Velocity Radar Applied in the Research of Muzzle Velocity Measurement and System Correction Method of Naval Gun

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Abstract. During naval gun firing at sea, shore or air target, the muzzle velocity of projectile is the important factor for naval gun to increase firing accuracy. Because velocity radar holds the merits of high accuracy and good real-time performance, it has become the main approach for naval gun to measure muzzle velocity. Firstly, this paper analyses the influencing factors of naval gun’s muzzle velocity, and studies the measurement and correction principle of velocity radar. Then the paper discusses the composition and operation process of velocity radar, and demonstrates the necessity to enhance the measurement accuracy of velocity radar. This research has practical value on equipment development and combat application for velocity radar.

Keywords: Muzzle velocity, firing accuracy, velocity radar, firing data.

1. Introduction
Naval gun has the advantages of fast response, small firing dead zone, sustained firing time, easy to maintain and so on. Naval gun can accompany with warship to attack or defense the enemy continuously, and it can effectively undertake the task of firing on shore, attacking against sea targets or air defense. It is a kind of shipborne weapon system with strong comprehensive combat capacity.

An important development trend of modern naval gun is first-round hit, and muzzle velocity is the focal influence factor of first-round hit. The muzzle velocity of projectile is the instantaneous velocity when projectile leaves gun muzzle. During naval gun aiming and firing at target, the muzzle velocity of projectile is an important factor for naval gun to calculate firing data, and its accuracy will affect the hit probability of naval gun directly.

In order to put long-range and high-accuracy striking into practice for naval gun, the technology of directly measuring the muzzle velocity of projectile is developed continuously. The common measurement methods are as follows: velocity measurement by zone-block device or velocity radar. The way of zone-block device to measure muzzle velocity is to measure the time for a certain flight distance, then determine the average flying speed. Based on the Siacci equation, we may calculate trajectory’s muzzle velocity by extrapolation method. The zone-block device set up two coil targets in front of muzzle [1]. Supposed that the distance between two coil targets is \( L \), the time difference to pass through two coil targets is \( t \), then the average flight speed of projectile is as follows:

\[ V = \frac{L}{t} \]
When zone-block device is used to measure muzzle velocity, the barrel structure and mechanical properties of naval gun won’t be destroyed. The zone-block device won’t be affected by muzzle’s smoke and light [2], but its precision of velocity measurement is difficult to meet the requirement of naval gun.

With the development of computer technology, in order to improve firing accuracy of naval gun, some countries begin to develop advanced velocity radar to measure projectile’s muzzle velocity. Due to the merits of little affected by weather, simple structure, high accuracy and good real-time performance, the velocity radar has become the main method to measure muzzle velocity of projectile.

2. The factors to affect naval gun’s muzzle velocity

For convenience of calculating the naval gun’s firing data, the standard muzzle velocity of projectile is provided. However, in actual firing process, the muzzle velocity $V_0$ varies with loading condition. So called loading condition is to the state of projectile, gunpowder which are put into naval gun, and the state of bore. Among them: (1) projectile state mainly contains weight, type, caliber of projectile, (2) gunpowder state mainly contains type, charge, temperature, humidity of gunpowder, (3) bore state mainly contains chamber volume, caliber of bore [3]. As a result, the influence factors of naval gun’s muzzle velocity are quite complex.

When the ammunition of naval gun has been selected, numerous above factors are identified. But some factors are still in flux, they mainly include: chamber volume of bore; charge, temperature, humidity of gunpowder; weight of each projectile [4]. The calculation formula of naval gun’s muzzle velocity deviation $\Delta V_0$ is as below:

$$
\Delta V_0 = \Delta V_c + \Delta V_z + \Delta V_g + \Delta V_t + \Delta V_s
$$

In above formula, $\Delta V_c$ is deviation value of muzzle velocity which is caused by the variation of chamber volume; $\Delta V_z$ is deviation value of muzzle velocity which is caused by variation of gunpowder’s charge, $\Delta V_g$ is deviation value of muzzle velocity which is caused by projectile’s weight; $\Delta V_t$ is deviation value of muzzle velocity which is caused by gunpowder’s temperature; $\Delta V_s$ is deviation value of muzzle velocity which is caused by gunpowder’s humidity.

Among them, $\Delta V_c$, $\Delta V_z$, $\Delta V_g$ are system deviation values which depend on performance of naval gun and gunpowder, $\Delta V_t$, $\Delta V_s$ are random deviation values which are caused by meteorological conditions.

According to formula (2), the influence of these deviation can be converted into deviation value of muzzle velocity, and we use $\Delta V_0$ to implement firing correction. However, this kind of firing correction method is large error, low real-time, and it usually can only measure and correct some factors.

Therefore, in modern sea combating situation, in order to accurately attack enemy’s target, especially maneuvering air target, it is necessary to use velocity radar to synthetically measure and correct naval gun’s muzzle velocity.

3. The principle of velocity radar

When velocity radar measuring muzzle velocity, it will make use of Doppler effect. The so-called Doppler effect means that: when there is relative radial movement between the transmitter and receiver, the received signal frequency will change. If the velocity radar’s transmitter and receiver sharing the same antenna, according to Doppler effect, the frequency Doppler caused by relative motion between projectile and radar is as follows:
In above formula, $V_r$ is radial velocity of projectile, $\lambda$ is working wavelength of radar.

According to formula (3), after radar obtains Doppler frequency $f_d$ by measuring echo signal, radial velocity $V_r$ between target and radar is as follows:

$$ V_r = \frac{\lambda}{2} \cdot f_d $$

The calculation formula of radar’s working wavelength is: $\lambda = \frac{c}{f_0}$, in which $f_0$ is radar’s working frequency, $c$ is electromagnetic wave’s transmission speed in the air.

![Figure 1](image_url)

**Figure 1.** The principle for velocity radar to measure muzzle velocity.

After velocity radar gets projectile’s radial velocity $V_r$ which is in the flight trajectory, it can transfer $V_r$ to trajectory tangential velocity $V_0$ which choose naval gun as the reference [5]. The principle for velocity radar to measure muzzle velocity is as Figure 1.

In order to improve firing accuracy of naval gun, we need to know projectile’s muzzle velocity in advance. But only after firing, velocity radar can obtain muzzle velocity $V_0$. So if put velocity radar into practice, we must predict next projectile’s muzzle velocity according to previous measuring result [6], then correct naval gun’s firing data.

If the deviation of muzzle velocity between measured value and standard value is $\Delta V_0$, then distance correction value $\Delta d$ which caused by deviation of muzzle velocity is as below:

$$ \Delta d = -\Delta V_0 \cdot f_{\Delta V_0} $$

In above formula, $f_{\Delta V_0}$ is the distance variation value when muzzle velocity changes one meter per second.

4. The working process of velocity radar

In order to accurately and continuously measure projectile’s muzzle velocity, the composition of naval gun’s velocity radar usually includes transmitter, receiver, antenna, detector, terminal and so on [7], it is as Figure 2.

The working process for velocity radar to measure muzzle velocity of naval gun is as follows:

1. When naval gun is firing, at the moment of projectile leaving muzzle, the detector can detect the firelight which is discharged by naval gun. It offers time zero point of velocity radar.
(2) Radar transmitter emits high frequency electromagnet wave from the antenna to the space, and the electromagnet wave exposes to projectile of naval gun. Then the Doppler echo signal with projectile’s velocity is reflected back.

(3) When echo signal is received by antenna, it enters into receiver to be processed, then receiver gets Doppler signal.

(4) When Doppler signal enters into terminal of velocity radar, it is processed for the second time, and Doppler frequency value $f_d$ is obtained.

(5) Terminal works out muzzle velocity value $V_0$, and the result is transferred to firing control system.

![Figure 2](#)

**Figure 2.** The composition of naval gun’s velocity radar.

5. **Application analysis of velocity radar**

Velocity radar’s effect is accurately and timely measure projectile’s muzzle velocity, and offers it to firing control system continuously. According to deviation value between measured muzzle velocity and standard muzzle velocity, firing control system automatically corrects firing data, and the firing accuracy of naval gun will be improved obviously.

Then we will utilize simulation calculation to analyse the necessity to use velocity radar measuring muzzle velocity, and the necessity to enhance measurement accuracy of velocity radar.

5.1. **The analysis of necessity for naval gun to use velocity radar**

Firstly, we may analyse the necessity to use velocity radar measuring muzzle velocity. In the simulation model of hitting probability, if all error sources don’t change, and we only need to confirm the muzzle velocity error by two different methods:

(1) According to previous measuring result, the terminal of velocity radar can predict next projectile’s muzzle velocity, and offer it to firing control system to calculate firing data.

(2) According to accumulative number of fired projectile, the muzzle velocity is estimated and offered to firing control system to calculate firing data.

By use of simulation model of hitting probability, the computer may simulate the fire effect when naval gun shoot on target route. Simulation calculation express that, as far as hitting probability is concerned, the first method is 0.81, the second method is 0.59. Compared with the two methods, estimating muzzle velocity by accumulative number of fired projectile and measuring muzzle velocity by velocity radar, the hitting probability increase 37 percent. It indicates that velocity radar obviously enhances hitting accuracy, and also proves that velocity radar plays an important role [8].
5.2. The analysis of necessity to enhance velocity radar’s accuracy
We will simulation analyze the necessity to enhance measurement accuracy of velocity radar. If firing
data is corrected by velocity radar’s muzzle measuring value, according to radar’s measuring accuracy,
we can calculate the distance impact deviation (deviation between impact point and aiming point) in
different distance, which is caused by radar’s velocity measurement error $\delta V_0$ and $\delta V_2$ (between
them $\delta V_2 = 2\delta V_0$). The result is as Figure 3.

From the calculate result, we may know: (1) With the growth of firing distance, the distance impact
deviation caused by radar’s velocity measurement error increases obviously, (2) If firing distance is
fixed, the distance impact deviation correspond to radar’s velocity measurement error increases
almost proportionately.

Therefore, aiming at development trend of new type naval gun will significantly enhance firing
distance, velocity radar of naval gun should take technical measures to further enhance measuring
accuracy [9], so that firing accuracy of naval gun can be guaranteed in long distance.

![Figure 3. The distance impact deviation caused by radar’s velocity measurement error.](image)

6. Conclusion
During naval gun firing on the sea, projectile’s muzzle velocity which is measured by velocity radar
may be used to correct firing data, then to increase hitting probability. This paper analyses the
influencing factors of naval gun’s muzzle velocity, and studies muzzle velocity measurement and
correction method by using velocity radar, it has practical value on equipment development and
combat application for velocity radar.

References
[1] Hongwei Zhang, Feng Ju, Qiang He, Xintao Ren, The Research on Muzzle Velocity Test
Technology for High Rate-of-fire Artillery’s Ripple Fire, Journal of Projectiles, Rockets,
Missiles and Guidance. 34 (2014) 176-179.
[2] Xiuling Wang, Gang Zhao, Integrated Prediction of Muzzle Velocity based Muzzle Radar, Fire
Control &Command Control. 34 (2009) 165-167.
[3] Wei Kong, Rong Zeng, Jinyu Du, Influence of Accuracy of Continuous Wave Doppler Radar on
Muzzle Velocity Evaluation, Journal of Projectiles, Rockets, Missiles and Guidance. 36
(2016) 171-173.
[4] Tao Li, Dong Yang, Cunliang Xu, The Application of Velocity Radar’s Historical Data in
Projectile’s Muzzle Velocity Prediction, Technology Innovation and Application. 32 (2017) 144-145.

[5] Hailin Liu, Popular Approaches for Determining Time Zero of Speed Measuring Radar, Radio Engineering. 38 (2008) 61-64.

[6] Yanchun Shu, Analysis on Velocity Prediction Precision for Muzzle Velocity Radar of A Type of Gun, Ship Electronic Engineering. 34 (2014) 80-83.

[7] Yuansheng Li, Liguo Chen, Research on New Method of Velocity Radar, Command Control & Simulation. 38 (2016) 123-126.

[8] Lin Ma, Zhengyu Cai, Fenglei Cheng, The Principle of Microwave Velocity Radar, Journal of Ballistics. 15 (2003) 87-91.