The Metal Magnetic Memory Method - a New Trend in Engineering Diagnostics

Traditional methods and means of diagnostics (ultrasonic inspection, magnetic particle inspection, X-ray) are oriented to detecting the already developed defects and by their designation can not prevent sudden fatigue damages of equipment, which are the main reasons of failures and sources of maintenance staff traumatism.

It is known that stress concentration (SC) zones, in which corrosion, fatigue and creep processes develop most intensively, are the main sources of damages occurrence in operating structures. Consequently, detecting SC zones is one of the most important tasks of equipment and structures diagnostics.

Variations of metal properties (corrosion, fatigue, creep) in SC zones are the processes preceding operating damaging. Metal magnetization, reflecting the actual stress-strained state of pipelines, equipment and structures, changes accordingly.

At present a principally new method of equipment and structures diagnostics based on using of metal magnetic memory has been developed and implemented successfully in practice. The MMM method unites the potential opportunities of non-destructive testing (NDT) and fracture mechanics due to which it has a number of significant advantages over other methods at inspection of industrial objects.

Basic practical advantages of the new diagnostics method as compared to the known magnetic and other traditional methods of non-destructive testing (NDT) are:

- application of the method does not require special magnetizing devices as the phenomenon of equipment and structures units magnetization in the process of their operation is used;
- locations of stress concentration due to working loads, which are unknown beforehand, are determined in the course of their inspection;
- metal dressing or any other preparation of the test surface is not required;
- small-sized instruments, self-contained power supply, recording systems and a memory unit up to 32 Mb are used to perform inspection by the proposed method;
- special scanning devices allow testing of pipelines, vessels and equipment in the express-control mode at a speed of 100 m/hr and more.

The MMM method is the most suitable practical NDT method at assessment of actual stress-strained state. Therefore application of the new diagnostics method is the most effective for equipment units life assessment.

The suggested diagnostic method, based on application of metal magnetic memory, allows performing an integral evaluation of a unit state considering the metal quality, actual operating conditions and its structural features.

The main task of the MMM method is detecting on the test object of the most dangerous sections and units characterized by SC zones. Then, using, for example, UT in SC zones, the presence of a specific defect is detected. Based on calibration strength calculations of the most stressed units, detected by the MMM method, the equipment actual life assessment is carried out.

Besides that, MMM and the appropriate inspection devices allow:

- carrying out early diagnostics of fatigue damages and predicting equipment reliability;
- documenting inspection results and making the equipment state data bank;
- performing express grading of new and old parts by their susceptibility to damaging;
- detecting the future crack location and propagation direction on the test object with accuracy up to 1 mm as well as recording of the already formed cracks;
- inspecting in some cases of pipelines and vessels without insulation removal.

What is principally new in the suggested inspection method?

From the analysis of known magnetic methods the following obligatory conditions of their application are arise. Firstly, the magnetizing devices should be necessarily used, and secondly, the known magnetic methods can be applied effectively only on condition that locations of stress concentration and defects in the control object are known in advance. Besides, the known magnetic inspection methods require, as a rule, metal dressing and other preparatory operations. It is obvious that application of conventional magnetic inspection methods in extended structures and on equipment at such conditions is practically impossible. For example, the task of specially magnetizing the tube system, whose length on a modern power boiler approaches 500 km, is unreal. It is impossible to know in advance stress concentration zones (the main sources of damages development) on each boiler tube due to different process, design and operating factors influencing their formation.

It is known at the same time that most of metal structures and equipment of ferromagnetic materials is susceptible to "self-magnetization" in the magnetic field of the Earth under influence of working loads.

The figure shows the scheme of magneto-elastic effect action (ΔB_r - residual inductions change; $\Delta\sigma$ - cyclic loads change; H_e - external magnetic field). If a cyclic load σ acts in some area of a structure and an external field is present (for example, the magnetic field of the Earth), the residual induction and residual magnetization growth occurs in this area.

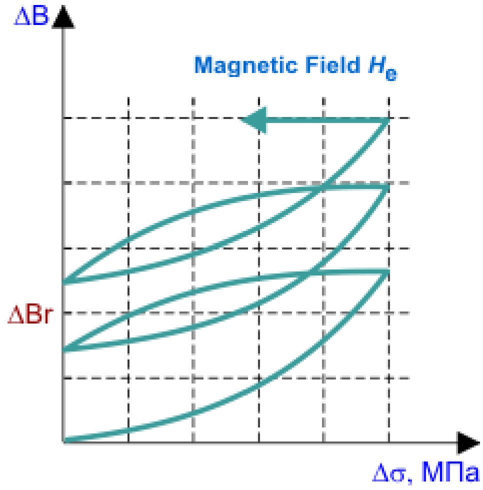


Fig.1. The scheme of magneto-elastic effect action.

The phenomenon of equipment and structures "self-magnetization" is fought against everywhere (shipbuilding, power engineering, ball bearing and other industries). Upon studying this magnetization phenomenon on the example of boiler tubes, it was suggested for the first time to use it for the purposes of engineering diagnostics. At equipment and structures "self-magnetization" various magnetostriction effects appear. However, the new inspection method uses an aftereffect (in all varieties of magnetostriction effects), which becomes apparent as the metal magnetic memory to actual strains and structural changes in equipment metal. The more detailed information on the principal differences of the MMM method from other known magnetic NDT methods can be found in a A. A. Dubov "Principal Features of the Metal Magnetic Memory Method and Inspection Tools as Compared to Known Magnetic NDT methods".

Metal magnetic memory is an aftereffect, which becomes apparent in the form of residual magnetization of products and welded joints metal formed in the course of their fabrication and cooling in a weak magnetic field or in the form of irreversible changing of products magnetization in stress concentration and damaging zones due to working loads.

Note: A weak magnetic field is a geomagnetic field and other low-intensity external fields. The more clear boundary between weak and strong magnetic fields is considered in the book "The Physical Bases of the Metal Magnetic Memory Method" by Vlasov V.T., Dubov A.A. M.: ZAO "TISSO", 2004.

The metal magnetic memory method is a non-destructive testing method based on registration and analysis of self-magnetic leakage fields (SMLF) distribution on products surface for determination of stress concentration zones, defects, metal and welded joints structure inhomogeneity.

The self-magnetic leakage field of a product is a magnetic leakage field occurring on the product surface in the zones of dislocations stable slipbands under the influence of operational or residual stresses or in zones of maximum inhomogeneity of metal structure in new products.

For individual items, products and welded joints MMM is based on registration of own leakage magnetic fields occurring in residual stress concentration zones after their fabrication and cooling in the magnetic field of the Earth. During fabrication of any ferromagnetic products (fusion, forging, heat and mechanical treatment) the mechanism of real magnetic texture formation takes place simultaneously with solidification at cooling, as a rule, in the magnetic field of the Earth. In areas of

the maximum lattice defects concentration (for example, dislocation clusters) and structural inhomogeneities domain boundaries occur with exit to the product surface in the form of SMLF normal component sign alternation lines. These lines correspond to the part section with the maximum magnetic resistance and characterize the maximum metal structure inhomogeneity zone and, accordingly, the internal stresses maximum concentration zone (SCZs).

Currently more than 40 guidance documents and inspection techniques has been developed and practically applied in power engineering, chemical, petrochemical, oil- and gas-refining, oil, gas and other Russian industries. The complex of researches for theoretical substantiation of the method is conducted jointly with a number of Russian institutes. The quantitative and qualitative criteria allowing performing early diagnostics of equipment fatigue damages and life assessment using the MMM method are developed.

During the period from 1990 to 2010 the experts of Energodiagnostika Co. Ltd carried out industrial researches with a state assessment of more than 310 steam and hot-water boilers, more than 220 steam and gas turbines, more than 200 vessels and apparatuses, more than 1000 km of various process purpose pipelines; the quality inspection of machine-building products at more than 50 plants and companies both in Russia and other countries is carried out; experimental control of a rails and wheel sets on railway transport enterprises, bridge structures, hoisting mechanisms and other technical objects is performed.

Based on the results of 2011, diagnostic companies and organizations, which bought instruments and passed training at "Energodiagnostika Co. Ltd" Certification Center, applied the MMM method at equipment diagnostics at more than 1000 enterprises of Russia. Besides Russia, the method was implemented at a number of enterprises of 31 countries: Angola, Argentina, Australia, Belarus, Bulgaria, Canada, China, Colombia, Czech Republic, Finland, Germany, Hungary, India, Iran, Iraq, Israel, Japan, Kazakhstan, Latvia, Lithuania, Macedonia, Malaysia, Moldova, Mongolia, Montenegro, Poland, Serbia, South Africa, South Korea, Ukraine, USA.

The following Russian standards were prepared and put into effect:

- GOST R ISO 24497-1-2009. Non-destructive testing. Metal magnetic memory method. Part 1. Terms and definitions.
- GOST R ISO 24497-2-2009. Non-destructive testing. Metal magnetic memory method. Part 2. General requirements.
- GOST R ISO 24497-3-2009. Non-destructive testing. Metal magnetic memory method. Part 3. Inspection of welded joints.
- GOST R 52330-2005. Non-destructive testing. Evaluation of deformations in industrial and vehicle structures. General requirements.
- GOST R 53006-2008. Estimation of potential dangerous objects lifetime on the basis of express methods. General requirements.

During the period from 1994 till 2010 45 IIW documents with positive resolutions on the metal magnetic memory method were issued.

The International Standard ISO 24497-1:2007(E), 24497-2:2007(E), 24497-3:2007(E) on the metal magnetic memory method is approved in 2007 as a result of positive voting among 18 IIW member countries and more than 10 ISO Committee countries.

Significant experience of industrial and laboratory investigations, availability of techniques, guidance documents, scientific and technical reports allowed developing the normative-technical documentation (NTD) on certification of the metal magnetic memory method, inspection devices and personnel. Besides the techniques and GD, the normative-technical documentation includes: the requirements to technical knowledge of the experts studying the MMM method; the program of Level I, II and III experts training (approved by the State Engineering Supervision (Rostechnadzor) of Russia); passports and technical specifications to inspection instruments; operating manuals, techniques for inspection instruments calibration and testing; the users manual to the software for computer processing of results; training handbook.

Articles on the metal magnetic memory method:

- A.A. Dubov
  The metal magnetic memory method
- A.A. Dubov, V.T. Vlasov
  About the new classification NDT methods based on positions of risks and eguipment life assessment
- V.T. Vlasov, A.A. Dubov
  Physical criteria of materials and structural elements stress-strain state assessment
- A.A. Dubov
  Principal features of the metal magnetic memory method and inspection tools as compared to known magnetic NDT methods
- A.A. Dubov
  The totals of application of the metal magnetic memory method to industry in Russia and other countries
- A.A. Dubov, V.T. Vlasov
  On the problem of stress-strained state characteristics measurement of structural materials on complex engineering objects. Energy concept of materials stress-strained state (SSS) diagnostics
- A.A. Dubov
  Problems of ageing equipment residual life assessment
- A.A. Dubov
  Assessment of eguipment lifetime using the metal magnetic memory method
- A.A. Dubov, Al.A. Dubov
  Non-contact diagnostics of buried pipelines using the magnetometric testers of stress concentration
- A.A. Dubov
  Metal magnetic memory method and its capabilities for diagnostics of power boiler elements
- A.A. Dubov
  Detection of local stress concentration zones in engineering products - the lacking link in the non-

destructive testing system

- A.A. Dubov, I.I. Veliulin
  Gas and oil pipelines residual life assessment based on modern methods of engineering diagnostics
- A.A. Dubov, M.Yu. Evdokimov, A.V. Pavlov
  The experience of scanning devices application for quick inspection of operated gas pipelines
- A.A. Dubov, S.M. Kolokolnikov
  Review of welding problems and allied processed and their solving using metal magnetic memory effect
- A.A. Dubov, Al.A. Dubov, A.A. Sobranin
  Diagnostics of oil-production drilling rig units and components using the metal magnetic memory method
- A.A. Dubov
  New requirements to methods and devices for diagnostics of materials stress-strain state

Basic publications:

1. Dubov A.A., Dubov Al.A., Kolokolnikov S.M. Method of metal magnetic memory and inspection instruments. Training handbook. Moscow: ZAO "TISSO", 2008.

2. Vlasov V.T., Dubov A.A. Physical theory of the "strain-failure" process. Part I. Physical criteria of metals limiting states. Moscow: ZAO "TISSO", 2007.

3. Vlasov V.T., Dubov A.A. Physical bases of the metal magnetic memory method. Moscow: ZAO "TISSO", 2004.

4. Dubov A.A. Metal magnetic memory method. History of origin and development. Moscow: FSUE "Izvestiya" Publishing House, 2011.

5. Dubov A.A. I.C. 2029263. Patent of Russia and the C.I.S. countries. Method for residual stresses determination in products made of ferromagnetic materials. List of Inventions, No.5, 1995.

6. Proceedings of the First, the Second, -the Third, the Fourth, the Fifth and the Sixth International Scientific-Technical Conferences "Equipment and structures diagnostics using the metal magnetic memory". Papers and summary to papers. Moscow: Energodiagnostika Co. Ltd, 1999, 2001, 2003, 2007, 2009, 2011.

7. Dubov A.A. Diagnostics of boiler tubes using the metal magnetic memory. Moscow: Energoatomizdat, 1995.

8. Dubov A.A. Diagnostics of turbine equipment using the metal magnetic memory. Moscow: ZAO "TISSO", 2009.

9. Dubov A.A. Diagnostics of pipelines, equipment and structures using the metal magnetic memory. Collection of papers and reports. Moscow: Energodiagnostika Co. Ltd, 2001.

10. Dubov A.A. Investigation of metal properties using the magnetic memory method // Physical metallurgy and thermal treatment of metals, No.9, 1997.

11. Dubov A.A. Express method of welding stresses inspection // Welding fabrication, No.11, 1996.

12. Dubov A.A. Diagnostics of rails fatigue damaging using the metal magnetic memory // In the world of NDT, No.5, 1999.

13. Goritzky V.M., Dubov A.A., Demin E.A. Investigation of steel samples structural damaging using the metal magnetic memory method // Testing. Diagnostics, No.7, 2000.

14. Dubov A.A. The problems of the ageing equipment life assessment // Labour safety in industry, No.12, 2002, pp.30-38.

15. Dubov A.A. The method of metal limiting state determining and equipment life assessment by magnetic diagnostic parameters // Testing. Diagnostics, No.5, 2003.

Energodiagnostika

Energodiagnostika Co. Ltd, founded in 1992 in Moscow, operates in sphere of industrial safety assurance in different industries and in the sphere of engineering industry products quality control. Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

About MMM method

The metal magnetic memory method has been developed practically and theoretically for more than 30 years. The method and the appropriate inspection instruments are used at more than 1000 enterprises of Russia. The method became widespread in 33 countries of the world. The International Standard ISO 24497-1:2007(E), 24497-2:2007(E), 24497-3:2007(E) on the metal magnetic memory method is approved in 2007 as a result of positive voting among 18 IIW member countries and more than 10 ISO Committee countries.

MMM application

Area of MMM method application: quality control of metal and welded joints of products at engineering industry plants; pipelines, vessels, equipment, any constructions and products (from ferromagnetic and paramagnetic austenitic material) in all industries at manufacturing, repair and maintenance; hoisting devices and running mechanisms; research of metal mechanical properties in laboratory conditions.

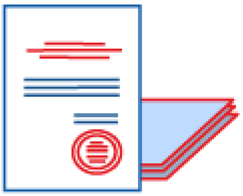
Production

Design and manufacture of specialized inspection instruments and sensors for the metal magnetic memory method, warranty and post-warranty service. Software engineering. Development of guideline documents of Rostechnadzor, Russian and International standards in the field of non-destructive testing. Development of specialized inspection techniques for various industries using the metal magnetic memory method.

Diagnostic works

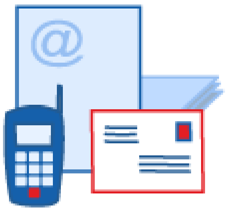
Energodiagnostika Co. Ltd has the license of Rostechnadzor No.DE-00-008978

(DKPS) from August 07, 2008 giving the right to perform activity on carrying out industrial safety examination. Energodiagnostika Co. Ltd non-destructive testing laboratory meets all the requirements of non-destructive testing system. Certificate No. 00A020351 from September 25, 2015.



Certification of specialists

An independent body for personnel certification in the sphere of non-destructive testing "Energodiagnostika Co. Ltd" operates in Moscow on a regular basis. Accreditation Certificate of Rostechnadzor No. NOAP-0019 from November 21, 2014. At present more than 2000 specialists in Russia, more than 450 specialists in China, 75 specialists in Poland and more than 85 specialists in other countries passed training in the method of metal magnetic memory.



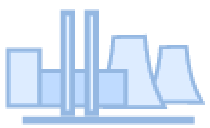
Contacts

Energodiagnostika Co. Ltd: Office 12, Yubileiny Prospekt 8, Reutov, Moscow region, 143965, Russia. Phone/fax: +7-498-6619281, +7-498-6616135.
Email: mail@energodiagnostika.ru

Certification Center of Energodiagnostika Co. Ltd: Office 13, October Street 38, Reutov, Moscow region, 143962, Russia. Phone/fax: +7-498-6502523.
Email: noap@energodiagnostika.ru

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

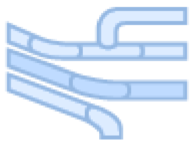
Application of the Metal Magnetic Memory Method



Power Engineering

Engineering diagnostics, assessment of power equipment's basic elements residual life

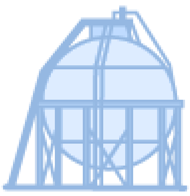
Boilers: pipelines, vessels and apparatuses, welded joints, armature.
Turbine equipment: steam turbine rotors, steam turbine blades, support equipment.



Oil and Gas Complex

Engineering diagnostics, residual life assessment

Oil and gas trunk pipelines. Industrial pipelines. Compressor plant equipment. Production tree.



Chemical Industry

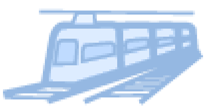
Engineering diagnostics, residual life assessment

Pipelines for various technological purposes. Vessels and apparatuses. Welded joints. Armature.

Metal Structures

Inspection and engineering diagnostics

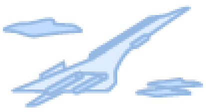
Bridge structures. High-rise structures. Mine plants. Drilling rigs. Fastening members.



Railway Transport

Inspection and engineering diagnostics

Rails. Wheel pairs. Automatic coupling elements. Locomotive and car parts. Support equipment.



Aviation

Inspection and engineering diagnostics

Power plant parts. Undercarriage bolted joints. Aircraft hull elements.

Sea Transport

Engineering diagnostics

Power plant elements. Industrial pipelines. Hoisting devices. Support equipment.

Hoisting Machines

Inspection and engineering diagnostics

Main bearing components of hoisting machines for various purposes and design.

Mechanical Engineering

Quality control of machine-building products. Inspection of residual stresses in products

Components. Welded joints. Products.

Metallurgy

Quality control of cast products and sections

Rolling-mill machinery elements for various applications. Finished products. Support equipment.

Scientific Researches

Stress-strained state testing

Stress-strained state testing. Detection of stress concentration zones.
Investigation of structural-mechanical properties of metal.

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

Principal Features of the Metal Magnetic Memory Method and Inspection Tools as Compared to Known Magnetic NDT methods

Dr., Professor A.A. Dubov

In connection with arising hitherto questions and doubts on novelty of the metal magnetic memory method (MMM) as compared to known (in Russia and other countries) magnetic NDT methods, it became necessary to describe once more principal features of MMM and the appropriate inspection tools.

Methods and tools, used in 70-80 years of the last century at the Institute of Metals Physics (Sverdlovsk), the Institute of Applied Physics (Minsk), F.Ferster Institute (Germany) and other Research Centers, were aimed at measurement of residual magnetization of products after their premagnetization (and in many cases after their preliminary demagnetization with further magnetization). Natural magnetization of products (or metal magnetic memory) used in the metal magnetic memory method was not studied here and was taken as an interference at measurements.

We established this fact and confirmed it by examination at ROSPATENT while registering first patents on the metal magnetic memory method. Besides, basic MMM features were revealed during experimental works at Mosenergo's power plants in the course of researches of tubes. Scientific report of the Institute of Metals Physics (Sverdlovsk, 1988) and monograph [1] contain these basic features.

The concept of "Metal Magnetic Memory" was first introduced by the author in 1994. Before that time it was not used in the technical literature. The following terms and concepts were known: "Magnetic Memory of the Earth" - in archeological studies; "Magnetic Memory" - in sound recording; "Shape Memory Effect", due to structural and phase transformations oriented by internal stresses in metal products.

Based on the established correlation of dislocation processes with the magnetic phenomena physics, the concept of "metal magnetic memory" was introduced in products' metals and a new method of diagnostics was developed. The uniqueness of the metal magnetic memory method is that it is based on use of the self-magnetic leakage field (SMLF), occurring in zones of steady strips of dislocations sliding, stipulated by working loads action. SMLF occur because of domain boundaries formation at accumulations of high-density dislocations (dislocation walls). It is impossible to obtain an information source like a self-magnetic field at any conditions with artificial magnetization in working constructions. Such information is formed and can be obtained only in a weak external field, as the Earth's magnetic field is, in loaded constructions when deformation energy is a cut above the energy of the external magnetic field. It is shown in practical works that MMM can be used both at the equipment operation and after working loads relief during the repairs. Magnetic texture, formed under the action of working loads, becomes, so to say, "frozen" after unloading by virtue of the "magnetic dislocation hysteresis". Thus, there appears a unique possibility to evaluate the actual stress-strained state of the equipment and to reveal at an early stage maximal damage zones in metal by reading this information using special tools.

Physical fundamentals of SMLF occurrence are principally different compared to magnetic leakage fields (MLF) occurring on defects of products at their artificial magnetization used in well-known magnetic NDT methods. SMLF occurs in local zones (from 0,1 up to tens of microns) on the surface and in depth layers of products metal. Nobody has never performed investigation of SMLF and the physical fundamentals of its occurrence till "birth" of MMM (the 90-s of the last century). There was no such task at all! [2, 3] gives more detailed description of the mechanism of SMLF formation in ferromagnetic products.

SMLF was found also on new machine-building products directly after their manufacturing. It is known that at heating of a ferromagnetic above the Curie temperature (for example, for iron T_C=780°C) and its further cooling even in a weak external magnetic field of the Earth, it gains such a degree of magnetization that can be reached at normal temperature only in a high-intensity magnetic field. Natural magnetization at manufacturing of machine-building products forms, as a rule, exactly at such conditions. The mechanism of the product's real magnetic texture formation (fusing, forging, thermal treatment, welding) occurs directly after crystallization at cooling below the Curie point. Here the process of real products cooling is, as a rule, non-uniform. The metal external layers cool faster than the internal ones. Thermal stresses form across the product's volume. They form the lattice and the appropriate magnetic texture. In areas of the greatest lattice defects concentration (i.e., clusters of dislocations) and of the structural non-uniformity the domain boundaries (DB) attachment points form with outcrop in the form of the lines of SMLF normal component's sign changing (H_p=0 lines). It was established in industrial researches that natural magnetization, formed in such a way, reflects the product's structural and technological heredity, and H_p=0 lines correspond to the lines of residual stresses concentration. A series of methods on quality control of machine-building products using MMM was developed.

Special scanning devices including not only the known flux-gate sensors but also the length meter, analog-digital converter (ADC), the processor and other devices were first developed to register local micron SMLF areas giving MMM characteristic of the stress concentration zone. Such scanning devices have never been used in magnetic NDT methods before the MMM "birth" (there are no analogues in the world). Scanning devices and the control method are patented in Russia, Germany and Poland.

It is known that development of tools providing the opportunity to perform any researches with enlarged sensitivity or precision as compared to the existing ones results, as a rule, in big achievements in this or that branch of science and technology. When we manage to create tools with special, principally new qualities, providing the possibility of reliable registration of changes in physical processes that were elusive before, i.e. allowing to bring to practice tools with completely different performance capabilities, it always leads to discoveries representing the breakthrough in the most important areas of our natural knowledge.

This exactly happened to information provided by the construction or product itself in the form of SMLF. It is principally impossible to register regularities in SMLF distribution on test objects without special scanning devices, transformers and program-controlled processors used in tools for MMM. Before the MMM "birth" generic the residual magnetization field of products was considered as an interference, and in many cases actions were taken to eliminate this, so to say, random magnetization.

At operation most of metal constructions work in conditions of cycling loads and stresses Δσ action and in presence of the external magnetic field *H*o (for example, Earth's field). Due to the known magneto-elastic effect, "self-magnetization" of equipment and constructions occurs. Figure 1 shows the magneto-elastic effect action diagram. Equipment and constructions "self-magnetization" phenomenon is being fought against everywhere by their periodic demagnetization (shipbuilding, power engineering, ball-bearing and other industries). Upon studying of this phenomenon on the example of boiler tubes and other units operation, the author offered for the first time to use it for the purposes of technical diagnostics [1, 4].

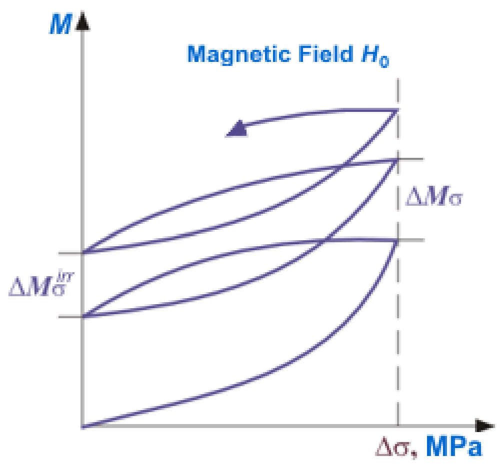


Fig.1. The diagram of magneto-elastic effect action: $\Delta M\sigma$ and $\Delta M\sigma^{irr}$ - change of residual magnetization, accordingly, under loading and after unloading; Δσ - change of cyclic loading; H_0 - external magnetic field.

MMM has been developed in practical and theoretical aspects for more than 25 years. As of 2011, there are more than 40 guiding documents and methods agreed with RF State Engineering Supervision (Rostechnadzor) and being valid for various industries.

Special inspection instruments and the appropriate software for them was developed and put to full-scale production by Energodiagnostika Co. Ltd. The instruments are certificated in Rosstandard and are included in the State List of Measuring Instruments. Certificates RU.C.34.003.A No.42683, RU.C.27.002.A No.35003.

Since 1996 the Russian and International Centre for experts training and certification by the method of metal magnetic memory with issuing of Level I, II and III Certificates operates in Moscow. The branches of the centre operate in Warsaw and Beijing. As of 2011, more than 1700 experts in Russia, more than 450 experts in China, 70 experts in Poland and more than 60 experts in other countries passed training.

Five Russian and International standards are published:

- GOST R ISO 24497-1-2009. Non-destructive testing. Metal magnetic memory method. Part 1. Terms and definitions.
- GOST R ISO 24497-2-2009. Non-destructive testing. Metal magnetic memory method. Part 2. General requirements.
- GOST R ISO 24497-3-2009. Non-destructive testing. Metal magnetic memory method. Part 3. Inspection of welded joints.
- GOST R 52330-2005. Non-destructive testing. Evaluation of deformations in industrial and vehicle structures. General requirements.
- GOST R 53006-2008. Estimation of potential dangerous objects lifetime on the basis of express methods. General requirements.

16 terms and definitions reflecting the novelty and features distinguishing MMM from all other known magnetic NDT methods were brought to effect by GOST R ISO 24497-1-2009.

Interest of experts of Russia and other countries from various industries to essentially new magnetic method of non-destructive testing (NDT) grows steadily. Application of the MMM method and corresponding inspection devices to industry, as a rule, is carried out on a voluntary basis that is vivid confirmation of the method efficiency.

The metal magnetic memory method and appropriate testing instruments are used at more than 1000 Russian enterprises. Besides Russia, the method was implemented at a number of enterprises of 31 countries: Angola, Argentina, Australia, Belarus, Bulgaria, Canada, China, Colombia, Czech Republic, Finland, Germany, Hungary, India, Iran, Iraq, Israel, Japan, Kazakhstan, Latvia, Lithuania, Macedonia, Malaysia, Moldova, Mongolia, Montenegro, Poland, Serbia, South Africa, South Korea, Ukraine, USA.

Interest to the method is caused by unsolved problems, which arise in practice at quality control of engineering products, at reliability control and at equipment life estimation.

Let’s denote the basic from them.

- Till now on the majority of manufacturing plants in Russia and other countries there are no 100% quality control of production on heterogeneity of metal structure. Due to this reason the spread of mechanical properties on new products reaches 20% and more, that considerably reduces their lifetime.
- Welding exists more than 100 years, and NDT methods, which allow in practice to carry out express quality control of welded joints in the united complex system of the factors "structural-mechanical inhomogeneity – defects of a weld – structural and technological stress concentrator", till now are not present. Now non-destructive test is commonly applied with detection of inadmissible defects (at that, the scientifically-grounded norms for the sizes of permissible defects in welded joints from the point of view of fracture mechanics, as a rule, are not present). The most important – distribution of the residual welding stresses determining welded joint reliability till now is not examined.
- Existing problems of a lifetime estimation of the aging equipment with usage of conventional

methods and control devices are not solved because of their unfitness for early diagnostics of fatigue damages.

It is possible to speak confidently, that if we have the old equipment, which we cannot 100% inspect on metal structural damaging and detect imminent damages; in this case we work on sudden failure.

Thus, in spite of the fact that nondestructive testing exists in Russia and other countries already more than 100 years, many problems of machine-building products quality control and diagnostics of equipment in service are still unsolved. Therefore demand of the MMM method directed on the solution of specified NDT problems, is caused by daily practice and a life of the enterprises.

The metal magnetic memory method by its contents and physical essence (principally different physical field - SMLF - is measured) represents not only the principally new magnetic NDT method, but it also opens a new direction in technical diagnostics as it combines potential opportunities of NDT, fracture mechanics and metal science.

From the viewpoint of tasks solved by MMM, this method, similarly to the acoustic emission method, shall be referred to as a method of early diagnostics of the equipment fatigue damages, and it is feasible to found a Special Advisory Committee at the RF State Engineering Supervision (Gosgortechnadzor) to consider this item. Taking into account the current availability of all standard-technical documentation, a training center ("Energodiagnostika") independent body for personnel certification) and certified inspection tools, it is feasible to include this method in the State Engineering Supervision’s system of non-destructive testing as a separate type of NDT.

Reference

1. Dubov A.A. Diagnostics of boiler tubes with usage of metal magnetic memory. Moscow: Energoatomizdat, 1995. 112p.

2. Vlasov V.T., Dubov A.A. Physical bases of the metal magnetic memory method. Moscow: ZAO "TISSO", 2004, 389p.

3. Dubov A.A., Dubov Al.A., Kolokolnikov S.M. Method of metal magnetic memory and inspection devices. Training handbook. Moscow: ZAO "TISSO", 2008. 365p.

4. Dubov A.A. Method of definition of service durability of pipes of ferromagnetic materials. Inventors certificate 1769105. The patent of Russia // The bulletin of the inventions, No.38, 1992.

Standards on the metal magnetic memory method

ISO 24497-1:2007(E)

Non-destructive testing – Metal magnetic memory – Part 1: Vocabulary

Publication date November 01, 2007

Scope

This part of ISO 24497 specifies terms and definitions for procedures in the sphere of non-destructive testing by the method of metal magnetic memory.

The terms specified in this part of ISO 24497 are mandatory for application in all types of documentation and literature in the sphere of non-destructive testing, using the method of metal magnetic memory included in the scope of standardization works and/or using the results of these works.

ISO 24497-2:2007(E)

Non-destructive testing – Metal magnetic memory – Part 2: General requirements

Publication date November 01, 2007

Scope

This part of ISO 24497 specifies the general requirements for the application of the method of metal magnetic memory of components, units, equipment and structures for various application purposes. It covers non-destructive testing.

The purposes of the method are the following:

- Determination of heterogeneity of the stress/strain state of equipment and structures and revealing of stress concentration zones as the main sources of damage.
- Determination of locations to perform metal sampling in stress concentration zones for assessment of the microstructural-mechanical state.
- Early diagnostics of fatigue damage and evaluation of equipment and structure life.
-

Reduction of testing and material costs with its utilization in combination with conventional methods of non-destructive testing.

- Quality control of welded joints of various types and embodiment (including contact and spot welding).
- Very quick sorting of new and used machine-building products by their microstructural heterogeneity.

ISO 24497-3:2007(E)

Non-destructive testing - Metal magnetic memory - Part 3: Inspection of welded joints

Publication date November 01, 2007

Scope

This part of ISO 24497 specifies the general requirements for the application of the metal magnetic memory inspection method (MMM inspection) as a non-destructive testing method for quality assurance of welded joints of pressurized components.

This part of ISO 24497 may be applied to welded joints in any type of products, pipelines, vessels, equipment and metal constructions, as agreed with the purchaser.

The terms and definitions for the process are contained in ISO 24497-1, and the general requirements of the process are in ISO 24497-2.

GOST R ISO 24497-1-2009 (instead of GOST R 52081-2003)

State Standard of Russian Federation. Non-destructive Testing. Method of Metal Magnetic Memory. Part 1. Terms and Definitions

Introduction date December 01, 2010

Scope

This standard specifies terms and definitions for procedures in the sphere of non-destructive testing by the method of metal magnetic memory.

The terms specified in this standard are mandatory for application in all types of documentation and literature in the sphere of non-destructive testing, using the method of metal magnetic memory included in the scope of standardization works and/or using the results of these works.

GOST R ISO 24497-2-2009 (instead of GOST R 52005-2003)

State Standard of Russian Federation. Non-destructive Testing. Method of Metal Magnetic Memory. Part 2. General Requirements

Introduction date December 01, 2010

Scope

This standard specifies the general requirements for the application of the method of metal magnetic memory of components, units, equipment and structures for various application purposes.

The purposes of the method are the following:

- Determination of heterogeneity of the stress/strain state of equipment and structures and revealing of stress concentration zones as the main sources of damage.
- Determination of locations to perform metal sampling in stress concentration zones for assessment of the microstructural-mechanical state.
- Early diagnostics of fatigue damage and evaluation of equipment and structures life.
- Reduction of testing and material costs with its utilization in combination with conventional methods of non-destructive testing.
- Quality control of welded joints of various types and embodiment (including contact and spot welding).
- Very quick sorting of new and used machine-building products by their microstructural heterogeneity.

GOST R ISO 24497-3-2009

State Standard of Russian Federation. Non-destructive Testing. Method of Metal Magnetic Memory. Part 3. Inspection of welded joints

Introduction date December 01, 2010

Scope

This standard specifies the general requirements for the application of the metal magnetic memory inspection method (MMM inspection) as a non-destructive testing method for quality assurance of welded joints of pressurized components.

This standard may be applied to welded joints in any type of products, pipelines, vessels, equipment and metal constructions, as agreed with the purchaser.

The terms and definitions for the process are contained in GOST R ISO 24497-1-2009, and the general requirements of the process are in GOST R ISO 24497-2-2009.

GOST R 52330-2005

State Standard of Russian Federation. Non-destructive Testing. Evaluation of Deformations in Industrial and Vehicle Structures. General Requirements

Introduction date September 01, 2005

Scope

This standard specifies general requirements to application of methods and means of non-destructive testing of stress-strained state on industrial objects and transport.

This standard applies to products and equipment made of steel and alloys, cast iron and other structural materials without limitations on size and thickness including welded joints.

GOST R 53006-2008

State Standard of Russian Federation. Estimation of Potential Dangerous Objects Lifetime on the Basis of Express Methods. General Requirements

Introduction date September 01, 2009

Scope

This standard covers the objects (various-purpose pipelines, vessels and structures and their elements, including the welded joints of any structural configuration) with exhausted specified (by the manufacturer) design lifetimes, which require the assessment of lifetime characteristics before the expiry of the specified service life, as well as the objects after emergencies and renewals.

This standard specifies the basic requirements to the contents of techniques and standards regulating the procedures of the residual lifetime assessment of the potentially dangerous technical objects with application of non-destructive quick methods of the engineering diagnostics.

The metal magnetic memory method

Dr., Professor A.A. Dubov

For the first time the author introduced the concept "the magnetic memory of metal" in 1994. Before that this concept was not used in the technical literature. The following terms and concepts were known: "the magnetic memory of the earth" in archeological investigations, "the magnetic memory" in sound recording and "the effect of shape memory" conditioned by the oriented internal stresses in metal products.

Based on the established correlation of dislocation processes with the physics of magnetic phenomena in the metal of products, the concept "the magnetic memory of metal" was introduced and a new diagnostic method was developed. Similar to the effect of shape memory, "the magnetic memory of metal" - is the effect of the magnetic memory of metal strain conditioned by the oriented internal stresses. The uniqueness of the metal magnetic memory (MMM) method consists in the fact that it is based on application of the effect of occurrence of high metal magnetization in the areas of large strains of structural elements' metal due to the exposure to working loads. At the same time there is no artificial source of magnetization, except for the weak magnetic field of the earth, in which we all exist.

Many of us also observed the effects of occurrence of high metal magnetization, for example, in case of cutting of some metallic product with a hack-saw, or at the end of the screwdriver after its influence on the screws, as well as in places of friction at contact of metallic products (for instance, of gear wheel teeth). Occurrence of anomalous magnetization can be observed on the metallic wire in the area of its cyclic strain. When we break the wire by its cyclic bending in different directions, our fingers feel the wire heating in the maximum strain site. And if we carry out some measurement in this place using a magnetometer, we shall record the increase of the metal's magnetization. Oscillation damping – absorption of the energy of mechanical oscillations (for example, of turbine blades) is accompanied by generation of the magnetic energy and, accordingly, by the growth of the metal's residual magnetization. The list of the observed in practice cases of the products metal magnetization without the source of the artificial magnetic field can be continued further.

The phenomenon of strong magnetization of boiler pipes metal in places of their damaging, discovered in the 70-s of the last century by the Chief of "Volgogradenergo" metals laboratory O.V. Philimonov, should be attributed to the history of occurrence and development of the metal magnetic memory method as a new direction in diagnostics. The discovered phenomenon roused the interest of many power engineering experts, including me. At that time I worked for the production service of "Mosenergo" and dealt with the problems of boiler pipes reliability assurance. At that time an assumption was made about the possibility to use the phenomenon of operated pipes self-magnetization in order to detect potential damages. And occurrence of high magnetization was presumably explained by the action of cyclic strains and stresses due to working loads.

In case of confirmation of this assumption there opened a unique possibility to detect by the residual magnetization of metal in the location of stress concentration - the source of damages occurrence and development - by means of readout of the magnetic information presented to the researcher by the boiler piping itself.

In connection with this circumstance the author of this paper, jointly with the experts of the Institute of Metals Physics of the Russian Academy of Sciences (Yekaterinburg), arranged and carried out special laboratory and industrial researches aimed at investigation of the phenomenon of boiler pipes magnetization in conditions of their operation. The results of these investigations are described in the dissertation and monograph by A.A. Dubov "Diagnostics of boiler pipes using the magnetic memory of metal" (Moscow: Energoatomizdat, 1995, 112 p.).

As a result of the carried out investigations it was demonstrated that the reason of anomalously high magnetization of individual segments of boiler pipes is the magnetoelastic effect, which is known in the physics of magnetic phenomena.

Fig.1 shows the scheme of appearance of the magnetoelastic effect causing the growth of residual magnetization (M), for instance, in any place of the structure there is a cyclic load $\Delta\sigma$ and an external magnetic field H_0 (for example, the field of the earth), then the residual magnetization $\Delta M\sigma$ growth takes place in this location. Upon the load relief the reversible component disappears, and only the irreversible component of the residual magnetization ($\Delta M_\sigma{}^{irr}$) remains. Due to the magnetoelastic effect the pipes are as though "self-magnetizing" in the zones of stress concentration due to working loads. In the course of further industrial investigations it was established that practically all units of metal components and structures are subject to "self-magnetization".

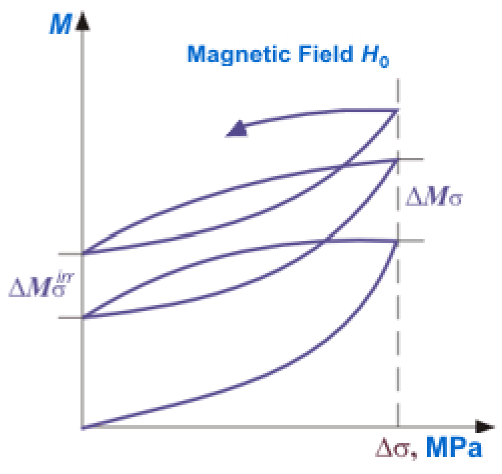


Fig.1.

The phenomenon metal components and structures "self-magnetization" is fought against everywhere by means of their periodic demagnetization (shipbuilding, power engineering, ball bearing and other industries). It would be sufficient to give as an example of struggle against self-magnetization, as a "harmful" phenomenon, the well-known story of struggle against the mines combated by our scientists at the beginning of the World War II against Germany. At that time, for example, occurrence of strong magnetization of hulls was discovered due to impacts of waves, especially after the storm. And then this phenomenon of hulls magnetization under exposure to cyclic stresses due to wave impacts in conditions of the weak magnetic field of the earth was first investigated under the supervision of academician A.P. Alexandrov. This phenomenon was explained by the action of the magnetoelastic effect. Then, in order to fight against the magnetic mines, special demagnetizing devices for periodic demagnetization of hulls were developed.

Since then the natural phenomenon of metal components and structures "self-magnetization" is everywhere fought against by means of their periodic demagnetization.

Upon investigating of this phenomenon on the example of boiler pipes and other units, it was suggested for the first time to use it for the purposes of engineering diagnostics, and the new diagnostic method was called "the metal magnetic memory method".

Based on experimental investigation of the metal magnetic memory phenomenon, a number of practical inspection techniques and specialized modern instruments were developed, allowing registration of magnetic anomalies location sites, corresponding to stress concentration zones (SCZs), being the sources of damages, in the quick-inspection mode without any preparation of the inspection object (IO) (in some cases through the layer of paint or insulation) by scanning along the surface (for example, of a long pipeline). Obtaining such an information source like a proper magnetic field is not possible under any conditions of artificial active magnetization in operated structures. Such information is formed and can be obtained only in a weak external field like the magnetic field of the earth in loaded structures, when the strain energy exceeds the external magnetic field energy by at least an order of magnitude. It was demonstrated in practical investigations that MMM may be applied both for equipment operation (in the monitoring mode) and after relief of working loads, during the repairs. By virtue of "magnetodislocation hysteresis" the magnetic texture formed under the effect of working loads somehow "congeals" after their relief. Thus, there is a unique opportunity to perform assessment of equipment stress-strain state and detect zones of maximum metal damage by measuring this information using specialized instruments. Application of MMM for assessment of metal structural life and survivability looks very promising since this method unites potential opportunities of non-destructive testing, materials science and fracture mechanics.

The unique opportunities of the MMM method reveal themselves in cases of finding out the reasons of failure of various structural elements of buildings, constructions, bridges, etc. For example, at failure of one of the piers supporting the roof in aqua park (Moscow, 2005) or at failure of the so-called "finger" carrying the heavy load in a complex structure of the new skating rink building (Moscow, 2007), the arouse some arguments between the metallographers (and, accordingly, between the manufacturing plant) and the designers of these structures. In these cases it is impossible to assess the actual stress-strain state (SSS) using the design methods with application of current design norms and relying on the theory of metals' resistance, which does not take into account the structure inhomogeneity. If in these cases of occurred failures of structures (and best of all – not waiting for failure to occur) there was a possibility of their inspection using the MMM method and the appropriate scanning devices, then it would be possible to assess the actual SSS of any structural element by the diagram of the self-magnetic field distribution. SSS assessment using the MMM method has an integral nature, taking into account all the factors: design peculiarities, structural inhomogeneity of each element, factory, installation and operational factors. Now the designer has the opportunity to see the work of his "brainchild".

Due to the use of the metal magnetic memory effect during the diagnostics of metal components and structures it became possible to fulfill many problem tasks. First of all, this is prediction of metal components' reliability and lifetime. Based on the 100% inspection of structures, the MMM method and the appropriate instruments allow detecting all potentially dangerous areas (SCZs) and revealing the reasons for their occurrence. Using the program software, these zones are classified by the degree of their danger. It allows timely conducting the repairs or replacement of individual elements and granted prolongation of the IO's lifetime, at least till the next overhaul and/or inspection.

Welding exists in the world for more than 100 years, and the most important factor determining reliability of a welded joint - distribution of residual welding stresses - is so far not controlled due to the lack of NDT methods suitable for wide practical application. The use of the metal magnetic memory effect allows solving this problem. Reading out of the residual magnetization, formed naturally during welding with subsequent metal cooling, provides a unique possibility to integrally assess the actual weld state: to detect welding defects simultaneously with the distribution residual welding stresses.

Formation of the magnetic (domain) texture in welded joints occurs simultaneously with crystallization during metal cooling in the weak magnetic field of the earth (or of the workshop) and its passing through the well-known Curie point (760-770°C for carbon steel grades). In conditions, when the energy of thermal strains and stresses is by order higher than that of the weak magnetic field, the residual magnetization distribution in the weld metal is conditioned by the appropriate distribution of residual stresses (RS).

An amazing fact! The physical Curie point (P_c) and the effects of magnetization disappearance, when the metal is heated above the P_c and, on the contrary, of high magnetization appearance when the metal is cooled below the P_c have been known to experts as far back as since 1895, when the French scientist Pierre Curie first discovered this physical effect. However till date this effect has not been used in the everyday practice, for example, for quality assessment of products at engineering plants.

In the course of industrial investigations we established that the magnetic memory of metal on ferromagnetic products (and in some cases on the products made of a paramagnetic material) reflects their structure and process history. During fabrication of any products (melting, forging, punching, heat treatment, welding) when they are cooled below the P_c in a weak magnetic field of the earth (or of the workshop) the magnetic texture is formed naturally. Upon studying the distribution of the natural magnetization on a large number of new products after various technological processes at manufacturing plants, a number of practical techniques for inspection of the products' quality was developed. And the unique possibilities of the metal magnetic memory application for testing of the effectiveness of products manufacturing technologies (quality inspection of casting, heat treatments, etc.) were revealed.

It should be noted that nowadays there is no 100% quality inspection of products for structural inhomogeneity at engineering plants both in Russia and abroad. According to the statistics, it is known that approximately up to 20% of the new products (pipes, rails, shafts, etc.) are put in operation with unacceptable metal defects. Application of the metal magnetic memory effect during the quality inspection of products at the manufacturing plants will allow carrying out rapid sorting of products and not to let the products with metal defects and process manufacturing defects be put in operation. Equipment and instrument-computer complexes using the metal magnetic memory effect during the inspection are considerably simpler and cheaper as compared to the available ultrasound-based equipment or equipment using artificial magnetization.

At present the magnetic NDT methods applied at manufacturing plants use artificial magnetization of products. At that the natural magnetization (the magnetic memory of metal – the most valuable information!) is removed by means of preliminary demagnetization.

What keeps from wider implementation in practice of the new direction in the engineering diagnostics based on the use of the metal magnetic memory effect today? Here it is appropriate to quote the words of the German poet and thinker Johann Goethe (28.08.1749 – 22.03.1832): "**If somebody points out something new … people reject it as hard as they can; they behave as if they do not hear or cannot understand, speaking about the new opinion with contempt, as if it was not worth the effort spent on investigation or attention at all, and, thus, the new truth has to wait for a long time until it manages to pave its way**".

Appearance of the first publications about the magnetic memory method was at first met in the scientific circles with indulgent indifference: "mister is a little bit lost". However further results of original experimental investigations and practical diagnostics using the MMM method, the quantity and quality of which grew rapidly, also rapidly gave rise to transition from indulgent bewilderment to aggressive indignation in the circles of scientists and experts both in the field of magnetism and diagnostics. And it is no wonder: many results, obtained using the magnetic memory method, contradicted the established during many decades' ideas about magnetism and, first of all, the concepts like magnetoelasticity and magnetization. Moreover, the necessity to explain the multiple results of practical diagnostics using the metal magnetic memory effect revealed the "white spots" existing till date in the theory of magnetism. As it turned out, the basic provisions of the theory of magnetic phenomena in ferromagnetic materials were developed in the 30-s - 40-s of the last century without application of modern conclusions and achievements of quantum physics and theories of dislocations in the metal.

Consideration of magnetism development in the historical aspect made it possible to understand that some results could not be used yet and some were already "rejected" by the theory of magnetism formed.

For these reasons the following questions remained unanswered:

- what the starting point is and how the process of self-magnetization develops in the volume of a ferromagnetic;
- what restricts the domain growth and what its sizes are in absence of external exposures;
- what the three-dimensional shape of the domain is, whether its dimensions are interrelated and if yes, then how;
- how in conditions of spontaneous self-magnetization the domains form and group in the volume of a ferromagnetic; whether "closing" domains really exist as some auxiliary formations;
-

what actually the boundaries between the domains are, since the quantum physics proved the impossibility of arbitrary spatial position of the atom's magnetic moment vector within the lattice. Consequently, the hypothesis about the gradual smooth turning of the magnetic moment vector in the transition layer - the interdomain boundary - is wrong;

- why there is no symmetry in the processes of self-magnetization during tension and compression of polycrystalline ferromagnetic specimens;
- why even an ideal monocrystal of a ferromagnetic still initially shows the magnetic anisotropy;
- what physically determines the amount of the residual magnetization;
- what the criterion of magnetic fields division into weak and strong is;
- whether the magnetic field of the earth influences the process of self-magnetization;
- what the influence of weak magnetic fields on the process of magnetization variation at cyclic loads is;
- why during the specimens loading their magnetization increases abruptly at transition to the plastic strain region;
- how magnetization and the domain structure, determining it, are related to dislocations and their clusters;
- why in a loaded ferromagnetic there occur local magnetic fields, the orientation of which is not related to external magnetic fields, and what determines their spatial direction;
- whether the boundary between weak and strong magnetic fields depends on the state of the environment (of the magnetized material).

Thus, one has to state that, despite the large number of the obtained by the present time in theoretical and experimental investigations results and conclusions, developing and supplementing the basic provisions of the domain structure formation, the theory of the domain structure cannot be considered completed.

With the purpose of searching for the answers to the formulated question and explaining the phenomenon of the magnetic memory of metal some theoretical and experimental investigations were performed. The results of these are reflected in the book by V.T. Vlasov and A.A. Dubov "Physical bases of the metal magnetic memory method" (Moscow: ZAO "TISSO", 2004, 424p.).

The carried out investigations resulted in obtaining of the answers to many above-mentioned questions. It was demonstrated that several physical effects underlie the phenomenon of the magnetic memory of metal. Besides the known till date magnetoelastic effect, a new, not studied before effect of magnetoplasticity - the process of a ferromagnetic object's self-magnetic field formation in conditions of plastic strain - was revealed. The direct experimental proof, confirming the considerable increase of the dislocations density in stress concentration zones, was obtained during the specimens tensile testing using the specialized magnetometers and investigation of the dislocation structure using the electronic microscope. The rules of the magnetomechanical effect, showing itself at the macro level in the product's volume, were investigated.

Based on the analysis of experimental investigations of various industrial objects using the MMM method and the analysis of the reasons of low effectiveness of the existing stress control methods, the contradictions between the diagnostic results and the formed ideas about the characteristics of internal stresses were revealed.

The bases of the physical theory of the "strain - failure" process were developed. This theory will ensure objective effectiveness evaluation of various stress-strained state inspection methods, strength calculations and equipment life prediction. It will allow providing scientific grounding of defects admissibility norms and the degree of their hazard in non-destructive testing, as well as more effective solution of other problems of fracture mechanics.

And, of course, in conclusion it is necessary to quote a well-known phrase: "Practice is a criterion of truth".

The new direction in engineering diagnostics based on the use of the metal magnetic memory phenomenon, which was born in Russia, has been developed practically and theoretically for more than 25 years. The method and the appropriate inspection instruments are used at more than 1000 enterprises of Russia. Besides Russia, the method became widespread in 31 countries of the world.

The inspection technology based on the MMM method was brought to the level of National and International Standards. In November 2007 International Standards were published:

- ISO 24497-1:2007(E). Non-destructive testing. Metal magnetic memory. Vocabulary.
- ISO 24497-2:2007(E). Non-destructive testing. Metal magnetic memory. General requirements.
- ISO 24497-3:2007(E). Non-destructive testing. Metal magnetic memory. Inspection of welded joints.

GOST R ISO 24497-1-2009, GOST R ISO 24497-2-2009 and GOST R ISO 24497-3-2009 were put in effect in 2009 under the Federal Agency for Technical Regulation and Metrology Decrees No.499-st, 586-st and 587-st, respectively.

Since 1996 a Certification Center "Energodiagnostika", being an independent body for personnel certification and conducting training of experts under the licence of the Russian Technical Supervision Body (Rostechnadzor), has been operating in Moscow. By the present time more than 1700 Russian and about 600 foreign experts were trained.

About the new classification NDT methods based on positions of risks and eguipment life assessment

Professor A.A. Dubov, Dr. V.T. Vlasov

The most important stages of risk and inspection object's (IO) residual life assessment process should comprise not only defects detection and determination of their parameters (flaw detection measurements) but, which is more essential:

- detection of local zones of developing damages – stress concentration zones (SCZs);
- detection of the most dangerous SCZs, which are the most probable sites of an object's failure;
- determination of stress-strained (energy) state parameters in the most dangerous SCZs;
- determination of actual structural-mechanical characteristics of the material in SCZs;
- evaluation of damage development rate and direction based on the revealed mechanism of damaging development.

It follows that the main function of non-destructive testing methods is obtaining of information in the volume required and sufficient for carrying out life calculations and risks assessment. This implies that a 100% object inspection is required for guaranteed detection of the most dangerous zones – SCZs and of developing damages. At present the TC-371 Technical Committee of the Russian Technical Regulation Body (Rostechregulation) reviews GOST 18353 "Non-destructive testing. Classification of types and methods". Current standard classification of NDT methods, which was introduced for the field of flaw detection, has a formal character and distinguishes the entire variety of NDT methods and means rather by the way of identification of the applied effect than by the type of physical fields.

Upon classifying of the known NDT and diagnostic methods by the type of physical fields we obtain the following types:

- electric;
- magnetic;
- electromagnetic;
- thermal;

- mechanical.

At the same time such well-known and widely used methods as optic, radiowave, X-ray, acoustic, holographic, capillary, methods of electrical resistance, strain gage methods as well as moire, net, photoelasticity and other methods did not disappear. They occupied their places within these five types.

It is principally important to classify in the new GOST the NDT methods by: **active** - with creation in the inspected object's material of a "forced" physical field with specified orientation, and **passive** using proper physical fields reflecting the internal energy of the inspection object's material.

The following NDT methods may be referred to passive ones:

- autoemission method;
- acoustic emission method;
- metal magnetic memory method (contact and non-invasive);
- thermal method (contact and non-invasive).

Active NDT methods include all other methods listed in the draft GOST document.

Classification of NDT methods by active and passive ones creates the background for objective classification of detected defects by dangerous (developing) and not dangerous (not developing) ones. The supposed classification of NDT methods is virtual for the sake of inspection objects industrial safety assurance at equipment life assessment, reliability and risks evaluation at operation of various industrial objects.

"Stress control"must be included in the list of NDT types. Various methods and means of stresses NDT are widely spread in Russia and abroad nowadays. "Stress control" is included in the list of inspection types for personnel training in ISO 9712 (2005). The same NDT type is included in the draft EN-473 (personnel certification).

In 2005 the RSNDTD President V.V. Kluev approved the "System of voluntary personnel certification in the file of non-destructive testing and diagnostics" where "Stress control" is included in the list of NDT methods.

At present the topic of "Stress control" is actual both for machine-building products quality inspection and in operation at equipment life assessment.

Thus, the necessity of "Stress control" inclusion in the list of NDT methods has become imminent. At the same time classification of certain stress control methods by the type of physical fields used will correspond to classification of flaw detection methods.

GOST R 52330-2005 "Non-destructive testing. Stress-strained state tests on industrial objects and transport. General requirements" was put into effect in 2005 in Russia.

It is known that stress concentration zones (SCZs), occurring due to manufacturing process defects, working loads or their combinations, are main sources of equipment damaging.

SCZs may vary from fractions of microns (product's micro volume) to sizes comparable to those of the product itself (macro volume).

A SCZ – stress concentration zone – is a local zone of a product, in which large strain occurred compared to the average strain across the entire product's volume.

For new machine-building products SCZs are determined by structural inhomogeneity and manufacturing technology.

Presence of SCZs both on new and used products sufficiently reduces their life. Therefore inspection of products' stress-strained state and SCZ detection using non-destructive means is an important national economic task.

This Standard specifies general requirements to application of methods and means of industrial objects' and transport's stress-strained state non-destructive testing at machine-building products, equipment and structures life assessment.

The Standard covers products and equipment manufactured of steel and alloys, cast iron and other structural materials without limitations by size and thickness including welded joints.

Energodiagnostika Co. Ltd. specialists first prepared the new National Standard on the above-indicated theme, and it has no analogues in Russia and abroad. This Standard was presented by the Russian delegation as a draft ISO International Standard at the Annual Assembly of the International Institute of Welding in Quebec (Canada).

At present a large arsenal of methods and means for materials' SSS diagnostics has been accumulated in Russia and other countries. However till date there are no standard specimens, programs and centers for specialists straining in non-destructive testing of equipment and structures' SSS for objective comparison of these methods and means application effectiveness. Unfortunately, currently the theoretical basis is insufficiently developed as well for objective comparison of SSS inspection methods effectiveness and determination of boundary conditions and scope of their application.

A uniform theoretical basis developed based on modern scientific achievements in the field of fracture mechanics, material engineering, solid-state physics may become a basis for resolution of contradictions occurring nowadays at practical implementation of various methods and means of materials' SSS inspection.

Based on many years' experimental and theoretical investigations, the authors made an attempt of developing such a uniform theoretical basis for comparison. The Proceedings of the 4th International Scientific-Technical Conference"Equipment and Structures Diagnostics Using the Magnetic Memory of Metal" (February 14-16, 2007, Moscow) contain one fragment of investigations carried out in the form of an article by Vlasov V.T. and Dubov A.A. "Physical criteria of structures materials' and elements' stress-strained state assessment".

A Program for specialists training in "Stress-strained state inspection" was developed in 2006 on the initiative of the Scientific-Training Center "Quality" with involvement of DIGAZ Co. Ltd. and STC DIATECH Co. Ltd. specialists. Energodiagnostika Co. Ltd. experts were actively involved in the discussion and approval of this Program. Table 1 shows the list of topics, which, to our opinion, should be included in the Program of specialists training in "SSS inspection". At present this Program, upon agreement with SIU "RISCOM", was submitted to Rostechnadzor for consideration.

Table 1.

No	Topic name	Hours
1.	Study of the "Provision about the order of technical devices, equipment and constructions safe operation period prolongation at hazardous industrial objects" (GD 03-484-02).	4
2.	Problems of ageing equipment residual life assessment.	2
3.	Analysis of IO state based on technical documentation (operational, repair, design). Analysis of equipment failures by units and reasons. Reliability criteria.	4
4.	Study of the "Methodical guideline for residual life determination of potentially dangerous objects under control of Rostechnadzor" (GD 09-102-95). Study of branch GDs on life assessment.	6
5.	Study of standards on engineering diagnostics GOST 27.004-85 and safety GOST 27.002-89.	4
6.	Basics of fracture mechanics. Energy criteria.	10
7.	GOST R 52330-2005. Non-destructive testing. Stress-strained state tests on industrial objects and transport. General requirements.	4
8.	Methods and instruments for stress-strained state (SSS) inspection. Theory and practice.	10
9.	The procedure of SSS and metal's mechanical properties inspection methods and flaw detection methods application at life assessment.	8
10.	Drawing up of expert conclusions at equipment life assessment.	4
11.	Laboratory classes. Sitting for a practical examination in methods of SSS inspection, mechanical properties investigation and flaw detection methods.	16
12.	Examinations.	8
	TOTAL	**80**

Physical criteria of materials and structural elements stress-strain state assessment

Dr. V.T. Vlasov, Dr., Professor A.A. Dubov

Many times we paid attention to the paradoxicality of the situation formed in solution of the most crucial problem of assessment of structural materials' stress-strain state and of the residual life of complex technical objects. On the one hand, the modern diagnostics offers "the entire arsenal" of means for measuring of materials' mechanical characteristics, internal stresses and even the residual, applying various non-destructive physical methods, which quite complies with the urgency of the problem. And on the other hand, along with the extremely high demand for the means of assessment of the actually formed state of the material, practically the complete refusal of fracture mechanics experts to use the offered means during the residual life determination is observed. And the motivation of the refusal is quite fair and based on the well-known and little known objective reasons.

The many-years experimental and practical experience, gained in the course of the development and practical application of the magnetic memory method during the diagnostics of various objects, revealed and proved the objectiveness of "discrepancies" between the actual values of physical internal stress parameters and the "usual" limiting values of mechanical characteristics, for example, to the time strength limit.

The results of theoretical investigations of the rules of physical strains distribution allowed explaining the observed "discrepancies" and proved the delusiveness of the well-known criterion of the actual material's state assessment in local zones of the developing damaging by the degree of closeness to the reference limiting mechanical characteristics of the material.

In fact, this was known long ago, because by variation of the strained specimen's shape we can easily judge about the non-uniformity of the strains distribution on the specimen (see fig.1). However it did not allow speaking about the quantitative ratios of strains in different areas of the specimen. We managed to solve this problem.

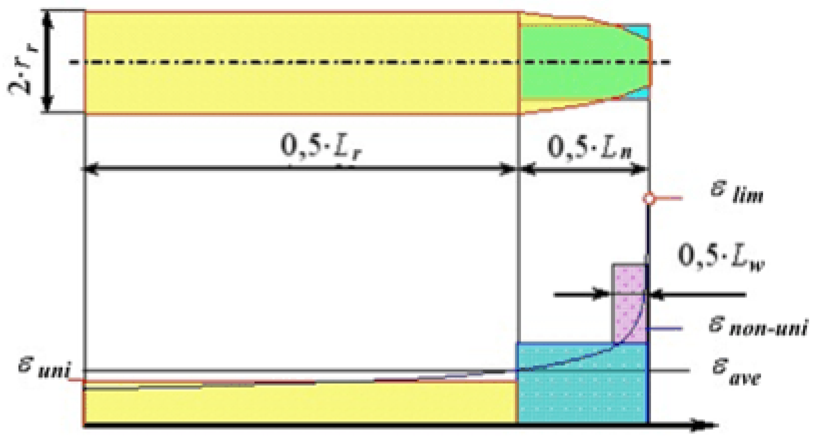


Fig.1. Areas of the uniform and non-uniform straining and the "neck"of the destroyed specimen: ε_{lim} - the limiting strain in the neck area; ε_{ave} - the average strain along the entire specimen length; ε_{uni} - uniform straining along the length L_r; $\varepsilon_{non\text{-}uni}$ – non-uniform straining along the length L_n .

Investigations of the strain-force characteristics of ninety-seven specimens of various steels and alloys (see table 1) showed that the values of the limiting external specific forces, reduced to the non-uniform and uniform strain areas, will notably differ from those for the entire specimen.

Table 1.

No	Specific features of the group	Grades of metals and alloys	Source of parameters	Number of metals and specimens
1.	various steel grades	st.3; st.6; st.8; st.10; st.15; st.20; st.25; st.30; st.35; st.40; st.45; st.60; Fe	reference data	**13**
2.	various alloy grades	Cr13; 20Cr; 38 CrAl; 40Cr; 30CrMo; 34 CrMoAl; 35CrMo; 40CrF; 40CrNi; 1Cr18Ni9Ti; 12Cr1MoF; 15Cr1MoF	reference data	**12**
3.	various alloy grades	1Cr17Ni2; 12CrNi3Al; 30CrNi3Al; 30CrGSAl; 25Cr2GMoTiAl; 34CrNi3MoAl; 40CrNi3MoAl; 18Cr2Ni4MoAl; 38Cr2MoUAl; 50CrFAl; 60S2	reference data	**11**
4.	various specimens of the same grade	Rail steel (for P-50)	experiment	**27**
		Aluminum alloy AlMg6	experiment	**22**
		Titanium alloy VTi8	experiment	**12**
		Total		**97**

Fig.2 and 3 show the values of the ratios of the limiting load in the non-uniform and uniform strain areas to the time strength limit, depending on the average value of the maximum strain in the non-uniform strain area.

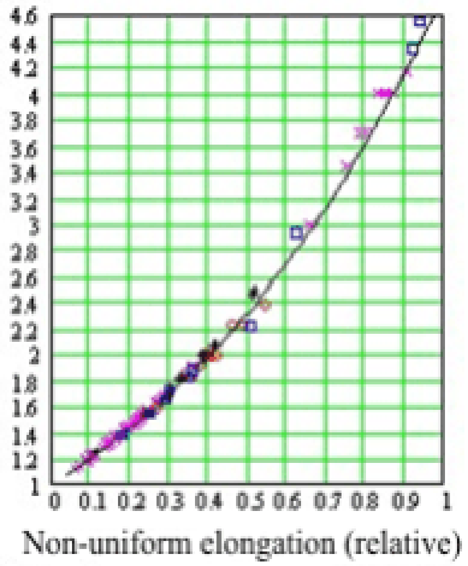


Fig.2. The ratios of the limiting values of the specific load in the non-uniform strain area to the time strength limit for various materials.

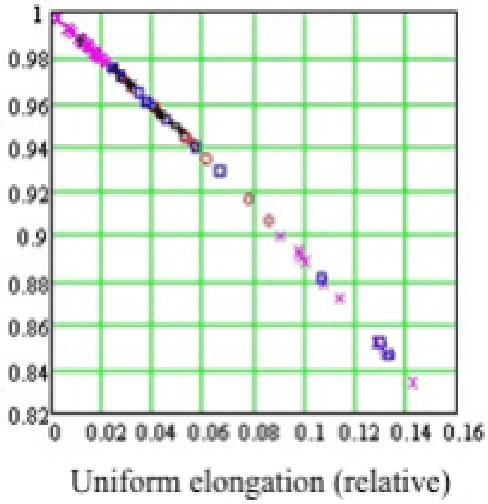


Fig.3. The ratios of the limiting values of the specific load in the uniform strain area to the time strength limit for various materials.

If we speak about strain during the specimens' tension, then at time strength the average strain values in the non-uniform and uniform strain areas differ even more from the reference values of the material's relative strains. Fig.4 shows the values of the ratios of average longitudinal strains in the non-uniform strain area of the specimen to the average values in the uniform strain area when the external load value corresponds to the time strength limit. And fig.5 shows the ratios of transverse strains.

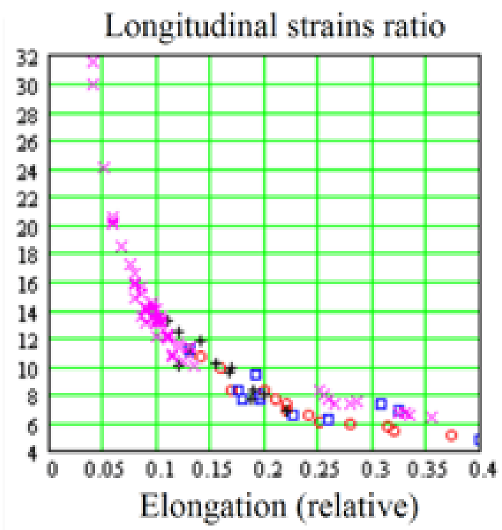


Fig.4. The ratio of average longitudinal strains in the non-uniform strain area to the values in the uniform strain area.

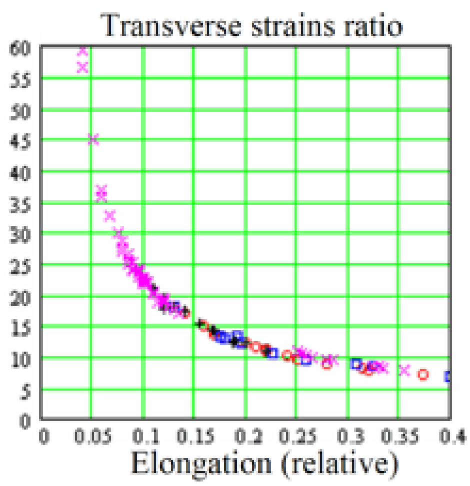


Fig.5. The ratio of average transverse strains in the non-uniform strain area to the values in the uniform strain area.

At the same time in local areas the strain values will already differ by orders! Not only the experimental data but also the obtained by us functions of local strains distribution across the specimen thickness indicate this (see fig.6). And it means that the limiting state criteria, obtained in the course of simple mechanical tests of the specimens, cannot reflect the limiting state of the material and, particularly, the limiting state of the structural element.

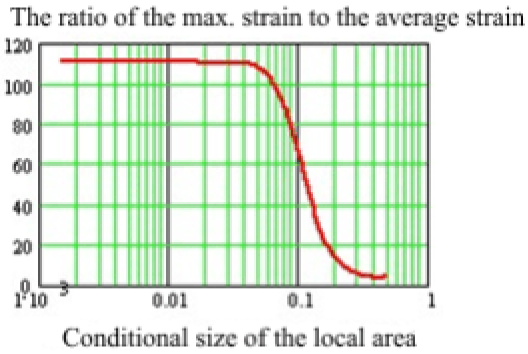


Fig.6. Dependence of the ratio of maximum strain values in the local failure initiation area to the average strain on the size of the local area.

But, in order to realize this, it is necessary to overcome the well-established idea about the internal stresses and to remember that the stresses - "sigmas", which we are all so much used to – are not stresses. This is an external specific force applied to the specifically shaped specimen, which changes the internal stresses. Thus, this is a conditional equivalent of internal stresses!

"Conditional" - because the indispensable conditions are: the specific shape of the specimen and the specific procedure of testing.

Only upon understanding the physics of the process of the material's resistance to straining it is possible to realize what the internal stresses are and how and when they occur. Here the well-known from fracture mechanics concept of a "structural element" - an elementary volume, in which the characteristic changes of the material take place during its straining – is of great help.

Fig.7 shows sequentially, how the external specific force, while "splitting" to components, influences the material, straining it in different directions (glide, normal, width) and rotating it in the space, which causes occurrence of the appropriate internal forces of the material's resistance to straining and which finally determines the input of the material's proper energy for resistance to the external load. It is obvious that the strains, which we can measure (longitudinal and transverse), represent the algebraic sums of projections of the internal physical strain vectors onto the usual for us directions – along and across the applied force axis.

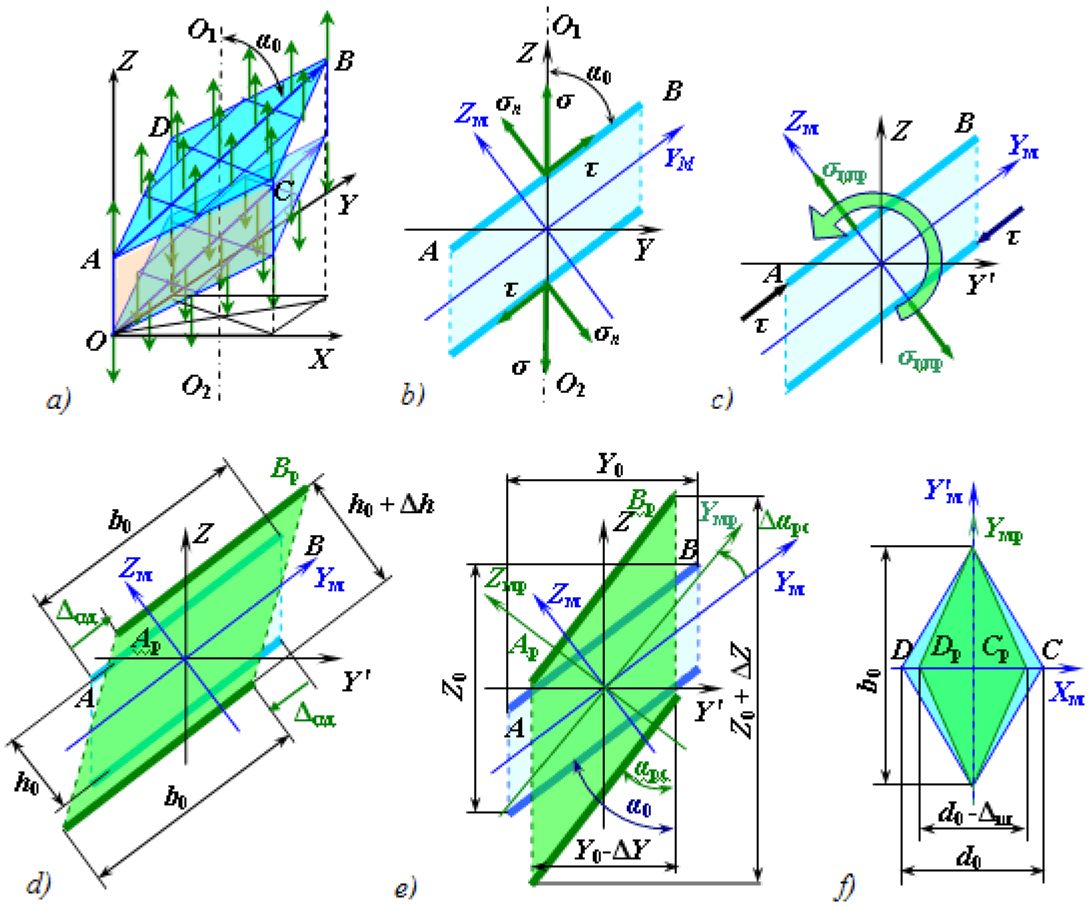


Fig.7. Structural element strain at uniaxial tension.

Schematically the process of the material's resistance to the external load can be represented as follows (see fig.8). Any external exposure (from simple uniaxial to the most complex one) of a specific object made from the investigated material, including the specimen or a complex part, always "splits" in the material to three force and three moment (rotational) components, except for the uniaxial loading of a cylindrical specimen, when it "splits" to two force and one moment component. The presented scheme shows that the internal stresses – the difference of the internal energy density in the local and the adjacent to it areas - represent the difference of potentials.

Moreover, now we can say that **internal stresses - are a special unified energy characteristic of the material's equilibrium state, which is determined (see fig.8) by the set of physical strain-force parameters reflecting various types of the internal energy variation as a result of various types of exposure of the specifically shaped material.**

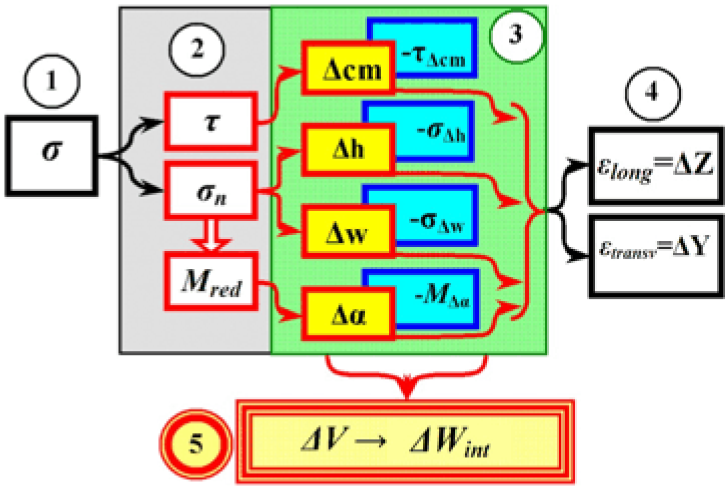


Fig.8. The material's reaction to external force exposure: 1 - external specific force; 2 - force components of external exposure inside the material; 3 - an aggregate of local strains and material's resistance – parameters of internal stresses; 4 - external characteristics of the material's reaction; 5 - internal stresses - variations of internal energy density.

Expressly for "gourmets" the following definitions of the material's state can be offered. Any material possessed a proper internal energy characterized by the average energy density, which could be represented by the two zero-rank tensors - scalar and vector potentials. The energy distribution in the volume of even "isotropic" material is non-uniform. But it is characterized by the strict order along each of the possible, quite definite directions of variation of the initial energy value - by the three linear (ordinary) vectors (the first-rank tensors) and one axial (rotational) vector. All these - are individual qualities or properties of the material, determined by one characteristic - the average energy density, which depends neither on the object's shape nor on the nature of the external exposure. But at the same time the "quite definite" linear directions of variation of the initial energy value - normal, shear and width, determined by the glide plane position in the force or another external field space - already depend on the shape of the object made of the investigated material.

While resisting to the external exposure, the material uses its proper energy. The input of this energy can be evaluated by the work of the external field - the strain-force parameters expressed by two complete second-rank tensors (force and strain), or by two pairs of linear (symmetrical) and rotational (antisymmetric) tensors. It should be noted that the loss of an antisymmetric rotational tensor in the theory of materials' resistance led to the deeply wrong idea about the existence of "principal stresses" and "principal strains". It is impossible either theoretically (in case no mistake is made) or in real conditions to find such a "plane", where there will be no shear forces and angular moments! It is simpler to understand it physically: the material's energy consists of the two, practically equal by quantity components - potential (electrostatic), determining the "repulsion" of atoms, and quantum, determining the "attraction" of atoms. And it follows that during any impact on the material in any of its areas both fields - quantum (attraction) and potential (repulsion) - always "work". So, the pair of antisymmetric tensors, lost by the theory of materials' resistance, exactly describes the input of the quantum component of the material's internal energy for resistance to the external exposure. And, as a matter of fact, what would remain from the material if the forces, attracting atoms to each other, were really cast away?!

The obtained by us investigation results allow "seeing" how the material resists the external exposure.

Variations of the internal forces of the material's resistance in the non-uniform specimen strain area to the external tensile force are shown in fig.9, where for the sake of comparison the graph of the external specific force variation is presented.

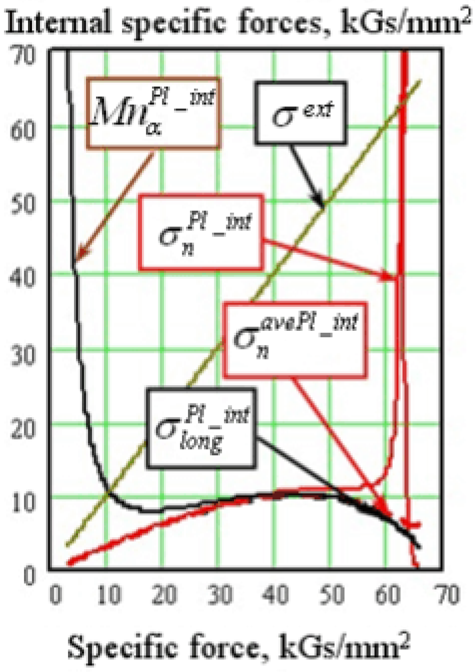


Fig.9. Dependence of internal forces of resistance to elastic and plastic strains St.6 on the specific force in the non-uniform strain area: σ^{ext} - stresses due to the specific force of the external load; $\sigma_{long}^{Pl\_int}$ - the graph of stresses due to the normal longitudinal plastic (mechanical) strain; $\sigma_{n}^{Pl\_int}$ - the graph of stresses due to the normal longitudinal plastic (physical) strain; $\sigma_{n}^{avePl\_int}$ - the graph of variation of the average across the specimen value of the internal force of resistance to the longitudinal strain; $Mn_{\alpha}^{Pl\_int}$ - the moment of resistance to plastic variation of the glide angle.

As it is seen, the force physical characteristics of the material's resistance to straining depend on the external specific force, which is taken for internal stresses. Their appearance is not simple and they are far from being proportional to it! Moreover, the special or critical points, which can be seen on the graphs, can hardly be linked with the yield strength or the time strength limit.

If we return to the latest ideas of the classical fracture mechanics about the process of failure development, formed by the 80-s of the XXth century and based on various experimental and theoretical investigations, it can be seen that, "to put it mildly", they do not rely on the well-known mechanical characteristics of materials either (though in absence of anything else, they are used in calculations).

It should be noted that the most terrible consequence of the established mistake in realizing of the internal stress physics, one might say, the craftiness of the mistake shows itself only now, when the problem of the material's state and efficiency determination - an important component of the problem of complex technical objects' residual life assessment - has become so urgent.

The danger consists in the fact that the mechanical characteristics obtained in the course of the specimens testing – the reference limiting values of the specimens strains and specific forces – the conditional equivalents of internal stresses, are considered to be proper characteristics of the material, determining its resistance to any external loads independently from the shape of the product made of this material. This was the source of the principal mistake being peculiar to all methods of internal stress "measurement" without exception.

Thus, the obtained by us results of experimental and theoretical investigations allows "materializing" the conclusions, which the fracture mechanics approached practically in real earnest long ago, as well as presenting the limiting states and the inseparably linked with them background concepts, as follows:

- the limiting state of the material - is the minimum possible density of the internal energy – a limiting potential determined only by the value of the average density of the internal energy, being an individual quality of the material. It depends neither on the dimensions of the structural element nor on its loading conditions;
- the limiting state of the structural element is determined by the ratio of the dimensions of the local are, in which the material reached the limiting state, as well as by the dimensions of the structural element's area, in which this local area is located;
- the local area dimensions are determined by the material's individual qualities, the structural element's dimensions and its loading conditions and, in turn, they determine the nature of the actual distribution of local strain in the structural element's volume;
- the actual state of the material in the local area - the value of the actual density of the internal energy - is an actual potential determined by the individual qualities of the material, the location site of the investigated area in the structural element's volume and by its loading conditions;
- the internal stresses - the difference of potentials - is the difference of the internal energy density in the local and the adjacent to it areas.

As it can be seen, the commonly known values of the limiting states - yield and time strength, obtained in the course of simple mechanical testing of the specimens, cannot reflect the limiting state of the material and, particularly, the limiting state of a structural element.

Thus, the investigation results analysis brings us to the known from the fracture mechanics conclusion that we should already speak about several different criteria of failure: the limiting value of normal strain at uniaxial tension, the limiting value of strain by width at uniaxial compression and the limiting value of shear strain at torsion or bending, as well as various combinations of the limiting values at complex loading.

All this requires more attentive approach to the diagnostics of the material's stress-strain state and to the procedure of assessment of the degree of the material's actual state closeness in the structural element's local area to the limiting state, both for the material and for the entire structural element, because now it is clear that these are far from being the same!

It is quite obvious that prediction of possible periods of safe operation of real "ageing" structural elements (the main type of damages development) based on the results of the material's SSS diagnostics using calibration dependences, obtained in the course of simple mechanical testing of specimens without evaluation of a fatigue failure development time and rate in a specific object and under specific conditions, is not simply useless but extremely dangerous!

The point is that all the known methods react to elastic strains. And in a real structure elastic strains never exceed the values, which correspond to the yield strength.

Moreover, taking into account the acute (from units to several tens of micrometers) locality of the fatigue damaging development process, the peculiarities of the local physical strains distribution and their ratios with average values of strains, one might state that, using conventional active methods of diagnostics, possessing the large averaging base (10 mm at best), most probably, we shall not simply detect the damaging development area, not to mention the possibility of the developing damaging parameters determination.

The obtained results of investigation of the rules of the physical strains distribution directly indicate the necessity of development of the new normative documentation, which would regulate certification of means for structural materials' stress-strain state diagnostics, as well as the techniques for "adjustment" of means for SSS diagnostics.

We used the term "adjustment" instead of the more usual term "calibration", because we wanted to stress that the obtained by us results of experimental and theoretical investigations make it possible to carry out the diagnostics without the preliminary testing of the specimens, the shape of which is most often selected based on the conditions of convenience of the diagnostic means' sensors installation. And, as a rule, it does not comply with the standard for performing of mechanical tests.

Thus, the new State Standard of the Russian Federation GOST R 52330-2005 "Non-destructive testing. Stress-strain state test on industrial objects and transport. General requirements", which was put in effect in 2005, is the first little but, perhaps, the most difficult and important step on the way of turning of structural materials' SSS diagnostic methods and means from the spectacular but self-sufficient (and therefore useless) field of diagnostics into an effective - really necessary and useful - tool for actual state assessment of structural materials and structures.

The Totals of Application of the Metal Magnetic Memory Method to Industry in Russia and Other Countries

Dr., Professor A. A. Dubov

The metal magnetic memory method (MMM) is the non-destructive testing method based on the analysis of self-magnetic leakage fields (SMLF) distribution on components' surface, and is intended for determination of stress concentration zones, imperfections, heterogeneity of metal structure and welded joints.

Based on the established correlation of dislocation processes with the magnetic phenomena physics in products' metals the concept "metal magnetic memory" was introduced and a new diagnostic method was developed. The uniqueness of the metal magnetic memory is that it is based using of the self-leakage magnetic field (SLMF). Occurrence of SLMF is caused by formation of domain boundaries at accumulation of high-density dislocations (dislocation walls). Obtaining of such an information source like self-leakage magnetic field is not possible in any conditions with artificial magnetization. Such information is formed and can be obtained only in a weak external field like the Earth's magnetic field in loaded structures, when the strain energy exceeds the external magnetic field energy by order. It was demonstrated in practical works that MMM can be applied both at equipment operation and after working unloading, during the repairs. Magnetic texture, formed under the action of working loads, becomes, so to say, "frozen" after unloading by virtue of the "magnetic dislocation hysteresis". Thus, there is a unique opportunity to perform assessment of equipment's stress-strained state and detect zones of metal maximum damaging by reading this information using specialized instruments.

Interest of experts of Russia and other countries from various industries to essentially new magnetic method of non-destructive testing (NDT) grows steadily. Application of the MMM method and corresponding inspection devices to industry, as a rule, is carried out on a voluntary basis that is vivid confirmation of the method efficiency.

Interest to the method is caused by unsolved problems, which arise in practice at quality control of engineering products, at reliability control and at equipment life estimation.

Let's denote the basic from them.

- Till now on the majority of manufacturing plants in Russia and other countries there are no 100%

quality control of production on heterogeneity of metal structure. Due to this reason the spread of mechanical properties on new products reaches 20% and more, that considerably reduces their lifetime.

- Welding exists more than 100 years, and NDT methods, which allow in practice to carry out express quality control of welded joints in the united complex system of the factors "structural-mechanical inhomogeneity – defects of a weld – structural and technological stress concentrator", till now are not present. Now non-destructive test is commonly applied with detection of inadmissible defects (at that, the scientifically-grounded norms for the sizes of permissible defects in welded joints from the point of view of fracture mechanics, as a rule, are not present). The most important – distribution of the residual welding stresses determining welded joint reliability till now is not examined.
- Existing problems of a lifetime estimation of the aging equipment with usage of conventional methods and control devices are not solved because of their unfitness for early diagnostics of fatigue damages.

It is possible to speak confidently, that if we have the old equipment, which we cannot 100% inspect on metal structural damaging and detect imminent damages; in this case we work on sudden failure.

Thus, in spite of the fact that non-destructive testing exists in Russia and other countries already more than 100 years, many problems of products quality control and diagnostics are still unsolved. Therefore demand of the MMM method directed on the solution of specified NDT problems, is caused by daily practice and a life of the enterprises.

The method of metal magnetic memory under the physical substance represents not only essentially new NDT magnetic method, the method is a new trend in engineering diagnostics as it unites potentials of non-destructive testing, fracture mechanics and materials science.

The following guidance documents based on the method of metal magnetic memory are developed and applied nowadays in power engineering, petrochemical, gas production and other industries in Russia:

- GD 10-577-03. Standard instruction for metal control and lifetime prolongation of boilers, turbines and pipelines main units at thermal power stations.
- GD 34.17.446-97. Technical guideline for engineering diagnostics of heating surface pipes of steam and hot-water boilers.
- GD 34.17.437-95. Technical guideline for engineering diagnostics of welded joints on pipelines and vessels (temporary document).
- GD 51-1-98. The technique for on-line computer diagnostics of local gas pipeline segments using the metal magnetic memory.
- GD 03-380-00. The instruction for inspection of ball vessels and gasholders for pressurized liquefied gases storage.
- GD 03-410-01. The instruction for complex engineering examination of isothermal vessels for liquefied gases.
- GD 12-411-01. The instruction for diagnostics of gas pipelines underground networks.

- GD 102-008-2002. The instruction for diagnostics of pipelines technical condition by non-contact method.
- GD 08.00-29.13.00-KTN-012-1-05. The regulations for procedure of engineering examination and lifetime prolongation of oil pipelines fitting.
- GD 23.040.00-KTN-387-07. The technique for diagnostics of the technological and auxiliary oil pipelines.
- MR-10-72-04. Methodical recommendations for technical condition assessment and residual life estimation in order to determine the possibility to prolong elevators safe operation life.
- GD 05-112-2005. Hoisting cranes. Non-destructive testing. Technical guideline for magnetic inspection (metal magnetic memory method) of metallic structures of lifting machines.

The techniques and methodical guidelines developed by Energodiagnostika Co. Ltd and agreed with State Engineering Supervision of Russia (Rostechnadzor):

- Technical guideline for engineering diagnostics of pipelines.
- Technical guideline for engineering diagnostics of vessels and apparatuses.
- The technique for assessment of steam boiler drums condition.
- The technique for assessment of boiler and steampipe bends condition.
- Technical guideline for magnetic inspection of elevators metallic structures.
- Technical guideline for engineering diagnostics of electrical rotary pump systems (ERPS) end parts.

The techniques and methodical guidelines developed by Energodiagnostika Co. Ltd:

- The technique for assessment of steam turbine rotors condition.
- The technique for assessment of steam turbine blades condition.
- The technique for control of turbine rotors flushing holes.
- The technique for assessment of individual parts condition in turbine equipment (studs, bearing inserts, etc.).
- The technique for assessment of turbine bodies, cylinders, lock and control valves condition.
- The technique for assessment of generator sleeve tubes condition.
- The technique for assessment of compressor system blades and rotors condition.
- The technique for control of babbit abutment density on sliding bearing inserts.
- The technique for detecting mechanical stress concentration zones in gear wheels.
- The technique for control of crane pivots, buckets, hooks and hook hangers.
- Technical guideline for engineering diagnostics of compressor-boring pipes and couplings.
- Technical guideline for in-pipe diagnostics of heat exchangers.
- The technique for control of production trees at oil and gas fields.
- Technical guideline for non-contact magnetometric inspection of gas and oil pipelines, hot-water

system, conduits using TSC-type devices.

- The technique for assessment of technical state of operating heat pipes using non-contact magnetometric method.
- Instruction for inspection of heat pipes in manifolds without isolation removal.
- The technique for inspection of circular welded joints on gas and oil main pipelines by the MMM.
- Technical guideline for inspection of large-diameter pipelines (530-1420mm) using specialized scanning devices and the MMM method.
- Technical guideline for inspection of rolling-mill working and back-up rolls.
- Technical guideline for 2,0 and 2,6 steel wire inspection.
- Technical guideline for inspection of locomotive power components (frog, shaft, spline joints).
- The technique for control of stress distribution in tightened bolted joints.
- The methodical guidelines for engineering diagnostics of high-voltage line derrick guys fastening units.

Energodiagnostika Co. Ltd has developed and produces on a full-scale basis the following specialized inspection instruments and the appropriate program software:

- Electromagnetic Indicator of Cracks EMIC-1M, EMIC-2M.
- Testers of Stress Concentration TSC-M-2FM, TSC-1M-4, TSC-2M-8, TSC-3M-12, TSC-4M-16, TSC-5M-32, TSC-6M-8.
- The"MMM-System" software for computer processing of MMM-inspection results using Windows’XP/Vista.
- The "MMM-Lifetime" software.

The instruments are certificated in Rosstandard and are included in the State List of Measuring Instruments. Certificates: RU.C.34.003.A No.42683, RU.C.27.002.A No.35003.

Five Russian standards are published:

- GOST R ISO 24497-1-2009. Non-destructive testing. Metal magnetic memory method. Part 1. Terms and definitions.
- GOST R ISO 24497-2-2009. Non-destructive testing. Metal magnetic memory method. Part 2. General requirements.
- GOST R ISO 24497-3-2009. Non-destructive testing. Metal magnetic memory method. Part 3. Inspection of welded joints.
- GOST R 52330-2005. Non-destructive testing. Evaluation of deformations in industrial and vehicle structures. General requirements.
- GOST R 53006-2008. Estimation of potential dangerous objects lifetime on the basis of express methods. General requirements.

Since 1996 the Russian and International Center for experts training and certification by the method of metal magnetic memory with issuing of Level I, II and III Certificates operates in Moscow. The branches of the center operate in Warsaw and Beijing. As of 2011, more than 1700 experts in Russia, more than 450 experts in China, 70 experts in Poland and more than 60 experts in other countries passed training.

The International Conferences "Equipment and structures diagnostics using the method of metal magnetic memory" were held in Moscow in 1999, 2001, 2003, 2007, 2009 and 2011. The conference proceedings were considered at meetings of the International Institute of Welding (Lisbon, July 22, 1999, Ljubljana, July 11, 2001, Osaka, July 11, 2004). The totals of the conference are reflected in the IIW documents No.XI-714/99, No.V-1196-01 and No.V-1252-03.

During the period from 1994 till 2010 45 IIW documents with positive resolutions on the metal magnetic memory method were issued.

The International Standard ISO 24497-1:2007(E), 24497-2:2007(E), 24497-3:2007(E) on the metal magnetic memory method is approved in 2007 as a result of positive voting among 18 IIW member countries and more than 10 ISO Committee countries.

The metal magnetic memory method and appropriate testing instruments are used at more than 1000 Russian enterprises. Besides Russia, the method was implemented at a number of enterprises of 31 countries: Angola, Argentina, Australia, Belarus, Bulgaria, Canada, China, Colombia, Czech Republic, Finland, Germany, Hungary, India, Iran, Iraq, Israel, Japan, Kazakhstan, Latvia, Lithuania, Macedonia, Malaysia, Moldova, Mongolia, Montenegro, Poland, Serbia, South Africa, South Korea, Ukraine, USA.

On the Problem of Stress-Strained State Characteristics Measurement of Structural Materials on Complex Engineering Objects. Energy Concept of Materials Stress-Strained State (SSS) Diagnostics

Dr. V.T. Vlasov, Dr., Professor A.A. Dubov

Foreword

The ideological basis of the energy concept of SSS diagnostics was determined by investigation results of objective processes of the material's proper energy re-distribution and establishment of regularities describing the objectively existing relations of the material's macro characteristics with external impact parameters and impact response.

In the course of this concept development first the necessity and then the opportunity occurred for creation of a tool for carrying out further investigations and theory development – a new seven-dimensional dynamic self-regulating material model considering interaction of normal and shear stresses and strains, the model that varies its parameters depending on amplitude (up to breaking) and frequency (from statics and infrasonic to ultrasonic) characteristics of external impact.

V.T. Vlasov presented the energy concept of materials' SSS diagnostics and its most important consequences at Scientific-Technical Councils of the State Institute of Physical-Technical Problems (The STC Chairman is Academician L.N. Lupichev) and of the International Institute of Complex Engineering Systems Safety at the Russian Academy of Sciences (RAS) Institute of Engineering Science (The STC Chairman is a RAS Corresponding Member N.A. Makhutov) and they were highly appreciated.

1. Internal stresses, classification and effect on materials' strength

Internal residual mechanical stresses, occurring in a part, welded joint or structure in general, are the subtlest reason of unexpected failures of objects. These stresses in steels may approach the yield strength, and in aluminum and titanium alloys - 70-80% of the yield strength and they often turn out to be more dangerous in terms of strength reduction than some types of defects.

Stresses existing and getting balanced inside a solid, a rigid aggregate of materials, a fabricated or welded structure after removing the reasons causing their occurrence are accepted to be called residual stresses. These stresses are always internal and their occurrence is always associated with inhomogeneous linear or volume strains in the adjacent volumes of a material, an aggregate or a structure.

Residual stresses are divided in three types classified by the length of the force field created by them:

- **the first type** - balancing [1)] in macroscopic volumes (в пределах детали или конструкции);
- **the second type** - balancing in microvolumes (within the metal structure crystallites);
- **the third type** - balancing in ultra microscopic volumes (within the lattice). Such definitions of residual stresses were first given by N.N. Davidenkov in 1935.

1) The term "balancing" is not quite correct, and it is better to use another term, for example, "developing" or "occurring". The point is that stresses of all the three types are interrelated with each other and each of the stresses is the reason or a consequence of "adjacent"-type stresses, and in the case of "balancing" within the limits of their volumes we would have all-sufficient stresses not related to each other.

In general the study of residual stresses started very long ago. V.I. Rodman in 1857 and then I.A. Umov in 1871 conducted the first serious investigations. N.V. Kalakutsky, who first developed the method of residual stresses calculation and first suggested experimental methods of their measurement, started systematic investigations in 1887. During the following years the methods of residual stresses investigation were reduced mainly to development of their measurement methods – an important practical task within the problem of structures reliability assessment.

According to the above-said, residual stresses belong to internal stresses of the material. Internal stresses represent the demonstration of the material's proper internal energy interaction with the energy of the external field (force, thermal, etc.) influencing the material fabricated as a specific part or structure. Therefore stresses occurring in the operated part or structure material under the influence of external fields and determining the material's resistance to external effects - its strength - also belong to internal stresses. And variation and re-distribution of the material's internal energy among its components under the influence of operating load causes occurrence of "new" residual stresses. To avoid confusion **it is appropriate to introduce the following classification of internal stresses:**

- **process residual stresses** - are stresses being the consequence of physical and physical-chemical processes starting in the material at a part or a structure[2)] fabrication and continuing after fabrication;
- **load stresses** - are stresses occurring in the operated part or structure material as an elastic reaction of the material to external load, load stresses disappear at removing the external effect;
- **operating residual stresses** - are stresses being the consequence of processes of proper internal energy interaction of a part or a structure with external field energy, occurring and accumulating in the material during the entire period of a part of a structure operation;
- **working stresses** - are a vector sum of process, load and operating stresses;
- **actual stresses** - are a vector sum of process and operating stresses formed by the moment of measurements.

2) Every process operation of the entire cycle of a part or a structure fabrication introduces sequentially its residual stresses with their characteristic features. Residual process stress will present the result of their dynamic vector interaction.

Thus, **strength, reliability and suitability degree** of welded structures for application according to their operational designation are in many respects **determined by presence, nature and amount of working and actual internal stresses.** Material degradation during the process of the long-term operation in many respects, but not in all of them, contributes to this.

2. Material degradation and its role in the material's strength

Indeed, at the stage of objects design and construction the mechanical properties of structural materials used are known with the required accuracy, and at the possibility of experimental determining of residual stresses the initial life of an object's strength can be estimated as well. And the accuracy and authenticity of an object's life assessment at the stage of its erection does not seem to be a serious characteristic since there are pre-operational tests, and 15 or 20 years of life are not so important - it is still so far away!

But when the time of the assumed physical wear of equipment and structures is approaching, and in some cases it has already expired, the accuracy and authenticity of residual life assessment become vitally critical in the direct sense. And here methods of residual life estimation of critical objects and methods of their safe operation periods prolongation taking into account real conditions, which often lead to unpredictable variations of material's properties and its degradation, gain acute actuality. And the final stage of the material degradation is the newly appeared defects, the "growth" process of which in conditions of operation of a structure made of degrading material is poorly investigated and often develops avalanche-like, so the time left till the structure failure is unknown and often too little to prevent the disaster.

Therefore to obtain authentic results of strength residual life calculation of objects operated for a long time **it is necessary to know first of all the actual mechanical characteristics of the material[3)] and characteristics of its stress-strained state** formed by the present time as a result of an object operation.

[3)] It should be noted that senseless to require obtaining absolute values of internal stresses without the knowledge of actual mechanical characteristics of the material formed during the process of an object's long-term operation, - there is nothing to compare them with! In these cases qualitative variations of the stress field are more useful.

This task has become the major not only in investigation and assessment of objects' static strength, it becomes decisive in investigation and assessment of fatigue strength due to the local nature of fatigue failure and its strong dependence on the actual material's stress-strained state.

So, the following tasks sequentially occurred at solution of the problem of critical objects reliability:

- **determination of residual stresses;**
- **determining the nature of internal stresses and components values;**
- **determining the actual mechanical characteristics of the material and its stress-strained state characteristics.**

It is quite obvious that non-destructive methods of structural materials' state diagnostics should provide such a possibility. But are they ready to solve such tasks?

According to the authors' opinion, at present the metal magnetic memory (MMM) method meets to a greater extent the ideology of the energy concept of SSS diagnostics.

The principal novelty of the MMM method consists in the use of the objectively existing but not studied before phenomenon of "magnetoplastics". Investigation of complex processes of the material's proper energy re-distribution under the influence of external force and/or magnetic fields required the knowledge not only from the filed of metal physics, elasticity, plasticity and strength theories, fracture mechanics, basics of radio engineering and even thermodynamics, but it also required addressing such fields of science as quantum physics, solid-state physics, theory of dislocations, electromagnetic field theory, which seem to be quite remote from the practical problems solved. But the obtained results surpassed all expectations: not only the functional correlation of various internal energy fields with each other and with external fields was established, which ensures development of well-known active diagnostic methods like the coercive force method, the residual magnetization method, the Barkhausen noise method and others, but also to reveal quantitative criteria for determination of strong and weak magnetic fields, energy ratios of force and magnetic fields determining the magnetoelasticity boundaries and of the newly introduced in practical application phenomenon of magnetoplastics.

Indeed, some results of joint work in the field of experimental and theoretical investigations of magnetic phenomena physics are beyond the classical idea of magnetism and domain structure. However, at the same time there is not only absence of conflict between them, but they also erase "white" spots in the theory of magnetism, of which specialists working in this field have been aware for a long time.

It should be noted that **we obtained not a system of separately established facts**, confirmed by results of experimental investigations carried out by A.A. Dubov and by experiments obtained before, of course, independently from him by the well-known national and foreign researchers of magnetic phenomena, **but a domain structure theory logically built on the example of iron was developed**.

Theses of the obtained results were presented in 2002 in St.-Petersburg at the XVI-th All-Russian Diagnostics Conference and the more detailed presentation was made in 2003 at the III-d International Conference "Equipment and structures diagnostics using the MMM method". Specialists working actively in the field of materials' SSS diagnostics by magnetic methods demonstrated their interest to this work. However, unfortunately, we did not see any well-known national magnetic scientists at any of these our presentations.

A book presenting the detailed contents of the work performed is being prepared for publication at present.

3. Classification and analysis of physical methods of structural materials diagnostics

Analysis of the trends of current non-destructive inspection methods and means[4)] development allowed approaching the answer on this question. Let us consider the dynamics of scientists' efforts distribution in the field of diagnostics methods and means development by uniting the topics of allied investigations in directions.

4) The analysis was carried out by the materials of international conferences, symposiums and by special periodic literature for the periods from 1966 till 1974 (125 publications were selected) and from 1987 till 1994 (over 1000 reports and articles were analyzed here).

Table 1. Dynamics of scientific efforts distribution by directions

Direction index	Characteristic of direction	1966-1974	1987-1994
I	Development of new means realizing the traditional approach to diagnostics	**70%**	**26%**
II	Improvement of sorting norms based on statistic investigations	**15%**	**28%**
III	Search for new approaches to materials and structures diagnostics (stress measurement and the acoustic emission (AE) method)	**10%**	**36%**

It should be noted that since the beginning of the c 90-s the search for new approaches to materials diagnostics has become the major trend of diagnostic means development. And it is worth saying that the observed nowadays increased intensity of works on searching of new approaches to diagnostics is the third, stronger raise of interest towards this direction, which appeared in the late 50-s and had its first peak in the mid 80-s and the second - in early 90-s. The conclusion drawn is confirmed by the more and more noticeable re-orientation of the thematic orientation of presentations and exposition of not only Russian but also International scientific-technical conferences "Non-destructive testing and diagnostics" starting from 1997.

Growth of scientific interest towards new approaches to diagnostics is obvious. But one can not help drawing attention to the fact that the scope of works by the II-nd direction - **improvement of sorting norms based on statistic investigations** - has grown sufficiently as well. And this, to the authors' opinion, indicates not only the will to improve the authenticity of flaw detection results but also the more and more noticeable insufficiency of information obtained at objects diagnostics for assessment of their state.

The analysis of works presenting scientific directions demonstrates that, in fact, the final goals of some works belonging to different directions are the same. Indeed, the actual goal of works dedicated to improvement of sorting norms and investigation of defects influence on structures strength is the search for new informative characteristics of defects determining the degree of their danger at a structure operation. And topics associated with stress waves emission investigation and development of materials' stressed state detection methods and means are an attempt to solve the problem of structures reliability assessment by new ways.

The correctness of determination of diagnostic means development trends revealed in early 90-s, when the world applied science has accumulated large experience in the field of diagnostic methods and means development, is of no doubt because, in fact, it is nothing but statistics. However, the perspectiveness of directions in the aspect of usefulness of their results in solution of the task of complex engineering objects residual life assessment is not doubtless.

The deeper analysis of works by national and foreign researchers has drawn the author to the following two preliminary conclusions:

Firstly, in no way trying to humiliate the importance of the I-st and the II-nd directions and the significance of success achieved there, the author considers that from the viewpoint of the **possibility to enter the qualitatively new**, in the principal aspect, **level** of object reliability determination these two directions **have no future** since they are restricted to each other: new instruments allow improving inspection norms and new norms stimulate instruments improvement.

Secondly, as the analysis of works by the III-d direction demonstrated, despite the inflow of new intellectual forces and modern computer means a **"breakthrough" to the qualitatively new level is not so far foreseen**.

The point is that the III-d direction develops two different non-intersecting concepts, which have not suffered any variations since late 50-s (from the moment of the AE method appearance), though, in fact, both methods of stress state measurement and AE methods have as a test object different phases of the same process - the material reactions to loading and environment factors effect.

Besides, capabilities of modern macroelectronics and computer engineering led many of western specialists away from solution of merely physical tasks, and the searched answer is hidden exactly there, in the physics of processes. Many national specialists, trying to catch up with foreign colleagues in the direction of inspection means improvement, "drove" into the same, but already broken track[5)].

[5)]Lately a number of private national companies has occupied advanced positions in terms of program software development for diagnostics, leaving the well-known foreign companies behind. The most interesting results were obtained at Intellect Co. Ltd. in Nizhny Novgorod (the Head is A.L.Uglov).

So, the analysis results may be formulated as follows:

- **the major direction of materials diagnostics means development is the search for possibilities to determine certain mechanical characteristics of the material**, associated with its stressed state by parameters of physical fields used for diagnostics;
- **perspectiveness of current concepts, forming the basis of important and interesting investigations by the major direction, raises serious doubts**.

Of course, doubts in the perspectiveness of concepts lying in basis of the major direction of the material state diagnostics means development, in the aspect of sufficient improvement of structures reliability assessment authenticity, required serious proof.

Modern diagnostics possesses large arsenal of various methods and means for measurement of mechanical characteristics of materials. Methods and means of residual and elastic internal stresses measurement are presented most widely.

There is a **standard classification** of non-destructive diagnostics methods dividing them by the nature of physical fields interaction and by the ways of obtaining of primary information in nine types: **magnetic**, **electric**, **eddy-current**, **radio-wave**, **thermal**, **optic**, **infra-red**, **acoustic** and **capillary**. Each type, in turn, is divided in various groups.

This classification, introduced for flaw detection methods and means and applied nowadays for classification of materials' stressed state diagnostics methods and means, has a **formal nature**, dividing all the variety of non-destructive diagnostic methods rather **by the way of the used effect selection** than by the type of physical fields.

However, at solving the tasks of the next, higher level of complexity - the tasks of materials' properties determination, and, in particular, of mechanical characteristics - more distinct division of methods exactly **by the type of physical fields** need to be done.

In fact, determination of material's properties is reduced to measuring of variations of certain used physical fields parameters. In other words, if a test object with certain known beforehand abilities to resist external effects is influenced by a physical field with known or specified parameters[6)], the used field parameters variations caused by the object's reaction will represent an "imprint" of its properties in the area specified by the type of the physical field. And the reactions "echoes" will be seen also in spaces of other fields but as indirect "imprints" or a secondary reaction. Thus, for example, in case of a thermal field influence, the direct characteristics will be thermal ones and indirect characteristics – mechanical, electromagnetic and others. If an object is influenced by a mechanical force field the direct reaction characteristics will belong to mechanical characteristics, and indirect demonstrations can be observes in thermal, electromagnetic and other fields.

6) "Known" and "specified" do not always mean the same. Generally speaking, "specified" parameters are known but they often belong to external conditions of the field excitation in the investigated material, and the parameters of actually excited field remain partially or completely unknown.

Sorting the known methods of materials' state diagnostics by the type of physical fields, we obtain the following types:

- **electric**;
- **magnetic**;
- **electromagnetic**;
- **thermal**;
- **mechanical**.

And the well-known and widely used methods like optic, radio-wave, X-ray, acoustic, holographic, capillary, electric resistance methods, strain gage as well as moire, grid, photoelasticity and other methods did not disappear but occupied their places within these five types.

Keeping in mind that classification of diagnostic methods is not an end in itself but it is only a means in the search for the reasons of low authenticity of their results, let us consider in more detail just some most characteristic types of diagnostics.

Electromagnetic methods, which are often divided depending on the frequency range in the following groups or subtypes (by the increase of the excited field frequency): **radio-wave, microwave methods, infra-red, optic (the visible range), ultraviolet, X-ray and gamma-methods** are the most widely represented in investigations of materials' properties. All these varieties are in this or that way based on interaction of the exciting electromagnetic fields with proper electromagnetic fields of the investigated material created by its molecules, atoms or their electron shells. And the greatest effect is displayed when frequencies of the exciting and the proper fields are close to each other, which in fact follows from the molecular thermodynamics and confirms its conclusions. And frequencies of proper electromagnetic fields being in sufficiently different ranges, of course, depend on the stressed state of the material. This explains the occurrence of such a variety of subtypes of electromagnetic methods.

The most widely spread in practice X-ray method uses variation of the reflected rays spectrum caused by variation of the lattice units oscillation frequency and by change of the distance between the units and crystallographic planes. **The informative parameters of the X-ray method are: intensity, position and**

width of spectrum diffraction peaks determined by the lattice strain.

Mechanical methods[7)] of material properties diagnostics **include** various **types of static and dynamic** measurement **methods** of hardness and other mechanical material characteristics using the results of **contact interaction of the test object – indenter with the investigated material**[8)]. ЭThis has been known for a long time and is absolutely obvious.

7) The most widespread mechanical method of diagnostics - materials' hardness measurement - is conventionally non-destructive since an object surface quality still changes. Operating requirements to the surface quality restricts application of this method.

8) V.A. Rudnitsky's doctoral thesis gives the analysis of current methods of materials' characteristics determination by contact strain parameters and the vast bibliography.

As for **referring of the acoustic**, including **ultrasound methods to mechanical methods** - it looks, to put it mildly, somewhat unusual. But this is, in fact, fair since the acoustic field is a mechanical stress field created in this or that way in the restricted volume of the investigated material and causing oscillatory or aperiodic displacements of material particles, i.e. local material strains. In fact, this limited strained material volume is an indenter, whose remarkable feature is that it can move inside the investigated material. And the strained area dimensions are determined not by the lattice parameters (in case of metals and other crystalline or polycrystalline materials) and dimensions of molecules (in case of amorphous materials), **but by the length of the excited field inside the material, and they make from fractions to tens of mm**.

Now, comparing the two considered methods, one can understand why the results of internal stresses measurement by the X-ray and acoustic methods simply have to be different since in the first case the determining factor is strain at the microlevel, creating the III-d type stresses, and in the second case - an aggregate of the I-st and the II-nd type stresses. And all these three types of stresses, at all the integrity of correlation between them, have not only sufficiently different values but also the different nature and very often different signs. Moreover, while calibrating the X-ray method reacting to microstrains, determining the III-d type stresses, on specimens by tensile or compression efforts, i.e. actually by the I-st type stresses, a gross principal error is made, which is often not even suspected of.

As we can see, the suggested **classification of physical methods of diagnostics**, while allowing looking at diagnostics methods from another, less usual side, **gives the grounds to think about the mechanism of parameters correlation of physical fields used for diagnostics with the measured material characteristics and the material properties in general**, as well as demonstrates the degree of closeness of the used for diagnostics physical method to the measured characteristics of the investigated material.

In other words, **classification of physical methods gains a principal nature in the aspect of the task of the material's stressed state determination**, specifying the way of establishing the reasons of very low authenticity[9)] of materials' stressed state characteristics measurement results.

9) Here it is appropriate to remind of comparative testing results of various physical methods at residual stresses measurement when the measured values differed not only quantitatively but also by their sign: some methods indicated the compressed state of the materials, others - the extended state.

Thus, classification and analysis of physical methods of materials' stressed state diagnostics allow drawing the first, not quite sensational but important conclusion: **mechanical methods of diagnostics are direct research methods, and all other methods (according to the suggested classification) are indirect**.

4. Assessment of materials' state diagnostics results authenticity

So, practically all methods of materials' stressed state diagnostics are either indirect or are used as indirect ones.

Ideological basis of indirect methods is application of certain approximating functions more often obtained experimentally and sometimes theoretically and reflecting the objectively existing correlation of the recorded variation of the used field parameters with the actually occurred variations of material's state usually expressed by separate mechanical characteristics or a certain aggregate of its characteristics. But since this correlation, being the consequence of secondary phenomena of the internal material's energy transformation accompanying the process of its state variation, is determined by many factors, **the area of rightful application of indirect methods is restricted by adequacy of the approximating functions used by the investigated process. And the boundaries of this area can be determined, is possible at all, only qualitatively**.

Energy parameters and, first of all, intensity and instantaneous power[10)] are principally important parameters of fields introduced in the material in order to investigate its properties. The point is that the introduced in the investigated material field, interacting with proper material's field, changes its properties. And the nature, amount and lifetime[11)] of variations are determined by the dynamic ratio of interacting fields' energies. Most often variations of material properties in the process of carrying out diagnostics are simply not noticed or, either not assuming the possibility of such variations or being aware of them, neglected on purpose considering the intensity of fields used for diagnostics to be small. But in both cases we have another source of methodical error at material's characteristics measurement by indirect methods. And the value of this error can be very high.

10) Power is energy transmitted by the introduced field through the considered surface per time unit. Intensity is a time-average energy transmitted by the introduced field through a unitary pad perpendicular to the energy propagation direction, i.e. intensity is an average specific power. Instantaneous power is a field power at a specific moment of time.

11) Lifetime is a conventional time period during which the amount of variations caused by external effect decreases to the pre-specified value. Variations lifetime is determined by the ratio of relaxation and retardation (aftereffect) rates.

Besides, **most of the methods** pretending to the quantitative evaluation of the measured material's characteristics **are relative** since they are based on measurement of used physical field informative parameter variations in the loaded and unloaded states of the material. This is achieved either by relieving the load from the test object (which is seldom practicable) or by the use of reference specimens compared to the test object. It is clear that both alternatives i**ntroduce additional error of known value**: in the first case - due to relaxation-retardation processes flow, in the second case – due to non-identity both of measurement conditions and of the very materials of the specimen and the object, having not only different pre-histories but most frequently different shapes.

Consequently, these not taken into account before **methodical mistakes**[12)] in determination of mechanical characteristics by indirect methods, being a basic component of the resulting measurement error **cannot be expressed quantitatively**. And this means that at such an approach **it is not correct to speak about the authenticity of quantitative results of mechanical characteristics measurement by indirect methods**.

12) Methodical mistakes are traditionally considered the mistakes associated with correctness of the measurement process performing - the measurement technique, which leads, as it follows from the above-said, to principal errors.

The last comment is also fair because **there is no sufficiently convincing expert method of assessing the material's stressed state determination correctness and authenticity**.

Indeed, one of the most widespread methods of stress measurement - the method using strain sensors, being the most trusted by specialists, though it may seem strange, is also indirect and belongs to electric methods since it uses the dependence of a sensitive element's electric resistance on its geometric dimensions. I.e., this is actually an indirect method of strain measurement, which is, of course associated with the mechanical stress value via the elastic modulus but, unfortunately, not only with it. Therefore the application scope of the strain-gage method of stress measurement is restricted to elastic area, and the less we know about the investigated materials' properties, the less we can say about the stress, and besides, not inside the material but only on its surface.

Even destructive methods like the method of holes, the method of columns, trepanation method and others, in fact, cannot be standard since they introduce their own residual stresses due to material machining at hole drilling or columns cutting.

And, finally, the main and the most unpleasant drawback of all non-destructive methods is that, while allowing assessing with this or that (even high) error the amount of stress, they do not provide the opportunity to determine the nature of strains caused by stresses actually existing in the material, i.e. to determine the material's state (brittle or plastic) and to assess the degree of its closeness to the material's critical states (creep or failure). The reason is in **limited informative capabilities of the methods** traditionally using for measurements not more than 4 independent informative parameters of physical fields used for diagnostics.

5. Conclusions

Thus, while noting the highest development level of modern non-destructive methods and means of materials and structures diagnostics, one has to state not only **the lack of means for authentic determination of materials' SSS characteristics in structures of operated objects but also impossibility to assess the very authenticity** of the obtained results.

Generalizing the results of the carried out analysis, the following conclusions can be drawn:

- **all the currently known methods, except for mechanical ones, are indirect and relative**;
- **the variety of ultrasound methods indicates their potentially high self-descriptiveness, however, the currently available means use not more than 4 independent informative parameters**;
- **ultrasound methods** realized by the well-known technical means, at all their variety, **being integral spectral or integral amplitude-phase, are used as indirect methods**;
- all currently known **diagnostic means measure only certain parameters of the sued physical fields associated in a general case not with mechanical stresses but with a certain aggregate of the material's SSS characteristics, by the way correlated by insufficiently studied and not always monotonous and unambiguous regularities**;

- **it is impossible to determine the nature and amount of the methodical error of the material's stressed state characteristics measurement**;
- **authenticity and, moreover, accuracy of the material's stressed state characteristics measurement by non-destructive physical methods**, described by diagnostic means developers, raise serious doubts;
- **there is no sufficiently convincing expert method for assessing the correctness of the material's stressed state characteristics determination by non-destructive physical methods.**.

6. Analysis and systematization of the reasons for low effectiveness of non-destructive methods application for SSS diagnostics

The obvious reason for such a long lack of vitally necessary improvement of **authenticity of assessment and predicting of terms and conditions of critical objects safe operation is dissociation of strength specialists and diagnostic methods and means developers**. This dissociation is the reason that strength specialists, due to the lack of objective characteristics reflecting the currently formed material's properties, develop various calculation techniques based on any available characteristics, which at least qualitatively and at least partially provide the idea of the current material's state. And diagnostic methods and means developers, being in the proud solitude, "became thoroughly engrossed" in the search for methods and means of residual stresses determination sometimes not thinking about the authenticity of measurement results.

This obvious reason for insufficient application effectiveness of structural materials' SSS diagnostic means at objects life assessment cane be formulated more strictly: **the lack of scientifically grounded concept of materials' stress-strained state (SSS) diagnostics and of the general concept of complex diagnostics**. Such formulation is so far of a private nature, so to say, not concerning the state of things with strength specialists, but it already brings in some elements of constructivism as it points out the direction of actions and requires deeper analysis of the situation formed.

The results of further analysis demonstrate that the true depth reasons of "stagnation" in solution of the main problem are more complex and form two problems, which are common for strength sciences and diagnostic methods sciences:

- **ideological:** the lack of clear idea of the determining role of a certain number of basic independent characteristics of the material and about their functional-determining interrelation with the material's stress-strained state (SSS) characteristics and, as a consequence, **the lack of scientifically grounded methodology** determining the goals, tasks and criteria of structural materials' SSS diagnostics;

  Indeed, the lack of requirements to the measured SSS characteristics, the lack of metrological basis for certification and calibration of materials' SSS characteristics measurement means lead to ambiguity of initial requirements and wrong methodical approach to developed means, which results in not only inadmissibly low authenticity of measurement results but very often impossibility of correct identification of the measured parameter of the physical field used and of the measured physical characteristic of the investigated material as well. Besides, it is practically impossible to assess the authenticity of results (if, as it was note above, it can be spoken about at all) due to the lack of methodical and metrological recommendations and norms.
- **physical**: insufficient understanding, and in a number of cases unstudied physical processes of interaction of fields used for material's properties diagnostics with its proper fields and, as a

consequence, no idea of insufficient self-descriptiveness of non-destructive diagnostic methods and means used for investigation of complex physical processes of the material's internal energy re-distribution in the form of re-distribution of the I-st, the II-nd and the III-d type stresses determined by basic characteristics of the material and, at the same time, determining its SSS.

It should be especially noted that dangerous trends of simplified approach to residual life assessment of complex objects appeared during the last years. Some developers of residual stress measurement means, carrying out tests on samples in conditions of uniaxial loading, obtain good correlation of measurement results for one, or in the best case, two parameters of the used physical fields with the value of the load being variable right up to failure. Not troubling themselves by studying the processes of material's resistance to external loads, not trying to understand fracture mechanics, they transfer the obtained results to real objects thinking that a unique means for measurement of the test object's residual life was developed. This, at the least, discredits the new interesting solutions, but the main point is that the price of such an approach to wards the most complex problem of residual life estimation may be terrible.

The conducted analysis if the reasons for insufficient application effectiveness of structural materials' SSS diagnostic means at life assessment of complex engineering constructions demonstrates their objectiveness, the most important consequence of which in the moral aspect should be the fair shared responsibility for the lack of the required means for materials' properties diagnostics among the strength specialists and the developers of diagnostic methods and means. Realizing the equal responsibility will, of course, bring together positions of both parties solving, in fact, the same problem - providing acceptable guarantees of objects safety, but the efforts can be united only on condition of constructive approach.

The main thing is that analytically grouped reasons already gain another, constructive nature specifying the way of solving of the most actual problem of assurance of complex engineering objects safe operation.

7. Suggestions

To the authors' opinion, in order to solve the problem of authentic measurement of structural materials' and welded joints' stress-strained state characteristics the following particular measures need to be performed:

7.1. Development of unified scientifically grounded requirements to methods and means for the material's SSS measurement. These requirements should:

- be based on clear idea of the determining role and of interrelation of independent basic characteristics of the material - this is an ideological basis;
- have **a new classification of methods and means for stress-strained state characteristics measurement of materials** in general and of welded joints in particular;
- contain **classification, list and criteria for assessment of the material's basic characteristics and of its SSS characteristics,** and these characteristics should, on the one hand, be subject to obligatory measurement at diagnostics of the material's state and, on the other hand, they should be subject to obligatory application as basic characteristics at calculations of the actual or predicted life. This will, of course, require correction of the life estimation techniques, but only in this way**, by creating conditions for bringing together strength sciences and diagnostics sciences, the problem of achieving the required level of objects safety can be solved.**

7.2. Development of the technique and means for metrological calibration and qualification of SSS

parameters measurement means allowing assessing objectively the effectiveness and accuracy of the developed means. Creating of authentic expert method for diagnostic means calibration, of course, seems to be a rather difficult task, the solution of which may be delayed. Nevertheless, a unified system of standard calibration means (for example, of samples and techniques) need to be introduced urgently, at least conventionally. Such a unified system will allow not only comparing correctly various methods of diagnostics but it may become in future a certain prototype of diagnostic results assessment criteria.

7.3. It is necessary to start the development of normative documents regulating measurement of materials' SSS parameters at object diagnostics depending on the category of their potential danger for man and environment.

In 2003 under the authors' initiative and jointly with Gosstandard TC-132 "Engineering diagnostics" the draft standard "Non-destructive testing. Stress-strained state tests on industrial objects and transport. General requirements" was developed. Concerned organizations and private persons have discussed this draft standard.

It should be noted in conclusion that investigation of complex processes of the materials' proper energy re-distribution under the influence of external force, magnetic and other fields will require knowledge from the fields of science, which seem to be far away from practical problems solved: quantum physics, solid-state physics, metal physics, dislocations theory, elasticity, plasticity and strength theories, fracture mechanics, electromagnetic field theory and even radio engineering basics. This, of course, determines the high level of requirements to specialists developing various SSS inspection methods. It should be noted that **structural materials' SSS diagnostics represents the next after flaw detection, higher level of diagnostics** and requires a new ideology, a new concept. Only the new concept is able not only to reconcile various physical methods of non-destructive testing, which excellently got together and supplemented each other within flaw detection but "conflicting" with each other at present within this new type of diagnostics, but also, taking into account specificity of their physical "interrelations", to unite them in a unified system able to sufficiently accelerate the solution of the problem of authenticity improvement of complex engineering objects' residual life assessment.

Problems of Ageing Equipment Residual Life Assessment

Dr., Professor A.A. Dubov

Based on the analysis of existing approaches to the ageing equipment residual life assessment formed in various branches of industry, general problems were revealed that are caused by low effectiveness of conventional methods and means of non-destructive testing and by imperfection of calibration calculations of strength. It was shown that equipment and structures reliability and life are determined by stress concentration zones (SCZ), being the main sources of damaging development. Application of "passive" diagnostics methods using radiant energy of structures (acoustic emission and metal magnetic memory methods) is valid for SCZ detecting in proper time.

The problem of providing the reliable operation of equipment, vessels, gas and oil pipelines and various structures becomes more and more relevant every year as the equipment ageing in many branches of industry significantly surpasses the rates of technical re-equipment. For instance, in power engineering as of September, 2002, about 90% of thermoelectric power stations equipment had exhausted its park life and the significant part of it had achieved physical wear. The above-mentioned problem is aggravated by the lack of scientifically grounded concept of technical diagnostics and life determination and by insufficient effectiveness of conventional methods and means of metal non-destructive testing.

Based on the analysis of existing approaches to the ageing equipment residual life assessment formed in various branches of industry, the following general trends can be marked out.

Firstly, many specialists in the sphere of equipment reliability pass from probabilistic methods of life assessment based on failure statistics to assessment of individual life of the ageing equipment base on the complex approach combining the results of destructive and non-destructive testing with calibrating calculations of strength.

Secondly, at life assessment a tendency has been noticed of shifting from crack detection to technical diagnostics methods based on combination of fracture mechanics, physical metallurgy and NDT. Equipment and structures stress-strained state NDT methods come to the forefront.

Thirdly, the necessity for a 100% examination of the ageing equipment aimed at determination of potentially dangerous zones has been realized.

At the same time the following drawbacks and defects existing at realization of these approaches should be noted.

At a complex application of various methods and means of non-destructive and destructive testing there is no strictly specified order and sequence of their application for a specific test object.

As it is known, the order, the scope and the frequency of equipment inspection is determined, on the one hand, by the park (design) life, damageability, overhaul life and, on the other hand, by availability of inspection methods and means and their capabilities.

Special instructions on the order and frequency of inspection and prolongation of equipment life are available only in certain most critical branches of industry (for example, nuclear-power engineering and heat-power engineering) [1, 2, 3]. And even in these advanced fields (from the viewpoint of arrangement of the equipment metal state control) there is a problem of metal limiting state determination and the equipment individual life assessment [4].

The suggested methods of strength calibration calculation can be conditionally divided in four groups:

- methods of calculation by metal corrosion rate;
- metal crack resistance calculation methods;
- metal fatigue calculation methods;
- calculation methods for equipment units operating in conditions of creep.

The main defect of well-known methods here is that they suggest a low level of permissible stresses [σ]. As a rule, the level [σ]?$\sigma_{0,2}$/2, where $\sigma_{0,2}$ - is the conditional metal yield strength. There is a requirement in level calculation for critical structures [σ]<0,3$\sigma_{0,2}$. It is known that these requirements are governed by the equipment metal work in conditions of glide and by shear strain. As the practice shows, these conditions of metal work are determining for the structure reliability. However, it is impossible to predict in advance the zone of metal glide areas on the equipment using calculation methods.

Besides, the existing strength calculation methods assume, as a rule, independent flow of corrosion, fatigue and creep processes, though in practice these processes flow simultaneously in various combinations.

The tendency of shifting from traditional crack detection to technical diagnostics using the complex approach incorporating: defect parameters determination, internal (residual) stresses distribution assessment, determination of actual structural-mechanical characteristics of metal, is restrained, first of all, by the low effectiveness of the current methods and means of equipment stress-strained state control. For example, the paper [5] states that at a current stage none of the tested means of stress determination (about 10 various stress inspection instruments were tested) can provide authentic data on the stress-strained state (SSS) of gas pipelines in real operational conditions.

The analysis of the known inspection means capabilities and stress measurements in the base metal of equipment and structures weldments and welded joints allow naming their major drawbacks. The basic drawbacks are:

- impossibility to use most of methods in the plastic strain area;
- control locality, their unsuitability for long structures inspection;
- metal structure change is not considered;
-

inspection is carried out only on the surface of weldments, impossibility to assess the depth layers of metal and welded joints metal;

- the need to make graduated diagrams based on preliminarily prepared samples;
- the need for test surface and test objects preparation (dressing, active magnetization, sensors adhesion, etc.);
- complexity of testing sensors location determination related to the direction of the action of main stresses and strains determining the structure reliability.

It was noted earlier that stress concentration zones were the main sources of damages development. The metal structural-mechanical properties need to be first of all investigated exactly in SCZ. The existing traditional methods of stresses non-destructive testing (X-ray, ultrasonic inspection, Barkhausen noise and others) do not allow solving this complex problem of SCZ determination on equipment due to operational loads action.

Though the necessity for 100% equipment examination at life assessment is realized, however, much time and large material and financial costs are required for implementation of this task in practice. This task is not realized in practice using conventional NDT methods (ultrasonic inspection, X-ray, magnetic particle inspection). For instance, the length of pipe heating surfaces on a modern 1000 t/h steam boiler makes more than 500km. Therefore it is practically impossible to tap, clean and measure by ultrasonic inspection method such a number of pipes, and none of electric power stations does this work. Similar problems occur at inspection of gas and oil pipelines the length of which in Russia reaches hundreds of thousands of kilometers, in petroleum and chemical industries at inspection of a large park of vessels and pipelines as well as in other branches of industry at inspection of ageing equipment and structures.

Let us consider further the capabilities of current (conventional) NDT methods and means at solution of tasks occurring at equipment life assessment.

The existing conventional NDT methods and means (ultrasonic inspection, magnetic particle inspection, X-ray) are known to aim at searching and detection of a specific defect. Determination of the size of defects (occurrence depth, length), located in the volume of the base metal or in the welded joint metal is a complex practical task. However, if the size of the defect is determined (modern crack detectors solve this task), it is necessary to determine the extent of this defect danger and to answer the question: "Is this defect developing or not?". To answer this question a calibration calculation of this unit strength should be made taking into account the defect size. It is obvious that such calculations are not carried out in general practice. Therefore the existing norms on defects permissibility (revealed by ultrasonic inspection, X-ray) for instance, in welded joints are mainly based on statistics and in most instructions have conditional nature. There are no scientifically grounded norms on defect size permissibility from the viewpoint of fracture mechanics in the general practice.

If capabilities of, for instance, magnetic particle inspection and eddy-current control methods, aimed at surface cracks detection, are considered, the following should be noted here. Despite the fact that the modern instrumentation and testing technology using the indicated methods has been significantly developed nowadays, there are till date no norms on surface defects size permissibility for equipment in operation in many branches of industry.

The existing norms and samples used, for example, in magnetic particle inspection, were developed for new machine-building products. These norms are nor suitable for equipment in operation for the following reasons: firstly, the slag, the metal external layer corrosion do not allow applying the indicated control means and methods without cleaning and removal of this layer, and secondly, these norms from the viewpoint of fracture mechanics require special grounding practically for every test object. Therefore for the critical equipment in operation, for example, at thermoelectric power stations surface cracks on most test units are not allowed and should be removed [1]. Thus, samples and norms specified in instructions for magnetic particle inspection and eddy-current control methods are applied in general practice as a measure of sensitivity of the instruments used.

The tasks of internal defects control in fillet, branch and T-joints, in contact welded joints, in small-size joints (up to 6 mm), determination of corrosion pits on pipeline internal surfaces are complex and not till date solved by traditional crack detection methods.

Unsuitability of conventional NDT methods for defects detection at an early stage of their development should be noted as well. More and more specialists start realizing that "pre-defec" metal state is in many cases (especially on the ageing equipment) more dangerous, when irreversible changes took place at a structural level and the fatigue-assisted damage may occur all of a sudden and, as a rule, in unexpected zones. The sensitivity level of conventional NDT methods does not allow revealing the "pre-defect" state of a metal.

Methods and means of metal structural-mechanical properties NDT (measurement of hardness, coercive force and of other magnetic characteristics of metal, "replicas" taking for structural changes determination and other methods) are widely used at equipment life assessment nowadays. Complex methods of metal’s physical-mechanic properties NDT are developed and being applied in practice, for example, plants for combined application of magnetographic method and kinetic indenting method [3], the Moscow Power Institute’s instruments and methods for materials testing by indentation or scratching for rapid evaluation of mechanical properties [6] and others.

At present there are about 20 standards for non-destructive and partially destructive sampling methods in Russia. All the available standards determine the sampling mechanism, i.e. answer the question: "How to carry out sampling?". This variety does not contain a single standard answering the question: "Where to take a metal sample from?". Therefore at carrying our sampling on the equipment after long operation to assess metal degradation specialists make conclusion on the metal state only at the place of sampling. It is impossible to extend the results of this conclusion on the entire metal of the test object (and even of an individual element, for instance, the steam-water pipe bend). Metal samples are taken, as a rule, from zones of the most probable development of damages (or from zones where metal damages already existed).

It was noted earlier that SCZ, occurring at the stable dislocation slipbands zones and caused by the action of operational loads, are the major sources of equipment damages. According to the inspection experience, these zones on the equipment metal surface show themselves in the form of lines with the size by width and depth at the beginning of their development of not more than several microns. The probability to hit these zones at metal sampling is very low. It is obvious that such task can be solved only at a 100% metal examination on the entire surface of the test object using highly sensitive methods. There were no such methods enabling to solve this task till date.

In this connection it should be noted that if there is no opportunity to determine SCZ and to carry out metal sampling, then, accordingly, the intention to make strength calibration calculation for residual life assessment loses its sense. Only in exclusive cases, when, for instance, the metal is affected by corrosion with pipe wall (or vessel shell) thinning on a large area, it makes sense to calculated strength taking into account wall thickness and corrosion rate decrease.

Thus, the presented brief analysis of existing methods of metal damages and degradation NDT demonstrates their low effectiveness at industrial equipment life assessment. The tendency of shifting from traditional crack detection to technical diagnostics using principally different control methods and approaches becomes clear and appropriate. More complicated tasks occurring at equipment life assessment (as compared to conventional crack detection at normal operation) require application of means and methods that are more difficult to master but more effective at control of altering metal properties. First of all, means and methods allowing practical control of equipment's stress-strained state should be assigned to such methods.

All leading diagnostic centers of the world are occupied nowadays by the problem of mechanical stresses measurement in operating structures in order to assess their state. However, no effective methods of stress control, suitable for practical application, have been suggested till date.

Major drawbacks of traditional stresses and strains NDT methods were marked out above.

Besides, traditional methods and means of stresses NDT based on active interaction of the instrument signal with the structure metal obtain indirect information on the test object's stressed state, i.e. have insufficient self-descriptiveness of physical fields used at control.

Indeed, the introduced into the investigated material field, interacting with the material's proper fields, alters its properties and the test object's stress-strained state characteristics. The alterations life nature, amount and time are determined by the dynamic relationship of interacting fields' energies. In practice at carrying out diagnostics such alterations are simply neglected.

Thus, the above listed drawbacks of the known SSS control methods are caused not only by metrological peculiarities, but also to a certain extent by these methods' physics, i.e. they are regular. Lack of metrological basis for materials' SSS characteristics measurement certification and calibration (there are no unified standards and samples in Russia and abroad) leads to requirements ambiguity and wrong methodological approach to the developed control means.

Paper [7] states that thermodynamic constitutive equation of solids must be taken as a basis of equipment reliability theory and prediction. Basic physical effects accompanying the metal fracture mechanism: mechanic, thermal, ultrasonic, magnetic, electric and electromagnetic are determined. It implies that using one or simultaneously several control parameters, reflecting the listed effects, it is possible to most objectively assess the test object's stress-strained state.

It was stated earlier that the equipment metal work is mainly determined by dislocations glide and shear strain. The metal fatigue damaging accumulation in many cases occur in conditions of low- and multicycle operational load. The question is, how the traditional methods of stress control can asses actual structure SSS, when in the general case stress concentration zones due to shear strain are unknown. It is obvious that only "passive" methods of SSS diagnostics are able to answer the questions put and are the most suitable for practical application.

Passive NDT methods using radiant energy of structures, first of all, are:

- acoustic emission method (AE);
- metal magnetic memory method (MMM).

These two methods are nowadays widely spread in practice for early diagnostics of equipment and structures damages.

As it was demonstrated in practice, MMM, as compared to the AE method, gives additionally the information on the test object's actual stress-strained state, which allows more objective determining of the reason for stress concentration zones formation, being the source of damaging development. Besides, application of MMM enables a 100% equipment examination with SCZ and defects detecting at an early stage of their development. Having the complete information on the revealed defects and on the possible influence of each of them on the equipment residual life, one can easily solve the task of recovery work scope determination necessary for improvement of units' efficiency life to the required level.

Paper [8] gives the method for metal limiting state and equipment life determination using metal magnetic memory parameters.

References

1. GD 10-577-03. Standard instruction for metal control and lifetime prolongation of boilers, turbines and pipelines main units at thermal power stations. Moscow: ORGRES, 2003.

2. GD EO 0186-00. Method for Atomic Power Plant power unit vessels' technical state and residual life assessment. Moscow: Concern "Rosenergoatom", 1999, 75p.

3. GD EO 0185-00. Method for Atomic Power Plant power unit pipelines' technical state and residual life assessment. Moscow: Concern "Rosenergoatom", 1999, 63p.

4. The concept of power objects technical reequipment at RAO "Russian Unified Electric Power Systems" during the period till 2015. Document of RAO "Russian Unified Electric Power Systems". Moscow, November, 2001.

5. Dubov A.A., Demin E.A., Milyaev A.I., Steklov O.I. Gas pipelines stress-strained state control // Gas industry, 2002, No.2, pp.58-61.

6. Matunin V.M. Methods and means of rapid assessment of structural materials' mechanical properties without sampling. Moscow: Publishing House of Moscow Power Institute, 2001.

7. Komarovsky A.A. Stress-strained state diagnostics // Testing. Diagnostics, 2000, No.2, pp.22-27.

8. Dubov A.A. Means of metal limiting state and equipment life determination using metal magnetic memory parameters. Proceedings of the XVIth Russian Scientific-Technical Conference "Non-Destructive Testing and Diagnostics". St.-Petersburg, September, 2002.

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

Assessment of eguipment lifetime using the metal magnetic memory method

Dr., professor Anatoly Dubov

According to the "Standard guideline for metal inspection and prolongation of TPS boilers, turbines and pipelines basic elements life", it is suggested to consider crack resistance as the main parameter characterizing the survivorship of power equipment units operating in conditions of cyclic loads. However, this characteristic is determined on samples, and transferring of laboratory testing results to real operational conditions does not provide an objective assessment of metal condition.

The article considers the abilities of the method of metal magnetic memory (MMM) to detect crack initiation zones directly on equipment and to trace the development of metal fatigue failure process in these zones. Based on 100% power equipment inspection using the MMM method it is suggested to detect all potentially dangerous zones with developing defects and to timely remove them during the repairs. Thus, an opportunity is offered to assess the real equipment life.

Paper [1] presented in detail the problems of aging equipment's residual life assessment.

Among the basic scientific-technical problems of power equipment life assessment the following should be singled out:

- the lack of scientifically grounded concept of engineering diagnostics and life estimation;
- insufficient effectiveness of traditional non-destructive testing (NDT) methods and means at early diagnostics of fatigue damages and investigation of metal's structural-mechanical properties;
- low effectiveness of the current techniques for calibrating strength calculation due to the lack of actual structural-mechanical properties of metal by all equipment elements and units;
- the lack in the broad practice of effective NDT methods and means allowing performing 100% equipment inspection in order to assess the stress-strained state and individual life of each unit and the entire aggregate.

The scientific-technical problems of equipment reliability assuring and prolongation of its life are aggravated by the lack of the required financial finds. According to estimation presented in the Concept of Technical re-equipment of RSC "UES of Russia" Electric Power Plants till 2015, the man-hours for providing of expert-predicted life, at its prolongation beyond the body life, may be about 50% from the cost of complete replacement of similar equipment's power units. It is indicated that this high level of costs should be aimed at a 100% diagnostic examination of equipment, execution of calibration strength calculations and the analysis of technical-economic documentation on the experience in equipment operation. It is obvious that these costs were reasonable based on the experience in power equipment metal inspection gained by RSC "UES of Russia" counting on a 100% examination by traditional destructive and non-destructive testing methods.

Thus, nowadays at large Electric Power Plants, where equipment has exhausted its body life, a deadlock condition has formed. There is no money for equipment replacement and even for its 100% examination, and not a single organization will obviously take a responsibility to prolong the life without such an examination! At such conditions Power Plant management has to provide safe and reliable operation of the equipment.

It should be noted that execution of a 100% examination of power equipment using traditional NDT methods (UT, MPI, etc.) is associated not only with the high level of costs, but also it has low effectiveness due to its unsuitability for detection of fatigue damages at an early stage of their development.

According to standard guideline [2], it is suggested to consider crack resistance as the main parameter characterizing the survivorship of power equipment units operating in conditions of cyclic loads. It should be kept in mind that this is a conventional material characteristic determined by the ratio of the current (actual at a specific time and in specific conditions) crack growth rate to the critical rate for a specific material. However, this characteristic is determined on samples, and transferring of laboratory testing results to real operational conditions does not provide an objective assessment of equipment operability and efficiency.

Can assessment of cracks growth be made and their development zones be detected in real conditions directly on equipment?

It is known that the main goal of a 100% examination is to detect potentially dangerous stress concentration zones (SCZ), in which development of corrosion, fatigue and creep damages occur. Exactly for solution of this problem it is suggested to use the method of metal magnetic memory (MMM) the main designation of which is SCZs detection based on express control of the entire equipment surface. No preparatory works are required for this.

Most of power equipment units and elements operate in conditions of cyclic loads, and after their long-term operation fatigue and/or creep damages should be expected, which occur, as a rule, unexpectedly in local SCZs.

SCZs are not only the known beforehand areas, where structure peculiarities create various conditions for distribution of stresses due to external operating load, but also are randomly located areas, where large strains (shear strains, as a rule) occurred due to metal inhomogeneity combined with off-design additional working loads.

Paper [3] considers the physics of metal fatigue damaging and offers the development model of this process opening the possibility of material's state quantitative assessment at using the MMM method.

It is established that fatigue damaging of metal has three phases:

- the first stage is preparatory, it is characterized by comparatively high rate and lasts for comparatively short period of 1,0-1,5% of the limiting number of cycles;

- the second phase - being the basic one - is an accumulative phase characterized by very slow development of propagation process in one direction - to the depth (from units to tens of microns) and lasting very long - for 90-95% of the limiting number of cycles;
- the third phase - is the final one flowing very rapidly and causing occurrence of microcracks in "random sites" and their propagation at a very high speed to the depth and along the length and their growing into macrocracks.

It should be noted that the first two phases of metal fatigue damaging development in conditions of cyclic loading are well investigated, but the third phase, which became a subject of numerous investigations, remains a secret to a great extent.

Fig.1 shows graphic representation of the three phases of metal fatigue damaging accumulation process in the form of dependence of metal weakened (loosened) layer thickness δ on the number of load cycles *N*.

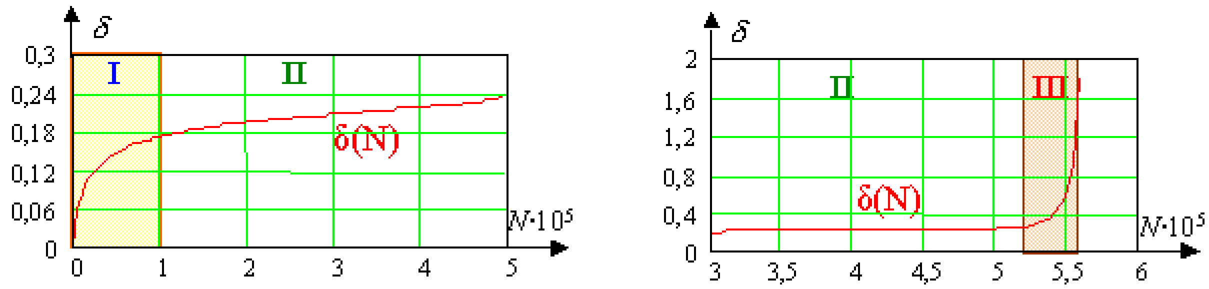


Fig.1*a***.** **Fig.1***b***.**

Paper [3] gives quantitative representation of this diagram based on design investigation for pipe sample in conditions of symmetric cyclic loading along the radius.

Transience of the third phase and uncertainty of damaging initiation site did not allow till date the detailed investigation of events preceding the failure directly on equipment.

Let us further consider the abilities of the MMM method to trace the development of metal fatigue failure process directly on equipment.

The main diagnostic parameter by the MMM method is the magnetic leakage field gradient H_p (dH_p/dx) or this field variation intensity coefficient (K_{in})[1], registered at scanning with a special magnetometer sensor along the equipment surface. It was established that this very diagnostic parameter due to magnetometric effect directly reflects the energy state of surface and depth metal layers in SCZ [3]. And the maximum field gradient value, determined on the metal surface with accuracy up to one millimeter, corresponds to the source of crack occurrence. In the area of the most intensive strain and, finally, failure process the domain structure suffers sufficient changes. Sizes of domains, whose directions coincide with glide direction, reach critical sizes. As a result, the maximum-size domain "breaks" and a microcrack appears. Design investigations in paper [3] demonstrated that the domain of iron can have a volume covering up to ten grains. At present Energodiagnostika Co. Ltd, due to its large experience in power equipment examination, possesses quantitative values of K_{in} characterizing metal limiting state by strength conditions and micro- and macrocracks[2] development.

[1] $K_{in}=|\Delta H_p|/\Delta x$ where $|\Delta H_p|$ is the modular difference of the H_p magnetic field intensity between the adjacent measurement points located at a distance Δx. At $\Delta x\to 0$, $K_{in}=dH_p/dx$.

[2] It should be noted that cracks division by micro and macrocracks has till date a conventional nature in the technical literature.

Fig.2 shows inspection results of No.29 stage disk rim of No.3 unit K-300-240 turbine average-pressure rotor (APR) at Konakovo TPS (July, 2001). H_p field and its gradient dH_p/dx distribution shown in Fig.2, a characterizes the disk rim metal's state. A "replica" for metal structure investigation was taken in the H_p field and the maximum gradient value local variation on the disk. Fig.2, *b* shows the photo illustrating the results of metallographic investigation. Microcracks with 1 or 2 microns opening can be seen.

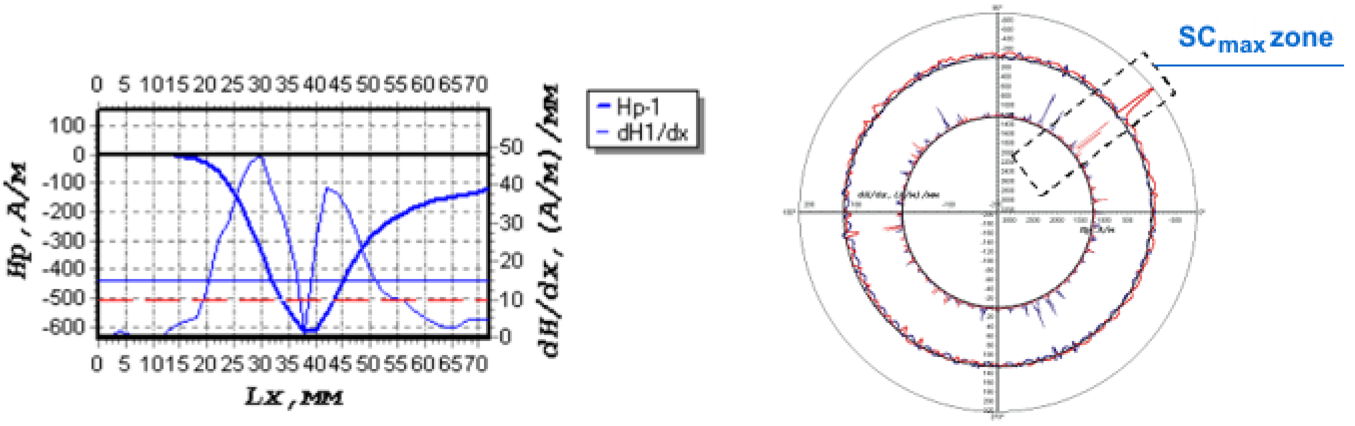


Fig.2 ***a*****.** Results of disk rim inspection. Distribution diagram of the H_p in SCZ.

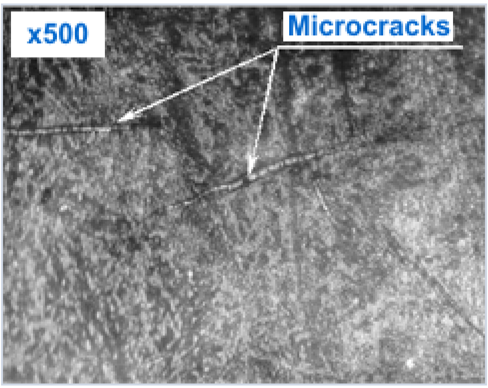


Fig.2 ***b*****.** Results of metallographic investigation.

Fig.3, *a* shows the results of MMM-inspection along the output edge of K-300-240 turbine LPR stage 38 blade No.12, unit No.5 at Konakovo TPS. A "replica" for metal structure investigation was taken in the zone of abrupt local variation of the H_p field and its gradient. Fig.3, *b* shows the results of metallographic investigation. A microcrack with 5-8 microns opening was revealed in the zone of the field maximum gradient value dH_p/dx.

This figure represents as well the results of the H_p field and its gradient measurements in the microcrack zone before grinding (*a*), after primary grinding for taking a replica (*c*) and after the secondary grinding (*d*). In this case grinding on blade No.12 was perform to the depth of about 200 microns. The dark stripe presented in Fig.3, *b*, corresponding to the crack location on the blade surface, obviously represents the loosened metal layer. The dense metal layer with increased hardness is under the loose layer. The results of experimental investigation of similar blades, presented in paper [4], confirm this.

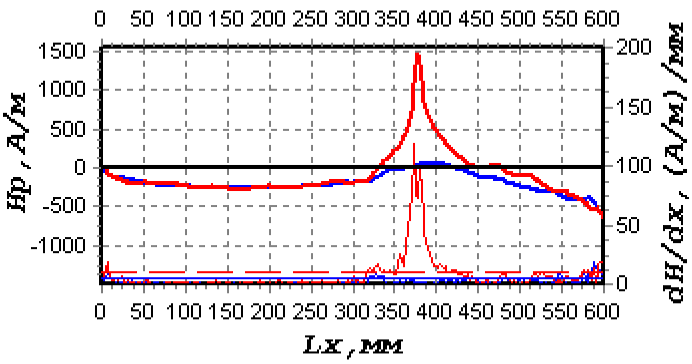


Fig.3 ***a*****.**

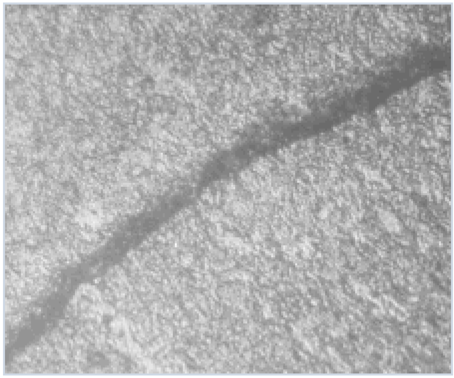


Fig.3 ***b*****.**

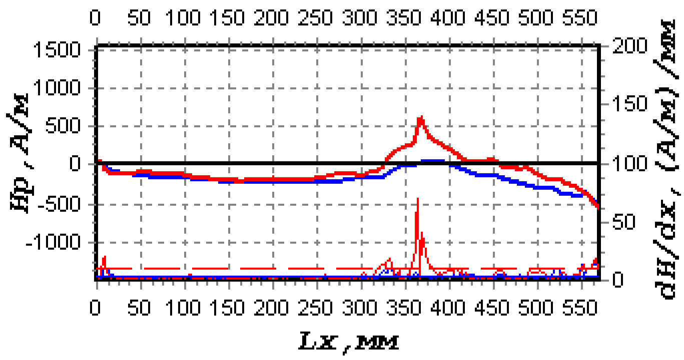


Fig.3 ***c*****.**

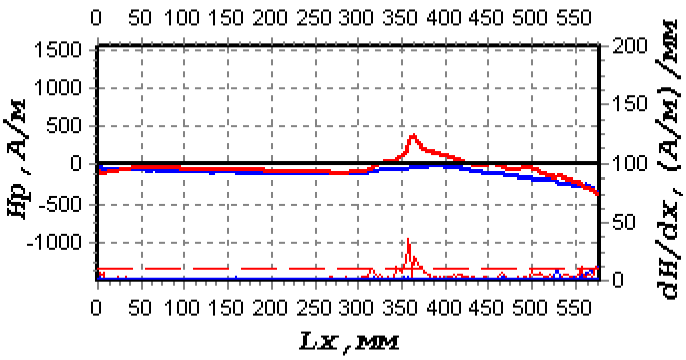


Fig.3 ***d*****.**

With the increase of the number of load cycles the dense metal layer cracks increasing the size of the loose layer. Thus, a crack develops on the blade surface. The results of experiment with blade No.12 grinding in the developing crack region obviously demonstrate correlation of the diagnostic parameter dH_p/dx with the damages metal layer dimensions (depth and width). This correlation is also proved by the physical "magnetodislocation" mechanism of the H_p magnetic field formation in the local SCZ [3].

It should be noted that if the damaged metal layer is not removed in due time, it may cause a serious blade or disk failure during the overhaul life. The rate of a microcrack growing into a macrocrack is obviously different for each specific unit. Such investigations are, as a rule, not carried out in real conditional of critical equipment operation. Application of MMM at a 100% examination of aging equipment will allow detecting crack formation zones and assessing their propagation rate for various power equipment units in future. At present there are some techniques for classification of the degree of metal damaging in SCZs by the field gradient value.

It was established in the course of industrial investigations that the diagnostic parameter values K_{in} in SCZs for the same-type elements (for example, for blades of the same disk) during the same operation time are, as a rule, different, for instance, due to the different amplitude of cyclic load.

It is known that the damaging development rate in phases II and III for the same-type elements is also, as a rule, different. This rate can be traced by the K_{in} value. This is the basis of the methodology of life assessment by the K_{in} value presented in paper [5]. Paper [3] shows that decreasing of metal density in SCZs at accumulation of fatigue damaging is accompanied by increasing of magnetic energy density and by the diagnostic parameter K_{in} increasing respectively.

The gained experience in a 100% examination of K-300 turbines at Konakovo TPS, K-200 at Cherepovetsk TPS and Zainsk TPS, T-100 at Severodvinsk TPS-2, PT-60 and T-100 at Petrozavodsk TPS and others (more than 50 various types of turbines were examined in total) allows making the following conclusion: SCZs are the sources of damages development (in the form of cracks, as a rule), which occupy not more than 3-5% of the total rotors metal surface or volume. The remaining 95% of the turbine rotors metal volume after their long-term operation are in a satisfactory condition! Thus, the problem of turbine rotors life assessment is solved by timely detection of maximum stress concentration zones and their removal by ordinary grinding in the course of repairs. Similar approach at life assessment with 100% examination by the MMM method is used by Energodiagnostika Co. Ltd. on all types of power equipment: turbines, boilers, steam and water pipelines, etc. And the costs for execution of such an examination are sufficiently lower as compared to the cost of diagnostic works indicated in the Concept of RSC "UES of Russia". For example, examination of all three rotors of K-200 and K-300 turbines will make not more than 1 million rubles (as of January, 2005).

References

1. Dubov A.A. Problems of aging equipment residual lifetime assessment // Teploenergetika, No.11, 2003, p.54-58.

2. GD 10-577-03. Standard instruction for metal control and prolongation of basic power station elements life. Moscow: SPO ORGRES, 2003.

3. Vlasov V.T., Dubov A.A. Physical bases of the metal magnetic memory method. Moscow: ZAO "TISSO", 2004. 424p.

4. Dubov A.A., Matunin V.M., Ryzhkov F.E., Chechko I.I. Early diagnostics of blades damaging using the method of metal magnetic memory // Tyazheloye mashinistroyenie, No.10, 2001, p.32-34.

5. Dubov A.A., Dubov Al.An., Kolokolnikov S.M. Method of metal magnetic memory and inspection devices. Training Handbook. Moscow: ZAO "TISSO", 2008. 365p.

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

Non-contact diagnostics of buried pipelines using the magnetometric testers of stress concentration

Dr., Professor A.A. Dubov, Al.A. Dubov

At present practical application of non-contact magnetometric diagnostics (NCMD) during the assessment of underground or underwater gas and oil pipelines, heat lines, water mains and other pipelines constantly grows.

The article considers the main problems revealed by the authors as a result of the long-term application of NCMD, the issues of experts training at Energodiagnostika Co. Ltd. Certification Body and the perspectives of NCMD technology development.

NCMD is based on measurement of distortions of the magnetic field of the earth (H_{earth}), conditioned by the variation of the pipe metal's magnetic permeability in stress concentration zones (SCZs) and in zones of developing corrosion-fatigue damages. The pattern of the H_{earth} field variations (frequency, amplitude) is conditioned by the pipeline strain occurring in it due to the exposure to a number of factors: the residual process and installation stresses, the working load and self-compensation stresses at outdoor air and environment (soil, water, etc.) temperature fluctuation.

The criteria and the program software, developed at Energodiagnostika Co. Ltd. based on the metal magnetic memory method [1,2], are applied for decoding of the information about the pipelines condition by variations of the magnetic field of the earth recorded at the depth of 200 to 300 mm from the earth surface.

In particular, clear relation between the variation frequency of all the three magnetic field components and the pipe standard size (diameter, wall thickness and pipe length between the joints) was found. These qualitative diagnostic parameters, detected during NCMD, characterize stress concentration zones (SCZs)- the sources of various-type damages development - within the pipe metal macro volume.

At present a number of Russian companies use the NCMD technology during the diagnostics of gas and oil pipelines. Among them Energodiagnostika Co. Ltd., LLC RDC "Transkor-K", and CJSC NPC "Molniya", having their own instrument complexes and guidance documents approved by the Russian Technical Supervisory Body (Rostekhnadzor), JSC "Gazprom" and AC "Transneft", develop this technology most actively.

There is a standard of the Moscow Hear Distribution Company (JSC "MTK") on assessment of heat lines condition using NCMD. The technique for heat lines inspection by the non-contact magnetometric method was developed in 2009 by Energodiagnostika Co. Ltd. experts under the Contract with JSC "MTK". Every year diagnostic companies perform the inspection of several hundreds of kilometers of the Moscow heat distribution system heat lines using this technique and the appropriate instrument complexes.

Figure 1 shows the instrument complex for NCMD manufactured by Energodiagnostika Co. Ltd. on a commercial basis.

Figure 1. Appearance of the scanning device: *1* - road wheel; *2* - length-counting unit; *3* - Type 11 sensor attachment unit; *4* - Type 11 sensor; *5* - handle; *6* - measuring instrument mounting unit; *7* - folding support leg; *8* - universal head.

A center for experts training in NCMD operates at Energodiagnostika Co. Ltd. Certification Body (Reutov, Moscow region). The training program incorporates the course of training in the metal magnetic memory method (8 working days) and the additional course of training in NCMD (2 working days). During the last six years more than 200 experts in NCMD from 40 diagnostic companies were trained in Russia.

The following tasks are the most complex at practical learning to use NCMD:

- selection of the optimal expert movement speed along the route without loosing of authentic data (magnetic parameters) on the pipeline condition;
- determination of the pipeline axis with a pipeline finder and of the pipeline field location using a GPS-navigator;
- route preparation for the inspection and offsetting from interferences encountered on the experts travel path along the route (power lines, automobile roads, metal barriers, buildings and structures, etc.);
- processing of inspection results and classification of magnetic anomalies by categories of the pipeline damages development hazard;
- selection of top priority sites for soil opening ("prospecting").

At magnetograms decoding the most complex task is classification of magnetic anomalies by types of damages. Some companies, while trying to make an impact on the customer during the solution of this problem, indulge in wishful thinking. During the additional pipeline inspection in prospect holes the detected defects are further presented as defects found by NCMD before the segment opening. In fact, the current level of NCMD development, as a rule, does not allow to state before prospecting the type of defect that corresponds to the detected anomaly.

At present the attempt to perform classification of magnetic anomalies using only the software product "without using the brain" of an expert causes large error.

In the course of experts training in NCMD Energodiagnostika Co. Ltd. Certification Body issues recommendations on the distinctive features of magnetic anomalies and diagnostic parameters that allow to distinguish maximum stress concentration zones (before the damage development) from the zone of the developing corrosion damage. The existing criteria allow to detect defected welded joints and to distinguish them from the joints in a satisfactory condition.

At magnetograms decoding it is necessary to consider the specific conditions and structural features of inspected pipelines. For example, operating conditions and, accordingly, the condition of gas pipelines located in southern regions of the country noticeably differ from gas pipelines located in the north.

Pipelines of different process purposes have even greater differences. For example, heat lines with fundamentally different self-compensation conditions and specific supporting structures as compared to gas mains, as a rule, demonstrate noticeable differences in magnetograms recorded during NCMD.

Taking into account the process features of pipelines, it is necessary to develop separate methodical guidelines for NCMD.

Having more than 30-years experience of the metal magnetic memory (MMM) method development during the diagnostics of power boiler heating surface tubes, various types of process pipelines, including gas and oil pipelines, we know how difficult it is, for example to distinguish a corrosion-fatigue damage developing from inside of the pipeline from a similar damage that develops on the external wall. Besides, in many cases the formed damage or stress-corrosion crack relieves the stress level. In this case carrying out of the detailed analysis of all the three components of the measured magnetic field is required. It should be also noted that in order to develop NCMD for assessment of gas and oil pipelines' stress-strain state (SSS) and damages it is necessary to study the physical bases of the MMM method and the new provisions on strain and fracture mechanics and physics that were not studied before.

Multiple experimental works, performed by us in the laboratory and industrial conditions in the course of the MMM method development, revealed a number of unexplored before effects in the field of metal's magnetism and deformation resistance [2, 3]. Efficient development of NCMD is impossible without studying of the bases of force and weak magnetic fields (as a rule, this is the magnetic field of the earth) interaction.

In conclusion we would like to note the following.

The main task of all diagnostic methods and means during the assessment of the condition of long-term operated gas and oil pipelines is searching (or detection) of potentially hazardous segments with developing damages. As a result of the inspection it is necessary to answer the question: "Where and when damages or accidents should be expected?" If such task is solved, it provides the possibility of timely replacement or repairs of the potentially hazardous segment. Application of NCMD in combination with the additional pipelines inspection (UT, eddy-current, etc.) in prospect holes, determined by NCMD, is aimed at exactly this task solution. At the same time the Customer has the question: "Is it possible to apply the results of the direct pipelines inspection in prospect holes to the entire route length where only NCMD was used?" The answer to this question shoes the degree of responsibility of the experts performing NCMD to the Customer for inspection results. The cost of such complex diagnostics is determined depending on the degree of responsibility.

When speaking about the potentials of NCMD development, the following should be noted.

About 300 thousand kilometers of various process purpose pipelines are operated in Russia. The service life of the majority of pipelines has reached 30 years and longer. The diagnostics of pipelines' condition using in-pipe flaw detectors, which has its own drawbacks, nowadays, covers the minor part of the total pipeline length. Besides, the major part of the pipelines is not designed for passing of in-pipe flaw detectors.

Soil opening to assess the pipelines' condition along their total length, especially in urban conditions, seems to be a complicated and costly operation. As the practice shows, selective prospecting "at random" (for example, every 500 meters as per recommendation of the instructions) is low efficient without assessment of the pipelines' actual stress-strain state. In addition, such selective inspection ensures assessment of only 2-3 % of the total pipeline length.

Appearance of the metal magnetic memory method in the 90-s of the last century and its recognition at the level of national and international standards [4,5,6] as well as the development of non-contact magnetometric diagnostics based on it in the late 90-s and early 2000-created a unique possibility to solve the problem of state assessment (with 100 % coverage) of long pipelines operated on the Russian territory. The considered NCMD technology, born in Russia, is becoming more common in other countries as well. For example, every year Energodiagnostika Co. Ltd. Experts perform contract works on pipelines NCMD in Poland, Czech Republic, Argentina, China and other countries. And LLC RDC "Transkor-K" experts perform such works in foreign countries on a regular basis.

Every year Russian and foreign companies owning many-kilometer segments of gas and oil pipelines, heat and water lines and other pipelines, upon gaining a real hope for the real opportunity to assess their condition using the NCMD technology, put out to tender tens of thousand kilometers of pipelines.

In these circumstances it is necessary to mote the appearance on the service market of diagnostic companies, who, without burdening themselves with the above-mentioned difficulties in NCMD development, in pursuit of profit, offer the customers to quickly solve the problem of pipelines' actual state assessment at a relatively low cost and in a short time. The customers should keep in mind that only the results of additional inspection in prospect holes, preliminarily identified by NCMD, can objectively prove or disapprove the performance efficiency of a diagnostic company.

At this stage it is recommended to require from the diagnostic company experts a Qualification Certificate in the MMM method and NCMD in accordance with Rostekhnadzor PB 03-440-02.

Moreover, the large companies (JSC "Gazprom", JSC "Lukoil", TNK, Rosneft, gas distribution, urban heat and water supplying companies) are recommended to require from diagnostic companies availability of guidance documents describing the NCMD procedure.

The perspective of the NCMD technology development depends, on the one hand, on the efficiency and fairness of diagnostic companies, improvement of instrument complexes and software products for processing of pipeline inspection results and, on the other hand, on increasing of the customer's requirements to diagnostic companies on objective assessment of pipelines' condition based on comparison of the obtained NCMD results with those of the additional inspection in prospect holes using other NDT methods.

Bibliography

1. A.A. Dubov, Al.A. Dubov, S.M. Kolokolnikov. The metal magnetic memory method and inspection instruments. Training handbook. Moscow: "Spectr" Publishing House, 2012. 395 p.

2. V.T. Vlasov, A.A. Dubov. Physical bases of the metal magnetic memory method. Moscow: ZAO "TISSO", 2004. 424p.

3. V.T. Vlasov, A.A. Dubov. Physical theory of the "Strain-failure" process. Part I. Physical criteria of the metal's limiting states. Moscow: ZAO "TISSO", 2007. 517 p.

4. GOST R ISO 24497-1-2009. Non-destructive testing. Metal magnetic memory method. Part 1. Vocabulary.

5. GOST R ISO 24497-2-2009. Non-destructive testing. Metal magnetic memory method. Part 2. General requirements.

6. GOST R ISO 24497-3-2009. Non-destructive testing. Metal magnetic memory method. Part 3. Inspection of welded joints.

Metal magnetic memory method and its capabilities for diagnostics of power boiler elements

Dr., Professor A.A. Dubov

The article considers the reasons of boiler tubes damaging and the existing problems in the diagnostics of these damages at an early stage of their development. Capabilities of the metal magnetic memory method for early diagnostics of developing damages of steam pipes and power boiler waterwall tube bends are presented.

Zones of mechanical stress concentrations (SCZs), in which corrosion, fatigue and creep processes flow the most intensively, are the main sources of heating surface (HS) pipes failure. Stress concentration on some sections is mainly caused by insufficient pipes self-compensation and occurs due to various deviations from the design pipes movement in movable fittings accepted at boilers installation and repairs; increasing of thermal-hydraulic sweep; incorrect installation of repair inserts; pipes jams in repair "dies" and in sites of pipes and coils passing through setting. Timely detection of pipe sections with maximum stress concentration is the main task solved by the diagnostic method based on the metal magnetic memory (MMM) effect.

International ISO Standards on the MMM method 24497-1:2007(E), 24497-2:2007(E) and 24497-3:2007(E) are published. Based on the international standards, national standards were put into effect in Russia, Ukraine, Poland, China, Mongolia, and Iran. In Russia the Russian Technical Supervisory Body (Rostekhnadzor) included the MMM method in the list of basic non-destructive testing methods recommended for application at hazardous industrial facilities (HIF). More than 50 Rostekhnadzor guidance documents for various industries are currently effective, recommending the MMM method for inspection of pipelines, vessels, equipment and structures. TUV Rheinland Inter Cert Kft Certificate (01202 HU/V 11-3420) permitting the MMM method application at HIF was obtained in 2011.

It is known that tubes in "as delivered" condition have a certain level of residual magnetization. In installation conditions the residual magnetization varies and re-distributes under the influence of welding and installation stresses. At operating of boiler tubes the residual magnetization formed during fabrication and installation changes under the effect of working loads.

It was established in the course of special laboratory and industrial testing that re-distribution of residual magnetization and of self-magnetic leakage field (SMLF) H_p respectively on the pipes surface is caused by the action of the magnetoelastic and magnetomechanical effects. It was also established that variation of residual magnetization and of the measured field H_p respectively at tensile, compression, torque and cyclic loading of ferromagnetic pipes is unambiguously associated with the maximum action of operating stresses, which allowed using this parameter as a memory element at development of this diagnostic method.

It is known that pipes stability loss occurs at axial force approaching the critical load value. An elastic pipe deflection occurs, which disappears after axial load relief.

In conditions of a boiler pipe operation a bend with torque occurs, as a rule, on a section with insufficient self-compensation (for example, at jamming in fitting units) at stability loss. An appropriate stress field and shear planes with maximum metal strain occur in the weakened area of such pipe section. Stable slipbands and glide pads appear in the same zone on the pipe surface long before approaching the conventional yield strength of metal. Stable slipbands also occur in cases of local metal overheating due to the lack of self-compensation along the pipe perimeter and wall thickness. The moment of stable glide pads occurrence is associated with internal stresses (tensile or compression stresses) level and orientation. Stable dislocation slipbands, occurring under the influence of repeating in the same place cyclic loads, may develop to channels up to tens and hundreds of microns in depth and width, which will be already visible at the macro level. Development of plastic strain and, as a result, cracks initiation takes place along these channels boundaries.

The many-years experience in magnetic field investigation on boiler and steam pipes revealed presence of stable lines of the H_p field intensity normal component's sign alternation in zones of developing metal damages (H_p=0 lines). Interpretation of this diagnostic magnetic parameter as the main stresses line occurring on pipes surface under the influence of operating loads is confirmed by design investigations [2, 3]. It is obvious that coincidence of H_p=0 lines with welded joints and bends is most dangerous for HS pipes reliability.

For quantitative estimation of stress concentration level the H_p magnetic field normal and/or tangential component's gradient (variation intensity) is determined [4]:

$K_{in}=|\Delta H_p|/\Delta x$ (1)

where K_{in} - is the magnetic leakage field gradient characterized by the intensity of metal magnetization in stress concentration zone (SCZ) and by the H_p field variation intensity, respectively; $|\Delta H_p|$ - is the modulus of the H_p field difference between the two points of inspection; Δx - is the distance between the two points of inspection.

The suggested in the technique criteria allow distinguishing pipe sections operating in the zone of metal elastic strain from sections operating in the zone of metal plastic strain and being in the metal pre-failure state.

As a rule, zero lines of the normal component of the magnetic field (H_p=0 lines) correspond to stress concentration zones, being the sources of damages development. However, in some cases of developed local defects (for instance, corrosion pits) the local variation of the H_p field takes place without sign alternation. The common feature of SCZs and developed defects is an abrupt local variation of the H_p

field and its gradient K_{in}. Zones of maximum SC correspond to zones with maximum values of field gradients K_{in}.

The considered magnetic method of heating surfaces (HS) diagnostics can be used independently and in combination with other destructive and non-destructive inspection methods.

TSC (magnetometric Tester of Stress Concentration) type instruments and specialized scanning devices (SD) manufactured by Energodiagnostika Co. Ltd. are use to perform the inspection of boiler tubes.

Inspection is carried out on the left for repairs or reserve boiler. Special dressing is not required to carry out measurements of the magnetic leakage field intensity (H_p) along the inspected heating surface tube generating lines, but the slag coverage has to be removed.

Two operators carry out inspection. One of them performs scanning with the sensor along the tube surface. Another operator records the measured H_p values in the inspection results registration log.

One operator is allowed to carry out the inspection on condition of safety rules observance and in case the operator has the appropriate qualification and inspection experience.

Let us further consider some examples from the practice of the MMM method application during the diagnostics of boiler tubes and steam pipes.

At present thermal and atomic power stations face the problem of SCZs detection on steam pipe bends, being the sources of damages development.

Figure 1 shows the results of inspection by the MMM method of the extended bend zone 219x19 mm, st.15Cr1MoV. Figure 1, *a* shows the scheme of the bend inspection and figure 1, *b* - the scanning device used for the inspection. Figure 1, *c* presents the magnetogram recorded during the inspection. The upper part of the magnetogram shows the bend's self-magnetic field distribution, and the bottom part - the distribution of this field's gradient.

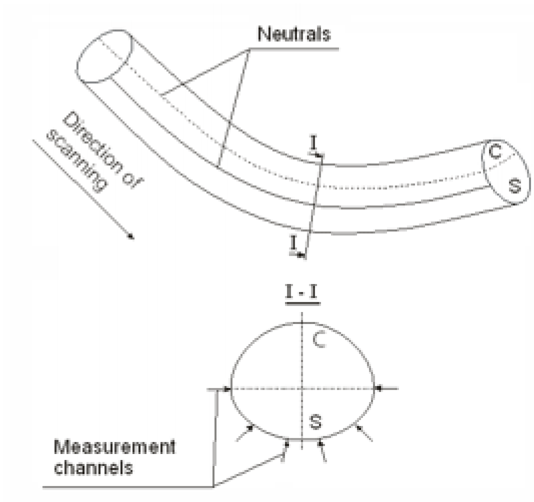


Figure 1*a.*

Figure 1*b.*

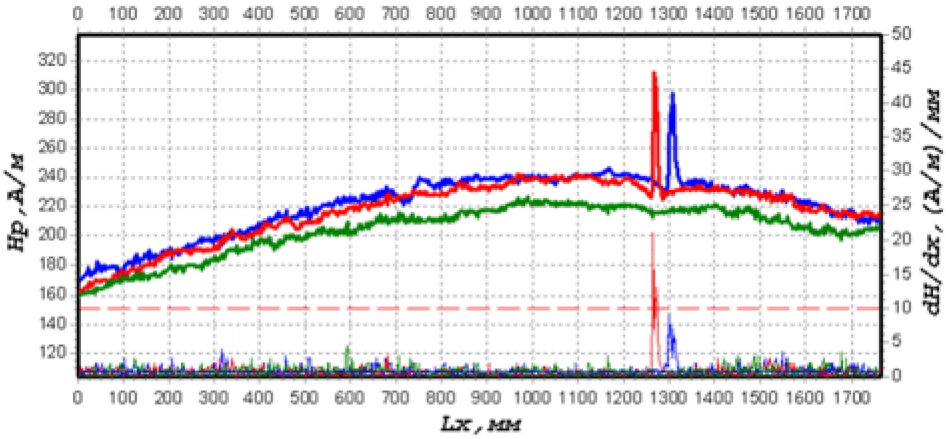


Figure 1*c.*

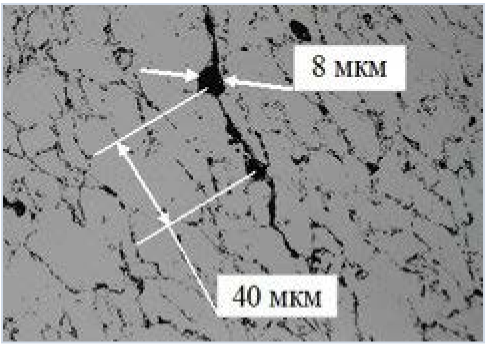


Figure 1*d.*

Figure 1. Results of inspection by the MMM method of the extended bend zone 219x25 mm (st.15Cr1MoV) of a steam-circulating tube: *a* - scheme of the bend inspection; *b* - scanning device used for the inspection; *c* - distribution of the magnetic field H_p and its gradient dH_p/dx along the extended bend generation line; *d* - metal structure recorded in the area of local variation of the magnetic field.

A "replica" for the metal structure analysis was taken from the bend surface in the area of abrupt local variation of the field and its gradient. Figure 1,*d* presents the metal structure recorded in the area of abrupt local variation of the magnetic field. In this case metal grinding to the depth of 100-150 micrometers was carried out to remove the damaged metal layer from the external surface. After removal of the damaged metal layer in the SCZ the bend was admitted for further operation.

Let us consider another example of the MMM method application. A problem of corrosion pits detection on internal heating surfaces of power boilers exists nowadays.

Figure 2, *a* shows the results of a heavy-duty power boiler 60x6mm (st.12Cr1MoV) waterwall tube inspection. Figure 2, *b* shows the tube segment cut out from the SCZ detected by the MMM method. Corrosion pits were detected on the internal surface of the cutout tube segment.

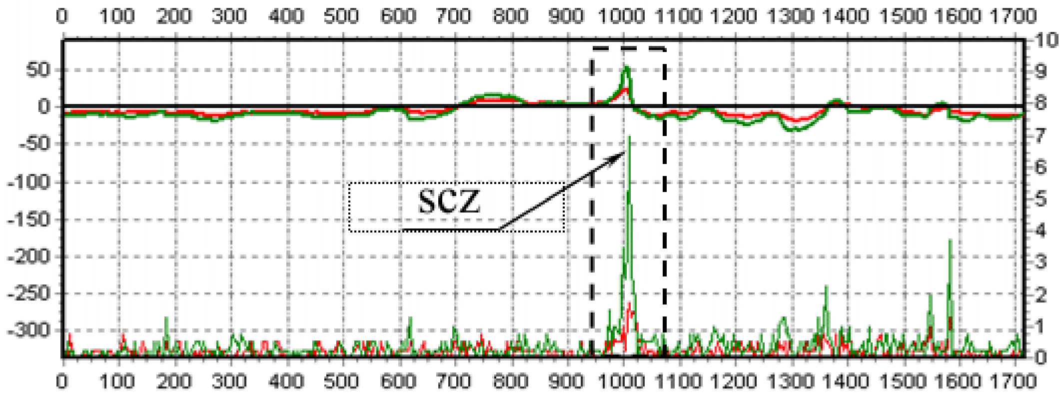


Figure 2*a.*

Figure 2*b.*

Figure 2. Results of the TGMP-206 boiler front waterwall 60x6mm tube inspection.

It is known that gas-proof panels ensure furnace sealing against the cold air suction, increase the area of heating surfaces and thus improve boilers efficiency. However, from the very beginning of boilers operation with gas-proof panels their low maintainability was revealed. In addition, higher sensitivity of gas-proof panels to tube-to-tube thermal and hydraulic unbalancing and especially to local overheating of the metal was revealed in the course of operation. Even minor violations of "water-fuel" or "fuel-air" ratios allowed for conventional boilers can cause mass damaging of gas-proof panel tubes with their failure.

Figure 3 presents the fragment of the rear waterwall gas-proof panel tubes damaging in the form of their mass deflection in the area of field welded joints. Such type of damages was detected by Energodiagnostika Co. Ltd. experts in March 2004 on the gas-proof boiler 525 t/hr, st.No.4 at "Dora" TPS (Iraq).

Figure 3. Mass deflection of gas-proof panel waterwall tubes in the field welded joints area detected on boiler No. 4 of "Dora" TPS (Iraq).

Similar damages are found on gas-proof boilers of electric power stations in Russia.

It is obvious that operation and repairs of boilers with gas-proof panels require higher qualification level of electric power station personnel performing maintenance of these boilers. It is also obvious that the gas-proof panels repair technique requires improvement and application of modern methods of technical diagnostics.

Investigation of gas-proof panels' stress-strain state (SSS) using the MMM method established that over 90% of all SCZs and damages developing in them are located near commercial, field and repair welded joints. Only in some cases SCZs and damages in them occur on tube segments located between welded joints. It was also established that metal damages are located mostly in welding heat-affected zones (HAZ), which are known to be process and structural stress concentrators. The established regularity of tube damages preferred location near welded joints is characteristic of gas-proof boilers, and it seems to be conditioned by their structural features and fundamentally different distribution of stresses and strains at thermal compensation as compared with waterwall tubes that have flexible attachment mounts in every 2 to 4 m along the furnace height. In case of insufficient self-compensation of an individual tube and/or several tubes within a gas-proof panel the distribution of associated stresses and strains occurring on each separate tube is conditioned by mutual impact of mass of tubes rigidly connected with each other inside the panel. And welding HAZ, being the weakest link by strength conditions, are the most susceptible to stresses due to lack self-compensation.

In confirmation of the above said, let us consider an example from the practice of the MMM method application during the diagnostics of gas-proof panels' SSS.

Figure 4 presents the results of individual tubes inspection in gas-proof panels on a boiler 525 t/hr, st.No.4 at "Dora" TPS (Iraq). It can be seen that abrupt increase of the magnetic field H_p and its gradient dH_p/dx was recorded near field welded joints.

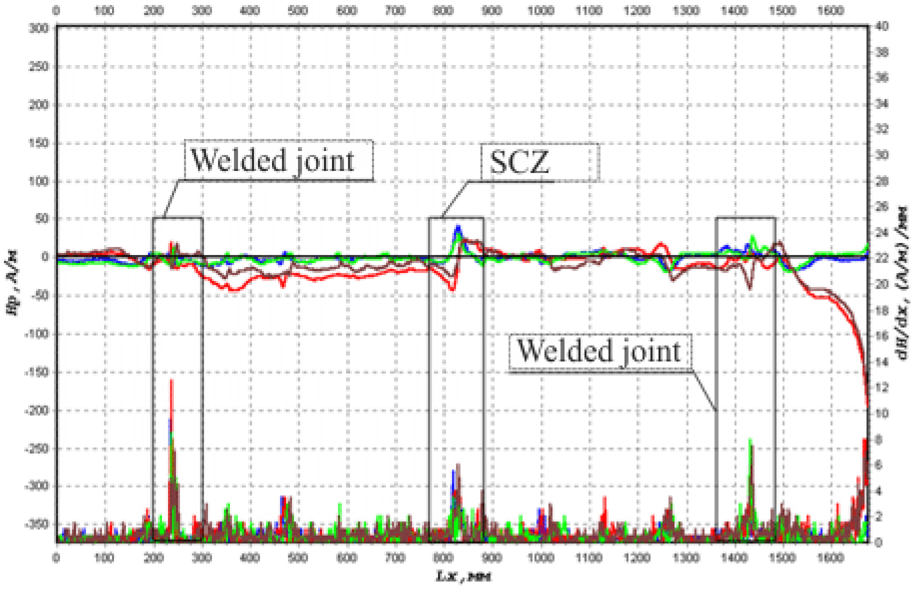


Figure 4*a.*

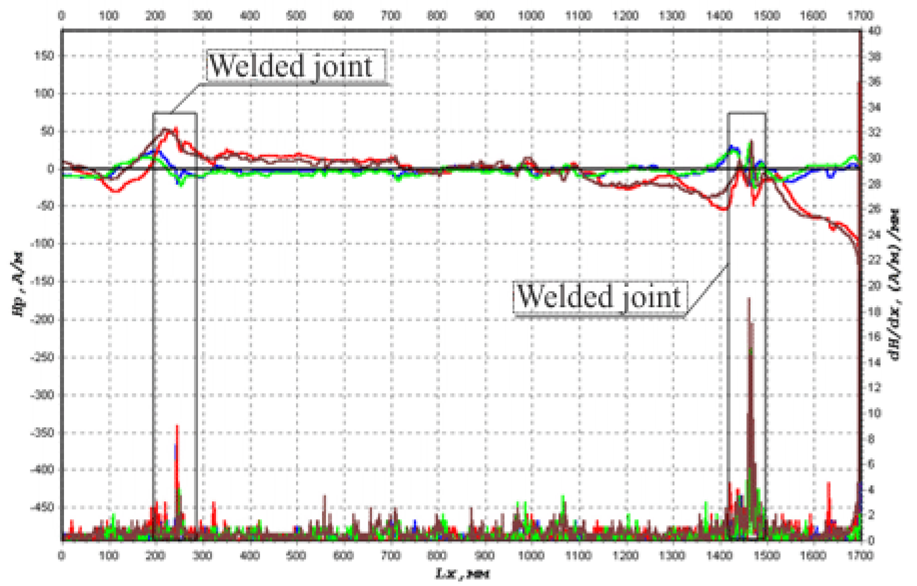


Figure 4*b.*

Figure 4. Inspection results of tube №26 (*a*) and tube №28 (*b*) of the front waterwall at the level of the upper bank of burners of boiler No. 4 of "Dora" TPS (Iraq).

The presented in figure 4 fragments of the magnetic field distribution are characteristic of individual tubes within the panels. By cutting out of specimens and the analysis of their condition, it was established that metal damages develop exactly on tube segments with the maximum value of the magnetic field gradient. The pattern of damages in SCZs located near the welded joints can differ depending on a number of operating factors. Based on the performed investigations of the metal's state of specimens cut out from tube segments with SCZs, it was established that damages can develop both on the internal and on the external surfaces.

Damage in a SCZ develops mainly on the internal surface of a tube in case of low-quality boiler water and on the external surface in presence of corrosive components in furnace gases (for example, at burning of the low-quality fuel and the lack of air). As a rule, on internal tube surfaces damages develop in the form of separate pits or a pit chain (figure 2), and on external tube surfaces damages develop in the form of transverse scratches with frequency divisible by the tube wall thickness.

Papers [5, 6] consider the MMM method's capabilities for solution of various tasks of power boilers' heating surface tubes reliability assurance. In particular, the above mentioned papers [5, 6] consider the MMM method's capabilities for detection of segments with developing damages due to metal overheating, during inspection of welded joints in contact-welded parts and in points of coils welding to headers, at determination of intergranular corrosion on austenite tubes, at detection of jamming sites on tubes and in the support-suspension system of boilers causing the development of damages due to the lack of self-compensation of thermal expansion joints.

In conclusion it should be noted that till date at most of thermal power stations and in boiler-houses in Russia the mass tubes replacement remains the main measure for boiler tubes reliability assurance in case of their damaging. One of the reasons for such an approach to boilers safety and reliability assurance is the lack of efficient methods of early diagnostics of tube segments with developing damages. Based on the long-term experience (over 30 years) of the MMM method application at a number of power and hot-water boilers at electric power stations of Russia, Poland, China, Bulgaria, India and other countries, we can state the efficiency of the method in solution of the above mentioned problems.

Bibliography

1. V.T. Vlasov, A.A. Dubov. Physical bases of the metal magnetic memory method. Moscow: ZAO "TISSO", 2004. 424p.

2. G.V. Vstovsky, A.A. Dubov. Solution of the inverse problem of stress fields calculation on tube walls by magnetic leakage fields based on the non-linear model of the magnetoelastic effect // Zavodskaya Laboratoria, 2000, No.3.

3. V.G. Kuleev, A.A. Dubov, V.V. Lopatin. Zero lines of the normal leakage field on a defect-free tube surface at its elastic bending in any external magnetic field // Defectoscopia, 2002, No.1. pp. 13-26.

4. A.A. Dubov, Al.A. Dubov, S.M. Kolokolnikov. The metal magnetic memory method and inspection instruments. Training handbook. Moscow: ZAO "Tisso", 2008. 363 p.

5. A.A. Dubov. Boiler pipes diagnostics using the metal magnetic memory. Moscow: Energoatomizdat, 1995. 112 p.

6. A.A. Dubov, Al.A. Dubov, S.M. Kolokolnikov. Technical diagnostics of steam and hot-water boiler heating surface tubes the metal magnetic memory: Guidance Manual of Public Administration Institute of Advanced Training, 2006. 110 p.

instruments based on application of the method of metal magnetic memory (MMM method).

Detection of local stress concentration zones in engineering products - the lacking link in the non-destructive testing system

Dr., Professor A.A. Dubov

It is known that the main sources of damaging during engineering products operation are local stress concentration zones (SCZs) that form under the effect of working loads, first of all, on metallurgical and process defects.

Metallurgical and process manufacturing defects are known to cause high level of residual stresses (RS) in local zones of the product. RS control at some productions is performed on a selective basis. In this case the average (volumetric) level of RS is inspected, and local RS zones due to internal defects of the metal, as a rule, are not inspected and omitted. Besides, the location of these local zones and the method of their detection are unknown.

As a rule, RS control during the incoming inspection is not performed. For these reasons, during the very first years of products operation under the working load their "rejection" takes place. Process and metallurgical defects, causing the high level of RS in local zones of products at unfavorable combinations with stresses due to working loads, cause accelerated development of damages.

It is known that conventional NDT methods - X-ray, ultrasonic testing, the eddy-current method, magnetic powder and dye penetrant inspection - are aimed at searching and detection of pronounced defects located primarily on the products’ surface. Internal casting defects, various types of structural inhomogeneity as well as manufacturing process defects (welding, rolling, bending, heat treatment defects, etc.) remain undetected in products due to the lack of 100% quality inspection at most of the plants as well as due to imperfection of NDT methods applied. Moreover, these rejection standards of NDT methods used at products manufacturing plants are aimed at detection of defects with sizes that many times exceed those of metallurgical defects. For example, according to the norms of austenite pipes ultrasonic testing, the sizes of admissible defects do not exceed 25 mm in length and 0,3 mm in opening and depth. As practice shows, metallurgical defects of smaller sizes, when exposed to working loads, are the main sources of operational damages. In conditions of products operation practically all NDT methods are also aimed at detection of various-type discontinuity flaws with sizes significantly exceeding the size of defects that cause the development of damages.

Thus, it must be stated that the lack of RS inspection in order to detect stress concentrations on structural defects of products, both at manufacturing plants and during operation, is the lacking link in system of products NDT, which considerably reduces their safety and reliability.

Figure 1 shows the scheme of engineering products NDT arrangement that formed at present both at manufacturing plants and during operation. It can be seen in figure 1 that products inspection consists in the usual flaw detection without any assessment of stress concentration level on apparent (discontinuity flaws) and implicit (structural) defects. The lacking link in the NDT system is marked with a dotted line in figure 1.

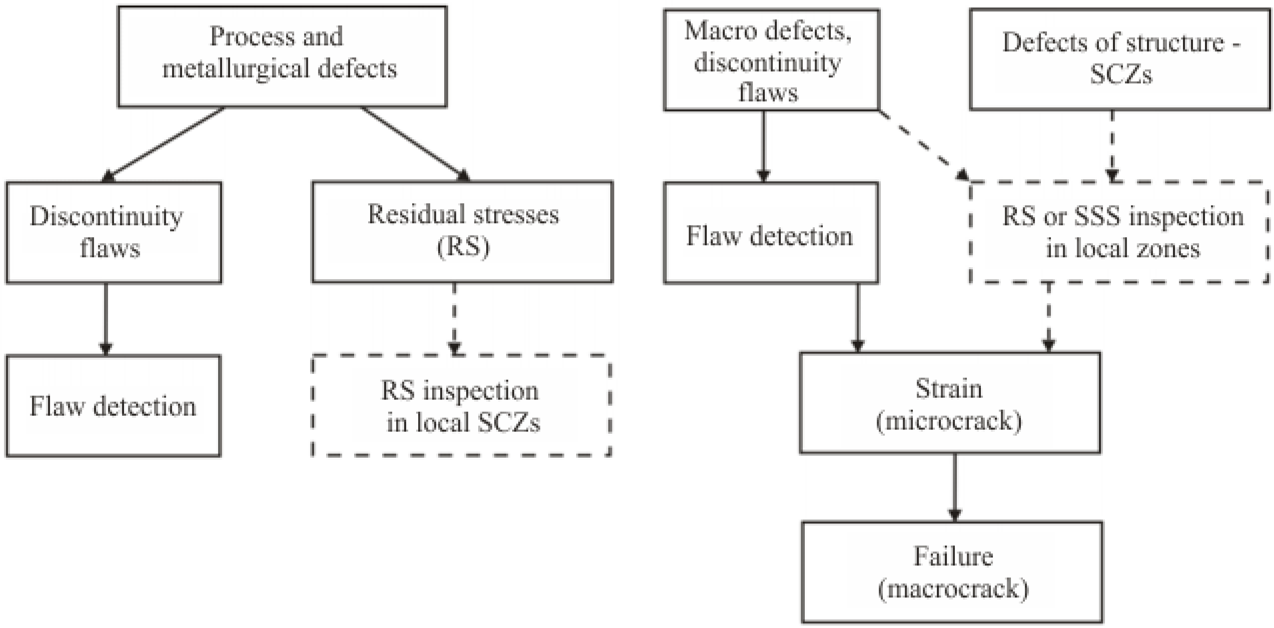


Figure 1. Block diagram of engineering products non-destructive testing at manufacturing plants and during operation.

It should be noted that nowadays, when in most industries equipment and structures became obsolete and worn out, and the material resources are not sufficient for their mass replacement, the value of non-destructive testing and technical diagnostics gains more relevance. In these circumstances the role of quick NDT methods increases in order to ensure 100% equipment inspection and detect local SCZs, in which damages development can be expected in the course of further operation of various technical devices.

In 2008 the National Standard GOST R 53006-2008 "Lifetime assessment of potentially dangerous objects based on quick methods. General requirements" was put into effect.

Passive NDT methods that use the internal energy of structures' metal are referred to quick methods:

- acoustic emission (AE) method;
- metal magnetic memory (MMM) method;
- thermal control.

At present these method have become the most widespread in practice for early diagnostics of equipment and structures damaging. The fundamental difference of such an approach to the lifetime assessment is performance of the 100% IO examination with detection of all potentially hazardous stress concentration zones (SCZs) - the sources of damages occurrence during the equipment operation.

The new National Standard GOST R 53006-2008 also contains the following basic provisions:

- it is suggested to use actual energy characteristics, which can be detected by the MMM, AE and thermal methods, as basic criteria of the metal's limiting state;
- block diagram for residual life determination with focus on modern quick methods is proposed;
- it is suggested to perform verification strength calculations with residual life assessment for SCZs remaining in operation considering the metal's actual structural and mechanical properties determined during the inspection;
- recommendations of the National Standard GOST R 52330-2005 "Non-destructive testing. Stress-strain state control of industrial objects and transport. General requirements" were taken into account.

At implementation of the GOST R 53006-2008 standard it is possible to perform the lifetime expert estimation based on the complex examination of the equipment and to specify safe operation time in most cases without carrying out complex calibration strength calculations. It is possible to develop more specific technique for specific equipment considering the specific features and requirements of this industry.

The metal magnetic memory (MMM) method developed by Energodiagnostika Co. Ltd. (Moscow) becomes more practically implemented for solution of the problem of determination of local SCZs in new and operated products. Russian and International standards on the MMM method are published.

In accordance with GOST R ISO 24497-1-2009 "Non-destructive testing. Metal magnetic memory method. Terms and definitions" the MMM method is a non-destructive testing method based on recording and analysis of distribution of self-magnetic leakage fields (SMLF) occurring on stress concentration zones (SCZs)[1] and of structural inhomogeneity of products. IN this case SMLF reflect the irreversible variation of magnetization in the direction of the effect of maximal stresses due to working (external) loads, as well as structural and process history of products and welded joints after their fabrication and cooling in the magnetic field of the earth.

[1)]One should distinguish the traditional concept "stress concentrator" from the material science concept "stress concentration" occurring on structural defects and in zones of stable dislocation slipbands conditioned by the effect of working loads.

The MMM method differs fundamentally from all known magnetic NDT methods by the fact that its application does not require artificial magnetization of the product, but it uses the natural magnetization and aftereffect that appears in the form of the magnetic memory of metal related to actual strains and structural changes.

The MMM method requires no preparatory works during the inspection and differs from other NDT methods by the fact that it indicates the level of stress concentration, i.e. it indicates the degree of the detected defects' hazard.

Let us further consider the MMM method's capabilities at diagnostics of new and operated products in order to detect local SCZs - the sources of damages development.

Fig.2 shows the inspection results of a new 2222mm (St.05Cr16Ni4Cu2BT13) rod used for fabrication of the shaft of electrical centrifugal pump (ECP) manufactured at LLC "PC Borets" production works (Lebedyan').

Figure 2, *a* shows the distribution magnetogram of the normal component of the self-magnetic leakage field H_p and its gradient dH_p/dx recorded in the stress concentration zone (SCZ) during scanning with the instrument sensor along one of the generating lines of the rod №2204. Figure 2, *b* shows the metal's structural state of the rod №2204 in the section that coincides with the SCZ. Figures indicate the micro hardness values along the line of a metallurgical defect and outside it.

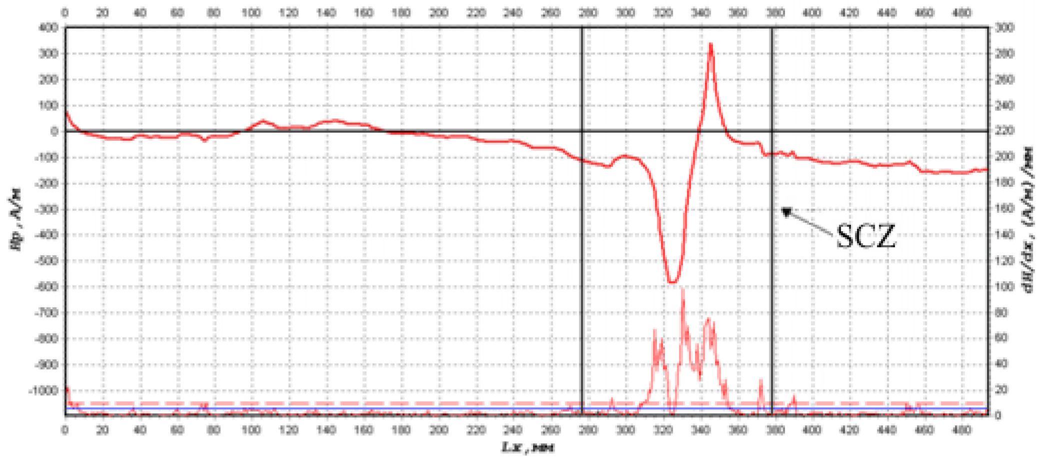


Figure 2*a.*

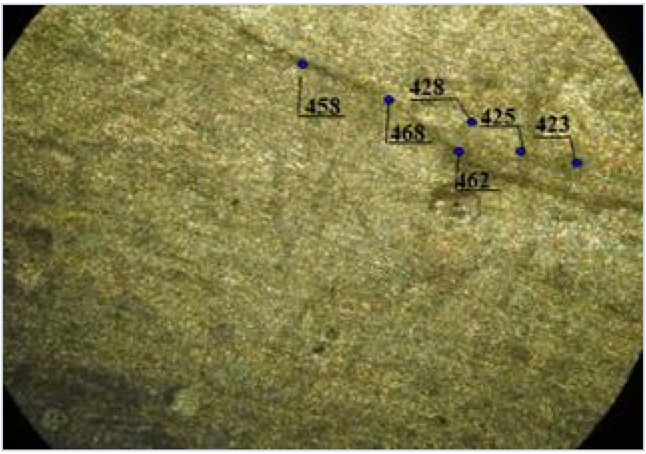


Figure 2*b.*

Figure 2. Inspection results of a new 2222mm (St.05Cr16Ni4Cu2BT13) rod used for fabrication of the shaft of electrical centrifugal pump (ECP) manufactured at LLC "PC Borets" production works (Lebedyan'): *a* - distribution magnetogram of the normal component of the self-magnetic leakage field *H* and its gradient dH_p/dx, recorded in the stress concentration zone (SCZ) during scanning with the instrument sensor along one of the generating lines of the rod №2204; *b* - metal's structural state of the rod № 2204 in the section that coincides with the SCZ. Figures indicate the micro hardness values along the line of a metallurgical defect and outside it.

Figure 3 presents the results of inspection by the MMM method of a new hydraulic turbine blade. Figure 3, *a* shows the distribution of the magnetic field H_p and its gradient dH_p/dx recorded during the inspection along the external surface of the blade. SCZ characterized by local variations of the field gradient is indicated in the bottom part of the magnetogram. Figure 3, *b* shows casting defects detected in the metal depth after cutting of the blade opposite the SCZ recorded by the MMM method on the external surface.

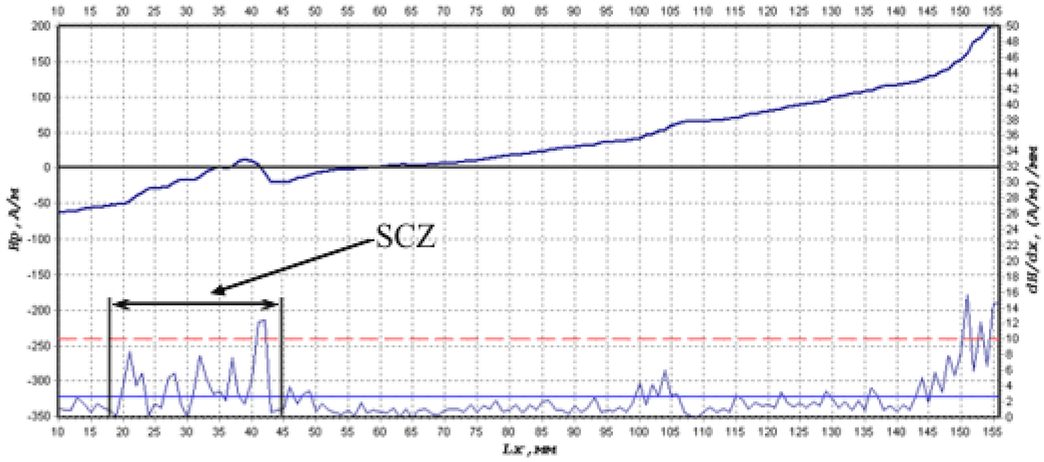


Figure 3*a.*

Figure 3*b.*

Figure 3. Results of inspection by the MMM method of a new hydraulic turbine blade: *a* - distribution of the magnetic field *H* and its gradient *dH*/*dx* recorded during the inspection along the external surface of the blade; *b* - casting defects detected in the metal depth after cutting of the blade.

Figure 4 presents the results of inspection by the MMM method of a 42x7mm pipe of steel 10Cr13G12BS2Ni2Cu2 cut out of the new power boiler platen superheater. Figure 4, *a* shows the distribution magnetogram of the self-magnetic leakage field dH_p and its gradient dH/dx recorded in the SCZ on one of the pipe generating lines. Despite the fact that this pipe was fabricated of stainless steel that should be practically non-magnetic in the initial (as-fabricated) state, however, a ferrite phase, recorded during the inspection by the MMM method as a magnetic anomaly, formed in the local zone due to violations of its manufacturing technology. Figure 4, *b* shows the cracks detected on the internal surface of the pipe cut out from the zone of the magnetic anomaly that corresponds to the SCZ.

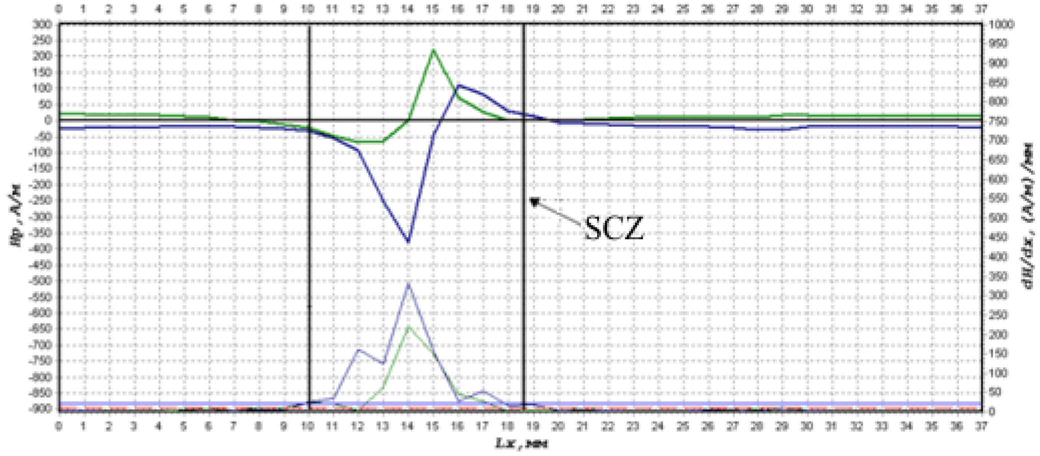


Figure 4*a.*

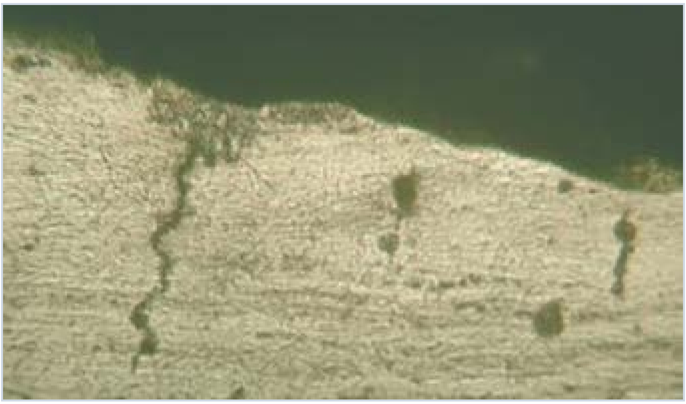


Figure 4*b.*

Figure 4. Results of inspection by the MMM method of a 42x7mm pipe of steel 10Cr13G12BS2Ni2Cu2 cut out of the new power boiler platen superheater: *a* - distribution magnetogram of the self-magnetic leakage field *H* и and its gradient *dH*/*dx* recorded in the stress concentration zone (SCZ) on one of the pipe generating lines; *b* - cracks detected on the internal surface of the pipe sample cut out from the SCZ detected by the MMM method.

The presented in figures 2, 3 and 4 example from the practice of the MMM method application on new products of various productions clearly demonstrate general drawbacks in organization of NDT at manufacturing plants. All the above-mentioned products were tested by the NDT system currently existing at plants. However, as it was noted above, at present most of the manufacturing plants lack the inspection for detection of metal defects beyond the standardized sensitivity limits of the applied inspection methods and means. Application of the MMM method, which reveals metallurgical and technological production defects in the form of magnetic anomalies corresponding to local stress concentration zones, would allow to ensure the 100% products inspection even in mass production.

During operation of engineering products the major sources of damages development are also local SCZs, the formation sites of which are practically impossible to predict by calculation methods. Application of the MMM method offers a unique opportunity to detect the local zones with maximum stress concentration at an early stage by means of performance of the 100% inspection of various equipment units.

For classification of magnetic anomalies, characterizing SCZs by the degree of their hazard in accordance with the technique described in [1], a comparison of all magnetic anomalies detected on a specific unit by the field gradient dH/dx value is performed.

For the same-type equipment units, based on the laboratory and industrial investigations, the limiting value of the field gradient is determined, at which a microcrack is formed and the damage development starts.

In accordance with the definitions presented in paper [2], the physical sense of the magnetic parameter dH/dx is that it reflects concentration (or density) of the magnetic energy in the product's volume conditioned by the strain energy density.

Figure 5 presents the inspection results of a 120 MW steam turbine stage disk rim. Figure 5, *a* shows the magnetogram recorded on the external surface of the disk rim. The upper part of the magnetogram shows the distribution of the tangential *2* and the normal *3* components of the self-magnetic field *H*, and the bottom part shows the distribution of the field gradient from the above-mentioned components. The maximum value of the field gradient 55A/m/mm (or $55x10^3 A/m^2$)turned out to be approximately equal to the limiting state for this turbine disk. Therefore in this case additional inspection by ultrasonic testing was performed. Mounting of the UT transducer on the disk was adjusted to the maximum field gradient value location site. During performance of the UT a discontinuity flaw was recorded in the SCZ on the internal slot surface. After cutting out of the disk segment a 2 mm deep and20 mm long crack was detected on the internal slot surface (see figure 5, *b* and figure 5, *c*).

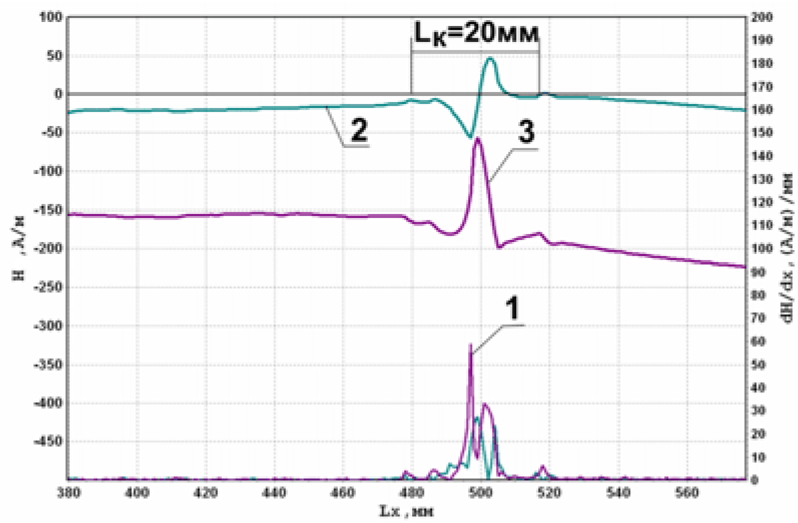


Figure 5*a.*

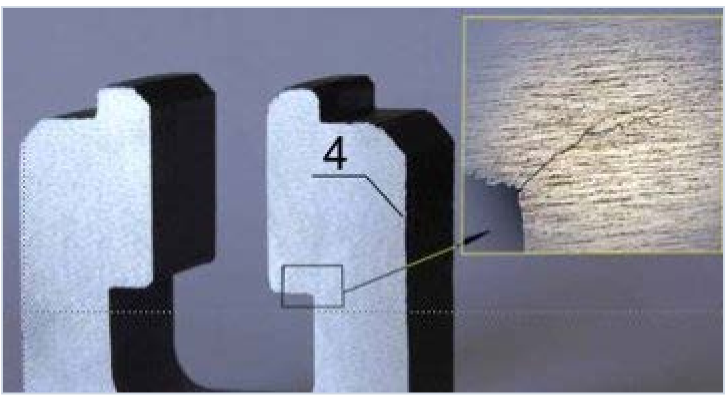


Figure 5*b.*

Figure 5*c.*

Figure 5. Inspection results of a 120 MW steam turbine stage disk rim: *a* -magnetogram fragment recorded on the external surface of the disk rim with upward shift approximately by 45 degree from the crack location on the internal surface of the disk; *b* - location of the detected ~2mm deep crack; *c* - location of the ~20mm long (*lк*) crack along the internal surface of the disk rim; *1* - maximum value of the gradient *dH*/*dx*; *2* - distribution of the tangential component of the field *H*; *3* - distribution of the normal component of the field H; *4* - zone of inspection by the MMM method on the external side of the disk before the fragment cutout.

It should be noted here that at present, in accordance with the effective guideline [3], turbine disks with T-shaped blades attachment are inspected by ultrasonic testing for cracks detection in slots with the use of special specimens, but the inspection itself is a complex practical task. During the performance of the disk rim UT combined with the MMM method the technique of UT signals comparison in the SCZ, pre-detected by the MMM method, and outside this zone can be used instead of a standard specimen. In these conditions standard specimens are not required, and the ultrasonic testing can be performed by an expert with medium qualification.

The considered example of the MMM method application for detection of the local SCZ at an early stage of the damage development clearly demonstrates the significance and efficiency of its application in combination with other NDT methods. The experience of the MMM method application on different equipment under long-term operation in various industries shows that only 5 to 10% of the total metal volume reaches the limiting state (physical ultimate strength) and achieve the stage of damage development. Unfortunately, it is practically impossible to determine these local SCZs - the sources of damages development - by calculation methods. Such problem can be solved using the methods of early diagnostics (the MMM and AE methods).

During the analysis of products fracture mechanism determination of local zone dimensions (volume, area, length), at which the limiting state of the metal and the product itself occurs, is the most valuable. Exactly this challenge, that has so far been the subject of study on specimens in fracture mechanics, is solved using the MMM method directly on the equipment during the diagnostics of various units' condition.

Bibliography

1. A.A. Dubov, Al. A. Dubov, S.M. Kolokolnikov. Metal magnetic memory method and inspection instruments: Training handbook. Moscow: ZAO "Tisso", 2008. 364 p.

2. V.T. Vlasov, A.A. Dubov. Physical theory of the "strain-failure" process. Part I. Physical criteria of the metal's limiting states. Moscow: ZAO "Tisso", 2007. 517 p.

3. Guidelines for service life extension of fleet life steam turbines. Moscow: CPTI ORGRES, 2004. 170 p.

Gas and oil pipelines residual life assessment based on modern methods of engineering diagnostics

Dr., Professor A.A. Dubov (Energodiagnostika Co. Ltd), I.I. Veliulin (VNIIGAZ Co. Ltd)

Ageing of oil- and gas-trunk pipelines places the task of their functioning safety and reliability assurance in the list of the most important state problems. The suggested complex diagnostics is based on assessment of the real lifetime: it most optimally combines the operational experience and the early diagnostics of future damages. Timely replacement of segments with stress concentration zones (5-10% of the entire main length) will allow ensuring the fail-safety of pipelines operation.

The traditional approach to maintaining pipelines operability by performing overhauls of individual sections mainly with complete insulation coating and pipes replacement cannot provide safety and reliability of gas-trunk pipelines because of their long length and distinctly different state. Therefore operation and repair "according to the actual state", i.e. shifting to selective "spot" repairs of elements and sections based on results of a 100% diagnostic inspection of many-kilometers-long pipelines becomes the main strategy for providing high reliability of trunk systems.

In order to ensure reliable and safe operation of gas and oil pipelines, operated for a long time, a concept is proposed, which incorporates the following stages:

- Analysis of damages, non-destructive and destructive metal testing and worn-out sections replacement according to the available statistics of an operating organization.
- A 100% inspection of all gas and oil pipeline sections using up-to-date NDT methods and means (in-pipe diagnostics, non-invasive magnetometric diagnostics, the metal magnetic memory method, acoustic emission) allowing carrying out early diagnostics of damages and detecting stress concentration zones (SCZ), which are the main sources of developing damages.
- Inspection with traditional NDT means (USD, X-ray, metal mechanical properties and structure investigations) is performed on gas and oil pipelines with detected SCZ after the "prospecting" operation.
- A 100% diagnostics of pipes using the scanning devices and instrument-computer complexes, making it possible to carry out the pipes’ state assessment and sorting in the rapid inspection mode during

the planned replacement of insulation.

- A 100% fittings examination using the metal magnetic memory method and other NDT methods.
- Summarizing the results of a complex 100% inspection and developing of measures aimed at assuring gas and oil pipelines reliability with making the schedule of the physically worn-out most susceptible to damaging pipe sections replacement.
- Confirmatory strength calculation taking into account the metal damaging and wear nature of pipelines for certain most stressed sections with SCZ left in operation.

The proposed concept is based on assessment of the real life of gas and oil pipelines since such an assessment most optimally combines the operational experience (former damaging statistics) and the early diagnostics of future damages using the up-to-date methods.

Energodiagnostika Co. Ltd. has more than 12-year experience of gas and oil pipelines inspection using the metal magnetic memory (MMM) method, specialized instruments and scanning devices. This experience is reflected in the Guideline Document GD 51-1-98 "The technique for on-line diagnostics of local gas and oil pipeline segments using the metal magnetic memory method". This Guideline Document was approved in 1998 by "Gazprom" JSC and agreed with the Supervision Agency in the oil and gas industry of the Russian State Technical Supervision Bureau (Rostechnadzor).

During the period from 1998 till 2004 the above-mentioned technique and the appropriate inspection instruments of the type TSC-1M (Tester of Stress Concentration) were used at a number of "Gazprom" JAC and "Transneft" JSC enterprises. In particular, the following enterprises should be noted: Urengoigazprom, Severgazprom, Mostransgaz, Uraltransgaz, Yamburggazdobytscha, STC Nizhnevartovsk, a number of "Transneft" JSC enterprises and others.

It should be noted that the Russian National Standard GOST R 52005-2003 "Non-destructive testing. Metal magnetic memory method. General requirements" on the metal magnetic memory (MMM) method was put in effect in 2003.

For on-line inspection of welds and walls of large-diameter (530÷ 1420 mm) gas and oil pipelines in 2004 Energodiagnostika Co. Ltd. jointly with "VNIIGAZ" Co. Ltd. developed a scanning flaw detector, allowing carrying out the state assessment of the entire pipe surface at an average rate of 200 meters per hour (the scanning rate of 10 meters per minute can be ensured). At that insulation removal and pipe surface dressing are not required and the natural magnetization of the metal, formed in the course of operation (the magnetic memory of metal) is used.

The scanning flaw detector (fig.1) is a device made in the form of two attached to each other rings, on which there mounted 24 flux-gate transducers, integrated with the wheels, allowing the operator to move the scanning device along the pipeline. The operator moves the scanner along the external pipe surface using the spacer rod. At the same time the operator may be directly on the pipe or near the pipe (at a distance of 5-6 m), moving on the ground together with another operator, who watches the inspection results on the screen of a specialized TSC-type (Tester of Stress Concentration, RF Gosstandard Certificate RU.C.37.003 A No.9192) instrument. The scanning device can be used as a set with a laptop-based instrument.

Fig.1. General view of the scanning device covering the entire diameter of a 1420 mm pipe with application of the instrument-computer complex based on the metal magnetic memory method.

For a pipe with the maximum diameter of 1420 mm the distance between the sensors, arranged along the perimeter, is 180 mm. According to the experience of such-diameter gas pipelines inspection, the anomalous magnetic field spot in the area of, for example, a surface stress corrosion crack represents an ellipse with the large axis length up to 500 mm and the small axis length up to 200 mm. Presence of 24 sensors (their number may be increased up to 32) allows reliably covering the entire pipe surface. For smaller-diameter pipes the distance between the sensors is reduced and, accordingly, the inspection efficiency increases.

The basic diagnostic parameter during the inspection of the outer surface of pipes using the MMM method is the gradient dH_p/dx of the magnetic field intensity (or the intensity of its variation) in the zone of stresses and strains concentration due to the development of various-type defects. While assessing the state of the pipeline metal, it is necessary to know the limiting field gradient, corresponding to the ultimate strength of the metal (fig.2). These limiting values are determined in the course of industrial and laboratory investigations. From the positions of fracture mechanics, meeting the limiting state by the metal does not depend on the type of defect causing this state. It is characterized by the integral diagnostic parameter – the density of the mechanical and, accordingly, the magnetic energy on the surface and in the volume of the pipe body [1].

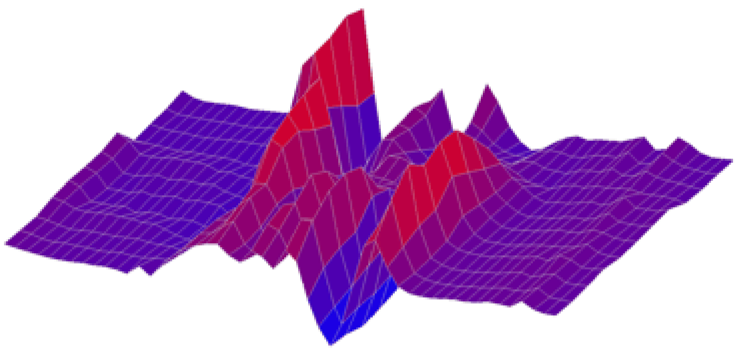


Fig.2. Fragment of the magnetic field H_p distribution on stress corrosion cracks.

The magnetic field gradient, detected automatically in the course of scanning, is displayed on the instrument screen as columns with binding to the number of the sensor on the scanning device (see fig.3, *a*) as soon as it crosses the defected zone.

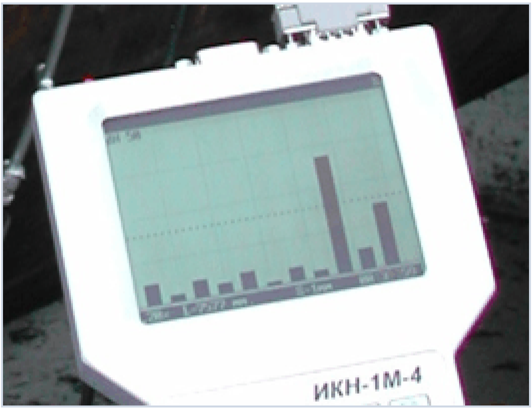


Fig.3*a*. Display of inspection results on the screen of the instrument when the scanning device moves along the pipe surface.

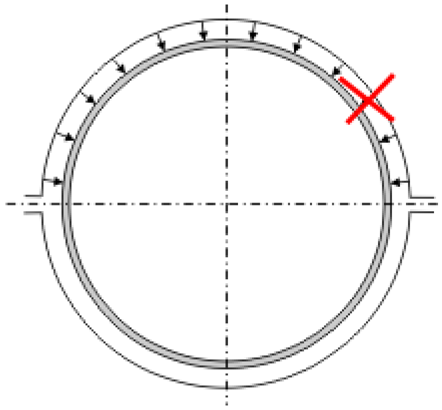


Fig.3*b*. Marking of the defected zone in the pipe logbook.

When the limiting field gradient, which is preliminarily set up during the instrument adjustment, is exceeded along any of the measurement channels, the operator stops, records this area to the instrument's memory and tells another operator to put a corresponding mark on the logbook or directly on the pipe surface (see fig.3, *b*).

The Methodical Guideline (MG) on carrying out the inspection of large-diameter (530÷ 1420mm) pipelines using the specialized scanning devices were developed. This MG specifies the limiting field gradients for the above mentioned diameters of pipes. These gradients characterize the limiting state of the metal by the strength conditions, as well as the initial development of cracks.

The existing experience in inspection using the metal magnetic memory method, the TSC-type instruments and the scanning devices, which do not require any pipe surface preparation, demonstrates the following: pipes, located on the same gas pipeline segment and being in the long-time operation under identical conditions, are in a distinctly different state. If in the course of the inspection no magnetic anomalies are displayed on the screen, it indicates that the pipe metal's state is satisfactory and there are no developing defects on it. At that the inspection speed is not higher than 2 min per 10 m of the pipe length. In case the zones with the magnetic field gradient value higher than the limiting values are detected, all these zones are marked in the pipe logbook according to the described above technique. Then the qualifying inspection using the eddy-current instruments and UFD is carried out in these zones.

It is appropriate to carry out the described above diagnostics of pipes using the scanning devices in the field or factory conditions during the planned replacement of insulation, on open above-ground pipeline segments, during grading of used pipes, as well as before laying of new pipes into trenches.

In order to solve the problem of a 100% inspection of gas and oil pipelines non-invasive magnetometric diagnostics (NIMD), allowing determining the most stressed pipe segments located at the soil depth of 2 m and deeper without artificial magnetization and changing of operating mode, has been developed during the recent years.

Experimental samples of "IAM" instrumentation (development of VNIIGAZ and "Gazpribortechnologia-M" LLC), "MBS" series "SKIF" instruments (development of "Transkor-K" SRC, TSC-3M instruments (development of "Energodiagnostika" LLC) passed route survey and demonstrated their effectiveness. The appropriate reference-legal documents (on NIMD technology of NDT performing) [2, 3] are known.

Energodiagnostika Co. Ltd. developed a measuring complex for NIMD of gas and oil pipelines, located at the soil depth of 2 m and deeper. When the operator moves along the route at a speed of not less than 2 km per hour, the segments operating in the most stressed conditions and being susceptible to damaging are detected. Prospecting and additional inspection are carried out on these segments in order to detect specific defects.

NIMD is based on measurement of the magnetic field of the earth (H_e) distortions due to changing of the pipe metal's magnetic permeability in SCZ and in the corrosion-fatigue damaging development zones. The nature of the field H_e variation (frequency, amplitude) is conditioned by the pipeline strain occurring in it due to the influence of a number of factors: residual process and installation stresses, the working load and self-compensation stresses at outdoor air and environment (soil, water, etc.) temperature fluctuation.

The local variation of the magnetic field by all the three components with the maximum value of the field's gradient (see the bottom part of the magnetogram in fig.4) takes place in the zone of the assumed stress concentration. The inspection was carried out using the magnetometric tester of stress concentration (TSC-3M) and the specialized highly sensitive sensors manufactured by Energodiagnostika Co. Ltd.

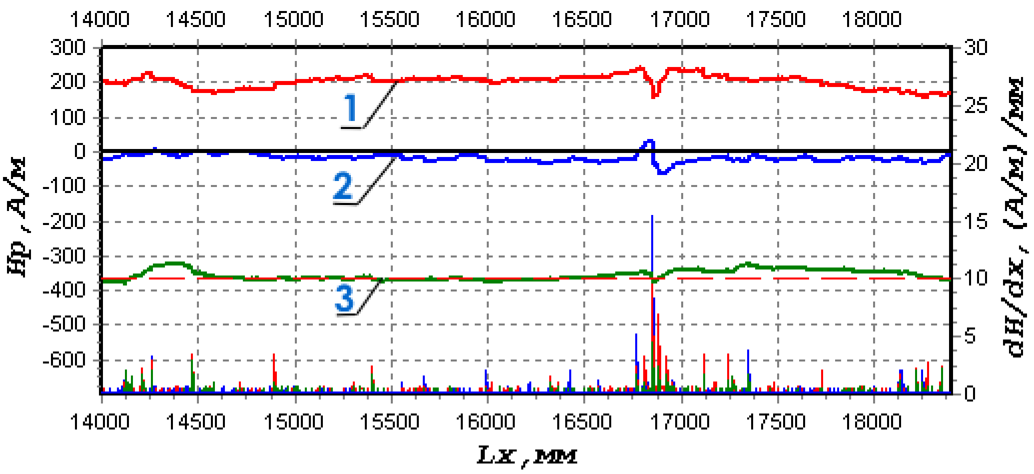


Fig.4. Fragment of the H_p magnetic field distribution in the stress concentration zone on a buried gas pipeline segment (530mm, St.20): 1 - the horizontal component of the H_p field along the pipe axis; 2 - the horizontal component of the H_p field across the pipe axis; 3 - the normal (vertical) component of the H_p field.

The criteria developed based on the 20-year experience of the use of the metal magnetic memory method directly during the inspection of pipelines are used at magnetograms decoding and classification of magnetic anomalies. A program software "MMM-System" is used for processing of the results and detecting of the segments operating in the most stressed conditions.

The Methodical Guideline (MG) for carrying out the non-invasive magnetometric diagnostics of gas and oil pipelines using the TSC-2M-8 and TSC-3M-12 type instruments was developed. The proposed MG contains the description of the NIMD principle, which allows detecting and localizing the stress-strain states, as well as detecting the presence of various-nature damages in the metal of buried and under-water pipelines and of the pipelines exposed to other environments.

The experience of the practical application of the measuring complex with confirmation of the inspection results directly on the pipe after carrying out prospecting ensures that NIMD is efficient "in the hands" of well-trained experts. At present experts in the metal magnetic memory method and NIMD are trained at Energodiagnostika Training Center (Moscow).

Bibliography

1. Vlasov V.T., Dubov A.A. Physical Bases of the Metal Magnetic Memory Method. Moscow: ZAO "TISSO", 2004. 424 p.

2. GD 12-411-01. The instruction for technical state diagnostics of buried steel gas pipelines. Moscow: STC "Promyshlennaya Bezopasnost", 2002.

3. GD 102-008-2002. The instruction for technical state diagnostics of pipelines by the non-invasive magnetometric method. Moscow: "VNIIST" JSC, 2003.

The experience of scanning devices application for quick inspection of operated gas pipelines

Dr., Professor A.A. Dubov, M.Yu. Evdokimov, A.V. Pavlov

A number of outer flaw detecting scanners was developed and manufactured on the instructions of GAZPROM JSC during the period of 2004-2006 for application at diagnostics of gas pipelines in the course of re-isolation and other repair works.

Multi-channel scanning devices (SD) for large-diameter (530÷1420 mm) pipes inspection by the metal magnetic memory method supplied as a set with the TSC-type instruments (Tester of Stress Concentration) were developed for the same purpose.

At present Energodiagnostika Co. Ltd. manufactures three types of SD:

- with full coverage of the entire pipe diameter and with the number of the magnetic field measurement channels from 24 to 32;
- with half-perimeter coverage of the pipe (up to 24 measurement channels);
- with partial pipe coverage on the perimeter length of 300-400 mm (12 measurement channels).

When these SDs are used, the inspection of the entire pipe surface can be carried out at an average scanning speed of 10 m/min. At the same time isolation removal and pipe surface dressing are not required. The method uses natural magnetization of the metal formed in the course of operation (the magnetic memory of metal). A flaw detecting scanner represents a device consisting of two rings, being attached to each other, on which from 24 to 32 flux-gate sensors are installed. These sensors are integrated with the wheels allowing the operator to move the SD quickly along the pipeline. Papers [1, 2] present the general view of the SD covering the entire pipe perimeter. SDs with partial coverage of the pipe surface along its perimeter gained wide practical application. The SC with 12 measurement channels of the magnetic field for inspection of the most damaged pipe area, located near the longitudinal weld at a distance of 200-300 mm to different sides of the weld, can serve as an example of this.

The operator moves the scanner along the outer pipe surface using a distance bar. The operator can be directly on the pipe or near the pipe (at a distance of 5-6 m), walking together with another operator, who watches the inspection results on the screen of the specialized TSC-type instrument (Tester of

Stress Concentration, Certificate of the Russian Technical Regulation body RU.C.34.003.A No.22257). The scanning device can be used as a set with a laptop-based instrument.

The basic diagnostic parameter during the inspection of the outer surface of pipes using the MMM method is the gradient dH_p/dx of the magnetic field intensity (or the intensity of its variation), which is recorded in the zones of developing defects occurring due to stresses and strains concentration. While assessing the state of the pipeline metal, it is necessary to know the limiting field gradient, corresponding to the ultimate strength of the metal. These limiting values are determined in the course of industrial and laboratory investigations. From the positions of fracture mechanics, meeting the limiting state by the metal does not depend on the type of defect causing this state. It is characterized by the integral diagnostic parameter – the density of the mechanical and, accordingly, the magnetic energy on the surface and in the volume of the pipe body [3].

The magnetic field gradient, detected automatically in the course of scanning, is displayed on the instrument screen as columns with binding to the number of the sensor on the scanning device (see fig.1, *a*) as soon as it crosses the defected zone.

When the limiting gradient of the field, set up beforehand at the instrument adjustment, is exceeded on any of the measurement channels, the operator stops, saves this zone in the instrument memory and tells another operator to make the corresponding mark in the logbook or directly on the pipe surface (see fig.1, *b*).

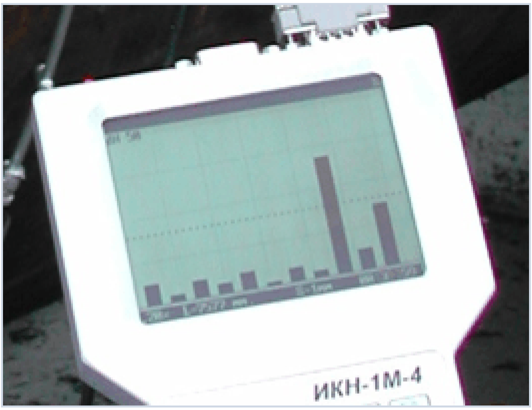


Fig.1*a*. Display of inspection results on the screen of the instrument when the scanning device moves along the pipe surface.

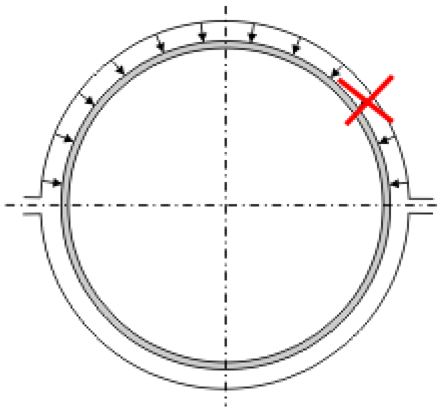


Fig.1*b*. Marking of the defected zone in the pipe logbook.

The Methodical Guideline (MG) on carrying out the inspection of large-diameter (530÷1420mm) pipelines using the specialized scanning devices were developed. This MG specifies the limiting field gradients for the above mentioned diameters of pipes. These gradients characterize the limiting state of the metal by the strength conditions, as well as the initial development of cracks.

The existing experience in inspection using the metal magnetic memory method, the TSC-type instruments and the scanning devices, which do not require any pipe surface preparation, demonstrates the following: pipes, located on the same gas pipeline segment and being in the long-time operation under identical conditions, are in a distinctly different state. If in the course of the inspection no magnetic anomalies are displayed on the screen, it indicates that the pipe metal's state is satisfactory and there are no developing defects on it. At that the inspection speed is not higher than 2 min per 10 m of the pipe length. In case the zones with the magnetic field gradient value higher than the limiting values are detected, all these zones are marked in the pipe logbook according to the described above technique. Then the qualifying inspection using the eddy-current instruments and UFD is carried out in these zones.

It is appropriate to carry out the described above diagnostics of pipes using the scanning devices in the field or factory conditions during the planned replacement of insulation, on open above-ground pipeline segments, during grading of used pipes, as well as before laying of new pipes into trenches.

In 2005 experts of Energodiagnostika Co. Ltd. carried out inspection in winter route conditions of 1695 pipes (1020ммx11mm), operated on the segment of 141-170 km of the Parabel-Kuzbass gas-main pipeline, and 1796 (1020мм) pipes, with thickness of 9,5 and 10,5 mm on the foundry-production section (FPS) in Urga. In 2006 the same method way applied at various objects of Tomsktransgaz Co. Ltd. for inspection of about 3000 pipes with the diameter of 1020 and 1220 mm. The pipes had been in operation for 20 years and longer.

The pipes, on which no unacceptable defects and stress concentration zones - SCZs (the sources of damages) - were detected, were accepted as ready for further operation. The wall thickness of these pipes was within the acceptable limits.

The pipes with the limiting gradient of the magnetic field dH/dx in SCZs, containing various defects (pits on the internal and external surface, lamination of the metal, mechanical damages, etc.) and wall thinning in individual zones by more than 15÷20% were considered as unsuitable for further operation.

As an example, fig.2 and 3 show the magnetograms, characterizing various states of the metal of individual pipes. The magnetogram, shown in fig.2, characterizes the unsatisfactory metal’s state of the pipe #46n. On this pipe in the zone, where the values of the leakage field gradient dH/dx are higher than $15x10^3 A/m^2$, the developing defects in the form of corrosion pits were detected. Fig.3 shows the magnetogram, characterizing the satisfactory metal’s state of the pipe #22n.

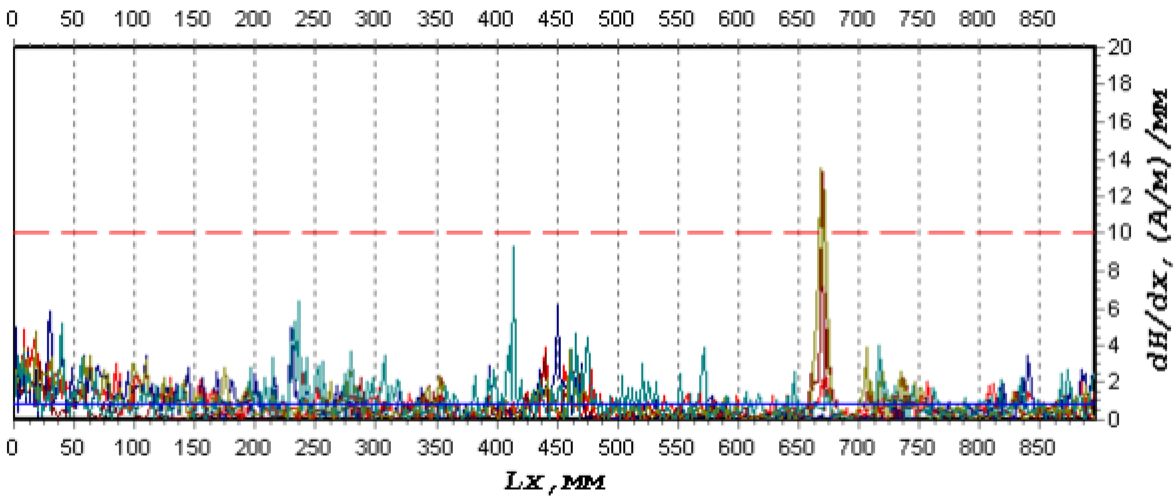


Fig.2. The inspection results of the pipe #46n with pit-like defects at 141-170 km of the Parabel-Kuzbass GMP.

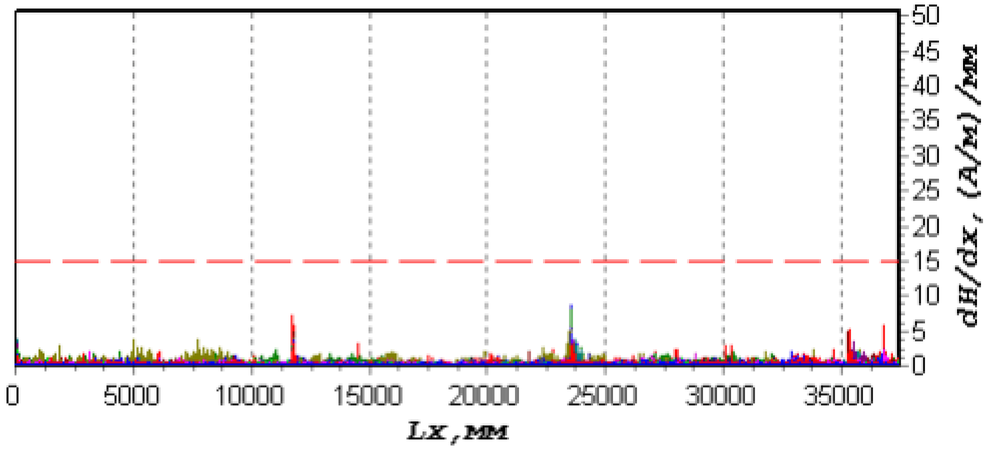


Fig.3. The inspection results of the defect-free pipe #22n at 141-170 km of the Parabel-Kuzbass GMP.

It should be noted that on the above mentioned objects the inspection was carried out with application of the described above scanning devices without removal of the old insulation and without any pipe surface preparation.

In the course of inspection in route conditions 1131 (about 70%) of the inspected 1695 pipes were accepted as ready for re-operation. The obtained results of the quick inspection without insulation removal were further confirmed by other NDT methods after the pipes were cleaned in the course of their laying and re-insulation.

Application of SDs and instruments by the metal magnetic memory method provides the opportunity to present the results of the quick inspection in the pipe layout logbook. Fig.4 shows the distribution of stress concentration zones (SCZs) with the field gradient value dH_p/dx?$5.0x10^3$A/m^2. This pipe layout was obtained based on the computer processing of the inspection results using the "MMM-System" program after transferring to the PC of the data saved in the TSC instrument memory. In fig.4 the isolines of the field gradient with the field value of ?$5.0x10^3$A/m^2 are outlined with thick lines, corresponding to the boundaries of the defected zones.

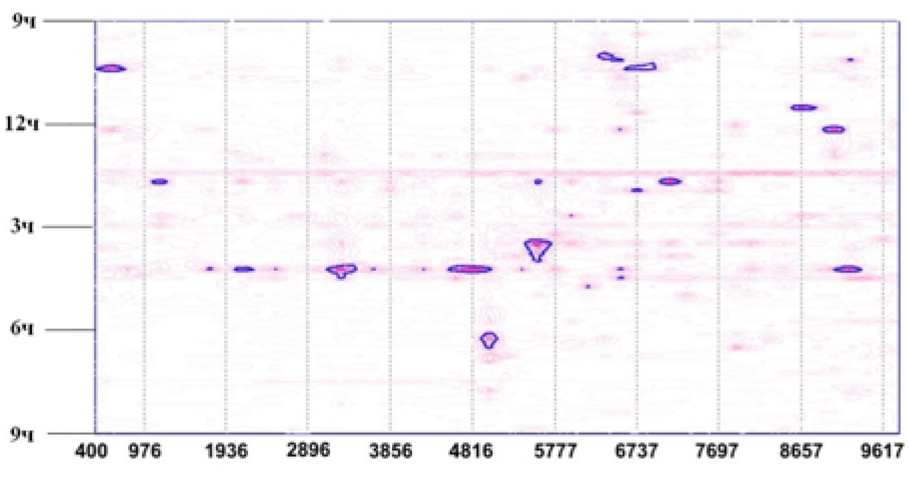


Fig.4. Distribution of SCZs with maximum values of the H_p field gradient (dHp/dx) on the layout of the pipe # 7321 (1020x12mm).

In conclusion the following should be noted.

At present in the experimental-industrial operation of GAAZPROM JSC enterprises there is already a diversity of flaw-detecting scanners by different companies. These devices use magnetic (with artificial magnetization), eddy-current and ultrasonic methods of inspection. However, to our opinion, at scanners certification the commissions of GAAZPROM JSC pay insufficient attention to the most important question - **classification of recorded signals by types of defects and processing of inspection results with binding to the pipe layout**. Exactly the inspection results and their objectivity, i.e. their correspondence to actual defects, should be the basic factor when the effectiveness of various flaw-detecting scanners is compared. This is especially important because till date no standard and classification of signals by the defect type and size exist for any of the inspection types (magnetic, eddy-current, and ultrasonic) for the base metal of gas pipelines!

Based on the great experience in gas- and oil pipelines diagnostics using the metal magnetic memory method Energodiagnostika Co. Ltd. possesses such classification of defects by the parameters of the measured magnetic field and its gradient. Further they have to be normalized. While carrying out the diagnostic works on gas- and oil pipelines during their re-insulation and performing of other repair works with the purpose of their acceptance for further operation during a long period, to our opinion, it is necessary, besides the ordinary flaw detection, to carry out the inspection of the pipes’ stress-strain state (SSS) with detection of SCZs, being the potential sources of damages.

It is also necessary to carry out the inspection of pipelines’ SSS Контроль in connection with putting in operation of the corresponding Russian and International standards. In 2005 based on the International standard ISO 9712 and the European normative documents the RSNDTTD introduced a new type of inspection - "Stress Control" - for the base metal and welded joints. Besides, a new national standard of Russia GOST R 52330-2005 "Non-destructive testing. Stressed-strained state test on industrial objects and transport. General requirements" was put in operation in 2005.

As it is known, the MMM method and the appropriate TSC-type inspection instruments simultaneously perform two tasks:

- inspection of pipelines’ SSS with detection of SCZs (early diagnostics of damages);
- detection of already existing defects.

Application of the MMM method provides the possibility to carry out the assessment of the degree of the defect’s hazard and to answer the question: "Is the defect developing or not?" Such an approach is of principal significance as well at carrying out the engineering diagnostics for risks evaluation during gas- and oil pipelines operation.

Bibliography

1. A.A. Dubov, A.M. Gneushev, I.I. Veliulin. Assessment of gas- and oil pipelines’ residual life based on modern methods of engineering diagnostics // Gazovaya Promyshlennost. 2005. No.2. pp.76-78.

2. A.A. Dubov, V.A. Markelov, V.D. Kotov, Yu.I. Usenko. Inspection and assessment of long gas pipeline segments’ lifetime // Gazovaya Promyshlennost. 2006. No.8. pp.46-48.

3. V.T. Vlasov, A.A. Dubov. Physical Bases of the Metal Magnetic Memory Method. Moscow: ZAO

"TISSO", 2004. 424 p.

Review of welding problems and allied processes and their solving using metal magnetic memory effect

Dr., Professor A.A. Dubov, S.M. Kolokolnikov

The welding exists in the world more than 100 years, however the many problems of a quality control of products welded joints and reliability control of welded constructions, till now take place. Among the most important problems are:

- Low effectiveness of traditional means and methods at stress-strained state control of welded joints and determination of stress concentration zones - the sources of damages development.
- Lack in the general practice of norms on defect size tolerances from the position of fracture mechanics.
- Structure buckling or its shape and dimensions variation due to inhomogeneous heating and cooling at welding.
- Lack of effective non-destructive (NDT) methods of quality control of thermal and other welded joints treatment technologies for residual stresses relief.
- Lack of effective methods of contact welding NDT in products of mechanical engineering; till date in practice detachment testing is conducted by impact at the spot welding location with hammer and chisel.
- Selection of optimum welding technologies, deposits, spraying, is a problem task.
- Low effectiveness of traditional NDT methods at control of contact welding of pipes, fillet and welded T-joints.

One of the important and complex problems of a modern non-destructive testing (NDT) of quality of different types weld joints is the searching and definition in them of "a weak link" in a uniform overall system of the factors "structural-mechanical heterogeneity - flaws of a weld - constructive and technological stress concentrator", i.e. zones with high heterogeneity of the stress-strained state or zones of stress concentration (SCZ). It is important for optimisation of technological procedure both at manufacture of welded joints, i.e. immediately after welding, and at their exploitation.

Traditional non-destructive testing, oriented only at detection of discontinuity flaws in welded joints, cannot provide authentic assessment of their quality. It is difficult for a welding technologist to reveal the reasons of weld unsoundness and improve welding technology based only on NDT results.

In conditions when many factors influence reliability of welded joints, it is necessary NDT method for integral estimate of welded joint metal state.

Now in Russia a principally new method for diagnostics of products metal and welded joints with usage of metal magnetic memory (MMM) is developed at a level of the national standard and successfully applied in various industries.

The MMM method is oriented to solution of the above indicated problems of base metal and welded joints NDT on industrial and transport objects.

Method of metal magnetic memory is non-destructive testing method based on the analysis of distribution of self-magnetic leakage field (SMLF) on components' surfaces for determination of stress concentration zones (SCZ), imperfections and heterogeneity of metal structures and welded joints.

By reading SMLF, reflected residual magnetization, which is formed during welding, the unique opportunity is given us to execute an estimation of an actual state of a weld. And this estimation is integral and represents in each weld simultaneously features of a structural state, distribution of residual stresses and defects of welding.

The forming of magnetic (domain) structure in welded joints occurs simultaneously with crystallization at metal cooling in the magnetic field of the Earth while transiting through a Curie point (768°C) under action of stresses and strains arisen from welding. On arising imperfections of welding the points of domains attachment are formed with an exit on a surface of a weld as self-magnetic leakage fields. Thus, by reading SMLF, which are formed during welding, the opportunity is given us to execute an integral estimation of an actual state of a weld.

The inspection is carrying out by MMM method without dressing of metal and special magnetization. MMM method allows to carry out express quality control of welded joints in a manual both automatic mode at mass production of various products from carbonaceous, austenitic and ferrite-austenitic steel grade.

The inspection is carrying out with usage of the specialized small-sized devices with self-contained power supply, scanning and recording devices. The magnetometric testers of stress concentration (TSC) have no analogues. The devices are manufactured by Energodiagnostika Co. Ltd (Moscow, Russia), are certificated in Gosstandart of the Russian Federation and included in the state register of measuring instruments.

The inspection scheme of butt welded joint is shown on the figure 1. As it is visible from the figure 1, at inspection the ferro-probe converters *1* and *3* is arranged in heat-affected zones (HAZ) from both sides of a weld, the converter *2* is arranged between them in the middle, and the converter *4* is arranged vertically in the opposite direction and intended for tuning out of an external magnetic field.

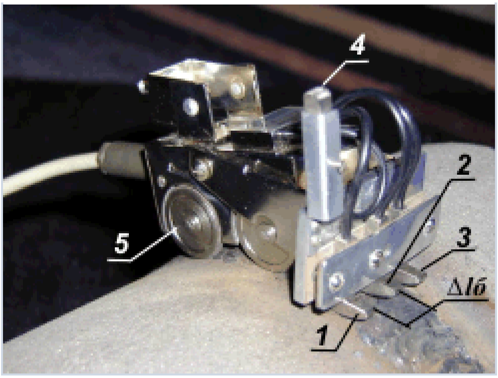


Fig.1. The scheme of monitoring of butt welded joints of tubes by the four-channels sensor of the device TSC-1M-4: 1, 2, 3 - the ferro-probe converters of the scanner for registration of H_p field on a surface of a weld; 4 - the ferro-probe converter for tuning out of an external magnetic field H_p; 5 - driving wheels of the meter of length; ΔL_b - base distance between ferro-probe converters.

Fig.2, *a* shows typical distribution of residual stresses on a welded joint of plates. Fig.2, *b* shows distribution of the tangential component of the magnetic leakage field H_p^x registered at MMM inspection at measurement of the field perpendicular to the weld. These figures show a good qualitative convergence of residual stresses and the magnetic field distributions.

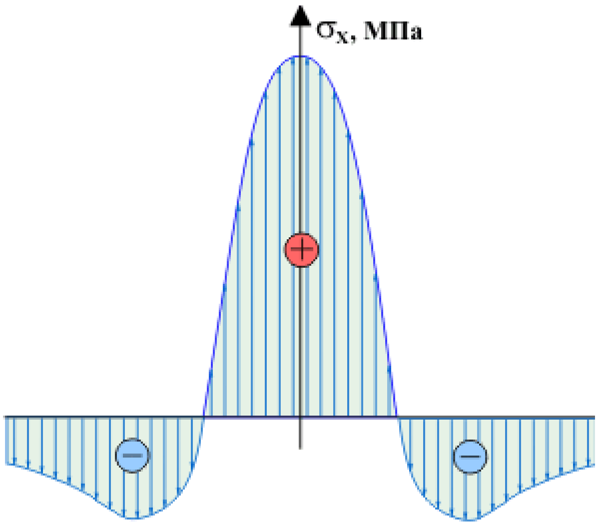


Fig.2 ***a.*** Typical distribution of residual stresses on a welded joint of plates.

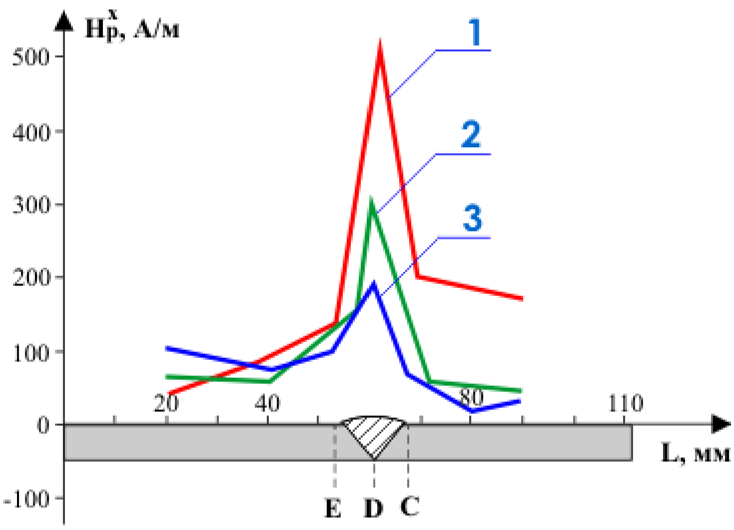


Fig.2 ***b.*** Distribution of the tangential component of the field

H_p^x at measurement of the field perpendicular to the weld: 1, 2, 3 - different sections of the plate.

It is known that the on-line inspection of welded joints heat treatment quality is conducted, as a rule, only by measuring of metal hardness. However, such spot inspection does not ensure the absence of mechanical stresses concentrators across the entire weld and in the regions adjacent to it.

Let us further consider the MMM method effectiveness at quality control of the weld heat treatment on a 220x20 mm pipe length of the 12Cr1MoV type low-alloyed steel grade. Heat treatment was conducted with weld metal heating from the induction coil up to 700°C with subsequent cooling in air.

Fig.3 presents magnetograms characterizing the pipe length's stress-strained state far from the weld (3, *a*) and the weld metal respectively before (3, *b*) and after the heat treatment (3, *c*). The magnetograms were obtained as a result of MLPC measurements along the pipe and the weld perimeter according the scheme presented in Fig.1. From comparison of Fig.3, *b* and 3, *c* it is seen that the magnetogram registered on the weld after the heat treatment turned out to be similar to that registered in the initial state on the pipe surface far from the weld. The experiment shown in Fig.3 suggests a conclusion that a magnetogram measured along the pipe perimeter near the welded joint, where there is no influence of welding, can be taken as a standard reference sample.

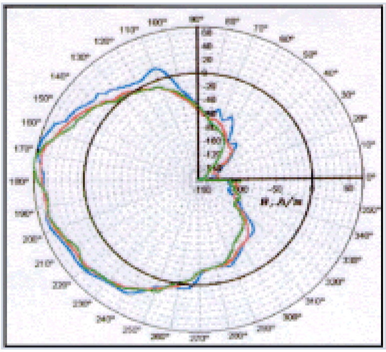


Fig.3 *a*.

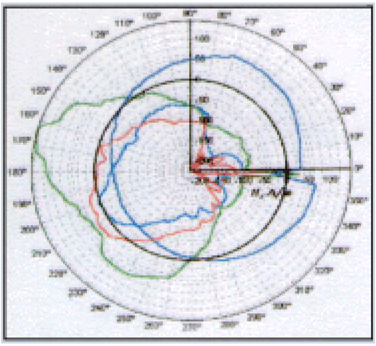


Fig.3 *b*.

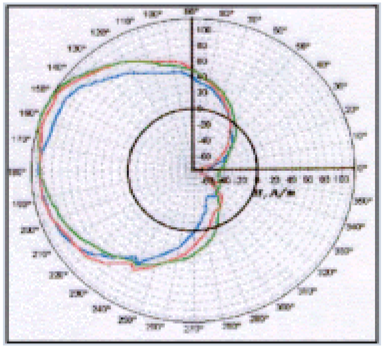


Fig.3 *c*.

Fig.3. Magnetograms characterizing the pipe length's stress-strained state far from the weld (*a*) and the weld metal respectively before heat treatment (*b*) and after heat treatment (*c*).

Fig.4 shows measurement results of the H_p field normal component characterizing distribution of residual stresses and strains after welding of two identical plates. During welding plates were loose and bent slightly upwards. The H_p field distribution in the considered case shows visually the influence of plates geometrical dimensions and their buckling on residual strains and stresses distribution level and pattern.

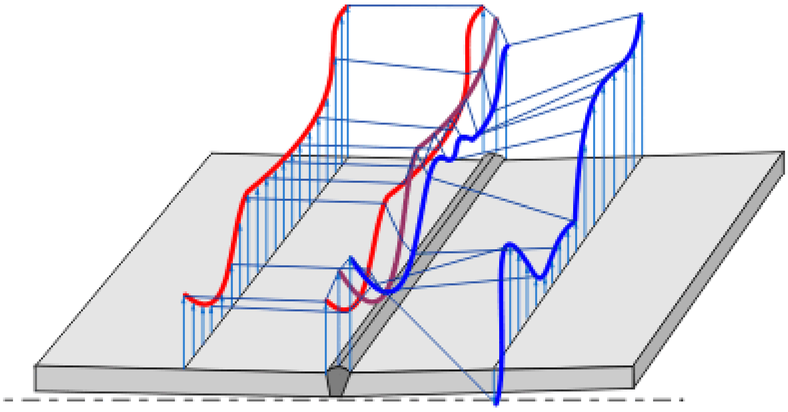


Fig.4.

Fig.5, *a* shows the H_p field distribution on the pipe welded joint registered in heat affected zones (HAZ), and Fig.5, *b* shows distribution of residual stresses measured on the weld by an X-ray diffractometer in the same zones.

The welded joint quality according to the MMM method is assessed by the distribution pattern of the magnetic field H_p and its gradient dH_p/dx where dx is the minimum distance between two adjacent measurement points of the H_p field. The gradient value is determined automatically as a modular difference $|\Delta H_p|$ divided by the discrete distance Δx between the two adjacent measurement points, set at preliminary adjustment of the instrument.

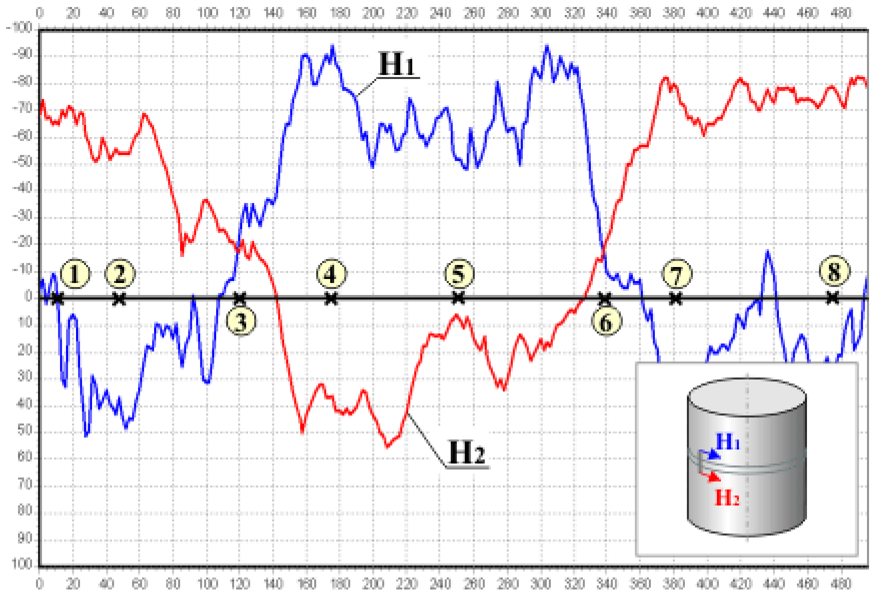


Fig.5 ***a.*** Stressed-strained state of the pipe welded joint (160x8mm, steel 3) according to inspection results by the metal magnetic memory method: H_1 и H_2 - field distribution on first and second measurement channel.

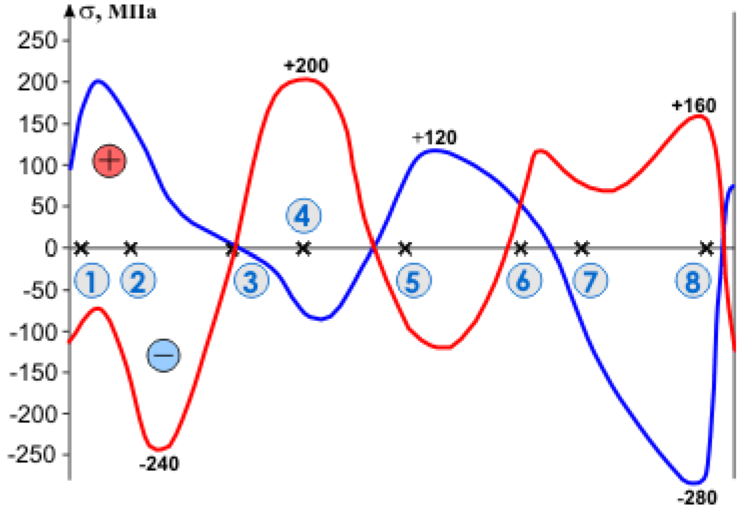


Fig.5*b.* Stressed-strained state of the pipe welded joint (160x8mm, steel 3) according to inspection results by an X-ray diffractometer: 1...8 - points of stress measurement by an X-ray diffractometer symmetrically from two sides of the weld in HAZ; --- results of stress measurement corresponding to H_1; --- results of stress measurement corresponding to H_2.

In the Fig.6, *a* the distribution of the normal component of a field H_p lengthways of the inspected weld segment of the lower floor of the polymerization reactor at the enterprise "Anwil" S.A. (Vlotslavek, Poland) is shown. In the Fig.6, *b* the disposition of detected cracks is marked. In zones of the detected cracks the polar distribution of a magnetic field on channels H_1 and H_2 is recorded. The segment of a SC line (H_p=0) (see Fig.6, *б*) with the maximal gradient dH_p/dx is situated in HAZ of the weld and is the prolongation of the detected crack.

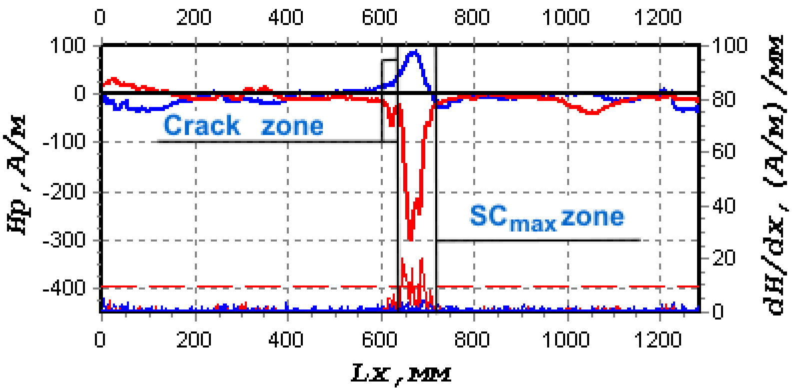


Fig.6*a.* The distribution of the normal component of a field H_p lengthways of the inspected weld segment.

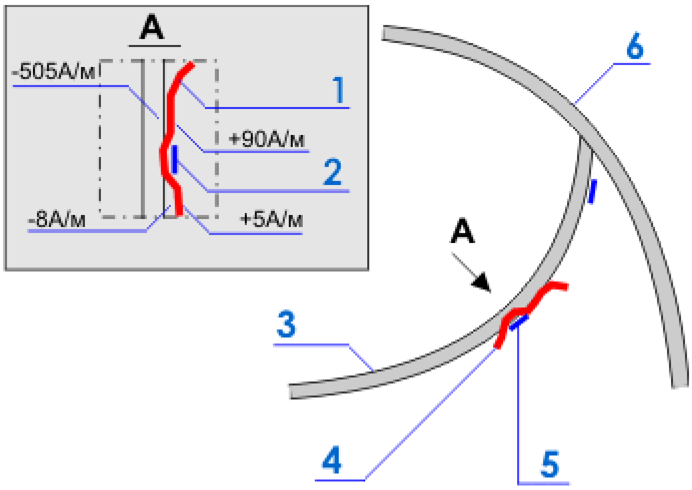


Fig.6 ***b.*** The disposition of detected cracks: 1, 4 - SC line (H_p=0); 2, 5 - crack; 3 - radial weld; 6 - girth weld.

As a result of inspection the following outputs and recommendations were made:

- The crack is an developing imperfection in the direction of the maximal SCZ.
- Removing of metal and welding should be carried out not only in area of detected crack, but also in area of maximal stress concentration for prevention of a crack development while in service.

It is known that the residual strain of the weld metal is formed due to shear plastic strain occurring at crystallization in the course of metal cooling. Diagnostic parameters H_p and its gradien K_{in} (dH_p/dx) owing to "magnetic-dislocation" hysteresis due to duality of the magnetic plane and the glade plane of dislocations, reflect distribution of residual strains and stresses along the welded joint perimeter.

The ratio between limiting values of magnetic parameters m_{lim}, K_{in}^t, K_{in}^y and mechanical characteristics of metal σ_t and σ_y is given in the paper [1]:

$$m_{lim} = K_{in}^t / K_{in}^y \approx (\sigma_t / \sigma_y)^2, \quad (1)$$

where m_{lim} - is magnetic index of limiting strain hardening; K_{in}^t and K_{in}^y - are gradients of a field obtained at tensile test of samples at attainment of the yield strength σ_y and the tensile strength σ_t accordingly.

It should be noted that the ratio (1), obtained in the course of experimental investigations, was confirmed by the design investigations presented in the paper [2], and it is conditioned by the squared relationship of the parameter K_{in} to the magnetic and, accordingly, the mechanical energy accumulated in the metal of a SCZ.

The method of the field gradient K_{in}^t and K_{in}^y determination in industrial conditions is stated in paper [1]. As a rule, the maximum value K_{in}^{max} revealed in certain HAZ, corresponds to K_{in}^t and the average value K_{in}^{ave} calculated for all HAZs revealed at equipment inspection, is conventionally equated to the value of K_{in}^y.

Then the ratio (1) can be expressed as follows:

$$m \quad = K^{max} / K^{ave} \approx (\sigma \quad / \sigma \quad)^2, \quad (2)$$

lim in in max ave

where σ_{max} and σ_{ave} - are accordingly maximal value of stress in SCZ and average value of stress for all SCZs detected at the inspection.

Ratios (1) and (2) were obtained in the course of laboratory and industrial investigations for the base metal. These ratios can be applied to welded joints, except for local stress concentration zones due to welding defects (pores, slag inclusions, poor penetration, etc.).

According to [3], the stress concentration coefficient for a welded joint is equal to:

$K_d \approx \sigma_{max} / \sigma_{ave}$, (3)

where σ_{max} - are maximum stresses in HAZ; σ_{ave} - is an average stress in a welded joint.

Paper [3] gives evaluation of K_d:

- 2÷3 for pores;
- 3÷10 for slag inclusions;
- 10÷100 for cracks, undercuts and poor penetration in the weld root.

It is obvious that ratios (1) and (2) can be also used for local HAZs due to welding defects with correction for defect dimensions and depth of their bedding.

Here it is important to point out the delusiveness in the existing approaches of various inspection means developers at assessment of residual stress distribution in welded joints. As a rule, according to the results of the inspection by various methods (strain measurement and interferometry with metal drilling, X-ray, UT, Barkhausen effect, the magnetic anisotropy method, etc.), the level of residual stresses on welds does not exceed the yield strength σ_y, which, as a rule, does not correspond to the actual distribution of stresses.

As the practice shows, the level of the directed residual stresses (normal or tangential) in a SCZ may meet 1000 MPa and greater. This stress level may have much greater values in the zones of the developing welding defects and cracks. These practical observations clearly confirm the results of welded joints inspection by the MMM method in a SCZ and outside it combination, for example, with hardness measurement and conversion of its results to stress units. For example, the level of "contact" stresses measured with hardness gages at MEI in SCZs, detected by eth MMM method, often met 1500 MPa and greater. One should keep in mind that strains and stresses are volumetric and have at least three components (radial and two tangential) in each inspection point.

Distribution of SMLF in each inspection "point", measured with three-component sensors with the accuracy up to 1 mm on the weld metal surface and in HAZ, according to the available technique, directly reflects the triaxial distribution of residual stresses and strains. At that it isn't important to know the level of absolute stresses (though this problem is solved in the MMM method!), but their distribution to the depth and along the surface. And the most important thing is, at the same time, not to allow the limiting state of the metal before the crack formation.

Now in Russia the method of metal magnetic memory has obtained wide development:

- More than 45 guiding documents and techniques for inspection of equipment in different industries are developed.

- Three standards of Russia are approved: GOST R ISO 24497-1-2009 "Non-destructive testing. Metal magnetic memory method. Part 1. Terms and definitions", GOST R ISO 24497-2-2009 "Non-destructive testing. Metal magnetic memory method. Part 2. General requirements", GOST R ISO 24497-3-2009 "Non-destructive testing. Metal magnetic memory method. Part 3. Inspection of welded joints".

The International Standard ISO 24497-1, 24497-2, 24497-3 on the metal magnetic memory method is approved in 2007 as a result of positive voting among 18 IIW member countries and more than 10 ISO Committee countries.

Reference

1. Dubov A.A., Dubov Al.A., Kolokolnikov S.M. Method of metal magnetic memory and inspection devices. Training handbook. Moscow: ZAO "TISSO", 2008. 365p.

2. Vlasov V.T., Dubov A.A. Basis physics of the metal magnetic memory method. Moscow: ZAO "TISSO", 2004. 424p.

3. Fedorov S.A. Quality control of welded and soldered joints. Training handbook. Moscow: MATI, 1989. 201p.

Diagnostics of oil-production drilling rig units and components using the metal magnetic memory method

A.A. Dubov, Al.A. Dubov, A.A. Sobranin

One of the reasons for oil-production plant components and units damages occurrence is imperfection of non-destructive testing methods used both at manufacturing plants (starting with rough parts) and during their operation.
The article presents the experience of the metal magnetic memory method application during early diagnostics of damages on new and used components of oil-production plants.

At present periodical damages of individual most loaded units and components occur on oil-production plants due to unfavorable combination of process manufacturing defects with operation conditions.

It is known that conventional NDT methods: X-ray, ultrasonic testing (UT), eddy-current method, magnetic particle method, dye penetrant method are aimed at searching and detecting of express defects located mostly on the products' surface [1].

Internal casting defects, various types of structural inhomogeneity as well as process manufacturing defects (defects of welding, rolling, bending, heat treatment, etc.) still remain undetected in products due to the lack of 100% quality control of products at most of manufacturing plants and also due to imperfection of NDT methods applied.

It is known that process manufacturing defects and metallurgical defects form high level of residual stresses (RS) in local zones of a product. RS control at some enterprises is performed selectively. This procedure controls the average (volume) level of RS, and the local RS zones formed due to internal defects of the metal, as a rule, are not inspected and ignored. Besides, it is not known where these local zones are and how they can be detected.

As a rule, enterprises operating the newly supplied engineering products do not perform at all or perform partial acceptance inspection by conventional NDT methods. And it is a common practice that RS control during the acceptance inspection is not carried out. For these reasons "screening" of products due to exposure to the working load takes place during the very first years of operation. Process and metallurgical defects cause accelerated development of damages by forming the high level of RS in local zones of products at unfavorable combinations with stresses due to the working load.

Nowadays the metal magnetic memory (MMM) method developed by Energodiagnostika Co. Ltd.

(Moscow) becomes more and more widespread in practical application during solution of NDT problems in new products and detection of local RS zones in them. There are Russian and International Standards on the MMM method [2, 3].

In accordance with GOST R ISO 24497-1-2009 "Non-destructive testing. Metal magnetic memory method. Part 1. Terms and definitions", the MMM method is a non-destructive testing method based on recording and distribution analysis of self-magnetic leakage fields (SMLF) occurring in stress concentration zones (SCZs)[1)] and of products' structural inhomogeneity. SMLF reflect irreversible variation of magnetization in the direction of action of maximum stresses due to working (internal) loads as well as structural and process history of products and welded joints after their fabrication and cooling in the magnetic field of the earth.

[1)] One should distinguish the conventional concept "concentrator of stress" from the material science concept "stress concentration" occurring in zones of stable dislocation slip bands formed under the effect of working loads.

The principal difference of the MMM method from all known magnetic NDT methods is that it during its application no artificial magnetization of a product is required. The method uses the natural magnetization and after-effect displayed in the form of the magnetic memory of metal relative to actual strains and structural changes.

During non-destructive testing the MMM method fulfils two tasks simultaneously.

The first task consists in detection of defected areas on the internal and external surface of a product with their further classification, i.e. performance of a usual flaw detection task.

The second task consists in carrying out of the metal's stress-strain state inspection in products and welded joints and detection of stress concentration zones - the sources of all types of damages at an early stage of their development.

Moreover, the MMM method does not require any preparatory works during the inspection. Its difference from other NST methods is that it indicates the level of stress concentration, i.e. indicates the degree of hazard of the detected defects.

The features of the MMM method during the diagnostics of oil-production drilling rig individual units and components are considered below.

Figure 1 shows the photo of a borehole (stator) pipe section. The stator has a female (internal) thread on both sides. In the course of operation annular cracks form at internal thread start points under exposure to loads.

Figure 1. Borehole section (pump stator), female thread end view. SD (scanning device) is connected to the TSC type instrument.

A batch of new stators was inspected using the MMM method at an oil wells drilling fabrication yard. The inspection was carried out by moving a scanning device connected to a TSC type (Tester of Stress Concentration) instrument along the external generating lines of the pipe (figure 1). If under such inspection pattern an abrupt local variation of the magnetic field was recorded in any place of the pipe along its length, then the additional inspection was carried out along the pipe perimeter. Figure 2 presents the magnetogram recorded during the inspection along generating lines with one of the new stator sides. The results of inspection by the MMM method, presented in figure 2, characterize satisfactory state of the new stator.

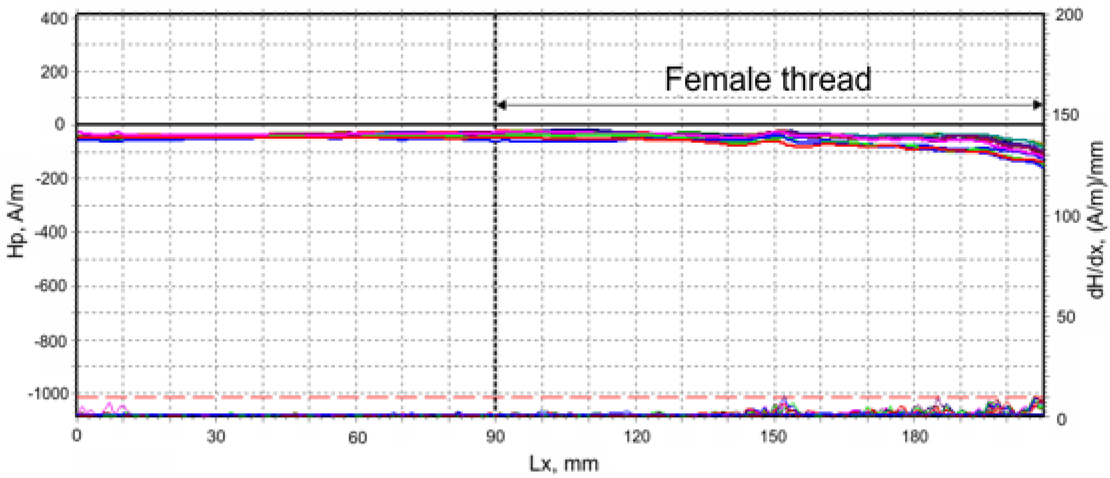


Figure 2. Magnetogram recorded during the inspection along generating lines with one of the new stator sides.

Figures 3, *a* and 3, *b* show the inspection results of another new stator with another works (serial) number. The inspection was carried out under a similar pattern. It can be seen in figure 3 that the magnetic field H_p and its gradient *dH/dx* display abrupt local variation in the female thread start area of the new stator. The polar magnetogram (figure 3, *b*) shows that there are abrupt local variations of the field in two diametrally opposite zones. According to the technique, these zones correspond to residual stress concentration zones (SCZ 1 and SCZ 2) formed during fabrication of this stator. Formation of annular cracks in SCZ 1 and SCZ 2 can be expected on this stator during its operation under load. These are exactly the stator areas where annular cracks on first turns of female thread are frequently detected during operation or preventive maintenance.

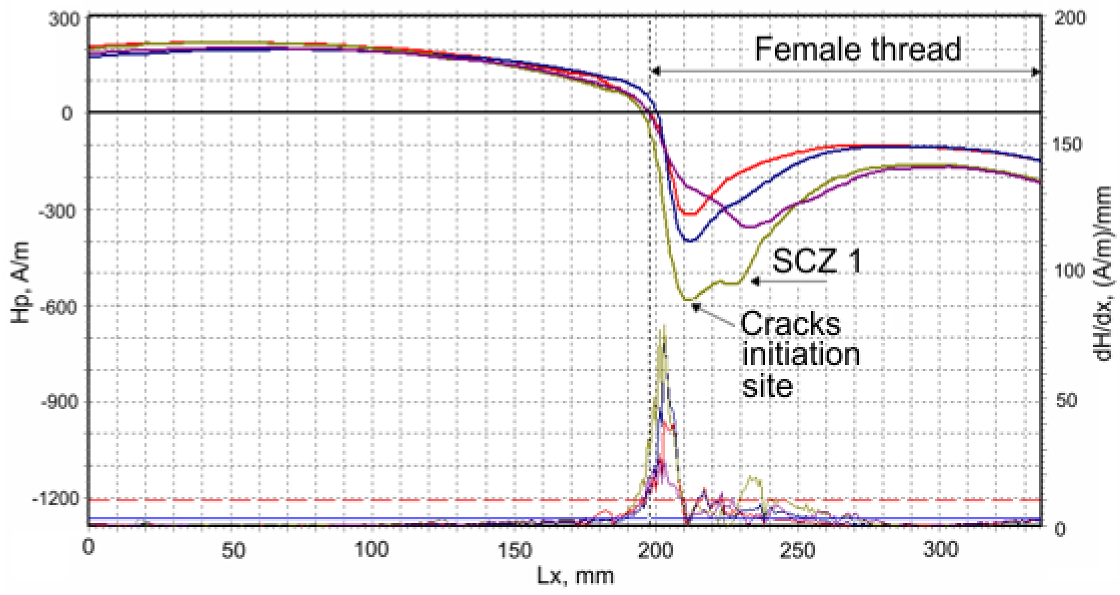


Figure 3*a*. Results of inspection by the MMM method of a new stator with detected zones of residual stress concentration (SCZ 1 and SCZ 2). Magnetogram recorded during the inspection along generation lines with one of the stator sides

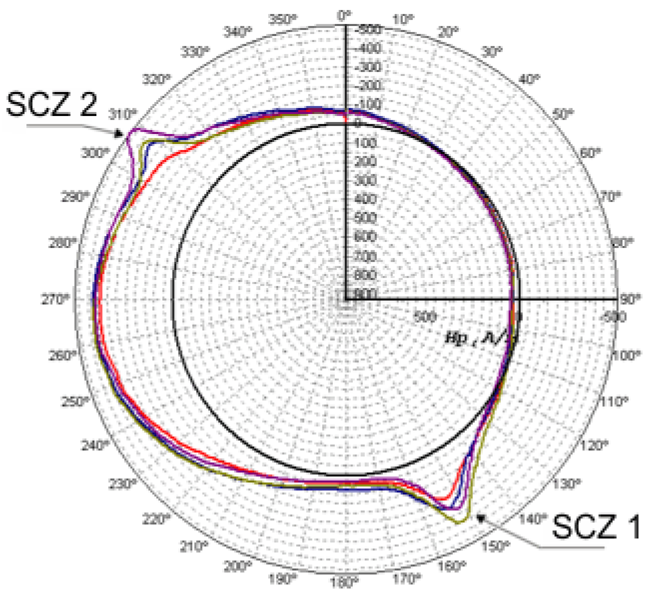


Figure 3*b*. Results of inspection by the MMM method of a new stator with detected zones of residual stress concentration (SCZ 1 and SCZ 2). Magnetogram recorded during the inspection along the perimeter in the section located opposite to the female thread border.

To prove the above stated, figure 4 shows the results of inspection by the MMM method of a used stator. It can be seen in figure 4 that an abrupt variation the magnetic field and its gradient is recorded in the crack initiation site.

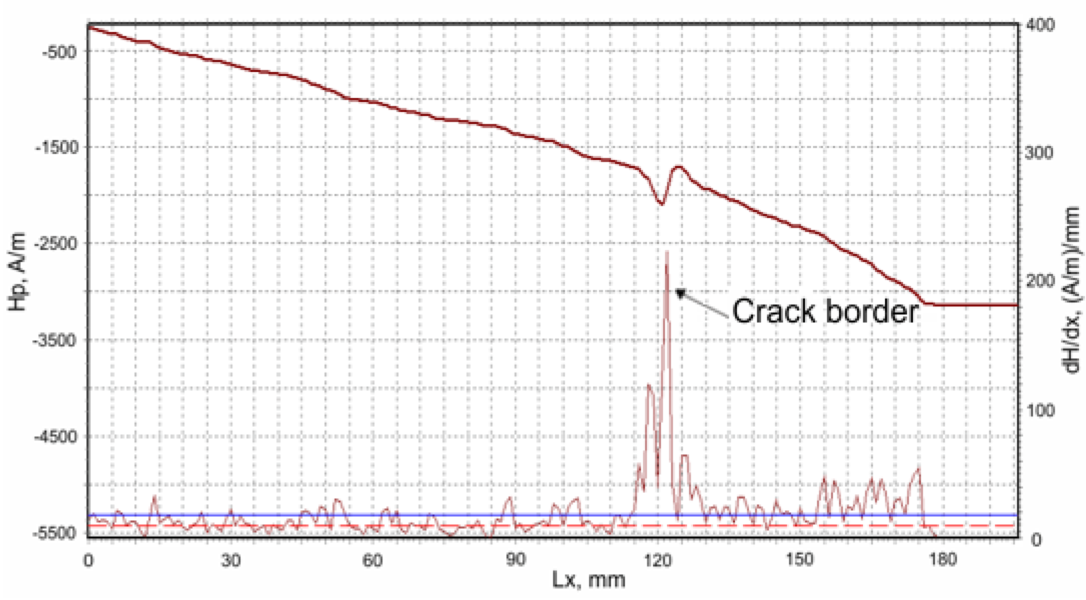


Figure 4. Magnetogram recorded during the inspection along the cracked stator's generating lines.

Let us further consider the results of inspection by the MMM method of restrictors (limiters) used to change the cross-section and, accordingly, to change the flow rate of the moving medium inside the drilling rig. Figure 5 shows the general view of a restrictor; the direction of inspection by the MMM method is indicated with arrows on the restrictor casing. The casing also indicates the crack formed in the course of the restrictor operation.

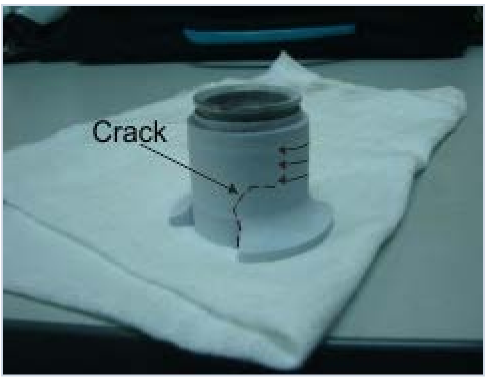


Figure 5. General view of a restrictor with a surface crack.

Figure 6 shows the scheme of inspection with the SD integrated in a special device. Turning of the restrictor by 360 degree around its axis provides recording of self-magnetic field distribution along the restrictor's perimeter in section coinciding with arrangement of the SD sensors.

Figure 6. Scheme of a restrictor inspection using a SD integrated in a special device.

Figure 7 presents the results of new restrictors inspection by the MMM method. Figure 7, *a* shows the magnetogram recorded during the inspection along the perimeter in the bottom (fillet) part of the model No.6 restrictor. The SCZ recorded on this restrictor coincides with structural stress concentrator - the site of abrupt variation of the base shape. Figure 7, *b* shows the magnetogram recorded during the inspection in the bottom part of the model No.7 restrictor, which characterizes its satisfactory state.

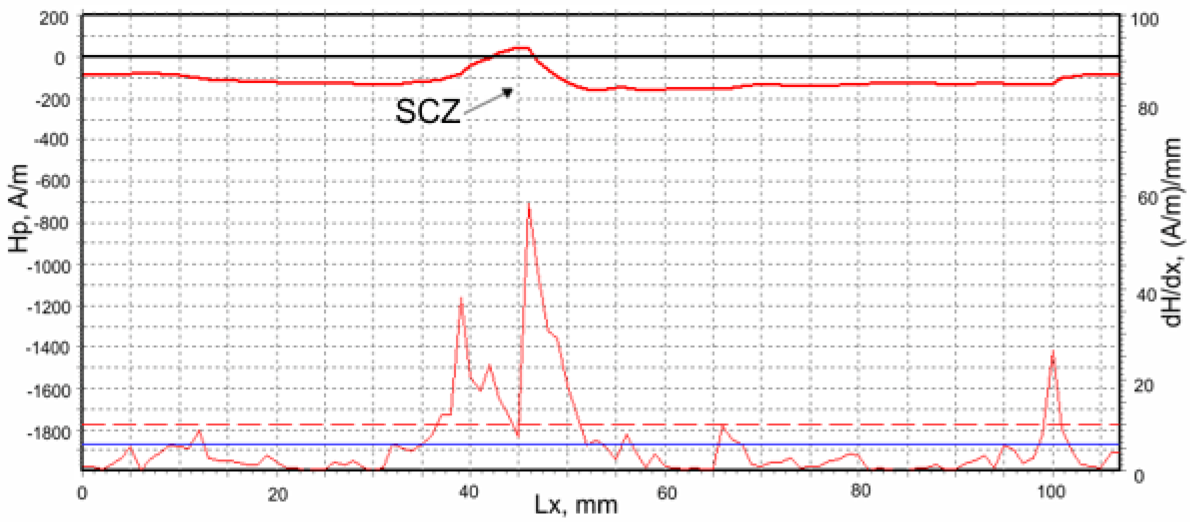


Figure 7*a*. Magnetogram recorded during the inspection along the perimeter in the bottom (fillet) part of the model No.6 restrictor

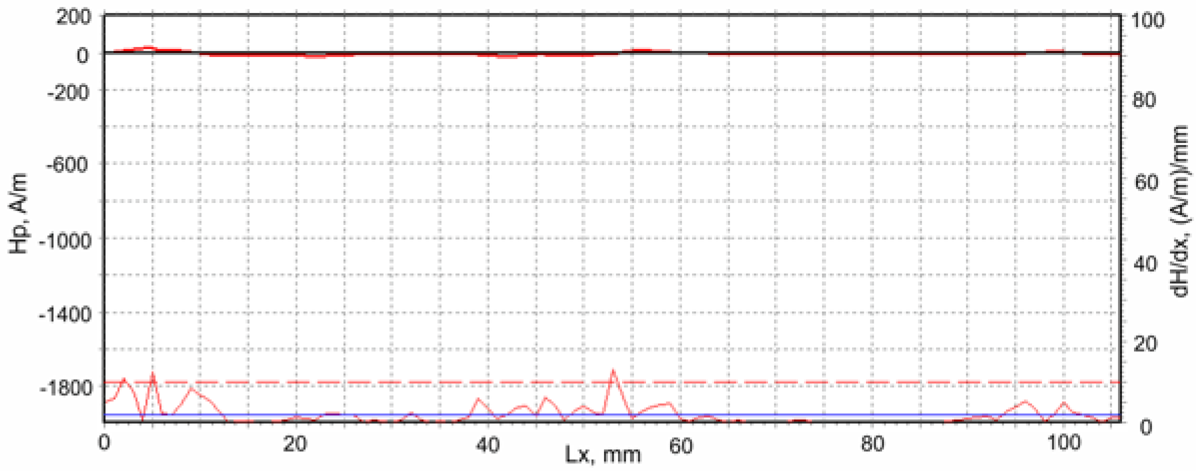


Figure 7б. Magnetogram recorded during the inspection along the perimeter in the bottom (fillet) part of the model No. 7 restrictor.

Similar results of inspection by the MMM method were also obtained on other oil-production plant unit and components: fishing heads of oil well tubing, shafts of electric centrifugal pumps, etc.

Based on the results of inspection by the MMM method of the above-mentioned products for drilling rigs and oil-production plants a conclusion can be drawn that accelerated development of damages during operation occurs on units and components containing local SCZs due to metallurgical and process fabrication defects in condition as supplied (initial condition).

It is practically impossible to detect process and metallurgical defects located in the products metal depth using the applied common NDT methods. For example, if the task is to perform 100% inspection in the manual mode and during flow-line production of products using ultrasonic testing (UT), in this case a special guideline for operation in a search mode should be developed for an operator. However, even in this case, the operator should know where and how to install the UT sensor in order to try to detect an internal defect located at an unknown depth.

In automatic mode such inspection of products in on-line mode is even more impracticable.

The MMM method makes it possible in the quick control mode to record magnetic anomalies occurring on the products' surface in local RS zones that form due to internal defects of the metal. Additional inspection, for example, ultrasonic testing, may be performed in zones of magnetic anomalies (RS concentration zones). In this case, when the local RS zones is known, the UT operator knows where and how to install the sensor, and efficiency of a product's complex NDT increases considerably.

Conclusion

The presented in this paper application experience of the NDT technology based on the use of the magnetic memory of metal allows to state the possibility to perform 100% inspection of both new and used products in order to detect internal process and metallurgical defects.

Inspection using the MMM method requiring no preparatory operations can be automated on condition of development of specialized scanning devices that take into account structural features of products.

Bibliography

1. Nondestructive Testing and Diagnostics: Handbook / Edited by RAS academician V.V. Klyuev. Moscow: Machine building, 1995. 487 p.

2. Vlasov V.T., Dubov A.A. Physical bases of the metal magnetic memory method. Moscow: ZAO "TISSO", 2004. 424p.

3. Dubov A.A., Dubov Al.A., Kolokolnikov S.M. Metal magnetic memory method and inspection instruments: Training handbook. Moscow: Publishing House Spektr, 2012. 395 p.

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

New requirements to methods and devices for diagnostics of materials' stress-strain state

Dr. Tech. sc., Professor A.A. Dubov, Energodiagnostika Co. Ltd.

At present all leading diagnostic centers of the world are occupied with the problem of stress and strain control in working structures with the purpose of their state assessment. However it is known that the effectiveness of the inspection methods remains low when they are used in practice. Improvement of effectiveness of non-destructive testing (NDT) of technical objects' stress-strain state (SSS) during their lifetime assessment gains special significance.
At present a large arsenal of methods and means for non-destructive testing of residual stresses (RS) in engineering products and stress-strain state (SSS) control in operated industrial objects has been accumulated. However during their practical use a large number of scientific-technical problems occur and the lack of scientifically proven metrological base for certification and calibration of devices and instruments for products' SSS characteristics measurement should be noted among them.
In particular, one of the most important metrological problems is that most of methods and means for SSS NDT are calibrated during the tensile testing of specimens focusing on conventional mechanical characteristics. Then the dependencies obtained in such a way are transferred to the real equipment without taking into account the scale factor, locality, time and speed of damages development.
Based on experimental and theoretical investigations of physical strains distribution patterns on standard specimens of various steels as well as on the accumulated experience of the metal magnetic memory development and practical application, the paper points out the discrepancy between the actual physical parameters of the internal stresses with the "usual" conventional mechanical properties of materials.
The presented in the paper results of investigations point to the necessity to develop new regulatory metrological documentation in the field of SSS NDT in order to eliminate the discrepancy revealed. The developed by the author in collaboration with TC-132 of Federal Agency for Technical Regulation and Metrology (Rosstandart) new national standards that establish general requirements to various methods and devices for SSS NDT are the first and the most significant step towards improvement of efficiency of equipment and structures' actual state assessment.

Many years of experimental and practical experience in development and practical application of the magnetic memory method for diagnostics of various objects revealed and proved objectiveness of the "discrepancy" of real values of internal stress physical parameters with "usual" limiting values of mechanical characteristics, for example, ultimate strength limit.

The results if theoretical investigations of physical strains distribution patterns [1] made it possible to explain the observed "discrepancies" and proved the incorrectness of the known assessment criterion of the material's true state in local zones of the developing damage by the degree of closeness to reference limiting mechanical characteristics of the material.

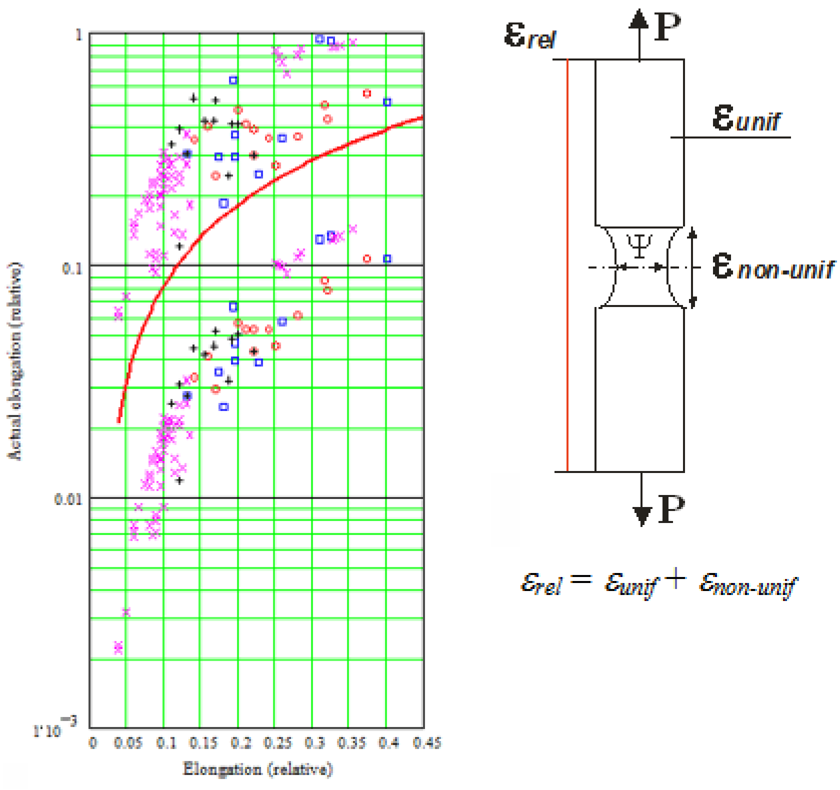


Figure 1. The ratio of relative elongation (ε_{rel}) at fracture (solid curve) and actual values of average strain in areas of: non-uniform ($\varepsilon_{non\text{-}unif}$ - points above the curve) and uniform (ε_{unif} - points below the curve) strain for various materials.

Investigations of strain and strength properties of 98 different steels and alloys showed сталей (figure 1) that average values of specimens tensile strain in areas of non-uniform and uniform strain differ essentially (by several times) from the values of limiting mechanical strain characteristics of the material (ε_{rel}). And local values of strains differ by orders already! It means that the limiting state criteria obtained during ordinary mechanical testing of specimens cannot reflect the limiting state of the material and, moreover, the limiting state of a structural element.

But in order to realize this it is necessary to overcome the ingrained notion of internal stresses and to remember that the stresses - "sigma", which we are all so used to, are not stresses. They are the internal specific force applied to a specimen of a specific shape and changing internal stresses - they are a conditional equivalent of internal stresses!

"Conditional" is because the prerequisites are: the specimen of a specific shape and a specific sequence of testing.

Figure 2 shows in sequential order how the external specific force, while "splitting" into components, affects the material deforming it in different directions (sliding, normal, latitudinal) and rotating it in space, thereby causing occurrence of corresponding internal forces of the material's resistance to strain, which finally determines the input of the material's self-energy for resistance to external load. It is obvious that the strains that can be measured (ε_{long} - longitudinal and ε_{trans} - transverse) represent algebraic sums of internal physical strain vectors projections to the directions usual for us - along and transverse the axis of the applied force.

It should be noted that the most terrible consequence of the deep-seated confusion in understanding of the nature of internal stresses, we may say insidious delusion, begins to emerge only now when there arose a vital problem of determination of the material's state and performance - an important component of the problem of complex engineering objects' residual lifetime assessment.

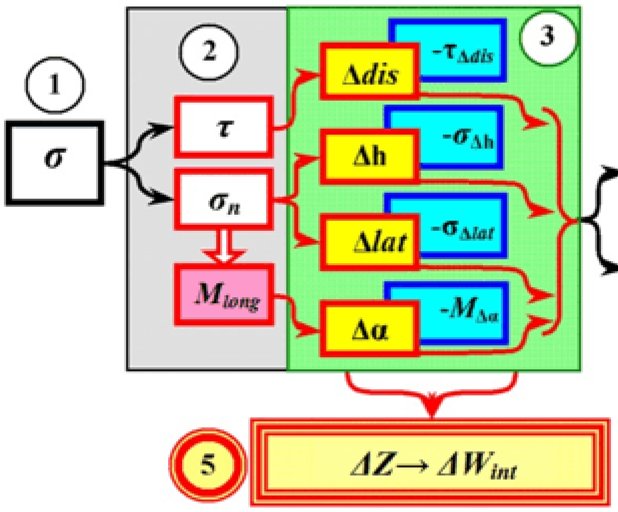


Figure 2. The material's reaction to exposure to external force: *1* - external specific force; *2* - force components of external impact on the model of the structural element (inside the material); *3* - aggregate of local strain-force characteristics of the material's resistance; *4* - external characteristics of the material's reaction; *5* - internal stresses - variation of the internal energy density.
τ - shear stress;
σ_n - normal stress;
M_{long} - torque;
ΔZ and ΔY- axes, along which the longitudinal ε_{long} and transverse ε_{trans} are measured, respectively;
Δdis and $\tau_{\Delta dis}$ - displacement (slip) strain and stress;
Δh and $\sigma_{\Delta h}$ - normal strain and stress;
Δlat and $\sigma_{\Delta lat}$ - latitudinal strain and stress;
$\Delta\alpha$ and $M_{\Delta\alpha}$ - angular strain and torque;
ΔV - volume of structural element;
ΔW_{int} - internal energy of resistance to strain.

There is a danger that the mechanical properties obtained during the specimens testing - reference limiting values of the specimens strain and specific forces - conditional equivalents of internal stresses - began to be considered the inherent characteristics of the material that determine its ability to resist any external loads regardless of the product's shape, in which this material is embodied. This was the source of the principal error common to all methods of internal stress "measurement" without any exception.

The results of experimental and theoretical investigations obtained in [1] allowed to "materialize" the conclusions, which facture mechanics practically came to grips with long ago, and to represent the limiting states and basic concepts closely related to them as follows:

- limiting state of the material - the minimum possible density of internal energy - the limiting potential determined solely by the average internal energy density, which is an individual quality of the material, and it does not depend on the size of structural elements, or its conditions of loading;

- limiting state of the structural element is determined by the size of the local area in which the material has reached the ultimate state, and the size of the structural element where this local area is located;

- the size of the local area is determined by individual characteristics of the material, the dimensions of the structural element and its loading conditions and, in turn, determine the nature of the local strain actual distribution in the volume of the structural element;

- the actual state of the material in the local area is the value of the actual internal energy density - the actual potential determined by individual characteristics of the material, the location of the investigated area in the structural element’s volume, the element size and conditions of its loading;

- internal stresses - the difference of potentials - is the difference between the internal energy density in the local area and in the areas adjacent to it.

Moreover, now it can be said that internal stresses are a special unified energy characteristic of the material’s equilibrium state, which is determined (see figure 2) by a number of physical strain-force parameters displaying a variety of options of internal energy variation at various variants of impact on the material embedded in a specific shape.

Any material has its own internal energy characterized by the average energy density that can be represented by two zero rank tensors - scalar and vector potentials. The energy distribution in the volume of even "isotropic" material is not homogeneous but is characterized by strict order of each of the possible and quite certain directions of the initial energy variation - three linear (normal) vectors (first rank tensor) and one axial (rotational) vector. These are all individual qualities or properties of the material determined by one characteristic - the average energy density that depends neither on the object’s shape nor on the external impact nature. But at the same time "rather definite" linear directions of initial energy value variation - normal, shear and latitudinal, determined by the glide plane position in the force or other external field space, - depend already on the objects’ shape, in which the investigated material is embedded.

Any external impact - from simple uniaxial to the most complex - on a specific object made of the investigated material, whether a specimen or a complex part, always "splits" in the material into three force and three torque (rotational) components (and only during uniaxial loading of a cylindrical specimen - into two force and one torque components).

During resistance to external impact the material uses its own energy. Its input can be evaluated by the work of the external field - strain-force parameters expressed by two full second-rank tensors (force and strain) or two pairs of linear (symmetrical) and rotational (antisymmetric) tensors. It should be noted that the loss of antisymmetric rotational tensor in the theory of materials’ resistance led to deep misconception of "main stresses" and "main strain" existence. It is impossible neither theoretically (of course, unless a mistake is made), nor in real conditions to find such an “area without shear forces” and torques! It is easier to understand in physically: the material’s energy consists of two practically equal in value components - potential (electrostatic) that determines "repulsion" of atoms and quantum that determines "attraction" of atoms. And it follows that during any impact on the material both fields - quantum (gravity) and potential (repulsive) always "work" in any of its areas. So, a pair of antisymmetric tensors lost by the theory of materials’ resistance precisely describes the input of the quantum component of the materials’ internal energy for resistance to external impact. And in general, what would remain of the material if we really ignore the forces drawing the atoms together?

As we can see, the well-known values of limiting states - yield strength and ultimate strength, obtained during ordinary mechanical testing of specimens, can not reflect the material’s limiting state and, moreover, the limiting state of a structural element.

Thus, the analysis of investigation results prompts a conclusion known from the facture mechanics that we should already speak about several different failure criteria: the limiting value of normal strain during uniaxial tension, the limiting value of latitudinal strain during uniaxial compression and the limiting value of shear strain during torsion or bending as well as various combinations of limiting values during complex loading.

All this requires a more careful approach to the diagnostics of the material’s stress-strain state and to the procedure of assessment of the extent of the actual material’s state closeness in a local area of a structural element to the limiting value both for the material and for the entire structural element because its is clear now that this is far from being the same!

It is completely obvious that prediction of possible period of safe elements operation in real "ageing" structures (basic alternative of damages development) by the results of the material’s SSS diagnostics using calibration curves, obtained during ordinary mechanical testing of specimens without evaluation of time and speed of fatigue damage development in a specific and in specific conditions, is not only useless but is extremely dangerous!

Moreover, considering the acute (from units to several tens of microns) locality of the fatigue damaging development process, peculiarities of local physical strains distribution and their correlation with the average strain values it can be stated that, using the conventional active methods of diagnostics with a large averaging base (10 mm at best), we, most probably, shall not simply detect the developing damage area, not to mention the possibility to determine the parameters of the developing damage.

The obtained results of physical strains distribution patterns investigation clearly indicate the necessity to develop the new regulatory documentation regulating certification of devices and instruments for diagnostics of structural materials’ stress-strain state and, of course, of the techniques for calibration of devices and instruments for SSS diagnostics.

It should be noted here that the diagnostics of structural materials’ SSS represents the next after flaw detection and higher level of diagnostics. It requires a new ideology, a new scientifically grounded methodology that would define goals and tasks of diagnostics as well as the assessment criteria of structural materials’ actual stress-strain state.

The point is that the lack of general requirements to measured SSS characteristics and the lack of metrological base for certification and calibration of devices and instruments for materials’ SSS characteristics measurement lead to ambiguity of initial requirements and erroneous methodological approach to the developed devices and instruments. It causes not only unacceptably low reliability of measurement results (although, as was shown earlier, in this context it cannot be spoken about at all) but also very often makes it impossible to identify correctly the measured parameter of the physical field used and of the measured physical characteristic of the investigated material.

GOST R 52330-2005 "Non-destructive testing. Stressed-strained state test on industrial objects and transport. General requirements" put into effect in 2005 is the first and important step in making methods and means of structural materials’ SSS diagnostics an efficient and truly necessary and useful tool for actual state assessment of structural materials’ and structures’ as such.

One of the main general requirements to all SSS NDT methods and means in the above mentioned national standard is the necessity to detect maximum stress concentration zones (SCZs) - the sources of damages development - in structural elements. SCZs are not only the areas known in advance where the structural features create various conditions for distribution of stresses due to the external working load. But these are also the randomly located areas with large local strains occurred due to initial inhomogeneity of the metal in combination with off-design additional working loads.

The new standard GOST R 53006-2008 "Engineering diagnostics. Lifetime assessment of potentially dangerous objects based on the quick methods. General requirements" was approved and put into effect in November 2008 by the order of the Federal Agency for Regulation and Metrology of RF No.309-st. dated 13.11.2008.

Passive NDT methods, which use the internal energy of the structures' metal, are referred to quick methods, namely:

- the method of acoustic emission (AE);

- the metal magnetic memory (MMM) method;

- thermal inspection.

At present these methods are most widespread in practice for the purposes of early diagnostics of damages in metal components and structures. The principal distinctive feature of such an approach to assessment of the lifetime is execution of a 100% inspection of the IO with detection of all potentially dangerous stress concentration zones (SCZs), which are the sources of damages occurrence in the course of further operation of metal components.

The new National Standard GOST R 53006-2008 also reflects the following basic provisions:

- it is suggested to use the actual energy characteristics, which can be determined using the MMM, AE and thermal methods, as basic criteria of the limiting state of the metal;

- the block diagram of the residual lifetime determination was corrected with the emphasis on the modern quick methods of engineering diagnostics;

- it is suggested to carry out calibration strength calculations with residual lifetime assessment for SCZs being in operation, taking into account the actual structural-mechanical properties of the metal, detected during the inspection;

- recommendations of the National Standard GOST R 52330-2005 were taken into account.

In 2010 the Federal Agency for Technical Regulation and Metrology (Rosstandart) approved two new national standards [2, 3] specifying general requirements to classification and procedure of SSS NDT methods selection.

In conclusion it should be noted that in contrast to the regulatory-metrological problems, being the objective problems, for which the methods of solution is clear and described in this paper, the psychological problems, which SSS NDT experts have to overcome, have already gained the subjective and widespread nature. The quicker the wide range of experts overcomes these psychological problems in perception of the new requirements to SSS NDT methods and means, the quicker we shall get closer to the objective assessment of equipment and structures' lifetime.

Bibliography

1. Vlasov V.T., Dubov A.A. Physical theory of the "Strain-failure" process. M.: ZAO “TISSO”, 2007. 517 p.

2. GOST R 53966-2010. Non-destructive testing. Stress-strain state control of the material in structures. General requirements to methods selection procedure.

3. GOST R 53965-2010. Non-destructive testing. Determination of mechanical stresses. General requirements to methods classification.

Diagnostic works

Energodiagnostika Co. Ltd performs works on diagnostics and life estimation of power equipment of Electric Power Stations and Boiler Plants (steam and hot-water boilers, steam and gas turbines, steam and water pipeline auxiliary equipment), pipelines, vessels and of any other equipment at petroleum refineries and chemical productions, compressor plant gas pipelines and equipment, gas- and oil-fields equipment, tracks and wheel sets in railway transport, bridge structures.

Energodiagnostika Co. Ltd develops principally new techniques for products and equipment inspection using the metal magnetic memory for machine-building plants and metallurgical productions, paper mills, shafts and aircraft industry. The techniques are aimed at solving of complex problems of products and welded joints metal quality inspection and at solving the problems in the field of improving technologies of manufacturing, heat treatment, etc.

Energodiagnostika Co. Ltd has the license of Rostechnadzor No. DE-00-008978 (DKPS) from August 07, 2008 giving the right to perform: Activity on carrying out industrial safety examination (examination of design documentation for construction, expansion, reconstruction, technical re-equipment, conservation and liquidation of a dangerous production object; engineering devices used at a dangerous production object; buildings and facilities at a dangerous production object).

Energodiagnostika Co. Ltd non-destructive testing laboratory meets all the requirements of Non-destructive testing system (Certificate No. 00A020351 from September 25, 2015) in the field of:

Equipment (objects) name:

- Objects of boiler inspection.
- Gas supply (gas distribution) systems.
- Lifting system.
- Equipment for oil and gas industry.
- Equipment for metallurgy industry.
- Equipment for explosive and fire-risky productions and chemically dangerous productions.
- Buildings (metal constructions).

Types (methods) of non-destructive testing and diagnostics:

- Ultrasonic testing.
- Magnetic testing.
- Eddy-current testing.
- Visual testing.
- Stress-strain state testing.

Types of activity:

- Carrying out equipment and materials inspection by non-destructive methods at fabrication, construction, installation, repairs (re-construction), engineering diagnostics on the listed above objects.

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

Management System ISO 9001:2008 Valid until: 17.12.2016. www.tuv.com ID 9105070025

TÜVRheinland CERTIFIED

Training and certification of NDT specialists. The unique Russian and International Center for training of specialists by the method of metal magnetic memory

Energodiagnostika Co. Ltd. independent body for personnel certification in the field of non-destructive testing, operating since 1996, is accredited at the Integrated System of Conformity evaluation in the field of industrial and ecological safety, power engineering and construction safety. Accreditation Certificate No. NOAP-0019 of November 21, 2014.

Basic activities of "Energodiagnostika" Certification Body:

- Practical and theoretical training and certification of non-destructive testing experts with issuing of Qualification Certificates in magnetic testing (MT) (including the metal magnetic memory method) for Levels I, II and III; ultrasonic testing (UT), visual testing (VT), eddy-current testing (ET), stress-strain state testing (SSS NDT) for Levels I and II.
- Scientific-research work and development of specialized inspection techniques and equipment's lifetime estimation.

"Energodiagnostika" Certification Body is the only Russian and international center, which trains experts in the metal magnetic memory method based on the "Program and Examination Digests for NDT experts training and certification in the metal magnetic memory method", approved by the appropriate Rostechnadzor Departments.

Training in new technologies of products quality control, non-destructive testing of equipment using the metal magnetic memory method is carried out for experts working in any industry including machine-building and metallurgical plants, companies and organizations.

"Energodiagnostika" Certification Body pays special attention to experts training in complex non-destructive testing of equipment based on complementary capabilities of the MMM method, traditional inspection methods (UT, ET) as well as metal properties assessment means (hardness measurement, metallography, etc.). Equipment NDT efficiency improves considerably when at the first stage the MMM method detects in the rapid control mode stress concentration zones (SCZs) – sources of damages, and then inadmissible and developing defects and structural changes of the equipment's metal are detected using traditional NDT devices in SCZs.



"Energodiagnostika" Certification Body is the only center for experts training in non-contact magnetometric diagnostics (NCMD) of gas and oil pipelines, heating system pipelines and other communications buried under the soil layer, in difficult-to-access channels, etc. Training in NCMD using the specialized Type 11 sensor is carried out on the Customer's request additionally to the basic program of training in the MMM method within two working days.



Practical training of NDT experts in eddy-current testing with consideration of various-purpose equipment's features is carried out using EMIC instruments, which can be used for ferrous, stainless and non-ferrous metals.


During training of experts for qualification Level III, along with the basic program, new developments and normative documents are considered, including documents on stress-strain state (SSS) assessment and lifetime estimation based on rapid NDT methods and, first of all, the MMM method according to GOST R 52330-2005 and GOST R 53006-2008.

Training and Certification are based on:

- Normative-technical documentation in the field of non-destructive testing (including documents on certification of the metal magnetic memory method, inspection instruments and personnel agreed with Rostechnadzor).
- Rules of pipelines, boilers, vessels and other equipment safe operation.
- Techniques for inspection and lifetime estimation of equipment and structures in power engineering, gas industry, petrochemistry and other industries.
- Technique for machine-building products inspection at manufacturing plants.
- Instrumentation-computer diagnostic complex.
- "MMM-System" and "MMM-Lifetime" program software.
- Practical training in the use of techniques and instruments on industrial specimens.

By present time more than 2000 experts in Russia, more than 450 experts in China, 75 experts in Poland and more than 85 experts in other countries have been train in the metal magnetic memory method.

A candidate for training and certification should submit the following documents: application for certification; 3 mat photographs (sized 3x4 cm); medical reference about the level of health; copy of the document on education; copies of available non-destructive testing certificates; reference from the place of employment indicating the work experience in NDT.

During the primary certification qualification Level I is assigned if the working experience in MT, VT and ET makes at least 3 months and at least 6 months in UT. Certification for Level II may be performed in case an expert has Level I Certificate and working experience at least 9 months in MT, VT and ET and 12 months in UT. Experienced flaw detection experts with working experience of at least 9 months in VT, 12 months in MT and ET and 18 months in UT may be certified for Level II as well.

Application Form:

Application form for certification of an expert in the field of non-destructive testing

Medical Reference

News

News Energodiagnostika Co. Ltd.

Category : All categories

November 26, 2015

The International Conference on Diagnostics of Structures and Components Using Metal Magnetic Memory Method

The International Conference on Diagnostics of Structures and Components Using Metal Magnetic Memory Method. May 19-20, 2016, Budapest, Hungary

February 28, 2015

VIII international scientific and technical conference "Diagnostics of equipment and structures using the metal magnetic memory"

VIII International Scientific and Technical Conference "Diagnostics of Equipment and Structures Using the Metal Magnetic Memory" took place on February 17-19, 2015, in Moscow.

May 20, 2014

European conference about the metal magnetic memory method

The European conference about the Metal Magnetic Memory method took place on May 08, 2014 in Budapest (Hungary) under the chairmanship of President of Hungarian society for non-destructive testing, Professor Peter Trampus

December 18, 2013

Quality Management System

Quality Management System of Energodiagnostica Co. Ltd was certified by TUV Rheinland Cert GmbH according to ISO 9001:2008.

December 01, 2013

TSC-7M-16, TSC-8M-4

Fabrication of new devices - Testers of Stress Concentration TSC-7M-16 and TSC-8M-4.

- **February 25, 2013**

VII international scientific and technical conference "Diagnostics of equipment and structures using the metal magnetic memory"

Totals of the VII International Scientific and Technical Conference "Diagnostics of Equipment and Structures Using the Metal Magnetic Memory"

- **July 01, 2011**

Expansion of the accreditation of "Energodiagnostika" Certification Body

Since September 2009 "Energodiagnostika" Certification Body, in addition to the already existing courses in magnetic and ultrasonic testing methods, organizes training courses in the eddy-current method.

- **March 01, 2011**

New articles on the MMM method

At our web-site you can find the new articles on the metal magnetic memory method, which were published in specialized scientific-technical editions.

- **March 01, 2011**

The New Methodical Guidelines and Inspection Techniques

The new guideline documents and inspection techniques using the metal magnetic memory method.

- **February 17, 2011**

Book "Metal Magnetic Memory Method. History of origin and development"

The book considers the origin and development history of the metal magnetic memory method

1 2 3 4 Page Size : 10 Items from 1 to 10 of 37

Home MMM method MMM application Diagnostics Certification News Contact

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

Contact us at

Energodiagnostika Co. Ltd:

Russia, 143965 Reutov, Moscow region, Yubileiny prospekt 8, office 12.

Phone/Fax: +7-498-6619281, +7-498-6616135. E-mail: mail@energodiagnostika.ru

Certification Center "Energodiagnostika Co. Ltd":

Russia, 143962 Reutov, Moscow region, October Street 38, office 13.

Phone/Fax: +7-498-6502523. E-mail: noap@energodiagnostika.ru

* Name :

* E-mail :

* Subject :

* Letter :

Send

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

The International Conference on Diagnostics of Structures and Components Using Metal Magnetic Memory Method

May 19-20, 2016, Budapest, Hungary

Organizer

HUNGARIAN ASSOCIATION FOR NON-DESTRUCTIVE TESTING
co-sponsored by EUROPEAN FEDERATION FOR NON-DESTRUCTIVE TESTING

The Conference is supported by:

ENERGODIAGNOSTIKA CO LTD.

RUSSIAN WELDING SOCIETY

RUSSIAN SOCIETY FOR NON-DESTRUCTIVE TESTING AND TECHNICAL DIAGNOSTICS

Organising Committee

- **Anatoly Dubov,** Russia, Co-Chairman of Conference Organizing Committee
- **Peter Ladanyi,** Hungary, Co-Chairman of Conference Organizing Committee
- **Gerd Dobmann,** Germany
- **Len Gelman,** United Kingdom

- **Marc Kreutzbruck,** Germany
- **Sergey Kolokolnikov,** Russia
- **Lajos Magyar,** Hungary
- **Istvan Meszaros,** Hungary
- **Alexander Mozgovoy,** Ukraine
- **Alexander Mullin,** Russia
- **Maciej Roskosz,** Poland
- **Vaclav Svoboda,** Czech Republic
- **Peter Trampus,** Hungary
- Secretary of Conference: **Laszlo Gillemot,** Hungary, gillemot@marovisz.hu, Office phone: +36 1 278 0632, Private mobile: +36 20 984 5878

Conference Topics

- Physical bases of the Metal Magnetic Memory (MMM) method. Experimental research of the physical-mechanical properties of metals using the MMM method
- New theories in the magnetization of metals
- Magneto-elastic effects and domain structures
- Totals of development of the MMM method in Europe, Russia and other countries
- Non-contact diagnostics of buried pipelines based on the MMM method
- Stress-strained states properties of formed materials
- Inspection of machine-building products quality by structural inhomogeneity and residual stresses
- Experience in the use of the MMM method at inspection and lifetime assessment of pipelines, structures and components
- Metal limiting state criteria at assessment of residual lifetime. Stress-strain state tests of structures and components
- Using the MMM method in the Fitness for Services Procedures and in the Asset Management System
- Personnel training on the MMM method and training in the field of stress-strain state testing and engineering diagnostics

The official language of the Conference is: English.

Intended Audience

- Managers for quality and integrity, maintenance and inspection, and NDT personnel of manufacturing and operation in the field of oil, gas, off-shore and chemical industry, thermal and nuclear power stations, steel constructions and bridges, structures of transportation as well as metallurgical industries

- Research engineers and experts of Universities and Research Institutes
- Staff of NDT training institutions
- Responsible people of national authorities and supervisor agencies
- Engineers and technicians of NDT equipment manufacturers and distributors

Schedule for Abstracts and Papers Submissions

Deadlines of abstracts: **31st of January, 2016**.

Acceptance of presentation will be confirmed not later than **28th of February, 2016**.

The full text of presentation for the Proceeding as well as the presentation for projecting should be handed over at the **beginning of the Conference**.

The abstract shall be in **English** and not more than two pages A4 size with 25 mm margin on all sides.

The abstract and the paper should be sent by e-mail.

Registration

Registration is possible only using the enclosed form which has to be returned to the MAROVISZ not later than **20th of April, 2016**.

The participants of the conference shall receive the Conference Proceedings and other materials dedicated to the metal magnetic memory method and inspection instruments.

The Registration fee includes the cost of the Conference Proceedings, lunches and banquet, organization expenses and must be paid till **1th of May, 2016** by transfer to the account of MAROVISZ

IBAN: HU 72 10200830-32323070-00000000 (Bank: K&H Swift code OKHBHUHB).

Early registration fee till to 31th of January, 2016: **400 € / participant**

Registration fee: **450 € / participant**

The registration fee includes all taxes.

Conference Venue

The conference will be organised in the **Hotel Mercure Budapest Korona** (Kecskeméti str 14., 1053 Budapest, Hungary) located in the Centre of Budapest.

Accommodation should be booked directly in the Hotel referring to the MMM Conference using the attached form.

Forms

Registration Form

Hotel Reservation

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

VIII international scientific and technical conference "Diagnostics of equipment and structures using the metal magnetic memory"

February 17-19, 2015, Moscow, "Izmailovo" hotel complex (Alfa)

Organizing Committee

Energodiagnostika Co. Ltd

Support

RUSSIAN SOCIETY FOR NON-DESTRUCTIVE TESTING AND TECHNICAL DIAGNOSTICS (RSNDTTD)

RUSSIAN WELDING SOCIETY (RWS)

TECHNICAL COMMITTEE TC-132 OF RF FEDERAL AGENCY FOR ENGINEERING REGULATION AND METROLOGY

SCIENTIFIC AND INDUSTRIAL UNION "RISKS MANAGEMENT, INDUSTRIAL SAFETY, CONTROL AND MONITORING" (SIU "RISCOM")

SELF-REGULATING ORGANIZATION NON-COMMERCIAL PARTNERSHIP "INTERREGIONAL ASSOCIATION IN THE FIELD OF INDUSTRIAL SAFETY" (SRO NP "MEZHREGION IS")

The conference "Diagnostics of Equipment and Structures Using the Metal Magnetic Memory" took place on February 17-19, 2015, in Moscow. Holding of the Conference was initiated by Energodiagnostika co. Ltd. Organization of the Conference was supported by: the Russian Society for Non-Destructive Testing and Technical Diagnostics (RSNDTTD), Russian Welding Society (RWS), Scientific and Industrial Union "Risks Management, Industrial Safety, Control and Monitoring" (SIU "RISCOM"), Technical Committee TC-132 of RF Federal Agency for Engineering Regulation and Metrology, and Self-Regulating Organization Non-Commercial Partnership "Interregional Association in the Field of Industrial Safety" (SRO NP "MEZHREGION IS").

About 70 experts from different cities and towns of Russia and other countries: Argentine, Czech Republic, Hungary, Kazakhstan, Latvia, Lithuania, Malaysia, Mongolia, Poland, Switzerland and Ukraine, participated in the work of the Conference.

Within the framework of the Conference reports on the following topics were presented:

- Totals of the metal magnetic memory (MMM) method development and implementation in Russia and other countries (as of January 2015 the MMM method became widespread in 33 countries of the world).
- Experience of the metal magnetic memory method application during the inspection and lifetime assessment of gas and oil pipelines, equipment of nuclear and thermal power engineering and petrochemical industry, sea transport and other industries.
- The metal's limiting state criteria during the residual lifetime assessment. Stress-strain state control of equipment and structures.
- Engineering products' quality control by structural inhomogeneity and residual stresses.
- Non-contact magnetometric diagnostics (NCMD) of pipelines buried in the soil layer (gas and oil pipelines, heat lines, water pipelines).
- New Russian and International standards in the field of technical diagnostics.
- Experts training in the MMM and NCMD methods and in stress-strain state (SSS) control.
- Industrial Safety Expert Review in conditions of self-regulating organizations operation.

The main attention was paid to the practical experience of the MMM method application in various industries and at various facilities. In particular, reports were presented on modern problems of non-destructive testing and lifetime assessment of engineering products, equipment and structures and the ways of their solution based on application of the metal magnetic memory method, as well as on the perspective of the MMM method and inspection instruments development and distribution in Russia and other countries. Papers were presented on determination of mechanical properties and stress concentration level in products' local zones detected by the MMM method, on the experience of the MMM method application on oil and gas industry, sea transport, hydraulic power engineering and other industries. Separate reports were presented on the non-contact magnetometric diagnostics of underground and underwater pipelines. An exhibition of modern inspection instruments, scanning devices and informational materials was organized within the framework of the Conference.

More than 30 reports were presented by scientists and practicing experts in total. In particular, the following persons were among the speakers:

- RSNDTTD Vice-President, RWS Director A.V. Mullin;
- Ukraine NDT Society Vice-President A.V. Mozgovoy;
- Head of Chair "Dynamics and strength of machines" of State University-UNPK, Dr.tech.sc., Professor V.G. Malinin;
- Head of Physical Metallurgy Chair of R.E. Alexeyev's State Technical University of Nizhny Novgorod, Dr.tech.sc., Professor V.A. Skudnov;
- Director of "Preditest" company, Professor V. Svoboda (Czech Republic);
- Professor of SRU-MEI, Dr.tech.sc. V.M. Matunin;

Representative of Hungarian NDT Society, expert of TUV Rheinland P. Ladanyi;

- Head of Chair of Mongolian State University of Science and Technology, Professor Ya. Duynherzhav;
- Director of "Resurs" company A. Radziszewski (Poland);
- General Director of Energodiagnostika Co. Ltd., Dr.tech.sc., Professor A.A. Dubov.

The reports were published in the Conference Materials Digest.

The general opinion of the Conference participants was the need for further practical implementation of the MMM method as an efficient method for early diagnostics of the metal and welded joints of vessels, pipelines and other equipment for various industrial applications, continuation of theoretical and experimental investigations to improve the inspection method and criteria. The Conference participants from European countries: Poland, Czech Republic, Hungary, Ukraine, Lithuania, Latvia and Switzerland suggested to include the MMM method in the list of NDT methods, based on which experts certification is performed in accordance with the International Standard ISO 9712, and to organize the working group by the MMM method in the European NDT Society.





All news

Return

European conference about the metal magnetic memory method

May 08, 2014, Budapest, Hungary

The European conference about the Metal Magnetic Memory method took place on May 08, 2014 in Budapest (Hungary) under the chairmanship of President of Hungarian society for non-destructive testing, Professor Peter Trampus.

Conference topics:

- Theory of the metal magnetic memory (MMM) method.
- Experience of the metal magnetic memory method application in gas and oil industry, machine building, power engineering and transport.

The organizers of the Conference were Hungarian society for non-destructive testing and TUV Rheinland InterCert.

About 50 specialists from scientific and industrial enterprises of Hungary, Czech Republic, Poland and Russia participated in the work of the Conference.

The author of the MMM method, Professor Anatoly Dubov was the main speaker.

The reports about practical experience of the MMM method application were presented by:

- Representative of TUV Rheinland InterCert – P. Ladanyi (Hungary);
- Technical Director of "TLW" company L. Magyar (Hungary);
- Director of "Preditest" company, Professor V. Svoboda (Czech Republic);
- Manager of "Resurs" company A. Shozda (Poland).

About 10 specialists - representatives of engineering universities and diagnostic companies of Hungary spoke in the discussions. The participants decided:

- to prepare the information about the Conference for publication in engineering journals of non-destructive testing and engineering supervision;
- for diagnostic companies of Hungary and Czech Republic, which use MMM method, to recommend

to initiate adaptation of International Standards ISO 24497-1:2007(E), 24497-2:2007(E), and 24497-3:2007(E) by the MMM method on territory of these countries.

All news

Return

Home MMM method MMM application Diagnostics Certification News Contact

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

Design by: OOO "Modern Media"

Quality Management System

Quality Management System of Energodiagnostica Co. Ltd was certified by TUV Rheinland Cert GmbH according to ISO 9001:2008.

All news

Return

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

TSC-7M-16, TSC-8M-4

Fabrication of new devices – Testers of Stress Concentration TSC-7M-16 and TSC-8M-4, sufficiently enlarging the capabilities of the metal magnetic memory method application and improving inspection efficiency and quality, has been started.

All news

Return

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

Russian

Energodiagnostika
Metal Magnetic Memory Method

Energodiagnostika MMM method MMM application Production Diagnostics Certification

VII international scientific and technical conference "Diagnostics of equipment and structures using the metal magnetic memory"

February 19-21, 2013, Moscow, "Izmailovo" hotel complex

Organizing Committee

Energodiagnostika Co. Ltd

Support

RUSSIAN SOCIETY FOR NON-DESTRUCTIVE TESTING AND TECHNICAL DIAGNOSTICS (RSNDTTD)

RUSSIAN WELDING SOCIETY (RWS)

TECHNICAL COMMITTEE TC-132 OF RF FEDERAL AGENCY FOR ENGINEERING REGULATION AND METROLOGY

SCIENTIFIC AND INDUSTRIAL UNION "RISKS MANAGEMENT, INDUSTRIAL SAFETY, CONTROL AND MONITORING" (SIU "RISCOM")

SELF-REGULATING ORGANIZATION NON-COMMERCIAL PARTNERSHIP "INTERREGIONAL ASSOCIATION IN THE FIELD OF INDUSTRIAL SAFETY" (SRO NP "MEZHREGION IS")

The conference "Diagnostics of Equipment and Structures Using the Metal Magnetic Memory" took place on February 19-21, 2013, in Moscow. Holding of the Conference was initiated by Energodiagnostika co. Ltd. Organization of the Conference was supported by: the Russian Welding Society (RWS), Scientific and Industrial Union "Risks Management, Industrial Safety, Control and Monitoring" (SIU "RISCOM"), Technical Committee TC-132 of RF Federal Agency for Engineering Regulation and Metrology, and Self-Regulating Organization Non-Profit Partnership "Interregional Cooperation in the Field of Industrial Safety" (SRO NP "MEZHREGION PB").

More than 90 experts from different cities and towns of Russia and other countries: Poland, Hungary, Czech Republic, Ukraine, Lithuania, Latvia, Norway, Argentine, Uzbekistan and Japan participated in the work of the Conference.

Within the framework of the Conference reports on the following topics were presented:

- Totals of the metal magnetic memory (MMM) method development and implementation in Russia and other countries (as of January 2013 the MMM method became widespread in 32 countries of the world).
- Experience of the metal magnetic memory method application during the inspection and lifetime assessment of gas and oil pipelines, and equipment of power engineering and petrochemical industry, railway transport and other industries.
- The metal's limiting state criteria during the residual lifetime assessment. Stress-strain state control of equipment and structures.
- Engineering products' quality control by structural inhomogeneity and residual stresses.
- Non-contact magnetometric diagnostics (NCMD) of pipelines buried in the soil layer (gas and oil pipelines, heat lines, water pipelines).
- New Russian and International standards in the field of technical diagnostics.
- Experts training in the MMM and NCMD methods and in stress-strain state (SSS) control.
- Industrial Safety Expert Review in conditions of self-regulating organizations operation.

The main attention was paid to the practical experience of the MMM method application in various industries and at various facilities. In particular, reports were presented on modern problems of non-destructive testing and lifetime assessment of engineering products, equipment and structures and the ways of their solution based on application of the metal magnetic memory method, as well as on the perspective of the MMM method and inspection instruments development and distribution in Russia and other countries. Papers were presented on determination of mechanical properties and stress concentration level in products' local zones detected by the MMM method, on the experience of the MMM method application on oil and gas industry, railway transport, hydraulic power engineering and other industries. Separate reports were presented on the non-contact magnetometric diagnostics of underground and underwater pipelines. A wide range of practical results of works performed using the MMM method was presented as poster presentations and informational materials. An exhibition of modern inspection instruments was organized within the framework of the Conference.

Special attention was paid to the experience of the MMM method standardization and its harmonization with International Standards ISO 24497-1:2007(E), 24497-2:2007(E), and 24497-3:2007(E) in Russia, Ukraine, Poland, China, Mongolia, and Iran.

More than 30 reports were presented by scientists and practicing experts in total. In particular, the following persons were among the speakers:

- RSNDTTD Vice President, RWS Director A.V. Mullin;
- SIU "RISCOM" President, RAS Correspondent Member N.A. Makhutov;
- Head of Strength Chair of Orel UNPK University, Dr.tech.sc, Professor V.G. Malinin;
- Professor, Dr.tech.sc. of R.E. Alexeyev's State Technical University of Nizhny Novgorod - V.A. Skudnov;

- Director of "Preditest" company, Professor V. Svoboda (Czech Republic);
- Professor, Dr.tech.sc. of SRU MEI - V.M. Matunin;
- Head of "TUV Rheinland" Eastern Industrial Services - Peter Ladanyi (Hungary);
- Dr.tech.sc, LLC "Information Technologies" - N.A. Semashko;
- Director of "Resurs" company A. Radzishevsky (Poland);
- General Director of Energodiagnostika Co. Ltd., Professor, Dr.tech.sc. A.A. Dubov.

The reports were published in the Conference Materials Digest.

The general opinion of the Conference participants was the need for further practical implementation of the MMM method as an efficient method for early diagnostics of the metal and welded joints of vessels, pipelines and other equipment for various industrial applications, continuation of theoretical and experimental investigations to improve the inspection method and criteria. The Conference Resolution stressed that in 2010 JSC "STC "Industrial Safety" included the MMM method in the list of basic NDT methods, based on which experts are trained in accordance with PB 03-440-02 and NDT laboratories are accredited in accordance with SDA-13-2009. And in 2011 the TUV Rheinland Certificate was obtained for the MMM method, which allows the method application during the expert review and diagnostics of industrial facilities. The Conference participants from European countries: Poland, Czech Republic, Hungary, Ukraine, Lithuania, and Latvia suggested to include the MMM method in the list of NDT methods, based on which experts certification is performed in accordance with the International Standard EN-ISO9712.



Expansion of the accreditation of "Energodiagnostika" Certification Body

Since September 2009 "Energodiagnostika" Certification Body, in addition to the already existing courses in magnetic and ultrasonic testing methods, organizes training courses in the eddy-current method. The Program includes: training operation of the eddy-current flaw detector EMIC and complex inspection by the metal magnetic memory and the eddy-current methods.

All news

Return

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

New articles on the MMM method

At our web-site you can find the new articles on the metal magnetic memory method, which were published in specialized scientific-technical editions.

All news

Return

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

The New Methodical Guidelines and Inspection Techniques

The new methodical guidelines and inspection techniques developed by Energodiagnostika Co. Ltd:

- Technical guideline for non-contact magnetometric inspection of gas and oil pipelines using the TSC-type instruments.
- Technical guideline for inspection of large-diameter pipelines (530÷1420mm) using specialized scanning devices and the MMM method.
- Technical guideline for inspection of rolling-mill working and back-up rolls.
- Technical guideline for   2,0 and   2,6 steel wire inspection.
- Technical guideline for inspection of locomotive power components (frog, shaft, spline joints).
- The technique for control of stress distribution in tightened bolted joints.
- The methodical guidelines for engineering diagnostics of high-voltage line derrick guys fastening units.

Energodiagnostika Co. Ltd is the main developer of a principally new non-destructive testing method and inspection instruments based on application of the method of metal magnetic memory (MMM method).

Book "Metal Magnetic Memory Method. History of origin and development"

UDC 537

BBC 31.19

ISBN 978-5-206-00812-8

FSUE "Izvestiya" Publishing House UDP RF, Moscow, 2011. 256 p.

The book "Metal Magnetic Memory Method. History of origin and development" was written by the author of the method, Dr., Professor of "Power Equipment Repairs and Modernization" Chair at the State Service Institution of Advanced Training Dubov A.A.

The book considers the origin and development history of the metal magnetic memory method representing a new direction in the technical diagnostics. The author describes the difficulties and obstacles he faced on the way of the method promotion to the level of national and international standards and its recognition in Russia and abroad.

The book is intended for wide audience of readers interested in current problems of equipment technical diagnostics and lifetime assessment.

Individual guest room reservation request
"Metal Magnetic Memory Conference"
19-20.05.2016

THE DEADLINE FOR MAKING RESERVATIONS IS 18 April, 2016.
After this date we can provide rooms upon availability.

Please make the following hotel reservation:

Mercure Budapest Korona

◊ Single standard room with breakfast:	EUR 95,-	☐
◊ Double standard room with breakfast:	EUR 105,-	☐

Please return to **Mercure Budapest Korona** to the **banquet sales office:**
Kecskeméti u. 14
H-1053 Budapest
Hungary
T: +36 1 486 8892
F: +36 1 318 3867
Mrs Ildikó Fejérvári
H1765-sb4@accor.com

Or

Ibis Budapest Centrum

◊ Single standard room with breakfast:	EUR 85,-	☐
◊ Double standard room with breakfast:	EUR 95,-	☐

Please return to **Ibis Budapest Centrum** to the **banquet sales office:**
Ráday u. 6
H-1092 Budapest
Hungary
T: +36 1 456 4190
F: +36 1 456 4116
Ms Csilla Szeberényi
csilla.szeberenyi@accor.com

The rate given is quoted per room, per night and <u>includes</u> the buffet breakfast, the 18 % VAT and the 4% city tax.

Arrival date:.. Departure date:................................

Number of guests in the reserved room:……….person(s)
Name:...
Address:..
....
Phone:..Fax:..

Payment for accommodation should be made directly to the hotel. In order to guarantee your room please supply the following credit card information and the copy of your credit card.

Without these details we cannot accept and confirm the reservation.
Credit card type:...
Credit card number:...
Expiry date:...

"I guarantee this room reservation with my credit card. I agree that in case of non-arrival, the whole stay room rate will be charged to my credit card, unless the reservation has been cancelled and the cancellation confirmed 72 hours before the arrival date."
Date:..
Signature/authorisation:...
Reservation number:
Date of confirmation:


ВЫХОД


РАЗВИ
РАЗРУ
НЕР


Подготовительные
контроля

Articles on the metal magnetic memory method

- A.A. Dubov
  The metal magnetic memory method
- A.A. Dubov, V.T. Vlasov
  About the new classification NDT methods based on positions of risks and eguipment life assessment
- V.T. Vlasov, A.A. Dubov
  Physical criteria of materials and structural elements stress-strain state assessment
- A.A. Dubov
  Principal features of the metal magnetic memory method and inspection tools as compared to known magnetic NDT methods
- A.A. Dubov
  The totals of application of the metal magnetic memory method to industry in Russia and other countries
- A.A. Dubov, V.T. Vlasov
  On the problem of stress-strained state characteristics measurement of structural materials on complex engineering objects. Energy concept of materials stress-strained state (SSS) diagnostics
- A.A. Dubov
  Problems of ageing equipment residual life assessment
- A.A. Dubov
  Assessment of eguipment lifetime using the metal magnetic memory method
- A.A. Dubov, Al.A. Dubov
  Non-contact diagnostics of buried pipelines using the magnetometric testers of stress concentration
- A.A. Dubov
  Metal magnetic memory method and its capabilities for diagnostics of power boiler elements
- A.A. Dubov
  Detection of local stress concentration zones in engineering products - the lacking link in the non-destructive testing system
- A.A. Dubov, I.I. Veliulin

Gas and oil pipelines residual life assessment based on modern methods of engineering diagnostics

- A.A. Dubov, M.Yu. Evdokimov, A.V. Pavlov
  The experience of scanning devices application for quick inspection of operated gas pipelines
- A.A. Dubov, S.M. Kolokolnikov
  Review of welding problems and allied processed and their solving using metal magnetic memory effect
- A.A. Dubov, Al.A. Dubov, A.A. Sobranin
  Diagnostics of oil-production drilling rig units and components using the metal magnetic memory method
- A.A. Dubov
  New requirements to methods and devices for diagnostics of materials stress-strain state

Basic publications:

1. Dubov A.A., Dubov Al.A., Kolokolnikov S.M. Method of metal magnetic memory and inspection instruments. Training handbook. Moscow: ZAO "TISSO", 2008.

2. Vlasov V.T., Dubov A.A. Physical theory of the "strain-failure" process. Part I. Physical criteria of metals limiting states. Moscow: ZAO "TISSO", 2007.

3. Vlasov V.T., Dubov A.A. Physical bases of the metal magnetic memory method. Moscow: ZAO "TISSO", 2004.

4. Dubov A.A. Metal magnetic memory method. History of origin and development. Moscow: FSUE "Izvestiya" Publishing House, 2011.

5. Dubov A.A. I.C. 2029263. Patent of Russia and the C.I.S. countries. Method for residual stresses determination in products made of ferromagnetic materials. List of Inventions, No.5, 1995.

6. Proceedings of the First, the Second, the Third, the Fourth, the Fifth and the Sixth International Scientific-Technical Conferences "Equipment and structures diagnostics using the metal magnetic memory". Papers and summary to papers. Moscow: Energodiagnostika Co. Ltd, 1999, 2001, 2003, 2007, 2009, 2011.

7. Dubov A.A. Diagnostics of boiler tubes using the metal magnetic memory. Moscow: Energoatomizdat, 1995.

8. Dubov A.A. Diagnostics of turbine equipment using the metal magnetic memory. Moscow: ZAO "TISSO", 2009.

9. Dubov A.A. Diagnostics of pipelines, equipment and structures using the metal magnetic memory. Collection of papers and reports. Moscow: Energodiagnostika Co. Ltd, 2001.

10. Dubov A.A. Investigation of metal properties using the magnetic memory method // Physical metallurgy and thermal treatment of metals, No.9, 1997.

11. Dubov A.A. Express method of welding stresses inspection // Welding fabrication, No.11, 1996.

12. Dubov A.A. Diagnostics of rails fatigue damaging using the metal magnetic memory // In the world of

NDT, No.5, 1999.

13. Goritzky V.M., Dubov A.A., Demin E.A. Investigation of steel samples structural damaging using the metal magnetic memory method // Testing. Diagnostics, No.7, 2000.

14. Dubov A.A. The problems of the ageing equipment life assessment // Labour safety in industry, No.12, 2002, pp.30-38.

15. Dubov A.A. The method of metal limiting state determining and equipment life assessment by magnetic diagnostic parameters // Testing. Diagnostics, No.5, 2003.