# List of Abstracts of QIRT 1992 (Paris, France)

## New method of digital modulative adaptative auto-calibration of infrared imaging devices

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**Abstract**

This paper describes the new method of digital auto-calibration IR imaging systems based on using low-amplitude 2D cyclic scanning and solving multi-dimensional inverse problem. The method does not require the use of reference bodies and stages of registration and calibration can coincide. Mathematical algorithms require $\approx 100\ N^2$ operations and are realized by using IBM PC/AT for $N < 256$.

## Methods for achieving enhanced temporal resolution in IR image acquisition

By S.M. SHEPARD, D.T. SASS, T.P. IMIROWICZ

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**Abstract**

Temporal aliasing is a problem common to all video imaging systems. In the infrared, targets which undergo temperature variations at frequencies above the frame rate will be inaccurately imaged. We have developed two novel methods for achieving Enhanced Temporal Resolution (ETR), using optomechanical and focal plane array technology. These systems employ phase synchronous detection methods to compensate for the effects of aliasing, and allow above-frame-rate events to be imaged. The optomechanically based ETR system utilizes an unmodified 8-12 μm commercial imager (Inframetrics IR 600), and allows images of repetitive thermal events at frequencies up to 4 kHz to be imaged with an effective integration time of 125μs. Data is acquired selectively by comparing the motion of the camera's horizontal scanning mirror to a reference signal correlated to the event of interest. The focal plane array ETR system is based on a 160 x 244 PtSi Schottky-barrier sensor operating at the standard 30 Hz frame rate. Frame integration time is variable to a minimum of 10μs. Data is acquired synchronously with respect to an external reference signal derived from the target. The relative merits and weaknesses of the two approaches are discussed.

## Improving the accuracy of inferred temperatures in small spot size experiments

By J. PEARCE (*), M. SCHULZE (*) AND Z. RYU (**)

(*) Biomedical Engineering Program, The University of Texas at Austin, Austin Texas, USA.
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**Abstract**

Accurate inference of surface temperature distribution in transient thermal images requires the reduction of detector noise effects, correction for small features in a relatively large Instantaneous Field Of View (IFOV) imager, and correction for thermal gradients along the optical axis. We have investigated non linear smoothing operators, specifically the median filter and linear combinations of non linear morphologic operators. Both types are effective but the one-dimensional median filter is both most accurate, simplest and fastest to implement and use. The underestimated caused by IFOV problems is best corrected by Wiener filter de-convolution, in our view. Finally, optical axis thermal gradients can require significant correction factors to be applied to the measured emittance in order to estimate maximum surface temperature.

## Theoretical and experimental applications of the flying spot camera

By C. GRUSS AND D. BALAGEAS

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**Abstract**

The principle of the flying spot camera, a non destructive testing system, is to heat a sample with a moving laser spot and to observe the time evolution of the temperature with an IR detector viewing an area attached to the laser spot with a constant offset. In this paper, to obtain a better understanding of the experimental data, models are developed for several cases : semi-infinite adiabatic solid, solid of finite thickness, infinite vertical crack, effect of convective losses, effect of an optical penetration of the laser beam. For all theses cases analytical solutions are proposed. Two experimental set-up are described: their performances are discussed and some experimental results are compared with the theory.

## Infrared thermography on Tore-Supra, the French experimental Tokamak on nuclear controlled fusion

By D. GUILHEM, H GARCIN, A. SEIGNEUR,
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**Abstract**

Nuclear fission and fusion are exoenergetic reactions. Fission is largely entered in its industrial age. Controlled nuclear fusion is still under development before building an experimental reactor of industrial power plant size. *Tore-Supra* is *the French* experimental reactor, member of the large size Tokamaks' family. The most significant experimental results are presented and particularly the temperature maps of the limiters, components in direct contact with the plasma. The thermographic system is a major diagnostic of Tore-Supra: its main role is to prevent from deterioration or destruction of the components directly exposed to the plasma. The comparison between the thermal maps of components obtained during shots and a model of plasma edge physics. So, we have measured the characteristic length of power deposition on plasma facing components for various experimental conditions. This is essential to check the adequacy between the conception of plasma facing components submitted to high heat ñuxes and their ability to face and sustain such a plasma. Three of the actively cooled limiters have been successfully tested in a steady state regime with surface temperatures under 1 000$^{o}$C. The design value for power removal has been obtained. Peak power fluxes of 10 WM.m$^{-2}$ (3.5 MW.m$^{-2}$ on average) have been estimated. This represents a breakthrough for high heat flux components since critical heat flux and burnout with subcooled now boiling are major aspects for this kind of design. The time constant to reach a stabilized temperature on the whole head is less than 2 s (shot duration = 10 s) as expected from modelling of heat transmission through the thin 2.5 mm graphite layer tile, to the water through the brazed joint.

## Remote temperature measurement of highly reflecting objects in outdoor conditions

By K. CHRZANOWSKI

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**Abstract**

A new method for contactless temperature measurement using multispectral infrared pyrometers was presented by V. TANK a few years ago. The method is advantageously applied to highly reflecting objects of moderate temperatures. Good accuracy was achieved but only for indoor conditions. The method assumes that the environment is a blackbody. The assumption cannot be acceptable for some industrial cases, especially for outdoor conditions as the sky radiation does not fulfil Planck law. A new method acceptable also for outdoor conditions has been developed.

## Accurate temperature measurement in thermography

By T. HAMRELIUS

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**Abstract**

In thermography there are many factors that affect and disturb the temperature measurement. For accurate temperature measurement it is crucial to know what those factors are and how they affect the measurement. This paper is an attempt to make an overview of these factors. It describes and exemplifies: how the atmosphere and emissivity affect the measurement; what algorithms the thermal imager uses to compensate for the radiation that does not originate from the object; how small object size affects the measurement; what features are needed to achieve instrument stability as a function of ambient temperature and time; and how these factors differ between 3-5 and 8-12 µm waveband systems.

## Sofradir infrared detectors

By J.P. CHATARD, P. ANGEBAULT AND P. TRIBOLET

SOFRADIR, 43/47 rue Camille Pelletan, 92290 CHATENAY-MALABRY, France.

**Abstract**

Starting mid 70's, France has developed a new infrared focal plane array technology based on Cadmium Mercury Telluride (CMT) and silicon materials.

The infrared laboratory (LIR/LETI) has prepared an Infra Red Charge Coupled Device technology which uses photovoltaic technique on Cadmium Mercury Telluride waters for detection and Charge Coupled Devices (CCD) on silicon for the read-out circuit.

Due to this new approach it is possible to fabricate infrared detectors sensitive from 2 µm to 13 µm with a very large number of pixels (up to 16 000).

SOFRADIR has built a development center which uses now this process in production and there is no more question mark about producibility of such Infra red Focal Plane Array. Typical (IRFPA) results on large detectors will be presented.

## The MFT of thermal imaging cameras - its relevance and measurement

By T.L WILLIAMS

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**Abstract**

The use of MTF (modulation transfer function) for correcting thermal measurements is discussed and an equipment for measuring the MTF of thermal cameras described.

## Computer-based thermographic system

By B. WIECEK (*), M GRECKI (*) AND J. PACHOLIK (*)

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**Abstract**

Computer-based thermography system developed lately, is presented. It allows to record and process thermal images captured by electrically-cooled Hughes-40TE thermal camera. The system can be configured as a stand-alone portable unit, equipped with printers, different kinds of displays, disks, etc. In a laboratory version, it is a powerful, PC486-compatible machine with a special computer-card interface, which gives enormous possibilities of thermal image processing and measurement automation. The system is adapted to widely used AGEMA-compatible thermography equipment as well.

## Retrospective on aerodynamic research with infrared imaging

By E. GARTENBERG (*)

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**Abstract**

Infrared imaging used in aerodynamic research evolved during the last 25 years into a rewarding experimental technique for investigations of body flow field viscous interactions, such as heat-flux determination and boundary-layer transition. The technique of infrared imaging matched well its capability to produce useful results with the expansion of testing conditions in the entire spectrum of wind tunnels, from hypersonic high-enthalpy facilities to cryogenic transonic wind tunnels. With unique achievements credited to its past, the current trend suggests a change in attitude towards this technique: from the perception of it as an exotic, project-oriented tool, to the status of a routine experimental procedure.

This review is an updated version (containing about 40 more references) of "Twenty-five Years of Aerodynamic Research with IR Imaging," a survey by Ehud Gartenberg and A. Sidney Roberts, Jr., presented at Thermosense XIII, an International Conference on Thermal Applications and Image Diagnostics, SPIE 1991, and published in the Journal of Aircraft, Vol. 29, N$^{o}$ 2, A\AA, March-April 1992 [1].

## Study of free convection by infrared thermography over a constant heat-flux heated plate

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**Abstract**

This study presents experimental free convection heat transfer correlations obtained, in case of air, over vertical and inclined flat plate as well as vertical plate with transverse disturbing elements located in the laminar boundary layer. In the last case, the aim of this study is to define the geometric configuration giving rise to the largest increase of the heat transfer performance. Temperature measurements were performed using IR thermography in parallel with a satisfactory experimental procedure. These measurements were also completed with some flow visualizations.

## Infrared thermography characterization of Görtler vortex type patterns in hypersonic flows

By D. BOSCHER (*), B. BAUDOUY (*), A. DEOM (*), M.-C. COET (**), J. DELERY (**) AND D. BALAGEAS (*)

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**Abstract**

The spanwise modulation of the heat transfer occuring, in hypersonic, on a two-dimensional compression ramp following a flat plate (Görtler vortices type structures) has been studied using infrared thermography. The technique allows a quantitative analysis. In particular, parameters like the relative amplitude of the heat transfer coefficient ($h$) modulation, amplitude of the local recovery temperature ($T_r$) modulation, spatial frequencies of theses modulations were obtained from the time-resolved thermography of the model surface. The two modulations ($h$ and $T_r$) are in phase opposition, fact until now unexplained.

## Fluid dynamics applications of IR imaging system

By L. DE LUCA, G. CARDONE AND G.M CARLOMAGNO

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**Abstract**

The use of infrared thermography in several heat transfer and fluid dynamics problems is analysed and discussed. Different operating modes and their implementations are presented. Particular emphasis is given to the measurement of convective heat transfer coefficients. It is shown that, if the heat flux varies along the tested surface with relatively high spatial frequencies, the need arises of analysing the response of the heat flux sensors and of characterizing the spatial resolution of the IR imaging system.

## Infrared temperature measurement of vaporizing droplets

By L. NANA (*), J. FARRE (*) And A. GIOVANNINI (**)

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(**) Université Paul Sabatier, UFR MIG, Département de Mécanique, 118 Route de Narbonne, 31062 Toulouse Cedex, France

**Abstract**

Our objective, is the measurement using infrared thermography (IR), of the temperature field of a methanol droplet. A mathematical model has been devised to give the performance (signal-noise ratio) of a proposed experimental system that measures the temperature of a droplet using IR thermography. Based on that simulation, an experimental system working in the long wavelength range (8-12 μm) has been built and characterized in terms of temperature calibration and in terms of space and temperature resolutions. In order to validate the IR measurement, the temperature evolution of a droplet of one millimeter in diameter has been measured with the IR system and with a thermocouple. For that purpose, the droplet fixed at the thermocouple is heated by a laser beam and cooled in still ambient air. The results obtained from both experimental techniques have shown very good agreement, along with the results obtained from a numerical model of the problem.

## Application of quantitative infrared thermography in the VKI Mach 6 hypersonic wind tunnel

By G. SIMEONIDES, J.P. VERMEULEN And S. ZEMSCH

von Karman Institute for Fluid Dynamics, Chaussée de Waterloo 72, B-1640 Rhode St-Genèse, Belgium.

**Abstract**

The application of infrared thermography to the measurement of heat transfer over models tested in the VKI H-3 hypersonic wind tunnel at a Mach number of 6 is described. The performance of the technique in quantifying heat transfer rates over aerodynamic surfaces is found to be comparable to that of discrete point gauges, such as thin film surface resistance thermometers and coaxial thermocouples. The merits and limitations of infrared thermography in wind tunnel testing are illustrated by a series of examples representing quantitative heat transfer measurements over regions of hypersonic shock wave boundary layer interactions.

## Heat transfer of impinging multijet system An application of the quantitative thermography

By J.M. BUCHLIN (*) and M. DUBOIS (**)

(*) von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium.
(**) Cockerill Sambre, Branche Phenix, Flemalle, Belgium.

**Abstract**

The paper deals with an infrared thermographic technique to find the heat transfer coefficient in the impacting region of an array of slotted jets. The IR method allows to study the effect of the geometrical arrangement and fluid flow parameters upon the system effectiveness. The results are in good agreement with correlation obtained from mass transfer technique. Their applicability to industrial situation is illustrated.

## Infrared thermography and the numerical heat transfer analysis

By S. SVAIC (*)

(*) Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia.

**Abstract**

A method which enables the use of the data obtained by the IR thermography in the numerical heat transfer analysis has been developed. The method was tested on the model created for the determination of the local heat transfer coefficients on the extended surfaces. The temperature field on the single annular and square fins were measured by means of an IR camera. The values of the temperatures were used directly as the input data in the mathematical model developed for the calculation and graphical interpretation of the local heat transfer coefficients. The model is based on the method of control volumes and is adopted to be used on a PC.

## An infrared set-up continuum thermomechanics

By A. CHRYSOCHOOS (*) and J.C. DUPRE (**)

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**Abstract**

The determination of the constitutive equations of solid materials behaviour is henceforth realized in a thermomechanical framework. Thermodynamics of Irreversible Processes (TIP) allows to introduce internal variables describing the hardening state evolution. This paper presents the performances and the applications of a thermomechanical set-up using infrared thermography elaborated to observe the energetical phenomena accompanying

the deformation of the matter. In the case of homogeneous tests, energy balance can be performed to control the validity of behaviour laws.

## Infrared thermography of plastic instabilities in a single crystal superalloy

By P. LEVESQUE (*), B. LISIECKI (**), L. KUBIN (**),
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**Abstract**

A tensile test of a AM3 single crystal superalloy is analysed with the help of the thermographic technique. During the plastic flow, with a moderate strain rate at room temperature, the deformation is very localized and large slip bands occur on the surface of the specimen, and the stress-strain curve exhibits yielding serrations. The IR thermography is used to measure local heatings. The heating associated with the deformation band occurrence, during the instability, is evaluated by a time-resolved analysis of the thermograms delivered by the IR camera, using a very simple thermal model. A value of about $140^{o}$ is found and compared to the upper possible limit of this parameter, given by theoretical calculations and analysis of the tensile curve.

## Thermographic characterisaiton of defects and failure in polymer composites

By M. BAUER, Ch. GUNTRUM, M. OTA, W. RIPPEL And G. BUSSE (*)

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**Abstract**

Vibrothermography is compared to heat flow methods and then applied to analyse the history of a failure starting from an artificial defect in laminates of glass fibre reinforced polymers (GFRP) or carbon fibre reinforced polymers (CFRP). The development of failure depends both on the kind of material and the laminate structure. Thermal instability "ping-pong-effect" could be observed immediately before failure in $\pm 45^{o}$ CFRP laminate.

## The investigation of metals' damage through thermal field kinetics

By G. KURILENKO and A. PSHENICHNY

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**Abstract**

The possibilities of modern equipment for measuring the temperature without a contact allowed us to calculate the characteristics of damage through the kinetics of thermal field formed on top of the developing crack, and thus to prognose crack resistance of the investigated object. The proposed method has some advantages with comparison to traditional methods.

## Application of infrared thermography for determining the temperature distribution in Taylor's impact test

By L. KRUSZKA (*), W.K. NOWACKI (**) and W. OLIFERUK (**)

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(**) Institute of Fundamental Technological Research, Polish Academy of Sciences, ul. Swietokrzyska 21, 00-049 Warsaw, Poland.

**Abstract**

The object of the work is to measure the temperature field in solids (aluminium) during its dynamic plastic deformation at high strain rates. The present paper describes the testing stand based on Hopkinson's pressure bar system and AGA thermovision set, details of the experiment and analysis of the experimental results.

## Lockin vibrothermal inspection of polymer composites

By G. BUSSE, M. BAUER, W. RIPPEL and D. WU (*)

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**Abstract**

Vibrothermography uses thermographic equipment to image the average temperature distribution of oscillating components. In this paper we report on experiments where magnitude and phase of the temperature modulation generated by modulated stress were analysed. Investigations on various polymer composites reveal both the thermoelastic effect and loss angle induced energy dissipation as the mechanism for thermal wave generation.

## Quantitative evaluation of aging in bearings and electric brushes using infrared thermography

By A. MADRID (*)

(*) Engineering Consultant, Ramonet 48/50, Madrid 28033, Spain.

**Abstract**

The quantitative evaluation of aging in both bearings and electric brushes, and the estimation of their respective failure rates by means of IR thermal mapping are discussed using the DIRT-FREE technique. Aging is characterized by component wear due to friction-induced dissipative heating and mild corrosion. Ad hoc thermal analyses yield both the actual component wears and wear rates, and the basis for the appraisal of potential thermal stresses in regard to component failure.

## Thermomechanical evaluation of polypropylene fracture resistance

By G. MEDRI (*) and R. RICCI (**)

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(**) Dipartimento di Energetica, Università di Ancona, Italy.

**Abstract**

The results of thermomechanical analyses performed on polypropylene specimens during fracture tests are presented. A thermodynamic approach to the fracture mechanics of dissipative materials is discussed.

## Quantifying matrix cracking in composites by a thermoelastic method

By B. J. MAHONEY (*) and B. I. SANDOR (**)

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(**) Professor, Department of Engineering Mechanics, University of Wisconsin-Madison, Madison, WI USA 53706.

**Abstract**

A new experimental and theoretical methodology has been developed to quantify transverse matrix cracking in composite laminates. A model was developed to relate changes in laminate longitudinal stiffness and Poisson's ratio to cyclically-induced temperature changes arising from the thermoelastic effect. Experiments have been performed to measure the above parameters in $(0_3/90_3)_S$ GI/Ep laminates, and very good correlations were observed between the results and theoretical predictions.

## Thermal non destructive testing: short history and state-of-art

By V. VAVILOV (*)

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**Abstract**

History of thermal non destructive testing could be traced up to the first patents concerning the distant detection of warm objects. In more narrow sense this method includes the heat stimulation of a specimen and measurement of its temperature-in-time response. Theoretically, thermal testing involves the solving of direct and inverse heat transfer problems. Variations of thermal properties and presence of internal defects disturb dynamically the thermal pattern of a specimen. Experimentally, the infrared equipment is mostly used. Infrared imagers are able to produce the space-domain and time-domain images which could be calibrated in diffusivity or effusivity values, defect depth or thickness. Image processing techniques could suppress the noise caused by structural non-uniformity, non-even heating and background radiation. Thermal testing application fields concern the composites and layered materials used in aerospace, building and oil & gas industry.

## Time-resolved pulsed stimulated infrared thermography applied to carbon-epoxy non destructive evaluation

By J.-C. KRAPEZ, D. BOSCHER, Ph. DESPECH, A. DEOM,
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**Abstract**

Since several years, time-resolved pulsed stimulated infrared thermography (SIRT) has been developed at ONERA with the aim of combining fast screening and quantitative characterization. The analysis of pixel by pixel thermograms leads to depth-location and thermal resistance images of delaminations. In this paper we present recent enhancements of the portable SIRT system and refinement of the data reduction procedure which demonstrate the possibility of detecting and evaluating delaminations in C-epoxy at depths higher than 3mm. A 2-D inversion procedure is proposed to better characterize defects of reduced lateral extend as compared to the former 1-D method.

## Time-resolved pulsed stimulated infrared thermography applied to carbon/carbon non destructive evaluation

By Ph. M. DELPECH, D. M. BOSCHER, F. LEPOUTRE,
A.A. DEOM and D.L. BALAGEAS

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**Abstract**

The pulsed stimulated infrared thermography is used for the non destructive evaluation of the thermal protection of the European space shuttle Hermès. The hottest parts of the thermal protection are made of coated carbon/carbon composite materials which is a rather good thermal conductor. After a brief presentation of the model and of the identification procedure, results are compared with micrography examinations and Compton back scattering showing a good agreement between the different methods.

## A quantitative analysis of pulsed video thermography

D. P. ALMOND and S. K. LAU

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**Abstract**

The defect imaging capability of a pulsed video thermography system is assessed by a quantitative analysis of its performance in imaging well characterised artificial defects. The experimental data show marked deviations from the predictions of one-dimensional heat flow theory. An analytical model is presented which provides a basic understandings of the imaging process for finite sized defects. A method for the determination of defect depth is proposed.

## Non destructive transient thermal evaluation of delaminations inside a laminate: a thermal processing technique of thermal images

By D. MAILLET, S. DIDIERJEAN, A.S. HOULBERT and A. DEGIOVANNI (*)

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**Abstract**

Delaminations in laminate composite slabs can be detected and measured using a heat pulse excitation on one side and temperature measurement through infrared thermography on either side of the slab. The delamination is characterized in terms of its depth, thermal contact resistance (thickness) and transverse extent. An identification method of the first two defect parameters is developed and experimentally validated. It uses, as input, the Laplace transforms of a local contrast thermogram and, as output, thickness and depth profiles of the possible delamination.

## Non destructive transient thermal evaluation of laminated composites: discrimination between delaminations thickness variations and multidelaminations

By A. BENDADA, D. MAILLET and A. DEGIOVANNI (*)

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**Abstract**

Different types of anomalies, such as local thickness changes, single or multi-delaminations, can be detected in carbon epoxy laminates using photothermal stimulation and infrared thermography. Discrimination functions, that allow to sort out the different types of the above-mentioned defects are constructed.

## Shape correction in transient thermography inspection of non-planar components

By A. NOUAH, X. MALDAGUE and F. ROBITAILLE

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**Abstract**

Transient thermography is a very attractive non destructive evaluation tool however; despite recent advances, some difficulties still remain. One important concern is the inspection of non planar components for which the required external thermal stimulation produces isotherm disparities perturbing the interpretation stage. In this paper a novel method is proposed to solve this problem. The method is based on depth correction using the reflectance information obtained from a visible spectrum camera. Theory is discussed and results are presented.

## Transient thermal NDT: conception in formulae

By V. VAVILOV (*)

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**Abstract**

Thermal Non Destructive Testing acquired some new aspects during the last decade. Now it essentially concerns the characterization of defects requiring the quantitative estimation of involved parameters. In this paper estimation of TNDT sensitivity using classic solutions of heat transfer theory is discussed.

## A simple transportable imaging system for fast thermal non-destructive testing

By J. VARIS, J. HARTIKAINEN, R. LEHTINIEMI and M. LUUKKALA (*)

(*) Department of Physics, University of Helsinki, Siltavuorenpenger 20 D, SF-00170 Helsinki, Finland.

**Abstract**

A transportable thermal imaging system based on a simple infrared line scanner is described. Either a line focused laser beam or radio frequency induction coil can be used for heating. A carbon-glass fibre composite plate having artificial defects made with Brinell and Vickers indentors was inspected in order to demonstrate the performance of the system. Examples of the results are presented.

## Real-time 3D-representation of time-resolved infrared thermographic data

By U. NETZELMANN, G. WALLE and G. DOBMANN

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Saarbrücken, Fed. Rep. of Germany.

**Abstract**

A graphic workstation with volume-rendering software is used to visualize the cooling process of samples measured by time-resolved infrared thermography. The recorded data set, consisting of images of up to 80 frames with 320 x 256 pixels each, can be sliced in any desired plane in real time. Ray-tracing techniques are applied to achieve a comprehensive representation of inner structures of the specimen.

## Energy deposit by a xenon flash lamp illuminator dedicated to photothermal IR thermography: calculations and measurements

By J.L. BEAUDOIN (*), J-F. HENRY (**), E. MERIENNE (*) and
R. DANJOUX (**), P. EGEE (***), P. COSTE (***)

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**Abstract**

This communication deals with Non Destructive Evaluation of materials or structures via the measurement of their (thermal) impulse response function. The excitation is produced by a short and intense light pulse from xenon flash lamps. The repartition of the energy deposited over the object surface must be known qualitatively as well as quantitatively. A glass sheet is used as a calibration standard, the measurement of the heating being made by infared thermography. The various possible configurations are discussed. The validation of the procedure is established by a *priori* calculations and by experimental measurements.

## Some remarks on definition, resolution and contrast in photothermal imaging

By H.G. WALTHER and U. SEIDEL

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**Abstract**

Photothermal imaging can be described quantitatively by means of a point spread function (PSF), which represents the image of a buried thermal point defect. From this PSF conclusions can be drawn about amplitude and phase contrast, halfwidth and resolution of photothermal imaging. Radiometric and mirage measurements from an appropriately designed model sample confirm the theoretical results.

## Some new ideas in dynamic thermal tomography

By V. VAVILOV (*), P.G. BISON (**), C. BRESSAN (**), E. GRINZATO (**) and S. MARINETTI (**)

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**Abstract**

Dynamic Thermal Tomography (DTT) is a new area of Thermal Non Destructive Techniques (TNDT), very attractive for *in field* detection of defects inside materials. It is

based on the energetic excitation of solids, resulting in the dynamic distribution of the temperature field on their surface. Defects, inside the solid, change the evolution and the distribution of the surface temperature field. Solving the inverse thermal problem, which involves the processing of surface temperature field, one gets information on the inner structure of solids.

Tests has been performed on two specimens compound of 5 layers, with thickness 1.8 mm each. Air holes in internal layers, performed in different shapes and arrangements, simulate defects. Another defect was simulated by a lack of glue.

The results for the surface temperature in correspondence of defects show a dependence with time close to that of the simulated curves. Synthesized images of different inner layers of the material show the presence of defects whose position and depth are in good accordance with those of the real one, as it has been verified after destroying the specimens at the end of the experiment.

## Numerical reconstruction of interfacial defects and interface thermal resistances using thermal measurements

By M. BONNET, H. MAIGRE and M. MANAA

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**Abstract**

Thermography provides an experimental mean to control the quality of interface in laminates or in coatings. It is thus important to link thermal measurements obtained on free surfaces to the possible interfacial defects. In this paper a numerical inverse method is proposed to localize and quantify the defects from measured thermal data. The identification problem leads to a non-linear minimization problem solved using gradient methods.

## Thermal distribution in circular slabs: a thermographic method

By G. CESINI (*) M. PARONCINI (*) and R. RICCI (*)

(*) Dipartimento di Energetica, Università degli Studi di Ancona, via Brecce Bianche, 60100 Ancona, Italy.

**Abstract**

Infrared thermography is commonly used as a qualitative method to investigate anomalies located inside solid bodies; the quantitative approach to the thermographic results is less extensive.

Nevertheless in many situations (e.g. industrial quality control or painting conditions) it is very important to find a thermographic method to obtain quantitative information from the infrared pictures. The transient thermal behaviour of a circular slab with an internal air bubble is numerically and experimentally investigated. Two different materials have been used and the results are presented for different locations and sizes of the air bubble.

## Inversion of thermal wave infrared images

By R.L. THOMAS, L.D. FAVRO, D. J. CROWTHER and P.K. KUO(*)

(*) Department of Physics and Institute for Manufacturing Research, Wayne State University, Detroit, MI 48202, USA.

**Abstract**

Pulse-echo thermal wave imaging is becoming a very useful technique for nondestructive evaluation of materials. However, the blurring created by lateral heat diffusion remains as an important problem affecting the quality of the images. We describe here an inversion technique, based on the Born approximation, which permits the elimination of this blurring in the case of planar defects, such as delaminations, which are parallel to the surface. Tested on experimental images, this technique demonstrates that it is possible to make significant improvements in the quality of thermal images.

## Quantitative infrared thermography application for thermal defectometry

By V.A. STOROZHENKO (*)

(*) Kharkov Institute of Radio Electronics, the Ukraine, 310726, Kharkov, Lenin Avenue, 14.

**Abstract**

A new method is described to solve the inverse problem of active thermal non destructive testing. This method allows to establish in an analytical form an interconnection between the defect parameters and the temperature response of the object. The possibility to define four defect parameters such as thickness, depth location, heat conductivity and diffusivity is shown.

## Thermal measurements of power semiconductor devices using thermographic system

By B. WIECEK (*), M. GRECKI (*), J. PACHOLIK(*)

(*) Politechnika Lodzka, Instytut Elektroniki, ul. Stefanowskiego 18/22, 90-924 Lodz, Poland.

**Abstract**

The non-uniformity of temperature distribution in the semiconductor structure may cause some problems, especially when the power dissipated in the device is high. In general, there is no easy way to find out the method of evaluating temperature inside the semiconductor wafer. Thermovision gives the possibilities to obtain temperature maps only on the upper surface of the semiconductor device in direct, non-invasive way. In order to find the hot spots inside the silicon, multidimensional modelling is being used. Certain measurements of power bipolar transistor and thyristors either for static and transient states have been performed. For transient state surveys a unique method of shortening the time of the image scanning has been worked out.

## Thermal imaging of synchrotron beams on silicon crystals

By R.K. SMITHER (*)

(*) Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439 USA

**Abstract**

The Advanced Photon Source, a next generation synchrotron source, currently under construction at Argonne National Laboratory, will deliver large thermal loads of 1 to 10 kW to the first optical elements (usually a silicon crystal) in the synchrotron, X-ray beam lines. The first optical elements will distort and attenuate the X-ray beam if they are not extremely well cooled. An infrared camera is used to monitor the temperature distribution of the these first optical elements. This measurement is complicated because the silicon crystal is transparent to the infrared radiation and requires a special approach to the analysis of the data to get a meaningful temperature for the crystal.

## Non destructive evaluation of absorbing materials using microwave stimulated infrared thermography

By P. LEVESQUE, A. DEOM and D. BALAGEAS (*)

(*) ONERA, Thermophysics Division, BP 72, F-92322 CHATILLON-Cedex, France.

**Abstract**

The electromagnetic wave non destructive evaluation methods that appeared some years ago are attractive because many materials can absorb hyperfrequency energy. A new method was developed which associates a microwave stimulation and an infrared detection by IR thermography. An experimental 10 GHz setup was built to verify the feasability of the method. Results are shown of the use of this method for non destructive evaluation of absorbing materials containing artificial defects.

## Infrared measurements of electromagnetic fields

By J. NORGARD (*), D. METZGER (*), R. SEGA (*), M. HARRISON (**), R. KOMAR (**), H. POHLE (**), A. SCHMELZEL (**), M. SMITH (**), J. STUPIC (**), M. SEIFERT (***) and J. CLEARY (***)

(*) Electromagnetics Laboratory, University of Colorado/Colorado Springs, Colorado, USA.
(**) Phillips Laboratory, Kirtland AFB, New Mexico, USA
(***) Rome Laboratory, Griffiss AFB, New York, USA.

**Abstract**

In this paper, an infrared (IR) measurement technique is presented which has been developed to measure electromagnetic (EM) fields. This technique uses a minimally perturbing planar IR detection screen to map the intensity of the EM energy over a two-dimensional region. Several examples of measured EM fields near radiating sources and scattering bodies using IR thermograms are presented.

## Air in- and exfiltration through the joints of external walls

By E. DUC (*) and J. JAWORSKI (**)

(*) Technical University of Wroclaw, Institute of Building Engineering, Poland.
(**) Polish Academy of Sciences, Institute of Fundamental Technological Research, Poland.

**Abstract**

This paper presents a new method of investigating and checking airtighness of the joints of external walls by means of a thermovision system. This typical investigation is very

efficient and more accurate as compared to that of the pressure method. The investigation of airtightness was performed on joints with the simple cracks which were extra made by cutting off and polishing typical sandwich walls. The two half-sandwich walls were joined up or framed into one, to conduct the airtightness test for the crack. The obtained frame was mounted (fixed) in the empty external window-frame. The room was situated in the half height of a few story building. The instruments for measuring of the climate (radiation, pressure, temperature, air speed, etc.), blower door with ventilators (regulating the pressure difference across the joint), and thermovision equipment (880 LWP + TIC 8000) were used. In the calculation, of temperature fields in unsteady state the program BLOW-CRACK for temperature bridge with crack was used.

## Analysis of atmospheric pollution by quantitative infrared thermography

By S. BEDNARCZYK (*), P. HERVE (*), P. ADAM (**)

(*) Laboratoire d'Energétique et d'Economie d'Energie, Université PARIS X, 1, chemin Desvallières, 92410 VILLE D'AVRAY, France.
(**) Etablissement Technique Central de l'Armement, CEB B.P. 3, 91710 VERT-LE-PETIT, France.

**Abstract**

The radiation emitted by a cloud of particles depends on a lot of parameters: *d*, the particle diameter, $\lambda$ the wavelength, the cloud dimensions and the complex refractive index. The presence of a functional grouping of a pollutant is characterized by an absorption band whose wavelength is always in the infrared range. We have carried out a quantitative analysis of the factors governing the monochromatic emission of radiation from a cloud. The concentration, dimensions and shape of the cloud are far less significant that the particle size. For water cloud the contrast between two wavelengths can thus vary from -20% to -40% according to the type of cloud, and for an oil cloud from +10% to +50%. The comparison of two intensity levels obtained with a spectrophotometer, the first one in this range and the second one as a reference value, allows us to determine the presence/absence of a pollutant within the cloud of identical particles.

## Some problems in analysing premixed flames by infrared termography

By B. IMBERT, Y. LE MAOULT, J. QUINARD

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**Abstract**

Quantitative studies of flames by IR thermography can be achieved if we solve properly two problems. At first, there is a low thermal level but corresponding to very high temperatures at which calibration curves are not available, therefore we are concerned with the question of the extrapolability of these curves. Then burned gases are semi-transparent media so that we have to account for 3D effects. Our approach is proved by comparing thermal images of premixed flames in simple configurations and the images calculated by simulation of the complete acquisition system.

## Visualizing airflow using IR-techniques

By J. SUNDBERG

Indoor Climate Measurement Unit, The National Swedish Institute for Building Research, Box 785, S-801 29 Gävle, Sweden.

**Abstract**

To visualize the air flow into a room, we used a plastic screen, placed parallel to the air flow from a supply air diffuser placed at floor level. The screen takes the temperature of the air stream and registration of the screen temperature is made with an IR-camera. This gives a picture of the temperature distribution of the air stream. The information can be used to control the technical characteristics of the supply air device and to judge the impact of the air flow on human comfort.

## Atmospheric effects in infrared thermography

By P. PREGOWSKI (*)

(*) PIRS-Pregowski Infrared Services, P.O. Box 2, 00-908 Warsaw, Poland.

**Abstract**

For some sort of interpretation of thermographic works, as well as for devices designing and for planning of investigations it is recommended to considerate not only transmission but also emission effects of the atmosphere. Basing on modeling and spectral calculations some of examples there are shown the same as some results off long-term measurements of the reflected signals going from the atmosphere.

## Applications of infrared thermogrammetry in thermal engineering

By I. BENKÖ (*)

(*) Institute of Thermal Energy and Systems Engineering, Technical University Budapest (BME-HRI), H-1521 Budapest, Hungary.

**Abstract**

Examples from energy saving, thermotechnology, electrotechnics, agriculture and human biology confirm practical applications of IR-thermogrammetric CAD: examination of emissivity, halogen lamp, wall heating, radiators, venetian blinds, green houses, furnaces, insulations, high-voltage lines, district heating and leakage spots.

## Surface temperature measurements of thin films in the range -100oC to 100oC using infrared thermography

By Yves DELCLAUD

Observation and Remote Sensing Department, Aerospatiale, Space and Defense Division, Cannes Center, France.

**Abstract**

The temperature of thin films (of thickness around 10 µm) placed inside a vacuum chamber can be provided by thermography in the range -100$^{o}$C to +100$^{o}$C.

Following a description of the device and the experimental setup, method of temperature conversion, and associated sequence of calibration is described. The choice of suitable samples and structural supports influences the characterization of the method and its performance. Tests results corresponding to two samples representatives for typical applications (black paint and a thin film) are described.

## Emissivity measurements on graphite and composite materials in the visible and infrared spectral range

By G. NEUER (*)

(*) Institut für kernenergetik & Energiesysteme (IKE), Universität Stuttgart, Postfach 80 11 40, D-7000 Stuttgart 80, Germany.

**Abstract**

Quantitative thermography, especially thermometry needs knowledge of emissivity values of the observed surface and careful calibration of the camera. Emissivity measurements have to be carried out either by means of the thermography system itself or by determination of the spectral emissivity and calculation of the relating emissivity by integration. A measurement device will be described, which enables both, whereby the radiation comparison technique is used. The most important details of the equipment will be described with special emphasis of the calibration procedure applying heat pipe technology in the temperature range up to 1 100°C and a graphite furnace at higher temperatures. Results of measurements on different types of graphite, carbon/carbon, and carbon/silicon carbide-composites in the temperature range 800°C to 1 600°C will be presented.

## A quantitative thermal wave assessment of the characteristics of sub-surface defects

By D. P. ALMOND and P.M. PATEL (*)

(*) School of Materials Science, University of Bath, Bath, BA2 7AY, UK.

**Abstract**

The thermal characteristics of well characterised air-gap defects are compared with the predictions of one-dimensional heat flow theory. It is found the lateral dimensions significantly affect thermal wave response. A first order finite defect model is presented which accounts for much of the response obtained from real finite defects.

## Lockin thermography for multiplex photothermal nondestructive evaluation

By D. WU, W. KARPEN and G. BUSSE

Institut für Kunststoffprüfung and Kunststoffkunde, Universität Stuffgart, Pfaffenwaldring 32, W-7000 Stuttgart 80, Germany.

**Abstract**

The point by point thermal wave scan method is improved by combining it with the thermographic technique. The resulting lockin thermography can provide three images in a short time: phase image, magnitude image and thermographic image. Compared to thermography this technique has the advantage that phase angle images obtained in this

way are not affected by non-uniformity of area heating and optical or infrared surface structure of the sample under investigation. An additional advantage is that due to parallel excitation of thermal waves one can use low modulation frequencies to obtain a larger depth range.

## Photothermal method with arbitrary phase shift

By A. FIGARI (*)

(*) CISE technologie Innovative, Via Reggio Emilia 39, 20090 Segrate (Milano), Italy.

**Abstract**

An intensity-modulated pump beam generates a thermal wave in a sample. The relationship between the phase of the photothermal signal and the thermal wavelength ?$_{th}$ is pointed out, as the probe beam explores the thermal wave. On the basis of this analysis, the wavelength and the thermal diffusivity a of a sample can be measured with a new experimental procedure which uses arbitrary signal phase shifts relative to the heating spot centre. An application is reported.

## Differential stimulated infrared radiometry: application to remote detection of cracks

By A.C BOCCARA (*), D. FOURNIER (**), J. GUITONNY (**),
M. LE LIBOUX (*) and A.M. MANSANARES (**)

(*) Laboratoire d'Optique ESPCI-UPRA 0005 du CNRS, ESPCI, 10 rue Vauquelin, F-75005 Paris.
(**) Laboratoire d'Instrumentation UPMC - UPRA 0005 du CNRS, ESPCI, 10 rue Vauquelin, F-75005 Paris.

**Abstract**

We present a new approach for remote detection of cracks using a modulated local excitation and an infrared detection. In order to improve the contrast of the detection signals and to reveal more easily the dissymetry of the temperature field in the heated area close to a crack, we have used a differential detection. This set up whose rejection of the average signal is of the order of $10^2$ - $10^3$ allows an almost *zero background detection*.

## Monitoring of paint adhesion on polymers using photothermal detection

By H.G. WALTHER (*), W. KARPEN (**)

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(**) IKP Universität Stuttgard, W-7000 Stuttgart 80, Federal Republic of Germany.

**Abstract**

Photothermal detection allows for remote and non destructive inspection of near-surface areas. The physical mechanism involved is reflection of thermal waves at discontinuities. Based on theoretical models we investigate the kind of paint/polymer boundary and correlate it to surface preparation and to the resulting adhesion.

## Modulated infrared radiometry of rough surfaces at high temperatures

By B.K. BEIN (*), J.H. GU (*), A. MENSING (*), T. SOMMER (*),
B. WUNDERLICH (*), J. PELZL (*) And U. SEIDEL (**)

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(**) Friedrich-Schiller-Universität, Inst. Optik u. Quantenelektronik, D-0-6900 Jena, Max-Wien-Platz 1, F.R. Germany.

**Abstract**

Thermal waves detected by IR radiation are shown to be an ideal tool for non-contact remote surface and subsurface characterization of rough graphite samples, where the characteristic lengths and depths of the roughness structures are of the order of some microns up to several hundreds of microns.