A Method Calculating the Automation's Load for a Small-Bore Naval Gun

ZHIFANG WEI, GUOGUANG CHEN
Department of Electronic and Mechanical Control Engineering
North University of China
North University of China, Taiyuan, Shanxi
CHINA
http://www.nuc.edu.cn

Abstract: - By analyzing the structure and motion characteristics of the flexible guide system of the projectile-feeding chain of a small-bore naval gun, a mathematical model of three-dimensional space attitude dynamic simulation for the flexible guide is proposed; also the corresponding dynamic simulation software is developed. Through which the position of each guide piece in the flexible guide can be determined when the naval gun's rotating and pitching angle of fire is of any degree. Then the friction force between the projectile-chain and the flexible guide can be calculated according to each guide piece's position and projectile-chain's moving velocity and the friction factor. Consequently the automation's load can be determined. The result of computing can be the criteria to the automation's designing parameters. Moreover, it is significant to study the adaptive technology of the raise-feed system of the small-bore naval gun.

Key-Words: - Navel gun; Simulation; Projectile-chain; Automation; Load; Raise-feed system

1 Introduction

In recent years, researchers have made studies of modeling and simulation of naval gun feed-on system [1,2]. They also researched the Projectile Queue Motion of Magazine System [3,4]. Therefore, the adaptive technology of the raise-feed system of the naval gun has become an important field of research. The technology studying the interface between the feeding system and the automation, i.e. the technology to ensure the consistency of the feeding frequency and the automation's firing frequency is one key problem. It is important to study the problem computing the automation's load.

The automation is an important part of a roll-tube and high-firing frequency naval gun. It can provide force to feed projectiles for firing. It is important to determine the automation's designing parameters computing the automation's load. In fact the automation's load is the stretching force of the projectile-chain at the entrance to the automation. And it is composed of two parts: the stretching force of the projectile-chain at the entrance to lower flexible guide and the friction force between the projectile-chain and the flexible guide. The former may be calculated by the projectile-chain's linear moving velocity and linear density according to the momentum law, while the latter can be determined by each guide piece's central position and the projectile-chain's linear moving velocity and friction factor and so on.

2 Feeding Process Specification

Feeding process is defined as the moving process of the projectiles with chains in the channel composed of upper flexible guide and lower flexible guide, as is shown in Fig.1. It is a simple and smart structure where the top end of upper guide is connected with the automation fixedly, the lower end of lower guide is connected with the fixed caisson through the straight guide and helical guide, upper and lower guide are joined by transition part. With the logical structure, projectiles are ensured to arrive at the position where the automation received them, as long as they enter into the channel composed of the upper guide and the lower guide. Because the automation is gyring together with the naval gun's rotary part and pitching together with the naval gun's elevating part, also the fixed caisson is installed on the naval gun's immovable part, the joint of upper guide and the automation is moving point while the joint of lower guide and fixed caisson is fixed point. To make the channel composed of guide continuous, guide is designed as the structure joining many guide pieces together flexibly, and each guide piece has 4 DOFs relative to neighboring guide pieces [6]. Therefore, the guide is named as flexible guide. Because guide pieces are connected flexibly, guide piece's attitude and position is compensated by the change of 4 DOFs when the gun is gyring and elevating.

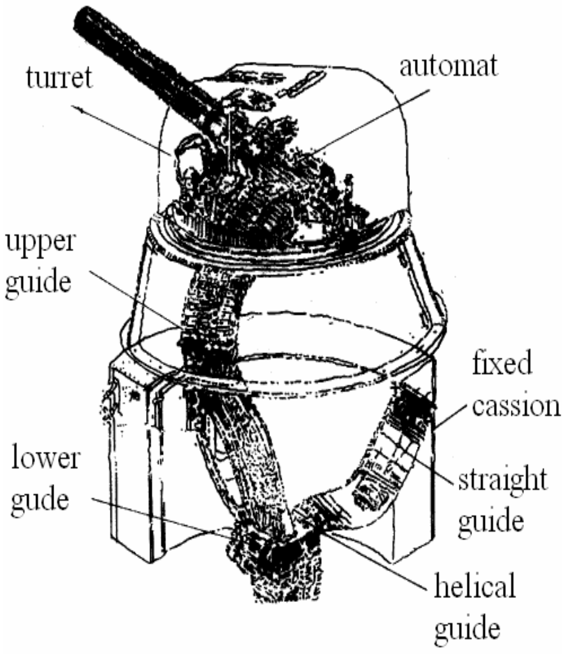


Fig.1 feeding system of a naval gun

Fig.2 shows $No.i$ guide piece's initial position relative to $No.i-1$ guide piece.

Fig.3 illustrates the abridged drawing of $No.i$ guide piece translating a displacement of Δz_i along z axis relative to $No.i-1$ guide piece.

Fig.4 illustrates the abridged drawing of $No.i$ guide piece rotating θ_i° round y axis relative to $No.i-1$ guide piece.

Fig.5 illustrates the abridged drawing of $No.i$ guide piece rotating ψ_i° round x axis relative to $No.i-1$ guide piece.

Fig.6 illustrates the abridged drawing of $No.i$ guide piece rotating φ_i° round z axis relative to $No.i-1$ guide piece.

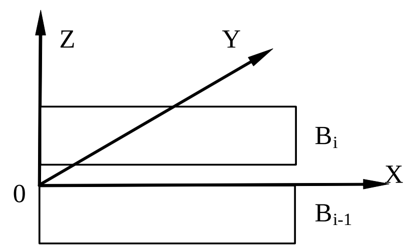
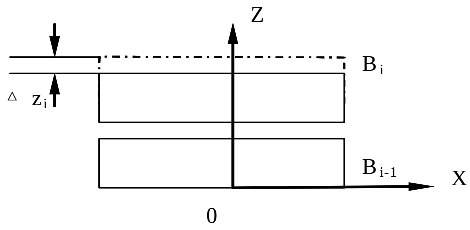
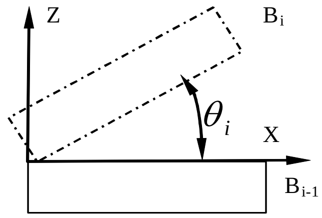


Fig.2 the initial position of B_i relative to B_{i-1}



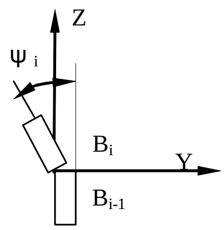
(Z axis points outwards vertically)

Fig.3 B_i translates Δz_i along Z axis based on B_{i-1}



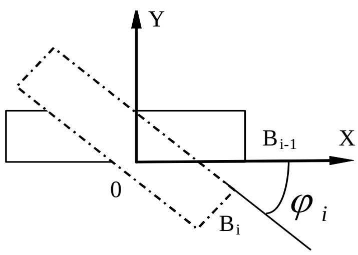
(Y axis points inside vertically)

Fig.4 B_i rotates θ_i around Y axis based on B_{i-1}



(X axis points outward vertically)

Fig.5 B_i rotates Ψ_i round X axis based on B_{i-1}



(Z axis points outward vertically)

Fig.6 B_i rotates φ_i round Z axis based on B_{i-1}

In fig.2~fig.6, B_i and B_{i-1} represent $No.i$ guide piece and $No.i-1$ guide piece respectively. Provided that n is defined as the total number of guide pieces of the upper or the lower flexible guide, and the serial number of guide pieces begins with 0.

Hence, the feeding system ensure the feeding channel's continuity and veracity, where upper flexible guide mostly satisfy the need of elevating while lower flexible guide mostly satisfy the need of gyring.

At last the projectiles from feeding system are transferred to the automation's transmission line, and the required force is provided by the automation.

3 Calculation of the Automation's Load

The automation's load is actually the stretching force of the projectile-chain at the entrance to the automation, and it is composed of two parts: the stretching force of the projectile-chain at the entrance to lower flexible guide and the friction force between the projectile-chain and the flexible guide.

3.1 Stretching Force F_1 of the Projectile-Chain at the Entrance to Lower Flexible Guide

We assumed that F_0 is the initial stretching force to draw the projectile-chain from the fixed caisson. In addition, there would be friction force because of the centripetal force when the projectile-chain passes through the crook of the fixed guide. We also assumed that the sum of the friction forces arising from several crooks of the fixed guide is expressed by F_f . So, the stretching force of the projectile-chain at the entrance to lower flexible guide is represented as follows

$$F_1 = F_0 + F_f$$

Let v be the velocity of the projectile-chain and ρ be the density, we may write the following relations according to the momentum law

$$F_0 \cdot \Delta t = (\Delta t \cdot v \cdot \rho) \cdot v$$

So,

$$F_0 = \rho v^2 \quad (1)$$

If F_f is ignored , we may obtain the following expressions

$$F_1 = F_0$$

3.2 Friction Force F_2 between the Projectile-Chain and the Flexible Guide

Provided that r is defined as the radius of curvature at any place of the flexible guide, we may write the normal pressure applied by the projectile-chain to the flexible guide as follows

$$F_n = mv^2 / r \quad (2)$$

So,

$$F_2 = f \sum_{i=1}^{n-1} mv^2 / r_i \quad (3)$$

Where, n is the number of all nonlinear subsections of the guide, f is the friction factor between the projectile-chain and the flexible guide, and the radius of curvature r_i is the radius of the circle formed by three points which are the central positions of the guide pieces B_{i-1} , B_i ,and B_{i+1} respectively.

3.3 Automation's Load F

Summarizing, the automation's load is

$$F = F_1 + F_2 \quad (4)$$

As long as the automation's load are respectively calculated at any horizontal and elevating angle of fire, the automation's total load can be determined by the sum of the both at the corresponding horizontal and elevating angle.

3.4 The Key of the Problem

In order to compute the automation's total load when the naval gun's rotating and pitching angle of fire is of any degree, it is necessary to determine all guide pieces' central position at the corresponding rotating and pitching angle of fire.

4 Calculation of Each Guide Piece's Central Position

Because the initiative and terminative guide pieces' attitudes can be determined when the naval gun's rotating and pitching angle of fire is of any degree, all guide pieces' position can be calculated as long as $\theta_i, \psi_i, \varphi_i, \Delta z_i \ (i = 1, 2, \cdots, n-1)$ between neighboring guide pieces are known. By analyzing the structure and motion characteristics of the flexible guide system of the projectile-feeding chain of a naval gun, a basic assumption that the flexible guide is the elastic system composed of multi-rigid body is presented. According to the fact that the whole system's potential energy must be minimum when the flexible guide is in natural equilibrium state, a mathematical model of three-dimensional space attitude dynamic simulation for the flexible guide is proposed, where the rotated angles and tension values between adjacent guide pieces are arguments, the whole system's total potential energy is objective function, and the boundary conditions of flexible guide are constraints.

4.1 Objective Function

Because the flexible guide is an elastic system composed of multi-rigid body, the whole system's potential energy is the sum of the elastic element's potential energy between the guide pieces.

$$E = E_x + E_y + E_z + E_d = \sum_{i=1}^{n}\frac{1}{2}k_x\psi_i^2 + \sum_{i=1}^{n}\frac{1}{2}k_y\theta_i^2 + \sum_{i=1}^{n}\frac{1}{2}k_z\varphi_i^2 + \sum_{i=1}^{n}\frac{1}{2}k_d\Delta z_i^2 \quad (5)$$

Where, E is the whole system's potential energy, E_x is the potential energy from the rotation around x axis, E_y is the potential energy from the rotation around y axis, E_z is the potential energy from the rotation around z axis, and E_d is the potential energy from the movement along z axis.

4.2 Boundary Conditions

4.2.1 Attitude (the Angle's Deformation among Guide Pieces)

A_j is defined as the attitude transition matrix from the guide piece B_{j-1} to B_j, which is the fuction of θ_j, φ_j and ψ_j.

$$A_j = \begin{bmatrix}\cos\theta_j & 0 & -\sin\theta_j \\ 0 & 1 & 0 \\ \sin\theta_j & 0 & \cos\theta_j\end{bmatrix}\begin{bmatrix}\cos\psi_j & \sin\psi_j & 0 \\ -\sin\psi_j & \cos\psi_j & 0 \\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0 & 0 \\ 0 & \cos\varphi_j & \sin\varphi_j \\ 0 & -\sin\varphi_j & \cos\varphi_j\end{bmatrix} \quad (6)$$

Because the initiative and terminative guide piece's attitudes are known, the attitude transition matrix A_{0n} from the initiative guide piece B_0 to the terminative guide piece B_{n-1} can be calculated. We may write the Following expressions

$$\prod_{j=1}^{n} A_j = A_{0n} \quad (7)$$

4.2.2 Center Position of Guide Pieces

The slippage vector is fixedly connected with the rigid body B_i, $\vec{r}_i$ is the vector from the origin to the center of $No.i$ guide piece . So,

$$\vec{r_i} = \overrightarrow{r_{i-1}} + \overrightarrow{\Delta z_i} \quad (8)$$

In equation (8), $\overline{\Delta z_i}$ is the slippage vector. It is written in matrix format as follows:

$$\Delta z_i = [0, 0, l + \Delta z_i]^T \quad (9)$$

Where, l is the length of guide piece.

W_i is defined as the transition matrix from B_i 's coordinate system to the fixed coordinate system, which is expressed by the following relation:

$$W_i = \prod_{j=1}^{i} A_j \quad (10)$$

So,

$$r_i = r_{i-1} + W_i^T \Delta z_i \quad (11)$$

And,

$$r_{n-1} = r_0 + \sum_{i=1}^{n-1} W_i^T \Delta z_i \quad (12)$$

$$\sum_{i=1}^{n-1} W_i^T \Delta z_i = r_{n-1} - r_0 \quad (13)$$

4. 3 Mathematical Model

Hence, the problem is transformed to an optimization problem with equality constraints. And the mathematical model of space attitude's dynamic simulation for flexible guide system is listed as follows:

$$\begin{aligned} &\min E(X) = E_x + E_y + E_z + E_d \\ &X = (\psi_1 \cdots \psi_{n-1}, \theta_1 \cdots \theta_{n-1}, \varphi_1 \cdots \varphi_{n-1}, \Delta z_1 \cdots \Delta z_{n-1})^T \in D \\ &s.t. \quad \prod_{j=1}^{n-1} A_j = A_{0n} \\ &\qquad \sum_{i=1}^{n-1} W_i^T \Delta z_i = r_{n-1} - r_0 \end{aligned} \quad (14)$$

5 Example

Because the mathematical model is an optimization model with only one objective function and many equality constraints, punished-function method can be selected to solve the problem [7,8]. And the corresponding simulation software is also developed. By running the program, we can calculate each guide piece's position and the automation's load at any horizontal rotating and elevating angle of fire. When the naval gun's horizontal and elevating firing angle is respectively 45° and 30°, the space attitude of the lower flexible guide is shown in Fig.7 and the automation's load is 236.6388N, at the same time the attitude of the upper flexible guide is shown in Fig.8 and the automation's load is 266.2594N, and the automation's total load is 502.8982N.

6 Conclusions

The central position of each guide piece in the flexible guide can be calculated and the automation's total load is consequently determined by the methods developed in this paper when the gun's horizontal rotating and elevating angle of fire is any degree. The result of computing shows that the mathematical model presented in the article is reasonable, and it can be the criteria to the automation's designing parameters. Moreover, it is significant to study the adaptive technology of the raise-feed system of the small-bore naval gun.

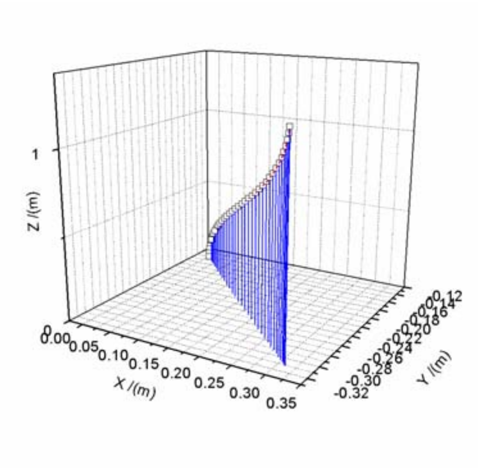


Fig.7 lower guide's attitude

(Horizontal firing direction: 45°)

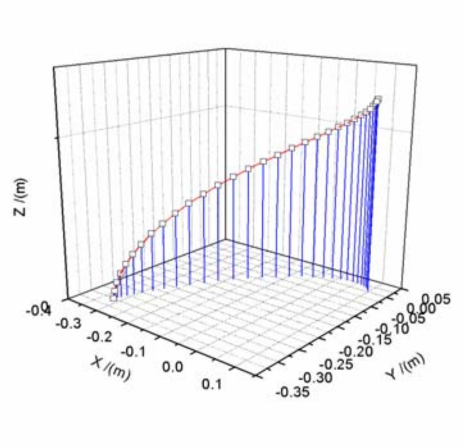


Fig.8 upper guide's attitude(Elevating angle: 30°)

References:

[1]Jin Meng, Luo Ani, Li Shouren, Design and simulation of adaptive feed system for naval gun, Journal of Harbin Engineering University, 2003,24(4): 373-375

[2]Ge Yang, Xiao Haiyan, Shu Haisheng, Zhang Jiatai, Simulation design of new style of naval gun feed-on system, 2005,26(3): 323-328

[3] Hu Xuegong, Shi Lei, Shan Jiayuan, Modelling and Simulation on Projectile Queue Motion of Magazine System, Computer Simulation. 2003,20(10): 24-26.

[4]Zhao Zhiwen, Shan Jiayuan,Objiect Orientation Programming on Projectile Queue Motion of Magazine System, microcomputer information. 2004,20(4):76-77

[5] Zhang Dianyin,Wei Lixin, Study of Adaptive Raise-Feed Technology of Small-Bore Naval Gun, GUN LAUNCH & CONTROL JOURNAL. 1998(1): 13-18.

[6] Dai Jinsong, Fang Yuanyuan, Control Motion Models of Space Soft Feed-band, GUN LAUNCH & CONTROL JOURNAL,2003(4): 5-9.

[7] Cui Hua-lin, Mechanical optimized methods[M], Shen yang: Publishing company in Northeast University, 1989

[8] [USA]W. H. Press,S. A. Teukolsky, W. T. Vetterling, B. P. Flannery. Numerical Recipes in C, The Art of Scientific Computing, Second Edition. Beijing: Publishing company of electronic engineering, 1995