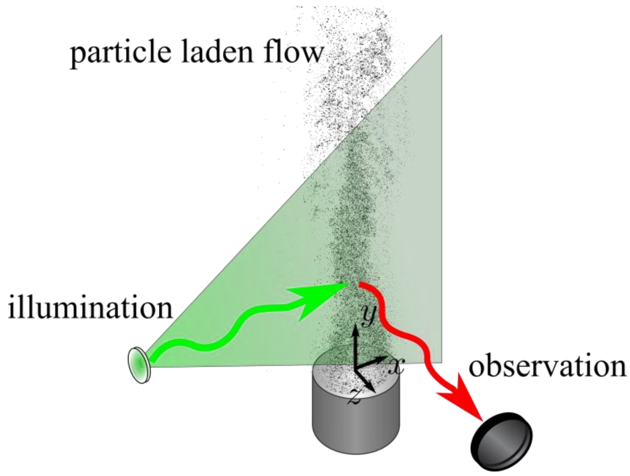
Date of thesis defense: 25 Aug 2021

Supervisor: Prof. Dr.-Ing. habil. Andreas Fischer

Valid measurements of flow fields are necessary for understanding and optimizing technical flow processes. Particle Image Velocimetry (PIV) is the most commonly used optical flow field measurement method, where the motion of particles following the flow is measured by at least one camera. However, applying PIV within hot gas, combustion, and two-phase flows, disturbing light refractions occur due to inhomogeneous refractive index fields. Since this causes a so far unknown measurement error, this work aims to quantify and, if necessary, correct the resulting PIV measurement errors.

For this purpose, the measurement error caused by the refractive index is described theoretically. In addition, a simulative and an experimental method for quantifying the PIV measurement error caused by light refraction are validated, which allows the correction of the systematic error. In hot gas, combustion, and two-phase test flows, these methods are applied to reveal the quality of PIV measurements in these environments.

For two hot air flows with a maximum temperature of 291 °C and a diameter of 6 cm, the resulting velocity error is not relevant for PIV measurements. In contrast, a dominant measurement error can occur in combustion flows. For the investigated premixed propane flame flows, an increasing measurement error is identified for higher Reynolds numbers. Furthermore, the mean flame diameter correlates with the amount of light deflection. Depending on the PIV measurement variant, the measurement error varies from not relevant, over 1-2 % up to 12 %. In macroscopic two-phase flows with unknown fluctuating surfaces, the proposed experimental quantification method enables valid PIV measurements, where the relative PIV measurement error could be reduced from up to 20 % to a low single-digit percentage range.



Schematic of occurring light refractions during PIV measurements in non-isothermal flows

[1] C. Vanselow, O. Hoppe, D. Stöbener, A. Fischer: Stereoscopic particle image velocimetry in inhomogeneous refractive index fields of combustion flows. Applied Optics 60:8716-8727, 2021.

[2] C. Vanselow, D. Stöbener, J. Kiefer und A. Fischer: Particle image velocimetry in refractive index fields of combustion flows. Experiments in Fluids 60(10):149 2019.

Model-based optical and photothermal layer thickness measurement for near-process and in-process application in manufacturing processes

Dr.-Ing. Merlin Mikulewitsch

Date of thesis defense: 21 Apr 2022

Supervisor: Prof. Dr.-Ing. habil. Andreas Fischer

Ensuring acceptable manufacturing quality of miniaturized or stress and corrosion resistant metallic components is a major engineering challenge. This challenge is met by thermochemical production processes, such as laser chemical machining and gas nitriding. However, due to the complex and difficult-to-access process environments of these processes, there is currently no process internal measurement technology for the produced microstructures and nitriding layers, respectively.

The laser-chemically produced microstructures are covered by a fluid layer and can so far only be measured under laboratory conditions by removing them from the process environment. In the nitriding process, the nitride layer formation can only be indirectly and unreliably predicted by gas sensors in the 550°C nitriding furnace. In view of this lack of process measurement technology for the layers produced in both processes, the development of suitable measurement methods is of great importance.

For the application in these two complex manufacturing environments, the optical layer thickness measurement techniques of confocal fluorescence microscopy and photothermal radiometry are studied. The focus was the development and application of signal models required for the layer thickness quantification as well as investigating the two measurement methods regarding their measurability and application limits.

As a result, a metrological access was created for both thermochemical manufacturing processes for the first time, despite the non-linearity of the systems. Quantitative layer thickness measurements of the LCM fluid layer and the nitriding layer were enabled with micrometer uncertainty by means of physical modeling of the measurement principles, even in the chaotic LCM fluid environment and blazing hot nitriding furnace, respectively.

The thickness of the opaque nitriding layer can be measured using a contactless optical system even in an industrial environment.

[1] M. Mikulewitsch, A. von Freyberg, A. Fischer: Confocal fluorescence microscopy for geometry parameter measurements of submerged micro-structures. Optics Letters 44(5):1237-1240, 2019.

[2] A. Fischer, M. Mikulewitsch, D. Stöbener: Indirect fluorescence-based in situ geometry measurement for laser chemical machining. CIRP Annals - Manufacturing Technology 69(1):481-484, 2020.

Publications and qualification of young academics

Awards

Deutsche WindGuard Young Scientists Award 2021

For the fifth time, Deutsche WindGuard GmbH and BIMAQ awarded the Young Talent Award for outstanding student works.

In awarding the prize, particular emphasis was placed on progress in science, understanding of measurement systems and the relevance of research results for practical measurement tasks. The awards were presented to

- Jacob ***Friedrich*** for his bachelor thesis: *Evaluation of Laser-Optical Measurement Data of Wind Power Rotor Blades*

and to

- Marina ***Terlau*** for her master thesis: *Investigation of heat propagation in rotor blade leading edges during active thermography*

Congratulations from the BIMAQ team!

Prof. Andreas Fischer presented the certificates and the donated prize money after the digitally performed annual closing ceremony of the institute.

Jacob Friedrich, Prof. Andreas Fischer, Marina Terlau

Prof. Fischer receives ERC grant

European Research Council
Established by the European Commission

The European Research Council (ERC) has awarded Prof. Fischer a Consolidator Grant for the investigation of a groundbreaking research approach on indirect optical measurements. This will enable him to conduct research over a period of 5 years with an interdisciplinary research team to overcome current limits of optical geometry measurements and build the foundation for a new class of measurement instruments.

Events

Participation at events and conferences

Date	Event / Conference	Location	Participant(s)	
22 – 29 Aug 2021	**70th CIRP General Assembly**	München International E-Conference	A. Fischer	oral presentation
7 – 9 Sep 2021	**27. GALA-Fachtagung "Experimentelle Strömungsmechanik"**	Bremen	A. Fischer B. Espenhahn D. Gleichauf F. Oehme A.-M. Parrey	oral presentations
21 Sep – 23 Sep 2021	**DGaO 123th Annual Meeting 2021**	Pforzheim	G. Behrends L. Schweickhadt	oral presentation
22 Sep – 23 Sep 2021	**XXXV. Messtechnisches Symposium des AHMT**	Kassel	M. Pillarz	oral presentation
26 Oct – 28 Oct 2021	**HK – 77th HärtereiKongress 2021**	Köln E-Conference	M. Mikulewitsch	oral presentation
5 May 2022	**Best Energy Solutions Symposium Bremen**	Bremen	A. Fischer M. Sorg	steering committee member
10 – 11 May 2022	**21st ITG/GMA Fachtagung Sensoren und Messsysteme**	Nürnberg	A. v. Freyberg	oral presentation
12 May 2022	**MAPEX Methods Workshop – Fluid Dynamics**	Bremen	A. Fischer D. Stöbener B. Espenhahn	oral presentation
1 Jun – 3 Jun 2022	**TORQUE 2022 The Science of Making Torque from Wind 9th Editon**	Delft	D. Gleichauf P. Helming F. Oehme	Poster presentation
30 May – 3 Jun 2022	**EUSPEN 22st International Conference**	Genf	D. Stöbener	Poster presentation
8 Jun – 10 Jun 2022	**6th CIRP Conference on Surface Integrity**	Lyon	A. Tausendfreund	oral presentation
4 Jul – 8 Jul 2022	**QIRT 2022 Conférence sur la thermographie infrarouge quantitative**	Paris	F. Jensen A.-M. Parrey	oral presentation

Events

Events @ BIMAQ

Date	Event	Organizing institution
12 Oct 2021	**Hot enough to melt your bicycle frame – but not for precision measurements of ultrathin metallic layers**	BIMAQ
2 Nov 2021	**BEST - Ring lecture** **Wind turbines: Challenges of on-site research**	Universität Bremen / BIMAQ
12 Nov 2021	**Measurement campaign for thermographic detection of flow separation at the wind farm in Thedinghausen**	BIMAQ
30 Nov 2021	**From the lab to the app: challenging in-process measurements in real-world environments**	BIMAQ
1 Dec 2022	**Informing students and exchanging experiences about scholarships in Germany: „Begabtenförderungswerke in Deutschland - Erfahrungen und Wege zur Förderung des eigenen Studiums“**	Dies Academicus / BIMAQ
18 Jan 2022	**Invited talk: Prof. C. Rembe (TU Clausthal)** **Moderne Methoden der Laser-Doppler-Vibrometrie**	BIMAQ
3 Mar 2022	**Jugend forscht – Pupils are experimenting (regional competition Bremen-Mitte)**	Jugend forscht / BIMAQ
28 Apr 2022	**Girls Day – Mädchen-Zukunftstag**	BIMAQ
2 Jun 2022	**Kids University 2022:** **We can see colors and temperatures, too?**	BIMAQ
7 Jun 2022	**Exchange with expert on biomechanics - Dr. Adrien Baldit, Université of Lorraine**	BIMAQ
14 Jun 2022	**Invited talk: Dr. S. Stemmler / Prof. D. Abel (RWTH Aachen)** **Potenziale virtueller Sensoren zur Qualitäts- und Prozessregelung von Fertigungssystemen**	BIMAQ
29 Jun 2022	**Student excursion to Bremen’s hydropower plant**	BIMAQ

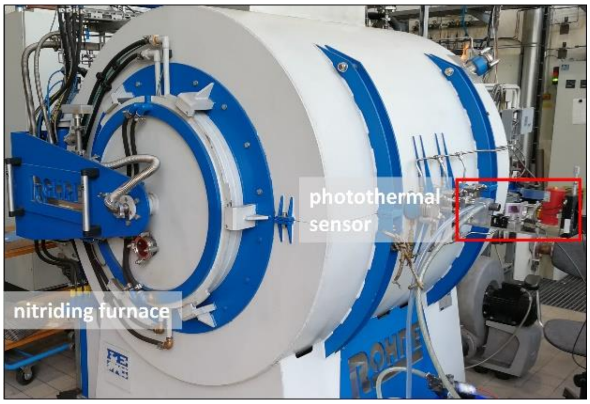
- *Prominent guest speakers in BIMAQ’s seminar on measurement techniques*

  Within the scope of our seminar, outstanding guest speakers gave inspiring presentations on their topical scientific work. The BIMAQ-team says thank you to:

  - Prof. Dr.-Ing. C. Rembe (TU Clausthal): *Modern methods of laser Doppler vibrometry.* 18 Jan 2022
  - Dr.-Ing. S. Stemmler (RWTH Aachen): *Potentials of virtual sensors for quality and process control of manufacturing systems.* 14 Jun 2022

- *Hot enough to melt your bicycle frame – but not too hot for precision measurements of ultra-thin metallic layers*

At temperatures of up to 550 °C, some aluminum alloys, such as those used in bicycle frames, will begin to melt. At these temperatures, technical components are chemically modified in nitriding furnaces using the toxic ammonia gas to increase their surface hardness and corrosion resistance. Measuring the protective nitriding layer that forms on the surface, which is one-tenth the thickness of a human hair, initially seems impossible under these circumstances.



However, recent experiments at BIMAQ have shown that with a clever measurement approach and adaptations to the process environment, high-precision measurements of the optically opaque nitriding layer are possible even during formation of the layer. For it turns out that if the already very hot surface is periodically heated with a laser, the resulting surface temperature exhibits a dependence on the layer thickness. This fact can be exploited using a model-based measurement approach such as photothermal radiometry to determine the actual thickness of the opaque layer with sub-micrometer accuracy.

In a measurement campaign 2021 successful in-process quantifications of the µm-thick nitrided layer was demonstrated for the first time in experiments at an industrial nitriding furnace together with our project partner IWT.

Events @ BIMAQ

- *Wool threads confirm thermographic detection of flow separation*

  For the verification of a measurement method for thermographic detection of flow separation on rotor blades of running wind turbines in open field, tufts were glued onto the rotor blade of a wind turbine at the wind farm in Thedinghausen. Figure 1 shows the team work preparing the tufts, for which wool threads were attached to adhesive tapes. The tufts were then attached manually to one of the rotor blades at a great height with the aid of a cherry picker, see Fig. 2. The view from that working place was a fantastic and extraordinary experience. Figure 3 shows the glued tufts on one of the rotor blades ready for use to serve as a reference for our brand-new thermographic flow visualisation. Thanks to the excellent team work and experiment preparation, the validation succeeded!

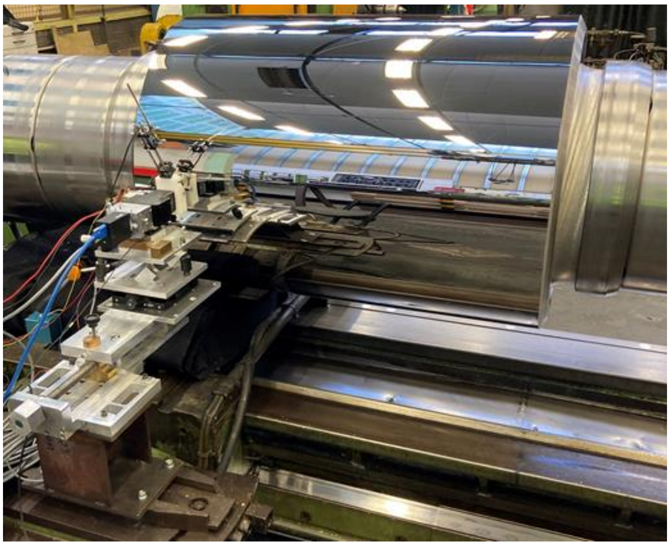
Fig. 1: Fixing the wool threads on an adhesive tape in preparation for tuft assembly.

Fig. 2: Assembly of the tufts at great heights using a cherry picker

Fig. 3: WEA with tufts glued on

- *From the lab to the app: Challenging in-process measurements in real-world environments*

  Designing and testing a new measurement system is already no small feat in the comfort of the scientist's laboratory. However, at some point the freshly conceived system has to make its debut in the real world. BIMAQ and its partners in the project SiToH were up to the challenge and travelled to the sheet metal plant of Tata Steel in Düsseldorf with their lateral scanning white-light interferometer setup to put it through a series of tests on a 600 mm roller. The pulse of the busy factory could be felt on every surface, the hum of the lathe could not only be heard, but seen in the camera live-feed of the device. The conditions were less than ideal, some voices of concern deemed the task impossible. Of course, it was a huge jump from the lab to the factory; difficulty -pessimists might even say failure- was expected on the first outing of a new technology. While the measurement approach did work as intended, the uncertainty needs to reduced in future. As a result, the project team came home with Gigabytes of valuable data, which will lead the further way to ultimately enable nanometer precision under harsh industrial conditions.



LSWLI setup measuring on a 600 mm roller at Tatasteel's sheet metal plant in Düsseldorf.

- *MAPEX Methods Workshop – Fluid Dynamics*

  As part of the MAPEX Workshop - Fluid Dynamics held in Bremen on 12 May 2022, Prof. Andreas Fischer enjoyed holding an invited a scientific lecture on 'Introduction to experimental fluid dynamics'. Scientific equipment and methods are crucial for achieving a progress in research. Therefore, the MAPEX Methods Workshops offer a platform for exchanging on the scientific equipment and the expertise available within the MAPEX community. The workshop covered the whole beauty of flow research, including the areas of computational and experimental fluid dynamics.

Events

Events @ BIMAQ

- *Jugend forscht - regional competition*

In March 2022, the regional competition 2022 of the initiative 'Jugend forscht' was held as an online event. Over three days, the jury discussions took place with over 120 papers from various disciplines. As a result, twenty placements each from the 'Schüler experimentieren' and 'Jugend forscht' sections qualified for the state competition. Dr. von Freyberg from the BIMAQ once again was part of the jury team and enjoyed the enthusiasm of the pupils who presented their innovative ideas and experimental results.

- *Girl's Day*

28. April 2022

On 28 April 2022, the BIMAQ offered two activities for the Girl's Day. In the morning workshop, prepared by Mr. Behrendt, the girls in grade 7 and 8 were able to discover the world through electronic senses. By combining different electronic components like resistors, the girls were able to build a working thermometer or measure their own height.

For the afternoon workshop, Ms. Parrey and Ms. Terlau provided an insight into the world of temperature visualization through thermal cameras. The girls from school grade 5 and 6 were able to experiment with water of different temperatures and explore how different materials, like balloons, appear in the thermal image. The session was concluded by a photo shoot with the thermal camera.

- *BIMAQ meets expert on biomechanics*

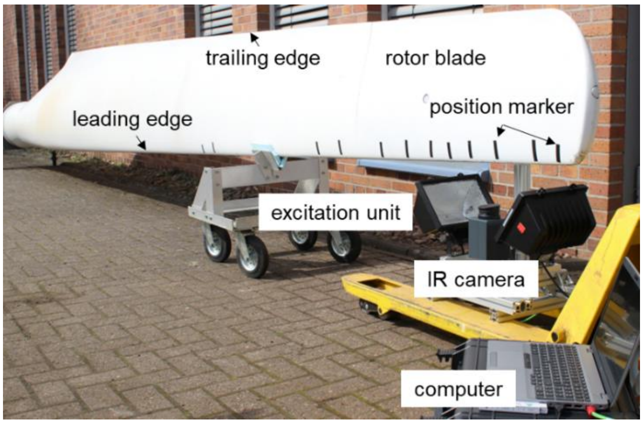
In June 2022, Dr. Adrien Baldit from the Université of Lorraine visited the BIMAQ. We enjoyed learning the metrological challenges in the different application fields of manufacturing workpieces and engineering biological tissues, respectively. The exchange of the newest findings on commonly applied measurement principles revealed an excellent basis for a stronger cooperation between both institutions in future.

- *Thermographic in-situ measurements on BIMAQ rotor blade*

  During the first warm days of the year 2022, a spontaneous cleaning action of the existing rotor blade of a wind turbine took place in front of the BIMAQ technical center. The reason for this was a planned measurement campaign to investigate the damage condition of the rotor blade leading edge using active thermography. This measurement method enables large-area, non-destructive and non-contact material testing with regard to the detection of different types of defects. In addition, the measurement method is very flexible and thus provides the basis for in-situ use on the rotor blade. Thermographic examinations, which had previously only taken place in the laboratory at BIMAQ, were to find their way out into the field during this measurement campaign.

  The figure shows the cleaned rotor blade and the mobile thermographic measurement system attached to it. The results of this measurement campaign demonstrated that active thermography allows for recording the prevailing state of damage on a real rotor blade, showing different states of the material. Surface damage can be clearly distinguished in the thermogram from other types of defects such as sub-surface defects. However, the interpretation of the measured data needs further aspects to taken into account. In contrast to the investigations in the lab, the test object has for instance dents, which also influence the thermographic signals. The in-situ measurement situation thus differs significantly from what was considered at first in the laboratory, which demonstrates the need for further research.

  As a result, the measurement campaign underlines the importance of applied research outside the laboratory for the successful transfer of knowledge from the laboratory to the industrial application to serve our society.



Photograph of the mobile thermographic measurement set-up outside at a rotor blade

Events

Events @ BIMAQ

- *Kids University*

We did it again on 2 June 2022: The BIMAQ contributed to the annual Kids University. Prof. Fischer talked about the topic 'We see colors... and also temperatures?'. Together with children, he explored the basics about colors and light, the riddle of the rainbow and the rich beauty of light. Beyond what human beings are able to see, a new perception of our daily world waited for the children. As a result the answer was found: With technology we are indeed able to see temperatures! Dear pupils stay curious and never stop asking questions!

- *Student excursion to Bremen's hydro-power plant*

In addition to the lecture series on renewable energies, we visited the Bremen hydroelectric power plant in the river Weser on June 29. The plant, equipped with Kaplan turbines, is currently the largest tide-dependent run-of-river power plant in Germany with an electrical output of up to 10 MW. Depending on the ebb and flow of the tide, the electricity generated is sufficient to supply up to 15,000 households with an annual saving of 13,000 tons of the greenhouse gas carbon dioxide. Many thanks to the company SWB for enabling the excursion and the amazing insights!

- *Return of the seminar on measurement techniques*

After almost two years of Covid19-related knowledge sharing via digital channels, the seminar on measurement techniques has returned as a live event. The seminar on measurement techniques now once again offers the platform at the university of Bremen to gain insights into the current metrology research, to discuss together in 3d and to learn about the limits of measurability. In addition, the seminar will continue to be offered as a Zoom stream, so that participants can also tune in from outside. We look forward to welcoming you to our seminar on measurement techniques - live in 3D and in true colors, or in the stream!

Notes

Impressum

BIMAQ

Universität Bremen
BIMAQ
Bremer Institut für
Messtechnik, Automatisierung
und Qualitätswissenschaft
Prof. Dr.-Ing. habil. Andreas Fischer
Linzer Straße 13
28359 Bremen
Germany

Phone: +49/421/218-64600
Fax: +49/421/218-64670
info@bimaq.de
www.bimaq.de

June 2022

Universität Bremen

Did you like what you read and you want to be a part of it?

We look forward to receiving your informative application at any time, preferably in the form of a pdf file by e-mail to

info@bimaq.de

with your
- cover letter,
- curriculum vitae and
- copies of certificates!