ONE HUNDRED AND ONE NDT-AND MACHINE DIAGNOSTIC METHODS FOR THE PREVENTION OF LOSSES IN CRITICAL MACHINERY

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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 reviews the interaction between the most important machine diagnostic methods used in loss prevention. It lists the abundance of various methods available today for loss prevention of critical components and for finding the root causes of failures. In addition to the best known diagnostic methods used for instance at an in-service outage at a utility - i.e. efficiency measurements, mechanical, vibration, thermographic and oil-analysis measurements - an abundance of contemporary other machine diagnostic methods of varying complexity exits, which, furthermore, almost all utilize different physical phenomena. Some of these are straightforward methods like the replica method for evaluating creep damage, and others are utterly complicated methods like Nuclear Magnetic Resonance for finding material discontinuities.

To demonstrate the close interrelation between the diagnostic methods and loss prevention some damage examples are presented in the oral presentation from critical industrial components. Hereby the paper presents the interaction of the various diagnostic methods for finding the root causes of the failures in question.

Introduction: Today the increased competition in an expanding, almost global market, the occupational safety and health and environmental requirements presuppose a high availability of the production machinery and a high and stable quality of the products. These goals are reached only if the production machinery is kept in shape by utilizing a functioning maintenance philosophy and the right machine diagnostic methods for above all preventing machinery break downs and loss of profit as a result of them. Regardless of the fact if the maintenance philosophy is repairing, preventive or corrective, it always strives to reach these goals by utilizing different tools and methods. 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 are 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 as an elongation to our senses and a prognosis of the integrity of the machinery is often done without interrupting the industrial process.

For those working in the NDT-field it is advantageous to know the main principles of the other important machine diagnostic methods and applications due to the fact 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. The diagnostic methods 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 areas mentioned above.

Discussion: The main machine diagnostic methods are shortly presented below:

1. Efficiency measurements

Efficiency measurement of a machine like that of a steam turbine serves primarily the needs of economy management of operation, but can also be a preventive diagnostic tool typically at a point where the efficiency has dropped and the reason can be mechanical. Efficiency measurement is a working prognostic method when for instance there is an internal leakage in the machine due to damaged labyrinth gaskets or pits due to erosion or / and corrosion on the blades lowering the steam throughput or alternatively the blades are simply dirty as a result of bad water chemistry.

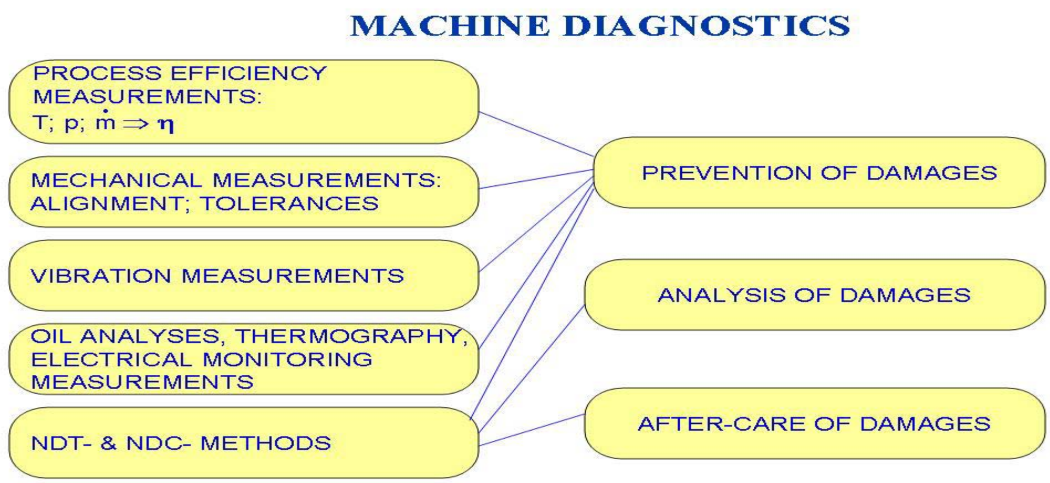

Fig.1 The interaction between machine diagnostics and damage analysis

2. Mechanical measurements; Alignment, tolerance measurements

Measuring tolerances i.e. running and alignment control are not normally considered to represent any machine diagnostic methods, but the methods are important not only by the assembly but also in connection with measurements after use. False tolerances or alignment lead to premature wearing down. In revolving machinery they normally lead to unbalance and due to that to excessive vibrations, which again result in overstraining of the components. For alignment one may use rulers, feeler-gauges, dial-indicators, displacement sensors, program-analyzers, laser-units and optical alignment devices.

3. Vibration measurements

Many persons only think of vibration measurement or vibration analyses when hearing the word machine diagnostics. This is due to the fact that vibration measurements of plant rotating equipment have been used for decades and in almost all areas of industry. Vibration measurements of bearings in particular can predict, when applied in the right manner, failures of the bearings in due time for replacements. The measurement can be performed at a specific frequency like approx. 30 kHz for the shock pulse method or within a given frequency range like 10 to 1000 Hz, which is a range standardized by an ISO-standard for measuring vibration severity. Measurements utilize the displacement of a component like a bearing case, the speed that is the first derivate of the movement, the acceleration i.e. the second derivate of the movement, the jerk, which would be the third derivate. For slowly moving parts even a fourth derivate may be taken.

The first option is merely to measure the vibration level, the second is to analyze the reason for the spectrum, and the third measure would be to eliminate the reason for it like balancing or lining a component or machine.

4. Oil-analyses

A somewhat newer machine diagnostic method is oil analysis. The method is not new, but has merely taken a newer form as a result of modern instrument development. In older times car engines used to have a magnetic plug that gathered on it possible loosened magnetic parts and also particles resulting from normal wear. An educated eye and a sensible hand could make a diagnosis of the stage of the slide bearings in particular.

Nowadays the analysis of lubricants and hydraulic steering oils are made either on a sample basis, or even in the most sophisticated applications, by on-line monitoring. The analysis is made by fractography i.e. the sizes and distributions of bigger particles in the lubricant are counted and measured, and the product classified into given cleanliness classes. In more critical cases it is even possible to make a chemical analysis utilizing spectroscopy of single particles.

5. Thermography

One of the most versatile machine diagnostics methods is thermography. The only restrictive factor in finding applications for this method is actually the imagination of the user. Most processes in industry involve the use of heat in the sense that heat is developed and dispersed to the environment when the process is working. Any difference in heat dispersion is usually a sign for an abnormality. Either the unit is overheating due to too big a load or the unit is too cold due to the fact that it is only working partially or not working at all.

The integrity control of refractory linings of ovens, the control of electrical shift-boards in looking for bad connections are well known applications. In maintenance a fast view of bearings like in coal conveyers is a functioning predictive method for finding bearing wear before they heat up enough to start a fire. For instance in a Pulp&Paper-factory thermography can be used not only for finding "cold" or "hot spots" like monitoring the lime kiln for damages in the heat refractory lining. It can also be used for monitoring the quality of the papermaking process, in other words for quality monitoring of the production processes themselves.

6. Monitoring measurements of electrical machines

Both in manufacturing and in industrial processes huge numbers of electrical motors are used and many times these are serviced after a specific number of hours regardless of the actual need for service. This has led to the development of a number of on-line methods for their diagnosis. The reasons for breakdowns in electrical motors are to great extent dependent on the type of machine. The most frequent reasons for faults are bearing damages and time degradation or wetting of the insulation used. The Appendix lists a number of on-line methods that have already been in use long enough to be able to be standardized /1/.

7. NDT- methods

In short, one could claim that primarily the idea of using NDT-methods is to find discontinuities in the material, mostly cracks or thinning caused either by erosion or corrosion. In other words, the first objective of NDT is to locate the discontinuities. Thereafter the second objective is to measure the dimensions and directions of the discontinuities. When this is done, the following step is to evaluate if a flaw conforms to the stipulated acceptance criteria or not. For stipulating the criteria one would have to know the critical flaw size and the speed of extension of the flaw. To calculate these two factors one has to utilize fracture mechanics. As base facts fracture mechanics utilizes the dimensions of the flaws found out via the use of NDT-methods, the applied stress, and the fracture toughness of the material in question, thus producing acceptance criteria for different components and geometries.

After finding the discontinuities, here more briefly called the flaws, and after having calculated a probable speed of extension of the flaws, 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 possibility of having a sudden failure of the component, by brittle fracture or plastic collapse, leading to vast, and consequently, expensive damages.

8. NDC-methods

When NDT-methods are used to investigate the properties of materials, they are more exactly called NDC-methods deriving from the words Non Destructive Characterization. Utilizing these methods the results of the investigations would e.g. be the grain size, the hardness or the elastic or magnetic properties of the material. One of the most well-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.

9. "IBTIR"-method

One highly demanding and very frequently used method is the "IBTIR"-method whereby the shortening 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 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 an impressive number of new machine diagnostic methods are now available. In the Appendix the methods are listed and divided into nine major areas.

References:

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Appendix

LIST OF MACHINE DIAGNOSTIC METHODS

1 Efficiency measurements

1. Fuel efficiency of entire plant $\eta = f(J, kW)$
2. Efficiency of turbine steam-water circuit $\eta = f(T, p, V, \dot{m})$
3. Efficiency of steam-water circuit of the entire plant $\eta = f(T, p, V, \dot{m})$

2 Mechanical measurements;

Alignment, tolerance measurements

1. Mechanical measurements
2. Optical measurements
3. Laser - measurements

3 Vibration measurements

1. Key figure monitoring (intensity; phase angle; root mean square value; peak to peak value; peak value; crest factor ; kurtosis)
2. Time domain monitoring
3. Spectrum monitoring
4. Envelope monitoring
5. Vector monitoring
6. Profile monitoring
7. High frequency monitoring methods
    7.1 Acoustic emission
    7.2 Shock pulse method (SPM)
    7.3 Ultrasound
8. Capstrum monitoring
9. Shaft position and orbit monitoring
10. State of lubrication monitoring
11. Resonance frequency measurement (Natural frequency measurement)
12. Mobility measurement
13. Mode analysis (+FEM-calculation)

4 Oil-analyses

1. Magnetic plug collection + Ferroscopy (Particle concentration and -distribution)
2. Water content measurement
3. Viscosity measurement
4. TAN (Total Acid Number)- measurement
5. TBN (Total Base Number)- measurement
6. Chemical spectrometry

5 Thermography

1. Contact- measurement
2. Infrared measurement through air
3. Infrared thermography

6 Monitoring measurements of electrical machines

1. Insulation resistance measurement
2. Impedance measurement and Barkhausen noise measurement
3. Surge wave measurement
4. Dissipation factor (tan Δ) measurement
5. Current spectrum measurement
6. Shaft voltage and – current measurement
7. Partial discharge measurement (PD- measurement)
8. Magnetic flux measurement
9. Terminal voltage measurement
10. Corona measurement

7 NDT-methods

1. Visual Inspection
    1.1 General without aid

- 1.2 Aided inspection (mirrors, endoscopes etc.)
- 1.3 Stroboscopic inspection
- 1.4 Surface microscopy
- 1.5 Video-endoscopy

2. Magnetic Particle Testing
   - 2.1 Flux magnetization
   - 2.2 Current magnetization
3. Penetrant testing
   - 3.1 Spot testing
   - 3.2 Immersion testing
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 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 Spray-jet Testing
5. Radiographic testing
   - 5.1 Film radiography
     - 5.1.1 X-ray testing
     - 5.1.2 γ-ray testing
     - 5.1.3 Accelerator testing
   - 5.2 Paper radiography
   - 5.3 Radioscopy
     - 5.3.1 Film radioscopy
     - 5.3.2 Screen radioscopy
   - 5.4 CRS Computed Radiography Systems (i.e. Phosphor Imaging Plates)
   - 5.5 XD x-ray Diffraction
   - 5.6 XDT x-ray Diffraction Tomography
   - 5.7 Neutron Diffraction
6. Eddy current testing
   - 6.1 Conventional (near field) techniques
   - 6.2 RFT Remote Field Technique
   - 6.3 SLOFEC Saturation low frequency eddy current
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. MFL Magnetic Field Leakage testing
    10. Acoustic Emission
        - 10.1 Loose part monitoring & Leakage monitoring
        - 10.2 Crack initiation monitoring
    11. Surface holography
    12. PA Positron Annihilation spectroscopy
    13. Laser Shearography
    14. MAE Magneto Acoustic Emission
    15. NMR (or MRI) Nuclear Magnetic Resonance Imaging
    16. EPR Electron Paramagnetic Resonance Microscopy (Imaging)
    17. SMA Stress Induced Magnetic Anisotropy
    18. FSM Field Signature Method
    19. Leak detection testing
        - 19.1 Vacuum techniques
        - 19.2 Tracer gas methods
        - 19.3 Bubble test methods
        - 19.4 Total pressure change methods
        - [19.5 Ultrasonic monitoring]

8 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)
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 x-ray fluorescence (i.e. X-MET)
    - 4.2 Optical Emission Analyzers (i.e. ARC-MET)
    - 4.3 NAA Neutron Activation Analyses
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

9 "IBTIR"-method

101. method !