A TUTORIAL ON THE PENETRATION OF KINETIC-ENERGY (KE) ROUNDS

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Abstract. In World War II non-deforming kinetic energy (KE) projectiles with velocities beneath 1 000 m/s achieved perforation of the target by volume deformation and/or plugging. The design of KE projectiles has changed significantly as muzzle velocities have increased, leading to much higher impact velocities. For projectile velocities above 1 000 m/s the mechanisms of volume deformation and plugging are replaced by hydrodynamic penetration, where the projectiles are eroding during the penetration process. This paper provides a brief tutorial on the penetration of KE rounds for projectile velocities below and above 1 000 m/s. The corresponding penetration equations are described, after which the paper presents a useful rule-of-thumb, the experimentally obtained diagram of Hohler and Stilp, and an analytical equation by Lanz, Jeanquartier and Odermatt. The paper concludes with a numerical example.

INTRODUCTION

The design of short KE projectiles has changed drastically with increasing muzzle velocity producing much higher impact velocities on the target. During World War II muzzle velocities were typically lower than 1 000 m/sec. The best penetration could be achieved by very hard non-deforming projectiles, which penetrated and perforated by volume deformations in the target plates or by plugging out a hole, working like a piston. The energy threshold for the projectile can be described by the “volume deformation” as follows:

$$0.5 \cdot m \cdot v_j^2 = C_v \cdot D^2 \cdot d \tag{1}$$

or by plugging as:

$$0.5 \cdot m \cdot v_j^2 = C_p \cdot D \cdot d^2 \tag{2}$$

where m is the projectile mass, v_j the impact velocity, D the projectile diameter, d the target plate thickness (or the line-of-sight thickness $d/\cos\theta$ for inclined plates, where θ is the NATO angle), and C_v and C_p are the corresponding constants for volume deformation and plugging respectively.

In the Equation (1) the diameter D is raised to the power of two and the plate thickness d to the power of one, whereas in the plugging Equation (2) the projectile diameter D is raised to the power of one and the plate thickness d to the power of two.

In reality the perforation mechanism lies in between the extremes of Equations (1) and (2). In practice the initial penetration by a non-deforming projectile of a thicker target plate is typically by volume deformation and the final perforation is by a more-or-less plugging process. The critical velocities for plate perforations are been described by the Krupp and the DeMarre equations in which the sum of exponents for the projectile diameter D and the plate thickness d is three or approximately three.

The sum of the exponents in the Krupp equation is exactly three:

$$E_{cr} = C_K \cdot D^{1.67} \cdot d^{1.33} \tag{3}$$

whereas the sum of the exponents in the DeMarre equation is approximately three:

$$E_{cr} = C_M \cdot D^{1.5} \cdot d^{1.4} \tag{4}$$

where E_{cr} is the critical kinetic energy for a perforation and C_K and C_M are the corresponding constants [1].

As muzzle velocities increase the contact pressure begins to exceed the strength of possible projectile materials, requiring the use of very hard materials such as tungsten carbide. The velocity limit between the possibilities of non-deformation projectile penetrations and eroding projectiles is approximately 1 000 m/s.

Current projectile velocities are running in the so-called partially hydrodynamic regime where fluid dynamic behaviour of the materials provides the dominant features. For ordnance velocities in the range of typically 1 400–1 800 m/s, however, the hardness of the projectile is still important.

The development of the projectiles extends from the full-caliber projectiles, to the so-called APDS (Armour Piercing Discarding Sabot, spin-stabilised) projectiles, to APDSFS (Armour Piercing Discarding Sabot Fin Stabilized) projectiles. The penetrators are reduced in diameter and elongated in length. They are accelerated and launched from the gun tubes with the help of the sabots. The projectiles are typically made from heavy metals, like sintered tungsten alloys or depleted uranium.

Early KE projectiles were only spin-stabilized. But this can be done only over a length-to-diameter ratio of about 3.5. To meet the desired increase in lengths, the long rods have to be fin-stabilized and are now fired from smooth-bore guns or from rifled guns using slipping driving bands. While there had initially been doubts about the hit probability of long-rod projectiles fired from smooth-bore guns, they can now achieve the same hit dispersion on the target as those fired from rifled guns.

These projectiles, with their very low area-to-mass ratio, undergo a very low reduction in velocity as the move through the air—typically 30–50 m/sec over a distance of 1 000m—and therefore have short flying times over extremely long distances. They also have high impact velocities and good hit probabilities against moving targets.

PENETRATIONS OF APDSFS PROJECTILES

Rule of Thumb

For these long heavy metal projectiles with high velocities, we can use following equation derived from the modified Bernoulli equation:

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