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On the Application of Reliability and Sensitivity Methods on Vehicle Systems under Stochastic Wind Excitation

*** Christian Wetzel[1] and Carsten Proppe[2]**

[1] Institut of Engineering Mechanics
University of Karlsruhe
76128 Karlsruhe, Germany
wetzel@itm.uni-karlsruhe.de
http://www.itm.uni-karlsruhe.de/itm/

[2] Institut of Engineering Mechanics
University of Karlsruhe
76128 Karlsruhe, Germany
proppe@itm.uni-karlsruhe.de
http://www.itm.uni-karlsruhe.de/itm/

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ABSTRACT

Introduction

The modern developments in railway engineering have been showing a trend to faster and more energy efficient trains. These efforts are directly leading to light-weight cars with distributed actuation. Unfortunately these developments are in contrast to a save use in strong crosswind conditions. Especially the first car of the train is highly endangered as it is exposed by the strongest wind forces and moments.

Figure 1: Switzerland January 2007, courtesy of Schweizer Fernsehen - Schweiz Aktuell.

Consequently the crosswind stability is a major topic which has to be considered and which cannot be solved easily as all counter-measures are very expensive.

Probabilistic approach

At present the approval processes are based on worst case scenarios in which the stochastic nature of the uncertainties are not explicitly modeled but are considered by using safety factors, [1]. This approach is an antagonism to the intention to optimize the railway vehicle behavior under strong crosswind. Taking the uncertainties during the computation of the characteristic wind curve into account, Carrarini [2] for the first time, proposed a probabilistic characteristic wind curve.
To determine the probability of failure P_f it is necessary to evaluate the high dimensional integral

$$P_f = \int_{\Omega_f} p_{Z^*}(\underline{z}^*) d\underline{z}^* \tag{1}$$

over the failure domain Ω_f where $\underline{z}^*$ contains all stochastic variables of the system and $p_{Z^*}(\underline{z}^*)$ are the corresponding probability density functions. These computations are done by semi-analytical (e.g. FORM or SORM) and by Monte Carlo simulations (e.g. Importance Sampling or Line Sampling) [3].
In this work the sensitivity analysis is performed to deal with the impact of the stochastic excitation variables on the crosswind stability of the railway vehicle. To separate the unimportant variables from the important ones several local and global sensitivity simulations are undertaken. Gradients at the Most Probable Point are computed and a Latin Hypercube Sampling scheme is performed. In this case also a response surface method and the so-called Morris-Method is tested.

Modelling of the system

The system can be divided into two separate parts: the environmental model and the vehicle model. The environmental model itself consists of two distinct components: the track and the aerodynamic forces and moments.

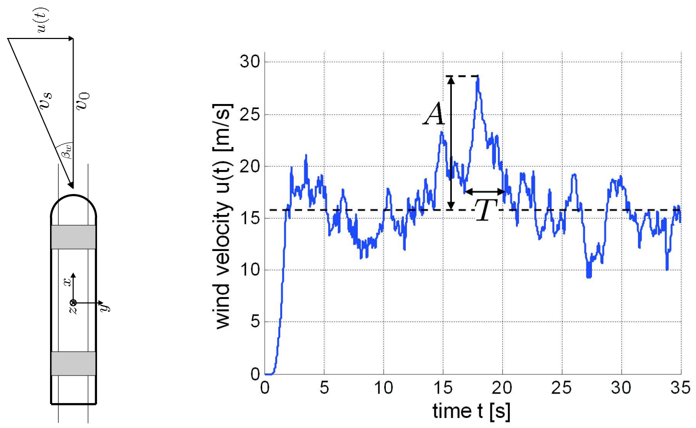

Figure 2: Vehicle model and turbulent wind characteristic with gust amplitude A and gust duration T.

The railway vehicle is simulated in a commercial MBS-Software where stochastic track irregularities can be taken into account. The stochastic crosswind model $u(t)$ consists of a superposition of the mean wind u_0, the turbulent wind $u^*(t)$ and the gust $u_B(t)$.

Summary

A consistent probabilistic approach is presented to quantify the crosswind stability of railway vehicles. Reliability and sensitivity methods are implemented in the MBS dynamics environment to take care of the stochastic behavior of the system as deterministic calculations would not provide complete information about the mentioned problem. The probability of overturning and the sensitivity of the stochastic variables on the crosswind stability are computed.

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