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OPTIMIZATION OF GEOMETRY OF PLASTIC SHOCK ABSORBER

PLASTISKĀ TRIECIENSLĀPĒTĀJA ĢEOMETRIJAS OPTIMIZĀCIJA

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1. Introduction

Extreme dynamic longitudinal forces are capable to cause significant damages of the rolling-stock, track and goods. Therefore it is essential to reduce the multiple impact loads in the heavy freight trains. Results of research on longitudinal dynamics of a train are important for designing the rolling-stock and braking equipment, and also for selecting the safest driving regime and forming the freight trains. Several additional plastic shock absorber designs, capable to prevent destruction of railway car, have been offered [1, 2]. However, such devices work only once in the case of repeated collisions. The design of the additional multi–action plastic shock absorber capable of functioning several times in a short interval of time is offered in [3]. The offered structure [3] of a coupling between the railway cars includes additional multi-action plastic shock absorbers having working elements (mandrel – deformable tube).

2. The Research Problem

The finite element method (FEM) is a common engineer method for research of structural strength in the vehicle systems [4]. The plastic deformation behaviour of working element has been examined by the simulation of a thick-walled tube under shock loadings at collisions in the heavy freight trains. The scheme of the stressed state is assumed flat (σ_ρ – axial compressive stress, σ_φ – hoopential tensile stress), with the maximal stress σ_φ. The following plasticity condition (Eqn.1) is applied

$$\sigma_\varphi = \sigma_{S0} + D \cdot \ln \frac{R}{R_0} \quad (1)$$

where σ_{S0} – extrapolated yield stress; D - modulus of hardening, $\ln R/R_0$ – general tangential tensile deformation. All tests were performed by the finite element method using the program ANSYS. FEM contains plastic, dry friction, viscoplastic and solid elements. The criterion of optimization is the increase of energy absorption. Parameters of optimization are geometrical parameters of a working element: α – cone angle, (R_{dK} -R_{d0}) – values of tube expansion, heights of cylindrical (h_K – working and h_0 – direction) surfaces of mandrel, S – thickness of tube and RAD – radius of curvature of cone. Constraints of optimization are the value of a yield stress Gt of a tube material in the centre of plastic deformation and the allowable value of tensile strength; under condition that the plastic element works without formation of cracks in the wall of the deformable tube. The research problem is axisymmetric and consequently, calculation only on the half of an element section concerning an axis of symmetry was carried out. Thus the time of calculations becomes smaller and the task - simpler. A finite-element model is submitted in Fig.1. The properties of deformable tube 2 are described by a finite element having viscoelastic properties with hardening. For the description of this element the isotropic and BISO (bilinear isotropic hardening) materials are satisfactory. The properties of a mandrel are described by a solid-state finite element. The contact between the surfaces of a mandrel and deformable tube is simulated by 3-nodal element with Coulomb friction, as shown on Fig. 2, 3The purpose of the research was the optimization of mandrel generating line form and dimensions by a variation of the form of friction surfaces. The modeling of the tube expansion process by indentation of mandrel with weight M (weight of the railway car) in a tube of a smaller diameter was carried out for various initial speeds of loading (Fig. 1). The complete transitional dynamic analysis for plastic elements was used in ANSYS processor.

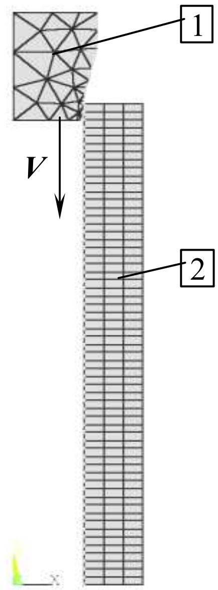


Figure 1. Initial position of FEM model

As a result of the research of the properties of a plastic working element installed on the emergency absorbing device, it is necessary to obtain: the distributions of the stresses in a wall of deformable tube for various loading speeds; regimes of metal flow without strain cracks in a wall of tube. For this purpose the accelerations and efforts values that were transmitted on the freight car during the operation of a plastic element at collisions were determined.

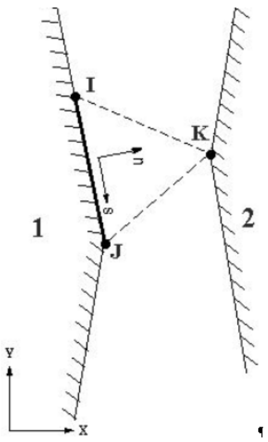


Figure 2. Scheme of contact element

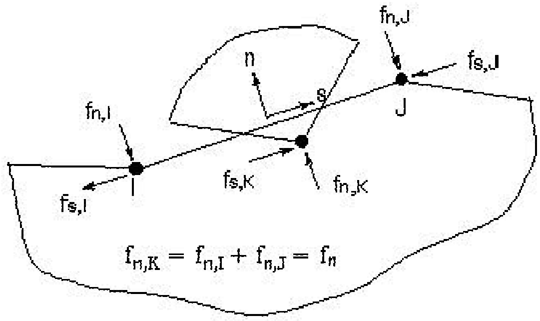


Figure 3. Scheme of contact forces with Coulomb friction

3. Model Validation

A comparison with the results of a working experiment at static loading was carried out for a validation of the accuracy of the created finite element model in ANSYS (ANSYS computer program, release 8.0) [5]. The calculations were made on a reduced model. The experiment was carried out with a deformable tube (sizes 0,02×0,0013×0,115 m), executed out of steel (Steel-5), slowly loaded by a mandrel (material Steel-6) of a large diameter (values of tube expansion $R_{dK} - R_{d0}$ = 0,0012 m). The mandrel obliquity's angle was presumed to be equal with α = 20° with the cone generating line in the form of straight line RAD = ∞, thickness of tube S = 0,0013m (Fig.4.).

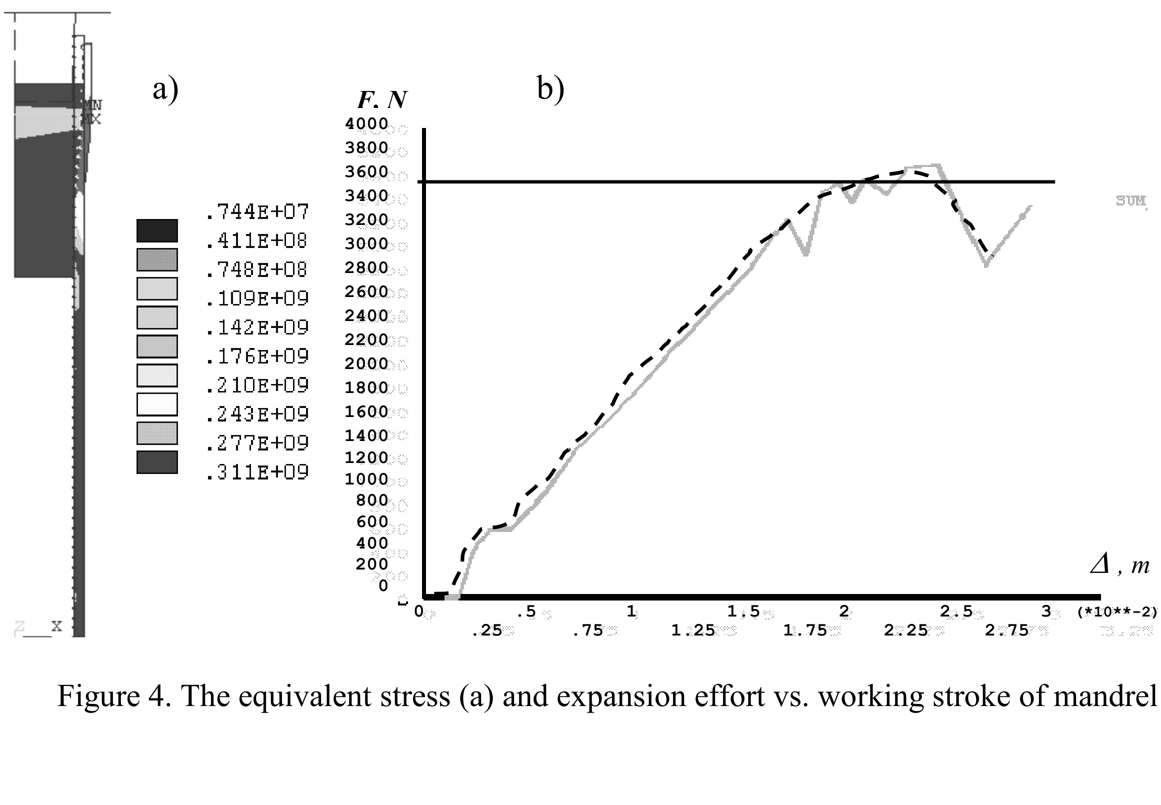


Figure 4. The equivalent stress (a) and expansion effort vs. working stroke of mandrel (b)

The results of n tests of the experiment, realizing on the initial data described above, are shown in Fig.4. In the process of pipe expansion the effort P=3560 N with a deviation ±182 N (~ 5%) is obtained. A comparison of the results of calculation by FE program ANSYS and the experiment results has confirmed the accuracy of the model (Table 1.). The effects of the effort's smooth decrease in the initial phase of deformation (bending of free end of tube Fig.4 b.), with following increasing of effort and subsequent formation of a steady centre of deformation characteristic for the process of tube expansion are reflected perfectly in the model.

Table 1. Results Comparison

Compared parameter	Experimental result Steel-5	**ANSYS** *Fig.4b.* — — —	Relative deviation %
1	2	3	4
Expansion effort *F*	$3560^{\pm 182}$ N	3610 N	+1,4

The modeling of a plastic working element by program ANSYS shows a deviation of 1,4% in relation to the result of the experiment, which satisfies the research problem requirements.

4. Dynamic Calculation of a Full-Scale Construction

In the result of the dynamic calculation of plastic working element's full-scale construction and optimization of the mandrel sizes the characteristics of a plastic element are obtained. The parameters of deformable tube for a plastic element (preferable length and materials) are determined in Table 2.

Table 2. The parameters of a plastic element

Properties of material:		Geometric properties:	
Steel 30HGS (mandrel)	Steel 20H (tube)		
$M = 84{\cdot}10^3$ kg	$\mu = 0{,}15$ friction coef.	$Rd_0 = 0{,}026$ m	$Rd_K = 0{,}031$ m
$Gt = 600$ MPa	yield stress	$h_0 = 0{,}010$ m	$h_K = 0{,}005$ m
$ETAN = 0.01$GPa	tangent modulus	$S = 0{,}022$ m	thickness of tube
$EXXd = 198$GPa	elastic modulus of mandrel	$\alpha = 30°$	cone angle of mandrel
$EXXp = 200$GPa	elastic modulus of tube	$\Delta_m = 0{,}2$ m	maximum working stroke of plastic element
$Pr = 0{,}3$	Poisson's ratio	$\dot{x} = 1 \div 5\ m/s$	initial velocity
$DENS = 7850$ kg/m^3	material density		

During the calculations, a 4-axles open wagon with a mass of 84 103 kg was accepted as the basic type of railway car.

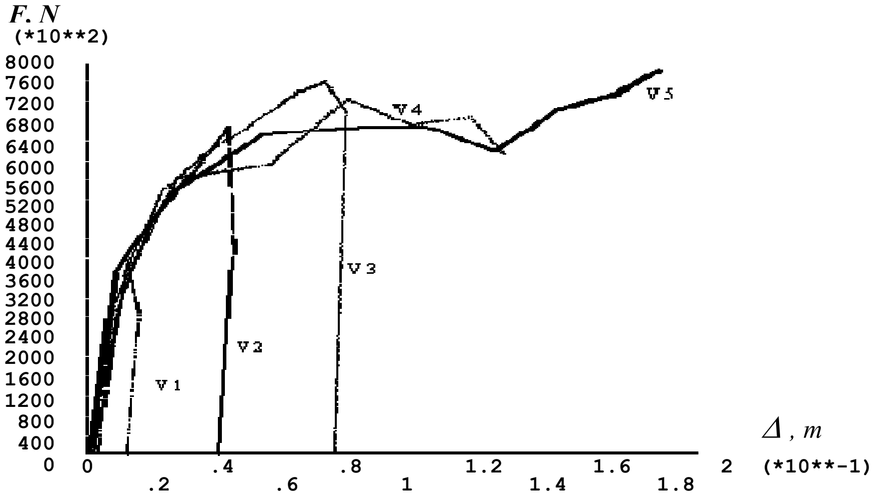
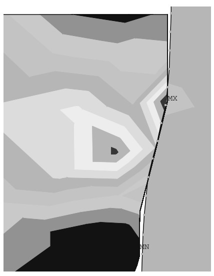
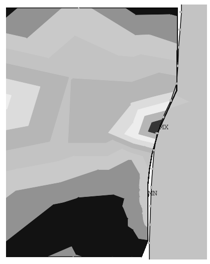


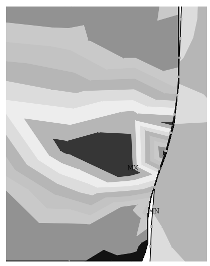
Figure 5. Expansion effort vs. working stroke of mandrel velocity: V_1 – 1m/s, V_2 – 2m/s,…,V_5 – 5m/s

The dynamic behavior of a plastic working element (mandrel 1- deformable tube 2) for various loading speeds was investigated (Fig.5). As a result of the modeling, the influence of loading's speed on the working element characteristics was determined, and the effects of yield stress increase and temporary resistance were revealed.

For obtaining of the plastic element best working characteristics (maximal contact surface, maximal expansion effort, minimal equivalent stress) optimization by variation of the value of RAD - form of friction surface of a mandrel (convex, straight or concave generating line of a cone) (Fig. 6. a, b, c) - also was carried out.

a) 

b) 

c) 

	a)	b)	c)
Tube:	σ_e = 0.665e+09N	σ_e = 0.647e+09N	σ_e = 0.626e+09N
Mandrel:	σ_e = 0.116e+10N	σ_e = 0.140e+10N	σ_e = 0.101e+10N

Figure 6. The equivalent stress σ_e of plastic working element for different forms of the cone generating line of mandrel: a) – straight line, b) – concave line, c) – convex line. Speed of loading – $\dot{x} = 3{,}05\ m/s$

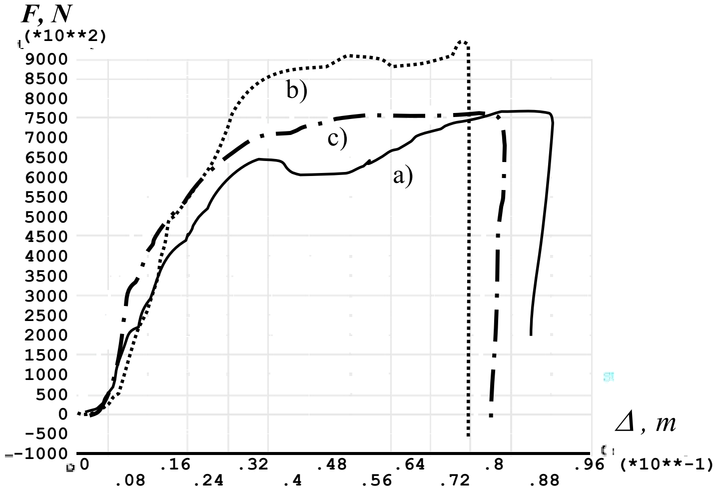


Figure 7. Calculation of expansion effort vs. working stroke of mandrel for different forms of cone generating line: a) – straight line, ——— – *RAD= ∞;* b) – concave line, ···· – *RAD= 0,04m*; c) – convex line, –•–•–• – *RAD= 0,04m,* $\dot{x} = 3{,}05\ m/s$

During the optimization it was discovered that for RAD = ∞ expansion effort insignificantly exceeds effort for convex surface only in the end of working stroke of mandrel (Fig. 7). The use of a concave surface of mandrel (Fig. 6b, 7b) gives maximal expansion effort F = 90·104 N, but the stress in mandrel reaches the limiting values for the chosen material (steel 30HGS). Thus concave friction surface of mandrel will require a more durable (expensive) brand of steel.
Therefore mandrel form with a convex friction surface RAD = 0,04m (Fig. 6c, 7c) is accepted as closest to the optimum from the point of view of maximal energy absorption of a plastic element. The expansion effort F = 74·104 N at working stroke Δ=0,0831m is insignificantly less than at RAD = ∞ (F = 75·104 N, Δ=0,0939m), but the contact surface length is maximal (Fig. 6c), the equivalent stress is minimal and do not reach allowable value.

5. Conclusions

As a result of the optimization the energy absorption of a plastic element has been brought to the maximum by improvement of mandrel geometry, namely: the forms of cone friction surface, cone angle, values of tube expansion, heights of cylindrical surfaces of mandrel. The effects of interaction of dry friction, elastic and solid elements are obtained. Comparison of numerical results and experimental results shows the satisfactory accuracy of calculation. Mandrel form with a convex friction surface (RAD = 0,04m) is calculated as closest to the optimum from the point of view of maximal energy absorption of a plastic element in this case.
Mathematical modeling and optimization of a plastic working element will significantly increase the accuracy of a new complete coupling model that would include emergency multi-action plastic shock absorbers. The model of plastic element will be used for the construction of a complex model of longitudinal dynamics of heavy trains.

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Boiko A. Plastiskā triecienslāpētāja ģeometrijas optimizācija
Tiek optimizēta daudzkārtējas darbības plastiskā triecienslāpētāja darba elementa ģeometriskā forma pie dažādiem triecienu slodžu gadījumiem. Radīts darba elementa ar dažādiem dorņu un deformējamo cauruļu tipiem GEM modelis, lai noteiktu trieciena viļņu izplatīšanos smago kravas vilcienu sakabes elementos. Veiktie matemātiskie eksperimenti, modelējot avārijas slodžu slāpēšanas procesu daudzkārtējas darbības ierīcē, liecina par tādu dorņu pielietošanas efektivitāti, kuru berzes virsmai ir izliekta forma.

Boyko A. Optimization of Geometry of Plastic Shock Absorber
The geometric form of working elements of a multi-action plastic absorber was optimized for different cases shock loadings. The finite element model of working element with different types of mandrels and deformable tubes for evaluation of propagation of shock wave in heavy freight trains was elaborated. During the executed mathematical experiments on simulation of emergency shock loadings absorption by the multi-action device the expediency of application of working elements with a convex friction surface of mandrels was proved.

Бойко А. Оптимизация геометрии пластического поглощающего аппарата
Оптимизировалась геометрическая форма рабочих элементов пластического поглотителя многократного срабатывания при различных случаях ударных нагружений. Для определения распространения ударной волны в соединении тяжеловесного грузового поезда построена конечно-элементная модель рабочего элемента с различными типами дорнов и деформируемых трубок. В ходе выполненных математических экспериментов по моделированию процесса поглощения аварийных ударных нагрузок устройством многократного срабатывания доказана целесообразность применения рабочих элементов с выпуклой поверхностью трения дорнов.