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STUDY ON MUZZLE VIBRATION MODEL OF GAS-OPERATED GARTLING GUN OF CARRIER BASED

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Abstract

This paper analyzes the kinetic model of muzzle vibration of gas-operated gartling-gun on the basis of muzzle vibration displacement when measuring the shooting of gas-operated gartling-gun by applying the high-speed photography system, and carries out the parameter estimation by applying the Levenberg-Marguardt nonlinearity minimum mean-square value arithmetic. The educed conclusion is consistent with dispersion test result of 200m vertical target.

1. FOREWORD

The vibration in the course of high-speed shooting（4800 round/minute）of gas-operated gartling-gun is a very complex phenomenon, which is closely related with structural performance and drive characteristic of gas-operated gartling-gun as well as kinetic characteristic of each part, and the existing research method (such as, multiple rigid body dynamics and finite element method etc) is difficult for analyzing this problem. In order to solve the problem of firing precision of gas-operated gartling-gun in practice, this paper introduces the underdamping elastic system on the basis of muzzle vibration displacement when the high-speed photography system measuring the shooting, the external force added to system as a running fire is equivalent to sum of impulse excitation, which gives the kinetic model to describe the muzzle vibration of gas-operated gartling-gun. To adopt this method carries out the in-depth study on internal energy tube gun system, which is convenient for theory and application, and meet the demand of engineering practice.

2. MUZZLE VIBRATION MODEL OF GAS-OPERATED GARTLING GUN

The time of gas-operated gartling-gun impacted by stimulation is very short. Meantime, it can be found out from measured data that the vibration impacted by damp of system is attenuated gradually after effected by impact force. Thus, the following differential equation can be used for describing the mathematical model as shooting of internal energy tube gun.

$$m\ddot{y} + c\dot{y} + ky = z(t) \tag{2.1}$$

In the equation, m is the theoretical inertial mass of system, k is theoretical coefficient of rigidity of system, c is (the)theoretical damping coefficient of system, y indicates the longitudinal vibration displacement of the muzzle, and Z(T) is excitation function of system. Because it is to assume that the excitation is instantaneous, so the excitation generated by shooting every time can be described by function. Thus, the excitation of system impacted by s shells shot at t time can be written as:

$$z(t) = \sum_{i=1}^{s} A_i \delta(t - t_i) \tag{2.2}$$

In the equation, A_i indicates the excitation density of i round, $A_i > 0, i = 1,2,\cdots,s, \delta(t)$ is Dirac function, which defines as $\delta(t) = \begin{cases} \infty, & t=0 \\ 0, & t\neq 0 \end{cases}$ and $\int_{-\infty}^{\infty} \delta(t)dt = 1$.

Therewith, the solution of system（2.1）to general excitation（2.2）is:

$$y(t) = \sum_{j=1}^{s} A_j \exp\{-\xi\omega_0(t - t_j)\} \left(h_0 \cos(\omega_0 \sqrt{1-\xi^2}(t`-t_j)) + \frac{1 + m\omega_0\xi h_0}{m\omega_0\sqrt{1-\xi^2}} \sin(\omega_0\sqrt{1-\xi^2}(t - t_j)) \right) u(t - t_j - 0_+) \tag{2.3}$$

In eq(2.3), $\omega_0 = \sqrt{\dfrac{k}{m}}$ is thenatural frequency of system, $\xi = \dfrac{c}{2\sqrt{mk}}$ is the damping ratio of system, and $\xi < 1,$ h_0 is the initial displacement, $u(t) = 1, t > 0; u(t) = 0, t \le 0.$ It is known from eq.(2.3) that the vibration wave is superposed, and the superposition is the index attenuation factor after shooting and of each elementary wave existing. In view of vibration resulted by fusillading, the damping ratio of system will change, the model shall be corrected as:

$$y(t) = \sum_{j=1}^{s} A_j \exp\{-\xi_j \omega_j (t - t_j)\} \left(h_0 \cos(\omega_j \sqrt{1-\xi_j{}^2}(t`-t_j)) + \frac{1 + m\omega_j \xi_j h_0}{m\omega_0 \sqrt{1-\xi_j{}^2}} \sin(\omega_j \sqrt{1-\xi_j{}^2}(t - t_j)) \right) u(t - t_j - 0_+) \tag{2.4}$$

With superposition model of vibration wave, the parameter in model (2.4) can be estimated by measuring the muzzle vibration displacement $y(t)$ of system in the course of shooting.

Making:

$$\theta_j = \omega_j \sqrt{1-\xi_j^2} \quad , \quad \varphi_j = tg^{-1} \frac{h_0 m \omega_j \sqrt{1-\xi_j^2}}{1 + m\omega_j \xi_j h_0} ,$$

$$c_j = A_j \sqrt{\frac{1 + 2m\omega_j \xi_j h_0 + m^2 \omega_j^2}{m^2 \omega_j^2 (1-\xi_j^2)}} \qquad j = 1,2,3 \cdots, s$$

Therefore, （2.4）can be written as:

$$y(t) = \sum_{j=1}^{s} c_j \exp\left\{-\xi_j \omega_j \left(t - t_j\right)\right\} \sin\left(\theta_j \left(t - t_j\right) + \varphi_j\right) u\left(t - t_j - 0_+\right) \tag{2.5}$$

The result by analyzing the actual vibration displacement data shows that the difference of ω_j, ξ_j is with small effect in amplitude taper, but with big effect in angular frequency of θ_j and φ_j of vibration, thus, the model is:

$$y(t) = \sum_{j=1}^{s} c_j \exp\left\{-\theta_0 \left(t - t_j\right)\right\} \sin\left(\theta_j \left(t - t_j\right) + \varphi_j\right) u\left(t - t_j - 0_+\right) \tag{2.6}$$

3. PARAMETER ESTIMATION OF SYSTEM

It is given that $\{y_n, n = 1,2,\cdots,N\}$ is a sample measured actually, $t_j = k_j \Delta t$ is the shooting time of j round, Δt is the sampling interval, ξ_n is the observational error of nth measuring point, so there is:

$$y_n = \sum_{j=1}^{s} c_j \exp\left\{-\theta_0 \left(n - k_j\right)\Delta t\right\} \sin\left(\theta_j \left(n - k_j\right)\Delta t + \varphi_j\right) u\left(n - k_j - 0_+\right)\Delta t + \varepsilon_n$$

$$n = 1,2,\cdots,N \tag{3.1}$$

In equation, ε_n is the random variable series of independent and distribution subordinated to $N(0,\sigma^2)$.

The parameter estimation adopts the Levenberg-Marguardt nonlinearity minimum mean-square value arithmetic. Under condition of obtaining the estimated value of model parameter, it can be to estimate the characteristic parameter of system.

The characteristic parameter of system is the natural frequency ω_j and damping ratio ξ_j of system. The parameter definition in model is:

$$\theta_0^{(j)} = \xi_j \omega_j$$
$$\theta_j = \omega_j \sqrt{1-\xi_j^2} \qquad j = 1, \cdots, s \tag{3.2}$$

Because the effect value of change of ω_j , ξ_j to attenuation factor $\theta_0^{(j)}$ is small, thus, taking $\theta_0^{(j)} = \theta_0$, $j = 1, \cdots, s$ in fact. There are:

$$\xi_j = \sqrt{1-\left(\theta_j / \omega_j\right)^2} \ , \qquad j = 1, \cdots, s$$

$$\omega_j = \sqrt{\theta_j^2 + \left(\theta_0^j\right)} \ , \qquad j = 1, \cdots, s$$

Therefore, the estimation of ω_j and ξ_j is as follows:

$$\omega_j = \sqrt{\hat{\theta}_j^2 + \left(\hat{\theta}_0^2\right)} \ , \quad \xi_j = \sqrt{1-\left(\hat{\theta}_j / \hat{\omega}_j\right)^2} \ , \quad j = 1, \cdots, s \tag{3.3}$$

4. COMPUTING RESULT AND ANALYSIS

The some type of home-made continuous shooting sand filling shell of internal energy tube gun adopts Type 4540MX high-speed photography system, its document image refers to Fig 1, the shooting time interval is 0.014ms, and the estimated result of numerical value refers to Table 1.

Fig 1 High-speed photography test image of some type of nternal energy tube gun

Table 1 Estimated result of the system parameters

Shell(ronud) order	1	3	6	9	12	15
θ'_j	112.4390	114.4902	116.0131	116.4238	117.0462	116.8414
ξ_j	0.011	0.034	0.014	0.012	0.030	0.023
ω_j	112.4458	114.5574	116.0243	116.4325	117.0976	116.8723

This Table shows that the vibration frequency of muzzle increases along with the increase of shooting time, and the vibration frequency tends to stabilization after firing 6th round. The shooting of the first round of gas-operated gartling gun of carrier based is started by compressed air, and there is a short-time transient process from starting to stable speed for gun barrel group. Under the action of load suddenly added to system, the speed of automatic machine is not stable, the amplitude value of gun barrel vibration is bigger relatively, and the gun barrel is at nonlinearity transient vibration state. After shooting the 6 round, the vibration of gun barrel tends to stabilization, and the gun barrel is at steady forced vibration state. The intensity test result of 200m vertical target shows that in test of 6 groups, at least two bombfalls in the first 6 round of each group are apart from the aiming point, and all of other bombfalls are distributed densely nearby center of the aiming point. The computational analysis conclusion of muzzle vibration model set in this paper is consistent with experimental result.

Reference

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