in Aerospace

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PROGRAMME & ABSTRACTS

10th International Symposium on NDT in Aerospace


© Frauenkirche, Dresden

24 – 26 October 2018 in Dresden Germany


Antonov 124 Maintenance at Leipzig Airport © VD-Group

A warm welcome to all of those attending the 10th Symposium on NDT in Aerospace. This symposium has now achieved a ten years' tradition having been held since 2010 in various places where aerospace has a home including Fürth, Hamburg, Montreal, Augsburg, Singapore, Madrid, Bremen, Bangalore, Xiamen and now in Dresden. The reason why the symposium is taking place more often in Germany than in other countries stems from the fact that the German Society for NDT (DGZfP) has been the originator of this event. The mix between Germany and the rest of the world as a location for the symposium has allowed an insight into the aerospace related NDT activities within the different countries the symposium has been held so far.

Saxony with Dresden as its capital is traditionally characterised by perfectionism in engineering and art and among this aerospace plays an important role. Even during the post WW II East German time Dresden was dedicated to become the East German hub for aerospace having been mainly turned down through Soviet influence in the end. However, the aerospace spirit remained alive in Dresden since this time from a research, testing, maintenance and manufacturing point of view and became an asset within the German reunification in 1989. The result can be seen with aerospace being well represented within the Technical University of Dresden, IMA as an internationally renowned testing company for aeronautical components or Elbe Flugzeugwerke as a major passenger to freighter aircraft conversion company. In addition to this IABG is another big aerostructures testing house which established a branch in Dresden, AMTES opened a major cargo aircraft maintenance facility at Leipzig/Halle airport and a variety of aircraft suppliers as well as NDT research organisations such as Fraunhofer and NDT companies settled down in Saxony over the past years. Finally even one of the very few master courses in NDT worldwide has found its home at Dresden International University (DIU).

This year's symposium will again provide a broad spectrum of activities, some of those in the traditional format such as technical presentations or the exhibition, some being specific and informative such as the special sessions related to prognostics and health management (PHM), student activities, the PhD programme „NDTonAir“ or NDT in Aerospace live and finally some being 'exotic' such as the keynote lectures addressing relevant topics including additive manufacturing, big data, robotics and simulation combined with some hopefully exciting workshop sessions. Together with this there is a fully booked exhibition and very much stimulating technical visits. We as the organisers hope that with such a mix many expectations can be met and some new spirit of inspiration may be created that may help to fuel participants' minds towards new ideas and the continuity of this event, representing a lively dialogue between academic research and true application in aerospace-related NDT.

Last but not least thank you for participating and to our sponsors for having again made this event to become feasible and hopefully successful with those little extra features we want to provide.

Prof. Dr.-Ing. Christian Boller
Saarland University

Prof. Dr.-Ing. Henning Heuer
Fraunhofer Institute
for Ceramic Technologies
and Systems IKTS

Dr.-Ing. Matthias Purschke
German Society for
Non-Destructive Testing

OVERVIEW

Wednesday, 24 October 2018

Room Frauenkirche 1+2

09:00	Opening and Welcome Address
09:30 – 10:15	**We.1.A** **Plenary Talk | Numerical Simulation in NDT** | *C. Boller*
10:15 – 10:45	**We.2.A** **Numerical Simulation in NDT** (Short Presentations) | *C. Boller*
11:15 – 12:00	**We.3.A** **Plenary Talk | NDT and Big Data** | *C. Boller*
12:00 – 12:30	**We.4.A** **NDT and Big Data** (Short Presentations) | *C. Boller*

	Room Frauenkirche 1+2	Room Blaues Wunder 1+2	Room Goldener Reiter
14:00 – 16:00	**We.5.A** **Workshop Numerical Simulation in NDT** *P. Calmon*	**We.5.B** **Prognostics & Health Management** (Special Session) *M. Buderath*	**We.5.C** **Composites** (Technical Session) *J. Jonuscheit*
16:30 – 18:30	**We.6.A** **Workshop NDT and Big Data** *D. Söffker*	**We.6.B** **NDT in Aerospace live** *C. Boller*	**We.6.C** **Eddy Current** (Technical Session) *H. Heuer*

19:00 Welcome reception *(poster and exhibition area)*

Thursday, 25 October 2018

Room Frauenkirche 1+2

08:30 – 09:15	**Th.1.A** **Plenary Talk | Robotics in NDT** | *H. Heuer*
09:15 – 09:40	**Th.2.A** **Robotics in NDT** (Short Presentations) | *H. Heuer*
10:15 – 11:00	**Th.3.A** **Plenary Talk | NDT and Additive Manufacturing** | *H. Heuer*
11:00 – 11:25	**Th.4.A** **NDT and Additive Manufacturing** (Short Presentations) | *H. Heuer*

	Room Frauenkirche 1+2	Room Blaues Wunder 1+2	Room Goldener Reiter
13:00 – 14:40	**Th.5.A** **Workshop Robotics in NDT** *W. Prosser*	**Th.5.B** **Student Activities in NDT in Aerospace** (Student Session) *C. Boller*	**Th.5.C** **Ultrasonics 1** (Technical Session) *B. Köhler*
15:10 – 16:50	**Th.6.A** **Workshop NDT and Additive Manufacturing** *G. Bruno*	**Th.6.B** **EU PhD Programme „NDT on Air“** (Special Session) *H. Pfeiffer*	**Th.6.C** **Ultrasonics 2** (Technical Session) *K. Bente*

17:30 Guided tour through the historic centre
19:00 Banquet at restaurant „Pulverturm“

Friday, 26 October 2018

	Room Frauenkirche 1+2	Room Blaues Wunder 1+2	Room Goldener Reiter
08:30 – 10:10	**Fr.1.A** **Applications** (Technical Session) *A. Güemes*	**Fr.1.B** **Different Methods** (Technical Session) *G. Mayr*	**Fr.1.C** **Structural Health Monitoring** (Technical Session) *M. Gaal*

10:30 Technical visits

Room Frauenkirche 1+2

09:00 **OPENING AND WELCOME ADDRESS |** *W. Göhler, LRT Sachsen/Thüringen, Dresden, Germany; C. Boller, Universität des Saarlandes, Saarbrücken, Germany; H. Heuer, Fraunhofer IKTS, Dresden, Germany*

We.1.A

▶ **PLENARY TALK | NUMERICAL SIMULATION IN NDT |** *C. Boller*

09:30 **We.1.A.1**

NDE & SHM computational tools for enhanced diagnostics and reliability assessment
P. Calmon [1], C. Reboud, [1] E. Demaldent [1], O. Mesnil, [1] S. Leberre [1]
[1] CEA LIST, Gif-sur-Yvette, France

We.2.A

▶ **NUMERICAL SIMULATION IN NDT** (Short Presentations) **|** *C. Boller*

10:15 **We.2.A.1**

Simulation of a fiber-optic based SHM system. Application to a bonded repair patch
A. Güemes [1], M.E. Reyes [1], J. Garcia-Ramirez [1], C. Aguilar [1], A. Fernandez-Lopez [1]
[1] Universidad Politecnica de Madrid, Spain

10:20 **We.2.A.2**

Development of multi-physics multi-scale modelling platform for CFRP composites using inductive thermography techniques
A. Ba [1], B. Yilmaz [2], H.K. Bui [1], E. Jasiuniene [2], G. Berthiau [1]
[1] IREENA, Saint Nazaire, France; [2] Kaunas University of Technology, Kaunas, Lithuania

10:25 **We.2.A.3**

Simulation-supported Analysis of Complex Radiographs
N. Brierley [1]
[1] The Manufacturing Technology Centre, Coventry, UK

10:30 **We.2.A.4**

NOVI-SIM: A new fast simulation tool for X-ray computed tomography testing
A. Autret [1], G. Bravais [1], O. Guiraud [1], B. Fayard [1]
[1] NOVITOM, Grenoble, France

10:35 **We.2.A.5**

Semi-analytical modeling of eddy current inspection of stratified and homogenized composite materials
H. Chebbi [1], D. Prémel [1]
[1] CEA LIST, Gif-sur-Yvette, France

10:40 **We.2.A.6**

Guided Waves Simulation Capabilities in Isotropic and Anisotropic Structures in View of Structural Health Monitoring Applications
R. Sridaran Venkat [1], M. El Bakouri [1], A. Ernst [1], C. Boller [1]
[1] Universität des Saarlandes, Saarbrücken, Germany

10:45 Break

We.3.A

▶ **PLENARY TALK | NDT AND BIG DATA |** *C. Boller*

11:15 **We.3.A.1**

From data-driven NDT of systems to BIG DATA-based modeling
D. Söffker [1]
[1] Univ. Duisburg-Essen, Duisburg, Germany

We.4.A

▶ **NDT AND BIG DATA** (Short Presentations) **|** *C. Boller*

12:00 **We.4.A.1**

Incorporating Inductive Bias into Deep Learning: A Perspective from Automated Visual Inspection in Aircraft Maintenance
V. Ewald [1], X. Goby [1], H. Jansen [1], R. Groves [1], R. Benedictus [1]
[1] Delft University of Technology, Netherlands

12:05 **We.4.A.2**

PCRT Resonance Solutions for Additive Manufacturing
T. Köhler [1]
[1] Vibrant, Elz, Germany

Room Frauenkirche 1+2

12:10 **We.4.A.3**

Non-destructive testing for detection, localization and quantification of damage on composite structures for composite repair applications
P. Shrestha [1], R.M. Groves [1]
[1] Delft University of Technology, Netherlands

12:15 **We.4.A.4**

Simultaneous multi-frequency dielectric measurement technique for fast curing reactions
S. Geinitz [1], M. Eberhardt [1], D. Walser [1], D. Grund [1], B. Hollaus [2], A. Wedel [1]
[1] Fraunhofer IGCV, Augsburg, Germany; [2] MCI, Innsbruck, Austria

12:20 **We.4.A.5**

Comparison of Machine Learning Algorithms for NDT in Aerospace
C. Tschöpe [1], F. Duckhorn [1], M. Wolff [2]
[1] Fraunhofer IKTS, Dresden, Germany; [2] Brandenburg University of Technology Cottbus-Senftenberg, Cottbus, Germany

12:25 **We.4.A.6**

Utilise AI for NDT Inspection
P. Chow [1]
[1] Fujitsu, Lewes, UK

12:30 Lunch

Room Frauenkirche 1+2

We.5.A
WORKSHOP NUMERICAL SIMULATION IN NDT
P. Calmon

14:00

Discussion on Short Presentations of Session We.2.A
„Numerical Simulation in NDT“

Room Blaues Wunder 1+2

We.5.B
PROGNOSTICS & HEALTH MANAGEMENT (Special Session)
M. Buderath

We.5.B.1 14:00

Development of a Prognostic Framework
A.M. Siddiolo [1], M. Buderath [1]
[1] Airbus Defence and Space, Manching, Germany

We.5.B.2 14:20

Application of a PHM-based reliability prediction for an UAV's control surface actuation system
S. Mehringskötter [1], H. Heier [1]
[1] TU Darmstadt, Germany

We.5.B.3 14:40

Machine Learning based Data Driven Diagnostics & Prognostics Framework for Aircraft Predictive Maintenance
P. Adhikari [1], H. Gururaja Rao [1], M. Buderath [2]
[1] Airbus India, Bangalore, India; [2] Airbus Defence and Space, Manching, Germany

We.5.B.4 15:00

Satellite battery degradation prognostic based on data analytics and big data infrastructure
L. Boussouf [1], C. Barreyre [1], A. Charcosset [1]
[1] Airbus Defence and Space, Toulouse, France

Room Goldener Reiter

We.5.C
COMPOSITES
(Technical Session)
J. Jonuscheit

We.5.C.1 14:00

Spatially resolved non-invasive strain measurement on fast rotating composite rotors
J. Lich [1], R. Kuschmierz [1], T. Wollmann [1], A. Filippatos [1], M. Gude [1], J. Czarske [1]
[1] TU Dresden, Germany

We.5.C.2 14:20

Advanced and automatic turbine blade inspection, CT resolution optimization and error estimation in reconstructed volumes
P. Westenberger [1], T. Lowe [2]
[1] Thermo Fisher Scientific, Düsseldorf, Germany; [2] University of Manchester, UK

We.5.C.3 14:40

Study of CFRP subjected to moisture and thermal treatment with the scanning laser vibrometry
P. Malinowski [1], M. Radzienski [1], W. Ostachowicz [1]
[1] Polish Academy of Sciences, Gdansk, Poland

We.5.C.4 15:00

Virtual wave concept for thermographic porosity estimation in carbon fiber reinforced plastics
H. Plasser [1], G. Mayr [1], G. Stockner [1], G. Hendorfer [1], P. Burgholzer [2]
[1] University of Applied Sciences Upper Austria, Wels, Austria; [2] RECENDT – Research Center for Non Destructive Testing, Linz, Austria

Room Frauenkirche 1+2	Room Blaues Wunder 1+2	Room Goldener Reiter
	We.5.B.5 15:20 Data Visualisation using Augmented Reality with a Focus set on Head Mounted Displays and Collaborative Tasks *T. Drey* [1] [1] *Airbus Defence and Space, Ulm, Germany*	**We.5.C.5** 15:20 Lock-in thermography inspection for heat damaged composite materials *A. Ngo* [1], *L. Ding* [1], *V.K. Sivaraja* [1] [1] *IMRE, Singapore*

16:00 Break

Room Frauenkirche 1+2	Room Blaues Wunder 1+2	Room Goldener Reiter
We.6.A **WORKSHOP NDT AND BIG DATA** *D. Söffker*	**We.6.B** **NDT IN AEROSPACE LIVE** *C. Boller*	**We.6.C** **EDDY CURRENT** (Technical Session) *H. Heuer*
16:30 Discussion on Short Presentations of Session Th.4.A **„NDT and Big Data“**	16:30 Easy POD for Liquid Penetrant Testing *Trueflaw, Espoo, Finland*	**We.6.C.1** 16:30 Inspection techniques for aero engine components of Ceramic-Matrix-Composites using High-Frequency Eddy Current Techniques *S. Hillmann* [1], *M.H. Schulze* [1], *H. Heuer* [1] [1] *Fraunhofer IKTS, Dresden, Germany*
	16:40 Portable Phased Array – applications using the “Total Focusing Method” TFM *Karl Deutsch Prüf- und Messgerätebau, Wuppertal, Germany*	**We.6.C.2** 16:50 Characterization of Wet Conducting Coatings Using High-Frequency Eddy Current Techniques *I. Patsora* [1], *S. Hillmann* [2], *H. Heuer* [2] [1] *Fraunhofer IWU, Dresden, Germany;* [2] *Fraunhofer IKTS, Dresden, Germany*
	16:50 Real time ultrasound video and 3D images for fast NDE of solid structures Rolling data capture principle *ELOP, Hamar, Norway*	**We.6.C.3** 17:10 Determination of Indication Depths at High Frequency Eddy Current Testing of CFRP *N. Matvieieva* [1], *M.H. Schulze* [2], *K. Mizukami* [3], *I. Kharabet* [1], *H. Heuer* [2] [1] *TU Dresden, Germany;* [2] *Fraunhofer IKTS, Dresden, Germany;* [3] *Ehime University, Matsuyama, Japan*
	17:00 NDT Multi-Modality Accubot T. Gramberger1 *Fill, Gurten, Austria*	
	17:10 Detection of ice in the tank via acoustic emission *KU Leuven, Heverlee, Belgium; Brussels Airlines, Zaventem, Belgium*	**We.6.C.4** 17:30 Eddy Current Array for Aircraft Engine Component Inspection *A. Lamarre* [1] [1] *Olympus Scientific Solutions Americas, Quebec City, Canada*
	17:20 Detection of water in confined spaces of aircraft *KU Leuven, Heverlee, Belgium; Lufthansa Technik Frankfurt, Germany*	**We.6.C.5** 17:50 Development of a Contactless Inductive Strain Gauge for Monitoring Mechanical Load in CFRP *I. Kharabet* [1], *S. Hillmann* [2], *M.H. Schulze* [2], *N. Matvieieva* [1], *H. Heuer* [2] [1] *TU Dresden, Germany;* [2] *Fraunhofer IKTS, Dresden, Germany*
	17:30 Automation of additive manufactured components evaluation using computed tomography *Testia, Bremen, Germany*	
	17:40 Testing of Cubesats *ALTER Technology, Sevilla, Spain*	

19:00 Welcome reception *(poster and exhibition area)*

Th.1.A

PLENARY TALK | ROBOTICS IN NDT | *H. Heuer*

08:30 **Th.1.A.1**

NASA Applications of Robotics for NDT of Aerospace Vehicles
W. Prosser[1], G. Studor[1], M. Rollins[2], E. Burke[1], K. Hodges[1], B. Bartha[3], E. Cramer[1]
[1] NASA, Hampton, USA; [2] NASA, Houston, USA; [3] NASA, Cape Canaveral, USA

Th.2.A

ROBOTICS IN NDT (Short Presentations) | *H. Heuer*

09:15 **Th.2.A.1**

Development of a method for the non-destructive evaluation of fiber orientation in multilayer 3D carbon fiber preforms and CFRP with robot-guided high-frequency eddy current testing technology
J. Mersch[1], G. Bardl[1], A. Nocke[1], C. Cherif[1], M.H. Schulze[2], H. Heuer[2]
[1] TU Dresden, Germany; [2] Fraunhofer IKTS, Dresden, Germany

09:20 **Th.2.A.2**

Automated single view 3D Texture Mapping and Defect Localisation of Thermography Measurement on Fuselage utilising an industrial robot and laser system
S. Dutta[1], K. Drechsler[2], M. Kupke[1], A. Schuster[1]
[1] DLR, Augsburg, Germany; [2] TU München, Garching, Germany

09:25 **Th.2.A.3**

Autonomous Systems Imaging of Aerospace Structures
S. Deane[1], N. Avdelidis[1,2], A. Tsourdos[1], H. Yazdani Nezhad[1], C. Ibarra-Castanedo[2], X. Maldague[2], H. Zhang[2], A.A. Williamson[3]
[1] Cranfield University, UK; [2] Université Laval, Quebec City, Canada; [3] Mapair Thermography, Melbourn, UK

09:30 **Th.2.A.4**

How to improve NDT inspections on Airframe structures by using a climbing robot
C. Dürager[1], M. Jocham[2], A. Hetterich[2]
[1] IMITec, Meilen, Switzerland; [2] DEKRA Visatec, Sulzberg, Germany

09:35 **Th.2.A.5**

Accubot – a precision Robot NDT Kinematics for several modalities
W. Haase[1], T. Gramberger[1]
[1] Fill, Gurten, Austria

09:40 Break

Th.3.A

PLENARY TALK | NDT AND ADDITIVE MANUFACTURING | *H. Heuer*

10:15 **Th.3.A.1**

Microstructure and residual stresses in AM metallic parts: Do we know what we do not know?
G. Bruno[1]
[1] BAM, Berlin, Germany

Th.4.A

NDT AND ADDITIVE MANUFACTURING (Short Presentations) | *H. Heuer*

11:00 **Th.4.A.1**

Quality assurance of additively manufactured alloys for aerospace industry by non-destructive testing and numerical modeling
M. Awd[1], S. Siddique[1], J. Johannsen[2], T. Wiegold[1], S. Klinge[1], C. Emmelmann[2], F. Walther[1]
[1] TU Dortmund, Germany; [2] Fraunhofer IAPT, Hamburg, Germany

11:05 **Th.4.A.2**

Utilising Advanced Computed Tomography as NDT Technique in Additive Manufacturing
J. Lübbehüsen[1], G. Zacher[1]
[1] GE Sensing & Inspection Technologies, Wunstorf, Germany

11:10 **Th.4.A.3**

Computed Tomography in NDT and Metrology for Additively Manufactured Aerospace Components
N. Achilles[1], G. Mäurer[1], J. Robbins[2]
[1] YXLON International, Hamburg, Germany; [2] YXLON International, Cuyahoga Falls, USA

Room Frauenkirche 1+2

11:15 Th.4.A.4

Inline Monitoring of Material Parameters in Additive Manufacturing by Laser Speckle Photometry
U. Cikalova [1], B. Bendjus [1]
[1] Fraunhofer IKTS, Dresden, Germany

11:20 Th.4.A.5

Laser generated narrowband Lamb waves for in-situ inspection of additively manufactured components
G. Davis [1], P. Rajagopal [1], K. Balasubramaniam [1], S. Palanisamy [2], R. Nagarajah [2]
[1] Indian Institute of Technology Madras, Chennai, India; [2] Swinburne University of Technology, Melbourne, Australia

12:00 Lunch

Room Frauenkirche 1+2

Th.5.A
WORKSHOP ROBOTICS IN NDT

W. Prosser

13:00

Discussion on Short Presentations of Session Th.2.A
„Robotics in NDT“

14:40 Break

Room Blaues Wunder 1+2

Th.5.B
STUDENT ACTIVITIES IN NDT IN AEROSPACE (Student Session)
C. Boller

Th.5.B.1 13:00

Local Acoustic Resonance Spectroscopy: An Escalation Approach for Fast Non-Destructive Testing
P. Jatzlau [1], C.U. Große [1]
[1] TU München, Germany

Th.5.B.2 13:20

Simulation Based Key Performance Indicator Determination in Guided Wave Monitored Metallic Patched Repairs
A. Asokkumar [1], R. Sridaran Venkat [2], C. Boller [2]
[1] Dresden International University, Germany; [2] Universität des Saarlandes, Saarbrücken, Germany

Th.5.B.3 13:40

Guided Wave Monitoring of a Riveted Metallic Patched Repair Using a Model Based Approach
H. Mohd Noor [1], C. Dürager [2], R. Sridaran Venkat [3], C. Boller [1,3]
[1] Dresden International University, Germany; [2] IMITec, Meilen, Switzerland; [3] Universität des Saarlandes, Saarbrücken, Germany

Th.5.B.4 14:00

Methods and Options in Analysing Big Amounts of Data in NDT
A. Lozak [1], C. Boller [1]
[1] Universität des Saarlandes, Saarbrücken, Germany

Discussion 14:20

How to raise conference attraction for students?

Room Goldener Reiter

Th.5.C
ULTRASONICS 1 (Technical Session)
B. Köhler

Th.5.C.1 13:00

Detection of delamination and impact damage in multilayered lightweight materials
T. Gautzsch [1], A. Bodi [1], M. Lucas [2], R. Steinhausen [3], M. Kiel [3]
[1] SONOTEC, Halle (Saale), Germany; [2] SONOTEC US, Islandia, New York, USA; [3] Forschungszentrum Ultraschall, Halle (Saale), Germany

Th.5.C.2 13:20

Detection of porosity and water inclusion in carbon fiber composites using a novel laser-based air-coupled ultrasound method with optical microphone
B. Fischer [1], N. Panzer [1], W. Rohringer [1]
[1] XARION Laser Acoustics, Wien, Austria

Th.5.C.3 13:40

SITAU TRITON: High Speed Ultrasound Inspection System for Complex Geometry Composites
M. Acebes [1], R. Gonzalez Bueno [2], R. Delgado de Molina [1], A. Morales [3], J.F. Cruza [2], I. Gauna [1], R. Giacchetta [2]
[1] Tecnitest Ingenieros, Madrid, Spain; [2] DASEL, Madrid, Spain; [3] Aciturri Aeronáutica S.L.U., Spain

Th.5.C.4 14:00

Coherent Adaptive Focusing Technology for the Inspection of Variable Geometry Composite Material
A. Lamarre [1], E. Grondin [1]
[1] Olympus Scientific Solutions Americas, Quebec City, Canada

Th.5.C.5 14:20

Combined characterisation of residual stress and cold work at surface treated aeroengine materials by Rayleigh wave refraction
B. Köhler [1], J. Kissing [2], S. Gartsev [1], M. Barth [1], M. Rjelka [1], J. Bamberg [3], R. Hessert [3]
[1] Fraunhofer IKTS, Dresden, Germany; [2] TU Darmstadt, Griesheim, Germany; [3] MTU Aero Engines, München, Germany

Room Frauenkirche 1+2

Th.6.A

WORKSHOP NDT AND ADDITIVE MANUFACTURING

G. Bruno

15:10

Discussion on Short Presentations of Session Th.4.A
„NDT and Additive Manufacturing“

Room Blaues Wunder 1+2

Th.6.B

EU PHD PROGRAMME „NDT ON AIR“ (Special Session)

H. Pfeiffer

Th.6.B.1 15:10

NDTonAIR: Training Network in Non-Destructive Testing and Structural Health Monitoring of Aircraft structures

S. Amato[1], A. Ba[2], H. Chebbi[3], S. Gartsev[4], Y. Kim[4], H. Malekmohammadi[5], M.K. Rizwan[5], T. Seresini[6], M. Stamm[7], S. Sunetchiieva[6], J. Vyas[8], S. Waters[9], Q. Yi[10], B. Yilmaz[8], A. Zitoun[11], A. Angulo[11], G. Berthiau[2], P. Burgholzer[9], P. Burrascano[5], S. Dixon[1], C. Glorieux[6], D.A. Hutchins[1], E. Jasiuniene[8], R. Kazys[8], B. Köhler[4], S. Laureti[5], L. Mazeika[8], H. Pfeiffer[6], D. Premel[3], C. Reboud[3], J. Reynaert[7], M. Ricci[12], S. Soua[11], G.Y. Tian[10], M. Wevers[6]

[1] University of Warwick, Coventry, UK; [2] Université de Nantes, France; [3] CEA LIST, Gif-sur-Yvette, France; [4] Fraunhofer IKTS, Dresden, Germany; [5] University of Perugia, Italy; [6] KU Leuven, Belgium; [7] Brussels Airlines, Zaventem, Belgium; [8] Kaunas University of Technology, Kaunas, Lithuania; [9] RECENDT, Linz, Austria; [10] Newcastle University, UK; [11] TWI, Cambridge, UK; [12] University of Calabria, Rende, Italy

Th.6.B.2 15:30

Quantitative evaluation of delamination depth in CFRP based on pulse compression eddy current pulse thermography

Q. Yi[1], G.Y. Tian[1], J. Zhu[1], S. Laureti[2], H. Malekmohammadi[2], M. Ricci[2]

[1] Newcastle University, UK; [2] University of Perugia, Italy

Th.6.B.3 15:50

Improved shear horizontal wave piezoelectric fiber patch (SH-PFP) for structural health monitoring applications

Y. Kim[1], B. Köhler[1]

[1] Fraunhofer IKTS, Dresden, Germany

Th.6.B.4 16:10

About acoustic detection of ice in the fuel aircraft tanks

M. Stamm[1], H. Pfeiffer[2], J. Reynaert[1], M. Wevers[2]

[1] Brussels Airlines, Zaventem, Belgium; [2] Katholieke Universiteit Leuven, Heverlee, Belgium

Th.6.B.5 16:30

Applying features of nonlinear ultrasonic modulation for defect detection in vibrating structures

S. Sunetchiieva[1], H. Pfeiffer[1], S. Creten[1], C. Glorieux[1], M. Wevers[1]

[1] Katholieke Universiteit Leuven, Heverlee, Belgium

Room Goldener Reiter

Th.6.C

ULTRASONICS 2 (Technical Session)

K. Bente

Th.6.C.1 15:10

Airborne testing of molded polymer compounds

D. Kotschate[1], S. Wendland[1,2], M. Gaal[1]

[1] BAM, Berlin, Germany; [2] TU Ilmenau, Germany

Th.6.C.2 15:30

Ultrasonic Volume Scanning of Forged Materials with a Prefocused Annular Phased Array Probe

M. Barth[1], T. Beggerow[2], M. Rjelka[1], F. Schubert[1], B. Köhler[1], W. Spruch[2], M. Bron[3]

[1] Fraunhofer IKTS, Dresden, Germany; [2] Büro für Technische Diagnostik, Brandenburg, Germany; [3] ScanMaster Systems (IRT), Rosh Ha'ayin, Israel

Th.6.C.3 15:50

New Developments and applications for Air Coupled Ultrasonic Imaging Systems

A. Szewieczek[1], W. Hillger[1], L. Bühling[1], D. Ilse[1]

[1] Ingenieurbüro Dr. Hillger, Braunschweig, Germany

Th.6.C.4 16:10

Air-coupled ultrasonic ferroelectret transducers with additional bias voltage for testing of composite structures

M. Gaal[1], F. Schadow[1], D. Nielow[1], V. Trappe[1]

[1] BAM, Berlin, Germany

Th.6.C.5 16:30

NUTHIC: Non-Contact Ultrasound Inspection Machine of Highly Integrated Composite Parts

R. Giacchetta[1], J.F. Cruza[1], R. Taneja[2]

[1] DASEL, Madrid, Spain; [2] Innotecuk, Cambridge, UK

17:30 Guided tour through the historic centre | **19:00** Banquet at restaurant „Pulverturm“

Room Frauenkirche 1+2

Fr.1.A
APPLICATIONS
(Technical Session)
A. Güemes

08:30 – Fr.1.A.1
Radome Inspection with Terahertz Waves
J. Jonuscheit[1]
[1] Fraunhofer ITWM, Kaiserslautern, Germany

08:50 – Fr.1.A.2
Crack detection on aerospace composites by means of photorefractive interferometry
T. Seresini[1], *X. Jichuan*[2], *M. Wevers*[1], *H. Pfeiffer*[1], *C. Glorieux*[1]
[1] Katholieke Universiteit Leuven, Heverlee, Belgium; [2] NJU, Nanjing, China

09:10 – Fr.1.A.3
On detecting kissing bonds in adhesively bonded joints using electric time domain reflectometry
P.J. Steinbild[1], *R. Höhne*[1], *R. Füßel*[1], *N. Modler*[1]
[1] TU Dresden, Germany

09:30 – Fr.1.A.4
Determination of the nonlinear elastic constants in a surface treated layer for aero-engine disk residual stress measurement
S. Gartsev[1], *M. Rjelka*[1], *B. Köhler*[1], *A. Mayer*[2]
[1] Fraunhofer IKTS, Dresden, Germany; [2] HS Offenburg, Gengenbach, Germany

09:50 – Fr.1.A.5
The Use of Pulse Compression Technique in Non-Destructive Testing: A Review
M.K. Rizwan[1], *H. Malekmohammadi*[1], *S. Laureti*[1], *P. Burrascano*[1], *D.A. Hutchins*[2], *G.Y. Tian*[3], *J. Zhu*[3], *Q. Yi*[3,] *M. Ricci*[1]
[1] University of Perugia, Terni, Italy; [2] University of Warwick, Coventry, UK; [3] Newcastle University, UK

Room Blaues Wunder 1+2

Fr.1.B
DIFFERENT METHODS
(Technical Session)
G. Mayr

08:30 – Fr.1.B.1
Impact of UV LED Technology to the Fluorescent Magnetic Particle Inspection (MPI) and Penetrant Inspection (FPI)
M. Breit[1]
[1] SECU-CHEK, Kleinblittersdorf, Germany

08:50 – Fr.1.B.2
Acoustic Shearography for Defect Detection in Aircraft Materials
L. Zhang[1], *H. Liu*[1], *M. Liu*[2], *Y.F. Chen*[1], *C.Y. Tan*[1], *S. Guo*[1], *F. Cui*[2], *Z.Z. Wong*[1]
[1] IMRE, Singapore; [2] Institute of High Performance Computing, Singapore

09:10 – Fr.1.B.3
Phase contrast tomography: a powerful tool for advanced NDT and 3D material characterisation
S. Terzi[1], *G. Bravais*[1], *O. Guiraud*[1], *H. Labriet*[1], *A. Autret*[1], *S. Berujon*[2], *B. Fayard*[1]
[1] NOVITOM, Grenoble, France; [2] ESRF, Grenoble, France

09:30 – Fr.1.B.4
Measurement of thermal diffusivity of solids and thermal resistance of cracks using Flying Spot Thermography
A. Oleaga[1], *A. Bedoya*[1], *J. Gonzalez*[1], *A. Mendioroz*[1], *C. Pradere*[2], *J.C. Batsale*[2], *A. Sommier*[2], *J. Malvaut*[3], *V. Delos*[2], *M. Romano*[4], *T. Bazire*[3], *A. Salazar*[1]
[1] University of the Basque, Bilbao, Spain; [2] I2M-TREFLE, Talence, France; [3] KUKA Systems Aerospace, Le Haillan, France; [4] EPSILON-Groupe ALCEN, Talence, France

09:50 – Fr.1.B.5
Characterization of open and kissing vertical cracks using vibrothermography
A. Mendioroz[1], *R. Celorrio*[2], *A. Cifuentes*[3], *K. Martinez*[3], *A. Salazar*[1]
[1] University of the Basque, Bilbao, Spain; [2] University of Zaragoza, Spain; [3] Instituto Politécnico Nacional, Mexico City, Mexico

Room Goldener Reiter

Fr.1.C
STRUCTURAL HEALTH MONITORING
(Technical Session)
M. Gaal

08:30 – Fr.1.C.1
Guided wave-Gaussian mixture model based damage monitoring method under varying load conditions
F. Fang[1], *L. Qiu*[1], *S. Yuan*, *Y. Wang*[1]
[1] Nanjing University of Aeronautics and Astronautics, Nanjing, China

08:50 – Fr.1.C.2
Non-uniform spatial sampling patterns for local wavenumber-based damage evaluation
J. Spytek[1], *P. Rusin*[1], *K. Dziedziech*[1], *L. Pieczonka*[1], *L. Ambrozinski*[1]
[1] AGH University of Science and Technology, Krakow, Poland

09:10 – Fr.1.C.3
Monitoring of structures and systems of aircraft by highly non-linear sensing devices
H. Pfeiffer[1], *S. Sunechiieva*[1], *H. Sekler*[2], *D. Backe*[3], *M. Wevers*[1]
[1] Katholieke Universiteit Leuven, Heverlee, Belgium; [2] Lufthansa Technik, Frankfurt am Main, Germany; [3] PFW Aerospace, Speyer, Germany

09:30 – Fr.1.C.4
A Bayesian Probabilistic Approach for Damage Imaging Utilizing Response at Vibration Nodes
T. Huang[1], *B. Hao*[1], *K.-U. Schröder*[1]
[1] RWTH Aachen University, Aachen, Germany

09:50 – Fr.1.C.5
Tailored Embeddable Sensor-Actuator Layers for CFRP Aerospace Structures
S. Nitschke[1], *A. Hornig*[1], *A. Winkler*[1], *N. Modler*[1]
[1] TU Dresden, Germany

10:30 Technical visits

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Ensuring the structural integrity specific structural analyses and adapted non-destructive inspections are required. IABG provides expert consulting concerning suitable measures for sustaining structural integrity and offers qualified technical personnel to perform structural inspections.

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We carry out inspections to meet our customers' unique needs as per requirements in compliance with the regulations by the authorities. We perform:

- NDT services for all requirements of structural testing
- Development and validation of NDT procedures
- Consultancy and quality assurance for the development and manufacturing of structures
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Our structural health monitoring expertise encompasses:

- Validation, verification and qualification of SHM sensor technologies
- Implementation and application of various SHM sensor technologies
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IABG **NDT Hotline**

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P1 A new non-contact measuring method for the evaluation of the curing status of glued lightweight components based on ultrasound

G. Schober [1], P. Pfeffer
[1] SKZ – Das Kunststoff-Zentrum, Würzburg, Germany

P2 Multiple-Flash Shearography – a New NDT Method for Reducing Thermal Stresses During the Inspection Process

P. Pfeffer [1], L. Wachter [1], D. Hoffmann[1], M. Bastian[1], G. Schober [1]
[1] SKZ – Das Kunststoff-Zentrum, Würzburg, Germany

P3 Deconvolution of laser-ultrasound signals for suppression of surface wave artifacts in high resolution imaging of composites

J. Mrówka [1], L. Ambrozinski [1], M. O'Donnell [2], I. Pelivanov [2]
[1] AGH University of Science and Technology, Krakow, Poland;
[2] University of Washington, Seattle, USA

P4 3D visualization of ultrasonic scanned data in the context of test methods for the approval of civil aeronautical components

A. Heinze [1]
[1] IMA Dresden, Germany

P5 Numerical study of laser-ultrasound excitability using multiphysics finite-difference approach

P. Pyzik [1], A. Ziaja-Sujdak [1], L. Ambrozinski [1]
[1] AGH University of Science and Technology, Krakow, Poland

P6 The thermoacoustic effect and its application in air-coupled testing of composite structures

K. Bente [1], D. Kotschate [1], S. Wendland [1,2], M. Gaal [1]
[1] BAM, Berlin, Germany; [2] TU Ilmenau, Germany

Abstracts

We.1.A | PLENARY TALK | NUMERICAL SIMULATION IN NDT

We.1.A.1 09:30

NDE & SHM computational tools for enhanced diagnostics and reliability assessment

P. Calmon [1], *E. Demaldent* [1], *S. Leberre* [1], *O. Mesnil* [1], *C. Reboud* [1]
[1] *CEA LIST, Gif-sur-Yvette, France*

Since now simulation has proven to be a powerful tool for the design and demonstration of performance of inspections for many years. However, the capability and the way of using simulation have significantly evolved accompanying new needs from industry. Over the years efforts are put on forwards models in order to increase the accuracy of the predictions in the most challenging situations. Alternative approaches (semi-analytical, FEM, hybrid models…) are now available which addresse a wide range of complex cases. Accompanying this progress new needs have emerged which imply intensive and/or ultrafast computations. On the one hand, a more comprehensive handling of uncertainties motivates statistical estimation of reliability and accuracy. On the other hand, new techniques emerge which imply to handle sophisticated data processing (UT array imaging, GW tomography, CT, etc), adaptive algorithms or robotized trajectories. These techniques require efficient and real-time computational tools embedded in complex systems and processes.
The development of meta-modelling strategies combined with machine-learning make fulfillment of those needs today in miscellaneous contexts. Simulation-based sensitivity analysis allows for the relative influence of application parameters on the performance of the inspection to be accounted. Inverse models are used to automate or enhance diagnostics. All these features are even amplified in the case of SHM applications where the automation of diagnostics is central. This presentation will give an overview of the activities being carried out at CEA related to these issues.

We.2.A | NUMERICAL SIMULATION IN NDT (Short Presentations)

We.2.A.1 10:15

Simulation of a fiber-optic based SHM system. Application to a bonded repair patch

A. Güemes [1], *M.E. Reyes* [1], *J. Garcia-Ramirez* [1], *C. Aguilar* [1], *A. Fernandez-Lopez* [1]
[1] *Universidad Politecnica de Madrid, Spain*

Simulation tools are very useful to understand and optimize NDT systems, and particularly the SHM systems. An algorithm has been proposed to quantify the damage detection capability of a fiber optic sensor network, with a finite number of strain measurements. A damage index is obtained by simulation, dependent of the damage size and position, and the number and distribution of sensors, and also of the noise of the signals; by repeating the simulation under random noise, a POD (Probability of Detection) can be calculated. The analysis is applied to a simple representative experiment, a bonded repair patch, under mechanical and thermal loads.

We.2.A.2 10:20

Development of multi-physics multi-scale modelling platform for CFRP composites using inductive thermography techniques

A. Ba [1], *B. Yilmaz* [2], *H.K. Bui* [1], *E. Jasiuniene* [2], *G. Berthiau* [1]
[1] *IREENA, Saint Nazaire, France;* [2] *Kaunas University of Technology, Kaunas, Lithuania*

Due to their excellent mechanical performance, the use of carbon fiber composites has been growing in recent decades. However, the large-scale development of these materials depends on the improvements of the processes during the various stages of their whole life cycle (producing, forming, assembly, inspection, recycling). At various stages of the life cycle of the material, non-destructive testing (NDT) methods can be used to characterize the health state of the material. They play a vital role in the quality control and risk management. The Induction Thermography is significantly promising NDT technique for inspection of composites and it based on the measurement of eddy current thermal effects. The development of these methods requires multiphysics electromagnetic – thermal modelling. The developed models will deal with some numerical issues concerning thin regions of strong anisotropy and the multiscale geometries. In this paper, we develop a FEM coupled electromagnetic-thermal model in order to investigate the detectability of metal foil incorporate on the interface of three layer composite-adhesive bond.

We.2.A.3 10:25

Simulation-supported Analysis of Complex Radiographs

N. Brierley [1]
[1] *The Manufacturing Technology Centre, Coventry, UK*

The analysis of radiographic images acquired for samples of complex geometry (such as those enabled by additive manufacturing techniques), where the imprint of the sample's geometric complexity in the radiograph is likely to undermine the ability to identify defect indications, is very challenging. An algorithm has been developed to assist in such circumstances, exploiting knowledge of the component geometry and approximate inspection configuration to generate a simulated baseline image with which a quantitative comparison can be conducted – in principle, allowing the geometric complexity to be subtracted out. This technique however requires the simulation to be accurately calibrated to the experimental configuration, necessitating the use of a numerical optimisation to fit the simulation parameters. As a by-product, the parameters of the imperfectly specified experimental set-up are recovered. The algorithm design is described, followed by results from increasingly complex test problems that illustrate the value of the approach.

We.2.A.4 10:30

NOVI-SIM: A new fast simulation tool for X-ray computed tomography testing

A. Autret [1], *G. Bravais* [1], *O. Guiraud* [1], *B. Fayard* [1]
[1] *NOVITOM, Grenoble, France*

X-ray computed tomography (CT) is a powerful imaging technique that has proven to be an effective tool for non-destructive 3D inspection. Nowadays, it is more and more employed as a standard characterisation method in R&D applications as well as a mean of control in production line. However, since X-ray CT acquisitions are time consuming and expensive, when compared to more classical NDT tools, its usage is still rather limited.
The image quality of a CT scan depends on many acquisition parameters and should be adapted to each object analyzed. The parameters

are often estimated based on the experience of the operator and then adjusted if the experimental result is not fully satisfactory. The procedure can be time consuming for non-experienced users and unusual or complex samples. In this context a simulation tool for tomography (and radiography) control is a key asset. It allows for calculating the best experimental parameters and reducing the acquisition time while optimizing the data quality.
Based on its experience of synchrotron tomography and interaction of X-rays with matter, Novitom has developed a new simulation tool for X-ray tomography: NOVI-SIM. It uses a mixed approach (ray-tracing and wave optics) for fast execution and simulation of a large variety of sources, several detectors and contrast modes: absorption, phase contrast, single distance phase estimation… The calculated images include a model for noise propagation and are fully representative of those experimentally obtained. The graphical interface allows for an intuitive use of the software and an easy adjustment of the parameters: exposure time, source type and power, type and thickness of filters, sample composition and geometry, noise level in the detector… The software is thus very valuable for operators of laboratory CT scanners and R&D engineers using tomography for NDT or material evaluation.
After a brief description of the physical approaches used to perform fast simulation of image formation in radiography and tomography, the presentation will focus on the comparison of the output results with respect to experimental results acquired on phantom objects and challenging parts.

We.2.A.5 **10:35**

Semi-analytical modeling of eddy current inspection of stratified and homogenized composite materials

H. Chebbi [1], *D. Prémel* [1]
[1] *CEA LIST, Gif-sur-Yvette, France*

Composite materials are increasingly used in the aeronautic industry to reduce the weight of aeronautical structures. Therefore, the inspection of these complex materials for the detection of potential defects is a major challenge due to their complex physical behavior, to ensure their good performance in different operations.
Within the Department « Imagerie Simulation pour le Contrôle » (DISC) from the institute CEA LIST, this thesis work is part of the European project NDTonAir (European Training Network in NDT and SHM of Aircraft structures). This project addresses several issues of NDT in the aeronautic field involving different methods of control based on several testing technics as ultrasonic waves, electromagnetic waves or infrared thermography.
We are interested in the interaction of an eddy current sensor with a composite material affected by a defect such as a delamination or a fiber breakage. The goal is to develop a robust, fast and accurate numerical model based on a semi-analytic approach to optimize electromagnetic testing methods for this type of material. This model will be implemented into the commercial software CIVA developed by CEA LIST.
In the first part of this thesis, we consider the computation of the EM field within a material without any defect. Therefore we assume in a preliminary step that each ply in the stratified material is homogenized. Thus, the modeling problem amounts to consider a homogeneous anisotropic media considering that an eddy current sensor is scanning the top surface of a planar specimen. The material is characterized by a conductivity tensor (axial or biaxial form) in each layer corresponding to the preferred orientation of the fibers. The semi-analytic model is based on writing Maxwell's equations in the Fourier domain in order to obtain a modal expansion of the EM field in each layer. The unknown coefficients are evaluated by applying boundary conditions at each interface. To address the multi-layered structure, a global S-matrix algorithm is implemented since it provides a stable behavior. Considering numerical experiments, the numerical data provided by the model will be compared to other simulated data obtained by a FE commercial software.

We.2.A.6 **10:40**

Guided Waves Simulation Capabilities in Isotropic and Anisotropic Structures in View of Structural Health Monitoring Applications

R. Sridaran Venkat [1], *M. El Bakouri* [1], *A. Ernst* [1], *C. Boller* [1]
[1] *Universität des Saarlandes, Saarbrücken, Germany*

Guided waves is a means very much sought in the context of Structural Health Monitoring (SHM). In view of a structure's damage tolerance and hence light weight potential a reliable SHM system has to be configured. Compared to classical NDT where the options of data sampling are virtually endless, SHM is fixed to a network of sensors and possibly also actuators, which hence has to be optimum. To determine this optimum, numerical simulation is possibly the best option. Specifically when a structure is designed damage tolerant the allowable size and location of a damage must be known. As a consequence guided wave propagation in a damage tolerant structure can be simulated and since the difference in the signals between a damaged and an undamaged condition is the key information to be 'harvested' by a sensing system it is this difference which has to be identified in view of configuring the optimum sensor network for monitoring. There are various bases on how such differential signals can be determined, being not just limited to the guided waves' amplitude and phase only but being also extended to so called damage indices, which have been continuously developed over the years to specifically retrieve features from guided wave signals. The paper to be presented will initially provide examples on how to identify such optimum sensor networks through simulation with regard to isotropic materials based on what is called 'differential imaging' before moving to anisotropic materials such as CFRP, where numerical simulation capabilities are quickly reaching limitations in case no specific measures can be taken, which will be briefly discussed as well.

We.3.A | PLENARY TALK | NDT AND BIG DATA

We.3.A.1 **11:15**

From data-driven NDT of systems to BIG DATA-based modeling

D. Söffker [1]
[1] *Universität Duisburg-Essen, Duisburg, Germany*

The world is changing. New approaches from the IT-field allow engineers to replace well experienced first-principle-based modeling by data-driven approaches to conclude to final statements like: system healthy yes/no? or fault type no. n exists yes/no? More or less the same approaches allow connections to be built between variables from different fields and therefore complex modeling like: build relations between systems usage and remaining useful lifetime, and economical parameters from this field (industry 4.0). Using unstructured data everything seems to be connectable (BIG DATA).
Using practical examples the keynote will introduce into NDT-related tasks like fault detection and isolation of composites and remaining lifetime estimation of technical systems being in use. The related filtering of measured AE-data as well as related supervised classification approaches are introduced as an example for a NDT technique as well as briefly compared to classical NDT approaches. Using non-supervised approaches within this BIG DATA world new insights and relations can be found defining not only a new quality of modeling but also extending the view to system limitations and relations. Advantages and disadvantages will be discussed.

We.4.A | NDT AND BIG DATA (Short Presentations)

We.4.A.1 12:00

Incorporating Inductive Bias into Deep Learning: A Perspective from Automated Visual Inspection in Aircraft Maintenance

V. Ewald[1], X. Goby [1], H. Jansen[1], R. Groves[1], R. Benedictus[1]
[1] Delft University of Technology, Netherlands

The near-term artificial intelligence, commonly referred as ‘weak AI’ in the last couple years was achieved thanks to the advances in machine learning (ML), particularly deep learning, which has currently the best in-class performance outperforming other machine learning algorithms. In the deep learning framework, many natural tasks such as object, image, and speech recognition that were impossible to be performed by classical ML algorithms in the previous decades can now be be done by typical home personal computer.
Deep learning requires large amount of data that has to be rapidly collected (also known as ‘big data’) in order to create robust model parameters that are able to predict future occurrences of certain event. In some domains, a large dataset such as CIFAR-10, MNIST, or Kaggle exist already. However, in many other domains such as aircraft visual inspection, such a large dataset is not easily available and this clearly restricts deep learning to perform well to recognize material damage in aircraft structures.
As many computer science researchers believe, we also think that in order to achieve a performance similar to human-level intelligence, AI could and should not start from scratch. Introducing an inductive bias into deep learning might be one solution to achieve that human-level intelligence. In this paper, we give an example how to incorporate aerospace domain knowledge into the development of deep learning algorithms. We performed a relatively simple procedure: we conducted fatigue testing of an aluminum plate that is typically used in aircraft fuselage and build a deep convolutional neural network that classifies crack length according to crack propagation curve obtained from fatigue test. The results of this network are then compared to the results of the same network that was not injected by domain knowledge.

We.4.A.2 12:05

PCRT Resonance Solutions for Additive Manufacturing

T. Köhler[1]
[1] Vibrant, Elz, Germany

Additive Manufacturing (AM) processes are being used increasingly in aerospace to produce even critical components to the detriment of legacy manufacturing systems like casting, forging or machining. Yet quality assurance tools have to catch up to the challenges posed by these new manufacturing methods: process variation, potential manufacturing defects, long-term stability and capability… all are essential concepts still insufficiently understood that need reliable solutions.
Process Compensated Resonance Testing (PCRT) offers Resonance Solutions to a variety of AM challenges. PCRT can:

- Monitor component consistency to provide manufacturing process control data, correlating final component attributes to process parameters, material (powder) batches, and machine-to-machine variation. PCRT’s precise, repeatable part-level data feed big data analytics, and combine with manufacturing and operational data to provide insight not available with other inspection methods.
- Monitor the consistency of critical processing operations such as hot isostatic pressing (HIP) and heat treatment (HT). These operations are critical to the confidence in AM components and manufacturers need certainty that they affect all components similarly.
- Validate models and quantitatively compare legacy and reverse-engineered components. Resonance is an integrity fingerprint to quantitatively verify that what was originally designed has been actually printed.

Emerging PCRT studies of AM parts show detection of porosity-related defects, powder supply variation, build process variation, retained powder and correlation to performance testing. PCRT assures part quality at every state, from verifying that the part printed is the part designed, to tracking the consistency of each and every part produced.
In addition, PCRT is production-line ready, capable of testing parts in seconds, integrated with parts-handling automation, and providing Pass/Fail results without highly trained inspectors.
All these turn PCRT into a powerful tool for the AM community to increase confidence in the manufacturing and inspection environment to allow them to take advantage of its tremendous potential.

We.4.A.3 12:10

Non-destructive testing for detection, localization and quantification of damage on composite structures for composite repair applications

P. Shrestha[1], R.M. Groves[1]
[1] Delft University of Technology, Netherlands

Composite materials are being widely used for manufacturing aircraft components due to their superior material properties such as high strength, light weight, corrosion resistance, etc. However, compared to isotropic materials, composite materials exhibit complex damage characteristics. Moreover, when the composite material is impacted by a foreign object they are prone to barely visible impact damages such as delamination, matrix cracking, etc. Since composite materials are being increasingly used in aircraft component production the likelihood of composite damage occurrence during aircraft operation increases as well. Therefore, it is crucial to address the challenges associated with detecting composite damage and performing composite repairs. The focus of this research is the development of automated depot repair technology for composite structures, which combines; non-destructive testing (NDT) for damage size determination, damage removal by milling, repair by adhesive bonding of a repair patch and NDT for post repair assessment. In this study, a damaged curved CFRP panel with dimensions of 1.3 × 1.3 m was used for the development of algorithms for automated composite repair process. NDT using a laser line scanner was performed to acquire the composite panel’s surface data, to assess features of the panel such as its shape, visible damage, etc., and the thermographic inspection was done to assess the extent and location of internal damage. Algorithms were developed to perform data fusion of the sensor data; a) to detect, localize, quantify and visualize the damage on the composite panel, through analysis of gradient changes between defined local sections of the panel, b) to generate a 3D model of the repair region based on the surface geometry and with design considerations that ensures the optimal structural integrity of the repaired panel, and c) to output suitable computer-aided design (CAD) files which can be imported to the milling tool, to perform the damage removal, and the CAD tool, to fabricate the repair patch. Finally, after the composite panel undergoes the milling and repair process, NDT inspections will be performed to ensure its safety and integrity.

We.4.A.4 **12:15**

Simultaneous multi-frequency dielectric measurement technique for fast curing reactions

S. Geinitz [1], M. Eberhardt [1], D. Walser [1], D. Grund [1], B. Hollaus [2], A. Wedel [1]
[1] Fraunhofer IGCV, Augsburg, Germany; [2] MCI, Innsbruck, Austria

Dielectric Analysis has proven to be an important tool in various industry and research sectors. But new developments, in particular, highly reactive thermosetting resins and adhesive systems with UV radiation activation reveal limitations of commercially available measurement systems. These systems achieve dynamics which reach a conversion rate of up to 90% in less than one second.
In dielectric analysis the material properties are determined by measuring the reaction current and the corresponding phase angle as a result of an input voltage signal. By determining the complex impedance and phase angle, different material properties, such as relative permittivity or ionic conductivity, can be calculated to evaluate the material conditions. In order to be able to adequately evaluate manufacturing processes and curing processes, a broadband measurement of the electric variables mentioned before is necessary. Unfortunately, commercially available systems achieve spectroscopic results only by the use of a frequency sweep, which is not applicable to monitor properly the behaviour for highly dynamic UV-curable resins. Likewise, this is similar for rheological measurement methods, which are equally limited in their measurement point rate and dependent on the applied excitation frequency.
To attain sufficient resolution in the time domain even for highly reactive systems, a system which offers the possibility of spectroscopic examinations combined with an extremely high measuring point density was developed. The actual simultaneous recording of all applied frequencies (up to 20 different ones) reduces significantly the measurement time per measurement point. Thus creating the potential to analyze extremely dynamic reactive systems in detail even at low frequencies. Limits in speed are only given by the lowest frequency monitored. In addition, the measurement points are recorded time-synchronously for all frequencies, allowing immediate spectroscopic analysis. Overall, this opens up the potential, especially in the area of UV-curing highly reactive resin systems, both in the laboratory and in the process environment, to realize material characterization and condition monitoring.

We.4.A.5 **12:20**

Comparison of Machine Learning Algorithms for NDT in Aerospace

C. Tschöpe [1], F. Duckhorn [1], M. Wolff [2]
[1] Fraunhofer IKTS, Dresden, Germany; [2] Brandenburg University of Technology Cottbus-Senftenberg, Cottbus, Germany

In the context of component inspection and structural health monitoring in aerospace, great amounts of data are generated which have to be evaluated and interpreted. Algorithms of machine learning and artificial intelligence are ideally suited for that purpose. Fraunhofer IKTS has longstanding and extensive experiences with acoustic diagnosis and analysis of technical signals. We present a comprehensive study on a large amount of data for active ultrasonic testing of airplane components. Beside good parts, the recordings include material damages like impacts or cracks of several characteristics. We performed a comparison between classifiers, including the ubiquitous deep and convolutional neural networks and "conventional" classifiers like support vector machines or statistical approaches. The ultimate goal of our investigations is to construct mobile inspection systems.

We.4.A.6 **12:25**

Utilise AI for NDT Inspection

P. Chow [1]
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Everyone is talking about machine learning (ML), deep learning (DL), and artificial intelligence (AI). In the consumer space it is used in many applications for our daily activities and conveniences. This technology marks a step change in productivities in virtually all areas of our lives. In this article we leverage the technology for Non-Destructive Testing (NDT) inspection. Today, virtually all manufactured products are inspected manually from visual (surface) to ultrasonic (internal) in quality control processes. NDT is one challenge and opportunity that could leverage AI for efficiency and productivity, and the potential of innovation in the manufacturing processes. In this presentation we will present real-world inspections achieved, including a customer case in wind turbine blade manufacturing.

We.5.B | PROGNOSTICS & HEALTH MANAGEMENT (Special Session)

We.5.B.1 **14:00**

Development of a Prognostic Framework

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This contribution reports the work carried out in "Airbus Defence and Space". The prognostic field is considered nowadays a key factor; for different reasons, however, real prognostic applications are scarce in industry.
Prognostic will enable: condition-based maintenance; maintenance schedule optimization; resource utilization optimization; reconfiguration strategy implementation; extension of item useful life; mission planning optimization.
Two subjects have been investigated: 1) a tool for the synthetic generation of representative degradation trends and the development of complementary mathematical approaches for performing prognostics. For the latter, two paths are usually followed: the model-based approach and the data-based approach. However, in order to embrace all possible situations, our research has also focused on the development of a hybrid technique capable of coping with the lack of knowledge and of data. In this contribution, we will focus on the performances of the conceived data-based and hybrid approaches (a metric has been set up to quantitatively measure the approaches' performances).
For the former a Gaussian-Process formulation has been adopted; different trained models operate in parallel within an "Interactive Multiple Model" approach by leveraging a bank of Kalman filters. The Bayesian approach is utilized to assess the relevance of the different models. For the latter, a Genetic Programming technique has been adopted. The mathematical approach has been utilized to derive the process equations corresponding to different dynamic aspects of the run-to-failure data. A following adaptive stage is afterwards choosing – from a Kalman perspective – the most suitable models to perform prognostic.
The developed approaches – after being successfully tested against synthetic data – have also been applied to a real environment, related to the Remaining Useful Lifetime (RUL) estimation of the ball bearings equipping an aeronautic fan. The results gained were satisfactory and allowed us to test and validate the effective usage of the conceived prognostic approaches in a representative environment. Results have showed a comparable and satisfactory application of the prognostic approaches developed for both the synthetic and real investigations.

We.5.B.2 **14:20**

Application of a PHM-based reliability prediction for an UAV's control surface actuation system

S. Mehringskötter [1], H. Heier [1]
[1] TU Darmstadt, Germany

Unmanned Aerial Vehicles (UAVs) become more and more important for the civil sector as they foster new business models and promise cost-savings for many applications. However, the acceptance and successful integration of this new aircraft type into the existing airspace largely depends on the overall system safety. From an operator's point of view, it is therefore interesting to get a feedback on the current and future health status of flight critical systems.
Current methods used to obtain and maintain safety constraints are based on reliability and safety engineering methods, which largely rely on the statistical processing of historic failure events to estimate the mean time to failure. In addition to this, modern systems are often equipped with Fault Detection and Isolation mechanisms. While the first approach is rather static and does not consider any feedback from an individual system (i.e. the actual health state), the latter is unable to give any predictions about the expected time to failure.
With the discipline of Prognostics and Health Management (PHM) there exists an alternative approach to overcome these limitations. By assessing the actual degradation state of a system from sensor data (diagnosis) and predicting it (prognosis), the current and future health state can be estimated during flight. By further combining PHM results with conventional reliability methods, an improved prediction up to system level can be achieved.
In this paper, the application of a PHM-based system reliability prediction is described. The system under study is the control surface actuation system for a hybrid UAV. By aggregating the Remaining Useful Lifetime (RUL) estimations of all monitored components, the future health states and system capabilities become predictable. By comparing these to the mission objectives the UAV's operator gets a precise information on mission safety and is supported in the decision making process.
The applicability of this approach is shown for a representative UAV mission scenario with exemplary RUL data. This paper is considered as a contribution to the PHM research at the end of the OSA-CBM process to connect RUL predictions with the decision-making process.

We.5.B.3 **14:40**

Machine Learning based Data Driven Diagnostics & Prognostics Framework for Aircraft Predictive Maintenance

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Recent trends of Digitalization across different industries have led to generation of massive amounts of data. As a natural consequence, there is a surge in Advanced Machine Learning techniques being applied to this Big Data. Simultaneously, there has been growing needs of increased Operational Reliability, driving down Maintenance costs and increase in Safety, due to which Predictive Maintenance is quickly becoming the most important strategy across many industries, especially in Aerospace. As newer Aircrafts are being equipped with more sensors, Machine Learning based Diagnostics and Prognostics techniques are becoming increasingly popular compared to conventional approaches in developing Predictive Maintenance solutions. Building a ML based Diagnostics & Prognostics Model requires massive amount of Run-to-Fail Sensor data, but the opportunity to capture this in-service failure related data is very limited in highly reliable & safety critical aircraft platforms in comparison to other domains. To address this challenge of lack of adequate & appropriate in-service failure data, Airbus DS has developed a Simulation Framework in the roadmap of Technology development of ISHM and Predictive Maintenance. To accelerate the development of Predictive Maintenance solutions for various aircraft systems, a Data Driven Diagnostics & Prognostics Framework has been developed. This paper outlines this unique framework and its validation using the data generated from the ISHM Simulation Framework.

We.5.B.4 **15:00**

Satellite battery degradation prognostic based on data analytics and big data infrastructure

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Communication satellites are complex systems remotely operated. As it is impossible to request any measure on the system that was not plan at design phase, it is assembled with hundreds of sensors. All those sensors capture many physical variables at a sampling rate of roughly one point per minute. Representing million points per sensor over years, this is the only information satellite operator have to diagnose the behavior of their satellite.
Satellite monitoring is today supported by expert definition of processing. It requires experienced understanding of physical or chemical behind a subsystem, and this knowledge is making use of available parameters. Being the most accurate method to monitor a subsystem, it is hardly applicable to a constellation of hundreds of satellites. Lessons learnt acquired from satellite operators and airlines lead as follows: while similar or even identical product at beginning of life, due to their operating conditions, each element of a fleet or a constellation rapidly behaves differently from the others. While still comparable, they are no longer identical. Expert approach not being scalable to a whole fleet or constellation at reasonable cost and in a reasonable planning, we investigate data analytics approach to support experts.
All battery data over all Airbus E3000 platforms represent about 300 years of observation. Benefiting from repetition of operating conditions due to the orbit and sun/shadow alternation, data was split in time windows. It is then demonstrated that Out Of Limits (OOL) monitoring can't capture all variability in data. Hence a functional decomposition is proposed to capture all signals dynamic and concentrate it into a smaller set of coefficients. Benefiting from this reduced dataset, a surrogate modeling approach is then applied to capture the correlation between battery data and battery age. This modeling technique accuracy is evaluated onto a test set and demonstrates good prognostic accuracy. It can be now an additional tool provided to experts to support decision on slowing or accelerating degradation of a given satellite battery.
This modeling does not rely on any strong assumption related to subsystem knowledge. It can be applied to other subsystems. But due to the data volume accessible and leveraged through this method, we investigate distributed storage and computation techniques on a Hadoop/Spark cluster. After a benchmark of storage techniques to store our time series, data analytics calculation is performed and measured. We present here final choice of techniques and time performance of overall process to support analytics on sensor data in a big data infrastructure.

We.5.B.5 **15:20**

Data Visualisation using Augmented Reality with a Focus set on Head Mounted Displays and Collaborative Tasks

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For data analytics a proper visualisation of the data is important to provide the user a good overview and help him to find and understand relationships in the data. Furthermore, appropriate visualisations can help

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to improve the efficiency of tasks. There are a lot of different approaches for 2D as well as 3D visualisation, which can be applied to existing rich client applications. Many of these rules are applicable for augmented and virtual reality, too. But especially when head mounted displays are used additional factors have to be considered and new possibilities exist. This paper will therefore describe related work regarding 2D and 3D visualisation. Factors like perspective, performed task, ambiguity, depth cues and the general user interface are discussed. Examples will be given for map centric applications and tasks, like the perception accuracy of objects on 3D maps. Furthermore, head mounted displays are categorised. They can provide stereoscopic vision, which is essential for human's binocular vision and adds benefits for some tasks. With augmented and virtual reality new concepts for collaborative tasks could be created. This paper will provide an overview of related literature and discuss the advantages and disadvantages of augmented and virtual reality. Especially augmented reality can support collaboration which is linked to the fact that all users can see each other. After the scientific basics, a concept for a big data visualisation is explained. For air traffic control it is important to use all available information to observe and secure the airspace. Automatic dependent surveillance – broadcast (ADS-B) is now equipped at most aircraft. It can be fused with the radar sensor data to generate an air picture. Historical data could be analysed with data analytics to recognize pattern and make predictions. This helps to improve live air surveillance. For collaborative decision making an augmented reality workspace was created. It offers an ADS-B flight data visualisation in 3D on a holographic geographic information system. Due to the holographic environment multiple persons can discuss together incidents in a way as the data would physically exist.

We.5.C | COMPOSITES (Technical session)

We.5.C.1 **14:00**

Spatially resolved non-invasive strain measurement on fast rotating composite rotors

J. Lich [1], *R. Kuschmierz* [1], *T. Wollmann* [1], *A. Filippatos* [1], *M. Gude* [1], *J. Czarske* [1]
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Fibre reinforced plastics (FRP) have a high potential for the application in high performance rotors as they provide high specific tensile strength and stiffness and low density. This combination enables composite rotors to run at very high rotational speeds. However, the complex mechanical behaviour of FRP impedes accurate failure prediction of the rotors. At TU Dresden, we develop numerical simulation models to display the structural vibration behaviour of FRP rotors as a function of their rotational speed and their structural health. To validate these models, we develop and apply measurement techniques to track the vibrational behaviour of the FRP rotors and consequently their mechanical properties spatially and temporally. A rotor test rig accelerates the cylindrical specimens to rotational speeds up to 200 Hz and circumferential speeds up to 300 m/s.
We already used the Laser Doppler Distance Sensor, developed at MST, to investigate the radial expansion of rotors as a function of their rotational speed. Next, we want to measure the strain as a function of the rotor radius to enable a spatially resolved validation of the simulation models.
To measure the surface strain, we glue a holographic diffraction grating foil onto the rotor surface. A collimated laser beam illuminates the grating, which splits the beam into several diffraction orders. We analyse the diffracted beams via cross correlation in order to measure the strain and the tilt of the observed spot on the surface simultaneously. By using a conventional line scan camera, we can reach measurement rates up to 12 kHz and we are able to perform vibrational measurements and real time processing.
Contrary to conventional strain gauges, the spot of measurement does not move with the rotor. The measurement rates and the strain resolution of the proposed optical approach are low in comparison to strain gauges. However, no cables, slip rings or telemetric transmitters are necessary. Furthermore, arbitrarily many spots on the surface are measurable with a spatial resolution of under 5 mm.
We demonstrated the robustness of the sensor towards rigid body movements, like in-plane displacement, out-of-plane displacement and tilt. Now, we want to test the system on a rotating object for the first time.

We.5.C.2 **14:20**

Advanced and automatic turbine blade inspection, CT resolution optimization and error estimation in reconstructed volumes

P. Westenberger [1], *T. Lowe* [2]
[1] *Thermo Fisher Scientific, Düsseldorf, Germany;* [2] *University of Manchester, UK*

The presentation will cover in detail the challenges in fully automatic turbine blade inspection workflows. The presented workflows have been advanced by techniques established and derived from radiography in order to optimize the spatial resolution in X-ray CT and to estimate the errors in the reconstructed volumes. We will demonstrate how such techniques help to speed up the inspection process in tomorrow‘s inline inspection visions where time really matters.
The blade inspection workflow itself will cover non-destructive testing standards like robust segmentation and sub-resolution precise surface determination which are the prerequisite for actual nominal comparison against CAD and/or reference models and for retrieving precise metrology and GD&T information. Furthermore it will also give attention to rather unpredictable and more challenging inspection tasks like proper and robust detection, segmentation, metrology, and analysis of air vents in turbine blades. We will present how to solve the problem of spatially unstable air vent drill patterns as well as how to properly detect foreign objects, or under- and over-drills for each individual air vent.
The inspection workflow together with the advanced optimization techniques will help to build automatic inline inspection scenarios for the future.

We.5.C.3 **14:40**

Study of CFRP subjected to moisture and thermal treatment with the scanning laser vibrometry

P. Malinowski [1], *M. Radzienski* [1], *W. Ostachowicz* [1]
[1] *Polish Academy of Sciences, Gdansk, Poland*

Carbon fibre reinforced polymers (CFRP) usage is growing in many branches of manufacturing. Their use in passenger aircrafts is clearly visible each time a new aircraft is offered at the market by either the Airbus or Boeing. The research presented here is focused on non-destructive testing (NDT) of CFRP structural parts using the scanning laser vibrometer. There is a need for detection of cracks, delamination, barely visible impact damage (BVID), weak bonds, etc. during the manufacturing and maintenance of the CFRP structures. In this work we focus on the assessment of the surface because the quality of adhesive bonds depends on the properties of the surfaces that are joint. The structural joints should ensure safe usage of a structure, but improper preparation of the surface may lead to weak bond that cannot carry the desired load.

In reported research we employ the scanning laser Doppler vibrometry (SLDV) for assessing of the surface state. Our SLDV approach uses a surface bonded piezoelectric sensors for excitation of propagating guided waves, while the laser beam is used for sensing of the elastic waves. The investigated samples were made of CFRP subjected to external factors that may negatively influence the composite. One set of CFRP plates were treated at the elevated temperatures. The other set was subjected to moisture treatment resulting in moisture absorption. The wave vector was analysed in order to study the wave propagation in pristine samples as well as those subjected to the mentioned factors. The results show the behaviour of guided wave depending on the inspected case.

We.5.C.4 **15:00**

Virtual wave concept for thermographic porosity estimation in carbon fiber reinforced plastics

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In this work the quantitative evaluation of porosity with pulsed thermography in carbon fiber reinforced plastics is shown by applying the virtual wave concept. A virtual temperature signal is calculated by applying a local transformation to the measured temperature data. This virtual temperature is a solution of the wave equation, whereby for the parameter estimation ultrasonic test methods can be used, e. g. pulse-echo method for time-of-flight measurements. The time-of-flight determined from the virtual temperature is directly related to the thermal diffusion time. Therefore, if the specimen thickness is known the effective thermal diffusivity can be carried out. The main advantage of the virtual wave concept is the possibility to use the same data algorithm for pulsed thermography measurements in reflection as well as in transmission mode for parameter estimation. The estimation of the porosity based on the virtual wave concept matches the porosity based on the well-known Parker method very well.
Effective medium theories are used to derive the porosity from the estimated thermal diffusivity. In the first step, this model-based porosity evaluation is validated on a range of different calibrated porous CFRP specimens with different number of plies and varying porosity contents. Furthermore, porosity evaluation on real aerospace parts will be demonstrated. All thermography results are validated with X-ray computed tomography.

We.5.C.5 **15:20**

Lock-in thermography inspection for heat damaged composite materials

A. Ngo [1], L. Ding [1], V.K. Sivaraja [1]
[1] IMRE, Singapore

Composites are being utilised extensively in many industries, ranging from aerospace to manufacturing to sports. Like all materials in an aircraft, composites can experience heat damage in-service resulting in delaminations and debonding. Eventually, the material will experience degradation in its strength properties and fatigue failure which can be catastrophic.
In this work, we report the use of lock-in thermography for non-destructive inspection of heat damaged composite material. The composite material considered is carbon fibre reinforced polymer (CFRP), and heat damage was induced with a heat gun. The effects of optical power density, lock-in frequency and detection frequency on the results will be reported in this work.

We.6.C | EDDY CURRENT (Technical session)

We.6.C.1 **16:30**

Inspection techniques for aero engine components of Ceramic-Matrix-Composites using High-Frequency Eddy Current Techniques

S. Hillmann [1], M.H. Schulze [1], H. Heuer [1]
[1] Fraunhofer IKTS, Dresden, Germany

Ceramic-Matrix Composites (CMC) are damage tolerant ceramics that are increasingly established in technical structures, which work in harsh environment, at high temperatures, under corrosive attack and high mechanical loads. That is why these new materials are under development actually amongst others for special components in aero engines. CMC can be based on carbon fibers as SiC (non-oxide CMC) or as oxide-fiber (oxide CMC) reinforcement. Thereby, these composites are suitable for highly stressed components in mobile and stationary turbines.
Due to its known advantages for characterization of Carbon-Fiber-Materials, High-Frequency Eddy-Current techniques (HF-EC) have also high potential to characterize CMC. HF-EC is optimized for materials with very low electrical conductivity. Additional, capacity effects and displacement currents plays an increasing role in these application. Due to Silicon Carbide (SiC), has a very low, but present electrical conductivity, a mixture of inductive and capacitive effects as well as effects by displacement currents influences the measurement signal and shows promising results.
The main topic of this publication is to evaluate carbon fiber reinforced ceramic matrix composite (C/SiC) at the CFRP, C/C and C/SiC state. The main focus lays on measurements using high-frequency eddy current technique, which has been optimized for these new materials based on extensive and long-term experience of the project team on CFRP materials. Different examples at very different samples from different production processes and with that different properties will be presented and discussed and tried to refer towards real material properties or defects within the material.

We.6.C.2 **16:50**

Characterization of Wet Conducting Coatings Using High-Frequency Eddy Current Techniques

I. Patsora [1], S. Hillmann [2], H. Heuer [2]
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The lightning protection of aircraft components made of fiber composite materials is an actual issue. Instead of nets of copper wire, which are laid around the outer skin of the aircraft, the use of electrically conductive lacquers is alternatively investigated. The conductivity of these layers must be homogeneous in order to avoid critical local current densities in the event of a lightning strike. It is therefore important to check the thickness or conductivity of the conductive coatings during application.
Such conductive coatings basically consist of an epoxy resin, conductive particles and a thinner. During drying, the chemicals evaporate and the structure shrinks. Thereby the particles percolate and form a conductive layer.
The eddy current method is one method, which can be used investigate the drying behavior of these electrically conductive layers regarding layer thickness and conductivity. It is possible, to use the method already in the liquid state of the conductive coating. That is important to generate the information about the final status of the layer at the earliest possible time, because then adjustments of the layer is still possible. Various parameters influence the drying behavior of the layer

and the eddy current measurements themselves. This includes not only the distance between the sensor and the layer (lift off) but also the size of the coated surface, the layer thickness itself, the composition of the conductive coating, the size and geometry of the particles and the material of the substrate.
This presentation shows experimental results of eddy current measurements on electrically conductive coatings by varying various parameters. Additional, analyzing methods are presented and discussed to separate different parasitic effects on the signal and to predicting the final state of the layer in terms of conductivity and thickness. Finally, a measurement system with a special sensor for wet layer based on the High frequency Eddy Current technique is presented.

We.6.C.3 17:10

Determination of Indication Depths at High Frequency Eddy Current Testing of CFRP

N. Matvieieva [1], M.H. Schulze [2], K. Mizukami [3], I. Kharabet [1], H. Heuer [1,2]
[1] TU Dresden, Germany; [2] Fraunhofer IKTS, Dresden, Germany; [3] Ehime University, Matsuyama, Japan

Nowadays, consumption and production of the carbon fiber reinforced polymer (CFRP) increase very fast, therefore a demand for the relatively simple and fast methods of quality control increases as well. Thanks to the sensitivity, ease of application and fast speed of utilization, High Frequency Eddy Current (HF EC) method is increasingly used for quality control of CFRP. One of the most important and complicated existing tasks for the method is the determination of the real depth of the indication or defect e.g. for carbon fiber ply determination.
In order to address this task experimental and numerical study has been made. The last was based on the concept of the coils combination with different operating frequencies, which provides different penetration depth into CFRP and, in the result, the possibility to quantify it. First experiments in this direction showed encouraging results, where half-transmission 2-coils sensors with different operating frequencies and penetration depth were used for the depth determination of copper elements embedded in laminated cross-ply CFRP specimen. The finite element modeling was done, compared with experiment and results are discussed in the paper.

We.6.C.4 17:30

Eddy Current Array for Aircraft Engine Component Inspection

A. Lamarre [1]
[1] Olympus Scientific Solutions Americas, Quebec City, Canada

Components of aircraft engines are submitted to very high stresses and temperatures during operation. Consequently, to assure the safety of the public, the integrity of these components must be ensured with reliable inspection methods. While the use of remote visual and dye penetrant inspection is widespread, the aircraft engine manufacturing and maintenance industries now benefit from recent developments in magnetic methods, namely eddy current array.
Eddy current testing (ECT) has long been considered the technique of choice to detect and size cracks on the surface of aircraft engine components. Unfortunately, inspections using single-coil eddy current probes can be slow with results that vary from operator to operator. In these and other respects, eddy current array (ECA) technology has advanced the technique significantly. The use of arrays helps to rapidly achieve full coverage of inspected zones while maintaining a high resolution. Portable eddy current electronics enable the use of large arrays and the image resulting from the software's data processing helps the operator perform a reliable analysis. Probe holders and mechanical supports are continuously being developed to address the different applications of ECA for engines.
Today, eddy current arrays are used by major aircraft engine manufacturers and maintenance companies for the assessment of engine components, such as dovetails, blade attachments, and turbine discs. This presentation will review how eddy current array technology contributes to public safety.

We.6.C.5 17:50

Development of a Contactless Inductive Strain Gauge for Monitoring Mechanical Load in CFRP

I. Kharabet [1], S. Hillmann [2], M.H. Schulze [2], N. Matvieieva [1], H. Heuer [2]
[1] TU Dresden, Germany; [2] Fraunhofer IKTS, Dresden, Germany

In this paper, results of the research on the feasibility of High Frequency Eddy Current (HFEC) based inductive strain sensor will be presented. Already conducted studies suggest that there is a possibility to utilize HFEC as an alternative for conventional strain gauges for CFRP parts monitoring. A carbon fiber changes its conductivity in the same way a conductive strain gauge changes during load. The main idea is to measure the change of the conductivity of fiber bundles inside CFRP during for determining the stress direct in the fiber. The advantage of the conductive strain gauge compared to classic conductive sensors are direct measurements of fibers load, not influenced by glue creeping and glue aging; tolerant for high defamation because no mechanical fixation of the inductive strain gauge is required. It was shown that there is a reliable correlation between measured EC signal and an applied mechanical strain. The reason for that are changes, introduced in the conductive structure of CFRP, which influence both conductivity of carbon fibers, and paths and distribution of eddy currents in the material. The theoretical basis for comparison of the sensor under development to the conventional strain gauges lays in the comparison of the k-factor of two methods. Strain gauges are generally characterized by k-factor of 1,9…3,0, which is a ratio between the change of sensor's resistivity and its length. Calculations, based on the obtained data, allow to predict that HFEC sensor should have a comparable "k-factor" of 2,2…3,5, which was calculated as ratio between change of measured EC signal and change of studied specimen's length. Forthcoming research is concentrated on the possibility to integrate prospective sensor design into the CFRP mesh, to allow localized health and strain monitoring of CFRP parts used in aerospace construction, to control the parameters of critical structural loci.

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Th.1.A | PLENARY TALK | ROBOTICS IN NDT

Th.1.A.1 **08:30**

NASA Applications of Robotics for NDT of Aerospace Vehicles

W. Prosser[1], G. Studor[1], M. Rollins[2], E. Burke[1], K. Hodges[1], B. Bartha[3], E. Cramer[1]
[1] NASA, Hampton, USA; [2] NASA, Houston, USA; [3] NASA, Cape Canaveral, USA

NASA has employed robotic methods to deploy NDT sensors and techniques for a number of critical inspection applications on aerospace vehicles and will continue to enhance robotic capability to support future missions. These robotic systems include both ground-based applications for inspection of aerospace components and vehicle assemblies as well as in flight inspections of spacecraft. Examples to be discussed include robotic x-ray systems that were used for the ground based inspection of a variety of Space Shuttle components such as the aft-skirt and carry structure assemblies, as well as the Orion spacecraft heatshield that flew on the Exploration Flight Test – 1 (EFT-1). Robotic NDT systems are also being employed for ultrasonic inspections of welds for the gigantic Space Launch System (SLS) propellant and oxidizer tanks. Additionally, NASA research efforts are underway to develop and demonstrate additional robotic NDT systems. A cutting edge coordinated multi-robotic inspection system to deploy infrared thermographic NDT systems on a full scale aircraft fuselage has been demonstrated, which can be expanded to accommodate other NDT sensor modalities. NASA is integrating in-situ NDE inspection techniques into large scale fiber placement robots to provide real-time NDE feedback for large scale composite structure construction. Further, more advanced deployment systems such as robotic "snake" technologies are being explored for NASA applications where access is an issue.
The need for in-space NDT was highlighted by the loss of the Space Shuttle Columbia due to impact damage to the thermal protection system (TPS). In response, the Shuttle Remote Manipulator System (SRMS), provided by the Canadian Space Agency, was augmented with a 50 ft. boom and the Orbiter Boom Sensor System (OBSS). The OBSS inspection sensor package provided optical and LIDAR measurement capabilities that were used to inspect the Shuttle TPS for impact damage. The results of these inspections were critical input for the decision to proceed with re-entry of the Shuttle and the safe return of its crew. In-space inspections are also important for the International Space Station (ISS). The ISS and visiting crewed vehicles are exposed to hypervelocity impacts from micrometeoroids and orbital debris (MMOD), which can cause damage to aging structures on the ISS as well as the TPS of vehicles docked there. NASA currently conducts surveys of the ISS exterior with visual cameras on the Space Station Remote Manipulator System (SSRMS) augmented by Dextre (Special Purpose Dextrous Manipulator or SPDM). NASA's Image Science and Analysis Team have improved on their Shuttle-era techniques to inspect the current and future visiting vehicles to ISS. New robotic inspection tools are also being developed to enhance the inspection capability on ISS. The Visual Inspection Poseable Invertebrate Robot (VIPIR) experiment for NASA's Satellite Repair Mission has a flexible-deployable videoscope with an articulating tip and the Canadian Dextre Deployable Vision System (DDVS) will provide high resolution imager, LIDAR and infrared imager for much improved effectiveness. It is hoped that the humanoid-like R2 Robot, flown aboard ISS, can be developed to accomplish inspections inside and eventually be adapted to be used outside the ISS to do at least some inspections that an astronaut might do with less human and mission risk. NASA has been testing robotic free-flying platforms (SPHERES and Astro-bee) to perform various tasks, including inspection, with the goal of little or no astronaut involvement. Also, new robotic gripping tools (Gecko gripper) have been tested on ISS that enable temporary adhesion for inspection tools, robotic crawlers and other applications in zero-g, including satellite capture!
Such robotic NDT systems will become increasingly important and enabling as humans travel deeper into the solar system, where return to Earth for vehicle inspection and repair is no longer a viable scenario. Robotic in-space inspection will require more autonomy to reduce or eliminate the need for ground communication or astronaut involvement. These robotic tools will need to perform over longer lifetimes in more severe environments. They will also need to support a wider variety of NDT sensor modalities to include penetrating imaging capabilities to examine structures under thermal blankets or MMOD shielding.

Th.2.A | ROBOTICS IN NDT (Short Presentations)

Th.2.A.1 **09:15**

Development of a method for the non-destructive evaluation of fiber orientation in multilayer 3D carbon fiber preforms and CFRP with robot-guided high-frequency eddy current testing technology

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This paper presents results of recent cooperative works at the ITM and IKTS on the 3D fiber orientation measurement with eddy current technique, which are the result of a recent dissertation. For the development of CFRP with load-adapted fiber orientations, a process is required that is able to nondestructively measure the fiber orientations in multi-layer, 3D preforms and CFRP structures.
Eddy-current testing (ECT) with frequencies in the megahertz range is able to reveal the filament structure in multilayer CF structures. To further expand its applicability a method is developed that can automatically generate the robotic paths for robot-guided ECT from an arbitrary 3D surface. From the obtained EC images, the local fiber orientation is determined on a grid of evaluation points. For this purpose the surface in near each point is projected onto a plane and converted into a pixel image. Fourier transformation is used to calculate the main fiber directions which are assigned to the individual layers by means of a robust algorithm and strategies are developed to exclude false information caused by faulty measurements or the misinterpretation of edges from the fiber orientation measurement.
The method is tested on a 3D geometry, a complex four-layer CFRP component. The fiber orientations can be determined in all four investigated layers. The results can be used to improve forming strategies and draping simulations or as inputs to structural simulations of CFRP components to verify the structural integrity under expected loads. This allows to further optimize CFRP design and manufacturing processes, exploiting CFRP's full potential in order to minimize costs and resource consumption while maximizing durability and robustness in aerospace applications.

Th.2.A.2 **09:20**

Automated single view 3D Texture Mapping and Defect Localisation of Thermography Measurement on Fuselage utilising an industrial robot and laser system

S. Dutta[1], K. Drechsler[2], M. Kupke[1], A. Schuster[1]
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Thermography measurements of large objects are always difficult and very expensive to automate. The main reason is that most large objects are bigger than measuring field. Furthermore continuous measurements are prevented due to lateral thermal diffusion. Another unhandy and less intuitive method is that certified examiners evaluate every 2D thermography image per measuring field one by one. Defect analysis from 2D images prevents to demine the accurate defect size and 3D defect propagation. 3D evaluation is complex but gives complete 3D

defect propagation knowledge. Furthermore absolute robot accuracy is major challenge for robot based automated thermography. Robot Tool-Centre-Point (TCP) positional accuracy depends mostly on robot pose their orientation. Many factors affect the absolute positioning accuracy of created robot TCP positions. 0.1° TCP inaccuracy can cause for 1 meter working distance up to 3mm position error.
In order to overcome this limitation and retrieve a 3D thermography texture for the observed object, DLR Augsburg has developed both hardware and software component. The essential information required to generate 3D thermography is objects geometry, location and orientation of objects with reference to Camera. DLR-AQP department is working on two different methods to calculate 2D-3D camera projection parameters. Method one projects predefined 3D points per measuring field by using laser projector and applies 2D-3D point correspondence algorithm. The second Method uses the robot pose and a kinematic-coordinate-relationships algorithm is applied to the images. For both methods single thermal image is captured by using thermography camera, which is also used for NDT. The first method is suited for research and development as well as for production inspection with or without using a robot for camera positioning while the second method requires a robot. The first method enables also contactless localisation of detected defects. About accuracy, reproducibility and flexibility of both methods have been compared and discussed in this paper. The 3D results are to be imported into the CAD environment for further structure analysis. Furthermore thermography results are visualised in accordance to their depth in 3D-Thermo-Thermography model.

Th.2.A.3 **09:25**

Autonomous Systems Imaging of Aerospace Structures

S. Deane [1], N. Avdelidis [1,2], A. Tsourdos [1], H. Yazdani Nezhad [1], C. Ibarra-Castanedo [2], X. Maldague [2], H. Zhang [2], A. A. Williamson [3]
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Aircraft manufacturers are constantly improving their aircraft ensuring they are more cost-efficient to do this the weight of the aircraft needs to be reduced, which results in less fuel required to power the aircraft. This has led to an increased use of composite materials within an aircraft. Carbon fibre reinforced polymer (CFRP) composite is used in industries where high strength and rigidity are required in relation to weight. e.g. in aviation – transport. The fibre-reinforced matrix systems are extremely strong (i.e. have excellent mechanical properties and high resistance to corrosion). However, because of the nature of the CFRP, it does not dint or bend, as aluminium would do when damaged, it makes it difficult to locate structural damage, especially subsurface. Non Destructive Testing (NDT) is a wide group of analysis techniques used to evaluate the properties of a material, component or system without causing damage to the operator or material. Active Thermography is one of the NDT risk-free methods used successfully in the evaluation of composite materials. This approach has the ability to provide both qualitative and quantitative information about hidden defects or features in a composite structure. Aircraft has to undergo routine maintenance – inspection to check for any critical damage and thus to ensure its safety. This work aims to address the challenge of NDT automated inspection and improve the defects' detection by performing automated aerial inspection using a Unmanned Aerial Vehicle (UAV) thermographic imaging system. The concept of active thermography is discussed and presented in the inspection of aircraft's CFRP panels along with the mission planning for aerial inspection using the UAV for real time inspection. Results indicate that this inspection approach could significantly reduce the inspection time, cost, and workload, whilst potentially increasing the probability of detection.

Th.2.A.4 **09:30**

How to improve NDT inspections on Airframe structures by using a climbing robot

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Over last two decades the number of NDT applications on aircrafts have increased. As recently as twenty years ago, an average of 40 NDT working hours were need for a C-Check. Nowadays, for the same C-Check an average of 200 NDT working hours are needed, and this number will not decrease in the future, particularly when thinking on new airplanes made of composite material. That might turn into a problem for airlines and MROs in the not so far future because first the costs for NDT labor hours are expensive and second the necessary NDT personnel is difficult to recruit.
In view of this desperate situation automated- or semi-automated NDT approaches are expected to increasingly entre the market of NDT inspections for airframe inspections. Thus, for example, drones or robots can be used for the NDT inspection. But, there is however a problem when using traditional climbing robot concepts, because they are normally based on movement with magnetic wheels, and therefore not suitable for airframe structures made of non-ferromagnetic materials. Exactly for that reason we present in this work a climbing robot, which enables the inspection of airframe structures in every conceivable positions, either vertically or even overhanging.
The moving principle of the robot is being based on negative air pressure between the lower side of the robot and the surrounding area. This will make it possible to move the robot to very remote locations on the airframe such as for example the upper tip of an aircraft rudder. In principle the climbing robot can be seen as a moving platform for many different kind of NDT inspections methods, starting from a simple visual inspection to more complex inspection methods such as ultrasonic or thermography inspection. In this work we equipped the climbing robot with thermography inspection equipment. The practical application of the robot is demonstrated based on a real rudder inspection on an aircraft.

Th.2.A.5 **09:35**

Accubot – a precision Robot NDT Kinematics for several modalities

W. Haase [1], T. Gramberger [1]
[1] Fill, Gurten, Austria

In Aerospace NDT applications especially for composite the demands for flexible NDT Solutions are increasing.
Linear kinematics was the standard approach for UT inspection systems for Through Transmission or Pulse Echo inspection due to the achievable accuracy of positioning required for the correct inspection paths. Especially for Through Transmission (TTU) using Squirter a high positional accuracy was required to be compliant to the specifications of Aerospace companies.
Robot based systems are nowadays an interesting alternative as possible accuracy enhancements allow to have the same or even better path accuracy as linear kinematics. The challenge is that the repeatability of robotics solutions is excellent while the dynamic positional accuracy along a path is not perfect or only achievable with reduced inspection speed and low data acquisition rates based on the position feedback. Additionally standard robots need to be protected against water splashes especially in Squirter Through Transmission technique.
This presentation shows the realized system based on standard Stäubli TX200 L robots with industrial standard Numerical Control SIEMENS Sinumerik 840 D and additional encoders to achieve high precision on complex scan paths still keeping a high inspection speed.

The robot kinematics is fully integrated in the Sinumerik control chain and based on that, flexible for any additional requirements as active tools, tool changers or multi-modality applications. Challenges to inspect narrow cavities with the robot hand are overcome by active extenders fully integrated in the system kinematics.
The inspection system is calibrated in the entire inspection volume in different arm configurations during the installation by a laser system. More than 1000 positions are taken into account to perform a mathematical correction higher order (not only the standard DH parameters) and introduced in the NC control system. During the inspection run the compensation parameters are online integrated in the path calculations.
By applying the compensation absolute positional TCP accuracies of 0.2 mm with additional encoders on all robot axes are achieved.
Accubot system layout and installed examples for Through Transmission, Pulse Echo and X-RAY are presented.

Th.3.A | PLENARY TALK | NDT AND ADDITIVE MANUFACTURING

Th.3.A.1 **10:15**

Microstructure and residual stresses in AM metallic parts: Do we know what we do not know?

G. Bruno [1]
[1] *BAM, Berlin, Germany*

The freeform and the revolutionary design possibilities offered by additive manufacturing have skyrocketed the amount of optimization studies in the realm of engineering, and metallic additive manufactured parts are becoming a reality in industry. Not surprisingly, this has not been paralleled by a similar enthusiastic wave in the realm of materials science, and still very little is known about AM materials properties. This has the consequence that, typically, classic materials properties are still used in design and even in simulations.
In this talk, I will give a few examples of how necessary it is to dig a lot deeper than at present, in order to understand these new materials classes, and in particular their microstructure and their internal stresses, largely different from their cast or wrought companions.

Th.4.A | NDT AND ADDITIVE MANUFACTURING (Short Presentations)

Th.4.A.1 **11:00**

Quality assurance of additively manufactured alloys for aerospace industry by non-destructive testing and numerical modeling

M. Awd [1], *S. Siddique* [1], *J. Johannsen* [2], *T. Wiegold* [1], *S. Klinge* [1], *C. Emmelmann* [2], *F. Walther* [1]
[1] *TU Dortmund, Germany;* [2] *Fraunhofer IAPT, Hamburg, Germany*

Development of the layer-wise build-up of metallic materials offered significant technical and economic advantages for modern structural components. Airliners are now losing much weight which is due to efficient designs which were made possible by additive manufacturing technol-ogy. In addition to topology optimization, selective laser melting (SLM) induces enhanced mi-crostructural features and mechanical properties. Highly dynamic melt pools result in refined microstructures which increase the strength of the conventionally manufactured titanium and aluminum alloys. At the scanning electron microscope (SEM), it was revealed that SLM pro-duces a very fine cellular dendritic microstructure in aluminum alloys of the Al-Si system. In the recently developed Scalmalloy®, the ultra-fine ceramic precipitation of $Al\text{-}Sc_3$ enables the ten-sile strength to reach 490 MPa and improves fracture strain by 100%. Along with improved microstructures due to high cooling rates, unstable melt pools induce spherical porosity as the release of gases from the powder bed is entrapped by the high solidification rate.
Platform heating (PH) which slows down cooling and enhances energy density is proved to stabilize melt pools and improves degassing mechanism. Al-Si alloys are well-known cast al-loys in the automotive industry; however, with the application of SLM technology, the tensile strength of these alloys is now 200% of the cast counterparts. The interest of aerospace indus-try in a high-strength aluminum alloy encouraged the development of Scalmalloy® which has a similar tensile strength to the wrought EN AW 7075. The latter is sensitive to hot cracking dur-ing SLM. For assurance of quality of additively manufactured alloys for the aerospace industry, the non-destructive technology of X-ray computed tomography (CT) is applied in this study to develop finite element (FE) models which will be used in a statistical simulation to deduce a quality-controlled fatigue strength in high- and very high-cycle fatigue (HCF to VHCF) regimes. Modeling of fatigue strength will be based on the quasistatic and cyclic deformation behavior of SLM aluminum alloys.

Th.4.A.2 **11:05**

Utilising Advanced Computed Tomography as NDT Technique in Additive Manufacturing

J. Lübbehüsen [1], *G. Zacher* [1]
[1] *GE Sensing & Inspection Technologies, Wunstorf, Germany*

Additive Manufacturing (AM) is presently revolutionising industrial production in many sectors (Aerospace, Automotive, PowerGen, Oil&Gas, Medical, etc.) and is expected to substantially substitute traditional moulding and casting processes within the next decade to come. For many workpieces made of plastic and metal based materials, AM tends to be the more convenient manufacturing technique due to their complexity and geometry.
Apart from other known non-destructive techniques to assure quality of AM products such as e.g. in-situ monitoring during the build process, computed tomography (CT) turns out to be one of the most efficient NDT methods. Not only does CT enable the three-dimensional volumetric visualization of indications and internal geometries that traditional NDT methods can scarcely or not access, it also allows to be used for metrology application tasks, such as dimensional measurement of interior and exterior features, variance analyses (CAD data, part-to-part) and pre-machining workpiece control.
Moreover, CT may help analyse the granulometry, topology and sphericity of AM powder particles (new/recycled) to assure quality of the incoming material prior to the printing process.
In view of new types of defects and flaws to be detected in AM parts, CT can meet requirements for increased resolution, higher penetrability and X-ray scatter-corrected volume data sets of workpieces made of dense materials (e.g. Inconel, CoCr, etc.) allowing for reliable and reproducible measurement results. Thanks to this and to improved automatic workflows, CT continues its move from being a traditional expert R&D device towards the use as an automatic measurement technique on or close to the production floor.
Computed tomography can help to set standards for quality assurance of AM parts. Hence, standardisation organisations such as ISO and ASTM rely on the recommendations and the expertise of CT system suppliers and CT users among the AM community members.

Th.4.A.3 **11:10**

Computed Tomography in NDT and Metrology for Additively Manufactured Aerospace Components

N. Achilles [1], G. Mäurer [1], J. Robbins [2]
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Computed Tomography (CT) is becoming an increasingly important technique when checking the quality of additive manufactured parts. Complex AM parts, especially of dense mate-rials, require additional, more precise testing methods to detect smallest defects in µm scales and to ensure the reproducibility of the part quality. This presentation will demonstrate how CT contributes to the development of flight critical engine parts and how it improves the entire processing chain.

Th.4.A.4 **11:15**

Inline Monitoring of Material Parameters in Additive Manufacturing by Laser Speckle Photometry

U. Cikalova [1], B. Bendjus [1]
[1] Fraunhofer IKTS, Dresden, Germany

Additive manufacturing techniques, such as Selective Laser Melting (SLM), Selective Laser Sintering (SLS) or 3D-print, are well established to increase the performance of constructions, to produce of spare parts for older systems and allow to simplify of logistics / warehousing or to reduce production costs. The quality of SLM products depends strongly on material properties like porosity and residual stress distribution during manufacturing. Therefore in SLM components manufacturing is a need for robust process monitoring and control capabilities to be developed that reduce process variation and ensure quality.
In this work we introduce to novel optical nondestructive and contactless testing method – Laser Speckle Photometry (LSP) – that was applied for the inline monitoring of SLM products. LSP is based on the detection and analysis of thermally or mechanically activated characteristic speckle dynamics in the non-stationary optical field. With the development of speckle theories, it is found that speckle pattern contain information of the object’s surface.
The implementation of LSP for control of additive processes shows a great potential. Moreover, the defects such as pores and microcracks occurring during the laser-melting process is possible to detect immediately after their formation by appropriate countermeasures. So the defects can be eliminated by re-melting of the affected area. As result time and cost of intensive material testing and rework will be significantly reduced. At the same time, the thermal diffusivity of material increase with decreasing porosity of material. The thermal material properties of the sample are related to the optical speckle dynamics during the heat treatment of the investigated layer by SLM process. The parametrization of the optical speckle dynamics is a key for the detection of material porosity at the same time.
The sensor system under development supports the minimization of the dropout rate of process conclusively, so that it significantly reduces energy, material and inert gas consumption. This LSP sensor will be able to be integrated directly in the manufactured machine.

Th.4.A.5 **11:20**

Laser generated narrowband Lamb waves for in-situ inspection of additively manufactured components

G. Davis [1], P. Rajagopal [1], K. Balasubramaniam [1], S. Palanisamy [2], R. Nagarajah [2]
[1] Indian Institute of Technology Madras, Chennai, India; [2] Swinburne University of Technology, Melbourne, Australia

Recent developments in metal additive manufacturing (AM) has generated a lot of interest in the aerospace sector. With the rapid growth in additive manufacturing of metallic components there has been a rising demand to ensure the quality of these components. Non-destructive testing (NDT) techniques such as ultrasonic testing and X-ray computed tomography have been demonstrated by various researchers to inspect AM components. Laser Ultrasonics (LU) is a recent addition to this list owing to its broadband and non-contact nature. The possibility to incorporate the LU system in to the AM equipment for an online in-situ inspection further accentuates its capability. In our study, narrow band Lamb waves were generated in an additively manufactured metallic sample using a pulsed Nd:YAG laser system consisting of a slit mask. The different wave modes generated were detected with a high signal-to-noise ratio (SNR) using a laser interferometer based on two-wave mixing in a photorefractive crystal. The wavelength-matched method enabled generation of specific Lamb wave modes with a dominant wavelength according to the pitch of the slits. Selecting the dominant wavelength in signals can reduce signal complexity and the speeds and frequencies of wave modes with the selected wavelength can be determined through dispersion curves and thus can be applied for the in-situ inspection of additively manufactured components.

Th.5.B | STUDENT ACTIVITIES IN NDT IN AEROSPACE (Student Session)

Th.5.B.1 **13:00**

Local Acoustic Resonance Spectroscopy: An Escalation Approach for Fast Non-Destructive Testing

P. Jatzlau [1], C.U. Große [1]
[1] TU München, Germany

Local acoustic resonance spectroscopy (LARS) is a non-destructive technique suitable for fast defect detection in large planar parts, especially in fiber composite structures. Applied in the acoustic frequency spectrum LARS is closely related to the coin tap test. In recent years, several applications in mechanical engineering have been established. These include the inspection of GFRP rotor blades as well as defect detection in CFRP parts in the automotive and aeronautic sectors. In addition, there are similarities to the impact-echo method, which is used in civil engineering for the detection of delaminations in concrete pavements or for thickness measurements of concrete slabs and structures. In all cases LARS is suitable for fast and therefore inexpensive measurements, also because it can be automated easily. Potential defect locations can then be more closely inspected by more complex non-destructive or destructive methods. The integration of LARS into such an inspection approach is subject of this paper. Moreover, an overview is given of the various applications of LARS and the respective measurement and analysis methods, where excitation technique and sensor technology are of major importance. While excitation is normally performed using an impulse hammer, the response signal is typically recorded by several microphones (capacitive or MEMS). Alongside experimental data, numerical simulation of the impulse response within the part is particularly useful to optimize the configuration on both the transmitting and receiving side for early identification of possible disturbances.

Th.5.B.2 13:20

Simulation Based Key Performance Indicator Determination in Guided Wave Monitored Metallic Patched Repairs

A. Asokkumar [1], R. Sridaran Venkat [2], C. Boller [2]
[1] Dresden International University, Germany; [2] Universität des Saarlandes, Saarbrücken, Germany

Monitoring of structures based on structural health monitoring (SHM) provides a variety of significant challenges. One of them is related to simulation, which is a necessity with respect to determining an optimum transducer configuration for a SHM system. The example to be considered in the paper is a metallic patched repair of an aircraft fuselage component considering different damage scenarios for which guided wave simulations have been performed such that an SHM system can be developed. In this context the sensor pattern, actuation pattern and the input signal have been varied for reasons of optimisation. The guided waves generated have been used to analyse the signals obtained with artificial intelligence (AI) algorithms trying to identify key performance indicators with respect to SHM. Further methods considered with respect to AI are principal component analysis (PCA), artificial neural networks (ANN), time reversal methods or the Gaussian mixture model. The results obtained will be presented and discussed in light of concluding the significance of simulation in SHM.

Th.5.B.3 13:40

Guided Wave Monitoring of a Riveted Metallic Patched Repair Using a Model Based Approach

H. Mohd Noor [1], C. Dürager [2], R. Sridaran Venkat [3], C. Boller [1,3]
[1] Dresden International University, Germany; [2] IMITec, Meilen, Switzerland;
[3] Universität des Saarlandes, Saarbrücken, Germany

A challenge with respect to structures based on structural health monitoring (SHM) is to extract the right features from the signals having been measured. A way on how to get this done is on the basis of a model-based damage feature extraction procedure. In that case a numerical model of the structure considered is taken as a basis to determine sensor signals such as being generated through guided ultrasonic waves. Signals are measured experimentally in parallel and are compared to the simulated results. In case of a mismatch the model is then adapted through a learning process to what is monitored in reality. The model can be of different levels of complexity starting from a baseline measurement being compared to an actual measurement and ending in a rather complex mathematical (i.e. numerical) model to be considered as the reference that may adaptively be adjusted through non-linear least mean square fits.
In the paper to be presented the model-based feature extraction process mentioned above will be validated experimentally for a flat plate with three holes and a patched metallic repair both considering an undamaged and an artificially damaged condition. The components to be considered relatively complex have been monitored with a wireless guided wave based SHM system. Locations of the transducers to be placed on the components were decided in accordance to numerical simulations performed in parallel.

Th.5.B.4 14:00

Methods and Options in Analysing Big Amounts of Data in NDT

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NDT is known to generate large amounts of data. It starts from A scans and makes its way through B, C and D scans and often results in 3D images. This is just one and maybe the most popular way in visualising NDT data, because it is understood by virtually everyone. However, NDT data consists of much more information being partially explored but also unexplored to a large extent. Some of this information may be explained by physics while other information will be obtained through a mathematical feature extraction of the signals only, where the result obtained still seeks for a physical explanation. Further options do exist with the introduction of physically justified parameters describing damage and other phenomena, which can be included in the signal processing procedure as well. Finally the emerging field of artificial intelligence and big data analysis provides a wide field of algorithms to be explored also with respect to the vast amount of NDT data being generated. The paper to be presented will look into different examples of electromagnetic and acoustic data and show what impact those algorithms may have with respect to an enhanced retrieval of additional material and structural information to be sought of.

Th.5.C | ULTRASONICS 1 (Technical Session)

Th.5.C.1 13:00

Detection of delamination and impact damage in multilayered lightweight materials

T. Gautzsch [1], A. Bodi [1], M. Lucas [2], R. Steinhausen [3], M. Kiel [3]
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[3] Forschungszentrum Ultraschall, Halle (Saale), Germany

A variety of lightweight composite materials are used in aerospace construction. Most common are multiple layers of aluminum with adhesive interfaces of different thicknesses, GFRP sandwich structures with and without honeycomb cores and glass fiber reinforced aluminum. The material properties of all materials are highly dependent on the integrity of all adhesive and matrix structures. These can be impaired by impacts, production problems, physical stress or aging.
Air-coupled ultrasonic testing (ACUT) can be a method for non-destructive quality control for semi-finished composite materials as well as products. Additionally, it can be applied for maintenance testing of parts to find impact and stress damage.
We will present a case study on the detection, measurement and evaluation of delamination in multi-layered aluminum bonds with up to 4 sheets of aluminum in various thicknesses. The aviation-specific specimen is measured in through-transmission with ACU with multiple frequencies, filters and averages with classic piezocomposite as well as phased-array ACU transducers. Delamination and flaws can be found in every adhesive layer. Depending on the composite thickness, different frequencies have to be applied.

Th.5.C.2 13:20

Detection of porosity and water inclusion in carbon fiber composites using a novel laser-based air-coupled ultrasound method with optical microphone

B. Fischer [1], N. Panzer [1], W. Rohringer [1]
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In state-of-the-art Laser Ultrasonic Testing (UT), the detection principle relies on the optical measurement of vibrations of the test object's surface. We present a different approach: the vibrating surface of the test object is emitting a dispersive ultrasonic pressure wave into the adjacent air. This airborne acoustic wave can be detected by a laser-based microphone.
The reason to access Laser UT with this alternative and novel approach is 1) to miniaturize the size of the testing head, 2) to become independent of the sample's surface orientation, and 3) to minimize cost.

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The excitation laser is delivered via optical fiber, so the sample can stay in a fixed position, while the excitation head is moving. The detection is based on assessing the acoustic waves, radiated into the air, by an optical microphone technology, where a miniaturized Fabry-Pérot etalon senses the air pressure via a change of local index of refraction. Since the detection laser is not directed onto the sample surface, but rather stays inside the detector head, the dependency on orientation and surface structure is reduced. Also, the compact-sized detector (having the size of half a pencil) can reach into confined spaces in an automated production environment. While a single fiber-coupled laser is used for the generation of the broadband acoustic pulse, on the detection side, this acoustic sensor can also be manufactured in an array configuration, where multiple laser beams retrieve multiple detection signals in parallel, hereby multiplying the acquisition speed.
Compared to optical detection methods traditionally used in Laser UT, the equipment pricing is favorable. This is at the expense of depth resolution accuracy, since the propagation of ultrasound in air is physically limited to a few MHz only. However, in materials with pronounced high-frequency absorption, such as many carbon fiber reinforced polymers (CFRP), the method leads to promising results.
The award-winning technology is being successfully applied on resistance spot welding joints in a car body construction context. In aerospace, we demonstrated the optical microphone technology to identify porous composite materials and water inclusion in honeycomb structures. Scan images will be presented and discussed.

Th.5.C.3 **13:40**

SITAU TRITON: High Speed Ultrasound Inspection System for Complex Geometry Composites

M. Acebes[1], R. Gonzalez[2], R. Delgado de Molina[1], A. Morales[3], J.F. Cruza[2], I. Gauna[1], R. Giacchetta[2]
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The aerospace composite industry demands the inspection of 100% of the manufactured components, which places the non-destructive-evaluation methods in the critical path of the manufacturing process. In one hand, inspection time has to be minimized to avoid the NDE process to be a bottleneck in the process, which requires increasing the inspection speed and/or incrementing the number of probes and electronic channels in the case of ultrasound inspections (UT).
We present in this work the result of 2 years of work, with the achievement of a highly modular, scalable and affordable solution for high-speed ultrasound automated inspection, called SITAU TRITON. It is the most advanced and flexible automated UT solution in the market, integrating in a single machine, three UT inspection systems:
1) SITAU TRITON GIMBAL: Able to perform like a 3 axes Cartesian system to inspect planar and smooth curvature parts, by using PA technology for high speed operation.
2) SITAU TRITON COMPLEX: With up to 896 ultrasonic channels, it is designed to inspect the 100 % of complex geometry components in one pass, which guarantees the minimum possible inspection time. A quick and automated interchangeable system allows using specific inspection heads for each component.
3) SITAU TRITON TTU: Is a through transmission system (TTU), able to work with conventional water coupled technology or with air-coupled ultrasound, and with single or dual frequency transducers. Trajectories are optimized for each component ensuring a collision-free operation.
One of the unique features of SITAU TRITON is PA AUTOFOCUS, which takes automatic UT inspections to the next level. Geometry changes and manufacturing tolerances along the component are automatically compensated in real-time by the UT equipment, which make the TRITON-SITAU system one of the most robust and reliable on the market, even for radius and complex geometries. Furthermore, our air-coupled ultrasound sub-system based on the AIRSCOPE technology, has proven to be one of the more sensitive and robust solutions in the market, able to face inspection problems only solved with water-coupled system up to date.
In this work we present the key innovations of the SITAU TRITON technology and the results obtained with the system.

Th.5.C.4 **14:00**

Coherent Adaptive Focusing Technology for the Inspection of Variable Geometry Composite Material

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[1] Olympus Scientific Solutions Americas, Quebec City, Canada

The aviation industry has seen above normal growth in recent years, owing in part to lower oil prices contributing to millions of dollars in savings for aircraft operators. As a result of this growth, production rates for new airplanes have increased, and new aircraft programs are being launched. Consequently, aviation component manufacturers are facing new challenges, including a rise in production rates, higher probability of detection (POD) requirements due to the critical nature of the parts being manufactured, a lack of skilled operators, and parts with increasingly complex geometry. To respond accordingly, ultrasonic phased array (PA) instruments have evolved, enabling the implementation of advanced acquisition strategies, such as adaptive focusing. Coherent adaptive focusing simplifies the inspection of variable radiuses, variable opening angles, and twisted components, and it also compensates for probe misalignment through innovative signal-processing algorithms. This paper presents an overview of coherent adaptive focusing technology with the goal of helping NDT integrators and composite material manufacturers address system performance, production output, and quality control issues.

Th.5.C.5 **14:20**

Combined characterisation of residual stress and cold work at surface treated aeroengine materials by Rayleigh wave refraction

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Aero Engine materials are exposed to high temperatures and high stresses in operation. To increase the fatigue strength, the surface is treated by shot peening, laser peening or deep rolling. These processes introduce compressive residual stress and structure modifications (cold work) in a near surface layer. There are several attempts to determine these advantageous surface property gradients nondestructively. The applied methods include eddy current and Rayleigh waves velocity measurements. Recently the application of the Hall-effect was also proposed. Besides selectivity, all these methods lack of good sensitivity. A very small change in a large signal has to be measured reliably; a big challenge for a method, supposed to be applied in a harsh repair shop environment. The here proposed new method builds up on Rayleigh wave propagation through a straight line between a surface treated and a non-treated area. Even a slight change of sound velocity between both regions lead to significant refraction effects for the wave paths with near grazing incidence. The wave propagation is visualized for such cases by laser vibrometer measurements. Moreover, the following is demonstrated: when the incidence angle to the border line in a pitch catch arrangement is varied, significant transmission drops of up to

30 % are observed. This comprises a very solid measurement effect. Possible arrangements for future practical applications are discussed.

Th.6.B | EU PHD PROGRAMME „NDT ON AIR“ (Special Session)

Th.6.B.1 **15:10**

NDTonAIR: Training Network in Non-Destructive Testing and Structural Health Monitoring of Aircraft structures

S. Amato [1], A. Ba [2], H. Chebbi [3], S. Gartsev [4], Y. Kim [4], H. Malekmohammadi [5], M.K. Rizwan [5], T. Seresini [6], M. Stamm [7], S. Sunetchiieva [6], J. Vyas [8], S. Waters [9], Q. Yi [10], B. Yilmaz [8], A. Zitoun [11], A. Angulo [11], G. Berthiau [2], P. Burgholzer [9], P. Burrascano [5], S. Dixon [1], C. Glorieux [6], D.A. Hutchins [1], E. Jasiuniene [8], R. Kazys [8], B. Köhler [4], S. Laureti [5], L. Mazeika [8], H. Pfeiffer [6], D. Premel [3], C. Reboud [3], J. Reynaert [7], M. Ricci [12], S. Soua [11], G.Y. Tian [10], M. Wevers [6]
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The “NDTonAIR” project is a Marie Skłodowska Curie European Training Network funded under the action: H2020-MSCA-ITN-2016- GRANT 722134. The “NDTonAIR” consortium joins Universities and Research Organisations working on the main Non-Destructive Testing (NDT) and Structural Health Monitoring (SHM) techniques with major European companies operating in aerospace for which NDT is a key ingredient of the daily work.
The goal is to train a new generation of scientists having a wide background of theoretical and experimental skills in NDT, capable of developing their research and entrepreneurial activities both in academy and industry and playing an active role in promoting the importance of quality inspection and structural monitoring in all the production processes. The objective of the training programme is to provide at the recruited researchers an extensive and varied training on: (1) “Fundamentals skills” for NDT and SHM through participation at short-courses and seminars organized by the Consortium; (2) “NDT Techniques for Aerospace“ through research training at host institutions and participation in Workshops and Conferences organized by the Consortium and by major international research associations; (3) “Technology Transfer and Entrepreneurial” through participation at short-courses and seminars organized by the Consortium.
The objective of the research programme is to consolidate and innovate current NDT and SHM techniques for Aircraft inspection by (1) investigating new physical phenomena and sensors; (2) developing analytical and numerical models to correlate the results of inspection with material properties; (3) quantifying NDT techniques through their probability of detecting reference defects; (4) developing procedures for the automatic detection and classification of defects; (5) transferring these results to industries.
The NDTonAIR consortium is eager to establish training and research collaborations with other companies and research organizations involved in aerospace and in NDT and SHM in general. NDTonAIR activities are open to students, PhD, Post-doc and researchers from outside the consortium. During the conference, more details will be given to attendees about the next training events and on the specific research projects carried out by Early Stage Researchers.

Th.6.B.2 **15:30**

Quantitative evaluation of delamination depth in CFRP based on pulse compression eddy current pulse thermography

Q. Yi [1], G.Y. Tian [1], J. Zhu [1], S. Laureti [2], H. Malekmohammadi [2], M. Ricci [2]
[1] Newcastle University, UK; [2] University of Perugia, Italy

With the growing interest to use engineering composite structures, much attention is devoted to the non-destructive testing (NDT) techniques for the evaluation of impact damage and delamination of Carbon Fiber Reinforced Plastic (CFRP). Eddy current pulsed thermography (ECPT) is an emerging NDT technique, which shows significant detectability for impact damage evaluation. However, the faithful characterization of possible delamination within a CFRP specimen is hampered by insignificant thermal diffusion reflecting the depth information which cannot be extracted in pulse excitation. To tackle with these challenges, eddy current pulsed thermography was firstly combined with pulse compression technique to increase detectability of delamination. Based on the impulse response retrieved from modulated heating data, this paper proposes the thermal pattern enhancement techniques as the post-processing method to locate and select the defected area and evaluate the feasibility of a new feature extracted from the enhanced thermal pattern to analyze the quantitative relationship of this new feature with delamination depth.

Th.6.B.3 **15:50**

Improved shear horizontal wave piezoelectric fiber patch (SH-PFP) for structural health monitoring applications

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Controlling the wave directivity of transducers is an important aspect of guided wave based structural health monitoring (SHM), because a strong directivity is not only energy efficient but also has an advantage of simple signal analysis. The fundamental shear horizontal (SH0) wave is gaining its popularity due to its non-dispersive characteristics. Piezoelectric fiber patches (PFP) are lightweight, thin, and flexible and therefore adaptable to curved surfaces. PFP can be designed to preferentially generate and receive either Lamb or shear horizontal guided waves. Building on previous work for a SH-PFP transducer its geometry is modified to optimize the mode purity and the directivity. Finally, a new version of SH0 wave PFP with improved directivity is proposed. The new transducer concept and its working principles are explained, and the numerical simulation is conducted to validate its performance. Results show that the new transducer can generate almost pure SH0 waves along the desired direction with high directivity.

Th.6.B.4 **16:10**

About acoustic detection of ice in the fuel aircraft tanks

M. Stamm [1], H. Pfeiffer [2], J. Reynaert [1], M. Wevers [2]
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During the daily aircraft operation, water accumulation in fuel tanks by condensation and contaminated fuel cannot be prevented. While the “free water” [Banea, 2013] potentially leads to microbial corrosion and the misreading of fuel meters, freezing water can harm the aircraft fuel system in the fuel tank, resulting in potentially hazardous situations for passengers, crew members and ground personnel.

The regular performed draining of the tank removes almost all liquid water from the bottom of the tank. Moreover, this procedure only reduced liquid water in the tank and is not applicable on ice in the tank. In addition, neither the remaining amount of liquid water in the tank nor the amount of ice can be estimated after or before the draining procedure. Up to now, there is no generally accepted "non-invasive" method available to determine the amount of water and ice in the tank. The detection of the ice in the tank is an ideal field of application for diverse advanced acoustic, ultrasonic and thermal NDT methods which are tested to estimate the location and volume of ice in the tank. First experiments showed the applicability of passive acoustic as well as thermal measurements for the detection of melting ice on plate-like structures.
Advanced experiments are performed on a tank model made from the materials comparable to the aircraft tank (material, thickness, coatings, etc.). To simulate realistic conditions, kerosene and water are cooled down as present in the fuel tank. Results show that passive ultrasonic measurements are applicable for the localization of subsurface ice in the tank.
Research leading to these results has received funding from the "NDTonAIR" project (Training Network in Non-Destructive Testing and Structural Health Monitoring of Aircraft structures) under the action: H2020-MSCA-ITN-2016-GRANT 722134.

Th.6.B.5 **16:30**

Applying features of nonlinear ultrasonic modulation for defect detection in vibrating structures

S. Sunetchiieva [1], H. Pfeiffer [1], S. Creten [1], C. Glorieux [1], M. Wevers [1]
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Aircraft structures are subjected to various external factors that influence their lifetime. Due to the high need for structural health monitoring in aerospace applications, numerous, quite mature linear ultrasonic NDT techniques have been developed for the detection of defects. Typically guided waves are used, which are based on mode conversion and reflection of probe waves by a defect, provided the defect is open, resulting in an acoustic impedance mismatch. However, in practical applications defects are often 'closed' when not under substantial stress. Moreover, in most nonlinear ultrasonic NDT techniques the lack of differentiation between sources of nonlinearity makes defects indistinguishable from e.g. nonlinearity induced by mechanical contacts.
Here, we aim to detect damage, addressing the practical difficulties of monitoring vibrating structures. Typical defects were created by fatigue facilities and detected in aluminium plate-like samples using PZT transducers to generate and detect probe waves. The presented diagnostic algorithms compare features of the nonlinear relation between the amplitude of the transmission probe wave and the load on the sample with a threshold value, in order to assess the state of the sample. The applications are robust to environmental changes, are based on durable components, while being sensitive to vibrating defects.
Part of the research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n°212912 and the "NDTonAIR" project (Training Network in Non-Destructive Testing and Structural Health Monitoring of Aircraft structures) under the action: H2020-MSCA-ITN-2016- GRANT 722134.

Th.6.C | ULTRASONICS 2 (Technical Session)

Th.6.C.1 **15:10**

Airborne testing of molded polymer compounds

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Modern and energy-efficient materials are essential for innovative designs for aerospace and automotive industries. Current technologies for rapid manufacturing such as additive manufacturing and liquid composite moulding by polymer extrusion allow innovative ways of creating robust and lightweight constructions. Commercially available printing devices often use polylactide (PLA) or acrylonitrile butadiene styrene (ABS) as raw material. Therefore, parameters like the infill ratio, influencing the ability to resist mechanical stress, may have a beneficial impact on the lifetime of components. These manufacturing technologies require a good knowledge about materials and even adapted non-destructive testing technologies and methods. Airborne ultrasonic testing has beneficial advantages for testing those lightweight constructions. It is a contact-free testing method, which does not require a liquid couplant. Therefore, it allows fast test cycles without any unwanted alternations of the material properties due to interactions with any coupling liquid. This contribution deals with the characterisation of printed specimens based on PLA by using airborne ultrasound and presents the current edge of non-destructive testing and evaluation using airborne ultrasonic transducers. The specimens, manufactured by polymer extrusion, are printed as thin plates. The infill ratio, as well as the material thickness, were varied to model density imperfections with different geometric shapes and properties. For better understanding of the limits of airborne ultrasonic testing in transmission, we compared own-developed transducers based on different physical principles: on ferroelectrets, on the thermoacoustic effect, as well as a new type of transducers based on gas discharges.

Th.6.C.2 **15:30**

Ultrasonic Volume Scanning of Forged Materials with a Prefocused Annular Phased Array Probe

M. Barth [1], T. Beggerow [2], M. Rjelka [1], F. Schubert [1], B. Köhler [1], W. Spruch [2], M. Bron [3]
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Intense ultrasonic testing procedures are necessary to ensure the required high quality of materials that are used for fast rotating components in aircraft jet engines. Finding very small flaws and inhomogeneities in highly scattering materials like titanium and nickel-based superalloys is challenging. State of the art is to perform multizone testing, which means a series of scans with various focused UT probes to cover the entire material volume. This method is very time consuming and can detect flaw sizes equivalent down to FBH 0.4 mm (flat bottom hole). The goals of the project were increasing the testing speed by reducing the number of scans needed to cover the volume and improving the flaw sensitivity. We propose to apply a prefocused annular phased array (APA) in combination with dynamic depth focusing (DDF). With the help of sound field simulations it is shown, that a non-planar APA with special curvature is more suited for this approach than APA transducers with plane faces, which are commercially available. The optimized transducer design enables a wide depth range of high sensitivity and high resolution inside the sample. DDF is a method of processing the APA element's signals according to the echo times of flight from different sample depths in order to achieve focusing to a large depth range.

The combination of the prefocused APA and DDF allows to cover nearly the entire sample depth with a single shot. Hence, several scans with conventional probes covering different depth zones can be replaced by one scan with the APA. Additionally, tests have proven that defects equivalent to FBH 0.2 mm can be detected in a specimen of forged titanium alloy.

Th.6.C.3 **15:50**

New Developments and applications for Air Coupled Ultrasonic Imaging Systems

A. Szewieczek [1], *W. Hillger* [1], *L. Bühling* [1], *D. Ilse* [1]
[1] *Ingenieurbüro Dr. Hillger, Braunschweig, Germany*

The ultrasonic testing of complex aerospace components is typically carried out with squirter technique. However, water coupling delivers disadvantages like pressure variations, air-bubbles, lime scales, algae and corrosion of the mechanics. Therefore, an air-coupled technique is preferable to avoid these disadvantages.
Problems caused by the large acoustic mismatch between solids and air are solved with special transducers, a powerful excitation as well as a hard- and software signal processing.
The testing is usually carried out in transmission technique with separate transducers on opposite sides of the component. The applications are mostly located in area of aerospace components, such as sandwich components. Also applications for monolithic CFRP components and metal structures are possible.
After 15 years of more or less laboratory applications the air-coupled ultrasonic technique (ACU) is used for large aerospace construction parts like the EC 145 tail boom and payload fairings. Because of the complex curved components robot scanners with 10 axes are necessary for the manipulation and the alignment of the transducers. The large size of such component requires travelling lengths of 20 meters and more.
The new developments are focussed to eight channel systems with sender and receiver arrays. This reduces the time for scanning to below 20% of the time for a one channel system. An ultra-low noise amplifier (ULNA) provides a 4 dB lower RMS value of noise.
A further area of development is the ACU with one sided access which is the research task of a LuFo project. Typical advantages of this technique is the reduction of scanning system complexity and the possibility to test hard accessible build-in components.

Th.6.C.4 **16:10**

Air-coupled ultrasonic ferroelectret transducers with additional bias voltage for testing of composite structures

M. Gaal [1], *F. Schadow* [1], *D. Nielow* [1], *V. Trappe* [1]
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Common air-coupled transducers for non-destructive testing consist of a piezocomposite material and several matching layers. Better acoustical matching to air is achieved by transducers based on charged cellular polypropylene (PP). This material has about hundred times lower acoustic impedance than any piezocomposite, having about the same piezoelectric coefficient. The piezoelectric properties of cellular PP are caused by the polarization of air cells. Alternatively, a ferroelectret receiver can be understood as a capacitive microphone with internal polarization creating permanent internal voltage. The sensitivity of the receiver can be increased by applying additional bias voltage. We present an ultrasonic receiver based on cellular PP including a high-voltage module providing bias voltage up to 2 kV. The application of bias voltage increased the signal by 12 to 15 dB with only 1 dB increase of the noise. This receiver was combined with a cellular PP transmitter in through transmission to inspect several test pieces consisting of glass-fiber-reinforced polymer cover layers and a porous closed-cell PVC core. These test pieces were inspected before and after load. Fatigue cracks in the porous PVC core and some fatigue damage in the cover layers were detected. These test pieces were originally developed to emulate a rotor blade segment of a wind power plant. Similar composite materials are used in lightweight aircrafts for the general aviation. The other inspected test piece was a composite consisted of glass-fiber-reinforced polymer cover layers and a wooden core. The structure of the wooden core could be detected only with cellular PP transducers, while commercial air-coupled transducers lacked the necessary sensitivity. Measured on a 4-mm thick carbon-fiber-reinforced polymer plate, cellular PP transducers with additional bias voltage achieved a 32 dB higher signal-to-noise ratio than commercial air-coupled transducers.

Th.6.C.5 **16:30**

NUTHIC: Non-Contact Ultrasound Inspection Machine of Highly Integrated Composite Parts

R. Giacchetta [1], *J.F. Cruza* [1], *R. Taneja* [2]
[1] *DASEL, Madrid, Spain;* [2] *Innotecuk, Cambridge, UK*

Aerospace industry is moving towards more integrated composite structures in order to reduce autoclave cycles and assembly operations, which leads to considerable cost, time and energy savings. However, the main drawback of this approach is that no inspection solution at a reasonable cost is given by ultrasound equipment in the market, because of the geometry complexity and access restrictions to those parts.
NUTHIC E! 8929 project (partial financed by Eurostar Program H2020) develop an adaptive and fully automated air-coupled ultrasound inspection system for highly integrated composite components, whose complex geometries and difficult access prevent using state of the art equipment.
The goal of this project is to provide the aerospace manufacturing industry with an adaptive and automated non-contact ultrasound inspection solution for highly integrated composite parts
This paper presents the final results of the project on multi spar structures, all of these measure with non-contact ultrasound technique, avoiding water coupling and reducing inspection time by integrating the inspection machine into the clean environment of the production line.

Fr.1.A | APPLICATIONS (Technical Session)

Fr.1.A.1 **08:30**

Radome Inspection with Terahertz Waves

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We present a terahertz imaging system for aircraft radome inspection based on a two-frequency FMCW radar working at center frequencies of 100 and 150 GHz and with 40 and60 GHz bandwidth, respectively. The imaging sensor combines two all-electronic multiplier chains at the respective frequencies and is integrated in the production environment of radomes built of glass fiber-reinforced composite structures. While images acquired at the two distinct working frequencies can yield different information of possible structural defects, at the same time, a data fusion algorithm is applied combining the signals of both terahertz sensors for enhanced depth resolution by a total FMCW bandwidth of 100 GHz.

I. INTRODUCTION
Fiber-reinforced plastic (FRP) composite structures are widely used in mechanical construction where a combination of light weight, high structural integrity, and – in the case of aircraft radomes – transparency for radio and microwave frequencies is required. Such composite structures commonly consist of multiple functional layers of various materials, e.g., aramide and glass fiber material. Since the structures are built layer by layer, an inline production quality control is desirable to detect possible delaminations, structural imperfections and other defects already during manufacturing. Defect detection is furthermore desired in in-field inspection of complete radome structures during maintenance procedures. Frequency-modulated continuous-wave (FMCW) terahertz imaging systems have shown to present an excellent combination of spatial and depth resolution for typical defect sizes while providing large penetration depths in the respective materials.
In this contribution we demonstrate a two-frequency FMCW imaging system which was integrated in an aircraft radome production environment. We show first measurements of a test radome structure as well as images of flat FRP panels with embedded artificial defects as well as real radomes.

Fr.1.A.2 **08:50**

Crack detection on aerospace composites by means of photorefractive interferometry

T. Seresini[1], X. Jichuan[2], M. Wevers[1], H. Pfeiffer[1], C. Glorieux[1]
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Aircraft industry requires fast, robust and reliable tools for assessing structural integrity. Linear ultrasonic techniques are among the tools of choice for Non-Destructive Testing, however they fail to sense a defect when the limbs are in contact.
The inspection tool presented in this work is based on the detection of defect-induced elastic cross-modulation phenomena using photorefractive interferometry (PRI). This non-contact method is full-field and ultimately, it will allow to inspect large areas at once and enable detection of defects at an early stage.
The novelty of the system lies in both the ultrasonic excitation and in the detection method. Two surface waves are sent along the sample: one of low amplitude and high frequency (probe wave) and one of high amplitude and low frequency (modulating wave). The modulating wave opens and closes the limbs of the defect so that the probing wave experiences a non-linear modulation, thus evidencing its existence.
To sense the surface motion and measure its spectrum accurately, we have opted for a PRI setup, which can be configured to detect vibration frequency components of interest without cross-talk from other vibrations, e.g. the high amplitude vibration that opens and closes the defect. Using standard interferometry, frequency mixing between the modulation frequency and the probe frequency resulting from the defect response would be scrambled by the presence of frequency mixing due to the nonlinear relation between the interferometer light intensity and the measured displacements. This work highlights that photorefractive interferometry allows for frequency sensitive detection and enables to identify the modulated probing signal amid an intense background.
An important aspect of this study is the aerospace applicability of this tool. Therefore, experimental observations were focused on plausible defects: surface breaking cracks in metallic plates and internal delamination in carbon fibre plates. The samples are observed both under static conditions as well as under a time dependent load.
Acknowledgment: "NDTonAIR" project (Training Network in Non-Destructive Testing and Structural Health Monitoring of Aircraft structures) H2020-MSCA-ITN-2016- GRANT 722134.

Fr.1.A.3 **09:10**

On detecting kissing bonds in adhesively bonded joints using electric time domain reflectometry

P.J. Steinbild[1], R. Höhne[1], R. Füßel[1], N. Modler[1]
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The use of fibre reinforced plastics to achieve low mass aircrafts calls for suitable joining technologies. The joining technology with the highest potential in lightweight construction with fibre reinforced plastics is adhesive bonding. However, in today's aircrafts the potential of adhesive bonding is limited due to the additional use of rivets as crack arrestors for regulation and safety issues. To meet the regulations and reduce the number of joint-weakening, heavy rivets, an adhesive bond needs to be monitored during its production and throughout its lifetime in operation. State of the art are ultrasound and thermal imaging technologies for non-destructive testing of adhesive bonds. The use of such technologies in a structural health management system is not practical. Additionally, ultrasound and thermal imaging technologies are only capable of detecting gross defects like areas of uncured adhesive and voids. The detection of adhesion defects like kissing bonds still pose a serious problem. This paper describes a novel adhesive sensor principle based on the electric time domain reflectometry, which can detect differences in the deformation of the adherents in an adhesively bonded joint under load to infer that a kissing bond is taking effect. The sensor is integrated into the joint. Results of the experimental validation by shear tension testing of single lap shear specimens with the adhesive sensor integrated into the joint are presented. The deformation of the adherents is monitored by digital image correlation and compared to the data obtained by the electric time domain reflectometry. The results show that by integrating the proposed sensor into an adhesively bonded joint the joint can be monitored operando. This novel technology can be used in a structural health management system to raise the confidence in adhesive bonds and reduce the number of rivets thus reducing mass. Further developments will include the use of a finite difference time domain model to numerically test sensor configurations regarding its geometry and electrical properties.

Fr.1.A.4 **09:30**

Determination of the nonlinear elastic constants in a surface treated layer for aero-engine disk residual stress measurement

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A common method to enhance the fatigue life of components is the introduction of compressive residual stress in the components' surfaces which suppresses the surface crack growth under (cyclic) tensile load. One major application is the surface treatment of blade discs in jet engines, produced of titanium and nickel based superalloys. Up to the moment, the presence of compressive stress can only be evaluated either during production by reference samples (Almen stripes) or with destructive (borehole drilling)/laboratory (x-ray) methods.
One of the difficulties in surface layer stress estimation by the acoustoelastic effect is that the surface wave velocity is not only influenced by the stress via the acoustoelastic effect but also directly by microstructure changes due to plastic deformation (cold work). The goal of the paper is the investigation of an independent way to determine the nonlinearity of the plastically deformed surface layer at the samples itself, as a prerequisite to correctly identify the stress contribution to the velocity change. Fortunately, beside the acoustoelastic effect nonlinear wave interactions like harmonics generation and wave mixing offer a way to assess the nonlinear material properties. The concept

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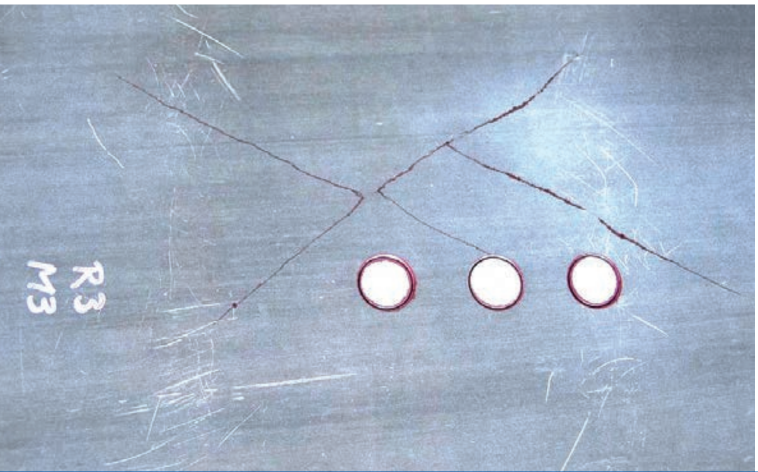

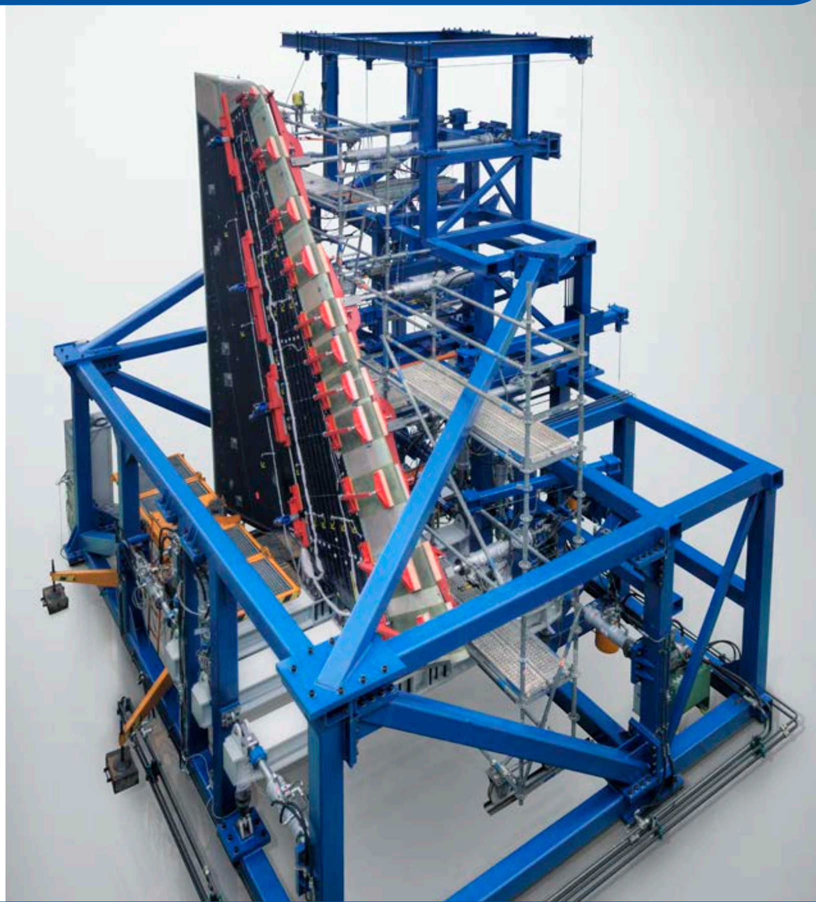

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of the present work is to use these interactions to get the third-order elastic constants (TOEC), which are linearly related to the sought acoustoelastic constants. Surprisingly, there are very few publications about the nonlinear interaction at surfaces of isotropic materials. Therefore, as a first step, we have to solve the forward problem of predicting the efficiency of harmonic generation and wave mixing for known TOEC. This is followed by the design of an appropriate experiment and the development of inversion strategies for extracting the TOEC from the measurement data.
In this work the current progress on the method development is presented. The possible interactions of surface guided waves and surface skimming bulk waves are described and formulae for the efficiency of harmonic generation and mode mixing are derived. First results for surface and bulk wave mixing with known second- and third-order elastic constants are shown. The concept of the inversion procedure for TOEC determination from the measurement data is introduced.

Fr.1.A.5 **09:50**

The Use of Pulse Compression Technique in Non-Destructive Testing: A Review

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Non-Destructive Testing (NDT) refers to an extended group of techniques used both in research and industry, which are exploited for inspecting, characterizing and evaluating various kinds of materials and goods. Eddy Current Testing (ECT), Ultrasonic Testing (UT) and InfraRed Thermography (IRT) are among the most employed NDT methods. In the said methods, a short duration delta-like signal provided by different types of transducers is typically employed to excite the sample under test (SUT) within an extended bandwidth. Features of interest, e.g. presence of flaws and inclusions inside the SUT, can be extracted by analyzing the system's impulse response both in time and frequency domains. However, the maximum achievable Signal-to-Noise Ratio (SNR) is directly related to the source power. This limit can be overcome by using coded excitations together with Pulse Compression (PuC) technique. In fact, in PuC the frequency spectrum of the coded excitation can be tailored to suit the investigation of a given sample, while the SNR can be increased almost arbitrarily by enhancing the signal time duration. Finally, the system's impulse response is retrieved by applying the PuC algorithm on the acquired data. In this paper, the use of PuC technique in IRT, UT, ECT will be reviewed and discussed.
A common method to enhance the fatigue life of components is the introduction of compressive residual stress in the components' surfaces which suppresses the surface crack growth under (cyclic) tensile load. One major application is the surface treatment of blade discs in jet engines, produced of titanium and nickel based superalloys. Up to the moment, the presence of compressive stress can only be evaluated either during production by reference samples (Almen stripes) or with destructive (borehole drilling)/laboratory (x-ray) methods.

Fr.1.B | DIFFERENT METHODS (Technical Session)

Fr.1.B.1 **08:30**

Impact of UV LED Technology to the Fluorescent Magnetic Particle Inspection (MPI) and Penetrant Inspection (FPI)

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UV LED technology is about to completely substitute discharge bulb based UV sources in NDT.
UV LED Technology offer possibilities to NDT the industry never had before.
The new technology has a fundamental impact to the fluorescent inspection processes. This impact is bigger than any other development in this field since decades.
UV LED Technology can sustainable improve the inspection process performance, but it is also able to critically affect the process adversely. This presentation will explain the physiology of the human vision, how the lamp characteristics affect the strain and performance of the inspector and how the inspection can be made better, easier and faster, while reducing the costs of the inspection.

Fr.1.B.2 **08:50**

Acoustic Shearography for Defect Detection in Aircraft Materials

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Shearography is a full-field non-destructive imaging technique which is suitable for large area and fast inspection of aircraft materials and structures. Conventional shearography methods are limited to the inspection of composites or compliant materials due to the ineffectiveness of conventional stress loading methods such as thermal, vacuum and vibration loadings for rigid materials and structures. Recently, we have demonstrated that it was feasible to use acoustic waves as stress loading in a shearography testing for defect detection. The wave-based acoustic shearography method not only extends the applications of shearography technique to rigid materials and structures but also significantly improves the detection depth and detection sensitivity of shearography technique. In this work, we report the demonstration of a wave-based acoustic shearography method for defect detection in metallic and composite materials used in aerospace structures. Piezoelectric acoustic transducers were used to generate acoustic waves in the testing materials. The acoustic waves interact with surface or sub-surface detects in the materials, which leads to changes in surface deformation.
These changes were captured by a charge-coupled device and the defects were imaged directly in a shearography testing. We systematically investigated the optimal testing frequencies of the acoustic shearography method with various piezoelectric acoustic transducers. Experimental results showed that the optimal testing frequency of the acoustic shearography technique is dependent on the characteristics of the piezoelectric acoustic transducers instead of the defects. Unlike vibration-based shearography technique which is dependent on the defects resonances, the wave-based acoustic shearography technique significantly improved the reliability of shearography testing. In addition, by controlling the acoustic waves, the detection depth and the detection sensitivity of the shearography technique were substantially increased. The wave-based acoustic shearography provides a novel and useful NDT tool for practical applications in aerospace industry.

Fr.1.B.3 09:10

Phase contrast tomography: a powerful tool for advanced NDT and 3D material characterisation

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Although NDT techniques are very efficient for the detection of defects in any types of part or materials, measuring the precise 3D location and geometry of the defects rapidly requires the use of X-ray computed tomography. It is the only nondestructive technique that allows for a straightforward quantification and measurement of any type of internal defects, through 3D digitization. The spatial resolution can be varied between sub-micron and few tenths of millimeter.
Today, the main limits of laboratory or industrial CT are (i) a limited X-ray energy and/or lack of spatial resolution to characterize fine cracks or porosities especially in metallic parts (ii) a lack of contrast to detect lightweight material in presence of denser materials (metallic or ceramic pieces).
Phase contrast tomography pushes back the limits of the current technology and provides an outstanding image quality and enhanced phase segmentation capability. Thanks to phase contrast which can be up to 1000 times higher than absorption contrast, the limit of detection of small defects is greatly enhanced and, even at high energy, it is possible to visualize both polymer and metallic components in a composite material or a complex part.
Today most of the phase contrast techniques are only accessible at synchrotron facilities where the spatial coherence of the source is required and can be fully exploited. Among the phase contrast techniques that can be transferred to laboratory sources, Novitom has worked on near-field speckle-based imaging (SBI) which is an innovative and recently introduced method whose interest from the community is growing due to its easiness of implementation even on low coherence sources. The distortions of a random reference speckle pattern induced by the sample are numerically tracked to reconstruct absorption and phase maps.
After the illustration of the advantages of phase contrast through several practical examples such as the rugosity characterisation of inaccessible surfaces in AM parts, the detection and analysis of cracks inside metallic components or the dimensional control by 3D mapping of the geometrical deviation from CAD files, the presentation will show the perspectives of speckle-based imaging transfer to conventional laboratory sources.

Fr.1.B.4 09:30

Measurement of thermal diffusivity of solids and thermal resistance of cracks using Flying Spot Thermography

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We propose several methods, based on laser spot infrared thermography, to measure the in-plane thermal diffusivity and to characterize the width of vertical cracks in aeronautical materials. These methods are valid in two complementary configurations of practical interest: (a) When the laser spot remains at rest and the sample is moving at constant velocity (as it is the case of in-line production or in-line quality control process in factories) and (b) when the sample is at rest while the laser spot moves at constant velocity (“Flying Spot”), which is of interest to test big parts.
By analyzing the surface temperature recorded by the infrared camera in logarithmic scale, three simple linear relations are obtained, whose slopes give the thermal diffusivity in the direction of the sample movement and in the perpendicular direction. These linear relations are valid for both opaque and semitransparent samples. Measurements performed on calibrated samples (thermal insulators as well as thermal conductors) confirm the validity of the methods. Moreover, we propose to use a robotic arm to analyse large samples of complex shapes. The main advantage of using the robot is to scan the complete area of the sample while orienting the non-flat surface of the sample perpendicularly to the optical axis of the infrared camera. The final product is a thermal diffusivity map of the sample allowing a fast visualization of heterogeneities and anisotropies.
Besides, both configurations are also used to characterize the thermal resistance (the width) of vertical cracks, which produce a discontinuity in the surface temperature field. An analytical expression for the latter has been found. By fitting the temperature profile along the laser (or sample) movement direction, the thermal resistance can be obtained. We have prepared calibrated vertical interfaces by inserting very thin metallic tapes (1 – 20 micrometers) between two blocks of the same material. The agreement between nominal and retrieved thermal resistances confirms the validity of the model.

Fr.1.B.5 09:50

Characterization of open and kissing vertical cracks using vibrothermography

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Ultrasound excited thermography or vibrothermography has arisen as a promising nondestructive evaluation technique due to its ability to detect cracks in a wide variety of materials. In this technique, the specimen is excited mechanically, with ultrasounds. This mechanical energy is converted into heat at cracks mainly due to friction between the crack faces. In metals, where ultrasounds damping is low, vibrothermography is a defect selective technique in which the flaw is revealed as a hot spot at the surface, which is monitored with an infrared camera.
The step beyond detection is the characterization of flaws. In this work, we present our approach to characterize the geometry and location of open surface breaking as well as kissing buried cracks from surface temperature data obtained in vibrothermography experiments. First we present the calculation of the surface temperature distribution generated by vertical heat sources of different geometries. Then we tackle the inverse problem. From a physical point of view, it consists in retrieving the heat flux generated at the crack. We do not assume any geometry of the heat flux, only the vertical plane containing the heat sources is assumed as prior knowledge. We address the problem as a least square minimization in which we mesh the vertical plane containing the heat sources and find the heat flux at each node that minimizes the squared differences between the data and the calculated temperatures. Due to the diffusive nature of heat propagation, this is a severely ill-posed inverse problem, and the minimization is unstable. We have developed a stabilized inversion algorithm that is able to retrieve the area and depth of the heat sources. We present inversions of synthetic data with added random noise to prove the ability of the algorithm to characterize heat sources of different geometries located at different depths, and we analyze the effect of the noise level in the data on the accuracy of the reconstructions. Finally, we present inversions of experimental vibrothermography data obtained from samples containing calibrated heat sources. The results show that it is possible to characterize the heat flux distribution down to a depth of 6 mm in AISI-304 stainless steel.

Fr.1.C | STRUCTURAL HEALTH MONITORING
(Technical Session)

Fr.1.C.1 **08:30**

Guided wave-Gaussian mixture model based damage monitoring method under varying load conditions

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The low reliability of damage monitoring under Time-Varying Conditions is a key challenge for the practical application of Structural Health Monitoring (SHM) technology to aircraft structures. Among the existing SHM methods, Guided Wave (GW) and piezoelectric sensor based SHM technique is a promising method due to its high damage sensitivity and long monitoring range. However, the reliability problem still should be addressed. To deal with this problem, a Guided Wave-Gaussian Mixture Model (GMM) based damage monitoring method is proposed. The probability distribution of GW features under Time Varying Conditions is represented by the GMM. In this method, an adaptive probability density peaks search clustering is proposed to initialize the GMM first. Then a unique GMM constructed by the Expectation Maximization algorithm is enabled to change with the Time Varying Conditions. Finally, the damage is evaluated by measuring the variation of GMMs. The utility of the proposed method is validated in the hole-edge crack monitoring of an aluminum tension sample under varying loading condition.

Fr.1.C.2 **08:50**

Non-uniform spatial sampling patterns for local wavenumber-based damage evaluation

J. Spytek[1], *P. Rusin*[1], *K. Dziedziech*[1], *L. Pieczonka*[1], *L. Ambrozinski*[1]
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A crucial factor for non-destructive inspections is time required to test the structural components. Local-wavenumber estimation of guided ultrasonic waves is a promising technique that permits to balance the required spatial resolution with the inspection time. In this method a single source generates guided waves propagating in a plate. Using laser interferometry the vibration responses are collected in a number of points. Next, the data are processed in the frequency-wavenumber domain to obtain spatial distribution map of the wavenumbers. Change of the wavenumber is typically due to a local change in thickness of the sample. Therefore, this method can be effectively applied for detection of corrosion patches, delamination, disbounds.
Usually, the measurement points are spaced uniformly at a distance smaller than half of the wavelength to satisfy the Nyquist theorem for spatial sampling. However, as we show in the paper, different distributions of sensing points are also possible. We discuss the imaging performance of various spatial sampling schemes using phased arrays of limited aperture and extend this concept to laser-probing over the complete imaged surface.

Fr.1.C.3 **09:10**

Monitoring of structures and systems of aircraft by highly non-linear sensing devices

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Sensing systems, especially when used for interrogating the structural integrity of aircraft in traditional inspections, are frequently working in a quasi-linear mode. This approach however creates difficulties in some cases, especially when applications for structural health monitoring (SHM) are concerned. One of the major problems are base-line deviations interfering with damage-related signals that are in some cases moreover complicated due to interferences at complex aircraft structures creating major obstacles for a broad-scale implementation of SHM in aircraft. Advanced data processing and dedicated high-end hardware components are certainly capable of tackling part of these problems, but additional hardware requirements require extra power supply, together with advanced data transmission and processing facilities, also additional maintenance needs emerge.
In some cases, an interesting alternative is offered by highly non-linear sensing devices. They produce a sharp sensor response that ideally only depends on a certain damage-related outer parameter representing in this way a material-based threshold. Moreover, this sharp sensor response ideally ranges over many orders of magnitude above the baseline variations and in this manner, an ideal tool would be established to finally enormously increase the probability of detection, at least within the range of damage to detect.
After a short review on examples taken from the literature, that are in some cases successfully applied in operations, new developments are presented, such as water leakage sensors based on the percolation effect, dedicated optical sensors for reliably detecting damage in hydraulic pipes as well as defects in bleed air ducts. Most of them are able to cover bigger surfaces and are, when appropriate, also partially equipped with dedicated facilities for reliable damage localisation. Finally, a couple of examples are given that were already implemented in operational airliners, such as devices for the detection of corrosive liquids in aircraft (Boeing 737-500, Boeing 747-400).

Fr.1.C.4 **09:30**

A Bayesian Probabilistic Approach for Damage Imaging Utilizing Response at Vibration Nodes

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Most of the Structural Health Monitoring (SHM) methods are struggling between the number of sensors and the accuracy in damage detection. This paper explores the possibility of using a Bayesian probabilistic approach for damage imaging utilizing dynamic response at a few vibration nodes. The vibration amplitude at the nodal points can be considered as an efficient structural damage indicator (SDI). This SDI serves as not only a global but also a local indicator, as nodal points are part of vibration mode shapes. Instead of giving a rough damage detection result, the posterior probability density function of the damage parameters is calculated under the Bayesian statistical system identification framework to quantify the confidence level of the identified results, which can be further interpreted as damage imaging results. In addition, the uncertainty in measurement due to the problems of measurement noise and time-varying environment can also be revealed by the framework. In the present paper, several case studies demonstrate the advantage and feasibility of the proposed method.

Fr.1.C.5 **09:50**

Tailored Embeddable Sensor-Actuator Layers for CFRP Aerospace Structures

S. Nitschke[1], *A. Hornig*[1], *A. Winkler*[1], *N. Modler*[1]
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The increasing structural integration of fibre-reinforced composites and the growing demand for more electrical and intelligent structural components are one of the future markets for aerospace and aviation industry to master growing economic and ecological challenges. Fibre-reinforced composites offer the opportunity to embed sensor and actuator networks in the material, which is of particular relevance for example for structural health monitoring (SHM) applications. In order to maintain the structural integrity and necessary safety margins of the carbon fibre-reinforced plastic (CFRP) components, the elements (e.g. sensors, conducting paths, carrier layer, etc.) which will be integrated will have to be selected by extensive experimental characterization. To realize this, a methodology has been developed to embed tailored functional layers, assembled with piezo ceramic elements, into structural components made of CFRP. Due to the high sensitivity, high temperature stability, commercially availability as well as the variable small element sizes of the piezo ceramic elements, they are predestined for the integration into CFRP. The resulting smart structures provide both, sensoric and actoric functionalities. Thus, the developed Tailored Embeddable Sensor-Actuator Layers (TEmSAL) are particularly characterized by „off-the-shelf" manufacturing, cost-efficiency, a high automation capability, tailored sensing capabilities for customized applications and parts, and a low impact on mechanical CFRP properties. The presented investigations show the aspects of the characterization and manufacturing strategy on specimen level, the resulting structural properties of the CFRP material and sensor as well as actuator performance. Additionally, TEmSAL CFRP engine components will be covered as an outlook for further investigations and applications.

P1

A new non-contact measuring method for the evaluation of the curing status of glued lightweight components based on ultrasound

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Curing processes of adhesives depend on application conditions such as temperature or humidity. In most times manufacturer information like pot life and processing time are not directly transferrable to the actual application, so that large safety factors in the curing time are taken into account. There are only a few non-destructive test methods that can be used to monitor the hardening processes of adhesives placed between lightweight structures. Often laboratory methods are used here which are not process-capable, have low penetration depths, high system costs and can only be applied to the adhesive itself and not to adhesive bonded component systems. Air-coupled ultrasound overcomes these limitations. A corresponding test setup and an evaluation method for the determination of ultrasound parameters that allow conclusions to be drawn about the degree of curing are presented. The evaluation method takes the influence of different ultrasonic modes into account to ensure a precise curing monitoring also in case of varying wall thicknesses of glued technical structures. The procedure is presented and discussed by means of adhesive bonded overlap joints. The referencing is carried out by rheological, nuclear magnetic resonance and differential scanning calorimetry investigations.

P2

Multiple-Flash Shearography – a New NDT Method for Reducing Thermal Stresses During the Inspection Process

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For the first time we present results of shearography measurements on fiber reinforced plastics samples being thermally excited using a flash sequence. Similar to lock-in shearography, flash shearography permits yielding higher contrasts and signal-to-noise ratios than conventional shearography and obtaining depth information of defects. For this, shearographic measurements are continuously taken during cooling of the samples. The resulting stack of images is afterwards analysed with regard to selected frequencies using Fourier-transformations. Depending on the chosen frequencies and on the sample's material, defects can be detected up to different depths. We find that flash shearography yields results of a quality similar to that of lock-in shearography while enabling much shorter measurement times. Utilizing the novel multiple-flash shearography which excites the device under test with a burst of lower energy flashes, it is for the first time possible to heat the structure with a sequence of flashes with adjustable flash duration, voltage and energy. This creates the possibility to use lower energy pulses, thereby reducing maximum surface temperature and thermal stresses while leaving the detectability of defects unimpaired. In a research project between Hensel-Visit GmbH & Co. KG and SKZ, a suitable pulse generator was developed and will be commercially available soon. Corresponding references measurements were carried out with the help of high speed thermography.

P3

Deconvolution of laser-ultrasound signals for suppression of surface wave artifacts in high resolution imaging of composites

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Recent developments in laser-ultrasound (LU) enable high resolution imaging of carbon-fiber reinforced plastics (CFRP) in a fully non-contact manner providing image quality comparable to X-ray computed tomography. The technique is suitable for both in production and in field inspections permitting detection of inclusions, delaminations and even imaging porosity, wrinkles and evaluate damages resulting from heat effects. Broad-band unipolar laser pulses offer superior resolution that permits resolving individual composite plies. On the other hand, laser excitation operating in the thermo-elastic regime can produce different elastic modes simultaneously. Shear and surface waves signals superimposed with longitudinal waves create image artifacts hindering data interpretation and damage detection in B-scans. Usually, surface waves can be observed as a low frequency component occurring after the front wall impulse. In this paper we present a signal processing technique to suppress these unwanted components. The method is based on deconvolution of each A-scan using a reference signal designed to reassembling temporal and frequency characteristics of the surface signal. The resulting B-scan images are significantly improved compared to the original one; the method is able to remove the unwanted components preserving damage-related features.

P4

3D visualization of ultrasonic scanned data in the context of test methods for the approval of civil aeronautical components

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The aviation of the future is a driving force for the further development of the global, highly interconnected civilization. By 2050, the number of flights in Europe alone will increase from currently nearly 10 million aircraft movements to about 25 million per year. Megatrends such as globalization, logistics and mobility as driving forces for it have to be balanced with the global challenges of resource conservation, environmental and climate protection as well as sustainability. Energy efficiency will be the key to create the necessary balance. These development trends are related to the use of new energy efficient and resource-conserving materials in the context of new comfortable and interconnected airframe and cabin concepts. Furthermore, they partly demand completely new standards for aircraft construction and maintenance of the future with regard to aspects such as test, inspection and maintenance. This results in an increase of the requirements on engineering, particularly on proving the lifetime of new materials and structures. A variety of development-related tests are needed to finally prove the resistance of the entire aviation structure and to guarantee its integrity.
IMA Materialforschung und Anwendungstechnik GmbH (IMA Dresden) offers all opportunities to compare material usage and construction principles, to verify calculation methods and to experimentally study different influences on strength combined with non-destructive testing methods. In lightweight construction in aviation, minor damages caused by fatigue or external impacts are no taboo but rather are a part of the security concept ´damage tolerance´ – the largest area in the spectrum of our experiments. IMA Dresden examines, when and where damages occur, how they increase, which residual strength remains and how a structure reacts to e. g. cyclic loads after an impact.

There, the specialists for non-destructive testing of IMA Dresden assist with the most appropriate process in each test and inspection phase. The concept of non-destructive testing aims at the quantitative determination of all arising damages and at their earliest recognizability.
An overview of materials and test methods for aerospace components is given in the poster contribution and a 3D visualization of ultrasonic scanned data is presented there.

P5

Numerical study of laser-ultrasound excitability using multiphysics finite-difference approach

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Recently laser-generated ultrasound has emerged as an attractive nondestructive inspection approach for aircraft structures inspections. One of the most important advantages of this method is possibility to develop fully non-contact system in which both wave generation and response measurement is implemented via laser-based techniques. Crucial aspect of an effective inspection system is an appropriate excitation characteristics. This requires in-depth understanding of the influence of spatial and temporal source characteristics of the elastic wave generation. Although some analytical and experimental analysis can be performed for source optymalization, numerical simulations are needed for close insight into the physics of ultrasound wave excitation in real structures.
In the presented paper, the excitability of ultrasonic waves with a pulsed laser source is investigated through finite difference-based numerical simulations. Various spatial source distributions are considered including: line source, Gaussian pulse, Gaussian ring shape pulse and exponential function. Influence of the beam shape on the wave generation mechanism is analyzed and compared with analytical models. The performed numerical simulations assume laser-induced excitation operating in the thermoelastic regime, which needs to be maintained to keep the method nondestructive. In the thermoelastic regime the mechanism of wave generation is based on thermal expansion of the irradiated surface. Therefore, numerical modelling of this process requires multiphysics approach that accounts for coupling of the heat transfer and the elastic wave equations. In the established numerical model, the thermoelastic generation process is performed in two-stage numerical simulation. First, the heat transfer with laser irradiation as an external source is modelled on a fine grid using finite differences technique. Next, the force resulting from volumetric thermal expansion is applied to the wave propagation model established using Local Interaction Simulation Approach.

P6

The thermoacoustic effect and its application in air-coupled testing of composite structures

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Airborne ultrasonic testing of lightweight, structured composite materials enables fast and contact-free non-destructive testing in aerospace and avoids material degradation due to contact with a coupling liquid. Established resonant air-coupled transducers consist of piezocomposite materials and several matching layers or more advanced materials like charged cellular polypropylene. The relaxation time and the specific frequency of such mechanical ultrasound emitters limit the spectrum of applications for each device. A short pulse length is key for reliable defect detection and each component at test can be best characterized at material- and geometry-specific frequencies. Here we show that focused thermoacoustic transducers are suited for testing lightweight, structured composite plates. Since the ultrasound is generated in air, these transducers show no resonance behavior and emit a broadband acoustic spectrum between 1.2 kHz and 1 MHz. Composite specimens of 3 mm to 9 mm thickness made of polylactide with a honeycomb structure were tested. Flat bottom holes were introduced to quantify the spatial resolution of the imaging method inside the strongly anisotropic specimen. As no broadband receivers are available yet, cellular polypropylene transducers were used as receivers, which limits the bandwidth of the method towards the bandwidth of the receiver. Nevertheless, we demonstrate the competitiveness of the thermoacoustic transducer compared to mechanical emitters at their respective resonance frequencies. Because a thermoacoustic transmitter features a nearly ideal pulse width, a single transmitter can be coupled with receivers with different resonance frequencies. With the development of broadband ultrasound receivers, air-coupled ultrasound spectroscopy will likely be possible in the near future. The analyzed transducer holds the potential to speed up testing during production and maintenance in aerospace and automotives. Its combination with a broadband receiver could also expand the application field of air-coupled ultrasonic testing from a qualitative error detection towards a quantitative, spatially resolved analysis of mechanical material properties.

Exhibitors

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Profile

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Profile

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Profile

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Profile

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Profile

Fraunhofer IKTS conducts applications-oriented research in the field of high-performance ceramics. The institute‘s three sites in Dresden and Hermsdorf (Thuringia), Germany, collectively represent Europe‘s largest R&D institute dedicated to the study of ceramics.
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Profile

Definitely Tested!
The privately owned company KARL DEUTSCH was founded in 1949 and develops and produces instruments for non-destructive material testing. Portable instruments, stationary testing systems, sensors and crack detection liquids are produces by 130 motivated employees in two works in Wuppertal. Additional 20 employees in international offices and a worldwide network of dealers support the export business which accounts for more than 50% of the turnover. Our customers are metal producing and processing industries, e.g. steel works, automotive companies and bearing manufacturers. Typical test tasks are ultrasonic weld testing, detection of shrink holes in castings, crack detection in forgings with magnetic particles and dye penetrants, safety components for railway and aerospace as well as the wall and coating thickness measurement.
Characterised by continuous innovation and product reliability, the trademarks ECHOGRAPH, ECHOMETER, GEKKO/MANTIS, DEUTROFLUX, LEPTOSKOP, FLUXA, KD-Check and RMG are well-recognised.
GEKKO and MANTIS are recognized benchmarks in PAUT performing all relevant techniques as sector-, linear- and compound scans plus FMC recording and TFM. Field proven and easy to use both units cover the widest range of applications in industry and inspection.

KU Leuven

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Profile

The KU Leuven is a Dutch-speaking university in Leuven, Flanders, Belgium. With almost 60000 students, it is the largest university in Belgium and the Low Countries and according to the Reuters‘ list, also the most innovative university of Europe. KU Leuven presents a selected range of technologies that were developed with industrial partners, such as Brussels Airlines, Lufthansa Technik of PFW Aerospace, Siemens-LMS, that are partially already implemented in aircraft. It regards sensing systems for structural damage and leakage as well as new materials. KU Leuven presents its range of expertise and pre-commercial products to come in contact with industry and create awareness on the potential collaborations. The added value of those technologies regards innovative approaches to solve persisting problems in maintenance operations of aircraft. The solutions can easily be tailored to specific requirements and the certification thresholds are low, such as in the case of water leakage monitoring developed for Lufthansa Technik, monitoring systems for leakage of hydraulic liquid, fuel and bleed air for PFW Aerospace, fuselage dent quantification by digital image correlation and others.

POLYTEC GmbH

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Profile

Polytec has been bringing light into the darkness for 50 years. With more than 400 employees worldwide Polytec developes, produces and distributes optical measurement technology solutions for research and industry.
Laser Doppler vibrometers from Polytec are firmly established as gold-standard for non-contact vibration measurement. Dedicated to reveal the true vibrations of a structure – with zero-mass loading, from long stand-off distances, with laser precision and Xtra sensitivity – they measure on almost any surface including on light-weight structures and enable NDT and lamb-wave testing. Clear and reliable vibration measurement leads to cost-efficient research and development enabling a fast time to market.

SECU-CHEK GmbH

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Profile

SECU-CHEK is a German NDT Expert who develops and manufactures technology leading UV LED lamps to make fluorescent magnetic particle and penetrant inspection faster, easier and fatigue-proof.SECU-CHEK UVE Series lamps enable the inspector to perform the inspection better than using any discharge bulb based UV sources without any compromises, limitations or degradation of the process. The UV-formity® technology makes the UVE series lamps to extreme uniform Flood Lamps with usable beams (area with more than 100 µW/cm²) up to double as large as the usable beam of Mercury vapour lamps and up to 10 times as large as the beam of common focused UV LED handlamps (with hard drop off to the edges).
These large beams with soft and smooth drop from the center to edges ensure fast and secure detection of indications, full orientation within the inspection area and allow ergonomic inspection where the lamp intuitively follows the focus of the eyes while having a totally clear and sharp view, even in short distances.
The hand flood lamps of the UVE series have a central beams (area with more than 1.200 µW/cm²), that is up to 7 times as larger as the central spot of a Mercury vapour lamp for optimal observation with the central vision.
Integrated features (like automatic white light dimming, UV LED monitoring, ECO-Mode and low battery security switch-off) make the lamps to the most reliable and secure tools for mission critical applications like fluorescent inspection without any additional burden to the user. All UVE Series Flood Lamps fulfil all major requirements like ASTM E-3022, Rolls-Royce RRES 90061, NADCAP and Airbus AITM 6-1001 (Issue 11). The individual test report can be ordered as required.

SHERWIN BABBCO / SHERWIN INC.

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Profile

Offering NDT products and materials throughout the world. The companies combine the resources of Sherwin Incorporated (USA), a leading penetrant manufacturer, and Babbco (France), a leading NDT products and materials provider.
We provide NDT materials, such as Dubl-Chek fluorescent and visible penetrants. We also offer magnetic particles and ultrasonic couplants. In addition, the companies supply a complete line of equipment and accessories for use with liquid NDT materials.
The companies have complete staff in the USA and EUROPE to provide NDT technical engineering and support. Services include consulting, equipment, accessories, and equipment calibration.
As a single source for liquid NDT materials, technology, and services, SHERWIN and SHERWIN BABBCO give their clients the best value and service through all phases of Penetrant and Magnetic Testing. From concept and design, through materials acquisition and usage, to after-market support, they are there for you.
PENETRANT – DEVELOPER – CLEANER – MAGNETIC INK – MAGNETIC POWDER
„THE reliable, worldwide source for Penetrant and Magnetic Testing“
„Products, Equipment, Services and Advice“

SONOTEC Ultraschallsensorik Halle GmbH

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Profile

SONOTEC is a leading specialist in ultrasonic measurement technology solutions with more than 25 years of experience. Together with more than 165 employees we develop and manufacture ultrasonic transducers and sensors as well as testing equipment and measuring technology solutions for non-destructive testing, preventive maintenance as well as medical technology and biotechnology.
In addition to our standard products, we work closely with our clients in order to develop specific solutions that meet their particular requirements. Together with you, our client, we initially analyse your exact measurement and metering requirements. This enables us to develop optimised ultrasonic solutions to suit your precise needs.
SONOTEC is headquartered in Halle, Germany.
Our US sales office is located in New York.

Trueflaw

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Profile

Trueflaw makes cracks and cracked samples for NDT. The cracked samples are used for training, method development and reliability assesment. The samples may range from simple plate samples to cracks manufactured into real components. Trueflaw also offers probability of detection (POD) evaluation services.
Recently introduced standard sample sets for aerospace applications make POD evaluation easier and more cost effective than ever before. With Trueflaw POD evaluation service, POD is so easy there‘s no reason to delay knowing your capability any more.

VOGT Ultrasonics GmbH

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Profile

For more than 35 years VOGT Ultrasonics, Hanover/Germany designs, configures and distributes automated and mechanized non-destructive testing systems and services for the inspection of metal and synthetic materials.
Innovative ultrasonic technology is the key to reliable and fast inspection in production and the laboratory. Whether it is a question of heavy-weight semi-finished products and forged parts, delicate welded seams or complex components: VOGT has a variety of methods and solutions to cope with the most varied of situations – from portable testing equipment to stationary high-precision systems.
VOGT offers customized design and engineering as well as installation, training of personnel and a full after-sales service for testing systems based on the VOGT PROline components which are marketed worldwide for various applications in laboratories, production lines and field operations.The fully digital, consumer orientated ultrasonic testing devices have a high potential for integration into mechanized and automated processes and therefore permit truly efficient quality control and process documentation. They belong to the premium class and therefore set standards. They decisively support the flexible and multifunctional usage. VOGT´s user-friendly associated ultrasonic inspection software PROlinePLUS focuses on a clear results presentation.
With the product line PHAsis, VOGT presented the first phased array spot weld inspection device offering a previously unattained physical resolution of the spot weld diameter more than 0.35. It was developed as the ideal solution for the requirements of fast and safe testing in production and in the laboratory.
VOGT also provides all conventional non-destructive testing services, as well as mechanized and automated ultrasonic inspection at your premises or in our testing centre. Our NDT technicians are certified according to ISO 9712 and qualified according to EN 4179.
Our extensive know-how, direct availability of NDT systems experts to customers and a partnership approach have led to successful completion of many projects all over the world.
VOGT is certified and accredited acc. to DIN EN ISO/IEC 17025 and ISO 9001, as well as EN 9100 and has representatives in major countries worldwide.