


InfraTec, Thermography and You

Agenda

- ➔ ☐ InfraTec
- ☐ Thermography
- ☐ Thermography in Materials testing – Methods
 - ☐ Thermal Treatment
 - ☐ Mechanical Treatment
 - ☐ Thermo-elastic stress analysis
- ☐ IR cameras
- ☐ Conclusion



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Thermographic Analysis of Mechanical Processes

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InfraTec, Thermography and You

Overview



FACTS

- ❑ Founded at Dresden in 1991
- ❑ Staff: 250
- ❑ Sensor Division
- ❑ Infrared Measurement Division

MISSION

Infrared technology specialists, offering best service and consultancy to customers and partners

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Sensor Division: Single and Multi Channel Pyroelectric Detectors

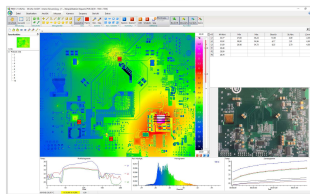
- ❑ Development, engineering and production of pyroelectric analogue and digital infrared detectors
- ❑ Production in 1,900 m² clean-room area in Dresden
- ❑ Modular concept with 50 standard detectors offers optimised solutions for nearly each application demands
- ❑ Development and production of customised single and multi channel IR detectors for:
 - ❑ Pyrometry
 - ❑ Gas and flame analysis
 - ❑ Heat and fire detection
 - ❑ Optical measurements



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Infrared Measurement Division: Development, Design and Production of Thermographic

- ❑ Thermographic systems for:
 - ❑ Research and development
 - ❑ Non-destructive testing
 - ❑ Process and quality control
- ❑ Turnkey solutions for:
 - ❑ Process monitoring
 - ❑ Automatic fire detection
 - ❑ Surveillance
- ❑ Thermography Training Courses
- ❑ Thermographic Services
- ❑ Thermographic Software
- ❑ Pre- & after-Sales Support



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In-time After-sales Customer Service for High System Availability



- ❑ > 35 years of thermography experience made available for our customers by:
 - ❑ Well designed products
 - ❑ Comprehensive application support
 - ❑ Feasibility studies
 - ❑ Qualified trainings at our headquarters and at customer sites
- ❑ Rental and lending service
- ❑ Up to 4 years guarantee (std. 2 years)
- ❑ Fast service response (24 h hotline)
- ❑ ISO 9001 certified



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Experts and Technology where They Are Needed



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More than 8,000 thermography solutions for customers all over the world



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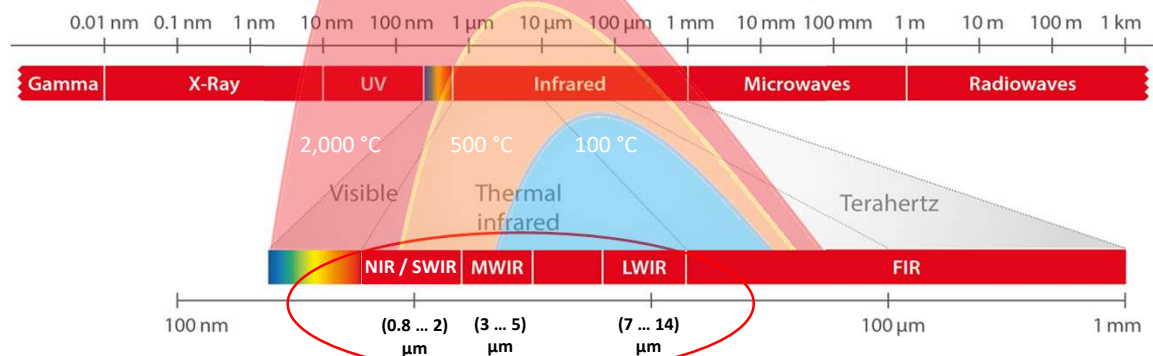
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Definition

- ☐ **Thermography** = Contactless (!) imaging & measuring (!) **InfraRed radiation** with FPA detectors
- ☐ Each object / material is emitting **IR radiation** because of its **temperature** > 0 (zero) Kelvin
 → IR-sensitive cameras measure IR-radiation and via Planck's law finally temperature as an **IR/T image**



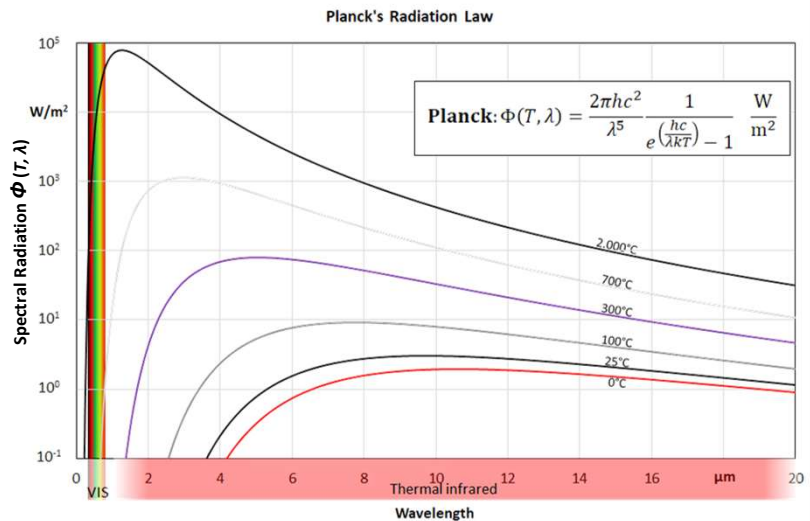
- ☐ MWIR and LWIR bands are most used for T-measurement – but SWIR as well can be beneficial

InfraTec, Thermography and You

IR Radiation → Temperature

- Every material / object is radiating electromagnetic radiation @ $T > 0$ Kelvin (-273.15 °Celsius)
- → (IR) Radiation is always and everywhere!!!
- Relation of Radiation Φ vs. Temperature T : Planck's Law:

$$\Phi_{\lambda} = f(T, \lambda)$$



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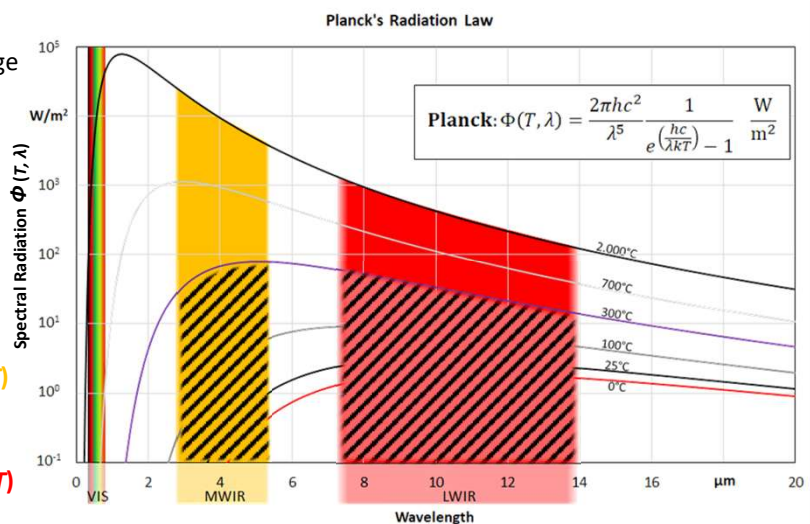
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IR Radiation → Temperature

- IR cameras are integrating over the MWIR or LWIR sensitive range → "Thermal wavebands" → "Thermal radiation"

- MWIR camera:
Sum ($\Phi_{\lambda(3 \dots 5) \mu\text{m}}$): $\Phi_{MW} = f_{MW}(T)$
- LWIR camera:
Sum ($\Phi_{\lambda(7 \dots 14) \mu\text{m}}$): $\Phi_{LW} = f_{LW}(T)$



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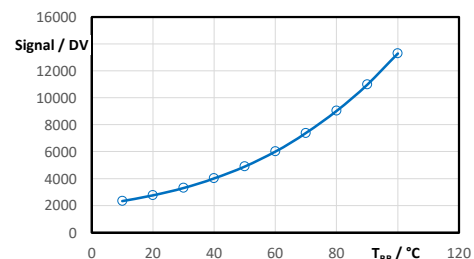
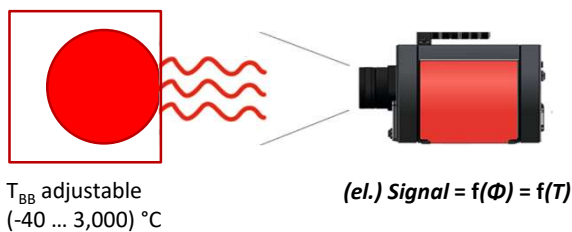
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IR Radiation → Temperature: Calibration

- ❑ A calibration is performed by using reference sources, called **Black Bodies**
- ❑ BBs are available for (-40 ... 3,000) °C equivalent radiation for MWIR and LWIR
- ❑ BBs are calibrated periodically
- ❑ Principle calibration process:
 - ❑ Camera temperature T_{cam} needs to be considered (rem.: IR radiation is always and everywhere!)



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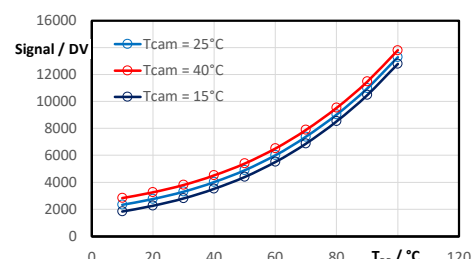
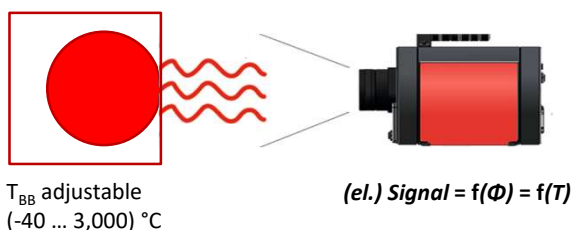
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IR Radiation → Temperature: Calibration

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Theory, Laboratory and Reality

- ❑ Black Body used as reference but “real” objects / materials are different due their optical properties:

❑ Emissivity / Emission coefficient ϵ:	Capability to emit (IR) radiation	$0 \leq \epsilon \leq 1$
❑ Transmissivity / Transmission coefficient τ:	Capability to transmit (IR) radiation	$0 \leq \tau \leq 1$
❑ Reflectivity / Reflection coefficient ρ:	Capability to reflect (IR) radiation	$0 \leq \rho \leq 1$

$$\epsilon_{\lambda} + \tau_{\lambda} + \rho_{\lambda} = 1$$

- ❑ Additionally: $(\epsilon, \tau, \rho = f(\lambda))$
- ❑ All these influences to the measurement are corrected within the analysis software

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Summary

- ❑ **Thermography** = Contactless (!) imaging & measuring (!) InfraRed radiation with FPA detectors
- ❑ **IR Radiation** = Electromagnetic radiation beyond the visible → red side
 - ❑ **MWIR & LWIR** = Most efficient and used IR ranges for (temperature) measurements
- ❑ **FPA Detector** = 2-dim array of detectors (= pixels) sensitive on IR radiation
 - ❑ **Quantum Detectors:** (Stirling) cooled, fast, snapshot, long-term stable, image-sync, SWIR, MWIR, LWIR
 - ❑ **Thermal Detectors (μ -Bolometers):** Rolling shutter, no cooler, cheap, LWIR
- ❑ **Measurement** = Calibration of the detected IR radiation into absolute temperature values
 - ❑ Physical relation of IR radiation and temperature of an object is described by **Planck's formular**
 - ❑ **Calibration** on accurate references allows absolute accuracy of $\pm 1 \%$ of reading; possible range (-40 ... 3,000) °C
 - ❑ **Emissivity ϵ** (0 ... 1) is a material-related value which requires correction of T-measurement (by software)

→ Thermography is an imaging method of precise and contactless temperature measurement!

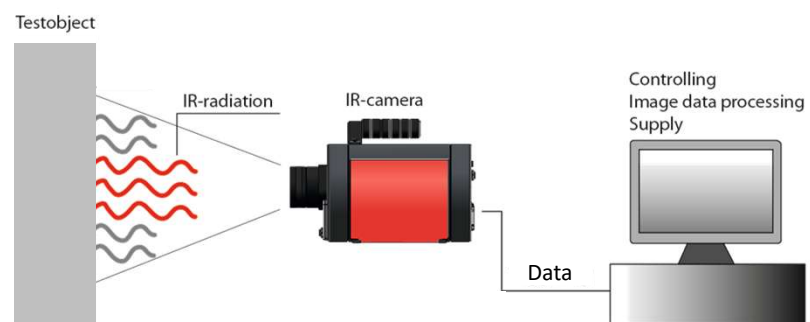
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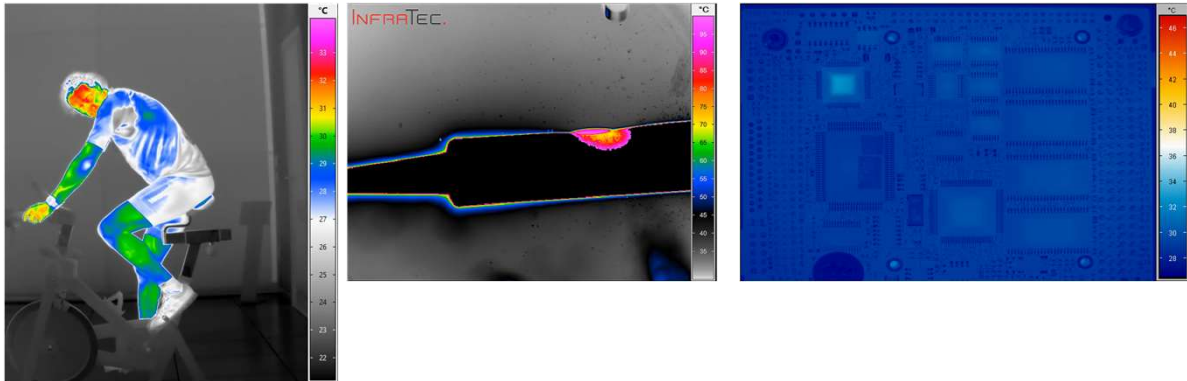
Passive Thermography – Principle



- ☐ Measuring the surface T-distribution of objects under „normal“ working conditions where the heat generation is part of the object's typical use – this is a „monitoring“

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Passive Thermography – Examples



- ❑ Measuring the surface T-distribution of objects under „normal“ working conditions where the heat generation is part of the object’s typical use – this is a „monitoring“

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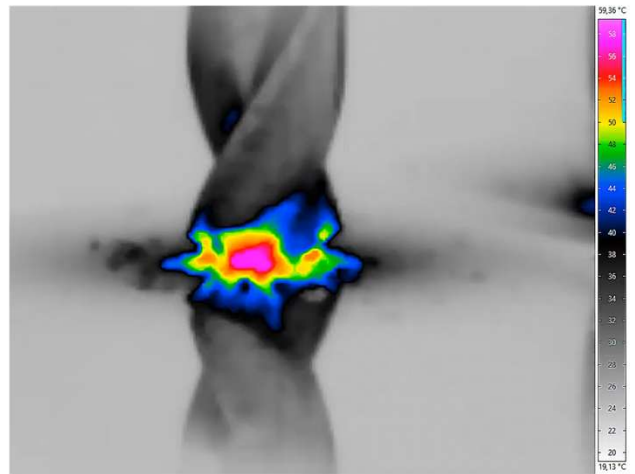
Thermography in Materials testing – Methods

- ❑ Observing thermal effects occurring during “normal” operation of materials/mechanics
- ❑ Testing materials/constructions by analyzing thermal “resistance” to analyze internal structure
- ❑ Testing materials/constructions by analyzing thermal response on simulated operation

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Drilling on stainless steel

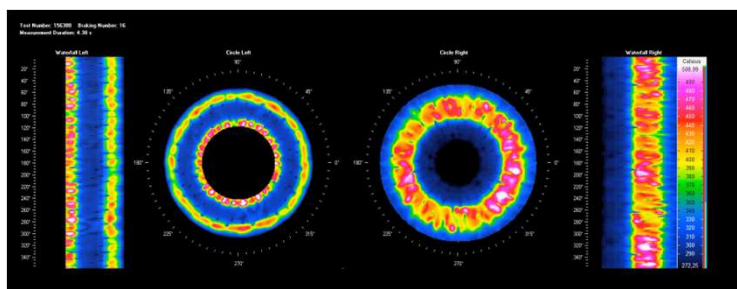
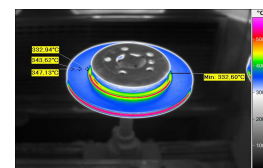
- ❑ Testing tool quality via thermal analysis during normal or overload conditions
- ❑ Challenge: IR reflecting materials
- ❑ High-speed 650 fps

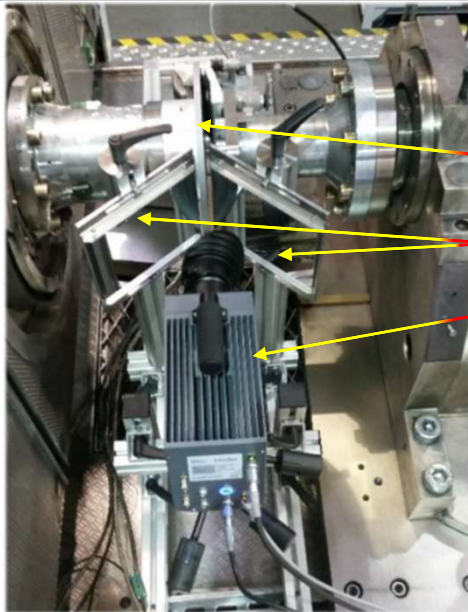


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THERMAL ROTATE CHECK: Solution for Testing of Fast Rotating Objects like Tires or Brake Disks

- ❑ Test bench for brake disc analysis, synchronized online for both sides of brake disc
- ❑ Measurements conducted at normal load and speed (300 km/h)

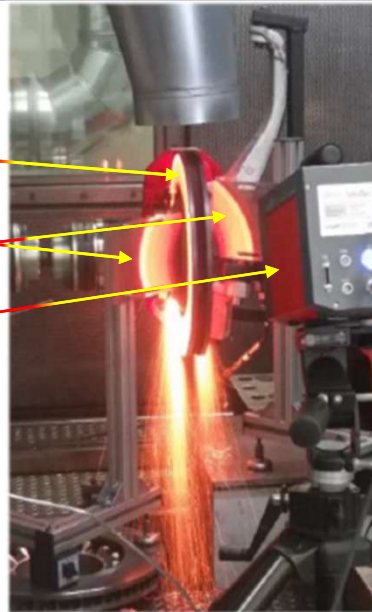




Break
Disks

IR Mirrors

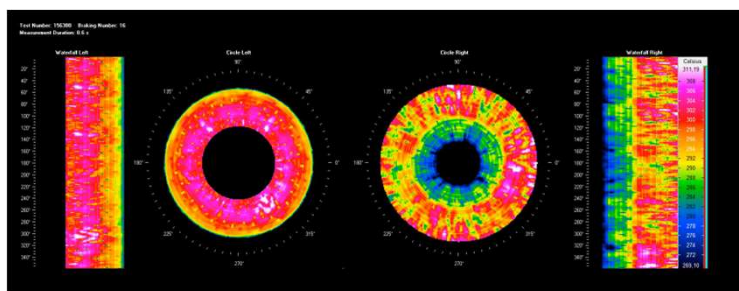
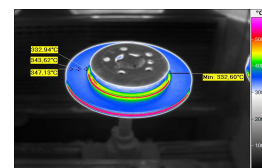
IR Camera



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THERMAL ROTATE CHECK: Solution for Testing of Fast Rotating Objects like Tires or Brake Disks

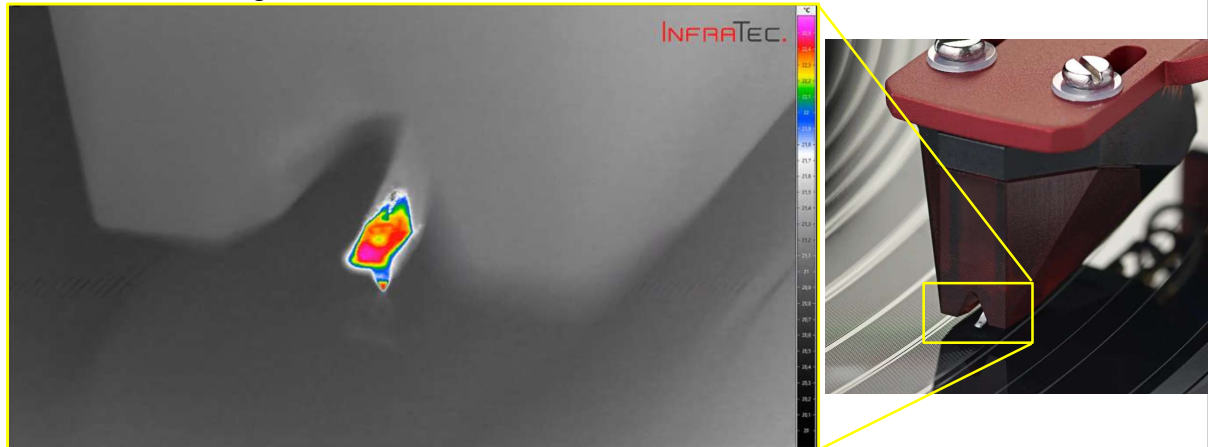
- ❑ Test bench for brake disc analysis, synchronised online for both sides of brake disc
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Low-Level friction

- ❑ Turn-Table needle in Action
- ❑ Even smallest heat generation based on rather low friction can be detected in real-time.



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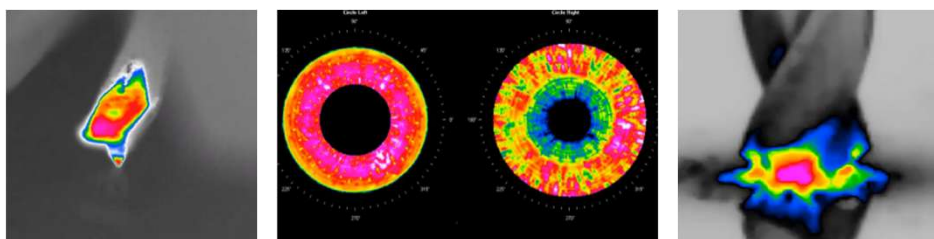
Pick-up Visual: © www.audiolounge.co.uk

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Thermography in Materials testing – Methods

- ❑ Observing thermal effects occurring during “normal” operation of materials/mechanics



- ❑ Testing materials/constructions by analyzing thermal “resistance” to analyze internal structure
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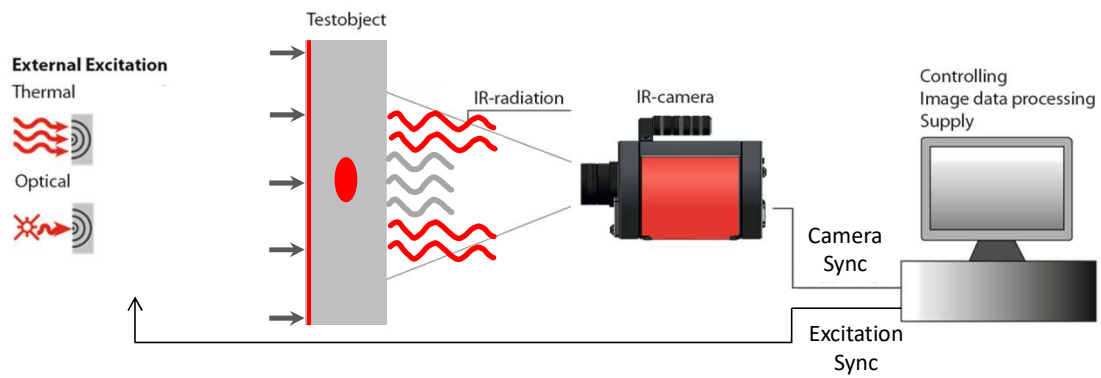
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Active Thermography – Principle – External Heat Generation (on Back Surface)



- Heat generation on the (back) surface of the material – „transmission“ mode

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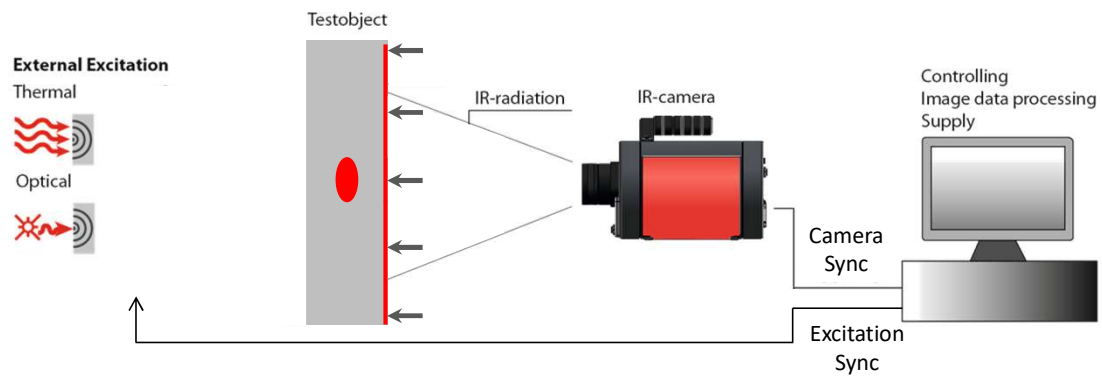
Active Thermography – Principle – External Heat Generation (on Back Surface)

- Welding seam inspection – Pulse-phase analysis for hidden defects



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Active Thermography – Principle – External Heat Generation (on Front Surface)

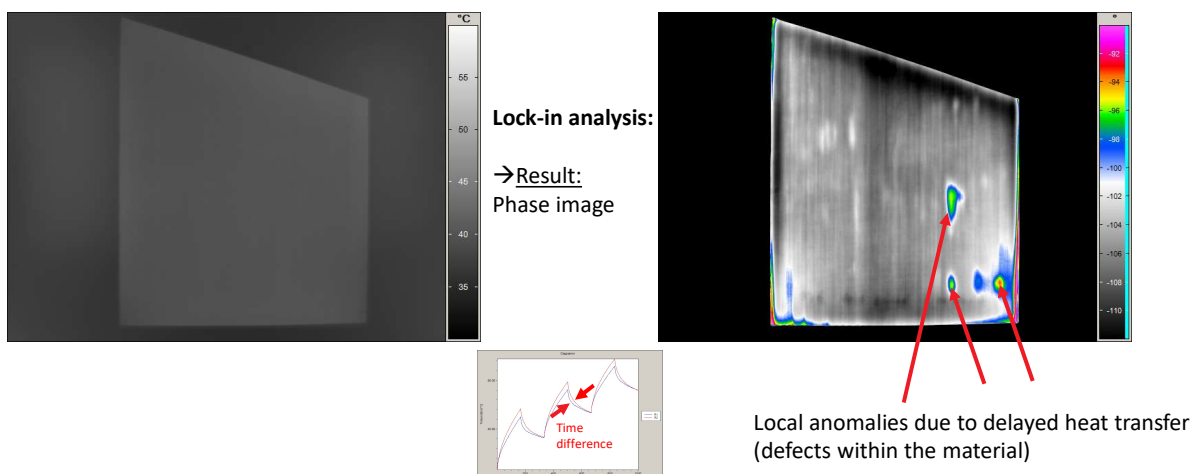


- Heat generation on the (front) surface of the material – „reflection“ mode

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Active Thermography – Example – Reflection Mode

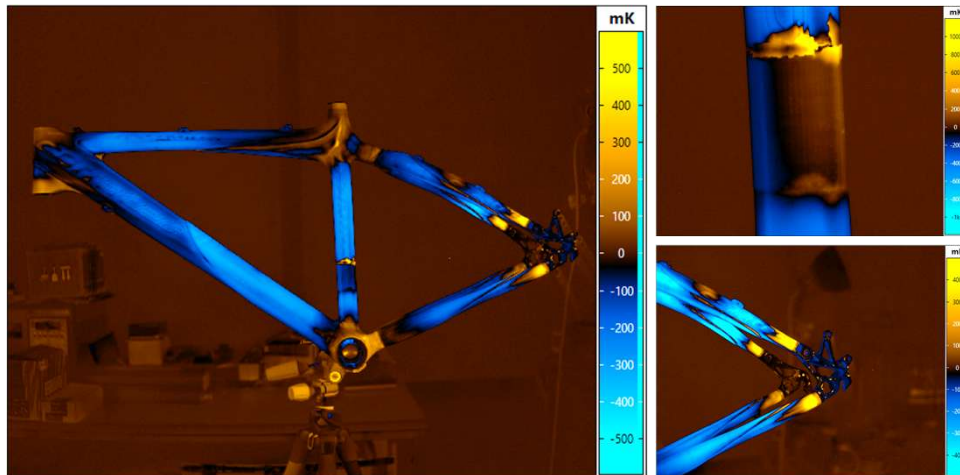
- Carbon fibre reinforced plastic material – Lock-in analysis for hidden defects



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Active Thermography – Example – Reflection Mode

- Carbon bicycle frame – internal structures and damages



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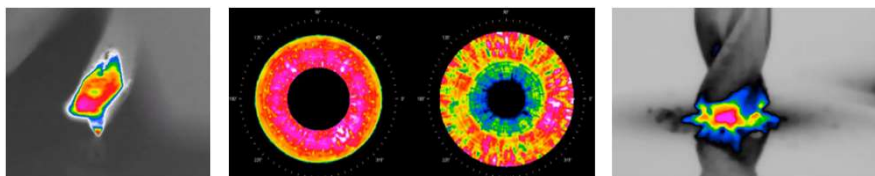
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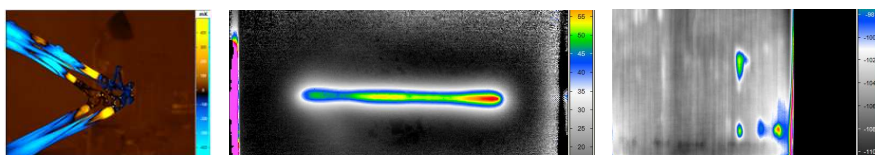
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Thermography in Materials testing – Methods

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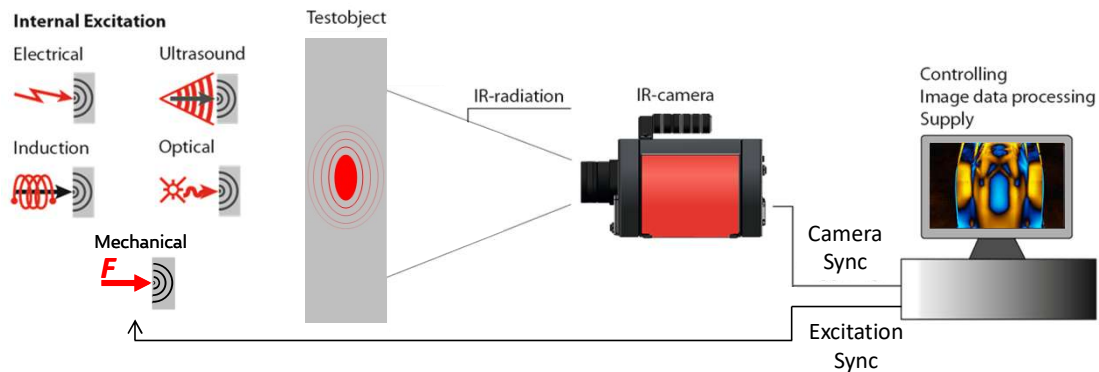
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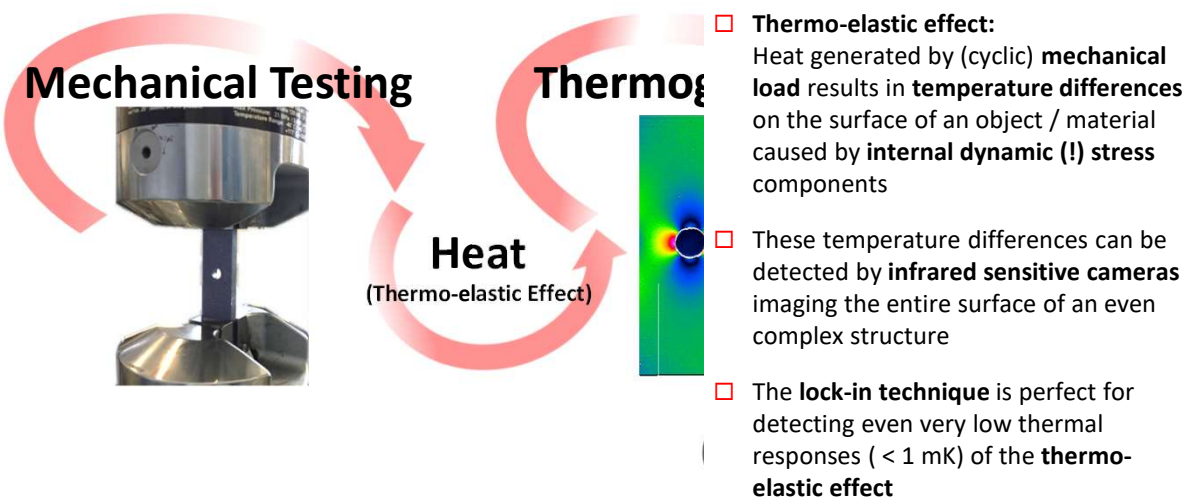
Active Thermography – Principle – Internal Heat Generation



- Correlated heat generation within the material by energy application to the object
- Lock-in principle is used mostly: Periodically induced energy with synchronized IR image acquisition

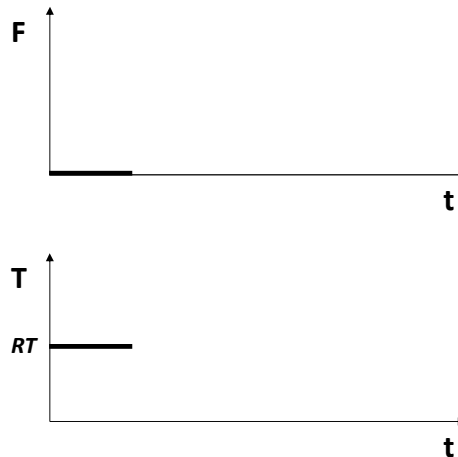
Advanced Applications: Thermo-elastic Stress Analysis – TSA

Contactless Measurements of Temperatures for Mechanical Stress Analysis



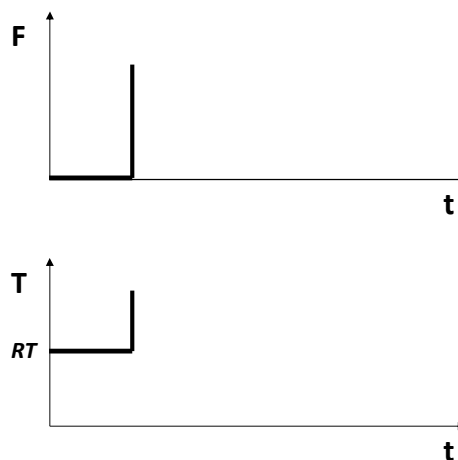
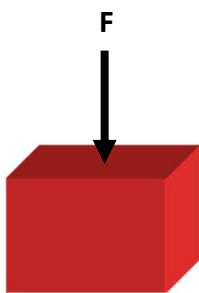
Thermo-elastic Effect

- (Quasi-) static case: Mechanical Force $F = 0$



Thermo-elastic Effect

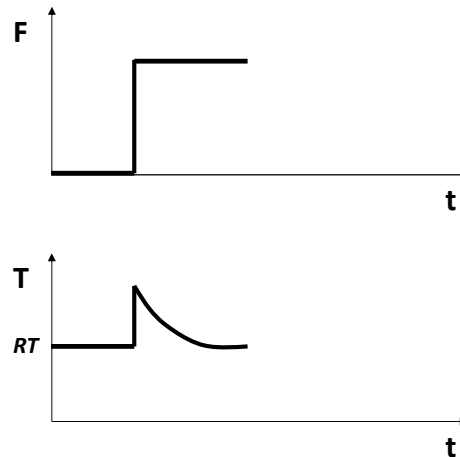
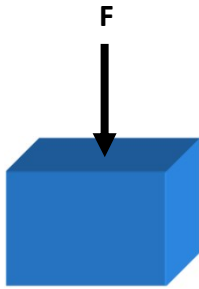
- (Quasi-) static case: $F > 0$



- An external mechanical force F applied on a material is causing a dynamic stress moment $\Delta\sigma$ within the material
- This dynamic stress $\Delta\sigma$ on the other hand is causing a temperature change ΔT within the material

Thermo-elastic Effect

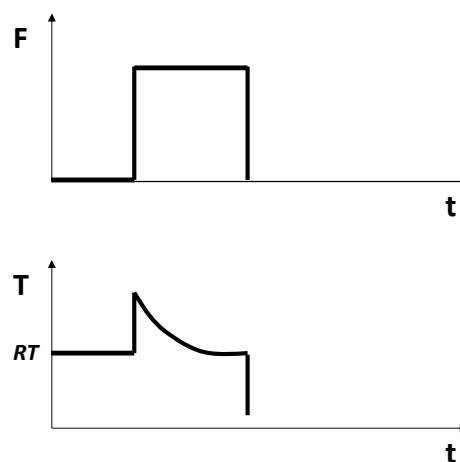
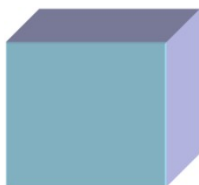
- (Quasi-) static case: $F > 0 = \text{const.}$



- With a constant load the dynamic stress moment $\Delta\sigma$ is zero and therefore this "heat" source is not existing in this static condition
- Consequently, the object will be leveling back to the room temperature RT by convection, radiation, external and internal heat conduction

Thermo-elastic Effect

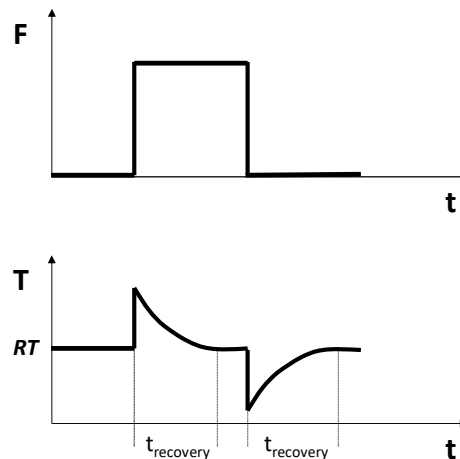
- (Quasi-) static case: $F = 0$



- Removing the external force F applied on a material is causing a negative dynamic stress moment $-\Delta\sigma$ within the material
- The change of the dynamic stress $-\Delta\sigma$ on the other hand is causing a temperature change $-\Delta T$ within the material

Thermo-elastic Effect

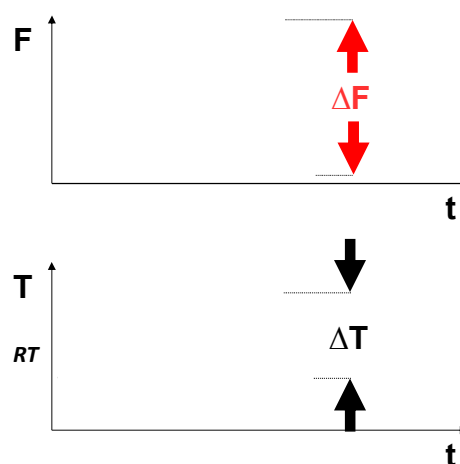
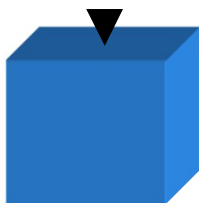
- (Quasi-) static case: $F = 0$



- With a constant load ($=0$) the dynamic stress moment $\Delta\sigma$ is zero and therefore this “heat” source is not existing in this static condition
- Consequently, the object will be leveling back to the room temperature RT by convection, radiation, external and internal heat conduction

Thermo-elastic Effect

- Dynamic case: $F = \sin(t)$ with $1/f_{\text{exc}} \ll t_{\text{recovery}}$ (= **adiabatic condition**)



- For **plastics**, the adiabatic condition is mostly fulfilled already at about $\geq 0,3 \text{ Hz}$
- For **steel**, the adiabatic condition is mostly fulfilled at about $\geq 3 \text{ Hz}$.
- For **aluminum**, the adiabatic condition is mostly fulfilled at about $\geq 10 \text{ Hz}$.

Advanced Applications: Thermo-elastic Stress Analysis – TSA

Stress and Temperature

- For dynamic and adiabatic conditions, the relation between ΔT and dynamic stress $\Delta \sigma$ is:

$$\Delta \sigma = \frac{\Delta T}{-K_m \cdot T}$$

$\Delta \sigma$ = Sum of dynamic stress

$[\Delta \sigma] = \text{Pa} = \text{N/m}^2$

$$K_m = \frac{\alpha}{\rho \cdot C_p}$$

$[K_m] = 1 / \text{Pa}$

α = Expansion coefficient

$[\alpha] = 1/\text{K}$

ρ = Density

$[\rho] = \text{kg/m}^3$

C_p = Heat capacity @ const pressure p

$[C_p] = \text{J}/(\text{kg} \cdot \text{K})$

(To be exact: $\Delta \sigma$ represents here the first invariant of the stress tensor)

Advanced Applications: Thermo-elastic Stress Analysis – TSA

Some Example Data

- Example Steel:

$$\alpha_{\text{Steel}} = 1.2 \cdot 10^{-5} \text{ 1/K}$$

$$\rho_{\text{Steel}} = 7800 \text{ kg/m}^3$$

$$C_{p,\text{Steel}} = 490 \text{ J}/(\text{kg} \cdot \text{K})$$

$$\Rightarrow K_{m,\text{Steel}} = 3.14 \cdot 10^{-6} \text{ 1/MPa}$$

$$\Rightarrow \Delta T = 1 \text{ mK}$$

$$\Rightarrow \Delta \sigma_{\text{Steel}@RT} \approx 1 \text{ MPa}$$

- Example Aluminum:

$$\alpha_{\text{Alu}} = 2.3 \cdot 10^{-5} \text{ 1/K}$$

$$\rho_{\text{Alu}} = 2700 \text{ kg/m}^3$$

$$C_{p,\text{Alu}} = 897 \text{ J}/(\text{kg} \cdot \text{K})$$

$$\Rightarrow K_{m,\text{Alu}} = 9.5 \cdot 10^{-6} \text{ 1/MPa}$$

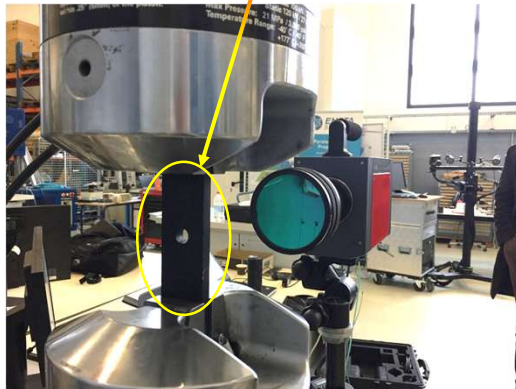
$$\Rightarrow \Delta T = 1 \text{ mK}$$

$$\Rightarrow \Delta \sigma_{\text{Alu}@RT} \approx 0.36 \text{ MPa}$$

Advanced Applications: Thermo-elastic Stress Analysis – TSA

Example 1 – Elastic Periodical Load Test

- ❑ Servo-hydraulic mechanical testing machine was used @ ENSTA Bretagne / France
- ❑ Tested sample (8 mm steel bar with 8 mm hole) was loaded @ 5 Hz with ± 20 kN load
- ❑ For best IR signal the sample was painted with IR paint (emissivity close to 0.95)



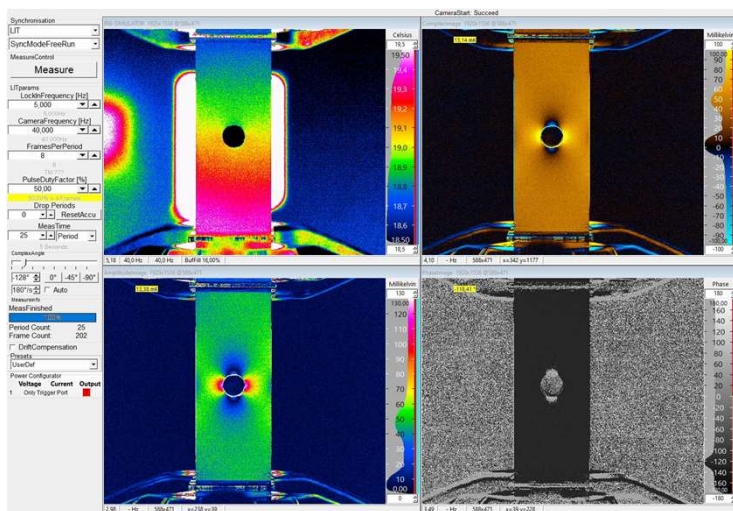
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Advanced Applications: Thermo-elastic Stress Analysis – TSA

Example 1 – Elastic Periodical Load Test



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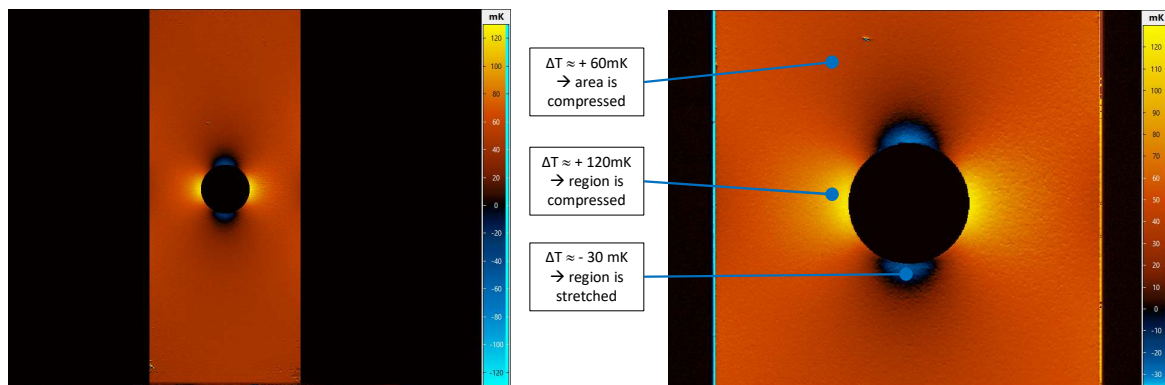
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Advanced Applications: Thermo-elastic Stress Analysis – TSA

Example 1 – Elastic Periodical Load Test

- Lock-in software “*IRBIS® active online*” and IR camera *ImageIR® 10300* are used:
Complex analysis: **ΔT amplitude result image @ specific phase angle** where sample is under pressure.



Advanced Applications: Thermo-elastic Stress Analysis – TSA

Example 2 – Elastic Periodical Load Test

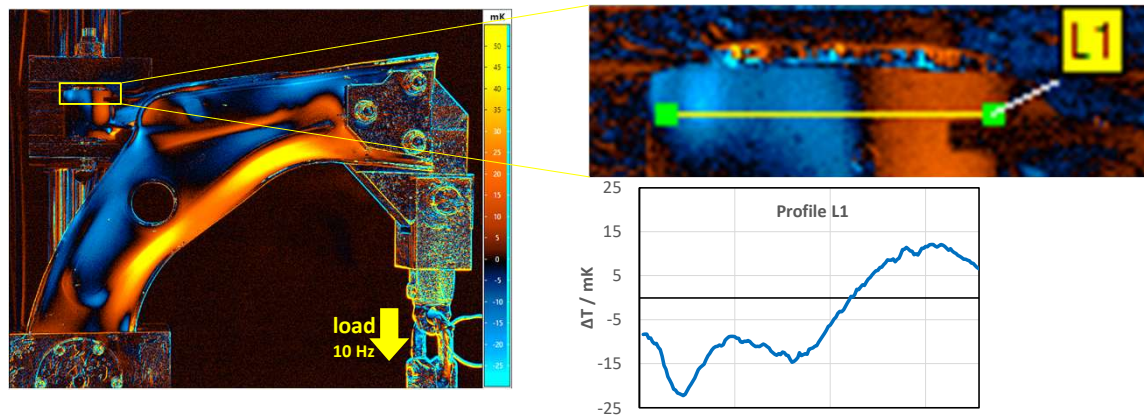
- Servo-hydraulic mechanical testing machine was used @ ENSTA Bretagne / France
- Tested sample (wishbone automotive part from front-axis) was driven @ $f_{\text{exc}} = 10 \text{ Hz}$ with unknown load
- For best IR signal the sample was painted with IR paint (emissivity close to 0.95)



Advanced Applications: Thermo-elastic Stress Analysis – TSA

Example 2 – Elastic Periodical Load Test

- Lock-in software “*IRBIS® active online*” and IR camera *ImageIR® 10300* are used:
Complex analysis: ΔT amplitude result image @ specific phase angle



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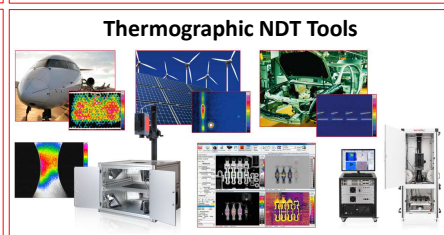
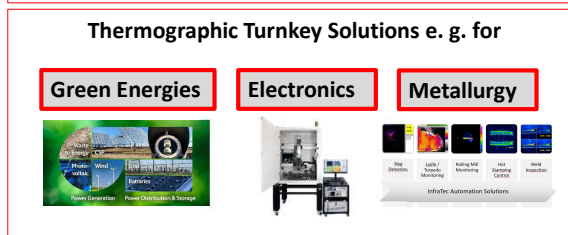
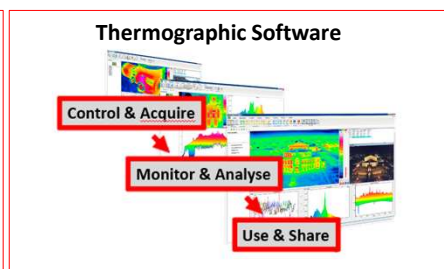
Agenda

- InfraTec
- Thermography
- Thermography in Materials testing – Methods
 - Thermal Treatment
 - Mechanical Treatment
 - Thermo-elastic stress analysis
- ➔ □ IR cameras
- Conclusion

IR CAMERAS

InfraTec, Thermography and You

IR Cameras & Software



InfraTec, Thermography and You

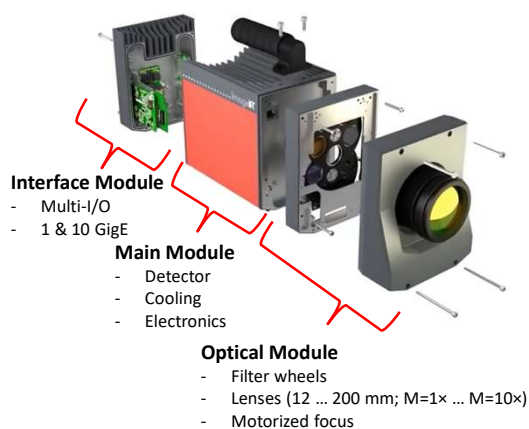
Cooled High-end Camera Series **ImageIR®**



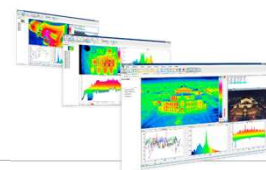
- ❑ Quantum Detector based
- ❑ SWIR, MWIR and LWIR ranges
- ❑ Modular Design for all demands
- ❑ Huge Lens Assortment
- ❑ Powerful Software

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Modular Concept of ImageIR® Series



- ❑ **IIR 5300** – *The Fast* (up to 105,000 fps)
- ❑ **IIR 6300(Z)** – *The Compact – The Zoom*
- ❑ **IIR 8100/9100** – *The SWIR* (VGA & XGA)
- ❑ **IIR 8300** – *The Standard* (640 × 512) – 355 fps / 1,105 fps
- ❑ **IIR 9400** – *The Flexible* (1,280 × 1,024) – **Binning 622** fps
- ❑ **IIR 12300** – *The Big* (2,560 × 2,048) – Binning 1,600 fps
- ❑ **IIR 8800** – *The LWIR* (640 × 512) – 232 fps
- ❑ **Big assortment of lenses** f=12 / 25 / 50 / 100 / 200 mm
M=1× / M=2.5× / M=3× / **M=5×** / **M=10×** / SIL lens
- ❑ **Comprehensive software family IRBIS®**



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Interfacing of the ImageIR®

I/O Interface (Trigger / Sync / anal.)

- ☐ 3 x OUT / 4 X IN
- ☐ Digital (LV)TTL
- ☐ Analogue (-10 ... 10) V / 24 bit
- ☐ Variable input impedance
- ☐ IRIG-B time stamp IN

Power supply

- ☐ Robust Lemo® connector
- ☐ Wide range input (9 ... 36) VDC
- ☐ UPoE

GigE interface as standard

- ☐ RJ45; ≥ Cat5e
- ☐ GigE vision compatible



HighSpeed Interface

- ☐ 10 GigE via SFP (optical or electrical)
- ☐ GigE vision compatible

Communication Interface

- ☐ Display Port (HDMI adaptor)
- ☐ USB 3.0 (WLAN option)
- ☐ Web interface

Optional on-board recording

- ☐ SSD
- ☐ 512 GB capacity
- ☐ Internal Buffer for high-speed

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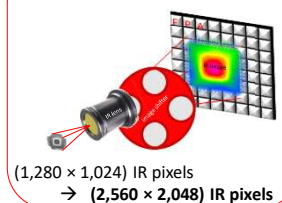
Cooled High-end Camera Series ImageIR® – Additional Features



Two Filter Wheels:



MicroScan:



Better than < 13 mK thermal sensitivity

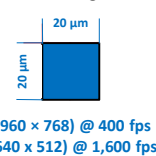
Up to 105,000 frames per second

Up to (2,560 × 2,048) native IR pixels

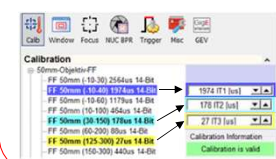
Down to 1.0 μm resolution / pixel

10 GigE optical interface for direct PC streaming

Binning:



Multi Integration Time / HDR:



InfraTec, Thermography and You

VarioCAM® HD head / VarioCAM® HDx head

**1,024
×
768**
Detector

Detector formats:
(640 × 480) / (1,024 × 768) IR pixels

**2,048
×
1,536**
MicroScan

Opto-mechanical **MicroScan** unit:
Image format: **(2,048 × 1,536) IR pixel**

**≥ 20
mK**

Thermal resolution up to 0.02 K
(0.03 K - VarioCAM® HDx head)

GigE
240 Hz

GigE Vision / GeniCAM
frame rates up to 240 fps

**±1
%**

Measurement accuracy: **± 1 °C or ± 1 %**
(± 2 °C or ± 2 % - VarioCAM® HDx head)

IP54

Optional **IP67**

Trigger

Integrated **Trigger and process interfacing**

**1,200
°C**

Highest precision in measurement ranges:
(-40 ... 1,200) °C

Variety of lenses:
f=10 mm ... 120 mm, M=1×, Macro lenses,
Temp-compensated, **motorized Focus**



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When SIZE Matters



Highlights:

- Dimensions/weight **(50 × 55 × 55) mm ; 220 g**
- Pixel Pitch **12 μm**
- Measurement range **(-40 ... 600) °C, fully radiometric**
- Lenses **6.2 mm / 13.6 mm / 25 mm**
- Interfaces **Gig-E, 2 x digital I/O**
- M Version **(50 × 30 × 30) mm ; 66 g**

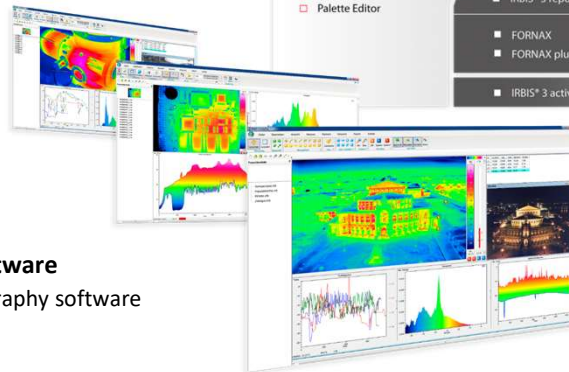


InfraTec, Thermography and You

Efficient and Convenient **Software Solutions** by InfraTec

□ IRBIS® plus / professional software

- Control
- Acquisition
- Analysis
- Exporting
- Reporting
- Presentation



Expansion Modules

- IRBIS® 3.1 active
- IRBIS® 3 mosaic
- AVI Generator
- Macro Editor
- Sequence Editor
- Palette Editor

Analysis Software

- IRBIS® 3.1
- IRBIS® 3.1 plus
- IRBIS® 3.1 professional
- IRBIS® 3 report
- FORNAX
- FORNAX plus
- IRBIS® 3 active online

Control and Acquisition Software

- IRBIS® 3 remote HD
- IRBIS® 3.1 control
- IRBIS® 3.1 online
- IRBIS® 3.1 process

Software Development

- Software Development Kit (SDK)
- LabVIEW Add-on
- MATLAB Add-on

□ IRBIS® active online software

- Special active thermography software
- Customised solutions

InfraTec, Thermography and You

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InfraTec, Thermography and You

Conclusion

- ❑ Thermography is a contactless imaging AND precisely temperature measuring method
- ❑ Thermography can be used perfectly for temperature measurements on even complex mechanical structures
- ❑ Some methods for material/structure testing based on Thermography were shown – but not all!
- ❑ InfraTec offers IR camera in various specifications fitting to nearly most of the measurement tasks
- ❑ InfraTec offers all necessary equipment AND Software for laboratory-based active Thermography
- ❑ Tailored Turn-key solutions can be designed especially for you!
- ❑ InfraTec feels always excited in new challenging tasks → contact us!

Thank you for your Attention ...

... just ask the Specialists!

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