Nonlinear Signal Processing for NDT 4.0

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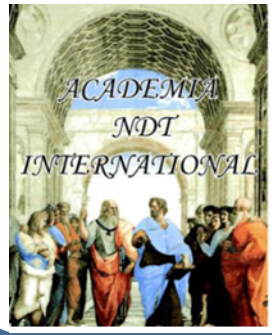


12th ECNDT

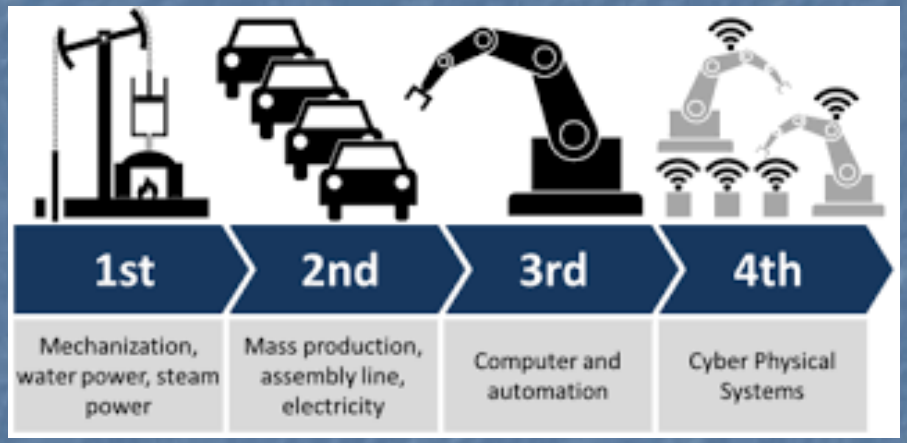
GOTHENBURG•SWEDEN•2018

For its 10th anniversary, Academia NDT International invites you to attend the European Research Day (June 13th, Room E1)

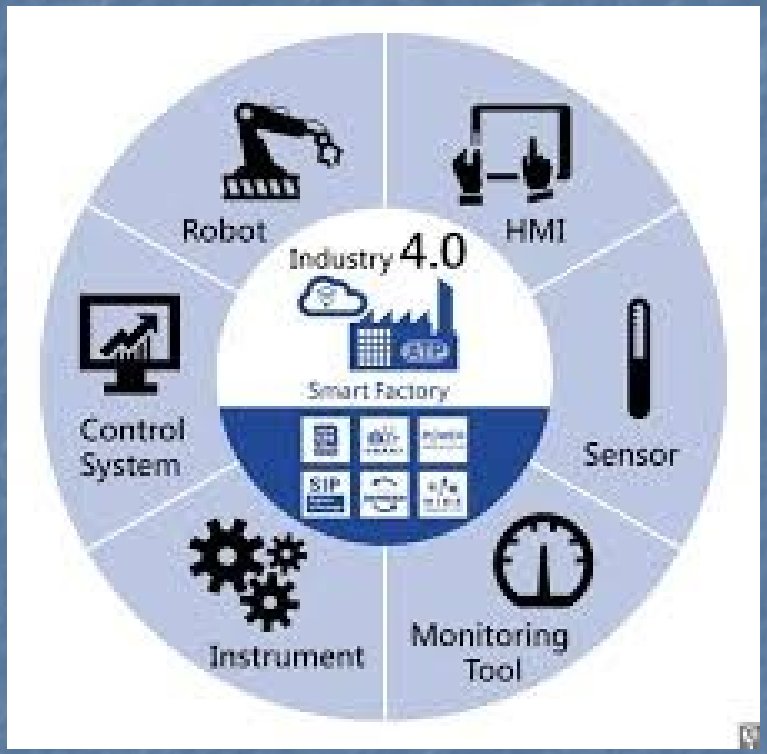
Outline

- Introduction
  - The growing interest for nondestructive testing (NDT) methods based on nonlinear acoustic effects
  - nonlinear ultrasonic (US) has become increasingly important due to the increase of higher sensitivity of electronic instrumentation and its associate signal processing algorithms
  - Instrumentation for NDT Integrity Engineering needs basics from applied physics and will concern all disciplines of engineering, including applied mathematics, computer science, modern automation and robotics, big data and artificial intelligence for Industry 4.0
- Methodology
  - One of the strategic plan of the international NDT community is to define standards for developing nonlinear NDT for automated set-up in mass production
  - The objective of this workshop is to define **the future of NDT 4.0** including **modern signal processing tools** such as big data reduction performed with an Artificial Intelligence (AI) and mapping of reduced data for modern NDT
  - The objective of this workshop will be used to prepare a guideline for application of nonlinear techniques. The working plan is to analyze strengths, weaknesses, opportunities and threats (SWOT) within the area of experimental nonlinear NDT.
- Conclusions, Discussion and Perspective

Industry 4.0



https://en.wikipedia.org/wiki/Industry_4.0

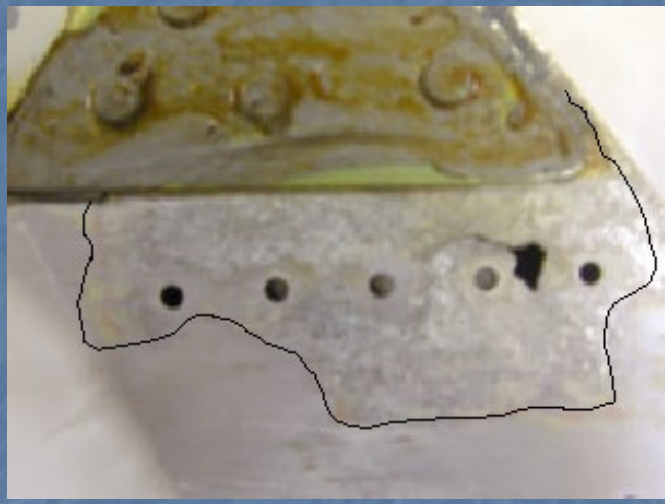


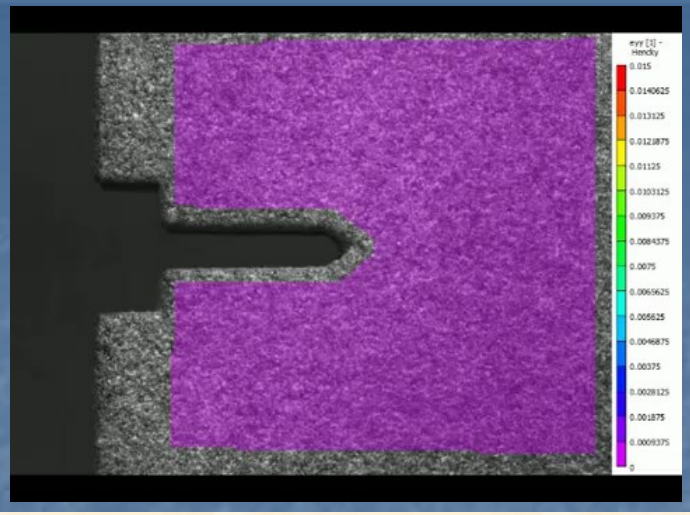
http://embedded-computing.com

This is time to enter in the era of NDT 4.0 !

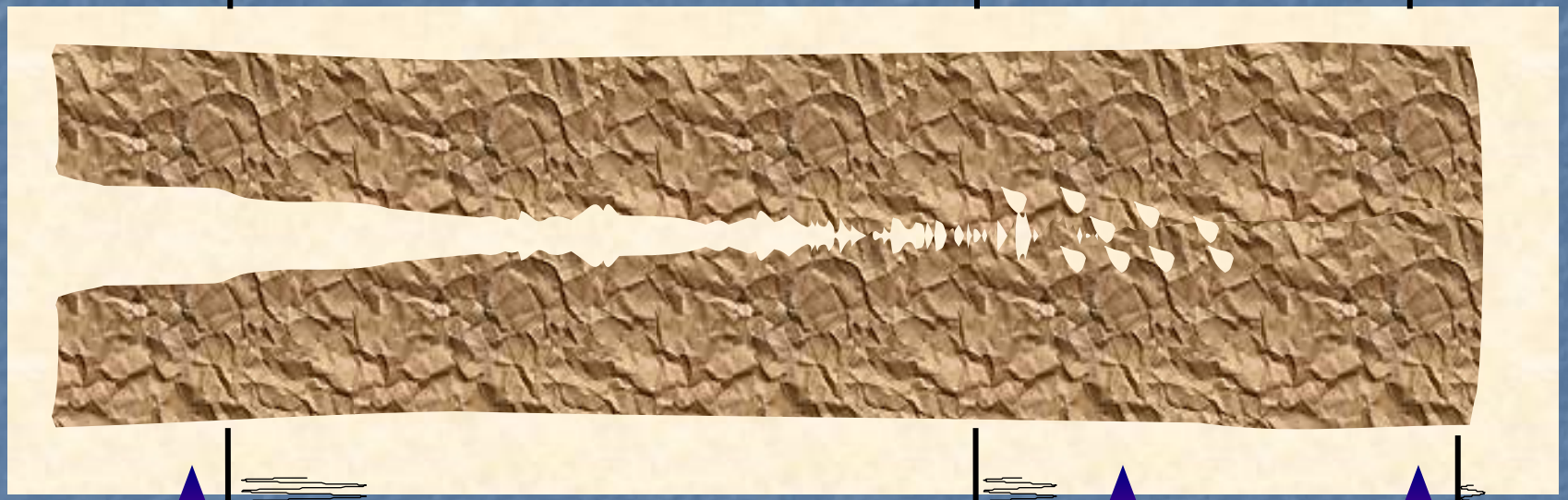
See "NDT 4.0 – Overall Significance and Implications to NDT", R. Link and N. Riess, ERD at ECNDT 2018

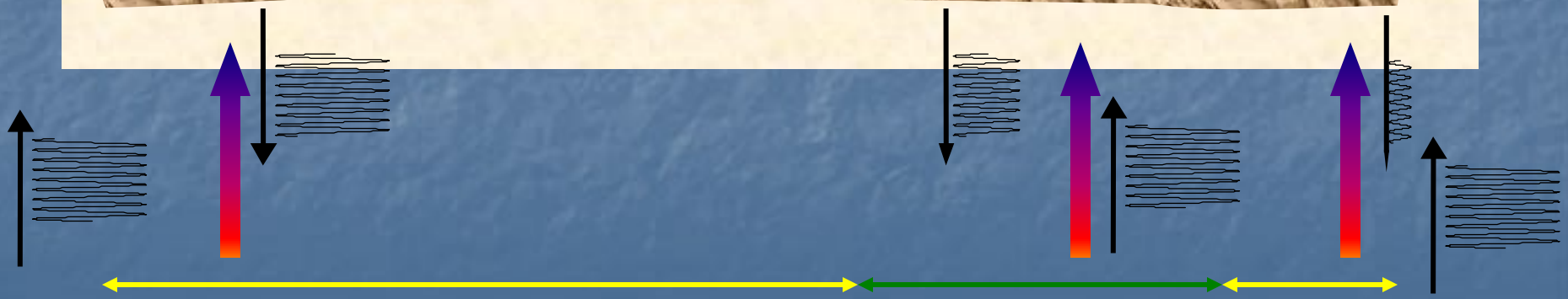
Damaged structures : macroscopic aspects





degradation ---> cracks





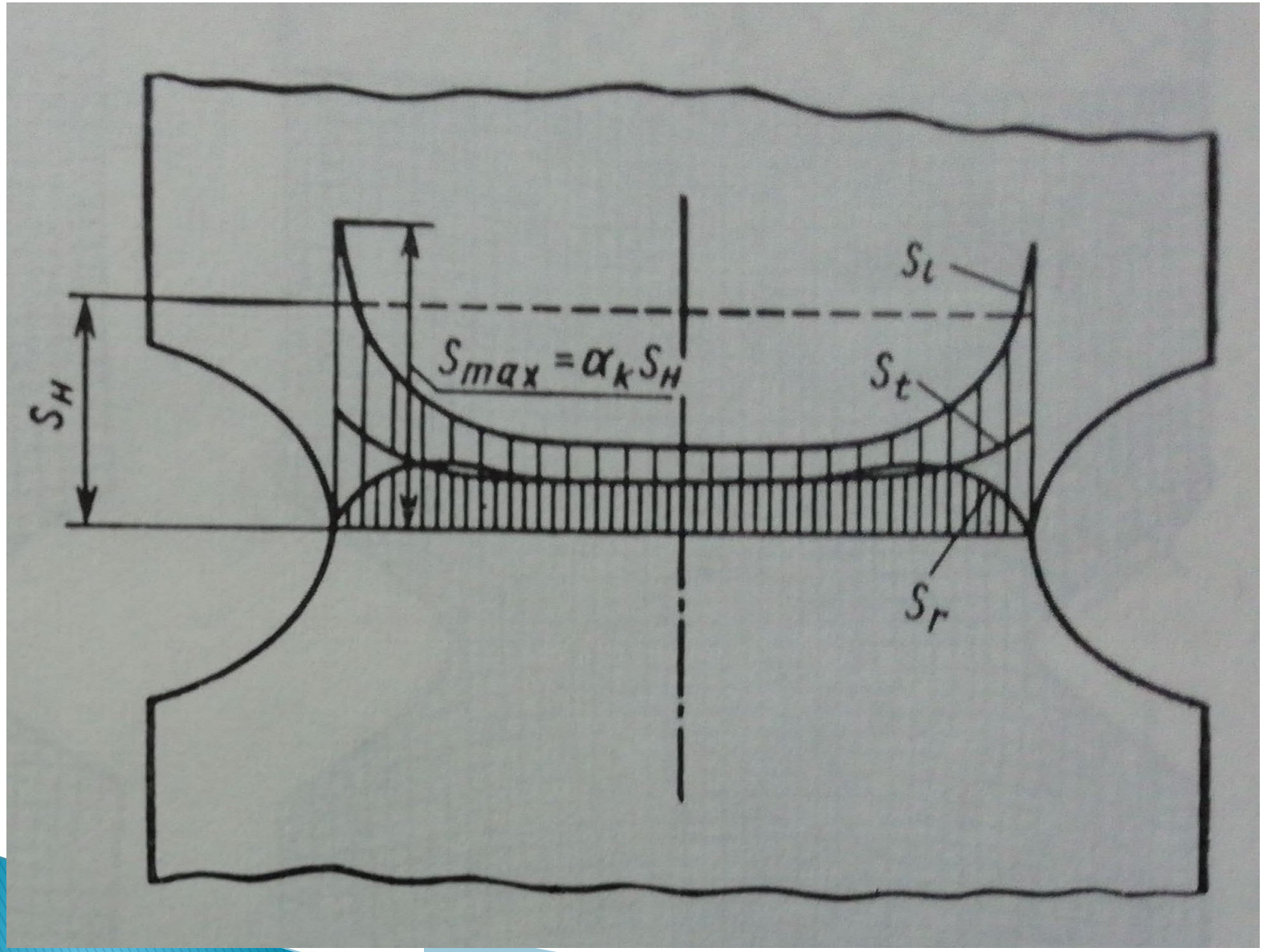
Linear region Nonlinear region Linear region

Non-Linear Mechanics and Mesomechanics- key to the Non-Linear NDT materials evaluation

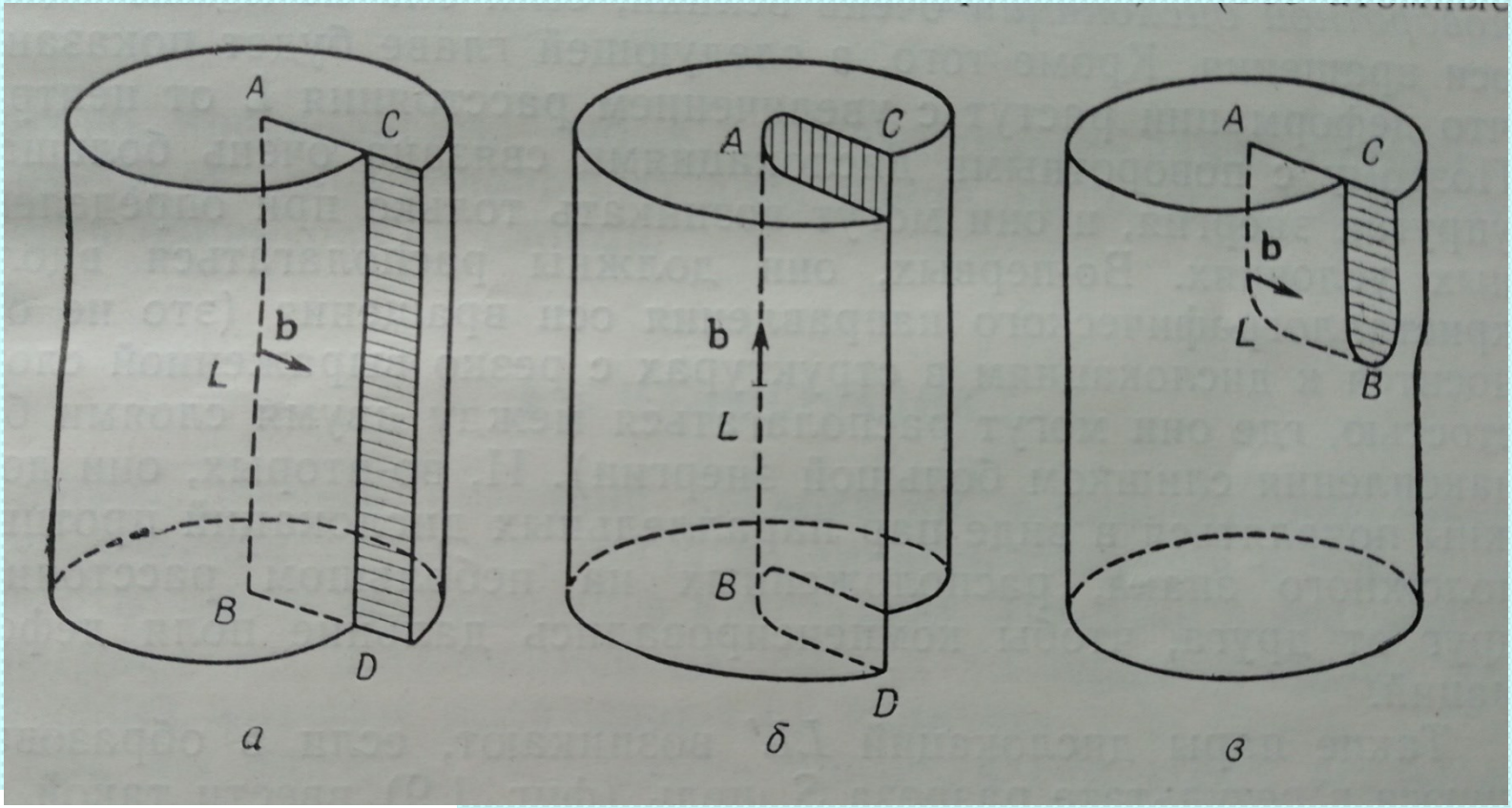
Prof.,Dr. Valeriy Vengrinovich
Belarus

Stress profiles in a rod under tension [MUrakami]

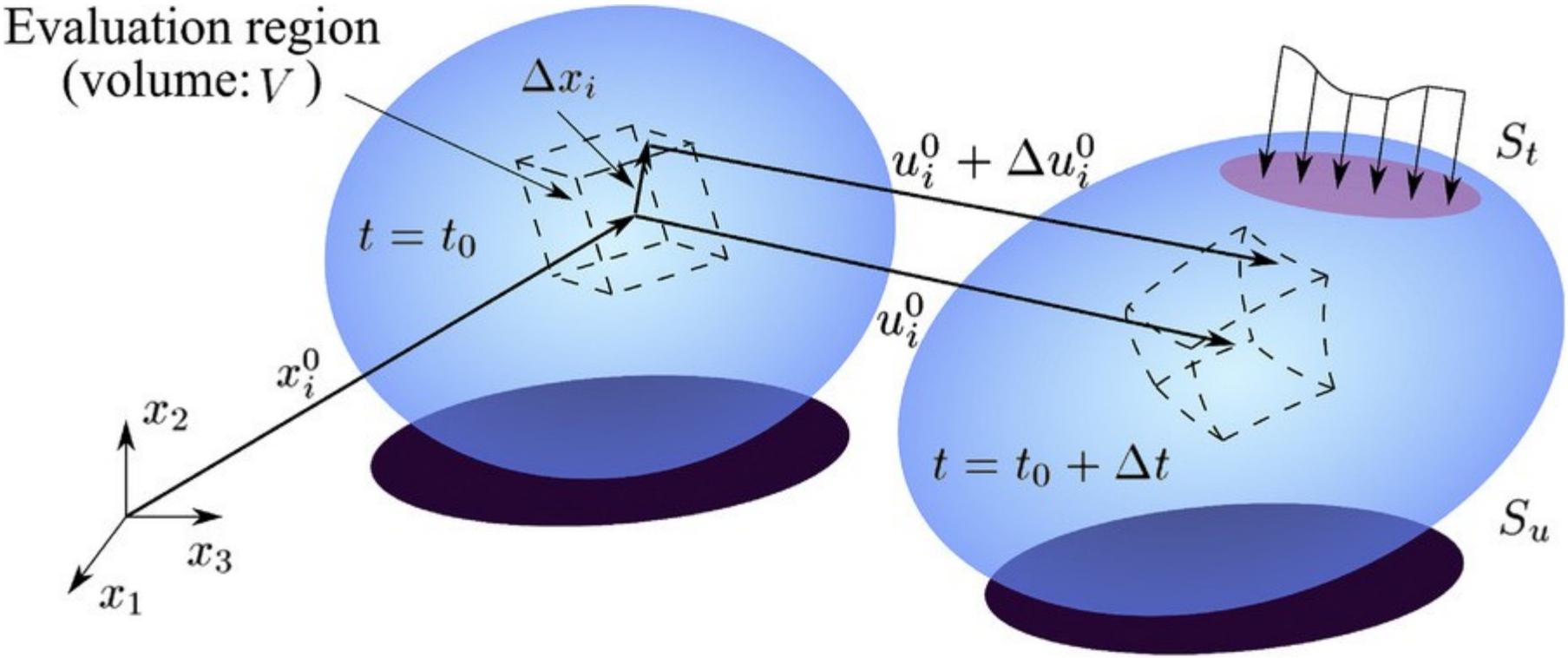
S_l – longitudinal, S_r – radial, S_t – tangential



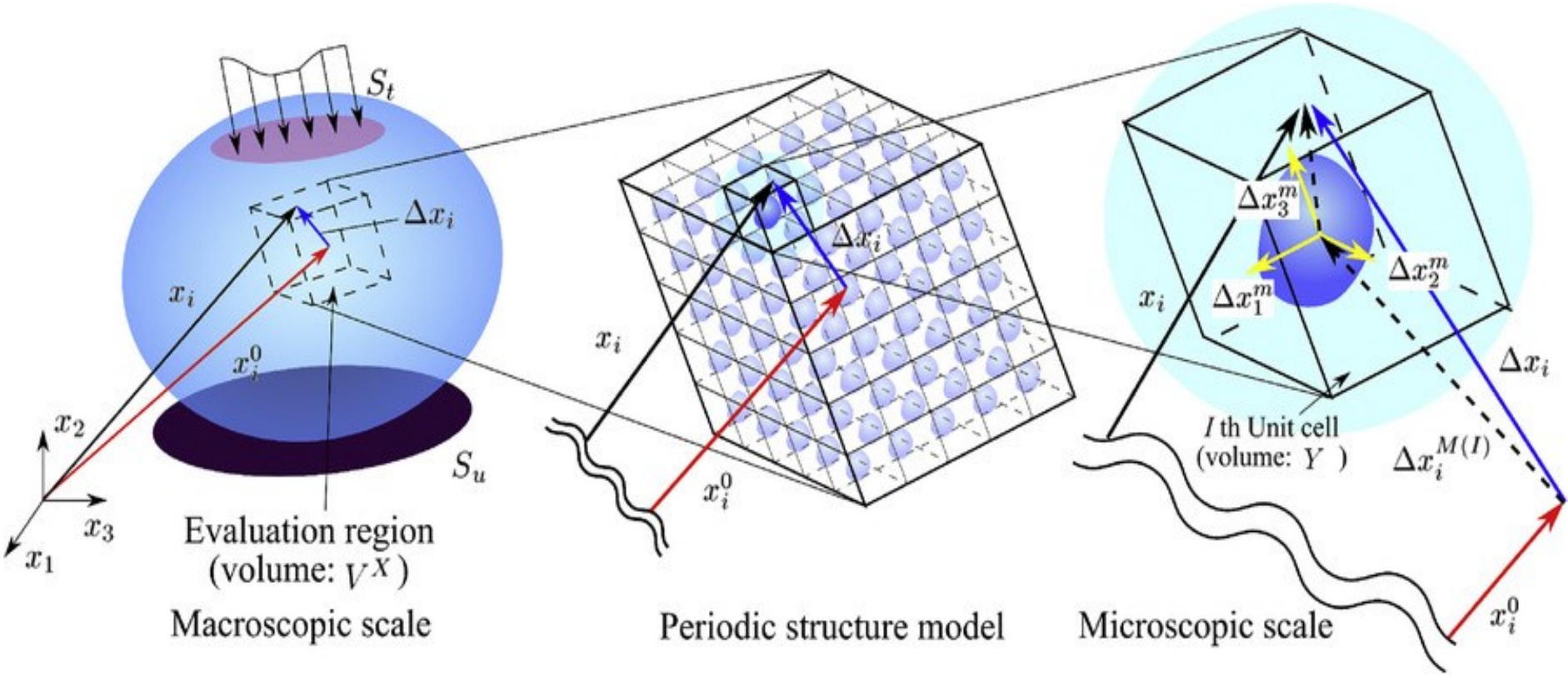
Edge, Screw and mixed Dislocations



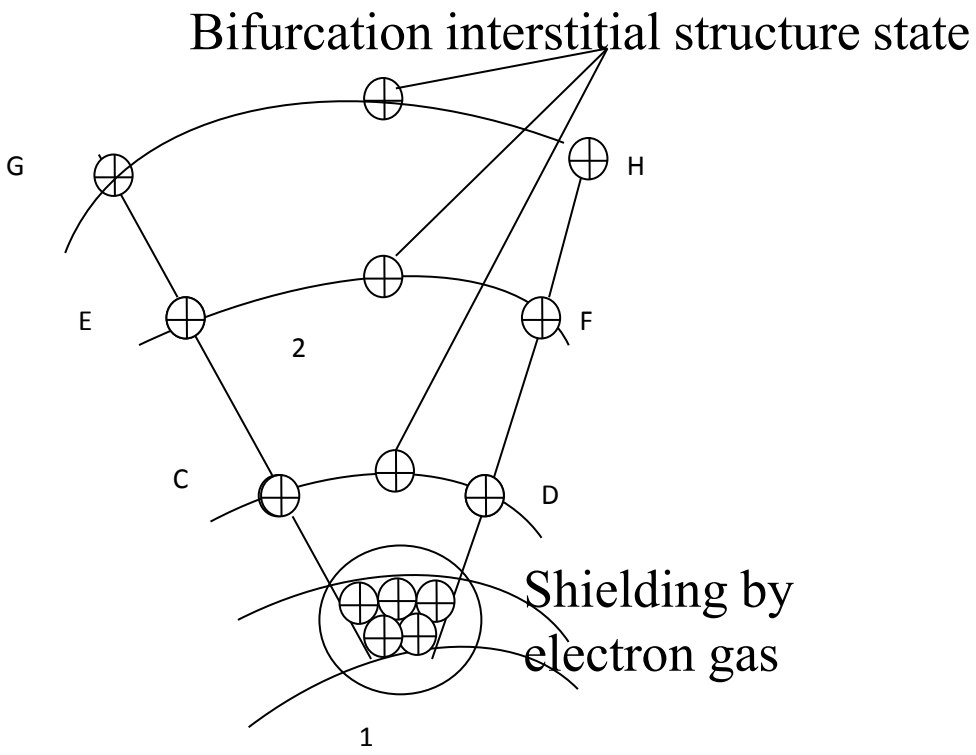
Schematics of deformation of a finite volume evaluation region in an object.



Microscopically heterogeneous material.



Generation of bifurcation interstitial structure states in the region of local curvature of crystalline grid. AB – Clasters of positive ions in the grain boundaries1-2 [5, Panin et al.].



DISLOCATION NET in STAINLESS STEEL Deformed by TENSION [Friedman].

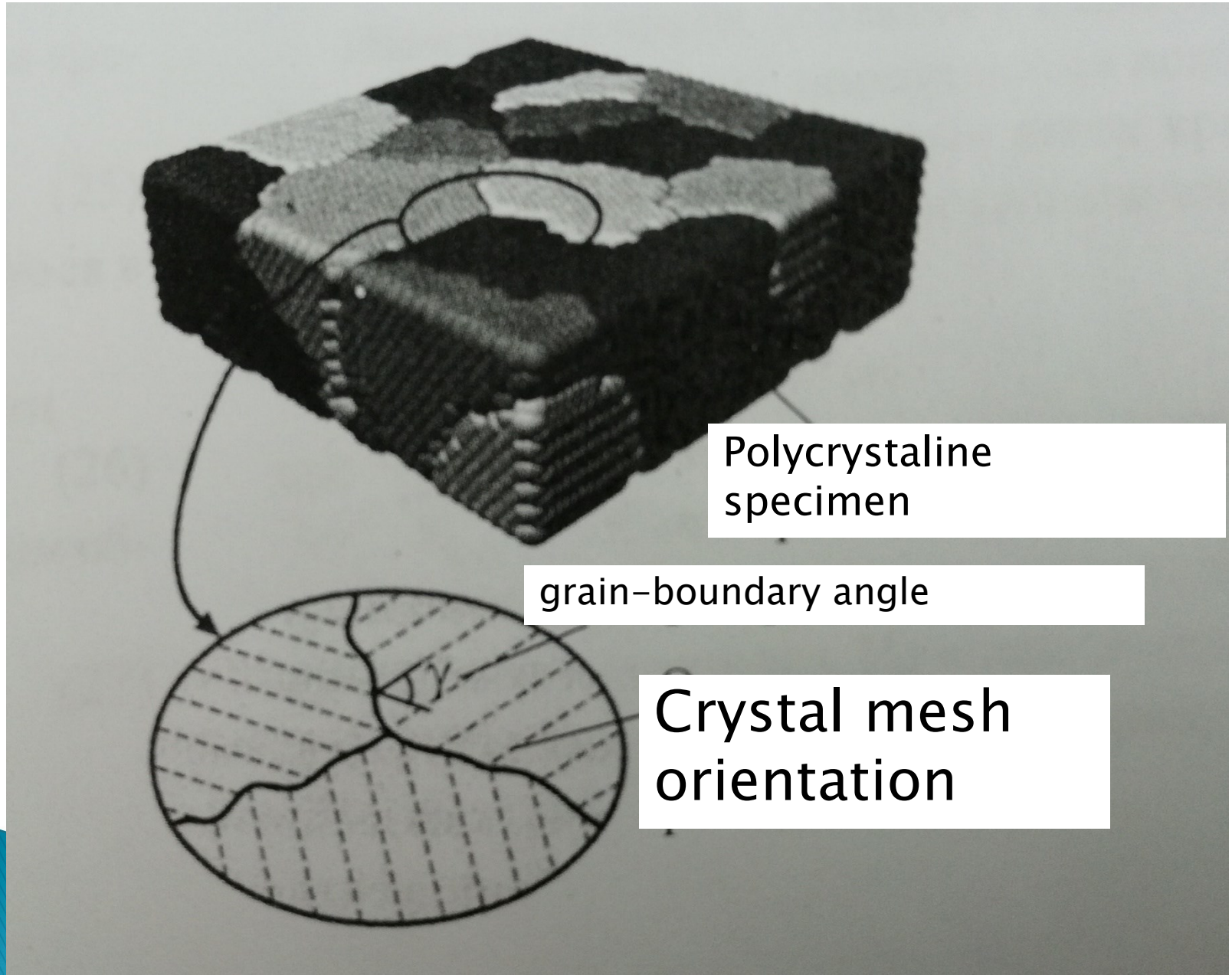
Alternation of stressed and unstressed surfaces is a typical non linear structure of a polycrystalline material with dislocations.

This Non Linear meso-structure precedes to **Macrodefect Origin.**

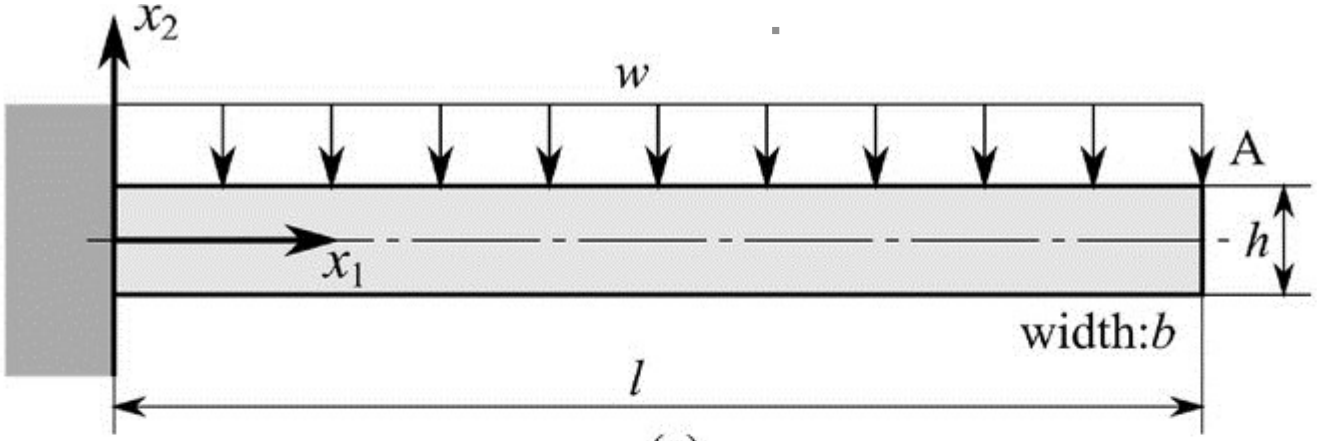
It could be detected like a prediction of life time of a construction.

The stochastic mesostructure is the characteristic of a deficiency of a crystal.

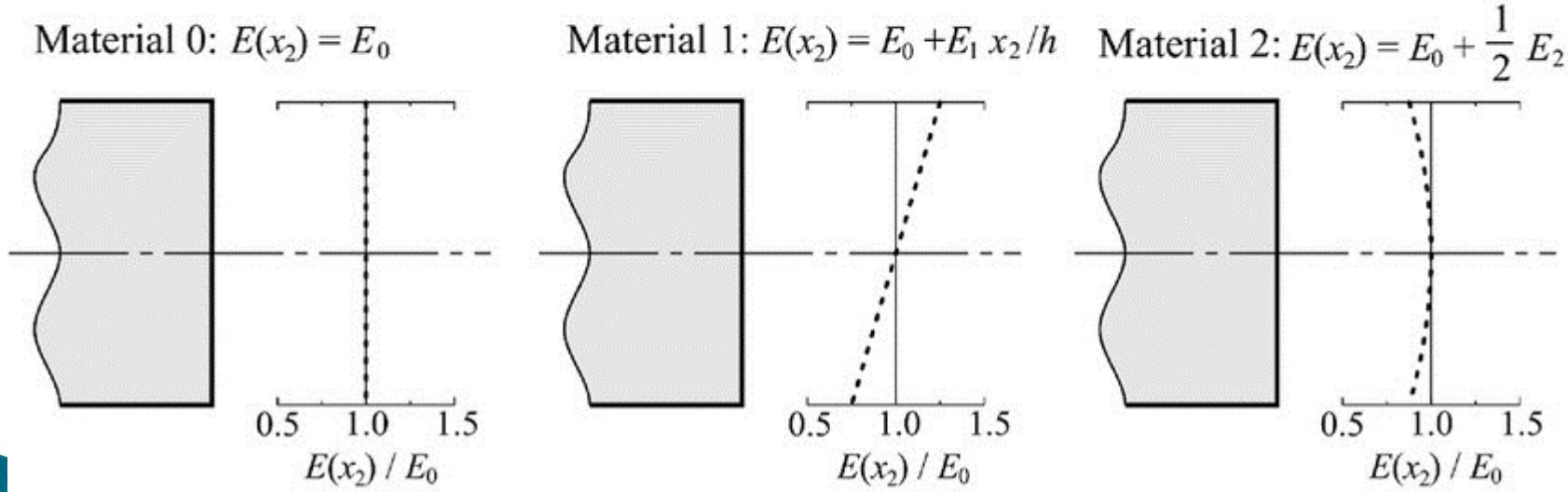
Mock of grains triple point in polycristalline structure



Model of the macroscopically heterogeneous cantilever. (a) boundary condition for the cantilever, and (b) distribution of the Young's modulus [M.Uchida@, Y. Kaneko]

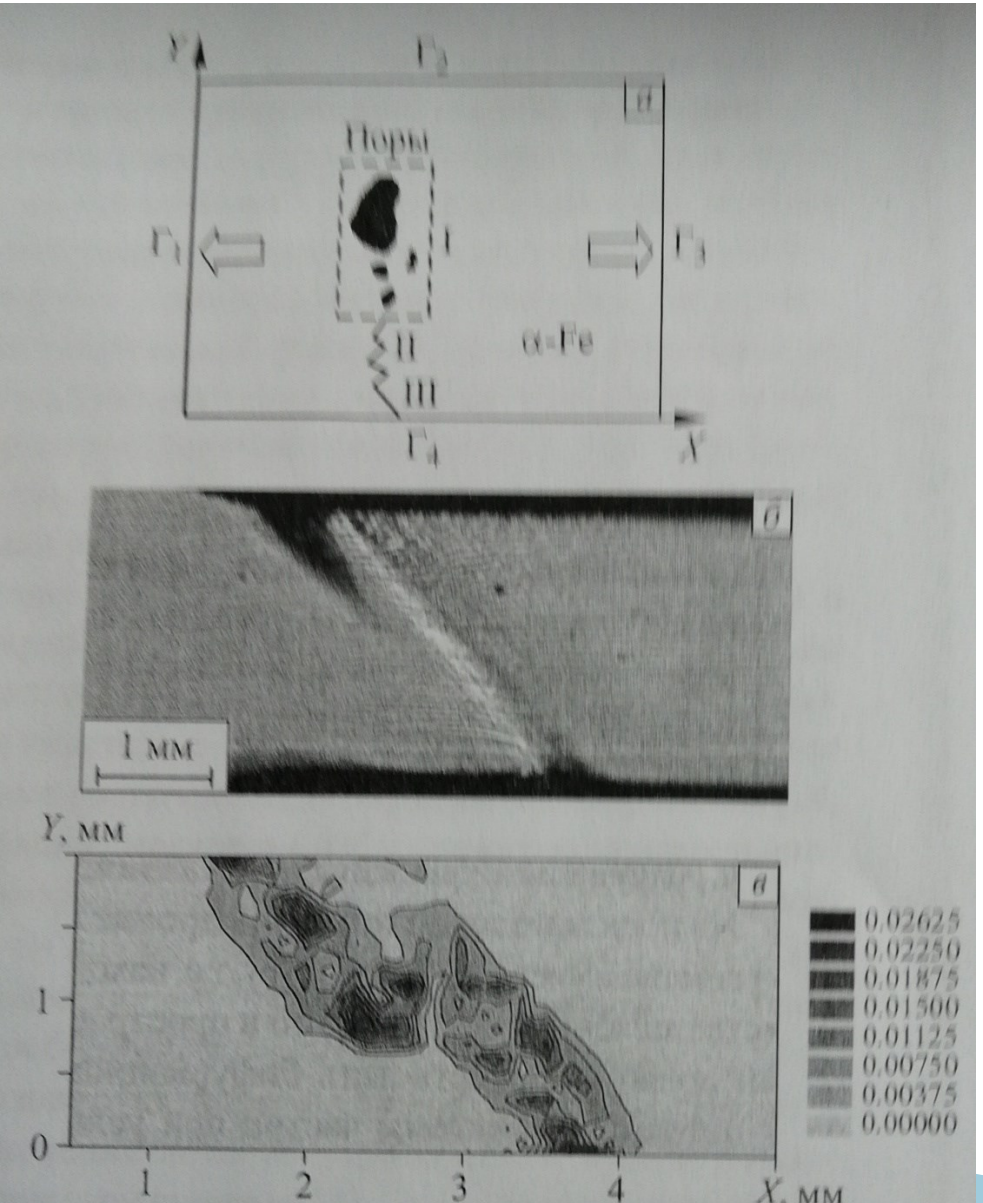


(a)

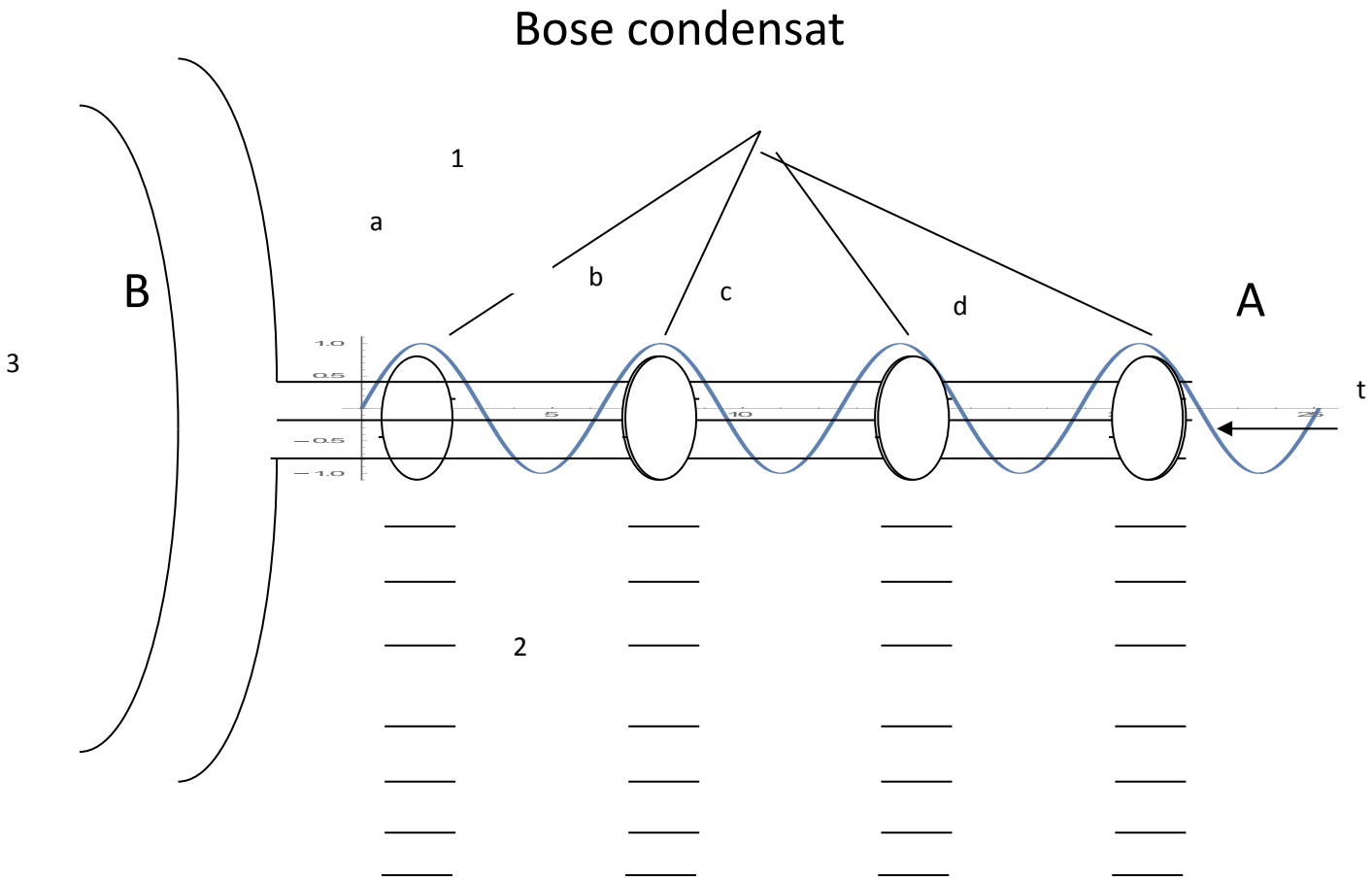


(b)

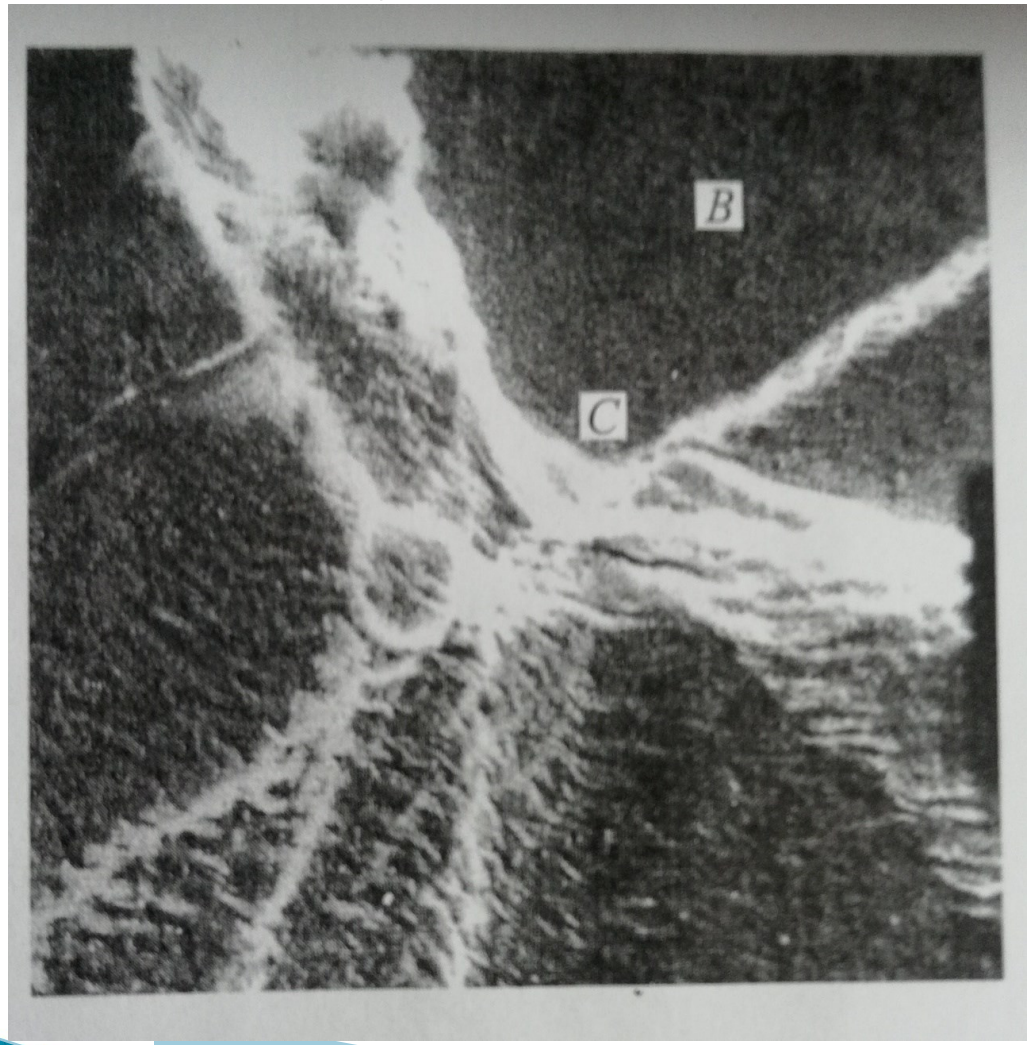
Distortion appearы in the neck of plane specimen under tension: I – separation pores; II – crack generation: III – crack propagation; optical image of a strip of localized deformation and the map of main plastic shear deformation in Fe PC. [Panin, et.al].



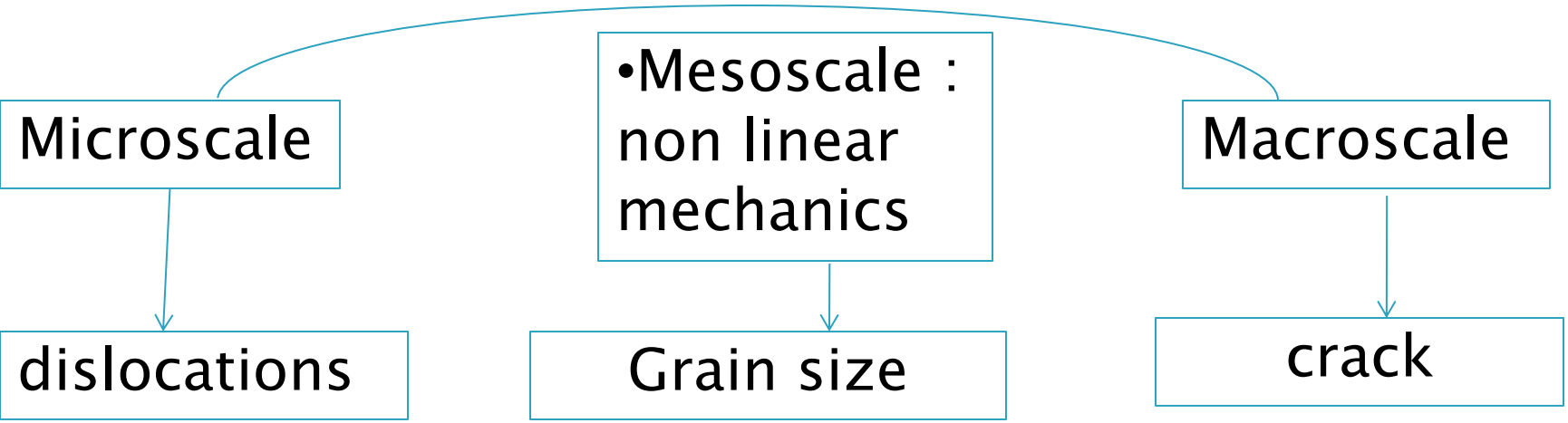
Multi Level Model of dislocations generation in 3D grain 2of polycrystal(1-2-3-) by a stream of structure transformations in the grain boundary AB by the mechanism of laser pumping with creation of clusters of positive ions a,b,c,d under stress influence [Panin, et.al].



Non-linear waves of localized plastic deformation in a surface layer in polycrystal Pb+1.9%Sn under uniaxial tension close to solubility limit, T=543 K, ϵ=30%, $\dot{\epsilon}$=0,1 min [Panin, et.al].

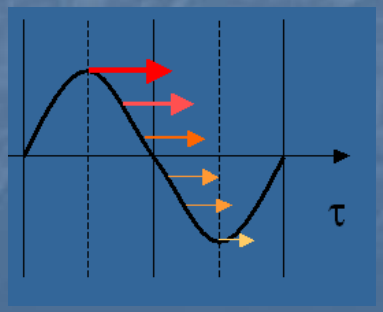


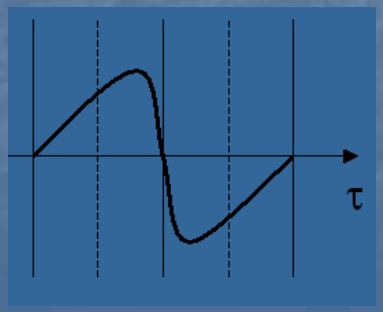
Fracture conditions in solids



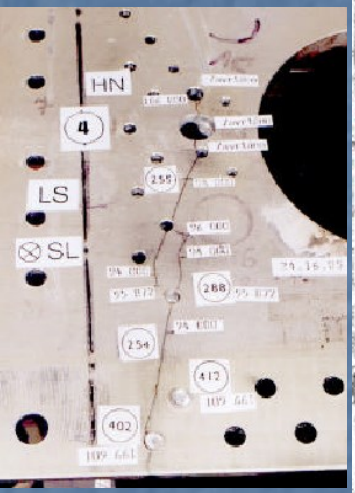
Advantage of ultrasonic nonlinear waves

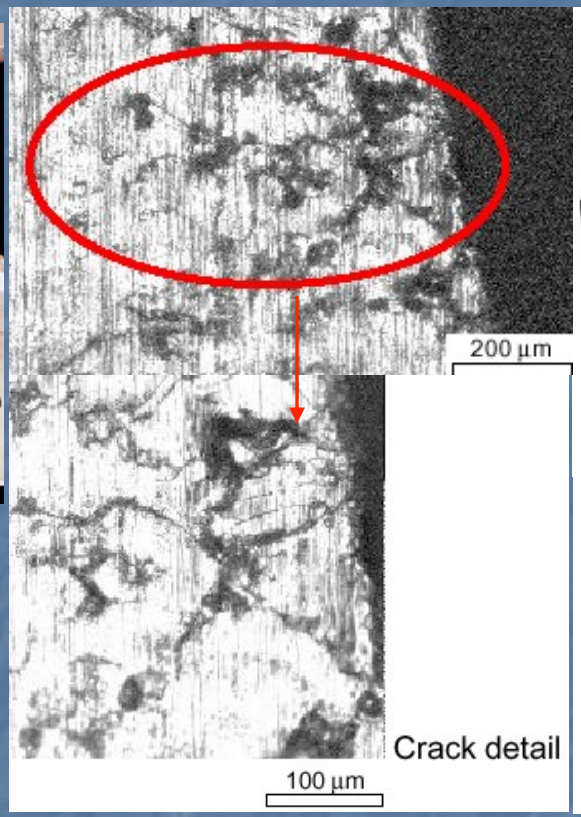
- How to detect smaller cracks :
  - Increase the frequency of ultrasound …
  - consequence : increase of attenuation …
- Solution :
  - … increase the ultrasonic power …
  - consequence : nonlinear effets are created (harmonics)
- Advantage :
  - « Natural » increase of the frequency thanks to harmonics

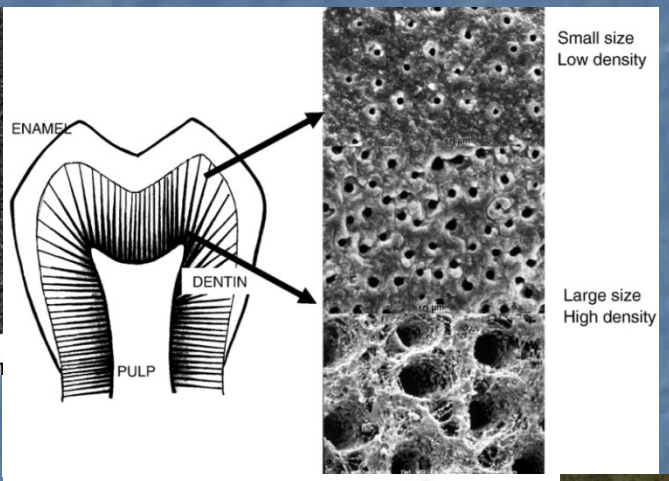




The (old) problem of aging !



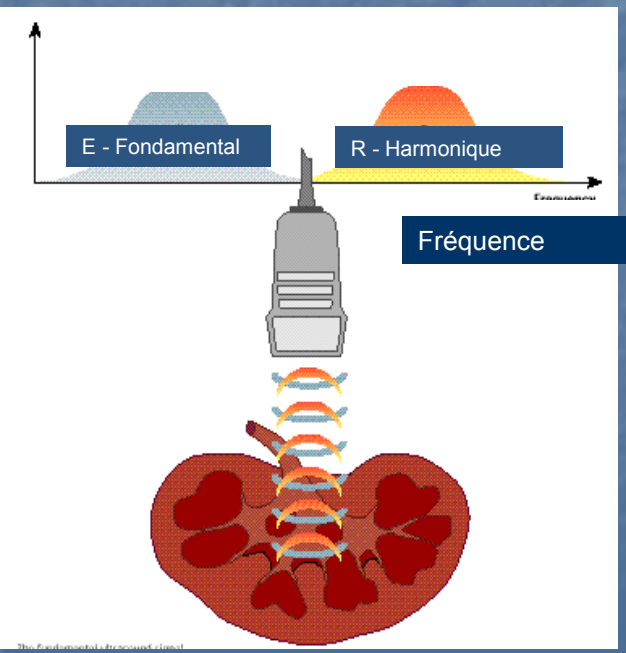


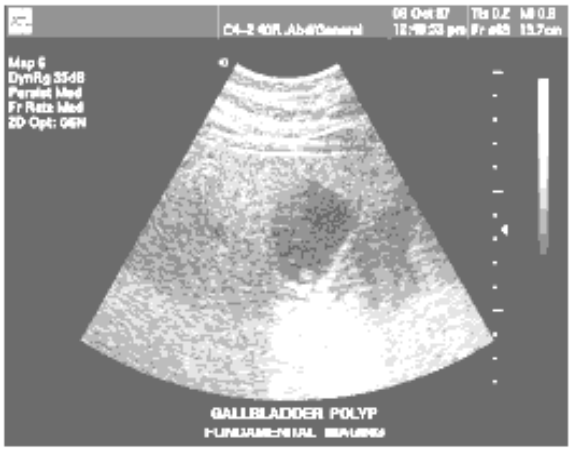


- What is the link between complex cracked structure from aeronautic industry, a human damaged tooth, the ancient stones, or skin …
- The internal complex structure …

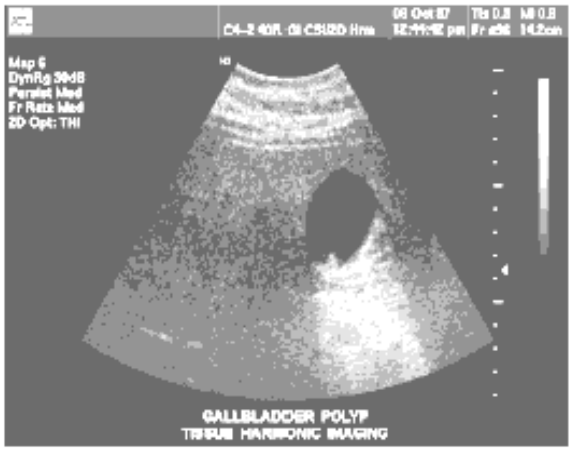
Medical applications of ultrasonic nonlinear waves

- **Harmonic Imaging**

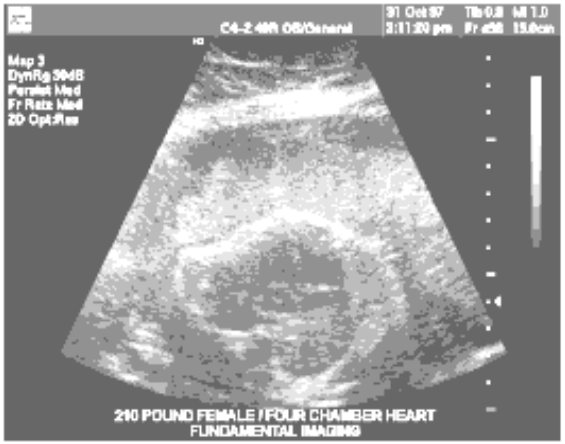




Fondamental



Harmonic



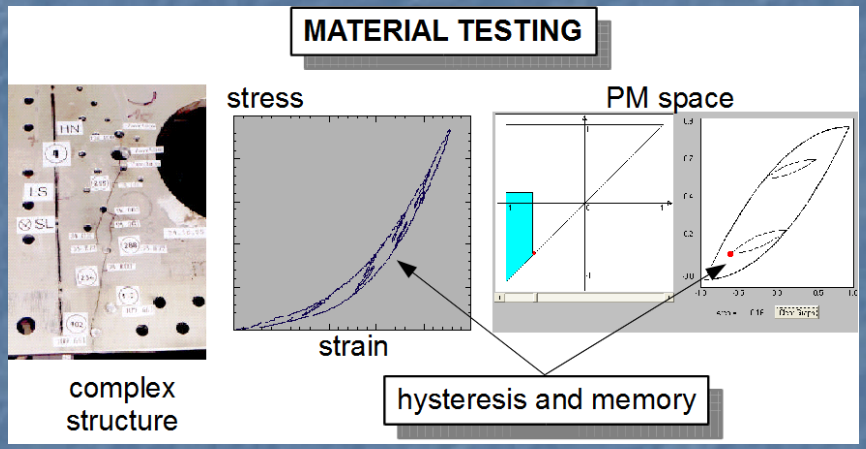
Nonlinear signature
Signal processing

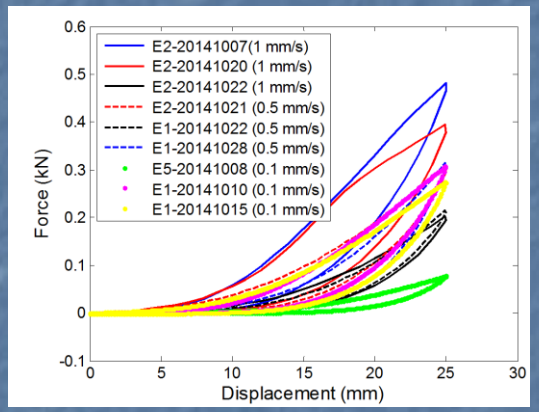
- harmonics generation
- intermodulation
- modulation, auto-modulation
- amplitude dependance of "classical linear signatures"
  - resonance frequency
  - attenuation
- sub-harmonics with arithmetical skeleton
- low frequency effects <-> slow dynamics
- chaos...

nonlinearity level

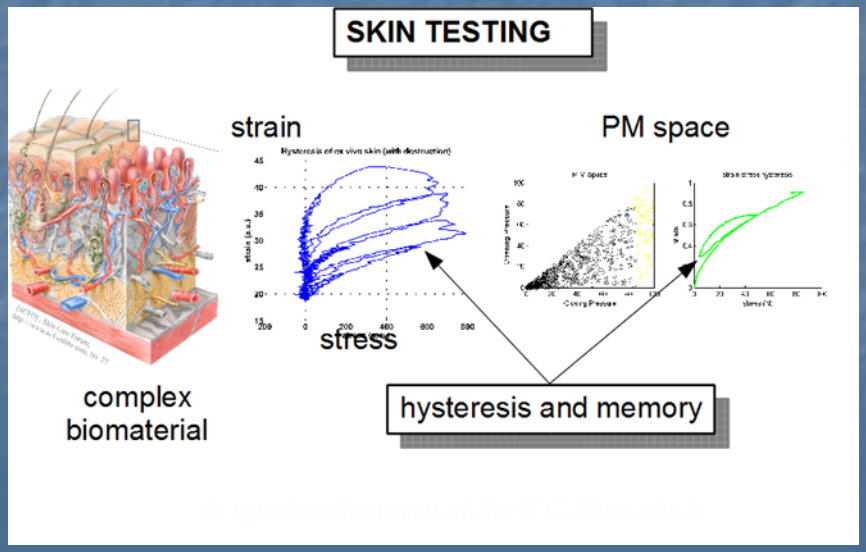
- <u>generic signature</u> in various physical systems
  - Mechanics, optics, electronics, acoustics, control

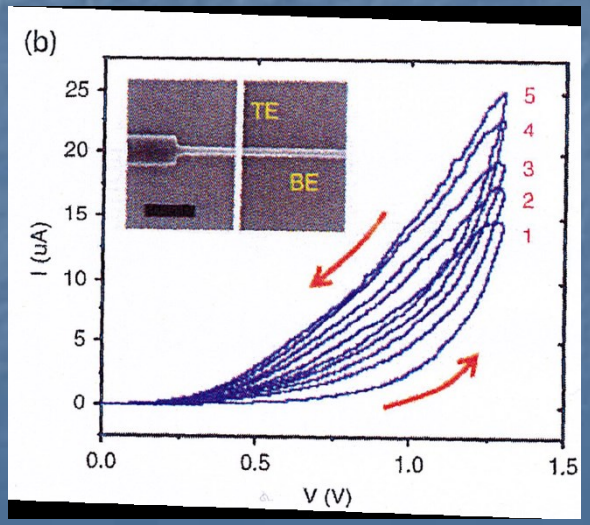
Aging, memory, nonlinearity and hysteresis networks





Plasticity and memory properties





Memristor networks :
T. Chang, Y. Yang, W. Lu, IEEE Circuits and Systems Magazine 13, 56 (2013)

Excitation of Nonlinear Systems : concept

- Linear systems

$E(t) = A\cos(2\pi f t)$ → R(t) → S(t)

$$S(t) = R(t) * E(t)$$
$$S(f) = R(f).E(f)$$

R(t)* not dependant of amplitude *A

  - output spectrum properties are « invariant » with respect to excitation
  - lots of invariants including scaling effects, reciprocity and time reversal

- Nonlinear systems
  - spectrum is modified : spectrum representation in not an « invariant »
  - is it still interesting to look at frequency components ?
  - what is the next "invariant" candidate instead of sine wave excitation?
    - time evolution of frequency representation : wavelets and second order tools …

⇒
- It depends on the system
- how to find such invariant ?

Excitation of Nonlinear Systems : experiments

- Linear systems (amplitude is not critical)
  - time domain : pulse
  - frequency domain : sine waves are eigen-functions
- Nonlinear systems (amplitude is critical)
  - time domain : pulse amplitude must be known (calibration)
  - frequency domain : sine waves are not eigen-functions (modulation)
  - attenuation and frequency are time-dependant (slow dynamic)
  - scaling effects : how to take into account them systematically

- It depends on the system
- how to find such excitations ?

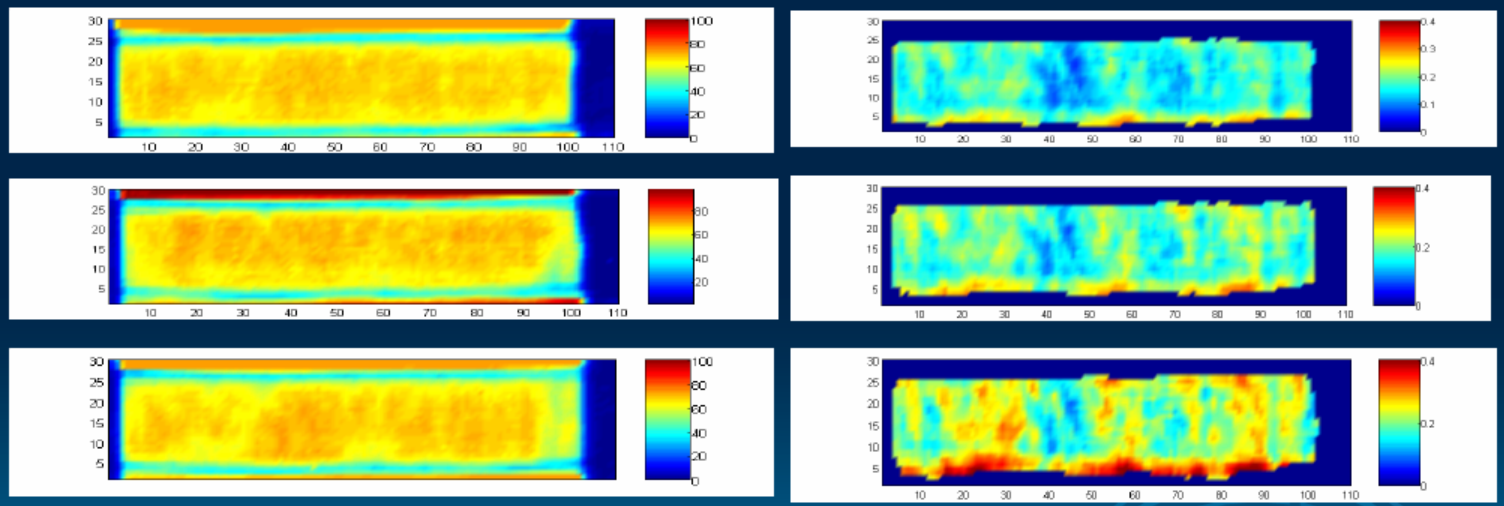
Basic Results (2002)

Example:
C-scan Imaging of fatigued CFRP samples

0 fatigue cycles
15000 fatigue cycles
17000 fatigue cycles

Classical C-scan

"2nd Harmonic Imaging"



AERONEWS

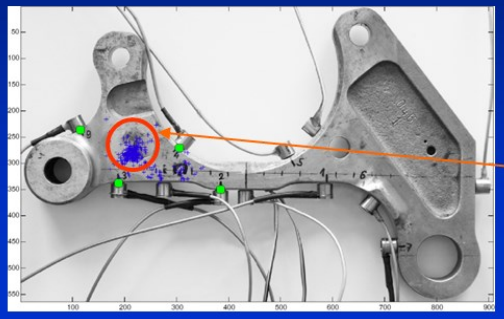
Bodycote Materialteknik, Sweden

Nonlinear Signal Processing for characterization of aeronautic structures

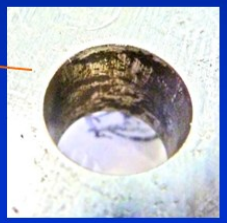
FATIGUE TESTS WITH NLTRM – ESAM on the STEERING ACTUATOR BRACKET

9th LOADING PERIOD (125 000 - 135 000 cycles)

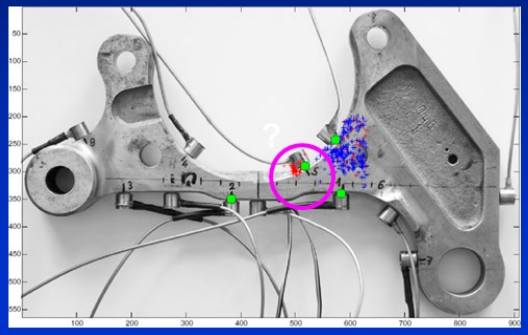
AE left-clusters



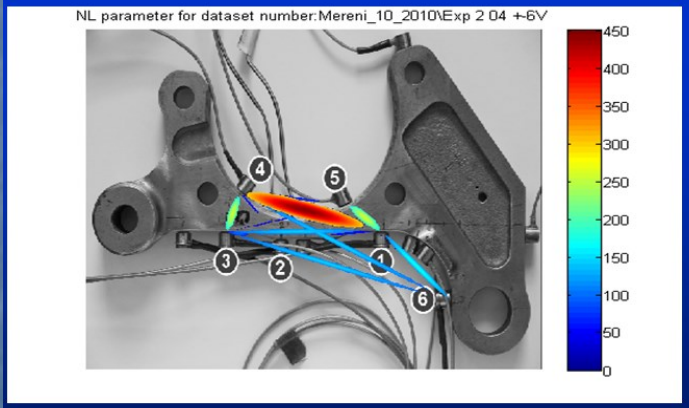
Damage of loading pinhole is one AE source cluster



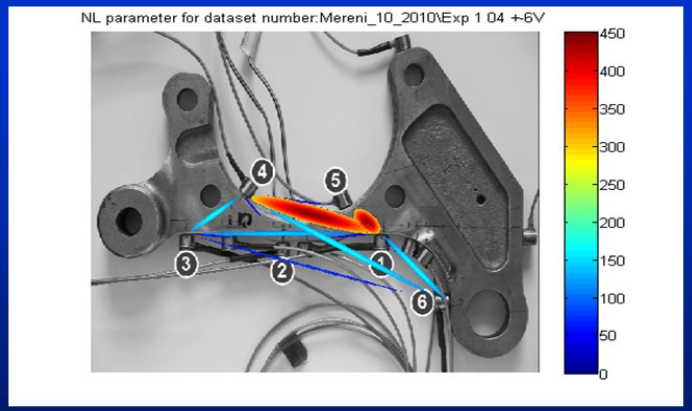
AE right-clusters



NLTRM – config. 1



NLTRM – config. 2



ACADEMIA NDT International
Durban, 17 April 2012

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Nonlinear ultrasonic time reversal mirrors in NDT, Zdenek Prevorovsky, Czech Academy of Science, Academia NDT lecture at WCNDT, Durban (2012)

TR-NEWS : the physical meaning of the autocorrelation function

Convolution equation

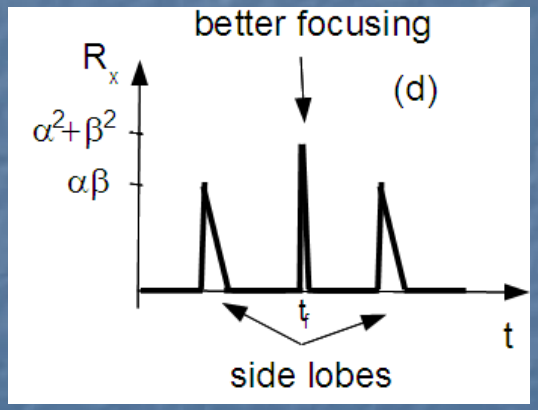
$$y(t) = c(t) * h(t) = \int_{\mathbb{R}} h(t-t')c(t')dt',$$

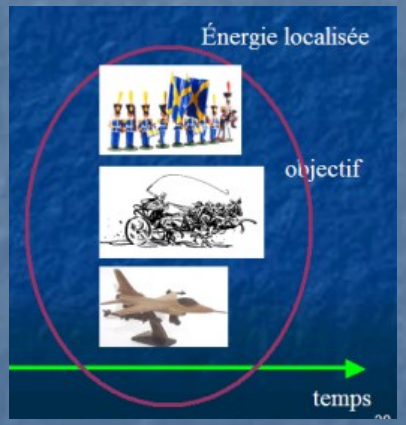
Correlation fonction

$$\gamma_{xx}(\tau) = \int_{\mathbb{R}} x(t)x^*(t-\tau)dt,$$

TR-NEWS

$$y_{TR}(t) = \Gamma(-t) * h(t) = \Gamma_h(-t),$$

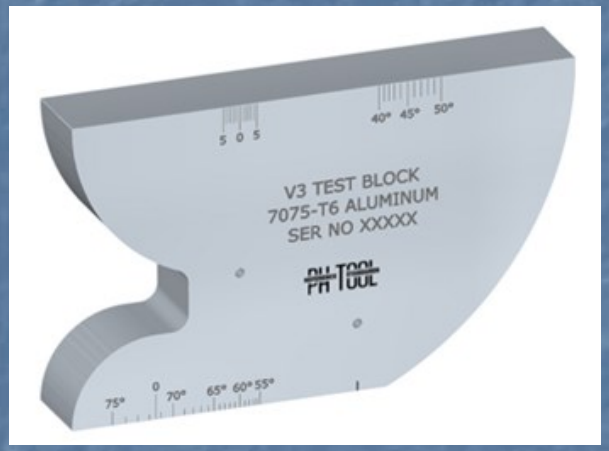


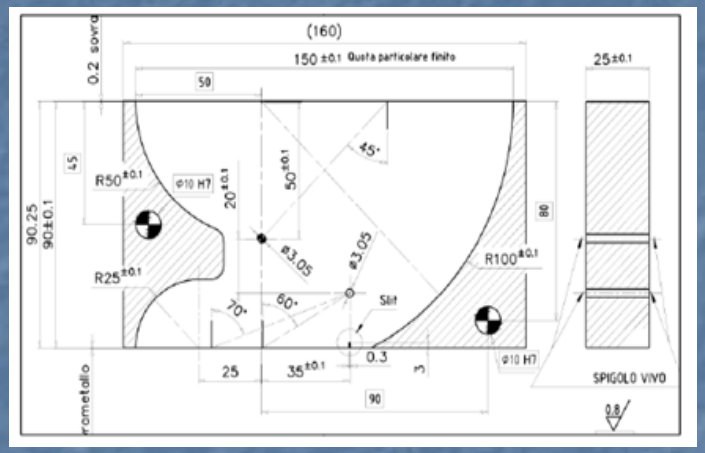


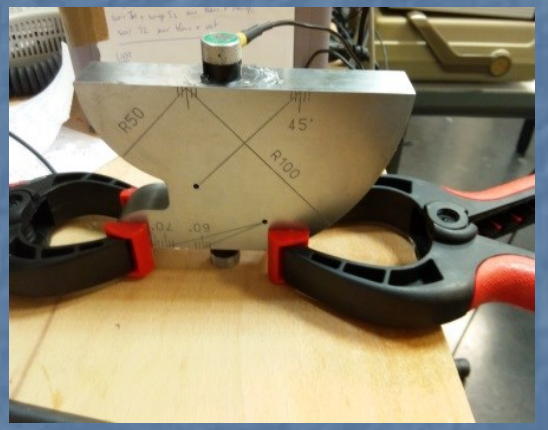
TR-NEWS process is a way to understand the physical interpretation (energetically) of the autocorrelation function of a complex medium

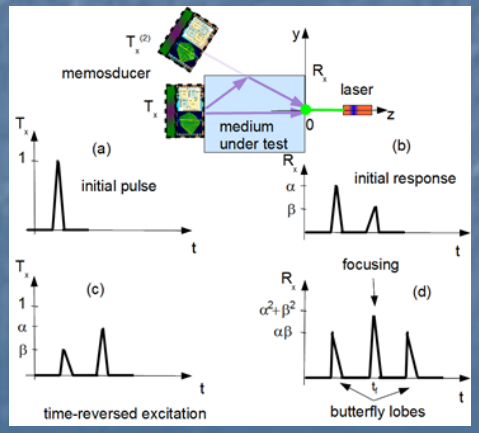
http://www.academia-ndt.org/admin/Downloads/Topo_Academia-Munich2016-V2.pdf

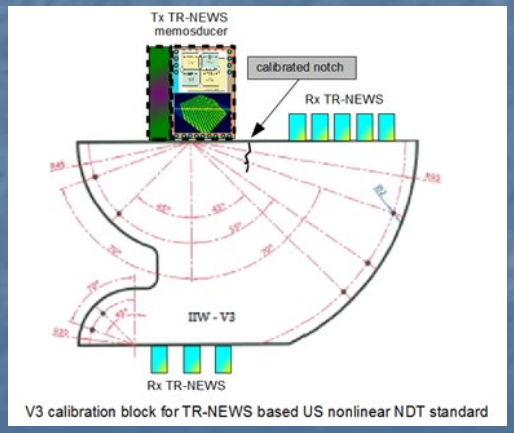
Standardisation with the V3 block











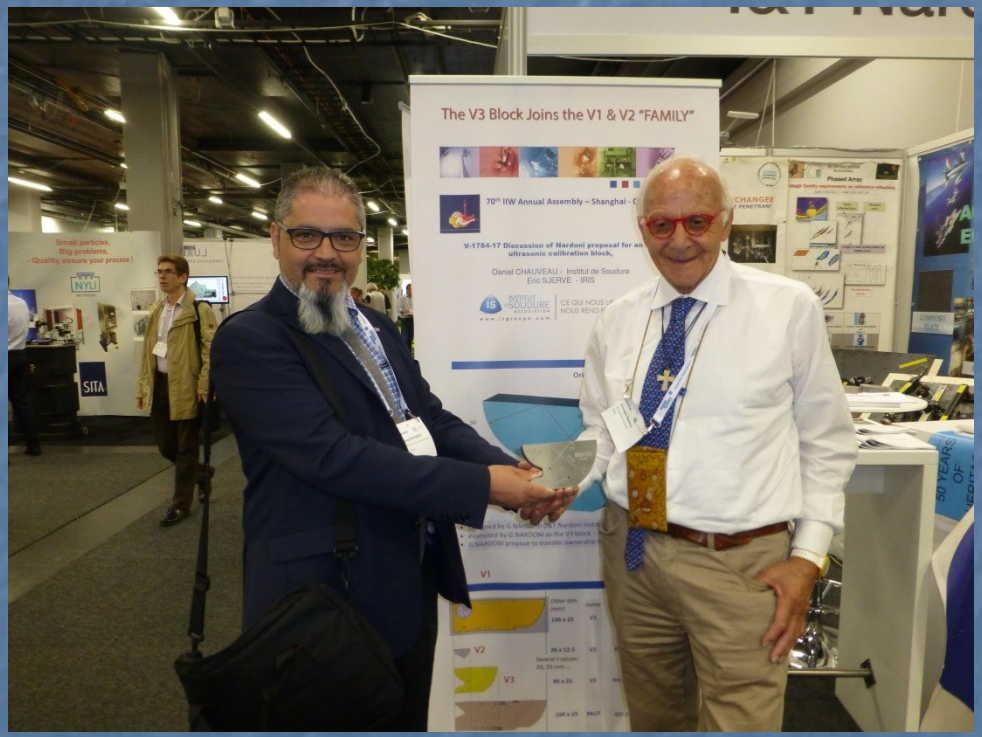
V3 calibration block for TR-NEWS based US nonlinear NDT standard

Download ECNDT 2018 papers under session Nonlinear Ultrasonics 1 :

http://www.ecndt2018.com/abstract/acousto-mechanical-evaluation-of-multiscale-hysteretic-parameters-of-complex-material-with-nonlinear-time-reversal-imaging/

http://www.ecndt2018.com/abstract/acousto-mechanical-evaluation-of-multiscale-hysteretic-parameters-of-complex-material-with-nonlinear-time-reversal-imaging/

ECNDT 2018, Gothenburg



PROJECT

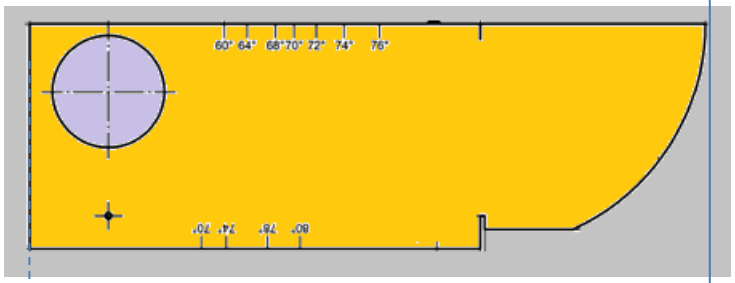
71th IIW Annual Assembly – Bali - indonesia

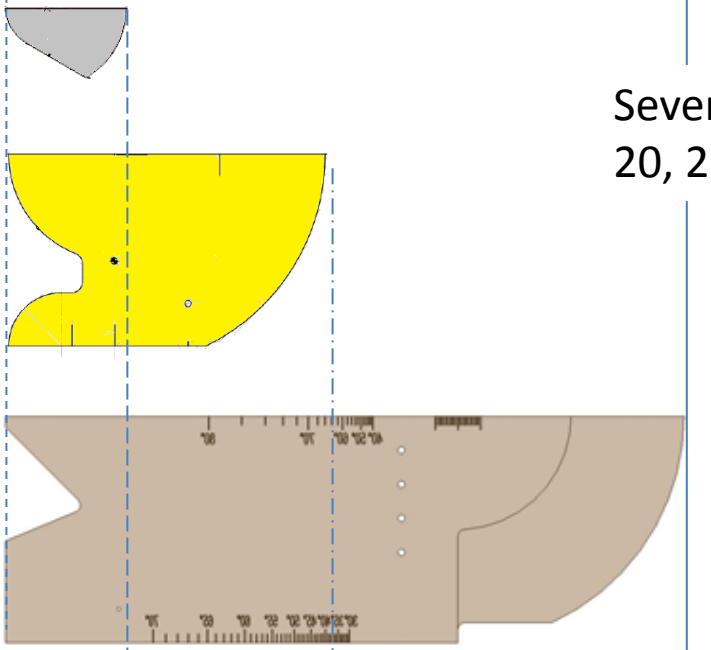
Bali Nusa Dua Convention Center, Bali - Indonesia
15 - 20 July 2018

V-1784-17 Discussion of Nardoni proposal for an IIW ultrasonic calibration block

Serge DOS SANTOS (INSA) - Daniel CHAUVEAU (Institut de Soudure) and Pierre CALMON (CEA)

> UT calibration blocks comparison





Other dim. (mm)	*name*	*ISO standard*	*weight* (St)
100 x 25	**V1**	**ISO 2400**	**5070 g**
26 x 12.5	**V2**	**ISO 7963**	**212 g**
90 x 25	**V3**	**No standard**	**< 2500? g**
100 x 25	**PAUT**	**ISO 19675**	**4660 g**

Several t values:
20, 25 mm …

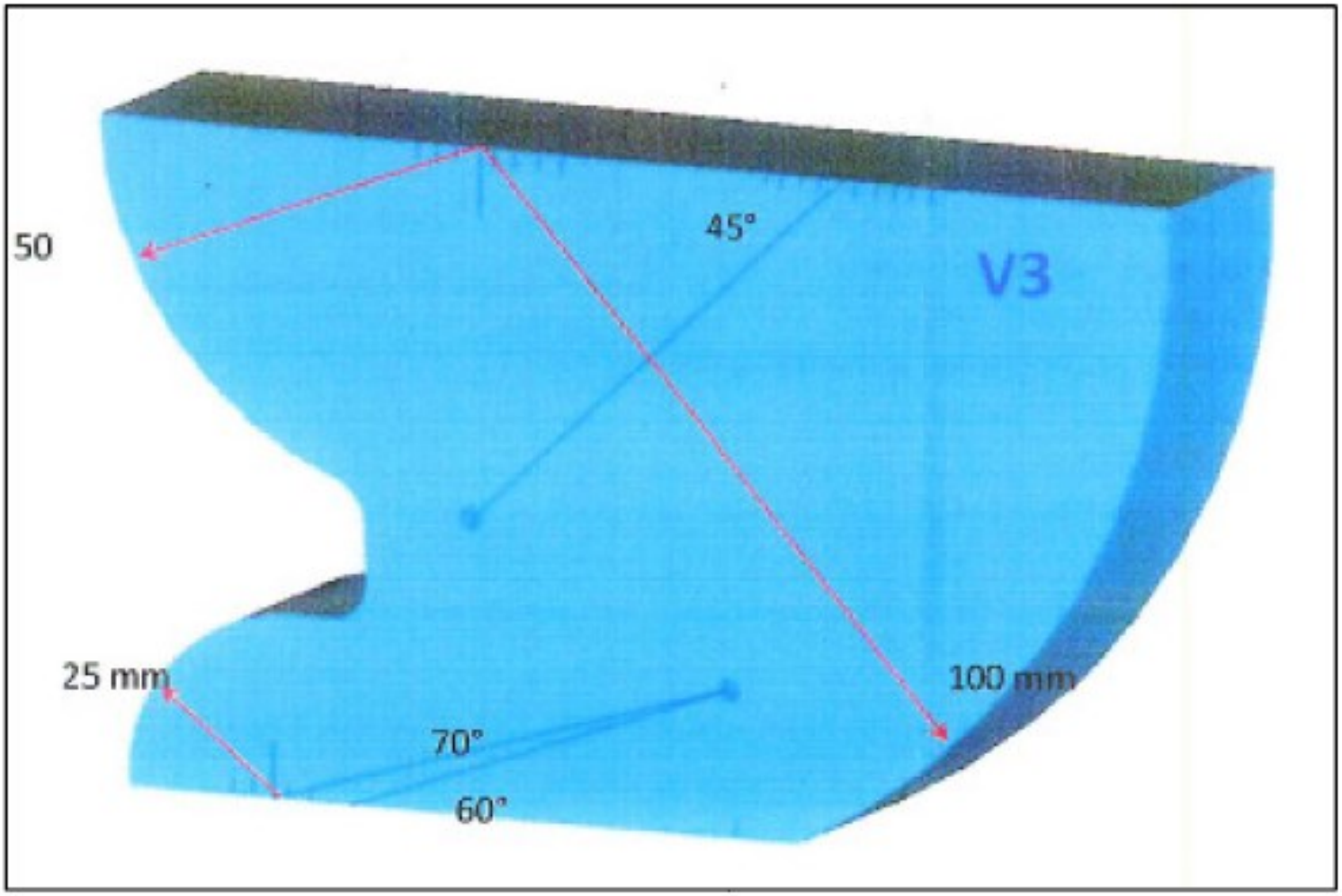
45 **150** **300**

length(mm)

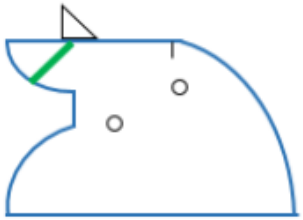
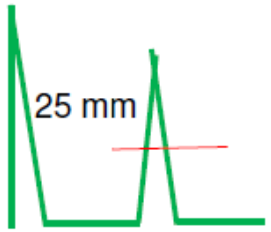
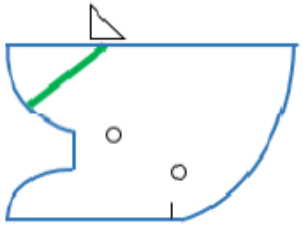
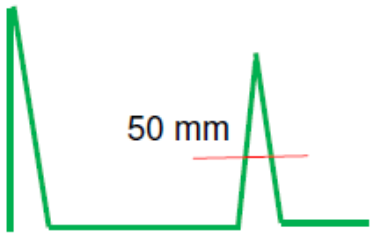
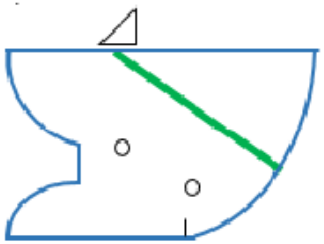
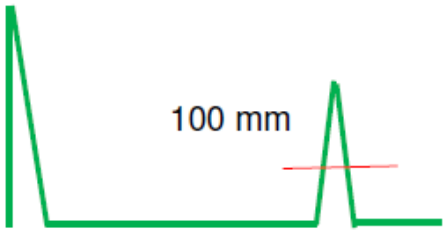
Main functions:

1. Three direct reflections: 25mm – 50mm – 100 mm
2. Two multi-reflections: 200mm – 250mm
3. Index point measurement for an angle beam probe
4. Incident angle measurement for an angle beam probe
5. Limited ability to set sensitivity on the 3 mm holes
6. Surface breaking slit for surface and sub-surface indications
7. Creeping wave calibration

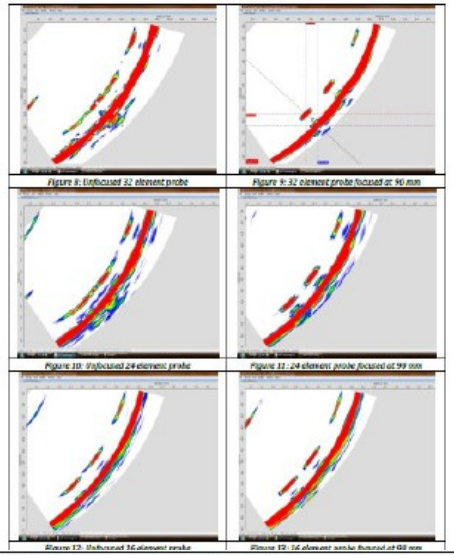
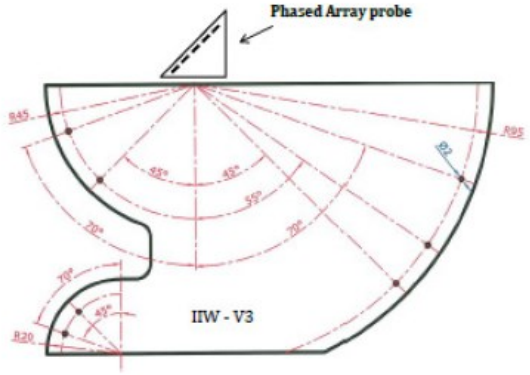
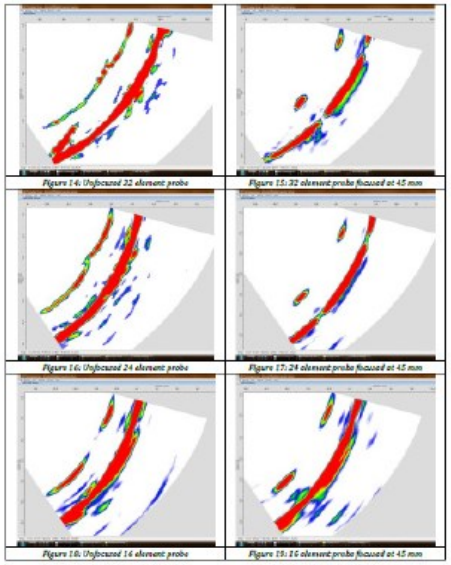
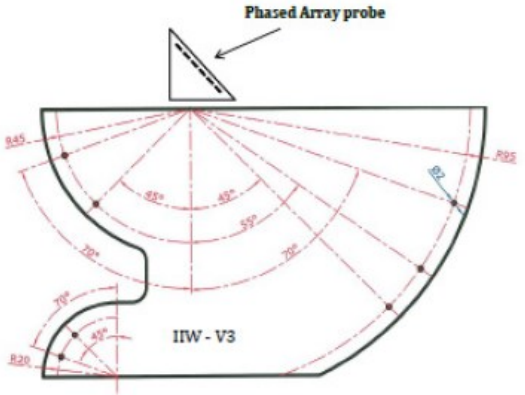
V3 – main functions



V3 – main functions

Main Functions	V3 Block	A-Scan
25 mm direct reflection	Radius 25 mm 	
50 mm direct reflection	Radius 50 mm 	
100 mm direct reflection	Radius 100 mm 	

V3 – other possible functions

Non-Focused Beam	Focused Beam	Probe Position
		Beam focus at 95 mm  Ultrasonic path at 100 mm
		Beam focus at 45 mm  Ultrasonic path at 50 mm

> Why a calibration is needed ?

Action Plan 4: Education & Research

- ***Continue to promote register of Research organisations***
- ***Review when to update Research and Education Guides***
- ***Prepare a list of NDT books with commentary on their suitability***
- ***Draw up a list of Universities offering courses in NDT, categorizing them as in the Guide***
- ***Sponsor International Specialist Groups, each hosted by a Member society***, internet meetings
  - –a) Full matrix capture - BINDT
  - –b) Teraherz imaging – BINDT
  - –c) Microwave NDT – ASNT
  - –d) Magnetic Memory Method- RSSNDT
  - –e) NDT of Art and Heritage - BINDT
  - –f) NDT Reliability – DGZfP
  - –g) Non-linear UT – KSNT
  - –h) Guided Wave UT - KSNT?
  - –ISGs will be open to all members of NDT Societies in ICNDT
- ***Promote more widely ICNDT Guide on importance of NDT and NDT research***
- ***Link to Academia NDT***
  - ***–Offer place for advertising Professorships and Studentships***
- ***Link to WFNDEC***

ICNDT
The World Organisation for NDT

Strategic Plan 2016-2020

The calibration is based on the selection of uncertain model parameters and the data that form the calibration metric together with an efficient optimization routine based on measurements

To obtain informative data, the excitation signal is designed to be optimized (sinusoidal, multisinusoidal, frequency chirp, etc.) and the resulting steady-state (linear and nonlinear) response data are measured

ICNDT Working Group on NDT Education and Research

ICNDT Working Group 3 is the focal point in ICNDT for activities relating to research, education and links to higher education. At a meeting held during the 19th WCNDT, Dr Manfred Johannes stepped down after four years of service as Chairman and Professor Younho Cho was elected as his successor.

Current members of the ICNDT Working Group on NDT Education and Research are:

- Professor Steve Holland, Iowa State University, USA
- Ekaterina Cheprasova, Russian Society for NDT, Russia
- Professor Vjera Krstelj, Croatian NDT Society, Croatia
- Harold Jansen, SAIW, South Africa
- Professor Marc Kreutzbruck, University of Stuttgart, Germany
- Kevin Smith, ASNT, USA
- Professor Uwe Ewert, BAM, Germany
- Dr Tony Erhard, DGZfP, Germany
- Professors Robert Smith and Keith Newton, BINDT, UK
- Dr Serge Dos Santos, INSA, France
- Mike Farley, ICNDT PGP Chairman.

Thursday, 14 June		
Authors lounge	08:00 – 17:00	Room 26
ICNDT GA	08:00 – 12:00	Room E1
ICNDT AC	12:00 – 15:00	Room E1
ICNDT WG3	15:00 – 17:00	Room E1

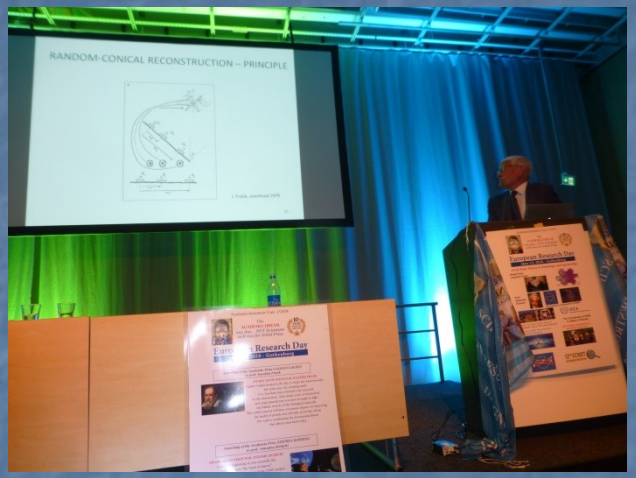
INSTITUT de SOUDURE ASSOCIATION

Academia document Univ. 1/2018

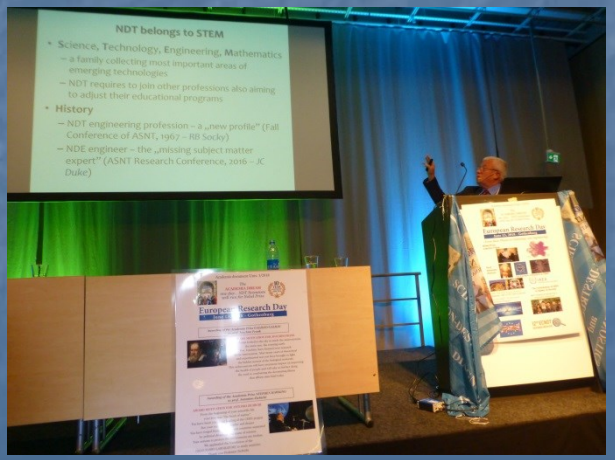
General scenario of the NDT methods and fields of application Presented at the 19th Wordl Conference Münich 2016

1 Acoustic Methods
2 Automotive Spot Welds
3 Aviation
4 CFRP Aircraft Structures
5 Civil Engineering
6 Composite Materials
7 Computed Tomography
8 Condition Monitoring
9 Corrosion Detection
10 Cultural Heritage
11 Digital Radiology and Radiography
12 Eddy Current
13 Energy Generation
14 Energy Nuclear
15 Guided Waves
16 ICNDT WG3
17 Image Processing
18 Imaging
19 Infrared and Optical
20 Laser Ultrasonic
21 Laser Ultrasonic and New Methods
22 Leak Testing
23 Lifetime Management
24 Magnetic and Penetrant
25 Microwaves and Terahertz
26 Modelling and Data Processing
27 Nano-Technologies and High Resolution NDT
28 NDT Adhesive Bonding
29 Non-Contact Ultrasonic
30 Non-Linear Acoustic
31 Nuclear Storage Casks Inspection
32 Other Applications
33 Pipeline In-Service Inspection
34 Process Monitoring
35 Project MAIzfp
36 Public Security and Humanitarian Safety
37 Qualification and Certification
38 Radiography/Computer Tomography
39 Railway
40 Reliability
41 Resonance Technology
42 Robotics Assisted NDE
43 Semi-finished Products
44 Sensor Concept
45 Standardization
46 Marine
47 Material Degradation
48 Materials Characterization
49 Medicine and Biology
50 Metal Magnetic Memory Technique
51 Stress Analysis
52 Structural Health Monitoring
53 Surface
54 Synchrotron Applications
55 Thermography
56 Ultrasonic
57 Underground Infrastructure
58 Welding

Advanced Signal Processing during the Gothenburg European Research Day



Joachim Frank, *Nobel Prize in Chemistry, 2017*



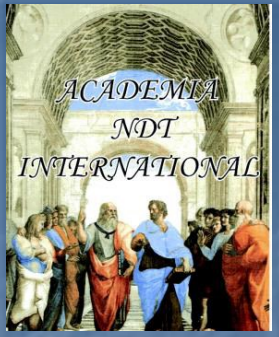
Peter Trampus

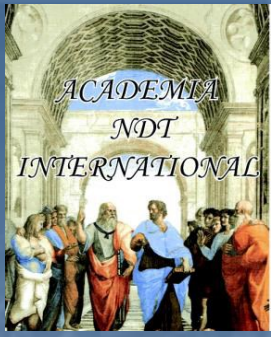
Christian Boller

Victor Udintsev

Conclusion and perspectives

- One of the strategic plan of the international NDT community is to define standards for developing nonlinear NDT for automated set-up in mass production
- The objective of this ERD workshop is to define the future of NDT 4.0 including modern signal processing tools such as big data reduction performed with an Artificial Intelligence (AI) and mapping of reduced data for modern NDT
- The objective of this workshop will be used to prepare a guideline for application of nonlinear techniques. The working plan is to analyze strengths, weaknesses, opportunities and threats (SWOT) within the area of experimental nonlinear NDT





Thank you ! Questions ?

http://exotic.univ-tours.fr/**tadiu**

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