Indoor measurement method of smoke screen disturbance efficiency based on Gaussian diffusion model

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Abstract: Because of ground clutter wave interference, it is difficult to measure smoke screen disturbance in the field. In this paper, a kind of indoor measurement method of smoke screen disturbance efficiency based on Gaussian diffusion model is put forward. As a characteristic, the measurement result of smoke screen area density proves that the indoor measurement method of smoke screen disturbance efficiency based on Gaussian diffusion model is feasible.

Key words: smoke screen disturbance efficiency; Gaussian diffusion model; indoor measurement

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The smoke projectile is an important tactical weapon in modern battle, which can confuse or disturb the enemy's photoelectric scout equipment and guided weapon. With the development of modern military technology, multiple-spectrum disturbance including visible light, laser light, infrared ray and millimeter-wave nowadays has been the important disturbance means used by smoke projectile. The smoke screen disturbance efficiency measurement has been very important for smoke projectile improvement and application.

Because of the effect of outdoor clutter-wave, the smoke screen disturbance efficiency measurement is difficult to do in the field[1,2]. In this paper, a kind of indoor measurement method of smoke screen disturbance efficiency based on the Gaussian diffusion model is researched deeply.

1 Smoke screen diffusion model

1.1 Basic smoke screen diffusion theory

According to diffusion theory[1], the diffusion substance in the hydro-gas cannot change the flowing characteristics of hydro-gas particles. Although the total volume of hydro-gas particles including the diffusion substance is invariable in diffusion course for the uncompressible hydro-gas, their space and shape are variable. The diffusion model is based on the hypothesis that the substance diffusion speed in unit area is proportional to the substance concentration, which can be described by

$$F = -D\frac{\partial C}{\partial x}, \tag{1}$$

where F is the particle quantity that transits the unit area in unit time; C is diffusion substance concentration; D is diffusion coefficient relating to the characteristics of hydro-gas and particles; The minus indicates that substance concentration decreases when substance diffuses in this direction.

According to mass conversation law[1], the basic differential equation about substance diffusion is

$$\frac{\partial C}{\partial t} + \frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial f_z}{\partial z} = 0, \tag{2}$$

where F_x, F_y and F_z are the particle quantities that diffuse unit area of direction x, y and z in unit time, respectively.

When the diffusion coefficient D is constant, the basic differential equation of diffusion particle can be got from Eqs. (1) and (2) as

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right). \tag{3}$$

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1.2 Gaussian smoke screen diffusion model

The gradient diffusion theory shows that the smoke screen diffusion rate is proportional to negative gradident concentration[3,4]. The Gaussian smoke screen diffusion model is based on three hypotheses as follows:

1) The distribution of smoke screen concentration is normal distribution in y and z direction;

2) The wind speed is symmetrical and invariable;

3) The smoke screen weight is conservational in diffusion course.

The Gaussian diffusion model is applied to calculate the explosion smoke screen concentration distribution, whose diffusion model is shown with diffusion mean square error as

$$C(x,y,z,t) = \frac{2Q_0\lambda\Omega}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \times \exp\left\{-\frac{1}{2}\left[\frac{(x-ut)^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} + \frac{(z-z(t))^2}{\sigma_z^2}\right]\right\}, \quad (4)$$

where Q_0 is smoke substance weight; λ is used smoke substance efficiency; Ω is smoke screen rate; $z(t)$ is function of smoke screen vertical motion caused by updraft; σ_x, σ_y and σ_z are smoke screen diffusion mean square errors in direction x, y and z, respectively.

1.3 Calculation method of smoke screen area density

Based on Roberts' opacity theory[5-7], the smoke screen area density is the smoke density summation in the light path. The smoke screen area density in direction y is described by

$$C(y) = \frac{Q_0\lambda\Omega}{(2\pi)^{1/2}\mu\sigma_z}\exp\left(-\frac{z^2}{2\sigma_z^2}\right), \quad (5)$$

where $C(y)$ is smoke screen area density in direction y; σ_z is smoke screen diffusion mean square error in direction z; u is mean wind speed on the ground.

2 Measurement

2.1 Smoke screen configuration and change

The width, height and thickness of initial smoke screen configuration formed by detonating four smoke projectiles is 25 m, 6 m and 7 m, respectively.

The smoke screen volume is 25 m × 6 m × 7 m = 1 050 m^3. The initial smoke screen configuration is shown in Fig. 1, and the change course is shown in Table 1.

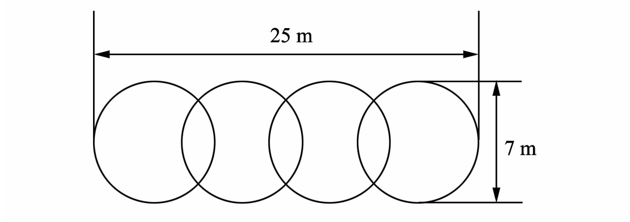

Fig. 1 Initial smoke screen configuration

Table 1 Smoke screen configuration's change course

Time(s)	Length(m)	Height(m)
4	27.05	12.3
8	27.35	13.5
12	27.85	14.1
16	28.50	14.6
20	28.90	15.6
24	31.00	16.3
28	31.15	17.2
32	31.90	18.3
36	32.45	19.4
40	33.10	20.2
44	34.20	21.7

2.2 Measurement theory and system

The sketch of measurement system is shown in Fig. 2, which includes special power supply subsystem, signal transmitter subsystem, signal receiver subsystem, computer signal processing subsystem and digital display subsystem.

The smoke screen is produced by detonating alternate smoke projectile which is based on certain project research, without the measurement circumstance being disturbed. The smoke screen area density in y direction can be measured and displayed.

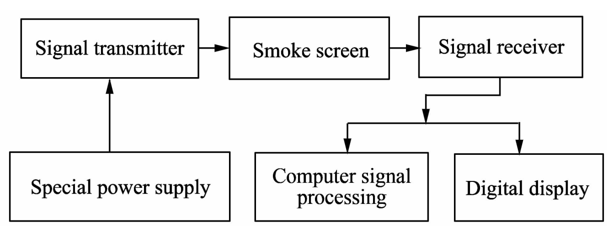

Fig. 2 Sketch of measurement system

The smoke screen area density is described by Lombard-Bill law as

$$I = I_0 e^{ckl}, \quad (6)$$

where I is received signal intensity, I_0 is transmit signal intensity, c is smoke screen mass concentration, k is smoke screen absorption coefficient and l is smoke screen thickness.

So the measurement area density can be got according to Table 1 and Eq. (6)[8,9].

2.3 Analysis of measurement results

The measurement results are shown in Table 2 and Fig.3, which include the Gaussian model calculation area density and measurement area density.

Table 2 Area density comparison between Gaussian model and measurement results

Time (s)	Gaussian model calculation area density($g\cdot cm^{-2}$)	Measurement area density ($g\cdot cm^{-2}$)	Error ($g\cdot cm^{-2}$)	Error percent (%)
1	45.70	19.10	26.60	139.2
10	20.35	15.40	4.95	32.1
15	15.60	13.60	2	14.7
20	12.65	12.00	0.65	5.4
30	9.20	9.35	−0.15	1.6
40	7.20	7.25	−0.05	0.7
50	5.95	5.65	0.35	6.2
60	5.05	4.35	0.65	14.9
70	4.40	3.40	1.00	29.4
80	3.85	2.60	1.25	48.1

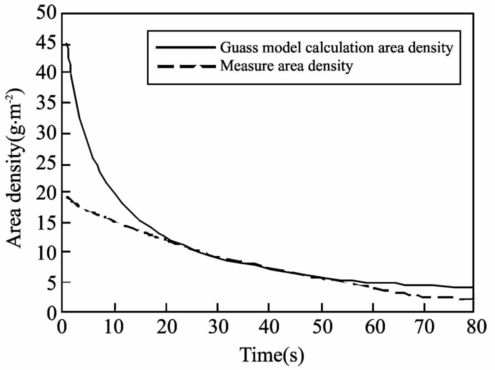

Fig. 3 Area density comparation between Gaussian model and measurement results

The results in Table 2 and Fig. 3 show that the maximum area density error percent between Gaussian calculation model and measurement is 14.9% between the 15th second and the 60th second that is critical for battle[10,11], which is acceptable and applicable. The error percent at the first second is 139.2% due to the initial smoke screen is instability and the 80th second is 48.1% due to the smoke screen is thin, which is not important for the smoke screen disturbance.

3 Conclusion

According to the theory calculation and measurement results, the Gaussian model area calculation density is consistent with the measurement area density, which indicates that the Gaussian smoke screen diffusion model is feasible. That is to say the indoor measurement method of smoke screen disturbance efficiency based on Gaussian diffusion model is usable.

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