Annual Report

2019/2020

Thermographic flow measurements on wind turbines in operation

BIMAQ

Bremer Institut für
Messtechnik, Automatisierung
und Qualitätswissenschaft

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Preface

Dear friends and partners of the institute!

In the year 2019/20, the Bremen Institute for Metrology, Automation and Quality Science (BIMAQ) of the University of Bremen strengthens its fruitful collaborations with research partners and industry in fundamental and applied research projects.

BIMAQ is a member of ForWind – the Center for Wind Energy Research of the Universities of Oldenburg, Hannover and Bremen. Being a supporting pillar of this center, we succeeded with a project within the 7th Energy Research Programme of the German Federal Government with a total volume of 3 million euros. The research aim is to develop a contactless, precise measurement system that enables to study the real dynamical flow behaviour of rotor blades of wind turbines in operation, where scientist from the University of Bremen and Hannover work together with industrial partners.

Furthermore, the BIMAQ already actively contributes the second time within two subsequent years to the general assembly of the well-known International Academy for Production Engineering (CIRP). The topic here is an indirect geometry measurement that enables in situ geometry measurements of submerged workpieces with micrometer accuracy by using confocal microscopy in combination with fluorescence and a novel model-based signal processing. However, there are far more research activities at BIMAQ that are reported subsequently and I hope you enjoy reading.

Regarding teaching activities, it is worth to mention our seminar on measurement techniques that was successfully introduced in winter semester 2018/19. Not only PhD candidates, graduates but also undergraduates and internationally esteemed scientists love to share and discuss the ongoing progress of measurement techniques together in a friendly and respectful atmosphere. I thank in particular our invited guests Prof. Kiefer (spectroscopy), Dr. Avila (flow experiments) and Prof. Baldit (micromechanics, bioengineering) for their inspiring talks.

Writing this, I have to mention that the corona crisis changes the way of performing research and teaching. Most of our work now runs via digital channels, which is a new way to go. What has not changed, however, is the tremendous enthusiasm and encouragement of all BIMAQ students, members, research and industrial partners. For the continuous support and contribution to the achievements in 2019/20, I would like to express my sincere thanks to you.

Bremen, June 2020

Prof. Dr.-Ing. habil. Andreas Fischer

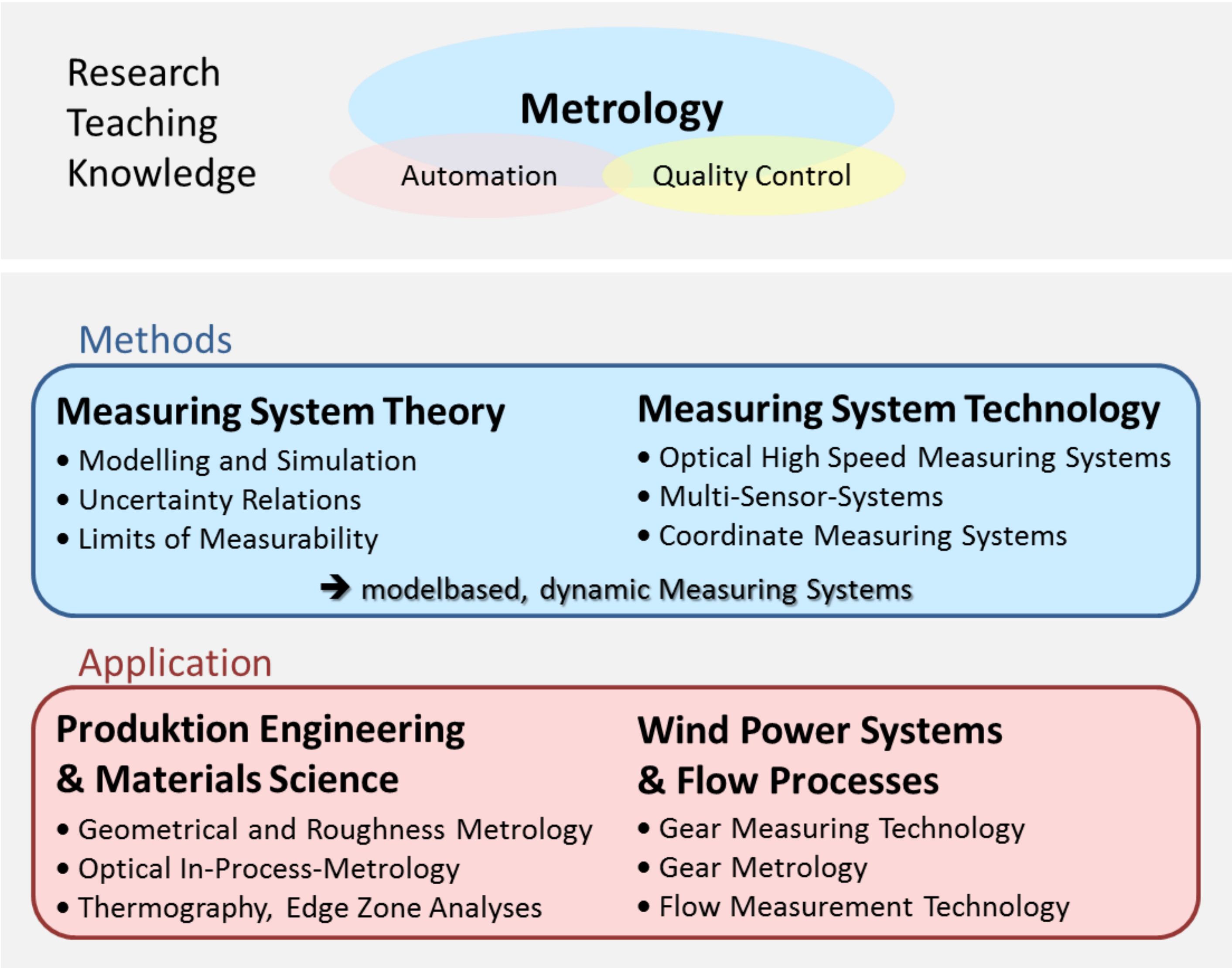
BIMAQ - the institute

Vision, topics and infrastructure

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

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

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



BIMAQ competences

BIMAQ - the institute

Staff

Director

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

Emeritus

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

Administration

Eva ***Schultze***

Ayfer ***Sakir*** (9/2019 – 2/2020)

Research Scientists

Dipl.-Phys. Gabriela ***Alexe*** (until 6/2020)

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

M. Sc. Björn ***Espenhahn*** (since 9/2019)

Dipl.-Ing. Axel von ***Freyberg***

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

Dipl.-Ing. Paula ***Helming*** (since 5/2020)

M. Sc. Friederike ***Jensen*** (since 11/2019)

M. Sc. Merlin ***Mikulewitsch***

Dipl. Ing. Felix ***Oehme*** (since 12/2019)

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

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

M. Sc. Volker ***Renken*** (until 4/2020)

M. Sc. Yannik ***Schädler***

M. Sc. León ***Schweickhardt*** (since 2/2020)

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

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

Dr.-Ing. Dirk ***Stöbener***

Dr.-Ing. Gerald ***Ströbel*** (until 4/2020)

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

M. Sc. Christoph ***Vanselow***

Student Research Assistant

Michael ***Arenz***

Torben ***Bührmann***

Eunice Doret ***David Selvaraj***

Friedrich ***Eickmann***

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Simon ***von Thaden***

Viviane ***Kelch***

Henrik ***Mahnke***

Puneet ***Mangal***

Egor ***Maul***

Md Al ***Mamun***

Daniel ***Musekamp***

Hasnain ***Moavia***

Ahmed Muhammad ***Salman***

Leonard ***Schröder***

Levke ***Wilke***

Anton ***Zitnikov***

Technical Assistants

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

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

Uwe ***Reinhard***

Alumni

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

Dipl.-Ing. Thomas ***Behrmann***

B. Sc. Marie ***Dethlefs***

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

Michael ***Essert***

M. Sc. Oskar ***Hoppe***

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

B. Sc. Robin ***Lipinski***

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

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

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

Participation in scientific committees and associations

Member		Short Name	Scientific Committee / Association
	BIMAQ	AUKOM	AUKOM Ausbildung Koordinatenmesstechnik e. V.
	BIMAQ	FQS	Forschungsvereinigung Qualität
Andreas	**Fischer**	DGaO	Deutsche Gesellschaft für angewandte Optik
Andreas	**Fischer**	AHMT	Arbeitskreis der Hochschullehrer für Messtechnik e. V.
Andreas	**Fischer**	ForWind	ForWind – Zentrum für Windenergieforschung
Andreas	**Fischer**	MAPEX	Center for Materials and Processes
Andreas	**Fischer**	SPIE	The International Society for Optics and Photonic
Andreas	**Fischer**	EOS	European Optical Society
Andreas	**Fischer**	OSA	The Optical Society
Andreas	**Fischer**	IEEE	Institute of Electrical and Electronics Engineers
Andreas	**Fischer**	VDI	Verein Deutscher Ingenieure
Andreas	**Fischer**	GALA	Deutsche Gesellschaft für Laser-Anemometrie
Andreas	**Fischer**	DHV	Deutscher Hochschulverband
Andreas	**Fischer**		Regelungstechnisches Kolloquium in Boppard
Andreas	**Fischer**	SFB TRR/136	Sonderforschungsbereich TRR 136 Prozesssignaturen
Andreas	**Fischer**	SFB 1232	Sonderforschungsbereich 1232 Farbige Zustände
Andreas	**Fischer**	BEST	Bremer Forschungszentrum für Energiesysteme
Gert	**Goch**	WGP	Wissenschaftliche Gesellschaft für Produktionstechnik
Michael	**Sorg**	DFMRS	Deutsche Forschungsvereinigung für Meß-, Regelungs- und Systemtechnik e. V.
Michael	**Sorg**		BMWi-Forschungsnetzwerke Energie: Systemanalyse, Stromnetze, Erneuerbare Energien
Dirk	**Stöbener**	MAPEX	Center for Materials and Processes
Dirk	**Stöbener**	SFB TRR/136	Sonderforschungsbereich TRR 136 Prozesssignaturen
Dirk	**Stöbener**	VDI	Verein Deutscher Ingenieure
Dirk	**Stöbener**	VDI FA 3.61	VDI Fachausschuss 3.61 Messen an Zahnrädern und Getrieben
Dirk	**Stöbener**	VDI /VDE-MA	VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik
Gerald	**Ströbel**	DFMRS	Deutsche Forschungsvereinigung für Meß-, Regelungs- und Systemtechnik e. V.
Gerald	**Ströbel**	VDI/VDE-GMA	VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik
Axel	**von Frey-berg**	FVA AK Messt.	Forschungsvereinigung Antriebstechnik e. V. - Arbeitskreis Mess-technik

BIMAQ - the institute

Laboratories

LAB

Laboratory for dimensional metrology

BIMAQ's infrastructure features a variety of modern high-precision measurement systems. The equipment ranges from tactile coordinate, gearing and roughness measuring devices via optical systems like stripe pattern projection and laser triangulation through testers for non-destructive analysis with thermal, magnetic and acoustic probe systems and sensors. This equipment is used for the calibration and validation of newly developed measurement and sensor systems, e. g. for optical gear measurements, 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 by dimensions of a few millimetres up to 3 meters and offers standardized measurement and evaluation procedures as well as customer-specific solutions, such as the evaluation of advanced features or the digitization of a component.

Services

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

Contact: a.freyberg@bimaq.de

Tactile measurement of a 5-axis milled gear segment

LAB

Laboratory for large gears (in BIMAQ-Technikum)

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

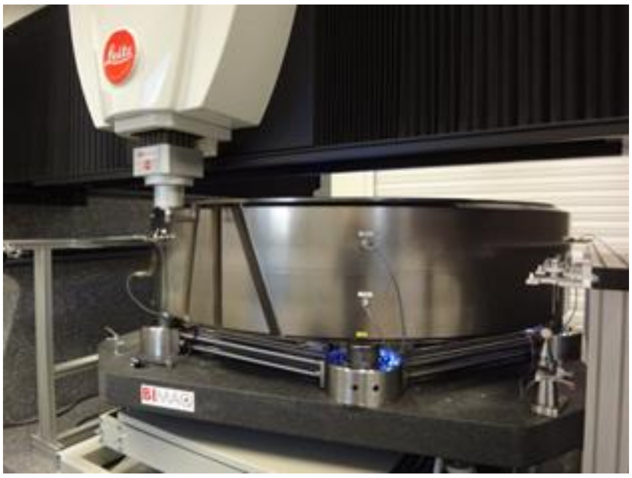
Furthermore, BIMAQ analyses the cause-effect relationships between gear manufacturing, geometric deviations and occurring gearbox damages. In the field of quality inspection of gears, algorithms are being developed in order to evaluate dimensional measurement data.

Technical specifications

Portal coordinate measuring machine Leitz PMM-F 30.20.7:

- measuring volume:
  3.0 x 2.0 x 0.7 m^3
- measuring uncertainty:
  MPE_E = (1.3 + (L in mm)/400) µm

Tactile measurement of large cylindrical gearing



Measuring a 2 m gear standard
on BIMAQ's large CMM

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

Services

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

Contact: a.freyberg@bimaq.de

Laboratories

LAB

Laboratory for optical metrology

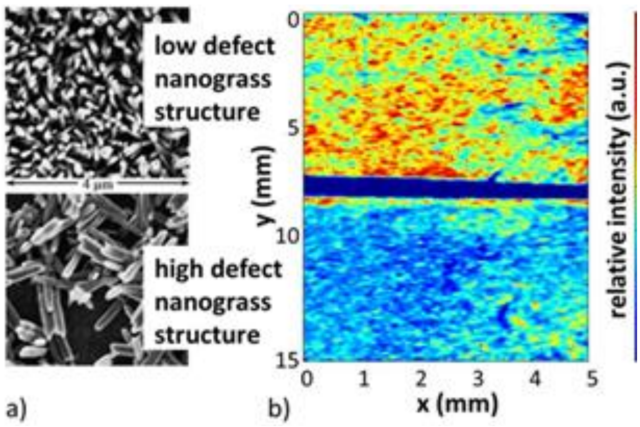
The laboratory for optical metrology focuses on two main research fields: in-process measuring methods and surface integrity evaluation.

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

The used light scattering methods allow a quick, 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 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 new application fields.

Services

- basic research for new measurement methods in the two fields of research
- 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 by comparison with reference samples
- feasibility studies on the application of measurement principles, particularly in manufacturing and heat treatment processes

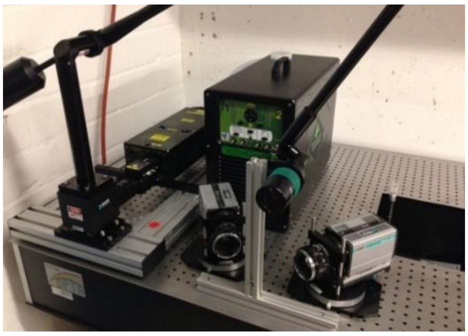


a) Examplary SEM images of intact and defective nanograss-structured surfaces.
b) Measured scattered intensities during a large area simultaneous scan over an intact and a defective nanograss structure.

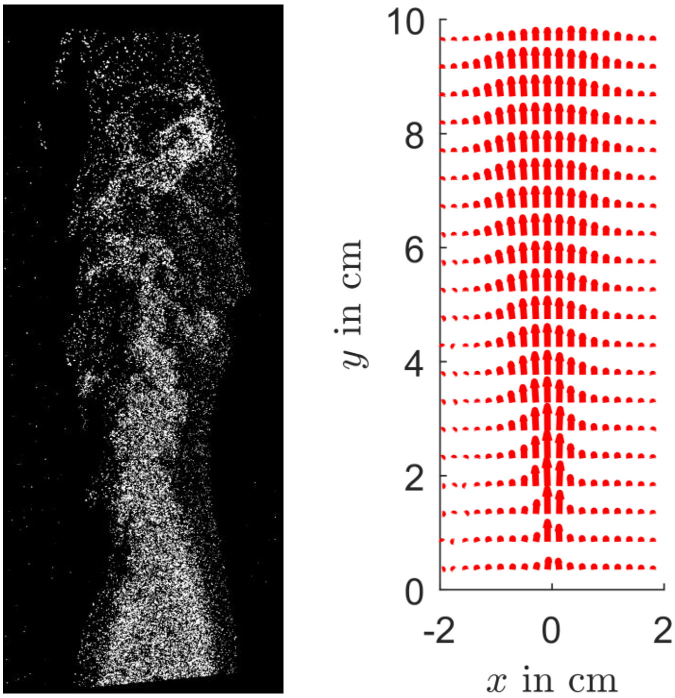
Contact: d.stoebener@bimaq.de

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 laser-based flow metrology laboratory. 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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BIMAQ - the institute

Laboratories

Laboratory for thermography

Boundary layer flow visualization on wind turbine rotor blades in operation

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

Technical data

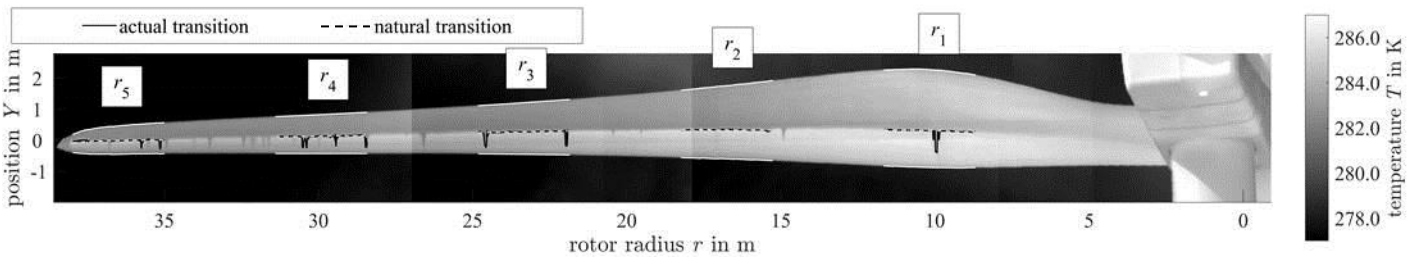
ImageIR thermographic imaging system:

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

ImageIR thermographic imaging system

Services

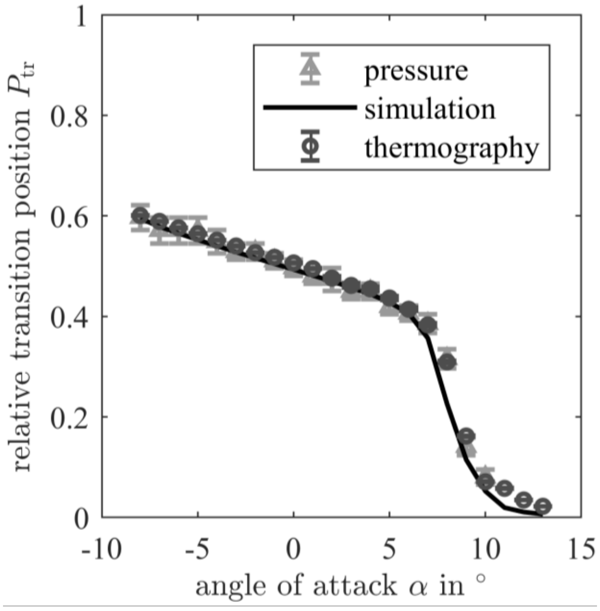
- determination of the laminar/turbulent transition location
- detection of early laminar-turbulent transition due to leading edge contamination, erosion, manufacturing irregularities or the effects of leading edge protection
- analysis of impact of leading edge protection on the boundary layer flow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



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

Boundary layer flow visualization in wind tunnel experiments

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

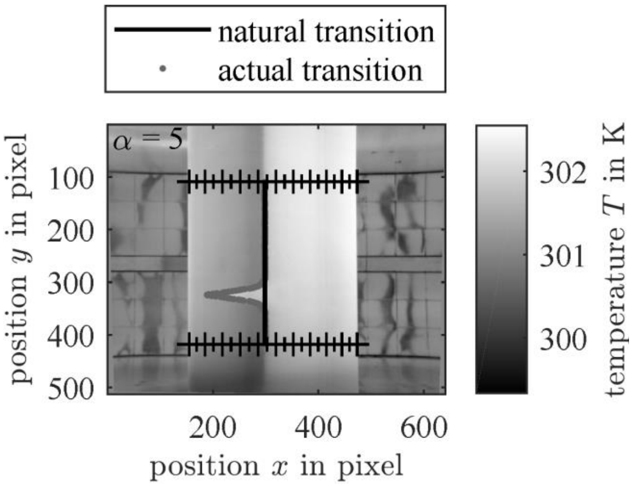


Relative position P_{tr} of the laminar-turbulent transition on the chord as a function of the angle of attack α

Technical data

VarioCam hr:

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



Thermographic flow visualization on an airfoil in the wind tunnel

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

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

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BIMAQ - the institute

Laboratories

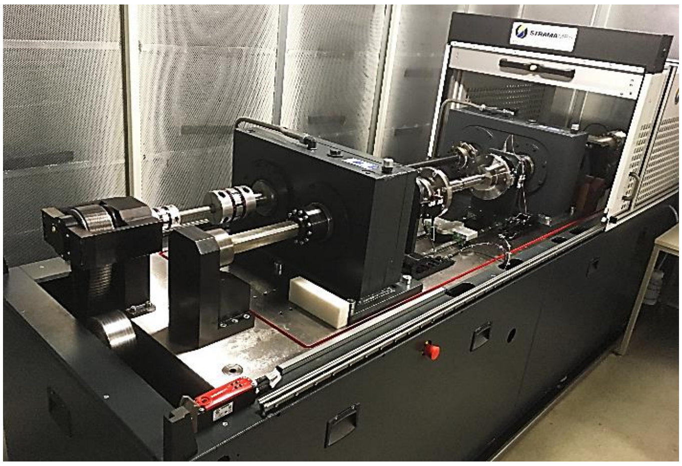
LAB

Laboratory for wind turbine sensors (in BIMAQ-Technikum)

Wind turbine generators (WTG) are dynamically highly stressed, which can lead to bearing and gear damages. For targeted improvements in design, production and choice of material meaningful metrics are missing. The individual transmission 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

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Wind turbine drive train for sensor tests

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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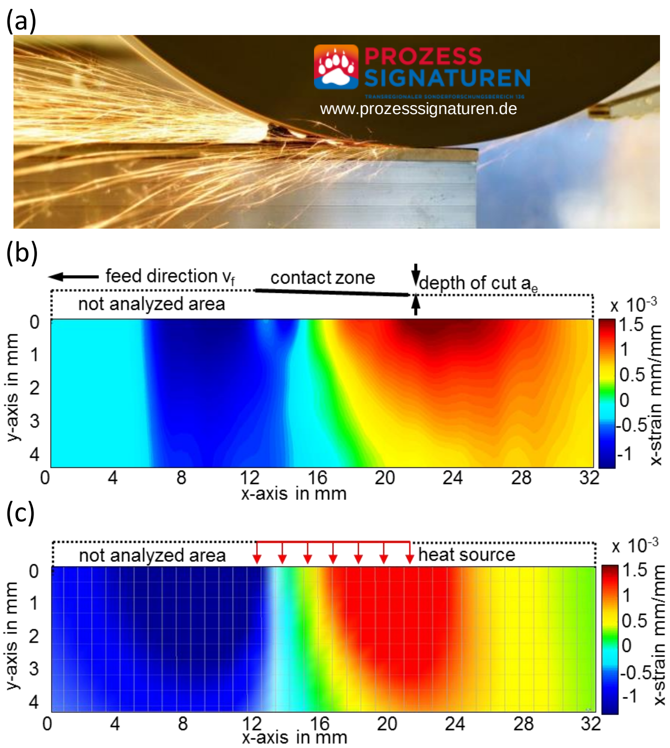
SFB/TRR 136 Process Signatures – Subproject C06

Surface-based optical measurements of mechanical material stresses

Funding organization: DFG/SFB
Funding ID: SFB Transregio 136
Duration: 1 Jan 2018 - 31 Dec 2021
Project scientist: Andreas Tausendfreund

In the first phase of the SFB, the suitability of speckle photography for in-process measurements in highly dynamic manufacturing processes was demonstrated. Specially adapted evaluation algorithms and measuring systems were developed for this purpose, so that the use of speckle photography could also be realized on fast-rotating systems such as single-tooth peripheral milling or grinding under strong flying sparks [1, 2, 3].

Three-dimensional deformations of the measured surface cannot be measured yet. This problem is to be solved by a novel approach for in-process measurements based on an analysis of the shape-modified speckle correlation functions. In addition to this three-dimensional reconstruction of the deformation fields, a central aim of the project is to determine parameters for establishing process signatures from the time-resolved stress fields measured in highly dynamic manufacturing processes. In this connection a quantification of the measurement uncertainty budget and a reduction of measurement uncertainty contributions are investigated. In addition, data analysis is to be 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 [2].

[1] A. Tausendfreund, D. Stöbener, A. Fischer: Precise In-Process Strain Measurements for the Investigation of Surface Modification Mechanisms. Journal of Manufacturing and Materials Processing 2(9):1-11, 2018.

[2] 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.

[3] A. Tausendfreund, D. Stöbener, A. Fischer: Induction of highly dynamic shock waves in machining processes with multiple loads and short tool impacts. Applied Sciences 9(11):2293 (13 pp.), 2019.

SFB 1232 Coloured States – Subproject D04

Characterization of coloured states by measuring the deformation history during forming

Funding organization: DFG/SFB

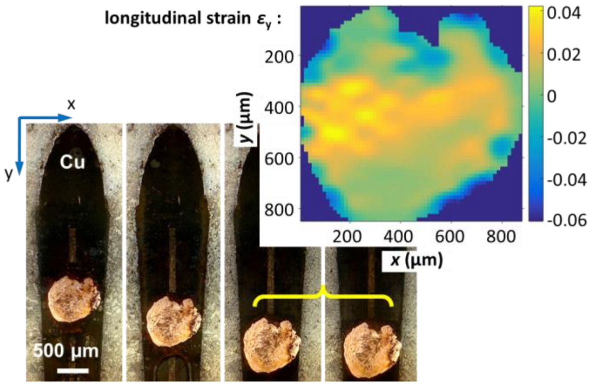
Funding ID: SFB 1232

Duration: 1 Apr 2018 – 30 Jun 2020

Project scientists: Dirk Stöbener,
Gabriela Alexe

The SFB initiative "From colored states to evolutionary structural materials" is developing a high-throughput experimental method to find targeted compositions and process chains for new metallic construction materials that meet a specific requirement profile. New methods for forming spherical micro samples, for the thermal treatment (colouring) and microscopic material characterization are combined with sample logistics and mathematical methods for the analysis of large amounts of data. Variously coloured micro samples are examined for characteristic parameters, called descriptors, which are transferred to the macroscopic material properties by a heuristic predictor function, requiring macroscopic results for only a few of the coloured states.

The classical tensile test is a standard method of material characterization and provides properties such as yield strength and strain hardening. The aim of this subproject is to investigate a comparable method for micro samples. Compressive stresses can be introduced into the sample by means of electrohydraulic forming. This leads to approximately uniaxial, homogeneous tensile stresses through a targeted deflection of the material flow in local areas.



In situ measurements of three steps in the forming history for a Cu micro sample with diameter of 700 µm (bottom left) and the strain ε_y in the forming y-direction induced in the micro sample after the last forming step (top right).

Combining the high resolution of speckle photography and the robustness of digital image correlation, the complex strain fields resulting from the compressive/tensile stresses are recorded in situ at the interface to a sapphire pane, acting as optical access in the tool. From the strain data for successive forming steps, supplemented by the forming energy and comparative material data from simulations, descriptors for the hardening behaviour of the material are generated.

[1] A. Fischer: Limiting uncertainty relations in laser-based measurements of position and velocity due to quantum shot noise. Entropy 21(3):264 (19 pp.), 2019.

[2] G. Alexe, A. Tausendfreund, D. Stöbener, L. Langstädtler, M. Herrmann, C. Schenck, A. Fischer: Uncertainty and Resolution of Speckle Photography on Micro Samples. Nanomanufacturing and Metrology (Online First), 2020.

MultiSenseo

Multisensory measurement of the geometry of large gears

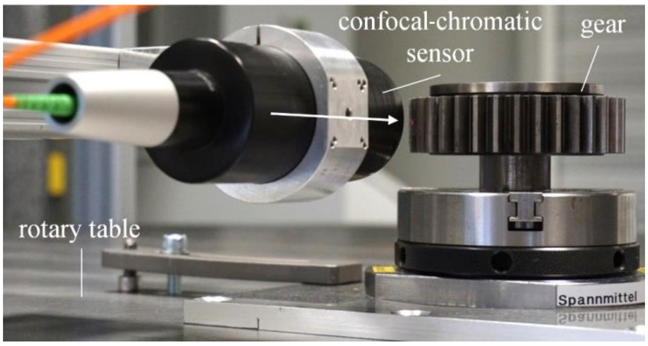
Funding organization: DFG
Funding ID: FI 1989/2-1
Duration: 1 Mar 2018 – 28 Feb 2021
Project scientist: Marc Pillarz

The quality inspection of large gears (d > 1 m) is a major challenge. With increasing gear dimensions, the required dynamic range of the measuring system is constantly rising. While the tolerances increase with increasing diameter and modulus of a gear, the ratio of the required measuring uncertainty to the measuring volume decreases. Measurements of the geometry parameters of large gears with an uncertainty < 5 µm are therefore necessary.

Coordinate and gear measuring machines are the standard measuring systems for gears. Due to a serial data acquisition and an individually fixed measuring volume, the standard measuring systems reach their limits for large gear measurements. Alternative measurement approaches, however, do not yet achieve the required measurement uncertainty.

For this reason, the aim of the research project is to determine shape parameters of large gears with a novel optical multi-sensor system with a model-based evaluation. The measuring system can be scaled to the required measuring volume by a modular design. The multisensory setup enables also a parallel and fast data acquisition. As fundamental shape parameter the base circle radius of gears is determined at first, but further gear parameters like the profile slope deviation are also examined.

By means of simulations, the theoretically achievable uncertainty of the base circle radius of large gears depending on the sensor uncertainty is estimated to less than 5 µm. A validation of the model-based multisensory approach is initially shown for a gear with a diameter of d = 0.105 m, where a measurement uncertainty of the base circle radius of < 4 µm is achieved. Hence, the experimental and theoretical results already prove the applicability of the multisensory approach for a precise inspection of gears. Scalability to larger gears is studied next.



Experimental setup of a single sensor measurement for emulation and validation of the multisensory measurement approach.

[1] A. Fischer: Fisher information and Cramér-Rao bound for unknown systematic errors. Measurement 113:131-136, 2018.

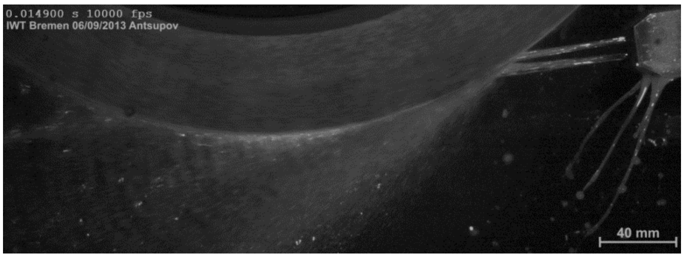
[2] M. Pillarz, A. von Freyberg, A. Fischer: Multisensory measurement of the base circle radius as a fundamental shape parameter of large gears. International Conference on Gears, München, 18.-20.9.2019, pp. 1207-1214.

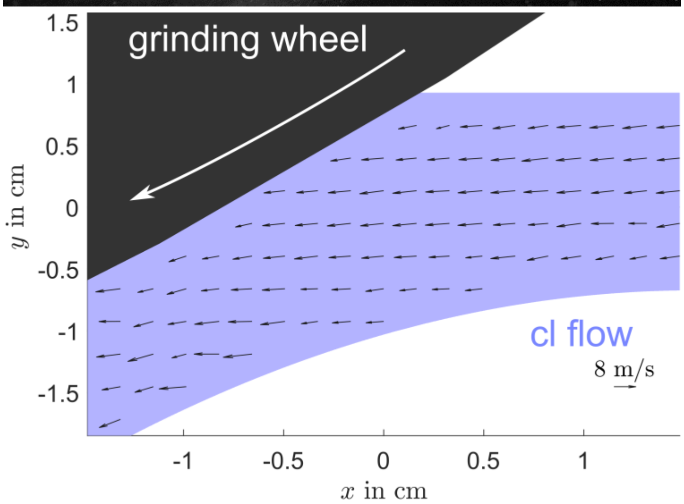
ProstKühl

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

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

Grinding is an essential manufacturing process for the production of, e. g., metallic or optical components. A high process speed requires an efficient cooling in order to avoid grinding burn. However, flow mechanisms for an efficient cooling lubricant (cl) supply are not yet known. Only heuristic optimization of the supplying cl jet flow was performed so far. To understand the flow mechanisms responsible for an efficient cooling of the grinding process, in-process-flow field measurements of the cl flow are necessary.





Visualization (top) and PIV measurement (bottom) of the mean cooling lubricant (cl) flow velocity field near the grinding wheel.

For this reason, the applicability of particle image velocimetry (PIV) in a grinding machine is investigated to determine the cooling lubricant flow velocity field. A big challenge is to achieve valid flow velocity field measurements due to the fluctuating refractive index field of the two-phase flow of cooling lubricant and air, which causes disturbing light refraction. Therefore the studied approach is to determine the flow field by a statistical evaluation of multiple PIV measurements. Furthermore, systematic and random measurement deviations due to light refraction are determined by a novel experimental technique which measures the resulting light deflections inside the cl flow. Based on these results, the feasibility of high-speed and stereoscopic PIV measurements is finally investigated.

[1] C. Vanselow, A. Fischer: Influence of inhomogeneous refractive index fields on particle image velocimetry. Optics and Lasers in Engineering 107:221-230, 2018.

[2] C. Vanselow, D. Stöbener, J. Kiefer, A. Fischer: Particle image velocimetry in refractive index fields of combustion flows. Experiments in Fluids 60:149 (11 pp.), 2019.

ThermoStall

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

Funding organization: DFG
Funding ID: 420278089
Duration: 16 Dec 2019 – 15 Dec 2022
Project scientist: Felix Oehme

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

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

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

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

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

[1] C. Dollinger, N. Balaresque, M. Sorg: Thermographic boundary layer visualization of wind turbine rotor blades in operation. EWEA 2014, Barcelona, Spain, 10 - 13 Mar 2014, No. 9. (Poster)

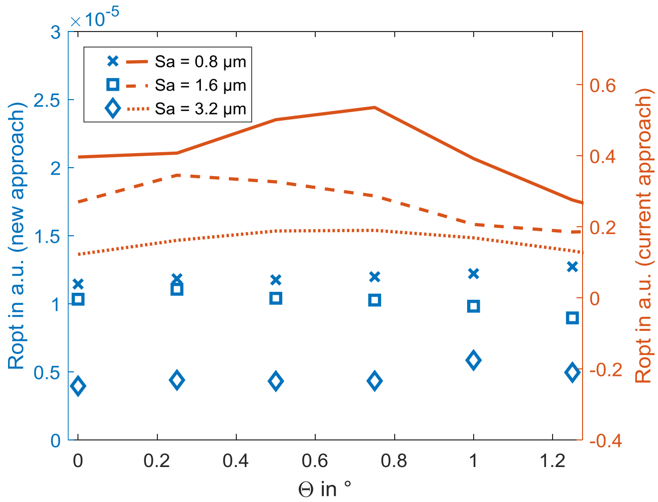
[2] C. Dollinger, N. Balaresque, M. Sorg, A. Fischer: IR thermographic visualization of flow separation in applications with low thermal contrast. Infrared Physics & Technology 88:254-264, 2018.

Inline quality control for zero-error-products

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

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

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



Result of the current (orange) and the newly proposed (blue) speckle evaluation algorithm with integrated surface tilt correction over the tilt angle Θ. Note the different axis scaling of Ropt, which is the output quantity of the measurement system that corresponds with the surface roughness. As a result, the cross-sensitivity with respect to the surface tilt angle is eliminated.

[1] P. Lehmann: Aspect ratio of elongated polychromatic far-field speckles of continuous and discrete spectral distribution with respect to surface roughness characterization. Applied optics 41(10):2008-2014, 2002.

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

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

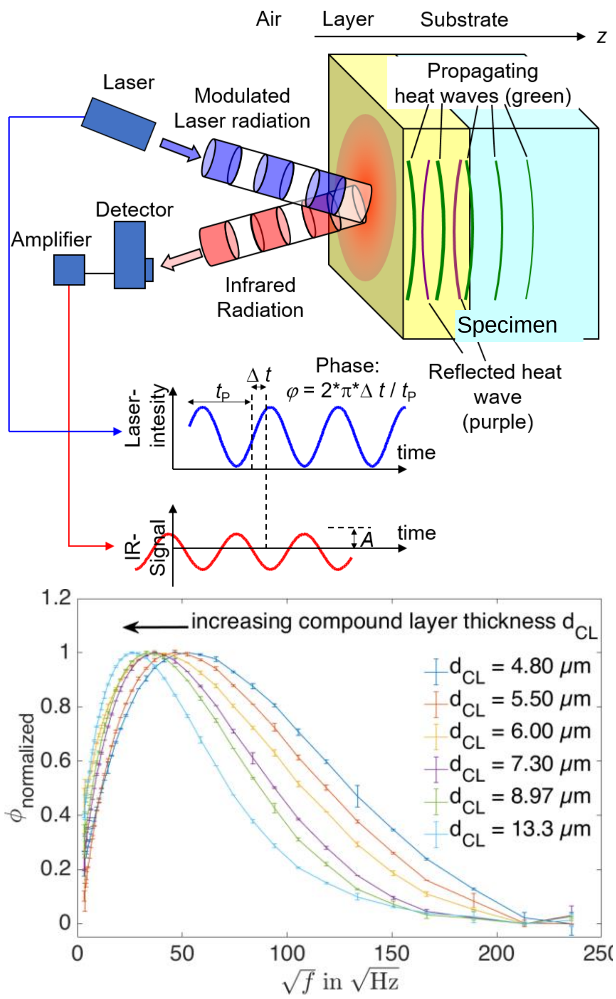
PhoMeNi

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

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

For many decades, gas nitriding has been one of the most important thermochemical surface layer treatment processes for steels in order to improve surface hardness and wear resistance. The resulting nitriding layer consists of the outer compound layer and the underlying diffusion layer. Gas nitriding can often lead to incorrect nitriding results such as soft spots, a nitriding layer that is too thin or highly porous. Currently, the nitriding process lacks a direct measuring method to observe the boundary layer development in-process, i.e. in an industrial nitriding furnace. While X-ray diffractometry enables an in-situ characterization of the nitride phase formation, it can also not be used in industrial nitriding furnaces.

The project *PhoMeNi* aims to employ photothermal radiometry, an alternative measurement technique that allows in-process, contact-free and non-destructive boundary layer examination. Since photothermal signals depend on the thermal properties of the surface, modifications to the boundary layer such as the diffusion and compound layer or near-surface porous zones can be observed during their formation and growth in process. Thus *PhoMeNi* aims to develop a photothermal sensor for industrial furnaces and to increase the general understanding of nitriding kinetics.



Top: Principle of photothermal radiometry.
Bottom: Phase signals of different compound layer thicknesses.

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

SelTon-X

Analysis of the leak tightness of the SelTon self-tonometer and its influence on the measurement uncertainty

Funding organization: BMWi
Funding ID: 03THW04H02
Duration: 1 Sep 2018 – 29 Feb 2020
Project scientist: Jan Osmers

Glaucoma is currently the most common cause of irreversible blindness worldwide. An increased intraocular pressure (IOP) is a major risk factor and its reduction describes the only therapeutical approach. A gentle tonometer that can be operated by the patient himself to determine the fluctuations of daily pressure would be desirable for optimal therapy monitoring. For this reason, BIMAQ has developed a self-tonometer in which the IOP is determined contactlessly from the oscillation characteristics of the eye. In the BMBF project SelTon, the measuring principle was tested on humans. In addition to promising results, air leakage was determined as a significant cross-sensitivity which may lead to large deviations. For this reason, the aim of *SelTon-X* is to investigate the cross-sensitivity and how it is compensated with a mathematical model.

In the past months a variety of measurements have been conducted. Fig. 1 shows the test rig that allows the parallel measurement of the corneal deflection of a porcine eye and the effect of a precisely adjusted amount of leakage to the pressure chamber.

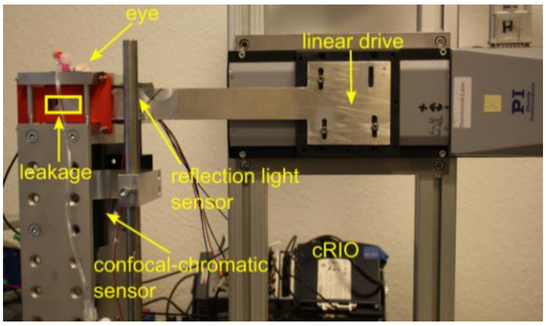


Fig. 1: Leakage test rig porcine eye on top.

The results show the effect of an increasing amount of leakage to the systems behaviour. In Fig. 2 the leakage effect on the corneal deflection of a porcine eye at different IOP-values is shown.

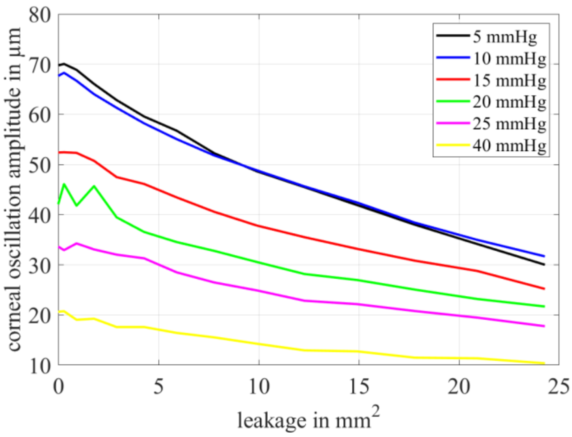


Fig. 2: Corneal deflection according to leakage at six IOP values.

The implementation of an optical sensor to the setup in principle would allow to compensate slight leakages and thus to reduce the measurement uncertainty for medical device approval.

[1] J. Osmers, M. Sorg, A. Fischer: Optical measurement of the corneal oscillation for the determination of the intraocular pressure. Biomedical Engineering / Biomedizinische Technik 64(4):471-480, 2019.

Geowisol2

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

Funding organization: BMBF
Funding ID: 40401065
Duration: 1 Jan 2019 – 31 Dec 2021
Project scientist: Yannik Schädler

The expansion of renewable energies for an alternative energy system is one of the main goals for energy system transformation and for the reduction of climate-damaging greenhouse gases. Due to the fluctuation of wind and solar power, the challenges for the German power grid are increasing with its share in power generation [1]. In order to optimally cover the increasing demand, it is necessary to have a precise knowledge of both the feed-in and demand quantities, resolved in terms of time and place. Such a comprehensive database is currently only available for parts of Germany or with limited spatiotemporal resolution.

For this reason, a database was developed which provides feed-in quantities for wind, solar and other renewable energies as well as energy demand time series, each as 15-minute average values and with a local resolution of 2-digit ZIP code regions. *GeoWiSol 2* now aims to extend the database further by adding the time series of conventional power plants. Also it is planned to map the determined geographical distribution to the existing power lines. On this basis, the transmission volumes in the current expansion state and for future expansion scenarios will be analysed and evaluated over time. In particular, the grid expansion and the integration of storage systems will taken into account as both aspects are becoming increasingly important. This will result in a tool that can evaluate future energy infrastructure projects.

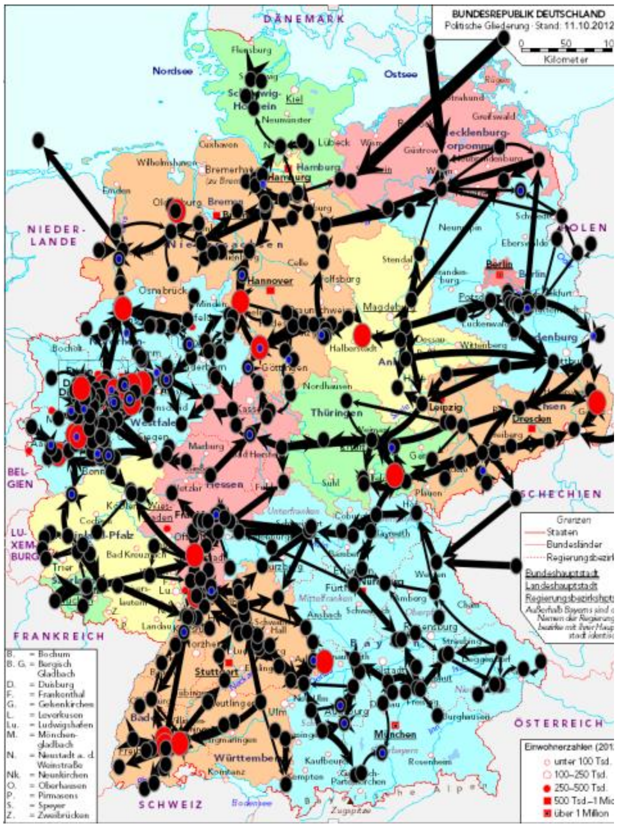


Fig. 1: German power transmission network in 2016. Data from the SciGrid Project [2].

[1] V. Renken et al.: Geographical comparison between wind power, solar power and demand for the German regions and data filling concepts. Renewable energy 126:475-484, 2018.

[2] C. Matke et al.: SciGRID - An Open Source Reference Model for the European Transmission Network (v0.2), www.scigrid.de, 2015.

BiSWind

Component integrated sensor system for wind energy systems

Funding organization: Federal Ministry BMWi
Funding ID: 0325891D
Duration: 1 Dec 2015 – 31 Jul 2019
Project scientist: Michael Sorg

Drive trains of wind energy systems experience a broad range of dynamic loads. Transient torque reversals originate in power loss and emergency stops, start cycles and in sheer winds and turbulence. These dynamic loads often lead to premature failures of bearings and gears. To improve the design of drive train components with precise load cycles, precise and long-term measurements are required.

Research wind energy system of the University of Bremen.

Torque sensors are currently used only sporadically and not in volume production. Direct measurements of loads are not available for most parts of the drive train, especially from the inside of the gearbox. Data over the lifetime are scarce and correlations to failure events are thus limited to a few cases.

The co-operative research project *BiSWind* develops a component-integrated measuring system. The key design aspects are measurement of torque, temperature, vibration and rotational speed with a sensor that is resistant to aging and aggressive media, and is self-sufficient.

The scientific and technical objectives cover a broad range beginning with the process development for direct coating and structuring of resistance structures and electrodes directly on shafts for the durable sensor itself. To be self-sufficient newly developed AlN and AlScN based piezoelectric structures have to provide the energy for the sensor module which in turn will be assembled on a cylindrical low temperature co-fired ceramics. This subproject investigates both the suitability and the performance of the measuring system for application in wind turbines.

[1] K. Tracht, G. Goch, P. Schuh, M. Sorg, J. F. Westerkamp: Failure probability prediction based on condition monitoring data of wind energy systems for spare parts supply. CIRP Annals 62(1):127-130, 2013.

InSensa

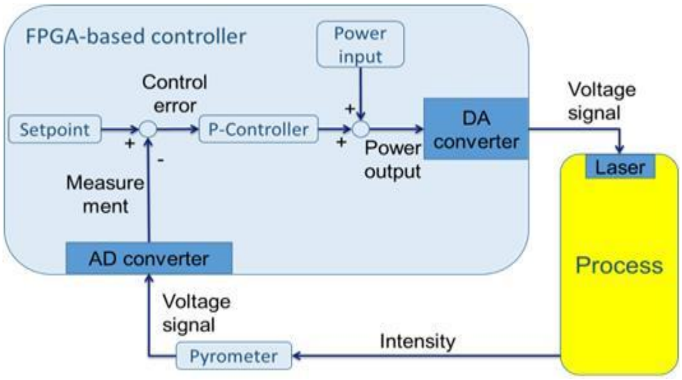
In-process sensors and adaptive control systems for additive manufacturing

Funding organization: BMBF
Funding ID: 02P15B076
Duration: 1 May 2017 – 31 Oct 2020
Project scientists: Volker Renken,
Michael Sorg

Selective laser melting (SLM) becomes an important factor for the manufacturing of different construction parts. The technology offers variances and functionalities going beyond conventional manufacturing. However, the SLM machines seldomly possess sensors to detect actual process states and have limited reaction on disturbances. That leads either to part errors and unnecessary follow-up costs or to a not optimized manufacturing procedure regarding resources and efficiency.

For this reason, the aim of the project *InSensa* is the integration of additional sensor and control technology into the machines. Different sensors measuring intensity in visible (RGB) and infrared range (IR) as well as topography (in-process depth meter - IDM) shall be included. Therefore, the process parameters as melt pool size and temperature will be reasoned and controlled by adaptive model-based control strategies within a cascaded control structure. For that purpose, techniques from machine learning are included in the control hardware. The process speed is a high challenge for the control hardware and software. In order to be able to react on measurable changes fast models and fast hardware are needed. First results show control times of below 50 µs [1].

Principal control ability has been shown for a proof-of-concept experiment by scanning with low scan speed over a bridge structure. Thus, a closed-loop P-controller approach leads to a temperature deviation reduction of up to 70 % compared to an open-loop control.



Control structure within closed-loop of manipulating the laser power by pyrometer measurement.

The standard deviation of a pyrometer measurement signal is also reduced by 25 % in closed loop control approach for build jobs of cubes and triangle geometries. Hence the results are promising to reduce error rates significantly for complex part geometries.

[1] V. Renken, L. Lübbert, H. Blom, A. von Freyberg, A. Fischer: Model assisted closed-loop control strategy for selective laser melting. LANE 2018 10th CIRP Conference on Photonic Technologies, Fürth, 3 - 6 Sep 2018, Procedia CIRP 74:659–663, 2018.

[2] V. Renken, A. von Freyberg, K. Schünemann, F. Pastors, A. Fischer: In-process closed-loop control for stabilising the melt pool temperature in selective laser melting. Progress in Additive Manufacturing 4(4):411-421, 2019.

PreciWind

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

Funding organization: PTJ
Funding ID: 03EE3013D
Duration: 1 Jan 2020 – 31 Dec 2022
Project scientists: Daniel Gleichauf,
Paula Helming

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

The state of the art metrology for a non-invasive measurement of the boundary layer flow on rotor blades of wind turbines in operation is thermographic flow visualization. Compared to state-of-the-art methods that use invasive preparations of the blade surface, thermographic flow visualization uses the effect of different surface temperatures due to different heat transfer coefficients in the boundary layer for a contactless differentiation between the flow regimes [1]. So far, the measurement system only visualizes static flow phenomena by taking single snap-shots of the rotor blade during operation [2]. Therefore, an advancement of the existing metrology is necessary that enables studying dynamic flow behaviour.

Therefore, the aim of project *PreciWind* is to develop a new co-rotating measurement system that allows the camera system to follow the rotor blade movement. This way, each radial section of the rotor blade is observed continuously during one revolution of the rotor. This allows a detailed measurement of the dynamic flow behaviour in the boundary layer flow as well as dynamic structural behaviour due to the changing flow conditions that also imply varying structural loads.

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

[1] C. Dollinger, N. Balaresque, M. Sorg, A. Fischer: IR thermographic visualization of flow separation in applications with low thermal contrast. Infrared Physics & Technology 88:254–264, 2018

[2] C. Dollinger, N. Balaresque, N. Gaudern, D. Gleichauf, M. Sorg, A. Fischer: IR thermographic flow visualization for the quantification of boundary layer flow disturbances due to the leading edge condition. Renew. Energy 138:709–721, 2019.

SiToH

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

Funding organization: BMBF
Funding ID: 100363507
Duration: 1 Aug 2018 – 31 Jul 2021
Project scientist: Gert Behrends

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

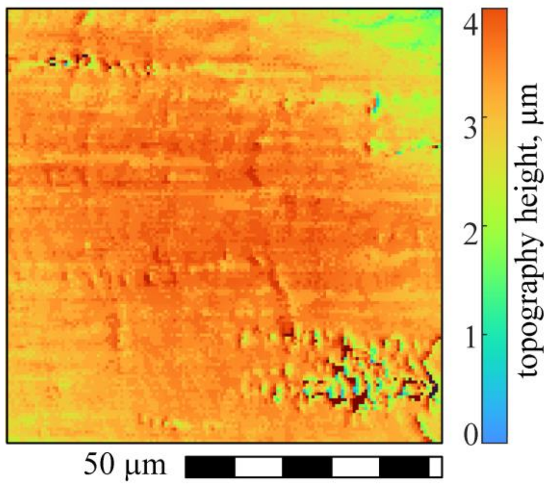
One suitable measurement technique is vertical scanning white light interferometry (VSWLI), as specified in DIN EN ISO 25178. State of the art VSWLI is able to accurately record surface topographies with a height resolution < 1 nm. Drawbacks of this method are its limitation to stationary surfaces and extensive post-processing when measuring large areas. *SiToH* overcomes these limitations by applying lateral scanning white light interferometry (LSWLI), as first described by Olszak [1]. LSWLI combines vertical and horizontal scanning into a single motion, enabling continuous measurements of moving surfaces. However, LSWLI here needs to be applied for the first time on curved surfaces.

On plain surfaces the signals' vertical measurement support points are evenly spaced dependent on the surface tilt angle. Experiments on plain samples show angles between 0.5° and 2° to yield the best results. Ambiguities in the recorded correlograms adversely affect the height evaluation at smaller angles. Shadows of tall surface features are a source of error at steeper angles.

On circular objects, the axial support point grid is densest where it is closest to the sensor and increasingly spreads out near the edge of the field of view. This non-linear spread of support points and the resulting laterally distributed object height uncertainty is subject of current research.

[1] A. Olszak: Lateral scanning white-light interferometer, Applied Optics, 39:6-13, 2000.

[2] G. Behrends, D. Stöbener, A. Fischer: Topografiemessung gekrümmter Oberflächen mittels lateral scannender Weißlichtinterferometrie, 120. Jahrestagung der DGaO, Darmstadt, 11 - 15 Jun 2019.



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

SUrfErCut

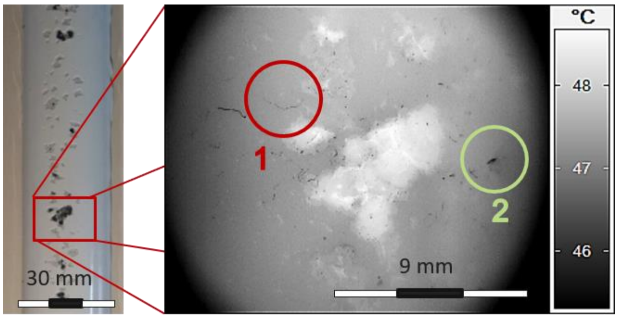
Systematic investigation of the causes of erosion damage to wind turbines

Funding organization: AiF
Funding ID: 40401106
Duration: 1 Sep 2019 – 31 Aug 2021
Project scientist: Friederike Jensen

The leading edge of a rotor blade is particularly exposed to mechanical and environmental stresses such as during rain, where the drops hit the blade with an impact speed of over 300 km/h. The impact of rain drops gradually removes the coated surface as well as parts of the underlying glass-fiber composite material. The condition of the leading edge of a wind turbine blade significantly influences the aerodynamic properties of the rotor blade and thus the performance of the wind turbine [1]. Damage caused primarily by erosion limits the lifetime of wind turbines and leads to high maintenance and repair costs. Studies suggest that initial subsurface defects such as pores in the border area between coating and GFRC can lead to premature erosion.

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

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



Thermogram of an eroded test sample;
1: micro-crack; 2: subsurface material inhomogeneity.

A first experiment shows that active micro-thermography can be used as a non-invasive, non-destructive measuring method to visualize material inhomogeneities in the micrometer range that remain hidden during visual inspection. Further investigations including computer tomography (CT) reference measurements are necessary to determine the influence of these detected inhomogeneities on premature rain erosion. Finally, in-situ measurements and damage analyses will be conducted on the leading edge of a real-scale wind turbine blade.

[1] C. Dollinger, N. Balaresque, N. Gaudern, D. Gleichauf, M. Sorg, A. Fischer: IR thermographic flow visualization for the quantification of boundary layer flow disturbances due to the leading edge condition. Renewable Energy 138:709-721, 2019.

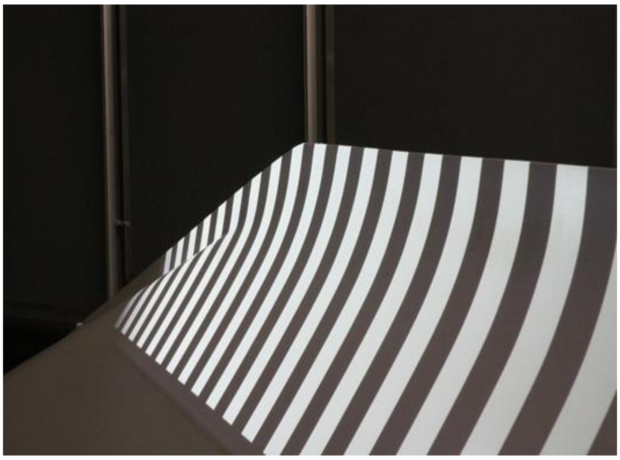
LoGAZ

Laser optical measurement method for the state analysis of wind turbines

Funding organization: BAB
Funding ID: AUF0007A
Duration: 1 May 2020 – 30 Apr 2021
Project scientists: Leon Schweickhardt,
Axel von Freyberg

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

By means of suitable evaluation algorithms, the measurement data acquired with the 3D laser scanner are transformed into the turbine coordinate system (TCS). By implementing geometric and mechanical degrees of freedom in the approximation of the measurement data by the rotor blade nominal profile, the orientation of the rotor blade chord is then calculated. The research question is: With which uncertainty can the position of the rotor blade chord be determined from a series of distance measurements (profiles)? In this context it has to be clarified whether the orientation of the measuring system to the wind turbine can be calculated intrinsically from the measured and nominal data or has to be determined by separate calibration measurements.



Reference measurement on a blade by means of stripe pattern projection.

[1] C. Dollinger, D. Gleichauf, N. Balaresque, A. Fischer: Messung des strömungsbeeinflussenden Kontaminationsgrads von Rotorblättern mittels thermografischer Strömungsvisualisierung. XXXII. Messtechnisches Symposium des AHMT, Bremen, 20.-21.9.2018. tm - Technisches Messen 85(S1):129-135, 2018.

Cooperations with industry and measurement services

Cooperation partners

A

- 3M Deutschland GmbH, ***Neuss***
- Aconity3D GmbH, ***Herzogenrath***
- Akzo Nobel Hilden GmbH, ***Neuss***
- *Alfavision*, ***Hutthurm***
- AneCom AeroTest GmbH, ***Wildau***
- ASENTEC GmbH, ***Heilbronn***
- AUKOM e. V., ***Braunschweig***

B

- Becker Photonik GmbH, ***Porta Westfalia***
- BIAS Bremer Institut für angewandte Strahltechnik, ***Bremen***
- BIBA Bremer Institut für Produktion und Logistik, ***Bremen***
- BIME Bremer Institut für Strukturmechanik und Produktionsanlagen, ***Bremen***

C

- Centre de Recherches Métallurgiques (CRM asbl), ***Lüttich***
- C.F.K. CNC-Fertigungstechnik Kriftel GmbH, ***Kriftel***
- CoSynth GmbH & Co. KG, ***Oldenburg***

D

- Deutsche Wind Guard GmbH, ***Varel***
- Deutsche WindGuard Engineering GmbH, ***Bremerhaven***
- Deutsche WindGuard Systems, ***Berlin***
- DEWI-OCC GmbH, ***Cuxhaven***
- DFMRS Deutsche Forschungsvereinigung für Meß-, Regelungs- und Systemtechnik e. V., ***Bremen***

E

- energy & meteo systems GmbH, ***Oldenburg***

F

- Faserinstitut Bremen e. V. FIBRE, ***Bremen***
- Fraunhofer-Einrichtung für Additive Produktionstechnologien IAPT, ***Hamburg-Bergedorf***
- Formtech GmbH, ***Weyhe***
- Fraunhofer Institut für Windenergie und Energiesystemtechnik IWES, ***Bremerhaven***
- Fraunhofer-Institut für Keramische Technologien und Systeme IKTS, ***Dresden***
- Fraunhofer-Institut für Organische Elektronik, Elektronenstrahl- und Plasmatechnik FEP, ***Dresden***
- Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik, ***Chemnitz***
- Fibretech Composites GmbH, ***Bremen***
- FRT GmbH, ***Bergisch Gladbach***
- FWBI Friedrich Wilhelm Bessel Institut Forschungsgesellschaft mbH, ***Bremen***

G

- Gesellschaft für Bild- und Signalverarbeitung (GBS) GmbH, ***Ilmenau***
- Gottwald Hydraulik, ***Bremen***

H

- Hansgrohe SE, ***Schiltach***
- Helmholtz-Zentrum, Institut für Fluiddynamik, ***Dresden***
- Hexagon Manufacturing Intelligence, ***Wetzlar***

Cooperations with industry and measurement services

Cooperation partners

I

- IMSAS Institut für Mikrosensoren, -aktoren und -systeme, Universität ***Bremen***
- InfraTec GmbH Infrarotsensorik und Messtechnik, ***Dresden***
- *in-situ GmbH,* ***Sauerlach***
- ISRA VISION AG, ***Darmstadt***
- iWP Innovative Werkstoffprüfung GmbH, ***Neuss***

K

- K & R enatec GmbH, ***Schwanewede***
- Klingelnberg GmbH, ***Hückeswagen***

L

- Labor für Mikrozerspanung, ***Bremen***
- Leibniz-Institut für Werkstofforien-tierte Technologien - IWT, ***Bremen***
- LASE Industrielle Lasertechnik GmbH, ***Bremen***

M

- Materialise GmbH, ***Bremen***
- Meridian Lightweight Technologies United Kingdom (MLTUK), Sutton-In-Ashfield, ***Nottingham/UK***
- *Mevisco Gmbh & Co. KG,* ***Bremen***
- Micro Systems Engineering GmbH, ***Berg***

N

- Nawrocki Alpin GmbH, ***Berlin***

O

- Oklahoma State University. School of Mechanical and Aerospace Engineering, ***Stillwater***
- OptoPrecision GmbH, ***Bremen***
- Optris GmbH, ***Berlin***

P

- Physikalisch-Technische Bundesanstalt PTB, ***Braunschweig***
- Pöppelmann GmbH & Co. KG, ***Lohne***
- Precitec GmbH & Co. KG, ***Gaggenau***

R

- Roland Klinik Bremen gGmbH, ***Bremen***

S

- Sachverständigenbüro Otto Lutz, ***Bundorf***
- Schaeffler Technologies AG & Co. KG, ***Herzogenaurach***
- Siegert Thinfilm Technology GmbH, ***Hermsdorf***
- Siemens AG, ***Bremen***
- *Stiftung OFFSHORE-WINDENERGIE,* ***Varel***

T

- Tata Steel Plating, Hille & Müller GmbH, ***Düsseldorf***
- Technische Universität Dresden, Institut für Festkörperelektronik, ***Dresden***
- Temicon GmbH, ***Dortmund***
- Tomey GmbH, ***Nürnberg***
- Technische Universität Ilmenau, Fachgebiet Elektroniktechnologie, ***Ilmenau***
- Technische Universität Ilmenau, Fachgebiet Mikromechanische Systeme, ***Ilmenau***
- Toho Tenax Europe GmbH, ***Wuppertal***
- Trecolan GmbH, ***Bremen***

U

- Universitätsklinikum, Augenklinik, ***Würzburg***
- Universitätsklinikum Hamburg-Eppendorf (UKE), ***Hamburg***

V

- VEW Vereinigte Elektronikwerkstätten GmbH, ***Bremen***
- VSB - Technická Univerzita ***Ostrava***
- VTD Vakuumtechnik Dresden GmbH, ***Dresden***

W

- Weiss Medizintechnik GmbH, ***Rednitzhembach***
- Weiss Umformwerkzeuge GmbH, ***Rednitzhembach***
- WindMW Service GmbH, ***Bremerhaven***
- WKA Blade Service GmbH, ***Fehmarn***
- WZL Werkzeugmaschinenlabor RWTH, ***Aachen***

Cooperations with industry and measurement services

Measurement services

Dimensional measurements

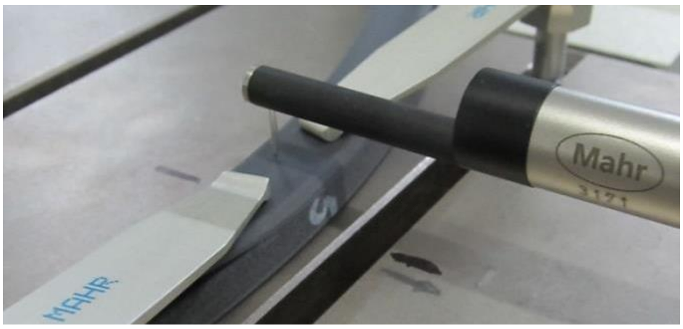
Duration: continuously

Contact: a.freyberg@bimaq.de

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

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

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



Roughness measurement on a flexible sealing element

Thermographic flow visualization

Duration: continuously

Contact: d.gleichauf@bimaq.de

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

Teaching

Teaching activities, student projects, graduation works

Teaching activities

Lecture	PT	SE	Wing	BB	Sem. BSc	Sem. MSc	CP	Students WiSe 19/20 and SoSe 2020
Messtechnik	●	●	○	○	3rd		3	131
Übung Messtechnik	●		○	○	3rd		1	134
Labor Messtechnik	●		○	○	3rd		1	39
Regelungstechnik	●		○		5th		3	66
Übung Regelungstechnik	●		○		5th		1	64
Labor Regelungstechnik	●		○		5th		1	50
Grundlagen der Qualitätswissenschaft	●	●	●		5th	1st	3	104
Regenerative Energien	●	○	○	○	4th 6th	1st	3	21
Prozessnahe und In-Prozess-Messtechnik	●	●	●		4th 6th	1st 2nd 3rd	3	27
Geometrische Messtechnik mit Labor* AUKOM	●	●	○		5th	1st	3	18
Methoden der Messtechnik - Signal- und Bildverarbeitung	●	●	●		5th	1st 2nd	3	7
Einführung in die Automatisierungstechnik mit Labor	●	●	○		5th	1st 2nd	3	25
Produktion von Verzahnungen (held by several chairs)	●	○				1st 2nd	6	9
Labor Produktion von Verzahnungen (held by several chairs)	●	○				1st 2nd	3	3
Grundlagenlabor Produktionstechnik		●			4th		2	34
Messtechnisches Seminar	●	●	●		4th	1st 2nd	3	8

Legend:
● - Pflicht-/Wahlpflicht-/Wahlfach, ○ - fakultativ
PT - Produktionstechnik, **SE** - Systems Engineering, **Wing** - Wirtschaftsingenieurwesen Produktionstechnik, **BB** - Berufliche Bildung
* - AUKOM Certificate: AUKOM is a manufacturer-independent association for training in the field of geometric measurement technology. AUKOM offers the students to earn the level 1 basic certificate at cost (in total, there are 3 levels of training: 1 basic, 2 advanced, 3 expert).

Teaching

Teaching activities, student projects, graduation works

Student projects

Kind of project	Title	Semester	Course of studies*
Informatikprojekt	Aufbau eines 3D-Laserscanners mit Signalauswertung und Geräteansteuerung unter MATLAB	SoSe 2019	BSc PT BSc WING
Bachelorprojekt	Webbasierte Visualisierung von Energieflüssen im Stromnetz bei verschiedenen Last- und Einspeisesituationen	WiSe 2019 /2020	BSC PT BSc WING
Bachelorprojekt	Maximale Übertragungsleistungen von Leiterseilen bis zur zulässigen Höchsttemperatur bei verschiedenen Wettersituationen	WiSE 2019 / 2020	BSC PT BSC WING

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

Graduation works

Bachelor theses

- Michael ***Arenz***:
  Optische Simulation eines lateral scannenden Weißlichtinterferometers.
  Colloquium: 18 Feb 2020.
- Ann-Kathrin ***Dannhauer***:
  Bestimmung der Bohrkanallänge beim handgeführten medizinischen Bohren von Knochen.
  Colloquium: 2 Oct 2019.
- Jonas ***Löcken***:
  Messunsicherheiten bei Leistungsmessungen im Rahmen erneuerbarer Energien auf deren Wirkung auf das Stromnetz.
  Colloquium: 21 Oct 2019.
- Daniel ***Musekamp***:
  Regelung additiver Fertigungsprozesse durch adaptive Modellbildung.
  Colloquium: 21 Aug 2019.
- Aage ***Rehfeldt***:
  Optimierung eines Windkanalmesssystems zur Untersuchung des Schräganströmverhaltens von Windmessgeräten.
  Colloquium: 16 Apr 2020.
- Leonard ***Schröder***:
  Experimentelle Machbarkeitsstudie zur thermographischen Tragbildanalyse.
  Colloquium: 9 Jul 2019.
- Jan Lukas ***Tiefensee***:
  Automatisiertes Entzerren und Zusammensetzen von Einzelaufnahmen für die thermografische Strömungsvisualisierung.
  Colloquium: 28 Feb 2020.

Master theses

- Andreas ***Nieto Belano***:
  Analyse des Kontaminationsgrades an Rotorblättern von Windenergieanalagen im Betrieb.
  Colloquium: 5 Jul 2019.

- Franziska ***Dralle***:
  Untersuchung der Wärmeentstehung beim medizinischen Bohren von Knochen.
  Colloquium: 18 Oct 2019.

- Ling-Feng ***He***:
  Einfluss von inhomogenen Brechungsindexfeldern bei Paricle-Image-Velocimetry in Zweiphasenströmungen.
  Colloquium: 7 Feb 2020.

- Oskar ***Hoppe***:
  Bestimmung von Messabweichungen für Particle-Image-Velocimetry in Flammen mittels optischer Messung des Brechungsindexfeldes.
  Colloquium: 18 Jun 2019.

- Dennis ***Jakob***:
  Verteilung der laminar-turbulenten Transition auf Rotoren von Windenergieanlagen.
  Colloquium: 21 Oct 2019.

- Nils ***Kaiser***:
  Betrachtung nichtlinearer Materialeigenschaften in der FEM-Analyse der innendruckabhängigen Schwingungsdynamik des Auges.
  Colloquium: 27 Aug 2019.

Publications and qualification of young academics

Publications

Books

- M. ***Agour***, A. von Freyberg, B. Staar, C. Falldorf, A. Fischer, M. Lütjen, M. Freitag, G. Goch, R. B. Bergmann:
  Quality inspection and logistic quality assurance of micro technical manufacturing processes.
  In: Cold micro metal forming.
  (Eds.: F. Vollertsen, S. Friedrich, B. Kuhfuß, P. Maaß, C. Thomy, H.-W. Zoch), Springer, Berlin, 2019, pp. 256-274.

- A. ***Fischer***:
  Scatter.
  In: Cold micro metal forming.
  (Eds.: F. Vollertsen, S. Friedrich, B. Kuhfuß, P. Maaß, C. Thomy, H.-W. Zoch), Springer, Berlin, 2019, pp. 18-21.

- H. ***Messaoudi***, M. Mikulewitsch, A. Fischer, G. Goch, F. Vollertsen:
  Controlled and scalable laser chemical removal for the manufacturing of micro forming tools.
  In: Cold micro metal forming.
  (Eds.: F. Vollertsen, S. Friedrich, B. Kuhfuß, P. Maaß, C. Thomy, H.-W. Zoch), Springer, Berlin, 2019, pp. 155-179.

- M. ***Mikulewitsch***, A. Fischer:
  In situ geometry measurement using confocal fluorescence microscopy.
  In: Cold micro metal forming. (Eds.: F. Vollertsen, S. Friedrich, B. Kuhfuß, P. Maaß, C. Thomy, H.-W. Zoch), Springer, Berlin, 2019, pp. 289-297.

- K. ***Ni***, Y. Peng, D. Stöbener, G.Goch:
  Cylindrical gear metrology.
  In: Metrology (Ed.: Wei Gao), pp. 1-29, Springer, Singapur, 2019.

- J. H. ***Osmers***:
  Realisierung eines akustischen Selbsttonometers unter Berücksichtigung der Biometrie des Auges.
  In: Forschungsberichte des Bremer Instituts für Messtechnik, Automatisierung und Qualitätswissenschaft (Hrsg.: A. Fischer), Vol. 3, Shaker, Aachen, 2020

- A. ***Tausendfreund***:
  Laser-optische Messverfahren zur Charakterisierung von Oberflächendefekten im Nanometerbereich.
  In: Forschungsberichte über Messtechnik, Automatisierung, Qualitätswissenschaft und Energiesysteme (Hrsg.: G. Goch, A. Fischer), Vol. 7, Verlag Mainz, Aachen, 2019.

- P. ***Thiemann***:
  In- und Post-Prozess-Messverfahren für die Erfassung von thermo-mechanischen Schädigungen.
  In: Forschungsberichte über Messtechnik, Automatisierung, Qualitätswissenschaft und Energiesysteme (Hrsg.: G. Goch, A. Fischer), Vol. 8, Verlag Mainz, Aachen, 2019.

Journals

- G. ***Alexe***, A. Tausendfreund, D. Stöbener, L. Langstädtler, M. Herrmann, C. Schenck, A. Fischer:
  Uncertainty and Resolution of Speckle Photography on Micro Samples.
  Nanomanufacturing and Metrology, 2020. (accepted, online first)
- M. ***Auerswald***, A. von Freyberg, A. Fischer:
  Laser line triangulation for fast 3D measurements on large gears.
  International Journal of Advanced Manufacturing Technology 100(9-12):2423-2433, 2019.
- C. ***Dollinger***, N. Balaresque, N. Gaudern, D. Gleichauf, M. Sorg, A. Fischer:
  IR thermographic flow visualization for the quantification of boundary layer flow disturbances due to the leading edge condition.
  Renewable Energy 138:709-721, 2019.
- A. ***Fischer***, D. Stöbener:
  In-process roughness quality inspection for metal sheet rolling.
  CIRP Annals - Manufacturing Technology 68(1):523-526, 2019.
- A. ***Fischer***, M. Mikulewitsch, D. Stöbener:
  Indirect fluorescence-based in situ geometry measurement for laser chemical machining.
  CIRP Annals - Manufacturing Technology, 2020. (accepted)
- A. ***Fischer***:
  Limiting uncertainty relations in laser-based measurements of position and velocity due to quantum shot noise.
  Entropy 21(3):264 (19 pp.), 2019.
- F. ***Greiffenhagen***, J. Peterleithner, J. Woisetschläger, A. Fischer, J. Gürtler, J. Czarske:
  Discussion of laser interferometric vibrometry for the determination of heat release fluctuations in an unconfined swirl-stabilized flame.
  Combustian and Flame 201:315-327, 2019.
- D. ***Gleichauf***, C. Dollinger, N. Balaresque, A. D. Gardner, M. Sorg, A. Fischer:
  Thermographic flow visualization by means of non-negative matrix factorization.
  International Journal of Heat and Fluid Flow 82:108528, 2020.
- H. ***Messaoudi***, M. Mikulewitsch, D. Brand, A. von Freyberg, A. Fischer:
  Removal behavior and output quality for laser chemical machining of tool steels.
  Manufacturing Review 6:13 (11 pp.), 2019.
- 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.

Publications and qualification of young academics

Publications

- J. ***Osmers***, M. Sorg, A. Fischer:
  Optical measurement of the corneal oscillation for the determination of the intraocular pressure.
  Biomedical Engineering 64(4):471-480, 2019.

- J. ***Osmers***, M. Sorg, A. Fischer:
  Die Biometrie des Auges als Ursache für systematische Messabweichungen bei der akustischen Tonometrie.
  tm - Technisches Messen 86(4):237-246, 2019.

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

- T. ***Reichstein***, A. P. Schaffarczyk, C. Dollinger, N. Balaresque, E. Schülein, C. Jauch, A. Fischer:
  Investigation of laminar-turbulent transition on a rotating wind-turbine blade of multi-megawatt class with thermography and microphone array.
  Energies 12(11):2102 (21 pp.), 2019.

- V. ***Renken***, A. von Freyberg, K. Schünemann, F. Pastors, A. Fischer:
  In-process closed-loop control for stabilising the melt pool temperature in selective laser melting.
  Progress in Additive Manufacturing 4(4):411-421, 2019.

- M. ***Sorg***, J. Osmers, A. Fischer:
  Methodical approach for determining the length of drill channels in osteosynthesis.
  Sensors 19(16):3532 (10 pp.), 2019.

- M. ***Steinbacher***, G. Alexe, M. Baune, I. Bobrov, I. Bösing, B. Clausen, T. Czotscher, J. Epp, A. Fischer, L. Langstädtler, D. Meyer, S. R. Menon, O. Riemer, H. Sonnenberg, A. Thomann, A. Toenjes, F. Vollertsen, N. Wielki, N. Ellendt:
  Descriptors for high throughput in structural materials development.
  High-Throughput 8(4):22 (27 pp.), 2019.

- A. ***Tausendfreund***, D. Stöbener, A. Fischer:
  Induction of highly dynamic shock waves in machining processes with multiple loads and short tool impacts.
  Applied Sciences 9(11):2293 (13 pp.), 2019

- A. ***Tausendfreund***, D. Stöbener, A. Fischer:
  Messung thermomechanische Beanspruchungen in laufenden Schleifprozessen.
  tm-Technisches Messen 87(3):201-209, 2020.

- C. ***Vanselow***, D. Stöbener, J. Kiefer, A. Fischer:
  Particle image velocimetry in refractive index fields of combustion flows.
  Experiments in Fluids 60:149 (11 pp.), 2019.

- C. ***Vanselow***, D. Stöbener, J. Kiefer, A. Fischer:
Revealing the impact of laser-induced breakdown on a gas flow.
Measurement Science and Technology 31(2):027001 (4 pp.), 2020.

- A. ***von Freyberg***, A. Fischer:
Geometric partitioning of complex surface measurements.
IEEE Transactions on Instrumentation & Measurement 69(7):4835-4842, 2020.

- C. ***Wolf***, C. Mertens, A. Gardner, C. Dollinger, A. Fischer:
Optimization of differential infrared thermography for unsteady boundary layer transition measurement.
Experiments in Fluids 60:19 (13 pp.), 2019.

Conference contributions

- G. ***Alexe***, A. Tausendfreund, D. Stöbener, A. Fischer:
Maschinelles Lernen für Abdeckungsmessungen von Oberflächen mit abgeschiedenen Au-Nanosphären mittels Lichtstreuung.
XXXIII. Messtechnisches Symposium des AHMT, Erlangen, 12.-13.9.2019.
tm - Technisches Messen 86(S1):47-51, 2019.

- G. ***Behrends***, D. Stöbener, A. Fischer:
Topografiemessung gekrümmter Oberflächen mittels lateral scannender Weißlichtinterferometrie.
120. Jahrestagung der Deutschen Gesellschaft für angewandte Optik e. V. (DGaO), Darmstadt, 11.-15.6.2019, No. B29 (2 pp.).

- A. ***Fischer***, D. Gleichauf, N. Balaresque, M. Sorg, N. Gaudern, C. Dollinger:
Thermografische Strömungsvisualisierung zur Bewertung des realen Strömungsverhaltens von Windenergierotorblättern.
27. GALA-Fachtagung "Experimentelle Strömungsmechanik", Erlangen, 3.-5.9.2019, No. 21 (8 pp.)

- D. ***Gleichauf***, C. Dollinger, N. Balaresque, A. D. Gardner, M. Sorg, A. Fischer:
Contrast enhancement in thermographic flow visualization.
Wind Energy Science Conference 2019, Cork, Ireland, 17.-20.6.2019. (1 pp.)

- F. ***Jensen***, M. Sorg, A. Fischer:
Detection of initial subsurface defects on coated glass-fiber reinforced composite components by means of active microthermography.
SMSI 2020 - Sensors and Instrumentation, 2020, No. C4.2, pp. 171-172.

- O. ***Jung***, M. Sorg, J. Osmers, M. Barbeck, M.-L. Schröder, T. Korzinskas, A. Fischer:
Development of an innovative ex vivo-test bench to measure heat development during medical drilling.
30th Annual Conference of the European Society for Biomaterials, 26th Annual

Publications and qualification of young academics

Publications

Conference of the German Society for Biomaterials, Dresden, 9. – 13. September 2019.

- M. ***Mikulewitsch***, D. Stöbener, A. Fischer: *Indirect geometry measurement method for in situ application in laser chemical machining.* SMSI 2020 - Measurement Science, 2020, No. P3.6, pp. 327-328.
- M. ***Mikulewitsch***, A. von Freyberg, D. Stöbener, A. Fischer: *Model-based confocal fluorescence microscopy measurements of submerged micro geometries.* SPIE Optical Metrology, München, 24.-27.6.2019, Vol. 11057, No. 110570E (8 pp.).
- M. ***Pillarz***, A. von Freyberg, A. Fischer: *Multisensory measurement of the base circle radius as a fundamental shape parameter of gears.* International Conference on Gears, München, 18.-20.9.2019, pp. 1207-1214.
- M. ***Pillarz***, A. von Freyberg, A. Fischer: *Optical multi-distance measurements of spur gears.* SMSI 2020 - Sensors and Instrumentation, 2020, No. C6.4, pp. 193-194.
- V. ***Renken***, D. Gleichauf, F. Pastors, L. Lübbert, A. von Freyberg, A. Fischer: *Reducing process variation of laser powder bed fusion by real-time closed-loop control.* Lasers in Manufacturing Conference 2019 (LiM), München, 24.-27.6.2019. (4 pp.)
- Y. ***Schädler***, V. Renken, M. Sorg, A. Fischer: *Analyse der gemessenen Energieeinspeise- und Laststrukturen in den deutschen Postleitzahlregionen.* Jahrestreffen Forschungsnetzwerk Energiesystemanalyse, Aachen, 23.05.2019. (Poster)
- D. ***Stöbener***, G. Alexe, L. Langstädtler, M. Herrmann, C. Schenck, A. Fischer: *An optical method to determine the strain field on micro samples during electrohydraulic forming.* 5th CIRP Conference on Surface Integrity, (CIRP CSI 2020), E-conference, 1.-5.6.2020. Procedia CIRP 87, pp. 438-443, 2020.
- A. ***Tausendfreund***, D. Stöbener, A. Fischer: *In-process workpiece displacement measurements under the rough environments of manufacturing technology*. 5th CIRP Conference on Surface Integrity, (CIRP CSI 2020), E-conference, 1.-5.6.2020. Procedia CIRP 87, pp. 409-414, 2020.
- A. ***Tausendfreund***, G. Alexe, D. Stöbener, A. Fischer: *Messung mechanischer Beanspruchungen in laufenden Schleifprozessen.* 20. GMA/ITG-Fachtagung "Sensoren und Messsysteme 2019", Nürnberg, 25.-26.6.2019, No. 4.1.1 (6 pp.).

- C. ***Vanselow***, D. Stöbener, J. Kiefer, A. Fischer:
  Messunsicherheit von PIV-Messungen durch Brechungsindexfelder in Flammen.
  27. GALA-Fachtagung "Experimentelle Strömungsmechanik", Erlangen, 3.-5.9.2019, No. 28 (7 pp.).
- C. ***Vanselow***, D. Stöbener, J. Kiefer, A. Fischer:
  PIV measurement uncertainty in combustion flows due to inhomogeneous refractive index fields.
  International Symposium on Particle Image Velocimetry, München, 22.-24.7.2019. (9 pp.)
- R. ***Vocke***, J. Stempin, P. Schiebel, A. Herrmann, A. Fischer:
  Model-based quality control system for error reduction in the thermoforming process.
  22nd Symposium on Composites, Kaiserslautern, 26.-28.06.2019.
  Key Engineering Materials 809:598-603, 2019.
- A. **von *Freyberg***, A. Fischer:
  Combined partitioning and approximation for optimized gear inspection.
  Euspen’s Virtual International Conference, E-conference, 8.-11.6.2020. (2 pp.)
- A. **von *Freyberg***, A. Fischer:
  Geometric partitioning by holistic approximation.
  3D Metrology Conference – 3DMC, London, 05.-07.11.2019.

Other contributions

- A. ***Fischer***:
  In-process flow measurements for wind turbines, combustion and manufacturing.
  Fluids and Space Engineering Seminar, Center of Applied Space Technology and Microgravity (ZARM), Bremen, 15.1.2020.
  (seminar talk invited by Prof. M. Avila)
- J. ***zur Jacobsmühlen***, V. Renken:
  InSensa - Prozesssensorik und regelung für die additive Fertigung,
  BMBF-Abschlussveranstaltung: Additive Fertigung - Individualisierte Produkte, komplexe Massenprodukte, innovative Materialien (ProMat_3D), Frankfurt, 18.09.2019.
- R. ***Vocke***, J. Stempin, A. Herrmann, A. Fischer:
  Weniger Ausschuss – Modellbasierte Qualitätsregelung zur fehlerfreien Bauteilproduktion und Anwendung im Thermoformprozess.
  QZ - Qualität und Zuverlässigkeit 65(3): 24-25, 2020.

Publications and qualification of young academics

PhD theses

Realisierung eines akustischen Selbsttonometers unter Berücksichtigung der Biometrie des Auges

Dr.-Ing. Jan Osmers

Date of thesis defense: 04. Dec 2019

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

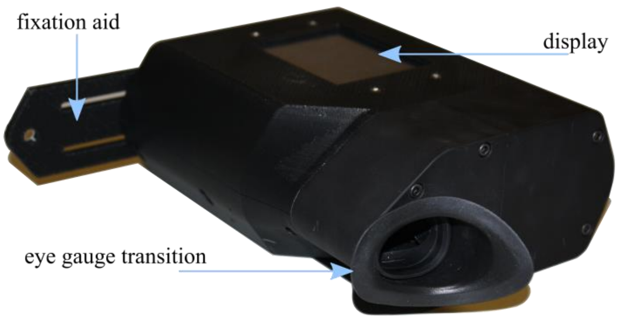
Glaucoma is a serious threat to vision. The eye disease has different causes, the common feature of which is the degeneration of retinal ganglion cells, which serve to transmit light stimuli from the retina. The only current method of treating glaucoma is to reduce intraocular pressure (IOP), which reduces mechanical stress on the ganglion cells and stagnates their degeneration.

The effectiveness of an operation or medication must then be checked by repeated IOP measurements with a tonometer. For optimal therapy control it is necessary to enable the patient to perform self-measurements distributed over the day in his home environment, so that in-patient clinical stays for IOP measurement are not necessary.

Current tonometry methods such as Goldmann applanation tonometer cannot be used by the patients themselves. The few devices supporting self-measurements are neither precise nor practical.

Therefore, the aim of this work is to investigate a gentle tonometry approach and to determine the achievable measurement uncertainty in humans as well as to identify and quantify cross sensitivities in IOP measurements.

The measuring principle, based on a pressure chamber, which is placed on the eye and a loudspeaker, which generates the pressure excitation of the eye in the chamber, is validated first by porcine eye experiments yielding a measurement uncertainty of 2 mmHg. Motivated by this, handheld self-measurements with a prototype of the self-tonometer took place at the University Eye Clinic Würzburg. A parametric eye model is developed in a finite elements software to understand and quantify the systematic uncertainty contributions of the varying shape of the human eye.



Realized self-tonometer that was used for first in vivo-trials.

[1] J. Osmers, Á. Patzkó, O. Hoppe, M. Sorg, A. von Freyberg, A. Fischer: The influence of intraocular pressure on the damping of a coupled speaker–air–eye system. Journal of Sensors and Sensor Systems 7:123–130, 2018.

[2] J. Osmers, M. Sorg, A. Fischer: Optical measurement of the corneal oscillation for the determination of the intraocular pressure. Biomedical Engineering 64(4):471-480, 2019.

Awards

Deutsche WindGuard Nachwuchs-Förderpreis 2019

For the third 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

- Daniel ***Musekamp*** for his bachelor thesis: "Closed-loop control of additive manufacturing processes"

and to

- Nils ***Kaiser*** for his master thesis: "Considering Nonlinear Material Properties in the FEM Analysis of the Internal Pressure-Dependent Vibration Dynamics of the Eye".

Congratulations from the BIMAQ team!

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

Daniel Musekamp, Prof. Andreas Fischer, Nils Kaiser

Events

Participation at events and conferences

Date	Event / Conference	Location	Participant(s)	
26 – 28 Jun 2019	**22th Symposium “Verbundwerkstoffe und Werkstoffverbunde”**	Kaiserslautern	J. Stempin	oral presentation
22 – 24 Jul 2019	**13th International Symposium on Particle Image Velocimetry**	München	C. Vanselow	oral presentation
18 – 23 Aug 2019	**69th CIRP General Assembly**	Birmingham	A. Fischer	oral presentations
3 – 5 Sep 2019	**27. GALA-Fachtagung "Experimentelle Strömungsmechanik"**	Erlangen	A. Fischer C. Vanselow	oral presentation
12 – 13 Sep 2019	**XXXIII. Messtechnisches Symposium des AHMT**	Erlangen	A. Fischer G. Alexe	oral presentation
18 – 20 Sep 2019	**International Conference on Gears**	München	M. Pillarz	poster presentations
5 – 7 Nov 2019	**3D Metrology Conference**	London	A. v. Freyberg	oral presentation
15 Jan 2020	**Fluids and Space Engineering Seminar**	Bremen	A. Fischer	seminar talk invited by Prof. Avila
27 Feb 2020	**Jugend forscht - Schüler experimentieren. Regionalwettbewerb Bremen-Mitte**	Bremen	A. v. Freyberg	jury member
1 – 5 Jun 2020	**5th CIRP Conference on Surface Integrity**	Virtual Conference	A. Tausendfreund D. Stöbener A. Fischer	video oral presentation
8 - 12 Jun 2020	**Euspen 20th International Conference**	Virtual International Conference	A. v. Freyberg	oral presentation
22 – 26 Jun 2020	**LACSEA -Laser Applications to Chemical, Security and Environmental Analysis**	Virtual Conference	C. Vanselow	oral presentation

Events @ BIMAQ

Date	Event	Organizing institution
5 Jun 2019	**Students meet BIMAQ**	BIMAQ
9 Oct 2019	**Seminar talk with Prof. J. Kiefer**	BIMAQ
18 Oct 2019	**Geowisol2 project meeting**	BIMAQ
19 Nov 2019	**BIMAQ meets GBS, Gesellschaft für Bild- und Signalverarbeitung – Technology Showcase**	BIMAQ
10 Dec 2019	**Deutsche WindGuard Nachwuchs-Förderpreis 2019**	Deutsche WindGuard GmbH
11 Dec 2019	**Wind turbine measurement campaign**	BIMAQ / Deutsche WindGuard
14 Jan 2020	**Seminar talk with Dr. K. Avila**	BIMAQ
26 Jan 2020	**Students visit BIMAQ laboratories**	BIMAQ
10 Feb 2020	**PreciWind Kick-Off**	BIMAQ
13 Feb 2020	**SiTOH project meeting**	BIMAQ
12 May 2020	**Seminar talk with Prof. A. Baldit**	BIMAQ
13 May 2020	**LoGAZ Kick-Off**	BIMAQ

- Prominent guest speakers in BIMAQ seminar on measurement techniques

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

  - Prof. Dr.-Ing. J. Kiefer: *Laser-induced breakdown spectroscopy*, 9 Oct 2019
  - Dr. rer. nat. K. Avila: *Particle image velocimetry in oscillating liquid sloshing*, 14 Jan 2020
  - Prof. A. Baldit: *Biomechanical measurement systems based on image analysis and optimized data processing*, 12 May 2020

- Students meet BIMAQ

  On 5 Jun 2019, Prof. Fischer and the BIMAQ team invited students of production engineering, systems engineering and industrial engineering to get in touch with BIMAQ research 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 and a Segway course was well received by the students and provided an excellent platform for a comprehensive exchange of ideas.

Events

Events @ BIMAQ

- Excursion to the waste-to-energy plant of the Stadtwerke Bremen

  The participants of the lecture on renewable energies made an excursion to visit the waste-to-energy plant of the Stadtwerke Bremen (swb AG) on 11 Jul 2019.

  The waste-to-energy plant process residual waste from Bremen and the surrounding area and generates up to 200,000 MWh of district heating and 270,000 MWh of electricity per year from the waste in a combined heat and power process. The students visited the waste bunkers, the incineration plant, the flue gas cleaning systems, the integrated medium-calorific power plant for electricity generation and the control room.

Inspection of the flue gas cleaning system

Visit of the control room

Visit to the steam generation plant

Tour of the power plant

- Geowisol2 project meeting

  The 3rd project meeting took place successfully on 18 Oct 2019 at the BIMAQ building. During the first part, the sources of the data to be collected were discussed. After a coffee break, the topics of the second part ranged from the uncertainties in the different time series to the appropriate timescale for the development of scenarios.

- BIMAQ meets GBS

  A sales representative of GBS mbH, Ilmenau/Germany visited BIMAQ on 19 Nov 2019 to showcase GBS's WLI technology. During his visit we had the opportunity get an insight into commercial application of white light interferometry and to take measurements of various objects, which are now used as reference data to validate the novel surface measurement systems under development at the BIMAQ.

- Internship

  From 28 Oct 2019 to 8 Nov 2019, Rune Eckermann from the Oberschule am Leibnitzplatz completed a student internship at the BIMAQ and worked at the revision of digital angle sensors on a solar tracker of the Institute.

  He has performed series of measurements on electro-optical components to optimize the dimensioning of the sensor circuit. He also gained an insight into the programming of the associated control and various other measurement techniques. According to his wishes, he also accompanied us different research and teaching activities in order to get insights into the work of a scientist of today. We wish him all the best for his future!

- Thermography measurement campaign

  On 11 and 12 Dec 2019, BIMAQ employees performed at the Høvsøre Wind Turbine Test Center in Bøvlingbjerg, Denmark a two-day measurement campaign in cooperation with Deutsche WindGuard Engineering for the customer Siemens Gamesa Renewable Energy. As a result, thermographic measurements for impact analysis of blade/plant modifications on a research wind turbine were realized.

Impressions from the thermography measurement campaign

Events

Events @ BIMAQ

- Students visit BIMAQ laboratories

  Triggered by the courses "Measurement" and "Control Engineering", many students of the 3rd and 5th semester visited the laboratories of the BIMAQ on 26 Jan 2020. During this visit, they could deepen their theoretical knowledge acquired in the lectures by means of practical demonstrations and discussions at the BIMAQ test benches.

- PreciWind Kick-off-meeting

  The first meeting (kick-off) for the project “PreciWind” took place on 10 Feb.2020 at the BIMAQ in Bremen. Each of the five partners was represented by its project manager. After a welcome by the project leader Prof. Andreas Fischer and the coordinator Daniel Gleichauf a short overview of the following three years of the project was given. Afterwards, each partner introduced himself and presented its contribution to the planned project goals. The kick-off-meeting was followed by the first workshop in which the partners discussed the first content-related tasks and the next meetings. An evening dinner allowed the members of the project consortium to exchange ideas further and to set the perfect kick-off for successfully mastering the project challenges together.

- SiToH project meeting

  During a project meeting on 13 Feb 2020, the project partners CoSynth, GBS, Hansgrohe and TataSteel presented their progress in the BMBF-funded SiToH project and took a tour of BIMAQ’s laboratory facilities with a focus on the lateral scanning white-light interferometer setup, which is under development in SiToH.

- LoGAZ Kick-off-meeting

  The project partners Deutsche WindGuard - Engineering GmbH and LASE industrielle Messtechnik GmbH as well as the project executive from BAB (Bremer Aufbaubank) were invited to the initial meeting, which took place on 13 May 2020 as a web-meeting (due to the Covid-19 situation).

  The project will analyse long-distance dimensional measurements of wind turbine rotor blades by means of a LIDAR-system in order to assess the condition of the blades. The first meeting served to introduce each other and to present the contribution of the project partners to the project. Furthermore, a discussion and fine-tuning of the first small and big steps followed in a creative atmosphere so that a smooth and effective kick-off was achieved.

Impressum

BIMAQ

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June 2020

Universität Bremen

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