



航空学报 2011, Vol. 32 Issue (5) :822-832 DOI: CNKI:11-1929/V.20110310.1709.000

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发动机谐振与箭体模态耦合稳定性及机理研究

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Study on Coupling Stability and Mechanism Between Engine Harmonic Oscillation and Launch Vehicle's Modes

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摘要

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摘要 针对发动机谐振可能与箭体弹性振动之间发生耦合共振,从而引起姿态控制系统不稳定的问题,首先将发动机谐振特性简化为一个二阶环节,建立了包含发动机谐振方程的火箭姿态动力学模型;然后分析了发动机谐振对箭体模态极点频率和阻尼比的影响,并从理论上分析了出现负阻尼比时发动机和箭体模态间的耦合共振机理,在此基础上计算了导致姿态控制系统不稳定的发动机谐振频率边界;最后通过时域仿真验证了分析结果的正确性。结果表明,当发动机谐振频率较低时可能与箭体低阶弹性模态之间产生耦合共振,导致姿态角和姿态角速度出现振荡甚至发散现象,发动机谐振频率必须高于谐振频率边界最大值才能保证系统稳定。相关工作对姿态控制系统的设计具有一定价值。

关键词: 运载火箭 发动机谐振 耦合共振 箭体模态 共振频率边界

Abstract: In consideration of the instability of attitude control system caused by coupling resonance between engine harmonic oscillation and launch vehicle's elastic vibration, dynamic coupling stability and mechanism between engine harmonic oscillation and launch vehicle's modes are studied, and the engine harmonic oscillation frequency boundary due to the instability of attitude control system is also computed. Firstly, the dynamics of engine oscillation is simplified as a second order system, and an attitude dynamic model of launch vehicle including engine oscillation equations is derived. Then, the influence of engine oscillation on launch vehicle's modal frequency and damping is analyzed, and the mechanism of coupling resonance between engine oscillation and launch vehicle's modes when the modal damping is negative is also analyzed theoretically. Based on this, the engine oscillation frequency boundary which leads to the instability of attitude control system is also computed. Finally, the analytical results are validated by time domain simulation. The results show that coupling resonance between engine harmonic oscillation and low order mode will arise when the the engine oscillation frequency is lower, at that time the phenomenon of attitude angle and attitude angular velocity's oscillation and divergence will appear. The stability requires that engine harmonic oscillation frequency is higher than the maximum of the harmonic oscillation frequency boundary. The studies in this paper can provide some references for the design of attitude control system.

Keywords: launch vehicles engine harmonic oscillation coupling resonance launch vehicle's modes resonance frequency boundary

Received 2010-05-25;

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引用本文:

李家文, 李道奎, 周建平. 发动机谐振与箭体模态耦合稳定性及机理研究[J]. 航空学报, 2011, 32(5): 822-832.

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