

## NOVEL DAMPER FOR PASSIVE SECURITY INCREASING

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### **Abstract**

*Horizontal crash at road and rail vehicles generates human and material injuries, many of them with important negative effects.*

*Damper in bumper a known solution for vehicles protection at crash is realized with different damping devices, from passive elements to actuators. Usually the devices are tuned for 5 km/h crash speed.*

*After collision the passive solutions destroy and must be removed with other new devices. The solutions using standard shock absorbers and actuators are improper the first dissipating insufficient energy and actuators being more expensive and having a long reaction time so the damping coefficient changing is realized in too low steps.*

*VZN damper concept granted with European Patent EP 1 190 184 and Romanian Patent RO 1 185 46, characterized by progressive damping coefficients with the stroke is a great opportunity to realize simple and cheap protection at crash, due to its capacity to realize constant damping force without mechanisms and electronics. It is necessary only to tune accordingly VZN damping characteristic to this desiderate.*

*VZN concept consist of a piston rod attached to a piston without valves moving inside inner cylinder close at both ends and filled at rebound and compression by specific filling valves placed in upper /bottom lids or on the ends of the inner cylinder. The damping effect is realized by valves or in cheap solution by metering orifices (holes/slots) placed sideways inner cylinder in convenient position. Due to this structure VZN tuning for constant damping force at different piston speed can be realized both with identical metering holes/slots placed at optimal distances, or placing metering holes/slots of different areas at equal distances.*

*The numbers of metering holes/slots are enough such that the steps speed evolution be practical continuous and thus the damping force be practical constant. The VZN behaviour is increased by new components e.g. levelling pistons, double guiding elements and balancing solutions. Paper presents the theory used to dimension VZN damper placing metering orifices at equal distances, a practical device with levelling piston and simulation comparative to standard one. The standard damper dissipates 30-40% lower energy comparative to VZN one. This means in the same situation in which VZN damper reduces constant speed from 30, respectively 20 [km/h] to zero, the standard dampers reduces speed up to 14, respectively 11 [km/h], then collapsing the vehicle.*

**Keywords:** *progressive damping, VZN, crash, passenger protection, body protection*

### **1. Novel damper principle**

The proposed self-adjustable shock absorber is called VZN, this acronym being abbreviation for Variable Zeta Necessary, for well displacement in all road and load conditions, where zeta represents the relative damping, which is adjusted automatically, stepwise, according to the piston position [1].

The VZN shock absorber consists of an inner cylinder having sideways valves or metering holes, inside a slidably piston moving. For VZN principle understanding, Fig. 1 presents

situations, with the piston in start position. When the stroke increases the number of active metering holes decreases, so the fluid flows out with increased resistance, generating increasing damping coefficients with the stroke. The situation is similar on rebound stroke.

Thus, for VZN the damping force is adjusted stepwise, as function of the instantaneous piston position, i.e., both on rebound and compression the damping coefficients have: low values at the beginning of the strokes (the hydraulic fluid flows out through all the metering holes); moderate values at the middle of the strokes, for a good tradeoff between comfort and wheel adherence (the hydraulic fluid flows out through half of the metering holes); high values in the working area between middle and end strokes, for better adherence and good axle movement brake (the fluid flows out through quarter of the metering holes); and very high values at the end of the strokes, for better body and axles protection (the fluid flows out through only one or two metering holes).

Using valves and/or metering slots or levelling piston the damping chart is very smoothly.

When the piston pass by the last valve/metering orifices the damping coefficient is multiplied comparative to the previous position, due to the fact the liquid flow is realized only in the gaps between inner cylinder – piston, on compression and between inner cylinder – piston and piston rod-guide on rebound, so a hydraulic bumper are realized, eliminating the risk of metal on metal contact. So the rubber bumpers can be substantially reduces or eliminate, reducing costs and gauges [3].

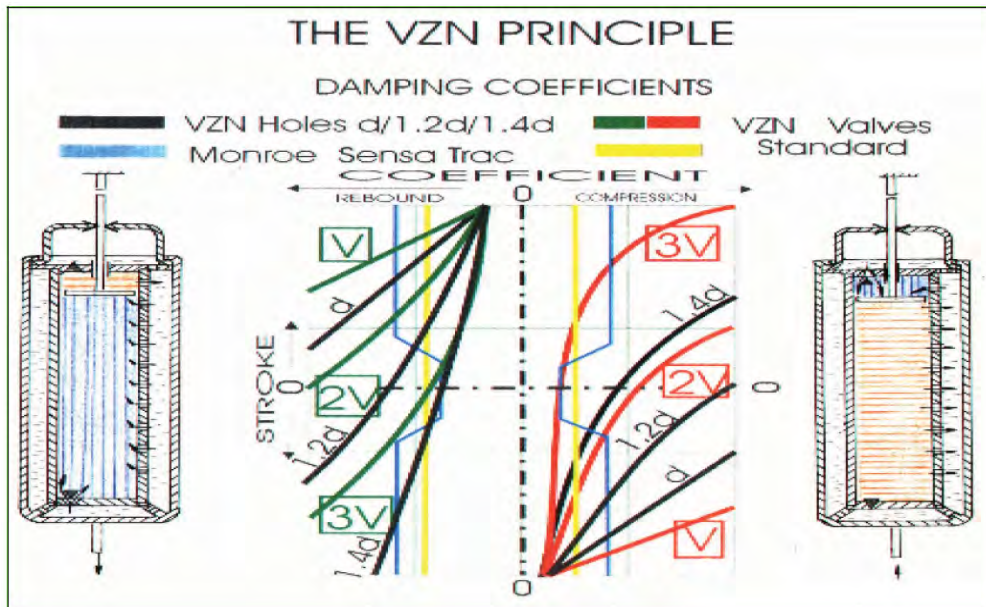


Fig. 1. The VZN principle, and damping coefficients, comparative standard and Monroe Sensa Trac

## 2. Controlled dissipation at crash

The most efficient solution to reduce crash effect is to dissipate it at constant deceleration. The limit vertical deceleration “d” for human body is:

$$d = ag, \tag{1}$$

$$\alpha = (1 - 9). \tag{2}$$

The speed “V<sub>ds</sub>” attenuated constant to 0 by the bumper damping system is function of deceleration “d” and damping stroke “s”:

$$V_{ds} = \sqrt{2ds} = \sqrt{2\alpha gs}. \tag{3}$$

The “V” speed limit for different factors “α” and “s” is presented in Tab. 1, below:

Tab. 1. Some values for safety crash speed, damped with constant decelerations  $g$ ,  $3g$ ,  $6g$ ,  $9g$ , on strokes  $0.10$  [m] and  $0.20$  [m] and  $0.4$  [m]

d [m/s <sup>2</sup> ]	g			3g			6g			9g		
s [m]	0.10	0.20	0.40	0.10	0.20	0.40	0.10	0.20	0.40	0.10	0.20	0.40
V <sub>ds</sub> [m/s]	1.4	1.98	2.80	2.42	3.43	4.85	3.43	4.85	6.86	4.2	5.94	8.4
V <sub>ds</sub> [km/h]	5.0	7.1	10.1	8.7	12.3	17.5	12.3	17.5	24.7	15.1	21.4	30.3

The results presented in Tab. 1 are illustrated in Fig. 2.

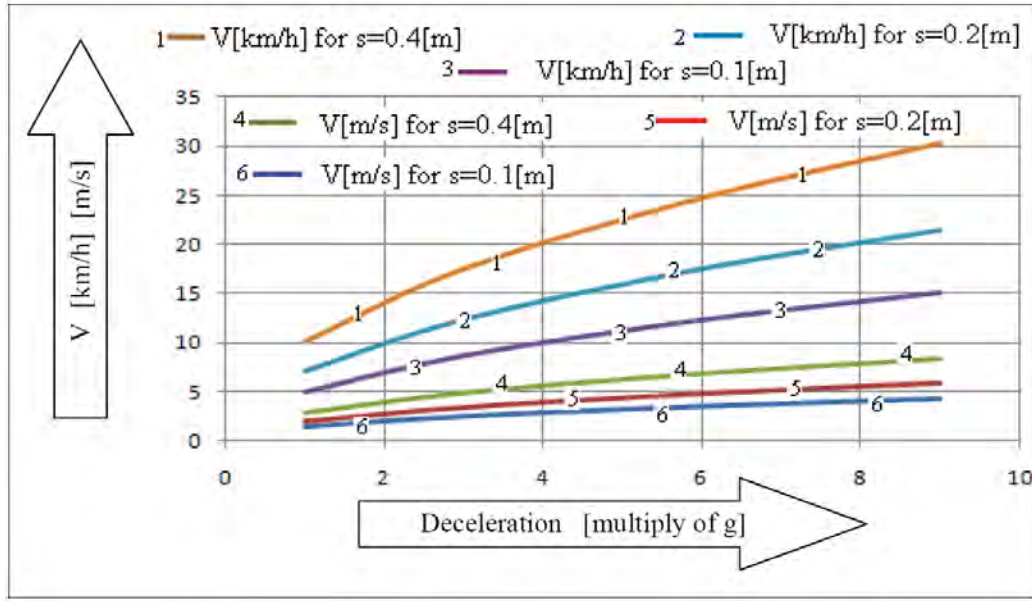


Fig. 2. Values for safety collision speed, with constant decelerations  $g$ , to  $9g$  on strokes  $0.10$  [m],  $0.20$  [m] and  $0.4$  [m]

### 3. Damping tuning solution

This solution consider the valve/metering orifices are placed at equal distance “ $\delta$ ” to each other [2].

Because the cinematic energy varies with square speed we divide this speed area in “ $n$ ” steps so the one step square speed is:

$$(\Delta V)^2 = (V)^2/n. \quad (4)$$

At the step “ $n$ ” the beginning square speed is  $V_n^2$  and final square speed is  $V_{n-1}^2$ , where:

$$V_n^2 = V_{n-1}^2 + \Delta V^2, \quad (5)$$

$$V_n = V. \quad (6)$$

The cinematic energy variation “ $\Delta E_c$ ”  $c \Delta E$  on a step “ $i$ ” for “ $m$ ” vehicle mass is:

$$\Delta E_{ci} = \frac{m}{2}(V_i^2 - V_{i-1}^2) = \frac{m}{2}\Delta V_i^2 = \frac{m}{2}\Delta V^2 = \Delta E_c. \quad (7)$$

On a step „ $i$ ” the damper dissipates “ $\Delta E_d$ ” energy:

$$\Delta E_{ci} = F_{di}\delta = F_d\delta = (c_i V_i^2)\delta = \Delta E_d. \quad (8)$$

From these energies  $c \Delta E_c, \Delta E_d$  equality results the equal distances  $\delta$  between – metering orifices:

$$\delta = \frac{m\Delta V_i^2}{2F_{di}} = \frac{m\Delta V^2}{2F_d} = \frac{m \frac{V^2}{n}}{2F_d} = \frac{mV^2}{2mn\alpha g}. \quad (9)$$

The damping force is calculated at human body admissible deceleration “ $d$ ” like multiply “ $\alpha g$ ” of gravitational acceleration “ $g = 9.81 [m/s^2]$ ”:

$$F_d = md = m\alpha g. \quad (10)$$

For step “ $i$ ” the damping force has expression:

$$F_{di} = c_i \overline{V}_i^2, \quad (11)$$

where:

“ $c_i$ ” - is damping coefficient at the step “ $i$ ”,

$F_{di} = F_d = \text{constant}$  - is damping force, imposing constant along stroke,

“ $\overline{V}_i$ ” - is average speed along step “ $i$ ”.

So the damping coefficients for each step “ $i$ ” will calculate with relation:

$$c_i = \frac{F_d}{\overline{V}_i^2} = \frac{m\alpha g}{\overline{V}_i^2}, \quad (12)$$

$$\overline{V}_i^2 = V_i^2 - \frac{\Delta V_i^2}{2} = V_i^2 - \frac{V^2}{2n}. \quad (13)$$

The average speed at the final step “ $n$ ” is calculated with relation:

$$\overline{V}_n^2 = V_n^2 - \Delta V^2 = V^2 - \Delta V^2. \quad (14)$$

The next average speeds for steps “ $i$ ” are calculates with:

$$\overline{V}_i^2 = V_i^2 = \Delta V^2. \quad (15)$$

So all elements necessary to calculate the damping coefficients are defined.

#### 4. Damper dimensions for a medium vehicle

Force for a mass “ $m$ ” constant deceleration from “ $V$ ” speed to zero is:

$$F_{md} = md = F_{ms} = m \frac{V^2}{2s}. \quad (16)$$

To constant decelerate a medium vehicle having 1500 kg fully loaded state, from 20 km/h to zero, during “ $s$ ” damping stroke, necessary force are presented in Tab. 2, and illustrated in Fig. 3.

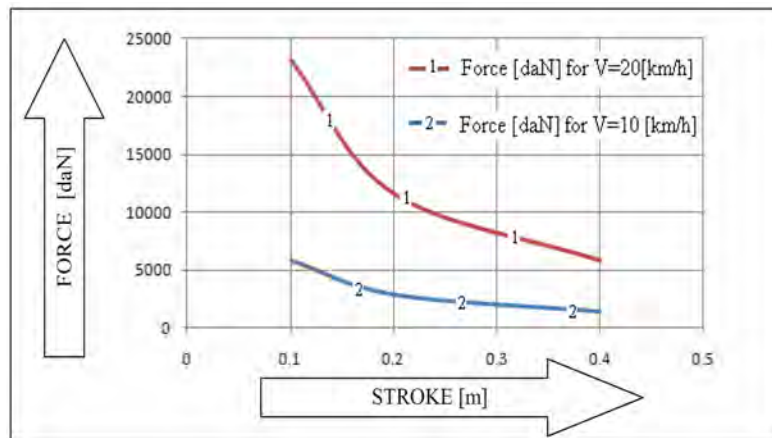


Fig. 3. Correlation between damping force and damping strokes at medium vehicle (having 1500 kg fully loaded state) constant deceleration from 20 [km/h] to zero

To realize damping forces the piston diameter 1 “D” function working pressure is:

$$D_1 = 2\sqrt{\frac{F}{\pi \cdot p_{tech}}} = 1.128\sqrt{\frac{F}{10^5 p_{IS}}} = 0.003567\sqrt{\frac{F}{p_{IS}}}. \quad (17)$$

The damping force is realized by 2 dampers so their diameter “D<sub>2</sub>” is:

$$D_2 = 2\sqrt{\frac{F/2}{\pi \cdot p_{tech}}} = \frac{0.003567}{\sqrt{2}}\sqrt{\frac{F}{p_{IS}}} = 0.00252\sqrt{\frac{F}{p_{IS}}} = \frac{D_1}{\sqrt{2}} = 0.707D_1. \quad (18)$$

Tab. 2 presents the diameters necessary to realize damping forces presented in Tab. 1, at 100 and 200 [daN/cm<sup>2</sup>] working pressure.

Tab. 2. Correlations between damping force, damping stroke, damping pressure and diameter damper, at medium vehicle (1500 kg) constant deceleration from 20 [km/h] to zero

V [km/h]	10						20					
s [m]	0.10		0.20		0.40		0.10		0.20		0.40	
F [daN]	5787		2894		1447		23148		11574		5787	
p [dan/cm <sup>2</sup> ]	100	200	100	200	100	200	100	200	100	200	100	200
D <sub>1</sub> *10 <sup>-3</sup> [m]	27.1	19.2	19.2	13.6	13.6	9.6	54.3	38.4	38.4	27.2	27.2	19.2
D <sub>2</sub> *10 <sup>-3</sup> [m]	19.2	13.6	13.6	9.6	9.6	6.8	38.4	27.2	27.2	19.2	19.2	13.6

## 5. Test conditions

The evaluation of the different behaviour conferred by VZN damper comparative to Standard one two tuning is used, each of them at two impact velocities. Both dampers are tuned to develop maximal deceleration of:

- Case 1 “9g” at V=30 [km/h] speed,
- Case 2 “6g” at V=20 [km/h] speed.

According (16) the maximal damping force for “6g” and “9g” constant decelerate a 1500 [kg] vehicle is:

$$F_{m,d} = md = m(\alpha g) = \begin{cases} F_{1500,9g} = 1500 \cdot (9g) = 1500 \cdot 88.29 \approx 133000[N] & \text{- Case 1,} \\ F_{1500,6g} = 1500 \cdot (6g) = 1500 \cdot 58.86 \approx 88300[N] & \text{- Case 2} \end{cases} \quad (19)$$

The standard damper gives constant damping force along stroke after formula:

$$F_{dMax} = c_{V^i}^S V^i, \quad (20)$$

$$i = \begin{cases} 0 \div 1 & \text{- at low piston speed,} \\ 1 \div 2 & \text{- at medium piston speed,} \\ 2 \div 3 & \text{- at high piston speed.} \end{cases} \quad (21)$$

The maximum energy is dissipated if “i=1”, so in order to be covered we have worked so.

The damping coefficients for standard damper to realize forces according (19) for “i=1” at 20 [km/h] and 30 [km/h] speeds, specific both cases, are:

$$c_{V^i}^S = \frac{F_{dMax}}{V^i} = \frac{F_{dMax}}{V^i} \left\{ \begin{array}{l} \frac{F_{dMax}}{V_{30}} = \frac{133000}{30} = \frac{133000}{8.33} \approx 16000 [N \cdot s / m] - \text{Case 1,} \\ \frac{F_{dMax}}{V_{20}} = \frac{88300}{20} = \frac{88300}{5.55} \approx 16000 [N \cdot s / m] - \text{Case 2.} \end{array} \right. \quad (22)$$

The damping force for VZN damper is constant both cases:

$$F_d^{VZN} = \begin{cases} 133000 [N] - \text{Case 1,} \\ 88300 [N] - \text{Case 2.} \end{cases} \quad (23)$$

To maintain the bumper at full extension position under air pressure and to redress it after collision a low inner damper pressure or an additional spring are used. Their values are neglected in simulation, representing less 1%.

### 6. Crash simulation model

The virtual model is presented in Fig. 4, where from left to right be presented:

- the initial moment when vehicle move with “V” constant velocity,
- the contact between vehicle bumper and obstacle contact, when started decelerated movement,
- the final moment when the damper had dissipated energy on the “s” distance.

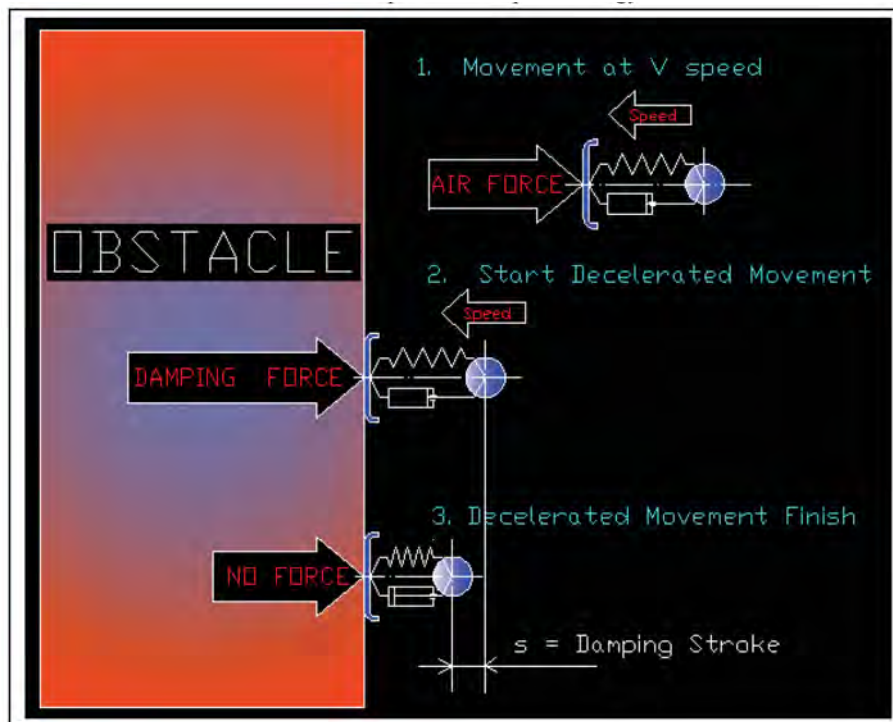


Fig. 4. The crash simulation model

### 7. Horizontal crash simulation, for bumpers equipped with VZN and standard damping

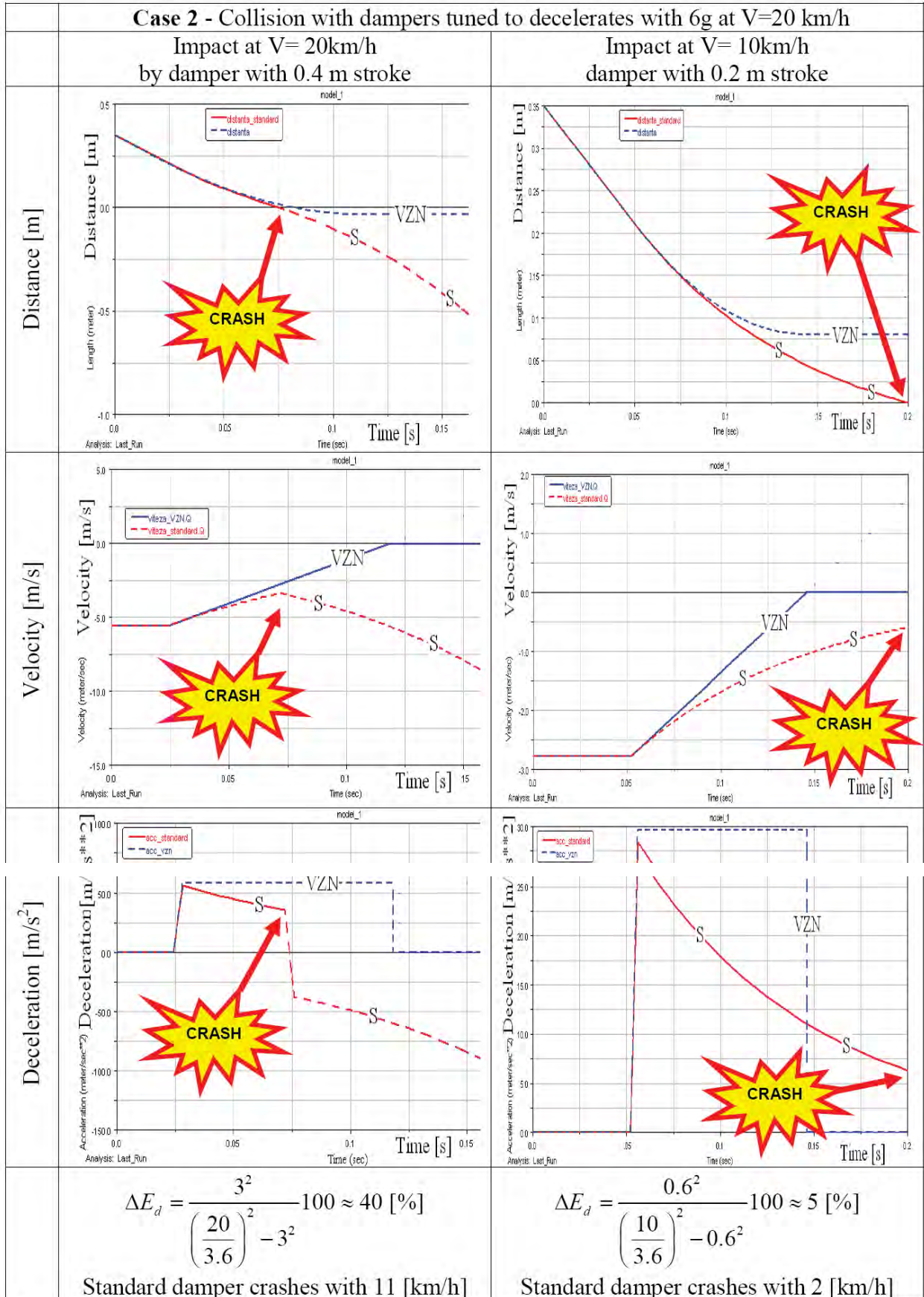
According previous chapter the simulation was made for two tuning cases, both at two impact velocities. Were used ADAMS software View module. The dampers behaviour were realized using functions Impact, Contact and If.

All simulations show Standard damper can't dissipates impact energy, crashing vehicle with 2-14 [km/h] speed, at the same time VZN one decreases speed to zero protecting the vehicle.

Tab. 3. Collision with dampers tune d to decelerate with “9g” at V=30 [km/h], tested at 30 [km/h] and 20 [km/h] impact velocities

Case 1 – Collision with dampers tuned to decelerate with 9g at V=3- km		
	Impact at V=30 km/h by damper with 0.4 m stroke	Impact at V=20 km/h by damper with 0.2 m stroke
Distance [m]		
Velocity [m/s]		
Deceleration [m/s <sup>2</sup> ]		
Conclusio	$\Delta E_d = \frac{4^2}{\left(\frac{30}{3.6}\right)^2 - 4^2} 100 \approx 30 \text{ [%]}$ <p>Standard damper crashes with 14 [km/h]</p>	$\Delta E_d = \frac{1.4^2}{\left(\frac{20}{3.6}\right)^2 - 1.4^2} 100 \approx 7 \text{ [%]}$ <p>Standard damper crashes with 5 [km/h]</p>

Tab. 4. Collision with dampers tune  $d$  to decelerate with “9g” at  $V=30$  [km/h], tested at 30 [km/h] and 20 [km/h] impact velocities





The energy dissipated difference “ $\Delta E_d$ ” is

$$\Delta E_d = \frac{E_d^{VZN} - E_d^S}{E_d^S} 100 = \frac{(V_{contact}^2 - V_{VZNstop}^2) - (V_{contact}^2 - V_{Sstop}^2)}{(V_{contact}^2 - V_{Sstop}^2)} 100 = \frac{V_{Sstop}^2}{(V_{contact}^2 - V_{Sstop}^2)} 100 [\%], \quad (24)$$

$$V_{VZNcontact} = V_{Scontact} = V_{contact} = \text{Impact velocity}, \quad (25)$$

$$E_d^{VZN} = \frac{m(V_{VZNcontact}^2 - V_{VZNstop}^2)}{2}, \quad (26)$$

$$E_d^S = \frac{m(V_{Scontact}^2 - V_{Scollapse}^2)}{2}. \quad (27)$$

where:

$E_d^{VZN}$ ,  $E_d^S$  are energies dissipated by VZN and standard dampers,

$V_{VZNcontact}$ ,  $V_{Scontact}$  are initial piston speed for VZN and standard dampers,

$V_{VZNstop}$ ,  $V_{VZNstop}$  are final piston speed for VZN and standard dampers.

## 8. Damper In Bumper Device

Figure 5 presents the structure and components for bumper with VZN damper.

To be proper for vehicle collision, the VZN damper concept has supplementary components presented below [4]:

- progressive attenuating system, realized with valve or metering orifices (5),
- double guiding elements (12),
- additional balance chamber (solid with, or separated by reservoir cylinder) (8),
- levelling piston (10).

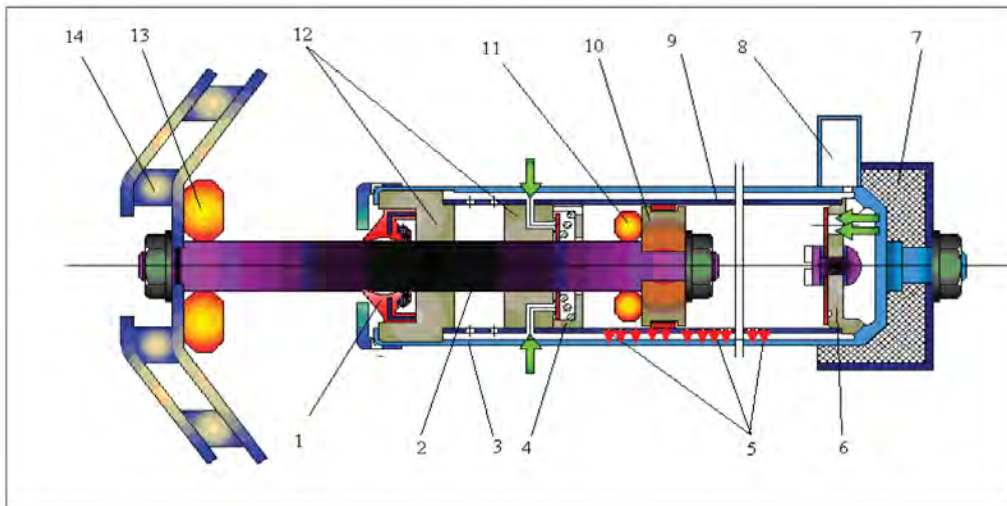


Fig. 5. Damper in bumper structure and components

Other elements in damper structure are:

- sealing element (1),
- piston rod (2),
- reservoir cylinder (3),
- compression filling valve (4),
- rebound filling valve (6),

- rubber mount on body (7),
- inner cylinder (9),
- rebound stopper bumper (11),
- compression stopper bumper (13),
- vehicle reinforced bumper (14).

Levelling piston has an inner chamber linked with working chamber by wall with metering orifices, the inner chamber volume being controlled by an additional piston/membrane reinforced with a spring or by pressurized air [4].

## 9. Conclusions

VZN damper concept has possibility to be tuned for gives constant deceleration at impact, being proper for automotive damper in bumper.

According simulation results VZN damper with 0.4 [m] stroke protects at collision with 30 km/h, and with stroke of 0.2 [m] protects at collision at 20 [km/h] vehicle speed, without damages. Of course the body structure must be consolidated accordingly.

At collision with increased speed the energy will be dissipated in first step by bumper damper and then by the body structure, and so the real safety collision speed being above 30 [km/h], situation with body damages but without passenger injures.

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