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# THE USE OF ADDITIONAL DEVICES FOR REDUCING THE DEFORMATION OF THE BUS BODY WHEN TIPPING

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**ABSTRACT**

The article is devoted to the solution of practical problems in the sphere of buses passive safety. Particularly, the methods of reducing bus body deformation when tipping due to reducing the height of fall of centre of gravity are worked out. The dependence of the distribution of impact energy for every stand of the left side of the bus body of LiAZ- 5256 from the length of sliding part of the piston rod device to prevent tipping is identified and investigated. The dependence of the displacement of every left cheek of bus body of LiAZ- 5256 from the length of retractable stem of suggested device is determined. The realized studies prove that devices like that the authors of the article offered are able to reduce the deformation of the pillars of the bus when while tipping. Thus, the greater is the length of the stroke of the device, the smaller is the amount of pillars movement in the direction of the residual space of the passenger compartment of the bus.

**Keywords:** bus, passive safety, potential energy, tipping, strength, deformation, load of failure, device, prevent tipping.

## 1. INTRODUCTION

The problem of passive safety of buses when tipping is very serious. According to statistics in such traffic collisions from 3 to 7 people get injured and from 1 to 4 died. The frequency of such road accidents in Russia is once a month, for comparison in Egypt, where the situation with bus transportation is one of the worst in the world, such road accidents happen twice a month. That shows that any studies about the safety increase of traffic including the perfection of passive safety of buses is important.

Such leading institutes of higher education as MSTU n. a. N. E. Bauman, MSARTU, NSTU n. a. R. E. Alekseev, DSTU, RTRI, SSC RF FSUE «NAMI» and others study the questions of increasing the passive safety of buses in RF.

In these article the way to reduce deformation of the bus body when tipping is offered. Since 2010 the device to prevent tipping of the vehicle on the top was patented [1]. Later it was improved [2, 3].

## 2. PROBLEM STATEMENT AND PRELIMINARIES

### 2.1. Problem statement

The device represents the following construction (Figure-1), which is installed under the bus body.

It consists of the angular position sensor 1 and the control package 2, which are united with constant-current source 3, gas-generator 5, pyrocatridge 4, pneumocylinder 6 with rod 9, at the end of which a thrust block is fixed 8, with pneumonic cell 7.

The tilting of the vehicle body by an angle which exceed the critical value the closure of the contacts of the sensor of angular position 1 happens. Control package 2 is connected with the constant current source 3, the actuator 4 of the gas generator 5, gas mixture, the combustible mixture being ignited, forms a gas ejector rod 9 of the pneumatic cylinder 6 with attached to its end thrust block 8. Pneumotic cell which also receives gas from the gas generator 5 is fixed to the inner side of thrust block 8. While pulling out the rod 9 on maximum length which is limited by pneumotic cell 7, the latches of the cylinder 6 prevent return movement of the rod 9.

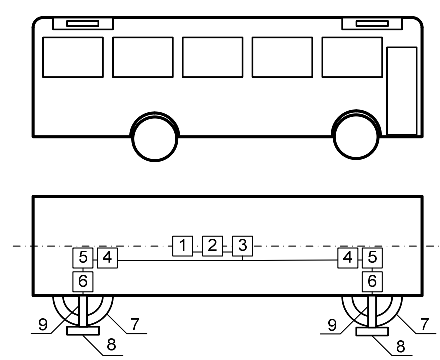


**Figure-1.**The design of the device to prevent tipping of.

### 2.2. Reduction of the potential energy generated from the overturning of the bus

The technical result that can be obtained by realizing the suggested invention is in reduction of the potential energy generated from the overturning of the bus, by reducing the drop height of the center of gravity of the bus. In detail these questions are illustrated in the work [4]. In this article the following formula for determining

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drop height of the center of gravity of the bus, equipped counter overturning block is published:

$$h = h_0 + \sqrt{\left(\frac{W}{2}\right)^2 + H_з^2} - \sqrt{a^2 + l_{\text{шт}}^2 + 2a \cdot l_{\text{шт}} \cdot \cos(\operatorname{arctg}\frac{2(H - H_з)}{W})} \times$$

$$\times \sin\left[\begin{array}{l} \arcsin\dfrac{h_0}{\sqrt{\left(\frac{W}{2}\right)^2 + H^2}} + \\ + \arccos\dfrac{a^2 + l_{\text{шт}}^2 + 2a \cdot l_{\text{шт}} \cdot \cos(\operatorname{arctg}\frac{2(H - H_з)}{W}) + H^2 - H_з^2}{2\sqrt{a^2 + l_{\text{шт}}^2 + 2a \cdot l_{\text{шт}} \cdot \cos(\operatorname{arctg}\frac{2(H - H_з)}{W})} \cdot \sqrt{\left(\frac{W}{2}\right)^2 + H^2}} \end{array}\right], \quad (1)$$

where

$W$, $H$= overall width and height of the bus

$H_3$ = the height of the center of gravity of the bus;

$h_o$= the minimum height of the tipping platform, $h_o$= 800 mm;

$l_{\text{шт}}$ = the length of the sliding part of the piston rod of counter over turning vehicle.

Formula (1) can be simplified by introducing the following notation:

$$a = \sqrt{\left(\frac{W}{2}\right)^2 + \left(H - H_з\right)^2}, \quad R = \sqrt{\left(\frac{W}{2}\right)^2 + H^2}, \quad R1 = \sqrt{\left(\frac{W}{2}\right)^2 + H_з^2}$$

$$Q = \sqrt{a^2 + l_{\text{шт}}^2 + 2a \cdot l_{\text{шт}} \cdot \cos(\operatorname{arctg}\frac{2(H - H_з)}{W})} = \sqrt{a^2 + l_{\text{шт}}^2 + \frac{2a \cdot l_{\text{шт}}}{\sqrt{1 + \left[\frac{2(H - H_з)}{W}\right]^2}}}$$

the result will be following:

$$h = h_0 + R1 - Q \cdot \sin\left[\arcsin\frac{h_0}{R} + \arccos\frac{Q^2 + H^2 - H_3^2}{2RQ}\right].$$

By using the conversion formula for the simplest trigonometric functions, we get the following formula:

$$h = h_0 + R1 - \frac{h_0 \cdot (Q^2 + H^2 - H_3^2)}{2R^2} - Q\sqrt{\left[1 - \left(\frac{h_0}{R}\right)^2\right] \cdot \left[1 - \left(\frac{Q^2 + H^2 - H_3^2}{2R \cdot Q}\right)^2\right]}. \quad (2)$$

Thus, the adjusted formula for determining the potential energy of the impact will be following:

$$E = 0.75 \cdot M \cdot g \cdot \left(\begin{array}{l} h_0 + R1 - \dfrac{h_0 \cdot (Q^2 + H^2 - H_3^2)}{2R^2} - \\ - Q\sqrt{\left[1 - \left(\frac{h_0}{R}\right)^2\right] \cdot \left[1 - \left(\frac{Q^2 + H^2 - H_3^2}{2R \cdot Q}\right)^2\right]} \end{array}\right), \quad (3)$$

where

*0,75*= index that takes into account the weight of the bus that affect the impact energy;

$M$ = the full weight of the bus;

$g$ = free fall acceleration.

Then we will determine the relationship between the movements of the window stands of sidewalls of the body when bus overturns from the value of the potential energy. We need:

a) To determine the distribution of the total energy impact on the pillars, taking into account the uneven distribution of the axle loads of the bus.

b) To determine the value of failure load for each pillars of investigated sidewalls of the body.

c) To establish the dependence of the moving window hours from the energy attributable to the pillar.

While distributing the total impact energy on the pillars taking into account the uneven distribution of the load on the axle of the bus one can use the following study [5]. According to this article, the adjusted share of energy per rack, the formula can be calculated by:

$$E_{ji} = E_{jcp}(1 + Y_i), \quad (4)$$

where

$E_{ji}$ = the amount of energy falling on each window rack sides of the bus body, $J$;

$E_{jcp}$ = the average energy falling on the i-th rack front or back of the bus

$Y_i$ = index, taking into account the uneven distribution of energy for the racks of bus body.

In the second stage, destroying load can be defined by the following method:

- Calculating [6, 7, 8, 9]
- Experimental-calculated [10]
- Damaging [11, 12, 13, 14, 15]

We will use the latter method, providing for preliminary determination of values of breaking load for each rack, $P_{kpi}'$, made of a rigid-plastic material (Figure-2 schedule a). The breaking load at that assumption will be determined by following formula:

$$P_{kpi}' = \frac{E_{ji}}{y_i}, \quad (5)$$

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where $y_i$ = motion of i-th rack, obtained by the overturning of the bus.

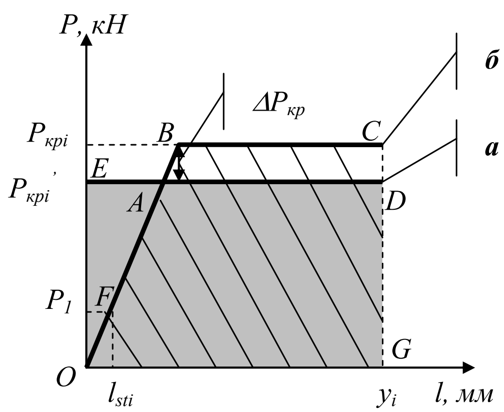


**Figure-2.**Diagram of deformation of pillars.

a - for material with rigid-plastic properties; b - for a material with ideai elastic-plastic properties

-the area of the rectangle OEDG, corresponding to strain energy $E_{ji}$ and used for $P_{kpi}'$ determination;

-the area of the trapezium OBCG, corresponding to strain energy $E_{ji}$ and used for $P_{kpi}$ determination

For an ideal elastic-plastic material (Figure-2 schedule b) breaking load $P_{кр}$ will be determined by the formula

$$P_{kpi} = \Delta P_{kpi} + P_{kpi}', \qquad (6)$$

where $\Delta P_{kpi}$ = the difference between the values of failour loads $P_{кр}$ and $P_{кр}'$. It can be determined by equating the area of a triangle the OAE ane the trapezium ABCD (Figure-2).

$$S_{\Delta} = S_{mpan}.$$

With the help of simple mathematical operations, we get the following quadratic equation:

$$A \cdot \Delta P_{kpi}^{2} + B \cdot \Delta P_{kpi} + C = 0, \qquad (7)$$

where

$$A = \frac{l_{sti}}{2 \cdot P_1};$$

$$B = P_{кpi}' \cdot \frac{l_{sti}}{P_1} - y_i;$$

$$C = P_{кpi}'^{2} \cdot \frac{l_{sti}}{2 \cdot P_1}.$$

It is possible to establish the dependence of movement of the rack from the energy by determining the value of the energy falling on each rack (3) and calculating the destructive load (4). We can use the diagram presented in Figure-2 schedule b. The rectangular area of a trapezium is equal to the potential energy and its value is determined by the formulas (2, 3). Therefore the motion of the pillar can be calculated by the formula:

$$l_i = \frac{E_i}{P_{кр}} - \frac{P_{кр} \cdot l_{sti}}{2P_1}, \qquad (8)$$

where

$l_i$ = required motion of the pillar, mm;

$E_i$ = impact energy per pillar, J;

$P_{кр}$ = critical load for pillar, kN;

$P_1$ = force applied to the body of the bus according to the scheme of the experiment presented in Figure-3.

$l_{sti}$ = the displacement corresponding to the value of the specified force $P_1$, mm.

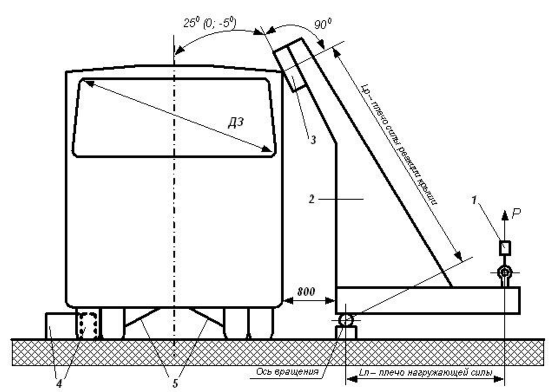


**Figure-3.**The scheme of bus body loading.

1 -place of effort, 2 - installation frame, 3 - wooden block, 4,5 - holding means respectively from the rollback and overturning of the bus.

The experiment which scheme is presented in Figure-3 was carried out on Dmitrovskiautorange SSC RF GFUP "NAMI". The bus LiAZ-5256 was loaded. Over 3, 5 and 8 racks movement pickups were installed at the level of 500 mm respectively (P1, P3, P5) and 1250 mm (P2, P4, P6) from the fastening seat. Over 3rd rack the sensors P5, P6 were installed, over 5th- P3, P4, over 8th- P1. Levels 500 mm and 1250 mm are the lower and upper limits of the residual space of the passenger compartment of the bus.

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For further calculations it is possible to select a single value of the load of the top of the bus, for example, $P_l$ = 67 kN and the corresponding movement of the rack on the level 1250 mm: $l_{st3}$ = 2,3 mm, $l_{st5}$ = 3,6 mm, $l_{st8}$ = 12,3 mm.

Lets define the relationship between the movement of the window racks of the sidewalls of the body when the overturning of the bus LiAZ- 5256 ($P_l$. 1) from the amount of the potential energy by the proposed method.

**Table-1.**The initial data for calculations.

| **Массогабаритныепараметры автобуса** | |
|---|---|
| **Brand and model of the bus** | **LiAZ-5256** |
| Height, H, m | 3,007 |
| Width, W, m | 2,5 |
| The height of the center of gravity, NC,m | 0,87 |
| The minimum height of tipping, h0,m | 0,8 |
| Total mass, M, kg | 17930 |
| The load on the rear axle, MoH, kg | 11500 |

Having received the input data for calculations we will investigate the bus LiAZ-5256 by the proposed method. After a gradual calculating of values according to the formulas (2-4), (6-8), we will obtain the following results, presented in Table-2.

First of all it should be noted that the results of calculations of the movements of the racks without the use of counteroverturning device (if 1 piece=0), are very close to the results of the experiment of the overturning of the complete bus LiAZ-5256 which is carried out on autorange Dmitrovski (Figure-4).

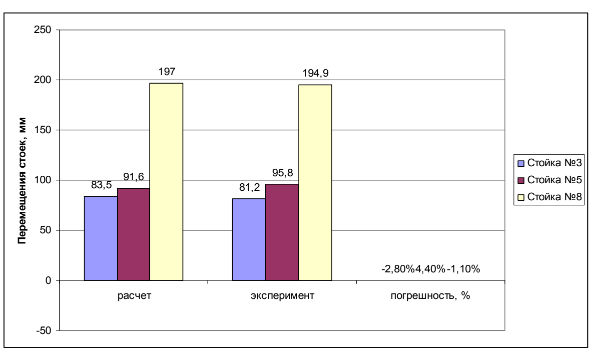


**Figure-4.**Comparative analysis of the calculated displacements ofracks and results of experimental studies on the complete overturning of the vehicle LiAZ-5256.

Figure-4 presents a comparative analysis of the calculated and experimental data. Foe the 3rd rack of left sidewall it is 2.8%, for the 5th rack - 4.4%. for 8th- 1.1%. This analysis shows that using the proposed method can predict the deformation of the bus body when tipping it under the terms of the certification testing according to the ECE Regilations NO.66 [16].

Then we will consider the change of height of overturning h. mm. and the total impact energy E, J, from the length of the sliding part of the rod of counteroverturning device (Figures 5, 6).

Let's build a parabolic regression equation for the graph presented in Figure-5. The coefficient of determination is $R_2$=0,9996 which indicates the coincidence of the estimated model with the regression equation. Thus, the model can be described by the following equation:

$$y = 45,633x^2 - 489,28x + 704,49. \quad (9)$$

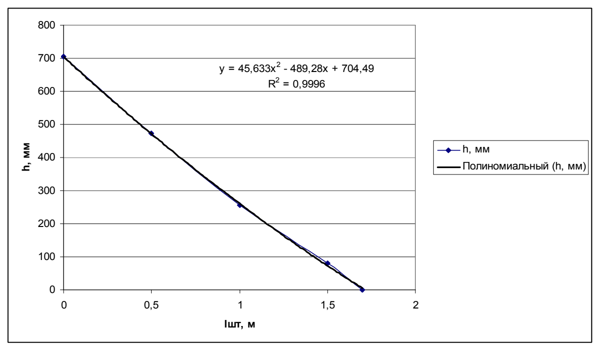


**Figure-5.**Regression analysis of the dependence of the drop height of the center of gravity of the bus LiAZ-5256 (h, mm) from the length of the sliding part of the rod of counter overturning device (*l* piece, m).

*At x* = 1,71 m *y* = 0, i.e. At the length of the rod $l_{шт}$= 1,71 m the center of gravity of the bus LiAZ-5256 reaches the highest point and will no longer make a rotational movement in the transverse plane. Accordingly, the impact energy *E*, *J*, according to the formula (3), must also be equal to zero (Figure-6). The dependence of the bus LiAZ-5256 impact energy (*E*, *j*) from the length of the sliding part of the rod of counter overturning device (*l* piece, m), is described by the following parabolic equation regression:

$$y = 9188,3x^2 - 68258x + 93282. \quad (10)$$

at*x* = 1,8 m, *y* = 0, i. e. at the length of the rod $l_{piece}$= 1,8 *m*, *E* = 0.

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**Table-2.** The dependence of distributed energy impact and displacement pillars from the length of the sliding part of the rod of counter overturning device.

| **No.** | $P_{кр i}$*, kN | $l_{экс}$**, mm | $l_{шт}$***=0 | | $l_{шт}$=0,5 m | | $l_{шт}$=1,0 m | | $l_{шт}$=1,5 m | | $l_{шт}$=1,7 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $E_i^{4*}$, J | $l_i^{5*}$, mm | $E_i$, J | $l_i$, mm | $E_i$, J | $l_i$, mm | $E_i$, J | $l_i$, mm | $E_i$, J | $l_i$, mm |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| 1 | 59,7 | - | 4562 | 75,4 | 3075 | 50,5 | 1652 | 26,6 | 528 | 7,8 | 224 | 2,7 |
| 2 | 68,2 | - | 5455 | 78,9 | 3676 | 52,7 | 1975 | 27,8 | 631 | 8,1 | 268 | 2,8 |
| 3 | 78,1 | 81,2 | 6630 | 83,5 | 4468 | 55,9 | 2400 | 29,4 | 767 | 8,5 | 325 | 2,8 |
| 4 | 87,5 | - | 7759 | 87,1 | 5229 | 58,3 | 2809 | 30,6 | 897 | 8,8 | 381 | 2,9 |
| 5 | 95,3 | 95,8 | 8888 | 91,6 | 5990 | 60,3 | 3218 | 31,2 | 1028 | 8,2 | 436 | 2,0 |
| 6 | 42,8 | - | 7589 | 173.4 | 5115 | 115,6 | 2747 | 60,3 | 878 | 16,6 | 372 | 4,8 |
| 7 | 54,1 | - | 10274 | 185.1 | 6925 | 123,0 | 3719 | 63,8 | 1188 | 17,0 | 504 | 4,4 |
| 8 | 63,9 | 194,9 | 12959 | 197,0 | 8734 | 130,8 | 4691 | 67,6 | 1499 | 17,6 | 636 | 4,1 |
| 9 | 68,0 | - | 14193 | 202.5 | 9566 | 134,4 | 5138 | 69,3 | 1642 | 17,9 | 697 | 4,0 |
| 10 | 69,1 | - | 14529 | 204.0 | 9792 | 135,4 | 5260 | 69,8 | 1680 | 18,0 | 713 | 4,0 |
| $E^{6*}=\Sigma E_i$, J | | | 92838 | | 6257 0 | | 33609 | | 10738 | | 4557 | |
| $h^{7*}$, mm | | | 704 | | 474 | | 255 | | 81,4 | | 0,034 | |

Note.
* The values of the breaking load for each rack. It is defined by the formulas (6, 7).
** The displacement values of 3, 5, 8 pillars, obtained as the result of the experiment on the overturning of the bus.
*** Set points of the sliding part of the length of the rod of counter overturning device.
4* The values of distributed energy impact (4) depending on *l* piece.
5* The displacement values of pillars (formula 8) depending on *l* piece.
6* The total impact energy value calculated by the formula (3), depending on *l* piece.
7* The value of the drop height of the center of gravity of the bus (formula 2), depending on *l* piece.

We will dwell in more detail on the relationship between the movements of each left-sides rack of the body of the bus LiAZ-5256 from the length of the sliding part of the rod of counter overturning device. ($l_{piece}$, m). For that we will consider how does the distribution of the total impact energy, $E_i$, $J$, depend on each rack (Figure-7). In this figure, on the *y*-axis, denoted by $E_i$, $J$, the distribution of the total impact energy, E, *J*, on each rack is presented. Thus $E = \Sigma E_i = 92838\ J$. On the x-axis the length of the rod of counter overturning site is marked. As we can see from the Figure-7 in process of increasing the length of the rod the value of the energy falling on each rack is reduced. In order to determine at what length stem energy will be equal to zero, we construct a regression equation, for example, for the 5-th rack:

$$y = 879{,}27x^2 - 6534{,}1x + 8930{,}4. \qquad (11)$$

This value is achieved at $x = 1{,}8$ m.

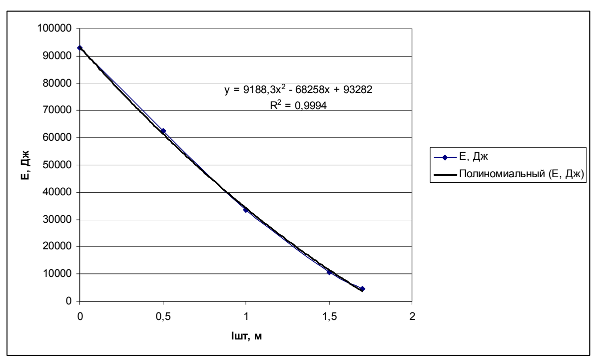


**Figure-6.** Regression analysis of the dependence of the total energy impact of LiAZ-5256 (*E, J*) from the length of the sliding part of the rod of counteroverturning device(*l* piece, m).

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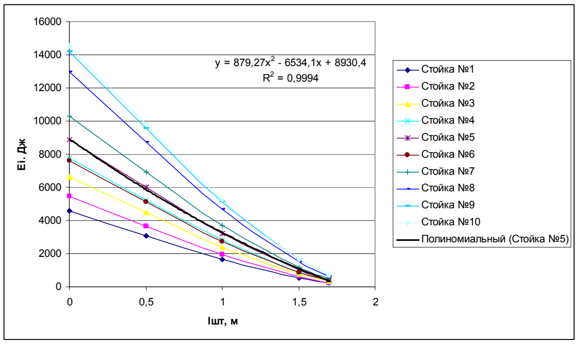


**Figure-7.**The dependence of the distribution of impact energy for each column of the left sides of the body of the bus LiAZ-5256 from the length of the sliding part of the rod of counter overturning device (*l* piece, m).

The dependence of the movement of each rack left sides of the body of the bus LiAZ-5256 from the length of the sliding part of the rod of counter overturning device is presented in Figure-8. Let's determine at what length stem energy will be equal to zero and displacement of this rack will not happen. For that we will create a regression equation for 5th rack:

$$y = 9{,}9449x^2 - 70{,}248x + 91{,}983, \quad (12)$$

at$x$ = 1,74 m displacement of the 5th rack in the direction of the residual space will not happen. The errors between the values calculated from equations (9-12), do not exceed 5%.

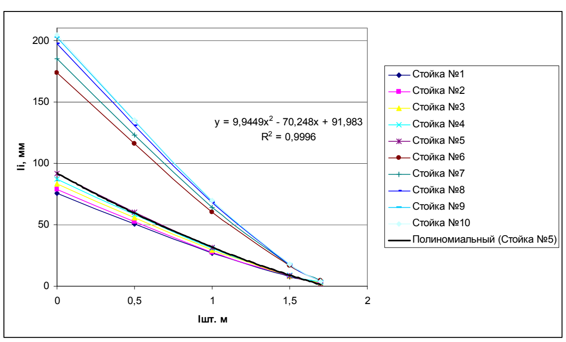


**Figure-8.**The dependence of the movement of each left sides rack of the body of the bus LiAZ-5256 from the length of the sliding part of the rod of counter overturning device.

## 3. CONCLUSIONS

This article specified formulae for calculating:

- the drop height of the center of gravity of the bus;
- The potential (general) impact energy.
- Following relationships are investigated:
- the distribution of impact energy for each column of the left sides of the body of the bus LiAZ-5256 from the length of the sliding part of the rod of counteroverturning device;
- The movement of each left sides rack of the body of the bus LiAZ-5256 from the length of the sliding part of the rod of the device.

Studies show that devices similar to the proposed by the authors of the article are able to reduce the deformation of the pillars of the bus when tilting it. Thus, the longer the length of the rod of the device is, the smaller is the amount of movement of the racks of the body in the direction of the residual space of the passenger compartment of the bus, i.e., inversely proportional dependence. In this case possible is the variant, in which at a specific length of the rod such movements will not occur. For a bus LiAZ-5256 this value is 1.8 m.

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