Andrzej **MORKA**
Sebastian **STANISŁAWEK**
Tadeusz **NIEZGODA**
Dariusz **RUDNIK**

APPLICATION OF COMPUTER MODELLING AND SIMULATION METHODS IN VERIFICATION OF A SYSTEM OF ADDITIONAL ARMOUR INSTALLATION

Abstract. The paper discusses the problem of verifying systems of additional armour installation with the use of computer modelling and simulation methods. To achieve this purpose, numerical models of essential structural elements of the fastening arrangement, of the panel and of the representative portion of hull plate have been developed. Suitable constitutive models of the materials used and proper parameters thereof have been selected. Tested panels were subjected to group N11 standard loads in accordance with the Defence Standard NO-06-A 103/2005 and AP 14.5x114 mm B32 projectile impact in accordance with the guidelines included in STANAG 4569. The results obtained by means of numerical analyses were studied in particular in terms of establishing the probability of permanent plastic deformations in the elements of the additional armour fastening system. It was found that in the cases studied the impact of a projectile results in permanent (plastic) deformations in the fastening arrangement elements (bushings, welds), but in quantitative terms these were far from destructive. No disturbing stresses or strains have been identified in bolts, washers and threaded connections. The only situation that needs to be looked into are permanent strains in the crush area of blind rivet nuts observed for loads from single and repeated impacts. Analysis of the impact of an AP 14.5 projectile centrally along the axis of the bolt of the fastening arrangement showed lack of protective capacity in this area. The projectile perforates elements of the fastening arrangement with no significant resistance, while its energy decreases only slightly and thereby the threat of hull penetration is still retained.

Keywords: computer mechanics, simulation.

1. INTRODUCTION

Contemporary armour systems play an extremely important role, both in the battlefield as well as in civilian applications. Still much more attention is paid to the passive systems [1, 2] than the active systems [3], mainly due to much lower cost and relatively simple design of the former. In most studies in this area an assumption is adopted that the tested piece of armour constitutes a separate ballistic panel and that it is subject only to local interaction with the threat. In effect it is assumed that the method of fastening is not important. This approach enables a reliable comparison of different types of materials. However there has to be a fastening system, which may have a significant impact on the ballistic resistance of the structure. This problem is the topic of this paper.

The subject of the study is the widely used mounting of a ballistic panel on brackets attached to the supporting structure at certain points. The brackets include bolts, blind rivet nuts, bushings, washers and weld joints that fasten structural components to the hull. The attached panel is spaced from the hull by 35 mm. The fastening system concept was analyzed using computer modelling and simulation. To this end appropriate numerical models of the proposed technical solutions were developed and subsequently subjected to group N11

Dr Andrzej **MORKA**, Dr Sebastian **STANISŁAWEK**, Prof. Tadeusz **NIEZGODA** – Military University of Technology, Warsaw
Dr Dariusz **RUDNIK** – Motor Transport Institute, Warsaw

standard loads in accordance with the Defence Standard NO-06-A 103/2005 [4] and AP 14.5x114 mm B32 projectile impact in accordance with the guidelines included in STANAG 4569 [5].

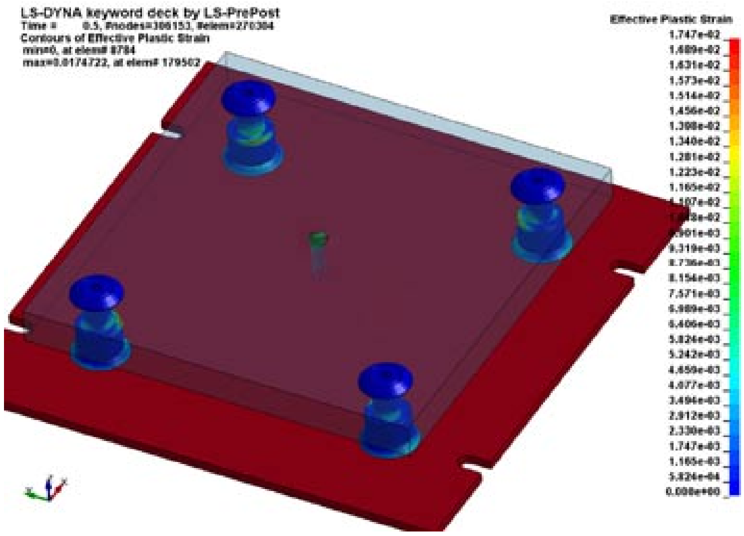
2. PROBLEM DESCRIPTION

During the first stage of developing numerical models, essential structural elements of the fastening arrangement, of the panel and of the representative portion of hull plate were spatially discretized. In the division into finite elements the most important geometrical features of the structure and the limited resources of the computing system (performance and number of available processors, RAM and space for data storage and processing) had to be taken into account. The second stage of developing numerical models consisted in selecting suitable constitutive models of the materials used and proper parameters thereof. Computer simulation of tensile test was used to determine stress-strain characteristics in real measure. These were based on the available manufacturers' data usually expressed in engineering measure. Sets of material parameters were developed for the linear-elastic model of Armox 500 steel (surrogate models of panels) and for the bilinear elastic-plastic model of: S355JR steel, 1.4570 stainless steel (blind rivet nuts), 65G/1.1260 spring steel (washer) and 10.9 steel (bolts). The Johnson-Cook material model was applied for brass (case of AP 14.5 projectile) and for HHS steel (core of AP 14.5 projectile). The third and last stage in building computer models was focused on defining the numerical implementation of the initial-boundary conditions. In this part of the study the characteristics of the input function (force, time) for load in single and repeated impacts were developed. The waveform and duration of pulses were determined on the basis of literature and standard data. Afterwards the amplitudes required to attain the accelerations specified in the standard were estimated using parametric studies. In the case of AP 14.5 projectile impact, the initial velocity was set to 910 m/s. The boundary conditions in the models were very complex and necessitated special attention. Among other things, modelling of contact interactions was carried out, with account taken of friction forces, using the penalty function method after adopting the logic of the segment-segment contact (or otherwise wall to wall contact in a finite element), welded and threaded joints and numerical implementation of bolt pre-tensioning were described .

3. PROBLEM SOLUTION AND DISCUSSION OF RESULTS

The first situation considered was the impact of an AP 14.5 B32 projectile in the centre of the ballistic panel (flat plate). Figs. 1. a)-b) present, in the form of colour maps, distribution of effective plastic strain in the components of the panel to hull fastening arrangement (bolt, bushing, washer, weld). To improve the visibility of the individual elements, the panel was shown as a translucent material. The initial assumption, according to which the panel was a linear-elastic material, proved to be an oversimplification: in such case the projectile would be subject to a much stronger deceleration than in the case of striking a multilayer ceramic-metal panel. Such armour, being much stronger (subject of a separate analysis omitted in this paper), slows the projectile to a greater extent. For this reason the elastic model was replaced with a bilinear elastic-plastic model. Offset yield strength for the panel was set to arrive at the real value of projectile deceleration. Unfortunately, with this approach, mapping of all the features of the panel-projectile interaction is not possible. For this reason the behaviour of the fastening arrangement was analyzed at two values of the yield strength: (a) σ_y=1 GPa and (b) σ_y=2 GPa. In case (a) the obtained value of projectile deceleration was close to actual, but the projectile has perforated the panel. In case (b) the projectile was stopped by the panel, but the resulting decelerations were twice as high as the values observed for ceramic-metal panels. Analysis of the figures shows that in both cases there were permanent deformations in the fastening components: weld and bushings. The highest value (ca. 0.04) occurred (case b) near the edge of the bushings. However, it was far from the destructive value of 0.3. Distribution of strains obtained for all four fastening joints was similar, which shows a symmetrical distribution of the loads, with a dominant tendency to bend in a plane perpendicular to the surface of the panel.

a)



b)

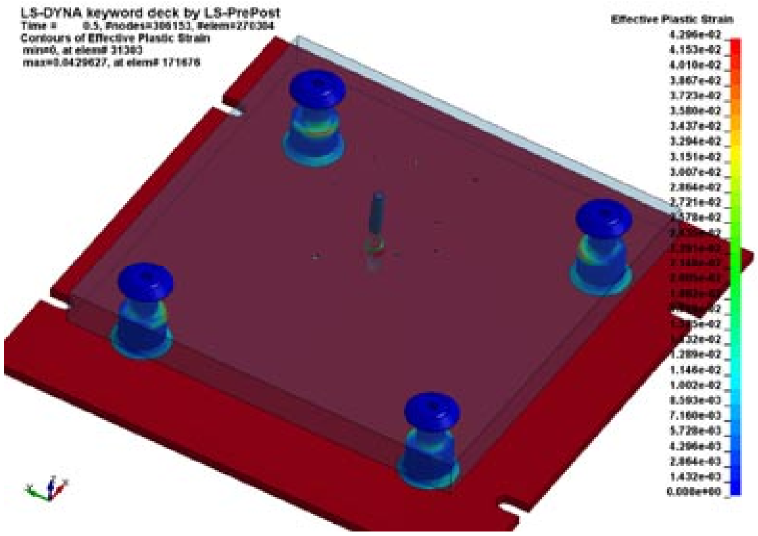


Fig. 1. Central impact of an AP 14.5 B32 projectile, 4 holes, panel spaced from the hull, initial velocity of projectile 910 m/s: a) σ_y=1 GPa, b) σ_y=2 GPa

Another analyzed case was the simulation of the impact of an AP 14.5x114 mm B32 projectile on the bolt of the fastening arrangement (Fig. 2). The components of the fastening arrangement and the panel are shown as translucent. The figure indicates that the projectile penetrates the system quite easily and destroys the bolt while losing only a small part of the penetrates the system quite easily and destroys the bolt while losing only a small part of the initial velocity of about 100 m/s (Fig. 3). It therefore still poses a threat to the vehicle. The situation may be improved by placing a ceramic cylinder of suitable diameter and height inside the bushing on the Armox plate side.

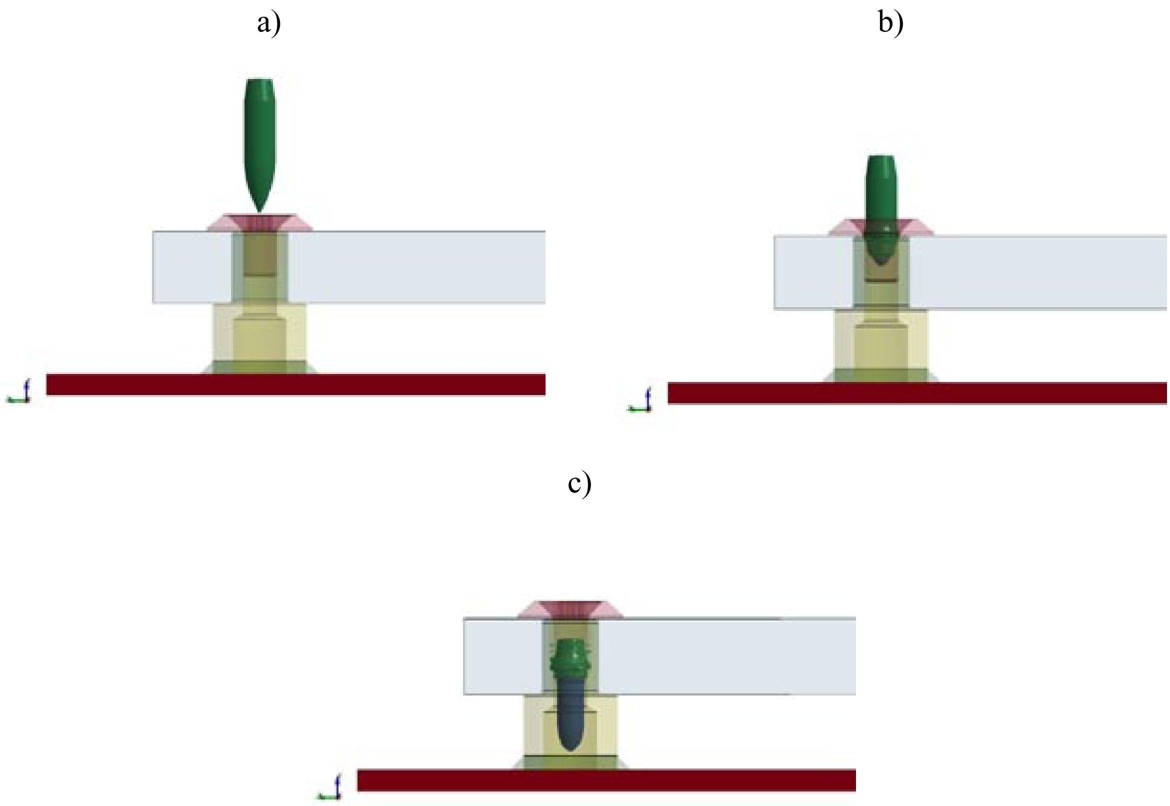


Fig. 2. Impact of an AP 14.5 B32 projectile on a bolt, 4 holes, panel spaced from the hull, initial velocity of projectile 910 m/s: a) t=0 ms, b) t=0.04 ms, c) t=0.1 ms

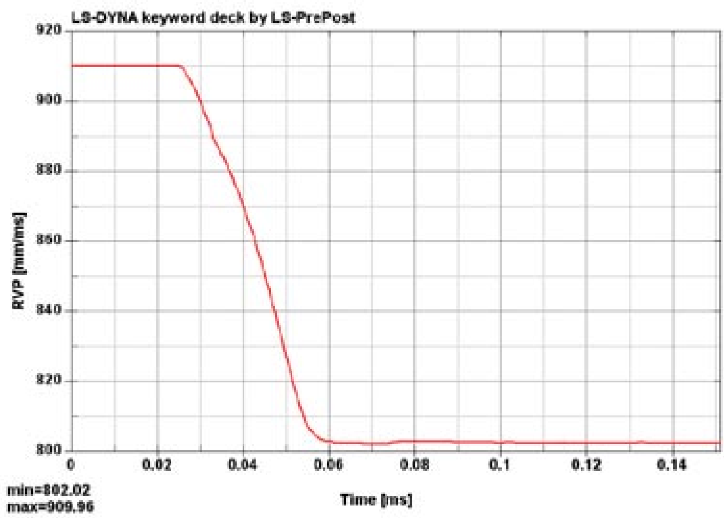
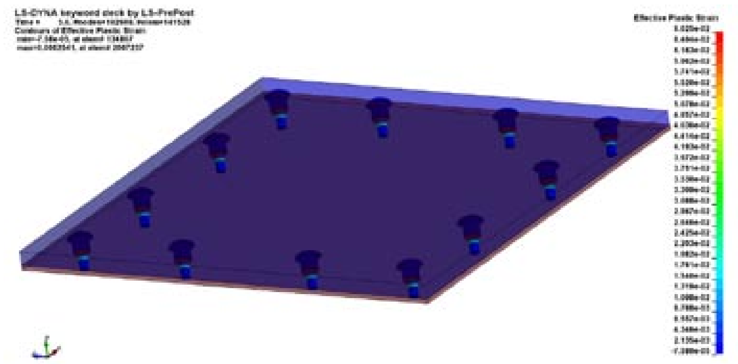


Fig. 3. Impact of an AP 14.5 B32 projectile on a bolt - change of core velocity in time

Further analyses were focused on repeated impacts. In this case the panel was fastened to the hull by means of a joint comprising a bolt, bushing, washer and blind rivet nut (in each obtain vibration amplitude as specified in standard [4]. Analysis of the figures shows that maximum plastic strain is 0.065, while the breaking value is 0.4 and occurs in the deformations in the crush area of the blind rivet nut. Distribution of strains obtained for all fastening joints is similar, which indicates that load distribution is uniform. Maximum values of reduced stress exceed 700 MPa and are located near the edges of spring washers, but these do not cause permanent deformations. Such a large concentration of stresses in the washers is probably slightly overestimated due to a simplified description of the geometry of the washer and due to reduced number of finite elements.

a)



b)

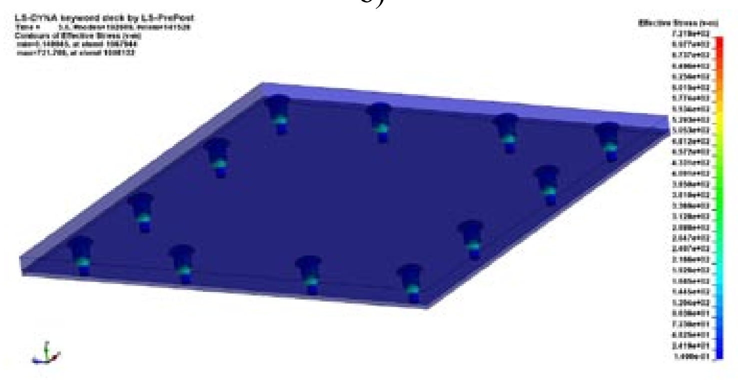


Fig. 4. Repeated impact, 12 holes, panel fastened to the hull by means of a blind rivet nut: a) plastic strain, b) stress

Fig. 5 shows the change in panel acceleration. The observed amplitude meets the requirements of the standard (1500 m/s^2), while the vibration frequency does not coincide with the input function frequency. This probably indicates that the panel vibrates at its natural frequency.

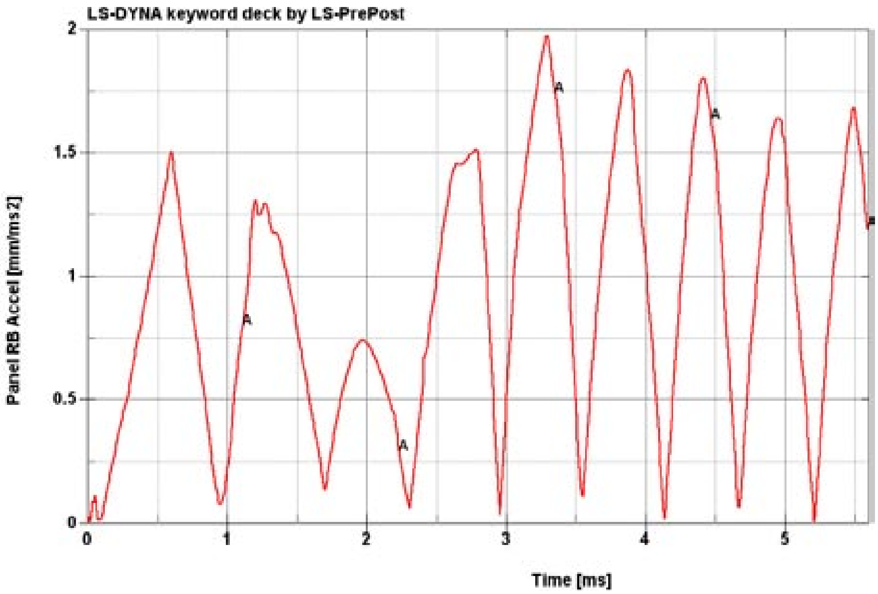
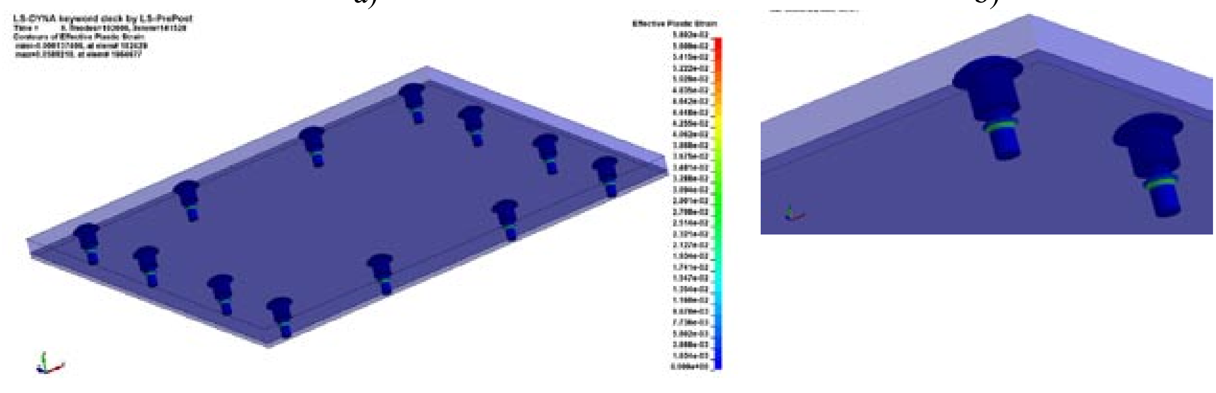
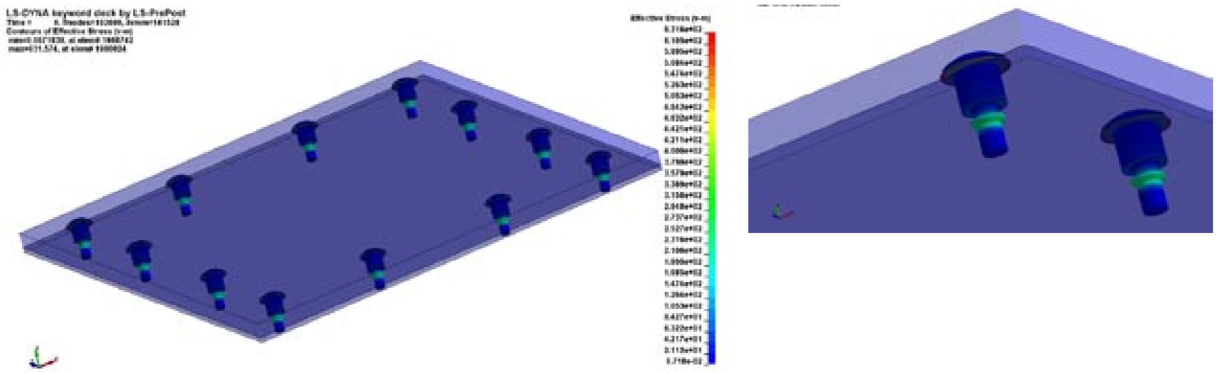


Fig. 5. Characteristics of panel acceleration values due to repeated impact tangential to the panel surface

A single impact was also subjected to numerical analysis. The panel was subjected to a single pressure pulse normal to panel surface to obtain vibration amplitude as specified in standard [4]. Fig. 6 shows the distribution of plastic strain and reduced stress in panel fastening arrangement. As in the case of repeated impact, maximum values of plastic strain after a single impact occurred in parts of crushed blind rivet nuts. In this case these values reached 0.06, which is slightly less than in the previous case. Maximum values of reduced stress of over 630 MPa were located near the edges of spring washers, but these did not cause permanent deformations. The interpretation is similar to that of the previous case.

a) b)





c) d)

Fig. 6. Single impact, 12 holes, panel fastened to the hull by means of a blind rivet nut: a) distribution of plastic strain – general view, b) distribution of plastic strain – close up view, c) distribution of reduced stress – general view, d) distribution of reduced stress – close up view

Fig. 7 shows the change in acceleration due to a single impact load. Analysis of the graph shows that set load pulse generated in the panel a vibration of an amplitude of ca. 400 m/s^2 and a frequency of ca. 500 Hz. The sudden short increase in acceleration in the final phase of the analysis is probably of a numeric nature.

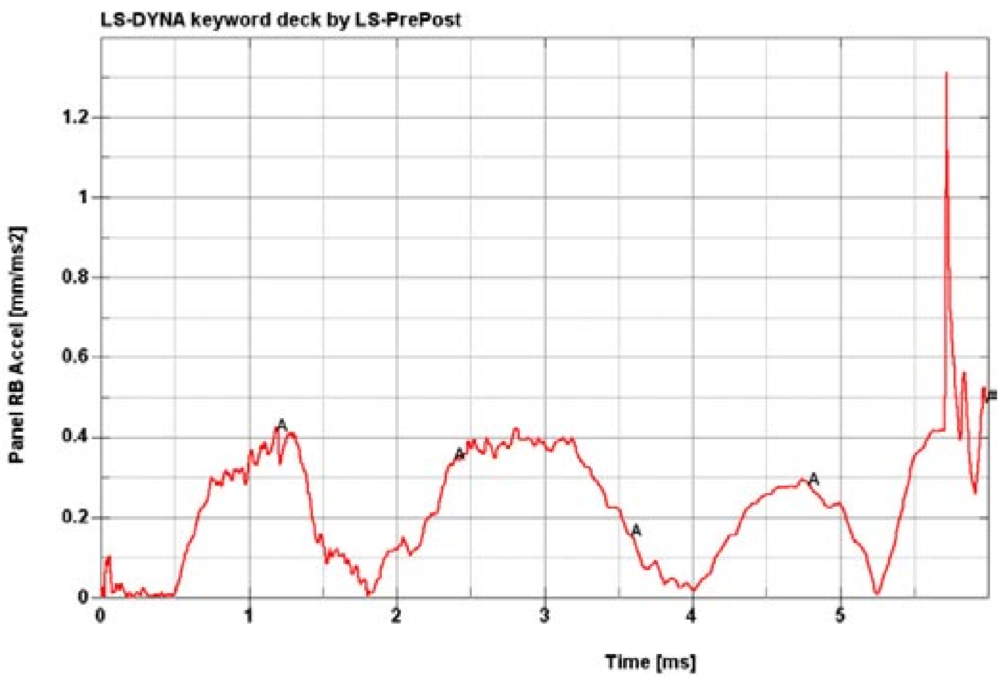


Fig. 7. Characteristics of panel acceleration values due to single impact normal to the panel surface

5. SUMMARY

The results of conducted studies made it possible to determine the impact of the system of additional armour installation on ballistic resistance of the panel. The results obtained by means of numerical analyses were studied in particular in terms of establishing the probability of permanent plastic deformations in the elements of the additional armour fastening system. In addition, the distribution of reduced stress, the values of panel acceleration and changes in velocity of the projectile during panel penetration were evaluated. On the basis of these data it was found that in the cases studied, the impact of a projectile results in permanent (plastic) deformations in the fastening arrangement elements (bushings, welds), but in quantitative terms these were far from destructive. No disturbing stresses or strains have been identified in bolts, washers and threaded connections. The only situation that needs to be looked into are permanent strains in the crush area of blind rivet nuts observed for loads from single and repeated impacts. Analysis of the impact of an AP 14.5 projectile centrally along the axis of the bolt of the fastening arrangement showed lack of protective capacity in this area. The projectile perforates elements of the fastening arrangement with no significant resistance, while its energy decreases only slightly and thereby the threat of hull penetration is still retained. A possible solution to this problem when the panel is spaced from the hull surface is to place a ceramic shape in the form of a disc or cylinder inside the bushing. However, it should be pointed out that due to the shape of a typical hull, perpendicular impact is unlikely. In most cases the projectile strikes at an angle, and while it hits the bolt of the fastening system, it also interacts with the ballistic panel.

6. REFERENCES

[1] Wiśniewski A.: *Pancerze, budowa, projektowanie i badanie.* Wydawnictwa Naukowo-Techniczne, Warsaw, 2001. ISBN 83-204-2609-X.

[2] Bhatnagar A.: *Lightweight ballistic composites: Military and law enforcement applications*. Woodhead Publishing Limited, Michigan, 2006.

[3] Galiński C.: „Pancerze reaktywne i aktywna ochrona balistyczna", Szybkobieżne Pojazdy Gąsienicowe (15), No. 1/2002 pp. 1-11 OBRUM Sp. z o. o. Gliwice, 2002.

[4] Defence Standard NO-06-A103: 2005. Uzbrojenie i sprzęt wojskowy. Ogólne wymagania techniczne, metody kontroli i badań. Wymagania środowiskowe.

[5] STANAG 4569, Edn 1, Protection Levels for Occupants of Logistic and Light Armoured Vehicles, NATO/PFP Unclassified. 2005.

This paper is based on the results of project no. DOBR-BIO4/024/13237/2013 titled "Additional modular armour for wheeled armoured personnel carriers and tracked platforms" financed by NCBiR (National Centre for Research and Development).