Analysis of structure borne noise in a high speed train

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Introduction

SEA (Statistical Energy Analysis) models are used in the railway industry for airborne noise analysis in the passenger area [1]. These models are generally reliable at high frequencies, where transmission of airborne noise from the vehicle exterior is the dominant transmission path. However, at low and mid frequencies (typically up to 1 kHz), the structure borne noise transmission path becomes significant.

A computationally efficient method has been recently proposed, by which the results of a Finite Element Analysis (FEA) can be post-processed to form energy flow models. It based on a modal description of the global structure.

This paper presents an industrial application of these techniques, for the analysis of structure borne transmission in a high speed train. The results of FEA are post-processed to form an Energy Influence Coefficient (EIC) model, which in turns allows to calculate Coupling Loss Factors between structural sub-systems. A methodology to define appropriate SEA structural sub-systems is also presented.

Energy model

Energy Influence Coefficient model (EIC)

The EIC method [2] allows to study the vibratory energy exchanges between coupled subsystems. The method is based on the knowledge of the global modal basis of the structure. For *K* subsystems, the energies $\{E\}$ of subsystems can be related to the input power $\{P_{inj}\}$ by :

$$\{E\} = [A]\,\{P_{inj}\} \tag{1}$$

The EIC matrix $[A]$ relates the energy of subsystem *i* per unit input power to subsystem *j*. It can be measured (using the power injection method) or calculated from a finite element model. This method relies on general assumptions (linearity, uncorrelated forces, …): the restrictive assumptions of SEA are not needed.

SEA model

The global structure is divided into subsystems which are excited by random, stationary and distributed forces. In SEA a power balance equation is written for each subsystem. Assembling these equations on all the sub-systems gives :

$$\frac{1}{\omega}\,\{P_{inj}\} = [L]\,\{E\} \tag{2}$$

where $[L]$ is a matrix of damping loss factors (DLF) and coupling loss factors (CLF). S.E.A. is very attractive because of its simplicity. However, in addition to general assumptions (linearity, uncorrelated forces, …), the SEA relies on very restrictive assumptions (non-dissipative coupling mechanism, weak coupling between sub-systems, "enough" modes in the frequency band of interest, …).

Derivation of energy models from FEA

Calculation procedure

A computationally efficient method [3-4] to post-process the global modal basis is used, in order to derive energy parameters. The procedure is as follows :

- Calculation of the natural frequencies ω_i and mode shapes ϕ_i of the global structure, from FEA.
- Definition of an initial partitioning of the FE model. For each group of elements, calculation of stiffness and mass distribution matrices.
- Definition of the calculation frequencies, and of the modal damping of global modes. Definition of excitation points per group of elements.
- For each force, calculation of the input power and calculation of potential and kinetic energies per group of elements.
- Spatial and frequency averaging of the energies and the input powers. One obtains the Energy Influence Coefficient matrix $[A]$ of the relation (1).
- Provided that the main SEA assumptions are satisfied, the matrix $[L]$ of CLF and DLF is deduced by inversion of the EIC matrix :

$$\omega[L] = [A]^{-1} \tag{3}$$

SEA sub-structuring

To apply SEA, one of the main difficulty consists in finding sub-systems that respect the weak coupling assumption. Furthermore, weak coupling between sub-systems is not well defined. This is a decisive step that often rely on user's expertise.

A decision assistant method in SEA sub-structuring has been recently proposed [5], to define automatically an appropriate portioning of the FE mesh. It is based on a cluster analysis to classify energy transfer function on the structure, and on principal component analysis to reduce data size.

Application to a high speed train

Finite element model and SEA sub-structuring

An existing FE model is used. These models are usually available from crash or vibroacoustic analysis. The modal basis is calculated up to 1 kHz (on a standard PC computer), which is sufficient with regards to the contribution of structure borne noise to internal noise.

A database of energy transfer function is calculated by modal superposition. An automatic partitioning of the FE mesh into sub-systems is then carried out. The figure 1 shows the SEA sub-structuring obtained at 250 Hz.

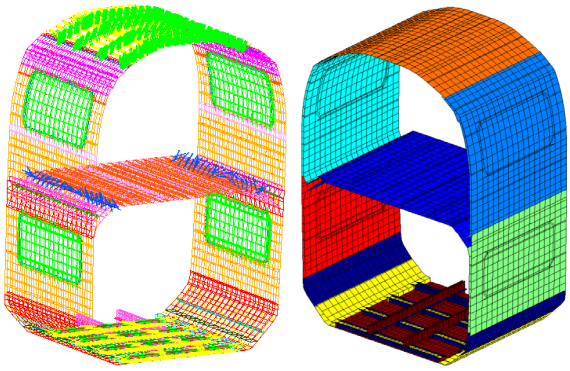

Figure 1: FE mesh (left) and results of automatic partitioning of the FE mesh into 9 SEA sub-systems, at 250 Hz (right)

Injected power

The first quantity that can be exploited for "local" design optimisation is the transfer function P_{inj}/F^2. The figure 2 presents different transfer function, as a function of the input force position (and dynamic stiffness) on the train floor.

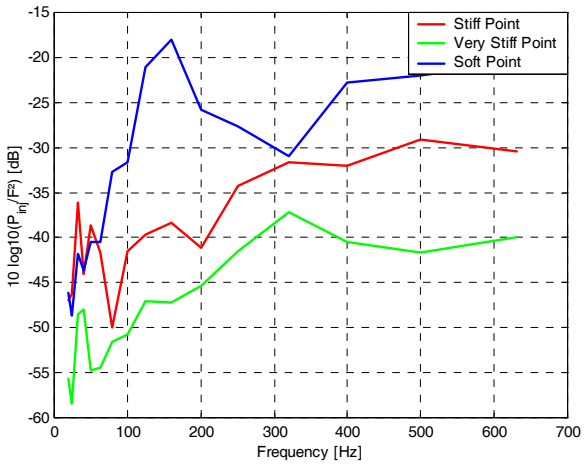

Figure 2: Example of transfer function Pinj/F², for different input point on floor of the train

Sub-system energy

The EIC matrix $[A]$ is then calculated (transfer functions $E_{ij}/P_{inj,i}$). Figure 3 presents the EIC coefficient, calculated for a unit power input on the train floor.

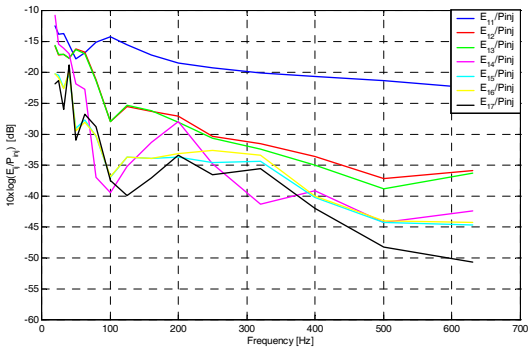

Figure 3: Example of transfer function $E_{ij}/P_{inj,i}$, for an input point on the train floor

Coupling Loss Factors

These CLF can be introduced in a SEA model, and this model can be used to assess the influence of damping of the sub-system on the transmission path.

Conclusion

This work shows the possibility to use existing finite element model to study structure borne transmission in the "medium" frequency range: the methodology allows to cover the 0-1000 Hz frequency range, where the structure borne noise can be significant.

The output of this methodology can be :

- Transfer functions P_{inj}/F^2, which can be used for "local" design optimization close to the input points.
- Transfer functions $E_{ij}/P_{inj,i}$, which describe the transmission paths,
- The definition of an appropriate SEA sub-structuring, and the calculation of the corresponding CLF.

Acknowledgement

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