

The Design and Simulation of Sloping Channel Stabilization Loop

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Abstract—This paper analyzes the main problems and technical requirements of sloping channel stabilization loop design, in order to make the static error of slope stability not big and reduce the sensitivity of "time-varying interference moment of couple" in the system, the integral correction is introduced. In parameter design, the method of describing function is used to study, design and optimize in frequency domain repeatedly. Mainly it is discussed for the flight speed at 24 m/s and 300 m/s, and given the corresponding frequency characteristics of the open-loop linear part in sloping channel stabilization loop, and there is a stable self sustaining oscillation points. According to the design results of sloping channel stabilization loop, using six degrees of freedom rigid body trajectory to do simulation experiment, the results show that the principle design and parameter design of sloping channel stabilization loop meet the technical requirements.

Keywords—sloping channel; stabilization loop; moment of couple; describing function; simulation

I. INTRODUCTION

The main problems of Sloping channel stabilization loop design : under the action of a larger interference torque ,achieved stable at a high enough precision; under the condition of the rapid drop of elevation angle in the initial flight period, ensured to finish the adjustment to the missile pitch yaw attitude in a short time; under the condition of the missile pitch yaw channel parameters changing dramatically, made missile on the response to the control instruction have a certain consistency.

II. SLOPING CHANNEL STABILIZATION LOOP DESIGN

A. The Basic Technical Requirements of Sloping Channel Stabilization Loop Design

The ideal state of slope stability is making the surface of the body coordinate system $Ox_b y_b$ vertical to the surface of platform coordinate system $Ox_p z_p$, that is, its tilt angle γ is zero[1].

It is assumed that the missile is 1.5 m above the target, in order to leave a margin, the warhead point error is not more than 0.15 m, which caused by static error of slope stability. From the above assumptions, we can calculate to obtain static error of slope stability is $\gamma < \pm 5^\circ$.

It is assumed that the adjustment time of pitch yaw attitude after missile out of barrel can't be more than 0.5 s. We hope that when pitch yaw attitude adjustment is complete [2], slope channel has reached a stable state, and then determine the adjusting time of the slope channel loop is $t_s < 0.5$ s.

B. Design Principle of Slope Channel Loop

To control the missile tilt of the moment of couple for input channel see type projectile link transfer function, can be seen in Eq.1.

$$\frac{\gamma}{M_{cdx}} = \frac{K_{dx}}{S(T_{dx}S + 1)} \quad (1)$$

Where S is the laplacian, M_{cdx} is the sloping channel output of the steering gear control moment of couple,

$K_{dx} = \frac{1}{b_2}$, $T_{dx} = \frac{b_1}{b_2}$. b_1 , b_2 is the dynamic coefficient,

$b_1 = J_x$, $b_2 = -\frac{1}{4}\rho v S l^2 m_x \bar{\omega}_x$, J_x is the missile of moment

of inertia ($J_x = J_{x_b}$), l is the reference length of the

projectile horizontal, $m_x \bar{\omega}_x$ is the derivative of tilt damping,

$\bar{\omega}_x = \frac{\omega_x l}{2v}$ is the dimensionless velocity, ω_x is the missile

angle velocity, thus, we have $\omega_x = \omega_{bx}^b$.

The slope channel circuit block diagram is shown in Fig. 1. After discretization by "Sampling-Zero Order Holder",

we can generate the control command by the on-missile computer.

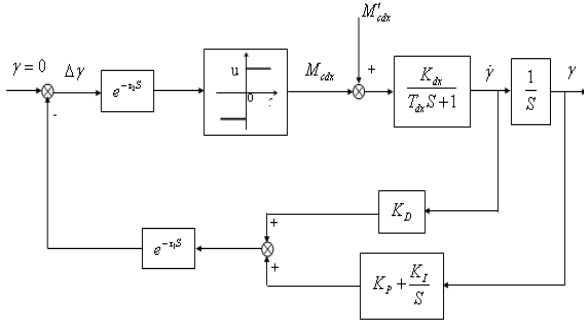


FIGURE I. SLOPE CHANNEL STABILIZATION LOOP DIAGRAM

In Fig. 1, the steering engine is signed as relay, M'_{cdx} is the sloping channel interference moment of couple, K_D is the angular velocity feedback channel transfer coefficient, $K_p + \frac{K_I}{S}$ is the slope angle feedback correction network channels, $e^{-\tau_1 s}$ is the instruction computing delay link, τ_1 is the slope channel command delay time, $e^{-\tau_2 s}$ is the steering gear delay link, τ_2 is the slope channel servo delay time, $\Delta\gamma$ is the tilt angle error angle. K_p , K_I and K_D are the parameters to design[3].to reduce the system sensitivity to the time-varying interference moment of couple, we introduce integral compensation.

We assume that the speed of the missile launch without power is less than 25m/s, the maximum value is nearby 300m/s. According to the above assumption, the following design work is in view of the two speed feature points which are 24m/s and 300m/s.

The phase lag computational formulation which is caused by Zero-Order holder can be seen in Eq. 2.

$$\Phi_{(ZOH)} = 180 \cdot f / f_s \quad (2)$$

where $\Phi_{(ZOH)}$ is the phase lag which is caused by Zero-Order holder(°); f is the frequency of the input signal(1/s); f_s is the sampling frequency(1/s).

The phase lag computational formulation which are caused by instruction computing delay and steering gear delay can be seen in Eq.3.

$$\Phi_{(DELAY)} = 360 \cdot f \cdot \tau_d \quad (3)$$

where $\Phi_{(DELAY)}$ is the phase lag which are caused by instruction computing delay and steering gear delay (°); τ_d is the total delay.

On the basis of above data and formulation, we study the model by describing function method[4]. By repeatedly frequency domain design and

optimization, we finally denote that $K_p=1.5$, $K_I=9.0$, $K_D=0.1$.

When the flight speed of the guided missile is 24m/s, the open and linear part frequency characteristics of slope channel stabilization loop is shown in Fig. 2. When the speed is 300m/s, the frequency characteristic is shown in Fig. 3.

From the figure 2 and figure 3, it can be seen that there is a stable self sustaining oscillation points, when the flight speed is 24 m/s, the self sustaining oscillation frequency is 186 rad/s = 29.6 Hz; When the flight speed is 300 m/s, the self sustaining oscillation frequency is 189 rad/s = 30.1 Hz.

Considering the calculation results of figure 2 and figure 3 is to simplify the steering gear into ideal relay, in the actual situation ,aerodynamic data and the transfer function will also change[5], and the research methods of used here is describing function method.

When missile launch, because of various disturbance, the slope angle may be larger, if immediately introduced Angle integral link in the slope stability loop, which may lead to overshoot increase[6]. Considering the adjustment time is not more than 0.5 s, then it is determined that the Angle integral link is introduced for 0.5 s after the missile launch, valued $K_I = 0.0$ before 0.5 s.

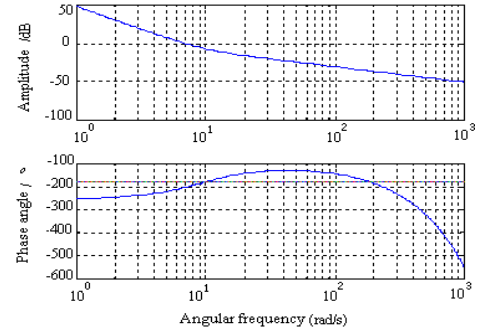


FIGURE II. SPEED AT 24M/S THE FREQUENCY CHARACTERISTICS

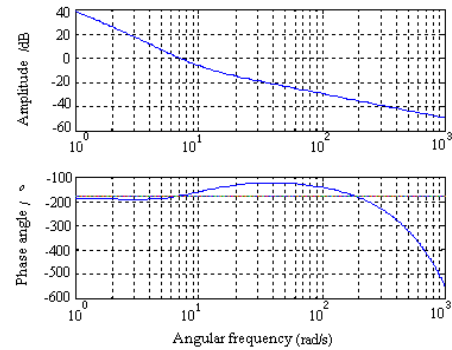


FIGURE III. SPEED AT 300M/S THE FREQUENCY CHARACTERISTICS

Before 0.5 s, valued $K_p=1.5$ 、 $K_I=0.0$ 、 $K_D=0.1$. At the moment, the missile flight speed is about 24 m/s, the slope channel stability loop open-loop frequency characteristics of the linear part as shown in Fig. 4.

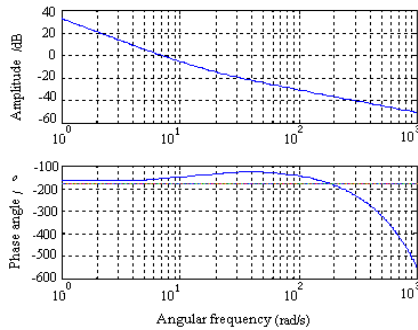


FIGURE IV. BEFORE 0.5S THE FREQUENCY CHARACTERISTICS

As it can be seen from the figure 4, there is a stable self sustaining oscillation points, self sustaining oscillation frequency is 186 rad/s = 29.6 Hz.

III. SLOPE STABLE LOOP SIMULATION TEST

According to the result of the above design, we can use six degrees of freedom rigid body trajectory to carry out simulation experiment [7].

When initial Angle of the missile is -18.3° , and interference moment of couple is zero, the controlled change process of the slope Angle is shown in Fig.5, and 0.5 s control moment of couple as shown in Fig .6.

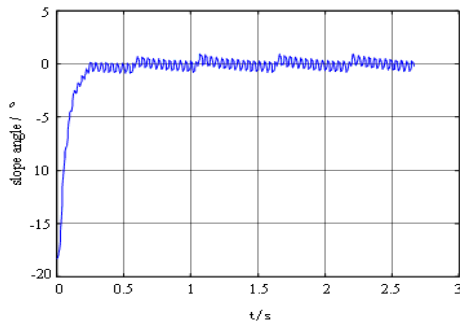


FIGURE V. HANGING PROCESS OF ANGLE CONTROLLED WHILE INTERFERENCE MOMENT OF COUPLE IS ZERO.

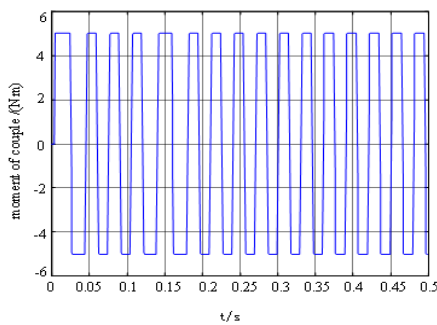


FIGURE VI. THE MOMENT OF COUPLE OF MISSILE FLIGHT CONTROLLED IN 0.5S

The simulation results show that the steering gear working frequency is between 27 ~ 32 (Hz), adjustment time is less than 0.5 s, and control process meet the requirements.

When the missile initial Angle is -18.3 , missile flight time $t = 0 \sim 1.315$ (s), interference moment of couple changes with $-2.5 \times t$; After $t > 1.315$ s, interference moment of couple changes into constant 0.2 Nm. slope Angle controlled change process as shown in Fig. 7.

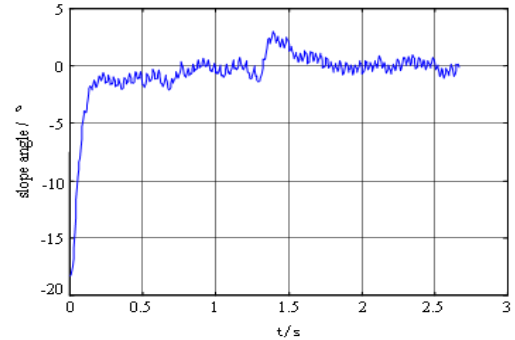


FIGURE VII. CHANGING PROCESS OF ANGLE CONTROLLED IN THE CASE OF TIME-VARYING INTERFERENCE MOMENT OF COUPLE.

From the simulation results, steering gear working frequency is between 24 and 33 (Hz), adjustment time is less than 0.5 s, control process meets requirements[8].

Figure 7 is the simulation results of a time-varying interference moment of couple under severe change, the disturbance moment of couple's largest value reaches -3.3 Nm, and then suddenly becomes into 0.2 Nm, but control system still meets the requirements [9].

Simulation experiment results show that the principle design and parameter design of Sloping channel stabilization loop meet the technical requirements.

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