The metal magnetic memory method and its application for early detection of stress zones in NPP Piping

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Abstract The policy of each NPP is to ensure safe production of electrical energy as well as security of supply. It is known that stress concentration (SC) zones, in which corrosion, fatigue and brittle processes develop most intensively, are the main sources for the occurrence of failures in operational structures. In this paper the method of magnetic memory of metal (MMM method) is discussed. This method was developed in order to conduct an early diagnosis of the condition of the metal of the technological equipment. The method is new and has not yet been studied in depth. The article presents the essence of the method, equipment and scheme of scanning the object. The method was applied to perform a pipeline test of NPP equipment. The results are given and verified. The aim of the article is to present the application of the Metal magnetic memory method in practical terms for performing technical diagnostics of the equipment in NPPs.

Key words: Metal magnetic memory method, nondestructive testing

Introduction It is known that stress concentration (SC) zones in which corrosion, fatigue and brittle processes develop most intensively are the main sources of damage occurrence in NPP equipment. The detection of SC zones is therefore one of the most important tasks of equipment diagnostics. The pipelines metal in NPP is subjected to ageing mechanisms. The degradation mechanisms of WWER type of reactors are known – corrosion, erosion, fatigue and wear [1, 2]. In order to ensure the safe operation of the NPP, control (testing) of the metal of the equipment is carried out. Standardized control (testing) methods are applied – visual testing (VT), penetrant testing (PT), ultrasonic testing (UT) and radiographic testing (RT) [3÷11]. The question of the effectiveness of the methods of equipment control (testing) is raised. The efficiency of the methods is considered from the point of view of the aging mechanisms of the pipelines. Studies are being conducted into whether the methods „cover“ all the observed effects of aging [12,13]. Modern diagnostics of the condition of structural materials has a large array of different physical methods and tools. Residual and working inner stresses measurement techniques and tools are getting wider application for determining the mechanical characteristics of materials. In this process, a central role is played by the methods and tools for measuring residual and working internal stresses. All the known magnetic diagnostics techniques can be classified as follows: 1) Active methods, in which a forced magnetic field with a predefined orientation is created in the material; 2) Passive methods, which use residual magnetism in the material caused by an external magnetic field of natural or man-made origin. Metal magnetic memory method (MMM method) is a passive non-destructive testing technology which has potentials to detect early damage [14,15]. The method is effective in evaluating of stress-strain conditions, and is used for early diagnosing of fatigue damages of equipment and pipelines. The MMM method is standardised [16,17]. At present, the method is not applied for periodic testing of pipelines in NPPs. The reason for this is that MMM method is still poorly studied and unpopular, not included in the scope of methodologies for metal control of NPP equipment. At the same time, it is increasingly necessary to use methods of early diagnosis of areas in equipment with a potential risk of destruction. Such zones in the metal of pipelines are: welded joints, places with cracks or with established corrosion hearths; locations with high acting local stresses, etc. In this paper the application of MMM method for the control of welded joints of pipelines in NPPs is discussed.

Materials and Methods The object of the test are butt welded joints of a pipeline of the second circuit of NPP, steel grade St 20. MMM method is applied. What is the physical nature of this method? It has been found that the crystal lattice of iron forms only as a result of interaction of electrostatic and exchange forces without the participation of external magnetic fields [18, 19]. The magnetic moment of atom is a vector sum of all elementary moments such as of nuclei, electrons, spin and orbital ones. As ensues from the electronic structure of atom within the lattice, the orbits of thermi 3-d electrons become collective and expand to include two atoms. As a result, each atom within the crystal lattice turns out to be part of 6 elliptic orbits, while its own 3-d electrons are only three in number. These three orbits create uncompensated magnetic moments that are oriented in space in a strictly defined way: Of the acceptable angles between the magnetic moments' vectors (or between the normal to the orbital planes), the 90°-angles appear to be the most favorable ones in terms of energy. In other words, the magnetic moment created by an electron whose orbit includes two atoms positioned in the angles of a cube at one of the crystallographic axes, has to be parallel to another crystallographic axis, as is shown in Fig. 1.

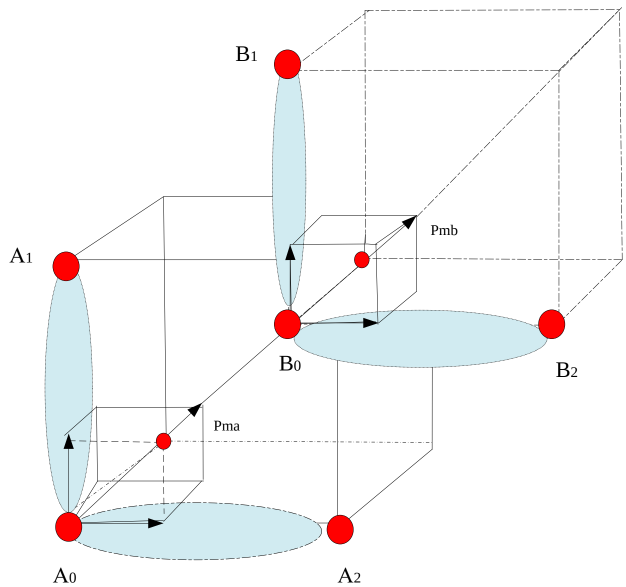

Fig. 1. The magnetic moment of atom Pm is a vector sum of all elementary moments Pma, Pmb; $Pm = Pma + Pmb$.

The arrangement of atoms in space results in as follows: in materials with unfilled elliptic envelopes, forced alignment happens of the orbital orientation of the shared 3-d electrons, and, therefore, forced orientation also occurs of their magnetic fields. The resulting magnetic alignment is termed spontaneous magnetism. The essence of magnetic alignment is in that the vectors of elementary magnetic moments (Pmi) existing in each iron-3 atom and equal as per module, are oriented parallel to the cube edges (elementary cell). The resulting magnetic moment of the atom integrated in the crystal lattice is *Pm*. The direction of the resultant magnetic moment appears to coincide with the spatial diagonal of the cube, and the point of its application – with the centre of the atomic nucleus. The iron crystal lattice contains a large number of elementary cells, and the magnetic moment vectors of the individual atoms provisionally merge in a single vector. When within the material there are areas with concentration of stress, this causes dissipation of their own magnetic fields. The MMM method is a non-destructive testing method, based on the registering and analysis of own magnetic fields. Moreover, the dissipated own magnetic fields have the property of: 1) reflecting the irreversible change of magnetisation along the direction of action of the operational loading maximum stress, 2) retaining the structural and technological heredity of elements and welded joints following their manufacturing and cooling in the Earth's magnetic field. The MMM method utilises the natural magnetisation and the after-effect that occurs in terms of magnetic memory of the metal in the actual deformations and structural alterations within the metal of components and equipment. The technical evaluation tools are apparatuses of the type of multichannel flux-gate magnetometer, Fig. 2. The magnetic field force H_p displayed on the face of the device has a graduation scale in A/m (ampere / meter). The length of the registered movement of the sensor is graduated in mm. The uniqueness of these devices lies in that they identify the stress concentration zones which are the basic sources for development of damages of equipment.

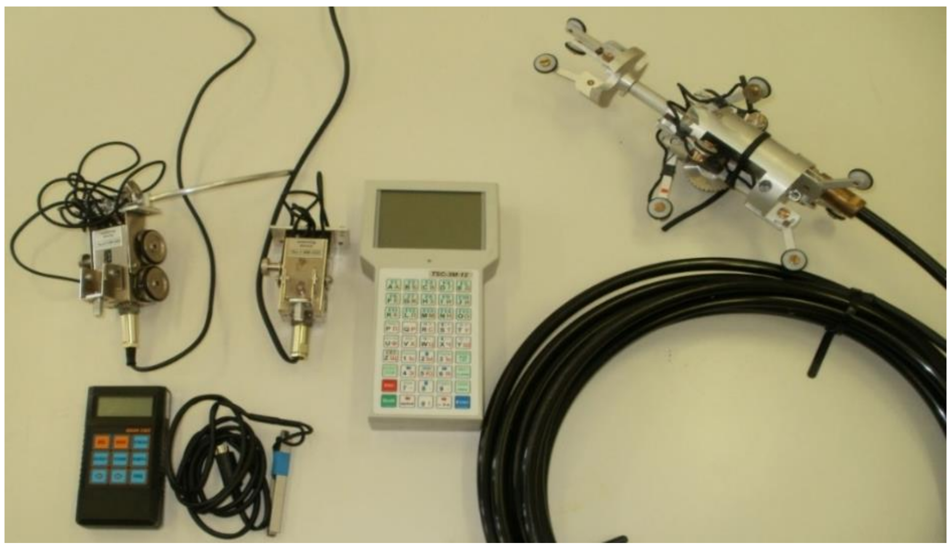

Fig. 2. Technical devices used by the metal magnetic memory method.

The apparatus is lightweight, compact and portable. It is designed for on-site control of the pipe line. The scanning schemes for a pipeline that has been tested using the MMM method are presented in Fig. 3. The pipeline is filled with fluid.

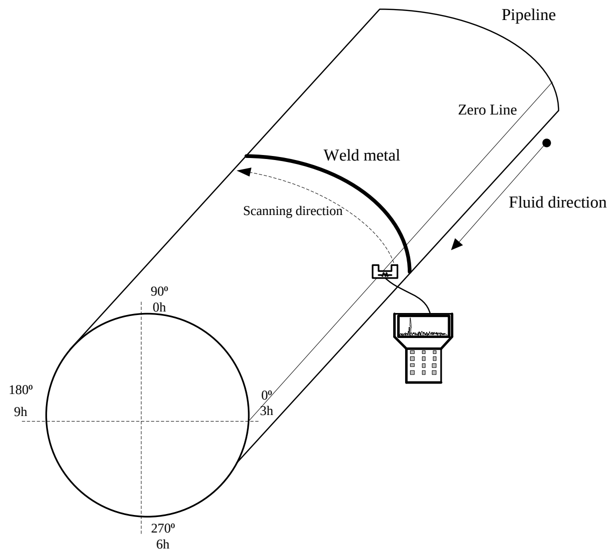

Fig. 3. The scanning schemes for a pipeline tested using the MMM method.

Results Technical data of the tests carried out on the pipeline metal are displayed on the screen of the apparatus as shown in Fig. 4.

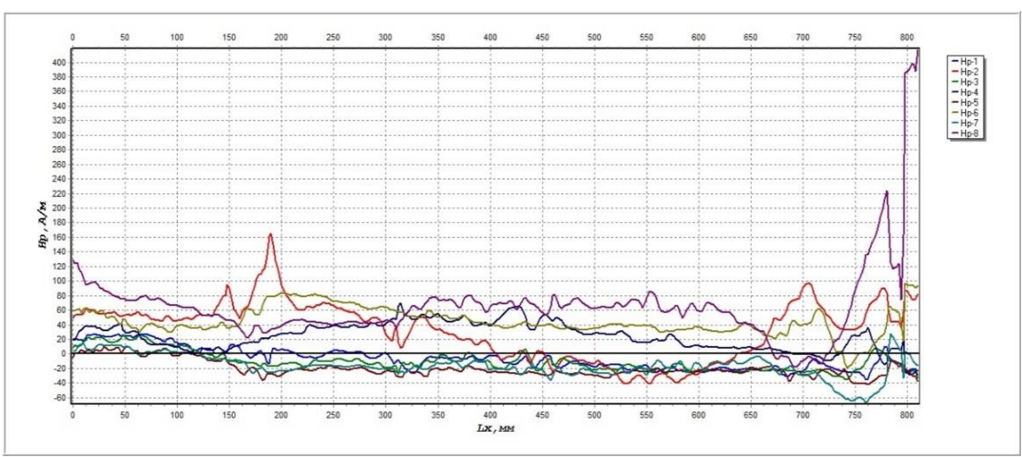

Fig. 4. Technical data from scanning the metal of the pipeline by the MMM method.

The behaviors of the signals for each of the generated frequencies is monitored. The signal peak observed is an evidence that at this point of the scanned object there are zones of stress concentration. Changes in metal properties in SC zones are the processes preceding operational failures. The magnetization of the metal, reflecting the actual stress-strain state of pipelines, equipment and structures, changes accordingly.

Discussion The method provides the link between the magnetic and mechanical indicators of the work hardened material. The results are verified by comparing data from MMM with those obtained through other testing methods applied on one and the same object. Usually, the comparative evaluation makes use of data from ultrasonic non-destructive testing. The results observed in practice show that the UT indications actually coincide with the MMM method ones. The welding technology of the specific welding seam of the pipeline has been reviewed in detail. The probable cause of the stress concentration occurring is an root failure.

Conclusions The MMM method is a new one and still little used for identifying the metal limit condition. The main practical advantage of the method is that it is possible to determine the locations of stress concentration from previously unknown operating loads. No metal treatment or other surface preparation is required for testing. Large areas of controlled objects can be easily and quickly Scanned. There are still unclear practical positions on issues, namely: 1) Up to what test depth is the method applicable?; 2) Are different signals obtained from different in nature structures (pores, silicate inclusions, etc.)?; 3) What are the signals in the presence of closely spaced SC zones of different origin? The method and apparatus provide the opportunity to conduct early diagnostics of equipment.

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