Identification of Car Body Deformation Applying Tensor Product Models

István Harmati

Department of Mathematics and Computational Sciences, Széchenyi István University, Győr, Hungary, harmati@sze.hu

András Rövid

Department of Vehicle and Light Weight Structures Analysis, Budapest University of Technology and Economics, Budapest, Hungary, rovid@auto.bme.hu

Dept. of Electrical & Electronics Engineering, Shizuoka University, Hamamatsu, Japan

László Szeidl

Budapest Tech Polytechnical Institution, Budapest, Hungary

Péter Várlaki

Department of Mathematics and Computational Sciences, Széchenyi István University, Győr, Hungary

Department of Vehicle and Light Weight Structures Analysis, Budapest University of Technology and Economics, Budapest, Hungary varlaki@kme.bme.hu

Abstract: Car body deformation modeling plays a very important role in crash accident analyses, as well as in safe car body design. The determination of the energy absorbed by the deformation and the corresponding Energy Equivalent Speed can be of key importance, however their precise determination is a very difficult task. Although, using the results of crash tests, intelligent and soft methods offer an automatic way to model the crash process itself, as well as to determine the absorbed energy, the before-crash speed of the car, etc. In this paper a modeling technique and an intelligent expert system are introduced which together are able to follow the deformation process of car bodies in car crashes and to

analyze the strength of the different parts without any human intervention thus significantly can contribute to the improvement of the modeling, (automatic) design, and safety of car bodies.

Keywords: crash analysis, 3D modeling, EES determination, car body deformation, intelligent systems

1 Introduction

Crash and catastrophe analysis has been a rather seldom discussed field of traditional engineering in the past. In recent time, both the research and theoretical analysis became the part of the everyday planning work [1] [2] [3]. The most interesting point in crash analysis is that even though the crash situations are random probability variables, the deterministic view plays an important role in them. The stochastic view, statistical analysis, and frequency testing all concern past accidents. Crash situations, which occur the most frequently (e.g. the characteristic features of the crash partner, the direction of the impact, the before-crash speed, etc.) are chosen from these statistics and are used as initial parameters of crash tests. These tests are quite expensive, thus only some hundred tests per factory are realized annually, which is not a sufficient amount for accident safety. For the construction of optimal car-body structures, more crash-tests were needed. Therefore, real-life tests are supplemented by computer-based simulations which increases the number of analyzed cases to 1-2 thousands. The computer-based simulations – like the tests – are limited to precisely defined deterministic cases. The statistics are used for the strategy planning of the analysis. The above mentioned example clearly shows that the stochastic view doesn't exclude the deterministic methods [4] [5].

Crash analysis is very helpful for experts of road vehicle accidents, as well, since their work requires simulations and data, which are as close to the reality as possible. By developing the applied methods and algorithms we can make the simulations more precise and so contribute towards the determination of the factors causing the accident.

Through the analysis of traffic accidents we can obtain information concerning the vehicle which can be of help in modifying the structure/parameters to improve its future safety. The energy absorbed by the deformed car body is one of the most important factors effecting the accidents thus it plays a very important role in car crash tests and accident analysis. There is an ever-increasing need for more correct techniques, which need less computational time and can more widely be used. Thus, new modeling and calculating methods are highly welcome in deformation analysis. The method of the finite elements can be usefully used for simulating the

deformation process, but this kind of simulation requires very detailed knowledge about the parameters and energy absorbing properties.

To summarize in general terms how the finite element method works we list main steps of the finite element solution procedure below.

1 Discretize the continuum. The first step is to divide a solution region into finite elements. The finite element mesh is typically generated by a preprocessor program. The description of mesh consists of several arrays main of which are nodal coordinates and element connectivities.

2 Select interpolation functions. Interpolation functions are used to interpolate the field variables over the element. Often, polynomials are selected as interpolation functions. The degree of the polynomial depends on the number of nodes assigned to the element.

3 Find the element properties. The matrix equation for the finite element should be established which relates the nodal values of the unknown function to other parameters. For this task different approaches can be used.

4 Assemble the element equations. To find the global equation system for the whole solution region we must assemble all the element equations. In other words we must combine local element equations for all elements used for discretization. Element connectivities are used for the assembly process. Before solution, boundary conditions (which are not accounted in element equations) should be imposed.

However the method of finite elements yields accurate results the high complexity, computational cost and time can be very height. The main aim of our experiment is to develop such methods, which are able to simulate the deformation process more quickly as the recently used ones. For this purpose rough estimated parameters are used which enable to decrease the complexity and the computational cost.

2 The Basic Idea

The most important thing which we have to know by a detailed analysis of the car body from the point of view of its deformation energy absorbing properties, is the inside structure of the car body. In most of the cases such detailed data about the car-body structure are not available, therefore it is proposed to approximate them from known discrete data.

The introduced method is starting from the so called energy cells. These energy cells are got by discretization of the car-body, to each of which a value for describing its energy absorbing properties is assigned. Other characteristic of these

cells is, that each of them can absorb and pass energy, which depends on the amount of the absorbed energy, e.g. as the stiffness property of a cell is changing during the deformation process proportionately to the absorbed energy. As higher the stiffness of the cells is, as more amount of energy is necessary to achieve the same rate of deformation. The energy passed trough the cell is proportional to its stiffness.

Taking into consideration the mentioned properties of the cell, relations can be defined between them, e.g. lets have two cells, one with higher and one with lower stiffness property. In this case the order of deformation will be the following: the cell with lower stiffness will be deformed in a higher degree as the second one, which has the higher stiffness. For describing the energy passing and absorbing property of a cell in function of the input energy we have chosen a mapping based on the so-called sigmoid function. These functions describe the rate of the absorbed and input energy ($f_a(x)$), and the rate of the passed and the input energy($f_p(x)$). For every cell should be satisfied the following criteria: the sum of the absorbed and the passed energy by the cell is equal to the input. Here the input stands for the energy transmitted to the cell. If the input energy for a certain cell is E_0, then the absorbed energy by this cell is $\int_0^{E_0} f_a(x)dx$, and the passed energy is $\int_0^{E_0} f_p(x)dx$, where the sum of the integrals is equal to the input energy E_0. From this follows the $f_a(x)+f_p(x)=1$ equation. The chosen functions:

$$f_a(x)=\frac{1}{1+e^{k(x-x_0)}}\cdot(1+e^{-kx_0}) \text{ and } f_p(x)=1-f_a(x)$$

The parameter *k* solves for describing the speed of transition between the almost whole absorption and the almost whole passing. The parameter x_0 describes the stiffness of the cell (as greater the value x_0 is as higher the stiffness).

Besides the absorbing and passing properties a new function is needed for describing the volumetric change as the function of the absorbed energy ($V_c(x)$). This could be similar to the absorbing function, because for smaller absorbed energy the volumetric change is almost linear, but in higher energy domain more energy is needed to achieve the same rate of change.

$$V_c(x)=\frac{1}{1+e^{k_v(x-x_v)}}\cdot V_0,$$

where V_0 denotes the volume of the cell before absorbing energy E_a, additionally k_v and x_v must satisfy the following criteria:

$$x_v < \frac{\ln(e^{k_v} - 1)}{k_v}.$$

Then the new volume of the cell is the following:

$$V_{new} = V_0 - \int_0^{E_a} V_c(x)dx.$$

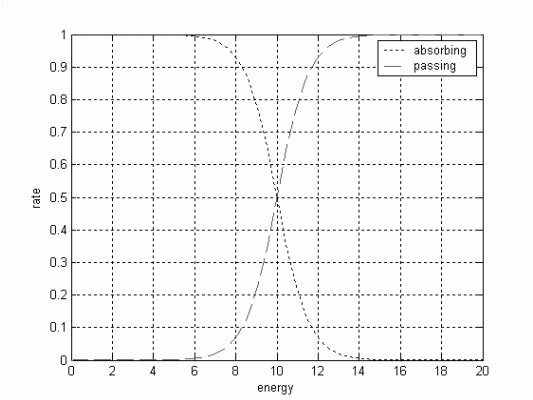

Figure 1
Absorbing and passing functions

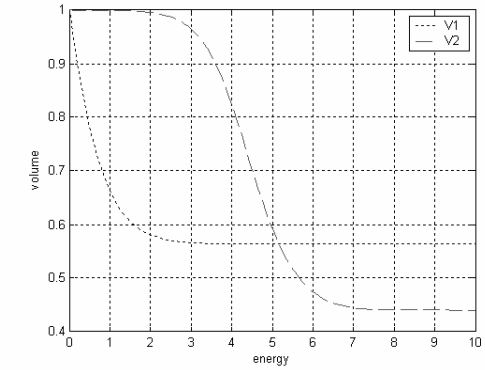

Figure 2
Volumetric change

3 Modeling with Tensors

After discretizing the car body, two functions could be assigned to a certain cell: one for determining the amount of energy could be absorbed from the input energy by the cell, and the other for determining the amount of the passed energy. Besides these, additional functions could be assigned to a cell, because the impact (input energy) from different directions cause different type of deformations. For example a cell is easy to deform in a certain direction, but very difficult in an orthogonal direction. A simple idea choosing three different absorbing functions for a certain cell according to the three different directions used in Cartesian coordinate system, and input energy form an arbitrary directions could be decomposed into orthogonal components.

An arbitrary cell absorbs a certain rate of the input energy, and passes the remains to the neighbours (a cell could have neighbours up to six) in different rates. So these weighted connections between cells could form another tensor. Finally, if one would like to discribe the real deformation process, the Cartesian coordinates of the cells form a tensor, too.

For instance, let have a discretized car-body (or anything else), and a frontal impact as input energy. We can determine the deformation process as follows: in a very simple case, we ignore forces between cells in the same level. We consider the input energy as coming in energy packages (quantums). In the first step (the first energy package) we determine the absorbed and the passed energy in he first level. In the next step (second energy package) we determine the the absorbed and the passed energy in the second level caused by the first step, and the absorbed and the passed energy in the first level caused by the second step, and so on (see Fig. 3).

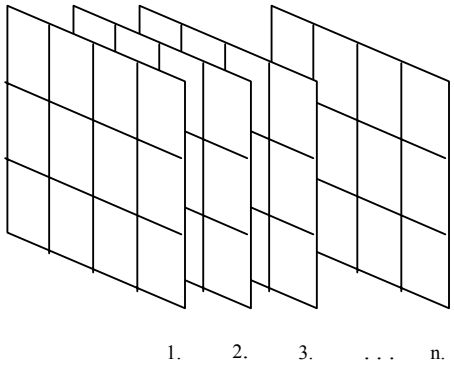

Figure 3
Illustrating the certain “energy” levels

Conclusions

This paper introduces a new concept for simulating the deformation of the car-body energy cells. For describing the energy absorbing and passing properties of the cells of the car-body new functions were introduced. Using these functions the volumetric change of the cells can be also simulated. In our future work we would like to describe the motion of the cells if a deformation occurs.

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