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Impact of Track Brakes on Magnetic Signatures for Localization of Trains

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Abstract

In this paper we analyse the effect of activated magnetic track brakes on the ferromagnetic environment and the so-called magnetic signatures, which are location dependent variations of the earth magnetic field along railway tracks. Such magnetic signatures can be used solely or in combination with other track features for train localization. For this application it is of fundamental importance to understand the permanent and volatile influencing factors that may change the magnetic track signatures. As implied by the name, magnetic track brakes might have such an influence. Therefore, we evaluate the characteristics and persistency of this influence based on a worldwide unique measurement campaign.

Keywords: railway, track brake, localization, onboard, magnetic, signatures.

1 Introduction

Shift of traffic from road to rail is a clear social and geopolitical goal in order to help reducing greenhouse gas emissions. However, the increased demand for railway transport has already led to capacity problems on many main lines. In most cases the options for building new tracks in crowded areas with high demand on land are very limited and extremely costly. Hence, efforts are taken to increase the efficiency of the existing infrastructure: Letting trains run at higher speeds and smaller headways, in conjunction with precisely managed maneuvers and coordinated acceleration and deceleration control, can significantly enhance the transport capacity on the existing infrastructure. This huge potential can be exploited by more digitalized and automated train operations that implement low latency exchange of positioning information among trains. Prospectively, this will enable virtual coupling of train sets [1], similar to platooning of road vehicles.

A key technological enabler for this enhancement is safe and robust self-localization of trains. The localization must be available in all the different railway environments and must provide a high accuracy and reliability. A single sensor may not achieve the required high safety and integrity levels, but a suitable combination of different sensor types can largely improve availability and as errors are mostly independent for different measurement principles, such a combination also allows identifying positioning errors of single sensors. GNSS for example will not be available in tunnels. On the other hand, distance measurements from odometry or inertial sensors lead to growing position uncertainty. As an advantageous complement we have developed an alternative localization method based on magnetic field measurements [2], which even works in GNSS-denied areas. Ferromagnetic material along the railway lines like rails, masts, catenaries or reinforcement steel cause position-dependent, mostly time-invariant variations of the earth magnetic field, which can be exploited for positioning. The so-called magnetic signatures allow for absolute location determination in the order of meters [3] and can specifically be used to identify the used track on multitrack lines [4].

Figure 1: Illustration of magnetic signatures along a railway track.

As any other method, magnetic localization is not error free and may be influenced by field disturbances. Signal processing techniques can reduce noise from e.g.

conductor rails, catenaries or onboard power converters and engines as shown in [5]. An open question investigated in this paper is how and to which extent the magnetic signature itself is influenced permanently by activated magnetic track brakes (MTBs) of a train.

2 Methods

For the measurements in the project IMPACT (Intelligent Magnetic Positioning for Avoiding Collisions of Trains) the advanced TrainLab ICE from Deutsche Bahn has been equipped with more than 40 magnetometers at various positions inside and underneath the train. For position reference, data from several GNSS (Global Navigation Satellite System) receivers, IMUs (Inertial Measurement Units) and odometry has been recorded. In addition, laser tachymeters operated at specific trackside locations were tracking the position of several prisms installed on the passing train. In this way, precise trajectories of the moving train with up to centimeter level accuracy could be determined in postprocessing even in tunnel sections where GNSS reception was degraded or not available at all.

Figure 2: Tracking the train's position with a laser tachymeter to obtain a position reference in tunnel sections and other GNSS degraded areas.

Magnetic field data at a sample rate of 100 Hz were recorded on more than 2200 km travelled throughout Germany during the campaign over 8 days. Video cameras in both driver cabinets completed the setup in order to have visual proof for labeling events that may have influenced the measurements, e.g. passing trains. Different environments like urban, suburban, and rural, and electrified and non-electrified single and multi-track lines, as well as various acceleration, braking, driving and track change maneuvers at different speeds were covered. Several maneuvers on the tracks between Berlin-Wannsee and Berlin-Tempelhof, on the highspeed section from Göttingen to Kassel, and on the regional Bavarian line between Dasing and Radersdorf were repeatedly performed to investigate the possible influence of activated MTBs of the ICE on the magnetic signatures. Within a series of four runs in the same direction on the same track with a separation time of at least one hour each, all the MTBs of the train were activated during the second run. It was completely open, whether their activation would be visible in the measurements at all, or if the signatures would be different after activation for a short time or even permanently.

Figure 3: Measurement setup with sensor X1 of type Xsens MTi-610 on the floor inside the train on the centerline, and magnetic track brake positions (purple). Background source: Deutsche Bahn AG

The MTBs on the ICE consist of pole shoes with coils and a suspension. When current through the coils is activated, a magnetic clamping force pulls the pole shoes against the rail head and generates friction which is not limited by wheel-rail contact and is therefore advantageous in slippery conditions. Since MTBs usually act unregulated and at their maximum brake force, they are primarily used as safety and emergency brakes. To avoid excessive jerk, they are automatically deactivated during the final braking phase well before standstill.

Figure 4: Lowered MTB at standstill.

3 Results

In the following analysis we focus on a rural section of the high-speed line between Göttingen and Kassel, where the magnetic signatures are less pronounced than at sites with buildings and construction next to the railway line, hence possible effects of the MTBs can be seen more easily. The raw field measurements in driving direction x of the floor mounted sensor X1 inside the train are plotted in Figure 5 for the four consecutive runs. Typically, the field variations in such rural environments are in the order of a few percent of the earth magnetic field's magnitude, but can reach more than 50% near constructions and buildings, e.g. as observed at the bridge over a freeway at 7.9 km into the track between Jühnde and Göttingen. Figure 5 also shows, that passing trains are observable in the measurement signal. For example, a cargo train passed during the first run between kilometer 3.6-4.2.

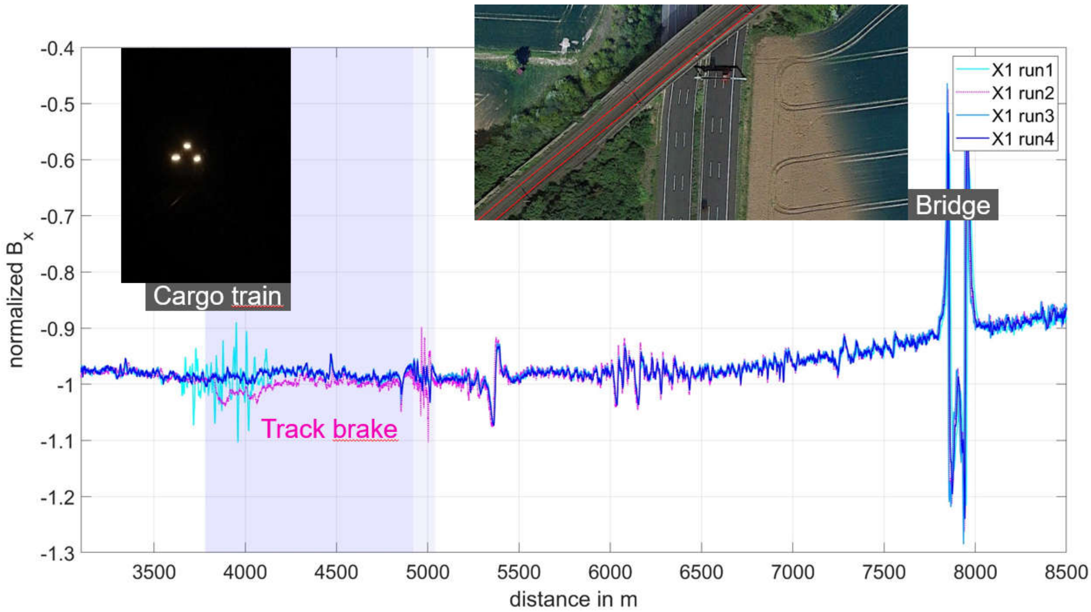

Figure 5: Comparison of magnetic field measurements of sensor X1 recorded during four consecutive runs. The MTBs were activated during the second run (pink).

In the second run, the MTBs were activated at almost 200 km/h near kilometer 3.8. It can be seen clearly that the activation caused the signal to deviate from other runs already during the run, and some strong variations occurred at the final braking phase (light grey zone). The detailed view in Figure 6 reveals that in particular these strong variations leave traces: Comparing the first run with the ones after braking (no MTBs activated during run one, three and four), the signatures have significantly changed within the light grey zone, whereas the change of the signatures in the dark grey zone is in the same order as noise.

When interpreting the behavior and results, it also has to be considered that five pairs of MTBs were distributed over three of the four consists of the train as illustrated in Figure 3. The train had a length of 107 meters and the sensor X1 was mounted in the third consist, the one without MTBs. Hence, during the activation run, the sensor signal already shows the impact from three MTB pairs, mounted up to 55 meters ahead of the sensor position, on the rails and does not yet account for the influence of those two MTB pairs mounted in the rear of the train. This explains why the altered signature extends over the track position around kilometer 5.0, which the sensor reached at the end of the braking maneuver where a speed minimum occurred in Figure 6.

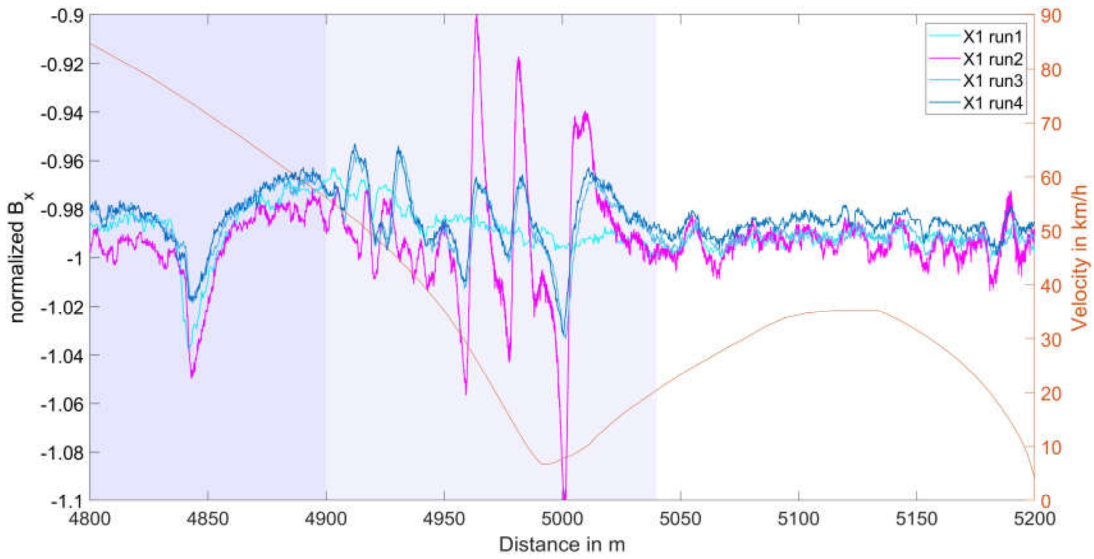

Figure 6: Detail view of Figure 5 with speed profile during the second run.

4 Conclusions and Contributions

Does the MTB have a lasting impact on the magnetic signature? The answer is yes, it can. From the experiment above we see that the most significant change is limited to a short distance span of about the train length. In fact, the three strong peaky variations in the measured signal of the second run seem to correspond to the three MTBs and their spatial separation in the front part of the train. The lasting effect of these peaky variations can be clearly seen in the signatures measured during the following runs. Moreover, the two MTBs at the rear end of the train left similar imprint in the light grey area behind. According to the positions of the signature changes, the main effect started to occur when the speed reached as low as 25 km/h (X1 at kilometer 4.95), which in fact is the typical trigger to deactivate the MTBs.

Whether the observed effects are caused by side-effects of the deactivation itself or the increased exposure time at low speed, or eventually both, is not verifiable without doubt at this point. Nevertheless, it is reasonable that the MTBs cause a change in magnetization of the rails lasting for at least hours, if not longer. That means, a magnetic localization method which compares live measurement with a mapped signature may not only be degraded during braking with MTBs, but may also be permanently affected at some sections. In such a case, a detector method can be used to identify permanent changes and update the map, may the reason be deployment of MTBs or e.g. construction work, which altered the signatures since they have been recorded for the map.

Apart from pure rural sections, the impact of MTBs can be considered rather small in urban or suburban environments, but also in tunnels, as the large magnitude of variation of the signature at the freeway bridge in Fig. 5 indicates. Because the signature is in such cases dominated by reinforced steel constructions and other ferromagnetic material along the line, the changes on the rail have only minor effect as could be seen from an equivalent MTB braking test in a suburban section in Berlin.

For future work, we are planning to investigate how the performance of magnetic localization algorithms may be affected by MTB usage, and consequently in a next step develop techniques to mitigate eventual performance degradations.

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