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Diameter Effect of Induced Voltage in Sensing Coil Buried in Projectile for Application of Air Bursting Munition

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We designed a model composed a ring type magnet, a yoke, and a sensing coil buried in a projectile for calculating the muzzle velocity based on the voltage induced from sensing coil by simulation. The muzzle velocity was calculated from the master curve obtained through the voltage induced from sensing coil by simulation. The induced voltage increased with increasing the diameter of sensing coil. The projectile's velocity was proportional to the induced voltage when the sensing coil was buried in projectile. The projectile will be surely exploded at the target region by inputting the information of muzzle velocity variation corrected the diameter effect of induced voltage of sensing coil.

Keywords : Air Bursting Munition (ABM), muzzle velocity, finite element method (FEM), eddy current, skin effect

공중파열탄용 포탄에 묻혀있는 탐지코일의 직경에 의한 유도전압 변화

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포탄에 묻혀있는 탐지코일에서 유도되는 전압으로부터 총구를 떠나는 포탄의 초기속도를 계산하기 위하여 링 형태의 자석, 요크 및 탐지코일로 모델을 구성하였다. 자기장 해석에 의해 탐지코일의 유도전압에서 구한 마스터 곡선으로부터 포탄의 초기속도를 구할 수 있다. 탐지코일의 유도전압은 포탄에 묻혀있는 탐지코일 직경의 크기에 영향을 받는데, 직경의 크기가 증가하면 유도전압도 비례하여 증가한다. 탐지코일에서 유도되는 전압의 직경 효과를 감안한 초기속도 변화에 대한 정보를 입력하면 목표에서 포탄이 정확하게 폭발할 수 있다.

주제어 : 공중파열탄(ABM), 총구속도, 유한요소법(FEM), 와전류, 표피효과

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I. Introduction

The projectile that be burst at a programmed distance from muzzle will be variously used for military purposes. In order to detonate at a present round-to-target distance, the velocity and trajectory of projectile must be measured when it leaves from a muzzle. As the projectiles start from muzzle, the projectile's velocities gained from the kinetic energy of the chemical explosion are not constant. For correctly bursting a projectile on the target area, the velocity information measured at the muzzle must be inputted to projectile by communicating between the device attached at a flash suppressor and the equipment attached the projectile.

The projectile's velocity can be measured two methods. Firstly, the projectile measures its own velocity by itself. Secondly, the velocity is measured at outside [1, 2]. The 40 mm low/medium air burst munitions (ABMs) system had micro-radar sensor for measuring the velocity [2]. The miniaturized magnetic induction sensor using geomagnetism was developed for measuring turn count of small-caliber ammunition [3]. Singapore Technologies Kinetics has identified the 40 mm low velocity ABM system as the way forward to meet the current and future threats [4]. The 40 mm x 53 ABM for automatic grenade launchers with two receive coils for measuring the projectile's velocity at the muzzle and a transmitter coil for feeding the projectile on the information for the velocity as the projectile goes past the muzzle was developed [1]. The voltage induced at the sensing coil buried in the projectile was simulated for estimating its velocity at muzzle [5].

In this paper, we simulated the diameter effects of the sensing coil and velocity effects of the projectile at the model composed of a ring type magnet, a yoke, and a sensing coil embedded in the projectile.

II. Eddy Current Effect for Diameter of Sensing Coil

In this paper, we used the method such as the projectile measures its own velocity. The sensing coil buried in the projectile measures the induced voltage when it goes past the magnetic field produced by permanent magnets as shown in Fig. 1. The system constructed with a ring type Nd magnet, a yoke, and a sensing coil was used for simulating the diameter effect of the voltage induced in the sensing coil. The permanent magnet parts constructed with a ring type Nd magnet and a pair of yokes to concentrate magnetic field on the projectile surface. The voltage will be induced at the sensing coil by the linking

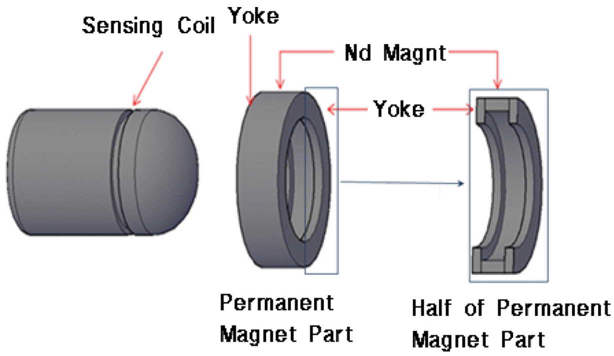

Fig. 1. (Color online) Schematic diagram for measuring the projectile's velocity. The sensing coil embedded in the projectile. The voltage is induced at the sensing coil as the projectile goes through the magnetic field produced by permanent magnet.

flux as the projectile goes past the magnetic field produced by the permanent magnet. It is described with Faraday's law of induction as follows;

$$V(t) = d\phi(t)/dt \tag{1}$$

$$\phi(t) = \int \vec{B}(t) \cdot d\vec{A} \tag{2}$$

where $V(t)$ is the voltage induced at the sensing coil and $\phi(t)$ is the magnetic flux linking at the sensing coil as it goes past the magnetic field produced by the magnet. $\vec{B}$ is the magnetic induction and $\vec{A}$ is the effective cross-sectional area of the sensing coil. The eddy current (EC) is produced by high speed of projectile made of aluminium as pass through the magnetic field. The EC is described by Maxwell's equation

$$\nabla \times \vec{J} = -\sigma \frac{d\vec{B}}{dt} \tag{3}$$

where $\vec{J}$ is the current density and σ is the electric conductivity. The EC is proportional to the conductivity and the times derivative of the flux density. The magnetic field direction produced by the EC is opposed to the direction of the original filed. So the EC disturbs the flow of the magnetic field into the conductor. This is skin effect and the penetration depth is the depth when the magnetic fields reach the half of its original intensity. The skip depth (δ) is given by equation as follows;

$$\delta = \sqrt{\frac{1}{\pi f \mu \sigma}} \tag{4}$$

where f is a frequency of the magnetic field and μ is a permeability of a material.

Because a frequency increased if a velocity is fast, the induced voltage is increasing with the increase of the projectile's velocity by equation (1), but it is also decreased the skin effect of equation (4). In order to obtain the optimal induced voltage from the magnetic circuit using permanent magnet, the voltage induced at the sensing coil buried in the projectile must be simulate by a computer.

3. Simulation for Voltage Induced at Sensing Coil

We simulated the diameter effects of the sensing coil and the velocity of the projectile at the model composed of a ring type Nd magnet, a yoke, and a sensing coil buried in a projectile. Fig. 2 shows a schematic diagram for simulating the voltage induced at the sensing coil. The projectile is shown a half the size in the Fig. 2. The groove depth *d* is changed for estimating the diameter effect of the voltage induced at the sensing coil. The model designed by Maxwell v15 3D is shown Fig. 3. The projectile is generally composed two parts, one is the aluminum with sensing coil and the other is steel for striking a hard blow to the target. The sensing coil is buried in the aluminum part. Also, Fig. 3 presents the mesh configuration for the designed model by Maxwell. The solver for the FEM was the Transient, and the size of mesh was approximately 62,000 tetrahedra.

The voltage profiles simulated by the FEM are shown in Fig. 4. The diameters of the sensing coil are Fig. 4 (a) 32.2 mm and (b) 39.2 mm. The voltages are increased with increasing the diameter of sensing coil. The peak of the graphs in the fourth quadrant will be used to give the muzzle velocity variation to the projectile [5].

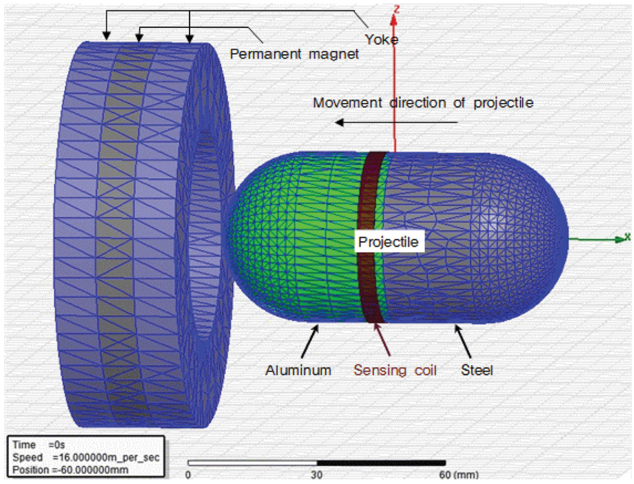

Fig. 3. (Color online) Maxwell model and mesh configuration for simulating the diameter effect of the voltage induced at the sensing coil buried in the projectile. Only the parts of a magnet, a yoke, and the projectile are shown in this figure. The size of the mesh was about 62,000 tetrahedra.

The calculated results for the diameters of sensing coil are shown in Fig. 5. When the sensing coil buried in the projectile, the induced voltage slowly increased with increasing the diameter of the sensing coil. But it suddenly increased as the sensing coil exposed from the projectile. As the diameter of sensing coil increases, the sensing coil is buried shallowly in the projectile. The voltage induced at the buried sensing coil decreases by eddy effect when the projectile passes through the magnetic field. The relation between the voltage induced at sensing coil and

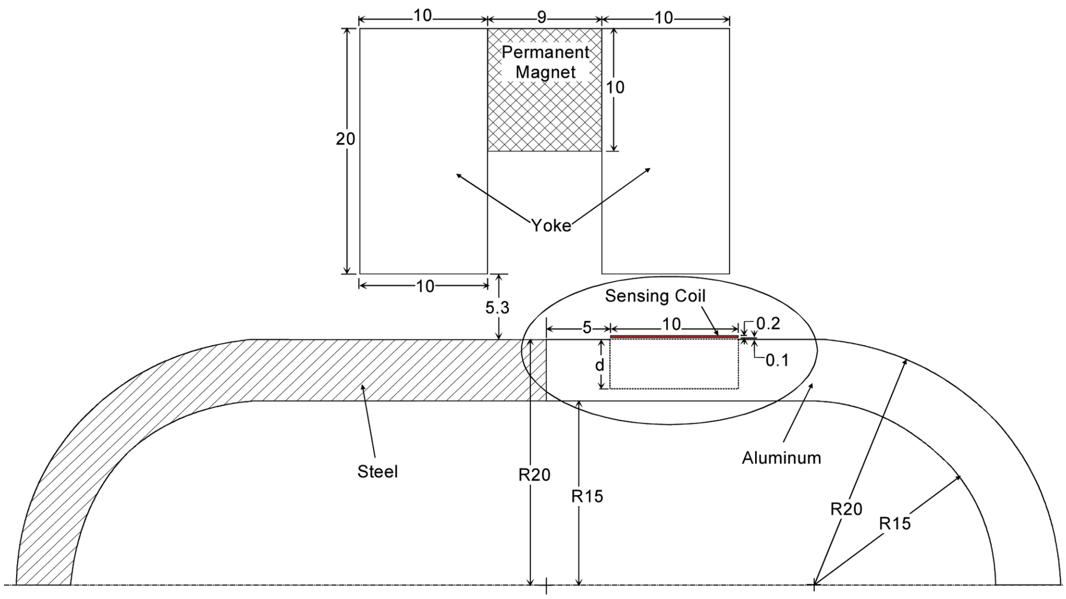

Fig. 2. (Color online) Schematic diagram for simulating the voltage induced at the sensing coil. The projectile is shown the half.

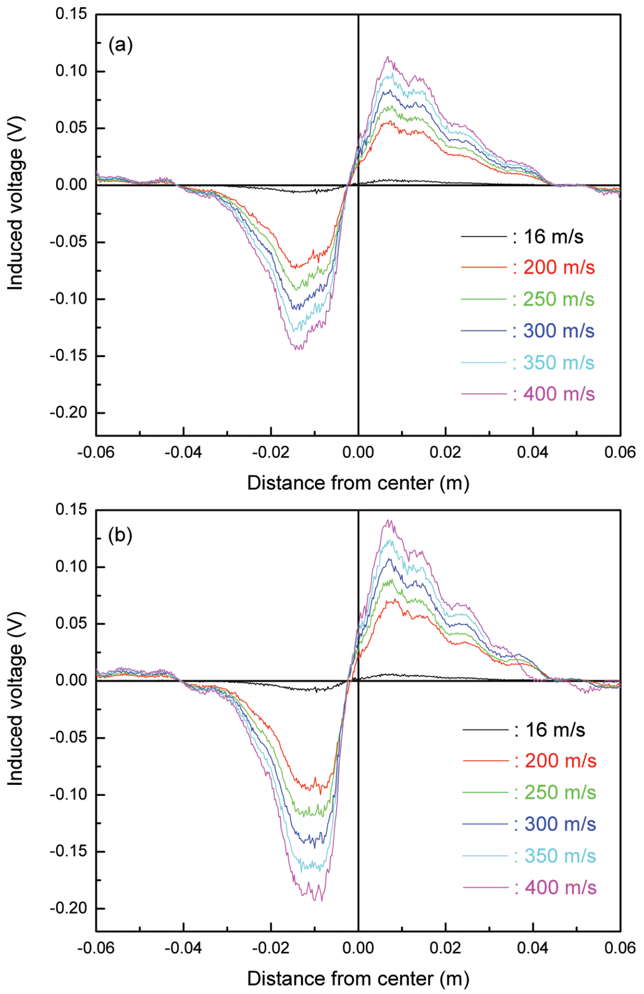

Fig. 4. (Color online) Simulated voltage profiles induced at the sensing coil as the projectile goes past the magnetic field at various velocities. The diameter of the sensing coil is (a) 32.2 mm and (b) 39.2 mm.

the projectile's velocity will be used in order to estimate the velocity by the measured voltage. In case that, The voltage induced at the buried sensing coil is proportional to the projectile's velocity as follows;

$$V_{ind} = A_1 + B_1 \cdot v \quad (5)$$

But the sensing coil exposed from the projectile, the voltage induced is increased by the 2nd order polynomial as follows;

$$V_{ind} = A_2 + B_2 \cdot v + C \cdot v^2 \quad (6)$$

where V_{ind} is the voltage induced at the sensing coil and v is projectile's velocity. In case of the diameter of the sensing coil is 39.2 mm, A_1 and B_1 are 1.78 and 0.47, respectively. When the diameter of the exposed sensing coil is 40.2 mm, A_2, B_2, and C are 44.4, 24.4, and -2.4×10^{-3}, respectively.

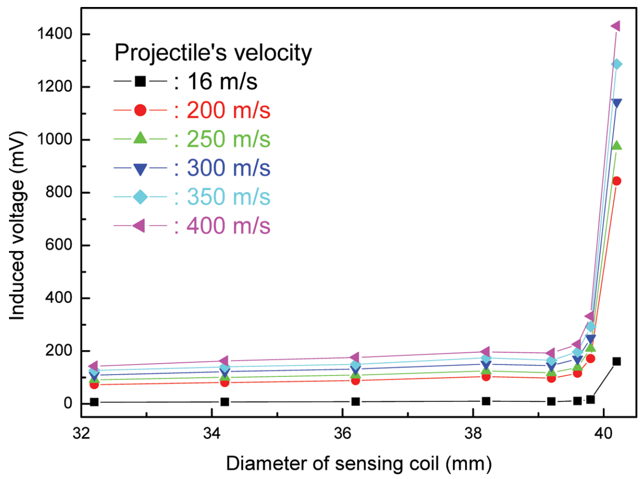

Fig. 5. (Color online) Voltage induced at the sensing coil vs. diameter of sensing coil. When the sensing coil buried in the projectile, the induced voltage slowly increased with increasing the diameter of sensing coil. But it suddenly increased as the sensing coil exposed from the projectile.

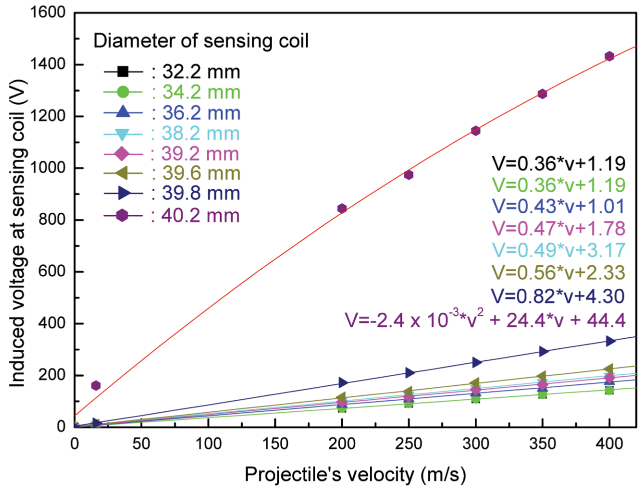

Fig. 6. (Color online) Voltage induced at the sensing coil vs. the projectile's velocity. The induced voltage is increased with increasing the projectile's velocity.

The ABM will be effectively exploded at target area using the projectile muzzle velocity calculated from the voltage induced at the sensing coil embedded in the projectile. Fig. 6 shows the induced voltage vs. projectile's velocity at the different diameters of sensing coil. The induced voltage is increased with increasing the projectile's velocity.

IV. Conclusions

The model for simulating the diameter effect of the voltage induced at the sensing coil buried in a projectile was presented. The model has a ring type magnet, a yoke, and a sensing coil buried in the projectile. When the sensing coil buried in the projectile, the induced voltage slowly increased with increasing the diameter of sensing coil. But it suddenly increased as the sensing coil exposed from the projectile. We can calculate the projectile's velocity by the master curves related to the diameter of sensing coil if we measure the voltage induced at the sensing coil. The projectile may precisely explode at the target region by inputting the information of muzzle velocity computed at the master curves related the diameter of sensing coil to the projectile.

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