Disturbance rejection program induced by strap-down seeker time delay

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Abstract: The disturbance rejection rate problem caused by strap-down seeker was studied, the parasitical loop model induced by strap-down seeker time delay was established, the principium of how time delay causes disturbance rejection was analyzed, and the function of disturbance rejection rate induced by strap-down seeker time delay was deduced. Moreover, stability of the parasitical loop caused by time delay was investigated and of the parasitical loop with different guidance parameters was illustrated. The simulation result shows that, if the guidance system lag increases relatively to the missile aerodynamic time constant, the system can overcome larger seeker time delay; if the missile aerodynamic time constant is reduced, the guidance can tolerate larger seeker time delay. Disturbance rejection rate problem discussed in the paper is significant in the practical utilization.

Key words: strap-down seeker; disturbance rejection; parasitical loop

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捷联导引头延时引起的隔离度问题研究

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摘 要: 研究了捷联导引头引起的隔离度问题,建立了捷联导引头延时造成的寄生回路模型,分析了捷联导引头延时引起隔离的机理,得到了捷联导引头延时引起的隔离度函数。研究了导引头延时造成寄生回路的稳定性,在制导参数取不同值情况下,绘制捷联导引头延时引起的寄生回路稳定区域。仿真结果表明:制导系统延迟环节动力学时间常数相对于弹体动力学时间常数越大,对系统克服导引头延时的影响越有利。减小弹体气动力时间常数,可以增强系统容忍导引头延时时间的能力。研究成果对于实现捷联导引头的工程应用具有重大意义。

关键词: 捷联导引头; 隔离度; 寄生回路

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0 Introduction

To provide more accurate target information, the seeker, as a core guidance system measurement component, should implement complicated signal processing. The complicated signal processing, nevertheless, must consume a lot of time, inducing the time delay to the output signal of seeker. For traditional gimbaled seekers, the time delay just increases the guidance system time constant and the guidance time. For strap-down seekers, however, the time delay causes the problem of disturbance rejection apart from that of the guidance system time constant. Focusing on the time delay of strap-down seeker, this paper mainly researches on the disturbance rejection problem.

1 Principium analysis of disturbance rejection problem with strap-down seeker time delay

The parasitical loop block model caused by the time delay of strap-down seeker is illustrated in Fig.1. q is the line-of-sight (LOS) angle, ε is the angle of seeker light axis with respect to the LOS, k_s is the calibration factor of staring strap-down seeker, $\dot{q}_s$ is the output LOS angular rate, T_d is the time constant of differential network, $1/(Ts+1)$ is the lag of guidance system, N is the navigation ratio of proportional navigation, v is the missile flight velocity, T_m and μ_m are correspondingly the time constant and damping ratio of missile autopilot, T_α is the missile turning rate time constant, ϑ_M is the missile attitude angle, k_g is the calibration factor of attitude gyro, and τ is the seeker time delay.

In Fig.1, missile body movement is coupled into seeker output signal of LOS angular rate through two channels: one is the missile disturbance channel and the other is compensation channel of attitude gyro. The detail coupling signals of the two channels will be discussed blow:

(1) Coupling signal component $\Delta\dot{q}_{s1}$ through missile disturbance channel is:

$$\Delta\dot{q}_{s1}=-\frac{e^{-\tau s}}{(T_d s+1)^2}\dot{\vartheta}_M \tag{1}$$

(2) Coupling signal component $\Delta\dot{q}_{s2}$ through missile attitude gyro compensation channel is:

$$\Delta\dot{q}_{s2}=-\frac{1}{(T_d s+1)^2}\dot{\vartheta}_M \tag{2}$$

Therefore, the total seeker output LOS angular rate $\Delta\dot{q}_s$ induced by missile movement:

$$\Delta\dot{q}_s=\frac{1-e^{-\tau s}}{(T_d s+1)^2}\dot{\vartheta}_M \tag{3}$$

Through Equ. (3), the seeker disturbance rejection function induced by time delay $G_{ts}(s)$ is:

$$G_{ts}(s)=\frac{\Delta\dot{q}_{s1}}{\dot{\vartheta}_M}=\frac{1-e^{-\tau s}}{(T_d s+1)^2} \tag{4}$$

Through Equ. (4), if the time delay τ is 0, missile movement would not be coupled into the seeker output signal of LOS angular rate. Therefore the Equ. (4) could be considered as the disturbance rejection function with the strap-down seeker time delay.

2 Parasitic loop stability analysis

As demonstrated in Fig.1, the close-loop characteristic

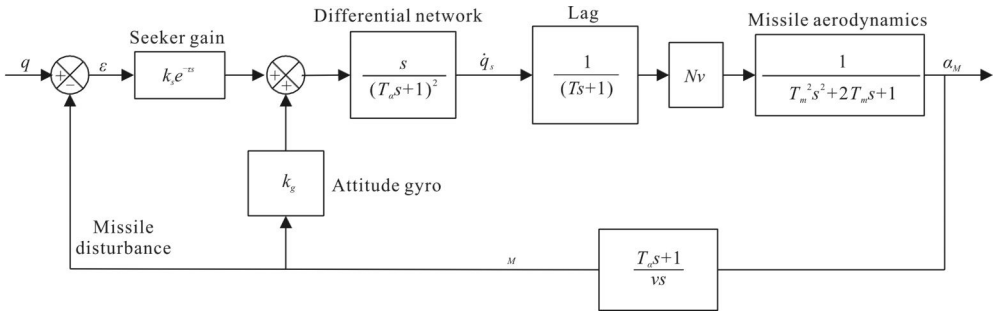

Fig.1 Parasitical loop induced by strap-down seeker time delay

equation of the parasitic loop caused by strap −down seeker is:

$$\frac{1}{e^{-\tau s}-1}+\frac{N(T_\alpha s+1)}{(T_d s+1)^2(Ts+1)(T_m^2 s^2+2\mu_m T_s s+1)}=0 \quad (5)$$

Define the dimensionless quantities:

$$B_d=\frac{T_m}{T_d},B=\frac{T_m}{T},B_\alpha=\frac{T_m}{T_\alpha},B_\tau=\frac{T_m}{\tau},\bar{\omega}=T_m\omega,$$

$$\bar{a}_0=\frac{T_d^2 TT_m^2}{T_m^5}=\frac{1}{B_d^2 B},$$

$$\bar{a}_1=\frac{2\mu_m T_m T_d^2 T+T_m^2(2T_d T+T_d^2)}{T_m^4}=\frac{2\mu_m}{B_d^2 B}+\frac{2}{B_d B}+\frac{1}{B_d^2},$$

$$\bar{a}_2=\frac{T_d^2 T+2\mu_m T_m(2T_d T+T_d^2)+T_m^2(T+2T_d)}{T_m^3}=\frac{2}{B_d B}+$$

$$\frac{1}{B_d^2}+2\mu_m\left(\frac{1}{B}+\frac{2}{B_d}\right)+1,$$

$$\bar{a}_3=\frac{(2T_d T+T_d^2)+2\mu_m T_m(T+2T_d)+T_m^2}{T_m^2}=\frac{2}{B_d B}+$$

$$\frac{1}{B_d^2}+2\mu_m\left(\frac{1}{B}+\frac{2}{B_d}\right)+1,$$

$$\bar{a}_4=\frac{(T+2T_d)+2\mu_m T_m}{T_m}=\frac{1}{B}+\frac{2}{B_d}+2\mu_m,$$

$$\bar{a}_6=\bar{a}_0\bar{\omega}^5-\bar{a}_4\bar{\omega}^3+\bar{a}_4\bar{\omega},\ \bar{a}_7=\bar{a}_1\bar{\omega}^4-\bar{a}_3\bar{\omega}^2+1,$$

$$\bar{a}_8=\frac{N\bar{a}_7+N\bar{a}_6\frac{1}{B_\alpha}\bar{\omega}}{\bar{a}_7^2+\bar{a}_6^2},\ \bar{a}_9=\frac{(N\bar{a}_7\frac{1}{B_\alpha}\bar{\omega}-N\bar{a}_6)}{\bar{a}_7^2+\bar{a}_6^2},$$

$$C_1=\frac{\sin\left(\frac{1}{B_\tau}\bar{\omega}\right)}{2\left[1-\cos\left(\frac{1}{B_\tau}\bar{\omega}\right)\right]},$$

So, the solution of system characteristic equation is:

$$B_\tau=\frac{\bar{\omega}}{\pi+2\arcsin\left(\frac{2C_1}{\sqrt{4C_1^2+1}}\right)} \quad (6)$$

The stable region obtained by Equ. (6) is shown in Fig.2 −5. Figure 2 plots the stable region defined by B_τ versus B_d in condition of B_α=0.05, B=2.5, μ_m=0.7, and N at different values of 3, 4, 5. In the figure, the stable region decreases with B_d increasing, which means that with the seeker differential network faster than the missile aerodynamics, the guidance system could tolerate shorter seeker time delay. Moreover, the stable region decreases if the navigation ratio N increases, which reflects that the guidance system could tolerate shorter time delay with the guidance system bandwidth increasing. Fig.3 plots the stable region defined by B_τ versus B_d in condition of B_α= 0.05, B=2.5, N=4, and μ_m at different values of 0.1, 0.5, and 0.9. It can be obtained that the missile damping ratio μ_m has heavy influence on the stable region from Fig.3.

The larger μ_m is, the larger system stability becomes. Figure 4 plots the stability defined by B_τ versus B_d in the condition of B_α=0.05, N=4, μ_m=0.7, at different values of 1, 2, and 3. In the figure, the stability decreases with B. So, if the guidance system lag increases relatively to the missile aerodynamic time constant, the system can overcome larger seeker time delay. Figure 5 plots the stable region defined by B_τ versus B_d in condition of B =

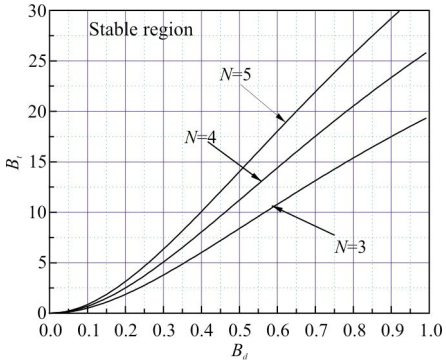

Fig.2 Stable region with N at 3, 4, and 5

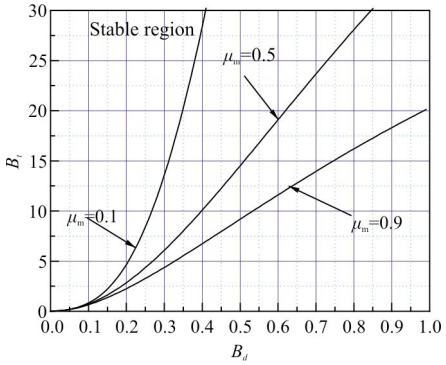

Fig. 3 Stable region with μ_m at 0.1, 0.5, and 0.9

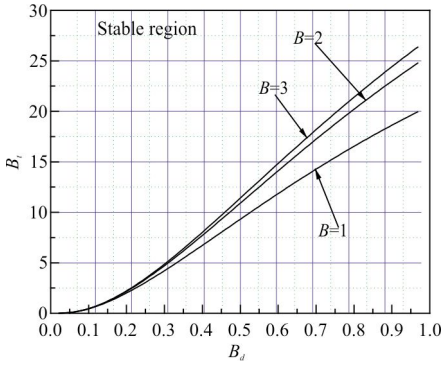

Fig.4 Stable region with B at 1, 2, 3

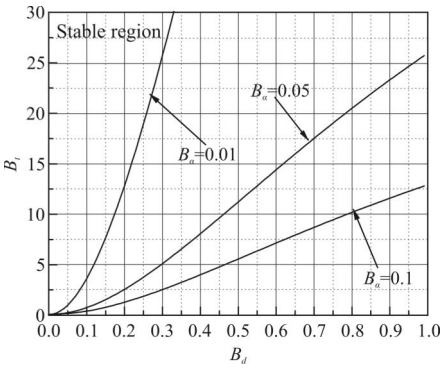

Fig.5 Stable region with B_α at 0.01, 0.05, 0.1

2.5, N=4, μ_m=0.7, and B_α at different values of 0.01, 0.05, and 0.1. In this figure, the stable region increases with B_α, reflecting that if the missile aerodynamic time constant is reduced, the guidance can tolerate larger seeker time delay.

3 Conclusion

It is meaningful for China military industry to occupy the technology of strap-down seeker, which respects the development of seeker technology. The paper investigated the disturbance rejection problem caused by strap-down seeker time delay and deduced the stable region of the parasitical loop caused by time delay. As one of the key problems of strap-down seeker, disturbance rejection rate problem discussed in the preceding sections is significant in the practical utilization.

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