

Utilization of the Adams system for simulating collisions of wagons equipped with elastomeric buffers

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Abstract. The article introduces an innovative method for modeling elastomer buffers using a rheological structure. This approach entails a detailed mathematical description of buffer properties, seamlessly integrated into the ADAMS/Rail computer code for simulating impacts between two wagons. The simulation within ADAMS/Rail provides insights into the dynamic behavior of elastomer buffers during wagon impacts, considering forces, deformations, and overall responses. Serving as a valuable optimization tool for railway system design, this methodology contributes to improved safety and efficiency. The study's comprehensive yet concise insights bridge the gap between theoretical modeling and practical application, enhancing our understanding of elastomer buffer dynamics and their pivotal role in railway operations.

1 Introduction

Research on railway bumpers (buffers) is crucial for ensuring the safety and effectiveness of railway systems. A precise analysis of their buffering properties allows for the design of solutions that effectively absorb energy in the event of collisions, minimizing potential damage and improving overall passenger safety. These studies represent a significant direction for railway engineers, enabling the development of modern technologies that enhance the resilience and efficiency of buffering systems in various operating conditions [1-3].

Elastomers play a crucial role in absorbing energy during the collision of trains for several reasons. Elastic materials, such as elastomers, have the ability to deform under external forces and return to their original shape after the load is removed [4]. This elasticity allows for the absorption of kinetic energy generated during train collisions.

Through deformation, elastomers absorb energy, resulting in a reduction of forces during the collision. This ability to absorb energy translates into a decrease in forces transmitted to the structures of the train cars and passengers. Additionally, the capability of elastomers to absorb energy and deform helps minimize damage to the structural components of train cars during collisions, contributing to overall safety improvements for both the vehicle and passengers.

Elastomers enable a controlled dynamic response during collisions, meaning gradual deceleration and energy absorption rather than abrupt stops. This controlled reaction leads to improved safety conditions for passengers and reduced structural loads on the vehicle [5, 6]. This phenomenon can also be achieved for sandwich composite materials [7].

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Research on the rheological properties of elastomers allows for the optimization of their structure, influencing better adaptation to various collision conditions and ensuring effective energy absorption [8, 9]. Overall, elastomers are a significant element in the design of bumpers and other safety features in railway vehicles, helping mitigate the consequences of collisions and enhancing the overall safety of railway transportation.

It is worth emphasizing that the possibility of studying energy absorption in elastomers in the context of train collisions is facilitated by the ADAMS/Rail system. Scientists conduct research using this system to simulate collisions, gaining a better understanding and optimizing the properties of elastomers under real collision conditions. These studies are essential for the development of safe and efficient solutions in the field of railway transportation. While other systems like LS-Dyna are also utilized [10].

We present a modeling method utilizing the ADAMS/Rail system [11] and a mathematical description of phenomena that cannot be adequately replicated using standard elements of this system. For instance, the interaction between two bodies is described in this system using a function that determines the force acting on fixed points of these bodies, as schematically illustrated in Figure 1a. The arguments of this function are quantities specifying the distance between the points of the bodies and the rate of change of that distance.

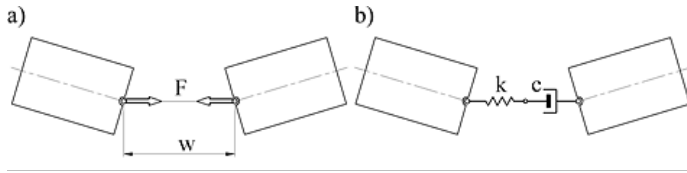


Fig. 1. Forces acting between the examined bodies.

In many cases, such a form of force description is not sufficient. This situation is illustrated in Figure 1b; in this case, the force is described by a differential equation (1).

$$\frac{\dot{F}}{k} + \frac{F}{c} = \dot{w} \tag{1}$$

In the proposed simulation method for the operational collision of wagons, we utilize wagon models developed in the ADAMS/Rail system. However, we describe the force arising in the elastomeric buffers in the form of a differential equation.

2 Elastomeric damper model

The rheological structure of the elastomeric bumper, whose design is illustrated in Figure 2. This scheme is complemented by an element representing an additional spring and local deformation of the wagon body at the bumper attachment point. As a result, we obtain the rheological structure shown in Figure 3.

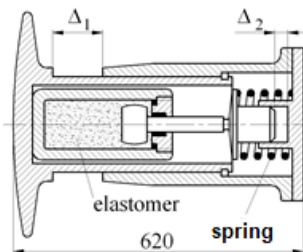


Fig. 2. Schematic structure of the elastomeric bumper.

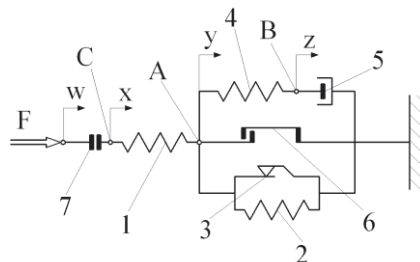


Fig. 3. Rheological schematic of the bumper.

Elements 2, 3, 4, 5 are used to represent the elastic and dissipative properties of the elastomeric damper, while using spring 1 represents the additional spring described earlier and the elasticity of the wagon frame.

Each element of the rheological structure (Fig. 3) is assigned a constitutive characteristic, determining the relationship between force and deformation or velocity. Schematic graphs illustrating the shapes of these characteristics are presented in Figure 4.

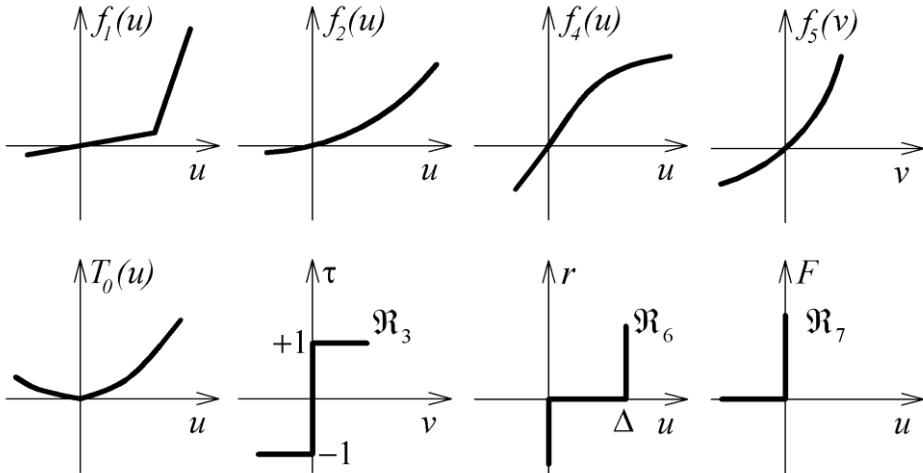


Fig. 4. Constitutive characteristics of rheological elements of the damper; u – deformation, v – velocity.

To provide a mathematical description of deformations in the presented structure, Cartesian coordinates x, y, z were selected. The equations describing the equilibrium of the structure nodes take the form (2-4).

$$-f_1(x - y) + f_2(y + y_0) + \tau T_0(y + y_0) + f_4(y - z) = r \tag{2}$$

$$f_5(\dot{z}) - f_4(y - z) = 0 \tag{3a}$$

$$f_1(x - y) = F \tag{3b}$$

$$(r, y) \in \mathfrak{R}_6 \tag{4a}$$

$$(\tau, \dot{y}) \in \mathfrak{R}_3 \tag{4b}$$

$$(F, (w - x)) \in \mathfrak{R}_7 \tag{4c}$$

where: y_0 represents the initial deformation of the spring f_2 .

Equation (2) pertains to node A, while equations (3) concern nodes B and C. Constitutive relationships $\mathfrak{R}_3, \mathfrak{R}_6, \mathfrak{R}_7$, described by formulas (4), have been illustrated in the graphs presented in Figure 4.

Based on the aforementioned equations and relationships, the following representation of the description of the deforming force F in the elastomeric damper can be established.

$$F = f_1(x - y), \tag{5a}$$

$$x = \varphi_3(w, y), \tag{5b}$$

$$\dot{y} = \varphi_1(w, \dot{w}, x, y, z, \tau), \tag{5c}$$

$$\dot{z} = \varphi_2(y, z). \tag{5d}$$

The functions appearing in equations (5), functions φ_1, φ_2 , are defined by relationships (2-4) and take the form (6).

$$\varphi_2(y, z) = f_5^{-1}(f_4(y - z)), \tag{6a}$$

$$\varphi_3(w, y) = \begin{cases} w, & \text{gdy } w - y \geq 0, \\ y, & \text{gdy } w - y \leq 0. \end{cases} \tag{6b}$$

The description of the function φ_1 is more complicated. It is established on the successive differentiation of equation (2) and the relation in (4). For equation (2) and the relationship \mathfrak{R}_7 , was obtained (7).

$$-f_1'(x - y)(\dot{x} - \dot{y}) + f_2'(y + y_0)\dot{y} + \tau T_0'(y + y_0) + \tau T_0''(y + y_0)\dot{y} + f_4'(y - z)(\dot{y} - \dot{z}) = \dot{r}. \tag{7a}$$

$$\dot{x} = \begin{cases} \dot{w}, & \text{gdy } w - y \geq 0, \\ \dot{y}, & \text{gdy } w - y < 0. \end{cases} \tag{7b}$$

After performing the appropriate transformations of relation (7), we obtain the equation in the form (8a).

$$A(w, \dot{w}, x, y, z, \tau)\dot{y} + T_0'(y + y_0)\dot{\tau} + B(w, \dot{w}, x, y, z, \tau) = \dot{r}, \tag{8a}$$

which was subsequently supplemented with the consequences of relations (4) and obtained (8b-c).

$$(\dot{\tau}, \dot{y}) \in D\mathfrak{R}_3(\tau), \tag{8b}$$

$$(\dot{r}, \dot{y}) \in D\mathfrak{R}_6(r, y). \tag{8c}$$

Relations (8) enable the determination of the values of \dot{y} , thus defining the function φ_1 . Due to the complicated nature of describing this function, it will be presented results for two sample arguments. If the arguments of the function φ_1 (see formulas 5) belong to the set defined by the conditions, then it is possible to get equation (9).

$$0 < y < \Delta, |\tau| < 1, \text{ to } \dot{y} = 0; \tag{9}$$

however, in the case where we determine alternative boundary conditions, then the value of \dot{y} will be visible in equation (10).

$$0 < y < \Delta, \tau = 1, w > y, B(w, \dot{w}, x, y, z) > 0, \text{ to } \dot{y} = \frac{B(w, \dot{w}, x, y, z)}{A(w, \dot{w}, x, y, z, \tau)}. \tag{10}$$

Similarly, we determine the values \dot{y} for the remaining arguments of the function φ_1 .

3 Identification of bumper model parameters

The rheological structure shown in Figure 3 serves to mathematically replicate the mechanical properties of the elastomeric bumper (Figure 2). The parameters defining the properties of the proposed structure are depicted in the plots in Figure 4. The goal of identification is to establish the detailed form of these plots. The basis for their identification consists of the bumper's design parameters and the results of experimental studies on the mechanical properties of the bumper. Based on the design documentation, one can determine the characteristics of the additional spring (Figure 2) as well as the dimensions Δ_1 i Δ_2 . The features of the elastomeric damper are established based on the force and deformation measurement results obtained during quasi-static loading or collisions between wagons.

Example results of such measurements conducted by CNTK are shown in Figure 5. Using the static characteristic plot provided, one can directly determine the shapes of the functions f_2 and f_3 , defining the features of the two elements of the rheological structure. The functions f_4 and f_5 were determined by comparing the dynamic characteristics (Figure 5) obtained experimentally with characteristics determined according to the results of computer simulations of wagon collisions.

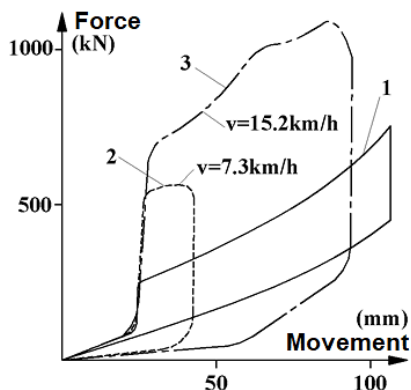


Fig. 5. Experimental characteristics of the elastomeric bumper: 1 – static characteristic, 2, 3 – dynamic characteristics obtained during the collision of wagons.

The forms of these functions were selected to a satisfactory extent to replicate the results of experimental studies in computer simulations. The degree of agreement of the dynamic characteristics (Figure 5) and the alignment of the force and deformation profiles of the bumper were adopted as criteria for the conformity between the simulation results and experimental studies.

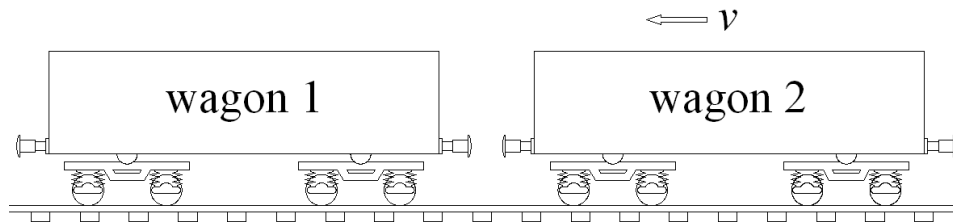


Fig. 6. Schematic of the wagon model developed in the ADAMS/Rail system.

4 Conclusions

1. We presented mechanical properties of the elastomeric bumper mathematical representation through a rheological structure. We utilized various functions and parameters to describe static and dynamic characteristics.
2. The process of identifying model parameters relies on the design documentation of the bumper and the results of experimental mechanical studies. The goal was to achieve consistency between computer simulation results and laboratory experiments.
3. The article emphasizes the application of the ADAMS/Rail system for simulating wagon collisions. The developed bumper model will be used to model loads during train motion, contributing to a better understanding of the dynamics of these systems.
4. Elastomers play a crucial role in absorbing energy during collisions. Research on their rheological properties allows for optimal design and application under various conditions.

5. Simulation results of wagon collisions are applicable in analyzing loads and the dynamic response of trains. They can also influence the design of elastomeric bumpers to enhance their effectiveness in energy absorption during collisions.

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