Principal Features of Metal Magnetic Memory Method and Inspection Tools As Compared To Known Magnetic NDT Methods

Anatoly DUBOV, Energodiagnostika, Moscow, Russia

Abstract. Principal features of method of metal magnetic memory (MMM) as compared to known magnetic NDT methods are considered.
Among the basic features of the MMM method, that it is based on use of the own magnetic leakage field (SMLF), arising in ferromagnetic and paramagnetic products on accumulations of high-density dislocations. Magnetodislocation hysteresis underlying effect of metal magnetic memory, takes place as at manufacture of products during formation of internal stresses and at their operation under action of working loads.
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 small 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.
Features and uniqueness of magnetometric instruments are considered. The instruments have no world analogues.
Opportunities of the MMM method for the solution of actual NDT problems are:
- 100% quality control of machine-building products and heterogeneity of metal structure in a line production;
- Express quality control of welded joints in the united complex system of the factors "structural-mechanical heterogeneity – defects of a weld – structural and technological stress concentrator";
- Early diagnostics of fatigue damages of metal at an estimation and forecasting of equipment lifetime.

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 small 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 $T_c \cong 780°C$) 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 $\Delta\sigma$ action and in presence of the external magnetic field H_0 (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].

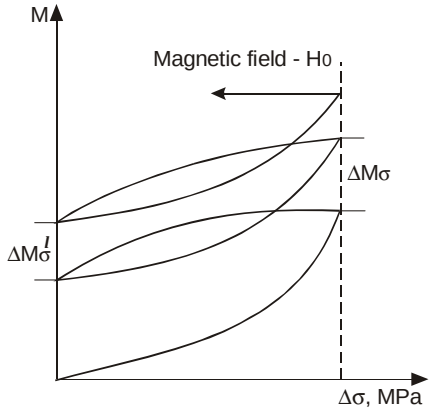

Figure 1. The diagram of magneto-elastic effect action: ΔM_σ and ΔM_σ^H – change of residual magnetization, accordingly, under loading and after unloading; $\Delta\sigma$ – change of cyclic loading; H_0 – external magnetic field.

MMM has been developed in practical and theoretical aspects for more than 20 years. As of the June, 2006, there are more than 30 guiding documents and methods agreed with RF State Engineering Supervision (Rostechnadzor) and being valid for various industries.

Special inspection tools and the appropriate software for them was developed and put to full-scale production by Energodiagnostika Co. Ltd. The tools underwent state testing by the special RF Gosstandard's method in 2000 at the All-Russian Scientific-Research Institute of Physical Investigations and at the State Scientific Metrological Center

(VNIIM) named after D.I. Mendeleev. According to test results Russian Federal Agency of Engineering Regulation and Metrology certificates for TSC type (RU.C.34.003.A No.22258) and TSCM-2FM type (RU.C.34.003.A No.22257) tools were obtained.

The Russian and international centre for training of the experts with the certification of competency in the metal magnetic memory method on I and II level (independent body for personnel certification Energodiagnostika Co. Ltd) works in Moscow, since 1998. The branches of the centre work in Warsaw and Beijing. Now more 1000 experts in Russia, 150 experts in China and 30 experts in Poland are trained. The handbook was published in 2003 [3].

Three standards of Russia are approved:

- The standard of the Russian Welding Society ST RWS 004-03 "Nondestructive testing. Welded joints of equipment and constructions. Method of metal magnetic memory".
- GOST R 52005-2003. Nondestructive testing. Method of metal magnetic memory. General requirements.
- GOST R 52081-2003. Nondestructive testing. Method of metal magnetic memory. The terms and definitions.

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 52081-2003.

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.

As of the June, 2006, 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 17 countries: Argentina, Australia, Bulgaria, Byelorussia, China, India, Iraq, Iran, Israel, Kazakhstan, Latvia, Lithuania, Moldova, Poland, South Korea, Ukraine and Yugoslavia.

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 (Rostechnadzor) 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.

References

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