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Identification of energy absorption deformational models of vehicle body

PhD Thesis Booklet

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Introduction, preliminaries

It is well known that with increasing road traffic, the number of accident is increasing too. According to the EU's governing principles, the number of accidents and the seriousness of accidents must be decreased. Consequently the more and more developing active and passive vehicle safety systems get a greater part. The vehicle's active safety mains avoiding road accidents the intelligent vehicle control systems, which can analyze the moving of other participants of road traffic, belong to this field. The passive safety mains if an accident has happened, the participants survive it with injuries as small as possible. The most important parts of passive vehicle safety systems the safety belt, different kind of airbags and the so-called energy absorbing elements, energy absorbing or deformation zones. The latter serve for absorbing the pre-collision kinetic energy of the vehicles, and in this way protect the passenger cabin from more serious consequences of the collision, up to a certain speed limit.

Developing of each of the above mentioned is a very difficult engineering task, and for solving this problem empirical data, mathematical models of the systems and the results of simulations are used ([13]). The empirical data may come from real road accidents, but in this care only few parameters are known, and their exact values are uncertain too. Because of this reason, more appropriate to carry out well-planned at least theoretically repeatable crash tests with known parameters. In these tests lot of parameters of the examined vehicle and the deformational process are registered, and then compare the theoretical model with the measured data ([6]). These crash tests are extremely expensive, only few thousand are carried out annually, and on the other side almost impossible to measure all of the system parameters during the very short time of the collision. For the reasons mentioned, estimations and modeling methods, which concern to certain subsystems or sub processes in vehicle collision, have emphasized importance.

For full-scale modeling of deformational processes in engineering practice, usually a kind of FEM based software used, which is able to handle the rapidly changing forces and the plastic deformation ([10], [12]). Well-known, that for the classical description of the problem we need the exact knowledge of physical parameters for all of the parts of the vehicle, for instance elasticity, stiffness etc. In general this parameter are unknown, but in case of exactly known parameters this problem leads to extremely difficult equations gives the exact

description of the deformational process. The recently applied FEM softwares, which are widely used for modeling elastic/plastic deformation, are based on this kind of approach. The finite element method gives the numerical solution of the system of differential equations, which have mechanical meaning, and yields a method which applicable almost everywhere.
This procedure has very high complexity and assumes the detailed knowledge of the parameters. On the other hand, these kinds of methods, which only deal with a well-defined part of the task (for example distribution of the absorbed energy), could be easy to handle, but of course not give overall description ([20], [26]).

In accident analysis the energy absorbing property of the vehicle structure get stressed attention, and as accurate as possible estimation of the absorbed kinetic energy by vehicle body's plastic deformation ([11]). There are several models for determining the absorbed energy during the deformational process and for approximately describing the appearing force. Make a comparison between these models and FEM based models we could establish that these models give less accurate results, but they have much more advantageous computational complexity, and require less known parameters.

The vehicle's stiffness is a widely used concept in the field of accident analysis and vehicle safety research ([16], [17], [18]). The stiffness value is well-defined for the linear force model, but vehicle deformational processes usually non treatable satisfactorily by linear model ([9], [22], [23]), moreover there are several possibilities for explanation of the 'stiffness' ([19]). In the models approximating the deformational force we can observe that force function, and in connection with this the stiffness becomes more and more complex ([5], [28]).

The measure of deformation caused by vehicle collision is highly correlated to the energy absorbed by the deformational process, which amount of energy is approximately equal to the initial kinetic energy of the vehicle. The role of the energy absorbing zones is to transform the vehicle's kinetic energy to deformational energy, of course according to the passenger safety. Measure of deformation is depend on the collision speed, but this dependence is influenced by several factors (type of collision, structure of the vehicle, location of the engine, etc.), but the energy absorbed during the deformation always includes essential information. Consequently examination of the measure and the distribution of energy absorbed during the deformational process is an important task, and similarly model identification and analysis of their dependence on parameters are essential problems.

In the last few years new methods were developed on the field on control theory for examination of linear parameter varying (LPV) system ([1], [2], [4],[7], [15]), based on high-level results in multilinear algebra ([18]). This gives the possibility of uniform numerical handling of a large class of nonlinear systems. Recently for modeling nonlinear systems widely used the so-called soft computing methods, which are based on fuzzy logic ([25], [29]). One aim of this dissertation is the examination of applicability for modeling vehicle deformation processes of these methods, which are applied with success recently on the field of control theory.

The goal of the dissertation

The object of the dissertation is developing new identification and estimation methods which describe well the whole (elastic and plastic) deformational process of vehicle bodies. The main aim is setting up such kind of models for energy absorption, which give description with acceptable accuracy for practical handling of the deformational process in a fast and efficient way. Further objective is executing examinations to improve modeling possibilities of nonlinear forces which occur during the deformational process. An important consideration was that we deal with the complex system of the whole vehicle as a black box, namely we don't suppose the detailed knowledge of the vehicle and its parameters. Further aim was examination of applicability in a different field of novel methods (which were) developed and applied recently in control theory.

Detailed aims of the research:

- Analyze and compare methods which usually applied for modeling forces during the deformational process with high respect to the stiffness function.
- Deformation of subsystem factures (for instance energy absorbing property) which are required for developing the simple heuristic model of the deformational process. Presentation of the heuristic model for typical road vehicle accidents.
- Description of the deformational process applying a nonlinear model with taking into consideration the dependence of deformation forces on further technical and physical parameters.

- Identification of a linear parameter varying (LPV) force model as a certain generalization of the approximately linear force-deformation dependence.
- Examination of the HOSVD based reduction of the LPV model.
- Presentation of the LPV/HOSVD based identification procedure on real crash test data set.

Summary of the results

I have summarized the main points of the dissertation in the followings.

The discretized vehicle body from the point of view of dynamical modeling can be handed as a multidimensional chain series of subsystems with nonlinear spring and damping characteristics. Behavior of the model examined only with respect to the energy can be described with simple nonlinear functions, and can be explained without detailed investigation of the dynamical system. The following theses are related to this concept.

Thesis 1: I have worked out a new method for examination of energy distributions correlating with deformation which occur vehicle collisions. ([S1], [S2], [S5])

Comments: The method approximates the energy distribution of the vehicle body divided by an orthogonal grid (for cells and directions) with so-called energy absorption functions, which describe the energy absorbing property of a given cell in a certain period of the deformational process. The computational complexity of the cell-model depends on the complexity of the applied absorbing functions. Because of this I have proposed functions as simple as possible which suitable for the character of the process: piecewise linear and for more precise approximation sigmoid-like functions. The suggested novel methods provides a flexible tool for analyzing and planning, and give a chance for the efficient application of the intelligent computational methods.

Thesis 2: For demonstration of this approach I have worked out the cell model of the full and partially overlapping frontal vehicle collisions, which give considerable proportion of the road accidents. ([S4], [S6], [S7], [S10])

Comments: The parameters of the functions which describe behavior of certain cells can be modified independently from each other, and such a way it gives a simple tool for modeling different stiffness relations of certain type of vehicles. The developed method makes possible for an accident analysis the successful and flexible describing of deformational processes which have different physical characteristics. It gives rough estimation, but advantage of this that fast and simple, easy to execute, and with changing the parameters of functions which describe the behavior of certain cells, the character of the whole vehicle can be modified in a simple way. This approach ensures tentative starting results for more comprehensive examinations, which are not worth starting without these kinds of results because of the great number of possible cases and computational complexity.

In the research work I have compared the recently used face models in the field of vehicle deformations process. Each of these models is a generalization of the well-known linear force model, and the more precise approximation property based on the complexity of the stiffness parameter. After analyzing real crash test data I've suggested modeling of deformational force via linear parameter varying method. I've summarized the results related to concept are summarized in the following theses.

Thesis 3: Applying the linear parameter varying (LPV) modeling paradigm for describing the highly nonlinear deformation, I have worked out a new approach for identification of deformation force models. ([S8], [S9])

Comments: Within this approach I have proposed a more complex stiffness concept as an alternative of the stiffness concepts used in the field of accident analysis and analysis of vehicle body's deformation process (which describes the deformational process more exactly).

Thesis 4: As a generalization of the linear force model, I have suggested the application of a LPV type force model, which includes as special cases the usual force models applied in crash analysis. ([S8], [S9])

Comments: I have proved that nonlinear deformational processes of vehicle collisions can be approximated well in case of certain type of vehicle collisions. The model developed suitable for setting up new, simpler force models, and gives chance to reduce the uncertainties for *more sophisticated and precise computational methods which come from the uncertain starting data set.*

Thesis 5: Applying the LPV paradigm and HOSVD methodology I have presented a practical identification procedure using real crash test data.

Comments: This novel modeling possibility makes connection between the intelligent heuristic methods and the so-called exact methods, which deal with analytical nonlinear functions.

Applications

The main field of application of these results is the improvement passive vehicle safety. In case of road accidents, the major part of vehicle's kinetic energy is absorbed by deformation of the vehicle body. Determination of the absorbed energy and its sufficient estimation has a great importance in accident analysis and in the planning of more safety vehicles. Similarly important from the point of view of increase passenger safety the sufficient, but possible simple modeling of the deformational force which approximates the reality as well as possible. The heuristic and LPV/HOSVD based approaches give a staring point for fine and more detailed investigations. The LPV-based description, which usually applied for control purposes, give further possibilities in the future to plan procedures decreasing vehicle crash severity.

Publications

[S1] Harmati, I., Rövid, A., Szeidl, L., Várlaki, P.: Identification and Reconstruction of Car Body Deformation Applying Tensor Product Models. In *Proc. of the 10th International Conference on Intelligent Engineering Systems*, pages 98–101, London, United Kingdom. 2006.

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