UNIVERSITY OF PETROSANI

DOCTORAL SCHOOL

# DOCTORAL THESIS ABSTRACT

## STUDY THROUGH MODELING AND SIMULATION OF THE THERMAL REGIME OF THE DRUM AND SHOE BRAKES AT MINE HOIST SYSTEMS

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CONTENT

In most cases, the exploitation of underground deposits, be it ores or coal, involves transporting them to the surface of the ground through shafts that can be vertical or inclined. The transportation in the shafts is provided using mine hoisting machines. These are complex electromechanical equipment that, in addition to bringing the exploited material, are also used to transport the equipment, materials and workers between surface and the underground.

As with other means of transport also in the case of mine hoists, the braking system plays a decisive role in their proper functioning. Thus, mine hoists can be equipped with two types of braking systems: drum and shoe brake, and disc and pads brake systems. During operation, the braking systems of the mine hoisting installations are used either to reduce the speed depending on the operating technological parameters (manoeuver braking), or for emergency stop when situations occur in the operation of the extraction installation that can cause major material damage or even the loss of human life (emergency or safety braking).

Regardless of the braking system of the mine hoist, the emergency or safety braking must occur automatically without human intervention, when: the maximum transport speed has been exceeded by 15%, the protection against over-winding of the transport conveyances has been activated or the overload and short-circuit protection of the electrical power installation of the mine hoist was triggered.

Braking causes an increase in temperature due to the friction between the pads or shoes with the rotating disc or drum. Thus the transformation of kinetic energy into heat takes place. The temperature increase of the friction elements can reduce the performance of the braking system or cause premature wear of its passive (drum or disc) and active (shoes or pads) elements.

The doctoral thesis studies the thermal regime of large braking systems used in mine hoists. Compared to the braking systems of road or railway vehicles, the passive elements (drum or disc) of mine hoist brake systems have much lower rotation speeds.

The study was carried out by modelling the drum and shoe braking system of the MK 5x2 mine hoist and simulating its thermal regime during emergency braking, with both SOLIDWORKS and COMSOL Multiphysics software as FEM modelling tools. For both software the simulations were performed for decelerations of 3, 3.5, 4 and 4.5 m/s2.

The results obtained are aimed at reducing operational and maintenance costs, but also increasing the performance, reliability and transport capacity of mine hoists. At the same time the results can be applied in the design and manufacturing phases of braking systems for mine hoists or other industrial transport systems.

The validation of the results obtained for emergency (safety) braking, allows the use of both the proposed model and the simulation method adopted for the study of the thermal regime during manoeuvre braking. This braking regime can be the basis of further research on the fatigue of the passive elements of the braking system.

In the Thesis, regardless of the software used for the simulation, a logical approach was used, that starts from simple towards complex, with the initial introduction of the theoretical aspects and finishing with case studies.

The thesis is structured in 5 chapters, introduction and a conclusion and personal contributions part.

Thus, in Chapter 1 entitled GENERAL NOTIONS REGARDING MINE HOIST SYSTEMS, I presented the importance of mine hoisting systems for the underground mining activity, as well as the main components of mine hoisting systems. Next a classification of these installations was created, depending on the destination, the position of the shaft, the type of transport conveyance, the number of ropes, the degree of balancing, the geometry of the cable drive wheel, the mode of operation, the location of the mine hoist and the location of the main drive in relation to the headframe tower. The characteristics of both the drum and friction wheel (Koepe) mine hoists were presented. For friction mine hoists, the advantages and disadvantages of single-rope versus multi-rope  types were analysed.

An important part of this chapter is dedicated to the presentation of the braking systems of the mine hoists. The important role the braking systems play in the safe operation of mine hoists, their functional requirements and structure, as well as the nature and source of the braking force generation were presented. Since the doctoral thesis aims to simulate the thermal regime of drum and shoe braking systems, emphasis was placed this brake type, by describing the operation, presenting the functional requirements, the operating mechanism with levers and tie-rods as well as the execution mechanism of non-pivoted brakes.

The second chapter, entitled KINEMATICS OF MINE HOISTS, is devoted -as the title indicates- to the study of kinematics of mine hoisting systems. At the beginning, the cyclic operation based on a tachogram of these systems is highlighted. The characteristics that determine the shape of the tachogram are highlighted: extraction depth, drive mode, operating conditions and operational safety requirements. The kinematics of mine hoists with non-tilting cages are analysed for operation with both asynchronous and direct current electric motor. Different tachogram types are presented next. Finally, the six-phase tachogram is calculated for the mine hoist subjected to modelling and simulation of the thermal regime during safety braking.

Chapter 3, entitled DYNAMICS OF MINE HOISTS, includes the theoretical elements necessary for the verification and dimensioning calculations of mine hoist systems, from the point of view of dynamics. Thus, we presented and analysed the static forces, the friction forces and the dynamic forces that appear during operation, as well as the approximate formula for the calculation of the reduced mass of the moving elements. The diagrams of the variation of the kinematic and dynamic parameters during a hoisting cycle were plotted for the mine hoist with non-tilting cages operated with both an asynchronous motor and a direct current motor.

Chapter 4, THE THERMAL REGIME OF DRUM AND SHOE BRAKES OF MINE HOISTS, starts with the introduction of a series of theoretical aspects regarding heat transfer. Thus, heat transfer by conduction, radiation, heat transfer to liquids, natural convection, specific power and transmissivity as global quantities and heat transfer between solid media limited by parallel planes were all presented. Next, it was showed that the friction between the passive and active elements causes heating of the mine hoist braking systems. It was highlighted that there are two distinct situations when the mine hoist is stopped by applying the brake: the manoeuvre braking, when the hoist is stopped in accordance with the preset tachogram and the emergency braking when the hoist is stopped suddenly, without human intervention, because of a potential safety hazard. In both cases, the kinetic energy transformed into heat is the same, the difference between the two situations being given by the time in which this energy is transformed into heat, which is much shorter in the case of emergency braking. This means that during emergency braking the power transmitted through friction is greater than in the case of manoeuvring braking. Since the heating of the brake system components depends on the ratio between the amount of heat released on the friction surfaces and the amount of heat dissipated from these surfaces by conduction, convection and radiation, it means that during emergency braking these components are subjected to a greater heating. Next, in the chapter a sequential logical schema was proposed for the analysis of the thermal regime of the mine hoist brakes using the finite element method. This schema can implemented into any software that has the appropriate analysis modules. The premises of the calculation of the thermal regime of the drum and shoe brakes of mine hoists constitute a significant part of this chapter. The maximum kinetic energy of the moving masses was calculated. Four calculation scenarios, corresponding to decelerations of 3, 3.5, 4 and 4.5 $m/s^2$ were considered. Taking into account the maximum admissible transport speed, for each value of the deceleration we calculated the stopping times, the total power and the braking power. At the end of the chapter, the geometric parameters and technical characteristics of the MK 5x2 mine hoist brake system were presented.

In Chapter 5 entitled THE SIMULATION OF THE THERMAL REGIME OF DRUM AND SHOE MINE HOIST BRAKES USING SOLIDWORKS, a true scale (1:1) CAD model of the MK5x2 mine hoist friction wheel was built. The model is an assembly consisting of two parts: the friction drum and the drum lining. On the outer surface of the drum lining, its contact surface with the brake shoes was delimited, this surface being where the kinetic energy transforms into heat. Following the step by step thermal simulation approach of SOLIDWORKS, the thermal regime was calculated for the braking powers corresponding to the four deceleration values. It was a transient regime simulation, with a total time of 6 seconds and a 0.05 second iteration step. The power transmitted to the friction surface was described as a time-dependent function, its variation diagrams being consistent with the moment when the speed is zero. Following the simulation, the time variation of the temperature and its distribution on the surface of the drum lining was obtained. For the point with the highest temperature indicated by the software, we plotted the temperature variation over time for all considered decelerations. The deceleration of 4.5 $m/s^2$ produces the greatest heating of lining. This observation led to further analysis of the variation of temperature gradients and heat flow in time and space for this deceleration. At the same time, the diagrams of the quantities of heat produced and dissipated by convection were determined and plotted as functions of time, on a logarithmic scale, for the time interval 0 to 3.1 seconds, corresponding to the stopping time of the mine hoist at a deceleration of 4.5 $m/s^2$.

Considering the results obtained from the thermal simulation as stresses in a static mechanical simulation, the von Mises stress and the deformations corresponding to moment of maximum temperature were also determined.

Chapter 6 of the thesis is entitled THE SIMULATION OF THE THERMAL REGIME OF DRUM AND SHOE MINE HOIST BRAKES USING COMSOL MULTIPHYSICS.

Since the results obtained in chapter 5 showed that during emergency braking, the significant heating appears on the drum lining while the thermal regime of the drum remains unchanged, in this chapter a simplified model of the brake system was used, with the CAD geometry also created in SOLIDWORKS. The model is built as an assembly, with the brake shoes included now. This geometry was imported using the live-link option into COMSOL Multiphysics where the thermal regime simulation will be conducted in chapter 6.

This approach is also a step-by-step one, where the simulation parameters were first defined, and starting from their values, the speed was described as a time-dependent function. The moments of: the start of the simulation, the engage of the brake, the total stop (speed is zero), and the end of the simulation are essential in this simulation. The duration of the simulation is 6 seconds with an iteration step of 0.02 seconds. Deceleration is defined as the time derivative of the velocity. The same thermal and mechanical characteristics of the materials were implemented for all parts and components as in the previous chapter.

A first result obtained from the simulation is the temperature distribution on the surface of the drum lining. In order to analyse and visualise the thermal regime as clearly as possible, three points were defined, all located on the surface of the drum lining in the middle area of the friction surface between the drum lining and the brake shoe: one at the hot end, another at the cold end and the third in the centre of the drum lining and brake shoe contact area. Thus, it was possible to plot the variation in time of the temperature, the temperature gradient, the heat flow, the von Mises stress and the deformation corresponding to these three defined points.

For the maximum temperature moment, images of the spatial distribution of all the above mentioned variables were generated, both on the friction surface between the lining and the brake shoe as well as in cross-section. In order to have a clear image of the ratio between the generated and dissipated heat, the integrals of the heat produced and dissipated as a function of time were calculated, the results obtained being presented graphically on a logarithmic scale.

Taking into account the content of the Thesis, the approach methodology, the relevance of the results obtained and their dissemination, I consider that the present work contributes to the advancement of knowledge in the field of studying the temperature of brake systems of large industrial applications, and it also represents a starting point for future research.

The personal contributions brought to the completion of this Ph.D. thesis are:

- carrying out a well-documented theoretical study regarding heat transfer by conduction, radiation and convection;

- carrying out an in-depth analysis of the thermal regime of the mine hoist braking systems;

- proposing a logical structural scheme for analysis by numerical modeling and simulation methods of the thermal regime of braking systems in general and of mine hoist braking systems in particular;

- building a true scale (1:1) model in SOLIDWORKS of the rope drive wheel for the MK 5x2 mine hoist in order to study the thermal regime of the braking system;

- simulation of the transient thermal regime of the drum and shoe type brakes of the MK 5x2 mine hoist during emergency braking, using SOLIDWORKS;

- building another true scale (1:1) simplified model in SOLIDWORKS of the rope drive wheel for the MK 5x2 mine hoist, in order to study the thermal regime of the braking system;

- simulation of the transient thermal regime of the drum and shoe brakes of the MK 5x2 mine hoist during emergency braking, using COMSOL Multiphysics;

- the implementation of the study of the thermal regime for three distinct points on the surface of drum lining, with special reference to a time analysis;

- creating a theoretical and applied documentation base, that can be used for the study of other drum and shoe braking systems.

The future directions of research, aim to carry out a fatigue study of the braking system, fatigue that is generated by the intermittent thermal regime caused by the cyclic operation of the mine hoist, as well as the extension of the complete studies for the disc and pad type of braking systems used in modernised mine hoist or other industrial applications.