ANNALS OF THE ORADEA UNIVERSITY
Fascicle of Management and Technological Engineering
ISSUE #1, MAY 2013, http://www.imtuoradea.ro/auo.fmte/

LASER PROFILOMETER METHOD FOR MEASURING THE DEFORMATIONS OF THE CAR BODY ELEMENTS

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Abstract—In this paper is presented a new method that uses a polar coordinate system to determine the vehicles deformation magnitude. The laser profilometer method is distinguished by the small size of the equipment used, the simplicity of the measuring methodology, data acquisition and processing and high accuracy of the results.

Keywords**—**vehicle deformations, laser telemeter, profilometer

I. INTRODUCTION

THE energy consumed during the complex process of a vehicle collision for the structure deformation, known as deformation energy, has a major importance both for passive safety and as a basis for calculating the kinematic and dynamic parameters of the vehicle, determined during the retrospective research of road events.

The deformation energy can be determined based on the deformation magnitude, taking into account the design parameters of the vehicle expressed by the stiffness coefficients.

The classical method for determining the deformation magnitude is the profilometer method, which uses a Cartesian coordinate system. In addition, methods have been developed based on photographic technique, such as the PhotoModeler method.

II. CAR DEFORMATIONS AND THE DEFORMING ENERGY

One of the main goals of reconstruction the road accidents is, in most cases, the determination of vehicles speed before the collision [1]. The main methods of approaching the reconstruction of road accidents are: impulse method, based on the laws of conservation of the linear and angular impulse and the deformation method based on the laws of conservation of the linear impulse, angular impulse and energy [2].

Using deformation method implies the existence or adoption of some models of deformation that expresses the correlation between the collision normal force per unit width of the deformed area and the deformation magnitude. The deformation models can be static or dynamic. For the dynamic deformation models the determination of the deformation energy is done based on the dynamic deformations and the static models use the magnitude of the remanent static deformations for calculating the deformation energy. While the dynamic models express the relationship between force and dynamic deformation of the vehicle body, the static models are showing the relationship between force and the plastic remanent deformation of the vehicle, assimilating this dependence as linear.

Therefore, determining the total kinetic energy consumed during the impact is done based on the deformation of the vehicle constructive elements, in particular the car body elements. The measurement of the vehicle deformations involves the determination of the magnitude of these deformations in several points of the deformed area. The energy consumed for the deformation of the vehicle constructive structure during the impact can be determined based on the remanent deformation of the car body elements, using the vehicle's stiffness coefficients specific to the deformed area.

The relation used to calculate the deformation energy in the PC Crash software is:

$$\mathbf{E_D} = \sum_{i=1}^{n\;\;1} \mathbf{w_i} \begin{array}{l} \dfrac{\mathbf{B}}{\mathbf{6}}\;\dfrac{\mathbf{C_{i+1}^3}\quad\mathbf{C_i^3}}{\mathbf{C_{i+1}}\quad\mathbf{C_i}} + \\ + \dfrac{\mathbf{A}}{\mathbf{2}}\;\left(\mathbf{C_{i+1}} + \mathbf{C_i}\right) + \\ + \mathbf{G}\;\left(\mathbf{1} + \mathbf{tan^2\,\Theta}\right) \end{array} \tag{1}$$

$$\mathbf{w_i} = \mathbf{L_{i+1}}\quad\mathbf{L_i} \tag{2}$$

where:

E_D - deformation energy (J);

A, B, G – stiffness coefficients;

C_i, C_{i+1} – the deformation measured at point i and point i+1 (m);

L_i, L_{i+1} – the rate of the measuring station from point i, and point i+1 (m);

w_i – the distance between two consecutive measuring stations (m);

Θ – angle between the longitudinal axis of the vehicle and the direction of the main impact force (degree).

The deformation energy thus calculated is corresponding to the remanent deformation. It is known that during compression, the car body dynamic deformation reaches the maximum value at the impulse point, then during the restitution phase, the deformation magnitude decreases to the static deformation value.

III. THE CLASSICAL METHOD FOR MEASURING THE DEFORMED PROFILE OF THE VEHICLE

The procedure of measuring the deformed profile is based on the assumption that the deformation is uniform on the vertical plane [3].

For the vehicle-to-vehicle collisions this assumption is not valid in all the cases, given the geometric and structural incompatibility of the collision partners, but it does not significantly affect the calculation of the speed variance because in these cases the total energy of deformation is used which characterize the impact as a whole [4].

The commonly used tool for measuring the deformed profile of the car is the profilometer "Fig. 1" [5].

Fig. 1. Measuring the deformed profile with the profilometer

The measurement procedure of the deformed profile using the profilometer has the following steps [6]:

- the measurement procedure is established
- the choice of the quotation base
- the width of the deformed area is determined
- the choice of the measuring stations number
- the deformation measurement at the points of measurement
- measurements are realized in the same points on an undeformed vehicle
- the deformation values $C_1 \ldots C_n$ are determined at the points of measurement, by the difference between the two sets of measurements.

When measuring the deformed profile in the frontal plane of the vehicle, the measuring base is positioned relative to the rear axle, at a distance higher than the sum between the wheelbase and the front console of the vehicle. Can be used 6 until 12 measuring stations positioned at equal or unequal distances to each other. In general 6 measuring stations are used and the measurement is done at the maximum deformation rate.

IV. THE MEASUREMENT OF THE DEFORMED PROFILE USING THE LASER PROFILOMETER

The laser profilometer method consists of measuring, in a system of Cartesian coordinates, the deformation values at several points of the deformed profile. In this paper is proposed a new measurement method of the deformed profile which uses the polar coordinate system. The measurement equipment consists in a laser telemeter mounted on a tripod "Fig. 2". The support on which the telemeter is fixed has a ball joint, so the rotation is allowed to position the light spot for the measuring points.

Fig. 2. Measuring device with the laser telemeter.

During the experimental research a Leica DISTO A2 telemeter has been used. The distance measurement using the laser telemeter is realized by fixing the light spot on the body surface, and by pressing the control buttons on the device screen, the distance between the device and the body is shown. The distance measurement with a good accuracy is up to 12 m, for favorable operating conditions. For adverse operating conditions, such as bright light, very poor reflective surfaces, large temperature variations, the measurement accuracy can be damaged. In addition, measurement errors can occur when the surface to which the distance is determined is transparent or semi-transparent. The device is available for single measurement, continuous measurement and the positioning at a desired distance to an object. The technical characteristics of the Leica DISTO A2 telemeter are presented in Table I.

TABLE I

TECHNICAL CHARACTERISTICS for Leica DISTO A2

Measurement domain	0,05 – 60 m
Measurement accuracy	± 1,5 m
Minimum measurement displayed unit	1 mm
Laser class	II
Laser type	635 nm, <1 mW
Automatic switch off	after 180 s
Measuring mode	- single measurement - continuous measurement
Add/subtract operations	yes
Battery life	more than 5.000 measurements
Dimensions	124 x 54 x 35 mm
Mass	155 g
Working temperature:	from -25ºC until +70ºC
Operation:	from 0ºC until +40ºC
Measurement base:	- back side of the device - front side of the device
Area measurement	yes
Volume measurement	yes
Other functions	positioning at a desired distance from the object

The measurement procedure of the deformation magnitude using this device is as follows [7]:

- the positioning of the device towards the vehicle;
- measuring the distances between the device and the points of the deformed / undeformed profile;
- the determination of the deformation values at the points of measurement, by calculation, based on the measurements done on the deformed / undeformed profile of the vehicle.

For the magnitude measurement of the deformed profile is necessary that the vehicle and the measurement device to be positioned on a plane surface.

The tripod is set so that the telemeter to be positioned at the same height as the height of the deformed profile. For measuring the profile of the front or rear area, the measuring device will be positioned on the longitudinal center line of the vehicle.

The positioning of the device towards the vehicle implies the choice of at least three points on the outer surface of the vehicle located outside the deformation zone.

By measuring the distance between the point where the telemeter is and the chosen points, the measuring device position is determined relative to the vehicle.

These marks and distances will be used later to position the device towards a similar vehicle brand and model, to determine the undeformed profile [8]. In "Fig. 3" is highlighted how the device is positioned towards the vehicle. In this case the P_1, P_2 and P_3 marks were selected, positioned on the upper corners of the windshield frame and on the rearview mirror housing. The spatial position of the point where is the telemeter, is determined relative to these marks. For positioning the device on the longitudinal axis of the vehicle is necessary that $OP_1=OP_2$.

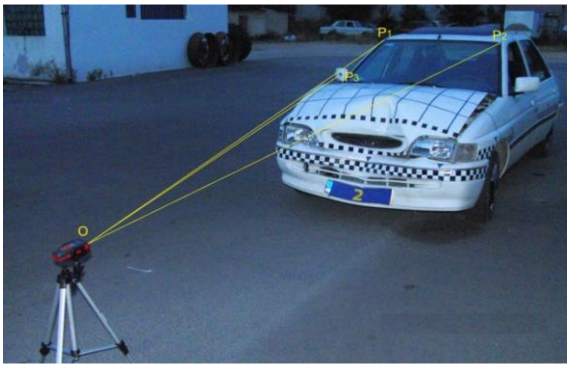

Fig. 3. The positioning of the measuring device towards the vehicle

Measuring the distances between point O and the deformed profile points, involves the marking of points on the vehicle where the measurements will take place: B_1...B_6 "Fig. 4".

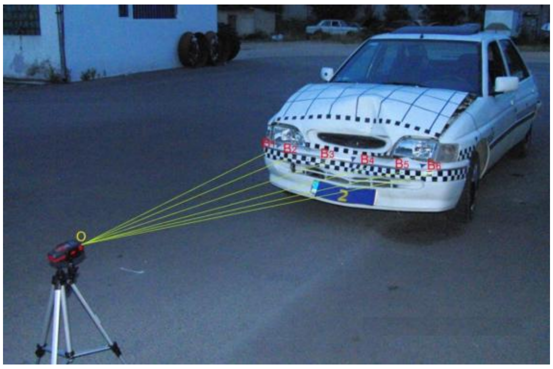

Fig. 4. Measurement of the deformed profile using a laser telemeter.

The point B_1...B_6 are chosen so that their projections in the transverse plane of the vehicle are equidistant and determine known length segments. The determination of the distances OB_1...OB_6 is realized by positioning the light spot on the measuring points and reading the measurements on the device screen.

The magnitude determination of the deformations at the measuring points is done based on the sketch from "Fig. 5", following the relations:

$$\mathbf{\Theta_0 = \arcsin\frac{A_0B_0}{OB_0};\quad \Theta_1 = \arcsin\frac{A_1B_1}{OB_1}} \tag{3}$$

By determining the angles Θ_0 and Θ_1, the polar coordinates of the points on the undeformed profile (B_0) and the deformed profile (B_1) will be known.

The deformation magnitude at point B_1 is:

$$\mathbf{C_1 = B_0B_1 = A_0A_1} \tag{4}$$

$$A_0A_1 = OA_1 - OA_0;$$

$$OA_1 = OB_1\cos\Theta_1;\quad OA_0 = OB_0\cos\Theta_0 \tag{5}$$

$$C_1 = OB_1\cos\Theta_1 - OB_0\cos\Theta_0 \tag{6}$$

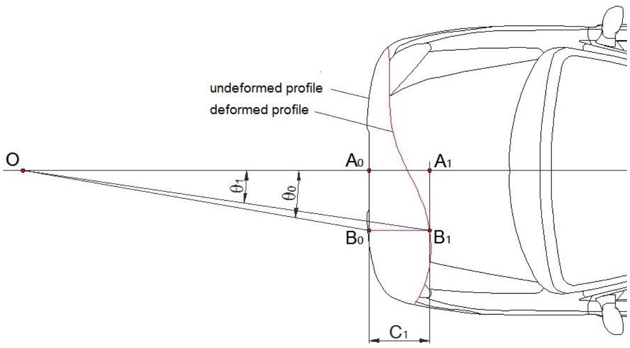

Fig. 5. Sketch for determining the deformation magnitude

Table II presents the values of the deformation for the frontal area of a car, measured at 6 points using the laser profilometer method and PhotoModeler method [9]. The maximum deviation of the deformation magnitude, determined using these two methods is 7,2 mm. This value does not significantly affect the amount of deformation energy calculated based on the remanent deformations [10].

TABLE II
VALUES OF THE DEFORMATION FOR THE FRONTAL AREA OF A CAR

Measuring method	Deformation (mm)					
	C_1	C_2	C_2	C_4	C_5	C_6
Laser method	72,5	195,5	194,3	212,5	235,6	39,3
PhotoModeler	69,6	193,1	187,1	210,7	235,2	41,2
Deviation (mm)	2,9	2,4	7,2	1,8	0,4	1,9

The laser profilometer method, for measuring the remanent deformations for auto vehicles is validated based on the results obtained using the PhotoModeler method.

V. THE ADVANTAGES AND DISADVANTAGES OF THE LASER PROFILOMETER METHOD

The main advantages of using laser profilometer method in comparison with other measuring methods are as follows:

- the equipment used can be transported easily due to its small size in comparison with classic profilometer equipment;
- the data acquisition methodology is simple and quick;
- further processing of the data acquired is simpler and can be realized in a short time compared to the time needed to process the photo images using the PhotoModeler method;
- the accuracy of results is very good.

Among the disadvantages of this method, the most important are:

- the method cannot be used with good results when measuring the magnitude of the deformations on transparent or semitransparent surfaces, when measurement errors can occur;
- the accuracy of the measurement can be altered during unfavorable conditions like high temperature variations or very bright light.

VI. CONCLUSION

During the experimental research conducted to determine the remanent deformations magnitude of the vehicles, were used both the PhotoModeler method and the laser profilometer method. The comparison of the obtained results by the two methods allowed the laser profilometer method validation.

The laser profilometer method can be improved, for this, the main objective being the design and implementation of a device that allows the angular indexing, in polar coordinates, of the measurement stations based on the width of the deformed profile.

The advantages of the laser profilometer compared with the other measurement methods, recommend this method to be used in the applicative and experimental technical-scientific researches.

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