Long Term Monitoring of Mass-Spring-Systems (MSS)

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ABSTRACT

To reduce noise, and in particular vibrations induced by modern high speed trains, reducing the stiffness of the conventional superstructure with an elastic layer is very efficiently. The vibration attenuating capacity of such superstructures, called Mass-Spring-Systems, depend on the natural frequency and the damping ratio. The source of noise and vibration emissions of railway lines mainly is the rough contact area of the wheel-rail system. The roughness causes vibrations which are induced into the superstructure and propagate through the soil to buildings in the neighbourhood. The paper is limited to low-frequency vibrations and ground-borne noise reduction. The goal of the developments is to reduce the stiffness of the conventional superstructure – consisting either of a ballasted track system or of a modern solid roadway – by using additional elastic members. Finally the superstructure consists of a mass – and an elastic layer which behaves like a spring.

1. INTRODUCTION

Due to their high transport capacity and their effective use of energy with lowest damage to the environment railways are one of the most important means of transportation for the future. In spite of the advantages of railways in comparison with other transport systems as for example motor cars the acceptance of new railway lines is very low especially by potential neighbours. One of the most important reasons for that is the fear of irritations from noise and vibrations induced by modern high speed trains. These problems especially occur in densely populated areas as in towns, where railway routes are in tunnels with low overburden and very close to residential buildings. Due to maintenance reasons ballast-less permanent ways become more and more important, especially for such tunnel lines. With regard to load carrying capability and to long-time stability of the track these solid roadways show a lot of advantages. Nevertheless the most important disadvantages of most kinds of permanent ways are the additional increasing noise and vibration emissions caused by using such superstructures.

2. TYPE OF PROBLEM

The source of noise and vibration emissions of railway lines is the rough contact area of the wheel-rail-system. The roughness causes vibrations which are induced into the superstructure and propagate through the soil to buildings in the neighbourhood.
The following report is limited to low frequency vibrations and structure- or ground-borne noise reduction measures. For the further remarks vibrations are defined as perceptible low frequency oscillations between 1 Hz and 80 Hz, whereas structure- or ground-borne noise are mechanical vibrations in a audible frequency range between 16 Hz and 20 kHz. Both kinds of emissions are transmitted through the soil by mechanical wave propagation. The distinction between noise and vibrations is shown in figure 1.

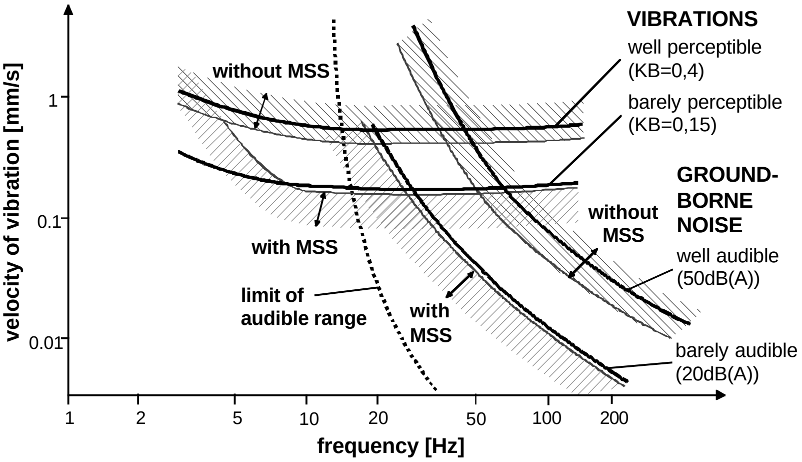

Figure 1. Distinction between noise and vibrations

In accordance to national codes and laws the allowed intensity of noise and vibrations caused by railways is limited to certain values. To reach these limits different kinds of superstructure modifications have been developed within the last 25 years.

3. THEORETIC BACKGROUND

The goal of all these developments is to reduce the stiffness of the conventional superstructure – consisting either of a ballasted track system or of a modern solid roadway – by using additional elastic members. Finally the superstructure consists of a mass – including the rails, the rail carrying system with the sleepers and the ballast bed or an alternative solid roadway – and an elastic layer which behaves like a spring.
The principle of mass-spring-systems is based on the response amplification factor of a dynamic system and can be explained in a very simple way by a linear single-degree-of-freedom system (SDOF-system).
These basic principles of the physics of a dynamic system can be transformed into possible variation parameters for realisation of a vibration mitigating construction, reduced to a SDOF system consisting of a vibrating mass *m*, a spring *k* and a damper *c*. These factors have a strong impact to the insertion loss of the MSS.

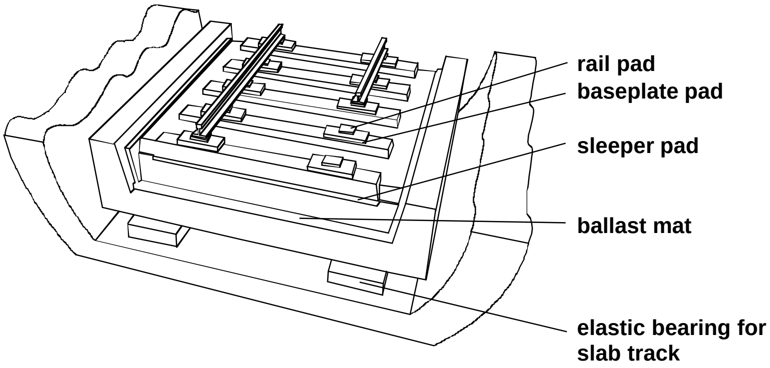

Figure 2. Elasticity in railway superstructures

The insertion loss ΔL_E is defined as the difference of the noise and vibration level induced by trains on conventional ballast bed track systems and on mass-spring-systems. According to the effectiveness of mass-spring-systems (MSS) the following division into three groups is commonly used:

- light-weight MSS with $m \leq 4$ t/m, $f_1 \geq 15$ Hz
- medium-weight MSS with $m \leq 8$ t/m, $f_1 \geq 10$ Hz
- heavy-weight MSS with $m > 8$ t/m, $f_1 < 10$ Hz

These theoretical thoughts can be summarised by the statement “elasticity in modern railway superstructures reduces noise and vibrations”.

4. REAL CONSTRUCTION

To put the shown principle into practice different construction philosophies have been developed during the last 25 years. Depending on where the elastic intermediate layer is situated a more or less heavy sprung mass can be achieved. The possible locations of the elastic elements are in the rail fastening system (rail pads or base plate pads), below the sleepers (sleeper pads), below the ballast bed (sub-ballast mats) or in case of a ballast-less solid roadway below a floating slab track. The last one mentioned are also known as classical Mass-Spring-Systems.

The mass consisting of reinforced concrete with a rail carrying system mounted can be either a chain of short elements connected by hinges or a joint less slab with several hundreds of meters length. In the first case a single-degree-of-freedom (SDOF) model seems to be an appropriate simplification, whereas for the second case – the joint-less system – more detailed investigations on a multi-degree-of-freedom (MDOF) model are necessary.

4.1 Elastic Elements – Bearings

As mentioned before the dynamic behaviour of Mass-Spring-Systems is dominantly influenced by the bearing material. For applications different groups of requirements for the elastic elements have to be defined.

The first group can be summarised under the headline “vibration requirements” – the dynamic characteristics of the bearing material are needed for the design. The most important quantity is the stiffness, the frequency and amplitude of excitation, and the inner damping. Furthermore, changes of the dynamic behaviour of the materials over time should be considered. Additionally, “mechanical requirements” can be defined. Long-time stability of the elastic elements has to be ensured for the relevant applied load combinations. Important for the serviceability of the bearings, are the load carrying capability, the fatigue behaviour, the deformations due to pressure and the long time settlements.

A third group of requirements must be defined to ensure the “integrity of the elastic elements” under site conditions. The material has to be stable not only against water but also against chemicals like diluted alkalis and acids, and against commonly used types of oil and fat. In summary, one can say that the most important parameter which describes the quality of a bearing made of natural or artificial rubber is the quotient between the static k_{stat} and the dynamic stiffness k_{dyn}. The static stiffness is responsible for the deflection of the mass-spring-system under dead and live loads, whereas the dynamic stiffness is the key-parameter for the insertion loss, and therefore responsible for the vibration attenuation.

4.2. Mass

In general the sprung mass consists of all elements laying on the elastic element. For classical Mass-Spring-Systems the sprung mass consists of a reinforced concrete trough or slab, the rail carrying system (sleepers in a ballast bed or any kind of solid roadway) and the rails. Beside for any noise and vibration damping reasons most kinds of rail fastening systems contain an elastic layer (rail pads, base plate pads) which make a defined deflection of the rail possible. Other kinds of solid roadways include sleeper pads which have the same function as elastic rail fasteners. Anyway, for the further reflections concerning classical Mass-Spring-Systems these elasticity will be neglected – the mass is assumed as a rigid element.

At least for medium- and heavy-weight MSS it is necessary to couple the single elements to reach a continuous deflection curve. In some cases for light-weight systems the bending stiffness of the tracks themselves is sufficient to reach a continuous deflection curve. To reduce the initial investment costs and to limit the maintenance expenditure for Mass-Spring-Systems, VCE developed a new type based on a continuous design philosophy which does not need expensive coupling elements any more.

5. INVESTIGATION PROGRAM

The paper should give an overview about the currently applied investigations performed on Mass-Spring-Systems in Austria. Basically deformation measurements, temperature measurements, dynamic response identification and measurement of the ground transmitted vibrations can be distinguished according figure 3. The long term measurements usually have a run time of more than 2 years in order to identify the walking line precisely. The so-called acceptance measurements consists of investigations only once during the whole measurement program.

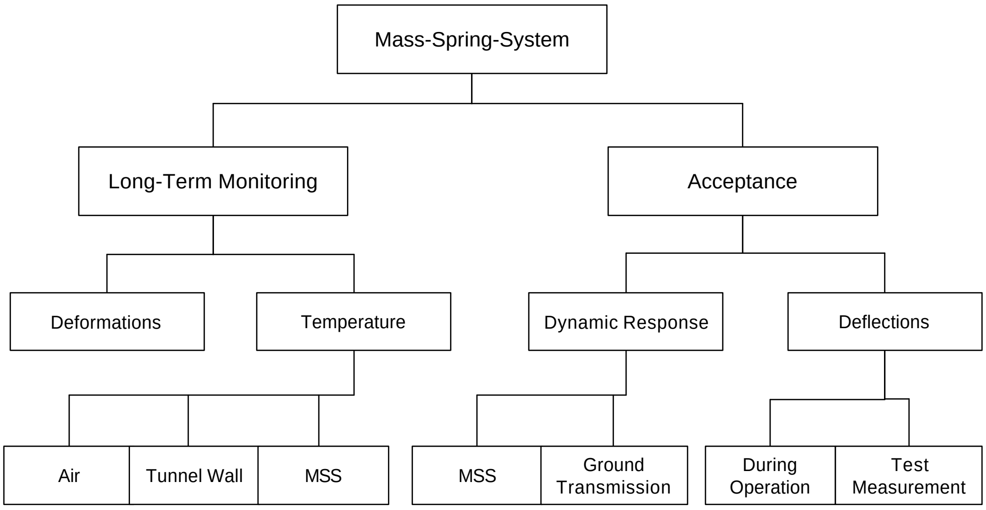

Figure 3. Investigation program for a Mass-Spring-System

5.1 Vertical Deflections of the MSS

This investigation usually is performed before the regular railway traffic starts, therefore a test train is necessary in order to identify and compare the measured to the calculated results. In addition tests are performed during regular traffic in order to obtain maximum deflections under high loads.

5.1.1 Test Measurements

The investigation usually is performed with a well known locomotive passing the MSS with different velocities. An average value is calculated from these tests; the maximum deflection for the static as well as the dynamic test is derived. The maximum deflection value usually is obtained from the static tests (lower bearing stiffness). In addition measurements of the rail supporting elements is performed in order to obtain a total deflection value of the whole system.

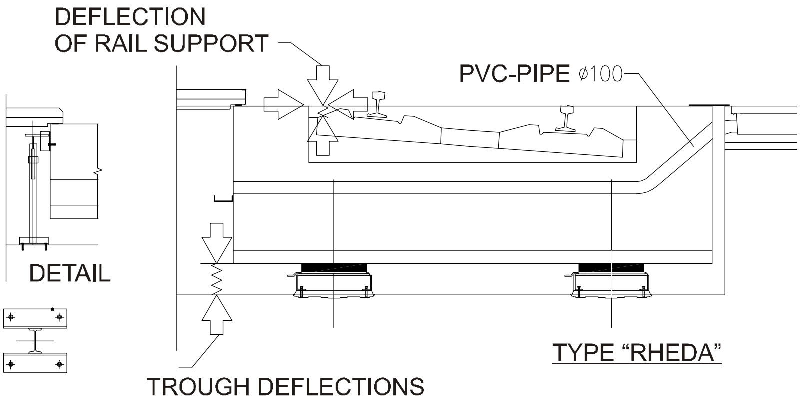

Figure 4. Cross section of a Mass-Spring-System

5.1.2 Investigations during regular traffic

In order to identify the behaviour of the system during regular traffic and to identify maximum displacement values usually a 24-hours measurement is performed. The deflections are compared to the train weight which is read out from the train schedule if possible. In order to make a comparison with the finite element calculation possible, several load cases according to the standards are applied. From the experiences it is well known, that the maximum deflection value usually is obtained during the passage of the locomotive. Generally speaking a passenger train leads to lower deflections than heavy goods trains.

Figure 5. Sensors installed to the MSS – Results of measurement

5.2 Long Time Monitoring

To make a long time monitoring of the longitudinal behaviour possible, displacement sensors are applied to characteristic locations of the MSS. The sensors are installed to critical points, e.g. longitudinal locking as well as the beginning and the end of the system. All data can be accessed easily, bye use of a data logger in combination with a GSM-data transmission unit. In order to identify deviations resulting from creep and shrinkage effects, the monitoring should least for a minimum time of 2 years. Long time temperature measurements which are described in chapter 5.5 are an important input for the assessment of the longitudinal deformations. A comparison between measured and calculated values is highly desired.

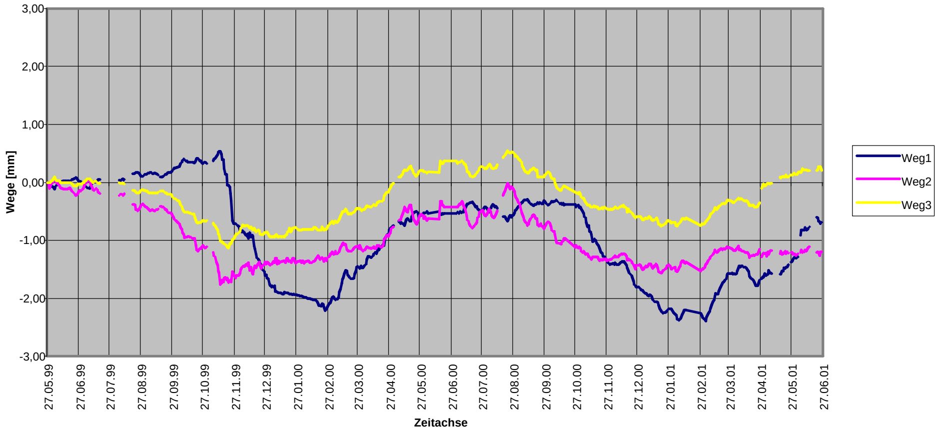

Figure 6. Long time deformation observation

5.3 Dynamic Response of the System

The identification of the dynamic response, which is represented in the modal parameters natural frequency and mode shapes is necessary in order to identify the vibration attenuation of the superstructure. Due to a variation of the modal parameters as well as the concrete mass, the efficiency of the system can be changed. In order to make a comparison to the static design (desired values) possible, a modified finite element simulation (real stiffness values for bearings) is used. During calculation the static values will lead to the lower limit for the natural frequencies, the dynamic stiffness will lead to the upper limit. The measured values then, have to be situated between these to border lines.

5.4 Ground Transmitted Vibrations

By measurement of the ground transmitted vibrations outside the tunnel, the efficiency of the MSS can be assessed easily. A comparison of the measured values is done according the limits shown in the valid national standard. The measurement usually take place in nearby buildings, where the foundation area as well as the top level is investigated. During assessment a differentiation is done for the specific train-type; the ground transmitted vibrations strongly depend on the train weight, train velocity as well as the quality of the wheel surface (roughness).

5.5 Temperature Monitoring

In order to make an accurate determination of the concrete temperature possible, several cross sections of the system are equipped with temperature sensors. Usually the concrete trough, the tunnel wall as well as the air temperature and humidity is measured. The observation of the concrete temperature consists of an assessment during the hydration process as well as acquisition of the long time walking line (> 2 years duration).

Due to several cross sections the temperature behaviour close to the tunnel portal as well as inside the tunnel can be assessed and compared. The long time temperature measurement in combination with the longitudinal deformation is an important factor for assessment according the static design of the system.

Specific equipment is required which should enable long time data acquisition and resist rough environmental conditions during construction of the MSS and during use. This measurements are an important factor to interpret and assess the longitudinal deformations of the system.

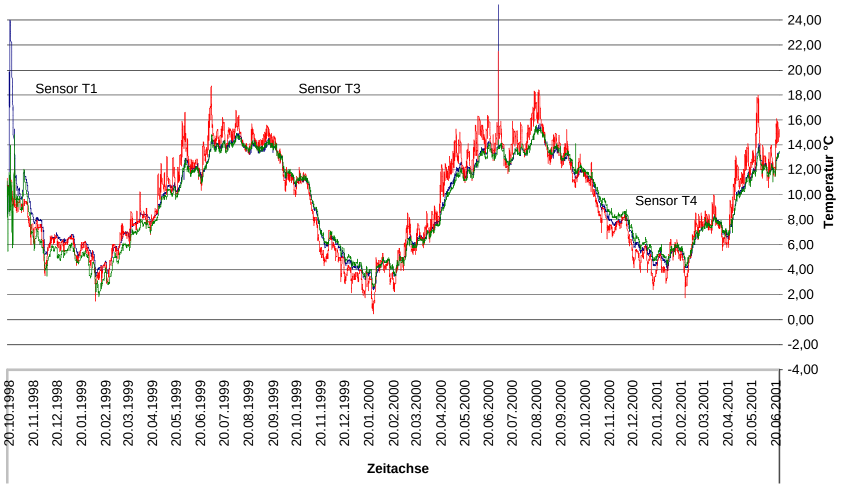

Figure 7 Long-Time Monitoring of the concrete temperature

6. SUMMARY

The investigation program described in this paper is sufficient for long-time monitoring as well as acceptance tests of Mass-Spring-Systems, which are required for the permission of regular traffic.

The importance of noise and vibration reduction motivated the Austrian railway companies ÖBB, HL-AG and BEG to establish a research programme. These research and development works started in 2000 and are going to run over two years. Experts of different sciences – dynamics, railway engineering, tunnelling, bridge engineering, concrete design – work together to develop optimised railway superstructures for the future based on the investigations made until now.

For Mass-Spring-systems further improvements will be achieved with the results of the research project “Consistent Semiactive System Control - CaSCo” supported by EC (FP5) started in spring 2000 under the co-ordination of VCE. The research work obtained during the first two years show very promising results to increase the damping capability and therefore reduce the ground transmitted vibrations of railway lines.

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