V. A. Ogorodnirov, Doctor of Science (Engineering), Professor; T. F. Arkhipova, Cand. Science (Engineering), Assistant Professor

DEFORMATION ENERGY OF THE TRANSPORT MEANS IN THE CONDITIONS OF THE TRAFFIC ACCIDENTS

The article considers the method for assessing the energy of deformations of the transport vehicles in road traffic accidents (RTAs). The intensity of the transport vehicles operation, as well as the increase in their number is accompanied by numerous accidents. In most cases, accidents are caused by the violation of speed limits. In this regard, methods, able to assess the strain energy consumed during the impacts of motor vehicles are relevant. The determination of the energy of deformation and destruction of the structural elements of vehicles is important for determining the speed of the transport vehicles motion before a collision. Besides, information, regarding the energy used to deform vehicles in road accident conditions allows vehicle manufacturers to reduce the amount of expensive, less informative and extremely inflexible car tests. In the given research, the problem of estimating the energy before a collision, based on full-scale tests is solved. On the example of automotive technical expertise, initial data were obtained to determine the values of the speeds of automobiles, as well as their deformation energy absorbed during the impact.

The essence of the model for assessing the strain energy is that any inelastic impact between transport vehicles leads to an equivalent elastic impact, which takes into account the total energy consumption, including the work of deformation, the work of the forces of resistance to the displacement of the transport vehicles in the process of the repulsion after the impact and kinetic losses in the process of the impact. The reliability of the developed method for assessing the energy of deformation of vehicles in the condition of the traffic accident is confirmed. Based on full-scale tests, the strain energy is determined by the energy equivalent method and the hardness method. Satisfactory convergence of the results of calculating the strain energy by two methods is shown. The results obtained confirm the reliability of determining the speed calculated by these methods, as well as using a surveillance camera. The hardness method, proposed as an alternative to the energy equivalent method, enables to calculate the energy in the conditions of the traffic accident of any transport vehicles, including cars for which "crash-tests" are not carried out.

***Key words**: strain energy, transport vehicle, roadtraffic accidents, technological heredity, hardness method, energy equivalent method.*

Introduction

For the determination of the vehicles speed values at their collision, the model described in the paper is used [1]. The essence of the model is that any inelastic impact between the vehicles results in the equivalent elastic impact. Total energy expenses, which include the work of deformation, work of resistance to the displacements of the vehicles in the process of throwing away after the impact and kinetic losses during the impact, are taken into account.

The main drawback of this model is that the experimental data, used in this model are the result of the «crash-tests», i. e., destruction tests. These tests are expensive and at the same time, give little information, these tests are performed manly for the cars.

Since 2003, the studies were published [2 – 5], where the experimental calculation method of the identification of the damaged elements of the transport means constructions by measuring the hardness of the damaged metal was developed. This enables to determine the work of deformation, caused by these damages.

Application of the given technique enables to determine with the sufficient degree of accuracy [6] the work of deformation of the damaged transport means and eliminate the drawbacks of the prior developed model [1].

Determination of the energy of deformation and destruction of the elements of the transport means construction is important not only for the determination of their motion speed before the collision. In the process of construction and manufacturing of modern motor vehicles there appeared the necessity to develop safe constructions, their strength and rigidity must be controllable, predictable and provided with the parameters of the metal working technology, i. e., technological heredity [5].

A number of foreign companies, for instance, company «MATFEM» (Germany, Munich) develop the software of the emergency destruction of the transport means in order to forecast the expected damages before the impact on the condition of the known motion speed.

Results of the research

Elaborating these approaches, the problem of energy assessment before the impact on the base of the tests in situ is solved.

On the example of the automotive technical examination, considered below, the output data for the determination of the motor vehicles speed, as well as, their deformation energy, absorbed in the process of impact, are obtained.

According to the report, completed by the road patrol service, the driver of the «HyndaiAccent» (further – car 1) slipped into the oncoming lane, this led to the collision with the car BMW (further – car 2), as a result both cars were damaged.

In order to assess the deformation energy of the cars 1 and 2, the volumes of the damage of the cars construction elements are investigated. These elements were photographed and the hardness was measured in the nodes of the preplotted grade grid with the step of the basic mesh 50 mm, by means of the portable hardness meter «Темп-3».

Adhering to the procedure, suggested in [2, 3], the expenditures for the plastic deformation work and destruction of the elements of vehicles structure were determined by the formula:

$$W_{cap} = W_0 exp \frac{lnk_H / D}{C}, \tag{1}$$

where W_{cap} – is specific potential energy, *J/cm*^{3}, $k_H = \frac{(H_T)_i}{(H_T)_0}$, $W_0 = \frac{\sigma_{0,2}^2}{2 \cdot E}$ – elastic specific potential energy, *J/cm*^{3}, $\sigma_{0,2}$ – is material limit of liquidity, *MPa*, E – is modulus of elasticity Type 1 (Young’s modulus), *MPa*.

D and C in the formula (1) – are the curve fitting coefficients $k_{HT} = f(k_W)$.

Value W_{cap} was calculated also by the formula:

$$W_{cap} = \int_0^e \sigma_u \, d\varepsilon_u \, , \tag{2}$$

where σ_u – is the stress intensity, *MPa*, ε_u– is the strain intensity (dimensionless value).

In plasticity theory the dependence of the stress intensity on the strain intensity $\sigma_u = f(\varepsilon_u)$is called single curve of the material plasticity. It does not depend on the type of the stress state. This dependence was approximated by the equation:

$$\sigma_u = A \cdot \varepsilon_u^n \, . \tag{3}$$

Thun, after the substitution of the formula (3) into (2) we obtain:

$$W_{cap} = A \int_0^e \varepsilon_u^n \, d\varepsilon_u = A \frac{\varepsilon_u^{n+1}}{n+1} \, , \tag{4}$$

where *A*, *n* – are the coefficients of the plasticity curve approximation which have the physical content, A – is flow stress at strain intensity $\varepsilon_u = 1$, n – is the degree of deformation, that corresponds to maximum load on the conventional tensile stress-deformation diagram.

Value ε_u in the formula (4) was determined in each specific case either by the hardness k_H, or by the diagram plasticity diagram or durability [7].

The data, regarding the materials, necessary for the calculations, were obtained from [7].

The output limit of liquidity $\sigma_{0,2}$ (*MPa*) is set in correspondence with the output hardness H_{m0}, according to the equation:

$$\sigma_{0,2} = B + 0{,}33 H_{m0} \, , \tag{5}$$

where the coefficient *B* in the process of hardness measurement by the hardness meter "Темп-3" equals *B* = 176.

Output limit of liquidity$\sigma_{0,2}$ is set in the correspondence with the approximation coefficient of the flow curve of the materials, following the equation:

$$A = 1000 \cdot \exp(-0{,}0008 \cdot \sigma_{0,2}), \qquad (6)$$

where A – is an approximation coefficient of the equation (3).

Coefficient n in the formula (3) for different materials, used in the automobile building industry, is within the limits $0.35 \le n \le 0.1$ and can be found from the equation:

$$N = 0{,}35 \cdot \exp(-0{,}0008 \cdot A)\ . \qquad (7)$$

Value W_{cap}, obtained by the formulas (1) and (2) were set in correspondence with the volume of the deformed metal of the construction elements, that enabled to calculate the value of full potential energy of deformation:

$$W_{def} = \Sigma (W_{cap})_i \cdot V_i\ . \qquad (8)$$

As a result of the summation of energy expenditures of all above-mentioned damaged elements of the automobiles 1 and 2 construction, the following values of deformation energy are obtained:

$$W_{def1} = (35500 \dots 36000)\,J \quad \text{and} \quad W_{def2} = (23500 \dots 23950)\,J\ .$$

The work of deformation of automobiles 1 and 2 is determined by the constants of power consumption, according to [2]. The given calculations were performed at the programming complex "КНДІСЕ АВТОФОРМУЛА" applying the technique, approved by the Ministry of Justice.

Automobile 1 had one global damage:

- lateral damage – width $\delta_{21} = 1{,}3\,m$ and height $\lambda_{21} = 0{,}15\,m$ in the form of a rectangular;

$$W_{def2} = 23{,}010\,J\ .$$

Automobile 2 had one global damage:

- frontal damage – width $\delta_{21} = 1{,}49\,m\ and$ height $\lambda_{21} = 0{,}2\,m$ in the form of a rectangular;

$$W_{def1} = 35{,}164\,J\ .$$

Further these data were used as they are lower than values, obtained by the hardness method. Thus, they correspond to the lower limit of the automobiles motion speed.

Let at the moment of the collision in the point of the primary contact the automobiles 1 and 2 have motion speeds, denoted by the vectors $\overrightarrow{V_1}$ and $\overrightarrow{V_2}$, directed along their longitudinal axles, correspondingly applied to their centres of mass C_1 and C_2. We set the rectangular coordinate system on the plane of the traffic way, directing axis OX along the speed vector horizontally. The angle between the longitudinal axles of the transport means relatively the common damages, as well as, the information of the surveillance camera is $\alpha \approx 90°$.

In the process of motion after the collusion the center of masses C_2 of the automobile 2 shifted at the distance $l_2 \approx 0{,}3\,m$ in the state of skidding (according to the scheme of the traffic accident), having certain initial speed of this motion, denoted by the vector $\overrightarrow{U_{20}}$, applied to the center of the masses C_2 and directed along the horizontal axis.

In the process of motion after the collision with the automobile 2, center of masses C_1 of the automobile 1 shifted at the distance $l_2 \approx 1{,}9\,m$ (according to the scheme of the traffic accident), having certain initial speed of this motion, denoted by the vector $\overrightarrow{U_{10}}$, applied to the center of masses C_1 and directed under the angle $\beta_1 \approx 10°$ in the direction of the vector of the initial motion. As a result of the traffic accident transport vehicles took the position 1 and 2, fixed on the diagram of the traffic accident, composed by the traffic officers (Fig. 1).

As the directions of the automobiles motion speeds at the moment of the collision are known, we determine their values, according to the method, described in [2].

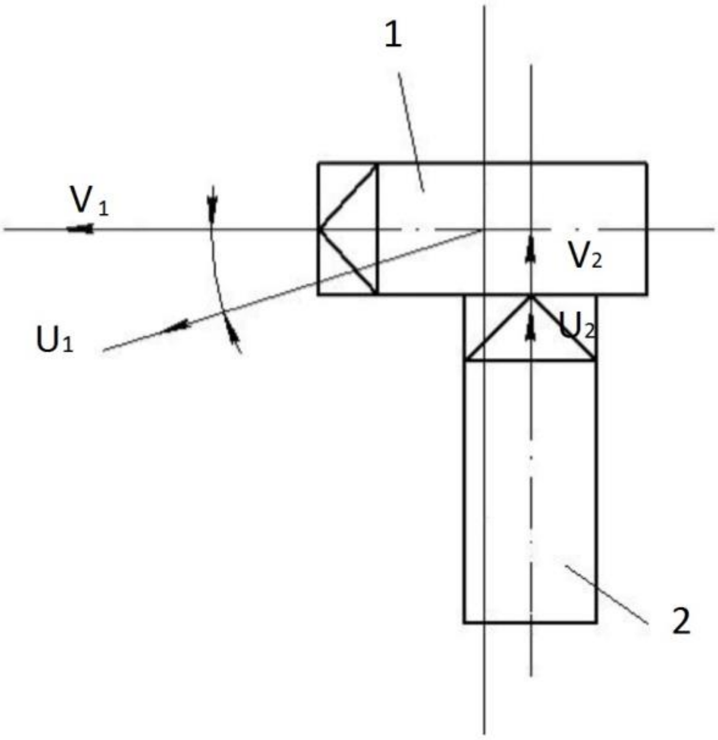

Fig. 1. Scheme of the traffic accident, with the participation of the automobiles 1 and 2

Works of the automobiles 2 and 1 shift resistance force after the collision are determined by the formulas:

$$W_{rez1} = m_1 \cdot g \cdot l_1 \cdot f_1', \quad (9)$$

$$W_{rez2} = m_2 \cdot g \cdot l_2 \cdot f_2', \quad (10)$$

where $m_1 = 1280\ kg$ mass of the automobile 2, taking into account the load; $m_2 = 2100\ kg$ mass of the automobile 1 taking into account the load; $g = 9{,}81\ {}^{m}/_{sec^2}$ acceleration of gravity; $f_1' = f_2' = (0{,}56 \dots 0{,}64)$ – is friction coefficient of the lateral sliding of the wheels on the dry surface with bituminous-concrete covering [5].

According to the calculation by the formulas (9) and (10) the given parameters are:

$$W_{rez1} = (13360 \dots 15269)\ J\ ,$$

$$W_{rez2} = (3461 \dots 3955)\ J\ .$$

Total energy expenditures for the displacement of the transport vehicles after the collision, for their deformation and destruction of the separate elements in the process of the collision, are determined by the formulas:

$$W_{\Sigma1} = W_{\mathrm{rez1}} + W_{\mathrm{def1}}, \quad (11)$$

$$W_{\Sigma2} = W_{\mathrm{rez2}} + W_{\mathrm{def2}}. \quad (12)$$

Substitution of the numerical values of the parameters of these formulas gives:

$$W_{\Sigma1} = (48524 \dots 50433)\ J\ ,$$

$$W_{\Sigma2} = (26471 \dots 26965)\ J\ .$$

Initial speeds of the automobiles motion while their displacement after the collision correspond to the total energy expenditures and are determined by the formulas:

$$U_{10} = \sqrt{\frac{2 \cdot W_{\Sigma1}}{m_1}}\ ; U_{20} = \sqrt{\frac{2 \cdot W_{\Sigma2}}{m_2}}\ . \quad (13)$$

Substitution of the numerical values of the parameters of the formula (13), gives:

$$U_{10} = (8{,}7 \dots 8{,}9)\ m/s; \qquad U_{20} = (5 \dots 5{,}1)\ m/s\ .$$

On the base of the law of conservation of momentum of the mechanical system (in the given case the system consists of two automobiles) in case of the collision, equivalent to absolute elastic collision, we will write the vector equation, that connects the motion speeds of the transport vehicles at the moments of the end and start of the collision:

$$m_1 \cdot \overrightarrow{U_{10}} + m_2 \cdot \overrightarrow{U_{20}} = m_1 \cdot \overrightarrow{V_1} + m_2 \cdot \overrightarrow{V_2} \qquad (14)$$

We find the projections of the vector values of the equation (14) on the coordinate axis OУ, and from the obtained expression we find the formula for the determination of the speed $\overrightarrow{V_2}$:

$$V_2 = \frac{m_1 U_{10} \sin\beta_2}{m_2}. \qquad (15)$$

We find the projections of the vector values of the equation (14) on the coordinate axis OX, and from the obtained expression we find the formula for the determination of the speed $\overrightarrow{V_1}$:

$$V_1 = \frac{m_1 U_{10} \cos\beta_1 + m_2 U_{20}}{m_1}\ . \qquad (16)$$

Substitution of the numerical values of the parameters of this formula, gives:

$$V_1 = (16{,}8 \dots 17{,}1)\ m/sec = (60{,}5 \dots 65{,}5)\ km/hr\ .$$

Speed of the automobile 1 at the moment of collision in the traffic accident was $(60{,}5 \dots 65{,}5)\ km/hr$.

Speed of the automobile 1 before braking is determined by the formula:

$$V_{a1} = 1{,}8 \cdot (t_z + t_{OT}) \cdot j + \sqrt{26 \cdot j \cdot S_b + V^2}, \qquad (17)$$

where t_z– is the time of deceleration increase to maximum value of 0.3 sec; t_{OT} – is the time of the braking process stop , 0.3 *sec*; j – is slowing down of the automobile, (6,9..7,5) m/sec^2; S_b – is the length of the braking path, 16.3 *m*.

After the substitution of the numerical values in the formula (9) we obtain:

$$V_{a1} = (88 \dots 94{,}6)\ km/hr\ .$$

Thus, taking into consideration the character of the automobile 1 motion in the given situation and damage of the transport vehicles, the speed of its motion was $(88 \dots 94{,}6)\ km/hr$.

We will determine the speed of the automobile 1 motion, using the recording of the surveillance camera. Automobile 1 appears in the viewing area of the camera (at the distance of about 152 ... 160 *m* from the place of the traffic accident) at the moment of time 23:24:59. The collision of the automobiles occurs after the second frame from the moment of time 23:25:05, i. e., in 6.2 sec.

Speed of automobile 1 motion is determined by the relation of the trip mileage to the time, during which the automobile covered the given distance and is:

(152…160) / 6,2 = (24,52..25,81) *m/sec* = (88,3..92,9) *km/hr*.

This practically coincides with the value of the automobile 1 speed. The speed is determined, taking into account the damages, recorded at the place of the accident.

Let us consider the results of the calculation of the strain energy, obtained by the hardness test [2] and method of the energy equivalent [1].

By the hardness test strain energy:

$$W_{def1} = (35{,}500 \dots 36{,}000)\ J \qquad W_{def2} = (23{,}500 \dots 23{,}950)\ J\ .$$

By Baykov method [1]:

$$W_{def1} = 35{,}164\ J \qquad W_{def2} = (23{,}500 \dots 23{,}950)\ J\ .$$

Aggregate value of the strain energy (see (11), (12)) is, correspondingly, by hardness:

$$W_{\Sigma 1} = (48{,}860 \dots 51{,}269)\ J\ W_{\Sigma 2} = (26{,}961 \dots 27{,}905)\ J\ .$$

By Baykov method, correspondingly:

$$W_{\Sigma 1} = (48{,}524 \ldots 50{,}433)\ J\ W_{\Sigma 2} = (26{,}471 \ldots 26{,}965)\ J.$$

Speed of the automobile 1 at the moment of loosing the road holding ability:

$$V_{av} = (88{,}85 \ldots 92{,}05) = 90{,}45\ \ km/hr\ .$$

By Baykov method:

$$V_{av} = (88{,}58 \ldots 91{,}47) = 90{,}025\ \ km/hr.$$

The obtained results prove the reliability of the speed determination, calculated by two methods, as well as, obtained by means of the surveillance camera.

Conclusions

1. Method of the strain energy of the transport means assessment in the conditions of the traffic accident has been elaborated.
2. On the base of the field tests the strain energy can be determined, applying the method of energy equivalent and hardness test. Sufficient coincidence of the results of the strain energy calculation by both methods is shown.
3. Hardness test, suggested as the alternative to the method of the energy equivalent, allows to calculate energy in the conditions of the traffic accident of any transport means, including automobiles, "crash-tests" for which are not performed.

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Ogorodnikov Vitaliy – Doctor of Science(Engineering) Head of the Department of Strength of Materials and Applied Mechanics, e-mail: va.ogorodnikow @gmail.com.

Arkhipova Tetiana – Cand. Science (Engineering), Assistant Professor with the Department of Strength of Materials and Applied Mechanics, e-mail: tfarhipova@ gmail.com.

Vinnytsia National Technical University.