Modelling of energy absorbing devices in railway vehicles with ADAMS

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Introduction

One of the greatest advantages of rail transportation is its ability to have a higher active safety system than other transport systems. Accidents are very seldom, but they can't be absolutely avoided. If accidents of rail vehicles occur, they are subject of huge public interest. Therefore, means of passive safety must be designed to prevent or to reduce the consequences of accidents and to reduce the severity of injuries of occupants in the case of a crash.

The most common philosophy of passive safety — both in Europe and in the USA — originates with the design of a stiff passenger cabin. This reduces the loss of passenger survival space. Later more and more the energy absorption at the ends of the vehicles gained in importance. Using energy absorption devices and defined deformation zones to absorb the kinetic energy in the case of a crash, the consequences of an accident can be reduced. Deformation elements can be either integrated into the supporting structure of the carbody or assembled at the outside of the carbody structure.

The combination of structural stiffness of the passenger compartment, defined deformation zones at the end of the cars, reversible and irreversible energy absorption devices and a safety optimised interior design have influence on the correlation of the deceleration of the vehicle and the occupants. This correlation is an important factor in injury severity.

The deceleration rate which an occupant undergoes depends both on the relative velocity which the occupant has with respect to the vehicle in the moment before he or her hits an interior object and the time between this collision and when his or her relative velocity with respect to the vehicle is zero. This correlation is shown in **Fig 1**.

To reduce the loads on an occupant, it is possible to either reduce his relative velocity with respect to the vehicle by using restraint systems (e.g. 2-point- or 3-point-belts) to achieve a deceleration together with the vehicle as soon as possible or to slow down his deceleration rate after contacting an interior surface by using energy absorbing materials in interior elements (e.g. energy absorbing composite structures which can be integrated within a sandwich panel construction).

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The third possibility to reduce the loads on the occupants of the vehicle in the case of a crash is to reduce the speed of deceleration of the car using energy absorbing devices or deformation zones (as a non-reversible energy absorbing device).

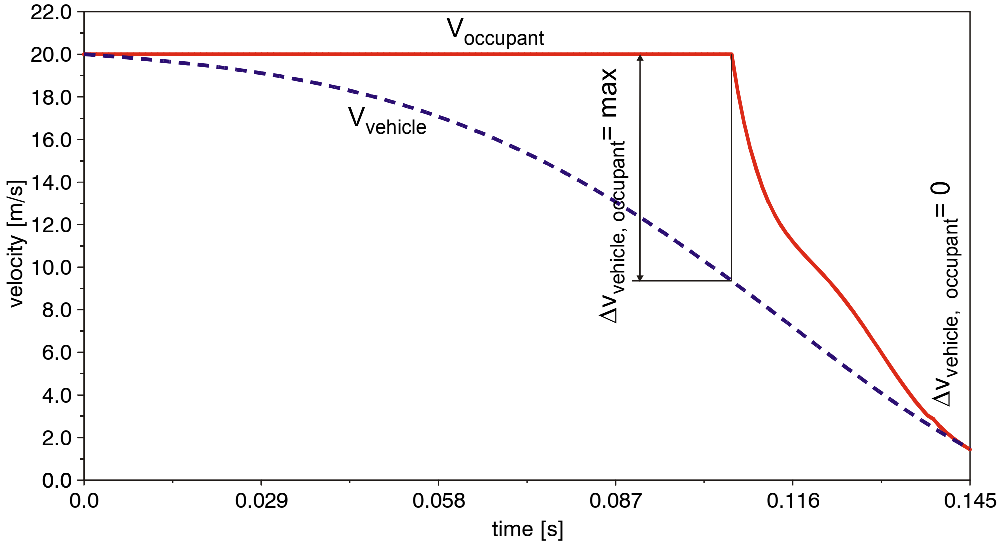


Fig 1. Correlation between deceleration of vehicle and occupant

Types of energy absorbing devices

For an optimal distribution of the absorbed kinetic energy among the train cars, the force-deformation-characteristic of the first deformation elements should be triangular. However, to absorb as much energy as possible, a rectangular force-deformation-characteristic is optimal. This conflict of different goals can be solved by combining both the triangular and rectangular designs within one deformation element.

The most simple deformation elements are springs with linear, degressive or progressive force-deformation-characteristic (e.g. helical springs or rubber springs). Generally these elements have no or only little damping, so that their force-stroke-characteristic has no hysteresis and therefore they are not suited for the absorption of a high amounts of kinetic energy in the case of crash. In rail vehicles they are used to compensate oscillations in longitudinal direction to reduce forces among the rake of wagons.

To absorb the kinetic energy in the case of crash up to a certain velocity reversible and non-reversible devices with a force-stroke-characteristic with remarkable hysteresis are used. Reversible devices are hydraulic and gas-hydraulic buffers or absorbers which use materials with a rubber-elastic characteristic like elastomer. An overview on non-reversible devices with approximate rectangular force-deformation-characteristic is given by **Fig 2**.

To avoid a high initial force peak at the beginning of the deformation so called triggers (defined reduction of area of cross section) are used. A high specific energy absorbing capacity[2], a low load factor[3] and a moderate compression coefficient[4] can be achieved by combination of different materials and devices. Because the demands on the buffers of rail vehicles are many and varied often reversible and non-reversible devices are used in combination to meet the energy management requirements for normal operation and for collisions at low and higher velocity levels.

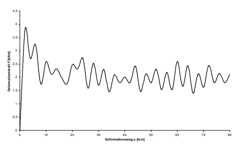
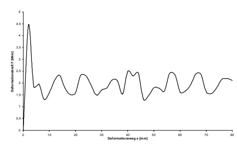
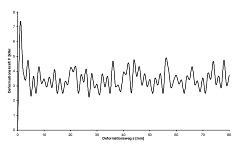
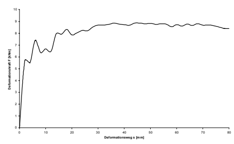
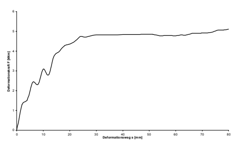
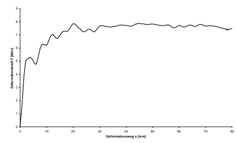
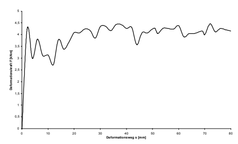
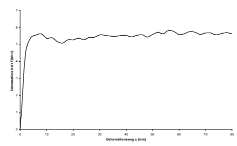
Energy absorbing devices	Force-deformation-characteristics (qualitative)	Energy absorbing devices	Force-deformation-characteristics (qualitative)
Thin-walled compression tube		Box-section (standardised profile)	
Thick-walled compression tube		Honeycombed structure (Aluminium)	
Reverse draw tube / Socket tube		Honeycombed structure (synthetic material)	
Fibre composite tube		Foam (Aluminium)	

Fig 2. Qualitative force-deformation-characteristic of non-reversible energy absorbing devices

Possibilities of simulation

The design of energy absorbing devices must be supported by simulation tools and practical tests (at least with components). These tests can be full-scale tests, tests with components or tests with small scale models. Due to the increasing calculating capacity of computer systems numerical simulations gained in importance during the last years. Nevertheless it is necessary to verify the simulation results by tests, which are mostly expensive.

A comparison between simulation, model tests, component tests and full-scale tests with whole vehicles is given by **Fig 3**.

[2] energy absorption related to mass
[3] ratio of average deformation force to initial force peak
[4] ratio of maximum deformation to original length

Criteria	Simulation	Model tests	Component tests	Full-scale tests
Realism	-	--	+	++
Reproducibility	++	++	+	--
Variations of parameters	++	++	+	--
Reliability of results	--	--	+	++
Costs	↓	↓	—	↑

Fig 3. Comparison and evaluation of simulation and tests

To develop components with a defined force-stroke-characteristic and required ability of energy absorption the Finite-Element-Method (FEM) is used. The simulation results are verified by component tests.

If the force-stroke-characteristic of the energy absorbing devices is known Multi-Body-Systems (MBS) such as ADAMS can be used for an evaluation of the deceleration-time-characteristics of the train cars by using a mathematical model of the energy absorbing elements within a simulation of the train.

Modelling energy absorbing devices in ADAMS

Small-scale crash model for verification of ADAMS simulations

The Section Railway Vehicles is able to verify results of ADAMS simulations with energy absorbing devices by tests with a small-scale crash model (**Fig 4**). Models of different deformation elements can be investigated concerning their force-stroke-characteristics, ability of energy absorption and influences on the deceleration-time-characteristics of the wagons.

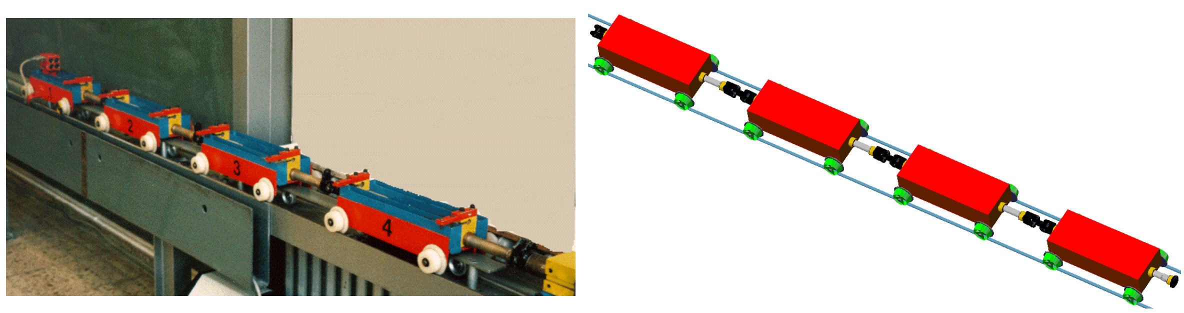


Fig 4. Small-scale model of four wagons with deformation elements (tubes) for comparision between tests and simulation

ADAMS-functions for simple deformation elements

Modelling energy absorbing devices is extremely difficult because of their high-grade non-linear characteristics with remarkable hysteresis and the dependence of force-deformation-characteristics on the deformation velocity.

Some simple deformation elements can be modelled by using standard ADAMS-functions like splines or one- or two-sided impact (**Fig 5**). With these functions the phase of compression can be reproduced with good results. But there are problems with discontinuous stiffness functions, changes between phases of compression and expansion and with the reproducing of hysteresis. These problems can not be solved with the above mentioned functions.

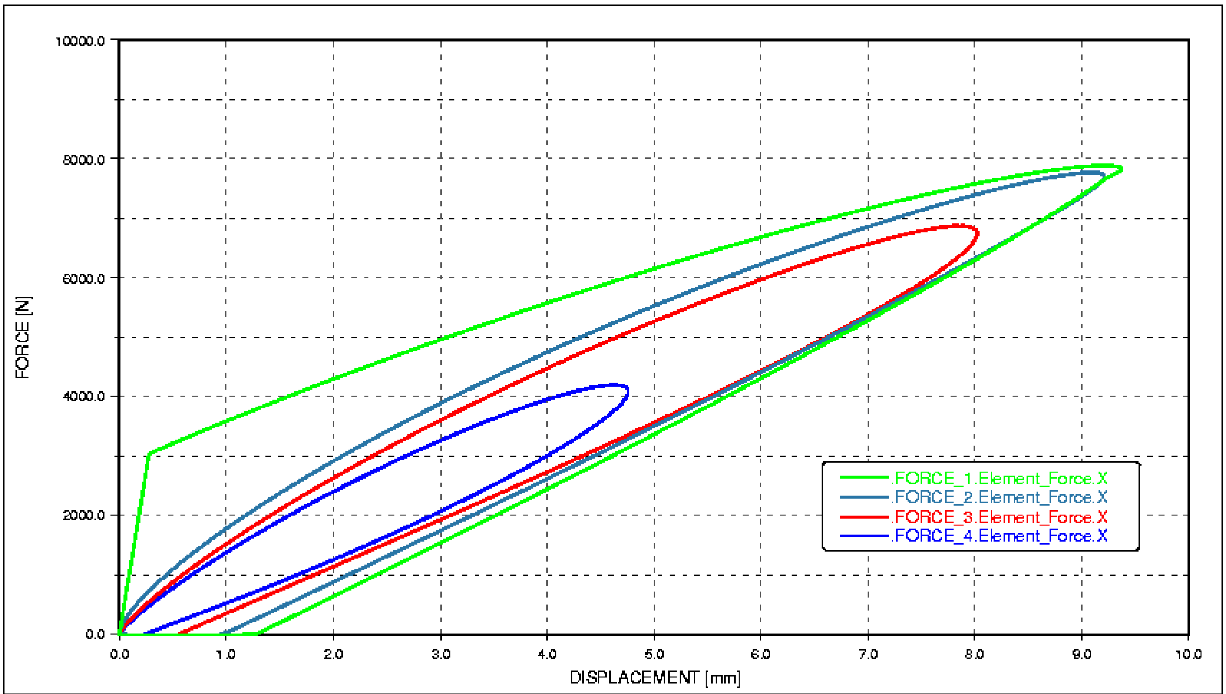
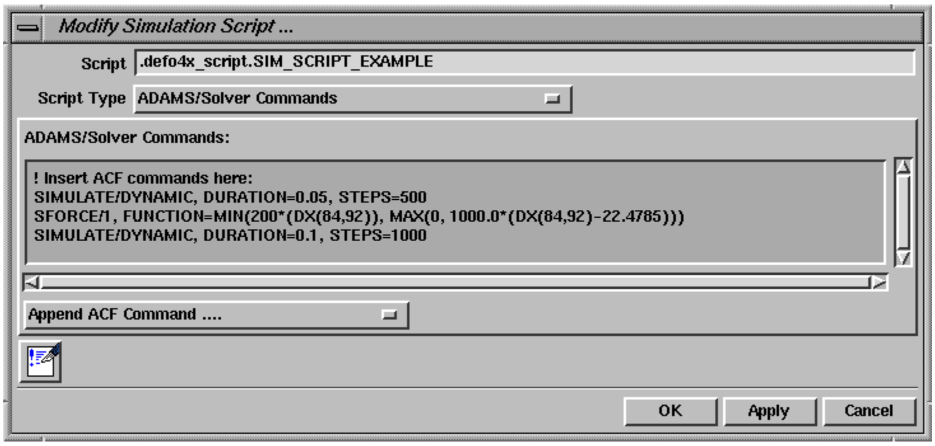


Fig 5. Force-stroke-characteristic of 4 deformation elements (using IMPACT-function)

ADAMS/Solver script

It is possible to use a sensor to stop the simulation at a particular point in time so that one can redefine the parameters of the model of the energy absorbing device according to the force-stroke-characteristic of the real device using an ADAMS/Solver script. An example for such a script is given by Fig 6.

For a model consisting of only a few parts it may be possible to use this method to model the force-stroke-characteristics with hysteresis, but if there are many deformation elements in the model of the train it is obvious, that this is not a satisfactory solution. In those cases — which are the most common in railway crash simulation — the only solution is to use user-written-subroutines.



1. Defining a sensor, which terminates the current simulation when the relative velocity between two parts (e.g. coupler head and wagon) is equal to or less than zero
2. Creating a simulation script with ADAMS/Solver commands to make possible the changing of the settings during the simulation
3. Specifying the type of simulation and defining the run time and the number or size of the output steps by using the SIMULATE command
4. Change the characteristics of the single-component force between coupler head and wagon in the simulation script (change the force definition function expression) by using the SFORCE command
5. Defining the run time and the number or size of the output steps by using the SIMULATE command — ADAMS/Solver continues the simulation script with the new characteristics of the single-component force

Fig 6. Example for changing an existing SFORCE element using ADAMS/Solver script

User-written-subroutines

ADAMS provides the possibility to use so called *user-written-subroutines* for nearly every element in the model. So it is possible to model an energy absorbing device with a single component force and to define this force in dependency of the relative displacement and/or the relative velocity between the two markers at the end of the energy absorbing device.

Within user-written-subroutines it is necessary to define so called external variables to specify the input arguments (e.g. identifier of variable statement, number and values of constants, current simulation time etc.) and output arguments (e.g. variable values returned to ADAMS) as well as so called local variables. The external variables are predefined by ADAMS, but one has the possibility to specify additional input arguments within an array of parameters. The local variables are defined only by the programmer of the subroutine.

The problem using the user-written-subroutines is to remember former simulation steps. ADAMS doesn't provide any possibility to get the values of an "old" simulation step. This is for example a problem modelling a RINGFEDER®, where it is necessary to save the displacement at the point where the direction of the motion changed. This problem can be solved using global variables.

The following three examples (**Fig 7** to **Fig 9**) show different applications of user-written-subroutines in modelling various deformation elements.

Example 1: Compression tube of small-scale models - comparison between tests and simulation

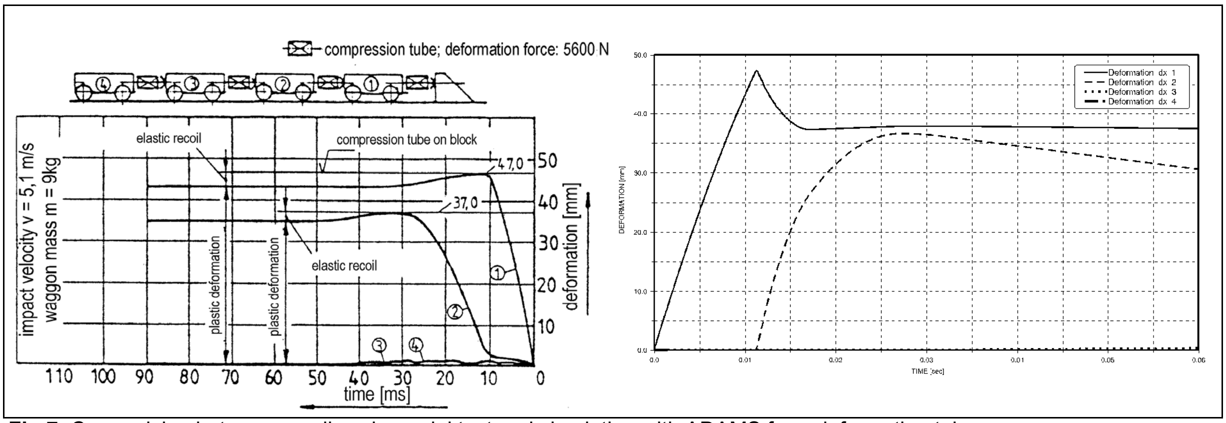


Fig 7. Comparision between small scale model test and simulation with ADAMS for a deformation tube

Example 2: RINGFEDER®

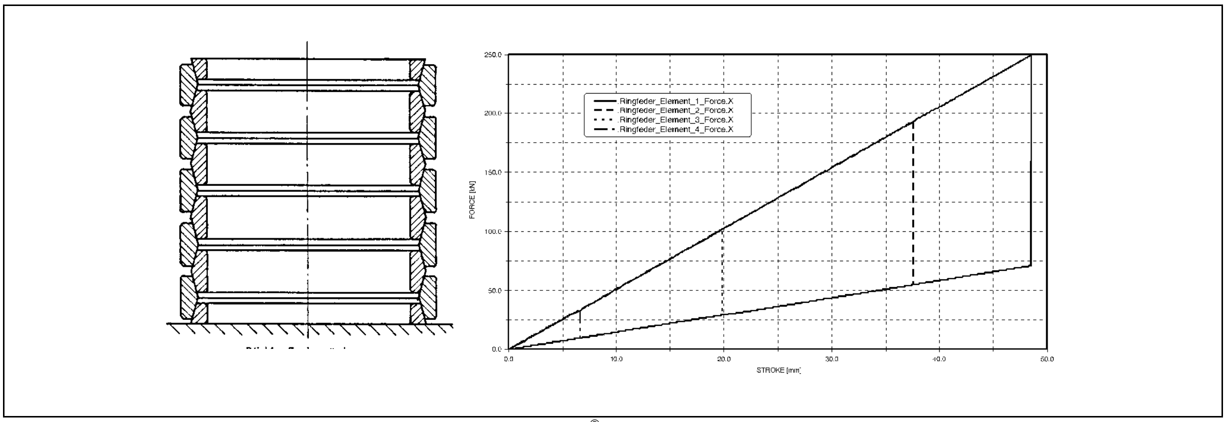


Fig 8. Simulated force-stroke-characteristic of a RINGFEDER® in a model with four wagons

To avoid problems with discontinuous force-stroke characteristics, it is necessary to connect two parts of the force describing function through a fading function (e.g. Hermite-polynomial) at the point of discontinuity.

Example 3: Combined deformation elements (hydraulic buffer in combination with RINGFEDER®)

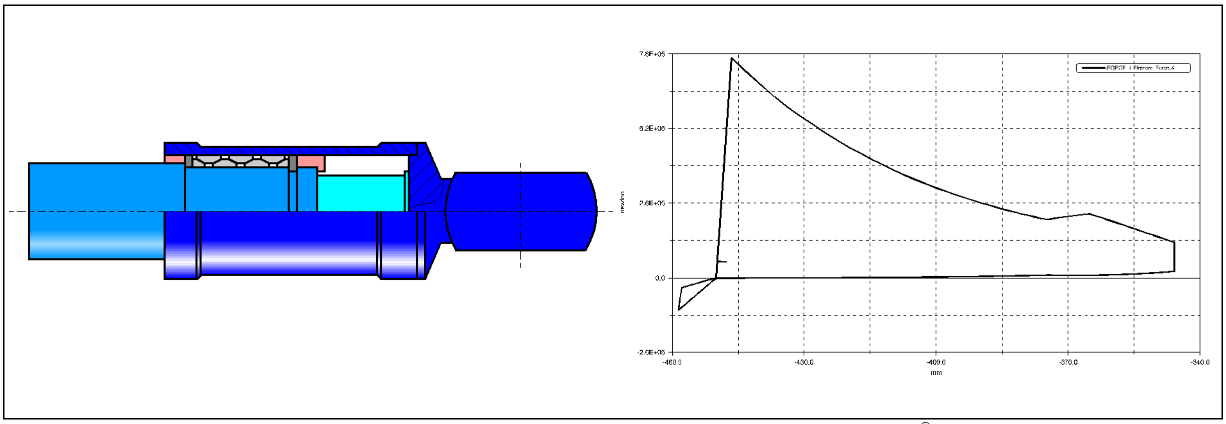


Fig 9. Simulated force-stroke-characteristic of a gashydraulic buffer with integrated RINGFEDER®

Summary

Using energy absorption devices and defined deformation zones to absorb the kinetic energy in a crash, the risks of accidents of rail vehicles can be reduced. The design of energy absorbing devices must be supported both by simulation tools and practical tests (at least with components or in a scale model).

If the characteristic of the energy absorbing device is known, Multi-Body-Systems (MBS) such as ADAMS can be used to determine the resulting *crash-pulses* of vehicles in the longitudinal direction and to investigate the distribution of energy absorption among train cars.

Because of their high-grade non-linear characteristics with large hysteresis and the dependency of force-deformation-characteristics on deformation velocity the modelling of deformation elements and energy absorbing devices respectively is difficult.

So called *user-written-subroutines*, which ADAMS provides for nearly every element in the model, enable the modelling of deformation elements and energy absorbing devices with single component forces for example. These forces can be defined in dependency of the relative displacement and/or the relative velocity between the ends of the energy absorbing devices. Discontinuities of the force describing function should be avoided through fading functions.

To show different applications of user-written-subroutines in modelling various deformation elements some examples are given, such as the modelling of the rectangular force-deformation-characteristic of deformation tubes, the triangular characteristic of RING-FEDER®-elements and the force-stroke-characteristic of combined deformation elements, which depends also on the deformation velocity. For a verification of the simulation results tests with a small-scale crash model of train cars with deformation elements are carried out.

References

Hecht, M., Sohr, S.: *Passive safety for passenger vehicles, reasons, criteria, objectives*. International Conference *Current problems in rail vehicles - PRORAIL '99*, October 6-8, 1999, Zilina, Slovakia.