Quantitative Analysis for Affecting Factors of Firing Dispersion of Tank

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Introduction

The traditional firing dispersion error analysis is based on the assumption that each error term is independent [3]. The research shows that there are coupling effects between the factors affecting the fire dispersion and the error terms caused by each factor are not independent. In this sense, the traditional fire dispersion error analysis method is insufficient. Sobol' global sensitivity analysis method [4-7] is a Monte Carlo method based on variance analysis. Compared with the traditional fire dispersion error analysis method, the core ideas of the two methods are based on variance decomposition.

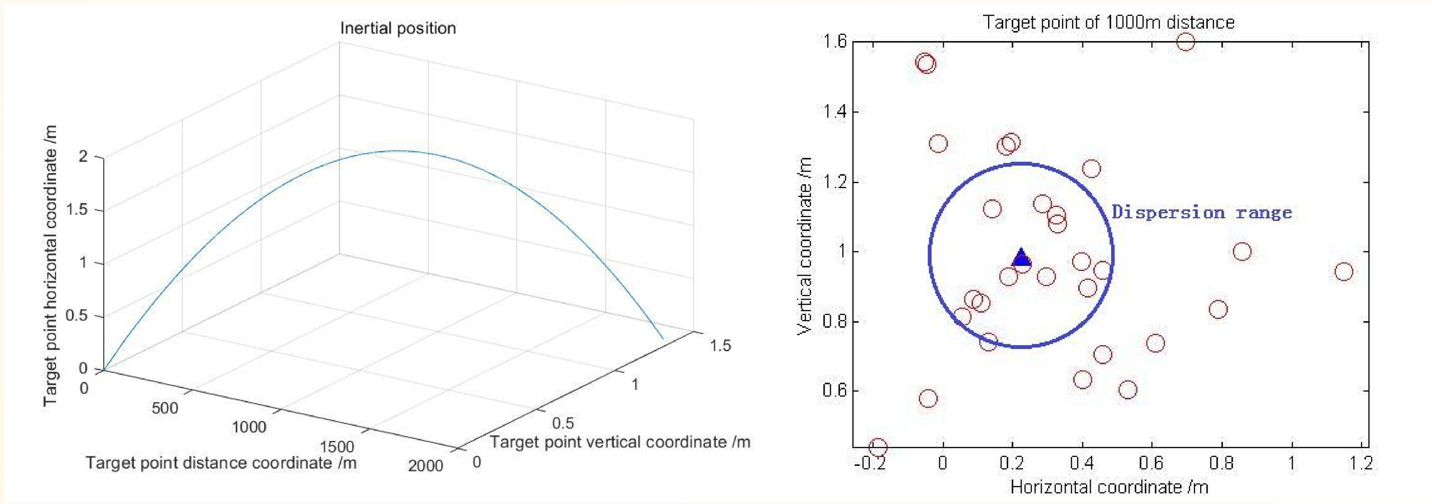


Fig. 1. Exterior ballistics and 1 kilometer firing dispersion

The traditional firing dispersion error analysis is based on the assumption that each error term is independent [3]. The research shows that there are coupling effects between the factors affecting the fire dispersion and the error terms caused by each factor are not independent. In this sense, the traditional fire dispersion error analysis method is insufficient. Sobol' global sensitivity analysis method [4-7] is a Monte Carlo method based on variance analysis. Compared with the traditional fire dispersion error analysis method, the core ideas of the two methods are based on variance decomposition.

The definitions of indicators both are based on the ratio of variance. The difference is that this method can evaluate the sensitivity of interactions of single factor and multiple factor to the indexes.

Objective

(1)Based on the exterior ballistic equation [8] considering the factors such as initial disturbance and random wind, using Sobol's global sensitivity analysis method, the sensitivity of each factor to the impact point can be obtained.

(2) Using the idea of the refenences [9,10], the sensitivity obtained by each factor is extended to the influence weight of fire dispersion of standing target.The research results provide an important basis for improving the firing dispersion of tank by controlling the initial disturbance.

Approach

1. Processing assembly error

According to the actual measurement results and historical data statistics, the probability distribution of the projectile characteristic parameters is a normal distribution. The statistical characteristics of the characteristic parameters of a batch of projectiles are shown in Table 1. The mass eccentricity and dynamic unbalance angles in Table 1 are the components of the mass eccentricity, Lm1and Lm2, and the dynamic unbalance angle, and in the two directions of the projectile coordinate system [11].

Tab 1. The statistical properties of characteristic parameters of projectile

Parameter name	Standard Deviation
Mass eccentricity L_{m_1} /mm	0.01
Mass eccentricity L_{m_2} /mm	0.01
Dynamic imbalance angle β_{D_1} /mrad	0.01
Dynamic imbalance angle β_{D_2} /mrad	0.01
Projectile quality m /kg	1.7×10^{-3}

Using the Monte Carlo stochastic simulation technology, the random launch dynamics simulation system for tanks with inter-vehicle firing was compiled, and the dynamic response of the tank, the internal ballistics, the force, the initial disturbance of the projectile, the exterior ballistics, and the vertical target density were obtained. The simulation results were verified by experiments. The initial disturbance of the projectile obtained by the simulation system approximates the normal distribution. Table 2 gives the simulation results of the statistical characteristics of the initial disturbance of a tank shooting at 0°/5 mil direction angle/shot angle.

Tab 2. The statistical properties of initial disturbances

Parameter name	Mean	Standard Deviation
Vertical deviation angle ψ_1 /mrad	-0.963	0.304
Lateral declination angle ψ_2 /mrad	-0.022	0.297
Vertical angle of attack δ_1 /mrad	-0.083	0.581
Lateral angle of attack δ_2 /mrad	0.039	0.555
vertical angular velocity of attack $\dot{\delta}_1$ /(rad/s)	-0.249	0.803
Lateral angular velocity of attack $\dot{\delta}_2$ /(rad/s)	0.069	0.819

2. Exterior ballistics

In order to consider the effects of projectile dynamic imbalance, mass eccentricity, winds and other factors on the flight process of the projectile, the 6D rigid-body ballistic equation is established as follows:

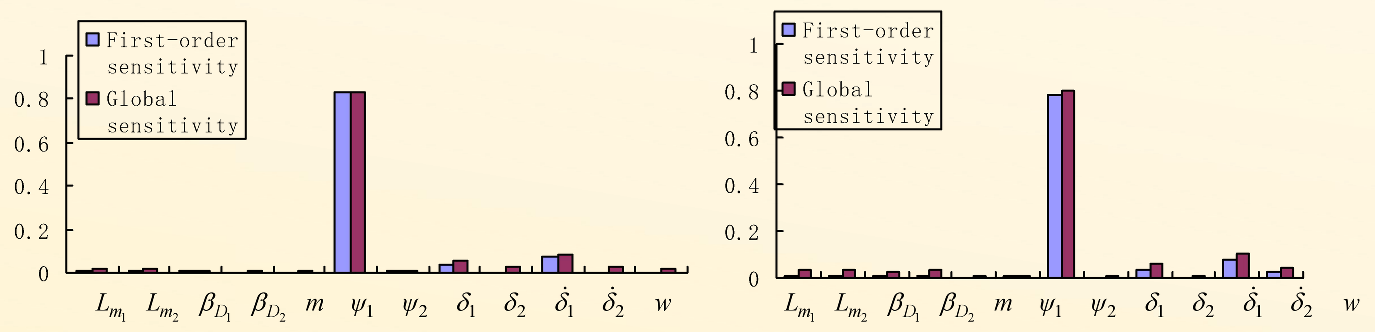
$$
\begin{cases}
\dfrac{dx}{dt}=v_x \quad \dfrac{dy}{dt}=v_y \quad \dfrac{dz}{dt}=v_z \quad \dfrac{d\gamma}{dt}=\dot{\gamma} \quad \dfrac{d\varphi_a}{dt}=\dot{\varphi}_a \quad \dfrac{d\varphi_2}{dt}=\dot{\varphi}_2 \\
\dfrac{dv_x}{dt}=-\dfrac{R_x}{m}\dfrac{v_x-w_x}{v_r}-\dfrac{R_x}{m\sin\delta_r}(\sin\delta_{r_1}\cos\delta_{r_2}\sin\theta_r+\sin\delta_{r_2}\sin\psi_r\cos\theta_r) \\
\qquad +\dfrac{R_Z}{m\sin\delta_r}(\sin\psi_r\cos\theta_r\cos\delta_{r_2}\sin\delta_{r_1}-\sin\theta_r\sin\delta_{r_2}) \\
\dfrac{dv_y}{dt}=-\dfrac{R_x}{m}\dfrac{v_y}{v_r}+\dfrac{R_y}{m\sin\delta_r}(\sin\delta_{r_1}\cos\delta_{r_2}\cos\theta_r-\sin\delta_{r_2}\sin\psi_r\sin\theta_r) \\
\qquad +\dfrac{R_Z}{m\sin\delta_r}(\sin\psi_r\sin\theta_r\cos\delta_{r_2}\sin\delta_{r_1}+\cos\theta_r\sin\delta_{r_2}) \\
\dfrac{dv_z}{dt}=-\dfrac{R_x}{m}\dfrac{v_z-w_z}{v_r}+\dfrac{R_y}{m\sin\delta_r}\sin\delta_{r_2}\cos\psi_r-\dfrac{R_Z}{m\sin\delta_r}\cos\psi_r\cos\delta_{r_2}\sin\delta_{r_1} \\
\dfrac{d\dot{\gamma}}{dt}=-\ddot{\varphi}_a\sin\varphi_2-\dot{\varphi}_a\dot{\varphi}_2\cos\varphi_2-k_{xD}(\dot{\gamma}+\dot{\varphi}_a\sin\varphi_2)v_r \\
\dfrac{d\dot{\varphi}_a}{dt}=\dfrac{M_z(\cos\delta_{r_1}\sin\delta_{r_2}\sin\alpha_r+\sin\delta_{r_1}\cos\alpha_r)-M_y(\cos\delta_{r_1}\sin\delta_{r_2}\cos\alpha_r-\sin\delta_{r_1}\cos\alpha_r)}{A\cos\varphi_2\sin\delta_r}+ \\
\qquad \dfrac{(2A-C)\dot{\varphi}_a\dot{\varphi}_2\sin\varphi_2-C\dot{\gamma}\dot{\varphi}_2}{A\cos\varphi_2}-k_{zD}\dot{\varphi}_a\cos\varphi_2 v_r+\dfrac{A-C}{A}(\ddot{\gamma}\beta_{D_\xi}+\dot{v}_x\beta_{D_\eta})+\dfrac{mL_{m_\eta}\dot{v}_x}{A} \\
\dfrac{d\dot{\varphi}_2}{dt}=\dfrac{M_z(\cos\delta_{r_1}\sin\delta_{r_2}\cos\alpha_r-\sin\delta_{r_1}\sin\alpha_r)+M_y(\cos\delta_{r_1}\sin\delta_{r_2}\cos\alpha_r+\sin\delta_{r_1}\cos\alpha_r)}{A\sin\delta_r}- \\
\qquad \dfrac{(A-C)\dot{\varphi}_a^2\cos\varphi_2\sin\varphi_2}{A}+\dfrac{C\dot{\gamma}\dot{\varphi}_a\cos\varphi_2}{A}-k_{zD}\dot{\varphi}_2 v_r+\dfrac{A-C}{A}(\dot{\gamma}^2\beta_{D_\xi}-\ddot{\gamma}\beta_{D_\eta})+\dfrac{mL_{m_\xi}\dot{\gamma}}{A}
\end{cases}
$$

3. Sobol' global sensitivity analysis principle

The core idea of Sobol' sensitivity analysis method is variance decomposition, which decomposes the model into single parameters or a function of combining parameters. The importance of the parameters is analyzed by calculating the influence of the variance of the single input parameters or the input parameters set on the total output variances and the interaction between the parameters.

4. Quantitative analysis for affecting factors of firing dispersion of tank

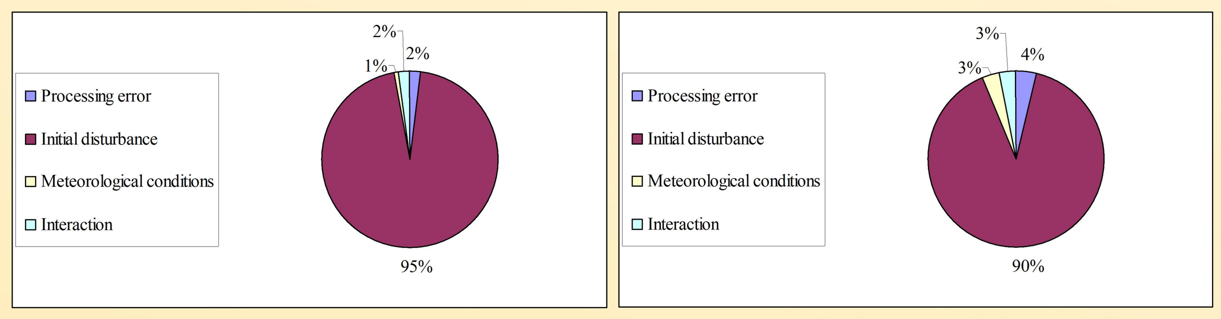
The calculation results of the first-order sensitivity and global sensitivity of each random factor to the impact point (Y,Z) in Figure 2.



(a) Vertical impact point (b) Lateral impact point

Fig.2. The sensitivities of affecting factors relative to impact points

The sensitivity of each factor obtained by Sobol' sensitivity analysis method is used to extend the sensitivity of the impact point to the weight of the fire dispersion of standing target. The first-order sensitivity is the weight of the independent role of factor of fire dispersion of standing target, and second-order and other high-order sensitivities are the weight influences of the interaction between the corresponding factors on the target concentration. The weights of the three types of random factors on the fire dispersion of standing target of a tank can be obtained, as shown in figure 3.



(a) Vertical fire dispersion (b) Lateral fire dispersion

Fig.3. The weights of affecting factors relative to the fire dispersion of tank

Conclusions

Based on the six-degree-of-freedom rigid-body ballistic equation, considering the effects of processing assembly error, initial disturbance and meteorological conditions on the flight process of the projectile, Sobol's global sensitivity analysis method is used to quantitatively analyze the weights of influence of random factors on the fire dispersion. The analysis results show that under the current processing assembly and measurement error level, for the tank with direct firing as the main firing mode, the initial disturbance of the projectile is the most important factor affecting the fire dispersion, and the initial declination angle is the main factor which affects fire dispersion. The work of this paper can provide support and reference for the measures to improve the fire dispersion of tank firing from the perspective of controlling the initial disturbance.

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