VIBROSCAN® - A POWERFUL TOOL FOR ENVIRONMENTAL VIBRATION PROTECTION INVESTIGATIONS

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1. INTRODUCTION

It is well known that railway transport is very advantageous with regard to environmental protection. Reduction of air pollution is a typical example. But railways have their characteristic environmental problems as well. According to an opinion poll in Vienna from 1991 noise immissions (41 %) and vibrations (19 %) are considered to be the most important ones by the urban population.

In planning new transit facilities it is therefore important to take these emissions into consideration. While prediction and abatement of noise are well established techniques, vibrations are more complicated to be handled. Successful vibration abatement requires emission control measures to be taken at the permanent way of a railway line. Consequently vibration forecasts are required before the permanent way of the railway track is built in.

VibroScan is a seismic method specially tailored to produce straight forward predictions of vibrations. It will be discussed which parameters are required to be forecasted and how a Vibroseis® vibrator can be used effectively for their determination.

2. HUMAN VIBRATION PERCEPTION

The human perception of vibration immissions is a twofold one. On one side they are directly observed as vibrations within the frequency range of 1 - 80 Hz. The corresponding frequency perceptivity function is shown in Fig. 1.

![Fig. 1: (left) Frequency dependence of the human perception of vibration velocity immission.](image1)

![Fig. 2: (right) Frequency dependence of the human perception of sound pressure levels: A-weighting function.](image2)
On the other side vibrations of solids are audible as groundborne noise with frequencies from 50 Hz upwards. The audibility of the groundborne noise is much more frequency dependent than the direct vibration perceptivity as the wellknown A-weighting function in Fig. 2 demonstrates. Groundborne noise is especially of interest in shallow tunnel sections in residential areas. As a consequence of these properties of the human vibration perception not only the vibration intensities but also the dominant frequencies for the future railway line vibration have to be predicted.

3. RAILWAY VIBRATION IMMISSIONS

Railway vibration emission intensities depend mainly on the speed of the trains, the smoothness of wheels and rails and installations like switches. The vibration emission spectra are governed by these parameters as well but in addition the geometry of axles and sleepers respectively are important too. Thus the conditions for broad band vibrations are created. Dominant vibration frequencies are typically 20 - 80 Hz at 100 km/h speed and 30 - 120 Hz at 200 km/h.

Which frequencies out of this broad range of stimulation mechanisms are transmitted best to the neighbours depend on the geodynamic transmission properties of the local underground. But also the dynamic properties of the buildings themselves, especially the natural frequencies of the floors are important for the vibration immission levels experienced by the local residents. This comprehensive frequency transfer function has to be known in order to calculate the required insertion loss of the permanent way. In doing so the eigenfrequency of the resilient system has to be determined with the accuracy of 1 Hz.

4. FREQUENCY TRANSFER FUNCTION DETERMINATION

Once a tunnel is built seismic servo hydraulic vibrators represent an ideal tool to determine the frequency transfer function for the entire transmission path from the tunnel bottom to the local residents. Already smaller vibrators deliver vibrations of the same magnitude as a train. The comparison of some parameters proofs this as it is shown in Table 1.

<table>
<thead>
<tr>
<th>parameter</th>
<th>seismic vibrator</th>
<th>train</th>
</tr>
</thead>
<tbody>
<tr>
<td>actuator mass (vibr.) / unsusp. axle mass (train)</td>
<td>1450 kg</td>
<td>950 - 1600 kg</td>
</tr>
<tr>
<td>peak excitation force</td>
<td>30 - 100 kN</td>
<td>69 kN</td>
</tr>
<tr>
<td>load on base plate / load per axle</td>
<td>107 kN</td>
<td>160 - 240 kN</td>
</tr>
<tr>
<td>mean peak ground pressure</td>
<td>4,8 - 8,5 N/cm²</td>
<td>6,2 N/cm²</td>
</tr>
<tr>
<td>frequency band</td>
<td>10 - 120 Hz</td>
<td>20 - 120 Hz</td>
</tr>
<tr>
<td>frequency characteristics</td>
<td>sweep</td>
<td>broad band</td>
</tr>
</tbody>
</table>

As the human vibration perceptivity is proportional to the vibration velocity for the largest part of the frequency spectrum a constant vibration velocity output of the vibrator for the entire frequency range is desirable. This is obtained by tuning the upward sweep from a low start drive to a high end drive. But of course, good seismic coupling adjustments for the sweeps are required primarily, wherefore deviations of ±1 dB from the flat velocity output occur. This is
acceptable as such deviations do not exceed the calibration accuracy anyway. In comparison to other impulse like types of vibration exciters it forms a major advantage that a sweep scans the frequency response consecutively and thus delivers the frequency transfer function directly.

The example in Fig. 3 demonstrates the effects of the transmission properties to the sweep signal from a vibrator position in a shallow tunnel to the ceilings of a residential building. Already at the tunnel bottom next to the vibrator the linear emissions are filtered considerably with a low and a high frequency band dominating. At the foundations of the neighbourhood building the frequency band width of the transmitted vibrations is further reduced considerably.

On the ceiling in the second floor of this building the frequency spectrum is transformed again due to the natural frequencies of the floor construction.

5. OTHER FORECAST PARAMETERS

As the measurements are carried out with calibrated seismometers also the dependence on distance of the vibration intensity can be determined under local conditions as it is shown in the example of Fig. 4.
Finally the groundborne noise can be determined out of the vibration velocity seismograms. For that purpose the power output of sound generated by the structural vibrations is calculated from the frequency spectrum and converted into third band frequency sound pressure levels. By applying the A-weighting function the groundborne noise can be expressed as weighted sound level what Fig. 5 demonstrates.

6. EXAMPLES

The accuracy of VibroScan based immission forecasts can be shown by the results of four projects where the railway line has been put into operation already. This concerns the Sittenberg Tunnel, Tunnel Lambach, the Inn Valley Tunnel and the Traun-Marchtrenk railway link. Both, the vibration and the groundborne noise forecasts were proved true by final railway immission measurements within the ±1 dB level.

Besides that VibroScan is also able to detect immission irregularities. At the Römerberg Tunnel for instance VibroScan tests revealed homogeneous immission conditions along the entire tunnel with exception of a single house where vibration immission were 20% as well as the groundborne noise immission were 7 dB (A) higher. The reason for that was found to be a constructional fault which caused a direct contact between the tunnel walls and the building foundations.

7. CONCLUSIONS

The advantages of VibroScan can be summarized as follows:

- VibroScan generates vibrations of the same magnitude as train emissions consequently having also the same range of perceptivity;
- the sweeps scan the frequency spectrum consecutively thus delivering the frequency transfer function directly;
- the frequency resolution of the harmonic analysis is superior to the third octave resolution which is used in standard acoustics techniques.
- the vibrator design as automotive machinery with 4 wheels steering allows high mobility even under such narrow conditions as in a tunnel under construction.

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