UNIVERSITY OF PETROŞANI

DOCTORAL SCHOOL

DOCTORAL THESIS
SUMMARY

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STUDY OF FATIGUE CAUSED BY THERMO-MECHANICAL STRESSES IN DRUM-AND-SHOE BRAKING SYSTEMS FOR MINE HOIST USING COMPUTER MODELING AND SIMULATION METHODS

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2024

SUMMARY

For the extraction to the surface or other levels of valuable minerals or waste, as well as for the descent and ascent of people or materials necessary for mining operations, mine hoist systems are used. These are defined as a complex of equipment, devices, and mechanisms without which mining activities would not be possible.

The exploitation of underground deposits, whether ores or coal, requires transport to the surface through extraction shafts. These shafts can be either vertical or inclined.

Mine hoist machines are components of the mine hoist systems, having the role of moving the traction cables and, implicitly, the transport vessels. They include braking systems, which play an important role in ensuring the safe operation of the mine hoist. Thus, the characteristics of the braking system are determined by the structural features of the extraction shaft (such as its depth and number of levels), the useful mass extracted in one transport cycle, as well as the structural features of the driving or winding element of the cables.

In general, we can say that mine hoist systems include the following braking systems:

- shoe and drum brakes;
- disc brakes with brake pads.

These systems serve a dual purpose, being used for:

- Maneuver braking, which involves adjusting the extraction speed according to the imposed technological parameters.
- Emergency or safety braking, which requires an emergency stop in the event of occurrences that could lead to loss of life or major material damage. The triggering of emergency braking does not require human intervention and must occur automatically.

In both repetitive maneuver braking and firm emergency braking, the friction between the active elements (shoes or brake pads) and the passive elements (drum or discs) leads to an increase in temperature due to the transformation of kinetic energy into heat. The reduction in the performance of braking systems due to the early wear of their components can also be caused by

the high temperature of these elements.

The cyclic operation of mine hoist systems leads to repeated heating followed by cooling of the braking systems, a phenomenon that occurs at the end of each transport cycle. This periodic thermal process leads to the expansion of the components of the braking systems, particularly the passive ones. Thus, fatigue of the constituent materials of the passive elements can occur.

Over time, the analysis of the thermal regime of brakes has been approached by various researchers. They have used different study methods, including analytical and theoretical approaches, experimental methods, or combinations of these, as well as numerical methods such as the finite element method for different configurations and materials of braking systems.

Most studies conducted on brake heating are limited to braking systems with small radii of friction surfaces and high rotational speeds, typical of automotive or railway transport.

The doctoral thesis addresses the study of fatigue caused by thermo-mechanical stresses on shoe-and-drum braking systems of mine hoist systems using computer modeling and simulation methods. Compared to the braking systems of railway or automotive vehicles, in the case of mine hoisting, the passive elements (drums or discs) are characterized by low rotational speeds.

The simulation for studying fatigue in cyclic maneuver braking was performed on a 1:1 scale virtual model corresponding to the drum and shoe braking system of the MK 5x2 mine hoisting machine. This model was created using SOLIDWORKS. The simulation of the thermo-mechanical regime for fatigue determination was conducted using the Comsol Multiphysics application.

The results obtained from the simulation can be used to reduce maintenance and operational costs, as well as to increase the transport capacity and reliability of the installation. The results also support the design and manufacture of these braking systems for mine hoisting.

The study method used in the thesis involves modeling and simulating the thermo-dynamic regime and studying the fatigue generated for a flexible model of the virtual shoe braking system, which is easily adaptable to different operating regimes of mine hoisting. The advantage of the new method used is that it does not lead to over-dimensioning and incompatibilities that may become evident only after the final construction of the designed product.

In the thesis, the issues were approached starting from theoretical elements, eventually leading to practical applications. This paper, entitled **"STUDY OF FATIGUE CAUSED BY THERMO-MECHANICAL STRESSES IN DRUM-AND-SHOE BRAKING SYSTEMS FOR MINE HOIST USING COMPUTER MODELING AND SIMULATION METHODS"** is structured into seven content chapters, an introduction, and a final chapter with conclusions, personal contributions, and future research directions.

In the first chapter of the thesis, titled **"MINE HOISTING SYSTEMS – GENERALITIES,"** the importance of mine hoisting systems in the exploitation of underground deposits is highlighted, along with their main components and classification. The main functional characteristics of drum mine hoisting machines and those with a Koepe wheel are also presented. For mine hoisting equipped with a Koepe wheel, specific advantages and disadvantages of using mono-cable and multi-cable Koepe wheels are highlighted.

A significant portion of Chapter 1 is dedicated to the presentation of braking systems. The importance of these systems in the safe operation of mine hoisting is emphasized. The functional requirements imposed on braking systems, their structure, and the method of generating braking force are presented. Given that the doctoral thesis focuses on the simulation of the thermo-mechanical regime of drum and shoe brakes, special attention is given to presenting these, particularly highlighting their functional requirements.

In Chapter 2, titled **"KINEMATICS OF MINE HOISTING SYSTEMS"** the cyclic operation of these installations is initially presented based on a tachogram. The factors influencing the shape of the tachogram are subsequently presented. These factors include the mode of operation, extraction depth, safety requirements, and operating conditions. The kinematics of mine hoisting corresponding to different transport vessels and modes of operation is presented.

Chapter 3, titled **"ASPECTS RELATED TO THE DYNAMICS OF MINE**

HOISTING SYSTEMS" contains the theoretical concepts used in the sizing and verification calculations regarding the dynamics of mine hoisting. The forces (static, friction, and dynamic) that occur during the operation of the installations are presented and analyzed. The empirical calculation of the reduced mass of moving components is also presented. Additionally, for an extraction cycle, graphs of the variation of kinematic and dynamic parameters are plotted for an mine hoisting with non-tipping cages, where the operation is performed with an asynchronous motor or a direct current motor.

Chapter 4, titled **"THEORETICAL CONCEPTS REGARDING HEAT TRANSFER,"** includes fundamental theoretical notions about heat transfer. The analysis covers heat transfer through the physical phenomena of conduction, radiation, and convection. Heat transfer between solid media is presented for situations where they are limited by parallel flat surfaces and coaxial cylindrical surfaces.

In Chapter 5, titled **"SPECIFIC CHARACTERISTICS OF THE THERMAL REGIME OF SHOE BRAKES IN MINE HOISTING SYSTEMS"** we initially show that friction between the shoes and the drum leads to the conversion of kinetic energy into heat. This results in an increase in temperature of both passive and active elements of the braking system. This phenomenon occurs in both safety braking and maneuver braking. If maneuver braking is done to stop the mine hoisting at ramps, the heat generated is equal to that of safety braking. The difference between the above situations is determined by the time required to convert kinetic energy into heat. Since the braking time is much shorter in safety braking than in maneuver braking, the power transmitted through friction is greater in emergency braking.

Continuing the chapter, we present analytical calculation formulas for the thermal regime of mine hoisting brakes. For the numerical calculation approach of brake heating in mine hoisting, we devised a structural logic diagram for the thermo-mechanical regime calculation using numerical methods. Within this chapter, we determined the mechanical and thermal parameters necessary for simulating the thermal regime of shoe brakes. Thus, we determined the kinematic parameters for an MK 5x2 mine hoisting, parameters that form the basis for plotting the tachogram to be implemented in the Comsol application. Here, we also determined the number of extraction cycles per hour.

Additionally, for the same mine hoisting, we determined the dynamic parameters, namely the value of the reduced mass, the power developed during braking, and the thermal power. Further, we determined the thermal parameters necessary for the simulation. Thus, for the dimensions and operating parameters of the analyzed mine hoisting, the thermal conductivity value of air was calculated, and based on the Reynolds number, the convective transmissivity for laminar flow was determined.

At the end of the chapter, the geometric dimensions and main functional characteristics of the MK 5x2 mine hoisting are presented.

In Chapter 6 of the doctoral thesis, titled **"THEORETICAL CONCEPTS REGARDING MATERIAL FATIGUE,"** the general principles specific to the Comsol application for fatigue study are presented. Comsol has implemented eight types of analysis for fatigue evaluation, namely:

- Stress-life analysis for high-cycle fatigue (HCF)
- Strain-life analysis for low-cycle fatigue (LCF)
- Stress-based analysis for high-cycle fatigue (HCF)
- Strain-based analysis for low-cycle fatigue (LCF)
- Energy-based analysis when dissipated energy controls crack formation and growth
- Cumulative damage analysis for variable load fatigue
- Harmonic vibration analysis based on the results of a frequency sweep
- Random vibration fatigue analysis based on the results of a random vibration analysis where loading is PSD (power spectral density)

A logic diagram with key questions is presented, which can be used to select the fatigue study model. The chapter highlights fatigue evaluation models of the stress-life type (S-N curve model, Basquin model, approximate S-N curve model) and strain-life type (E-N curve model, Coffin-Manson model, combined Basquin, Coffin-Manson model).

Stress-based fatigue evaluation models grounded in the critical plane method are also analyzed (Findley criterion, Matake criterion, maximum normal stress criterion, Dang Van criterion). The Findley and Matake criteria were used in the Comsol application to evaluate the fatigue of the components of the shoe braking system under thermo-mechanical stress due to periodic maneuver braking at the end of the extraction cycle. The chapter also presents a series of other fatigue evaluation models in detail.

Based on the structural logic diagram of the thermo-mechanical regime calculation using numerical methods presented in Chapter 5, a structural logic diagram for fatigue calculation is proposed based on the results of the thermo-mechanical stress simulation of the drum and shoe brakes of mine hoisting.

In Chapter 7, titled **"SIMULATION OF FATIGUE IN SHOE BRAKING SYSTEMS,"** I initially created the virtual model of the drum and shoe braking system of the MK 5x2 machine. This model consists of an assembly made up of four components. The geometry of this assembly was imported into the Comsol application, where a physical study of heat transfer with time variation of quantities was conducted. The results thus obtained served as input data for the mechanical study, determining the mechanical stresses and deformations of the simulated model. The mechanical and thermal parameters necessary for simulating the thermal regime of shoe brakes, which were calculated in Chapter 5, were implemented. The braking section of the tachogram, also plotted in Chapter 5, was described both analytically and graphically. Based on this, the variation in braking acceleration of the mine hoisting was determined. The characteristic values of the properties of the materials used in the construction of the components of the braking system model were also implemented.

Next, the parameters for heat transfer, the solid mechanics module parameters, and the criteria parameters for fatigue evaluation, Findley and Matake, were established. The simulation calculations began with the creation of the finite element geometry. Initially, the results related to the heat transfer generated by the friction of the shoes on the braking drum were obtained. The heating of the components of the simulated model causes mechanical stresses and deformation of the components. The cyclic nature of the maneuver braking process induces periodic mechanical stresses on the analyzed model components, which can lead to the phenomenon of material fatigue.

The thesis presents the variation in temperature on the surface of the braking drum. Temperature variation diagrams for the entire simulation period were plotted for three specified points: the point where the drum enters under the shoe, the midpoint of the shoe, and the point where the drum exits from under the shoe. Additionally, a temperature profile over time along a 3D transverse cut line, as well as the time variation of temperature along a 3D parametric circular curve, was plotted. To visualize the amount of heat produced and dissipated, logarithmic scale curves of these quantities' variation over the entire simulation time interval were plotted.

The results of the mechanical regime simulation of the shoe brakes were presented through a series of graphs and 3D images of von Mises stress variation. Subsequently, the deformations of the components comprising the model for which the simulation was conducted were presented through graphs and 3D images. The final results refer to the variation of fatigue usage factors according to the Findley and Matake criteria. The maximum values of these factors for both fatigue evaluation criteria are subunitary. A subunitary value of this factor indicates that the loads on the drum are below the material's fatigue limit.

Analyzing the content of this thesis, the way the issues in the title were addressed, the structuring of information, the methods used, as well as the dissemination of the obtained results, it can be stated that this work represents a step forward in the research of fatigue in large-scale industrial installation brakes. It could serve as a starting point for future research directions in this field.