Real-time track monitoring for sustainable maintenance strategies

The monitoring of train and infrastructure components is a fundamental task for railway operators. Highly specialised devices make it possible to monitor rails as well as vehicle and track components, but they are generally in one fixed location. With the introduction of Distributed Acoustic Sensing (DAS) to the railway industry, Frauscher is creating new possibilities for this particular application. Some of these possibilities have already been tested, while others are still to be developed; they are the subject of this contribution.

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1. MAINTENANCE AND SERVICING JOBS ON THE RAILWAY

Compliance with the prescribed maintenance cycles and the scheduled performance of maintenance jobs form the basis for safe, trouble-free railway operations. To achieve that, it is also necessary to detect and correct any damage that occurs unexpectedly. There could be many different causes. Flat wheels, for instance, cause an increase in the mechanical loads acting on the track. Futhermore, inadequately maintained tracks may lead to massive impacts at neuralgic points, such as rail joints. [1]

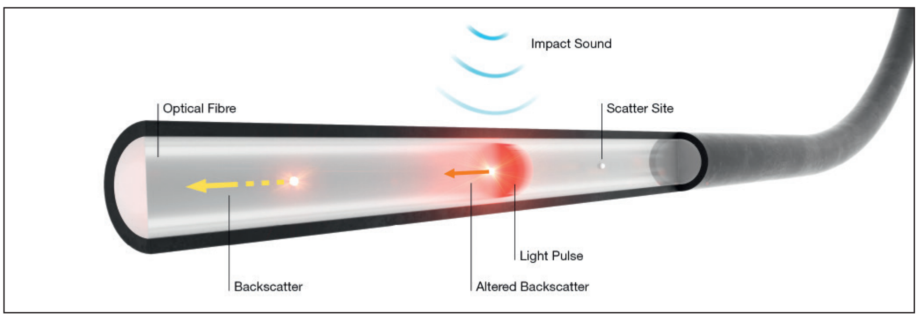
These interrelationships already give us a good idea of how closely the drawing up of servicing plans or maintenance strategies are connected with availability and safety in railway traffic. However, the monitoring systems mentioned at the beginning of this article often give only sporadic insights into the condition of the infrastructure and so they generally do not allow for more than the application of corresponding measures as reactions. With its evaluation of the possibilities of applying Distributed Acoustic Sensing (DAS) in railway operations, Frauscher, in cooperation with various operators, is developing a solution for the continuous, real-time monitoring over long distances of infrastructure components in the track network and on the railway vehicles.

The data acquired using DAS provides support for both the detection of defects that are acute in their occurrence as well as the development of predictive and preventive maintenance strategies. In that way, they are making an essential contribution to reducing costs and optimising utilisation. They do that, firstly, through the possibility of being able to react immediately to damage as it occurs and, secondly, through the precision planning and coordination of the deployment of maintenance vehicles and maintenance activities.

2. USE OF "DAS" IN RAILWAY OPERATIONS

In the course of the past six years, DAS has been subjected to extensive tests in various railway networks around the world. In cooperation with interested infrastructure managers, who have now been thinking seriously about strategies for using this approach throughout their whole networks, Frauscher has taken the findings and developed them further and has integrated this technology in its sensor portfolio. [2]

FIG. 1: Scatter sites and Rayleigh backscatter in an optical fibre cable



2.1. DAS TECHNOLOGY

DAS is based on the principle of recognising changes in the reflection of laser pulses injected into an optical fibre cable. The changes are triggered by sound waves that impact those fibres. DAS does that by making use of a phenomenon known as Rayleigh scattering, which was discovered by the 3. Baron Rayleigh,John William Strutt, when he realised that light waves are scattered by miniscule particles.

This phenomenon occurs in optical fibres when injected laser pulses are scattered by innumerable natural inclusions of atomic size, so-called scatter sites. The opposite end of the optical fibre to the emitter is adapted to absorb the injected laser pulses. It is possible to pinpoint scatter sites precisely on the basis of the reflexion and the elapsed time since the pulse was injected. If structure-borne sound waves or vibrations come into contact with the optical fibre, they have an effect on its physical structure, which, in turn, modifies the backscatter (cf. Fig. 1). It is possible to analyse such changes and to classify them by applying specific algorithms. In that way, an optical fibre cable can be transformed into a sensor that functions like a virtual microphone.

2.2. POSSIBILITIES AND LIMITATIONS IN THE RAILWAY INDUSTRY

Experiments using DAS on the railway have shown that a single DAS unit can cover a distance of up to 40 km of optical fibre. Within that range it is possible to classify various signatures of people on the railway track or moving trains. Whereas people and comparable noise sources can be detected within a radius of 5 m around the optical fibre cable, trains, which produce very much higher acoustic energy, can be detected at a distance of up to approximately 50 m.

The pulse repetition frequency is determined by the length of the optical fibre cable to be monitored, since the backscatter of each emitted pulse must return to the source before the next pulse can be injected. From that, it can be calculated that a section of track 40 km long can have 2500 pulses of laser light injected into it every second.

In the test installations that have been tried out to date, various applications have been set up for applying DAS for the functions of train tracking, infrastructure monitoring and safety/security requirements. The successes included recording trains in real time, recognising flat wheels, broken rails and rock fall and detecting people on the track.

Along with numerous advantages, certain limitations have also been identified and they must be taken into consideration when DAS is used on the railways. One example is that a solution based on this technology is not yet able to determine precisely which track a train is on in a group of parallel tracks. In order to provide that information, it is necessary to have the input from an additional sensor.

2.3. FRAUSCHER TRACKING SOLUTIONS FTS

To achieve that, Frauscher has integrated the fundamental potential of DAS in its existing sensor portfolio and combined it with other solutions that already exist. That has resulted in the Frauscher Tracking Solutions FTS, in which they offer various possibilities of combining the railway-specific DAS system, Frauscher Acoustic Sensing FAS, with tried-and-tested wheel sensors, wheel-detection systems and axle counters. In that way, it is possible to further improve on the quality of the data captured with FTS-FAS. The integration of SIL 4-certifed axle counters makes it possible, moreover, to supply additional information in safety-relevant applications. With a single FAS unit, it is possible to monitor a total of 80 kilometres of track, i. e. 40 km in each direction. With the fundamental possibility of recording all the trains moving on a track, FTS is creating several new approaches to train and operational management against that background.

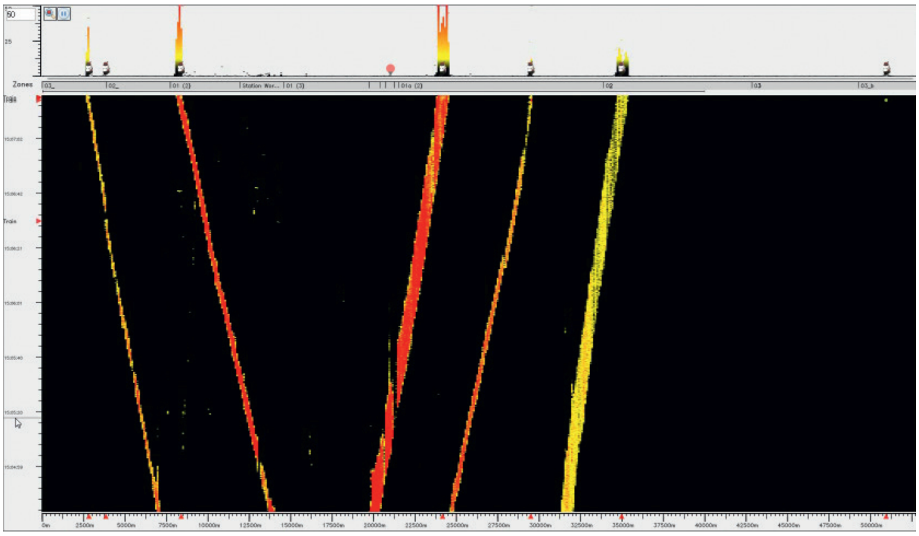


FIG. 2: Waterfall diagram of five trains within a section of 40 kilometres of track

Figure 2 contains an excerpt from a waterfall chart that is output when several trains move along an FTS-monitored section of track. Indications of time can be read off the Y axis, while distances are shown on the X axis. It is easy to recognise the trains detected on the basis of their acoustic energy and also their trajectories. It is possible to read off the length, speed and current position of each individual train.

The algorithm for detecting and classifying people on railway tracks was one of the first to be used when DAS was introduced for the railways. This application, which is already available, can be used as the basis for the accurate positioning of both people trespassing on railway tracks and work crews. It is also possible to detect particular activities, such as digging. Further development is currently going on with infrastructure managers around the world into generating information about single animals or herds of animals on railway tracks.

3. FTS-BASED APPLICATIONS FOR INFRASTRUCTURE MONITORING

The test installations for the applications described above gave rise to further insights into the possibilities that are opening up for the use of FTS for monitoring train and infrastructure components. It is particularly in combination with proven wheel- detection systems, which also make it possible to use it on complex track networks, that various advantages soon became evident.

3.1. RECOGNITION OF BROKEN RAILS

Given the current state of the art, it is track circuits that are the technology most frequently used for detecting broken rails. It is, however a method that is not capable of detecting all damage locations. Furthermore, it can only point to the section in which the rail break has occurred. FTS is an economic means of recognising and locating broken rails under a moving train along a monitored section of track. The positioning accuracy is around 10 m.

The basis for developing the algorithm for classifying broken rails was established over a two-year period in an experimental setup in the TTCI Test Center in Colorado, USA. Figure 3 shows what a broken rail detected by FTS under a 2.4-km-long freight train looks like. Detection and classification of the break is done in real time. Any train moving over the corresponding location afterwards also triggers the classification and the information to go with it. That gives the infrastructure manager the possibility of taking action immediately.

3.2. LOCATING ROCK FALL

In certain regions, rock fall may represent a very considerable threat to railway traffic. Falling lumps of rock produce a considerable amount of energy on impacting the track or landing near it, and that can also be detected using FTS. That gives the infrastructure managers the possibility of warning drivers in good time and of improving the management of train movements considerably to cope with the situation.

One installation for carrying out field tests has already built up an extensive library of acoustic signatures generated by falling »

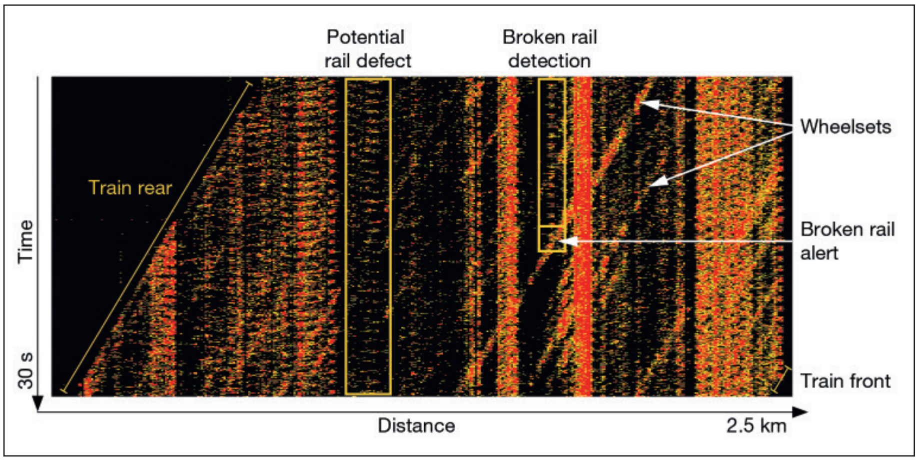


FIG. 3: In addition to broken rails, numerous other acoustic signatures were detected on the test track

rocks (cf. Fig. 4). The analysis of the data collected and its systematic arrangement and input back into the detection system are now making it possible to develop a precise classification and positioning of rock falls. Against this background, fine adjustments are now being made and possibilities examined for recognising the trajectory of rocks rolling down a slope.

3.3. LOCATION OF FLAT WHEELS

Currently, devices for detecting flat spots in wheels are installed in selected locations within the railway network and recognise such flat spots as trains pass over them. If FTS is used, then they are recognised in real time over the entire length of the monitored section, as is illustrated in Fig. 5.

The next step is to examine and further develop possibilities for the precise classification of the detected flat spots. One particular challenge is to recognise the continuous growth in the zone affected on the wheel, given that, as this zone "grows", so too do the negative consequences for the tracks and the components installed on them. Trend analyses can be used to identify sections in which flat wheels occur particularly frequently.

3.4. CATENARY FLASHOVER

Depending on circumstances, short circuits in the catenaries may lead to damage to the contact wire. The ability to locate such occurrences with the greatest possible accuracy may lead to targeted checks on the corresponding infrastructure components and thus possibly repairs to them and, finally, to keeping the railway operational.

A series of tests was performed with one infrastructure manager in order to investigate the use of FTS for detecting short circuits in overhead wires. The results show that most of the short circuits produced artificially in these tests can be successfully identified and that it is also possible to localise them. The next step is going to involve a further check on the results to date in new measurement processes along with a more detailed examination of particular parameters, with a view to defining the possibility for localising the short circuits detected as taking on various forms with greater accuracy. [3]

4. POTENTIAL AND PROSPECTS: INFRASTRUCTURE MONITORING

It has become clear, particularly in the process of researching the possibility for recognising broken rails (as is evident in Fig. 3), that when FTS is used for monitoring, numerous acoustic signals are detected. In focusing on broken rails, the developers initially assumed that when the corresponding signatures occurred these other signals would be caused by events wrongly interpreted as broken rails. However, when teams went and examined such locations more meticulously they found that various forms of damage had indeed occurred in the rails, the rail fastenings or the ballast.

It is true that no specific algorithms exist as of yet for classifying damage of this type. It has, however, been shown that the detection and location of these acoustic phenomena from around the track offers a series of advantageous development possibilities. The challenge now is to identify the cause of each individual signal and to set up a database of acoustic signatures to facilitate the precise identification and location of various forms of damage to the infrastructure.

The first thing to be done here is to distinguish between signals caused by progressive changes in the condition of the sound source (due to attrition, wear and similar causes) and those that can be ascribed to a component defect occurring suddenly.

4.1. MONITORING CHANGES IN ASSET CONDITION

Background noise may be caused, for instance, by switches and crossings, bridges or viaducts as well as air-conditioning plants, pumps and generators activated and deactivated close to the track. Given its high sensitivity, FTS-FAS also picks up acoustic interferences caused by such sources in the vicinity of the optical fibre cable. The precise categorisation of these environmental noises might therefore form a valuable and important basis for highly efficient real-time monitoring systems.

The challenge resides in identifying those acoustic signatures that point to a noise source that is relevant for the infrastructure manager against the general background of noise arising in this way. On that basis, it ought to be possible to rapidly derive a visual representation of the acoustic surroundings of the track over a length of 80 km and to determine at what interval each of the influences occurs:

- → permanent or regular
- → daily, weekly, monthly, annually
- → once, a single, isolated event

All those changes, which are recorded as comparisons with reference values indicat-

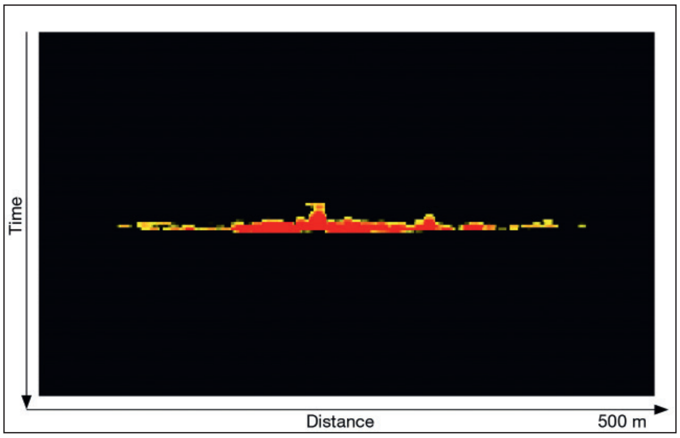


FIG. 4: Acoustic signature of a rock fall

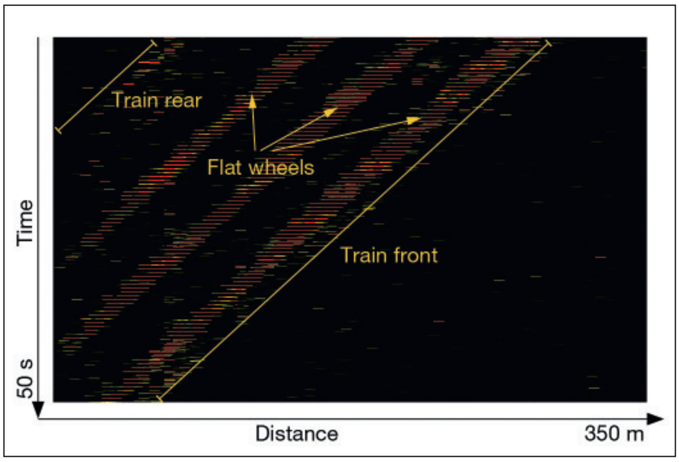


FIG. 5: It is possible to identify flat wheels

FIG. 6: The analysis of changes in rail joints supports the development of sustainable maintenance strategies

ing the optimum condition of the corresponding components, can be presented in an uncluttered form. Focal points and trends that stand out make it possible for the infrastructure manager to coordinate maintenance work better and to maximise the efficiency of the teams deployed. That shows clearly how the recording of environmental noise and the comparison of data sets produced in such a way can further enhance the quality of the information obtained with FTS.

4.2. POTENTIAL FOR PREDICTION AND PREVENTION

In order to maximise the potential in these approaches for monitoring infrastructure components and for bringing them up to a level that facilitates the development of preventive maintenance strategies on the basis of forecasts and trend analyses, railway infrastructure managers and their maintenance teams must work together closely with DAS technology and the data acquired through it. In that way, it is possible to analyse acoustic signatures and their triggers in fine detail. That process is described in the following section taking the example of monitoring the wear on rail joints in a case like the one illustrated in Fig. 6.

The first step involves recording the acoustic signature of a train's wheelset running over a rail joint. The corresponding spot in the track is subsequently classified and photographed by maintenance workers. This signature forms the basis for the following process. As the condition of the rail joint changes, the deviation in the acoustic signature to that previously recorded is analysed. In addition, the maintenance team inspects and documents the affected location in order to secure corresponding information material.

In the course of time, a clear picture is built up of how quickly rail joints show signs of wear, in what form and, importantly, of how this change is reflected in the acoustic signature. The algorithms developed on that basis might be able to contribute to issuing automatically generated alert messages, which would make it easier to achieve better coordination of the corresponding maintenance measures. The aim of this process is to categorise such alert messages depending on the level of wear detected. In that way, it might be possible to set visible marks to show that a rail joint is functioning correctly or to draw attention to the fact that maintenance will be required within a period of time defined beforehand.

This process is also applicable for other sources of noise in and around the track mentioned above. Apart from that, the occurrence of short circuits in overhead wires described in section 3.4, for instance, could be shown in time to allow for a precise analysis of particularly affected sections. It is also worth mentioning:

- → damage to track, such as corrosion or the formation of cracks, fissures and pits
- → damage to track fastenings, such as clips, fastening or connecting plates and also to sleepers
- → weak points in the ballast and track foundation, such as cavities, erosion or compacting, or problems affecting bridges, viaducts and tunnels.

The decisive point, whatever the case, is to record data accurately and to draw up those strategies that can be derived from it for the maintenance activity for which an infrastructure manager is responsible.

4.3. CLASSIFICATION OF ACUTE COMPONENT DEFECTS

This permanent monitoring of all infrastructure components also forms the basis for being able to identify and locate any acute damage that occurs suddenly. That includes, for example, the rock falls described in section 3, which usually occur without any prior warning and represent an acutely aggravated risk for railway traffic. Depending on circumstances, broken rails are not necessarily presaged by weaknesses developing beforehand and may appear suddenly.

In order to be able to issue appropriate alert messages, the system must clearly recognise the corresponding signatures from other acoustic sources. That permits the infrastructure manager to launch measures immediately.

5. PROSPECTS: FURTHER DEVELOPMENT OF THE TECHNOLOGY AND ITS POSSIBILITES

Currently, the Frauscher Tracking Solutions FTS support the implementation of a whole range of applications. In itself, the potential for further development, as regards the accuracy and classification of detected events, gives a good idea of further possibilities to come. In the course of the coming years, Frauscher will be working on the further development of the FTS in close cooperation with various railway operators. Just the different requirements coming from global railway markets are enough for generating a broad range of ideas and inputs for new applications.

In addition, developments in fields such as data management and data communication as well as optical fibre production or laser technology are further expanding the possibilities for using FTS. In the not too distant future, it is thus going to be possible to identify acoustic influences clearly and to locate them with more or less pinpoint accuracy. ◀

References

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