LÄRM FORSCHUNG EISEN BAHN FAHRBAHNLABOR

Strategic Orientation of the Railway Field Laboratory

Version	Date created	Changes	Author(s)	Released
V0.0	19.08.2021	-	A. Zemp	-
V0.1	01.12.2021	div.	SC	-
V1.0	16.12.2021	div.	SC	SC, 16.12.2021

Table of contents

To make this document easier to read, the masculine form is used to designate individuals and for nouns relating to individuals. In keeping with equal treatment, terms of this sort are generally applicable to all genders. Abbreviated linguistic forms are used purely for editorial reasons and do not imply any value judgements.

1 Background

1.1 Physical processes in the superstructure

Railway noise – in this context, rolling noise – is the result of complex interactions between the vehicle and the track. The roughness of the two contact partners – the running surfaces of the wheel and the rail – result in non-stationary excitation forces which act on the vehicle side as well as the track side. These excitation forces generate a structure-borne sound field in the rail and the wheel. This structure-borne sound field is radiated as audible airborne sound that nearby residents may perceive as noise. The vibrations in the railway superstructure caused by the excitation force may also damage the components of the superstructure, or lead to accelerated ageing. Moreover, there is a risk that the vibrational energy caused could be propagated into the ground and become a source of tremors. On the vehicle side, for example, these non-stationary excitation forces are taken into account by the axle suspension. In the case of the superstructure, elastic elements such as the intermediate pad or sleeper padding serve to diminish the force peaks or reduce the transferred energy.

1.2 Optimisation of the physical processes in the superstructure

Product development attempts to counteract noise radiation, ageing of components and the vibrations caused. This is achieved, for example, by inserting a soft intermediate pad between the rail and the sleeper. The structural-dynamic decoupling of the rail is thus increased, and less energy is transferred into the subjacent components. As the result of this measure, sleepers and ballast experience a reduced dynamic load, which positively impacts their lifetimes. It has nevertheless been proven that this causes more energy to be radiated into the rails as potentially disturbing airborne sound. It is therefore apparent that the optimum in one specific area (lifetime) can lead to problems in another specific area (noise).

Consequently, the ongoing development and optimisation of the railway infrastructure by means of newly developed components requires an approach based on a consideration of the overall superstructure-vehicle system. Equal consideration must be given to the aspects of noise reduction, safety and security, operation, lifecycle costs, and others.

1.3 Physical models

Realistically speaking, holistic optimisation of the railway superstructure is only possible with the use of physics-based models. Empirical tests would involve too much effort and cost.

The Railway Field Laboratory continuously supplies data that is of importance for the physical understanding of the superstructure. Thus, for example, changes in the measurement data are documented in relation to the type of vehicle passing over the track and the ambient meteorological conditions, and over time (ageing effects); these changes can be used as input for the formation of models, and can assist with validating the models.

1.4 Product tests

Because numerical models cannot comprehensively map the real world, a new or optimised component must be trialled in real operation.

Experience shows that critical issues arise when such trials are undertaken, if not before. Only in the rarest cases is the comparability of the data collected during the trial admissible without further processing, because the dynamic behaviour of the overall system depends on factors such as environmental conditions (e.g. temperature, air humidity, etc.), location (e.g. ground conditions) and ageing effects (new versus old intermediate pad), etc. In addition, the design of the experiment (corresponding sensor positions, data acquisition and evaluation, etc.) influences the comparability of the collected data. Many of these factors are not recorded (or are only recorded incompletely) during tests, and are difficult to monitor.

1.5 The Railway Field Laboratory as the solution

Remedies for many of the problems addressed in the foregoing sections are offered by the Railway Field Laboratory operated by the Federal Office for the Environment (FOEN) together with the Swiss Federal Office of Transport (FOT), Swiss Federal Railways (SBB), the Swiss Federal Laboratories for Materials Science and Technology (Empa) and the Allianz Fahrweg ("Swiss Permanent Way Alliance").

In the Railway Field Laboratory – which, to a certain extent, is a reference track in real operation but with meticulous and continuous recording of all influencing parameters – developments can be observed over time, or the influence of environmental conditions on the overall system can be monitored. The effects of modifications to individual components can be investigated and understood because the structural-dynamic baseline is recorded and known. These statistically validated statements are made possible thanks to the permanent basic equipment of the test track, comprising sensor technology, data acquisition and a data management system. As well as guaranteeing the comparability of the trials, this ensures that consideration is given to environmental and ageing influences on the data collected.

2 Key topics

2.1 Development of characteristics along the time axis

A statement about the temporal development of characteristics (e.g. static or dynamic characteristics of components or of the overall system) is based on observations at various points along the time axis. The greatest uncertainty is to be found in the fact that temporally induced effects (e.g. ageing effects) cannot be separated from environmental influences (e.g. influences of temperature or humidity) and location-related differences (e.g. if measurements are not always taken on one and the same cross-section). The Railway Field Laboratory minimises these uncertainties and allows statements about development along the time axis, clearly separated from environmental influences.

One point that should be taken into account here, however, is that the focus must be on rapid developments or major changes of characteristics within a comparatively short time in relation to typical lifecycles of individual system components.

2.2 Reliable findings that take account of environmental conditions

Outside of a laboratory setting, it is very difficult to undertake experimental investigations of components whose characteristics change greatly on account of changing environmental conditions. It is known that the dynamic characteristics of materials such as those used for sleeper paddings exhibit a relevant temperature dependency. In the Railway Field Laboratory, it is possible to record the interactions among components as well as the effects on the overall system under all prevailing environmental conditions.

In addition to the required time series, the prerequisites for this purpose include clear disentanglement of the influences caused by the load spectrum from those caused by the environmental conditions.

2.3 Development of new types of components and optimisation of existing systems

In the future, new types of components will be developed increasingly (and perhaps, at some point, exclusively) with the use of physics-based computer-aided models. Realistically, ongoing developments will be applied incrementally to the existing infrastructure. This implementation of virtual product development and system optimisation in respect of a wide variety of requirements (e.g. safety and security, noise, LCC, etc.) requires validated numerical models which can map the use of the components within the overall system during real operation. The quality of the models is directly dependent on the quality of the validation data. It is almost impossible to generate datasets that are more reliable or more complete than those produced by the Railway Field Laboratory. A critical factor in this regard is that the datasets really are "complete" – which means, for example, that they include detailed knowledge about the interacting partner. Moreover, the data will be available in structured form – the key phrase here is "quality of metadata" – and the data management system will allow efficient retrieval and extraction of the required datasets.

A further element in developing components of new types and in optimising existing systems is what is known as a "digital twin" of the Railway Field Laboratory. A digital twin is a multi-physics, multi-scale and probabilistic virtual representation of a complex component, system or process using physics-based models combined with sensor updates to emulate the lifetime of the corresponding physical twin. The concept of a digital twin, developed in the context of Product Lifecycle Management (PLM), was presented for the first time by Grieves at the University of Michigan in 2003 (Grieves, 2014). The concept comprises three main components:

(1) The physical component/the system/the process,

(2) The virtual component/the system/the process, and

(3) Data that links the physical and virtual domains.

The Railway Field Laboratory makes information available about the physical system (superstructure systems in the Railway Field Laboratory), and the data required to link the physical system to the virtual system. Physics-based model approaches to describe the superstructure systems are also in existence. This makes it obvious that the Railway Field Laboratory should target and support the development of a digital twin for the superstructure systems, in order to acquire knowledge about lifecycle costs in particular.

2.4 Reliable and timely results from component tests

Component tests (such as the trialling of a new intermediate pad) in real operation sometimes have the character of random sampling, or an experiment is specifically planned, set up and operated for a certain period at considerable effort and expense. In the Railway Field Laboratory, the condition of the superstructure system is known in detail, as a function of the environmental conditions during interactions with vehicles of various types. Within a relatively short timeframe, therefore, statements can be made regarding the effectiveness of new components in terms of track dynamics, ballast load and noise, etc.

However, component tests are by no means restricted to the infrastructure. Since the dynamic behaviour of the track is known, knowledge can also be gained promptly and efficiently in the Railway Field Laboratory about the influence of rolling stock components on the dynamics of the overall system. For example: the Railway Field Laboratory allows targeted investigations of the influence of individual rolling stock components on the resultant airborne and/or structure-borne sound field.

However, it is not the objective or purpose of the Railway Field Laboratory to provide a platform for empirical product developments. On the contrary: targeted trials are intended to enable conclusions to be drawn about functional requirements for individual components, and their effects on the dynamics as single elements of a complex overall system.

3 Benefits

Both operators and authorities, as well as researchers and developers, obtain detailed insights and information regarding the structural-dynamic behaviour of existing superstructure systems in interaction with rolling stock that is currently operating, in relation to environmental conditions and as a function of the condition of the components. Such knowledge leads to a better understanding of this complex system; it allows the continuing development and validation of physics-based models; and, ultimately, it opens the way for incremental optimisation of the overall system thanks to the virtual development of new components (and components of new types), taking account of the varied requirements that the system must meet. And, finally, the functional characteristics can be tested efficiently in a controlled environment during real operation.

The Railway Field Laboratory therefore generates added value in many respects, and provides the basis for associated disciplines such as the creation of a digital twin of the railway infrastructure installed in the Railway Field Laboratory, or the indirect characterisation of the rolling stock based on a solid trackside baseline.

4 Cooperation alliances

It is in the interest of all participants to make the Railway Field Laboratory (and, explicitly, the datasets it collects) usable by means of cooperation alliances. In no way, however, does the mere volume of raw data as such result in added value. To achieve this, relevant and clearly formulated questions are required; these can then be answered on the basis of targeted analysis of the raw data from the Railway Field Laboratory by suitable cooperation partners. The decision as to whether or not to enter into a cooperation alliance is incumbent upon the Steering Committee of the Railway Field Laboratory. Access to the required raw datasets will be granted exclusively within a cooperation project.

Relevant questions will originate, on the one hand, from basic research as well as application-oriented research and development; and, on the other hand, from the operators and the authorities. In principle, all interested individuals or teams who have the necessary knowledge at their disposal are eligible to provide answers to these questions. Scientific and/or technical support for the projects is generally possible.

Detailed information about the conditions for the use of data is provided in the relevant document: "Conditions for the Use of Data (Railway Field Laboratory)".

5 Communication

The Railway Field Laboratory is financed by the public sector. The following principle applies: not only the data acquired as the result of cooperation alliances, but also the knowledge and results developed from such data, shall be made publicly accessible. As an integral element of the projects, the aim is to publish articles in scientific journals and/or specialised periodicals; the results of the projects should be made publicly available to the industry, and should be presented at specialised symposiums and conferences.

Another essential communication channel is the website of the Railway Field Laboratory. The website explains the Railway Field Laboratory and its technical features, provides a platform for publishing information such as project results, and functions as the input portal for project cooperation enquiries which are then considered by the Steering Committee.

6 References

Grieves, M., http://www.apriso.com., *Digital twin: manufacturing excellence through virtual factory replication*, [online], 2014