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METHODS OF DETECTION OF TEMPERATURE FACTORS AFFECTING TRAFFIC SAFETY OF RAILWAY TRANSPORTATION AND RISK ANALYSIS

Abstract. The article is dedicated to the investigation of internal and external factors affecting traffic safety of railway transport, including researching and solving ever-present issue of investigating, reducing and eliminating human factors, emergency situations and other impacts through complex methods and means. The technical state of wagons, one of the important components for traffic safety in railway transport, methods and means of detecting faults during their diagnostics, and making right decisions according to the situation are investigated. Diagnostics of the state of wagons is carried out through the method of remote measurement at measuring points installed at certain distances with a certain rule. At measuring points, the temperatures of tire boxes are investigated according to the normal limits, and risk status is assessed according to the comparison results. Accuracy and stability of diagnostics are very important for safe operation. In order to make right decisions, assessment of measurement errors of temperature factors, performing self-monitoring and correction, execution of the algorithm based on repeated measurements and points, carrying out comparison with norm limits, and making decisions provided that they are confirmed are presented. Based on Fuzzy Logic in Matlab environment, assessment of processing risks and suitable combinations are presented.

Keywords: hot box detectors; railway vehicle gearboxes; fault diagnosis; railcar condition monitoring; calibration; bolometr; traffic safety; computer simulation.

Introduction

Investigation and reduction of internal and external factors affecting traffic safety of railway transport, as well as human factors, emergency situations, etc. and their elimination through complex methods and means are always urgent issues. In railway transport, wagon assemblies are one of the important components for traffic safety, and detection of failures during their diagnosis is very important for safe operation. Measurement and control points are located on certain sections of the railway line, where hot box detectors (HBD) are equipped with devices used to assess the working condition of wagon assemblies such as bearings, axles and brakes by controling their temperatures. At this time, infrared (IR) sensors are used to record the temperature of railway wagon assemblies. The results that give a warning signal or indicate that the temperature limit has been exceeded are drawn and sent for inspection. However, in many cases, faults that could cause a noticeable danger were not detected in the wagon assemblies, which led to accidents. Data obtained from various field and laboratory tests were used to assess the accuracy and effectiveness of measuring instruments at measuring points. Based on the results, it was found that the location of the temperature scan has a significant effect on the temperature measurement. Data obtained in the field and laboratory tests determined that it is important to regularly calibrate the instruments used in measurements. Optimized calibration technique and accurate IR sensor can significantly improve the accuracy of these measurements.

Currently, there are many designs of hot box detectors, the difference between them lies in the type of used infrared radiation receivers, design and placement of working cameras with equipment, data processing and transmission methods. Many years of experience in the operation of these thermal control devices showed that the best results can be obtained by controlling the heating of axle boxes at several control posts located one after the other in areas where trains run without stopping. This is performed by network control facilities and transferring data to structures of a higher hierarchy (centralization), as well as integrating into various traffic management systems. In addition, centralization allows monitoring and diagnosing technical state of axlebox heating control devices themselves, so companies do not limit themselves to the creation and production of detectors of overheated axles, but develop systems with data centralization.

In order to predict and prevent bearing failures, railway industry applied various bearing health monitoring systems. The most commonly used health monitoring system is the roadside hot box detector (HBD). This system uses individual infrared temperature sensors located at a distance of 24-40 km (15–25 miles) from each other along the railway. As each freight wagon passes, each HBD scans the underside of roller bearings and records the bearing temperatures along with ambient temperature. If the measured bearing temperature, compared to the ambient, exceeds a predetermined limit, HBD generates an alarm that is used to slow down or stop the train for inspection.

A number of HBDs are configured to alarm when a bearing is operating at temperature of 94,4°C (170°F) above ambient or when a bearing is operating at temperature of 52,8°C (95°F) above ambient. Another common practice includes average calculating of bearing temperatures on one side of the wagon and comparing each bearing temperature to that average.

Analysis of publications. Roadside bearing state monitoring systems collect data from bearings as they pass sensors and analyze. If the bearing works exceeding the predator mined limit, warning is given to stop and the faulty bearing and wheel-axle assembly are replaced. This requires the train to be stopped for several hours, which is very costly and can potentially damage temperature-sensitive cargo.

When a train enters the monitoring zone, wheel contacts are used to detect the train and the system is set to “ready” state - the scanner lids open, the scanners scan each wheel that passes them and record the temperatures of axle bearings and brakes. If the measured values (temperature, number of axles) are outside the predetermined limits, then appropriate maintenance or error message is provided to the control room, while if the plausibility checks are positive, the system sends temperature values to the control unit for the axles and brakes. If it exceeds the limit, the warning is given immediately after the train ends. The system monitors the wheel contacts when they are loose, as well as during the train crossing to detect a cable break or short circuit. If the measured values are outside the predetermined limits, appropriate maintenance or error message is provided. The wheel contacts are also checked for a maximum closed time (about 1 minute), after which an error message is sent to the control room.

“Growler” is an example of high-risk failure, where growler occupies a major part of the surface of a bearing component. The system is capable of identifying bearings that have reached the end of their service life, but cannot identify bearings with defects, ring (cone) defects in the early stages of development [1].

Although hot box detectors are widely used and can prevent components from overheating, the system is not without problems. Many variables such as carrier class and IR scan location can impact on temperature measurements. Because of this, HBD carrier can either underpredict or overpredict the temperature, leading to two possible outcomes. Bearing temperatures overpredicted by HBD can exceed the temperature limit, which usually results in bearing removal for further inspection. In many cases, high bearing temperatures concern to disintegrated, broken, and/or water-damaged components among other possible failures and causes. However, a significant number of bearings that exceeded the temperature limit were also found to have no noticeable defects. These bearings are further classified as “unconfirmed”.

Removal of unconfirmed bearings causes unnecessary stops and delays in trains, leading to disruption of the railway line and congestion in the railway network. From 2001 to 2007, approximately 40% of bearing removals were found to be “unconfirmed” bearings being a serious problem for railroad industry. While unconfirmed bearings are a cause of inefficiency, catastrophic events can occur if HBD underestimates the bearing temperature and fails to alarm because the bearing is overheating. From 2010 to 2016, roadside HBDs did not manage to detect 119 seriously failed bearings in the United States and Canada, many of which caused catastrophic derailments [2]. HBDs are usually located at a distance of 25 miles (1,6 x 25 km), some 40 miles (1,6 x 40 km) on railway lines with less traffic. As HBDs roll over the detector, they use non-contact infrared sensors to measure the temperature emitted by wheels, axles and brakes. HBD will alert the train operator of any bearings operating at temperatures of 94,4 C (170 F) above ambient conditions or any bearings operating at temperatures of 52,8 C (95 F) above bearing temperature [3].

Applying semi-quantitative risk assessment approach to defining safety requirements for hot box detection systems shows that such devices can be designed with permissible hazard rate of about $3\cdot10{-}5$/h for each function. Some well-developed parameters within BP’s risk procedure had to be adapted for this application as well. BP-Risk offers an opportunity to obtain an approximate assessment for the security requirements of hot box detection systems in a short period of time. The arguments considered in the decision-making process for each parameter are understandable and therefore allow simple modification during updates [4].

According to current research in railway service, laboratory HBD simulator was designed and developed to imitate the functionality of recorders by bypassing an infrared (IR) sensor under the bed to measure dynamic temperature. Numerous experiments were conducted in the laboratory using healthy and defective bearings at various speeds and load conditions. Analysis of the data showed that the registration of information varies depending on the bearing class, with changes in bearing dimensions causing the IR sensor to scan different regions of the bearing’s outer ring (cup). The results showed that the scan location significantly affects the temperature measurement of laboratory HBD simulator, with the most accurate and precise readings corresponding to the inboard sliding zone of the carrier cup. Less predictable, especially if faulty bearing is not detected, it can have dangerous consequences (catastrophic derailments). Optimized calibration and accurate IR sensor alignment can significantly improve the accuracy of measurements, which in turn can reduce the followings: (a) costly delays and train stops due to false hot bearing trend events, and (b) catastrophic bearing failures. Underestimating the operating temperature of bearings with high-risk defects reveals the inability to distinguish between healthy and defective bearings as a major drawback of these systems. Therefore, only measuring temperature is not an indication of proper bearing operation [5].

Measurement devices are commonly used to assess bearing integrity and measure the temperature of the underside of the bearing. It will alarm if it exceeds 94,4°C (170°F) of the ambient or the difference between the two is 52,8°C (95°F). In addition, one experiment involves average calculating the temperatures of the bearings on one side of the wagon and comparing each bearing to the average. The research presented here provides the summary of work done to evaluate the effectiveness of current roadside HBDs used in field service. In this regard, a laboratory system using an infrared (IR) sensor was designed and developed to imitate the functionality of roadside HBDs. This system was used to perform numerous laboratory experiments to investigate the accuracy and precision of infrared-based temperature measurement systems. The results of the research show that the IR sensor data obtained in the laboratory generally monitors similar trend to the data obtained in the field with both systems underpredicting the carrier temperature. However, the data obtained in the laboratory is supposed to be more accurate. Field data also show that there is some variation in readings where roadside HBDs tend to overestimate Class K carrier operating temperatures more often than Class F operating temperatures under similar speed and load conditions. Many healthy bearing temperatures were incorrectly overpredicted and demonstrated trending events. As it turns out: IR sensors (both in the laboratory and in the field) predict higher temperatures for healthy bearings than for defective ones, and field testing underestimated loaded Class F bearing temperatures by less than 17°C (31°F). The results mentioned above are very dangerous considering that fully loaded bearings are more susceptible to catastrophic failure if any rolling grooves or surfaces fail. The internal (IB) ray scan location was determined to be the most accurate location for measuring bed temperature using infrared-based sensors [6].

Currently, hot box detection systems enable control of an important aspect of train supervision, but this is only part of the overall concept for automatic roadside train supervision. The advantages of technical devices for observing trains can be seen in this example for hot box detection. In addition, such a system is required to be highly reliable and accurate for real-time use. Because every detected hot box can cause a high-cost derailment [7].

Due to the disastrous consequences that can occur in unreliable condition monitoring systems, it is very important to investigate the effectiveness of the system at roadside measuring points. Variables such as carrier class and IR scan location can significantly affect the accuracy of temperature data. These variables can lead to under- or over-prediction of the system's rail bearing operating temperature. In the event of over-predicted temperature, healthy (defectless) bearing may be erroneously marked as defective and removed from service. If no defects or other problems are found during the inspection, the bearing is classified as "uninspected". These unconfirmed bearings cause delays and unnecessary train stops, which cost both time and money. The research conducted from 2001 to 2007 found that approximately 40% of bearings marked and removed from service were classified as "uninspected". If the system underpredicts hot operating bearing temperature and the alarm is not triggered, catastrophic bearing failure can occur. Statistics show that from 2009 to 2018, 151 defective bearings could not be detected in the United States and Canada, all of which caused catastrophic derailments [8].

Purpose and problem statement. In order to detect defective components, it is necessary to determinine the optimal distance, correctly locate the sensors, determine the location and cause of the heat, investigate whether the problem is internal or external (for example, if the outermost scans are 6°C (10°F) hotter than the rest of boxes, the problem inside the box may be in the external box assembly), detecting temperature error between on-board thermocouples and IR temperature measurement, increasing the accuracy of the measurement-control system, which allows to reduce operating costs and prevent train derailment that could result in loss of life.

Proposed Strategy

Hot wheels and hot boxes, which can cause derailments, are a significant hazard to any railroad operation. More serious hazards and accidents are caused by locked brakes, overheated deflated tires and broken tires. A locked brake can cause fire and is one of the main causes of flat spots emergence. In addition, non-functional brakes can lead to very dangerous situations and significant wear.

Digital world, modern transportation system, high-speed equal comfort and reliable transportation, etc. stipulates the organization of management of various transport structures on the basis of safe, reliable, high-tech element base in the requirements and provision of smart industry, smart village and urban planning of modern times. In this regard, the issues related to the management and control of railway transport according to the requirements of the day are one of the most urgent issues of our time. In the article, the systems located at the measuring nodes placed on the railway side are of particular importance to monitor axle bearings, which are overheated and a source of danger and risk for accidents in harsh environmental conditions. Here, the algorithm of fault detection performed under fuzzy logic-based conditions and its simulation are presented. The proposed system is a monitoring system that is placed at different distance and measuring points that are important due to their danger and can be significant in ensuring railway safety, preventive maintenance and accident prevention. The main advantage of the presented concept is the joint analysis of external factors and technical state, the application of complex fuzzy model for decision-making at the cloud level, the possibility of self-monitoring and calibration, etc. with its advantages which allows to justify the accuracy of the results in better terms.

In order to detect measurement and calculation errors and assess the quality of measured signals, along with self-monitoring and calibration, error correction, signal processing, comparative analysis in the intelligent system, the application of risk assessment algorithm based on fuzzy logic is of particular importance. Since operational decisions require high-speed calculations, it becomes even more important to process information in cloud computing in order to detect overheated node (temperature, position, number of axles and train side) and assess the risk, take appropriate alarm measures and perform necessary operations. In this case, cloud computing stipulates technical state of the node, the type of maintenance and the need for planning and evaluation of decisions. The proposed algorithm fuzzy model is presented in Fig. 1 and Fig. 2, respectively.

Based on this, the authors developed a system that uses temperature, load and vibration sensors installed directly on the bearing adapter for continuous monitoring of bearing conditions. Infrared temperature measurement is considered to be provided with on-board thermocouples for scan location and scan angle.

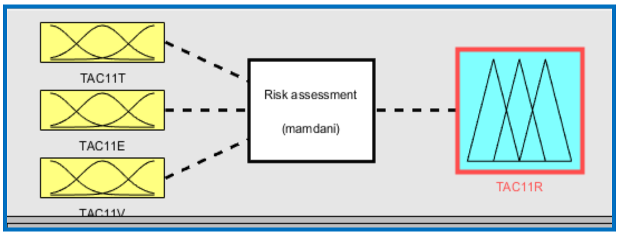

Fig. 1. Rule viewer Risk assesment

Simulation results

In order to ensure safe movement of trains in motion, when multi-sensor on-board system for the state of wagon wheels and intelligent measurement control system consisting of stationary system unit perform measurements, the results of which are processed in accordance with the temperature limits placed in that database before being placed in Big Data data unit.

At the same time, speedy processing allows reporting and analysis of information obtained from different sensors monitoring the condition of different regions according to various limits, not only determining the nodes where the temperature limits are violated, but also the area where the temperature limit of that node is violated.

Continuous comparative analysis with sample measurement allows for self-monitoring. Along with the existence of errors, based on the value of self-monitoring data, the correct evaluation of errors is determined, and correct decisions are made by determining whether defective nodes are evaluated accurately or not.

Risk assessment is performed with Fuzzy Logic Designer simulation in Matlab environment and simulation results are shown in Fig. 1 – Fig. 5.

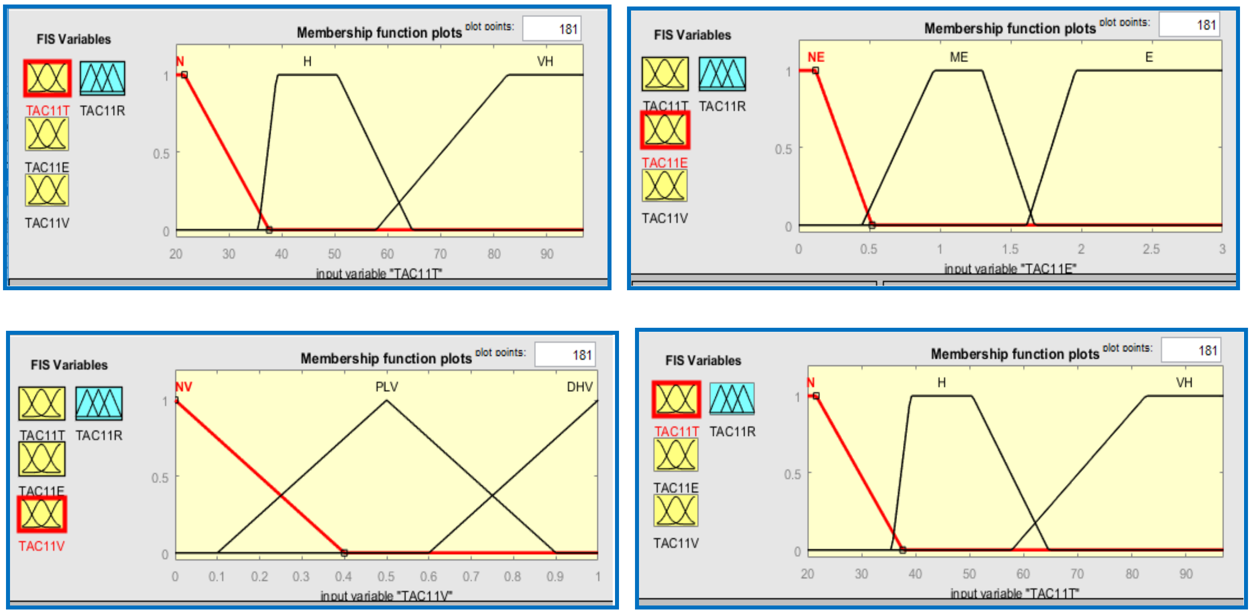

Fig. 2. Membership Function editor

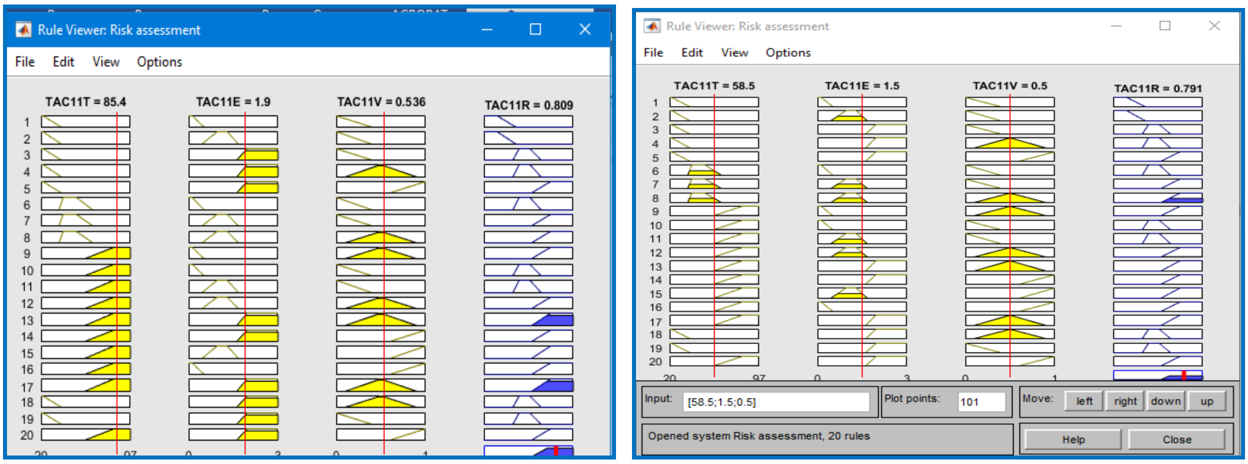

Fig. 3. Rule Viewer Risc assesment

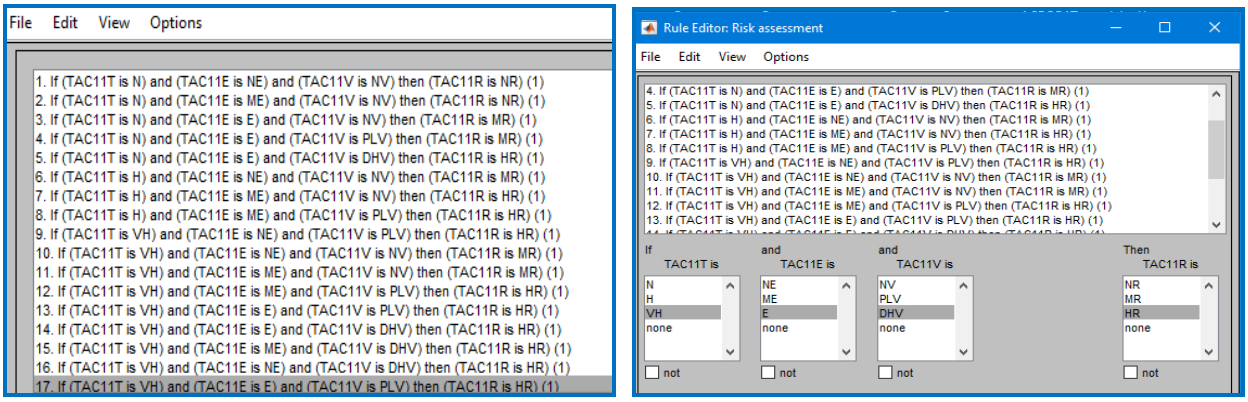

Fig. 4. Rule Editor Risk assesment

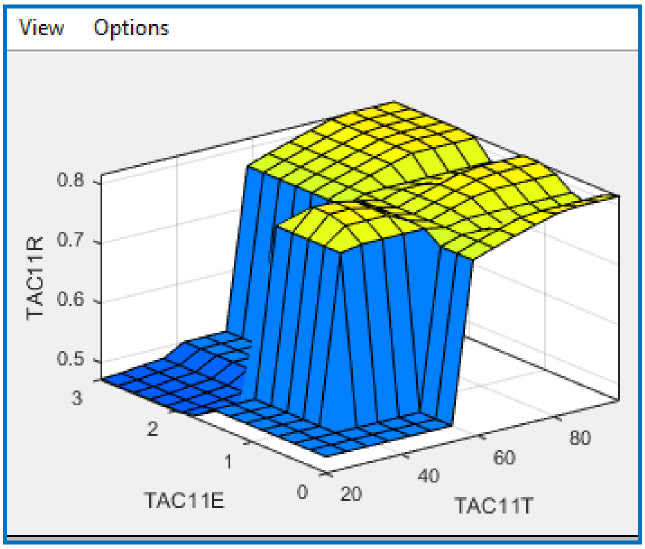

Fig. 5. Surface viewer Risk assesment

For this, input simulation parameters, Membership functhion are selected and train, train wagon and wagon wheel are marked, for example TAC11T.

Expression is identified as first wheel of the first wagon of train A, T is the temperature of the node of that wheel, N is normal temperature limits, H high and VH very high. At the same time, TAC11E is marked as an error of that node, NE as non-error, ME as permissible error, DE as dangerous error. TAC11V is defined as vibration at that node, NV as normal vibration, PLV as permissible limit of vibration, and DHV as dangerous high vibration. Risk assessment and decision making as output Membership functhion is recorded in TAC11R.

Conclusions

The proposed intelligent measurement-control system, which ensures traffic safety, detects faults in axle boxes, wheel sets, brake and coupling equipment, friction parts, at the physical level, and a part of it at the data level using expansion modules and standard connections, including directly connected with the means of the information transmission network, equipped with measuring methods and tools capable of performing contact measurements and remote, distance measurements (IR sensors). The system is intended for the management of double and unidirectional trains with on-board and stationary unit-modules. In order to reduce the impact of the environment, it is planned to select the placement angle so that IR receiver of the optical unit is not exposed to radiation effects, to use fiber-optic communication line (FOCL), radio channel or Ethernet as communication channels for the exchange of on-board information and stationary measurement-control station information.

Distributed infrared (IR) sensor allows scanning different regions of the outer ring (cup) of the bearing, significantly affects the simulator's temperature measurement, provides an accurate reading. For the accurate assessment of temperatures, determination of errors based on the comparison of measurement results with sample measurements and self-monitoring and calibration of these devices are provided.

Since under-predicted temperatures can lead to catastrophic consequences resulting in derailments, the system's effectiveness has been increased, especially by identifying faulty bearings, performing calibration process that can optimize measurements, detecting sources of errors, and determining and eliminating human factors. Self-monitoring, correction of measurement results and errors, optimized calibration and selection of the correct location and position of IR sensors can significantly increase the accuracy of measurements. At the same time, investigating, processing of the data on the base of fuzzy logic, and fuzzy logic simulation of them in Matlab environment allows optimal decisions to be made that can eliminate train stops at the wrong place and costly delays or tragic failures due to wrong measurements. It eliminates the drawback of systems that underestimate the operating temperature of nodes with high-risk defects. It allows separation of healthy and defective bearings. In order to be able to reliably detect the beginning of the development of defects in making optimal decisions and follow its deterioration through service operation, the monitor system is not only a temperature indicator, temperature sensor and its error, but also it should be processed by using temperature, load and vibration sensors installed directly on the bearing adapter for continuous monitoring of bearing conditions.

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Методи виявлення температурних факторів, що впливають на безпеку руху залізничного транспорту і аналіз ризику

Лала Бекірова, Аладдін Байрамов

Анотація. У статті розглядаються внутрішні та зовнішні фактори, що впливають на безпеку руху залізничного транспорту, в тому числі людський фактор, аварійні ситуації та ін. Матеріал статті присвячений дослідженню та вирішенню проблеми оцінки впливу температурних факторів, а також зниженню та усуненню даного впливу за допомогою складних методів і засобів. Однією з важливих складових безпеки руху на залізничному транспорті є технічний стан вагонів. Тому на сьогодні є актуальними методи та засоби виявлення несправностей при їх діагностиці та прийняття правильних рішень щодо ситуації, що виникла. Діагностика стану вагонів здійснюється методом дистанційних вимірів у точках виміру, встановлених на певних відстанях у визначеному порядку. У точках виміру досліджують температури боксів покришок, перевіряють, чи знаходиться вона у межах норми. За результатами порівняння оцінюють стан ризику. Точність та стабільність діагностики дуже важливі для безпечної експлуатації. Для прийняття правильних рішень представлено вимірювання похибок вимірювання температурних факторів у точках вимірювання, самоконтроль та корекція, виконання алгоритму на основі повторних вимірювань та точок, порівняння з межами норми. Рішення приймається лише у разі підтвердження відхилень від норми. На основі нечіткої логіки в середовищі Matlab розроблений апарат оцінки ризиків обробки та надані відповідні рекомендації.

Ключові слова: детектори гарячих боксів; коробки залізничного рухомого складу; діагностика несправностей; контроль стану вагона; калібрування; болометр; безпека руху; комп'ютерне моделювання.