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Man-gun model of shoulder supported firing and sensitivity analysis of structural parameters

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ABSTRACT

In order to study the impact of human action on the accuracy of weapons firing, a mathematical model of shoulder supported firing was established. Base on the body movement during shooting, the arms and weapon were simplified into two rigid body with two degrees of freedom, and the interactions between human and weapon was simplified into effect of a system with equivalent springs and dampers. The rigid body dynamics formula was solved by Lagrange method, and also experiment results proved this simulation movement. By parameters sensitivity analysis, the main factors on impact of weapons pitching motion were identified.

KEYWORDS

Shoulder supported firing; Man-weapon interaction model; Sensitivity analysis.

INTRODUCTION

Standing with automatic weapons firing is the body for sitting, shooting accuracy is affected in addition to weapons of factors, and the shooter in the shooting process, the role of arms control is inextricably linked to[1-3].

Shooting is a complex dynamic process. In biomechanical studies in humans, Kane proposed that we consider the body as multi-body systems articulated by limited rigid consisting; Hanavan simplified it as model of 15 rigid body[3,4]. According firing experiments of automatic weapons, the role of people in the shoulder gun system is simplified to two rigid system dynamics model who arrived in the shoulder shot gun system, through the system parameter sensitivity analysis to determine the key design parameters of the human role.

MODEL AND ASSUMPTIONS

The main factors affect the accuracy of the weapon bursts is the stability of the gun in the moment of the firing automatic weapons[5-7]. According to the high-speed photography shooting video data shows that people gun system has the following features in the shooting sports during[1,3]: (1) Arms relative to the upper torso with a more visible level of recoil movement; (2) Arms with respect to the trunk pitching obvious; (3) Upper torso relative to the lower torso has a pitching motion; (4) The human body has a very small horizontal deflection in the horizontal plane direction.

The basic structure of automatic weapons is symmetrical. Bore axis and the vertical rotary axis of the body are in the same vertical plane. Weapon deflection in the horizontal direction is small. A large number of automatic weapons firing tests also showed that the impact gun shooting accuracy by more obvious pitching motion. Therefore, this article focuses on the impact on human parameters on arms fire pitch stability. We do the following simplifying assumptions:

(1) Force of the propellant gas provides incentives to the system, and its role very short time, in the kinetic equation in the form of pulse signal equivalent treatment;

(2) According to the test shows that the lower limb portions remained stationary and the upper torso to the waist as the center of rotation with respect to the movement of the lower limbs of the pitch. In discussing the impact on arms fire against the shoulder pitching motion parameters can be fixed waist movement to simulate shooting on the torso has backed the case; (3) Clamping action of the human shoulder and head butt always make contact with the human body in the shooting process. Shoulder muscle tissue compression and buffer handling of weapons by a group of equivalent spring damper; (4) The support arm for weapons and arms control equivalent to acting on the center of rotation of a set of pitch elastic torsion spring and damper.

Shooting yoke simplified model is as shown in Figure 1. Establish the base coordinate system OXYZ in the weapons pitching rotation center: K_1, C_1 for arms A rear seat cushion produce the equivalent elastic modulus and damping; K_2, C_2 pitch for arms A cushioning effect of the equivalent elastic and damping coefficients.

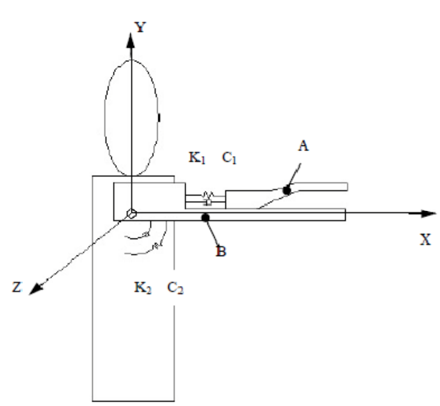

Figure 1: Simplified model of shoulder supported firing

CAMPAIGN ANALYSES AGAINST THE SHOULDER SHOT MODEL

Motion of the model includes: weapon A equivalent body relative to the arm B has recoil translational motion; A and B at the same pitch angular velocity relative to the upper torso do pitching motion. Coordinate system is established as shown in Figure 2. Establish inertial coordinate system OXYZ in pitching rotation center in connection with the earth solid, and coordinate system $OX_aY_aZ_a$ solid even piece B.

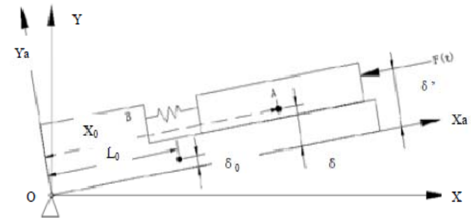

Figure 2: Coordinate system of simplified model

Where: L_0 and δ_0 are the coordinate components of the equivalent body for arm B centroid in the coordinate system $OX_aY_aZ_a$; X_0 and δ are the coordinate components of the equivalent body for arm A centroid in the coordinate system $OX_aY_aZ_a$; δ' is the distance of propellant gas force F (t) with respect to the center of rotation O.

SYSTEM DYNAMICS EQUATIONS DERIVED

Simplify shooting people against shoulder gun system model for two rigid systems. A relative translational motion of the B sit generalized displacement *x*, A and B with respect to the generalized displacement coordinates OXYZ Yang movement of θ. We use the Lagrange method to establish the system dynamics differential equation:

(a) The system kinetic energy

$$T=\frac{1}{2}[(I_A+I_B+M_Ax^2+M_A\dot{\delta}^2+M_BL_0{}^2 \\ +M_B\delta_0{}^2)\theta^2+M_A\dot{x}^2-2M_A\dot{x}\dot{\theta}\delta] \quad (1)$$

(b) System potential

$$V=\frac{1}{2}K_2\left(\theta-\theta_0\right)^2+\frac{1}{2}K_1\left(x-X_0\right)^2+ \\ M_Bg\left[L_0\left(\sin\theta-\sin\theta_0\right)+\delta_0\left(\cos\theta-\cos\theta_0\right)\right] \\ +M_Ag\left[x\sin\theta+\delta\cos\theta-X_0\sin\theta_0-\delta\cos\theta_0\right] \quad (2)$$

(c) System lagrange function

$$L=T-V \quad (3)$$

(d) The generalized force of system

The generalized force of system: Non-conservative force generated by the damper effect; Propellant gas generalized displacement relative to the generalized force generated. The generalized force generated Propellant gas generalized displacement relative. For non-conservative forces generated by the dissipation model damper, the dissipation function system is:

$$P = \frac{1}{2}\left(C_1^2 \dot{X}^2 + C_2^2 \dot{\theta}^2 \right) \quad \textbf{(4)}$$

(e) The system dynamics equations

Human yoke shooting system is non-free rigid system, application of the second class constraints Lagrange equations with complete:

$$a_{11} = M_A; a_{12} = a_{21} = -M_A\delta; a_{22} = I_A + I_B + M_A x^2 + M_A\delta^2 + M_B L_0^2 + M_B \delta_0^2;$$

$$f_1 = -F(t) - C_1 \dot{x} + M_A \dot{\theta} x - K_1 (x - X_0) - M_A g \sin\theta;$$

$$f_2 = F(t)\delta' - C_2 \dot{\theta} - 2\dot{\theta}\dot{x} x M_A - K_2 (\theta - \theta_0) - M_B g L_0 \cos\theta + M_B g \delta_0 \sin\theta - M_A g x \cos\theta$$
$$+ M_A g \delta \sin\theta$$

Where: I_A and I_B, are respectively the rotational inertia for A and B with respect to the rotation center O; g is the acceleration due to gravity; M_A as a weapon mass; M_B for arm equivalent mass.

MODEL CHECKING

Inertia parameters and centroid location of weapons obtained by actual measurement; The inertia of the body based on height and weight parameters, according to the laws of statistical calculation to obtain [1, 4]; Equivalent elastic and damping coefficients selected intermediate values within the reference range [3]. Respective parameter values are as shown in TABLE 1.

TABLE 1: Parameter estimations of model

Project	Symbol	Value	Project	Symbol	Value
Mass	M_A/kg	4.5	Damping	C_2/ N·m·s·deg^{-1}	1.13
Mass	M_B/kg	7.5	Geometry	L_0/ m	0.4
Moment of inertia	I_A/kg·m^2	0.2056	Geometry	δ_0/ m	0.02
Moment of inertia	I_B/kg·m^2	0.6349	Geometry	x_0/ m	0.205
Spring stiffness	K_1/ N·m^{-1}	2000	Geometry	δ/ m	0.02
Spring stiffness	K_2/N·m·deg^{-1}	0.96	Geometry	δ'/ m	0.02
Damping	C_1/N·s·m^{-1}	300			

Solving equations and dynamical systems draw weapons after sitting displacement, velocity and recoil time curve shown in Figure 3; Shooting experimental weapon recoil displacement, recoil velocity versus time curve shown in Figure 4. By comparison, the simulation displacement curve has an additive effect in the 0.3s, the maximum displacement and experimental firing achieve basically the same each time; Simulation speed curve of the overall trend is consistent with the experimental curve curve; Since the simulation only see the equivalent force of a propellant gas as impact load input, without regard to automatic weapons, machine vibrations caused by impact forces and other weapons, so the speed curve is the experimental curve smooth without jitter. In this paper we study the role of weapons and human impact on the pitch, so you can simplify the internal vibrations of weapons handling, simplified models can describe the movement against the shoulder shot of the main characteristics and laws.

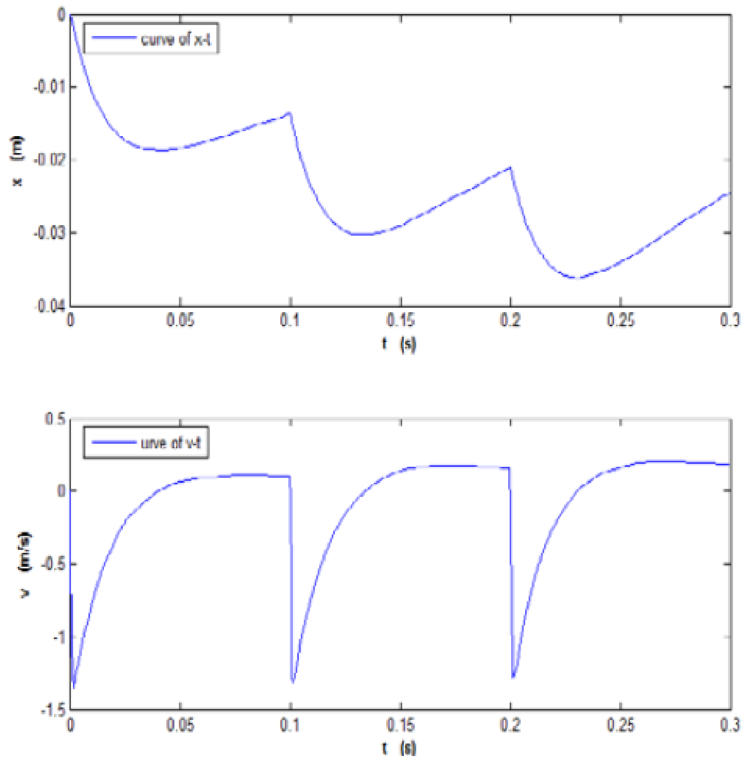

Figure 3: Simulated curves of recoil

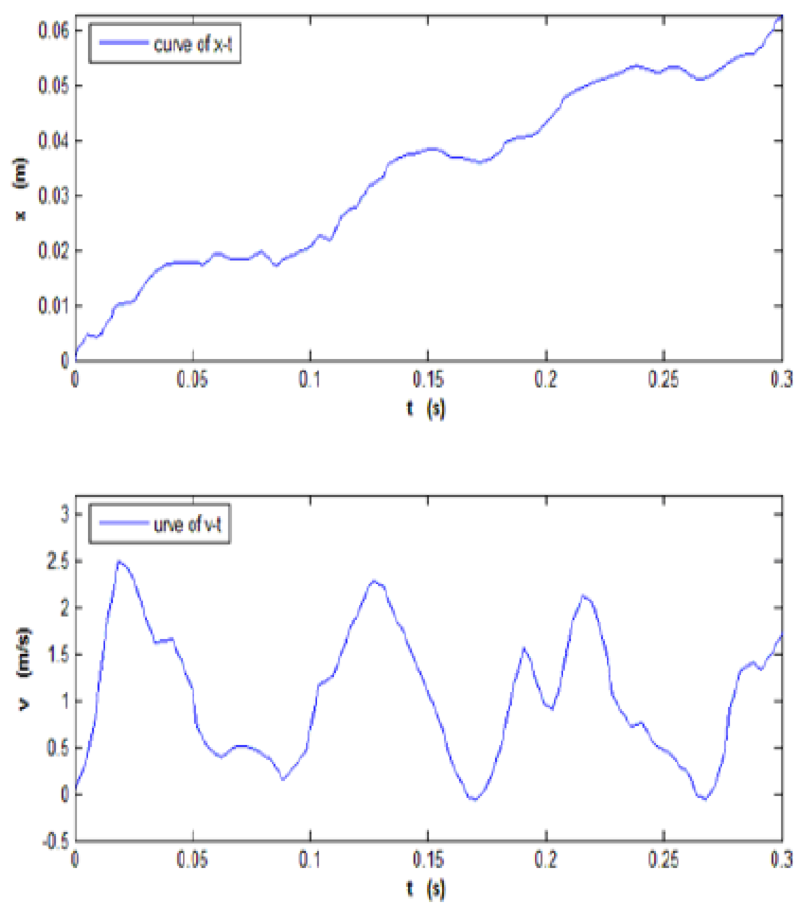

Figure 4: Tested curves of recoil displacement and velocity displacement and velocity

SENSITIVITY ANALYSIS OF THE SYSTEM PARAMETER

Human control of weapons mainly reflects by buffering the human shoulder and arm sitting on the arms and pitch movement. So select the parameters K_1, K_2, C_1, C_2 as the design variables for sensitivity analysis; Weapons firing instant pitch stability is an important factor affecting shooting accuracy, so choose the starting shooting weapons at the end of the pitch angle of the objective function. Parameter values are as shown in TABLE 1, the range within ± 50% of the sensitivity analysis of each parameter, respectively, results shown in Figure 5.

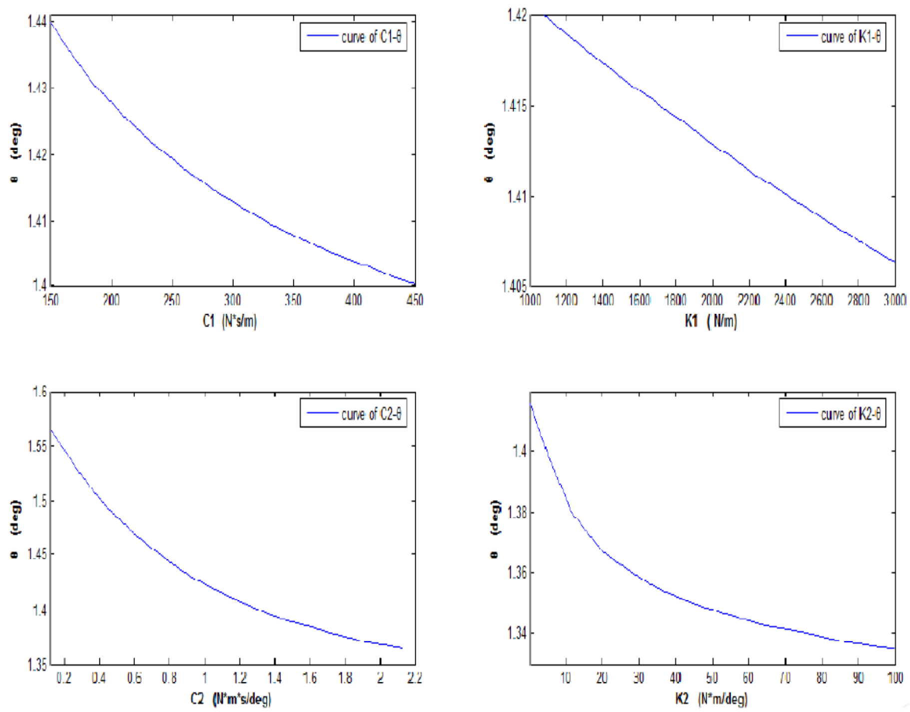

Figure 5: Sensitivity curves of shoulder supported parameters

Equivalent treatment yoke parameter sensitivity, can obtain one hundred meters piano to spread due to the design variables: The deviation K_1 leads to is 0.0237m; The deviation K_2 leads to is 0.0063m; The deviation C_1 leads to is 0.0698m; The deviation C_2 leads to is 0.3496m; Thus, the impact of C_2 to weapons pitching motion is significantly, and it is a major design variables of the human gun system. In model simulations, we must strictly control the range of variables; the impact of K_2 to weapons pitching motion is small.

CONCLUSIONS

According to the characteristics of human motion during shooting, people will arrive shoulder gun system simplifies shooting by two rigid arms and arm two degrees of freedom system consisting of equivalent quality. By solving the system dynamics model to obtain the movement of weapons in line with the experimental laws. By sensitivity analysis, identify the impact of the main weapons against the shoulder pitching motion parameters are: Pitch buffer equivalent damping coefficient C_2; Equivalent elastic recoil factor K_1 and damping coefficient C_1. Provide some reference to human gun system modeling and the design and optimization of key parameters. This article only discusses the impact of human action on the shoulder and arm shot pitch stability, the role of human gun research has some limitations, needs further comprehensive study of human factors in the role of impact weapon firing accuracy.

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