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# METAL EXAMINATION OF WELDED JOINTS OF MAIN CIRCULATION PIPELINE IN NUCLEAR POWER PLANTS USING THE METAL MAGNETIC MEMORY METHOD

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**Abstract**

This paper presents a study of the metal of welded joints of a main circulation pipeline in a nuclear power plant using the metal magnetic memory method (MMM method). The study is aimed at the influence of the operating conditions of the medium for the formation of zones with stress concentration in the metal. The MMM method was developed in order to conduct diagnosis of the condition of the metal of the technological equipment – zones with a concentration of stresses are detected, in which defects in the metal subsequently arise and develop. The method is new and has not yet been studied in depth. The results are given and verified. The aim of the article is to present the application of the MMM method in practical terms for performing technical diagnostics of the equipment in NPPs. The combined application of the MMM method together with traditional methods of non-destructive testing of metal will increase the reliability of the nuclear power plant.

**Key words:** metal magnetic memory method, nondestructive testing

**Introduction.** 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 zones (SCZs) in which corrosion, fatigue and brittle processes develop most intensively are the main sources of damage occurrence in NPP equipment. The detection of SCZs is therefore one of the most important tasks of equipment diagnostics. The pipelines metal in NPP is subjected to ageing mechanisms. The degradation

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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 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 is raised. The efficiency of the methods is considered from the point of view of the ageing mechanisms of the pipelines. Studies are being conducted to see if the methods "cover" all the observed effects of ageing [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. This article discusses the application of the metal magnetic memory method for diagnostics of welded joints of main circulation pipelines in nuclear power plants. Metal magnetic memory method (MMM method) is a passive non-destructive testing technology which has potentials to detect early damage [14–19]. The method is effective in evaluating of stress-strain conditions, and is used for early diagnosing of fatigue damages of equipment and pipelines.

**Materials and methods.** The objects of the study are part of welded joints of the main circulation pipeline in the NPP. The pipe assembly is made of a pipe with a plating, nominal outer diameter 990 mm, wall thickness 70 mm. The pipeline operates in the complex conditions of thermal, hydraulic and vibration loading, and in an environment of corrosion and erosion effects. The operating conditions that can form SCZs are: fluid pressure in steady state $16 \pm 0.3$ MPa, design pressure 18 MPa, operating temperature in steady state $320 \pm 3.5$ °C, design temperature 350 °C, coolant flow rate 21 200 $m^3/h$. For the purposes of this study, MMM method is applied. 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 favourable 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 shown in Fig. 1.

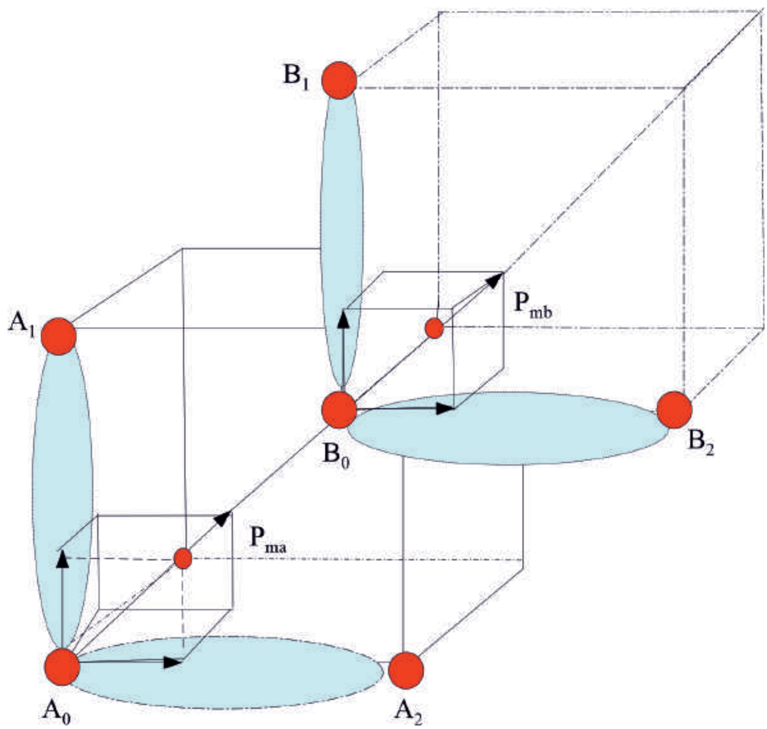



Fig. 1. The magnetic moment of atom $P_m$ is a vector sum of all elementary moments $P_{ma}$, $P_{mb}$; $P_m = P_{ma} + P_{mb}$

The arrangement of atoms in space leads to the following: in materials with unfilled elliptical shells, a forced alignment of the orbital orientation of the shared 3-d electrons occurs and therefore a forced orientation of their magnetic fields also occurs. The resulting magnetic alignment is termed spontaneous magnetism. The essence of magnetic alignment is in that the vectors of elementary magnetic moments ($P_{mi}$) 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 $P_m$. 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 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 SCZs which are the basic sources for development of damages of equipment.

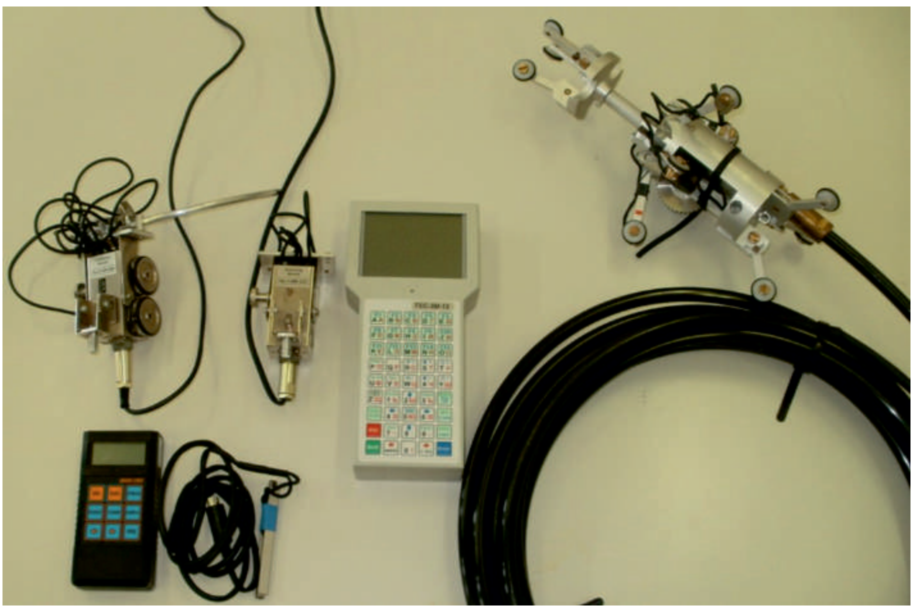


Fig. 2. Technical devices used by the metal magnetic memory method

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. The uniqueness of the device is that the SCZs are identified as the main sources for the development of equipment damages. The implementation of the MMM method in practice consists of several stages. The first stage is to study the capabilities of the method. The second stage is technical – the operating modes of the apparatus are studied, laboratory samples are tested. The third stage is the preparation of a methodology for testing using the MMM method on a specific site. The methodology is verified, and reproducibility and repeatability of the results should be achieved over 80%. The final stage is to conduct a test on a real object. Preparation of the pipeline surfaces is carried out (removal of insulation from the

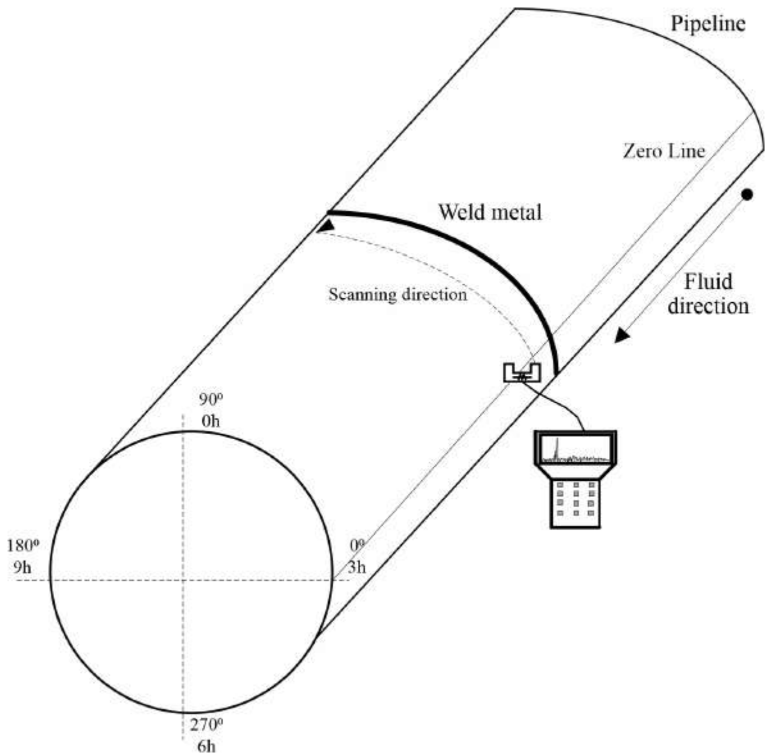


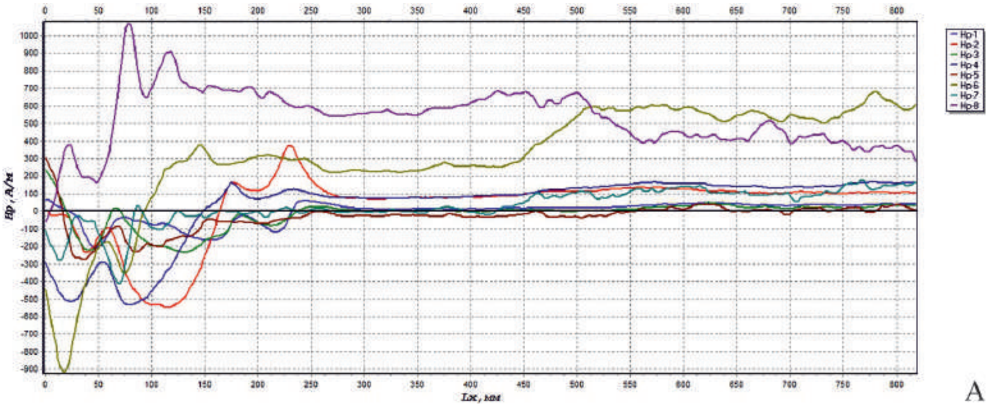

Fig. 3. The scanning schemes for a pipeline tested using the MMM method

facility, mechanical cleaning of the scanning areas), preparation of the apparatus (calibration and adjustment in laboratory conditions) and finally – conducting a real test (scanning of the site, collection of MMM data and data analysis).

**Results.** Testing was carried out on seven welded joints of the main circulation pipeline, straight section. Each welded joint is divided into four sectors, each sector is 70 mm long. Figure 4 shows some characteristic test results that represent the capabilities of the MMM method.

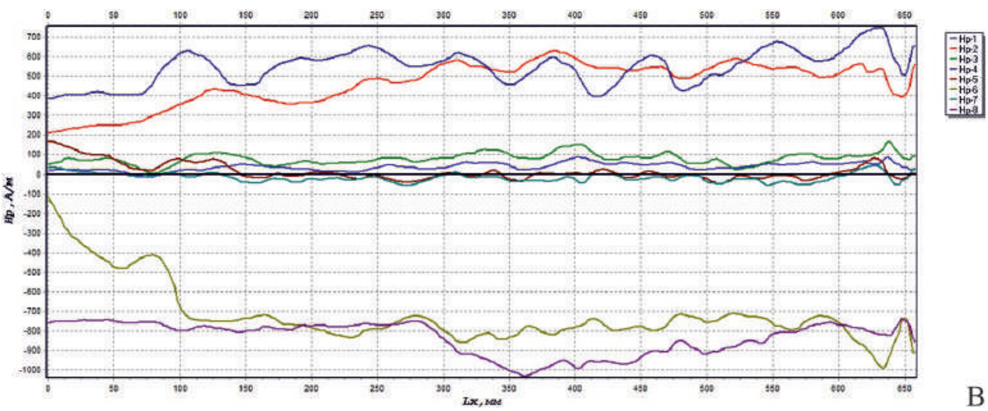
Since the MMM method is new, the results must be verified. Ultrasound testing was carried out at the same sites. A comparison of the data from the MMM method with those from ultrasound is made. It is observed that the indications from the ultrasound coincide with the indications from the MMM.

**Discussion.** The method provides the link between the magnetic and mechanical indicators of the work hardened material. The welding technology of the specific welding seam of the pipeline has been reviewed in detail. All the examined objects are made of the same material, they are made with the same welding technology and they work under the same working conditions. The results of the MMM metal test show that the most SCZ is observed at the site of the welded joint No y-3. What could be the reason? Welded joints No x-2–x-8 are located on



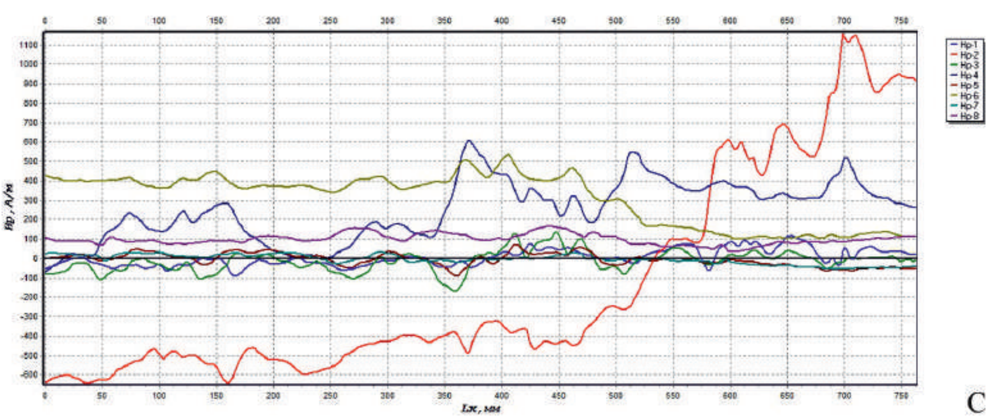

A

At the beginning of the scanned sector No x-2-2 there are amplitude peaks of signals from the 8 channels of the apparatus – the presence of SCZ



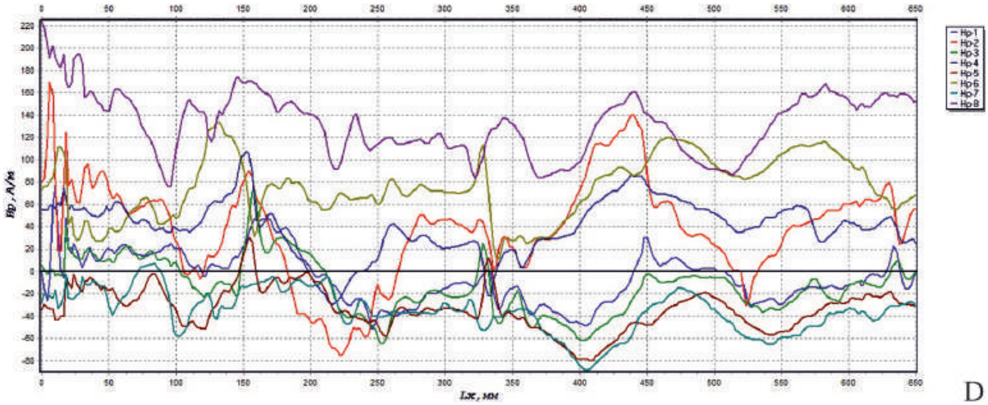

B

Welded joint No x-5-4, SCZs are not observed



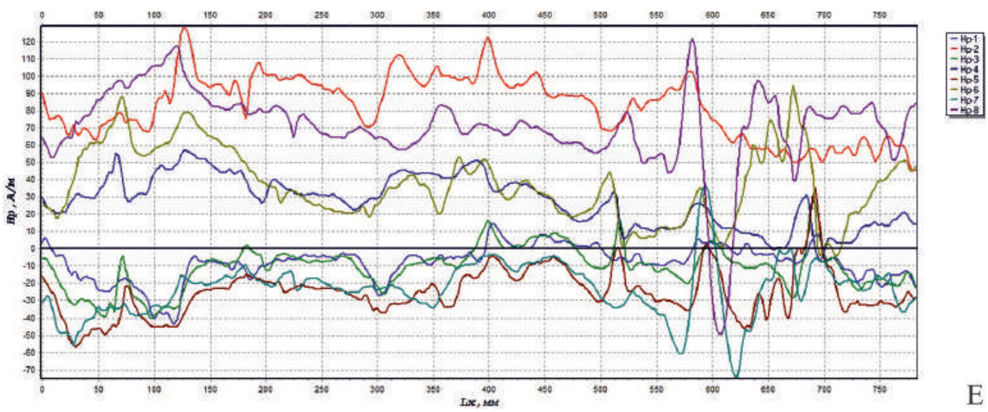

C

Welded joint No x-8-3, at a distance of 300–800 mm from the beginning of the sector, peaks of signals are observed



D

Welded joint No y-3-1. In the entire first sector of the welded joint, multiple peaks of signals from the 8 channels are observed, there are a lot of stress concentrators



E

Welded compound No y-3-2. An unstable signal is observed throughout the sector, but particularly strong stress concentrators are observed at 600 mm from the beginning of the sector

Fig. 4. Test results of the MMM method applied for metal control of welded joints of the Main Circulation Pipeline

the straight section of the pipeline and their geometric configuration is the same. The welded joint No y-3 is located on a main circulation pipeline, but close to a curved section (elbow). Here there is a transition from laminar fluid flow to mixed fluid flow (laminar + turbulent). The turbulence of the fluid forms a change in the direction of the hydraulic load vector. Thus it is possible to form zones of tension concentration.

**Conclusions.** The MMM method is a new one and still little used for identifying the metal limit condition. The joint application of the MMM method together with other standardized test methods leads to the best technical and economic results. The metal test of the main circulation pipeline by the MMM method demonstrates that the method is sensitive to areas in the metal for which increased fluid loads can be expected. The MMM method is effective because large areas of objects are quickly and easily tested and information about the "danger zones" in the metal that have the potential for destruction is obtained. These specific areas can subsequently (at the next shutdown of the unit) be tested using another well-known method of visual and ultrasonic methods to track the presence and development of defects in the metal – but only specific hazardous areas will be controlled, not the entire welded joint. In this way, the facilities are protected from subsequent destruction under the influence of operating conditions. The application of the MMM method saves dose load, unit downtime, saves money.

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