Electromagnetic interference analysis of magnetic resistance sensors inside a projectile under complex electromagnetic environments

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Abstract. Accurate measurement of angular motion has long been recognized as a daunting task. In recent years the measurement of projectiles utilizing magnetic resistance sensors has become a hot research field. Electromagnetic interference on attitude measurement cannot be ignored in complex electromagnetic environments such as battlefield conditions. In this paper, the influence and function pattern of electromagnetic interference on the measuring performance are theoretically analyzed, and the shielding effectiveness (SE) simulation of projectile is conducted via software Computer Simulation Technology (CST). Considering the specific tests, the intensity of the influence is judged. The simulation indicates that the battlefield's complex electromagnetic environment influences the environment inside the projectile, especially its electronic components and capability. The research results can provide important theoretical support on the errors compensation and precision improvement of the projectile attitude measurement with Magnetic Resistance sensor.

1. Introduction
With the improvement of new concept weapons, especially the high power microwave bombs, electromagnetic bombs, electromagnetic missiles and nuclear electromagnetic weapons, they make the battlefield environments more complex. In the recent battlefield environments, it is necessary to improve the combat power of weapon system, so it is important to analyze more precisely the battlefield electromagnetic environments and take action to protect from the harm. With the advance of ammunition, more intelligent, smaller, and more accurate electronic products are used more and more popularly in the projectile, and these products are becoming complicated and composite. Nowadays the magnetic resistance sensors broadly used in the ammunition are one kind of important sensor to measure the magnetic [1-3]. And researches pay more attention to the electromagnetic environment change in the projectile and its influence on the sensors, which provides technological support for the sensors applications.

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Magneto resistance effect (MRE) is a phenomenon that the resistance of material will change in the magnetic field. It can be divided into normal MRE based on Hall Effect and anisotropy MRE. The latter one aimed at strong ferromagnetic metal (iron, cobalt, nickel and the alloy of them and so on), the resistance remains when the outer magnetic field is in parallel with the magnetization direction of the metal, but it diminishes when the magnetic field direction departures. If the metal is made into a zonal lead and given the current, its resistance will change following the relationship between the magnetization direction of inside and outside magnetic field and the current direction, the same will be the bigger, and the different will be the smaller. As the resistance changing rate of perm-alloy is biggish, it is appropriate to low magnetic field. As shown in the figure 1 and figure 2.

**Figure 1.** The component of MRE.

**Figure 2.** The Wheatstone bridge and the sensor action.

From figure 2, the Wheatstone bridge is the foundation of the sensor and it gives the action principle. Supply power voltage $V_b$ provides the resistance with the current. If there is no magnetic field, the resistances of the four brachium points are the same, they are in balance and the output is zero. If there is magnetic field, the resistances change and the balance will be broken up, the resistances of brachium point 1 and 3 decrease and the brachium point 2 and 4 amplify, the output voltage is $V_{out}$. The output voltage will be $-V_{out}$ when the magnetic field reverses.

From the variation of the resistance, the relation function can be build:

$$\Delta V_{out} = \left( \frac{\Delta R}{R} \right) V_b$$  \hspace{1cm} (1)

$$\Delta V_{out} = SMV_b$$  \hspace{1cm} (2)

$R$ is film resistance;
$\Delta R$ is relative variation of the resistance;
$S$ is sensitivity of MRE;
$M$ is the outer magnetic field value.
3. Electromagnetic Interference Models Analysis

3.1. Electromagnetic SE Analysis of Projectile Cavity

Based on the Electromagnetic SE theory [2, 5], the projectile can be classified as circular cylinders cavity. Supposing that the inside and outside radius of projectile are \( r_1 \) and \( r_2 \), and dielectric constant is \( \varepsilon_r \), the electromagnetic \( E_i \) (the direction supposed to be perpendicular to projectile axle, \( u_i \)) is uniform inside and outside of the projectile, as well as the circular cylinder is perfect, as shown in the figure 3.

\[ E_i(r) = -\nabla V(r) = aE_iu_i \]  

(3)

Where, \( a \) and \( D_c \) is given by:

\[ a = 4 \frac{\varepsilon_r}{D_c} \]  

(4)

\[ D_c = (\varepsilon + 1)^2 - \left( \frac{r_1}{r_2} \right)^2 (\varepsilon - 1)^2 \]  

(5)

In that case, the thickness of projectile is \( h = r_2 - r_1 \); and \( \varepsilon_r >> 1 \). Analyzing the function (3), (4), (5), electromagnetic SE is gotten by

\[ SE = 20 \log \left( \frac{1}{\alpha} \right) \approx 20 \log \left( \frac{1 \varepsilon_r h}{2 r_1} \right) \]  

(6)

From the equation, the conclusion can be gotten: the bigger dielectric constants \( \varepsilon_r \), the better shielding effectiveness.

3.2. Electromagnetic Leak Analysis of Projectile Aperture

The projectile is comprised of many components; every component joins each other with the apertures. Especially the screw thread, it is one of the main reasons which result in the weakening of SE [4]. The small aperture will play a role as the antenna, which will receive and launch the electromagnetic signal and bring bad influence to the SE when it is in the field, as shown in figure 4.
Where the apertures can be looked as a linear interstice, the thickness is described as $b$. So the electromagnetic of the point that leaves the aperture about $l$ in distance are then given by

$$E_{g} = \left(\frac{2b}{\pi c}\right)^2 e^{-\frac{\pi}{b}H_0} \frac{1}{r^2} = \left(\frac{2}{\pi c}\right)^2 \left(\frac{b}{r}\right)^2 e^{-\frac{\pi}{b}H_0}$$ (7)

4. Electromagnetic SE Simulation Analysis of Projectile

In the recent years, the normal SE simulation methods are the Electromagnetic module of ANSYS and CST EM STUDIO. CST EM STUDIO is the software that simulates the static electricity, static magnetic, constant current and low frequencies electromagnetic [6]. Also it can be used in the DC-100MHz EMI, sensors, induction heating, non-destructive flaw detection and electromagnetic SE. The CST EM module can be used to simulate the electromagnetic SE of projectile and study the influence on the projectile of the outside complex electromagnetic.

4.1. Outside Electromagnetic Environment

In the battlefield environment, complex electromagnetic environment has become a significant component, especially after the improvement of operational forms and the renewal of the weapons, the study on the influence of the complex electromagnetic environment becomes a new topic. With analysis of the battlefield environment, the electromagnetic environments are composed of natural electromagnetic (such as thunderbolt, geomagnetism, and static electricity) and artificial electromagnetic (such as radar, broadcast television, and radio stations). As we know, the nature of electromagnetic are difficult to predict and control, then the attention is paid on the artificial factor. If the EMI is not deliberate, the radar signal will be the main object, so it will be used in the simulation.

4.2. Simulation Model

The simulation model is based on the projectile of US army Hydra-70, the particular parameters are shown in the table 1.

| parameters | rocket | Warhead | caliber | length | HARO | Fin blades |
|------------|--------|---------|---------|--------|------|------------|
| value      | MK66   | Javelin | 70mm    | 1060mm | yes  | three fin blades landscape orientation roll |

Base on this projectile and the built model, the math shape model is built using the parameters in table 1 and the figure building capability of CST.
4.3. The Influence on Projectile of Different Electromagnetic Direction

The EMI and electromagnetic SE will make a difference with different action direction. So we make the projectile axle as the datum line and detect the influence, and there are three different directions to be taken, namely, perpendicular to projectile axle, in parallel with projectile axle and with an intersection angle 45°. In the actual condition, the frequency cannot be a steady value; it is a variation which always ranges from 0 to 200 MHz.

![Figure 5. Electromagnetic SE with different action direction](image)

(a) perpendicular to projectile axle; (b) in parallel with projectile axle; (c) with an intersection angle 45°

From the simulation (see Figure 5), the electromagnetic in different directions has an influence on the environment inside the projectile. In the actual condition, the force value is around 4 V m⁻¹ and the rule of value change is similar. They all increase at first and surge in the following time. The intensity of the electromagnetic which is perpendicular to projectile axle can reach 5 V m⁻¹ and larger than the other two.
4.4. The Influence on Projectile of Different Frequencies
With the different outer environment, the influence will be changed in different areas or different conditions, so the range of signal frequency must be taken into consideration and the simulation can be closer to the actual battle environment. The radar signals are based on the US Army standard with different frequencies 0~200 MHz. Because the operational forms change, the both sides will not contact with each other. So the radar signal can be regarded as the planar waves.

(a) perpendicular to projectile axle; (b) in parallel with projectile axle; (c) with an intersection angle 45°

**Figure 6.** Electromagnetic SE with different frequency

From the figure 6, the influence is not intense that it just drops down so fast in the frequency range, especially in 0~15 MHz the value changes 95%. And the value can be ignored when the frequencies reach 160MHz. The rules are similar, which is changing from the beginning to the end, and the value has a little difference because the directions are different.

5. Conclusion
CST simulation analysis indicates that the battlefield complex electromagnetic environment influence the environment inside the projectile, especially for the its electronic components and capability, but the influence depends on different condition. When the frequency or the direction changes, the
influence varies small because the SE is so well, and the changing rules are similar. If the value is small, the influence to magnetic resistance sensor will be small too. With different conditions, it makes a small difference and the rules are similar. From the simulation results, the values are small. The battlefield complex electromagnetic environment can change the environment inside the projectile, but the changes are not obvious for the SE is working. As the situation is clear, it is useful for the researchers to make an improvement and perfect the design of future ammunition.

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