# FROM FIFTEEN TO TWO HUNDRED NDT- METHODS IN FIFTY YEARS

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T. Aastroem

Pohjola Non-Life Insurance Company Ltd, Helsinki, Finland

**Abstract:** Machine diagnostics is used for preventive maintenance, failure analysis, and for the after-care of damages. NDT-methods are utilized in all of these activities. Traditionally, NDT-methods were used for finding material discontinuities and sizing them. Naturally this is still the most important objective, but in addition to this traditional task an increasing amount of Non-Destructive Characterization methods are being introduced. These NDC-methods strive to measure the state of the material non-destructively in order to quantify parameters of the material that form the base for evaluating the safe use of the components in question.

The paper sets out to give an idea of the incredibly fast proliferation of NDT- and NDC- methods that has taken place during the fifty last years. The interaction between the most important machine diagnostic methods used in loss prevention and these NDT- and NDC- methods is reviewed. The paper gives a short glimpse of the early history i.e. the discoveries leading to the first "classical" NDT-methods. Some facts are also given about the development in standardization and the certification of operators.

The division of the two hundred various methods is hard to make, but the classical methods can be divided in a straight-forward way. The paper lists the abundance of the various methods available today for testing either in the field or in laboratory environment using the abbreviations for the methods in question without any attempt to explain their background or working principles. For some of the "exotic" methods the application area is given for clarity reasons.

Keywords: NDT-and NDC-methods, history, method-list.

## 1. Nondestructive testing in perspective to machine diagnostics

Today the increased competition in industry and the expectation of shorter investment repayment periods for complex and expensive machinery, as well as occupational safety, health and environmental requirements, presuppose a high availability of the production machinery and a high and stable quality of the products. These goals are met only if the machinery is kept in proper working condition by utilizing a functioning maintenance philosophy and the right machine diagnostic methods for preventing machinery breakdowns and loss of profit. In this preventive work the most important tools are the senses of a human being in connection with work experience and the "elongation of our senses", in other words the machine diagnostic methods.

Machine diagnostic methods are all those evaluation methods by which the integrity of different components or assembled pieces of equipment is being examined non-destructively. The examination can be performed directly after manufacturing during acceptance testing or on-line as a tool for preventive maintenance as well as for the location of damages, the analysis and the after-care of damages. The diagnostic methods utilize physical phenomena to monitor the health of the machinery and to make prognosis of the future use and this is often done on-line without interrupting the industrial process.

For those working in the NDT-field it is advantageous to know where the NDT-.methods fit into the entire field of loss prevention methods and to keep in mind that the simultaneous or successive use of different methods gives clear synergy benefits.

The concept of the writer of how the most important diagnostic methods are connected to the prevention, the analysis and the after-care of damages is presented in Fig. 1 /1/. The diagnostic methods in the figure are divided into five groups, and from the picture it can be concluded that the NDT- and NDC-methods are interconnected to all of the three damage prevention tasks shown in the picture to the right. The figure was presented in the last WCNDT with an Appendix of 101 methods out of which some 30 were other machine diagnostic methods and the rest NDT and NDC methods. The paper outlined the principles for the methods mentioned first.

This paper only deals with the latter group and sets out to show the incredibly fast proliferation of these. The methods are listed in Appendix 1 starting with the "classic" 15 or so methods and then continuing with more sophisticated and later developed methods. The list is by no means exhaustive, and the order of the methods can most likely be arranged in a more physically righteous way, but hopefully, the list shows the amazing abundance of methods that utilize physical phenomena in different ways.

The main machine diagnostic methods are shortly presented below:

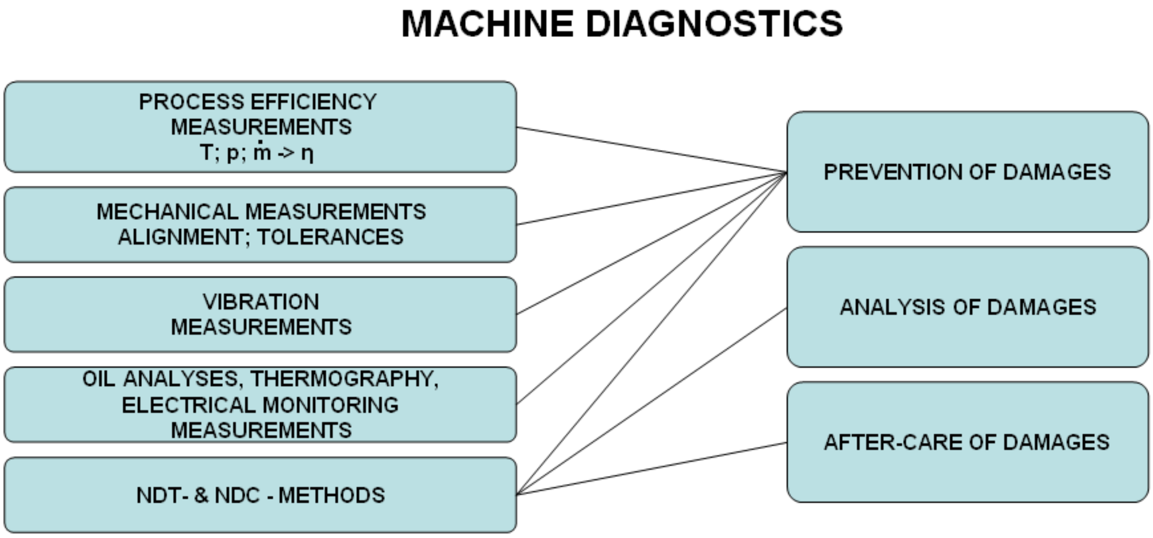


Fig.1 The interaction between machine diagnostics and damage analysis /1/

## 2. The early history of NDT-methods

Before an extremely brief history of the methods can be presented, one has to remember the definition of an NDT-method being one utilizing a physical phenomenon for the noninvasive testing of a product or a material.

With this definition in mind the oldest NDT-method by far is visual testing (VT) which is as old as mankind starting most likely from the visual checking of knives for cutting meat and spears for hunting.

Acoustics would be the second oldest method as it has been used for testing since ancient times when man started to make the first pottery vessels. The earliest known pottery vessels may be those made by the incipient Jõmon people in Japan around 10,500 BC and acoustics was surely used much later on for the testing of glassware. The glassware was probably first invented in Egypt around 4000 BC and was also most probably being tested using the "ringing technique". The same technique was used in the Middle Ages when testing for instance brass castings such as a huge church bell. This was, however, testing with audible sound.
The third oldest classical method would be magnet flux testing of gun barrels. According to Aristotle magnetism was first discovered by a Chinese named Thales (625 BC to 545 BC) and was utilized for compasses during the Middle Ages. The use for NDT is first accredited to an Englishman named S.H. Saxby,

who used a compass for finding cracks in gun pipes in 1868. Here he utilized the remanence of the steel giving detectable leakage fields.

Magnetic particle testing ( MT) was patented in The United States in 1922 when an American, Major W.E. Hooke, working with precision gage blocks at the American Bureau of Standards, devised a method for magnetizing an object producing a leakage field and using iron powder to delineate cracks invisible to the naked eye.

The real breakthrough for magnetic particle testing came, however, a decade or so later after the Americans F.B. Duane and A.V. de Forest had started a partnership in 1929 that later on in 1934 became the Magnaflux Corporation. In the 1960's their method was further greatly developed by C. Betz in the same company.

Before the breakthrough of magnetic particle testing the first classical NDT- method was, of course, radiography (RT). Nondestructive testing, the way we define it, started when Professor Wilhelm Conrad Röntgen in 1896, the following year after his discovery of the unknown i.e. the X-rays, took a radiograph of four soldered pieces of zinc and one of his own hunting rifle. The radiograph of the rifle showed some cast defects in the material and was thus the start of industrial radiography. Professor Röntgen disguised the publicity around him and never made any attempts to claim a patent on his discovery.

The second method to be patented was the penetrant method (PT) when in 1948 Professor F.B. Duane was awarded a patent for the fluorescent penetrant method. Penetrant testing was actually used before magnetic particle testing. The method was formerly called "The oil and whiting method" and was used for testing heavy cast parts used by the huge locomotives in the beginning of the 20th century. They applied used oil that had a dark pigment, i.e. contained dirt, and whiting was simply a water-based chalk-slurry that dried out to white film and worked as the developer.

The basis for ultrasonic testing (UT) was established in 1940 when the American F.A. Firestone achieved a patent for his invention concerning a flaw detection device. Then in 1942 Firestone was the first to use his method for the sonar. In Germany two physicists and brothers H. and J. Krautkrämer who had studied works by Firestone, made a bet of being able to tell if a cannonball, too thick to be radiographed with existing equipment, would have a casting flaw inside or not. They used ultrasound transmission for the bet and won the bet. They founded a firm that was to become the biggest ultrasonic testing equipment manufacturer ever since, a position still hold by the same company now extended with their greatest American former competitor to form the Krautkrämer-Branson company. These two German brothers did a lot of research of the method and greatly contributed to the development of the method. Since their time the method has gone through several phases of development and made enormous achievements in many countries and still has great potential for further applications.

The sixth classical method is Eddy-current testing (ET). This method was being developed primarily in the United States at the beginning of the 20th century. There were some useful applications like the Magna Q-equipment for sorting materials, but a working theory of the method was lacking. Then it was the German F. Förster who in the 1950s clarified the theory for Eddy Current testing and devised the necessary formulae. Today production testing of austenitic tubes and in-service testing of heat-exchanger tubes are well known applications of Eddy-current testing.

A somewhat more recent method finding new applications is the acoustic emission method (AE).The basis for the method lies in the Kaiser-effect discovered by the German Professor J. Kaiser in 1950. He noticed that the material emits sound in the ultrasound region when discontinuities are developing while straining over the former highest strain level the material has been exposed to. In other words, if a crack is not propagating, it does not emit sound and is thus fairly non-critical, but as the emission starts and rises the cracks are propagating. The emission for emitting areas can be tracked in huge components seismographically and other more local NDT-methods can then be applied for dimensioning of the discontinuities. The method has been successfully applied for detecting leaks, propagating cracks and lately also for monitoring the manufacturing processes for abnormal emissions. An example of this would be the monitoring of a continuous casting machine in a steel factory or a timber chopper in a pulp and paper mill.

The actual breakthrough for the use of NDT-methods took place during the Second World War starting from the testing of submarines and airplanes. During these good fifty years the use has then incorporated the inspection of nuclear power plant components, pressure vessels, bridges, elevators and car parts, which if measured in numbers is the biggest user today.

### 3. Standardization of NDT-methods

Some fifty yeas ago standardization of the first (here called) classical methods had started above all in the U.S. in Germany, Britain and Japan. Besides the national standards, the first ISO-standards were also presented. In those days it took something like ten years to get a standard finished and internationally accepted. By 1990 the European CEN-standardization had started. The author has been actively participating in this work and has been the chairman for one committee namely that for MT of welds. Originally, the intended pace was to produce a new standard a year, but at the fastest it was one standard in two years. Since the start, something like one hundred standards have been published and a great part of these have been accepted to international ISO-standards. Most of these basic standards have now already been revised.

### 4. Certification of NDT-operators

Also since some fifty years ago, attempts have been made to develop certification schemes and to get the national schemes mutually accepted and sound progress has lately been experienced in this field. The first to put up national certification schemes were once again the Americans, followed by the Germans and the British. Today there are national or international schemes in most industrial countries and certificates are mostly given in three levels (1, 2 and 3) in the following methods: VT, RT, UT, MT, PT, ET and leak detection. Likewise, there are schemes for the time being in development for vibration testing and thermography.

### 5. The division of NDT-methods

According to the author, the only feasible division of NDT- and NDC- methods is still the classic way of dividing the methods in three categories: visual, surface and volumetric methods. This way of dividing the methods is most likely originating from the ASME pressure vessel codes. The basic idea of these three categories is that the more a component or a part of the component will be stressed in use, the more of these categories are required. The classical approximately fifteen methods are divided in this way in Fig 2.

### 6. NDT- methods

In short, one could claim that primarily the idea of using NDT-methods is to find discontinuities in the material, either originating from the manufacturing process or from overstraining in use. The sought discontinuities are mostly cracks stemming from false manufacturing techniques or from fatigue or thinning caused either by corrosion or erosion. In other words, first the discontinuities have to be located. Thereafter the dimensions and directions of the discontinuities have to be measured, after which the flaws are to be evaluated for conformance to stipulated acceptance criteria. These criteria evolve from fracture mechanical calculations based on critical flaw size and the speed of the extension of the flaw.

After finding the discontinuities, and after having calculated a probable speed of extension for these, it enables us to stipulate the frequency of the in-service inspections that should be performed on the component in question. Hereby, the intervals are chosen in such a way that knowing the growth speed of a flaw the following in-service inspection has to be made before a flaw has had the time to grow to an extension where there is a

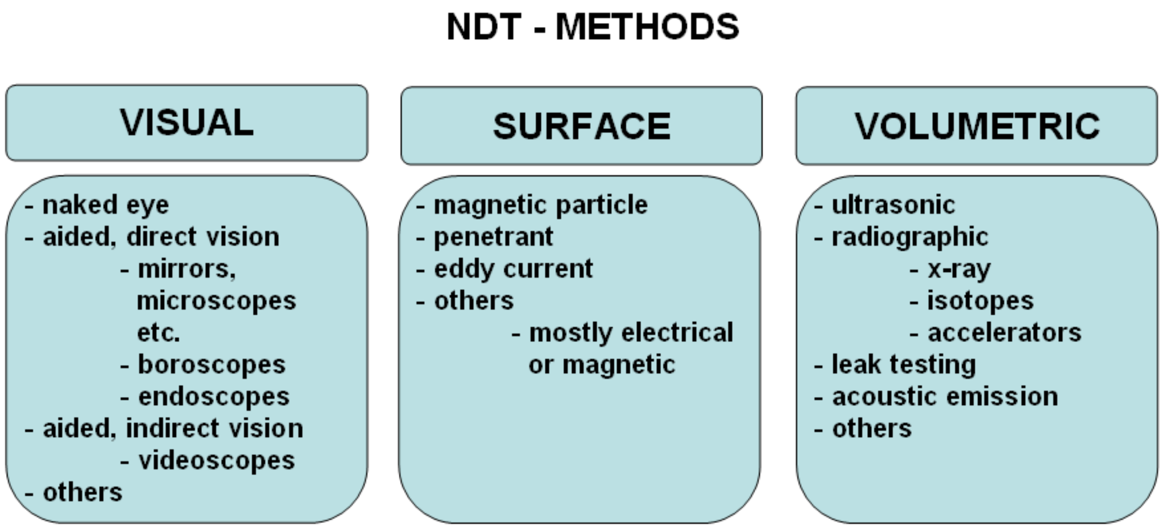


Fig.2 The traditional main division of the classical NDT-and NDC-methods

possibility of having a sudden failure of the component, by brittle fracture or plastic collapse, leading to vast and, consequently, expensive damages.

**7. NDC-methods**

When NDT-methods are used to investigate the properties of materials, they are called more exactly NDC-methods that derive from the words Non Destructive Characterization. Utilizing these methods the results of the investigations would be e.g. the grain size, the hardness or the elastic or magnetic properties of the material. One of the best known of these methods is e.g. the replica method by which hot components, like the steam pipes of a boiler, can be evaluated for creep damage and prognosis can be given for the expected remaining life-span of the pipe. In condition monitoring the NDT- and NDC -fields can be combined to monitor on an on-line basis changes in material characteristics.

**8. "IBTIR"-method**

One highly demanding and very frequently used method is the "IBTIR"-method /1/ whereby the abbreviation stands for: I believe this is right. The method requires education and above all a profound experience and works in such a way that the diagnosis is done without sampling, testing or research results and is thus based solely on subjective intuition. The accuracy of the method is normally enhanced as a direct function of time.

**Conclusions:** Due to new sensor technology and massively enhanced computation and memory capacities and the possibility to combine different methods, an impressive number of new NDT- and NDC- methods have been introduced. In the Appendix the methods are listed and divided into twenty three groups starting with the "classic" methods and continuing with newer sophisticated methods.

**References:**
/1/. Åström, T; One hundred and one NDT and machine diagnostic methods for the prevention of losses in critical machinery, Proc. of 16th WCNDT 2004, Montreal, 8 p

**Appendix**

## LIST OF NON - DESTRUCTIVE TESTING AND - CHARACTERIZATION METHODS

### 1. NDT-methods

1. Visual Inspection
    - 1.1 General without aid
    - 1.2 Aided inspection
        - 1.2.1 Magnifiers, mirrors, etc.
        - 1.2.2 Boroscopes
        - 1.2.3 Endoscopes
        - 1.2.4 Videoscopes
        - 1.2.5 TV-units (e.g. pipe testing)
    - 1.3 Stroboscopic inspection
    - 1.4 Surface microscopy
2. Magnetic Particle Testing
    - 2.1 Magnetization
        - 2.1.1 Current flow
            - 2.1.1.1 Axial
            - 2.1.1.2 Prods
            - 2.1.1.3 Induced
        - 2.1.2 Magnetic flow
            - 2.1.2.1 Threading conductor
            - 2.1.2.2 Adjacent conductor(s)
            - 2.1.2.3 Fixed installation
            - 2.1.2.4 Portable electromagnet (Yoke)
            - 2.1.2.5 Flexible coil
        - 2.1.3 Permanent magnet
    - 2.2 Viewing
        - 2.2.1 Colored
        - 2.2.2 Fluorescent
    - 2.3 Media
        - 2.3.1 Wet
        - 2.3.2 Dry
        - 2.3.3 Magnetic Rubber Inspection
3. Penetrant testing
    - 3.1 Application
        - 3.1.1 Spot testing
        - 3.1.2 Immersion testing
    - 3.2 Viewing
        - 3.2.1 Colored
        - 3.2.2 Fluorescent
        - 3.2.3 Dual purpose (Fluorescent color contrast )
    - 3.3 Excess penetrant remover
        - 3.3.1 Water
        - 3.3.2 Lipophilic
        - 3.3.3 Solvent
        - 3.3.4 Hydrophilic
        - 3.3.5 Water and solvent

- 3.4 Developer
  - 3.4.1 Dry
  - 3.4.2 Water soluble
  - 3.4.3 Water suspendable
  - 3.4.4 Solvent-based (non -aqueous wet)
  - 3.4.5 water or solvent-based for special appl. (e.g. peelable developer)
- 3.5 Filtered particle testing (testing of porous materials)

4. Ultrasonic testing
   - 4.1 Amplitude based techniques
     - 4.1.1 Pulse echo technique
     - 4.1.2 Through transmission technique
   - 4.2 Time of flight based techniques
     - 4.2.1 TOFT Time of Flight Diffraction
     - 4.2.2 PA Phased Array techniques
     - 4.2.3 SPA Sampling Phased Array techniques
     - 4.2.3 SAFT Synthetic Aperture Focusing Techniques
     - 4.2.4 EMAT Electro Magnetic Acoustic Transducer techniques
     - 4.2.5 Acoustic Holography
   - 4.3 Ultrasonic Tomography
   - 4.4 Ultrasonic Contact Testing
   - 4.5 Ultrasonic Immersion Testing
   - 4.6 Ultrasonic Spay-jet Testing
   - 4.7 Ultrasonic Acoustography
   - 4.8 Ultrasonic Spectral Analysis (e.g. thickness measurements)
   - 4.9 Guided wave ultrasonics
   - 4.10 Ultrasonic Guided Wave Tomography
   - 4.11 Sparce Array Ultrasonic Guided Wave Tomography
   - 4.12 Doppler-Based Airborne Ultrasound Technique
   - 4.13 Ultrasonic Corona Discharge Detection
   - 4.14 SSP Ultrasonic Split Spectrum Processing technique (testing of concrete)
   - 4.15 Narrowband Ultrasonic spectroscopy
   - 4.16 Thermoelastic technique (ultrasonically coupled for polymer matrix composites)
   - 4.17 UFFM Ultrasonic Friction Force Microscopy
   - 4.18 IWEX Inverse Wave Field Extrapolation ultrasonics
   - 4.19 UTTM Ultrasonic Transit Timing Method
   - 4.20 EMAR Electromagnetic Acoustic Resonance (e.g. oxide layer thicknesses)
   - 4.21 Laser generated ultrasonic testing
5. Radiographic testing
   - 5.1. Source
     - 5.1.1 X-ray testing
     - 5.1.2 γ-ray testing
     - 5.1.3 Accelerator testing
     - 5.1.4 Neutron testing
   - 5.2 Visualization
     - 5.2.1 Film radiography
     - 5.2.2 Paper radiography
     - 5.2.2 Screen radioscopy
     - 5.2.3 Flat panels
     - 5.2.4 DR Digital radiography
     - 5.2.5 CRS Computed Radiography Systems (e.g. Phosphor Imag. Plates)

- 5.3 Tangential radiography (e.g. corrosion testing of pipes)
- 5.4 MLX Motionless Laminography X-ray
- 5.6 X-ray Scanned Beam Laminography
- 5.7 XRD X-ray Diffraction
- 5.8 XDT X-ray Diffraction Tomography
- 5.9 Synchrotron Refraction Computer Tomography
- 5.10 Synchrotron Bragg Magnification Computer Tomography
- 5.11 LMR Lateral Migration Radiography
- 5.14 XBT X-ray Backscatter Technique
- 5.15 X-ray BDP X-ray Backscatter Depth Profilometry (Compton X-ray backscatter)
- 5.16 Phase Contrast Microradiography
- 5.17 Neutron Diffraction
- 5.18 Neutron Tomography
- 5.19 Dual energy radiography
- 5.20 Multienergy radiography
- 5.21 Flash X-ray technique
- 5.22 Flash X-ray Computed Tomography
- 5.23 Flash X-ray Cinematograhy
- 5.24 3-D Parallax Imaging Radiography

6. Eddy current testing
    - 6.1 Conventional (near field) techniques
    - 6.2 RFT Remote Field Technique
    - 6.3 SLOFEC Saturation Low Frequency Eddy Current
    - 6.4 PEC Pulsed Eddy Current Array Technique
    - 6.5 Magneto-optic Eddy Current technique
7. Layer-thickness measurements
    - 7.1 Magnetic pull force
    - 7.2 [Eddy current]
    - 7.3 β-scattering
8. Crack depth measurement
    - 8.1 PD Potential Drop method
    - 8.2 ACFM AC Field Measurement
9. Magnetic Field Leakage testing
    - 9.1 MFL Magnetic Field Leakage testing
    - 9.2 TMF Total Magnetic Flux technique
10. Leak detection testing
    - 10.1 Vacuum techniques
    - 10.2 Tracer gas methods
    - 10.3 Bubble test methods
    - 10.4 Total pressure change methods
    - 10.5 Ultrasonic monitoring + frequency drop
    - 10.6 [Penetrant testing applied on opposite sides]
11. Acoustic Emission
    - 11.1 Loose part monitoring & Leakage monitoring
    - 11.2 Crack initiation monitoring
    - 11.3 Process monitoring
    - 11.4 Acoustic Emission Induced Tomography
    - 11.5 Partial Discharge Source Location by AE
12. Acoustic testing
    - 12.1 Acoustic tomography
    - 12.2 AIT Acoustic Impact Technique (fatigue damages in carbon fiber composites)

- 12.3 Photoacoustic spectroscopy
- 12.4 Acoustic Elapsed Time Tomography
- 12.6 Single-sided reflection mode acuostography
- 12.7 SAM Scanning Acoustic Microscopy
- 12.8 AFAM Atomic Force Acoustic Microscopy
- 12.9 Acoustic cross correlation technique (leak detection in pipes)
- 12.10 IESA Impact Echo Signature Analysis (internal condition of concrete structures)

13 . Optical methods

- 13.1 Optical interferometry (e.g. measuring of minute surface displacements)
  - 13.1.1 LCI Low Coherence Interferometry
  - 13.1.2 Holographic interferometry
  - 13.1.3 Moire interferometry
  - 13.1.4 Film holography
- 13.2 OEHM Optoelectronic Holography Microscopy
- 13.3 Optical coherence tomography
- 13.4 Luminescence spectroscopy (piezo spectroscopy)
- 13.5 Photographic shearography
- 13.6 NEWS Nonlinear Elastic Wave Spectroscopy
- 13.7 NWMS Nonlinear Wave Modulation Spectroscopy
- 13.8 Time Domain Spectroscopy
- 13.9 Schlieren photography
- 13.10 PIT Parallax Imaging Tomography
- 13.11 OTDR Optical Time Domain Reflectrometry
- 13.12 Fractal geometry testing (characterization of corrosion surfaces)
  - 13.12.1 Box-Counting Method
  - 13.12.2 Coherent Light Scattering Method
- 13.13 OCT Optical Coherence Tomography (imaging of semitransparent structures)
- 13.14 EUS Electro-Ultrasonic Spectroscopy
- 13.15 FOS Fiber Optic Sensors
  - 13.15.1 FBGS Fiber Bragg Grating Sensor technique
  - 13.15.2 Embedded Fiber Optic sensing (e.g. flexural strains in concrete)
  - 13.15.3 DTS Distributed Temperature Sensing technique
  - 15.13.4 DTSS Distributed Temperature and Strain Sensing technique
- 13.16 Laser based acoustic microscopy

14. Laser testing

- 14.1 Laser backscatter= Elastic optical scattering laser
- 14.2 Scanning laser vibrometry
- 14.3 Laser shearography
- 14.4 DS Digital Shearography
- 14.5 Laser holography
- 14.6 Laser Profilometry (creep detection)
- 14.7 High-intensity Ultraviolet Laser Source Penetrant Testing
- 14.8 Speckle Interferometry
  - 14.8.1 DSPI Digital Speckle Pattern Interferometry
  - 14.8.2 ESPI Electronic Speckle Pattern Interferometry
  - 14.8.3 DSC Digital Speckle Correlation technique
- 14.9 Intensity based optical interference technique
- 14.10 Phase stepping shearography
- 14.11 Time resolved shearography
- 14.12 Laser Doppler Vibrometry
- 14.13 PCR Laser Photo-Carrier Radiometry (testing of semiconductor materials)

15. Infrared testing
    15.1 Pulse thermography
    15.2 PPT Pulse phase thermography
    15.3 Flash thermograhphy
    15.4 TTT Transient Thermal Tomography
    15.5 Ultrasonic exited thermal tomography
    15.6 Infrared exited thermal tomography
    15.7 Inductive exited thermal tomography
    15.8 Moving laser source exited thermal tomography
    15.9 Microthermography
    15.10 Mid-infrared back reflectance spectroscopy
    15.11 Focal plane array infrared technique
    15.12 TRIR Time Resolved Infrared Radiomerty
    15.13 TG/DTA Thermal Gravimetric/ Differential Thermal Analysis
    15.14 UBPT Ultrasound Burst-Phase Thermography
    15.15 Ultrasound Lock-in Thermography
    15.16 TWI Thermal Wave Interferometry ( testing of plasma sprayed coatings)
16. Microwave testing
    16.1 GPR Ground Penetrating Radar
    16.2 Impulse radar Technique
    16.3 Microwave exited tomography
    16.4 Millimeterwave inspection
    16.5 Millimeterwave permittivity measurement
    16.6 Coherent microwave transient spectroscopy
17. Other methods
    17.1 PA Positron Annihilation spectroscopy
    17.2 MAE Magneto Acoustic Emission
    17.3 NMR (or MRI) Nuclear Magnetic Resonance Imaging
    17.4 EPR Electron Paramagnetic Resonance Microscopy
    17.5 FSM Field Signature Method
    17.6 MMM Magnetic Memory Method
    17.7 Inductively induced Tomography
    17.8 Hot air induced Tomography
    17.9 Electromagnetic strain measurement
    17.10 Spectophotometry (for discharge analyses)
    17.11 MIM Mechanical Impedance Method
    17.12 PSC Pressure Stimulated Current Technique
    17.13 MsS Magnetostrictive Sensor technique (e.g. pipe testing)

## 2 NDC-methods

1. Hardness measurement
    1.1 Mechanical vibration attenuation (i.e. Echotip)
    1.2 UCI Ultrasonic Contact Impedance (i.e. Krautkrämer MIC)
    1.3 TIV Through Indenter Viewing (i.e. Krautkrämer TIV)
    1.4 RUS Resonant Ultrasound Spectroscopy (testing of tensile strength and hardness)
2. Metallographic replica technique (for surface examination)
3. Barkhausen Noise Emission
    3.1 MBN Magnetic Barkhausen Noise
    3.2 ABN Acoustic Barkhausen Noise

4. PMI Positive Material Identification
  - 4.1 EDXRF Energy Dispersive X-ray Fluorescence (i.e. X-MET)
  - 4.2 Optical Emission Spectroscopy (i.e. ARC-MET)
  - 4.3 NAA Neutron Activation Analyses
  - 4.4 EDX Energy Dispersive X-ray analysis
  - 4.5 WDX Wave-length Dispersive X-ray analysis

5. Micro-magnetic analysis methods
  - 5.1 CM Coersitivity Measurements
  - 5.2 MIVC Magnetically Induced Velocity Changes
  - 5.3 Incremental permeability measurements
  - 5.4 Analysis of harmonic magnetic vibrations
  - 5.5 Analysis of dynamic magnetostriction
  - 5.6. BEMI Barkhausen noise and Eddy current Microscopy
  - 5.7 MIPN Magnetically Induced Potential Noise (not Barkhausen noise)
  - 5.8 MI Magneto Impedance sensor Technique ( testing of surface flaws)
  - 5.9 The Jumpsum method (mechanical properties of ferromagnetic materials)
  - 5.10 TEM Thermoelectric Method ( non-contacting for residual stress measurements)
  - 5.11 SMA Stress Induced Magnetic Anisotropy

6. Other methods
  - 6.1 SEM Scanning Electron Microscopy
  - 6.2 TEM Transmission Electron microscopy
  - 6.3 ERUM Electromagnetic Resonance Ultrasound Microscopy ( e.g. elastic constant)
  - 6.4 TEP Thermo Electric Power Measurement (ageing of duplex steels)
  - 6.5 MRE Magnetic Resonance Elastography (elastic properties of tissues)
  - 6.6 TR Dielectric transmission / reflection measurement (material properties)
  - 6.7 TEM Magnetic transmission/reflection measurement (material properties)
  - 6.8 IS Impedance spectroscopy (testing of coating degradation)
  - 6.9 LIBS Laser-induced breakdown spectroscopy (e.g. material composition analysis)
  - 6.10 GMR Giant Magnetoresistance technique
  - 6.11 Dielectric spectroscopy (e.g. measuring of polymer curing)
  - 6.12 Magneto Optical Microscopy (e.g. detection of hidden defects/ Kerr effect)
  - 6.14 UAFM Ultrasonic Atomic Force Microscopy (elastic modulus measurement of pietsoelectric domain boundaries)

## 3 "IBTIR"-method