Usage of magneto-active elastomers in a bumper of a vehicle for front impact protection

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Abstract. The control of the rigidity of the bumper can be provided by an application of magneto-active elastomers (MAE), capable to change their properties in a reversible and fast manner under the action of an applied magnetic field. The dependence of the energy taken away by the bumper at the impact on variable weight and rigidity has been found taking into account the presence of controllable MAE elements in the bumper construction. The calculated fields of pressure and deformations are necessary for optimization of a design, form and material of a forward panel of a bumper.

1. Introduction

Notwithstanding the facts of continual improvement of design of vehicles, it is known that the number of automobile accidents has not decreased over the last few years. The bumper of a vehicle is a first element, which perceives the front impact in the most common cases of automobile accidents. Thus, the problem of optimization and improvement of design of a bumper with the purpose of increasing the safety level of the vehicle is an important topic. The dependences allowing to define a zone of optimum increase of mass and rigidity of a bumper have been found earlier, and the design of the bumper's protecting device has been developed [1, 2]. It has been shown that for each value of rigidity of a bumper there is a zone within the limits of which the value of absorbed energy is in direct dependence on rigidity. Thus, carrying out adjustment of rigidity of a bumper it is possible to control the absorbed energy. In this work the process of front impact of the vehicle with a motionless obstacle has been studied with the use of methods of mathematical modeling and the possibility of using of elements with magnetically controllable rigidity for the decrease in a power level of the front impact perceived by the vehicle has been investigated.
2. Mathematical model of impact
To consider dynamical processes at the impact of two objects as \( n \)-mass mathematical model, one has to use a system of \( m \) differential equations of order \( k \) with nonlinear right parts.

**Figure 1.** Dynamical representing of the front impact by a set of masses and springs: \( m_1, m_2 \) – masses of the bumper with fixing elements and vehicle; \( c_1, c_2 \) – deformation elements imitating the rigidity of the bumper with longeron fixing elements and rigidity of the vehicle; \( x_1, x_2 \) – coordinates of the centre of mass of the bumper and vehicle.

Movement of this dynamic system is considered in the inertial coordinates system related with a motionless obstacle. The well known second type Lagrange equations are used for the analyses of mathematical model of the dynamic system. The two-mass dynamic system with two degrees of freedom gives a rough but qualitative sufficient evaluation of the potential possibility to decrease the energy of the impact. Figure 1 shows the dynamical analogue of the front impact. The initial phase would be enough to concern the process of a real front impact, since the bumper doesn’t play an important role in the process of elastic recovery. In this case the kinetic \( T \) and potential energy \( \Pi \) are:

\[
\begin{align*}
T &= \frac{1}{2}(m_1 x_1^2 + m_2 x_2^2) \\
\Pi &= \frac{1}{2}(c_2 (x_2 - x_1)^2 + c_1 x_1^2)
\end{align*}
\]

(1)

Differentiating and considering the Lagrange equation one obtains:

\[
\begin{align*}
x_1 &= \frac{v_0(\lambda_2^* - 1)}{p_1(\lambda_2^* - \lambda)} \sin(p_1 t) + \frac{v_0(1 - \lambda)}{p_1(\lambda_2^* - \lambda)} \sin(p_2 t) \\
x_2 &= \frac{\lambda v_0(\lambda_2^* - 1)}{p_1(\lambda_2^* - \lambda)} \sin(p_1 t) + \frac{\lambda v_0(1 - \lambda)}{p_2(\lambda_2^* - \lambda)} \sin(p_2 t)
\end{align*}
\]

(2)

It is assumed that the deformation of the bumper take place within 10 ms after impact. For weight and rigidity initial data has been set and the energy absorbed by the bumper \( E_1 \) as well as by the vehicle itself \( E_2 \) are calculated:

\[
\begin{align*}
E_1 &= \frac{c_1 x_1^2}{2} \\
E_2 &= \frac{c_2 (x_2 - x_1)^2}{2}
\end{align*}
\]

(3)

(4)
The calculated value of the energy has been compared with the energy absorbed by a vehicle without active protection.

3. Magneto-active elastomers as active elements in construction of a bumper
The control of the rigidity of the bumper can be provided by an application of magneto-active elastomers (MAEs), capable to change their properties in a reversible and fast manner under the action of an applied magnetic field [3-8]. The most important property of a MAE, from the point of view of the considered problem, is the magnetorheological effect [9], i.e. increase of elasticity under the action of an external magnetic field. There are known works on MRE used in some automotive applications, e.g. as suspension bushings etc [3, 10, 11]. In this study elements of a typical anisotropic MAE [12,13] were supplemented in bumper construction to provide a semi-active control of its rigidity.

4. Simulation
Varying weight and rigidity of the bumper and taking into account a controllable MAE based element, it is possible to find dependence of the energy absorbed by the bumper on these parameters and to determine the resulting influence (figure 2). It is assumed in calculations that the deformations of the bumper take place within 10 ms after impact.

![Figure 2](image.png)

**Figure 2.** Energy absorbed by the bumper: a) as function of mass and speed of impact at fixed values of the rigidity (1/8), b) as function of rigidity and speed of impact at fixed values of the mass (10 kg).

For each value of rigidity of a bumper (including longeron fixing elements) there is a zone within the limits of which the value of absorbed energy is in direct dependence on rigidity. Out of this zone there is an inverse dependence. Hence one must take into account that changes of rigidity of a bumper can have a negative result, namely, decrease of absorbed energy.

For the calculations of pressure and deformation at a frontal impact a bumpers prototype of a middle class vehicle has been considered. The FEM mesh of the bumper is shown in figure 3.

![Figure 3](image.png)

**Figure 3.** FEM mesh of the bumper
Calculated by means of ANSYS Mechanical software distribution of pressure and deformations (figures 4-5) shows that the load ability of a bumper is defined by the loaded zones which area is in range of 10 – 20 % of the area of a surface of a bumper. The 20-40 % of the area of a surface of a bumper is poorly loaded zones and 40 – 60 % doesn’t have considerable pressure. As well as in a case of distribution of deformations, total zones of a field of distribution of pressure will be symmetric concerning vertical axial a bumper facade. Other part of a bumper is under action of a qualitatively lower pressure or even is not loaded, and these zones are supplied with MAEs with adjustable rigidity.

5. Outlooks

Using of a MAE in the bumpers construction is capable not only accumulate and absorb impact influence, but also distribute it on a surface, reduce the effect and consequences of a shock. The calculated fields of pressure and deformations allow to optimize a design and to choose a correct form and material for the forward panel of a bumper. Besides there is a possibility to use a magnetostriiction effect [14] as well as memory shape effect of MAE [12, 13] to develop an active surface of a bumper, which can be restored after impact (impacts at slow velocities 1-10 km/h).

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