The International Journal of
TRANSPORT & LOGISTICS
Medzinárodný časopis
DOPRAVA A LOGISTIKA

ISSN 1451-107X

VIRTUAL PROTOTYPING SUPPORTED BY MAGNETIC MEMORY METHOD

Janusz Juraszek [1]

Key words: metal magnetic memory, FEM, multibody systems, energetic links, prototype

Abstract:

The aim of this work is to implement of new Non-Destructive Testing (NDT) method (Metal Magnetic Memory-MMM) to comprehensive diagnostic of energetic connectors, what has a great practical importance. Essence of this method is detecting stress concentration zones (SCZs) in element's material during its work, already before micro cracks and fracture occurs. In compare with traditional NDT method, which shows SCZs after the failure occurs (post factum), this method gives crucial progress in NDT. In this paper connection numerical structural simulation (static and dynamic) with MMM diagnostic is also proposed. SCZs in single energetic connector were determined and dynamic analysis of complete energetic line, which included analysed connector, was carried out (MSC.ADAMS).

Uniqueness of this analysis consist in connecting FEM analysis, MSC.ADAMS multibody system analysis (for different work conditions testing already during virtual prototyping) and MMM method verification.

This procedure enable to take diagnostic analysis of chosen construction elements and give possibility of take the real work conditions of element into consideration (e.g. vibrations). Proposed diagnostics method can substantially increase work safeness of energetic connectors and lines.

1. Introduction

This paper presents an innovative connection between a new diagnostic method (Method of Metal Magnetic Memory MMMM) and numerical methods used in virtual prototyping (Finite Elements Method FEM and multibody system analyze). MMMM allows fast and efficient verification of state stress in prototype manufactured on base of numerical tests. In our opinion this kind of connection allows to increase optimization process effectiveness while designing new elements. This method was widely discussed by Dubov [1,2,3,4], Wang [5,6] and in already published works of this paper's authors [7], [8].

Along decades computer methods using numerical methods in virtual prototyping improved considerably. The most popular is Finite Elements Method (FEM) which allows to determine stress distribution and form of deformation in numerical model of the real element. While creating the numerical model many simplifications were introduced. This simplifications are the compromise between accuracy and the costs of analyses. Simplifications are exerted in less important areas (chamfer, fillets, etc.) basing on experience of designer. Apart from conscious defeating topologies of less important areas of construction material properties are simplified, too. This situation is caused by lack of possibility to verify the real material structure for example anisotropy caused by forming. That is the reason why in most cases the model of material in FEM is idealized. These results need experimental verification because they do not consistent with reality.

Unfortunately, sometimes there is no possibility for exact experimental verification. Such tests are time-consuming, expensive and often require special preparation of tested elements. Moreover, popular diagnostic methods allow detecting of only already developed cracks and do not allow

[1] **Prof. Dr hab. Ing. Janusz Juraszek** , Mechanical Dep. TU v Bielsku-Białej , Katedra Podstaw Budowy Maszyn ul. Willowa 2, PL 43 300 ielsko-Biała, Polsko, Tel.: +48 508 146 817, e-mail: jjuraszek@ath.eu

determining of stress state and history. There are not good enough methods verifying results of FEM analyzes in prototyping process.
Method of MMM could be a perfect supplement of prototyping process. MMMM allows to detect dangerous areas such as structure defects (even before occurrence of microcracks) and stress concentration zones (SCZ) basing on measurement of self magnetic leakage fields (SMLF) of ferromagnetic elements. Additionally MMMM is capable to determine stress history.

METHOD OF METAL MAGNETIC MEMORY

The Metal Magnetic Memory Method (MMMM) is a new diagnostic method invented by prof. Anatoli Dubov and maintained in European norms [9], [10], [11]. This method is based on a phenomena of ferromagnetism. Loading of a ferromagnetic part of a construction in a weak external magnetic field (magnetic field of the Earth) due to the Villary's effect causes its self-magnetization. Measuring of this field can show locations of the stress concentration zones (SCZ) and defects of material structure. In this places Self Magnetic Leakage Field (SMLF) is created. In areas where high density of dislocation is formed magnetic domain barriers are fastened. This phenomena generates magnetic signal which can be detected by a special measuring device used in MMMM. Such a signal can be represented by:

- sing changeover of normal component of SMLF (tangent component of SMLF) and simultaneously reaching local extreme by tangent component of SMLF (normal component of SMLF);
- great values of SMLF components gradient. The gradient of SMLF (K_{in}) is proportional to density of dislocations.

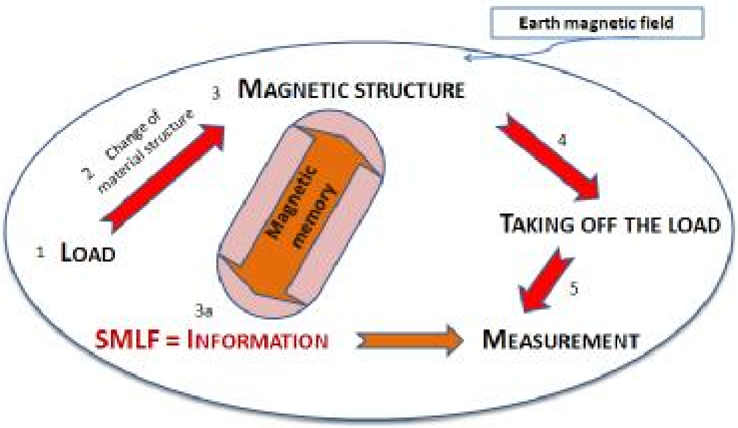

Fig. 1 *A scheme of measuring methodology using MMMM*

Fig. 1 shows methodology of measuring using MMMM. In weak external magnetic field of the Earth the ferromagnetic object is loaded. This could cause defects forming, material and magnetic structure changes. Defects and transformation of magnetic structure generates magnetic signal (SMLF). This signal does not change after taking off the loading. That is a reason why this method is called metal magnetic memory method. This signal inform about SCZs occurrence and it is measured by a special device (Fig. 2).

Fig. 2 *A Photography of MMMM measuring device*

The measuring kit consists of a measuring instrument (1 on Fig. 2.) and a sensor (2 on Fig. 2.) with two probes (3 on Fig. 2). The main advantage of this device is that is mobile and easy to use.

2. Virtual prototyping supported by MMMM - FEM

Advantages of MMMM such as fast and easy measurement, mobile measuring kit and no need to special preparation of tested elements allow effective supplement of prototyping process. This method has possibility of fast stress state determining and accordingly verification of numerical results.

The figure below shows the scheme of connection MMMM with FEM analyzes.

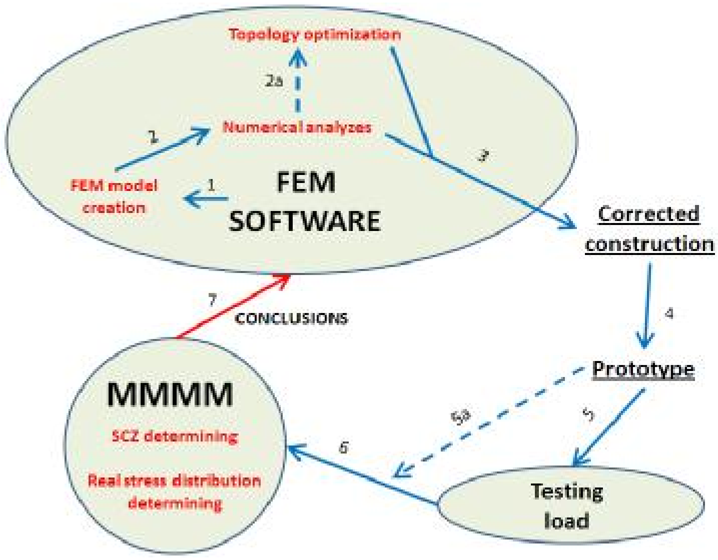

Fig. 3 *Scheme of connection MMMM with FEM analyzes*

As we can see on above scheme after creating of the FEM model (1) and numerical analyses (2) and optional topology optimization (2a) project of corrected construction is created (3), on base of which prototype is manufactured (4). In the next step of the algorithm prototype is loaded (5) and after this it is measured using MMMM (6). There is also possibility of verifying manufacturing process influence (5a) on material structure (SCZ, internal cracks). The whole process could be repeated (7) after element measurement using MMM and drawing conclusions. In the next cycle of this process corrections and geometry changes (based on last cycle) should be introduced.

The figure below shows comparison of results from FEM and MMMM in a energetic clumb.

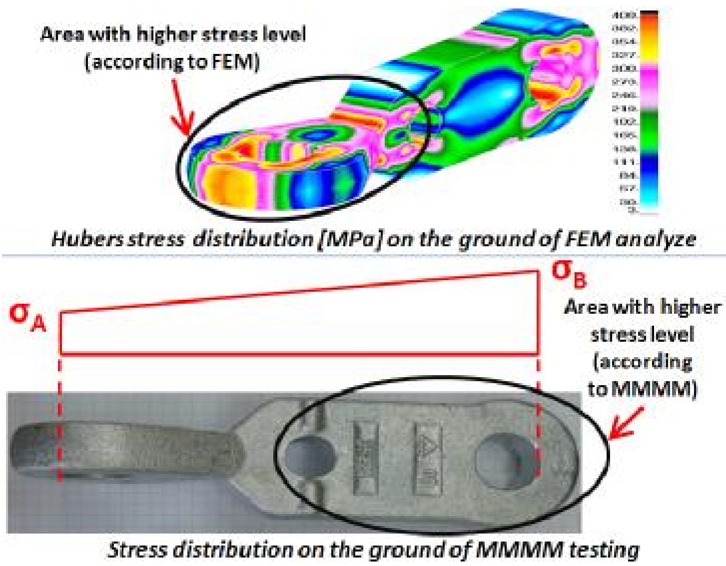

Fig. 4 *A comparison of results from FEM and MMMM in a energetic clumb*

Fig. 4 and Fig. 5 show the comparison of results from FEM and MMMM in an energetic clumb. On these figures convergence and divergence of the results can be observed. The convergence is related to SCZs located on the area marked as SCZ on the Fig. 5. Results showing SCZ in marked area (Fig. 5) obtained in FEM analyze and MMMM tests are convergent. Divergence affects areas with the highest level of stress. According to FEM analyze the smaller mounting eye shows the higher level of stress. MMMM tests basing on movement (Fig. 6) of normal components of SMLF plots showed that the larger mounting eye has higher level of stress (Fig. 4). Fig. 6 shows two plots of normal components of SMLF before and after loading. Difference in the loading values can be observed. In the first plot (showing situation before the loading) normal components have lower values than in the second plot (after the loading). That means that the level of stress increased after the loading.

The difference between FEM analyze and MMMM test results is probably caused by idealization of material in FEM model. In FEM analysis material (steel) had isotropic properties. Forming process of the element caused anisotropy and higher level of jumping-up in smaller mounting eye which could cause its empowerment. This situation (anisotropy and empowerment) was not reflected in FEM model.

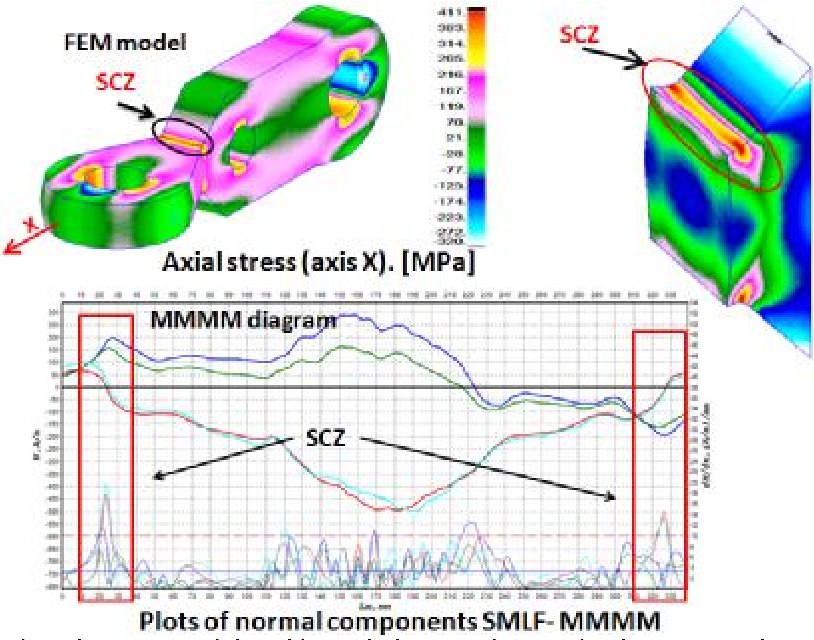

Fig. 5 *SCZs locations in FEM model and in real element detected using MMMM in an energetic clumb*

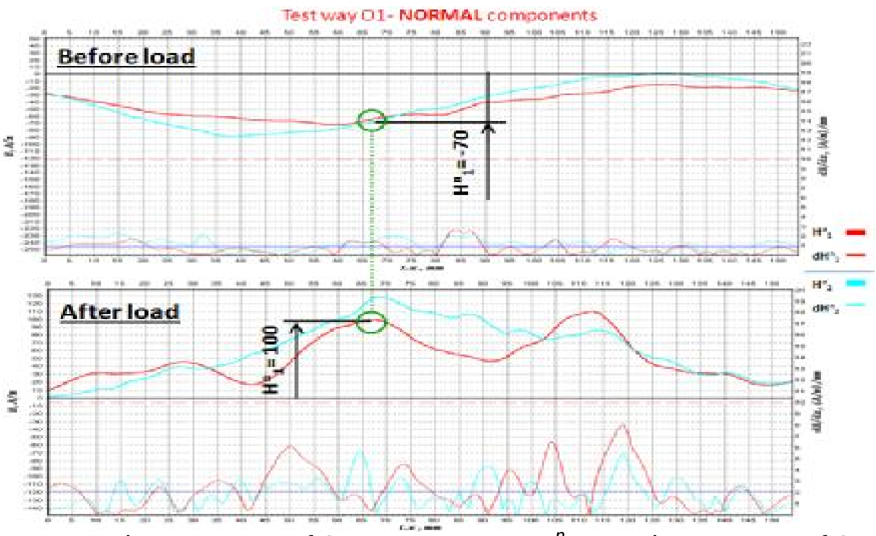

Fig. 6 *Normal components of SMLF movement; H^n-normal component of SMLF; dH^n- gradient of-normal component of SMLF*

3. Virtual prototyping supported by MMMM- Multibody Systems analysis

Virtual prototyping process could be enhanced by multibody system analyzing application. The right model loading is very important during the FEM analysis. Unfortunately it is not always possible to determine the whole spectrum of affecting element forces. In case of energetic clumbs standard experimental durability tests are based only on axial tension. This tests do not mirror real states of loading during work. The real loadings of energetic lines are connected basically with vibrations of energetic cable caused mostly by winds. This factors cause fatigue of energetic clumbs. In standard approach of FEM analysis directions and values of forces are determined by analytic calculations in characteristic states of loading or nominal loading is used (for example axial-tension loading for energetic clumbs).

Multibody system of analysing in MSC.ADAMS gives a possibility of analysing of elements which work in combined, changeable and hard to determine in analytic way loading states because it is necessary to appoint the real work conditions of the clumbs.

Analysis in MSC.ADAMS makes possible determining estimated real work conditions of the clumbs. Loading spectrum fixed in MSC.ADAMS could be used in FEM analysis by export to FEM software (in our case MSC.PATRAN/NASTRAN). This method increases the quality of the virtual prototyping process because it allows checking of designed part in estimated work conditions without any need prototype manufacturing. To get reliable results building of a correct multibody model (including the loading of energetic line and properties of multibody system parts) is necessary which in case of energetic clumbs enclosed the whole energetic span.

After preliminary results obtained in MSC.ADAMS of the loading from accurate time are exported to FEM software. Exported loadings are chosen on the base of forces plots in MSC.ADAMS. Due to this fact is possible to chose this time moments in which values of the loading were the biggest and/or loading was the most combined. Fatigue analyze is also possible to effectuate in base of loadings in specified time period. This opportunities allow better quality of FEM analysis effectuation.
Thus, manufactured prototype is more comparable to the optimal one. This fact is results in designing process effectiveness and speed increasing. Additional tool which can fast verify correctness of designed in this way construction is mentioned before MMMM.

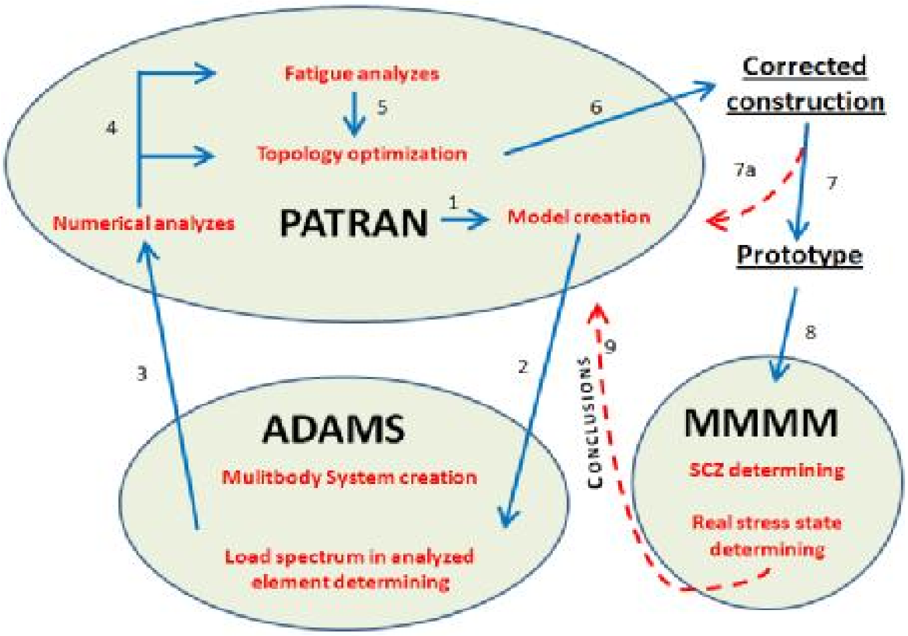

Fig. 7 *Scheme of virtual prototyping supported by MMMM*

Fig. 7 shows the scheme of virtual prototyping supported by MMMM. At the beginning numerical model is prepared (1). This model is exported to ADAMS (2) and placed in the proper area of the multibody system model. After analyses effectuation and preliminary estimation of the results, file with loadings chosen in accurate time moments is exported to FEM software in which structural analyze is effectuated (3). Next it is possible to make fatigue analyze and, if necessary topologic optimization (4). On the base of the results corrections should be made in designed part and the whole cycle of numerical analyze (1-6) could be repeated (7a) or prototype could be manufactured and after test loadings tested by MMMM (8). On the base of MMMM tests corrections should be made in designed part and the whole cycle could be repeated.

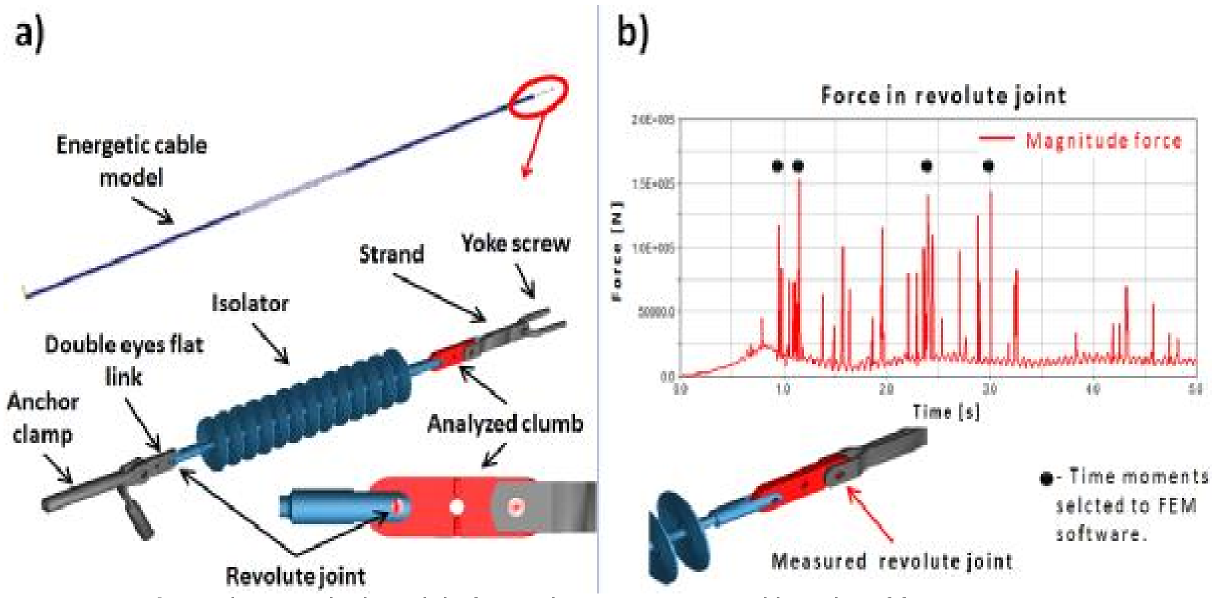

Fig. 8 *a) Numerical model of span in MSC.ADAMS; b) A plot of force spectrum.*

Fig. 8a shows an example of a model of an energetic span with marked (red colour) analyzed energetic clumb . This model is the preliminary phase of tests which aim is to model numerical properties of single parts of this model. These parts have the a great influence on loadings condition of energetic clumbs (energetic cable, composite isolator). Another significant issue is to find a proper model of energetic cable vibration. Despite the fact it was preliminary phase of the research it was possible to make introductory analyses in FEM software using loadings spectrum imported from MSC.ADAMS.

In FEM analyze loadings from four time moments (1.0 s, 1.2s, 2.4s, 3.0s) were used. This time moments were chosen in base of the force spectrum plot (Fig. 8b).

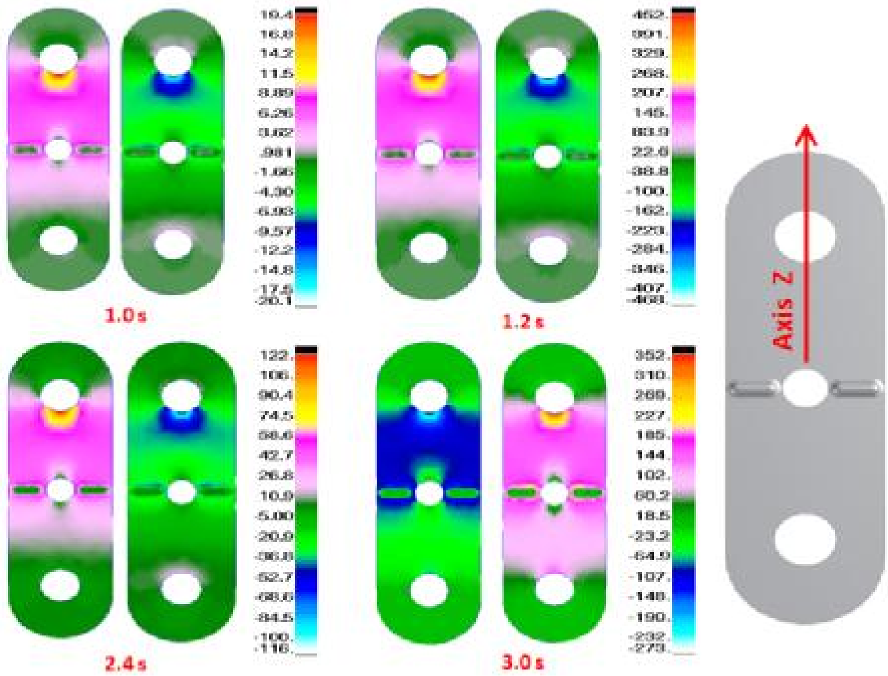

Fig. 9 *Axial stress (axis Z) in chosen time moments of the analyze; [MPa]*

Fig. 9 shows differentiated distribution of stress in different time moments of the analysis. The biggest loadings were created in time of 1.2 s. Basing on this it is possible to determine the most dangerous state of loading which causes the biggest stress concentration. It is shown that axial stresses are compressive (value below zero) on the one side of the energetic clumb and tensional (value above zero) on the other side. This means that electrical clumbs during its work are also bended. This information should be supplementary to standard analyses and tests in the process of designing.

4. Conclusion

Testing methodology suggested by authors shows the accuracy of combining numerical methods with new diagnostic method like MMMM. This combination allows us to obtain proper construction in short time and causes relative low costs. Connection of FEM analysis with multibody system analysis enables determining estimated work conditions of parts on the level of numerical analyzes. It is necessary to effectuate experimental tests verifying correctness numerical models and tests which target is to determine properties of the single parts of the multibody system. After the process of virtual prototyping is completed (numerical test in FEM and MSC.ADAMS software) a prototype should be manufactured. The next step is performing tests using MMMM which can determine the influence of the manufacturing process and topology of parts on the durability of the elements.

References:

[1] Dubov A.A, Kolokolnikov S.M, Evdokimov M., Pavlov A., Estimation of gas and oil pipelines condition based on the metod of metal magnetic memory, Conf. mat.: 17th World Conference on Nondestructive Testing, 25-28 October, Shanghai, China.

[2] Dubov A.A., Dubov Al.A., Kolokolnikov S.M., The problems of residual stress testing in welded joints and their solution using the MMM method, Conf. mat.: 5th International Scientific-Technical conference „Equipment and structures diagnostics using the magnetic memory of metal", 17-19 February, 2009, Moscow.

[3] Dubov A.A., Kolokolnikov S.M., Technical Diagnostics of Equipment and Constructions with Residual Life Assessment Using the Method of Metal Magnetic Memory, Conf. mat.: 17th World Conference on Nondestructive Testing, 25-28 October, Shanghai, China

[4] Dubov A.A., Physical base of the metod of metal magnetic memory, Conf. mat.: AMAS Course on Nondestructive Testing of Materials, NTM'02, 20-22 May 2002, Warsaw, Poland.

[5] Wang P., Zhu S., Tian G.Y., Wang H., Wang X.. Stress Measurement Using Magnetic Barkhausen Noise and Metal Magnetic Memory Testing, Conf. mat.: 17th World Conference on Nondestructive Testing, 5-28 October, Shanghai, China.

[6] Zhu S., Wang P., Tian G.Y., Wang H., Metal Magnetic Memory Testing Technique for Stress, Conf. mat.: 17th World Conference on Nondestructive Testing, 25-28 October, Shanghai, China

[7] Hatłas P., Juraszek J., Krupa K., Analiza łączników energetycznych za pomocą metody Magnetycznej Pamięci Metalu, Conf. mat.: IV International Conference „Working safety of transport mining equipment".

[8] Hatłas P., Juraszek J., Krupa K., Badanie zmęczeniowe modelu wału za pomocą metody Magnetycznej Pamięci Metalu, Conf. mat.: IV International Conference „Working safety of transport mining equipment", 5-7 November 2008, Ustroń, Poland.

[9] ISO 24497-1:2007 (E) Non-Destructive testing- Metal magnetic memory- Part 1: Vocabulary.

[10] ISO 24497-2:2007 (E) Non-Destructive testing- Metal magnetic memory- Part 2: General Requirements.

[11] ISO 24497-3:2007 (E) Non-Destructive testing- Metal magnetic memory- Part 3: Inspection of welded joint.

Recenzia/Review: *Ing. Janka Šaderová, PhD.*