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Acoustic Postprocessing of Multibody Simulations

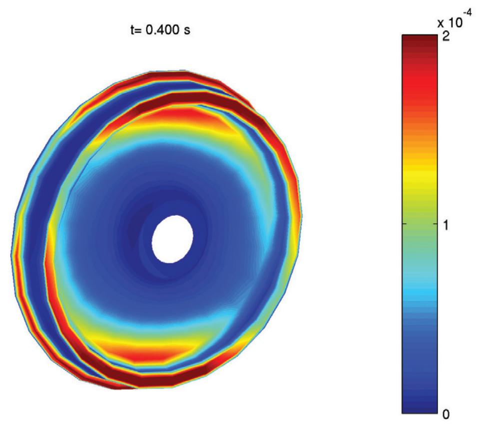

Fig. 1: Exemplary instantaneous distribution of the sound power level over a railway wheel (frame from a time animation)

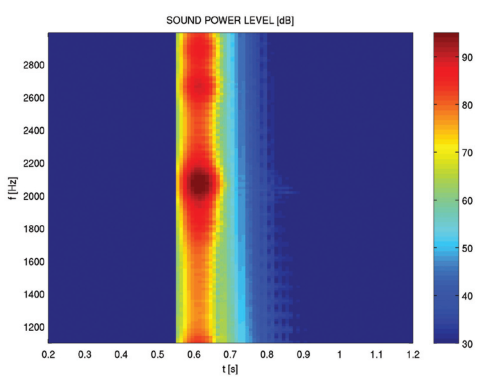

Fig. 2: Time/frequency diagram of the sound power for the switch crossing case. The wheelset hits the rail gap at t = 0.55 s

SIMPACK allows models including flexible bodies to be set up and simulated efficiently in up to very high, relevant acoustic frequency ranges. In this article, a postprocessor module for SIMPACK which computes the sound power of a generic vibrating flexible component (so called structure-borne sound) is presented. The computed quantity is an indicator of the acoustic behaviour of the component and can also be used as an input for subsequent computations of sound radiation and propagation. Two application examples from railway engineering are presented.

THE NOISE PROBLEM

The widespread attention for noise exposure in modern society, accompanied by legislative and normative intervention on different levels, encourages the development of numerical tools for the acoustic analysis of mechanical systems. In this context, the concept of a comprehensive "acoustic management" is becoming extremely important. But, in practice, the *ex post* acoustic improvement of existing systems can be a tough and costly task. It follows that the consideration of acoustic requirements by simulation in the earliest possible stage of the product development is an essential issue.

STATE OF THE ART

Due to the intrinsic complexity of the involved physical phenomena and the different fields which must be considered (sound generation, radiation, propagation), only a few computational methods and tools for acoustic analysis are available. Solely considering structure-borne sound, Finite Elements encompassing approaches based on modal decomposition are typically used. However, these tools are mainly restricted to the frequency domain and to the analysis of steady phenomena. Moreover, the set-up is often strongly simplified and the vibrating body considered as "stand-alone". This means that the boundary conditions and the applied loads are only a rough approximation of the real operative environment.

THE MULTIBODY APPROACH

Once a multibody simulation is performed, the dynamics of the flexible bodies included in the model are known. In particular, the motion of every point on the surface of the bodies can be computed from the time histories of the modal coordinates. On this basis, the sound power on the body's surface (structure-borne sound) can be evaluated with very little additional computational effort and without setting up dedicated acoustic models. Moreover, according to the time dependent approach incorporated in multibody simulation, transient phenomena can be efficiently studied.
In general, the multibody model does not need to be adapted for acoustic analysis: the user only has to ensure that the modal description of the acoustic relevant flexible bodies covers the acoustic frequency range of interest. The simulation itself is also a completely conventional one, with all the advantages of the integrated environment offered by SIMPACK.
The quantity computed by the postprocessor can be interpreted as the intensity of the acoustic source (the vibrating body) and is generally not equivalent to the sound intensity perceived by a virtual receiver. In fact, the *radiated* sound power *cannot* be computed because this would require the knowledge of the radiation efficiency. This parameter can, however, only be determined by a subsequent, computationally expensive analysis of the fluid/structure interface to be done in an appropriate Finite Element or Boundary Element code. Moreover, the propagation of sound from the radiating body to the receiver should be computed, too.
However, the knowledge of the sound power on the surface is sufficient for most engineering applications. This is the case for a *relative* acoustic assessment of mechanical parts with respect to design variations or modified boundary conditions. Additionally, the sound power on the surface directly leads to an estimate of the radiated power if the radiation efficiency can

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be deduced from experience, previous analyses or empiric formulas; this is possible in many engineering cases. Different kinds of analysis and representation of the results are possible. For example, the distribution of sound power over the vibrating body can be studied (Fig. 1), and classical time/frequency diagrams, particularly useful for transient phenomena, can be drawn (Fig. 2).

APPLICATION FIELDS

The acoustic postprocessing can be virtually performed on every vibrating body which is known or suspected to generate noise. The largest amount of possible applications is in the fields of machinery (gearwheels, casings, frames, etc.) but also peculiar problems can be addressed, as in railway engineering (see the examples below). In many cases, the acoustic postprocessing can be seen as an additional exploitation of the results of a high-frequency simulation. But, in other situations, the package "multibody simulation + acoustic postprocessing" can be seen as a proper acoustic analysis tool, especially when other approaches are not satisfactory. Such a situation occurs when unsteady phenomena must be studied or when the mechanical system in which the vibrating body is integrated plays an important role. This is the case for the railway wheelset presented below: the complete vehicle must be taken into account to correctly reproduce the bearing and rail/wheel contact forces acting on the vibrating wheelset.

APPLICATION EXAMPLE: SWITCH CROSSING

The first example deals with a railway vehicle running through a switch. It has been chosen for its extremely transient character, which clearly demonstrates the capabilities of the acoustic postprocessor. In fact, the rail gap in the middle of the switch (called "frog") causes an impact of the wheel rolling over it. The induced vibration of the wheelset eventually generates impulsive noise.
A generic passenger coach model was used, one wheelset having been modelled as flexible with a sufficient number of eigenmodes. S-variable rail profiles were deployed to model the switch on the basis of the standard SIMPACK Rail contact module. Apart from the frog geometry, the rails are perfectly smooth.
The results are plotted as a time/frequency diagram in Fig. 5, highlighting a strong peak around 2100 Hz. The question arises, which modes are mainly responsible for the noise? An analysis of the modal contributions to the sound power is reported in Fig. 3. As the phenomenon is transient, the modal contributions are also a function of time. The diagram clearly shows that the contributions from the modes no. 51/52 dominate the response.

APPLICATION EXAMPLE: RAIL ROUGHNESS

The roughness of rails and wheels and the resulting vibration of the wheelsets is responsible for the notorious *rolling noise*, the most dramatic environmental problem of modern railways. This is particularly true for freight trains, because the wheels are made very rough by the block brakes; on the contrary, passenger coaches, which use disc brakes, have smoother wheels and are quieter. On the basis of real measured rail roughness data (Fig. 4, courtesy of Prof. Hecht, TU Berlin, Fachgebiet Schienenfahrzeuge), the fluctuations in the normal contact force between wheel and rail were computed using PCM (Polygonal Contact Model, also available in SIMPACK as force element) on a simplified vehicle model. These fluctuations were then superimposed to the standard W/R contact forces on a complete railway vehicle model with flexible wheelsets. The run over a short rough rail section preceded and followed by smooth rail sections was simulated (Fig. 5).

CONCLUSIONS

The proposed acoustic postprocessor for SIMPACK is a valuable novel tool for a quick analysis of the acoustic behaviour of vibrating bodies in generic multibody models. Its capabilities have been successfully tested on real, complex application cases from railway engineering.

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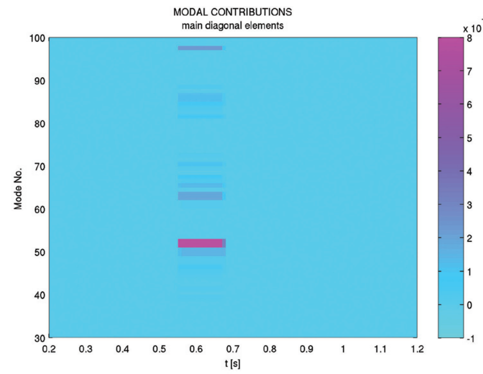

Fig. 3: Time/eigenmode diagram showing the modal contributions to the sound power for the switch crossing case

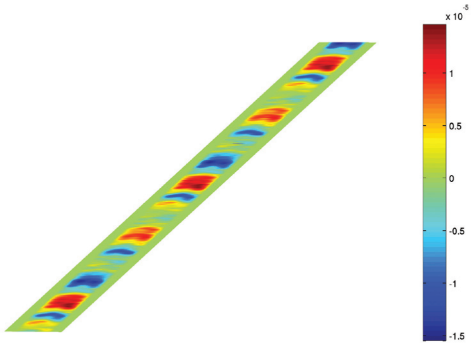

Fig. 4: Rough rail surface (interpolation of measured data) used for the PCM computations

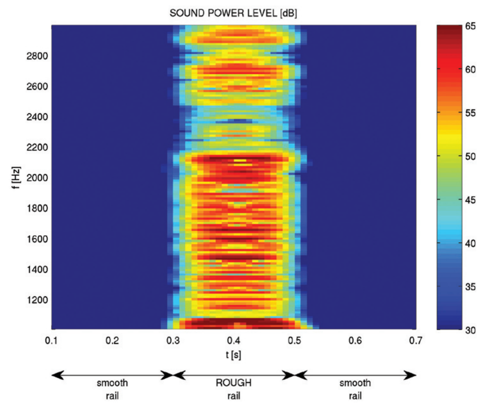

Fig. 5: Time/frequency diagram of the sound power for the rough rail case. For t < 0.3 s and t > 0.5 s the rail is smooth