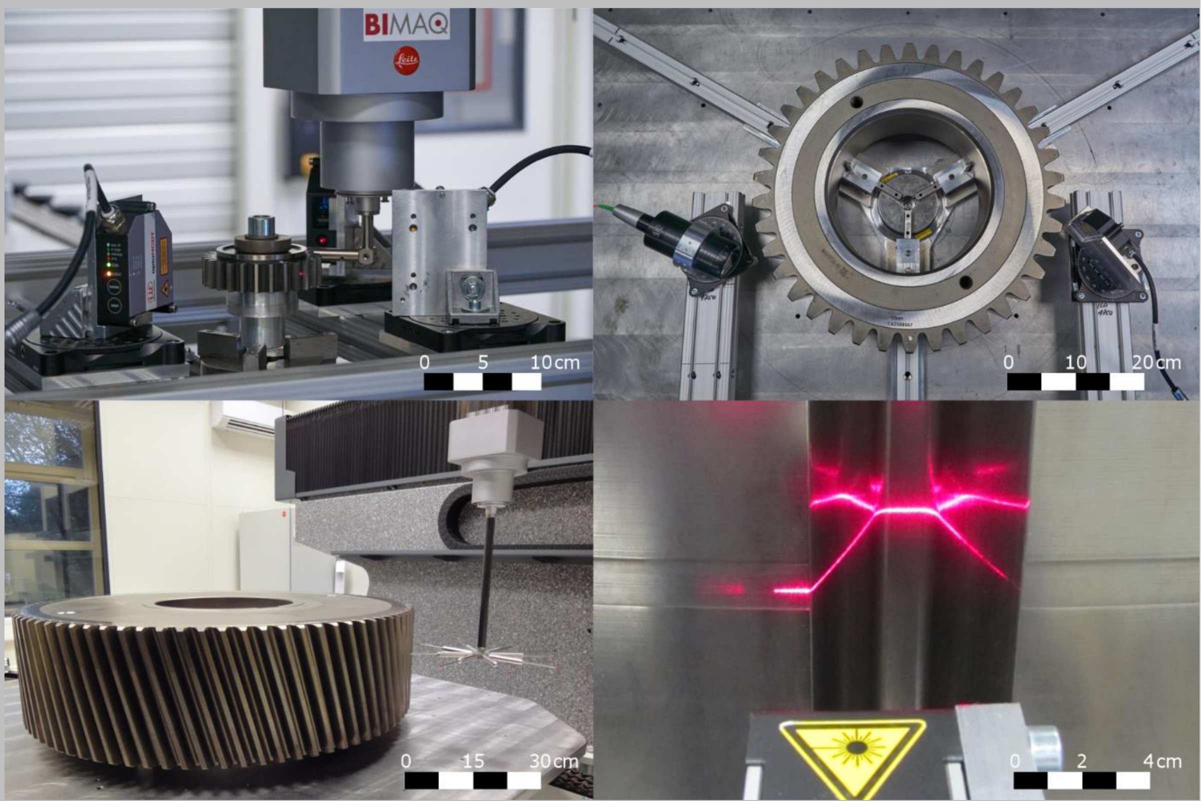
Annual Report

2020/2021



Gear measurement from small to large gears and on a large gear standard

BIMAQ

Bremer Institut für
Messtechnik, Automatisierung
und Qualitätswissenschaft

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Preface

Dear friends and partners of the institute!

Despite the challenging pandemic situation in the year 2020/21, the Bremen Institute for Metrology, Automation and Quality Science (BIMAQ) of the University of Bremen has successfully met the occurrent challenges in teaching and research.

Although the students had a very restricted access to the university, we succeeded in offering 100 % teaching by rapidly creating and realizing digital concepts for lectures, exercises, lab-exercises, seminars and tests. I am so thankful to have a vivid, agile and highly motivated team with me to keep our institute humming. Here, I would like to thank all supporters.

For instance, Deutsche WindGuard GmbH donated for the 4th time an award for young talents, and it was a pleasure for me to award two outstanding student theses in 2020. My congratulations to the students and many thanks to the Deutsche WindGuard GmbH, who made this possible.

Not only our teaching has been developed further, but also our research activities with partners in fundamental and applied research projects. In the context of ForWind – the Center for Wind Energy Research of the Universities of Oldenburg, Hannover and Bremen, our large joint project 'PreciWind' had a perfect start, and it is beautiful to see the first results exploring the flow and structural behaviour of rotor blades of real wind turbines on-site during operation.

Furthermore, we are very grateful that this year two of our publications in peer-reviewed journals have been selected by journal editors as being of special interest and outstanding scientific quality. And it is the third year within three subsequent years that a contribution from the BIMAQ was selected to be presented at the general assembly of the well-known International Academy for Production Engineering (CIRP) and to be published in the CIRP annals. These are just two examples of our continuing attempt to work for new findings with no compromise in quality. However, there is so much more to explore and I hope you enjoy reading this annual report about our activities for science, industry and society.

Before you start to read, let me in particular thank our guests PD Dr. Perlick from ZARM (gravitational wave measurements) and Ms. Hoffmann from PTB (optical form measurements with deep learning) for their inspiring talks in our now established seminar on measuring techniques, and of course all BIMAQ students, colleagues as well as research and industrial partners for their continuous support.

Bremen, June 2021

Andreas Fischer

Prof. Dr.-Ing. habil. Andreas Fischer

BIMAQ - the institute

Vision, topics and infrastructure

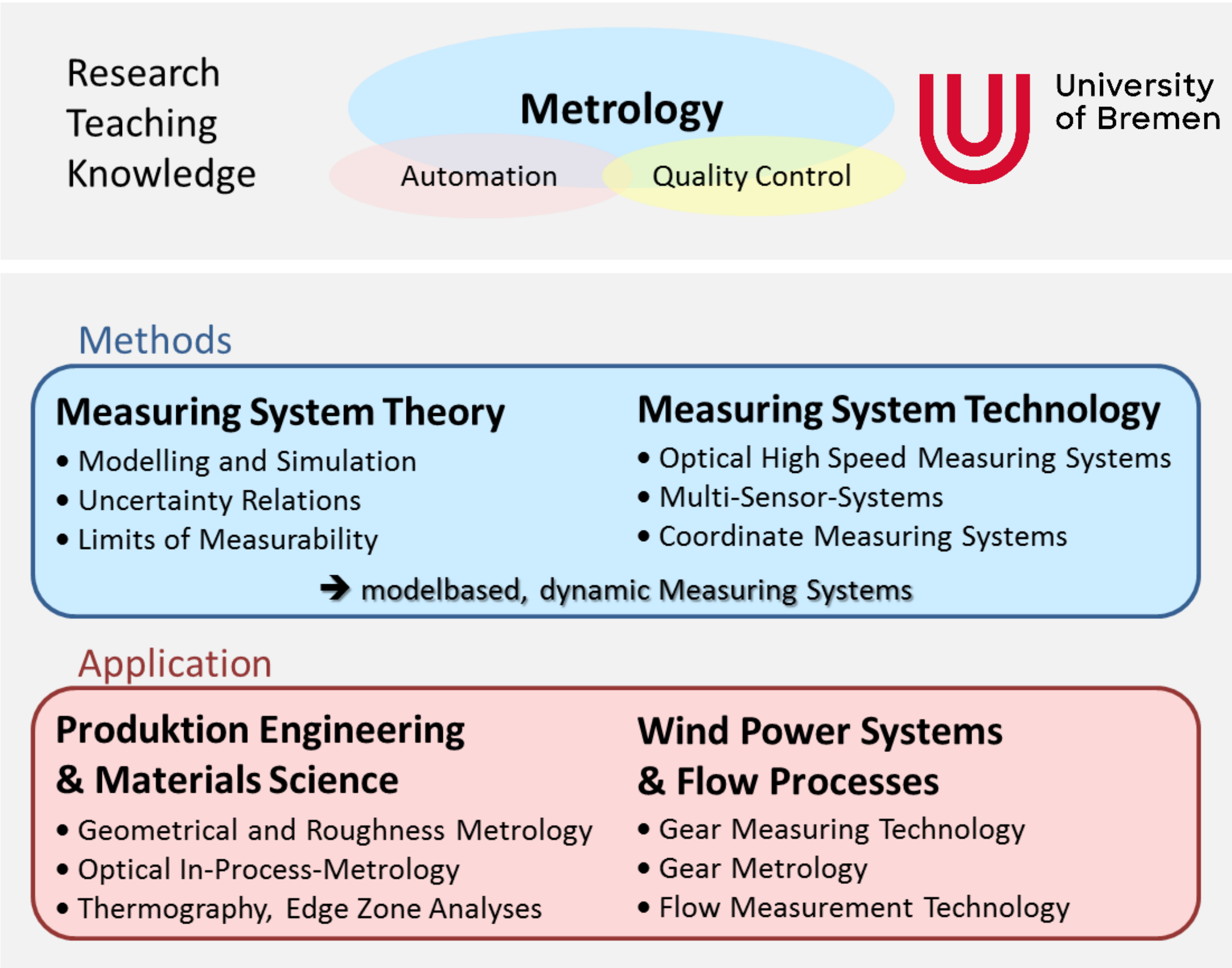
The research focus of the Bremen Institute for Metrology, Automation and Quality Science (BIMAQ) is the holistic investigation of optical measurement systems, which includes the design, realization, modelling, characterization and, finally, the application of novel measurement techniques. By applying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

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

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

BIMAQ

Bremen Institute for Metrology, Automation and Quality Science



BIMAQ competences

BIMAQ - the institute

Staff

Director

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

Emeritus

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

Administration

Eva ***Schultze***

Anja ***Jacoby*** (since 10/2020)

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

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Dr.-Ing. Jan ***Osmers*** (until 8/2020)

M. Sc. Ann-Marie ***Parrey*** (since 11/2020)

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M. Sc. Yannik ***Schädler***

M. Sc. León ***Schweickhardt***

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

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

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Jacob ***Friedrich***
Julian ***Gebken***
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Henrik ***Mahnke***
Md Al ***Mamun***
Puneet ***Mangal***
Egor ***Maul***
Hasnain ***Moavia***
Ahmed ***Salman***
Leonard ***Schröder***
Altin ***Shala***
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Technical Assistants

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

Uwe ***Reinhard***

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

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

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

Dr.-Ing. Karsten ***Lübke***

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

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

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

Dr.-Ing. Gerald ***Ströbel***

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

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

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

Participation in scientific committees and associations

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

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.

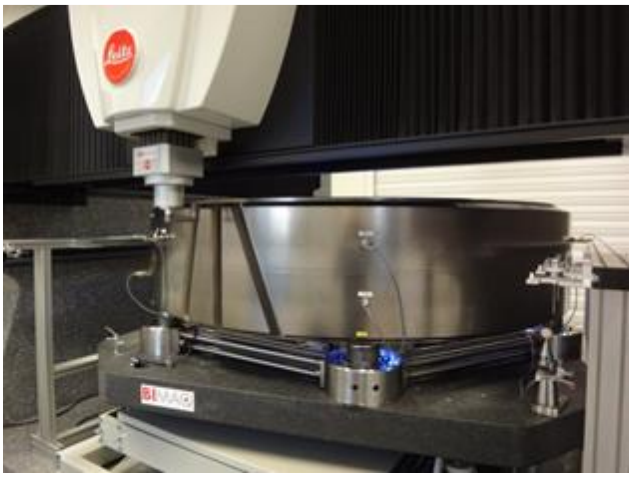
Furthermore, BIMAQ analyses the cause-effect relationships between gear manufacturing, geometric deviations and occurring gearbox damages. In the field of quality inspection of gears, algorithms are being developed in order to evaluate dimensional measurement data.

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



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

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

Services

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

Contact: a.freyberg@bimaq.de

BIMAQ - the institute

Laboratories

Laboratory for optical metrology

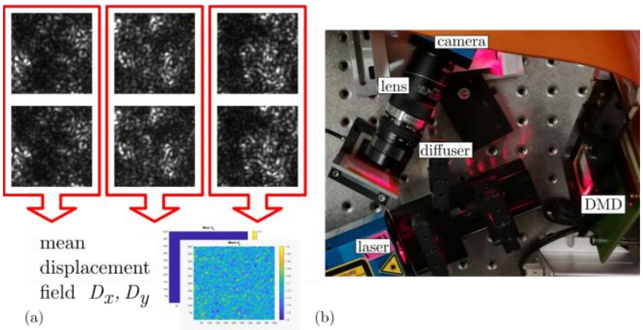
The laboratory for optical metrology focuses on two main research fields: in-process measuring methods and surface integrity evaluation.

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

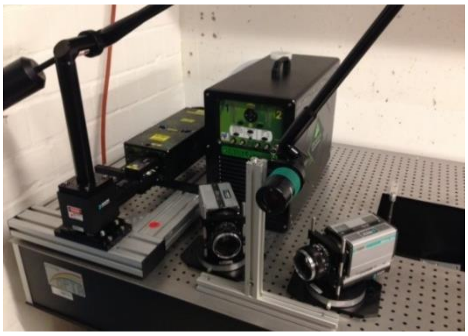


a) Ensemble averaged displacement field calculated from multiple uncorrelated speckle patterns.
b) Experimental setup where a digital micromirror device is used to generate multiple speckle pat terns on a sample.

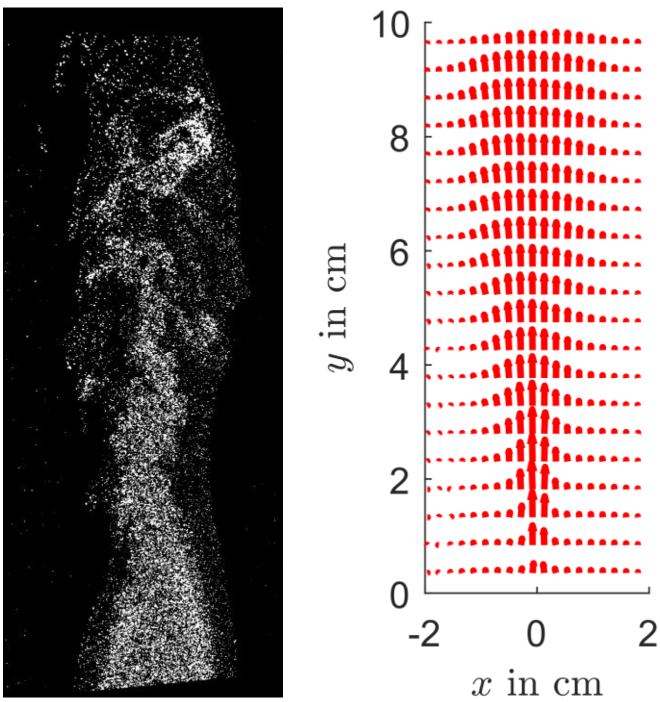
Contact: d.stoebener@bimaq.de

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

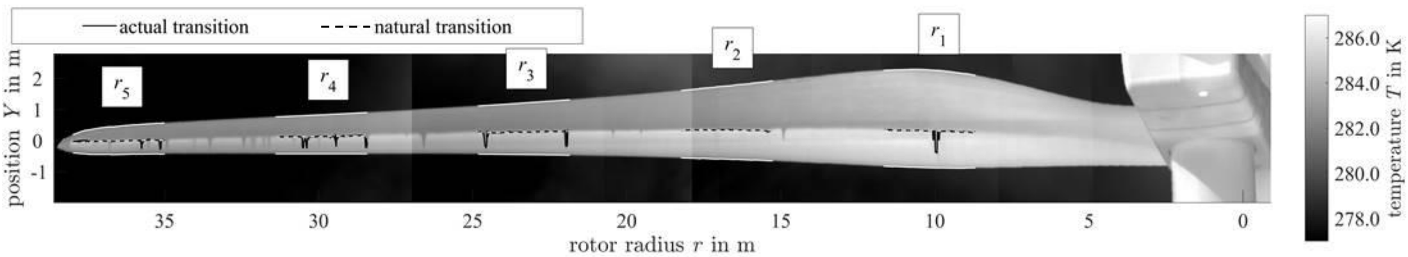
ImageIR thermographic imaging system:

- 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

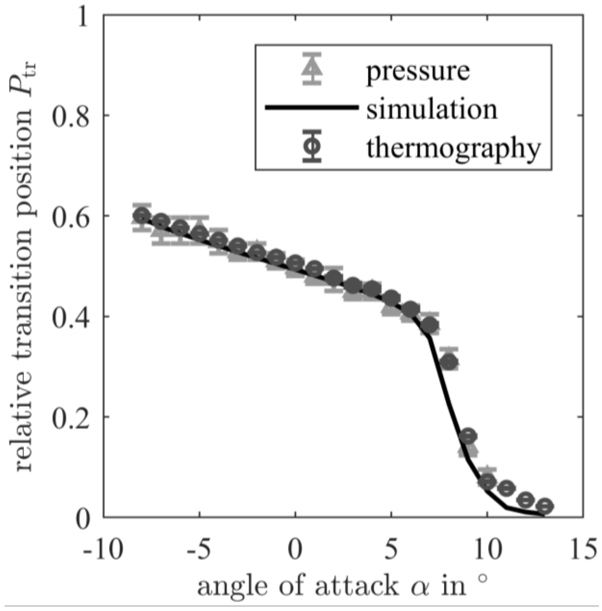
- determination of the laminar/turbulent transition location
- detection of early laminar-turbulent transition due to leading edge contamination, erosion, manufacturing irregularities or the effects of leading edge protection
- analysis of impact of leading edge protection on the boundary layer flow
- 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

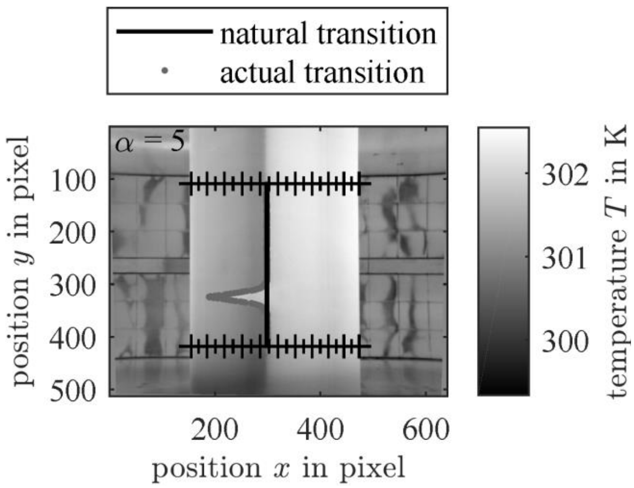
Technical data

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

ImageIR:

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



Thermographic flow visualization on an airfoil in the wind tunnel

Services

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

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Laboratories

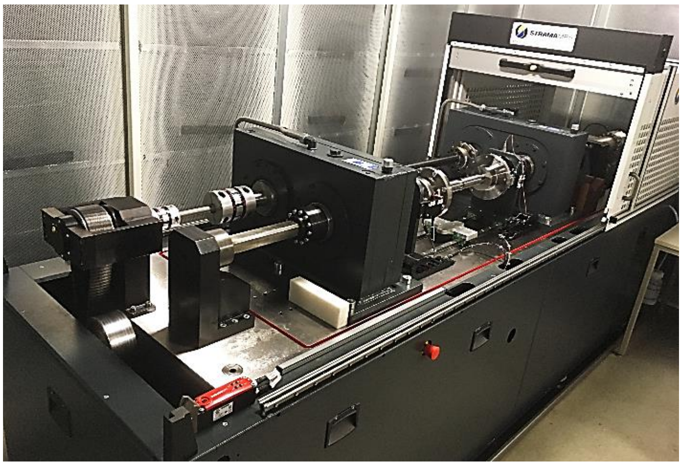
LAB

Laboratory for wind turbine sensors (in BIMAQ-Technikum)

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


Drivetrain inside the hub of a wind energy system

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


Torque test rig

Technical test rig specifications

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

Services

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


Wind turbine drive train for sensor tests

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LAB

BIMAQ-Technikum and Mechanical workshop

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

The Technikum contains:

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

Mechanical workshop

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

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

Services

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

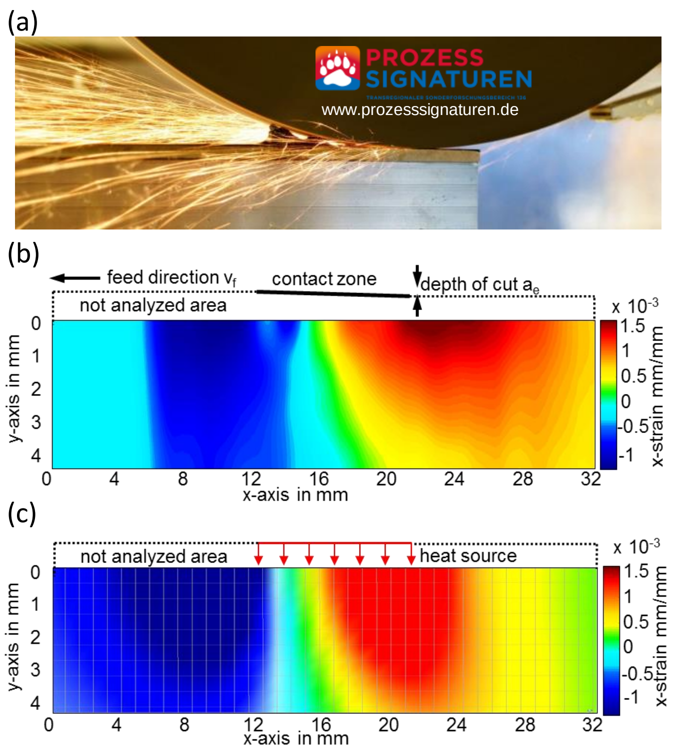
Contact: a.freyberg@bimaq.de

SFB/TRR 136 Process Signatures – Subproject C06

Surface-based optical measurements of mechanical material stresses

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

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



(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].

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.

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

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

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

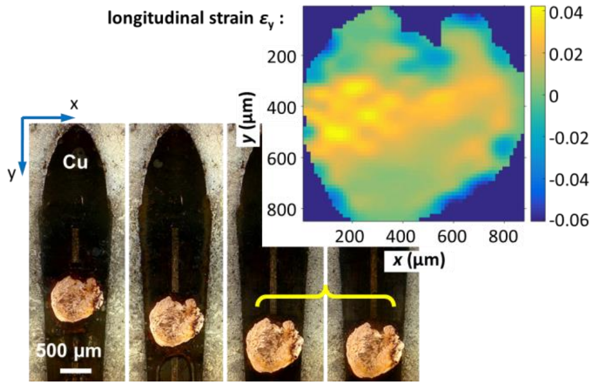
SFB 1232 Coloured States – Subproject D04

Characterization of coloured states by measuring the deformation history during forming

Funding organization: DFG/SFB
Funding ID: SFB 1232
Duration: 1 Apr 2018 – 31 Dec 2020
Project scientists: Gabriela Alexe
Dirk Stöbener

The SFB initiative "From colored states to evolutionary structural materials" develops 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. Various 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 was 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 simulated material data, descriptors for the hardening behaviour of the material are generated.

[1] 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. P. J. Arrazola, A. Madariaga (Hrsg.): 5th CIRP Conference on Surface Integrity (CIRP CSI) 2020, E-conference 1-5.6.2020. Procedia CIRP 87: 438-443, 2020.

[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 3(2):91-104, 2020.

PROTA

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

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

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

PROTA aims to increase the process understanding of LCM in order to use fluidic irradiation variations to minimize the influence of boiling bubbles on the removal quality. The process modeling will for the first time take the bubble influence into account, in particular with the aid of near-process measurements of the workpiece surface temperature, the boiling bubbles and the workpiece geometry in the removal zone. Due to the complexity of laser chemical machining with respect to its manufacturing environment, a suitable in-process measurement technique is essential for improved process understanding and modeling.

Confocal fluorescence microscopy is shown to be suitable for microgeometry measurements in liquids if a model-based signal processing approach is used [2]. However, the laser-induced surface temperature, which fundamentally affects the material removal result, has not been able to be measured in situ to date. PROTA will combine the confocal geometric measurement using a fluorescent liquid with a fluorescence-based temperature measurement in order to facilitate enhanced process modeling. The approach is based on the determination of the fluorescence lifetime, which depends on the temperature of the fluorophore that will enable determination of the spatial temperature distribution during manufacturing.

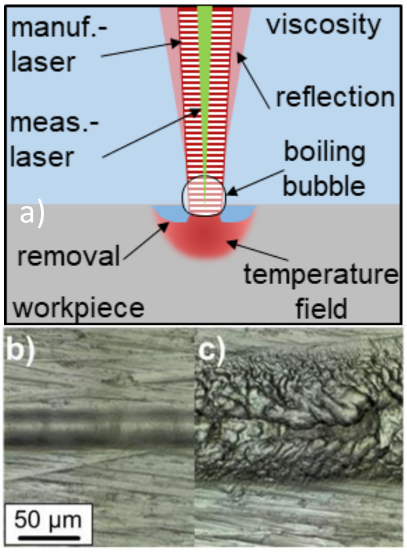


Fig. 1: a) Schematic representation of the LCM process and different manufacturing qualities for b) slow machining without boiling bubbles and c) fast machining with disturbances due to boiling bubbles.

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

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

Multisensory measurement of the geometry of large gears

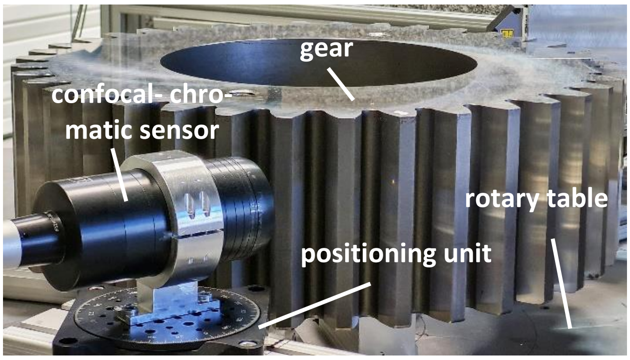
Funding organization: DFG
Funding ID: FI 1989/2-1
Duration: 1 Mar 2018 – 28 Febr 2021
Project scientist: Marc Pillarz

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.

Standard measuring systems for gears like coordinate and gear measuring machines reach tehier limits for large gear measuremenets due to a serial data acquisition and an individually fixed measuring volume. Alternative measurement approaches, currently 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 multisensory 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.

Simulations verify the scalability of the multisensory approach. The theoretically achievable uncertainty of the base circle radius of large gears is estimated to less than 5 µm. Measurements on large gears show that standard measurement uncertainties < 5 µm can also be achieved. At present, however, the achievable total measurement uncertainty is dominated by a systematic error > 5 µm. While the origin of this error is currently unknown, the experimental and theoretical results have proven the fundamental applicability of the multisensory approach for the precise inspection of gears.



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

[1] M. Pillarz, A. von Freyberg, A. Fischer: Gear shape parameter measurement using a model-based scanning multi-distance measurement approach. Sensors 20(14):3910 (16 pp.), 2020.

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

[3] M. Pillarz, A. von Freyberg, D. Stöbener, A. Fischer: Gear shape measurement potential of laser triangulation and confocal-chromatic distance sensors. Sensors 21(3):937 (22 pp.), 2021.

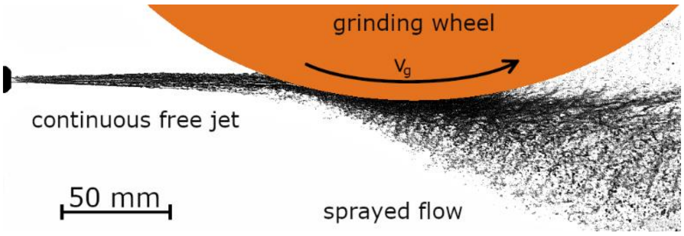
ProstKühl

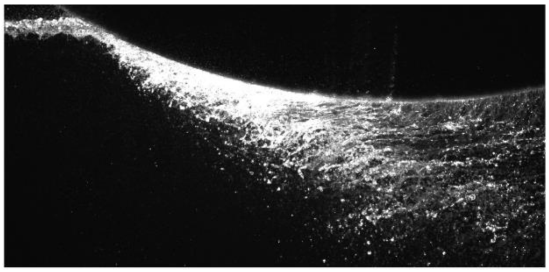
Near-process flow measurements of the cooling lubricant supply in grinding processes

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

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

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





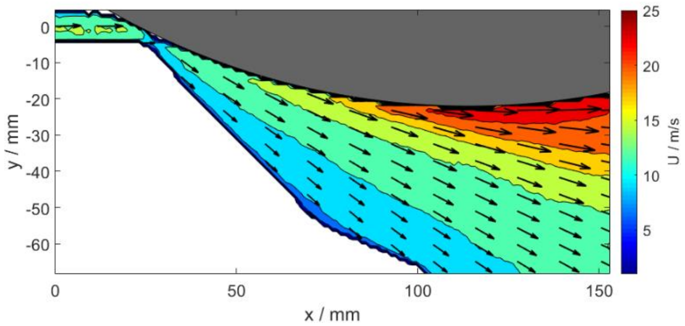


Illustration of the cooling process (top), visualization with laser sheet illumination (middle) and calculated average velocity flow field obtained with PIV (bottom).

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

[1] C. Dollinger, N. Balaresque, M. Sorg: Thermographic boundary layer visualization of wind turbine rotor blades in operation. EWEA 2014, Barcelona, Spain, 10.-13.5 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.

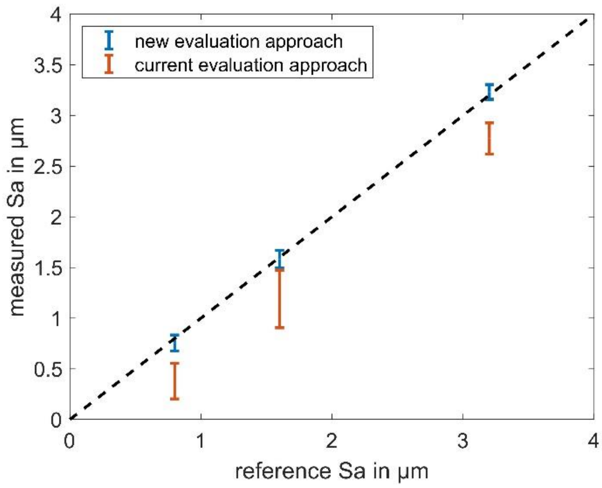
IQZeProd

Inline quality control for zero-error-products

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

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

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



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

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

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

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

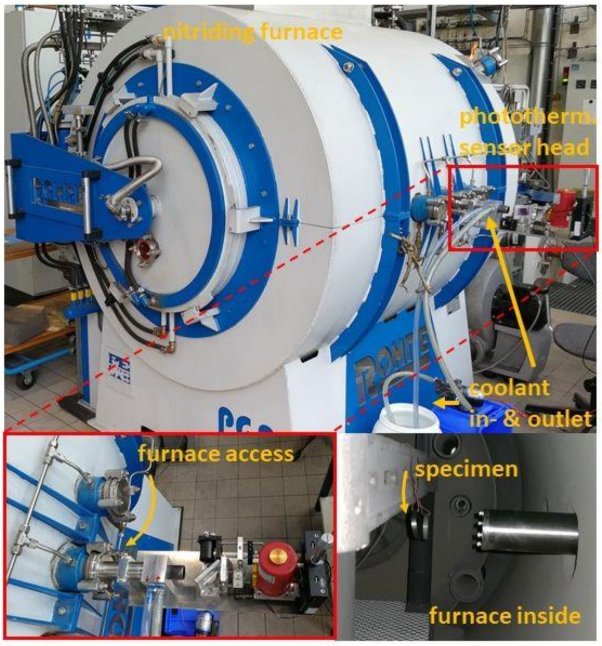
PhoMeNi

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

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

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

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



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

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

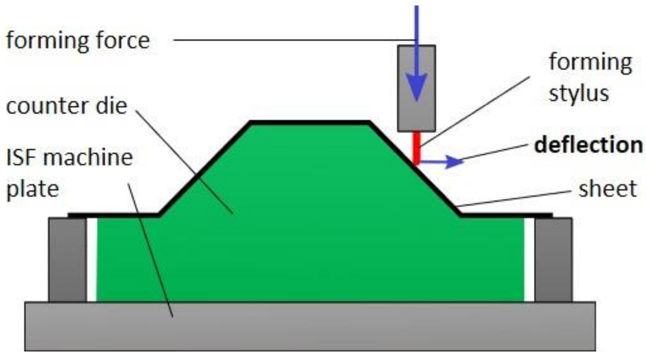
RapidSheet

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

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

Economic manufacturing of customized sheet metal parts in small lot sizes is a challenge in industrial production. As conventional deep drawing requires expensive tools, incremental sheet metal forming (ISF) is a suitable alternative. Thereby, a forming stylus forms the sheet metal over a counter die. The current counter die production in a separate milling machine is cost-intensive and time-consuming. Therefore, the innovative idea of the project RapidSheet is to combine an additive manufacturing process of the counter die and the ISF-process in one machine tool. The process optimization requires compensation strategies to avoid deviations resulting from the material behaviour as well as from the tool deflection. To compensate respective errors, an in-process tool deflection measurement is necessary.

Since the tool path affects the geometric accuracy of the final part, an adaptive forming path of the stylus is used to compensate the elastic springback of the sheet. For larger and thicker sheets, the greater forming forces cause horizontal deflections of the forming stylus. In previous investigations, these deflections have not been considered and lead to geometric deviations of the machined part. To ensure geometric accuracy, it is necessary to measure the tool deflection in all directions. Conventionally, integrated sensors such as glass scales are used to measure the tool position. However, these integrated sensors cannot detect deformations of the supporting structure for the tool head, so that external sensors are required. The expected deflections of the tool are composed of larger, slowly varying deflections and smaller deflections with higher frequencies. To monitor the slow deflections, an optical system is created that consists of multiple cameras measuring a shadow projection from a defined light source on the tool. In addition, a commercial acceleration sensor will measure the high-frequency deflections.



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

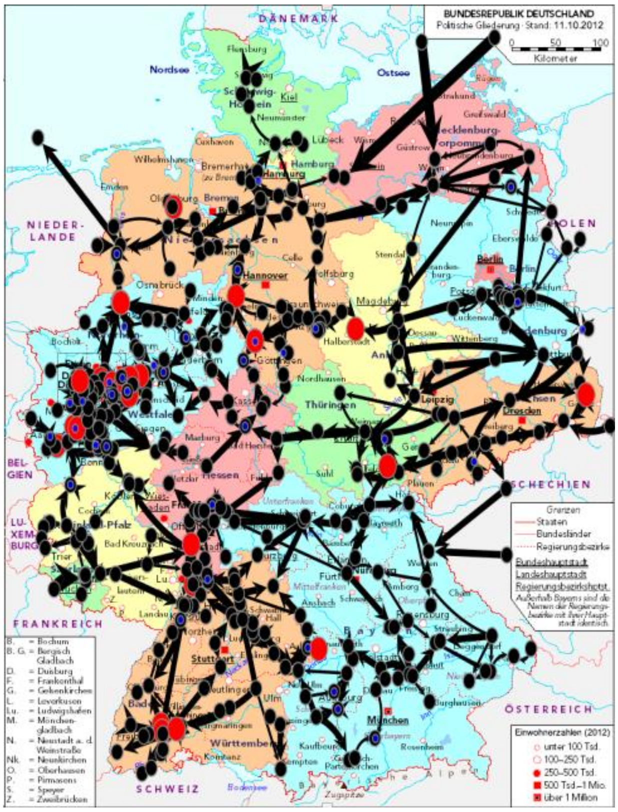
Geowisol2

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

Funding organization: BMWI
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 renewable and conventional power feed-in as well as energy demand time series, each as 15-minute average values and with a local resolution of 2-digit ZIP code regions. 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 those of future expansion scenarios will are analysed and evaluated over time [2]. In particular, the grid expansion and the integration of storage systems will be considered as both aspects are becoming increasingly important. This will result in a tool that can support and evaluate future energy infrastructure projects.



German power transmission network in 2016. Data from the SciGrid Project.

[1] V. Renken, M. Sorg, V. Marschner, L. Gerdes, G. Gerdes, A. Fischer: Geographical comparison between wind power, solar power and demand for the german regions and data filling concepts. Renewable energy 126:475-484, 2018.

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

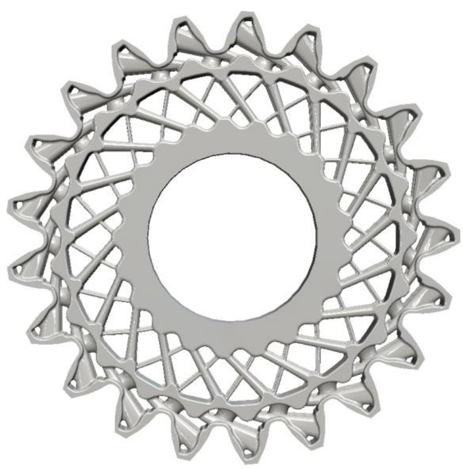
FlexGear

Establishment of lightweight design concepts for gearboxes of wind turbines

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

In order to meet climate protection targets, there is a trend in industry towards conserving resources and saving energy through lightweight construction. Coupled with the objective of expanding the wind energy sector and installing wind turbines ≥ 5 MW, lightweight construction is also becoming important for gear technology. If the output of wind turbines increases, the mass and material consumption of wind turbine components will rise. Gearboxes must also be dimensioned larger. In order to save resources and energy, the material consumption in the design and manufacture of the gearboxes must be minimized by lightweight construction. Due to the high dynamic loads to which wind turbine gearboxes are subjected, lightweight gears have not been used in wind turbine gearboxes to date. Previous lightweight construction concepts only consider the structural optimization of the gearwheel body when designing gears. The gear rim is currently not considered, which shows potential for new lightweight design concepts.

This joint project aims to develop design guidelines for holistic lightweight gears with an integrated load monitoring for wind turbine gearboxes. The realization of lightweight demonstrators, of a test rig for measuring the geometry of the demonstrators under static load, and of a test rig for investigating dynamic load peaks will validate the design. The holistic approach is to be manufactured additively and allows the integration of an inside sensing and telemetry system to record force curves and deformations, which contributes to the validation of the design. In addition, the integration of flexible structures within the gearing, e.g., by solid state joints and a condition monitoring system, coupled with the inside sensing system, will proactively compensate for peak loads. The holistic lightweight design approach thus enables direct and indirect potential for weight and material savings.



Holistic lightweight gear
based on initial simulations by the project partner Alfred-Wegener-Institute (concept idea).

InSensa

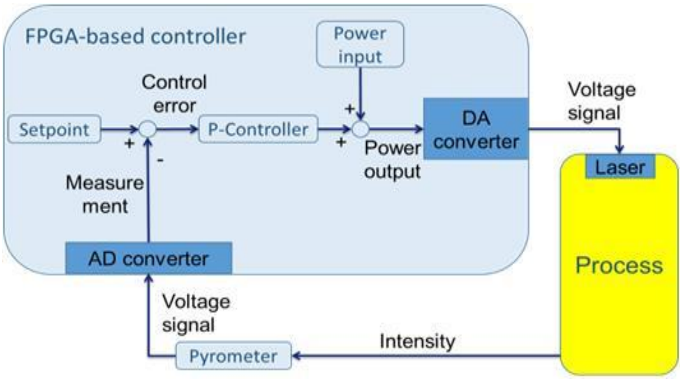
In-process sensors and adaptive control systems for additive manufacturing

Funding organization: BMBF
Funding ID: 02P15B076
Duration: 1 May 2017 – 31 March 2021
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.-6.9.2018, 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
Ann-Marie Parrey

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

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

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

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

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

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

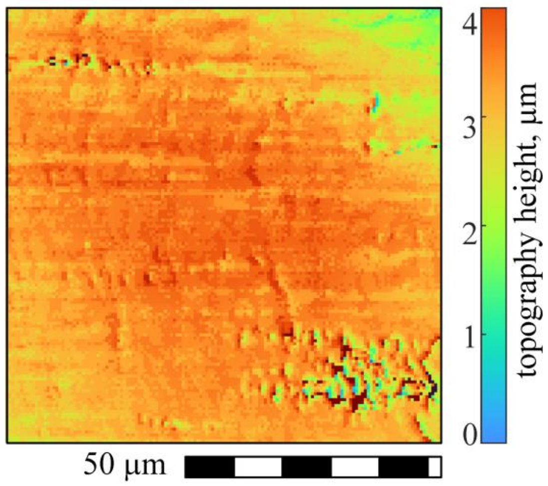
SiToH

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

Funding organization: BMBF
Funding ID: 100363507
Duration: 1 Aug 2018 – 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. 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.



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

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

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

SUrfErCut

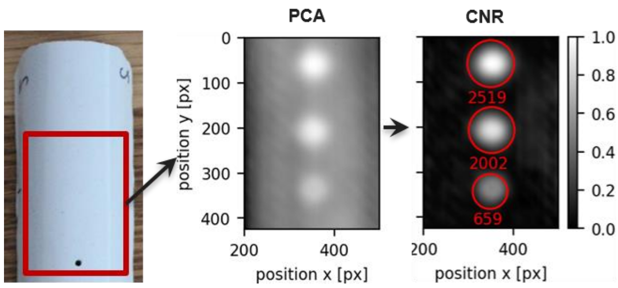
Systematic investigation of the causes of erosion damage to wind turbines

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. Damage caused primarily by erosion limits the lifetime of wind turbines and leads to high maintenance and repair costs. Studies suggest that initial subsurface defects such as pores in the border area between coating and glass-fiber reinforced composite can lead to 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 an erosion test rig.



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

The first experiments show, that sub-surface defects in different depths and with different diameters can be visualized and detected automatically, despite a coated and curved surface of the test sample [1]. Further investigations including computer tomography reference measurements 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] F. Jensen, M. Sorg, A. Fischer: Detection of initial subsurface defects in rotor blade leading edges of wind turbines by means of active thermography. Sensor and Measurement Science International (SMSI 2021), E-conference, 3.-6.5.2021, No. D9.4, pp. 289-290.

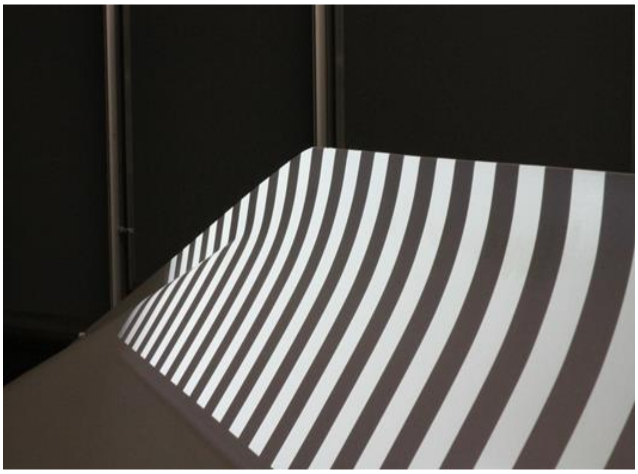
LoGAZ

Laser optical measurement method for the state analysis of wind turbines

Funding organization: BAB
Funding ID: AUF0007A
Duration: 1 May 2020 – 31 Oct 2021
Project scientists: León Schweickhardt,
Axel von Freyberg

In order to be able to evaluate the aerodynamic condition of wind turbines, for example with regard to pitch adjustments, and to plan and prepare necessary maintenance work, non-contact measurements 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 whether it 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***
- 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

- 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***

I

- IMSAS Institut für Mikrosensoren, -aktoren und -systeme, Universität ***Bremen***
- InfraTec GmbH Infrarotsensorik und Messtechnik, ***Dresden***
- in-situ GmbH, ***Sauerlach***
- ISD Hannover, Institut für Statik und Dynamik, ***Hannover***
- 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 Werkstofforientierte 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***
- Tomey GmbH, ***Nürnberg***
- Technische Universität Ilmenau, Fachgebiet Elektroniktechnologie, ***Ilmenau***
- Technische Universität Ilmenau, Fachgebiet Mikromechanische Systeme, ***Ilmenau***
- Toho Tenax Europe GmbH, ***Wuppertal***
- Trecolan GmbH, ***Bremen***

Cooperations with industry and measurement services

Cooperation partners

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***

Measurement services

Dimensional measurements

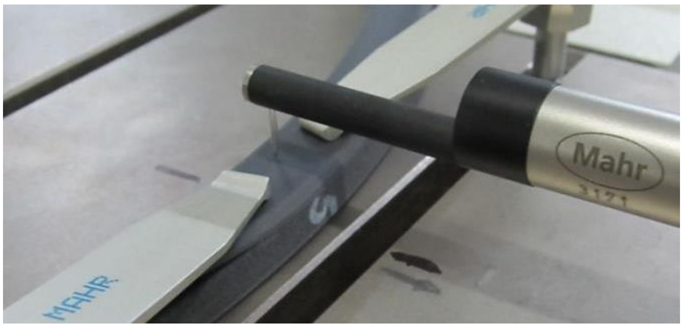
Duration: continuously

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 20/21 and SoSe 2021
Messtechnik	●	●	○	○	3rd		3	144
Übung Messtechnik	●		○	○	3rd		1	129
Labor Messtechnik	●		○	○	3rd		1	30
Regelungstechnik	●		○		5th		3	66
Übung Regelungstechnik	●		○		5th		1	63
Labor Regelungstechnik	●		○		5th		1	45
Grundlagen der Qualitätswissenschaft	●	●	●		5th	1st	3	133
Regenerative Energien	●	○	○	○	4th 6th	1st	3	14
Prozessnahe und In-Prozess-Messtechnik	●	●	●		4th 6th	1st 2nd 3rd	3	22
Geometrische Messtechnik mit Labor* AUKOM	●	●	○		5th	1st	3	32
Methoden der Messtechnik - Signal- und Bildverarbeitung	●	●	●		5th	1st 2nd	3	19
Einführung in die Automatisierungstechnik mit Labor	●	●	○		5th	1st 2nd	3	27
Produktion von Verzahnungen (held by several chairs)	●	○				1st 2nd	6	9
Labor Produktion von Verzahnungen (held by several chairs)	●	○				1st 2nd	3	5
Grundlagenlabor Produktionstechnik		●			4th		2	40
Messtechnisches Seminar	●	●	●		4th	1st 2nd	3	30

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.

Student projects

Kind of project	Title	Semester	Course of studies*
Informatikprojekt	Ansteuerung eines 3D-Laserscanners (Bilderfassung und -auswertung in Python	SoSe 2021	BSc PT BSc WING
Bachelorprojekt	Kalibrierung einer Thermografiekamera für Messungen an Windenergieanlagen	WiSe 2020 / 2021	BSC PT BSc WING
Bachelorprojekt	Modellierung der Speicherung und des Transports von Energie im Netz der Zukunft	WiSe 2020 / 2021	BSC PT BSC WING
Masterprojekt	Vergleich von taktilen und optischen Verfahren für die Verzahnungsmessung	WiSe 2020 / 2021	MSc PT

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

Graduation works

Bachelor theses

- Paul ***Agostini***:
  Erfassung des Zustandes der Hauptlager von getriebelosen Windenergieanlagen mittels Schwingungsanalyse.
  Colloquium: 26 Jun 2020
- Friedrich ***Eickmann***:
  Bestimmung der Messunsicherheit der Bohrkanallängenmessung beim handgeführten medizinischen Bohren von Knochen.
  Colloquium: 9 Oct 2020
- Jacob ***Friedrich***:
  Auswertung laser-optischer Messdaten von Windkraft-Rotorblättern.
  Colloquium: 14 Dec 2020
- Anna ***Johanning***:
  Einfluss von Metainformationen auf die Modellierung hochregenerativer Aubauszenarien des deutschen Energiesystems.
  Colloquium: 14 Apr 2020
- Georgii ***Kereselidze***:
  Laseroptische Geometriemessung an Windkraft-Rotorblättern.
  Colloquium: 11 Nov 2020
- Kevin ***Phung***:
  Vergrößerung des dynamischen Bereichs eines konfokal-chromatischen Sensors.
  Colloquium: 5 Nov 2020
- Joe ***Rode***:
  Messdatengestützte Bewertung des Zubaus von Anlagen zur Nutzung erneuerbarer Energien.
  Colloquium: 11 Sept 2020

Teaching

Teaching activities, student projects, graduation works

Master theses

- Marius ***Sontopski***:
  Messung der Turmbewegung einer Windenergieanlage mithilfe eines laseroptischen Abstandsmessgeräts.
  Colloquium: 19 Oct 2020
- Philipp ***Thomaneck***:
  Untersuchung optischer Abstandssensoren zur Formmessung von Verzahnungen.
  Colloquium: 5 Nov 2020
- Jonas ***Walther***:
  Messdatengestützte Bewertung von Betriebsführungsstrategien von Speichersystemen in Szenarien mit hohen Einspeiseraten erneuerbarer Energien.
  Colloquium: 24 Aug 2020
- Nils ***Poeck***:
  Optische Detektion der Rotordrehbewegung von Windenergieanlagen in Betrieb.
  Colloquium: 10 Dec 2020
- Fabian ***Glandorf***:
  Implementierung eines DMD Beleuchtungssystems zur Verringerung der spatiotemporalen Unschärfe bei Verschiebungsmessungen mittels Speckle-Fotografie.
  Colloquium: 22 Apr 2021
- Marina ***Terlau***:
  Untersuchung der Wärmeausbreitung in Rotorblattvorderkanten bei der aktiven Thermografie.
  Colloquium: 27 Jan 2021

Publications

Books

- A. von ***Freyberg***:
  Automatische Partitionierung komplexer kombinierter Geometrien durch Ganzheitliche Approximation.
  In: Forschungsberichte des Bremer Instituts für Messtechnik, Automatisierung und Qualitätswissenschaft (Hrsg.: A. Fischer).
  Vol. 4, Shaker, Düren, 2021.

Journals

- G. ***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, 3(2):91-104, 2020.
- G. ***Behrends***, D. Stöbener, A. Fischer:
  Integrated, speckle-based displacement measurement for lateral scanning white light interferometry.
  Sensors 21(7):2486 (17 pp.), 2021.
- G. ***Behrends***, D. Stöbener, A. Fischer:
  Lateral scanning white-light interferometry on rotating objects.
  Surface Topography: Metrology and Properties 8(3):035006 (13 pp.), 2020.
- A. ***Fischer***, M. Mikulewitsch, D. Stöbener:
  Indirect fluorescence-based in situ geometry measurement for laser chemical machining.
  CIRP Annals - Manufacturing Technology 69(1):481-484, 2020.
- A. ***Fischer***:
  Fundamental flow measurement capabilities of optical Doppler and time-of-flight principles.
  Experiments in Fluids 62(2):37 (19 pp.), 2021.
- 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
- D. ***Gleichauf,*** M. Sorg, A. Fischer:
  Contactless localization of premature laminar-turbulent flow transitions on wind turbine rotor blades in operation.
  Applied Sciences 10(18):6552 (21 pp.), 2020.
- D. ***Gleichauf***, F. Oehme, M. Sorg, A. Fischer:
  Laminar-turbulent transition tocalization in thermographic flow visualization by means of principal component analysis.
  Applied Sciences 11(12):5471 (22 pp), 2021.

Publications and qualification of young academics

Publications

- P. ***Helming***, A. von Freyberg, M. Sorg, A. Fischer:
  Wind turbine tower deformation measurement using terrestrial laser scanning on a 3.4 MW wind turbine.
  Energies 14(11):3255 (14 pp.), 2021.
- J. ***Osmers***, N. Kaiser, M. Sorg, A. Fischer:
  Adaptive finite element eye model for the compensation of biometric influences on acoustic tonometry.
  Computer Methods and Programs in Biomedicine 200:105930 (10 pp.), 2021.
- J. ***Osmers***, O. Hoppe, A. Strzalkowska, P. Strzalkowski, Á. Patzkó, S. Arnold, M. Sorg, A. Fischer:
  Results of first in vivo trial of an acoustic self-tonometer.
  Translational Vision Science & Technology 9(9):18 (9 pp.), 2020.
- M. ***Pillarz***, A. von Freyberg, A. Fischer:
  Determination of the mean base circle radius of gears by optical multi-distance measurements.
  Journal of Sensors and Sensor Systems 9(2):273–282, 2020.
- M. ***Pillarz***, A. von Freyberg, A. Fischer:
  Gear shape parameter measurement using a model-based scanning multi-distance measurement approach.
  Sensors 20(14):3910 (16 pp.), 2020.
- M. ***Pillarz***, A. von Freyberg, D. Stöbener, A. Fischer:
  Gear shape measurement potential of laser triangulation and confocal-chromatic distance Sensors.
  Sensors 21(3):937 (22 pp.), 2021.
- Y. ***Schädler***, V. Renken, M. Sorg, L. Gerdes, G. Gerdes, A. Fischer:
  Power transport needs for the German power grid for a major demand coverage by wind and solar power.
  Energy Strategy Reviews 34:100626 (9 pp.), 2021.
- L. ***Schweickhardt***, A. Tausendfreund, D. Stöbener, A. Fischer:
  Noise reduction in high-resolution speckle displacement measurements through ensemble averaging.
  Applied Optics 60(7):1871-1880, 2021.
  (highlighted article with excellent scientific quality, Editor's Pick)
- J. ***Stempin***, A. Tausendfreund, D. Stöbener, A.Fischer:
  Roughness measurements with polychromatic speckles on tilted surfaces.
  Nanomanufacturing and Metrology, 2021. (accepted)

- A. ***Tausendfreund***, D. Stöbener, A. Fischer: *Messung thermomechanische Beanspruchungen in laufenden Schleifprozessen.* tm-Technisches Messen 87(3):201-209, 2020.
- A. ***Tausendfreund***, D. Stöbener, A. Fischer: *In-process measurement of three-dimensional deformations based on speckle photography.* Applied Sciences 11(11):4981 (11 pp.), 2021.
- C. ***Vanselow***, 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.

Conference contributions

- A. ***Fischer***, M. Mikulewitsch, D. Stöbener: *Indirect fluorescence-based in situ geometry measurement for laser chemical machining*. CIRP video paper sessions, online, 24.-28.8.2020, No. P11.
- D. ***Gleichauf***, D. Jacob, M. Sorg, A. Fischer: *Advanced image processing for turbulence wedge detection in thermographic flow visualization.* TORQUE 2020 - The Science of Making Torque from Wind, E-conference, 28.9.-2.10.2020. Journal of Physics: Conference Series 1618:032029 (8 pp.), 2020.
- D. ***Gleichauf***, F. Oehme, M. Sorg, A. Fischer: *Contrast enhancement in thermographic flow visualization by means of principal component analysis*. Wind Energy Science Conference (WESC 2021), E-conference, 25.-28.05.2021, Session: Condition & structural health monitoring (III).
- P. ***Helming***, A. von Freyberg, M. Sorg, A. Fischer: *Wind turbine tower deformation measurement using 2d terrestrial laser scanning (TLS).* Wind Energy Science Conference (WESC 2021), E-conference, 25.-28.05.2021, Session: Novel sensing and new measurement concepts for wind turbines.
- F. ***Jensen***, M. Sorg, A. Fischer: *Detection of initial subsurface defects in rotor blade leading edges of wind turbines by means of active thermography.* Sensor and Measurement Science International (SMSI 2021), E-conference, 3.-6.5.2021, No. D9.4, pp. 289-290.

Publications and qualification of young academics

Publications

- J. **Kiefer**, C. Vanselow, A. Fischer:
  Combining laser-induced breakdown spectroscopy (LIBS) and particle imaging velocimetry (PIV) for flame diagnostics.
  Laser Applications to Chemical, Security and Environmental Analysis (LACSEA), E-conference, 22.-26.6.2020.
- M. ***Mikulewitsch***, D. Stöbener, A. Fischer:
  Indirect geometry measurement for laser chemical machining using a model-based signal processing approach.
  Sensor and Measurement Science International (SMSI 2021), E-conference, 3.-6.5.2021, No. C5.2, pp. 208 - 209.
- F. ***Oehme***, M. Sorg, A. Fischer:
  Thermographic stall detection using model-based evaluations of the surface temperature response to oscillating fluid temperatures.
  Sensor and Measurement Science International (SMSI 2021), E-conference, 3.-6.5.2021, No. D6.3, pp. 271-272.
- Y. ***Schädler***, M. Sorg, A. Fischer:
  Investigation of storage demands on a measured data base of wind and solar power as well as power load.
  STORENERGY 2020, E-conference, 11.-13.11.2020.
- Y. ***Schädler***, M. Sorg, A. Fischer:
  Spatiotemporale Messdaten optimieren die Energiewende.
  Jahrestreffen Forschungsnetzwerk Energiesystemanalyse, online, 18.05.2021. (Poster).
- Y. ***Schädler***, M. Sorg, A. Fischer:
  Transport cost evaluation in the power transmission network in highly renewable scenarios using measurement data.
  Wind Energy Science Conference (WESC 2021), E-conference, 25.-28.05.2021, Session: Wind energy and grids: a holistic view of future developments.
- C. ***Vanselow***, B. Espenhahn, L. Schumski, D. Stöbener, D. Meyer, A. Fischer:
  Near process coolant flow field measurements in a grinding machine.
  Sensor and Measurement Science International (SMSI 2021), E-conference, 3.-6.5.2021, No. C8.2, pp. 302-303.

Automatic partitioning of complex combined geometries by Holistic Approximation

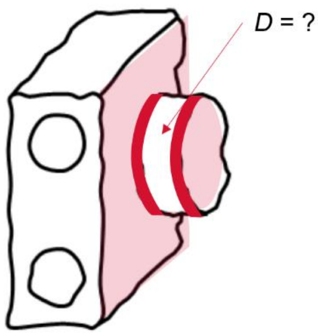
Dr.-Ing. Axel Freiherr von Freyberg
Date of thesis defense: 19 March 2021
Supervisor: Prof. Dr.-Ing. habil. Andreas Fischer

Modern production metrology aims at measurements close to the process and 100 % testing. Decreasing tolerances and the need for automatic measurements require new evaluation methods.

The quality inspection of technical components contains the evaluation of dimensional, shape and position deviations. Here, the association of measured surface data with ideal geometric elements requires partitioning of the measurement data. A model-based approach to automated partitioning is offered by the Holistic Approximation (HA).

So far, this approach was limited to geometric primitives, and it was not evaluated in terms of measurement uncertainty. Therefore, the objectives of the thesis were to extend the approach for a universal applicability without geometric limitations and to validate it in two challenging applications.

To extend the HA, a root point iteration was implemented in order to enable calculating the orthogonal distance between the measuring points and the associating geometric element even for complex elements. The extended HA was used for the automatic geometry inspection of microforming tools and for the determination of (unknown) gearing parameters. Both applications contain complex geometric elements such as an ellipse or a crowned involute and are subject to tolerances in the micrometer range. With deviations of 1 µm and below to reference measurements, the extended HA demonstrates its universal applicability without restrictions regarding geometric complexity. The integrated rule-based partitioning of the measurement data is optimized and enables the automatic evaluation of geometric deviations with minimal measurement uncertainty.



The geometric quality inspection requires partitioning the integral elements within the sampled surface model.

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

[2] A. Fischer, A. von Freyberg, D. Stöbener: Tooth flank approximation with root point iteration - potentials and limits in gear metrology. CIRP Annals - Manufacturing Technology, 2021. (accepted)

Publications and qualification of young academics

Awards

Deutsche WindGuard Nachwuchs-Förderpreis 2020

For the fourth 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

- Aage ***Rehfeldt*** for his bachelor thesis: "*Optimization of a wind tunnel measurement system for the investigation of the inclined flow behavior of wind measuring devices*"

and to

- Jan Lukas ***Tiefensee*** for his bachelor thesis: "*Automated rectification and compositing of single images for thermographic flow visualization”*

Congratulations from the BIMAQ team!

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

Prof. Andreas Fischer, Aage Rehfeldt, Jan Lukas Tiefensee

Events

Participation at events and conferences

Date	Event / Conference	Location	Participant(s)	
22 – 25 Jun 2020	**SMSI Sensor and Measurement Science International”**	Nürnberg E-Conference	F. Jensen M. Mikulewitsch M. Pillarz	oral presentation
23 – 29 Aug 2020	**70th CIRP General Assembly**	München International E-Conference	A. Fischer	oral presentations
28 Sep – 2 Oct 2020	**TORQUE 2020**	Delft E-Conference	D. Gleichauf	poster presentation
11 – 13 Nov 2020	**Storenergy 2020**	Offenburg E-Conference	Y. Schädler	oral presentation
1 – 4 Dec 2020	**WindEnergy**	Hamburg E-Conference	Y. Schädler	oral presentation
3 – 6 May 2021	**SMSI Sensor and Measurement Science International**	Nürnberg E-Conference	A. Fischer F. Jensen M. Mikulewitsch F. Oehme	oral presentation
18 May 2021	**Jahrestreffen 2021 Forschungsnetzwerk Energiesystemanalyse**	E-Conference	Y. Schädler	poster presentation
25 – 28 May 2021	**WESC Wind Energy Science Conference**	Hannover E-Conference	D. Gleichauf P. Helming Y. Schädler	oral presentation
7 – 11 Jun 2021	**Euspen 21st International Conference**	Copenhagen E-Conference	G. Behrends	oral presentation
20 - 24 Jun 2021	**SPIE The international society for optics and photonics**	München	L. Schweickhardt A. Tausendfreund	oral presentation

Events

Events @ BIMAQ

Date	Event	Organizing institution
22 Jul 2020	**LOGAZ - Kick-off meeting**	BIMAQ
27 Oct 2020	**Invited talk: PD Dr. Perlick (ZARM) Detecting gravitational waves with interferometry**	BIMAQ
2 Dec 2020	**Informing students and exchanging experiences about scholarships in Germany: „Begabtenförderungswerke in Deutschland - Erfahrungen und Wege zur Förderung des eigenen Studiums“**	Dies Academicus / BIMAQ
24 Nov 2020	**BEST – Ring lecture „Wind turbines: Challenges of on-site research“**	Universität Bremen / BIMAQ
9 Jan 2021	**Invited talk: Dr. Falldorf (Bias) About optical 7D metrology**	BIMAQ
10 Feb 2021	**FlexGear - Kick-off meeting**	BIMAQ
1 Mar 2021	**Jugend forscht – Pupils are experimenting (regional competition Bremen-Mitte)**	Jugend forscht / BIMAQ
5 Mar 2021	**RapidSheet - Kick-off meeting**	BIMAQ
1 Apr 2021	**PROTA - Kick-off meeting**	BIMAQ
9 June 2021	**Kids University 2021: We can see colors and temperatures, too?**	BIMAQ
15 Jun 2021	**Invited talk: L. Hoffmann (PTB) Deep learning for optical shape measurement**	BIMAQ

- Prominent guest speakers in BIMAQ's seminar on measurement techniques

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

  - Dr. rer. nat. V. Perlick (ZARM): *Detecting gravitational waves with interferometry*. 27 Oct 2020
  - Dr. C. Falldorf (BIAS): *7D Metrology, Characterising aspheres and free form surfaces by means of coherence function-measurements*. 9 Jan 2021
  - L. Hoffmann (PTB): *Deep Learning for optical shape measurement.* 15 Jun 2021

- 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 on 22 July 2020. In the following monthly web-meetings, the project progress was continuously presented and discussed. Although being a short term project, excellent experimental results have already been achieved.

- FlexGear - Kick-off meeting

  The first meeting (kick-off) for the joint research project 'FlexGear' took place on 12 February 2021 digitally via zoom. After a welcome by Dr. Stöbener (BIMAQ) and the coordinator Marc Pillarz (BIMAQ), a brief overview of the tasks of the following three years of the project was given. Each partner then introduced itself and presented its contribution to the planned project aims. Ms. Wesp also introduced the project management organization Jülich and explained the requirements for the joint project. Subsequently, the partners discussed the requirements of the first content tasks and agreed on further meetings to present the corresponding work steps. The meeting was an excellent event to strengthen the close collaboration and to provide a smooth project start.

- RapidSheet - Kick-off meeting

  The kick-off meeting of the European research project 'RapidSheet' took place on 5 March 2021 with all partners and the industrial user committee. It was also organized as a video conference and each partner presented their institutes and their contributions to the project. About the forming machine, which is the central part that will be bought for the project, the Fraunhofer IWU presented first machine details. This enabled an efficient start of our contribution concerning an in-process capable optical measurement technique for monitoring the tool movement during the incremental metal sheet forming.

- PROTA - Kick-off meeting

  The principal investigators (PI) and project scientists of the newly beginning joint DFG project 'PROTA' came together for an initial meeting on 1 April 2021 in a video call. As a result, the first steps have been arranged and coordinated to enable a successful start of the promising joint research work. PROTA constitutes a cooperation with the Bremen Institute for Applied Beam Technology (BIAS) and aims to improve the understanding of the underlying mechanisms characterizing the manufacturing process of laser chemical machining (LCM) by means of a novel measurement technique.

Events

Events @ BIMAQ

- Jugend forscht - regional competition

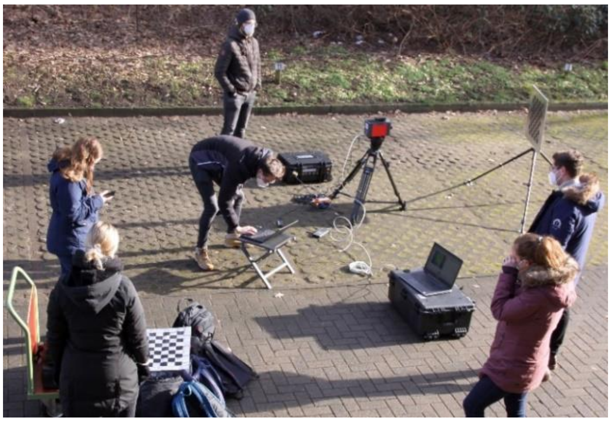
In March 2021, the regional competition 2021 of the initiative 'Jugend forscht' was held as an online event. Over three days, the jury discussions took place with over 120 papers from various disciplines. As a result, twenty placements each from the 'Schüler experimentieren' and 'Jugend forscht' sections qualified for the state competition. Dr. von Freyberg from the BIMAQ once again was part of the jury team and enjoyed the enthusiasm of the pupils who presented their innovative ideas and experimental results.

- Kids University

On 9 June 2021, the BIMAQ contributed to the annual Kids University. Ms. Jensen together with Prof. Fischer talked about the topic 'We see colors... and also temperatures?' At first, the children were taught some basics about colors and light. Videos with various experiments such as how to create a rainbow at home supported the lecture. Furthermore, examples and illustrative analogies provided the children with a first in-depth knowledge about heat and temperatures. Finally, temperatures were made visible by means of a thermal imaging camera, and the pupils had lots of fun experiencing the possibilities with a wider sense of vision. Dear pupils, preparing the lecture and experiments brought so much joy to us and we did enjoy asking your questions. Stay curious and never stop asking questions!

- Teaching project: Calibration of a thermography camera for wind turbine studies

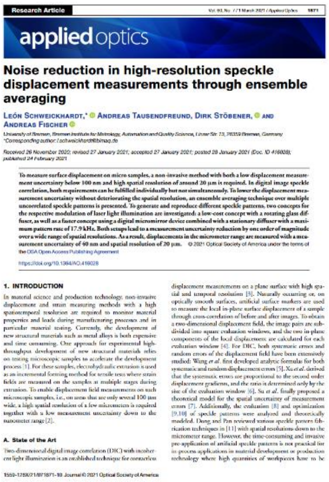
  A noteworthy and encouraging event in times of the Covid-19 pandemic: a measurement campaign at the BIMAQ conducted by students in presence. The free-field capability of the thermographic measurement system made it possible to measure on the parking lot in compliance with distance and hygiene regulations. As part of a teaching project, six students with the courses systems engineering and production engineering enjoyed their work on the research task of establishing a geometric calibration for thermographic measurements at wind turbines in operation.



Events

Events @ BIMAQ

- Publication with excellent scientific quality



Research Article

applied optics

Noise reduction in high-resolution speckle displacement measurements through ensemble averaging

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To measure surface displacement on micro samples, a non-invasive method with both a low displacement measurement uncertainty below 100 nm and high spatial resolution of around 20 µm is required. In digital image speckle correlation, both requirements can be fulfilled individually but not simultaneously. To lower the displacement measurement uncertainty without deteriorating the spatial resolution, an ensemble averaging technique over multiple uncorrelated speckle patterns is presented. To generate and reproduce different speckle patterns, two concepts for the respective modulation of laser light illumination are investigated: a low-cost concept with a rotating glass diffuser, as well as a faster concept using a digital micromirror device combined with a stationary diffuser with a maximum pattern rate of 17.9 kHz. Both setups lead to a measurement uncertainty reduction by one order of magnitude over a wide range of spatial resolutions. As a result, displacements in the micrometer range are measured with a measurement uncertainty of 40 nm and spatial resolution of 20 µm. © 2021 Optical Society of America under the terms of the OSA Open Access Publishing Agreement

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1. INTRODUCTION

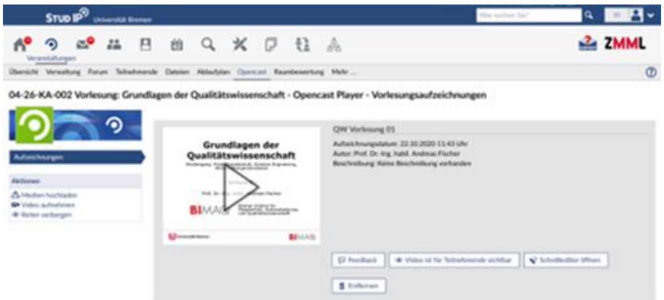
In material science and production technology, non-invasive displacement and strain measuring methods with a high spatiotemporal resolution are required to monitor material properties and loads during manufacturing processes and in particular material testing. Currently, the development of new structural materials such as metal alloys is both expensive and time consuming. One approach for experimental high-throughput development of new structural materials relies on testing microscopic samples to accelerate the development process [1]. For these samples, electrohydraulic extrusion is used as an incremental forming method for tensile tests where strain ...

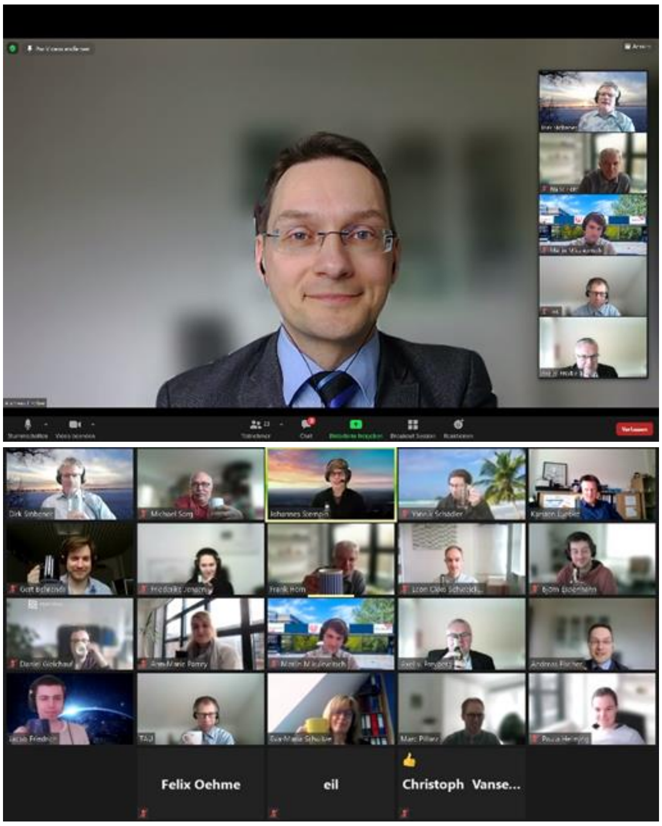
... displacement measurements on a plane surface with high spatial and temporal resolution [3]. Naturally occurring or, on optically smooth surfaces, artificial surface markers are used to measure the local in-plane surface displacement of a sample through cross-correlation of before and after images. To obtain a two-dimensional displacement field, the image pairs are subdivided into square evaluation windows, and the two in-plane components of the local displacement are calculated for each evaluation window [4]. For DIC, both systematic errors and random errors of the displacement field have been extensively studied: Wang et al. first developed analytic formulas for both systematic and random displacement errors [5]. Xu et al. derived that the systematic errors are proportional to the second order ...

The publication "Noise reduction in high-resolution speckle displacement measurements through ensemble averaging" (https://doi.org/10.1364/AO.416028) in the internationally renowned journal Applied Optics was highlighted by the editor as a selected article with excellent scientific quality ("Editor's Pick"). We thank the journal for this appreciation for one piece of our continuous attempt to work at highest scientific standards.

- Digitisation of research and teaching in times of the Covid 19 pandemic

The corona crisis changes the way of performing research and teaching. This year, most of our work is done via digital channels, and is a success of our entire team that we could continue our research and teaching activity with fantastic results and positive resonances.





- Team activity at Bremen’s cultural pub “Gastfeld” – and the winners are …

  On 22 September 2020, a group of 7 members of the BIMAQ team took part in the infamous pub quiz in Bremen's cultural pub "Gastfeld". Contrary to expectations, they were able to prevail against 15 other seasoned teams and win directly at the first attempt. It was a fun event that highlighted previously unknown, diverse interests of our colleagues.

  Congratulations!

Notes

Impressum

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