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METAL MAGNETIC MEMORY – A NON-INTRUSIVE NDT TECHNIQUE

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Abstract. *Metal magnetic memory (MMM) is a newly developed non-destructive testing (NDT) technique. It can detect and prevent early failure caused by defects such as corrosion, stress concentration, micro-crack, fatigue damage, Stress Corrosion Cracking (SCC) and weld defects, of ferromagnetic components. MMM technique relies on the measurement of self-magnetic flux leakage (SMFL), due to residual magnetization or irreversible change of the local magnetization state of components in stress concentration zones (SCZ) around damaged areas under operation. It was first studied in the 1980s, when researchers in Russia observed the stress-induced magnetic fields on defective areas of boiler pipes in a power station. Further, it was widespread in the world as a way to address structural integrity of ageing ferromagnetic pipelines. And it is being used to inspect unpiggable pipelines worldwide. This technique can also be applied to avoid exposition of personnel to hazards by eliminating internal inspections in some conditions, as non-intrusive inspection (NII). This paper will present a brief discussion on the physical basis and the boundary conditions for application of the MMM technique, the procedures for processing the inspection results in magnetic components and also in the practical assessment of defective welded joints. In Brazil the main application has been driven for pipeline inspection. In this case MMM is usually combined with pipe locating and GPS technologies. The pipeline operator usually locates the buried pipeline with a pipe locator device, inspects the pipeline using MMM equipment and records GPS coordinates along the segment in order to locate anomalies for further field correlations (dig verification trenches or even provide maintenance to the pipeline). It will be presented the results of buried pipeline inspection services in Brazil: more reliable reports in terms of anomalies identification, sizing and location.*

Keywords: *Metal Magnetic Memory, Non-Destructive Testing Techniques (NDT), Stress concentration zones, Non-Intrusive Inspection (NII)*

1. INTRODUCTION

The Metal Magnetic Memory method is now applied all over the world for a great variety of different test objects. Turbine blades, wires, cables, chains, and many other equipment can be inspected with different MMM sensors, as can be seen in figures 1a, 1b and 1c. The main objective for all these cases is to evaluate stress concentration, as one of the pioneers studies (Dubov, 1999), thus being able to detect the most probable place to occur a defect in the metal. Also, MMM can be applied to detect many different types of metal damages, such as metal loss, pitting, cracking, SCC (stress corrosion cracking), bending and others. All anomalies are determined by the stress caused in an area and these anomalies are classified in terms of dangerousness.

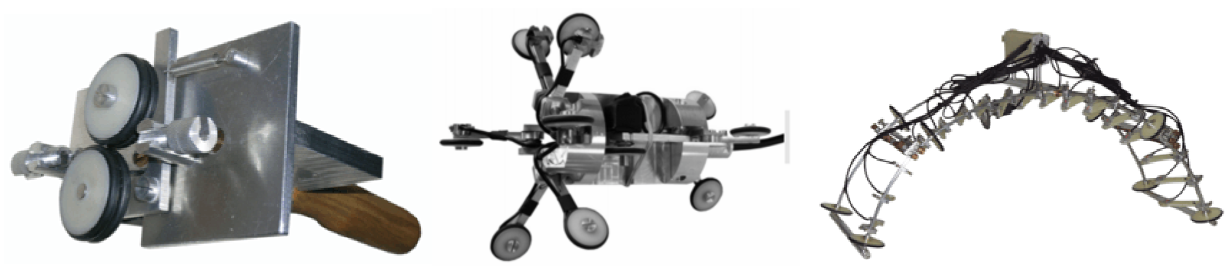

Figure 1a. Steel wire inspection sensor. Figure 1b. Tube internal inspection sensor. Figure 1c. Pipe external inspection sensor.

This technology is well stablished and standardized by the International Organization for Standardization (ISO STD 24497; 2020). This paper will focus on buried pipelines inspection, following all the requirements from that standard.

2. PHYSICAL FUNDAMENTALS OF THE MMM TECHNIQUE

The reaction of the terrestrial magnetic field (geomagnetism) induction with ferromagnetic structures results in the magnetization of these metallic bodies, revealing measurable and comparable magnetometric data through the Metal Magnetic Memory method application, as explained in recent work (Bao, 2016).

The structure of ferromagnetic compounds will produce and record a residual effect of magnetic memory when subjected to vectors from stress and under the effect of magnetic fields, even with altered operating and environmental conditions.

Ferromagnetic materials will have an effective magnetic field when they act under tensions from various sources and geomagnetism. This magnetic-mechanical phenomenon was attributed to the terminology MMM - Magnetic Memory of Metal.

Pipelines and tubes, theoretically "ideal", have a dipole derived from the interaction with geomagnetism.

It can be observed that the magnetic lines of geomagnetism force provide perturbations and detectable changes in the pipeline's areas that present imperfections. These small magnetic anomalies are added to the geomagnetism vector (F) and the result is a new and effective vector F.

In the case of ferromagnetic pipelines and tubes, when homogeneity is found along their metallic structure, that is, they do not present discontinuities, defects or damage caused by the manufacturing, construction or use and operation process, such as magnetic power lines derived from the interaction with geomagnetism is practically on the same level.

With the occurrence of heterogeneities, discontinuities, defects or damages, deformations and changes in the magnetic lines of force are found in pipeline structure affected segments. These deformations of the magnetic power lines (anomalies) are directly related to the extension and location of areas with disturbance and structural discrepancy (damage, defects, etc.) of the pipeline or tube.

The information derived from the processing of sensory data from magnetic power lines can identify defective areas and initiate the analysis and study of their degree of criticality, taking into account the behavior of the generated graphics and morphological, constructive, and operational aspects of the pipelines .

The ability to detect and interpret magnetometric data and its alterations (anomalies) gives the MMM – Metal Magnetic Memory method unique and exclusive characteristics and advantages in the segment of non-destructive testing applications in pipelines, industrial piping, and other equipment.

3. TOOLS AND APPLICATION

There are two main variations of the MMM tools when to be applied to tubes or pipelines, as presented in recent work (Fiorini, 2019). The first is based on non-contact equipment (figures 2, 3 and 4), where sensors are placed in a distance from the test object. This is a very unique method to evaluate the whole equipment, screening all its length and searching for stress concentration. It is suitable for above ground also, but its main advantage is when applied to buried equipment, and even under water pipelines. Thus, the operator can locate anomalies to the wall of the pipeline, for example, without the need for excavation.

Figure 2. Non-contact MMM equipment following pipe-locator information (position and depth of pipeline).

Figure 3. Non-contact MMM equipment (distance counting wheel, sensor and datalogger) for buried pipeline application.

Figure 4. Non-contact MMM equipment (sensor and datalogger) for above ground pipeline application.

The second MMM application methodology is by using contact sensors (figures 5 and 6). It can be applied in fully accessible equipment or to improve non-contact results, in buried pipelines, by identifying the exact position of anomalies in bell hole inspection, for example, or even as an alone inspection, such as for short above ground tubes.

Figures 5 and 6. Contact MMM equipment (sensor and datalogger) for inspection in bell holes after non-contact MMM inspection.

Contact MMM is a very useful tool to determine de exact location (longitudinally and circumferentially) and criticality on an anomaly in a shorter area after the whole pipeline has been inspected with non-contact MMM, used as screening tool.

3.1 Advantages and Limitations

The main advantage is the possibility of non-intrusive evaluating the whole ferromagnetic pipeline or tube in terms of stress, even if it is completely buried. Not only that, but the pressure and flow will not need to be changed and cathodic protection will not need to be turned off during inspection. That allows for a more cost-effective overall operation and lower risks involved.

There is no risk applied to the pipeline, since the inspection is done by a distance, and there is no risk of shortage of product delivered to customers, for example, since no operational condition is changed.

The main limitation is the ferromagnetic property of the component to be inspected. Steel or iron-based alloys are the most suitable for this technology. Other limitations lie on the depth the pipeline is buried. The lower it is buried, the weaker the signal is and so the accuracy is reduced. An usual rule of thumb for pipeline depth limitation for MMM application is 15 times the pipeline diameter.

Another main benefit is the possibility of evaluating the pipeline condition in terms of stress and not only by defects sizing. As will be shown later in this paper, segments submitted to ground movement, for example, may contain high level of stress, but no defects. On the other hand, this stress can cause severe damage in the future. So, this evaluation may bring a different approach and even complementary information for conventional NDT methods.

4. FIELD CASES

4.1 Current Long Term Project in Brazil

Nowadays, the largest MMM pipeline inspection project in the world is being executed in Brazil. The target are carbon steel pipelines in various diameters and pressure classes (from 7 to 35 bar). The scope of this project is to evaluate with remote inspection (non-contact) the structural integrity of these pipelines.

This project started in 2018 and is now running up to 2022 (annually renewed based on verified assertiveness of the nominations made in the cycle) and the inspected extension is of approximately 2,000 km. To the present date, more than 1,200km were already inspected.

The sites where the pipelines are installed varies from urban to rural areas, but also goes through highly industrialized zones.

For such a project is necessary one Field Team Lead Engineer (Level 2 MMM Certification), one Pipeline Technician (Level 1 MMM Certification) and one Survey Technician (Level 1 MMM Certification) on field activities.

4.1.1 Layout and Activity Flowchart

The project follows these steps:

1. Implementer delivers the pipeline list with extensions, diameters, and address for segments to be inspected in the annual cycle;
2. Implementer performs the prior analysis and applies selectivity filters to study the technical feasibility of the correct application of the MMM technique, based on intrinsic limiting parameters of the technique, human accessibility to the stretches and safety and health aspects of the inspectors;
3. Implementer delivers the schedule for the execution of services in a spreadsheet already containing operationally viable stretches, segregating the non-inspectable stretches (segments x regions x time);
4. Accepted by the client;
5. Start of field activities: Recognition "in loco" of sections, location (pipelocator) and pipeline georeferencing (submetric GPS system in real time), survey of magnetometric data (MMM sensor + dataloger);
6. Treatment, processing, and analysis of data obtained in the field at the Inspek's laboratory;
7. Delivery to the client of final reports containing geographic indications (GPS coordinates and physical references) of the geomagnetic anomalies and their criticality qualifications (risk for the operational operation of the inspected segment of the asset).

4.1.2 Verification of Assertiveness of Remote MMM Indications:

The assertiveness verification procedures of the indications of anomalies expressed in the final MMM reports delivered to the client are defined by the implementer and performed by third parties to open ditches and specialists in the application of ENDs using traditional inspection tools to locate, typify and quantify damages, issue opinions, perform repairs in the gas pipeline segment (when necessary) and promote the reconstruction of the coating and the terrain of the open trench for correlations.

The MMM was introduced in the implementer's inspection techniques list, after years of investigations and tests, replacing coating integrity assessment techniques and monitoring the effectiveness of cathodic protection systems (indirect assessment methods of metal integrity, bringing huge savings in the opening of trenches (cost x risk) and effectively reinforcing the reliability and operational safety of the client's important assets.

4.2 Specific Cases

The technique is suitable also to evaluate the stress caused by ground movement to the pipeline. When ground movement occurs, a very extensive segment of the pipeline is submitted to high stress levels. This evaluation is important to be done, not only right after the movement occurred, because of the possibility of collapse or rupture, but also for later crack or stress corrosion cracking (SCC) developments.

The usual signal visible on the magnetogram (graph obtained by MMM inspection) when submitted to a large area of stress, such as because of ground movement, is a sinusoidal curve. This signal is presented below, for a 36" diameter, ASTM-A283 Gr D steel buried pipeline in the region between 360 and 440 meters (figure 7).

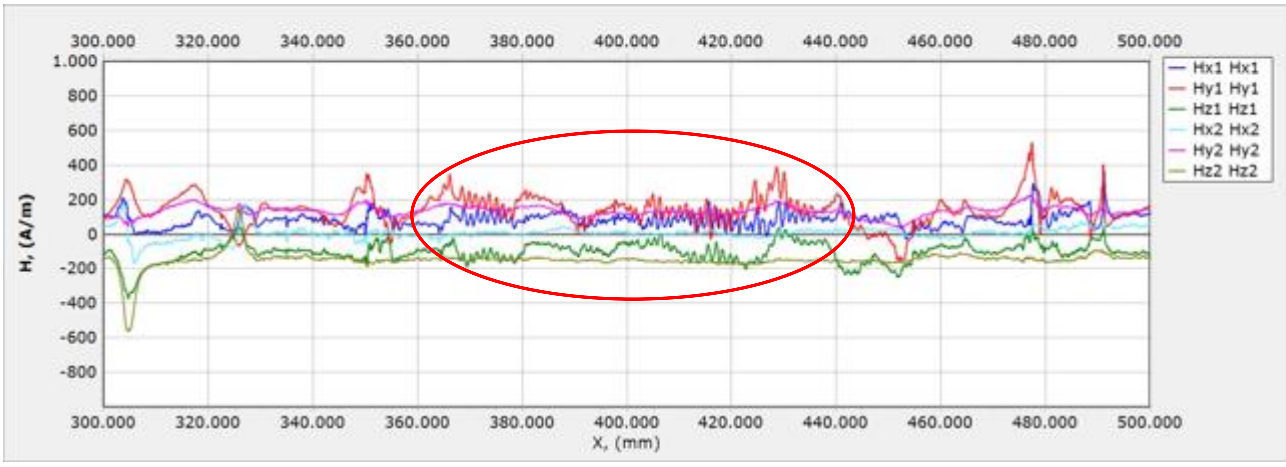

Figure 7. Non-contact MMM graph of a steel pipeline that suffered ground movement.

The graph presented above was obtained using non-contact sensors. This approach allows for above ground inspection without the need of excavation. It is possible, however, to use contact sensors or other NDT methods for later evaluation on bell holes to determine the exact location (longitudinally, clockwise and if it is internal or external) of the anomaly indicated previously.

Now we are going to detail a case demonstrating the sequence of MMM inspection until the contact inspection in the field bell holes, starting by the graph bellow (figure 8), obtained from a 10" diameter, API 5L Gr B steel pipeline, that transports gasoline.

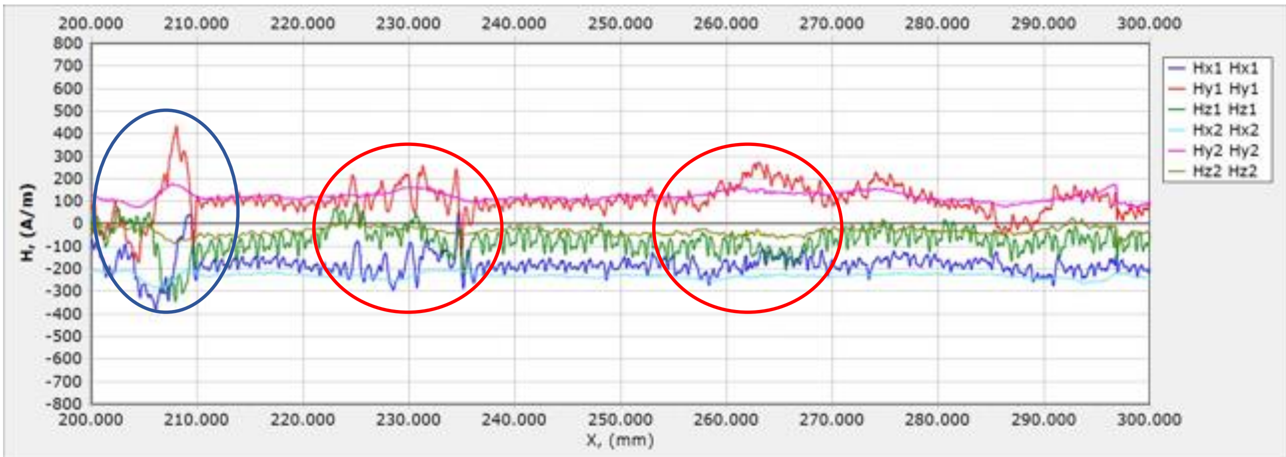

Figure 8. Non-contact MMM graph of a steel pipeline.

The graph above indicates 3 anomalies. The first one, in blue, is, actually, an interference caused by heavy traffic of vehicles on a reinforced concrete platform placed on the top of the pipeline, as informed by the client.

Now we are going to analyze the second indication in red, from the graph above, approximately at 260m position, that was further inspected by contact MMM technique in the bell hole. The magnetograms below (figures 9 and 10) were obtained in this place, after excavation, for the 6 o'clock position (below the pipeline):

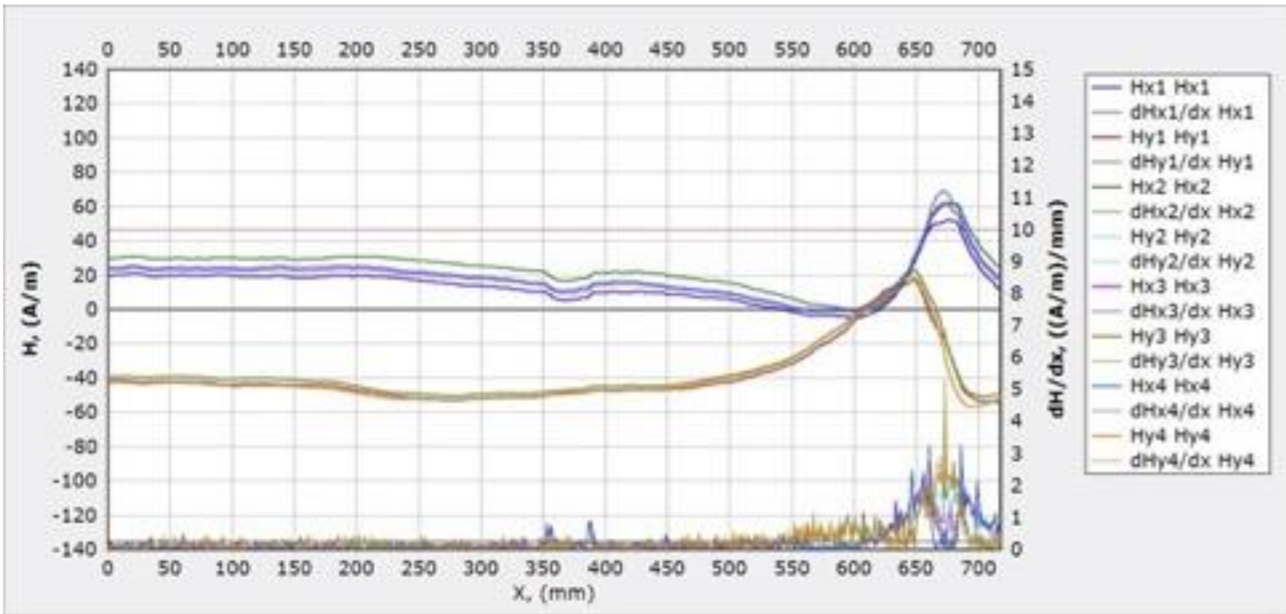

Figure 9. Contact MMM graph of a steel pipeline.

Figure 9 indicates the anomaly correspondent to the second red anomaly if Figure 8. This is a graph obtained via a contact sensor that ran on top of the Coal Tar coating at 6 o'clock (under the pipeline). It shows the anomaly in the end of the graph (approximately at 650mm).

The anomaly indicated in figure 9 matches the indication on figure 10, where there is a very clear orange line pointing to very close to 180° (6 o'clock) position. After the excavation, the MMM contact inspection was conducted over the circumferential weld to check.

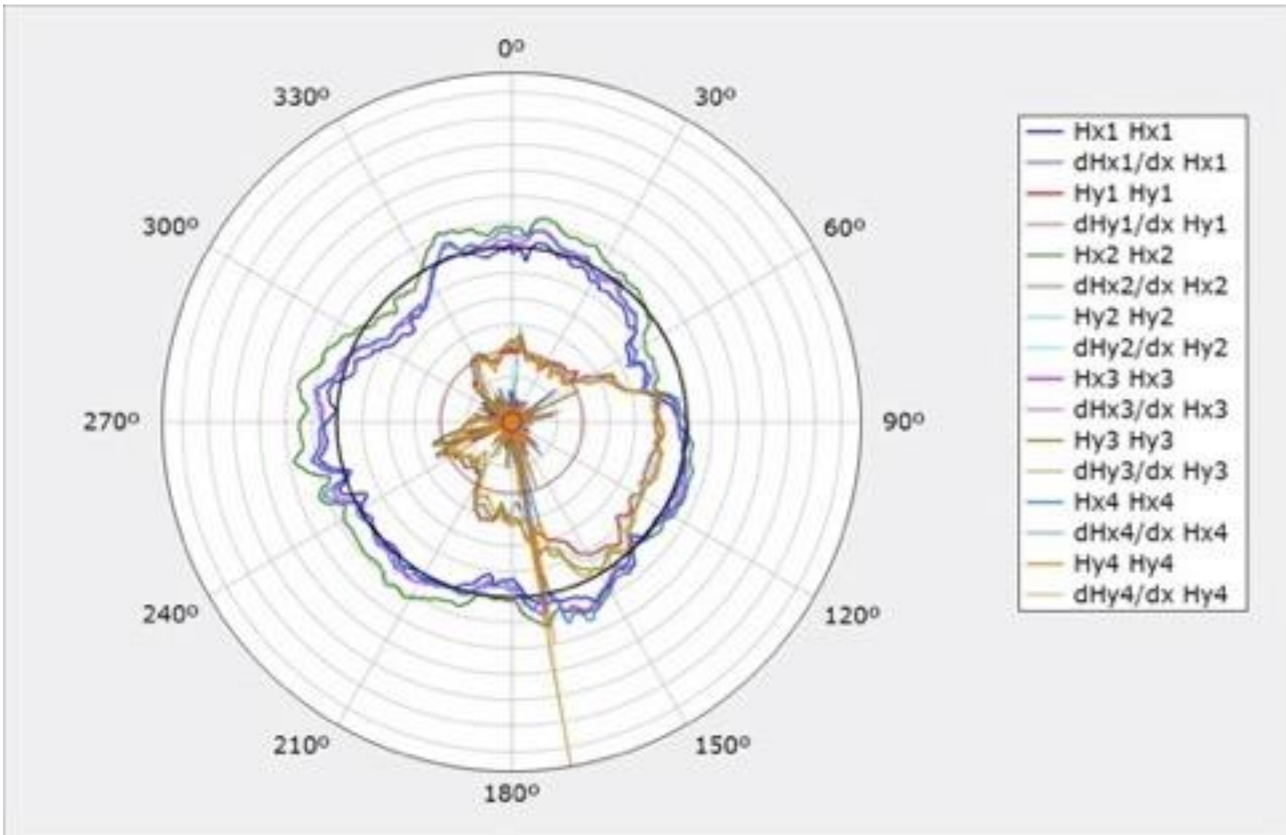

Figure 10. Clockwise contact MMM graph of a steel pipeline.

The positions of these indications (figures 9 and 10) were marked on the pipeline surface on the top of the coal tar coating (figures 11 and 12). After coating removal, the damage was visible (figure 13), confirming all results obtained during the MMM above ground inspection, from non-contact until longitudinal and circumferential scan contact inspections.

Figures 11 and 12. Anomaly position`s indication after the contact MMM inspection over the coal tar coating.

Figure 13. Anomaly founded on circumferential welding at 6 o'clock after coating removal, matching non-contact and contact inspections indications.

5. CONCLUSIONS

The Metal Magnetic Memory (MMM) method is now applied worldwide to several different test object types. Thousands of pipeline kilometers were inspected with great results. Not only that, but MMM has solved a great bottleneck for NDT methods – evaluating whole segments or complete buried pipelines as a screening tool applied to detect stress concentration. This made possible for buried pipelines to be fully inspected, and not only on bell holes after digging.

In Brazil, this technology was applied to a very wide range of pipeline types (mining, petrochemical, water, Oil & Gas, firefighting systems, and many others. More than 1,300km of pipelines were inspected only in Brazil and continuous or "in a row" contracts for the largest pipeline operators are common.

Several types of damages were confirmed over the years in Brazil, even some before undetected by other NDT methods, making MMM a complementary solution or as the only method to be applied.

Thinking about the future, to assure the massive application, this technology shall be standardized and certified by a Brazilian competent association, accredited by the INMETRO (*Instituto Nacional de Metrologia, Qualidade e Tecnolo*gia - National Institute of Metrology Standardization and Industrial Quality), such as ABENDI (*Associação Brasileira de Ensaios Não Destrutivos e Inspeção* - Brazilian Association of Non-Destructive Testing and Inspection), certifying operators and inspectors, but also stablishing national standards.

One other major step is to develop new applications. Now this technology is applied to under and above ground pipelines, but there is a large demand for great height and underwater applications. So, installing MMM sensors into drones and ROVs, can further improve its benefits to the NDT market as a NII Technique.

6. REFERENCES

(1) Dubov, A. A. (1999). Diagnostics of metal items and equipment by means of metal magnetic memory. NDT'99 and UK Corrosion'99;
(2) ISO 24497-1, 2 and 3; 2020 Edition; Non-destructive testing – Metal Magnetic Memory;
(3) Bao, S., Fu,M, Hu, S., Gu, Y., Lou, H.; 35th International Conference on Ocean, Offshore and Arctic Engineering (OMAE2016);
(4) Fiorini, S. L., 3rd International Conference on Diagnostics of Structures and Components Using Metal Magnetic Memory Method, May 22-23 Czech Republic Prague (MMM-NDT 2019).

7. RESPONSIBILITY NOTICE

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