

APPLICATION OF THE METAL MAGNETIC MEMORY METHOD FOR INVESTIGATION AND ANALYSIS OF STRESSED STATES OF HOISTING MINE STRUCTURE BEARING RODS

Anatoly DUBOV

Energodiagnostika Co. Ltd, Moscow, Russia

Andrzej KAWKA

Center for Investigation and Supervision of Underground Mining Co. Ltd, Ledziny, Poland

Janusz JURASHEK

Technical-Humanitarian Institute, Belsko-Byala, Poland

The paper presents the experience resulting from application of the metal magnetic memory method for investigation and analysis of the stressed states, as well as from the lifetime assessment of hoisting vessel bearing rods used in the mine hoists. The examples of the investigation results are given and the applied assessment criteria are presented.

The aim of this work is to prove that investigation of the actual stressed states in the hoisting vessel bearing rods by the metal magnetic memory method represents an alternative for other methods within the scope of diagnostics and reliability prediction of hoisting vessel structures during their operation.

1. Introduction

As an expert in the problems of a delft operation, authorized by the Chairman of the Supreme Mining Department, CISUM¹ carries out periodical investigations related to identification of natural threats as well as periodical control investigations and the technical state assessment of the machinery, metal components and various structures operated in underground openings and rock mines (in particular, periodic inspections of ropes, vessels, suspensions and hoist engines, shaft capers, equipment for horizontal transportation, pressure mechanisms).

For transportation of mining products, people, materials and equipment the underground mining uses various hoisting devices (skips, frames, cages, skip/cages). These are mostly welded steel structures with carrying capacity of up to 350kN and empty weight of up to 30 tons.

The main bearing components of the hoisting device structure are connected by the bearing rods. Fig.1 shows the general schemes of the hoisting device structures.

Taking into account the occurrence of fatigue cracks in bearing rods, as well as according to the requirements of the Mining Rules in Poland, the authorized expert should carry out the inspection and analysis of the stress condition in bearing rods of hoisting devices at least every three years.

¹ Center for Investigation and Supervision of Underground Mining Co. Ltd. - Ledziny, Poland.

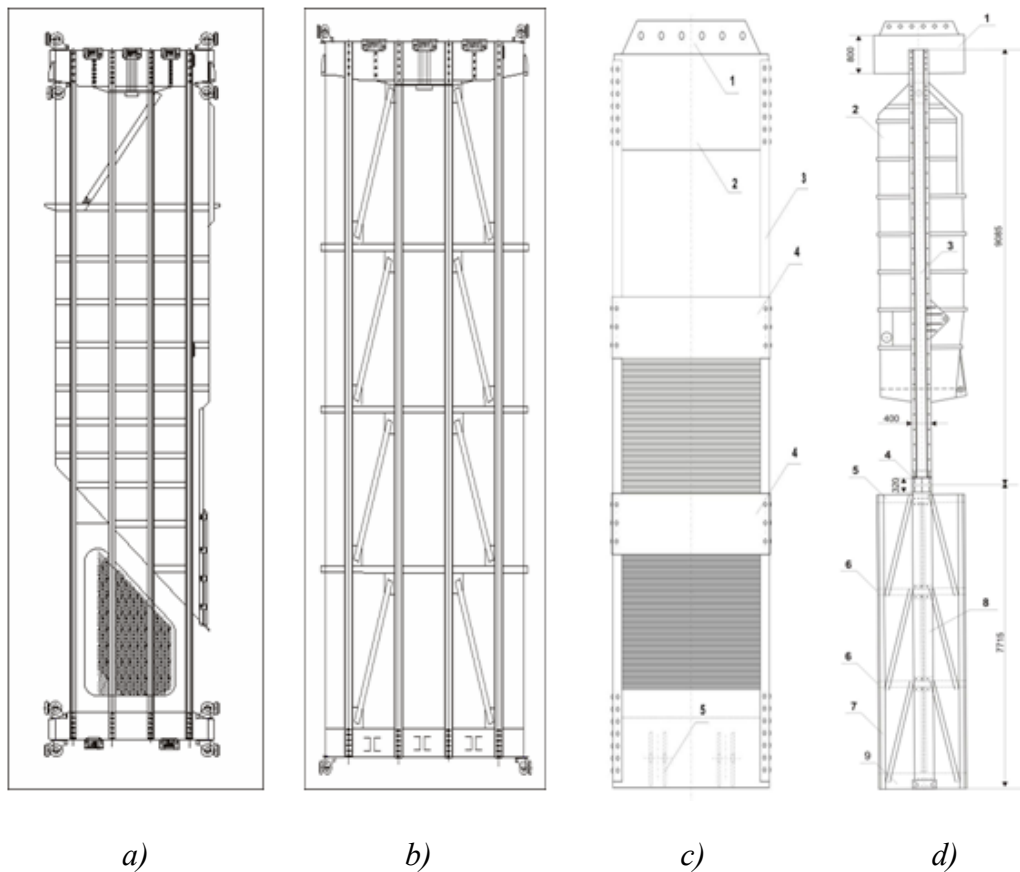


Fig.1. Examples of hoisting vessel structures: *a – skip; b – four-story cage; c – counterbalance; d – skip-cage.*

Upon the analysis of the capabilities of the available investigation methods, as well as execution of tests in conditions of the delfts operation, CISUM took a decision to apply the metal magnetic memory method for estimation of the lifetime and investigation of the stressed states in bearing rods of hoisting devices.

The main reason of making such a decision was the fact that application of the metal magnetic memory method provides the opportunity of:

- precise detection of the locations of stress concentration zones, representing the main sources of fatigue damages development;
- determination (using the magnetic parameters of the MMM method) of the maximum fatigue stress state of the bearing rods relative to the mechanical properties of the material, which they are made of;
- detection of the existing cracks;
- estimation of the assumed non-failure operation time (lifetime) of the bearing rods.

2. Magnetic parameters used

For the stressed states assessment in the hoisting device bearing rods the typical magnetic parameters, applied by the MMM method, are used:

Intensity of the product's self-magnetic leakage field (SMLF), H_p [A/m] – is a numerical value of the magnetic leakage field intensity measured on the product's surface. The basic diagnostic parameter used in the diagnostic procedures of the MMM method is the line of sign alternation of the normal component of the magnetic field H_p^y – the $H_p^y=0$ line. In the course of the laboratory and industrial investigations it was established that this line determines the area of the metal's structure maximum heterogeneity, concentration of defects and maximum concentration of internal stresses.

Gradient of the product's proper leakage field K_{in} [A/m²] (the magnetic stress intensity factor) – is a basic quantitative criterion for this method of inspection. This is a quotient of the magnetic leakage field difference modulus, measured in the two inspection points, and the distance between these points:

$$K_{in} = \frac{|\Delta H_p^y|}{\Delta l},$$

where Δl – is the distance between the inspection points located at equal distances on both sides of the stress concentration (SC) line (the $H_p^y=0$ line). The gradient value characterizes the density of dislocations accumulation (edgewise and in depth) in the stress concentration zone.

Limiting magnetic index of metal's deformability (m_{lim}) – is the ration of the maximum value of the SMLF gradient meeting the ultimate strength of the metal (R_s) to the average value of the SMLF gradient meeting the yield strength (R_y). This index is determined in the laboratory conditions for a certain steel grade.

The carried out laboratory investigations [1, 3] reveal the following dependence between the magnetic parameters m_{lim} , K_s , K_y and the mechanical properties of the metal R_s and R_y :

$$m_{lim} = \frac{K_s}{K_y} = \left(\frac{R_s}{R_y} \right)^2.$$

The index m_{lim} characterizes the degree of the metal strengthening and it is a magnetic measure of the limiting fatigue stress state of the inspected structure element's material.

Upon determination of the average gradient value, two or three SC zones with the highest field gradient values are selected from all SC zones detected during the investigation. Then the ratio, being a magnetic index m , is calculated:

$$\frac{K_{in}^{max}}{K_{in}^{ave}} = m .$$

3. Measurement procedure and analysis of the results

According to the developed by CISUM investigation technique, measurements and the analysis of the stressed states in the hoisting device bearing rods cover:

- analysis of the mine hoist documentation and of the hoisting device technical documentation;
- performance of measurements and their recording to the measuring instrument's memory;
- magnetograms analysis comprising
 - detection of stress concentration zones in the bearing rods;
 - determination for each inspected rod of the value of the magnetic damageability index m , being a measure of the actual fatigue stress state of the rod's material on the day of inspection;
- estimation of the assumed non-failure operation time based on the accepted criteria.

In connection with the fact that CISUM has applied the MMM method quite recently (the estimated non-failure operation time of bearing rods does not exceed the period of this method application), the criteria used for the lifetime assessment of bearing rods were accepted based on the criteria provided by Energodiagnostika Co. Ltd and those used for the technical state assessment of bearing rod structure in passenger elevators.

No.	Obtained results of detected defects	Assumed non-failure operation time
1	No inadmissible defects are detected (cracks, plastic strain, etc.) $m \leq 0,5m_{lim}$	6 years
2	No inadmissible defects are detected (cracks, plastic strain, etc.) $0,5m_{lim} \leq m \leq 0,75m_{lim}$	5 years
3	No inadmissible defects are detected (cracks, plastic strain, etc.) $0,75m_{lim} < m \leq m_{lim}$	3 years
4	No inadmissible defects are detected (cracks, plastic strain, etc.) $m > m_{lim}$	1 year Detailed inspection in SCZs is recommended
5	Occurrence of inadmissible defects (cracks, plastic strain, etc.)	Replacement or repairs

According to the accepted criteria, determination of the estimated non-failure operation time consists in the comparison of a certain magnetic parameter m , being a measure of the actual fatigue stress state of the rod's material, with the limiting value of the magnetic index m_{lim} for the steel grade used in fabrication of bearing rods.

If m exceeds the limiting value m_{lim} , then it means that the material of the rod is in the limiting state, preceding the fatigue damaging.

In connection with the fact that the estimated non-failure operation time does not take into account:

- the corrosion history of the investigated rods;
- emergency loads, etc.,

it should be taken as approximate.

Combinations of loads, to which the lifting elevator may be exposed during operation, are very varied and complex. In particular, they consist of:

- static loads due to the weight of the transported rock mass or materials, counterbalancing ropes and empty weight;
- dynamic load occurring during loading and unloading (for example, loading or unloading lasting several seconds);
- dynamic load occurring during the elevator motion in the shaft (irregularity of pilot paths in the shaft);
- dynamic loads occurring during the emergency braking of the elevator in the shaft;
- design and fabrication errors causing formation of stress concentration zones.

In connection with this the above-indicated criteria are checked and adjusted to the peculiarities as well as to operating conditions of hoisting devices on timely basis.

At present CISUM carries out the laboratory investigations on comparison of the magnetic parameters used by the MMM method with other investigation methods, which serve for determination of the stressed states in structural elements of machinery and equipment.

4. Examples of the results of bearing rods and other steel structures investigation by the MMM method

Several examples of measurements (distribution of the magnetic field gradient) of the stressed states in bearing rods of various-type hoisting devices, as well as of other steel structures, are presented below.

4.1. The results of the 270kN skip bearing rods investigation (fig.2)

As it can be seen in the distribution of the magnetic field gradient, the bearing rods of the investigated skip are not loaded uniformly. The noticeable stress concentration was determined in the bottom segments of central rods, as well as in the upper rod segments on the north side.

The specified for central rods maximum index m , being a measure of the rod material's fatigue stress state, is: $m=1,91 < m_{lim}=2,7$, and at present it is lower than the limiting index m_{lim} (for the steel grade 18G2A) characterizing the stage of the steel strengthening up to failure.

This allows establishing that at present the fatigue stress state of the investigated rods does not pose any threat of cracks formation.

According to the applied assessment technique and criteria, for the specified value of the factor m , being within the limits of:

$$0,5m_{lim} < m \leq 0,75m_{lim},$$

the estimated non-failure operation time of the bearing rods is specified for 5 years.

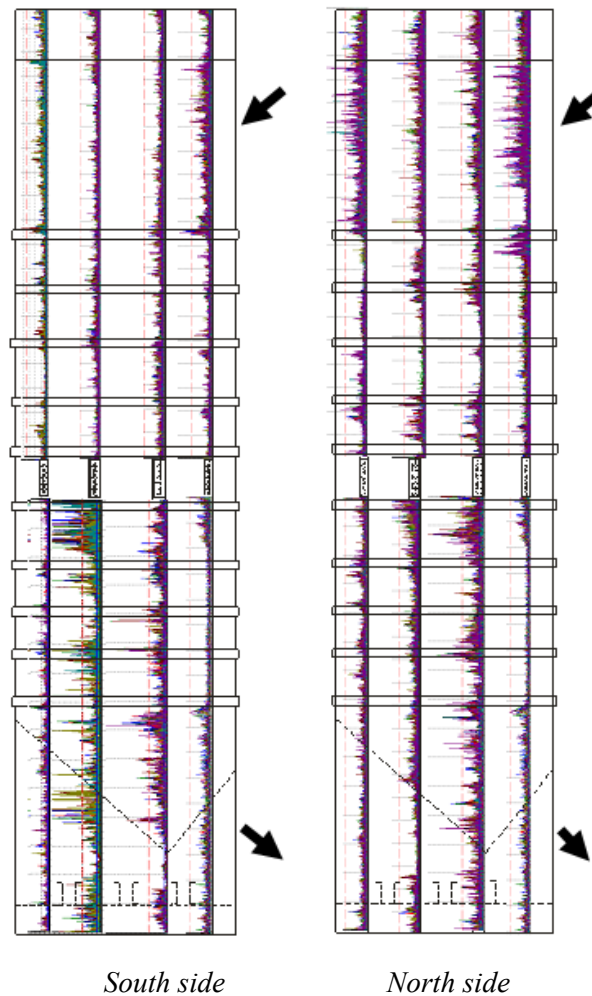


Fig.2. Distribution of the magnetic field gradient in the bearing rods of the 270kN skip.

4.2. The results of the 17/15Mg skip/cage bearing rods investigation (fig.3 and fig.4)

Based on the magnetograms analysis, the maximum index m , being a measure of the rods material's fatigue stress state: $m=2,42 > m_{lim}=2,4$ was determined.

According to the accepted assessment technique and criteria the estimated non-failure operation time was specified for 1 year. The additional UT did not detect any cracks. Thorough inspection in locations of SCZs was recommended.

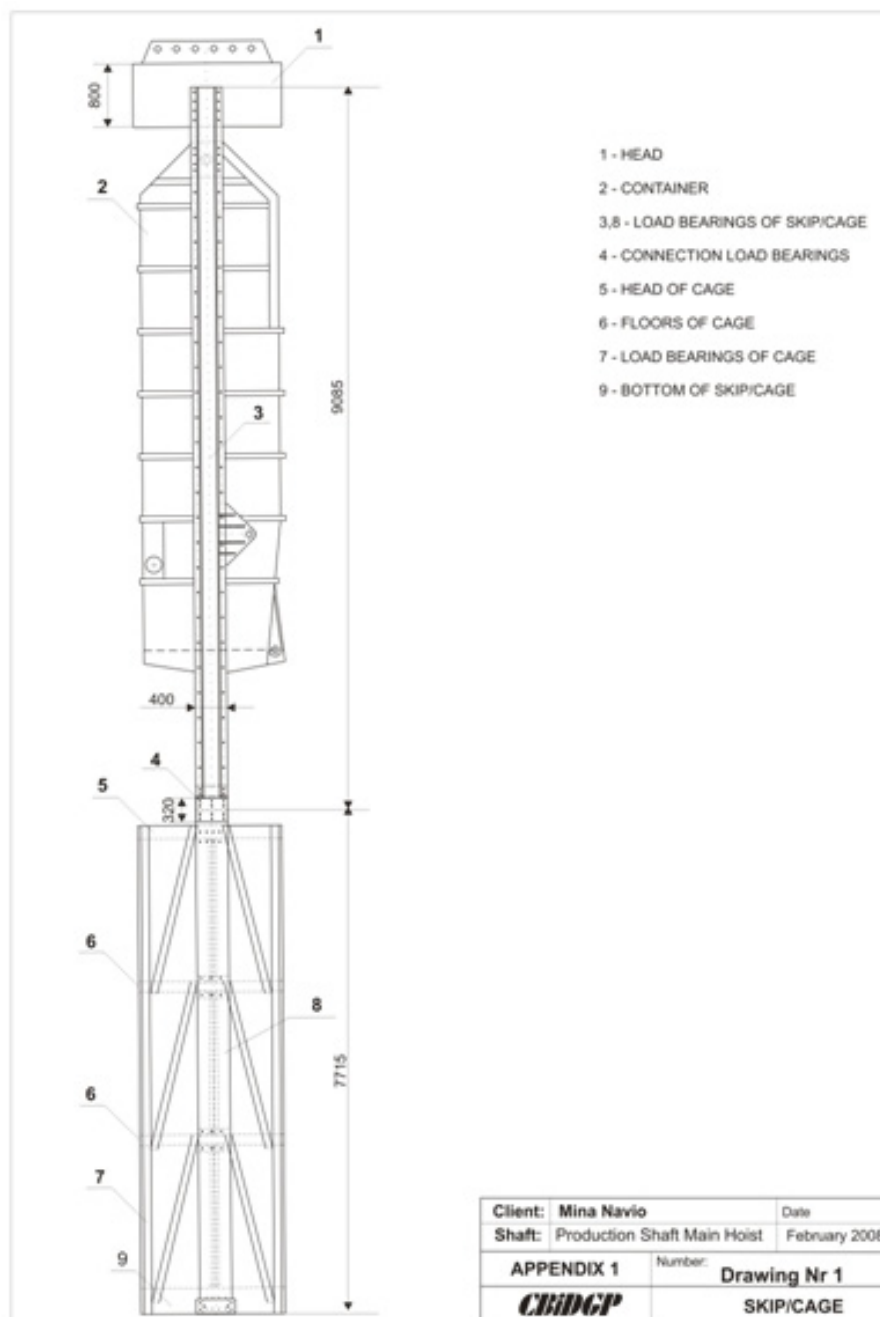


Fig.3. Structure of the skip-cage.

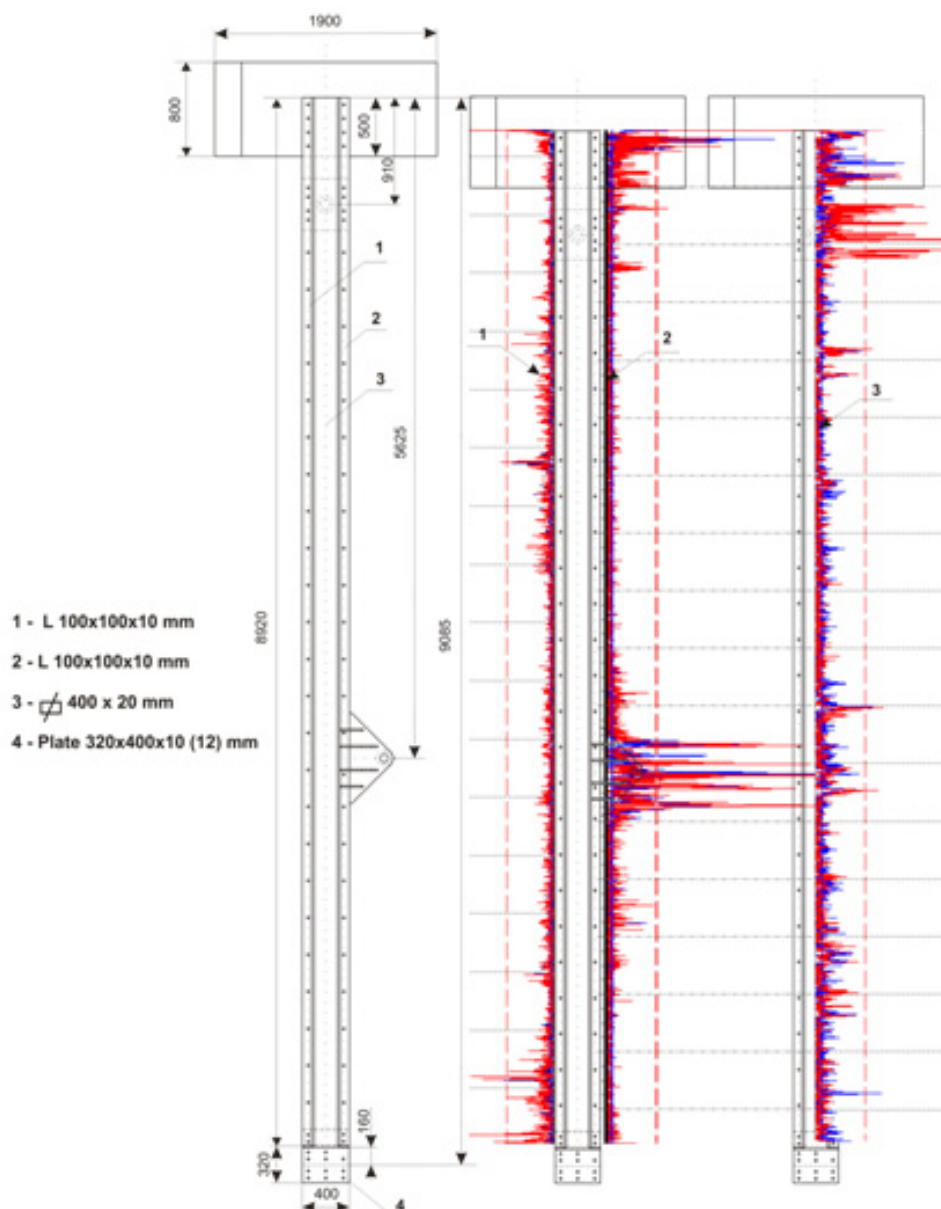


Fig.4. Distribution of the field gradient in the skip part.

4.3. Examples of the MMM method application for investigation of other structures

4.3.1. The results of the skip hole sheet inspection.

Fig.5 shows the inspection results of the 20Mg skip hole sheets connecting the skip head with the bearing suspension. The obtained magnetograms unambiguously indicate the non-uniform loading of the hole sheets. The sheet parts on the side opposite to loading display the high fatigue stress state. Inspection was carried out during re-installation of the above-mentioned sheets after reconditioning, that is, they were installed conversely relative to the previous installation.

The direction of the measuring head motion

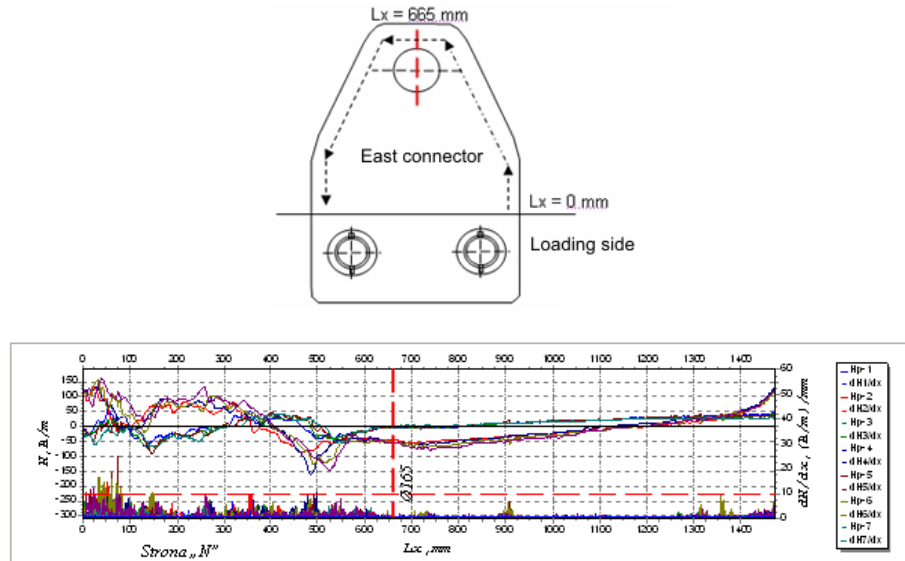


Fig.5. Distribution of the magnetic field gradient along the perimeter of the hole sheets.

4.3.2. Inspection of a steel smokestack.

Fig.6 shows the results of a steel smokestack inspection. The aim of investigation is detection of stress concentration zones for development of a guideline on inspection of the smokestack structure. The maximum stress concentration was detected in the second (central) segment of the smokestack, which is confirmed by the presented below magnetograms.

5. Conclusions

Based on the existing experience, it can be established that application of the MMM method for investigation of the stress states in bearing rods of hoisting devices allows obtaining a number of substantial data, which could not be provided by the applied till date methods of diagnostic investigations, namely:

- a) detection and determination of the stress concentration zones location in bearing rods, which occurred due to:
 - loads caused by irregularities of the motion paths during the elevator lifting in the shaft;
 - loads occurring during the elevator loading and unloading, device lifting during the ropes and suspensions replacement, lowering of heavy and bulky materials on the lifting elevators, emergency braking of lifts in the shaft, caper and sump;
 - non-uniformity of loads distribution in the bearing rods, caused by inaccuracy of the lifting elevator fabrication, strains of elements occurring during transportation, installation or operation;

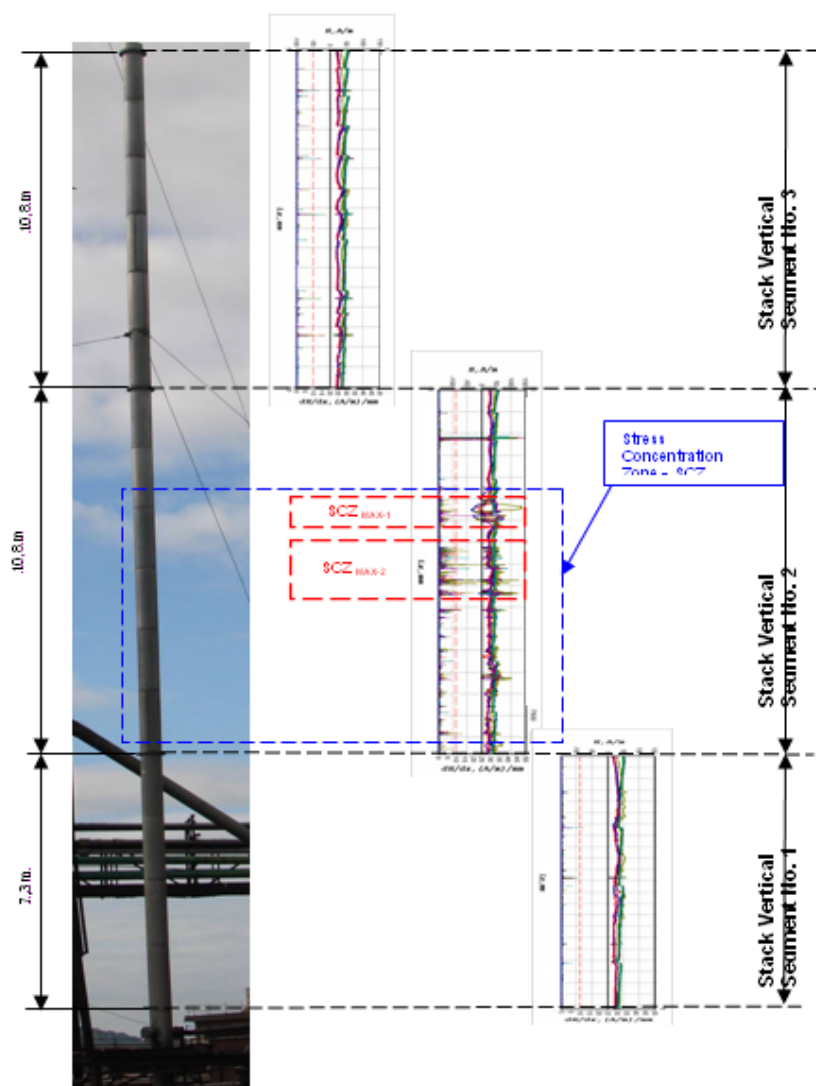


Fig.6. Distribution of the magnetic field gradient in the steel smokestack structure.

- b) early diagnostics of fatigue damages (cracks) of bearing rods;
- c) determination for the investigated rod of the actual fatigue stress state using the magnetic parameters applied by this method;
- d) evaluative estimation of the assumed non-failure operation time of bearing rods.

Based on the carried out investigations it was established that the basic advantages of the MMM method in conditions of the mine hoists operation are:

- no need for active magnetization, mounting of sensors, cable laying and connection to the registering equipment, etc.;
- rapid measuring without the necessity to move the vessels along the entire shaft length;
- possibility to carry out measurements from the locations adapted for inspection of hoisting vessels;

- the data relating to the location of stress concentration sites in the rods, actual fatigue stress state, as well as the estimated non-failure operation time, may be suitable for practical application by the user for determination of the scope of hoisting devices inspection.

6. Summary

Summarizing, it can be established that the MMM method applied for inspection of hoisting devices:

- represents an alternative to other methods within the scope of diagnostics and reliability prediction of hoisting device structures during their operation;
- is suitable for investigation of the technical state of other bearing components of hoisting devices, as well as of welding joints;
- can be applied during the non-destructive investigations of other machinery and equipment operated in mining.

Bibliography

1. A.Dubow, A.Radziszewski. Prognozowanie resursu oprzyrządowania z wykorzystaniem metody magnetycznej pamięci metalu – materiały 31-szej krajowej konferencji badań nieniszczących – Szczyrk 2002 – R-10.
2. M.Roskosz. Zastosowanie metody magnetycznej pamięci metalu do badań kół zębatych – Politechnika Śląska w Gliwicach – Instytut Maszyn i Urządzeń Energetycznych.
3. A.A.Dubow. Sposób określenia stanu granicznego metalu w obszarach koncentracji naprężeń na podstawie gradientu magnetycznego pola rozproszenia – materiały z II-giej międzynarodowej konferencji „Diagnostyka oprzyrządowania i konstrukcji z wykorzystaniem magnetycznej pamięci metalu – Moskwa 2001. Tłumaczenie – „Resurs” W-wa.
4. A.Dubow. Diagnostyka wytrzymałości oprzyrządowania i konstrukcji z wykorzystaniem magnetycznej pamięci metalu – Dozór techniczny 1/2002 s/14-18, 2/2002. S.37-40.
5. J.Deputat: Podstawy metody magnetycznej pamięci metalu – Dozór Techniczny 2/2002. S.97-105.
6. A.A.Dubow, E.A.Demin. Wyniki badań charakterystyk magneto-mechanicznych metalu próbek z wykorzystaniem metody magnetycznej pamięci metalu. – materiały z I-szej międzynarodowej konferencji „Diagnostyka oprzyrządowania i konstrukcji z wykorzystaniem magnetycznej pamięci metalu” Moskwa, 24-26 lutego 1999. Tłumaczenie „Resurs” W-wa.

7. A.P. Nichipuruk, N.I. Noskova, E.S. Gorkunov, E.G. Ponomaryova. Effect of the dislocation structure formed by the plastic strain on magnetic and magnetoelastic properties of iron and low-carbon steels // Physics and Physical Metallurgy, No.12, 1992. pp. 81-87.
8. A.A.Dubow – Zapytania o fizyczne podstawy metody magnetyczne pamięci metalu – materiały z II-giej międzynarodowej konferencji „Diagnostyka oprzyrządowania i konstrukcji z wykorzystaniem magnetycznej pamięci metalu –Moskwa 2001. Tłumaczenie „Resurs” W-wa.
9. Methodical guideline on the magnetic testing (the metal magnetic memory method) of metal structures, cranes, hoisting cranes, elevators. Moscow: Energodiagnostika Co. Ltd, 2007.