ISSN 1392 - 1207. MECHANIKA. 2013 Volume 19(5): 549-553

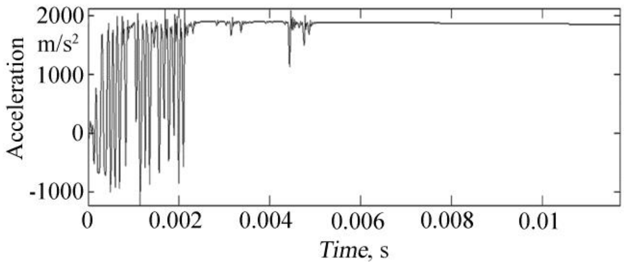
Effect of the attachment of the ballistic shields on modelling the piercing process

K. Jamroziak*, M. Bocian, M. Kulisiewicz****
**Gen. Tadeusz Kosciuszko Miltary Academy of Land Forces, Czajkowskiego 109, 51-150 Wroclaw, Poland, E-mail: krzysztof.jamroziak@wso.wroc.pl*
***Wroclaw University of Technology, Smoluchowskiego 25, 50-370 Wroclaw, Poland, E-mail: miroslaw.bocian@pwr.wroc.pl, maciej.kulisiewicz@pwr.wroc.pl*

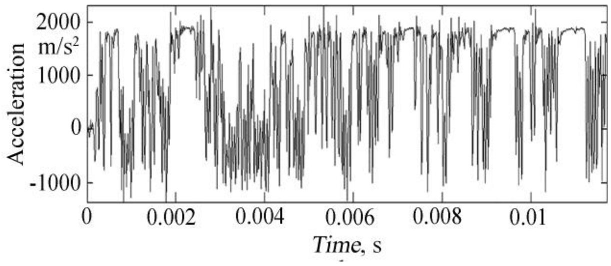
crossref http://dx.doi.org/10.5755/j01.mech.19.5.5536

1. Introduction

Modelling of impact phenomena is a complex issue that has been described in details in many titles from the professional literature [1-7]. The role of the decisive factor is played in this case by the variety of materials used in the shields and by the accompanying processes during piercing them with projectiles with different cores. For instance, just a simple comparison of the impact with a wooden shield and impact with a steel shield shows that in the second case the sound effects are long lasting and more significant than in the first case. This indicates that the effects of vibrations and the propagation of waves in the steel medium are dominant. As we know, the essential factors in the formation of vibrations are the elastic characteristics and weight distribution, as well as the properties of energy dissipation. It indicates that the smaller mass of the shield and the greater dissipation (suppression) of the energy the more minimal vibrations and associated wave effects which can therefore be omitted. Simulation studies of impact phenomena encountered in the available literature are usually conducted using numerical methods [8-11]. In the applied numerical models, material data are most often associated with Hooke's model (constants: E, G, ν) which has been applied to isotropic continuous mediums. Results of these studies show significant differences. Based on the example of overshooting steel and composite shields (Fig. 1) it can be noted that the noises associated with vibration are smaller for laminated shields than for steel shields.



a



b

Fig. 1 The courses of acceleration: a) composite shield; b) steel shield (armoured steel) recorded during the impact of 9 mm Parabellum FMJ projectile

The assumptions used in this study can be reduced to the application of simple dynamic models describing the process of piercing shields, which parameters: c_z, h, k, c, c_0 (Fig. 2) can be determined experimentally, e.g.: during static loads, quasi-static punching tests (with given speed of deformation) and under the condition of dynamic loads using the adequate methods of identification for degenerate models. The aim of the research was to develop the mathematical model of piercing the shield which takes into account its attachment.

2. Formulation of the problem

It was assumed that piercing projectile is under the influence of internal force of reaction of the shield with degenerate model with dry friction, presented in Fig. 2.

In the case of assumed degenerate model, constants that describe the properties of the material of the shield are:

a) constants defining behaviour of the material of the ballistic shield that describe conversion of impact energy to elastic energy – constants c, c_0;
b) constants defining behaviour of the material of the ballistic shield that describe conversion of impact energy to energy of dissipation – constants h, k;
c) constant defining the stiffness of the attachment of the shield - c_z.

It was assumed that losses of the impact energy are described by two parameters, that is dry friction represented by the constant h and damping in the plastic range represented by the constant k. Therefore, material constants of the shield's model have been described by parameters c, c_0, k, h, where:

– c is the coefficient of static stiffness in the elastic range;
– c_0 is the coefficient of dynamic stiffness in the elastic range;
– k is the viscous damping;
– h is the dry friction.

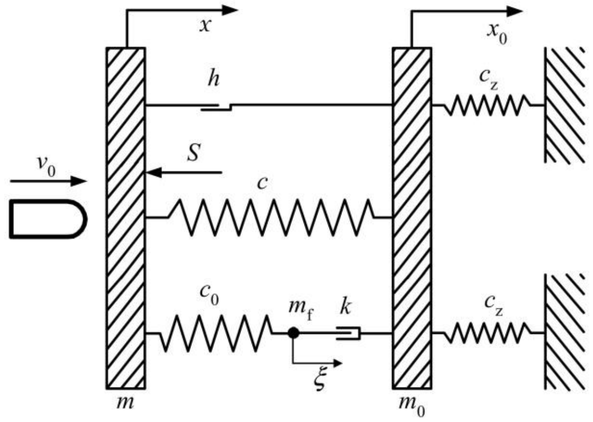


Fig. 2 The dynamic degenerate model of impact of the projectile on the shield

Variable ξ describes motion of fictitious mass $m_f = 0$, variable x describes motion of mass shield m and variable x_0 describes of mass frame m_0.

Resisting force $S(\tilde{x},\tilde{v})$, for the assumed dynamic model, where $\tilde{x}$ describes the relative displacement of the projectile in the material and $\tilde{v} = \dot{\tilde{x}}$ its relative speed, can be presented by the relation:

$$S(\tilde{x},\tilde{v}) = c\tilde{x} + c_0(\tilde{x} - \xi) + hSgn(\tilde{v}). \tag{1}$$

The system of equations that describes the dynamic model of the process of overshooting the shield can be presented in the following form:

$$m\ddot{x} + c_0(x-\xi) + c(x-x_0) + hSgn(\dot{x}-\dot{x}_0) = 0\,; \tag{2}$$

$$c_0(x-\xi) = k(\dot{\xi}-\dot{x}_0); \tag{3}$$

$$m_0\ddot{x}_0 + c_z x_0 + k(\dot{x}-\dot{\xi}) + c(x_0 - x) + hSgn(\dot{x}_0 - \dot{x}) = 0\,. \tag{4}$$

To estimate the frequency of the free vibrations of the system, the simple case have been examined. Assuming that $h \to 0$ and damping $k \to \infty$, then $\xi = x_0$. Thus, the differential equations of motion would take the form:

$$m\ddot{x} + (c_0 + c)(x - x_0) = 0\,; \tag{5}$$

$$m\ddot{x} + m_0\ddot{x}_0 + c_z x_0 = 0\,. \tag{6}$$

The system of Eqs. (5) and (6) can be presented in matrix notation of the form:

$$M = \begin{bmatrix} m & m_0 \\ m & 0 \end{bmatrix}; \qquad C = \begin{bmatrix} 0 & c_z \\ c + c_0 & -c - c_0 \end{bmatrix};$$

$$\bar{q} = \begin{bmatrix} x \\ x_0 \end{bmatrix}; \qquad \bar{0} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}. \tag{7}$$

Finally, the matrix form would take the form:

$$M\ddot{\bar{q}} + C\bar{q} = \bar{0}\,. \tag{8}$$

It can be noted that the dynamic model with perfectly stiff frame $(c_z = \infty)$ can be reduced to a system with just one degree of freedom of the form:

$$m\ddot{x} + (c_0 + c)x = 0\,. \tag{9}$$

On the other hand, if the mass of the shield is small in relation to the mass of the frame ($m << m_0$) it can be noted that this kind of system will vibrate as a system with one degree of freedom of the form:

$$m_0\ddot{x}_0 + c_z x_0 = 0\,. \tag{10}$$

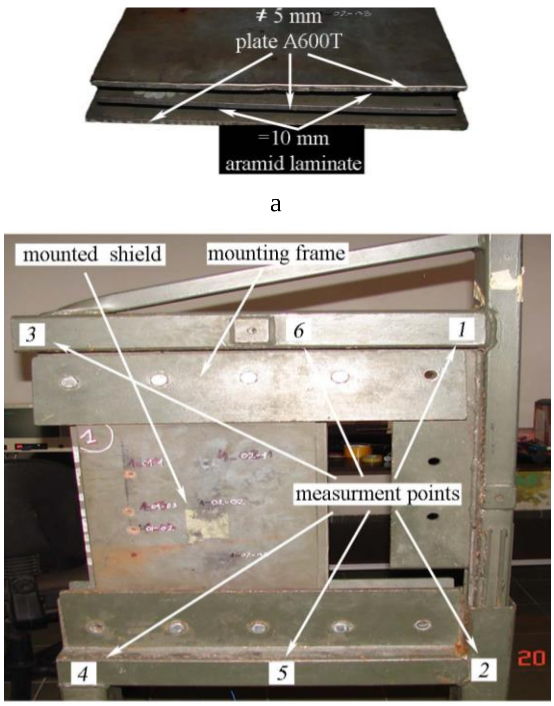
Dynamic model represented by Eq. (8) describes the free vibrations of the system of two undamped degrees of freedom. The variable $x(t)$ describes the vibrations of the shield, while the variable $x_0(t)$ - vibrations of the mounting frame. Whereas, in the case of $m << m_0$ (Eq. (10)) frequency of vibrations is expressed by a relation:

$$\omega_0 = \sqrt{\frac{c_z}{m_0}}\,. \tag{12}$$

It can be noted that the simplification of the analyzed model is, in this case, quite significant. It is because, although vibrations occur after the impact, they usually quickly disappear, as it was evidenced in numerous experimental tests such as in Fig. 1, a. For the further analysis, the dynamic model have been adopted (Fig. 2) with damping and dry friction.

3. The course of research

To set about modelling the force of reaction of the shield's material, several studies were conducted to verify the influence of the attachment of the shield on the effectiveness of its work. Shield mounted in the frame (Fig. 3) has been experimentally tested using an experimental modal analysis.

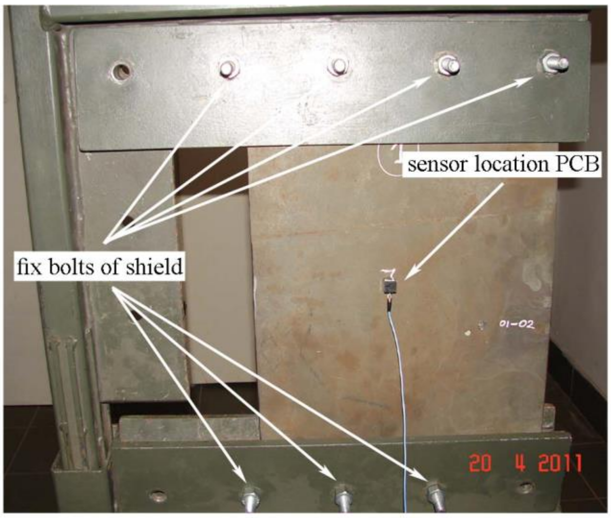


a

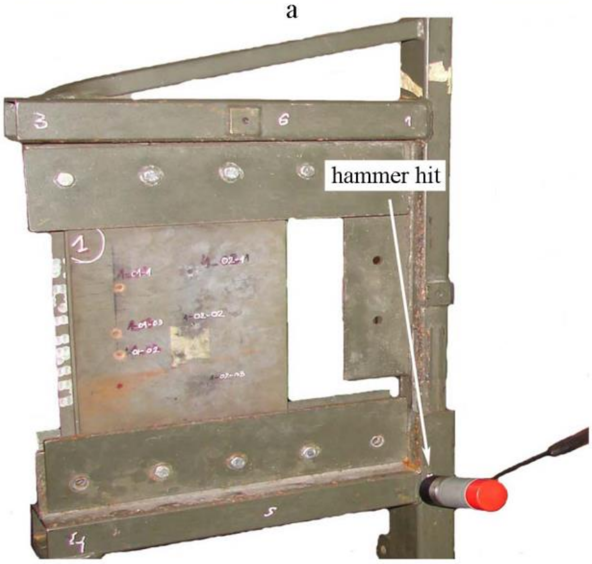
b

Fig. 3 Mounting of the ballistic shield in a frame along with measurement points (b) and the layered structure of overshot sample (a)

Tests of determining the characteristics consist of hitting with modal hammer in the specific points of the shield, marked with numbers from 1 to 6. Ordinal number indicates the order of hitting the frame with modal hammer. PCB sensor has been installed in the central position on the sample of the ballistic shields and collected the signals from the HP recorder (Fig. 4).



a



b

Fig. 4 View of the attached sensor (a) and the method of measurement with modal hammer (b)

Mass m_0 of the analyzed frame is 110 kg. Identification of the entire system has been conducted on a sample build with multi-layer composition of materials used in ballistic protection with a mass $m = 13.7$ kg. Multi-layered ballistic shield had been made of $z \neq 5$ mm armour plates ARMOX 600T and ballistic laminate that had a thickness of 10 mm made of aramid fabrics pressed together in the system of "plan" type on the epoxy matrix.

On the basis of conducted measurements, courses have been recorded, which main objective was to determine the specific parameters of the modal analysis, and consequently to determine the dynamic stiffness of the system. Selected results, in a form of frequency functions of imaginary axis in the range up to 100 Hz, are presented below (Figs. 5 and 6).

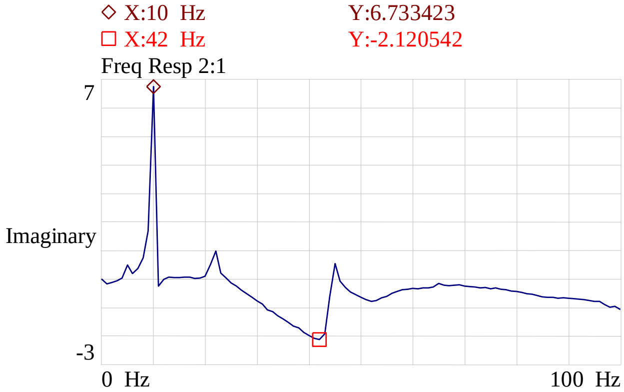


Fig. 5 Measurement No. 1

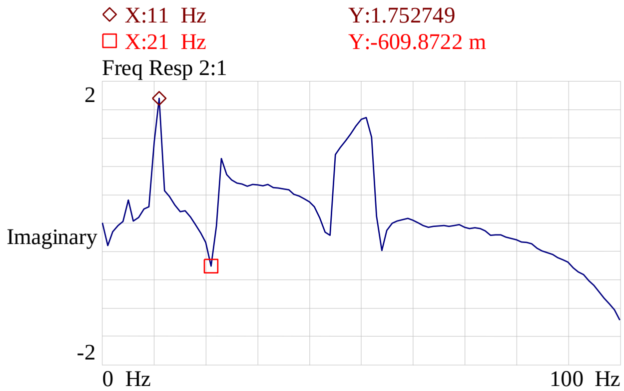


Fig. 6 Measurement No. 5

4. Analysis of the tests results

The aim of the experimental studies was to estimate an influence of the attachment of the shield on the behaviour of the model in the adopted dynamic analysis of the process of piercing the shield. As a result of modal analysis the first form of vibrations has been captured. For each of the conducted measurements it is situated in the range of about 10 Hz. For this reason, assuming that we have a system with one degree of freedom with the main mass of the size $m_0 = 110$ kg and the stiffness c_z, the dynamic stiffness can be estimated based on the known equation:

$$f = \frac{1}{2\pi}\sqrt{\frac{c_z}{m_0}}\,. \tag{15}$$

The stiffness of the mounting, estimated on the basis of the above relation, is about $c_z = 432000$ N/m.

To determine the influence of the stiffness on the vibrations and on the readings of the courses from the disc during the experiment with modal analysis, simulation studies were conducted using Mathematica software. The following parameters have been assumed for the simulation: $m_0 = 110$ kg; $m = 13.7$ kg; $c_z = 432000$ N/m for $k_z = 100$ kg/s; $c = 243900$ N/m for $k = 100$ kg/s; $h = 1000$ N. On this basis the motion of the system for the parameters x_0 and x has been determined, as it has been presented in Fig. 7. This was followed by another simulation, in which the stiffness of the system has been significantly increased (stiffness $4e^{25}$ N/m) to verify the results obtained from the first simulation. Results of the simulation are presented in the graphical form in Fig. 8.

The results obtained from the identification of the frame's stiffness show clearly, that in the analyzed case the influence of the process of overshoot is negligible. In both presented cases (Figs. 7-8) it turned out that the motion of the system for the parameter x_0 can be omitted. It follows that in the adopted model (dynamic system – Fig. 2) constant c_z can also be omitted and in the further stage of identification system can be considered as having one and a half degrees of freedom. This conclusions were already presented by authors in their previous papers [12]. To further confirm analytical considerations and simulations, the studied system (Fig. 3) has undergone testing at the shooting range that has been described in the paper [12], which also discusses the methodology of performing shooting trials.

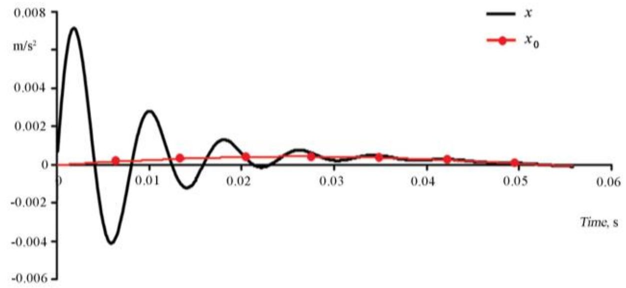


Fig. 7 The time characteristics of the analysed attachment of the shield for the parameters x_0, x of the dynamic model of projectile's impact on the shield

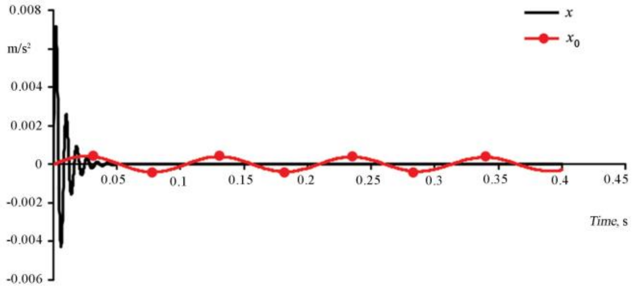
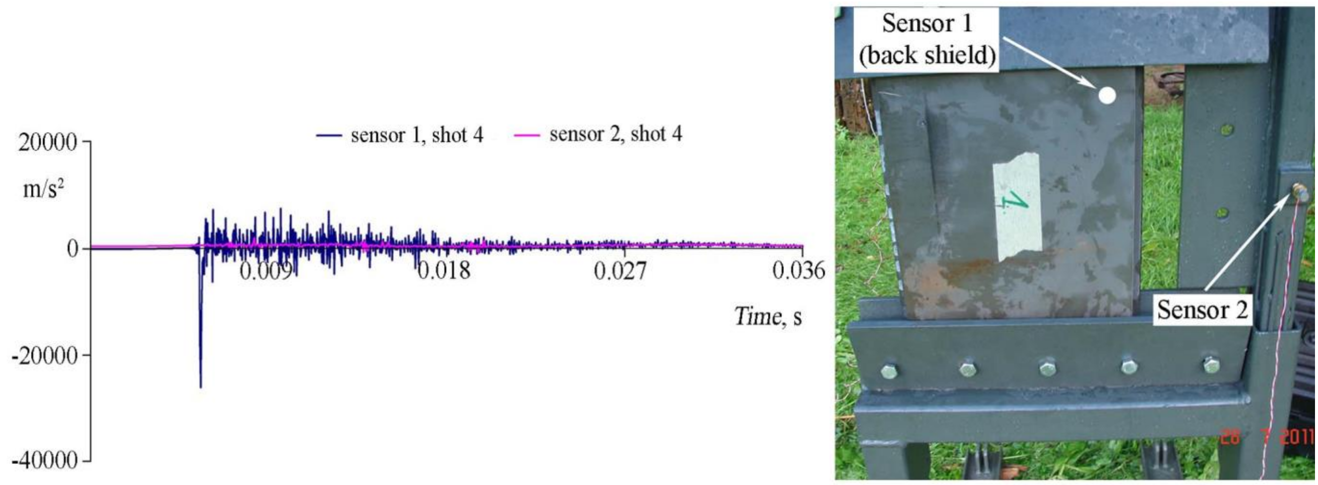


Fig. 8 The time characteristics of the analyzed attachment of the shield for the parameters x_0, x of the dynamic model of projectile's impact on the shield with increased stiffness

Shooting trials has been made with 7.62 mm armor-piercing cartridge with armor-piercing incendiary (API) projectile of the mass 0.00945 kg and outlet velocity of 835.2 m/s. Apart from the components of the striking energy (resulting from the rotary motion of the projectile) the system (frame-shield) was influenced by the energy of 3.3×10^3 J. Values connected with the acceleration of the hit shield (sensor No. 2) and frame (sensor No. 1) were also measured in the experiment. It has been graphically illustrated in Fig. 9.



a b

Fig. 9 Recorded course of acceleration of the frame-shield system in the test of piercing 7.62 mm API projectile (a), the acceleration sensor PCB M350B21 (b)

5. Conclusions

During the analysis of influence of the shield's attachment on the piercing process, it has been stated that the adoption of the dynamic model of piercing the shield is subjected to certain conditions. Assuming that $c_z \to \infty$ certain boundary conditions have to be assumed in the initially adopted model to obtain results consisted with the experiment.

Objective form of the analysed issue, that has been preceded by specific simulations which included modal analysis, poses many problems in this type of phenomena and forces simplified estimations. In this case, the simplification has been reduced to estimating the influence of the attachment of the shield to the frame. As it can be seen on the basis of the conducted research, the direction of the analysis has been properly adopted. Analysis regarding the effect of the attachment of the shield can be reduced to the adoption of a model with a specific number of degrees of freedom and further to the analytical deduction. Dynamic models and the development of mathematical tools which are useful for an analysis using approximate methods have been presented in the papers [13-15]. Also, the results of the shooting trials (limited to the recording of the accelerations) are an important source of information about impact of the attachment.

Summing up, the method of attachment of the ballistic shield do not affect significantly its piercing. Although it influences the behavior of the entire system after shooting through it.

From the standpoint of the technology of using modern "add on armour" type armours, considering the method of attachment of the shield seems to be the right way to proceed research.

References

1. **Bourke, P**. 2007. Ballistic Impact on Composite Armour, Cranfield University, 271p.
2. **Gryboś, R**. 1980. The stability of structures under shock load, PWN, Warszawa-Poznan 1980 (in Polish).
3. **Jamroziak, K.; Bocian, M.** 2008. Identification of composite materials at high speed deformation with the use of degenerated model, Journal of Achievements in Materials and Manufacturing Engineering 28(2): 171-174.
4. **Kulisiewicz, M.** 2005. Modeling and Identification of Nonlinear Mechanical Systems under Dynamic Complex Loads, Oficyna Wydawnicza Politechniki Wroclawskiej, 189p. (in Polish).
5. **Piesiak, S.** 2003. Identification of Mechanical Systems in Domain Nonlinear and Degenerated Dynamical Models, Oficyna Wydawnicza Politechniki Wroclawskiej, 150 p. (in Polish).
6. **Reid, A.R.; Zhou, G.** 2000. Impact Behaviour of Fibre-Reinforced Composite Materials and Structures, Woodhead Publishing Limited, Cambridge England, 302p.
7. **Stronge, W.J.** 2000. Impact Mechanics, Cambridge University Press, 300p. http://dx.doi.org/10.1017/CBO9780511626432.
8. **Barnat, W.** 2010. Selected Problems of Energy Consumption in New Types of Protective Panels Loaded Wave Explosion, Wydawnictwo BEL Studio Sp. z o.o. 237p. (in Polish).
9. **Jamroziak, K.** 2011. Identification of the selected parameters of the model in the process of ballistic impact, Journal of Achievements in Materials and Manufacturing Engineering 49(2): 305-312.
10. **Kopczyński, A.; Rusiński, E.** 2010. Passive Safety. Energy Absorption by Thin-Walled Sections, Oficyna Wydawnicza Politechniki Wrocławskiej, 195p. (in Polish).
11. **Jamroziak, K.; Koziolek, S.; Smolnicki, T.** 2012. Analysis of punching process of ballistic shield with the use of finite element method, Journal of Science of the Gen. Tadeusz Kosciuszko Military Academy of Land Forces 3(165): 289-302.
12. **Jamroziak, K.; Bocian, M.; Kulisiewicz, M.** 2010. Application examples of non-classical, elastic-damping models for ballistic impact process, Modelowanie Inżynierskie 40(9): 95-102.
13. **Buchacz, A.; Placzek, M.; Wrobel, A.** 2013. Control of characteristics of mechatronic systems using piezoelectric materials, Journal of Theoretical and Applied Mechanics 51(1): 225-234.
14. **Bialas, K.** 2012. Mechanical and electrical elements in reduction of vibrations, Journal of Vibroengineering 14(1): 123-128.
15. **Zolkiewski, S.** 2011. Dynamic flexibility of the supported-clamped beam in transportation, Journal of Vibroengineering 13(4): 810-816.

K. Jamroziak, M. Bocian, M. Kulisiewicz

BALISTINIŲ SKYDŲ ĮTVIRTINIMO ĮTAKA PRAMUŠIMO PROCESO MODELIAVIMUI

R e z i u m ė

Straipsnyje aptariami medžiagos pramušimo didelio greičio balistiniu smūgiu tyrimo rezultatai. Analizė atlikta naudojantis dinaminio degeneravimo modeliu, kuris įvertina sausąją trintį. Pasikliaujant medžiagos pramušimo dinaminio modelio parinktais parametrais, identifikuotos konstantos, kurių reikšmės gali turėti didelę įtaką skydo įtvirtinimui. Toks priartėjimas gali būti nagrinėjamas kaip dinaminių apkrovų identifikavimo, naudojant degeneravimo modelius, metodų sintezė.

K. Jamroziak, M. Bocian, M. Kulisiewicz

EFFECT OF THE ATTACHMENT OF THE BALLISTIC SHIELDS ON MODELLING THE PIERCING PROCESS

S u m m a r y

The article discusses issues related to the process of piercing the material at high speed of ballistic impact. The analysis assumes the dynamic degenerate model that takes into account the dry friction. On the basis of the adopted parameters of the dynamical model of piercing the material, constants were identified, which value can strongly influence the attachment of the shield. Such an approach can be considered as an introduction to synthesis of methods for identification of dynamic loads using degenerate models.

Keywords: ballistic shields, modelling of punching process.

Received June 05, 2012
Accepted October 10, 2013