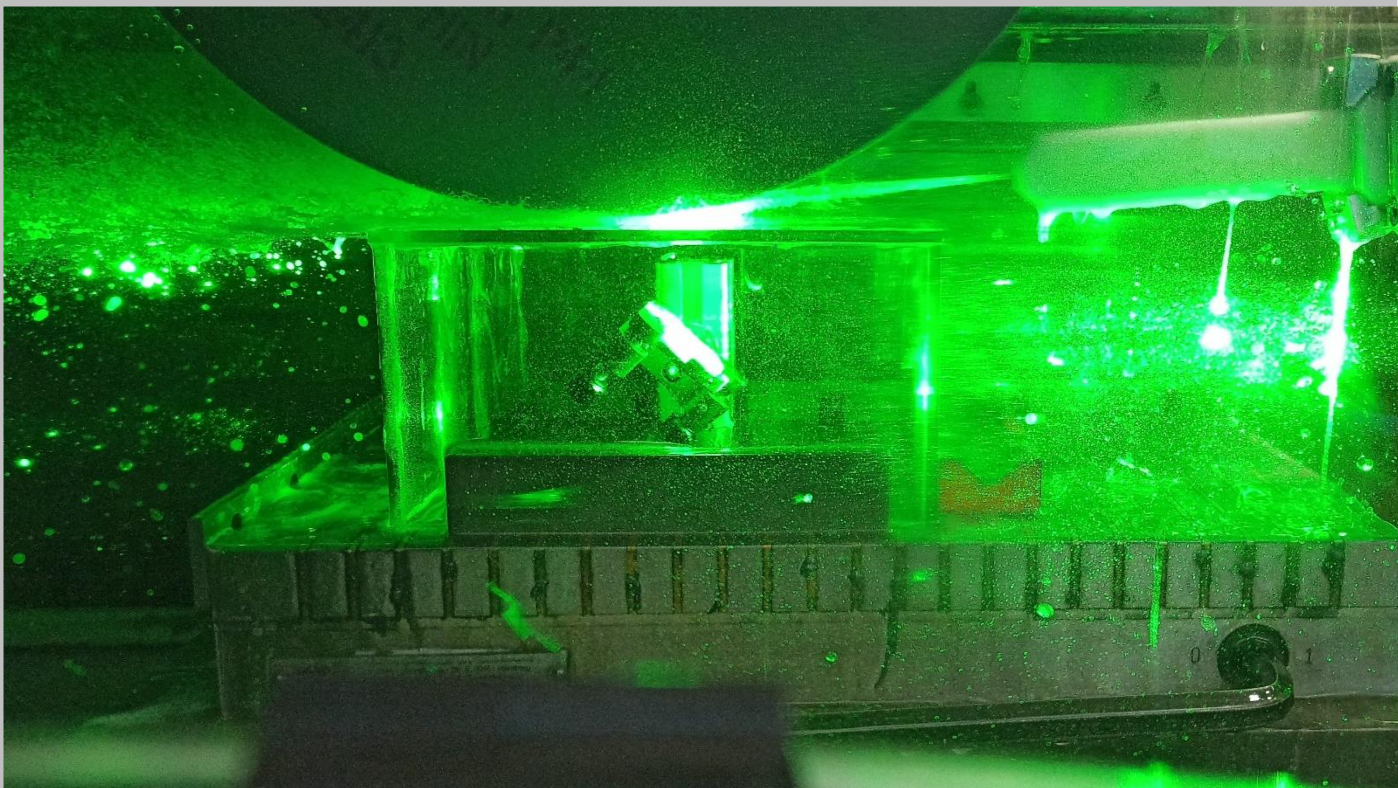
Annual Report

2022/2023



Laser-based measurements of the coolant flow velocity field in a grinding machine

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 continued its strong reseach and teaching activities 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. As an example, particle image velocity is used to measure the cooling liquid flow field during grinding, i.e. in a turbulent two-phase flow. As a further example, high-speed strain field measurements by means of laser speckles have been performed to understand the time-resolved mechanical load of the workpiece during the electrical discharge machining process. In both cases, the new process insights will contribute to our understanding of machining, which is crucial for a sustainable manufacturing of parts with no compromises in quality. The latter achievements will be presented at the general assembly of the well-known International Academy for Production Engineering (CIRP), which is the 5th year in series that a research work from the BIMAQ was selected for presentation at CIRP. Furthermore, I was elected to become an Associate Member of the CIRP.

Regarding wind turbines, we provided new measurement solutions for science and industry. For instance, thermographic flow visualization has been enabled to detect stall on wind turbines, and the capability to resolve the dynamic behaviour during a wind gust has been successfully demonstrated. Furthermore, a laser scanning system has been developed to measure the tower and the rotor blade deformations - at a commercial wind turbine in operation, with centimetre resolution, contactless from 150 m distance and with no turbine preparation.

And there is so much more to explore in the present annual report about our past and ongoing activities, e.g., the first results of our ERC project. Before you start to read, let me express my particular thanks to the continuing support of the Deutsche WindGuard GmbH, who donated for the 6th time a student award for young talents. My congratulations to the two awardees in 2022. I also thank our seminar guests Prof. Günther (MRI, Medical Imaging) and M. Abdollahpour, Dr. Bockelmann (Communication engineering) for their inspiring talks, and of course all BIMAQ students, colleagues as well as research and industrial partners for their continuous support.

Bremen, June 2023

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.

BIMAQ

Bremen Institute for Metrology, Automation and Quality Science

Research
Teaching
Knowledge

Metrology

Automation

Quality Control

University of Bremen

Methods

Measuring System Theory

- Modelling and Simulation
- Uncertainty Relations
- Limits of Measurability

Measuring System Technology

- Optical High Speed Measuring Systems
- Multi-Sensor-Systems
- Coordinate Measuring Systems

➔ modelbased, dynamic Measuring Systems

Application

Produktion Engineering & Materials Science

- Geometrical and Roughness Metrology
- Optical In-Process-Metrology
- Thermography, Edge Zone Analyses

Wind Power Systems & Flow Processes

- Gear Measuring Technology
- Gear Metrology
- Flow Measurement Technology

BIMAQ competences

BIMAQ - the institute

Staff

Director

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

Emeritus

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

Administration

Eva ***Schultze***

Research Scientists

Dr.-Ing. Gert ***Behrends***

Dipl.-Ing. Jakob ***Dieckmann*** (since 02/2023)

M. Sc. Caroline ***Dorszewski*** (since 02/2023)

M. Sc. Björn ***Espenhahn***

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

Dr.-Ing. Daniel ***Gleichauf*** (until 12/2022)

Dipl.-Ing. Paula ***Helming*** (until 04/2023)

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Dr.-Ing. Merlin ***Mikulewitsch*** (until 06/2023)

M. Sc. Claudia ***Niehaves*** (since 05/2023)

Dipl.-Ing. Felix ***Oehme*** (until 04/2023)

M. Sc. Ann-Marie ***Parrey*** (until 06/2023)

M. Sc. Marc ***Pillarz*** (until 02/2023)

M. Sc. Tajim ***Rahman*** (since 12/2023)

Dr.-Ing. Yannik ***Schädler*** (until 08/2022)

M. Sc. León ***Schweickhardt***

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Dr.-Ing. Dirk ***Stöbener***

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

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

M. Sc. Philipp ***Thomaneck*** (since 04/2023)

Dr.-Ing. Christoph ***Vanselow*** (until 01/2023)

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Josefa Feline ***Jerg***

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Sam ***Nilles***

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Arthur ***Süß***

Misri ***Talati***

Philipp ***Thomaneck***

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**	CIRP	International Academy for Production Engineering
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**	BEST	Bremen Research Centre for Energy Systems
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**		Regelungstechnisches Kolloquium in Boppard
Andreas **Fischer**	WGP	Wissenschaftliche Gesellschaft für Produktionstechnik
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**	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.

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 laser triangulation and terrestrial laser scanners as well as thermal, magnetic and acoustic probing 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 200 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 or measurements on wind turbines during operation.

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

BIMAQ - the institute

Laboratories

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 was involved in developing large gear standards with a diameter of 2000 mm and more.

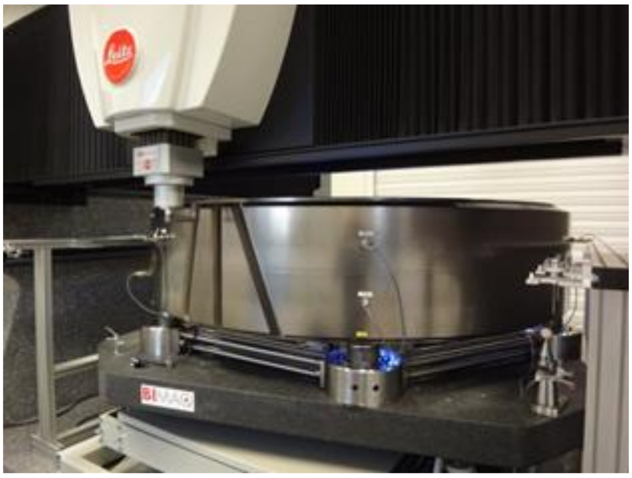
Furthermore, BIMAQ analyses the cause-effect relationships between gear manufacturing, geometric deviations and occurring gearbox damages. Also, special test rigs for lightweight gears were established. In the field of quality inspection of gears, algorithms are developed in order to evaluate dimensional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

Technical specifications

Portal coordinate measuring machine Leitz PMM-F 30.20.7:

- measuring volume:
  $3.0 \times 2.0 \times 0.7$ m³

Tactile measurement of large cylindrical gearing



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

- measuring uncertainty:
  $MPE_E = (1.3 + (L \text{ in mm})/400)$ µm
- 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
- calibration of inside sensor systems
- software development

Contact: a.freyberg@bimaq.de

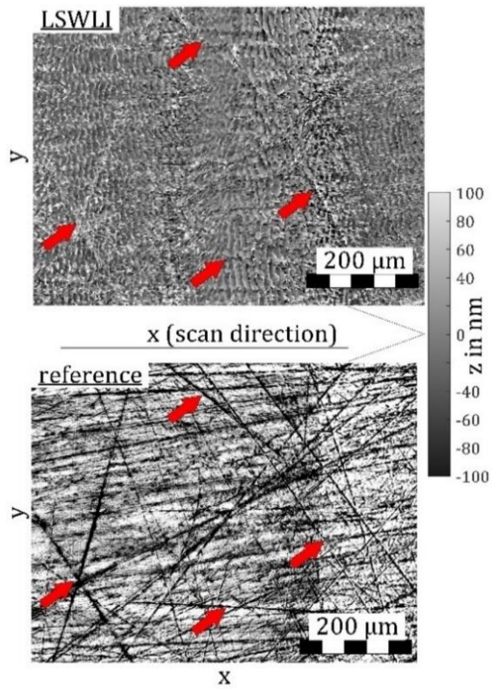
LAB

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 focuses 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

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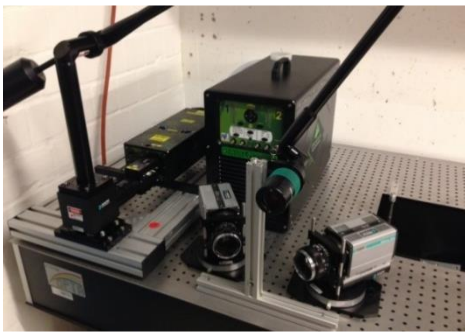
Laboratories

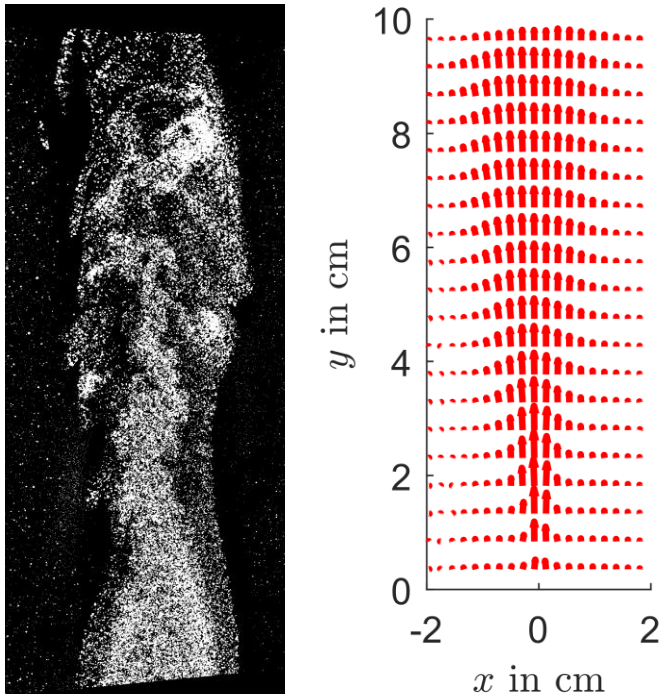
LAB

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

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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

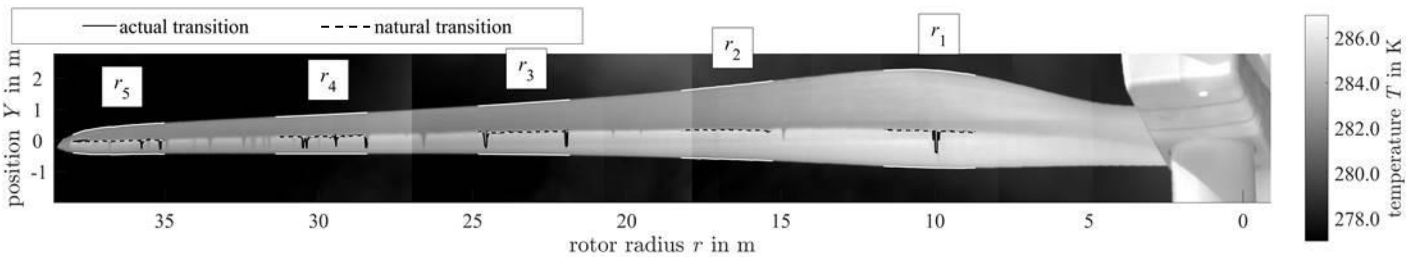
ImageIR thermographic imaging system:

- 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

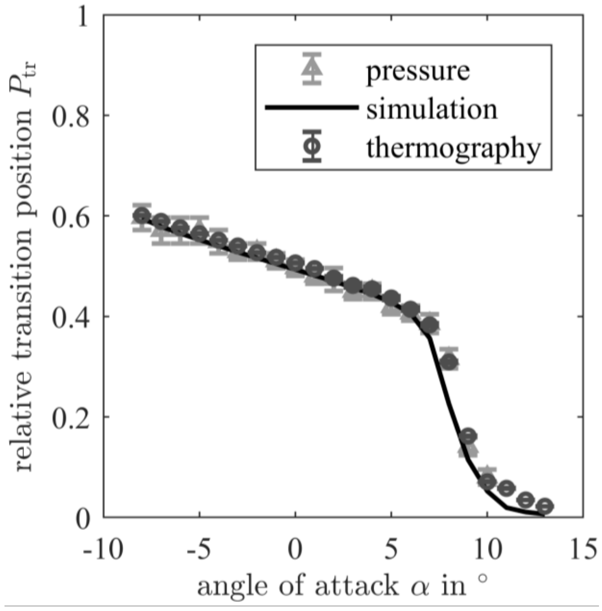


Evaluated thermographic image of the rotor blade of an 1.5 MW wind turbine with a 77 m rotor diameter

Laboratories

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

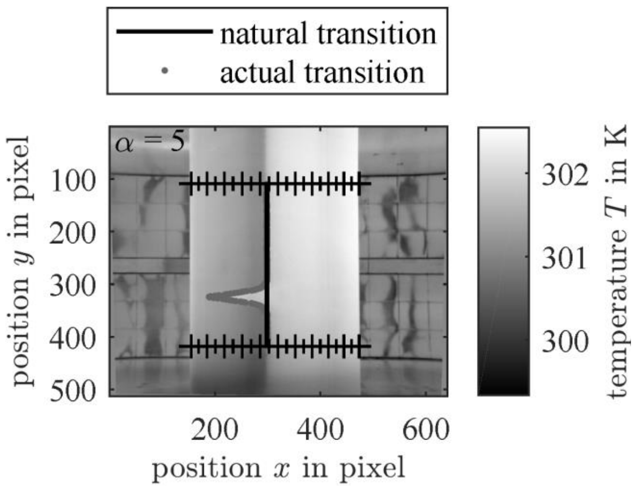
Technical data

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: m.sorg@bimaq.de

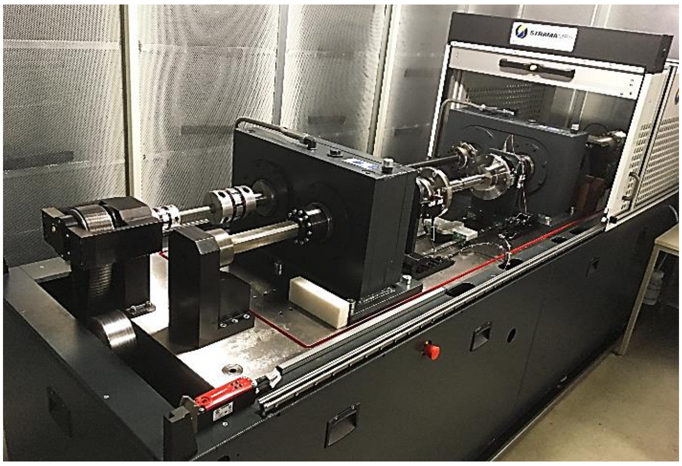
LAB

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

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Laboratories

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

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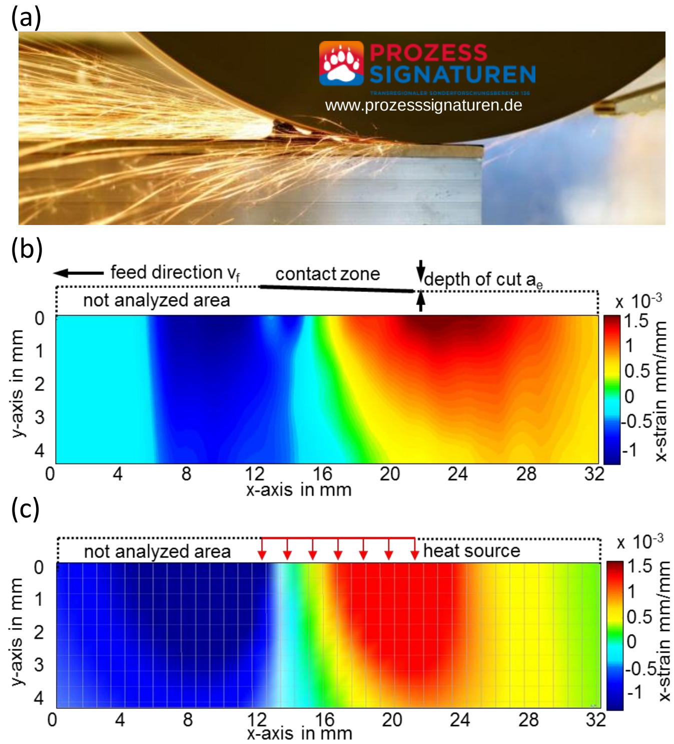
SFB/TRR 136 Process Signatures – Subproject C06

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

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, and laser hardening [2]. Furthermore, a novel approach for in-process measurements was presented, which is based on an analysis of the shape-modified speckle correlation function and enables three-dimensional deformation measurements [3].

In addition to the three-dimensional reconstruction of the deformation fields, a central objective of the project was to determine parameters for establishing process signatures from the time-resolved stress fields measured in highly dynamic manufacturing processes. In this context a quantification of the measurement uncertainty budget and a reduction of measurement uncertainty components were achieved. In addition, the data analysis was 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.

Research

PROTA

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,
Claudia Niehaves

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. However, the production speed of LCM is lower, in particular because the removal rate is limited to avoid obstructive boiling bubbles, see Fig. 1.

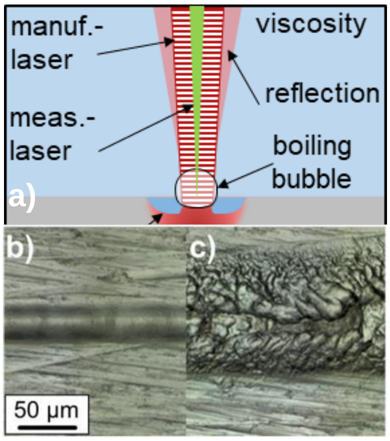


Fig. 1: a) Schematic representation of the LCM process and different manufacturing results for b) slow machining without boiling bubbles and c) fast machining with disturbances due to boiling bubbles caused by increased surface temperature.

The research project *Prota* aims to increase the process understanding of LCM in order to minimize the influence of boiling bubbles on the removal quality. For the first time, the process modeling will take the interaction between laser-induced surface temperature and boiling bubble generation into account, in particular with the aid of near-process measurements of the 2D surface temperature distribution and the geometry of the workpiece.

Confocal fluorescence microscopy was shown to be suitable for microgeometry measurements in liquids if a model-based signal processing approach is used [1]. To facilitate an enhanced process modeling, the confocal geometry measurement in the fluorescent liquid is combined with a temperature measurement by determining the temperature-dependent fluorescence lifetime τ. As a result of our current work, the lifetime can be measured with ns-precision, see Fig. 2. As next steps, reference measurements to convert the lifetime into a temperature as well as the implementation of two-dimensional lifetime measurements are needed to realize in-process temperature field measurements.

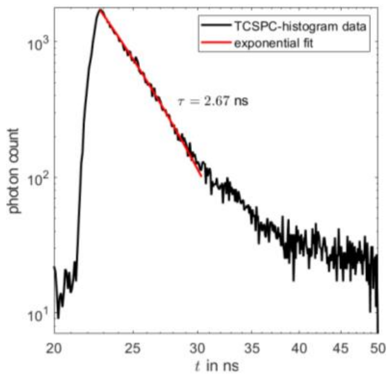


Fig. 2: Time-correlated single-photon measurement to determine the temperature-dependent fluorescence lifetime τ of the LCM process-fluid.

[1] 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.

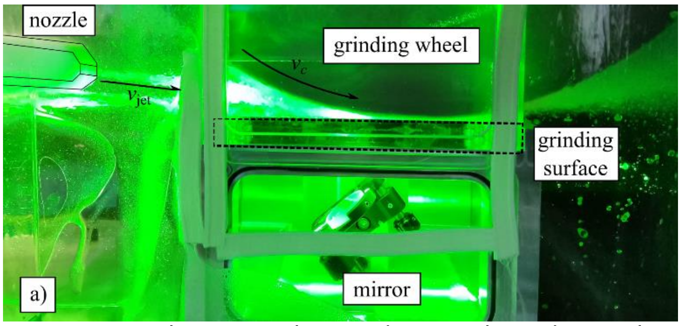
Near-process flow measurements of the cooling lubricant supply in grinding processes

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

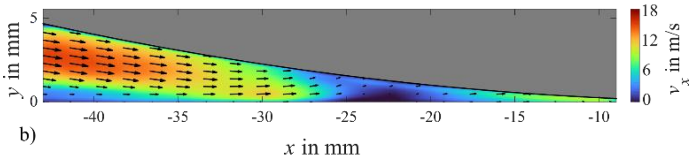
Grinding is an essential manufacturing process to produce high quality surfaces. To prevent surface damages from grinding burn, a liquid cooling is used. However, the key flow mechanisms for an efficient coolant supply are not yet understood, so that only heuristic, indirect optimizations of the coolant flow could be performed so far. To identify the flow mechanisms, optical in-process measurements of the coolant flow velocity are realized, and the achievable measurement uncertainty is assessed. Finally, the flow findings are jointly evaluated with the associated workpiece heating.

Due to the disturbing light refraction in the two-phase flow (coolant, air), a new method was derived to determine the coolant flow field. By tracking the visualized coolant surface structures with image correlation techniques known from particle image velocimetry (PIV), flow field measurements with an uncertainty of less than 1 % were achieved [1]. This result is an essential milestone to investigate the flow behaviour of the coolant in a grinding machine quantitatively while coping with the limited optical access.

Subsequently, the propagation of the coolant due to the liquid-tool interaction alongside the fast-rotating grinding wheel and, consequently, the supply of liquid into the grinding process were studied. For varied supply conditions, de- and acceleration effects were identified, which give important fluid flow information. The observed effects within the region of interaction are consistent with thermal limits of tapering grinding experiments [2]. By revealing the fluid's behaviour within the region of interaction, a physical explanation for the effectiveness of different supply conditions has been derived.



Experimental setup in the grinding machine during the optical flow field measurements.



Flow field of the coolant, which gets entrained via the grinding wheel into the grinding process.

[1] 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.

[2] 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 71(1):301-304, 2022.

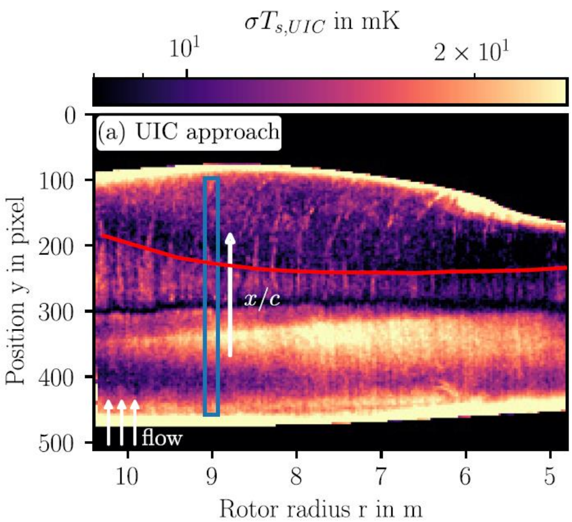
ThermoStall

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

As 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 emissions.

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



Turbulent flow separation detected in thermographic image with the UIC approach by optical contrasts [1].

The aim of this project was 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.

The principle potential of thermography for detecting flow separation was verified in both wind tunnel applications and field experiments [1]. Different spatiotemporal image processing methods are studied to increase the contrast between the flow separation and other flow states, while one open research question was how to record and evaluate image series on a moving rotor with unsteady inflow conditions [2]. As a result of the project findings, the in-process flow visualization on wind turbines in operation are fundamentally enhanced by the time-resolved stall detection capability.

[1] 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.

[2] F. Oehme, D. Gleichauf, N. Balaresque, M. Sorg, A. Fischer: Thermographic detection and localisation of unsteady flow separation on rotor blades of wind turbines. Frontiers in Energy Research 10:1043065 (15 pp.), 2022.

StreuCompress

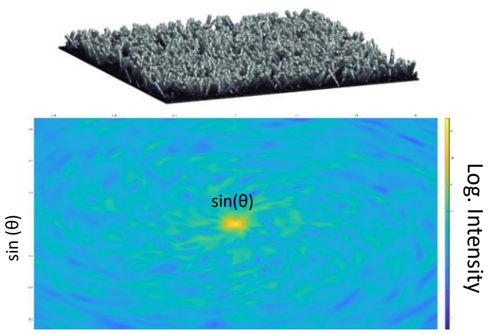
Design method for in-process testing of nanostructured surfaces based on scattered light measurements and machine learning

Funding organization: DFG
Funding ID: 497286574
Duration: 1 Dec 2022 – 30 Nov 2025
Project scientist: Tajim Md Hasibur Rahman

Precisely engineered nano-structured surfaces increase the quality and functionality of electrical and mechanical systems. Since the fabrication of nano-structured surfaces inherently includes process uncertainties, a surface quality inspection is required.

The inspection of nano surfaces must be non-invasive as well as fast and robust enough to be a part of the mass-production line. Since a scattered light measurement method matches the time resolution and robustness requirements [1], Angle-Resolved Scatterometry (ARS) is a promising measurement approach, where the angle of incidence of a coherent light source is varied and scattered light is detected for different angles [2]. However, the image processing for detecting defects in the surface nanostructure always needs an adaption on the manufactured nanostructure. Therefore, the project *StreuCompress* aims to develop a universally applicable method to design an ARS-based surface inspection that is suitable for any nanostructured surfaces.

As one-for-all solution, the design method relies on performing virtual measurements using a digital surface model and a rigorous scattered light simulation using the Discrete Dipole Approximation (DDA) algorithm, together with a machine-learning-based approach for training the image processing [3]. The resulting image processing enables to distinguish defective nano surfaces from the defect-free ones. In addition, compressive sensing approaches are investigated to speed up the measurement and to minimize the number of required sensor positions.



Light scattering simulation of a ZnO nanograss structure with 12 μm × 12 μm dimension by DDA: (a) ZnO nanograss surface, (b) Logarithmic intensity distribution of scattered light.

[1] G. Alexe, A. Tausendfreund, D. Stöbener, A. Fischer: Model-assisted measuring method for periodical subwavelength nanostructures. Applied Optics 57(1):92-101, 2018.

[2] A. Tausendfreund: Laser-optische Messverfahren zur Charakterisierung von Oberflächendefekten im Nanometerbereich. Dissertation, Universität Bremen, 2019.

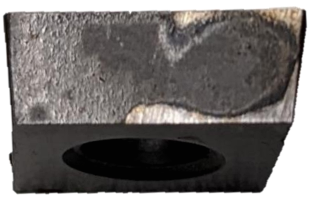
[3] G. Alexe, A. Tausendfreund, D. Stöbener, A. Fischer: Maschinelles Lernen für Abdeckungsmessungen von Oberflächen mit abgeschiedenen Au-Nanosphären mittels Lichtstreuung. tm - Technisches Messen 86(S1):S47 – S51, 2019.

MoVeHo

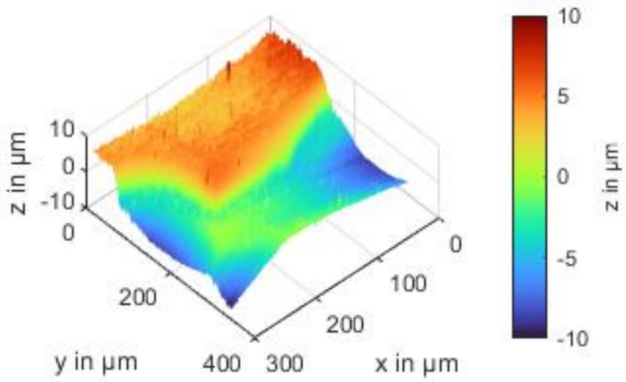
Model-based in-process tool wear determination in high-performance turning

Funding organization: DFG
Funding ID: 521384759
Duration: 1 Jul 2023 – 30 Jun 2026
Project scientist: León Schweickhardt

Tools are of central importance for productivity and manufacturing costs in metal-cutting production. The maximization of tool life is therefore the focus of tool development, especially in high-performance machining. Here, the main focus is on the use of hard coatings and coating systems to optimize the property profile of the tools. Despite the variety of tool coatings used, there are still considerable deficits in the understanding of the underlying wear mechanisms. To reduce these deficits, a novel greybox model is developed for the process of high-performance turning. The model combines complementary methods for tool wear determination (knowledge- and data-based models) and uses data sources from in-process measurements for the wear investigation that have not been considered so far.



Wear on the edges of a tipped turning tool.



WLI topography measurement of tipped turning tool with multi-layered surface.

For the training of the data-based neural network, the wear parameters of the cutting tool in the workspace of a machining process must be determined. This requires in-situ measurement methods for the tool geometry and layer thickness. In the project *MoVeHo*, optical measurement methods are studied, which do not affect the cutting process, allow good accessibility without spatial restriction of the process and offer high spatial and temporal resolutions.

A previous study showed that photothermal radiometry is suitable for quantitative thickness measurements of the nitride layer under in-process conditions in an industrial nitriding furnace [1]. In *MoVeHo*, the signal model will be enhanced from single-layer to multi-layer systems. In addition, a laser line triangulation sensor is used to measure the tool geometry. Both sensor systems will then be mounted on a 6-axis industrial robot in the turning machine, to collect an extensive data basis during numerous tool wear experiments for the training of the blackbox model component as part of the greybox model.

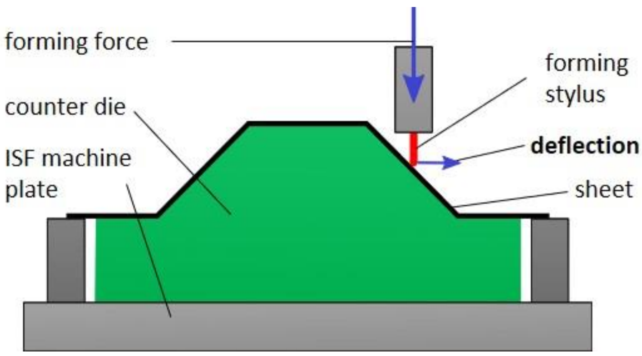
[1] M. Mikulewitsch, J. Dong, A. Fischer: Influences on quantitative nitriding layer thickness measurements using model-based photothermal radiometry. HTM J. of Heat Treatment and Materials 77(5):357-373, 2022.

RapidSheet

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. While 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. The combination of the ISF process with an additive manufacturing of the counter die in a single machine tool was proposed in the project *RapidSheet*. To also increase the accuracy of ISF, the deflection of the forming stylus must be corrected. For this purpose, an in-process tool deflection measurement was investigated.



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

To measure the tool deflection optically with a low uncertainty in a large machining volume, a novel multi-sensor-system was created, where the sensors cover overlapping sub-regions of the machining volume. Each sensor consists of a camera chip and a mask, through which an LED attached to the tool tip casts a shadow on the camera. The tool tip position is evaluated from the image of the shadow.

An experimental characterization of a single sensor proved an axial measurement range of at least 500 mm whereas the lateral measurement range is 300 mm. The sensor's potential for measuring the lateral position was shown, but a second sensor is required to determine the axial position component with a sufficient measurement uncertainty [1, 2].

In further experiments, the combination of two perpendicular sensors was investigated. The system is capable of measuring the 3d tool tip position, but the measurement error increases with larger angles of view. Compensating the systematic error, the measurement uncertainty is < 50 µm and thus sufficient for the tool tip position measurement in ISF.

[1] M. Terlau, A. von Freyberg, D. Stöbener, A. Fischer: In-Process tool deflection measurement in incremental sheet metal forming. IEEE Sensors Applications Symposium (SAS 2022), Sundsvall, Sweden, 1.-3.8.2022. No. 1570797357 (6 pp.).

[2] A. von Freyberg, M. Terlau, D. Stöbener, A. Fischer: Optische Messung der Werkzeugablenkung in der inkrementellen Blechumformung. tm – Technisches Messen, 2023.

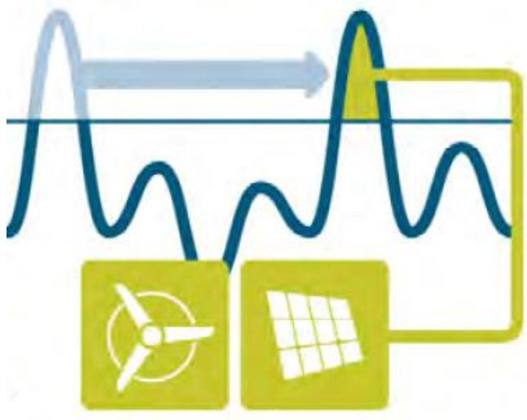
BrewFlex

Potentials of making energy loads flexible and efficiency increase – How brewerys can optimally use their potentials of a flexible loads to support and manage the energy transition

Funding organization: AiF
Funding ID: 22949 N
Duration: 1 May 2023 – 31 Oct 2024
Project scientist: Yannik Schädler

In order to defossilize the energy system, the development of operational potentials for load flexibility and energy efficiency increase is inevitable, because the use of renewable energies requires a significantly increased flexibility of the entire system, both on the supply and on the demand side, due to their fluctuating character.

Since in many cases smaller companies lack a systematic overview of the business potentials, the project *BrewFlex* aims to identify and quantify the potentials for load flexibilization and energy efficiency improvement from a technical and business perspective in small and mid-sized enterprises in the brewing industry.



Schematic visualization of load adaptation to a regenerative energy source (load flexibilization). ©freqcon.com

The potentials are recorded and evaluated on the basis of essential, real measured process data. At the same time, the costs and revenues for operational adjustments to utilize the potentials are collected in order to evaluate their impact. The aim of the project is to produce an industry guide that transparently presents the potential survey as well as the evaluation methods developed during the project.

The BIMAQ is contributing to the method development by developing a web-based data collection tool that can be used to collect real load characteristics in breweries and consolidate them in a database. Standardized analysis algorithms are developed for the collected data, which enable comprehensive data visualizations to understand data correlations and potentials. The analysis and visualization tools can then be used to derive possible measures for load profile flexibility and energy efficiency improvement and to assess their energy efficiency and economic consequences.

[1] 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.

[2] 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.

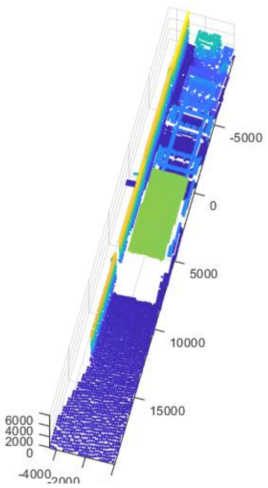
3D-Safety

Certified system for person safety

Funding organization: BAB
Funding ID: FUE0653B
Duration: 15 Nov 2022 – 31 Oct 2024
Project scientist: Philipp Thomaneck

In view of increasing competition, port operators are faced with the challenge of operating their ports and terminals efficiently and thus with increasing automation. The increasing degree of automation with simultaneous minimization of risks in turn places special demands on the technology used.

In order to ensure personal safety in the port area, a new class of so-called 3D multilayer scanners is to be used. In order to achieve certification status, it is not only necessary to evaluate the data sufficiently quickly, but it must also be ensured that person recognition is carried out redundantly, i.e. via several sensors and two independently operating algorithms.



3D measuring data of a scene within a container terminal showing a container (green) on a truck (light blue).

The goal of the project is the development of an evaluation system, which guarantees this certified person security in the port area, based on 3D multilayer scanners. In addition to the redundantly operating algorithms, this system is to have > 128-fold increased data processing, a frame rate of 10 Hz and a signal range of 100 m.

After a preparatory data processing, the data evaluation shall be developed, tested and evaluated via 4 different methodological approaches: The application of statistical algorithms, the use of a principal component analysis [1], the 2D image recognition via trained neural networks or the object recognition in the 3D point cloud via a trained AI are planned. Finally, the four developed algorithms are to be linked via ensemble learning in order to increase the uncertainty of the evaluation system on the one hand and to ensure the required redundancy on the other hand.

Due to the systems and functions to be developed, the safety of the logistics of goods weighing tons in a time-critical man-machine network can be significantly improved. In the future, the developed technology can also be transferred to other applications with necessary personal safety, e.g. driverless transport systems.

[1] 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.

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 scientists: Marc Pillarz,
Philipp Thomaneck

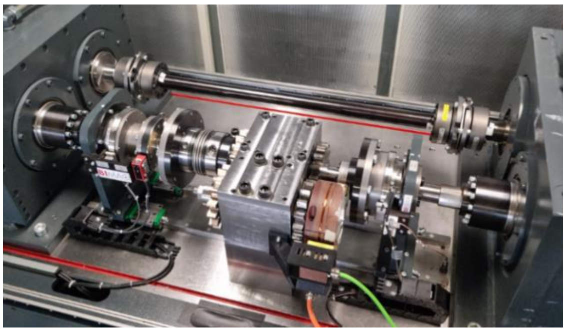
In order to meet climate protection targets, there is a trend in industry towards conserving resources and saving energy through lightweight construction. Coupled with the objective of expanding the wind energy sector and installing larger wind turbines with a power ≥ 5 MW, lightweight construction is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

If the output of wind turbines increases, the mass and material consumption of its components will also rise. In order to save resources and energy, the material consumption in the design and manufacturing of gearboxes must be reduced by lightweight construction. Due to the high dynamic loads acting on wind turbine gearboxes, lightweight gears have not been used in wind turbine gearboxes today. Previous lightweight construction concepts only considered the structural optimization of the gearwheel body, but not the gear rim. This shows potential for new, holistic lightweight design concepts.

The joint project *FlexGear* aims to develop design guidelines for holistic lightweight gears with integrated load monitoring for wind turbine gearboxes.

The additively manufactured lightweight demonstrator with a weight reduction of over 50 % compared to a conventional gear is being experimentally tested under static and dynamic loads as part of the project. As a result, the design concept was validated for the nominal load range by static load tests. In addition, experimental investigations were carried out in a dynamic gear test rig, where the inside sensor system was used for the first time. For this purpose, strain sensors were mounted at highly stressed positions of the gear, with which precise measurement signals from the tooth flank, tooth root and lightweight structure could be recorded and evaluated [1].

The remaining project period will be used to investigate further optimizations potentials of the lightweight design.



Dynamic gear test rig with lightweight gear and telemetry inside sensor measuring system

[1] M.Terlau, M. Pillarz, A. von Freyberg, A. Fischer: Validation of an inside sensor system for deformation measurements on bionic lightweight gears. Sensor and Measurement Science International (SMSI 2023), Nürnberg, 8.-11. Mai 2021, No. P22, pp. 322-323.

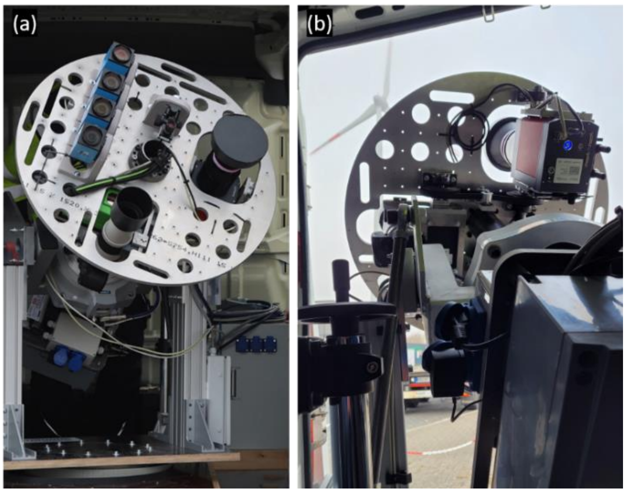
Precise measuring system for non-contact acquisition and analysis of the dynamic flow behaviour of wind turbine rotor blades

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, since the wind speed, the turbulence level and the angle of attack vary, e.g., 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 other methods that use invasive preparations of the blade surface, thermographic flow visualization enables a contactless differentiation between different flow regimes by evaluating the different surface temperatures as a result of the flow-dependent heat transfer coefficient [1]. So far, the measurement system only visualizes static flow phenomena by taking single snapshots of the rotor blade during operation and does not consider dynamic deformations [2].

To enable the study of the dynamic flow behaviour including blade deformations, a co-rotating measurement platform has been developed in the project *PreciWind*, so that the measurements can 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 combined thermographic and laser-based measurements of the dynamic flow in conjunction with the dynamic structural behaviour, and thus new insights in the dynamic behaviour of wind turbines.



(a) Front view of the co-rotating measurement system.
(b) Back view of co-rotating measurement system while performing measurements on a wind turbine.

[1] D. Gleichauf, F. Oehme, A.-M. Parrey, M. Sorg, N. Balaresque, A. Fischer: On-site contactless visualization of the laminar-turbulent flow transition dynamics on wind turbines. tm - Technisches Messen, 2023.

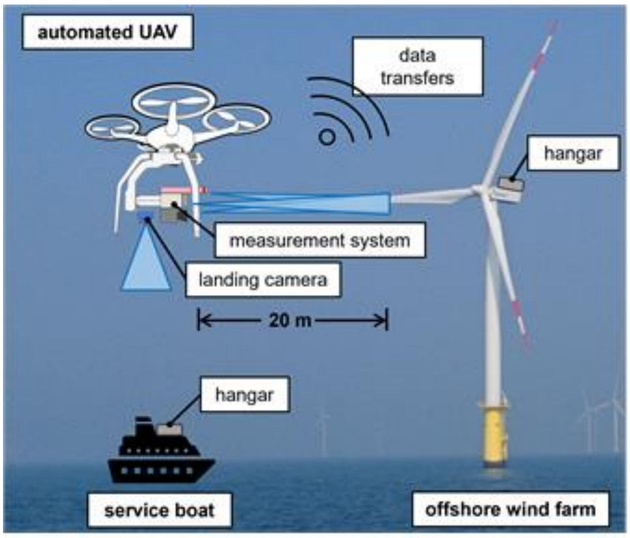
[2] P. Helming, A. Intemann, K.-P. Webersinke, A. von Freyberg, M. Sorg, A. Fischer: Assessing the rotor blade deformation and tower-blade tip clearance of a 3.4 MW wind turbine with terrestrial laser scanning. Wind Energy Science 8:421-431, 2023.

AutoFlow

Thermographic flow condition detection on rotor blades of offshore wind turbines during operation using an automated and disturbance robust flight system

Funding organization: BMWK
Funding ID: 03EE3064A
Duration: 1 Aug 2022 – 31 Jul 2025
Project scientist: Friederike Jensen

Currently, the wind turbines are shut down for a condition analysis, which leads to high downtime costs for maintenance. The research project *AutoFlow* focuses on recording and evaluating the blade condition during operation. An automated multi-sensor equipped flight system will be deployed, which can perform thermographic as well as laser-based measurements, as shown in the illustration. The results gained in this project should not only lead to significant savings in maintenance costs for system operators, but also increase the operational safety by enabling the detection and repair of potential damage at an early stage.



Schematic of a drone-based thermographic flow measurement for offshore wind turbine inspection.

A main focus of the project is the thermographic flow visualization as a tool for the analysis of the boundary layer flow condition of a rotor blade. Previous research shows that even small modifications of the aerodynamic airfoil such as contamination or erosion have a negative influence on the boundary layer flow [1]. For onshore wind turbines, ground-based measurement systems are currently used. For offshore wind turbines, however, ground-based measurements from a boat are not possible, which is why a drone-based thermography system will be developed in *AutoFlow*.

The specific requirements for the measurement system include a limited installation space of 60 x 60 x 120 mm³, a low weight of approx.. 500 g, a low power supply with max. 12 V, and a measurement distance of 20 m - 50 m to the rotor blade. Another challenge is the automated data acquisition. The flow conditions of the rotor blades will be recorded section by section, and an on-board quality check is performed to repeat measurements if necessary. Following the measurement session, the data will be stitched together so that the flow condition of the entire rotor blade can be analyzed and evaluated.

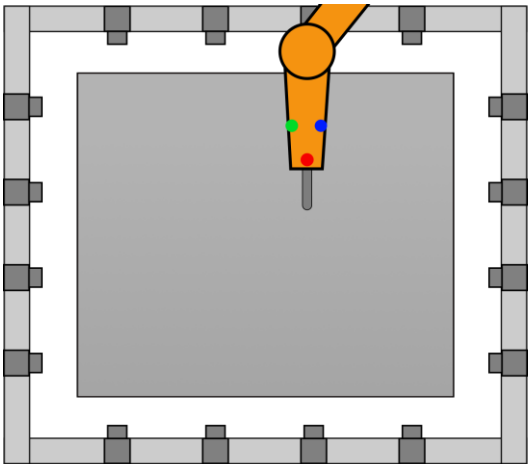
[1] C. Dollinger, N. Balaresque, N. Gaudern, M. Sorg, A. Fischer: IR thermographic flow visualization for the quantification of boundary layer flow disturbances due to the leading edge condition. Renewable Energy 138:709 (13 pp.), 2019.

High-precision formed parts through measurement-based real-time control of the volumetric compensation of robot-assisted forming processes

Founding organization: BMWK
Funding ID: 22860 BG
Duration: 1 Mar 2023 – 28 Feb 2025
Project scientist: Marina Terlau

The flexible production of customized sheet metal parts is a challenge in industrial production. Forming processes in particular require expensive tools adapted to the target geometry. Industrial robots offer a suitable alternative for forming sheet metal parts because of their flexibility and low cost for a comparatively large machining volume. However, the deformation and the additional positioning uncertainty of the robot result in larger geometric deviations of the formed parts than during forming with conventional machine tools.

The aim of the project *µRoboForm* is therefore to reduce the geometric deviations by means of a measurement-based compensation of the position and orientation deviations of the tool center point (TCP) in robotic forming processes. For this purpose, incremental forming (ISF) is considered as an example. A network of novel optical sensors, which are installed independently of the robot kinematics, is used for a precise detection of the position and orientation of the TCP. The position information is processed in the robot's motion control system in order to actively correct deviations. In the final phase of the project, the controlled forming process will be demonstrated and the reduction of geometric deviations of the formed workpieces will be validated.



Concept of sensor network for measuring the TCP position and orientation. LEDs at the TCP highlight the points to be measured.

Previous work showed that the developed optical sensors are suitable for measuring the three-dimensional TCP position in ISF [1, 2]. Precisely measuring not only the TCP position but also the TCP orientation, which means measuring at least three positions simultaneously, in real-time will be the key challenge of the project.

[1] M. Terlau, A. von Freyberg, D. Stöbener, A. Fischer: In-Process tool deflection measurement in incremental sheet metal forming. IEEE Sensors Applications Symposium (SAS 2022), Sundsvall, Sweden, 1.-3.8.2022. No. 1570797357 (6 pp.).

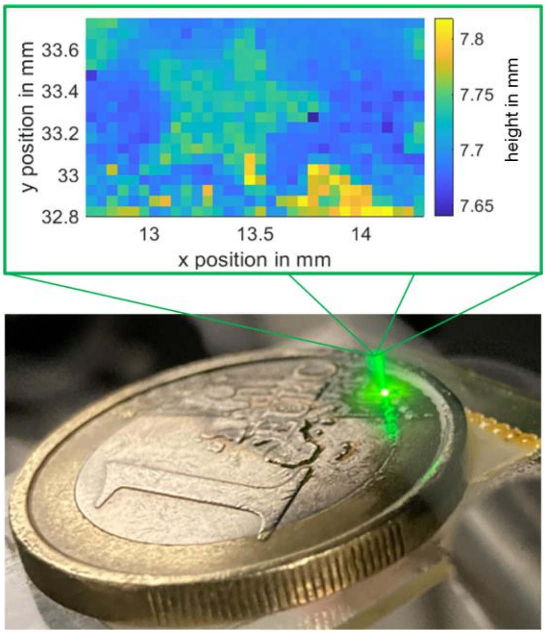
[2] A. von Freyberg, M. Terlau, D. Stöbener, A. Fischer: Optische Messung der Werkzeugablenkung in der inkrementellen Blechumformung. tm – Technisches Messen, 2023.

InOGeM

Indirect optical geometry measurement

Funding organization: ERC
Funding ID: 1010440456 - InOGeM
Duration: 1 Sept 2022 – 31 Aug 2027
Project scientists: Andreas Tausendfreund, Björn Espenhahn, Gert Behrends

Optical metrology is driving our society forward and has strong impacts on manufacturing, mobility, medicine and fundamental science. Optical techniques allow fast and precise geometry measurements, but only if sufficient light energy is reflected from the object's surface to the photo detection unit. For this reason, specific measurement approaches for each surface type had to be developed such as deflectometry for highly reflective surfaces. To provide one single measurement approach applicable to any surface and with the potential of sub-micrometre resolution, *InOGeM* will initiate a paradigm shift: instead of measuring the object's surface, the geometry of the surrounding atmosphere is measured.



3D geometry of the star of a 1 € coin using indirect optical measurement of the surrounding fluorescent atmosphere.

In the very first stage of the project, the feasibility of the InOGeM approach has been successfully determined. For this purpose, a solution of Pyrromethene 567 in Di-Ethyl-Hexyl-sebacate was used to seed the measurement atmosphere with fluorescent particles, while the the excitation and detection of the fluorescent light was carried out with a confocal microscope setup.

One challenge, in comparison to former experiments with completely liquid environments, is the small concentration of fluorescent particles. Less than 1 % of the recorded data contains a fluorescence event. Due to this scarcity of useful information, the current research work is focused on designing appropriate signal filtering algorithms and a model-based calculation of the object geometry, combining fluid dynamics, optics and statistical and numerical models.

Figure 1 shows the first result of a three-dimensional geometry measurement of one of the stars on the number-side of a 1 € coin. The star protrudes by approx. 50 µm, which is in agreement with the nominal embossing height.

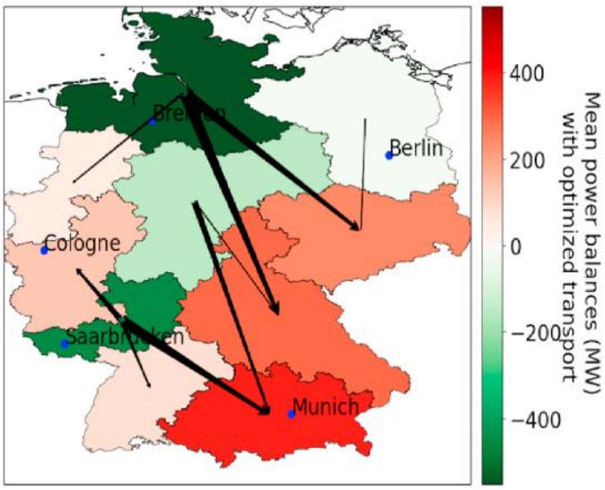
[1] M. Mikulewitsch, A. von Freyberg, A. Fischer: Confocal fluorescence microscopy for geometry parameter measurements of submerged micro-structures. Optics Letters 44(5):1237-1240, 2019.

Hydrogen for Bremen's industrial transformation

Funding organization: BMBF
Funding ID: 03SF0687A
Duration: 1 Sept 2022 – 28 Feb 2026
Project scientists: Caroline Dorszewski, Jakob Dieckmann

Studies on the potential of regenerative energies with respect to H_2 electrolysis have been performed on a coarse resolution and with certain assumptions [1]. As our part in the project *hyBit*, we will describe the regenerative potential for the region around Bremen with a higher resolution and based on measured data.

The measurement data are collected at different locations in the region by suitable measurement infrastructure. From these data, which includes wind speed, global radiation, humidity, the energy weather will be derived, which describes the potential of renewable energy sources. The data collection of the meteorological values together with the power feed-in and power load time series of the individual districts will then be used for realizing a reliable prediction of the residual load. This enables realistic planning of future energy supply for green hydrogen.



The mean residual power demand and following transfer needs for the windiest day in 2018 [2].

By matching the residual load values of the neighbouring counties, for example via the GEOWISOL database [2], not only Bremen's renewable potential but also the renewable generation supply of the surrounding regions will be considered via the distribution grid. Thus, *hyBit* enables Bremen to improve the grid integration of renewable energies in the entire region also beyond Bremen's borders.

Furthermore, by analysing power load profiles, the coverage of the load by renewable energies can be maximized with load flexibility potentials and a respective real-time control of the loads. Demonstrating this approach, 100 feed-in and load detection sensors on farms in the Bremen region will be tested exemplarily, while the derived methodological solutions will be transferable to other application areas - in the whole area of Bremen and beyond.

[1] G. Kakoulaki, I. Kougias, N. Taylor, F. Dolci, J. Moya, A. Jäger-Waldau: Green hydrogen in Europe – A regional assessment: Substituting existing production with electrolysis powered by renewables. Energy Conversion and Management 228:113649, 2021.

[2] 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, 2021.

Measurement services for the industry

Measurement services

Dimensional measurements

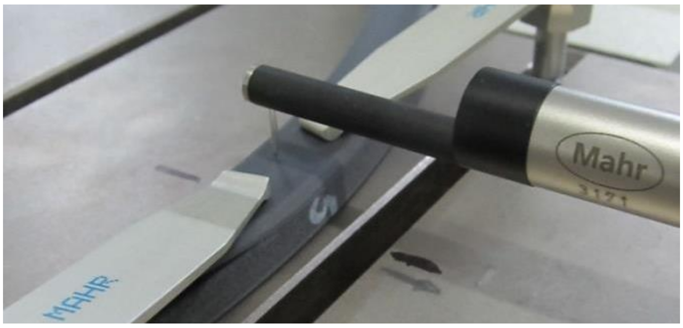
Duration: continuously

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: m.sorg@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	MuV	SE	WING	BB	Sem. BSc	Sem. MSc	CP	Students WiSe 22/23 and SoSe 2023
Messtechnik (SE, PT)	●		●	○	○	3rd		3	89
Übung Messtechnik	●			○	○	3rd		1	80
Labor Messtechnik	●			○	○	3rd		1	25
Regelungstechnik	●			○		5th		3	35
Übung Regelungstechnik	●			○		5th		1	34
Labor Regelungstechnik	●			○		5th		1	21
Grundlagen der Qualitätswissenschaft	●		●	●		5th	1st	3	80
Messtechnik (MuV)		●				2nd		3	29
Autonome mechatronische Systeme 2		●				2nd		3	29
Regenerative Energien	●		○	○	○	4th 6th	1st	3	8
Prozessnahe und In-Prozess-Messtechnik	●		●	●		4th 6th	1st 2nd 3rd	3	15
Geometrische Messtechnik mit Labor * AUKOM	●		●	○		5th	1st	3	19
Methoden der Messtechnik - Signal- und Bildverarbeitung	●		●	●		5th	1st 2nd	3	4
Einführung in die Automatisierungstechnik mit Labor	●		●	○		5th	1st 2nd	3	20
Produktion von Verzahnungen (held by several chairs)	●		○				1st 2nd	6	7
Labor Produktion von Verzahnungen (held by several chairs)	●		○				1st 2nd	3	4
Grundlagenlabor Produktionstechnik			●			4th		2	24
Messtechnisches Seminar	●		●	●		4th	1st 2nd	3	17

● mandatory (Pflicht/Wahlpflicht/Wahlfach)
○ facultative

Teaching

Teaching activities, student projects, graduation works

PT Produktionstechnik
MuV Maschinenbau und Verfahrenstechnik
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.

Student projects

Kind of project	Title	Semester	Course of studies*
Informatikprojekt	Ansteuerung eines 3D-Laserscanners (Bilderfassung und -auswertung in Python	SoSe 2023	BSc MuV

Teaching

Graduation works

Bachelor theses

- C. ***Drünert***:
  Thermografische Untersuchung der Turbulenzkeilbildung an Rotorblättern von Windenergieanlagen in Abhängigkeit der Defektposition.
  Colloquium: 30.08.2022
- L. ***Weise***:
  Untersuchung des Einflusses von Regen auf den Energieertrag von Windenergieanlagen.
  Colloquium:07.11.2022
- J. ***Schröder:***
  Messstrategie zur Charakterisierung des lastabhängigen Verformungszustandes von ganzheitlichen Leichtbauzahnrädern.
  Colloquium: 15.12.2022
- A. ***Süß***:
  Implementierung eines monochromatischen Speckle-Rauheitssenors am Roboterarm zur Quantifizierung der Quereinflüsse Neigung und Wölbung.
  Colloquium:16.01.2023

Master theses

- S. ***Buhr:***
  Charakterisierung eines Inside-Sensorsystems für Leichtbauzahnräder zur Erfassung von dynamischen Verformungen und Lastspitzen.
  Colloquium: 06.07.2022
- P. ***Thomaneck***:
  Validierung eines ganzheitlichen bionischen Leichtbaudesigns für Verzahnungen hinsichtlich dynamischer Belastungen.
  Colloquium: 14.03.2023
- J. ***Walther***:
  Drohnengeeignetes Messsystem zur Bestimmung der Geometrie von Rotorblattprofilen.
  Colloquium: 20.06.2023

Master thesis, co-supervised with TU Hamburg (TUHH)

- J. ***Manschke***:
  Thermografische Untersuchung der Strömungsbeeinflussung durch Erosionsschäden an Rotorblattvorderkanten von Windenergieanlagen.
  Colloquium: 31.01.2023

Publications and qualification of young academics

Publications

Books

- 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, Vol. 89(3), De Gruyter, Berlin, 2022.
- A. ***Fischer***, R. Bergmann (Eds.):
  Multi-dimensional optical measurement techniques.
  In: tm - Technisches Messen, Vol. 89(6), De Gruyter, Berlin, 2022.
- D. ***Gleichauf***:
  Beiträge zur thermografischen Strömungsvisualisierung und Lokalisierung der laminar-turbulenten Transition an Rotorblättern von Windenergieanlagen.
  Staats- und Universitätsbibliothek Bremen, 2022.
- M. ***Mikulewitsch***:
  Modellbasierte optische und photothermische Schichtdickenmessung für den prozessnahen und In-Prozess-Einsatz in Fertigungsverfahren.
  Staats- und Universitätsbibliothek Bremen, 2022.
- M. ***Pillarz***:
  Modellbasierter Multi-Distanz-Messansatz zur optischen Messung der Verzahnungsgeometrie.
  Staats- und Universitätsbibliothek Bremen, 2023.
- Y. ***Schädler***:
  Modellierung der Energiesystemtransformation in Deutschland basierend auf spatiotemporal hochaufgelösten Messdaten.
  Staats- und Universitätsbibliothek Bremen, 2023.
- 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.

Journals

- R. B. Bergmann, A. ***Fischer***, C. Bockelmann, A. Dekorsy, A. Garcia-Ortiz, C. Falldorf:
  The coherence function and its information content for optical metrology.
  tm - Technisches Messen 89(6):397-412, 2022.

- B. ***Espenhahn***, L. Schumski, D. Meyer, D. Stöbener, A. Fischer:
  Optical measurement approach to analyse the tool-workpiece interacting flow of grinding processes.
  Flow Measurement and Instrumentation 102407 (11 pp.), 2023. (in press)
- 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 71(1):437-440, 2022.
- A. ***Fischer***:
  Capabilities and limits of surface roughness measurements with monochromatic speckles.
  Applied Optics 62(14):3724-3736, 2023.
- D. ***Gleichauf***, F. Oehme, A.-M. Parrey, M. Sorg, N. Balaresque, A. Fischer:
  On-site contactless visualization of the laminar-turbulent flow transition dynamics on windturbines.
  tm - Technisches Messen, 2023. (accepted)
- P. ***Helming***, A. Intemann, K.-P. Webersinke, A. von Freyberg, M. Sorg, A. Fischer:
  Assessing the rotor blade deformation and tower-blade tip clearance of a 3.4 MW wind turbine with terrestrial laser scanning.
  Wind Energy Science 8:421-431, 2023.
- F. ***Jensen***, E.A. Aoun, O. Focke, A. Krenz, C. Tornow, M. Schlag, C. Lester, A. Herrmann, B. Mayer, M. Sorg, A. Fischer:
  Investigation of the causes of premature rain erosion evolution in rotor blade-like GFRP structures by means of CT, XRM, and active thermography.
  Applied Sciences 12(22):11307 (19 pp.), 2022.
- F. ***Jensen***, J. F. Jerg, M. Sorg, A. Fischer:
  Active thermography for the interpretation and detection of rain erosion damage evolution on GFRP airfoils.
  NDT & E International 135:102778 (10 pp.), 2023.
- 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.
- 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 71(1):301-304, 2022.

Publications and qualification of young academics

Publications

- M. ***Mikulewitsch***, J. Dong, D. Stöbener, J. Epp, A. Fischer: *Influences on quantitative nitriding layer thickness measurements using model-based photothermal radiometry.* HTM Journal of Heat Treatment and Materials 77(5):357-373, 2022.
- F. ***Oehme***, D. Gleichauf, N. Balaresque, M. Sorg, A. Fischer: *Thermographic detection and localisation of unsteady flow separation on rotor blades of wind turbines.* Frontiers in Energy Research 10:1043065 (15 pp.), 2022.
- F. ***Oehme***, D. Gleichauf, J. Suhr, N. Balaresue, M. Sorg, A. Fischer: *Thermographic detection of turbulent flow separation on rotor blades of wind turbines in operation.* Journal of Wind Engineering & Industrial Aerodynamics 226:105025 (12 pp.), 2022.
- M. ***Pillarz***, A. von Freyberg, A. Fischer: *Scalable multi-distance measurement approach for the optical assessment of tooth-individual shape parameters of large gearings.* tm - Technisches Messen, 89(7-8):544-553, 2022.
- 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.
- 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.
- L. ***Schweickhardt***, A. Tausendfreund, D. Stöbener, A. Fischer: *Parametric characterization of ground surfaces with laser speckles.* Optics Express 30(8):12615-12629, 2022.
- L. ***Schweickhardt***, A. Tausendfreund, D. Stöbener, A. Fischer: *Digital speckle photography in the presence of displacement gradients.* Journal of the European Optical Society-Rapid Publications 19(1):16 (10 pp.), 2023.

- A. ***von Freyberg***, M. Terlau, D. Stöbener, A. Fischer:
  Optische Messung der Werkzeugablenkung in der inkrementellen Blechumformung.
  tm - Technisches Messen, 2023. (accepted)

Conference contributions

- G. ***Behrends***, A. Tausendfreund, A. Fischer:
  Indirekte optische Geometriemessung mittels fluoreszierender Aerosole.
  124. Jahrestagung der Deutschen Gesellschaft für angewandte Optik e. V. (DGaO), Berlin, 30.5.-3.6.2023, No. A30.
- B. ***Espenhahn***, L. Schumski, D. Stöbener, D. Meyer, A. Fischer:
  Flow field measurements of the grinding cooling liquid jet.
  20th International Symposium on Application of Laser and Imaging Techniques to Fluid Mechanics, Lisbon, 11-14.7.2022, pp. 2444-2461.
- B. ***Espenhahn***, L. Schumski, D. Stöbener, D. Meyer, A. Fischer:
  Strömungsmessung des Kühlschmierstoffs in der Kontaktzone.
  29. GALA-Fachtagung "Experimentelle Strömungsmechanik", Ilmenau, 6.-8.9.2022, No. 45 (8 pp.).
- D. Feldmann, F. ***Oehme***, L. von Germersheim, R. L. Parras, A. Fischer, M. Avila:
  Towards indirect assessment of surface anomalies on wind turbine rotor blades.
  23. DGLR-Fachsymposium der STAB, Berlin, 9.-10.11.2022, No. S20.1.
- A. ***Fischer***, D. Stöbener, L. Schweickhardt:
  Characterizing anisotropic surfaces with laser speckles.
  World Congress for Optics and Photonics (ICO-25, OWLS-16), Dresden, 5.-9.9.2022, No. TS 6-3-03 (2 pp.).
- N. Guba, L. Schumski, B. ***Espenhahn***, A. Fischer, D. Meyer:
  Bedeutung der Wechselwirkung zwischen Kühlschmierstoff und Schleifscheibe für die Kühl- und Schmierwirkung beim Schleifen.
  Schweizer Schleif-Symposium (SSS2022), Zürich, 6.-7.9.2022, No. 4 (9 pp.).
- A. ***Fischer***, D. Stöbener, G. Behrends:
  A lateral-scanning white-light interferometer for topography measurements on rotating objects in process environments.
  71th CIRP General Assembly, Bilbao, Spain, 21.-27.8.2022, No. P05.

Publications and qualification of young academics

Publications

- F. ***Jensen***, M. Sorg, A. Fischer:
  Damage development of initial defects in coated GFRP-structures due to rain exposure.
  16th Quantitative InfraRed Thermography Conference (QIRT 2022), Paris, 5.-8.7.2022, No. 2.3.1 (6 pp.).

- M. ***Mikulewitsch***, D. Stöbener, A. Fischer:
  Prozessnahe indirekte Oberflächencharakterisierung von laserchemisch gefertigten Abtragskonturen.
  XXXVI. Messtechnisches Symposium des AHMT, Magdeburg, 28.-29.9.2022. tm - Technisches Messen 89(S1):S37-S42, 2022.

- M. ***Mikulewitsch***, D. Stöbener, A. Fischer:
  Near-process indirect surface characterization of laser-chemically produced removal contours.
  European Optical Society Annual Meeting (EOSAM), Porto, Portugal, 12.-16.9.2022, TOM10 S05:3 (2 pp.).

- M. ***Mikulewitsch***, Y. Bouraoui, T. Radel, D. Stöbener, A. Fischer:
  Near-process indirect surface geometry and temperature measurement for laser chemical machining (LCM).
  Sensor and Measurement Science International (SMSI 2023), Nürnberg, 8.-11.5.2021, No. P30, pp. 338-339.

- F. ***Oehme***, M. Sorg, A. Fischer:
  Thermografische Detektion von instationären Strömungsablösungen an Windenergieanlagen.
  29. GALA-Fachtagung "Experimentelle Strömungsmechanik", Ilmenau, 6.-8.9.2022, No. 26 (10 pp.).

- A.-M. ***Parrey***, M. Sorg, A. Fischer:
  Detection and localization of premature flow transitions on rotor blades.
  16th Quantitative InfraRed Thermography Conference (QIRT 2022), Paris, 5.-8.7.2022, No. 1.a.1 (7 pp.).

- M. ***Terlau***, M. Pillarz, A. von Freyberg, A. Fischer:
  Validation of an inside sensor system for deformation measurements on bionic lightweight gears.
  Sensor and Measurement Science International (SMSI 2023), Nürnberg, 8.-11.2021, No. P22, pp. 322-323.

- L. ***Schweickhardt***, A. Tausendfreund, D. Stöbener, A. Fischer:
  Influence of displacement gradients on laser speckle photography.
  European Optical Society Annual Meeting (EOSAM), Porto, Portugal, 12.-16.9.2022, TOM10 S01:2 (2 pp.).

- M. ***Sorg***, Y. Schädler, A. Fischer:
  Spatiotemporale Messdaten optimieren die Energiewende.
  Jahrestreffen Forschungsnetzwerk Energiesystemanalyse, Berlin, 8.-9.11.2022.

- D. ***Stöbener***, M. Mikulewitsch, A. Fischer:
  Fluorescence-based measurements of material removal and process temperature during laser chemical machining.
  23th International Conference & Exhibition of the European Society for Precision Engineering and Nanotechnology (euspen), Copenhagen, 12.-16.6. 2023, pp. 389-390.

- A. ***Tausendfreund***, B. Espenhahn, G. Behrends, A. Fischer:
  Indirect geometry measurement method based on confocal microscopy and fluorescent microparticles.
  SPIE Optical Metrology, München, 26.-29.6.2023, (8 pp.).

- M. ***Terlau***, A. von Freyberg, D. Stöbener, A. Fischer:
  In-Process tool deflection measurement in incremental sheet metal forming.
  IEEE Sensors Applications Symposium (SAS 2022), Sundsvall, Sweden, 1.-3.8.2022, No. 1570797357 (6 pp.).

- A. ***von Freyberg***, P. Helming, K.-P. Webersinke, A. Fischer:
  Laseroptisches Messverfahren zur Analyse geometrischer Kennwerte an Windenergieanlagen.
  DFMRS Windenergietagung 2023, Bremen, 23.3.2023.

- A. ***von Freyberg***, F. Oehme, A. Fischer:
  Thermographic flow visualization.
  DFMRS Windenergietagung 2023, Bremen, 23.3.2023.

Publications and qualification of young academics

PhD theses

Contributions to the thermographic flow visualization and the localization of the laminar-turbulent transition on wind turbine rotor blades

Dr.-Ing. Daniel Gleichauf

Date of thesis defense: 26 Sep 2022

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

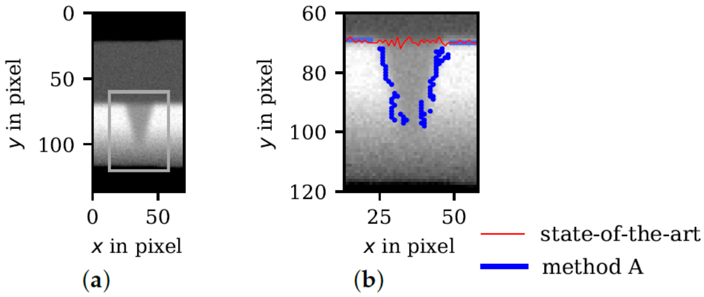
The boundary layer flow on rotor blades of operating wind turbines has a direct influence on the turbine's efficiency. Thermographic flow visualization is a known contactless imaging tool with in-process capability to measure the distribution of the laminar and turbulent flow regions, and to localize the laminar-turbulent transition position. This work focuses on extending the measurement system to achieve an increase in the contrast-to-noise ratio and a reduction in the measurement error in localizing the laminar-turbulent transition for applications with a low contrast < 1K.

First, the contrast-to-noise ratio is doubled at only about 1⁄3 of the required integration time when using a camera with a longer wavelength. Second, a trigger system is realized for recording image series and averaging. Third, feature extraction methods are applied to image series, which yielded a contrast-to-noise ratio increase of up to a factor of 5.

Regarding the localization of the laminar-turbulent transition, the random and systematic errors is minimized to 0.3 % and 0.1 % of the chord length, respectively, by extending the image processing. Especially, the systematic error is reduced by two orders of magnitude. As a result, the novel image processing methods in the free-field application even allow the localization of flow transitions, which could not be localized before due to the low CNR.

Localization is further adapted to the non-linear transition shape of a locally induced premature transition. In a free-field measurement with 14 so-called turbulence wedges, the new evaluation correctly detected 10 wedges, where previously no wedge could be detected. The error in quantifying the reduction of laminar flow was thus reduced from 21 % to 2 %.

Hence, the results extend the application range of thermographic flow visualization for its use on wind turbines in operation.



Thermographic detection of a turbulence wedge, i.e. a premature laminar-turbulent flow transition that is induced by a local disturbance on the blade surface.

[1] 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.

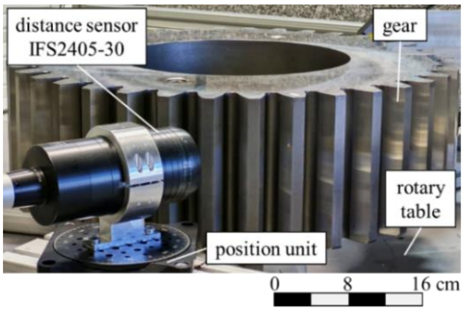
[2] D. Gleichauf, M. Sorg, A. Fischer: Contactless localization of premature laminar-turbulent flow transitions on wind turbine rotor blades in operation. Applied Sciences 10(18):6552 (21 pp.), 2020.

Model-based multi-distance measurement approach for optical measurement of gear geometry

Dr.-Ing. Marc Pillarz
Date of thesis defense: 16 Feb 2023
Supervisor: Prof. Dr.-Ing. habil. Andreas Fischer

Fast, scalable measuring systems for quality inspection of the geometry of all teeth are required to increase the reliability of gears or large gears with diameters > 1 m or normal modules > 10 mm. Tactile standard gear measuring systems are precise but limited in their suitability for rapid quality inspection of all teeth of gears of different sizes due to the limited measuring volume and speed. Current optical gear measurement approaches achieve comparable measurement uncertainties at higher measurement speeds compared to tactile measurement systems but have not yet been tested for quality inspection of all teeth on large gears.

Therefore, this work introduces a model-based multi-distance measurement approach for scalable gear measurement that enables fast optical measurements of the geometry of all teeth with a measurement uncertainty < 30 % of the required tolerances for a gear quality 6. For the evaluation of the measured gear geometry, the shape parameter base circle radius is selected and a model-based solution approach for the evaluation of the base circle radius based on the geometry of an involute gear is presented.



Setup for large gear multi-distance measurement.

Theoretical and experimental multi-distance measurements on a medium-sized gear prove an achievable measurement uncertainty < 30 % of the required tolerance for gear quality 6 for both the mean and the tooth-individual base circle radius. Experiments on a large gear demonstrate the scalability of the multi-distance measurement approach. Regarding the random errors, both the mean and the tooth-individual base circle radii meet the uncertainty requirements for gear quality 6. A comparison with tactile reference measurements validates that the measurement uncertainty of the optically acquired tooth-individual base circle radii reaches the level of tactile gear measurements and that the measurement speed of the multi-distance measurement approach is up to 15 times faster. The optical model-based multi-distance measurement approach is thus a promising alternative for gear measurements.

[1] M. Pillarz, A. von Freyberg, A. Fischer: Determination of the mean base circle radius of gears by optical multi-distance measurements. Journal of Sensors and Sensor Systems 9(2):273–282, 2020.

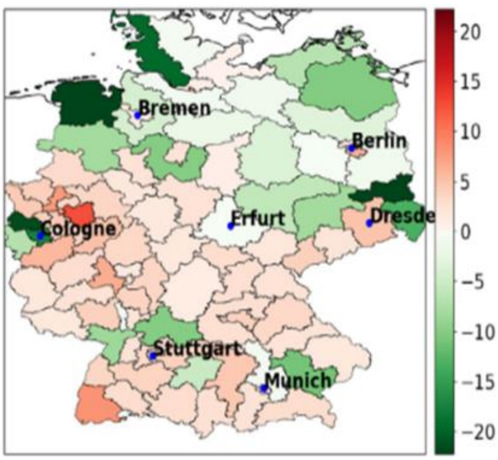
[2] M. Pillarz, A. von Freyberg, A. Fischer: Scalable multi-distance measurement approach for the optical gearings. tm - Technisches Messen, 89(7-8):544-553, 2022.

Publications and qualification of young academics

Modeling of the energy system transformation in Germany based on measured data in high spatiotemporal resolution

Dr.-Ing. Yannik Schädler
Date of thesis defense: 19 Apr 2023
Supervisor: Prof. Dr.-Ing. habil. Andreas Fischer

An efficient transformation of the German energy system is necessary for the rapid reduction of climate damaging CO_2 emissions. In particular, the energy production in the electrical energy system should be switched to renewable feeders. However, the natural fluctuations of renewable feeders lead to various technical challenges. Energy system models are an effective means of meeting these challenges. In order to produce stable and trustworthy results it is necessary that the underlying data fulfill four requirements: They must have an adequate resolution, be without gaps in the considered area and time, withstand a validity check and have an assessable quality, which can be described by an uncertainty. With the available measurement data base, modeling tasks can be defined as measurement tasks in the sense of metrology. After that, the tools of metrology can be applied to them. This makes it possible to add uncertainties to the results so that they become complete measurement results in the sense of metrology. In this thesis, the first step is to describe how the database was filled with measurement data of injection and load and how unavoidable gaps in the data sets are handled in order to not compromise the completeness requirement. Subsequently, different scenarios are modeled, whose residual load distribution is considered as a transport problem and processed as such. The result is twofold: optimal transportation routes and optimal total transport costs [1]. Thereafter, transports between zip code regions are neglected and storage of energy is modeled to answer the question of optimal storage parameters. These results were completed by an uncertainty analysis. Finally, the residual load distributions are mapped onto the power grid and the transport capacity of the grid is evaluated with an 'optimal power flow' algorithm



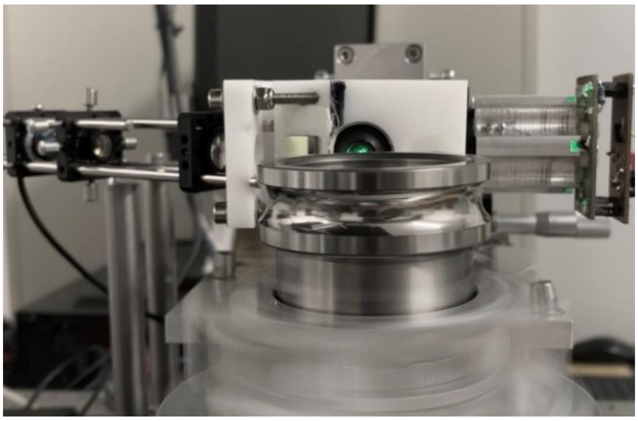
Annually summed residual loads in an exemplary scenario in Germany, energy surplus in green, energy shortage in red, values in TWh.

[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.

Non-contact, continuous topography measurement on moving objects

Dr.-Ing. Gert Behrends
Date of thesis defense: 28 Apr 2023
Supervisor: Prof. Dr.-Ing. habil. Andreas Fischer

Material surfaces are an important quality feature of many products. In order to be able to react to defects during production, surface properties need to measured close to the process. The ability to carry out near-process measurements on fast rotating objects requires tracking of the objects' movements. White light interferometry (WLI) is an established measurement technique for surfaces with measurement uncertainties in the order nanometers. Its standard implementation is vertically scanning WLI (VSWLI), which requires stationary measurement objects. Lateral scanning WLI (LSWLI) provides a solution for measurements surfaces moving on a straight path. The aim of this work is to enable LSWLI to also work for continuously rotating objects. For rotatory LSWLI, the curvature of the circular scan path of the measurement objects has to be considered, as it affects the height measurement uncertainty. The local scan path angles can be calculated from a wavelet-based frequency analysis of the LSLWLI signal. Simulations revealed, that the influence on height uncertainty of an uneven scanning movement is one order of magnitude smaller than the influence of the uncertainty of the movement measurement. Thus, an accurate displacement measurement system is required. An integrated, speckle-based measurement system achieved displacement measurement uncertainties of 11 nm, which, in simulation, allows for height measurement uncertainties of less than 25 nm. Experimentally, measurements of real surfaces had a height difference with a standard deviation of 37.5 nm compared to a VSWLI reference measurement. An example application on ball bearing raceways demonstrates the capability of continuous topography measurements. The near-process application on sheet metal rollers shows the potential of the measuring system for topography measurements on fast rotating surfaces in a factory environment.



The LSLWI-DSC-demonstrator measuring the topography of a rotating ball bearing raceway.

[1] 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 71(1):437-440, 2022.

[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.

Publications and qualification of young academics

Awards

Deutsche WindGuard Young Scientists Award 2022

For the sixth 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

- Alex Peer ***Intemann*** for his master thesis:

  Laserbasierte Schwingungs- und Deformationsmessungen an Windenergieanlagen

and to

- Söhren ***Buhr*** for his master thesis:

  Charakterisierung eines Inside-Sensorsystems für Leichtbauzahnräder zur Erfassung von dynamischen Verformungen und Lastspitzen

Congratulations from the BIMAQ team!

Alex Peer Intemann, Söhren Buhr

Best Presentation Award

Best Presentation Award at the international conference „IEEE Sensors Applications Symposium 2022“ in Sundsvall, Schweden, goes to: Marina Terlau !

M. ***Terlau***, A. von Freyberg, D. Stöbener, A. Fischer: In-Process tool deflection measurement in incremental sheet metal forming. IEEE Sensors Applications Symposium (SAS 2022), Sundsvall, 1.-3.8.2022.

Congratulations!

https://2022.sensorapps.org/awards/

Marina Terlau (left) receiving the award in Sundsvall, Sweden

CAMPUS Award – Research for a sustainable future

With his master thesis "Laser-based vibration and deformation measurements on wind turbines", Alex Peer Intemann provided an important contribution for a sustainable energy generation from wind. For the first time, he enabled highly resolved measurements of the vibration-mechanic behaviour of the rotor blade of wind turbines during operation, without the necessity to stop the wind turbine, without preparation of the rotor blade, and contactless from a distance of up to 200 m.

For his master thesis, he received the CAMPUS award 2022. Congratulations!

You want to learn more about his findings? Have a look in the fresh open-access publication:

P. Helming, A. Intemann, K.-P. Webersinke, A. von Freyberg, M. Sorg, A. Fischer:
Assessing the rotor blade deformation and tower-blade tip clearance of a 3.4 MW wind turbine with terrestrial laser scanning.
Wind Energy Science 8:421-431, 2023.
https://doi.org/10.5194/wes-8-421-2023

Alex Peer Intemann (left) at the prize ceremony on 27 Apr 2023

Press release:
https://www.uni-bremen.de/en/university/university-communication-and-marketing/all-news/details/campus-award-goes-to-biologist-and-production-technician

Publications and qualification of young academics

Awards

OLB Science Award

On 12 Jun 2023 Dr.-Ing. Merlin Mikulewitsch has received the second prize of the Science Award 2023 awarded by the OLB Foundation for his outstanding PhD thesis with the topic 'Model-based optical and photothermic layer thickness measurement for the process-near and in-process application in manufacturing processes' in the category doctoral theses.

His scientific progress in the field of optical microgeometry measurements for the application in manufacturing processes under real operating conditions was recognized as well as the successful transfer of his findings from the idea, over a realized laboratory setup and experiment under well-defined boundary conditions, to the validation in a real-world experiment. The award winners were selected from a total of more than 65 nominations, whereby the jury assessed both the (technical) scientific level of the work and the social significance, the courage in choosing the approach and the ability to develop and convincingly present topics.

Congratulations!

Merlin Mikulewitsch (4th from left) together with the other awardees and the jury at the prize ceremony on 12 Jun 2023

Participation at events and conferences

Date	Event / Conference	Location	Participant(s)	
5 – 8 Jul 2022	**16th Quantitative InfraRed Thermography Conference (QIRT 2022)**	Paris	A.-M. Parrey F. Jensen	oral presentations
11 – 14 Jul 2022	**20th International Symposium on Application of Laser and Imaging Techniques to Fluid Mechanics**	Lisbon	B. Espenhahn	oral presentation
1 – 3 Aug 2022	**IEEE Sensors Applications Symposium**	Sundsvall	M. Terlau	oral presentations
21 – 27 Aug 2022	**71st CIRP General Assembly**	Bilbao	A. Fischer D. Stöbener	oral presentation
6 – 8 Sep 2022	**29. GALA-Fachtagung „Experimentelle Strömungsmechanik“**	Ilmenau	A. Fischer F. Oehme B. Espenhahn	oral presentations
5 – 9 Sep 2022	**25th Congress of the International Commission for Optics (ICO) and 16th Conference of International Society on Optics Within Life Sciences (OWLS)**	Dresden	L. Schweickhardt	oral presentation
12 – 16 Sep 2022	**EOSAM European Optical Society Annual Meeting**	Porto	M. Mikulewitsch L. Schweickhardt	oral presentations
28 – 29 Sep 2022	**XXXVI Messtechnisches Symposium des AHMT**	Magdeburg	A. Fischer M. Mikulewitsch	oral presentation
8 – 9 Nov 2022	**Jahrestreffen Forschungsnetzwerk Energiesystemanalyse**	Berlin	M. Sorg	poster presentation
23 Mar 2023	**DFMRS-BAM-Windenergietagung**	Bremen	A. v. Freyberg	oral presentation and poster
9 – 11 May 2023	**SMSI - Sensor and Measurement Science International**	Nürnberg	A. Fischer M. Terlau	poster presentations
30 May – 3 Jun 2023	**DGaO 124 Annual Meeting 2023**	Berlin	G. Behrends	oral presentation

Participation at events and conferences

Date	Event / Conference	Location	Participant(s)	
12 – 16 Jun 2023	**23rd International Conference EUSPEN**	Kopenhagen	D. Stöbener	poster presentation
26 – 29 Jun 2023	**SPIE Optical Metrology**	München	A. Tausendfreund	oral presentation

Events @ BIMAQ

Date	Event	Organizing institution
1 Sep 2022	**Kick-off of our ERC project on Indirect Optical Geometry Measurement**	BIMAQ
1 Nov 2022	**BEST - Ring lecture Wind turbines: Challenges of on-site research**	University of Bremen / BIMAQ
22 Dec 2022	**BIMAQ crew obtains flight licenses for the use of drones**	BIMAQ
31 Dec 2022	**Special, special, special – 3 special issues in 2022**	BIMAQ
24 Jan 2023	**Invited talk: Prof. Dr. M. Günther (Fraunhofer Institute for Digital Medicine, MEVIS) Hersteller unabhängige Magnetresonanz Tomographie**	BIMAQ
1 Mar 2023	**Jugend forscht – Pupils are experimenting (regional competition Bremen-Mitte)**	Jugend forscht / BIMAQ
21 Mar 2023	**Kids University 2023: We can see colors and temperatures, too?**	BIMAQ
27 Apr 2023	**Girls Day – Mädchen-Zukunftstag**	BIMAQ
30 Apr 2023	**From the lab to the app: Challenging in-process measurements in real-world environments - Free-field measurements with a co-rotating measurement platform**	BIMAQ
23 May 2023	**Invited talk: M. Abdallapour, Dr. C. Bockelmann (Communication engineering, ANT) Machine learning for scatterometry on nano-structured surfaces**	BIMAQ
21 Jun 2023	**Exciting seminar on research data management**	BIMAQ
27 Jun 2023	**Students meet BIMAQ**	BIMAQ
30 Jun 2023	**International students meet BIMAQ**	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. M. Günther (Fraunhofer-Institut MEVIS): *Manufacturer independent magnetic resonance tomography*
    24 Jan 2023
  - M. Abdollahpour, Dr. C. Bockelmann (University Bremen): *Machine learning for scatterometry on nano-structured surfaces.*
    23 May 2023

Events & News

Events @ BIMAQ

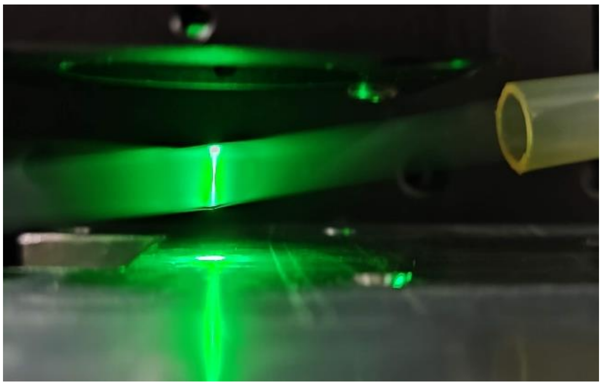
- *Kick-off of the ERC project*

European Research Council
Established by the European Commission

On the 1st of September 2022, a four-member research team under the lead of the Prof. Fischer started to break new ground in the field of optical geometry measurement. To conduct the breakthrough research, a Consolidator Grant funded by the European Research Council (ERC) was awarded to Prof. Fischer in 2022.

The core idea is to introduce a universally applicable optical measurement paradigm, which is independent on the optical surface response and, thus, is able to cope with a large variety of shapes, surface types and materials. This meets the requirements of the increasing components complexity and variety regarding geometry and material. Within the next 5 years, the research team will work on understanding the potential of indirect optical geometry measurements, which means to optically measure the imprint of the component geometry in the surrounding air.

The whole team and the institute is excited about the promising prospects of the fundamentally new approach, and we are highly motivated to beat the current limits of measurability - to make measurable what is not so today!



https://www.uni-bremen.de/en/university/university-communication-and-marketing/all-news/details/forschungsstarke-universitaet-erhaelt-zwei-erc-grants

- *Special, special, special – 3 special issues*

Part 1: Two special issues highlight the ongoing research work on optical measurements

Prof. Fischer belongs to the scientific board of the well-known journal tm – Technisches Messen, which regularly reports about achievements in metrology. It is an honor that two edited special issues have been published in this journal in 2022.

Volume 89, issue 3, is dedicated to '*Non-invasive measurement techniques for micro- and large-scale flows*'. The invited contributions provide insights into the newest research results in flow metrology.

Volume 89, issue 6, is dedicated to the topic '*Multi-dimensional optical measurement techniques*'. The editors A. Fischer and R. B. Bergmann invited contributions from the annual meeting of the German society of applied optics to present their newest findings.

Events & News

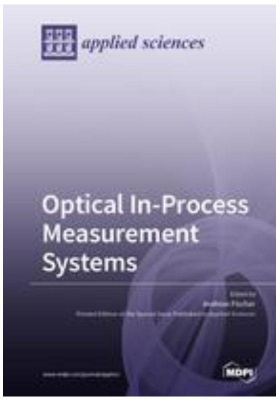
Events @ BIMAQ

- *Special, special, special – 3 special issues*

Part 2: Special challenges deserve our special attention

A special issue on 'Optical In-Process Measurement Systems' was created in the international journal Applied Sciences:

https://www.mdpi.com/journal/applsci/special_issues/Optical_Measurement



Why *optical* measurements?

Optical principles enable precise measurements down to the quantum mechanical limits and provide the fastest possible measurement speed, which is the speed of light. Driven by the ongoing advances in powerful light sources, accurate light modulation possibilities, and efficient light detectors, the capabilities of optical measurement systems are increasing.

Why *in-process* measurements?

A current challenge is to make use of the benefits of optical principles for in-process measurements on real-world objects. Examples are flow processes on wind turbines, on airplanes, and in combustors, thermal and mechanical processes on a workpiece during manufacturing, and the exploration of natural processes on Earth and in space. Studying non-idealized, non-scaled objects during their actual operation is an important task for the measurement science, since it allows us to gain new insights from the *actual* process behavior to be engineered.

Furthermore, in-process measurements are required to create in-process controls. In-process measurement conditions are often challenging and can mean a limited optical access, an uncooperative measurement environment, a large measurement distance, a large measurement object, or just a low signal-to-noise ratio.

What needs to be done?

In order to break new ground for the transition "from the lab to the app" (from the laboratory to the application), optical in-process measurements have to be realized at the limits of measurability and beyond.

- *BIMAQ crew obtains flight licenses for the use of drones*

On St. Nicholas Day in December 2022, four scientific researchers at BIMAQ were faced with a special challenge: the qualification for the A2 remote pilot certificate for the professional operation of drones. Despite difficult conditions (temperatures around freezing point and drizzle), various flight maneuvers were practiced and regularities and guidelines for the use of drones were studied on two consecutive days in preparation for the pilot exam. All participants passed both the theoretical and practical exams and were able to take home their remote pilot's license along with a chocolate Santa Claus. It is now time to equip the BIMAQ-owned drone, which was procured as part of the AutoFlow cooperation project, with measurement technology and prepare it for use on wind turbines. However, before the brave pilots dare to use the measuring drone, a few more hours of practice are required!

BIMAQ crew members after successful completion of the pilot's license with the new measuring drone in front, from left to right: Axel von Freyberg, Friederike Jensen, Frank Horn, Michael Sorg.

Events & News

Events @ BIMAQ

- *Jugend forscht - regional competition*

jugend forscht
Wir fördern Talente.

In March 2023, the regional competition 2023 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.

- *Kids University*

We did it again on 21 March 2023: 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!

- *Girl’s Day*

27. April 2023

On 27 April 2023, 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 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.

- *International pupils meet BIMAQ*

On 30 June 2023, about 20 international pupils between 14 and 18 years old visited the University Bremen, including the BIMAQ. The pupils take part in the youth camp of the Goethe Institut Bremen within the PASCH-initiative, which supports an international exchange of pupils.

PASCH is an initiative of the Federal Foreign Office in cooperation with the Central Agency for Schools Abroad (ZfA), the Goethe-Institut, the German Academic Exchange Service (DAAD) and the Educational Exchange Service (PAD) of the Secretariat of the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany.

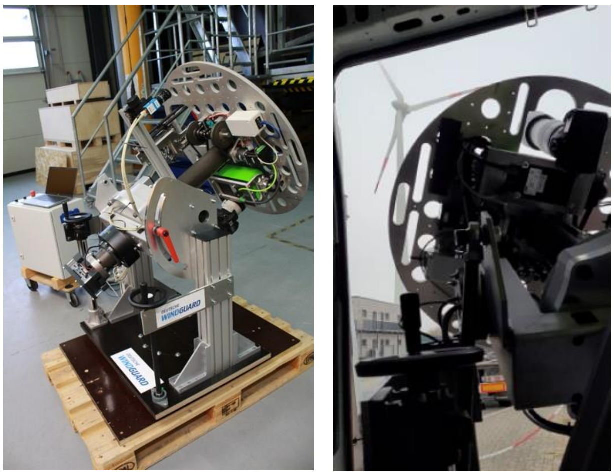
Prof. Fischer guided the highly interested pupils through the institute, demonstrating fundamental optical and laser-based measurement principles. He also presented and discussed the newest institute’s research work and findings, and what is needed to contribute to the engineering solution meeting our global challenges.

Thank you for the highly enjoyable discussions! It was a pleasure to meet you, to answer your questions and to present our work at the University of Bremen.

Events & News

Events @ BIMAQ

- *From the lab to the app: Challenging in-process measurements in real-world environments – Free-field measurements with a co-rotating measurement platform*



Co-rotating measuring platform.
Left: Side view, Right: Back view of the co-rotating measurement system while taking measurements of a wind turbine out of a van (right).

Within the project *PreciWind* project, a co-rotating measurement platform was developed to perform dynamic flow and deformation investigations on the rotor blades of wind turbines. The team successfully demonstrated the measurement system in various free-field measurements on wind turbines in operation.

The platform is equipped with a thermographic camera, a time-of-flight laser line scanner and various optical cameras. The kinematics of the platform allows not only a rotational movement but additionally a linear movement to enable a radial alignment of the sensors. This is important for an easy measuring setup, as it is not required to place the measuring system exactly behind the turbine anymore.

Via a visual camera, the movement and the geometrical setup between measuring platform and wind turbine is determined in real-time. This data is used for the motion control of the co-rotating platform in order to synchronize with the movement of the wind turbine.

By applying the realized measurement system with its worldwide unique features, the in-depth exploration of the actual deformation and flow behaviour of wind turbines is now possible.

- *Exciting seminar on research data management*

The BIMAQ team dealt with the topic of 'research data management' in the seminar of the same name on 21 June 2023.

The set up system to manage research data and gained knowledge and the respective new internal guidelines at the BIMAQ have been reflected. As a result, pulses have been collected to further improve our dealing with data and knowledge in a sustainable way. This will support our ongoing daily efforts to fulfill the requirements of the FAIR principles.

As a practical non-academia example for data handling, a tour through the Heide Park Resort provided special insights into the park's attraction technologies, with a focus on the measurement, automation and data management solutions.

In the end, the day was full of fruitful discussions, new pulses, and also some more than usual excitement around an overall exciting seminar topic.

- *Students meet BIMAQ*

On June 27, 2023, Prof. Fischer and the BIMAQ team invited students of production engineering, systems engineering and industrial engineering to get in touch with the BIMAQ research topics and people.

With its research focus in measurement and control, the BIMAQ has a lot to offer to students who are interested in non-contact optical measurement systems, signal and image processing tools, the analysis of flow and production processes, model-based quality controls and the inspection and optimization of wind turbines in operation.

Topics for Bachelor and Master theses offer the opportunity to participate in current research projects.

The event including a barbecue was well received by the students and provided an excellent platform for exchanging ideas.

News

up2date. University of Bremen Online Magazine

- When the Airflow Suddenly Changes
  At BIMAQ, Measurements Are Made at the Highest Level
  06.2022 / RESEARCH / KAI UWE BOHN / APOSTROPH GROUP

It remains invisible to the naked eye, but with the right technologies and equipment, you can track the airflows on a spinning wind turbine in real time. The latest developments at Professor Andreas Fischer's institute at the University of Bremen make it possible.

High tech from BIMAQ: taking noncontact flow measurements from a great distance on running systems up to 200 meters high is a "specialty" of the Bremen University institute. © Pugun & Photo Studio / Adobe Stock

The name of the facility already shows what Professor Andreas Fischer at the *Bremen Institute for Metrology, Automation and Quality Science (BIMAQ)* is interested in. "Metrology is the beginning of the information society," the institute director quickly makes clear – and explains the importance of his branch of research: "If I want to evaluate and interpret information, I have to have it first. And we get information – for example on the state of our environment or technical processes – from measurements."

Precise Measurements as a Service

Executing high-precision measurements in the smallest of dimensions or under difficult conditions: truly not just anyone can do that. But BIMAQ can. As a research institute, it plays a leading role in many fields throughout Europe. The Bremen University institute in the *Faculty of Production Engineering also offers its expertise* as a service, as there is great demand in industry for measuring and testing that is as exact as possible. "From measurement technology directly in processes to the tactile or optical evaluation of surface quality and nondestructive and noncontact edge-zone analysis, our knowledge is in high demand," says Fischer. The measurement technology expert had already been drawn to the specialization "automation, measurement, and control technology" during his main studies in electrical engineering at the TU Dresden.

Professor Andreas Fischer has headed BIMAQ for six years. When it comes to high-precision measurement in the smallest dimensions or under difficult conditions, the institute's expertise is in demand.
© BIMAQ

Among other things, he is interested in fundamental questions: "There are, after all, limits to measurement technology. It's all about the quality of the measurements – and at some point, accuracy reaches its quantum-mechanical limits. Things like that fascinate me." On the other hand, there are very specific applications in which high-precision measurement technology from BIMAQ is used. And in the process, Fischer and his team have achieved groundbreaking successes. For example, when it comes to thermographic flow visualization for wind turbines.

Even before he came to the University of Bremen six years ago, Fischer was heavily involved with laser-optical flow-measurement technology. "We are currently trying to understand and improve flows in wind turbines," explains the engineering scientist. "In the case of these systems, that specifically means that efficiency and reliability need to be optimized so that wind turbines provide a dependable yield over as many years as possible, meaning reliably produce electricity. The special challenge here: noncontact flow measurements from long distances on running equipment up to 200 meters high."

Ideal Exchange between Business and Science

BIMAQ has established a very close partnership with Deutsche WindGuard – a company that as an accredited measurement service provider and independent consultant also takes care of the maintenance of wind turbines on land and at sea. "There are, for instance, joint measurement campaigns with the order: 'We have a newly developed system; please measure the actual flow conditions on the prototype for us.'" Just recently, a team conducted a week-long measurement campaign in Denmark. "Our partner Deutsche WindGuard intends to use the data obtained to solve the problems that arise for customers with new turbines. We, in turn, can learn about the current challenges of the latest systems, research them, and enable solutions with our metrological

News

knowledge. An ideal exchange between business and science – as it should be."

> *"We have achieved breakthrough success in thermographic flow visualization on wind turbines."*
> *Professor Andreas Fischer, BIMAQ*

A very successful project, which even resulted in a powerful software, illustrates BIMAQ's concrete work in flow visualization. "It was essentially about the aerodynamic optimization of rotor blades. To achieve that, we developed image-processing algorithms for thermographic images to make the flow around the rotor blades visible. Valuable experience gained from many joint measurement campaigns in the large wind tunnel in Bremerhaven, which is operated by Deutsche WindGuard, and on wind turbines in the open operated by well-known manufacturers was incorporated into the software," says Fischer. This software is called "Transition Finder" and has since made the work of the company from northern Germany easier.

Flow: Laminar, Turbulent, or Detached

There are basically three different types of flow around an airfoil – regardless of whether it belongs to a wind turbine or an aircraft. The ideal condition is laminar or stratified flow: "The airflow passes undisturbed along the profile surface from front to back," Fischer explains. Turbulent flow is less efficient because "the energy yield is lower as a result." The worst, however, is detached flow, "which, of course, you don't want to have at all. In the case of airplanes this is called a stall; they then crash because they no longer have lift. You can imagine that similar phenomena become a real problem with wind turbines as well. Local flow separation stresses the material, causes noise emissions, and the energy yield drops dramatically."

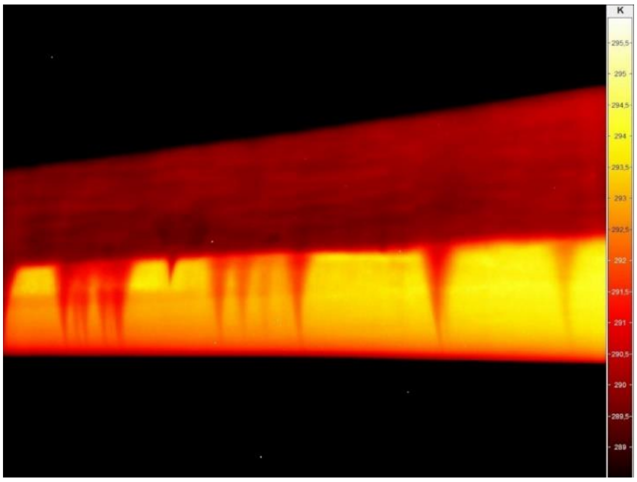
The noncontact temperature measurement from a distance takes place with special cameras and with the help of infrared thermal radiation.
© BIMAQ

The so-called transition points are of great importance for the operation of a wind turbine. "These are the moments when the flow changes from laminar to turbulent, or from turbulent to detached," says Fischer. Sometimes, he says, it is more effective to make minor modifications to create a defined transition from laminar to turbulent in order to make a system more efficient: “It’s not like a car you can just take to the shop. But rather a structure that is 200 meters high, possibly even located on the high seas.” Theoretically, the processes are already well researched – “but as they say in soccer: What matters is what happens on the field!”

What works well in the laboratory or wind tunnel does not necessarily work well in the final location under real conditions. That is precisely the source of Fischer’s research interest: “We are developing measurement systems that will monitor an operating turbine in real time ‘on the fly.’” Because a wind turbine is very large, he says, you have to think about how to “arrange” a measurement. Measurements are either taken from a great distance, or the measurement technology is brought into the turbine – “but that is time-consuming and leads to expensive downtimes.” A technology for sensors directly in the rotor blades has even been developed but has not yet become established – as it is said to be too costly and too complex.

The Infrared Range: Invisible Becomes Visible

This leaves the noncontact approach from a great distance. “The human eye, however, does not see how the flow behaves on the turbine during operation. That’s why we have to go into a range that is invisible to us: the infrared range.” In this spectral range, the flow processes on the rotor blade suddenly become visible. With lighter and darker areas, the transitional area between laminar and turbulent flow becomes comprehensible in photos. This is made possible by temperature differences. “When there is turbulent flow – that is, vigorous mixing – the heat caused by sunlight can be released more easily. We therefore find areas with a higher heat transfer and those with a lower heat transfer. The resulting contrast then shows us where the flow transitions are.”



It becomes visible in the infrared range: the resulting contrast shows researchers where the flow transitions occur on the rotor blade. © BIMAQ

The noncontact temperature measurement from a distance takes place with special cameras and with the help of infrared thermal radiation. “The challenge in a current research

News

project is now to do all of that while the system is running. After all, the rotor blade doesn't stay still but turns at considerable speeds at times – up to 300 km/h." Fischer and his group are very successful and global leaders in this field. Several papers on this topic have recently been internationally reviewed and accepted – proof of the quality of scientific results in this field, which, by the way, are funded by the Deutsche Forschungsgemeinschaft (German Research Foundation – DFG) and federal ministries.
Looking to the future, Fischer wants to further explore high-precision noncontact measurement in other contexts as well. He was recently awarded a consolidator grant from the European Research Council (ERC) to fund an interdisciplinary research team under his leadership for five years. In the Indirect Optical Geometry Measurement (InOGeM) project, he now wants to develop the fundamentals and the potential of a paradigm shift in the noncontact, precise measurement of component geometries.

"Up to now, noncontact measurement in production has mostly been carried out with light, but the variety of geometries and materials that can be produced is pushing the classic optical measurement principles to their limits," explains the BIMAQ boss. He has in mind the development of a method of component measurement using the surrounding air volume. Makes sense. After all, it's the limits of measurement technology that Fischer wants to push.

Official release:
https://www.up2date.uni-bremen.de/en/research/when-the-airflow-suddenly-changes

- *News / Press: The development bank for Bremen and Bremerhaven: Success stories of environmental innovations*

21.9.2022 - Jann Raveling

These Bremen residents unleash lasers on wind turbines

Inspection of wind turbines by laser during operation

The research team (from left): Klaus-Peter Webersinke, Nils Poeck, Axel von Freyberg and Nicholas Balaresque © BAB/Raveling

Inspecting wind turbines is complex and costs a lot of money. A team from Bremen wants to radically simplify some of the maintenance work and is using lasers to do so. In the process, they are pushing the technology to its limits.

In the course of their lives, the tower and rotor blades of a wind turbine are subjected to enormous stresses. The blade tips move at speeds of up to 250 kilometers per hour, bouncing back and forth several meters. Especially in gusty winds, enormous alternating loads press on the tower and cause it to vibrate.

These environmentally friendly power plants are designed to withstand all of this - but to ensure that all components function properly, the tower and rotor blades must be checked regularly: Do all components move within the tolerances, are there any misalignments?

Previous procedures for this are costly. The turbine is taken out of operation, specialists place sensors or measuring points on the rotors and then manually measure any deviations with special cameras or drones. This takes time and costs the wind farm operator a lot of money

The Bremen team took measurements by laser on different days and from different positions. © BIMAQ

Measurements under adverse conditions

Things get complex - as they often do - when you take a closer look at the problem. That's because the team of researchers and engineers in the Bremen-based "LOGAZ" project has to achieve high precision under challenging circumstances.

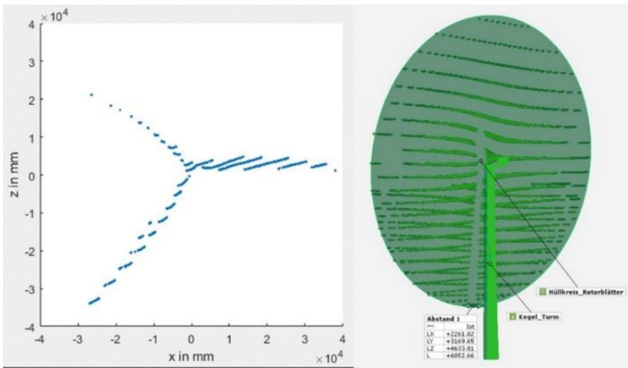
"We measure from the ground, the blade tips are 180 meters away and moving very fast. The whole turbine sways in the wind - and sometimes a tower rotation is added when the wind changes. This makes the measurements difficult," explains Axel von Freyberg, group leader for dimensional metrology at the Bremen Institute for Metrology, Automation and Quality Science BIMAQ, the project's research partner.

The laser always detects individual points - but if the system moves on between two measuring points, the resulting point cloud on the computer differs greatly from reality. The Bremen researchers then have to use complex algorithms to calculate out these errors. "And we want to achieve a measurement uncertainty of less than 2.5 centimeters," says Freyberg, setting the bar high.

Difficult without comparative data

But that's just where the challenges begin. The manufacturers of wind turbines are reluctant to disclose the exact construction plans of their turbines. The researchers in Bremen thus lack a reference model with which they can compare their real measurements to find deviations from the nominal value.

"This makes the validation of our system difficult. For our research project, we were able to use a research wind turbine at the University of Bremen on the one hand and take multiple measurements at a turbine of our partner Deutsche WindGuard on the other hand, which was very helpful," von Freyberg points out. In addition, they used a cross-sectional part of a blade that could be precisely measured in the laboratory to test the measurement system with regard to measurement uncertainty and possible cross-sensitivities.



Good to see on the left: The laser dots give a "distorted" view of the wind turbine due to the rotor blade movement. This must be corrected on the computer. © BIMAQ

Feasibility proven

In the one-year "LOGAZ" project, the first task was to prove the basic feasibility of the system. To this end, the team focused on two measured variables of a wind turbine: the detection of the rotor blade and its pitch angle, and the detection of the tower clearance, i.e.

the distance between the rotor blade and the tower.

Both have been successful. "The system offers great potential. Initially, many doubted its feasibility, so I am all the more pleased that we have positive results," says Nicholas Balaresque, Managing Director of Deutsche WindGuard Engineering GmbH, a subsidiary of the Bremen-based wind energy service provider of the same name and one of the three partners in the project. "For us, it is of course particularly interesting to develop a robust and at the same time efficient system that saves a lot of work and works during ongoing turbine operation."

Pushing the limits of technology

The third partner, LASE Industrielle Lasertechnik GmbH, also gained new insights from the project. The company provided the surveying laser as well as knowledge about its operation. "With LOGAZ, we were able to test the limits of our lasers; we normally use them at distances between 40 and 60 meters," explains Klaus-Peter Webersinke, project and IT consultant at the Bremen-based company. "The findings are in turn incorporated into our product development and are used to improve future devices."

Project set up with the help of Bremen funding

The project was implemented as part of the Applied Environmental Research (AUF) funding program of BAB - the development bank for Bremen and Bremerhaven. It aims to enable scientific projects in combination with industry to protect the environment.

"The project is a prime example of knowledge transfer: The combination of competencies from industry and science makes it possible to launch new and application-oriented developments. This lays the foundation for even greater efficiency in renewable energies," says Dr. Alla Kress, Innovation Manager at BAB.

The three partners now want to continue with the findings from "LOGAZ". They are planning follow-up research that will improve the technology and integrate further measurement parameters - until one day wind turbines can be measured easily from the ground.

Press release:
https://www.bab-bremen.de/de/page/aktuelles-presse/erfolgsgeschichten/inspektion-windenergie-laser

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