DEFEATING THE RPG7 THREAT BY USING ELECTRIC POWER IN REACTIVE ARMOUR APPLICATIONS

M.J. van de Voorde[1], J.J.A. van der Burgt[1], M.J. van der Jagt-Deutekom[1]

[1]TNO Defense, Security and Safety, Lange Kleiweg 137, P.O. Box 45, 2280 AA Rijswijk, The Netherlands, martin.vandevoorde@tno.nl

Shaped charges are considered to be a big threat. The Dutch army frequently encounters shaped charges like RPG7 while operating in countries like Afghanistan and Iraq. Conventional armour offers only limited protection against these types of threats, within the weight restrictions. One possible countermeasure is electric reactive armour (ELRA). This armour system is not yet available, but with the growth potential of the use of electric power it is possible in the future.
ELRA consists of two parallel conducting plates with a certain distance and a voltage difference between them. The plates are mounted on the basic armour of a vehicle. When the tip of the shaped charge jet hits the inner plate after having penetrated the outer plate, it triggers an electric current that starts to flow through it. The current through the jet causes enhanced break up, resulting in a reduced penetration capacity.
The potential of the ELRA system is evaluated with live firings with two types of shaped charges at the Ballistics Research Laboratory of TNO. The visual and electrical measurement results prove the principle of enhanced instability and reduced penetration capacity of a shaped charge jet caused by the supplied electric current.

INTRODUCTION

Shaped charges are considered to be a big threat. The Dutch army frequently encounters shaped charges like RPG7 while operating in countries like Afghanistan and Iraq. Operational requirements for platforms like Infantry Fighting Vehicles result in a constant trade-off between protection and mobility. Conventional armour offers only limited protection against these types of threats, within the weight restrictions. Therefore, TNO was asked by the Dutch Ministry of Defence to perform a technology watch on current and future (light weight) armour developments.

Besides the conventional 'passive' armour systems, which are relatively heavy and voluminous against shaped charge threats, active armour systems and reactive armour systems are possible. Active armour systems use sensors to detect the incoming threat before it hits the armoured vehicle and launch a countermeasure to prevent the threat even reaching the vehicle. Reactive armour systems react when the incoming threat touches the outside of the armoured vehicle.

Two reactive armour systems are already available as add-on systems on armoured vehicles: ERA (Explosive Reactive Armour) and NERA (Non-Explosive Reactive Armour). Drawback of these systems is that the front plate is launched away from the vehicle, which could be harmful for personnel in the surroundings of the vehicle. A third possible reactive armour system is electric reactive armour (ELRA).

ELRA consists of two parallel conducting plates with a certain distance and a voltage difference (connected to an energy source) between them. These plates are mounted on the basic armour of an armoured vehicle. When the tip of the shaped charge jet hits the second plate (the inner plate) after having penetrated the first plate (the outer plate), it triggers an electric current that starts to flow through it. As a consequence of the high electric current a magnetic pressure acts on the penetrating jet, which increases with decreasing diameter [1]. Because the diameter of the jet is not homogeneous, the magnetic pressure enhances the natural instability of the jet (see Figure 1). The current only flows through the part of the jet which is between the two electrode plates. The current flow has stopped in the front part of the jet which has left the ELRA plates, thereby relieving the jet from the magnetic pressure; as a consequence the internal tensile forces expand the diameter of the jet fragments up to five to ten times the jet diameter [2]. Both these effects cause the jet to break up, resulting in a reduced penetration capacity.

This armour system is still in a development stage by several institutes, although in 2002 a demonstration was given by Dstl [3]. With the growth potential of the use of electric power in armour applications however, it should be possible to use this system in the near future. With a proof-of-principle set-up of ELRA it is demonstrated in this paper that the supplied electric current enhanced instability and reduced penetration capacity of a RPG-like shaped charge and a DRAGON shaped charge.

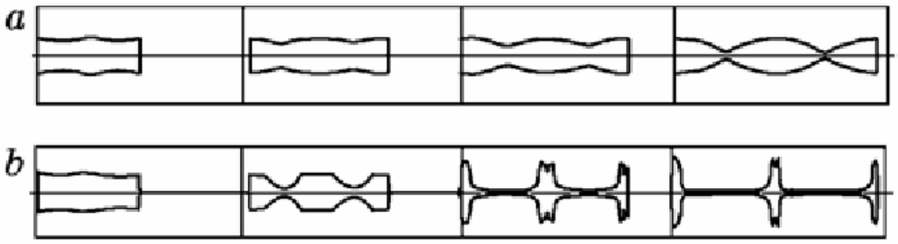

Figure 1: Schematic of (a) the natural instability and (b) ELRA enhanced instability of a shaped charge jet [4]

EXPERIMENTAL SET-UP

Live firings with two types of shaped charges were performed in the years 2005 and 2006 at the Ballistics Research Laboratory of TNO Defence, Security and Safety, The Netherlands. The aim of the experiments was to obtain visual and electrical measurement results to prove the principle of enhanced instability and reduced penetration capacity of a shaped charge jet caused by the supplied electric current. Once the principle is proven and better understanding of the working mechanisms is obtained, the ELRA concept can be optimized and the consequences of implementing this armour system on a vehicle can be addressed.

The first shaped charge used is the DN360, which is a RPG7-like shaped charge; it has a diameter of 70 mm and a comparable penetration capacity. The second shaped charge used is the DRAGON which is a heavier threat, with a diameter of 90 mm and with a higher tip velocity compared to the DN360.

For the prediction of the necessary current amplitude, rise time and pulse duration, formula's of Shvetsov and Matrosov [5] are used. The first equation gives an indication of the minimal required current for enhanced natural instability (I_{cr}):

$$I_{cr} = \frac{2\pi\alpha r_0^2}{\Delta}\sqrt{\frac{\rho}{\mu_0}} \cdot u_i \qquad (1)$$

Where α is a numerical coefficient, r_0 is the average radius of the shaped charge, Δ the distance between the two ELRA plates, ρ is the density of the jet, μ_0 is the magnetic permeability of vacuum and u_i is the velocity of the jet in-between the ELRA plates. It is known that the velocity of a shaped charge jet varies from a high velocity of the tip (u_0) to a lower velocity of the tail (u_{cr}). The following formula for the velocity distribution along the jet was used [5]:

$$u(x) = u_0\left[1 - \left(1 - \frac{u_{cr}}{u_0}\right)\left(\frac{x}{l_{eff}}\right)^n\right] \qquad (2)$$

Where l_{eff} is the effective length of the jet and n is a factor determined from experiment.

These two relations enabled us to predict the effects of varying the plate distance and the capacitor voltage. This is illustrated in figure 2 for the DRAGON for two plate distances. It is clear that with a larger distance between the ELRA plates, the critical current is reached sooner. In this case a larger part of the jet can be affected and thus the penetration capacity more reduced.

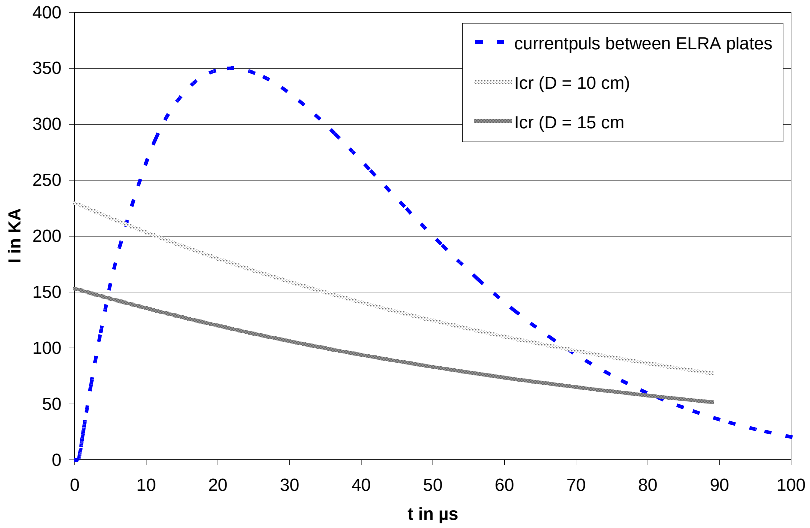

Figure 2: Current through the jet between the ELRA plates with the TNO set-up and the minimal current required for enhanced instability (Icr) for two plate distances (D) for the DRAGON

Figure 3 shows a schematic of the used test set-up. X-ray pictures were taken to visualize the breaking up of the jet. For these experiments the distance between the second ELRA plate and the base armour was more than a meter long. Also depth of penetration (DOP) measurements were done, to give an indication of the reduction on the penetration capacity. In these DOP experiments the distance between the second ELRA plate and the base armour was 150 mm.

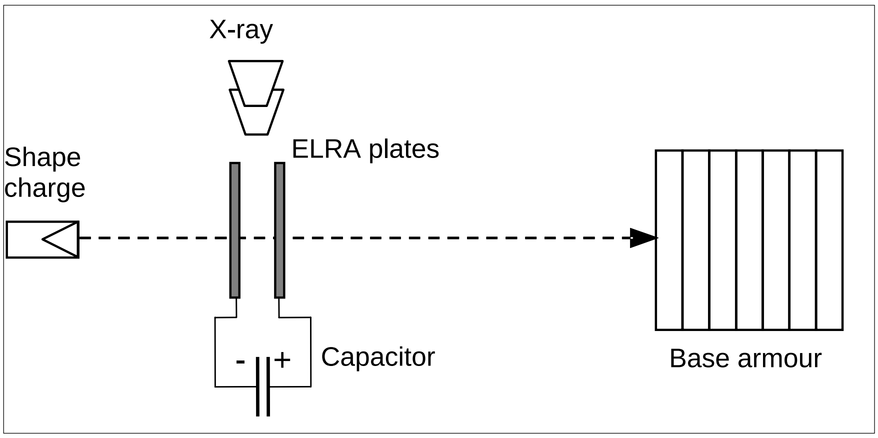

Figure 3: Schematic of the experimental set-up

RESULTS AND DISCUSSION

In this study the necking instability and the breaking up of the shaped charge jet was clearly visualized on X-ray photographs when a sufficient capacitor voltage of 20 kV was applied (see figure 4). With the DOP measurements a promising reduction in depth of penetration was achieved with a proof of principle set-up (see figure 5).

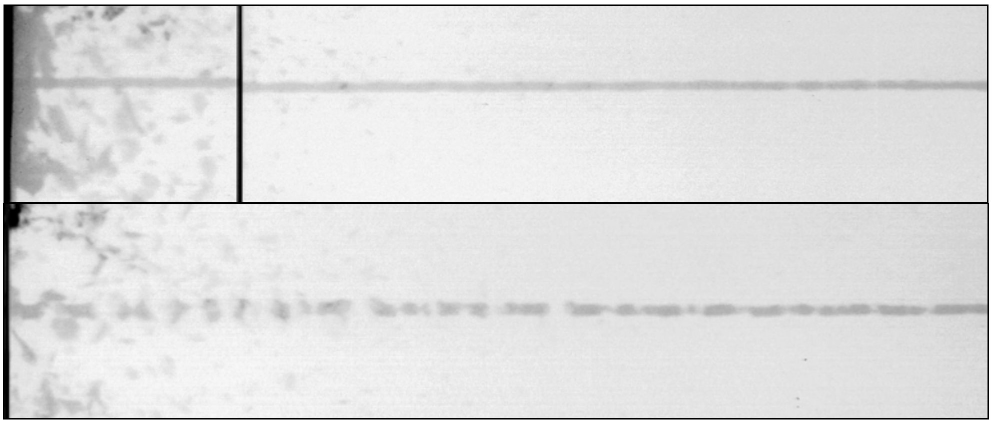

Figure 4: Detail of the X-rays of a shaped charge jet (moving from left to right) leaving the ELRA plates with no voltage (above) and a sufficient voltage of 20 kV (below)

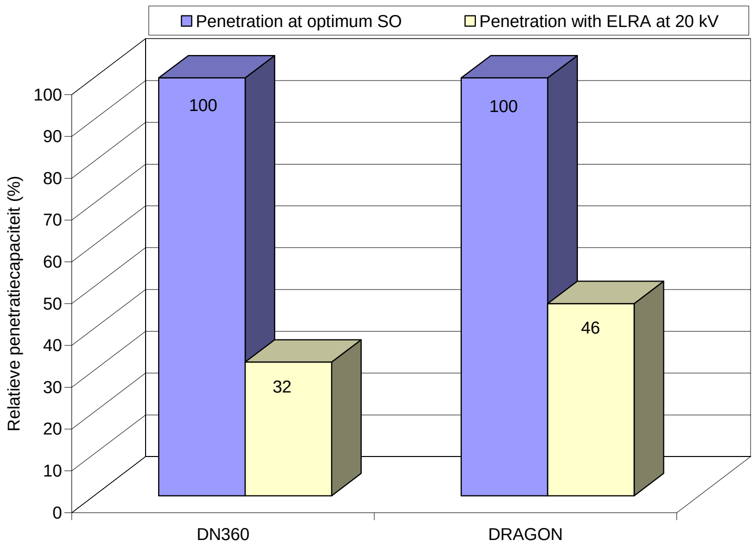

Figure 5: Relative DOP results for both shaped charges

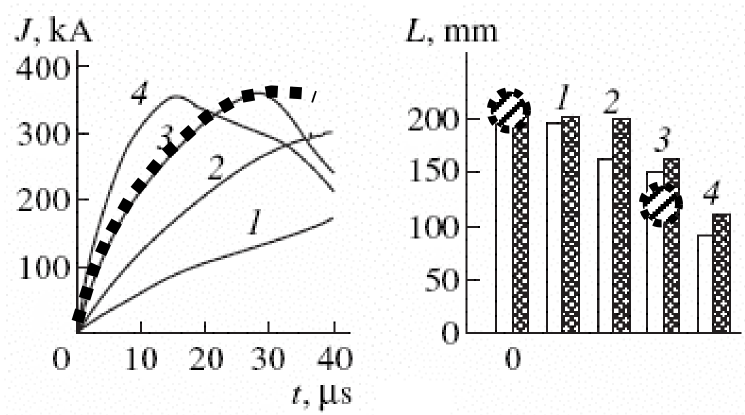

Figure 6: Experimental and simulation results of ELRA of Federov [6] and TNO results
Left: the measured current (J) through the jet (thick black dashed line are TNO results)
Right: penetration depth (L), simulated (crosshatched) and measured (white) by Federov and measured by TNO (hatched circles), “0” indicating the reference situation with no current through the jet

During all the experiments the jet current and the voltage difference between the ELRA plates were measured. The measured values of the jet current were in good correspondence with the theoretical predictions. Our experimental results were also comparable with the experimental and simulation results of Federov [6] even though some parameters were not similar (see figure 6). This to indicate that the TNO experiments were done with relevant parameters and current pulses.

With the use of the measured current and voltage difference between the ELRA plates, the energy dissipated in the jet could be calculated with a theoretical analysis. The remaining energy is lost, meanly dissipated in the resistors of the capacitor module. The calculated energy dissipated in the jet is approximately 25 kJ, which is only 12% of the released energy of the capacitors. This value is in good correspondence with the data given in literature. Pollock [7] found a dissipated energy in the jet of 14 kJ for a similar shaped charge as TNO used.

The effectiveness of the principle of ELRA has been proven using a straightforward experimental set-up. In the next phase, the optimization of the ELRA system has to be investigated further. Important parameters are the magnitude, pulse width and rise time of the current pulse. Especially, the current rise time needs to be decreased in order to attack the tip of the shaped charge jet. This asks for a pulsed power supply with low inductance. In the existing set-up, the inductances are rather large, mainly because of long cables between the capacitors and the ELRA plates. Therefore, solutions must be sought to minimize the cable length. This challenge has also been recognized by Wickert [8]: his solution is to place the capacitors directly behind the ELRA-plates. A further improvement could be reached by placing the capacitors between the ELRA-plates. This last option will be further investigated by TNO Defence, Security and Safety in simulations and experiments.

CONCLUSIONS

The potential of the ELRA system is evaluated with live firings with two types of shaped charges at the Ballistics Research Laboratory of TNO. The visual and electrical measurement results prove the principle of enhanced instability and reduced penetration capacity of a shaped charge jet caused by the supplied electric current. Reductions of 50 to 70 % were reached. This shows that the ELRA system is a promising light weight armour system against shaped charges.

Optimization of the ELRA system will be investigated further. A significant effect can be reached by decreasing the current rise time in order to attack the tip of the shaped charge jet. A possible solution is to place the capacitors directly behind the ELRA-plates or even placing the capacitors between the ELRA-plates. This last option is currently under investigation by TNO Defence, Security and Safety in simulations and experiments.

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