Proposal of an intelligent wayside monitoring system for detection of critical ice accumulations on railway vehicles

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Abstract. At railway lines with ballasted tracks, under unfavourable conditions, the so-called flying ballast can occur predominantly for trains driving at high speeds. Especially in wintertime, it is highly likely that the causes are adhered snow or ice deposits, which are falling off the vehicle. Due to the high kinetic energy, the impact can lead to the removal of ballast stones from the structure of the ballasted track. If the stones reach the height of vehicles underside, they may be accelerated significantly due to the collision with the vehicle or may detach further ice blocks. In the worst case, a reinforcing effect occurs, which can lead to considerable damage to railway vehicles (under-floor-area, vehicle exteriors, etc.) and infrastructure (signal masts, noise barriers, etc.). Additionally the flying gravel is a significant danger to people in the nearby area of the tracks. With this feasibility study the applicability and meaningfulness of an intelligent monitoring system for identification of the critical ice accumulation to prevent the ballast fly induced by ice dropping was examined. The key findings of the research are that the detection of ice on railway vehicles and the development of an intelligent monitoring seem to be possible with existing technologies, but a proof of concept in terms of field tests is necessary.

1. Introduction

Unfavorable conditions and predominantly high speeds of trains on ballasted railway tracks can cause the so called ballast flying. Especially in winter, it is considered to be highly probable that such phenomena are caused by the falling of snow or ice accumulation adhering on the bottom surface of vehicles. As a result of their high kinetic energy, the impact on the superstructure can strike stones out of their cohesion structure. When these disengaged stones gain enough height, collisions with the vehicles underside are possible. On the one hand, such stones may be significantly accelerated and are able to pull out further stones from the ballasted bed. On the other hand, the impact on the vehicle can lead to further detachments of snow or ice accumulations. Due to these mechanisms an avalanche effect can appear, which intensify damages of vehicles (under-floor-area, vehicle exteriors, etc.) and on the infrastructure (signal masts, noise barriers, etc.). Furthermore ballast flying is a serious threat to people which are nearby the railway track (railway staff, pedestrians at platforms or on streets or paths beside the track). Relevant research activities on this topic can be found for example within a project done by Deutsche Bahn AG Systemtechnik, and Bombardier Transportation GmbH in 2007 [1] or
within extensive research work in Korea for example by Kwon, H. B. [2]. Although this phenomenon of ballast flying is known for quite some time, due to the seldom occurrence in real life and the concomitant destruction of the initial situation there is no evidence about the concrete circumstances, which induce the avalanche effect. But some factors like the amount of adhesive snow or ice, the speed of the train and the weather conditions of the former trains run can be assumed, which may influence the probability of occurrence. Thus, this paper deals with the new approach of wayside monitoring of trains in operation to identify critical snow or ice formations before they falling off the vehicles.

2. Development
In order to find a solution for this problem, the University of Applied Sciences St. Pölten (Carl Ritter von Ghega Institute for Integrated Mobility), the Vienna University of Technology (Institute of Transportation and the Institute of Building Construction and Technology), the Johannes Kepler University in Linz (Institute of Technical Mechanics) and the Rail Tec Arsenal sat up the project EISMON. With this study, the applicability and meaningfulness of mentioned monitoring approach for identification of the critical ice accumulation was examined.

2.1. Environmental analysis
In a first step, a survey on international documented ballast flying incidents, including the boundary conditions prevailing in each case such as travel speed, weather conditions or vehicle types as well as research of the common practice and development of counter measures were done. These investigations showed that detailed scientific studies on ballast flying induced by ice droppings haven’t been made until now in a sufficient number. Nevertheless, some examples of strategies from railway operators were found, how to avoid these incidents. For instance, Deutsche Bahn (DB) uses for their intercity express trains (ICE), which are used in cross-border long-distance service, a wayside de-icing system. Thereby the train drives very slowly over the system and 42 nozzles spray a layer of glycol on their trains, so the ice attachment is minimized up to 80% [3]. In contrast Austrian Federal Railways (ÖBB) count on visual inspections if the weather conditions encourage ice adhesions. When this inspection reveals ice and snow on the train, the speed is limited to a maximum of 160 km/h [4].

In order to achieve a high degree of track and/or vehicle utilization railway operators have to assess the risks as accurately as possible. For this purpose a monitoring system might be beneficial, if it provides detailed and reliable information about the snow or ice attachments and their location on the vehicle underside. To develop such a system, it is necessary beforehand to gain experience of typical characteristics of snow and ice adhesions (e.g. areas which favor adhesions, shapes, degree of impurities, ratio between ice and snow). For this reason investigations on railway vehicles were made during snowy periods in winter. These showed that ice chunks can have considerable dimensions and masses (for instance Figure 1 shows an ice block with dimensions 40 x 20 x 10 cm and mass about 4 kg). Such attachments were predominantly found in the bogie areas and the areas between the vehicles, where many corners and juts can be found. The remaining surfaces of vehicles downsides have a smooth, flat surface. These areas were almost free of snow or ice or, at least, covered with considerably fewer adherences.

In the bogie and inter-vehicle areas the adhesions usually consist of a snow layer in the contact region to the vehicle surface and an iced layer on the top of the snow layer. This structure may be formed due to changing temperatures around the freezing point, where exposed surfaces of snow adherences are subject of an alternating thawing and freezing process (e.g. tunnel passages in winter). In corners and in sheltered areas were mostly found sole snow attachments.
2.2. Mechanical modelling
In a next step to get a deeper understanding of the phenomenon, the basics for a mechanical modelling were executed, mainly through calculation of the flight path from the ice block and the released gravel. For this purpose, input parameters such as the vehicle speed, the diameter of an idealized spherical-shaped, dropped off attachment, the density, the fall height and some more values are solved by setting up a differential equation. It is an interesting note, that in the case of mass equality between the ice dropping and the gravel, it’s possible that the gravel hits the vehicle.

2.3. Measurement methods
The future measurement system should be able to detect the volume of the ice or snow accumulation on the train by comparing the measured surface profile with a reference measurement without ice or snow adhesions. If dangerous ice or snow attachments are detected the measurement system has to send a warning to the next operation control centre. Because of the fact that mass equality of snow or ice droppings and gravel could be dangerous (Chapter 2.2.), some requirements in regarding accuracy and spatial resolution were specified. In addition to avoid blocking the line-of-sight between the sensor and the train surface due to snow resuspension the crossing speed is limited to up to 80 km/h. This assumption has to be evaluated in the further development. But because of operational issues the track speed must not be limited by the measurement system. Therefore potential measurement sites are primarily in station areas or other areas where the track speed is limited for example due to narrow curves anyway.

Due to the fact that there are no standard solutions for an automated identification of ice or snow accumulations on trains in operation, a general literature and internet research of applicable contact-free distance measurement methods was made. Through discussions with sensor manufacturers the feasibility of every method was investigated. A comparison of the considered measurement methods was shown through a rating matrix, where every measurement method was evaluated relating to the determined requirements of accuracy and spatial resolution. Based on this matrix the methods laser scanning and light-section appear to be best fitting for this application.

Cameras can additionally be used for verification especially for field tests of a monitoring system development. Thus area scan cameras and line scan cameras were compared separately to the distance measurement methods. Because of the considerably simpler uniform illumination of the recording area, which is necessary for high shutter speeds and in further consequence for sharp images, line scan cameras are preferable.

Up to now these distance measurement methods have never been used with icy or snowy surfaces on fast moved objects like a running train. This means that there is no experience for this measurement task, so the proof of concept for the measurement of ice and snow adhesions must still be provided. To
implement a measuring system under real conditions, a test phase with a prototype is therefore necessary. In this phase, the installation of an additional line scan camera to record the train surface is recommended to evaluate the results of the measurement system.

2.4. Intelligent wayside monitoring system

The basic idea of the proposed intelligent wayside monitoring system is the combination of different information. The more information can be used, the higher the quality of the result may be. Besides the output of above-described future measurement system, information already available for the infrastructure operator, like train data, infrastructure data or weather data seems to be applicable. Within these information categories, different levels of detail exist. For example train data can also include historic information about the train e.g. how long and where a train stopped before in a depot the night before, on which line the train ran the night or day before and so on. Also useful data of further measurement systems (e.g. temperature or air velocity in tunnels) may be included into the monitoring system. The basic architecture that was developed within the project is demonstrated in Figure 2.

![Figure 2. Architecture of intelligent monitoring system. [5]](image)

Within the central evaluation unit the data of the different sources are combined. Mainly for a reduction of maintenance cost due to shorter operating times, the measurement system for ice detection may be deactivated in periods without any danger of icing. For example if there are high temperatures along the complete course of a train in summer, there seems to be less need to measure ice adherences.

The output of the central evaluation are warnings about the detection of suspicious attachments. Based on the strategy of the infrastructure manager these warnings could be an input for the dispatching system where the dispatcher will set suitable measures. But the warning can also be a direct input to a train control system to set further actions automatically (e.g. define a speed limit or stop the train).
3. Problem Analysis
To evaluate the potential and applicability a SWOT analysis was carried out. The main results are illustrated in Figure 3.

| Strengths                          | Weaknesses                      |
|-----------------------------------|---------------------------------|
| Detection of underfloor is possible | Sufficient network of measuring points required |
| Assessment of ice volume is possible | Interfaces for data exchange are necessary |
|                                   | Interpretation of measuring data necessary |

| Opportunities                    | Threats                          |
|----------------------------------|---------------------------------|
| Reduction of train delays        | No detection of ice possible    |
| After prototype tests sufficient functionality is realistic | Algorithm not reliable |

**Figure 3.** SWOT-analysis. [5]

4. Conclusions
As a result of the project it can be concluded that the three-dimensional distance measurement methods laser scanning or light-section seem to be applicable for the detection of snow or ice adhesions on railway vehicles. These data are amongst other necessary as input for an intelligent wayside monitoring system that has the ability to give out a warning or information to the infrastructure manager in order to prevent ballast flying and therefore to avoid accidents or to avoid delays in operation. Measurements of ice or snow on the surface of trains have not been performed under real conditions up to now. As a next step, the development of a prototype measurement system and detailed field test as proof of concept for the measurement as well as for the intelligent monitoring system itself is vital.

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