RAILWAY NOISE MONITORING METHODS

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Abstract: Environmental conditions represent the main problem for permanent noise monitoring of a railway line. Influence of wind, rain or snow on the measurement results are difficult to quantify and compensate for. Therefore it is without processing and changes not possible to use monitoring results for a track access charging system which includes the actual pass-by noise measured. Rail and sleeper vibrations can be measured with accelerometers without being strongly affected by atmospheric and environmental conditions. Railway noise research in the past has demonstrated a relationship between rail vibration and rolling noise. Consequently, a method has been developed for the reconstruction of pass-by noise from rail vibrations measured data.

Key words: railway, noise, noise based user fee, vibrations, noise monitoring

1 LEGAL FRAMEWORK

Numerous people are affected by traffic noise; the main reason can be found within an increasing volume of traffic. In October 2004 a study on the subject of “External Costs of Traffic” [1] was published by the Swiss INFRAS institute. It shows an increase of the external costs of traffic (not including congestion costs) of 23% up to 650 bn € in total, whereas 7% of the total costs result from traffic noise; relating to rail traffic, noise costs account 17% of the total external costs. The study relates to EU member states as of 2000 (EU 17) including Switzerland and Norway. Although railways concerning environmental costs perform better than other traffic modes (road and aircraft), there is also a great potential for improvement in rail-borne traffic.

As the first European country Austria enacted a regulation in 1993 that limits noise emission of railway vehicles in the so-called “Schienenfahrzeug-Lärmmessenzulässigkeitsverordnung” (SchLV) [2]. All vehicles which are authorised for Austria later than June 1993 are affected by this regulation. Older ones (authorised before June 1993) and foreign vehicles are not affected. Because of the frequent international exchange of rolling stock, noise abatement cannot be seen as a national but as an international problem and therefore can only be solved by international collaboration.

Being aware of this problem, the European Union (EU) initiated the limitation of noise emission for Trans European Networks within the Technical Specification for Interoperability (TSI) for high-speed trains in 2003 [3] and in December 2005 for conventional rolling stock [4]. Like the SchLV in Austria also the European regulation refers only to new admitted vehicles.

2 TECHNICAL AND ECONOMICAL CONDITIONS OF RAILWAY-NOISE ABATEMENT

Traffic noise arises from two major sources: vehicles and infrastructure. Concerning vehicles, the biggest influence on noise emission results from the wheel. Especially the wheel’s roughness is of great importance. Relating to infrastructure, rail and sleeper are the most important parameters for noise emissions and again roughness of rail is most relevant [5]. In addition to that, velocity is another significant contribution for the level of noise emission.
Under today's circumstances the vehicle/the rail roughness can be considered as the dominant source of noise. The underlying reason is that the major part of freight trains is still equipped with block brakes which roughen the wheel surface with every process of braking. The consequence is a so-called corrugated wheel’s surface that causes vibrations in both rail and wheel. These vibrations are detected as noise emission – the pass-by noise. For all vehicles with block brakes it can be said that the wheel’s roughness is ten times higher than the roughness of the rail. As a consequence noise emission primarily results from the wheel and therefore noise reducing measures also have to be set for wheels. Only when total noise emission has been reduced to a certain low level, measures directed at infrastructure can develop their full positive effect.

Cost-benefit analyses have shown that from the economical point of view noise abatement makes more sense than building noise barriers exclusively, even though they will be necessary in any case for heavily trafficked routes. The combination of active and passive noise prevention shows the same positive effect like building noise barriers of 4m height but at two third of total costs, as the following example taken from the STAIRRS1 project shows: A reduction in a range of 7 dB(A) of the noise emission level of freight trains running at the Austrian railway network in addition with noise barriers of 2m height could protect 90% of all citizens, who are effected currently by a day-evening-night sound level (LDEN) [6] higher than 65 dB(A); that means the LDEN could be reduced down to 65 dB(A) or below. These facts are stated in Fig. 1.

To make noise reduction measures attractive for carrier and rolling stock owner it is necessary to announce benefits. This is possible by a user fee regarding noise emission level in terms of a bonus system: quiet vehicles pay less than louder ones. The benefit that accounts for the infrastructure manager because of lower costs for passive noise prevention measures, can be transferred to carriers and vehicle owners, who have to pay the costs for the fitting of their rolling stock.

3 RECENT RAILWAY NOISE RESEARCH PROJECTS

The research project „Railway Noise Monitoring and Management“ [8], [9] funded by the research program IV2S of the Austrian Federal Ministry of Transport, Innovation and Technology was aimed at surveying methods how to include noise as a taxable component in the railway undertaking’s user fee (IBE, “Infrastruktur-Benützungsentgelt”). The so-called IBE-Lärm (noise based user fee) should be organized as a bonus system instead of a punishment system. Silent vehicles should pay less fee than louder ones. It shall act as an incentive to change the fleet of rolling stock into modern, silent vehicles. In theory the problem seems to be quite simple. When considering the billing system in detail, there arise a number of challenging problems.

In a first step a simple solution was proposed. It was based on classifications due to constructive characteristics of the vehicle or compliance type testing [10], [8]. A track access charging system has to aim at a continuous noise (and/or vibration) monitoring for certain measurement profiles within the rail network. The main question is how to automatically detect vehicles and how to monitor their noise emissions. The monitoring station has to deliver definite and irrefutable results. The research project mentioned above had to work out the scientific basis for further management decisions.

Within the subsequent project „Safety - Instability - Noise“ (SIN) [11] which was also funded by the program IV2S of the Austrian Federal Ministry of Transport, Innovation and Technology, the theoretical basis was applied to a test site. PsiA-Consult GmbH in co-operation with Wölfel Messsysteme Software GmbH & Co developed a measuremet system for the Austrian Federal Railways (ÖBB Infrastruktur Bau AG). With the help of the system, real time noise monitoring as well as an automated consistency check of the Austrian rail traffic information system (ARTIS) is possible. The system’s brand name is acramos „acoustic railway monitoring system“. It is, since July 2006, installed at Track 2, km 14,'5 of the “Northern railway” close to Deutsch Wagram, Austria. It since then furnishes data considering railway caused noise and vibrations.

Based on the functions of acramos it is now possible to perform an automated noise monitoring for trains and a detection of the related train categories. Additionally, vibrations caused by trains can be surveyed. An

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1 STAIRRS – Strategies and Tools to Assess and Implement noise Reducing measures for Railway Systems
automated data analysis based on the measurements takes place. The obtained results contain helpful information for further scientific work on the subject of automated train detection and a noise based user fee.

4 MEASUREMENT SYSTEM

4.1 Configuration

The system consists of 2 redundant measurement profiles. There are 2 outdoor microphones (see Fig. 2), placed in a distance of 7.5 m from the track axis and 1.2 m above the rail head, 2 oscillating circuits detecting the wheelsets as well as accelerometers detecting vertical and horizontal rail vibrations and vertical sleeper vibrations.

![Fig. 2: Measurement devices at acramos test site at Deutsch Wagram, Austria (Source: PsiA-Consult).](image)

The 2 redundant profiles increase the statistical significance of the result. Together with the acoustic parameters also meteorological data is detected. Train detection is realised by detection and pass-by time of the single wheelsets within the measurement profile.

4.2 Data acquisition and management

During a train passage the sound levels at the 7.5 m distance position, rail and sleeper vibrations as well as the wheelset positions are recorded. With the help of the axis’ position of the (defined by the wheelset signal) the emissions (noise and vibrations) can be precisely localized and allocated for every wheelset or bogey position. The measured pattern can be compared to previously defined vehicle patterns which are stored in a database. Therefore a positioning of the single vehicle and the train type can be classified due to its characteristics (freight train, passenger train, locomotive). Currently 29 categories of trains are in use. The wheelset sensors also allow a detection of vehicle direction and velocity.

The implementation of the results of both research projects (SIN; Noise Monitoring and Management) into a noise based user fee demands a reproducible data management on the basis of a scientific concept. The acramos test site is collecting a large amount of data which allows a verification and plausibility check of the results on a statistical basis (see 6).

5 RESULTS FROM NOISE MONITORING

The mean values obtained for pass by noise can also be used to detect acoustic outliers. If the measured value of a train exceeds a certain limit for its category, the value is stored and an alarm signal can be sent to the control station. The bandwidth and the limit for each category has to be priorly defined. Fig. 4 shows an example for such outliers: Three axles exceed the limit of the category for the respective class.

![Fig. 4: Automatic detection of outliers (Source: PsiA-Consult).](image)
As Fig. 5 shows, also the exact detection of an axis exceeding the limit is possible. For a more detailed survey third octave band analyses can be performed and appropriate measures can be set.

With the available amount of data the good correlation of measured vibrations and measured sound levels can be shown. Fig. 6 shows results from the acramos test site. Both linear regression lines, one for horizontal and one for vertical rail vibrations are parallel, vertical rail vibrations are 5dB (re1m/s²) higher than the horizontal ones. Scattering of $R^2 = 0.4$ (vertical vibrations) und $R^2 = 0.46$ (horizontal vibrations) is similar. With both equations it is possible to calculate the sound level for this train category from the measured vibration independent of meteorologic conditions.

Fig. 6 is a first obvious validation of the method presented in chapter 6.

By applying the sensors to rail and sleeper, it is possible to acquire vertical and horizontal rail vibrations ($V_{rv} = \text{Vibration Rail Vertical}$, $V_{rh} = \text{Vibration Rail Horizontal}$) as well as vertical sleeper vibrations ($V_{sv} = \text{Vibration Sleeper Vertical}$). With the help of an oscillating circuit, which is attached at the inner side of the rail, a few millimetres below the moving wheel flange, the wheel is detected. The circuit acts as a trigger. Due to the electromagnetic field of the moving wheel, a change in the frequency of the resonance circuit occurs. Therefore the wheel can be detected and is recorded as an impulse in the designated recording channel. The position of the wheel can be allocated in the time-signal and the sound levels from microphone or vibration channels can be assigned to a certain wheel (or axis).

**6 RAIL VIBRATION BASED NOISE MONITORING**

The main problem which occurs when performing noise monitoring on a railway track is the environmental influence. Adverse environmental measurement conditions like wind, rain or snow cannot be quantified and compensated easily. During measurement campaigns with microphones, these atmospheric factors have a significant influence on the result. Therefore they have to be measured and recorded continually, which leads to higher investment costs for a noise monitoring station. Still, there is a large amount of uncertainty and reliable measurement methods need to be found. Currently, noise measurements are performed according to TSI and national standards [4], [2].

Measurements of vibrations, performed with accelerometers are lacking of influence from atmospheric conditions. With the help of these accelerometers, accelerations of rail and wheel caused by a passing train are recorded.

Fig. 7: Accelerometers applied to rail and sleeper (Foto: R. Hierzer).
When comparing the accelerometer signals and the microphone signals of single measurements or several measurement campaigns, it can be demonstrated that both signals show a good correlation. The time-signal of a wheel or bogey can be identified by the trigger signal and bogey groups can be grouped together. Afterwards a third-octave-band analysis of both the microphone and the vibration signal is calculated. Every wave band of both signals is compared and the regression coefficients are determined. With the help of these coefficients the sound level originating from the vibrations $L_{vib, A}(f)$ can be compared to the sound levels $L_{p,A}(f)$ measured by the microphones.

$$L_{p,A}(f) = a(f) + b(f) \cdot L_{vib, A}(f)$$ (1)

Afterwards for each bogey group the total sound level is calculated by the means of energetic summation of every wave band [8].

$$L_{p,A,\text{calc}} = 10 \cdot \log \left( \sum_f 10^{\frac{a(f) + b(f) \cdot L_{vib, A}(f)}{10}} \right)$$ (2)

In the end a “synthetic” sound level is obtained for every bogey group of the observed train. The following diagrams show a comparatively good correlation between measured and calculated sound levels for both A-weighting and LIN-weighting.

When comparing the calculated and the measured signals for a bypassing freight train, silent vehicles can be identified clearly.
Comparing calculated and measured sound levels for every bogey group of a passing freight train. Calculated sound levels result from different accelerometers and weightings (Vrv = Vibration Rail Vertical, Vrh = Vibration Rail Horizontal, Vsv = Vibration Sleeper Vertical). A low-noise vehicle with a sound level of 78 dB(A) can be clearly identified from the calculated signal [8].

7 CONCLUSIONS

If we want to charge the railways for actual noise generation of their trains it is essential to obtain a reliable method for noise monitoring even under adverse environmental conditions. In order to be able to generate sound levels from measurements of the rail vibrations, the exact configuration of the railway track with all its components and their acoustic behaviour (e.g. type of rail, type of sleeper, damping parameters,…) at the monitoring site has to be known. All these considerations have to be included in the planning process of a noise monitoring station to be able to obtained serious and reliable results. Today noise monitoring stations can be used not only to watch the environmental impact of rail traffic but as well as to inspect rolling stock and its condition mechanically. Irregularities like wheel flats can be detected easily and automatically and counteractions can be taken. Hence, maintenance money can be saved.

Finally, monitoring data can be used to charge for the environmental effects of railway noise. Correlating rail vibration data and pass-by levels is a possible way towards a reliable monitoring methodology and to compensate environmental measurement conditions for.

8 REFERENCES