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Assessment of the technical condition of lift guides using a magnetic field

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Assessment of the technical condition of lift guides using a magnetic field

P Lonkwic[1], T Krakowski[2] and H Ruta[2]

[1] The State School of Higher Education, The Institute of Technical Sciences and Aviation, ul. Pocztowa 54, Chełm 22 – 100, Poland
[2] AGH University of Science and Technology, Faculty of Mechanical Engineering and Robotics, Adama Mickiewicza30, Kraków 30-059, Poland

plonkwic@pwsz.chelm.pl

Abstract. The systems that monitor individual components of machines and devices are under constant development. The ability to detect damages at an early stage allows failures to be prevented, so any uncontrolled downtime can be predicted in a controlled manner. Continuous monitoring of technical condition is an activity that also helps to reduce the losses due to equipment failures. However, not all areas can be monitored continuously. Such areas include lift guides where wear and tear can occur naturally, i.e. through abrasion of the material layer due to interaction with moving guide shoes or after emergency braking. Emergency braking causes local damages to the guide through plastic deformation of its surface resulting from indentation of the knurled roller of the brake. Such places are cleaned mechanically, which results in local reduction of the cross-sectional area. In such a case, it is difficult to continuously assess the technical condition of guides due to the prevailing operating conditions. Therefore, a concept of a head enabling assessment of the technical condition of guides at every stage of their operation has been developed. This article presents the novel concept of a magnetic head used for assessing the technical condition of lift guide rails that are the running track of lifting equipment. The initial tests were performed on the original test setup. The concept of the developed measuring head was verified for correct operation on specially prepared flat bars with holes. The results obtained in the form of laboratory tests proved that the proposed measuring head concept can be applied to the measurements under real conditions.

1. Introduction

Diagnosis of technical equipment is an important factor affecting its service life. Diagnostics as a tool for assessment of technical condition is used in practically every field of engineering as well as in non-engineering domains. In the article [1], the authors presented the use of short-time Fourier transform (STFT) as a tool for detecting undesired states caused by various mechanical and physical phenomena.

The authors considered the use of STFT to monitor and assess the performance of a hydraulic pump system under various operating conditions. A hydraulic tester was used to measure the pressure and flow changes in the pump and a DAQ card was used to evaluate the qualitative and quantitative changes in the system. In the article [2], the author presented the use of diagnostics in medical industry as a tool for quality assurance. Special emphasis was placed on the investigation of hazards and possible product defects in food processing. The research aspect of this paper focuses on an attempt to transfer diagnostics to the food industry solutions applied mainly in in the automotive industry. The practical aspect of the paper presents an analysis of the causes of defects and risks carried out on the example of the baking industry.

In the conference materials [3], the author presented the use of a diagnostic tool to assess the chemical reaction and the electrical process, closely related to the flow of electric current during the electrochemical grinding process. Processing of this type of material is very difficult not only due to unfavourable physical properties of the material itself, but also due to the very high requirements resulting from the operating conditions of the product. Particular attention was paid to the flow of electric current as a function of changes in the active surface, understood as the geometrical surface through which electric current can flow. The calculation results for this surface and an example of the recorded current waveform shape were presented. Such results were used to build a control system based on maintaining a constant working current density. In the article [4], the authors presented the use of analytical data for tool condition assessment and tool life prediction, which are crucial for the manufacturing process reliability and quality. The authors presented a new mathematical model which is intended to effectively classify the condition of a cutting tool blade in real time. The developed model was verified on the basis of real measurement data from an industrial machine tool. Diagnostics is also used in the machine and device supervision processes. In the publication [5], the author described the properties of the most popular diagnostic systems used for the in-plant conveyor transport system operation. He also presented a new method of computer-aided maintenance of such systems.

The operational reliability of conveyor transport systems is a question of ensuring an appropriate level of readiness of the continuous transport system which, in the case of belt conveyors, depends not only on their functional qualities determined by the construction solutions applied and workmanship, but also significantly on the appropriate level of their use understood, among other things, as the degree of advancement and effectiveness of the methods and industrial diagnostics tools applied. In the publication [6], the authors presented the results of their own research on the application of diagnostics to evaluate the value of measured geometric errors of the FV-580A four-axis CNC vertical machining centre with the FANUC 0IMB numerical control system. The article presents the examples of modern, laser-based diagnostic systems for numerically controlled CNC machine tools: LaserTRACER self-tracking interferometer, LaserTRACER-MT diagnostic device, XL80 laser interferometer with XC80 environmental parameters measuring module and heat sensors with XR20-W calibrator. The authors of article [7] described the application of a diagnostic device of their concept, intended to assess hybrid hoisting ropes used in lifting devices. The construction of the ropes, as compared to traditional steel ropes with a round cross-section, made it possible to reduce the diameter of the driving wheel while maintaining the frictional contact conditions and the required ratio of driving wheel and hoisting rope diameters of at least 40. Despite the advantages mentioned above, an interesting but so far not fully examined research issue is the process of hybrid suspension rope wear and the assessment of technical condition of ropes being the load bearing elements in the applied solutions, especially during long-term operation. The paper presents the possibilities of applying the magnetic method to assess the technical condition of steel cables being the load-bearing element of hybrid belts. The authors presented their solution of a measuring head for magnetic testing of hybrid rope carriers, developed by a team of employees of the Department of Mechanical Engineering and Transport of the University of Science and Technology in Kraków.

In the publication [9], the authors presented a new approach to the classification of energy efficiency of lifts based on a heuristic estimator, using the parameters of energy characteristics of the lift installation recorded during a weekly operation cycle as a diagnostic tool. Due to the fact that energy performance evaluation by the commonly used methods involves many variables and complex non-linear relationships, an expert model was developed using a fuzzy logic approach. The basic objectives are defined together with the energy characteristics and operational parameters of the lift installation in the running and standby modes. The estimator is based on the operational efficiency of the equipment for each lift mode, and membership functions (model input and output) are defined. In the article [10], the authors presented the proposals for a monitoring system based on cloud-based databases. The monitoring system concerns the main components responsible for the safety of passenger lifts. The described system was successfully tested on several devices which were connected to a common base. In the publication [11], the authors described an intelligent remote monitoring system for lifts which is known as Eleview. Apart from supporting live or recorded video transmission over the Internet, it also provides intelligent monitoring and web-based monitoring. Intelligent monitoring analyses the movements of people in a lift to detect unusual or criminal activities. As the live video data transmission over the Internet can cause packet loss and quality degradation, the Eleview system implements an adaptive transmission and recovery mechanism to improve the quality of real-time video transmission. In the publication [12], the author presented a monitoring system for passenger lifts based on Big Data which he used for an early warning of possible equipment failure. In the publication [13], the authors described the operation of a system monitoring the lift guides in a plane perpendicular to the movement direction of the cabin and the counterweight. The described system was based on image processing of the guides to prevent wear of their surfaces. The images of guide surfaces are recorded by four digital cameras mounted in the lift cabin. The image processing methods are applied to the images recorded by the cameras to detect damage or wear of the guide surfaces. In the article [14], the authors described the influence of vibration arising during the ride of high-speed lifts on the comfort level of the travelling passengers. In order to assess the effect of vibration on the comfort of travellers, the authors developed a model of a high-speed lift and then analysed the effect of travel speed, the guide deviation from the vertical and the dynamic parameters associated with the rolling of guide shoes along the guides. The lifts moving at speeds of 5 m/s, 7 m/s, 8 m/s and 10 m/s were tested.

The publication [15] presents the application of a monitoring system to evaluate the vibration level and aerodynamic load changes of a high-speed lift. The authors presented a three-dimensional computational model of airflow coupling vibration in the shaft based on the Lagrange-Euler method and the finite volume method. Then, the authors evaluated the aerodynamic load and horizontal vibration acceleration of the cabin for different speed conditions using unidirectional and bidirectional numerical simulation methods of airflow coupling to influence the vibration response of the cabin. In the publication [16], the authors described the effect of non-linear contact between the guide shoe and the guide on the counterweight guide vibration. The results showed that the contact and separation between guide shoes and guides can be simulated using a numerical model. The efficient computational method proposed by the authors can be used for quantitative analysis of the lift vibration response. In the article [17], the authors presented a monitoring system in the form of an active control strategy for damping of horizontal lift vibration based on linear matrix inequalities. The 6-stage horizontal vibration model was used for the analysis. The authors proposed to monitor an effective vibration damping system on the adopted vibration model.

The guidance systems in the lifting equipment are constantly being developed mainly due to the increasingly faster operating speeds of lifts. In the article [18], the authors presented their own research on the use of a vibration absorbing insert in the guide bracket as a method to reduce vibration and noise in high-rise buildings. On the basis of the result of vibration-absorbing insert operation, the authors estimated that the vibration and noise levels were reduced by about 65.49% on the cabin side and by about 90.05% on the counterweight side. The article [19] deals with the quantification of uncertainty in a lift system subjected to lateral vibration induced by guide bumps with and without a feedback control system. A mathematical model of the lift system was derived and a stochastic model for the rail profile irregularities was constructed. This uncertainty model describes the guide profile as a random field, which is represented using the Karhunen-Loève expansion. The polynomial chaos is used to calculate the propagation of uncertainty through the stochastic model, in order to evaluate the disturbance rejection and robustness properties of the closed system.

In the articles [20, 21], the authors address the research with the application of a magnetic method in wire rope diagnostics. The article [20] compares the functional features of mine hoist ropes determined by organoleptic, strength and magnetic tests. The article [21] describes the authors' experience in assessing the technical condition of ropes used in the building structures.

2. Description of tests

The use of diagnostics for the assessment of technical facilities for their technical condition is still being developed in various branches of technology. Such a need has also arisen in the field of material handling equipment related to the vertical transport of people and goods. Various parameters are monitored, as shown in the graphical representation in Figure 1.

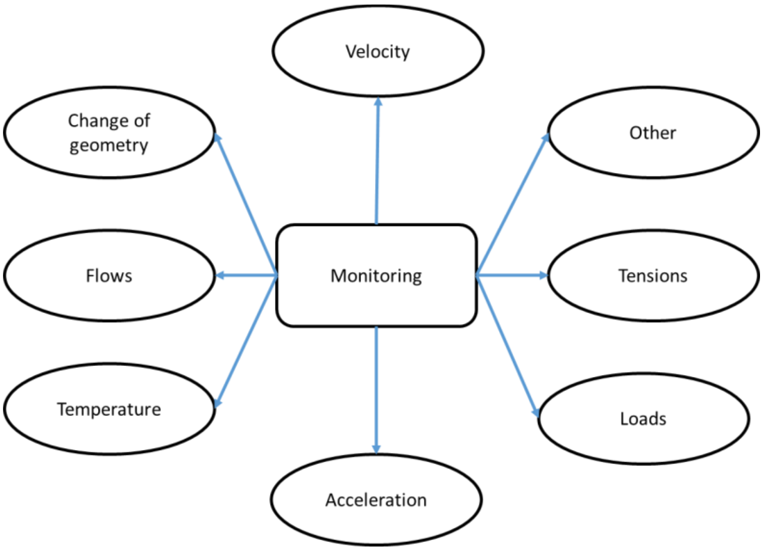

Figure 1. Monitoring of technical facilities [8].

Due to the fact that currently there are no available design solutions for the heads intended for the diagnostics of lift guide rails, the authors' own concept of a measuring head was developed, the main purpose of which would be the diagnostics of the technical condition of guide rails the exemplary cross-section of which is shown in Figure 2.

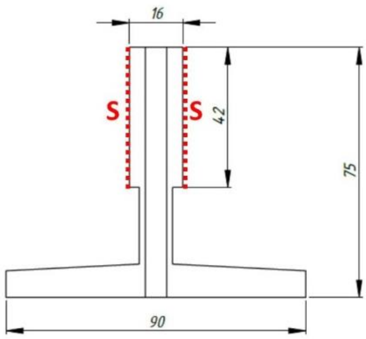

Figure 2. Cross-section of guide rail T90/A [8].

The guide rail system consists of two T-shaped guide rails positioned opposite one another. The working surfaces (marked red in Figure 2) are the surfaces exposed to the interaction of the components (a knurled roller) of the brake under unfavourable operating conditions. The guide rails are manufactured as T-shaped steel profiles using the drawing or rolling process with grinding of the "S" working surface. The material from which the E235B guide rails are manufactured according to ISO 630:1995 has the following physical and mechanical properties:

- Density 7.8 g/cm^3,
- Young's modulus 210 GPa,
- Elongation A5 23% at 20^{o}C,
- Poisson's ratio 0.29,
- Tensile strength Rm 405 MPa,

- Yield point Re 210 MPa

Figure 3 shows the guide rail with the surface formed after contact with the harder knurled roller that is an element of the brake.

Figure 3. View with plastic damage on the guide rail working surface [8].

Such a surface is levelled using mechanical methods that result in a reduction of the cross-sectional area at the point of contact between the roller and the guide rail. For both assessment and monitoring of the technical condition of guide rails, the authors developed a device (a magnetic head) the operation of which is based on the stray magnetic field analysis. Due to the commenced process of patenting the head, its technical description at the date of preparation of this publication has been omitted.

The initial method of verifying the developed head concept with the measurement method was based on the measurements of a flat bar in which a damage was modelled in the form of a 1 mm diameter hole that had been drilled (see Figure 4). In order to determine the possibility of damage detection depending on its depth, the position of the hole in relation to the surface was gradually increased, resulting in 7 samples.

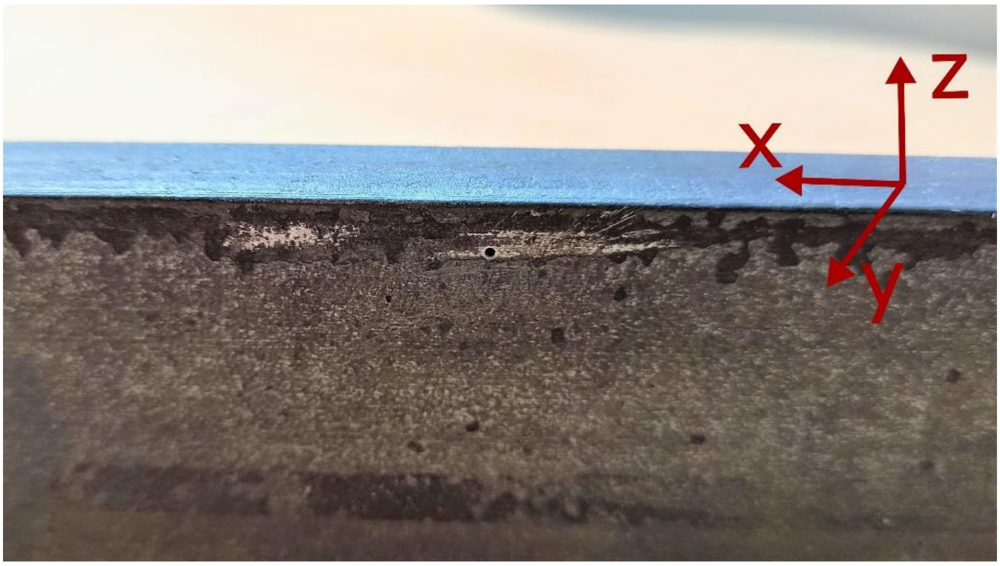

Figure 4. Flat bar with 1 mm diameter hole shown.

For the purpose of validating the measurement, 7 samples were prepared in which a hole was located at the following distances: 1 mm, 2 mm, 3 mm, 5 mm, 7 mm, 11 mm and 13 mm.

The influence of the sensor distance from the surface of the tested element was also verified. In this case, the tests involved moving the sensor away from the surface of the flat bar using spacers. The orientation of the magnetic coil remained unchanged during all the tests, which allowed the measurements to be carried out under constant conditions with a repeated value of the magnetic field, the same material and the same modelled defect. For the samples prepared in this way, it was examined how the signal changes as the sensor is moved away from the surface of the flat bar, and also as the distance between the hole and its surface increases. Figures 5, 6, 7 and 8 show the chosen variations of magnetic induction for the selected flat bars.

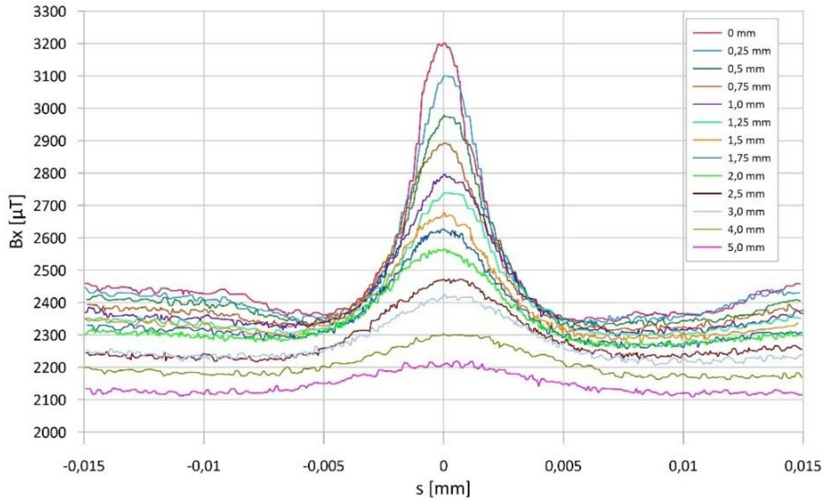

Figure 5. Dependence of the Bx component of magnetic induction on the position of the measuring head for all distances of the head from the tested surface for a flat bar with a hole located at a distance of 1 mm from its surface.

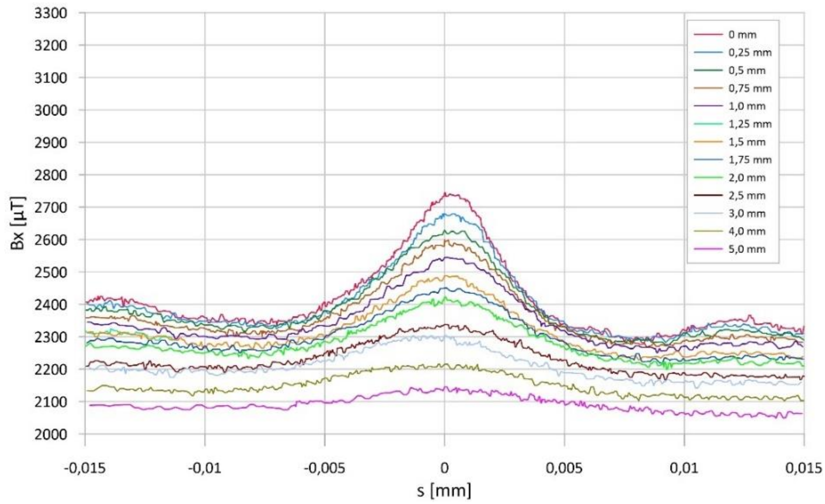

Figure 6. Dependence of the Bx component of magnetic induction on the position of the measuring head for all distances of the head from the tested surface for a flat bar with a hole located at a distance of 5 mm from its surface.

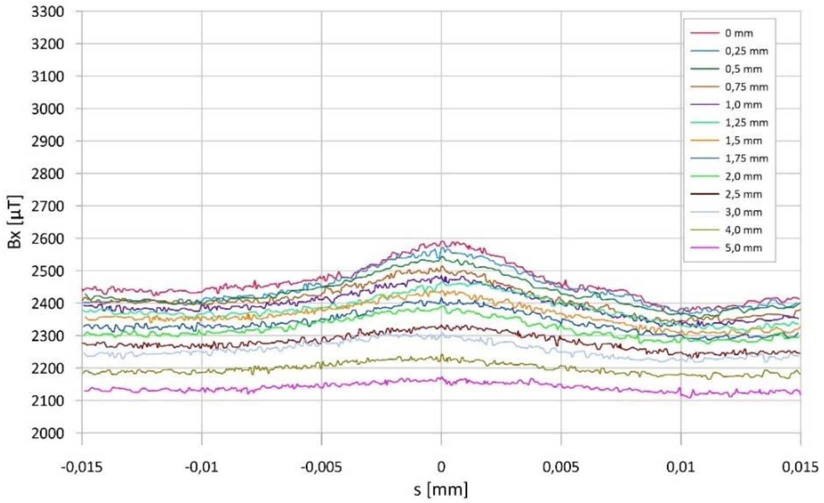

Figure 7. Dependence of the Bx component of magnetic induction on the position of the measuring head for all distances of the head from the tested surface for a flat bar with a hole located at a distance of 11 mm from its surface.

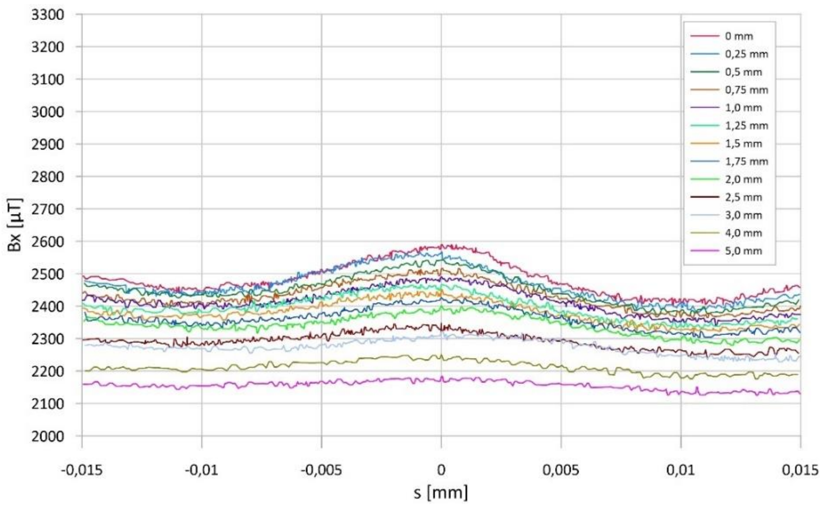

Figure 8. Dependence of the Bx component of magnetic induction on the position of the measuring head for all distances of the head from the tested surface for a flat bar with a hole located at a distance of 13 mm from its surface.

After performing the tests with a flat bar, the initial measurements were taken using a section of the actual lift guide rail. Due to the complexity of the issue, the initial stage of testing consisted in verifying the correct identification of damage of the guide rail surface. To this end, the initial reading tests were carried out on the guide rails on the surfaces of which the mechanical scratches were made, as shown in Figure 9.

Figure 9. View of guide rail working surface with scratches.

The prepared guide rail was used to take preliminary readings recorded by means of an initial prototype of the diagnostic system. The measurement methodology consisted in applying the magnetic system to the guide rail surface and manually moving it along the guide rail. In the location where the guide rail surface was intact, the voltage signal being a function of a change in stray magnetic field around the tested component (X and Z components, Figure 10) was maintained at a constant level of about -700 mV for the X axis and 560 mV for the Z axis. In the location where the modelled damage occurred for both X and Z components (about 35 mm in Figure 10) there is a clear change in the shape and amplitude of the voltage signal resulting from the damage (Figure 9). The Y axis signal was omitted because it did not carry any significant information from the diagnostic point of view.

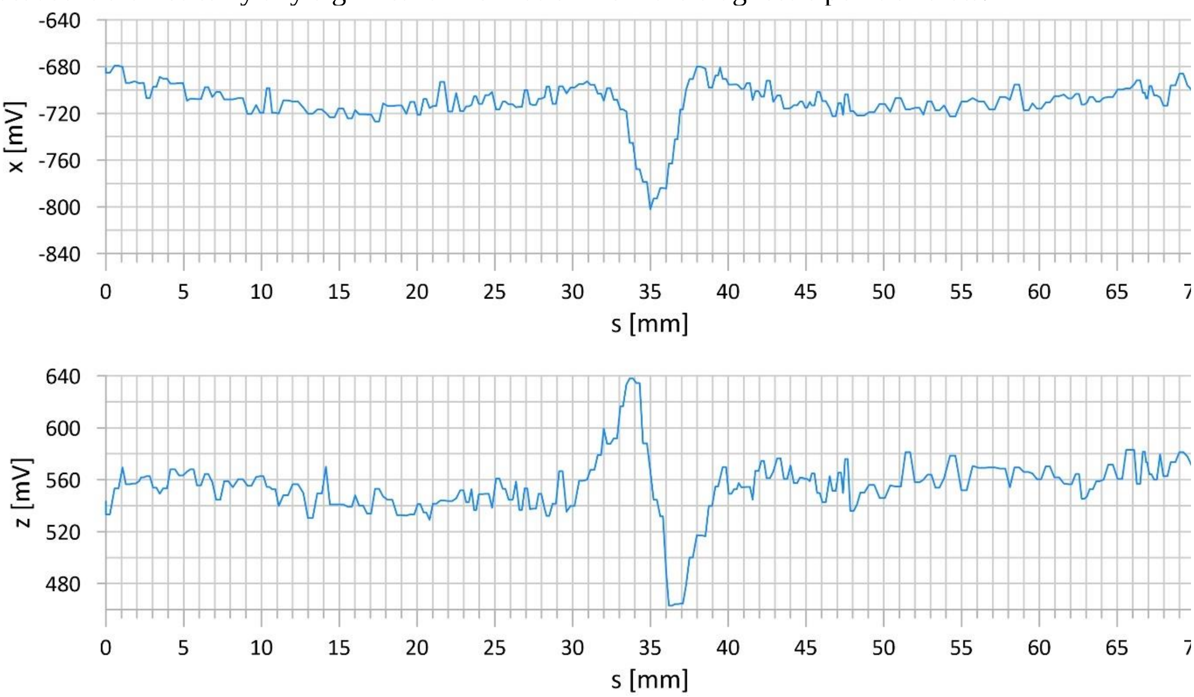

Figure 10. Voltage signal being a function of change in normal component of stray magnetic field of the tested guide rail.

According to the initial tests carried out with both flat bars and a guide rail, the proposed method enables the detection of defects on the surface or inside the material with an accuracy corresponding to the use of the information obtained for diagnosing the technical condition of guide rails. Such data can be used as the basis to answer the question whether a given guide rail can still be used, whether its wear limit was reached and whether it should be replaced.

The proposed method offers the possibility of detecting the damaged sections of guide rails which can then be partially replaced, thus significantly affecting the total cost of replacing the lifting equipment with a new one.

3. Conclusion

The presented results clearly show the possibility to apply the developed method for the diagnostics of lift guide rails. Each of the modelled changes in the metallic cross-section of the tested sample influenced the change in the value of magnetic induction and thus the voltage readout value. As it can be seen from Figures 5 to 8, an increase of the hole distance from the flat bar surface results in smoothing out the individual characteristics. Thus, for the hole located closest to the measuring surface of the flat bar, the change in the value of magnetic induction is most visible. This confirms the assumed thesis that the adopted diagnostics methodology for lift guide rails will bring the expected results. The presented results are a prelude to the next stage of work which will be related to design and construction of the measuring head. In its development, it will be important to ensure appropriate design parameters, e.g. a small distance between the sensor and the surface under test, as well as metrological parameters related to the selection of magnetometer elements. It will be also necessary to carry out the measurements on the actual device and to verify the reading in the cases where the guide rail surface is coated with oil or lubricant film.

References

1. Przystupa K, Ambrożkiewicz B and Litak G 2020 Diagnostics of Transient States in Hydraulic Pump System with Short Time Fourier Transform *Adv. Sci. Technol. Res. J.* **14**(1) 178–83
2. Przystupa K 2019 The methods analysis of hazards and product defects in food processing *Czech J. Food Sci.* **37** 44-50
3. Przystupa K 2019 Electrochemical ECG grinding of ceramic and tungsten sinter *Matec Web of Conf.* **252** 01001 DOI: 10.1051/matecconf/201925201001
4. Kozłowski E, Mazurkiewicz D, Żabiński T, Prucnal S and Sęp J 2019 Assessment model of cutting tool condition for real-time supervision system *Eksploat. i Niezawodn.* **21**(4) 679–85
5. Mazurkiewicz D 2014 Systemy informatycznego wspomagania eksploatacji i zapewnienia niezawodności przenośników taśmowych *Eksploat. i Niezawodn* **16**(3) 377-82
6. Lonkwic P, Józwik J, Saga M, Kuric I 2014 Diagnostic of CNC Machine Tools in Manufacturing Process with the Laser Interferometr Technology *Manuf. Technol.* **1**(14) 108–17
7. Krakowski T, Molski S, Ruta H, Lonkwic P and Tofil A 2020 Diagnostics of operational wear in hybrid load-carrying cables *J. Phys.: Conf. Ser.* **1736** 012012
8. Krakowski T, Lonkwic P and Ruta H 2020 Application of stray magnetic field for monitoring the wear degree in steel components of the lift guide rails system *Metals* **10**(8) 1008 doi:10.3390/met10081008
9. Krakowski T and Ruta, H 2019 Application of fuzzy logic in lift energy efficiency classification *Energy Effic* **12** 1973–85
10. Zhou Y, Wang K and Liu H 2018 An elevator monitoring system based on the internet of things *Procedia Comput. Sci.* **131** 541-44
11. Hui SC, Leung MKH and Wang F 2004 Remote intelligent elevator monitoring system *Int. J. Comput. Appl.* **26** 1-8
12. Yi X 2016 Design of elevator monitoring platform on big data *2016 International Conference on Industrial Informatics - Computing Technology, Intelligent Technology, Industrial Information Integration (ICIICII)* (Wuhan: Chiny)

13. Yaman O, Baygin M and Karakose M. 2016 A New approach based on image processing for detection of wear of guide-rail surface in elevator systems. IJAMEC **4** 296–300
14. Qiu L, Su G and Wang Z 2021 High-speed elevator car horizontal vibration fluid–solid interaction modeling method *J Vib and Control.* **2** https://doi.org/10.1177/10775463211023361
15. Liu M, Zhang R, Zhang Q, Liu L and Yang Z 2021 Analysis of the gas-solid coupling horizontal vibration response and aerodynamic characteristics of a high-speed elewator *Mech. Based Des. Struct. Mach.* https://doi.org/10.1080/15397734.2021.1923525
16. Wang W and Jiang Y, 2020 Seismic response of counterweight-roller-rail coupled system for high-speed traction elevator *Chapter of Book Experimental Vibration Analysis for Civil Structures Edition 1st Edition First Published* (Boca Rayton: CRC Press)
17. Cao S, He Q, Zhang R and Cong D 2020 Active control strategy of high-speed elevator horizontal vibration based on LMI optimization *CEAI* **22**(1) 72-83
18. Seung-Kwon R, Eundo K, Jong-Seok O and Jae-Ung Ch 2019 An analysis on the effect of application on vibration isolation liner of elevator guide rail bracket *Journal of the Korea Convergence Society* **10**(8), 145-51
19. Colón D, Cunha A Jr, Kaczmarczyk S and Balthazar J 2017 On dynamic analysis and control of an elevator system using polynomial chaos and Karhunen-Loève approaches *Procedia Eng.* **199**, 1629-34
20. Mańka E and Styp-Rekowski M 2011 Porównanie wybranych wielkości wykorzystywanych do oceny stanu lin określonych różnymi metodami *Studies & Proceedings of Polish Association for Knowledge Management* **47** 157-68
21. Kwaśniewski J, Krakowski T, Molski S, Roskosz M, Ruta H and Schabowicz K 2020 Diagnostics of steel ropes constituting structural elements of building objects *Builder science* **271** (2) 21-25