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ANALYTICAL MODEL TO ANALYZE THE PASSIVE REACTIVE CASSETTES

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A Passive Reactive Cassette (PRC) is a reactive armor cassette that integrates a passive cassette in it. This paper presents an analytical model that calculates the length of the precursor of a jet that penetrates through a PRC without disruption. The model analyzes the optimal configuration of the PRC, resulting in a shorter precursor.

INTRODUCTION

For the last 25 years, reactive cassettes have been used widely and successfully as an add-on-armor against shaped charge jets. There are two basic types of reactive cassettes: explosive and passive. A typical Explosive Reactive Armor (ERA) cassette, shown in Fig. 1, consists of two metallic plates and an explosive layer in between [1–2]. The penetration of the jet into the ERA cassette detonates the explosive, driving the two metal plates apart. The interaction between the moving plates and the jet disrupts the jet and reducing its penetration (Fig. 1). The ballistic performance of the ERA cassette is determined by the residual penetration of the disrupted jet, mostly generated by the intact forepart of the jet – the “precursor” (Fig. 2). An inert – passive cassette contains an inert layer instead of the explosive layer [3]. The penetration of the jet into the passive cassette expands the inert layer generating a local bulge in the metal plates. The effectiveness of the local bulge in disrupting the jet is smaller compared with that of the accelerated ERA metal plates.

It was suggested to integrate both reactive and passive cassettes. One such configuration is presented in reference [4] and shown in Figure 1. This cassette integrates a reactive cassette with three layers of backing (metal plate / inert sheet / metal plate).

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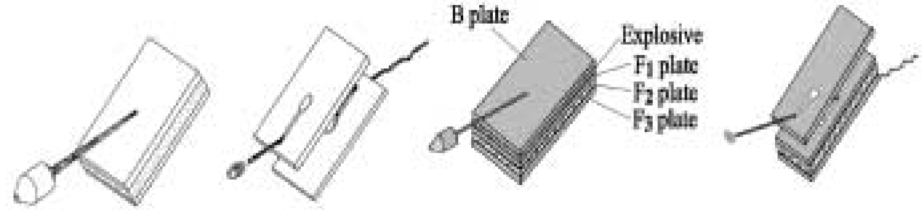

Figure 1. Schematic view of the ERA cassette in action (left) and the PRC (right).

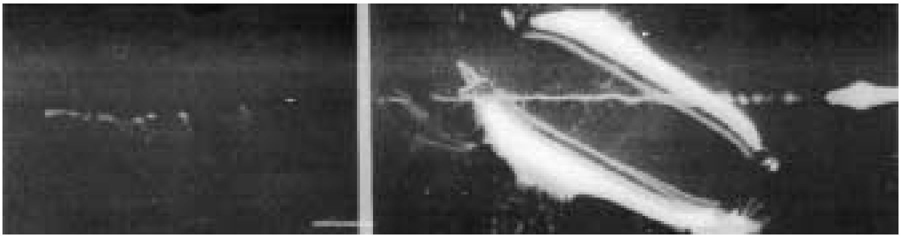

Figure 2. X-Ray viewgraphs of a reactive cassette interacting with a jet (on the left the "precursor").

This concept of Passive-Reactive-Cassette (PRC) sometimes performs better than each one of its components, see for example reference [4]. The inert layer can be placed in various places within the cassette. In this paper, the analyzed PRC consists of an inert layer placed at the backside of the cassette in between two steel layers. X-Ray viewgraphs showed that the improved ballistic performance of the PRC is sometimes a result of a shorter precursor, hence a faster interaction between the jet and the metal plates. The intuitive explanation was first that the back plate (the last forward-moving plate) moves faster compared to that of the standard ERA cassette and the interaction is therefore more intense. However, this explanation was not supported by explicit experimental evidence.

In order to understand the mechanism, by which the PRC configuration disrupts the jet effectively, we shall present, in the following chapters, the results of an analytical model clarifying and predicting the performance of PRCs.

Several experiments were carried out to defeat similar precision shaped-charges by different configurations of PRCs. The experiments were conducted according to the setup presented in Fig. 3, defining the standoff and the distance between the charge and the target.

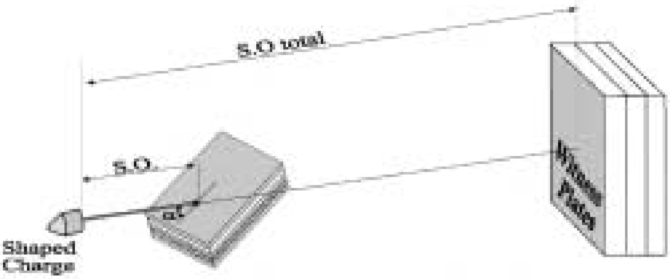

Figure 3. Schematic view of the experimental setup used to examine PRCs.

ANALYTICAL MODEL

The ballistics performance of the ERA cassettes is sometimes determined by the residual penetration of the jet, mostly generated by the intact forepart of the jet – the "Precursor" [5,6]. The precursor penetrates through the cassette before the jet interacts with the moving metal plates, as explained in references [1,6].

Some of the experimental results showed that the precursor was indeed reduced. Nevertheless, it seems that the main reason for this effect is not the added jet kinetic energy, but rather a combination of the pressure created by the explosive and the material properties of the three F-layers.

The analyzed PRC consists of five layers. The first layer that is being hit is the backward moving plate (B-plate). The second layer is the explosive one. The third layer consists of a metal plate and it is named F1. The forth layer is the inert plate, usually made of low-density material, and it is named F2. The fifth and last layer is a metal plate named F3. The B-plate moves backward with respect to the jet velocity vector while all three F plates move forward.

The sequence of events that occurs while the jet interacts with the cassette is as follows:

- The jet penetrates plate B and the explosive, detonating the explosive.
- The jet perforates the rest of the plates rupturing elliptical holes in the oblique plates [6] (The dimensions of the holes are larger than the diameter of the jet).
- The inert layer is being perforated, while moving sideways it push the adjacent F-plates. The F1-plate is being pushed backward and therefore is slowed while the F3 plate is being pushed forward.
- The head of the eroded jet emerges from the hole at the back of the cassette.
- The intact part of the jet: the precursor is stretched away from the back of the cassette.
- The detonation wave propagates into the explosive layer accelerating the two adjacent plates apart: one plate backward and the second plate forward.
- The forward moving plate F1 compresses the inert layer. The increased pressure in the inert layer accelerates the last plate F3 forward.
- All three F-layers are moving forward and regain contact with the jet (cutting short the precursor).
- Every time the plates interact with the jet new elliptical holes are formed and the interaction breaks off. In this manner, several intervals of interaction occur (the pebble stone model [1]).

There are two significant parameters affecting the operation of various configurations of PRCs: the time it takes the plates to re-interact with the precursor and the mass flow of the plates into the interaction zone.

Both parameters are governed by the exact profile in time of the velocity of the plates. In order to find out the velocity-profiles of the plates a simple one-dimensional model of concentrated masses and springs was used (Fig. 4).

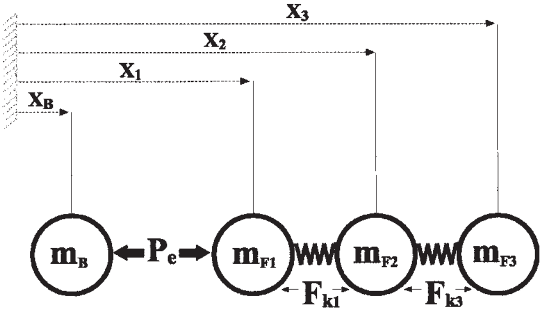

Figure 4. A mass-spring model of the PRC configuration.

In the model, the metal plates are represented as concentrated mass points with infinite rigidity. The inert layer is represented as a concentrated mass in between two identical springs. Hence, the mass of the inert layer is taken into account in the acceleration of the F-plates by the explosive and the momentum balance between the B-plate and the F-plates are maintained. The explosive is represented as an ideal pressurized gas. Three dynamic forces are acting in the model: P_E – the force of the explosive, F_{K1} – the force of the left side of the inert layer and F_{K3} – the force of the right side of the inert layer. Each force is governed by the momentary relative distance between its adjacent metal plates.

Once we know the forces, the plate's movement can be calculated by numerically integrating their accelerations in time as follows:

$$\begin{aligned} m_B\ddot{X}_B &= -P_E\,(X_B, X_1) \\ m_{F1}\ddot{X}_1 &= P_E(X_B,X_1) - F_{K1}\,(X_1,X_2) \\ m_{F2}\ddot{X}_2 &= F_{K1}\,(X_1,X_2) - F_{K3}\,(X_2, X_3) \\ m_{F3}\ddot{X}_3 &= F_{K3}\,(X_2, X_3) \end{aligned} \tag{1}$$

Where X_i is the position of the plate i measured from a fix point and m_i are the plate's masses, as presented in Fig. 4.

Upon detonation there are explosive forces acting on the B-plate and the F1-plate only. Both plates start to move simultaneously. While moving, the F1-plate compresses the F2-plate (the inert layer) and therefore creating a new force F_{k1} that starts to accelerate the inert layer and slow down the F1-plate. When the inert plate starts to move F_{k3} causes F3-plate to accelerate.

As stated above, the inert layer was modeled as a linear elastic element. The inert layer acts like a compression spring that pushes the F1 and F3 plates bot cannot apply tensile forces. The change in the thickness of each part of the inert is calculated as follows:

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$$
\begin{array}{c}
\Delta 1 = Tr - (X_2 - X_1) \\
F_{k1} = \mathrm{K} \cdot \Delta 1 \quad \text{if} \quad \mathrm{Tr} > \Delta 1 > 0 \\
F_{k1} = 0 \quad \text{if} \quad \Delta 1 \leq 0 \,/\, \Delta 1 \geq \mathrm{Tr} \\
\Delta 2 = Tr - (X_3 - X_2) \\
F_{k3} = \mathrm{K} \cdot \Delta 2 \quad \text{if} \quad \mathrm{Tr} > \Delta 2 > 0 \\
F_{k3} = 0 \quad \text{if} \quad \Delta 2 \leq 0 \,/\, \Delta 2 \geq \mathrm{Tr}
\end{array}
\tag{2}
$$

Tr – half the inert layer thickness,
K – the elastic constant of half of the inert layer,
Δ_i – the compression of the inert layer spring i = 1, 3
F_{ki} – the force acting on the i plate,

The elastic constant K was equal to ρC_0^2, where ρ is the inert layer density and C_0 is its longitudinal sound speed.

To check the accuracy of the model, its prediction of velocity profiles was compared to a numerical simulation conducted using the AUTODYN code. The first comparison was made on a basic configuration of three layers, hence reactive cassette. In this configuration, the F-plate was much thicker than the B-plate in order to examine the validity of the model in extreme cases. The results of this comparison are presented in Fig. 5.

As one can see, there is a good correlation between the model and the F.E analysis in predicting the velocity of the thick plate. However, there is some discrepancy between the calculated velocities of the thin plates in the two procedures. The main reason for this difference is that the explosive pressure and its neutral line are not accounted well in our simple model.

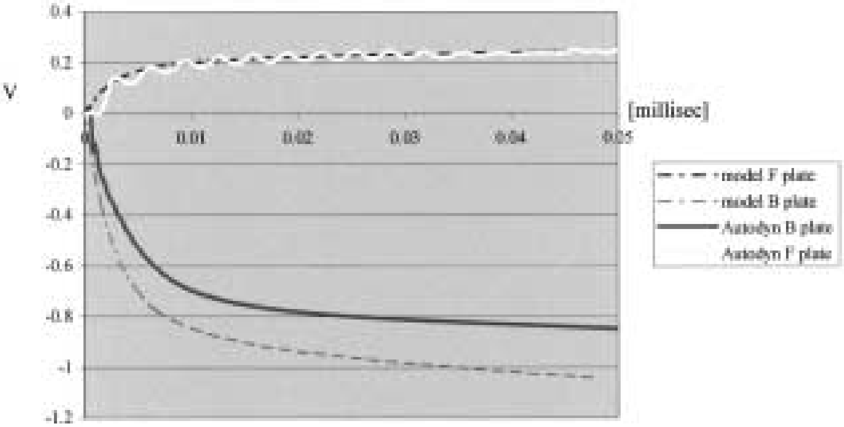

Figure 5: A comparison between the velocities of the model and an AUTODYN simulation.

Nevertheless, since our main interest is the velocity history of the thicker plate this small discrepancy is of no importance.

The second comparison was made on a more complicated configuration, the PRC cassette (Fig. 6). As one can see, both procedures predict that the F3-plate moves faster than the F1 one, while the F1-plate slows down after a short period of acceleration because of

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the forces that are developed in the inert layer. Again, the velocity of the F3-plate in the mass-spring model is faster compared with the predictions of the AUTODYN code, result, probably because of an even division of the inert layer, a similar effect to that of the explosive pressure. In addition, the elastic constant that is used is probably too high since in the AUTODYN simulation the inert layer has elasto-plastic strength model (Von-Mises).

The generation and the full size of the elliptical holes that the jet ruptured in the plates was calculated according to the formulations described in reference [6].

Knowing the characteristics of the velocity of jet and the rate of erosion during the perforation phase of the cassette, we can now calculate the moment the precursor head emerges from the back of the F3-plate and its velocity. By calculating the plates velocities and the holes diameters one can calculate the moment the edges of the hole re-interact with the jet, disrupting the "tail" of the precursor. The outcome of this calculation is the total length of the precursor.

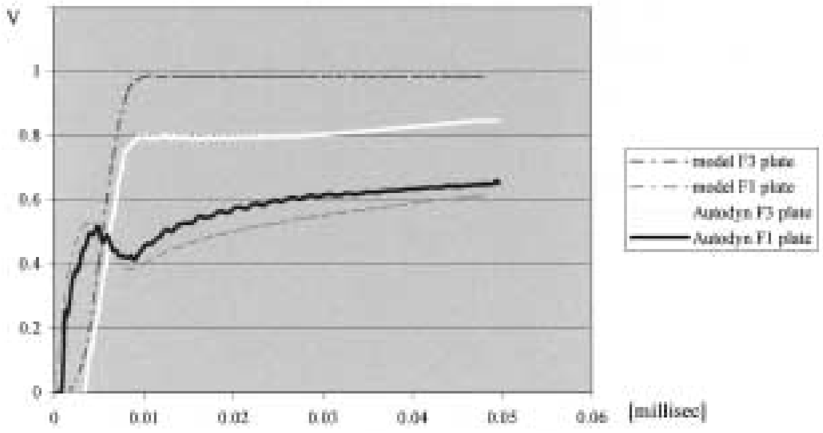

Figure 6: A comparison between the model predictions and an AUTODYN run for the two F-plates of a PRC.

According to our model, the jet is disrupted during the interaction with the plate if the ratio between the mass flux of the plate and of the jet reaches a minimum critical value. The first re-interaction that exceeds this value determines the length of the precursor and the velocity of its tail.

The D.O.P (Depth Of Penetration) was calculated from the precursor length, velocities and the geometric data [6].

DISCUSSION

Two sets of PRCs were examined: the first set utilizing a thin inert layer, the second set was with a thick inert layer. In each set only the thicknesses of the two back metal plates (plates F1 and F3 in Fig. 1), were varied in a manner that kept the total weight of the cassette, constant. DOP predictions of the model showed that for two different confi-

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gurations of PRC, differing in the thickness of the inert layer (thin or thick), there are two different optimal thicknesses of the last F-plate, yielding minimal DOP. These predictions are presented in Figure 7.

It can clearly be seen that the model predicts the existence of an optimal configuration of the PRC. A thick F3-plate is accelerated slower and reaches the position of fully disruption the jet late in time, while a thin F3 plate, although being fast accelerated, imposes a low mass flux onto the jet and hence does not disturb the jet. As a result, there is always an optimal F3 plate thickness, regardless of the inert layer thickness, that minimizes the precursor D.O.P.

The series of experiments is now being conducted to validate the model. The tests are not yet completed.

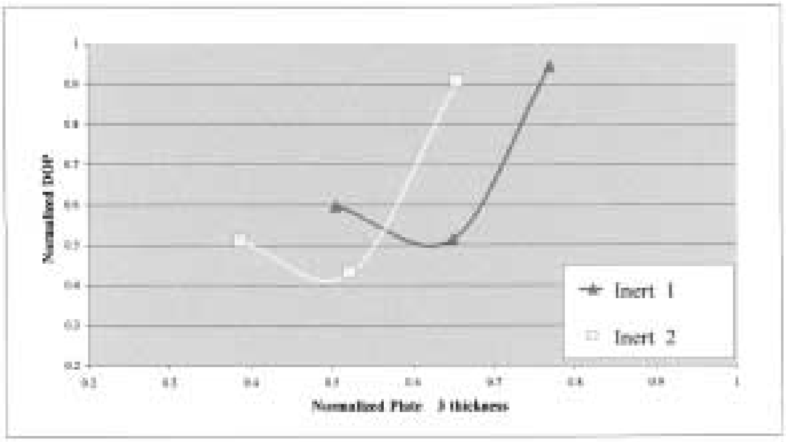

Figure 7: Model predictions for the DOP of the two types of PRCs.

SUMMARY AND CONCLUSIONS

In this paper we have presented an analytical model capable of analyzing the structure of PRC, for defined configuration of shaped charge jet and PRC, in order to minimize the DOP.

This model also provides an explanation why PRC is more effective then an ERA cassette with the same B-plate and explosive weight. The main reason is the ability to reduce the length of the precursor.

REFERENCES

1. M. Mayseless, Y. Ehrlich, Y. Falcovitz, D. Weihs, G. Rosenberg, "Interaction of Shaped-Charge Jets with Reactive Armor", Proceedings of the 8th Int. Sym. on Ballistics, pp. VII-15–VII-20, Orlando, Florida, (1984).
2. M. Held, M. Mayseless, E. Rototaev, "Explosive Reactive Armor", Proceedings of the 17th Int. Sym. on Ballistics, Vol 1, pp. 33–46, Midrand, South-Africa, (1998).
3. N. Gov, Y. Kivity, D. Yaziv, "On the Interaction of a Shaped Charge Jet with a Rubber Filled Cassette", Proceedings of the 13th Int. Sym. on Ballistics, Sweden, (1992)
4. H. Shevach, G. Rosenberg, Y. Partom, S. Friling, M. Benyami, Y. Erlich, RAFAEL, US Patent No. 5.070.764 (1991).
5. M. Held, "The importance of Jet Tip Velocity for the Performance of Shape Charge Against Explosive Reactive Armor", Prop. Exp. Pyro. 19, 15–18 (1994).
6. M. Mayseless, "Jet Plate Interaction: The Precursor", Proceedings of the 18th Int. Sym. on Ballistics, Vol 2, pp. 1019–1026, San Antonio, USA, (1999).