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Analiza sistemov pasivne varnosti v vozilu pri majhnih hitrostih
Evaluation of Vehicle Passive Safety Systems at Low Speeds

DJORDJE ŽEBELJAN

V delu je ovrednotena zmožnost absorpcije energije trka vozila pri majhnih hitrostih (do 8 km/h) z uporabo odbojnikov, ki so del sistema pasivne varnosti v vozilu. Pri simuliranju trkov ter za pridobitev referenčnih rezultatov sem uporabil standardni trk vozila v premično oviro (nihalo) s sredino odbojnika. Metodo končnih elementov sem uporabil kot orodje za ovrednotenje konstrukcijskih različic odbojnika. Obdelal sem tri mogoče konstrukcije odbojnikov: dve samonosni in eno tipa dušilka + nosilo odbojnika. Pri vseh treh različicah sem skušal s spremembami konstrukcije povečati izkoristek sistema glede na absorbirano energijo.

Possibilities of absorbing the energy of a car collision at low speeds (up to 8 km/h) using bumpers that are a part of the car passive safety system are evaluated in the paper. For simulations of car collisions and to obtain reference results, a standard pendulum test in the middle of the bumper was used. The finite element method was applied as a tool for evaluation of the designed bumper options. Two possible options for bumper systems are presented: one self-supported bumpers and one dash-pot + bumper beam system. In both systems, using structural modifications, an attempt is made to improve the efficiency of the system in terms of energy absorption.

0 UVOD

Glavni namen predstavljenega dela je ovrednotenje zmožnosti absorpcije energije trka vozila pri majhnih hitrostih (do 8 km/h) z odbojniki, ki so del sistema pasivne varnosti v vozilu. Pri simuliranju trkov ter za pridobitev referenčnih rezultatov sem uporabil standardni trk vozila v premično oviro (nihalo) s sredino odbojnika. Podroben opis izvedbe trka je podan z evropskimi standardi za varnost v prometu [9]. Mogoča simuliranja trkov na vozilu so prikazana na sliki 1.

Metodo končnih elementov sem uporabil kot orodje za ovrednotenje konstrukcijskih različic odbojnikov. Obdelal sem dve mogoči konstrukciji odbojnikov: samonosno in eno tipa dušilka + nosilo odbojnika. Pri obeh različicah sem skušal s spremembami v konstrukciji povečati izkoristek sistema glede na absorbirano energijo J/kg.

1 UPORABA METODE KONČNIH ELEMENTOV

Metoda končnih elementov je bila uporabljena pri reševanju geometrijsko in materialno nelinearnih problemov. Obe zahtevi sta bili namreč zastopani pri ovrednotenju predstavljenih sistemov. Odbojnik lahko modeliramo tudi kot sistem vzmeti in dušilk, kakor je razvidno s slike 2, pri čemer so določeni členi (K_v, C, K_c) konstantni ali pa funkcije hitrosti in/ali hitrosti deformacij [6], [7].

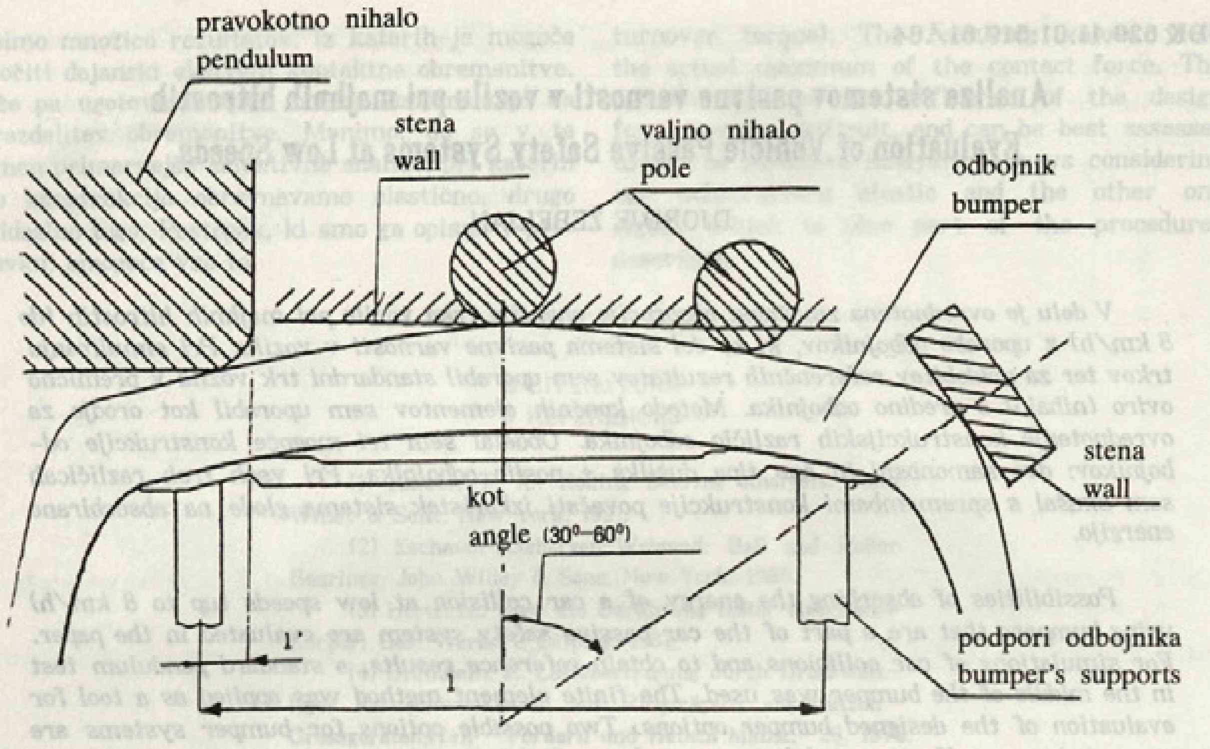
0 INTRODUCTION

The main goal of the presented paper is to evaluate possibilities of absorbing the energy of a car collision at low speeds (up to 8 km/h) using bumpers which are a part of the car passive safety system. For simulations of car collisions and to obtain reference results, a standard pendulum test in the middle of the bumper was used. A detailed description of the test is given by the European standards for car safety [9]. Possible collision simulations are presented in Figure 1.

The finite element method was used as a tool for evaluation of the designed bumpers. Two possible options for bumper systems are given: one self-supported bumpers and one dash-pot + bumper beam system. In both systems, using design modifications, an attempt was made to improve the efficiency of the system in terms of energy absorption J/kg.

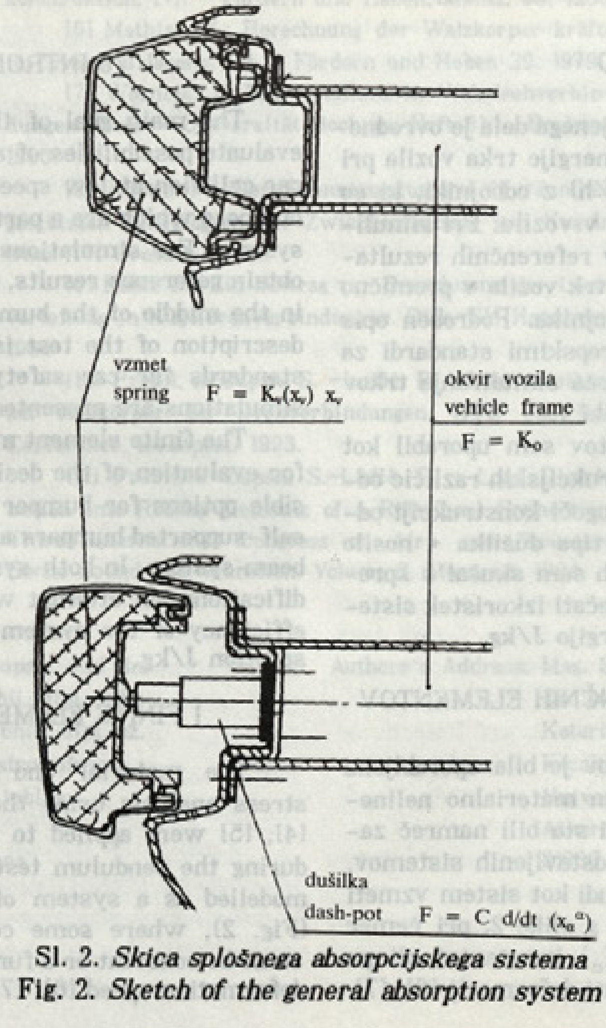
1 FINITE ELEMENT APPROACH

The material and geometrical non-linear stress analysis using the finite element method [4], [5] were applied to approach real conditions during the pendulum test. A bumper can also be modelled as a system of springs and dash-pots (Fig. 2), where some coefficients (K_v, C, K_c) could be constant or a function of velocity, and/or deformation speed [6], [7].



Sl. 1. *Smeri testnih trkov vozila*

Fig. 1. *Directions of the vehicle test collisions*

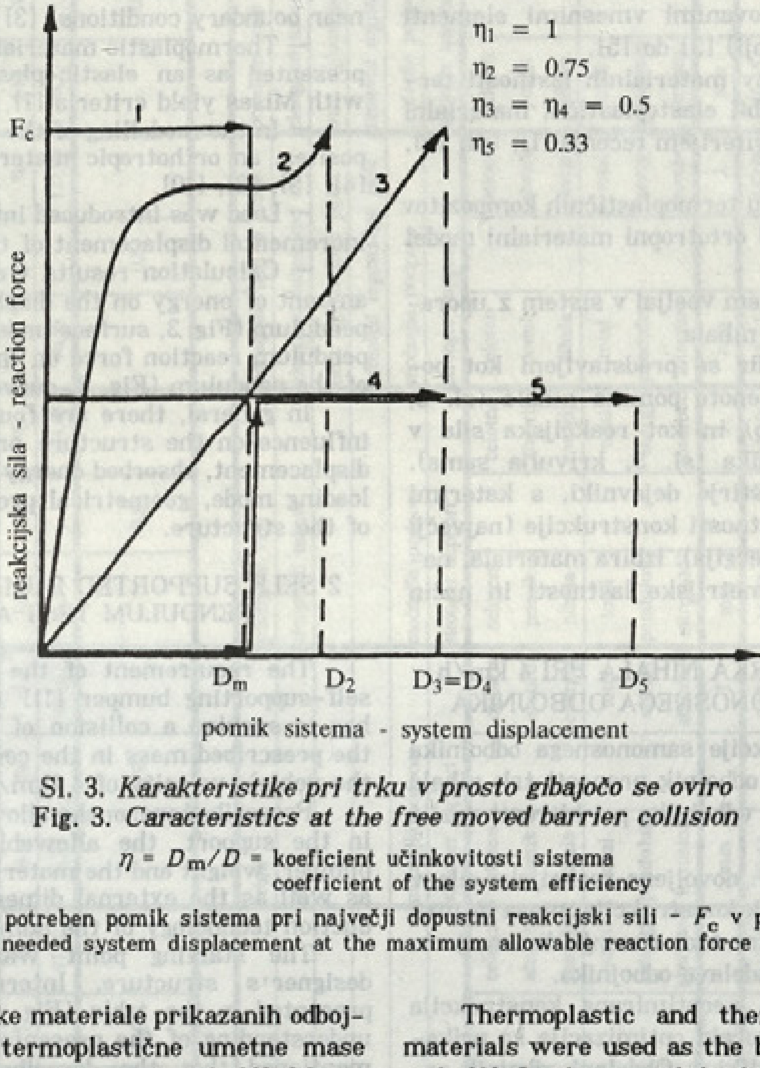


Sl. 2. *Skica splošnega absorpcijskega sistema*

Fig. 2. *Sketch of the general absorption system*

Zanimiva veličina pri primerjavi učinkovitosti različnih sistemov je koeficient η, med najmanjšim potrebnim pomikom sistema ob največji dovoljeni reakcijski sili in dejanskim pomikom sistema, potrebnega za absorpcijo predpisane količine energije. Sistemi z različnimi koeficienti so prikazani na sliki 3.

An interesting value in comparing the efficiency of two different system is the coefficient η between the minimum displacement at the maximum allowable reaction force and the real displacement of the system needed to absorb the prescribed amount of energy. Systems with different coefficients are presented (Fig. 3).



Sl. 3. *Karakteristike pri trku v prosto gibajočo se oviro*

Fig. 3. *Caracteristics at the free moved barrier collision*

$\eta = D_m/D$ = koeficient učinkovitosti sistema
coefficient of the system efficiency

D_m - najmanjši potreben pomik sistema pri največji dopustni reakcijski sili - F_c v podpori
minimum needed system displacement at the maximum allowable reaction force - F_c in the support

Za konstrukcijske materiale prikazanih odbojnikov sem uporabil termoplastične umetne mase in termoplastične kompozitne materiale [8]. Materialne lastnosti izbranih materialov so v veliki meri odvisne od smeri in hitrosti obremenitve ter temperature. Hitrost obremenitve in temperatura vplivata predvsem na lastnosti termoplastičnih umetnih mas, smer obremenitve glede na smer vlaken pa je pomembna pri termoplastičnih kompozitnih materialih.

Pri analizi in optimizaciji obdelanih konstrukcij sem uporabil komercialni računalniški programski paket MARC — K4 [4], [5], ki temelji na metodi končnih elementov, s široko možnostjo uporabe v strojni praksi. Predpostavke, na katerih temeljijo vsi izdelani preračuni, so:

— Nihalo, kakor tudi celotno vozilo (brez odbojnika), sem modeliral kot togo telo.

Thermoplastic and thermoplastic-composite materials were used as the bumper design materials [8]. Loading speed, loading direction and temperature have great influence on the properties of the materials used for bumpers. The loading speed and temperature have a greater influence on thermoplastics. Thermoplastic-composites are more sensitive to the load direction in relation to the fibre orientation.

For the analysis and optimisation of the evaluated structures, the commercial computer program package MARC — K4 [4], [5] based on the finite element method, with a wide application ability in engineering practice, was used. All evaluated calculations are based on the following assumptions:

— The pendulum, as well as the complete car (excluding bumper), were modelled as a rigid body.

— Pri modeliranju odbojnika sem uporabil izoparametrični lupinski element z bilinearno interpolacijsko funkcijo ob upoštevanju velikih deformacij in Lagrangeove formulacije [3] do [5].

— Zaradi simetričnosti geometrijske oblike odbojnikov kakor tudi robnih in začetnih pogojev, sem modeliral le eno polovico obdelanih odbojnikov.

— Stik med nihalom in odbojnikom je bil modeliran s tako imenovanimi vmesnimi elementi (nelinearni robni pogoji) [3] do [5].

— Za predstavitev materialnih lastnosti termoplastov sem uporabil elastoplastični materialni model z Misesovim kriterijem tečenja [1], [4], [5], [8], [10].

— Pri modeliranju termoplastičnih kompozitov sem uporabil elastični ortotropni materialni model [4], [5], [8], [10].

— Obremenitev sem vpeljal v sistem z uporabo koračnih pomikov nihala.

— Rezultati analiz so predstavljeni kot porabljena energija na enoto pomika nihala (sl. 3, površina pod krivuljo) in kot reakcijska sila v nihalu na enoto pomika (sl. 3, krivulja sama).

V splošnem so štirje dejavniki, s katerimi lahko vplivamo na lastnosti konstrukcije (največji pomik, absorbirana energija): izbira materiala, način obremenitve, geometrijske lastnosti in način vpetja.

2 SIMULIRANJE TRKA NIHALA PRI 4 km/h V SREDINO SAMONOSNEGA ODBOJNIKA

Zahteva konstrukcije samonosnega odbojnika je bila [11], da mora odbojnik prenesti trk nihala znane mase v sredino odbojnika pri hitrosti vozila 4 km/h.

Predpisani so bili: dovoljena reakcijska sila v podpori, dovoljen pomik konstrukcije, masa in material konstrukcij kakor tudi zunanje dimenzije in tehnološki postopek izdelave odbojnika.

Izhodišče je bila neoptimirana konstrukcija oblikovalca. Vmesni koraki optimizacije so prikazani v preglednici na sliki 4. Obdelani odbojnik sestavljajo štirje deli [11]:

— plašč odbojnika — debelina stene 3,5 mm,
— nosilo-U — debelina stene 3,0 mm,
— notranja struktura — deb. st. 2,0 do 3,0 mm,
— podpora — debelina stene 3,0 do 3,5 mm.

Za material obdelanih konstrukcijskih različic sem uporabil termoplast [10]. Odbojnik je moral biti izdelan z uporabo tehnologije tlačnega litja. Plašč odbojnika je zvarjen z nosilom U. Glavna naloga notranje strukture je preprečitev deformacij prečnega prereza nosila U (lokalni ukloni), kar z drugimi besedami pomeni vztrajnostni moment mora ostati med testom nespremenjen. V podpori si tudi nisem smel privoščiti uklona, ker je bil največji dovoljeni pomik odbojnika tudi predpisan.

— For the modelling of the bumper, an isoparametric thin shell element with a bi-linear interpolation function including large deformations and Lagrange formulation [3] do [5] was used.

— In view of the bumper symmetry, as well as the symmetry of the initial and boundary conditions, only one half of the bumper was modelled.

— Contact between the pendulum and the bumper was modelled with gap-elements (non-linear boundary conditions) [3] do [5].

— Thermoplastic material properties were represented as an elastic-plastic material model with Mises yield criteria [1], [4], [5], [8], [10].

— In the modelling of the thermoplastic-composites, an orthotropic material model was used [4], [5], [8], [10].

— Load was introduced into the system as the incremental displacement of the pendulum.

— Calculation results were presented as the amount of energy on the displacement unit of the pendulum (Fig. 3, surface under the curve) and the pendulum reaction force on the displacement unit of the pendulum (Fig. 3, curve intself).

In general, there are four factors having an influence on the structure properties (maximum displacement, absorbed energy): material selection, loading mode, geometrical properties and fixation of the structure.

2 SELF SUPPORTED BUMPER — CENTRAL PENDULUM TEST AT 4 km/h

The requirement of the first design of the self-supporting bumper [11] is that the bumper has to survive a collision of the pendulum with the prescribed mass in the centre of a bumper at the vehicle velocity of 4 [km/h].

Prescribed were: the allowable reaction force in the support, the allowable intrusion of the bumper, weight and the material of the structure, as well as the external dimensions and the production technology of the bumper.

The starting point was the unoptimised designer's structure. Intermediate steps are presented in the table (Fig. 4) [11]. For better understanding of the presented data, it should be mentioned that the described bumper consists of four basic parts:

— bumper skin — wall thickness 3.5 mm,
— U beam — wall thickness 3.0 mm,
— internal structure - w. thickn. 2.0—3.0 mm,
— support — wall thickness 3.0—3.5 mm.

All structural parts had to be produced from thermoplastics [10] with an injection moulding process which determines wall thicknesses and structure design. The bumper skin is welded into the U—beam of the bumper. The main function of the internal structure is to prevent deformation (local buckling) of the bumper cross section or, in the other words, the bumper beam moment of inertia should not be decreased during the test. Buckling should be also avoided in the support because maximum intrusion of the bumper is prescribed.

	osnovna verzija basic version			modificirane verzije modified versions															
	absolutno absolute	verzija version	relativno relative	absolutno absolute	verzija version	relativno relative	absolutno absolute	verzija version	relativno relative	absolutno absolute	verzija version	relativno relative	absolutno absolute	verzija version	relativno relative	absolutno absolute	verzija version	relativno relative	
enota	kg		%	kg		%	kg		%	kg		%	kg		%	kg		%	unit
masa	3,21		100,00	3,35		104,36	3,39		105,61	3,40		105,92	3,42		106,54	3,27		101,87	weight
enota	J/kg	original	%	J/kg	I	%	J/kg	II	%	J/kg	III	%	J/kg	IV	%	J/kg	V	%	unit
izkoristek	75,32		100,00	73,38		97,40	86,37		114,67	93,91		124,68	96,36		127,93	96,57		128,09	efficiency
masa na enoto izkoristka		1,00			1,07			0,92			0,85			0,83			0,80		weight per unit efficiency
spremembe																			modifications
struktura	rebra ribs			valji tubes			rebra ribs			podaljšani valji elongated tubes			podaljšani valji in rebra elongated tubes and ribs			podaljšani valji in rebra elongated tubes and ribs			structure
plašč													brez registracijske plošče removed registration plate			brez registracijske plošče removed registration plate			skin
nosilec U							močnejša podpora stronger support			močnejša podpora stronger support			močnejša podpora stronger support			močnejša podpora, stena stronger support, thin. wall			U beam
	celoten pomik nihala total pendulum intrusion		celotna absorb. energija total energy absorbed	celoten pomik nihala total pendulum intrusion		celotna absorb. energija total energy absorbed	celoten pomik nihala total pendulum intrusion		celotna absorb. energija total energy absorbed	celoten pomik nihala total pendulum intrusion		celotna absorb. energija total energy absorbed	celoten pomik nihala total pendulum intrusion		celotna absorb. energija total energy absorbed	celoten pomik nihala total pendulum intrusion		celotna absorb. energija total energy absorbed	
enota	mm		J	mm		J	mm		J	mm		J	mm		J	mm		J	unit
predvideno	54,04		347,00	53,59		347,00	48,61		347,00	46,33		347,00	45,61		347,00	46,65		347,00	predicted
izračunano	50,00		241,79	50,00		245,81	50,00		292,78	50,00		319,30	50,00		329,55	50,00		315,47	calculated
razlika %	8,10		-43,51	7,20		-41,17	-2,80		-18,52	-7,30		-8,68	-8,80		-5,30	-6,70		-9,99	difference %

Sl. 4. *Pregled rezultatov optimizacij samonosnega odbojnika pri centralnem trku nihala s hitrostjo 4 km/h*
Fig. 4. *Results overview of the self supported bumper optimisation at central pendulum test at 4 km/h*

Med procesom optimizacije sem obdelal šest konstrukcijskih različic (sl. 4) [11]. Glavno merilo učinkovitosti vpeljanih sprememb je bila absorbirana energija v enoti mase konstrukcije (J/kg). Dovoljen je bil pomik sistema za 50 mm. Na tej poti bi smel odbojnik absorbirati 347 J energije. V preglednici na sliki 4 sta zato prikazana dva parametra pri vsaki konstrukcijski različici in to absorbirana energija pri največjem dovoljenem pomiku ter pomik, potreben za absorpcijo predpisane količine energije.

Po opravljeni analizi sedanje konstrukcije in vnesenimi izboljšavami sem dosegel, da se ob 2-odstotnem povečanju mase odbojnika glede na izhodiščno verzijo poveča izkoristek za 28 odstotkov. Pri absorpciji predvidene količine energije potrebuje odbojnik 93,3 odstotkov dovoljenega pomika.

3 SIMULIRANJE UDARCA NIHALA PRI 8 km/h V ODBOJNIK TIPA — NOSILO IN DUŠILKA

Pri drugem obdelanem odbojniku sistema dušilka in nosilo se je, poleg že znanih, pojavila še ena zahteva. Aluminijsko nosilo je bilo treba namreč zamenjati z nosilom iz termoplastičnih kompozitnih materialov. Novo nosilo bi moralo, zaradi tržnih razlogov, biti vsaj 20 odstotkov lažje od sedanjega aluminijskega. Za kompozitno varianto pa je bilo dovoljeno le 15-odstotno povečanje pomika celotnega sistema.

Rezultati izdelanih analiz z izbranimi oblikami odbojnika so predstavljeni na slikah 5 in 6. Temeljno aluminijsko nosilo je sklenjen profil, izdelan z iztiskanjem (verzija A — sliki 5 in 6).

During the optimisation process, six different versions of the bumper were examined (Fig. 4) [11]. The main parameter to evaluate whether the applied changes in the bumper structure have brought some improvements was the energy absorbed per unit weight of the bumper J/kg. An intrusion of the system 50 mm for absorbing 347 J collision energy was allowed, therefore at the end of the table on (Fig. 4) energy absorbed is calculated at maximum allowable intrusion, and the intrusion needed to absorb the prescribed amount of energy is also given.

After analysis of the present structure and its improvement, the result was achieved that a 2 % bumper mass increase provided a 28 % increase in efficiency over the basic version. For the absorption of the prescribed energy, 93.3 % allowable bumper intrusion was needed.

3 DASH—POT + BUMPER BEAM SYSTEM PENDULUM TEST AT 8 km/h

The third evaluated bumper system, dash pot + bumper beam, in addition to the already described requirements, had also one additional requirement. The aluminium beam had to be exchanged for a beam from thermoplastics composites. The new beam, because of market requirements, should be at least 20 % lighter than the original one, with at least the same performance. For the composite option, only 15 % more bumper intrusion was allowed.

Results of the performed analysis with the selected shapes of the bumper are presented (Figures 5 and 6). In general, the aluminium cross-section is a closed beam made by extrusion (version A — Figures 5 and 6).

Parametri nosilca	enota	verzija A	verzija B	
površina prereza Ay	mm^2	1548,87	2199,59	cross-section area Ay
masa	kg	4,349	4,346	weight
material		Al	TPC	material
število komponent		1	1	number of components
debelina stene	mm	3,00	6,00	wall thickness
vztrajnostni moment Iy	mm^4	951053,42	1092796,78	moment of inertia Iy
Iy/Ay	mm^2	614,029	496,818	Iy/Ay
	unit	version A	version B	Beam Parameters
Parametri nosilca	enota	verzija C	verzija D	
površina prereza Ay	mm^2	1816,01	2167,16	cross-section area Ay
masa	kg	3,588	4,282	weight
material		TPC	TPC	material
število komponent		2	2	number of components
debelina stene	mm	3,00	3,00	wall thickness
vztrajnostni moment Iy	mm^4	1054925,12	1131428,48	moment of inertia Iy
Iy/Ay	mm^2	580,901	522,079	Iy/Ay
	unit	version C	version D	Beam Parameters
Parametri nosilca	enota	verzija E	verzija F	
površina prereza Ay	mm^2	1430,85	1676,40	cross-section area Ay
masa	kg	2,827	3,313	weight
material		TPC	TPC	material
število komponent		2	2	number of components
debelina stene	mm	3,00	3,00	wall thickness
vztrajnostni moment Iy	mm^4	965272,99	929850,36	moment of inertia Iy
Iy/Ay	mm^2	674,614	554,672	Iy/Ay
	unit	version E	version F	Beam Parameters

gostota aluminija - aluminium density 2700 kg/m^3
gostota TPC - TPC density 1900 kg/m^3

Sl. 5. *Skice obdelanih prečnih prerezov odbojnika tipa dušilka + nosilo [11]*
Fig. 5. *Sketches of the evaluated cross-sections of the bumper of type dashpot + beam [11]*

verzija	debelina lupine	material nosilca	upogib nosilca	upogib nosilca	dodatna vgreznitev dušilke	dodatna vgreznitev dušilke	celotna vgreznitev sistema	celotna vgreznitev sistema	
version	wall thickness	material of beam	intrusion of bumper beam	intrusion of bumper beam	additional intrusion of dashpot	additional intrusion of dashpot	total sistem intrusion	total sistem intrusion	
enota	mm		mm	%	mm	%	mm	%	unit
A-original	3,00	Al	1,72	100,00	35,19	100,00	36,91	100,00	A-original
B-odprta	6,00	TPC 2000	20,09	1168,14	26,00	73,90	46,10	124,89	B-opened
B-zaprta	6,00	TPC 2000	15,51	901,57	28,30	80,41	43,80	118,68	B-closed
F-odprta	3,00	TPC 2000	12,12	704,48	29,99	85,23	42,11	114,08	F-opened
F-odprta	4,00	TPC 2000	7,92	460,70	32,09	91,18	40,01	108,40	F-opened
F-odprta	6,00	TPC 2000	4,73	275,17	33,68	95,72	38,42	104,08	F-opened
F-zaprta	3,00	TPC 2000	11,23	652,85	30,44	86,49	41,66	112,88	F-closed
F-zaprta	4,00	TPC 2000	7,35	427,15	32,38	92,00	39,72	107,62	F-closed
F-odprta	3,00	TPC 3000	10,93	635,17	30,59	86,92	41,51	112,47	F-opened
F-odprta	4,00	TPC 3000	7,10	412,85	32,50	92,35	39,60	107,29	F-opened
F-zaprta	3,00	TPC 3000	9,98	580,23	31,06	88,26	41,04	111,19	F-closed
F-zaprta	4,00	TPC 3000	6,62	385,12	32,74	93,03	39,36	106,64	F-closed
F+-odprta	3,00	TPC 2000	9,22	536,05	31,44	89,34	40,66	110,16	F+-opened
F+-odprta	4,00	TPC 2000	6,14	356,74	32,98	93,73	39,12	105,98	F+-opened
F+-zaprta	3,00	TPC 2000	8,66	503,26	31,72	90,14	40,38	109,40	F+-closed
F+-zaprta	4,00	TPC 2000	5,52	320,81	33,29	94,60	38,81	105,14	F+-closed
F+-odprta	3,00	TPC 3000	8,19	475,93	31,96	90,81	40,14	108,76	F+-opened
F+-odprta	4,00	TPC 3000	5,41	314,53	33,35	94,76	38,76	105,00	F+-opened
F+-zaprta	3,00	TPC 3000	7,66	445,23	32,22	91,56	39,88	108,04	F+-closed
F+-zaprta	4,00	TPC 3000	5,16	300,17	33,47	95,11	38,63	104,66	F+-closed

zaprta - zadnja stran nosilca je zaprta (podobno kakor pri originalni verziji)

closed - back side of the beam is closed (similar to the original version)

"+" - zadnja stran nosilca je pomaknjena za 10 mm navzven (povečan prečni prerez)

"+" - back side of the beam is moved 10 mm backwards (cross section is larger)

Al: $E_x=E_y=70$ GPa, $\sigma_y=270$ MPa; TPC 2000 / 3000: $E_x=30$ / 36 GPa, $E_y=10$ / 10 GPa, $\varepsilon_{max}=2$ %

Sl. 6. ***Pregled rezultatov optimizacije odbojnika tipa dušilka + nosilo pri centralnem trku nihala s hitrostjo 8 km/h [11]***

Fig. 6. ***Results overview of the bumper of type dashpot + beam optimisation at central pendulum test at 8 km/h [11]***

Kompozitna nosila smo lahko izdelali samo s procesom stiskanja v izbranem materialu (TPC-2000/ /TPC-3000)[10]. Postopek je dovoljeval izdelavo odprtih prečnih prerezov (verzija B) ali zaprtih (zlepljenjih iz dveh delov) prečnih prerezov [11] (verzija B — zaprta, F, F+, sliki 5, 6). Vsi kompozitni prečni prerezi so morali biti večji od izhodiščnega.

Composite beams could only be made by compression moulding in the prescribed material (TPC-2000/TPC-3000 [10]) which means that the cross section should be open [11] (option B — Fig. 5 and 6) or closed by gluing two open cross sections [11] (options B — closed, F, F +, Figs. 5 and 6). All composite cross-sections should not be larger than the original.

Z izbiro ustrezne oblike odbojnika, ki sem jo moral med drugim prilagoditi tudi tehnološkemu procesu, uporabljenemu pri izdelavi delov iz termoplastičnih kompozitov, sem dosegel, da se ob 10-odstotnem povečanju pomika, ki je potreben za absorpcijo predpisane količine energije, masa nosila zmanjša za 25-odstotkov [11].

With the proper choice of bumper shape, which had to be adapted to the requirements of the technological process used in manufacturing parts from thermoplastic composites, by increasing the system displacement needed for prescribed energy absorption by 10 %, a 25 % mass reduction of the bumper beam was achieved [11].

4 SKLEP

Glede na obdelane primere lahko sklenemo, da optimizacija oblike in debeline odbojnika glede na vrsto obremenitve prinaša bistvene izboljšave pri absorpciji energije trka (pri nas do 30 odstotkov). Prav tako je razvidno, da termoplastične kompozitne materiale lahko uspešno uporabimo kot alternativne materiale za nosila odbojnikov. Njihova manjša togost se uspešno nadomesti z večjo trdnostjo in ugodno relativno togostjo (E/ρ J/kg).

4 CONCLUSION

Concerning the evaluated bumper examples, it could be concluded that applying optimisation of shape and wall thickness of the structure according to the prescribed load case could bring significant improvements in collision energy absorption (up to 30 %). It is also obvious that thermoplastics or thermoplastics—composites could successfully be used as alternative materials for bumper beams. The lower rigidity of the applied materials is efficietly compensated with higher toughness, which causes an increase in relative toughness (E/ρ J/kg).

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