南臺科技大學

機械工程系碩士班

碩士學位論文

結合適應性反饋與前饋控制之主動隔振系統設計、分析與實驗驗證

Design, Analysis and Experimental Verification of Active Vibration Isolation Systems by Integrating Adaptive Feedback and Feedforward Controls

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摘要

在強調精密製造與工業 4.0 時代，為了確保製程設備精度、生產週期及良率不受環境振動之影響，隔振設備的發展已是不可或缺的重要環節，同時隨著前瞻儀器設備解析度不斷往奈米、甚至次奈米尺度微縮，使得過往被動隔振器已無法滿足現今高科技產業的要求。為此，諸多研究與設備商則紛紛轉為投入發展更加新穎的「主動隔振系統」，其中一種基於「天鉤式阻尼器」構想的主動控制理念，由於能夠克服傳統隔振器為人所詬病的共振放大問題，並具有簡單、可靠及易實踐之特性，故已於許多商業化產品中得到廣泛應用。然而前述控制方法雖著實可靠、有效，但仍有眾多問題尚待解決，其一針對當前敏感設備所關注之低頻(<10Hz)衰減性能緩慢且有限，其二對於中高頻振動干擾並無顯著成效，故在較為嚴峻之基礎振動環境難以確保隔振性能符合前瞻設備需求，其三為獲得卓越的隔振性能，若採用高增益反饋控制，需以降低系統穩定性及增強雜訊功率作為代價。有鑒於此，本研究將從結構設計、電路及控制方法進行全面的探討，以此發展出一套性能符合前瞻奈米研發設備所需之主動隔振系統。在核心控制部份，將提出一種基於「結合適應性反饋與前饋控制」策略，而通過模擬分析結果證實，該控制技術不僅可消除結構共振放大效應，更能夠顯著增強 1~100Hz 頻帶範圍內的隔振性能。實驗結果表明，本系統可於極為嚴峻的廠房振動水平 VC-A 等級，降至前瞻奈米研發設備所需之 VC-G 等級，而在頻率 5Hz 與 10Hz 則具有高達-24dB 與-42dB 衰減性能。此外，通過結合適應性濾波器後，時域振幅更從原先 27.2ug rms 降至 11.8ug rms，衰減幅度高達 57%，系統穩定時間亦由 81ms 縮短至 50ms，以此闡明適應性濾波器卓越的濾波性能與暫態響應特性可有效增強此系統的隔振能力。綜合以上研究結果，本文聚焦於控制技術與隔振性能之探討，並由量化指標結果說明本系統卓越的衰減性能、暫穩響應與抗干擾能力，以此期盼將來此隔振技術能夠實際應用於前瞻敏感設備之中，引領科技產業發展。

關鍵字:主動隔振系統、天鉤式阻尼、虛擬質量、前饋控制、適應性濾波器

Abstract

This is the era of precision manufacturing and industry 4.0. In order to sustain production capacity of high quality, vibration isolation plays a big role to affirm the accuracy of particular instrument and equipment. Along with the resolution of instrument and equipment which has evolved towards nanometers and sub-nanometer, passive vibration isolator can no longer satisfied our demands within high-tech industry. Thus, we pay higher attention and invest more resources into active vibration isolator. Skyhook damping, a concept which can effectively help conquer resonance amplification, has been extensively put into practices on commercialization products. Although the technics as mentioned previously is reliable and effective, there are still room for improvement. First of all, the attenuation rate of the low frequency range(<10Hz), which the sensitive instrument deeply concerned about, is too slow. Besides, there is no notable and significant improvement in performance when it comes to mid to high frequency range. Therefore, the technics is easily to be restricted by environments when applied to practices. With a view to have better vibration isolation effects, usually the system stability and the noise power are sacrificed in the trade-off.   This thesis is discussing about mechanical design, electric circuit and control technics, developing an active vibration isolation system which fit into nano-tech instrument and equipment. This paper presents a strategy on the basis of "Integrating adaptive feedback and feedforward controls." Not only can this system perfectly eliminate structure resonance, but also significantly improved the vibration isolation performance during the frequencies from 1 to 100Hz. The experiment has proven that the system can effectively decrease vibration degree from VC-A level to VC-G level, as well as contribute to -24dB and -42dB attenuation performance at frequencies of 5Hz and 10Hz. Performing with adaptive filter, this system can obviously reduce time domain amplitude to from 27.2ug rms 11.8 ug rms, shorten transient response from 81ms to 50ms. That is to say that adaptive filter can notably strengthen the isolation performance of this system. In conclusion, this article is aim to discussing controlling technics. Based on the experiments results, the decay performance, transient response and anti-noise capability of this technics can be fully explained and described. I sincerely hope that this positive vibration isolation system can be applied to prospective instruments in the near future, leading this technical industry forward to a new page.

Keywords: Active vibration isolator, Skyhook damping, Virtual mass, Feedforward control, Adaptive filter