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THE METHODOLOGY ASPECTS FOR MONITORING THE MACHINE ELEMENTS, COMPONENTS AND SYSTEMS

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Abstract: *The aspects of present methodology for monitoring the machine elements, components and systems in relation to modern demands in mechanical engineering are presented in this paper. Monitoring of elements, components and systems is complex task that include set of procedures with define order with usage of specific testing and measuring equipment. For detection and analysis of cracks and leaks due to porosity and cracks, hydraulic and pneumatic methods are presented in the paper. Vibro-acoustic method is presented as methodology for testing of mashing, assembling and functioning of rotating elements, so as eccentricity and rigidity of joints. The surface conditions analysis such as impact damages, pits, flexions, deflections, damages of the surface properties are done visually, while the testing of the internal surfaces are done by endoscopic methods. The surface damages, cracks and flaws at ferromagnetic materials are tested by magnetic methods. Penetrant and luminescent methods are used for detection and analysis of the deep surface cracks. For detection and analysis of internal cracks and cavities the radiography, ultrasound testing and acoustic emission testing are used.*
Stress and strain state in present mechanical constructions becomes far more complex with simultaneous reduction in its weight, dimensions altogether with using of new lightweight materials, higher energy efficiency demands and environmental concerns. The risks of failures at mechanical constructions rise with simultaneous improving its safety and reliability. In those conditions, the importance of methodology for monitoring the machine elements, components and systems come in the focus of the present machine diagnostics.
Keywords: *monitoring, machine elements, safety, reliability, machine diagnostics*

1. INTRODUCTION

The object of mechanical construction testing in exploitative conditions is to provide relevant information about quality of constructions, technical conditions of

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those constructions and its elements, functional reliability and proper functionality, so as to provide data about exploitative conditions of constructions in order to define and verify data about load and environment conditions. The characteristic of technical systems, in general, are identified on the basis of the output value (output vector) for precise defined input (vector of control).

During exploitation, the technical systems are under the influence of large number of different factors that affect to their technical condition and functionality. The influence of those exploitative factors on system technical condition is basically through continual alterations of certain characteristics and parameters starting from nominal to critical values. These alterations of characteristics and parameters of the technical systems in time are consequences of unwanted but inevitable physical-chemical processes that act within those systems. Monitoring of technical systems enclose the set of precisely defined activities in aim to provide qualitative and quantitative analysis of the system characteristics. From the methodology aspects, the most important are the nondestructive testing methods that do not require disassemble of the technical systems elements and those testing methods are considered in this paper.

2. EXPERIMENTAL PROCEDURE FOR MONITORING OF TECHNICAL SYSTEMS

Experimental procedure for monitoring of technical systems enclose the set of the precisely define methods that are used in industry, so as for scientific researches for determination of their functional conditions and characteristics and usually do not have invasive approaches. Even if methods of mechanical constructions testing are strictly define in standards related to this topic, the methodologies for experimental procedures for monitoring of technical systems are still based on recommendations of the producers and on experience of their users. The experimental procedures for monitoring of technical systems have to provide reliable, efficient and prompt detection of dangerous conditions, so as to identify causes. In order to consider the methodology aspects of technical systems monitoring, the basic experimental procedures are briefly presented in this paper with focus on comparative characteristics of every procedure.

3. NONDECTRUCTIVE METHODES FOR EXPERIMENTAL TESTING OF MACHINE SYSTEMS

Visual control

The accuracy and reliability of visual control method is small and limited and depend on large number of factors that cannot be put under the influence.

a) b) c)

Fig. 1 *Endoscopes: a) flexible, b) rigid and c) endoscopes with camera*

Due to wide range of applications, minimal costs, small time need, this method still have significant usage for monitoring of technical systems. For the visual control of inaccessible areas without of disassembly, the endoscopes are used. The endoscopes can be flexible, rigid or can be equipped with camera (Fig. 1).

The special care during monitoring by those methods has to be focused on the zones of high temperature and mechanical loads, so as on zones with high levels of stress concentrations. The damages on specific elements of machine systems such as gears and connecting rod of piston identified by visual control are presented at Fig. 2 and Fig. 3.

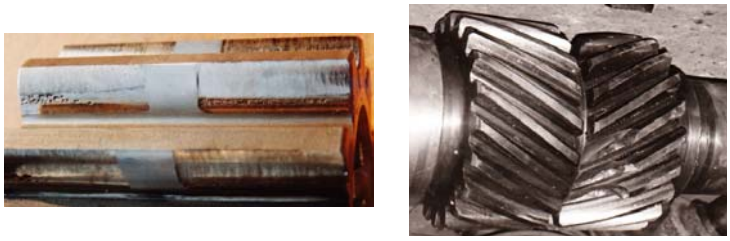

Fig. 2 *Gear damages identified by visual control*

Fig. 3 *Damages on connecting rod of piston*

Hydraulic and pneumatic methods

Hydraulic method for experimental testing of technical systems is used for detection of cracks and damages in machine elements such as housings, suction and exhaust pipes and so on. Liquid under the controlled pressure is bringing inside of the element that is subjected to testing. The confirmation of functionality of tested element is done by measuring of pressure during defined period of time. In case when pressure maintain within allowable limits, the tested characteristics of the element satisfied required conditions.

Pneumatic method is used for detection of cracks and failures at the elements of mechanical constructions such as heating elements and boilers. The openings at tested elements are sealed at the begging of the monitoring procedure, after that the element is put in liquid. The presence of the air bubbles in liquid is identification of cracks at tested elements of mechanical constructions. If dimensions of element do not allowed it to be put in the liquid, soap solution is applied on the surface of the tested element and at the zones of defects and cracks the bubbles of soap solution are formed.

Penetrant testing

The penetrant testing method at mechanical constructions is quantitative technique for detection of surface defects on elements of those constructions (Fig. 4). Penetrant is applied to the surface of examined object. The liquid is pulled into surface defects by capillary action. This method is used to trace cracks, porosity, and other defects that break the surface of a material and have enough volume to trap and hold the penetrant liquid. The developer pull penetrant to the surface, react with it and by that, form the clear visualization of the defect.

Fig. 4 *Penetrant nondestructive testing method*

Main advantages of penetrant nondestructive testing can be recognized as large surface or large volumes of parts can be tested fast and with low cost, parts with complex geometry are easily tested, indications are produced directly on surface of the part providing a visualisation of the discontinuity. Main disadvantages can be recognized as this method detects only surface defects and this method is sensitive to surface preparation because contaminants of surface can mask defects, requires a relatively smooth and nonporous surface, cleaning after procedure is necessary to remove chemicals, requires multiple operations under controlled conditions with chemical handling precautions.

Very similar approach is used for florescent testing method, with difference in the way that identification of defect is visible under the special type of light. This method provides the estimation of defect dimensions on the bases of wideness of the fluorescent zones. The efficiency of this method depends on type of applied solution for testing, the thickness of its layer, its penetrating ability and, also, on type and power of light source (Fig. 5).

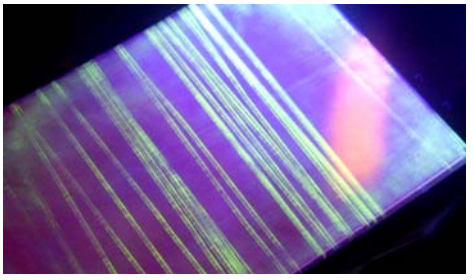

Fig. 5. *Identification of surface defects by fluorescent methods*

Magnetic particle testing

At zones of unhomogenity of the tested element the alterations of magnetic permeability are present, which result in alterations of magnetic particle orientations and by that, the identifications of defects are formed (Fig. 6).

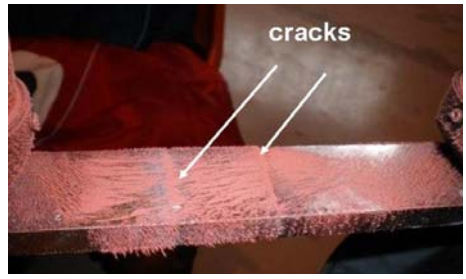

Fig. 6 *Magnetic particle nondestructive testing method*

Advantages of this nondestructive testing technique can be recognized as large surface of complex geometry parts can be examined fast with detecting surface and subsurface defects, surface preparation is less critical than it is in penetrant testing. The identifications of defects are formed on the surface of the tested element directly and by that, a special type of defect map is obtained. Disadvantages of magnetic particle testing can be recognized as only ferromagnetic materials can be examined, proper alignment of magnetic field and defect is critical, large homogeneous magnetic fields are needed for large parts, requires relatively smooth surface while paint or other nonmagnetic coverings badly affect sensitivity and also cleaning after testing procedure is necessary.

Strain gauge method – tensometric methods

The strain gauge method is based on the phenomena of alterations of electrical resistance in correlation to deformations of the tested element of mechanical construction with strain gauges placed on (Fig. 7). The main disadvantage of this monitoring method is in the fact that measuring is limited to small zones at the surface of the element with strain gauges placed on without possibility of 3D analysis. The main advantages of this method are in its simplicity, affordability, low costs and suitability for continual monitoring on remote locations.

Fig. 7 *System of strain gauges to continual monitoring*

Photoelastic Testing

Photoelasticity is method of analyzing stresses which is based on the characteristic of photoelastic materials to become optically anisotropic in loaded conditions. Optical anisotropy of these materials can be measured with polarized light in a polariscopes and depend on the values and the distributions of the stresses in them (Fig. 8). This method provide getting of relevant results by analysis at the models of the considered elements made of photoelastic sensitive materials with same shapes and stresses levels or directly on real constructions by the use of photoelastic layers or coatings.

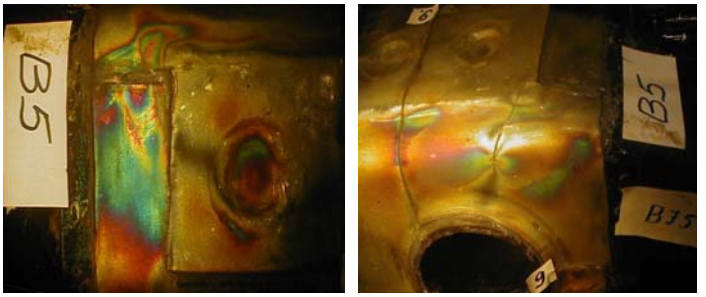

Fig. 8. *Identification of defects by photoelastic method*

Radioscopy

X-rays slightly loose in intensity during passing through metallic materials at the zones of unhomogenity and discontinuity, such as defects and cracks, while losses are bigger when there are no unhomogenities on their way. The presented phenomenon is base for the technical system monitoring by radioscopy method. The radioscopy method that uses gamma rays, which are characterized by higher penetrating than X-rays, is more sensitive and defects with dimensions higher than 5% of thickness of examined elements can be identified. The usage of radioscopy method required adequate protection of the environment from the radiation and that is major disadvantage of this method.

Ultrasonic Testing

Ultrasonic nondestructive testing method uses high frequency sound wave beams introduced into materials for the detection of subsurface discontinuities in examined object.

High frequency sound pass through material with constant decrease of energy within examined element and they are reflected by its surfaces and discontinuities. The reflected beams are registered, measured and analyzed in order to identify the present and location of defects (Fig. 9). Ultrasonic testing is suitable for automation of the technical system monitoring. The alterations of thickness and characteristics of the materials can also be measured. Advantages of this method are very significant such as depth of penetration for discontinuities detection or measurement is superior to other methods, only single sided access is required, provides distance information, minimum part preparation is required, method can be used for providing much more information and data than just defect detection of defects.

a) *b)*

Fig. 9. *Ultrasonic testing: a) Ultrasonic testing device; b) Testing probe*

Ultrasonic nondestructive testing method disadvantages are: surface must be accessible to probe, skill and training required is more general than other technique, surface finish and roughness can interfere with inspection, thin parts may be difficult to inspect, linear defects oriented parallel to the sound beam can be undetected, reference standards are often needed.

Vibro–acoustic method and acoustic emission method

Generation of sound and vibrations followed the operation of mechanical systems and present relevant parameters about their operation conditions. Acoustic oscillations and vibrations usually act simultaneously. These complex types of oscillations provide sufficient quantity of information and data about technical conditions of the monitored systems in exploitation. As acoustic oscillations can be detected by hearing sense and vibration can be detected by touch, those methods are one of the oldest methods of investigations that are still used in present. The evolutions of these methods are related to automatic spectral analysis of acoustic and other vibrations.

Acoustic emission method is nondestructive experimental method that is based on the phenomenon that discontinuities at rigid loaded body emitted short impulses of acoustic energy. Those acoustic emissions are identifications of defects at tested elements such as cracks. Acoustic emission method is different to other monitoring methods because the signal that is measured during testing are formed within tested element and not generated by external source. This method identified the formation and growth of the defect while other methods identified the presence of defects. Acoustic emission is related to movement of dislocations that followed the plastic deformations of the material, so as formation and growth of cracks at loaded element.

4. CONCLUSION

Complexity of modern mechanical constructions cannot be archived with simultaneous development of monitoring methods. The methods of technical systems monitoring are related to analysis of processes that conditioned the alterations of their characteristics in exploitation. Monitoring methods of technical systems are related with prevent maintains of those systems. The obtained data are basis for verifications of mathematical models or the examined mechanical constructions. Modern mechanical systems are very different in functions and in nature of its elements, so the mathematical models of those systems are very complex. The developments of computers open possibilities for numeric simulations of mechanical systems in real exploitation, stress-strain analysis by considerations of the mathematical models. The

wide range of numerical methods are developed, so as software packs that are based on application of those numeric methods as finite elements method, finite difference method and so on. Those numeric considerations can be very useful for identification and selection of optimal experimental monitoring method. As uniform microstructure and homogenous continuum are assumption at numeric methods, the relevant information and data, that are base for monitoring of mechanical systems in exploitation, can be provide only by experimental testing.

LITERATURE

[1] Doyle, J., F. (2004) MODERN EXPERIMENTAL STRESS ANALYSIS completing the solution of partially specified problems*, John Wiley & Sons Ltd, England,* ISBN 0-470-86156-8

[2] Dally, J. ,W. , Riley, W., F. (2008) Experimental Stress Analysis, *McGraw-hill Book company, N.Y.,* ISBN 978-0070152182

[3] Josifović, D. (2000) Examination of mechanical constructions I, Faculty of mechanical engineering, ISBN 86-80581-31-3

[4] Course (2009) "Structural Design by Experiments" (Methods and Tools of Experimental Aided Design), *University of Bologna - DIEM - Department of Mechanical Engineering, Handouts, participants report and results*

[5] Davies, A. (1998) Handbook of Condition Monitoring Techniques and Methodology. *Springer Publishing,* ISBN 978-0-412-61320-3

[6] Williams, J., H., Davies, A. , Drake, P., R. (1994) Condition-based Maintenance and Machine Diagnostics. *Chapman & Hall, London ; New York,* ISBN 978-0-412-46500-0

[7] Yardley, E., D. (2002) Condition monitoring: engineering the practice. *Bury St Edmunds : Professional Engineering Publ.*, ISBN 978-1-860-58361-2

[8] Watterson, J., M. (2011) Diagnostic skills: tapping the hidden capacity of your equipment. *Aylesbury: ShieldCrest,* ISBN *978-1-907-62909-9*

[9] Barron, R. (1996) Engineering condition monitoring: practice, methods and applications. *Harlow: Longman,* ISBN *978-0-582-24656-0*

[10]ISO (2011). ISO 17359:(2011), Condition monitoring and diagnostics of machines - General guidelines. *The International Organization for Standardization*

[11]Ilić, A., Ivanović, L., Josifović, D. (2009) Contemporary methods of nondestructive testing on mechanical construction. *9th International Conference "RaDMI 2009", Proceedings, pp. 218 – 225*

[12]Ilić, A., Josifović, D. (2010) Experimental methods for detection and analysis of mechanical constructions cracks. *26. International Conference "IBR 2010", Serbian society for nondestructive testing*