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Digital Twin for the Condition Monitoring of Railway Bogies Based on Multibody Dynamics Tools

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Abstract

The implementation of a condition-based maintenance policy for railway locomotives requires the development of models and methods to monitor the condition of bogie components using computer simulations, focusing on bogie frame damage and degradation of elements of the suspension system. First, the computational models of the locomotive and wagons are developed and verified, in selected operation conditions, through the comparison of their results against the actual vehicle response, recorded in an experimental measurement campaign. Figure 1 illustrates the model validation idea, in which the model assurance is inspired in the railway vehicle virtual homologation recommendations [1]. In the case of the application the train multibody model, made of a locomotive and two wagons, is operated in a mountainous track for which several experimental campaigns of data acquisitions were carried.

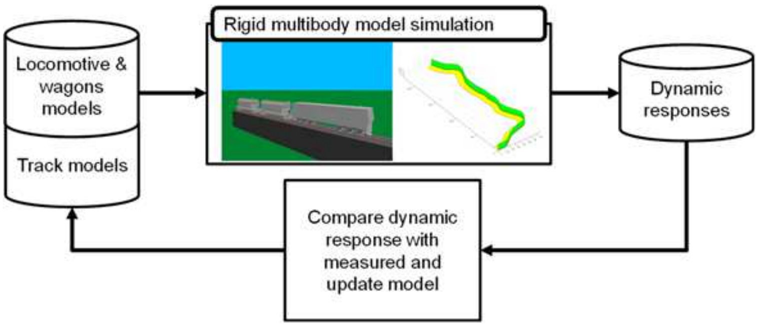

Figure 1: Comparative study of the model behavior against experimentally acquired dynamic responses

The train operator identified different degradation problems with the locomotive bogies, which require continuous monitoring, and periodic interventions. Such issues include bogie frame cracks and degradation of the suspension elements. Consequently, the multibody railway vehicle models are developed taking into account the need to be predictive with respect to these problems, in particular the identification of the bogie cracks from the vehicle dynamic response requires that flexible multibody models are used for the locomotive bogie components [2]. Different models for the suspension elements, i.e., springs and dampers, are also used in different locomotive models to appraise the effects on the dynamic response of different levels of suspension degradation.

The variability of the operating conditions and the parameter uncertainty are considered in the definition of the simulations using experimental design techniques. The use of Design-of-Experiment methods, and in particular of the Latin Hypercube Sampling provide the metric to devise the surrogate models (or meta-model) for each selected dynamic response with a minimal set of computer simulations [3]. These strategies also contribute to solve the problem of the high computational cost associated with simulations of highly non-linear railway dynamics using detailed vehicle models. These meta-models are in fact the digital twins in which for any given input to the system, i.e., mechanical conditions for the locomotive bogie, a dynamic response similar to that of the complex locomotive model is obtained immediately. The meta-model is in fact a surface response obtained via Kriging. The key issue is how to compare healthy dynamic responses, measured in terms of accelerations obtained in particular points of the bogie frame and suspension elements with those for damaged components. It is found that the natural frequencies of the damaged components are not sensitive enough to the level of damage. Instead, the use of the Transmissibility Damage Index (TDI) proposed by Maia et al. [4] shows a good sensitivity to the amount of damage with the extra benefit that it allows locating the defects in the bogie frame geometry.

The final result is the successful development of digital twins for the condition monitoring of the locomotive bogie structural heath and for the suspensions. The flowchart of the digital twins, with the characterization of the inputs and their association to the sensoring system, are described in Figure 2.

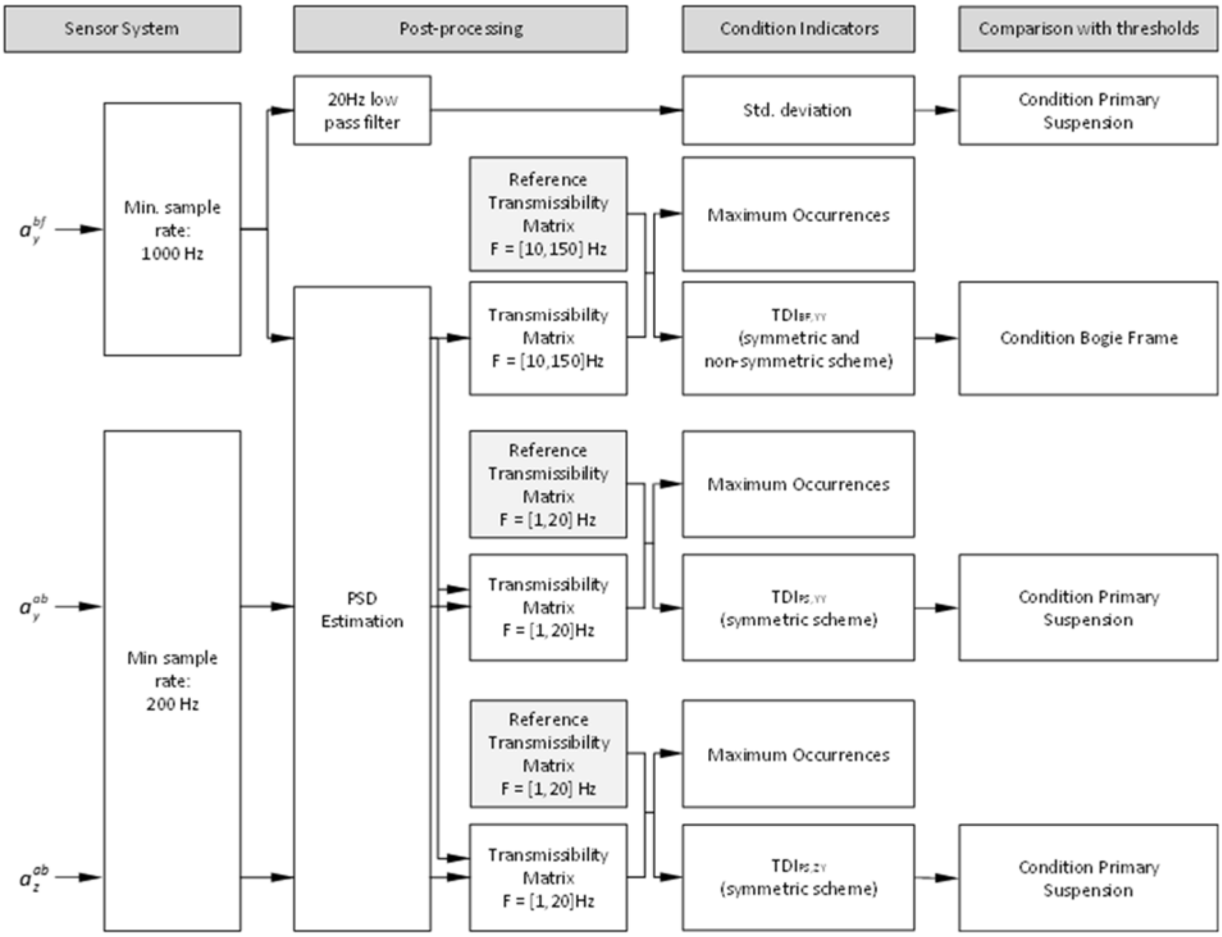

Figure 2: Data flow for the condition monitoring methods

In the process, a methodological framework is presented to allow the use of the developments obtained in other applications for which the identification of physically based digital twins are of importance. The methodologies now proposed and used not only favors the development of new multibody approaches, such as for flexible multibody systems and their industrial application.

References

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