Experimental Vibrational Mechanics – Case Studies

K-S Chen

Dec., 2021

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- Case 1: 高爾夫球桿振動量測
- Case 2: 電磁式獵能實驗
- Case 3: 線性輸入修正法
- Case 4: 天車減振實驗
- Case 5: 光碟機結構噪音量測
- Case 6: 慣性導航
- Case 7: Contact switches
- Case 8: Some examples from SICE 2011
- Case 9: An elastomer testing system
- Case 10: 成大校鐘聲學/振動測試
- Case 11:整合振動抑制與3D 列印結構研究

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System Dynamics Lab. For Mechatornics and Microsystems

成大機械

Case Study I (高爾夫球桿振動量測)

- October 2006 – March 2007
- Sponsored by 永南橡膠
- Performed by
  - 廖彥鳴 (機械所 2008畢),
  - 林韋澄, 戴辰軒, 鄧迪隆 (當時專題生, 機械所 2009 畢業)

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實驗目的

- 利用頻譜分析儀求出高爾夫球桿球頭受到撞擊時比較新舊不同球桿握把振動之自然頻率。
- 實驗可分為兩部份:
  1. 自由邊界實驗
  2. 固定邊界實驗

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新舊握把

新

舊

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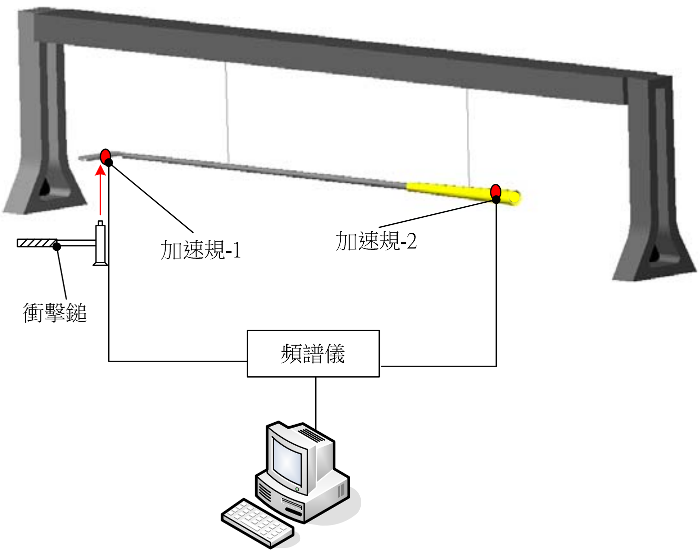
1. 自由邊界實驗示意圖



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實驗架設

頻譜分析儀

加速規

整體實驗架構

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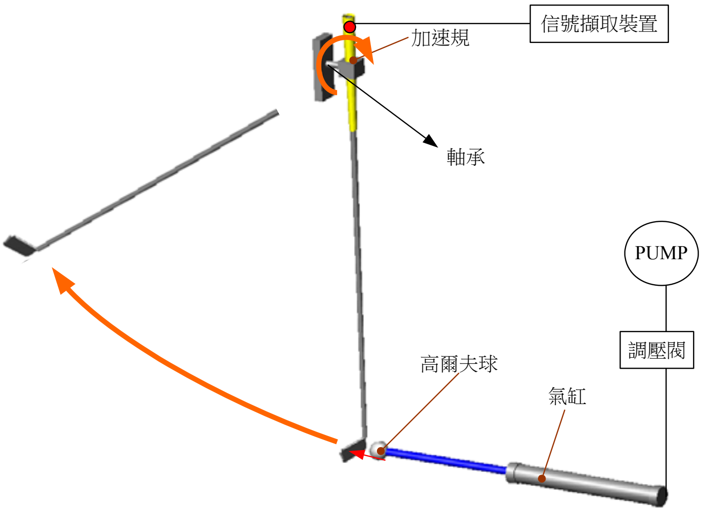
2.固定邊界實驗



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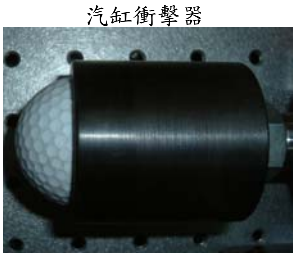
實驗設備

空壓機

汽缸衝擊器

調壓閥



衝擊器之高爾夫球衝擊頭

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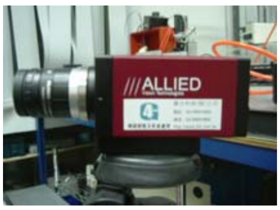
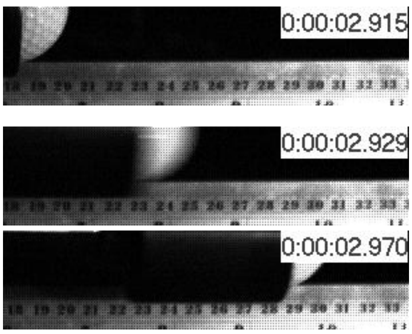
衝擊過程

高速攝影系統擷取衝擊器在撞擊時之圖片，如下圖，計算出衝擊器最大速度為487.5 cm/sec 。



高速攝影系統



衝擊過程

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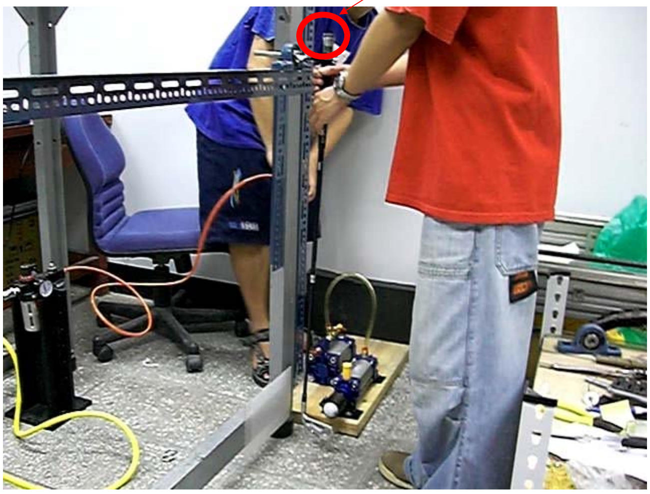
實驗情形

壓電式加速規



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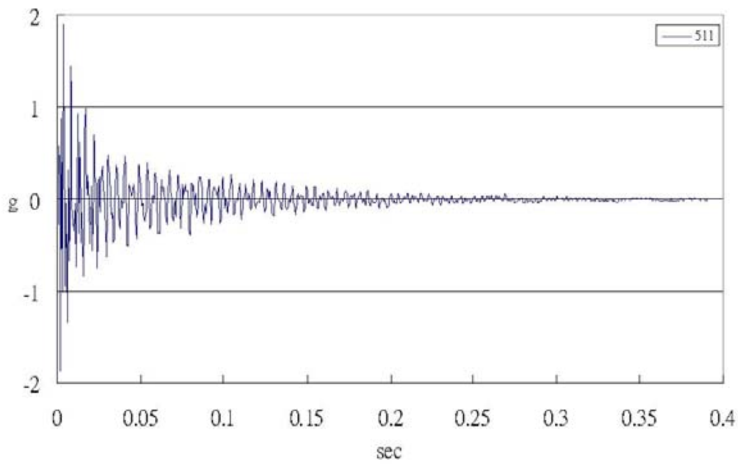
Original data (一號桿時域訊號)



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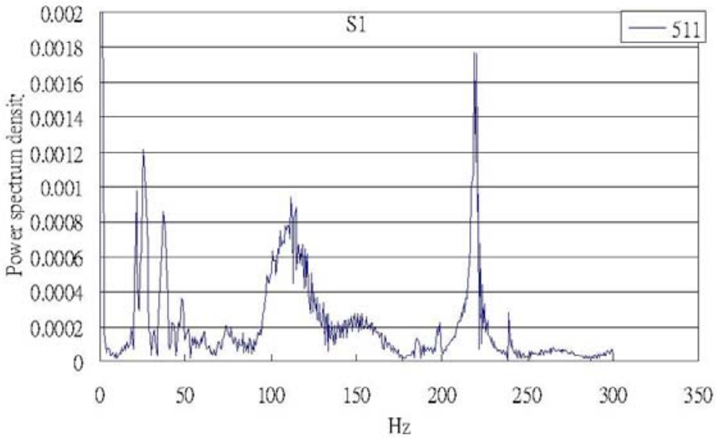
Original data (一號桿頻域訊號)



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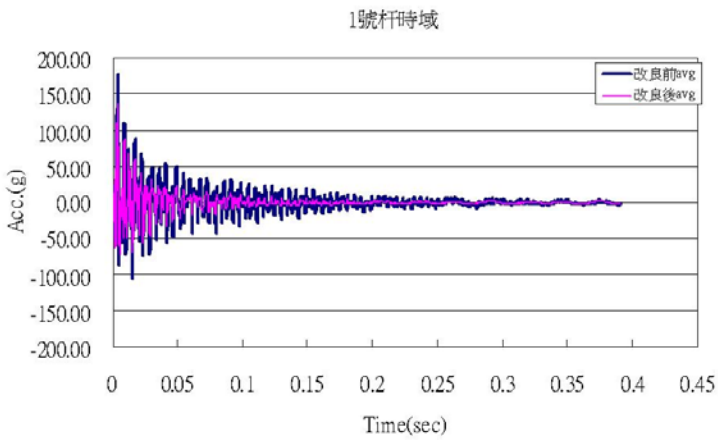
Reduced data (10 times average)



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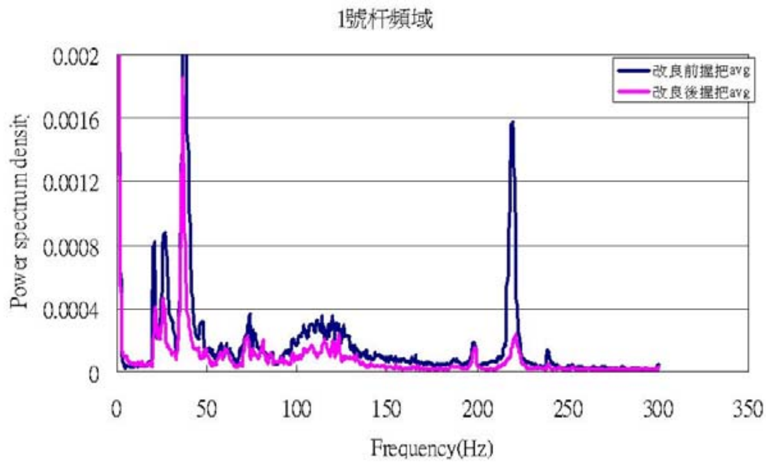
Reduced data (10 times average)



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Case Study II (壓電獵能)

- May 2007 – July 2008
- Sponsored by ITRI
- Performed by 林聖傑 (奈微所 2008畢業)

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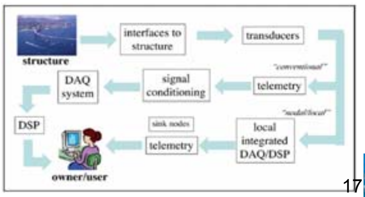
前言

- Sensor network在結構安全監測 (structural health monitoring, SHM)的應用上 ,其涵蓋之空間需求以及 sensor density 有日益增加之趨勢
- 無線傳輸成為了sensor傳送訊息的主要方法
- 替換Sensor network系統中數以百計個sensor的充電電池卻成為麻煩的任務
  - 需有自行發電的來源
  - 從環境中運用廢棄能源
- 可應用範圍
  - 結構安全, 車輛動態,水質, 生態

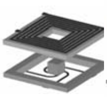
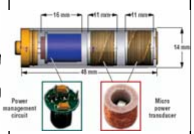
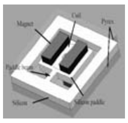
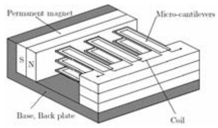
From LMS report, Los Alamos 2004

結構安全監測系統



水質檢測

相關文獻中各獵能器的比較

	W.S. Huang et al, 2007	Steve C.L. Yuen et al, 2007	S. P. Beeby *et al, 2004*	Makoto Mizuno and Derek G Chetwynd , 2003
structure				
Specification	Freq:100Hz Power Density: 4μW/cm^3 Size: (6*6*1)mm^3	Freq:70.5Hz Power Density: 53.1μW/cm^3 Size:(48*14*14)mm^3 Mass:10.5g	Freq:6.4kHz Voltage:0.38V Power:21nW Size:(48*14*14)mm^3	Freq:58kHz Cantilever:(500*100*20)μm^3 turn:12 magnet:(30*10*6)mm^3 Power:6nW for a typical single-element electromagnetic microgenerator voltage:1.4mV
Description	由微機電技術製作線圈與彈簧,將振動能轉成電能	線圈內的彈簧系統,將振動能轉成電能。串連兩個線圈,並將產生的感應電動勢透過增壓電路放大	為三層的結構,磁鐵放置在上下層的wafer,並靠近線圈的凹槽,中間層的結構側向振動產生感應電動勢。	懸臂樑末端裝置一質量,且線圈製作在懸臂樑上,而永久磁鐵靠近其末端。當懸臂樑震動時,切割磁力線而產生感應電動勢。

各式獵能比較[Roundy et al, 2003]

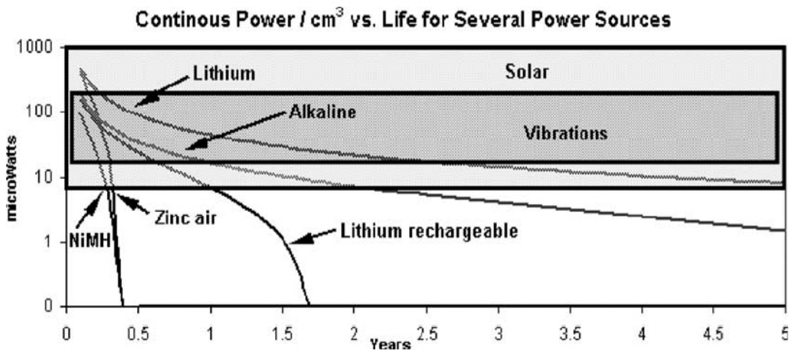


Fig. 1. Comparison of power from vibrations, solar, and various battery chemistries.

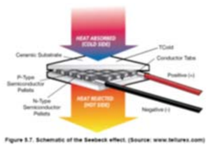
- 太陽能, 振動, 熱 均為可能之 能量獲得來源

轉換電能的可能方式

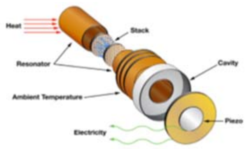
太陽能

壓電

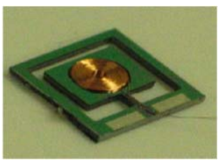
熱電獵能



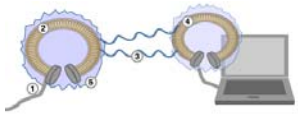
熱聲效應



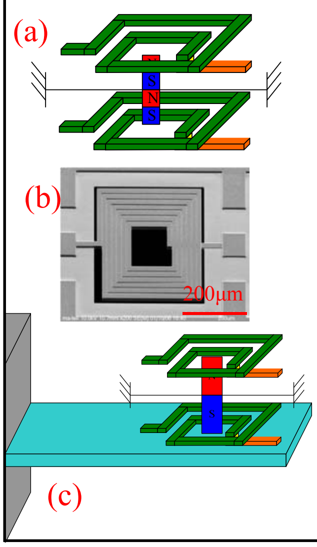
電磁獵能



無線充電



微電磁獵能器元件概念設計



■將線圈與彈簧微小化, 組合線圈與彈簧成單一模組, 由數個單元組合構成, 並由電路做倍壓與存能

■模組可藉由串連增加電壓或由並聯增加電流。可利用台積電提供給CIC的0.18μm製程進行設計與製作。彈簧系統將使用分子材料進行製作

■層與層之間亦可藉由串連增加電壓或由並聯增加電流

■外加懸臂樑使彈簧系統共振

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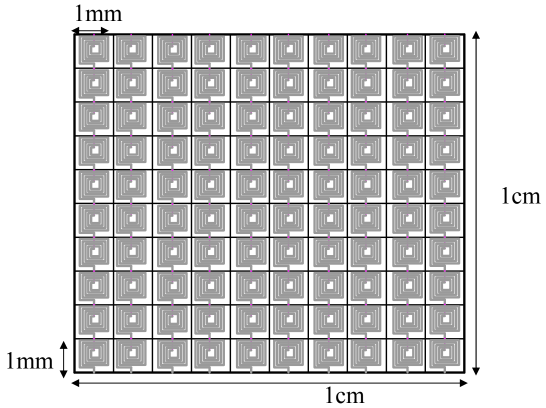
Design result (cont.)

- 由於單一個device面積(1mm^2)極小,因此將藉由多個device串聯,以增加電壓
- 同時一片(1cm^2)經過device串並聯的晶片,可再繼續多片串並聯,增加電壓或電流



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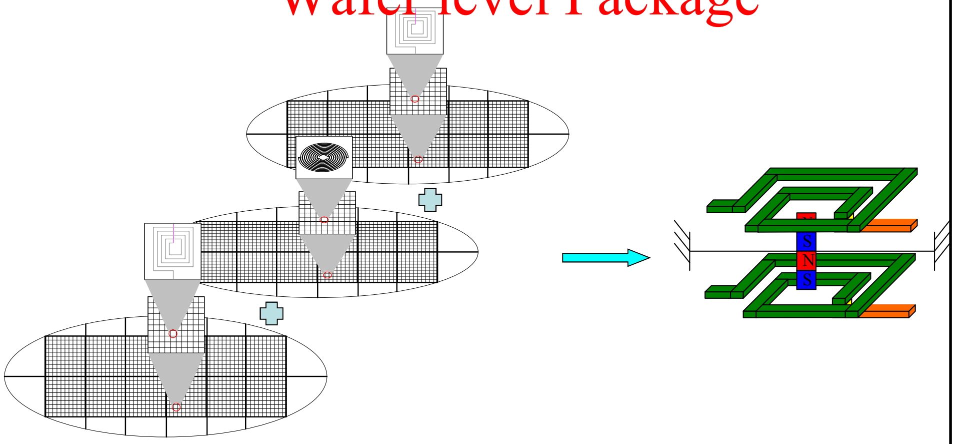
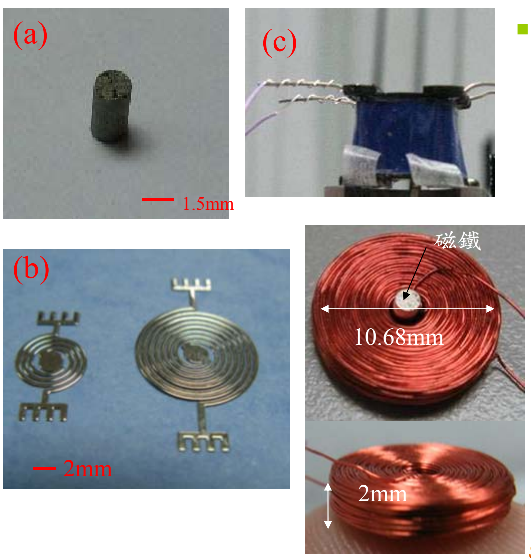
元件製作設計–Wafer level Package



- 將5吋或8吋wafer切成好幾個面積為1*1cm^{2}的方形,每一方形再partition 成100個小方形
- 利用微機電中的微影及蝕刻技術,在小方形裡製作線圈或彈簧

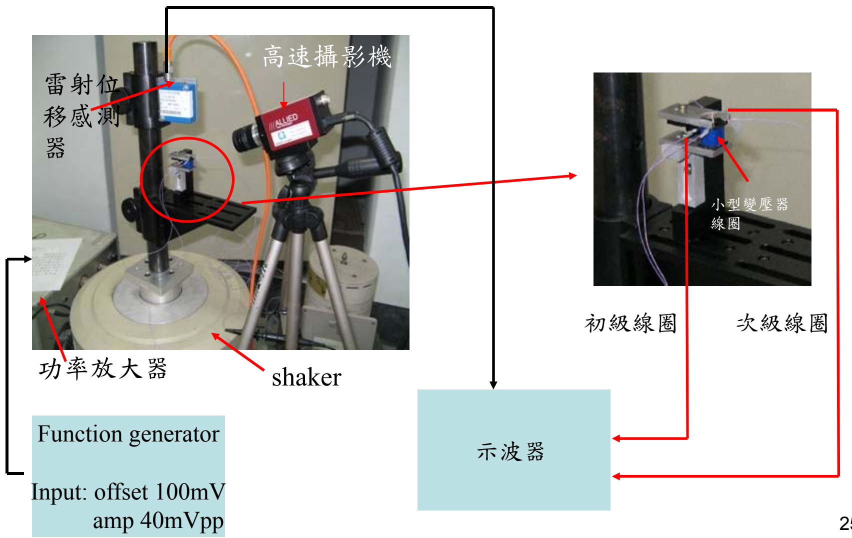
巨觀實驗



- 巨觀實驗的目的
  - 量測Ni彈簧及線圈的性質
  - 製作完大小相同的高分子彈簧後,進行相同的實驗,作為修正設計的依據

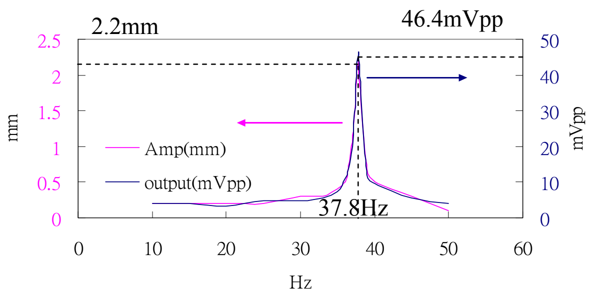
(a)SmCo 磁鐵 (b)厚度100 μm的Ni彈簧 (c)小型變壓器線圈 (d)測試用的線圈

巨觀實驗-電磁獵能器實驗架構



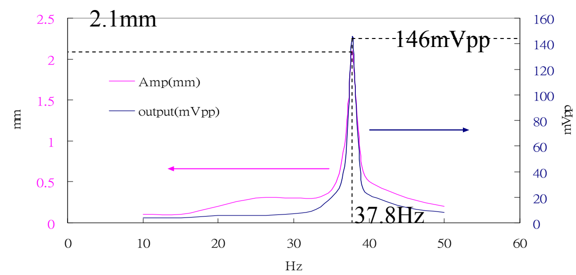
成大機械

電磁獵能器實驗結果



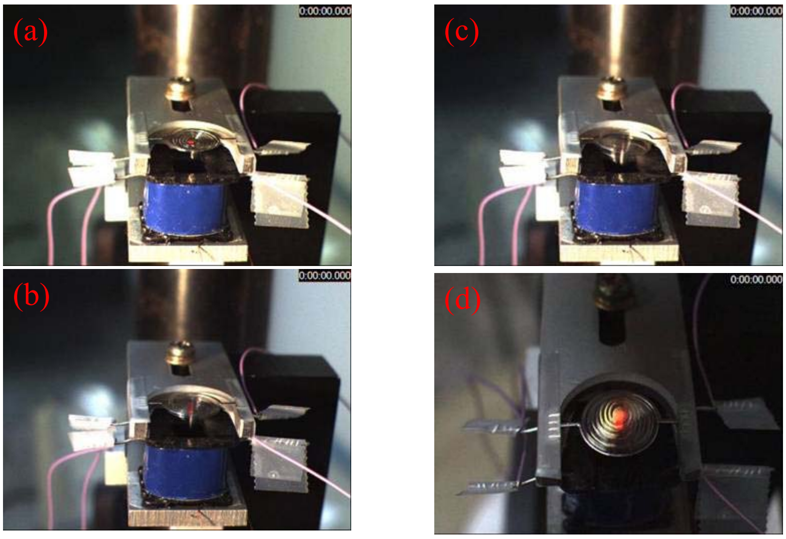
初級線圈

- 彈簧的共振頻率在37.8Hz, 但因變壓器的次極線圈圈數比初極線圈高,因此產生的電壓比初級線圈高



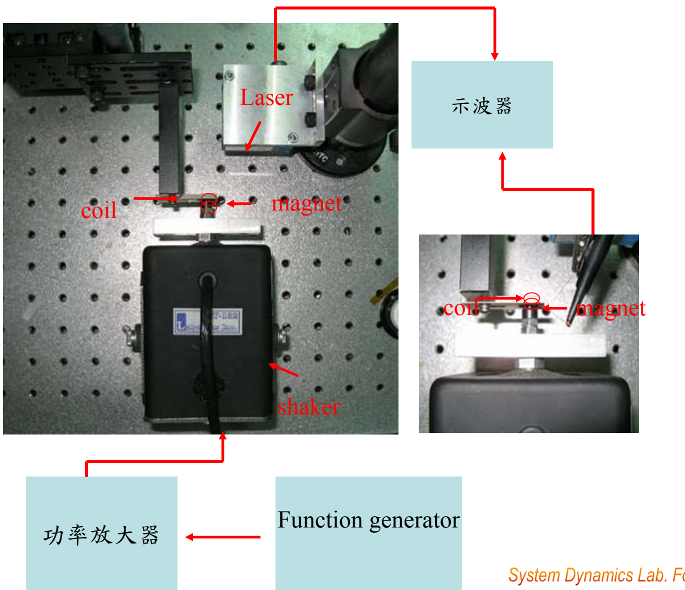
次級線圈

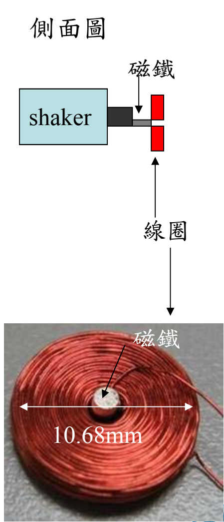
Ni彈簧高速攝影



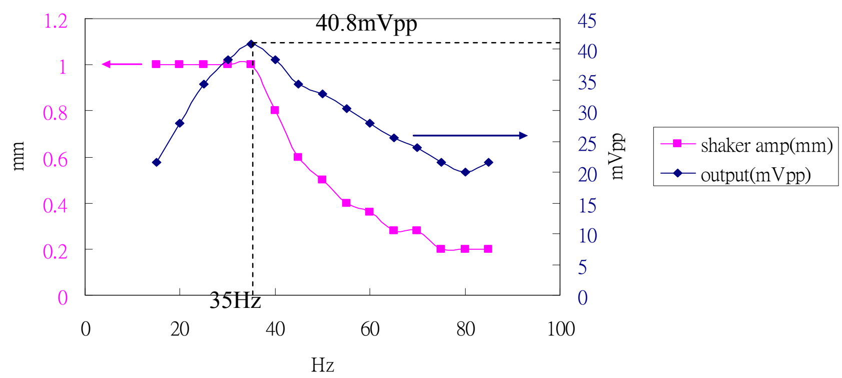
(a)30Hz (b)37.2Hz (c)37.8Hz (d)37.8Hz 時的高速攝影

巨觀實驗---線圈測試架構



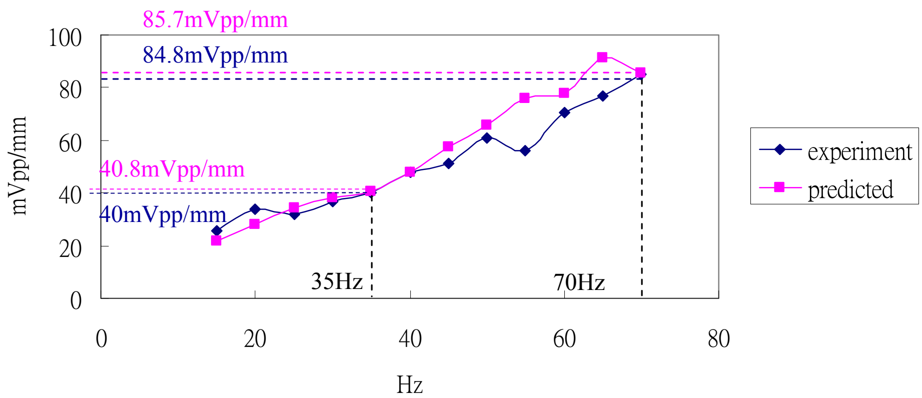


線圈測試實驗結果



- 固定輸入shaker的功率,改變頻率,量測電壓值

線圈測試實驗結果

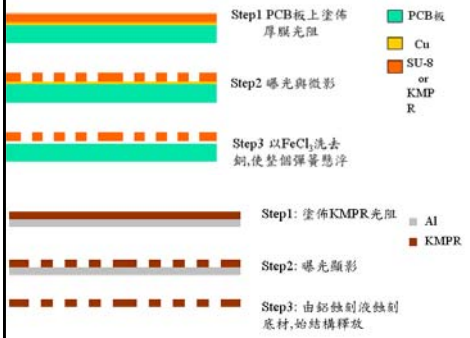


- 固定shaker振幅,改變頻率,量測電壓值,其實驗結果與預測的結果接近

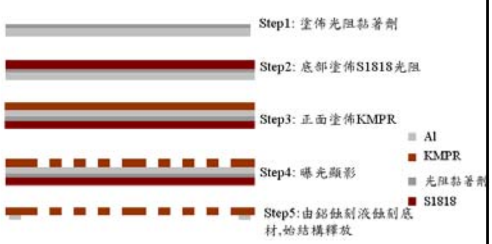
獵能器製作設計-彈簧製作設計

- 在巨觀實驗時,Ni彈簧可行,為降低共振頻率,而採用高分子材料當彈簧結構,製作一樣大小的彈簧,進行相同的實驗

第一種製程方法:彈簧整個懸浮



第二種製程方法:彈簧外圍留有金屬框,可增加結構強度



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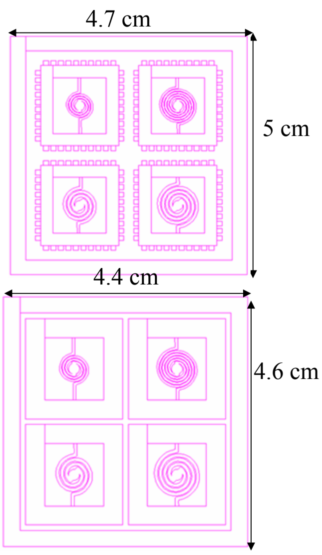
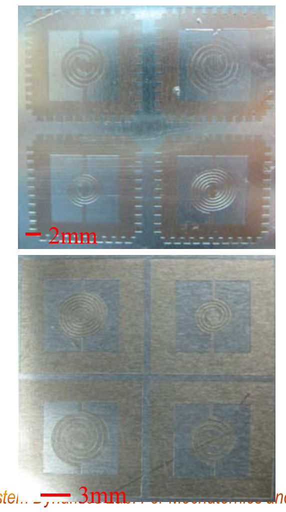
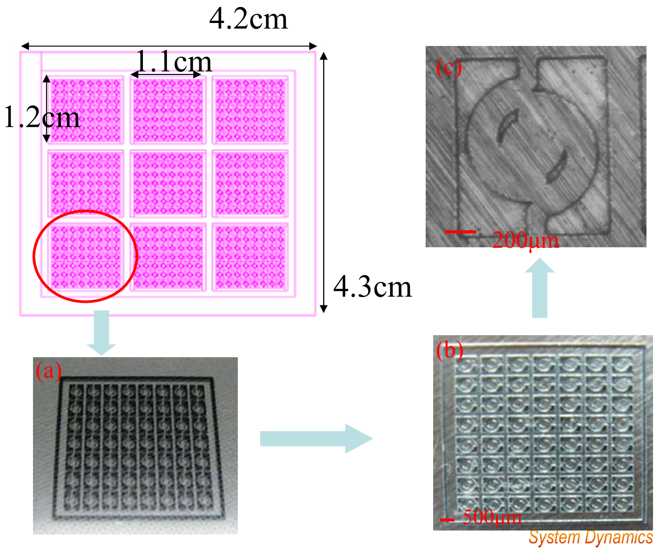
彈簧製作



曝光及顯影後



陣列式彈簧製作



(a)子陣列中有56個彈簧

(b) 曝光顯影後的彈簧陣列,厚度為110μm

(c) 單一小彈簧的OM影像。由於厚度太厚,曝光時間過長,未曝出完整的彈簧

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Case Study III 線性輸入修正法

- Dec 2002 – May 2004
- Sponsered by NSC
- Performed by
  - 尹瑞豐 (機械所2004畢業)

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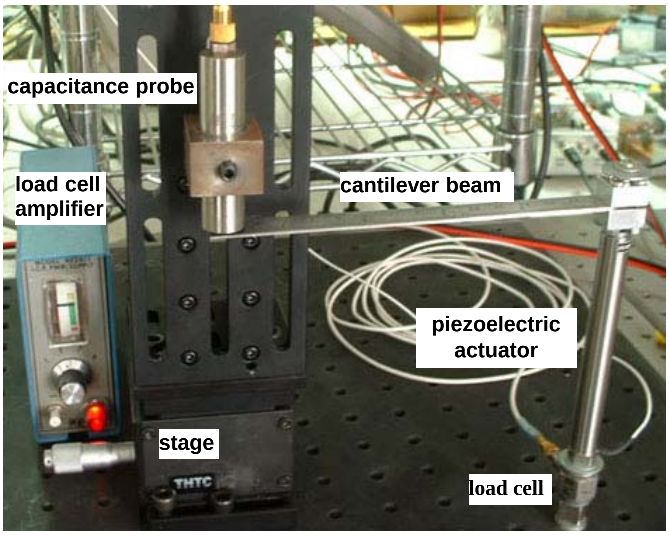
壓電致動懸臂樑系統實體圖



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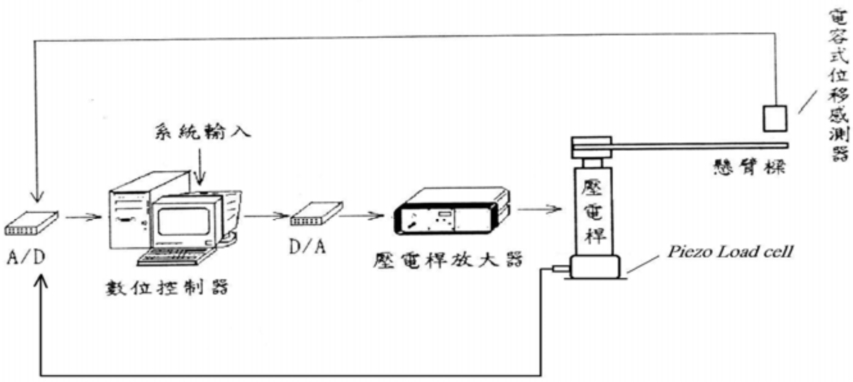

Steel ruler
L = 155 (mm)
B = 13.46 (mm)
H = 1.16 (mm)
E = 207(Gpa)

Calculation
m = 0.123 (kg)
k = 779 (N/m)
f1 = 40 (Hz)
T = 25 (ms)

Experiment
f1 = 39.94 Hz
f2 = 250.07 Hz

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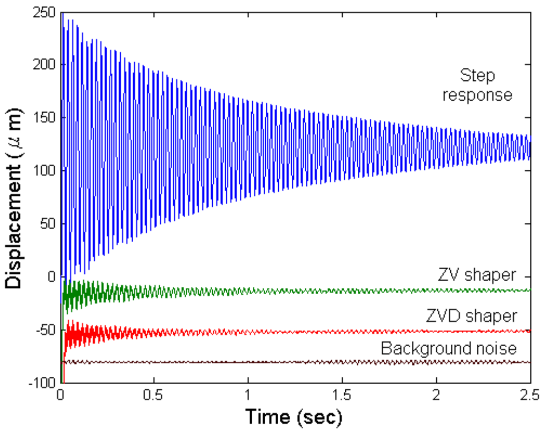
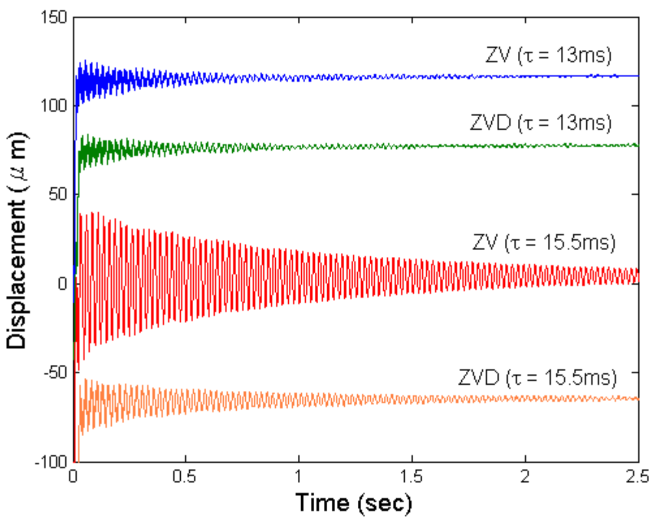
實驗結果

- ZV 與 ZVD shapers 皆能有效的抑制殘留振動，縮短系統安定時間。
- 背景雜訊的干擾約為3.2μm，約佔3 %的殘留振動量。

step responses - unshaped and shaped (τ = T/2=12.5ms)



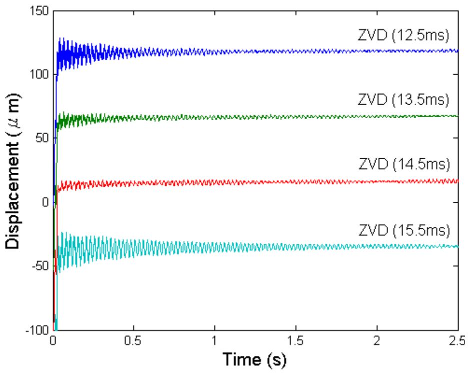
強健性實驗結果

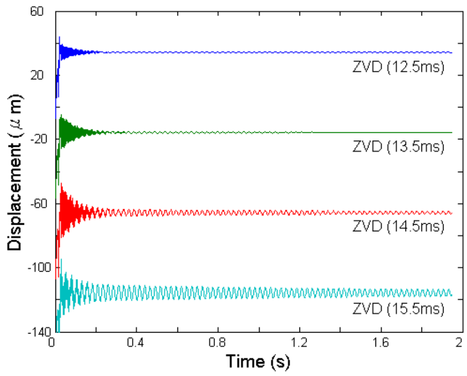


ZVD shaper 比 ZV shaper 有較佳的強健

FEM模擬分析與實驗結果比較

Experimental results　　FEM results





FE model的模擬結果，可與實驗相互驗證；
其中FE model並無背景雜訊干擾的問題。

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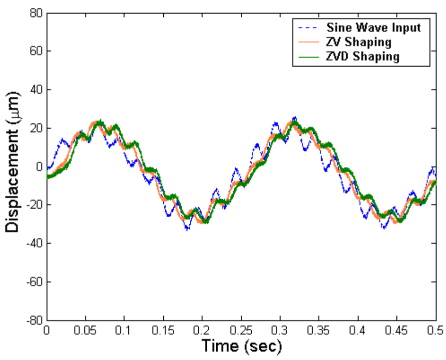
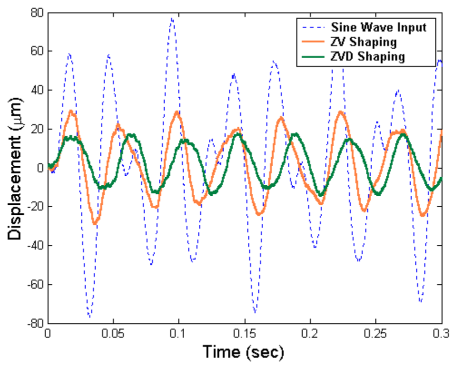
正弦輸入之實驗結果

Input = 2*sin(0.1*ω)　　Input = 2*sin(0.6*ω)





輸入接近共振頻率時，採用輸入修正方式，
表現較為穩定。

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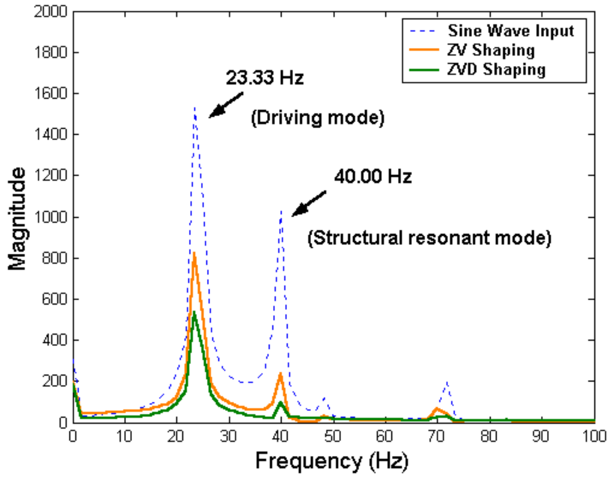
正弦輸入之頻域分析 Input =



系統的頻域響應於共振頻率所表現之強度，
在經由輸入修正後，明顯有效地減小。

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小結

- 經由FEM模擬分析與實驗驗證，線性輸入修正法仍能有效抑制線性連續系統之殘留振動。
- 正弦輸入頻率接近共振頻率時，輸入修正法有助於輸入的穩定表現；雖造成振幅變小，可以事先適當增加輸入之強度，做為補償。
- FEM模擬分析與實驗結果有不錯的相關性，未來有助於設計與測試新的輸入修正方法，以適用於結構較複雜的連續系統。

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System Dynamics Lab. For Mechatronics and Microsystems

Case Study IV (天車振動抑制)

- Jan 2008 –
- Sponsered by NSC
- Performed by 戴辰軒 (機械所 2009 畢業)

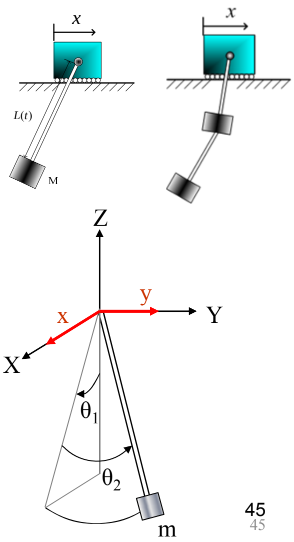
← Gantry crane

Rotary crane ↑

← Boom crane

研究目標

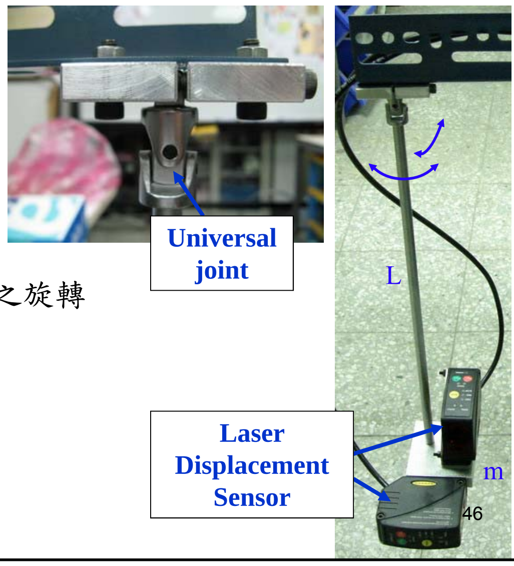
- 長距離天車減振系統 [陳敬元2005]
  雙單擺長距離減振系統 [林莞慈2007]
  - 主體為懸臂樑系統及雙單擺系統
  - 輸入修正法與回授控制
  - 實驗驗証可有效抑制系統殘餘振動
- 雙軸運動方向之單擺系統
  - 傳輸機構為線性馬達
  - 利用輸入修正法達成作動目標
  - 快速且準確地到達目標位置
  - 將殘餘振動降至最低



實驗系統建立

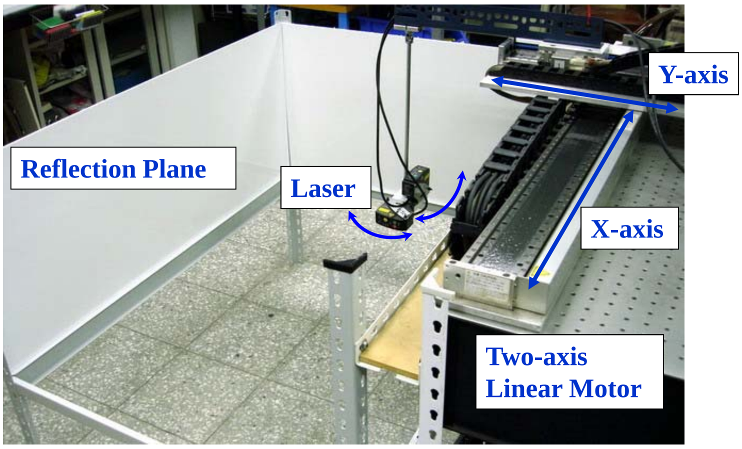
- 鋼絲最為理想
  - Z軸方向旋轉
  →量測上的困難
- 雙自由度單擺
  - 萬向接頭+不銹鋼柱
  - 只允許X、Y軸方向之旋轉

◆L=41.8 cm
◆m=1.5 kg
◆T=1.28 sec

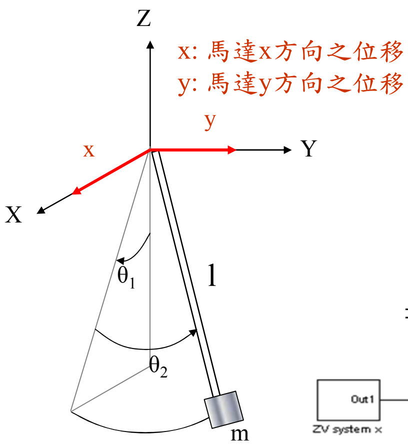


整體實驗系統架構

- 傳輸機構：YOKOGAWA雙軸線性馬達
- 感測器： BANNER長距離雷射位移感測器+反射面



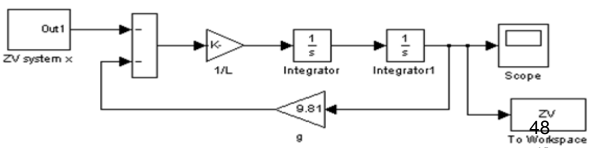
系統建模



$$\begin{cases} X = x + \ell \sin\theta_1 \cos\theta_2 \\ Y = y + \ell \sin\theta_2 \cos\theta_1 \\ Z = \ell \cos\theta_1 \cos\theta_2 \end{cases}$$

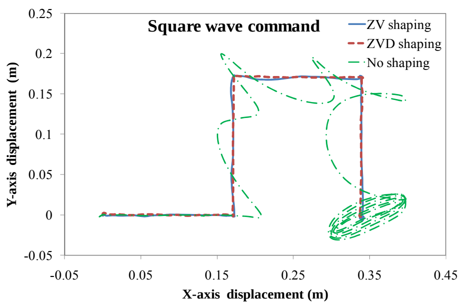
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}_i}\right) - \frac{\partial L}{\partial \theta_i} = 0 \qquad L = T - V$$

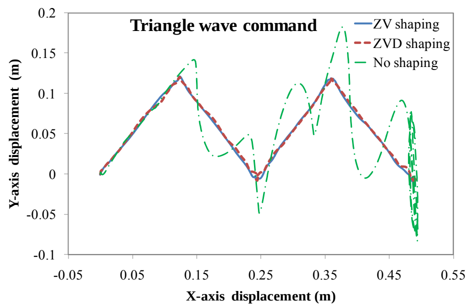
$$\Rightarrow \begin{cases} \ell \ddot{\theta}_1 + \ddot{x} + g\theta_1 = 0 \\ \ell \ddot{\theta}_2 + \ddot{y} + g\theta_2 = 0 \end{cases}$$



初步測試結果

- 馬達進給速度為10cm/s
- 由雷射位移感測器記錄其結果





- 輸入修正法能大幅降低單擺系統的擺動及殘餘振動

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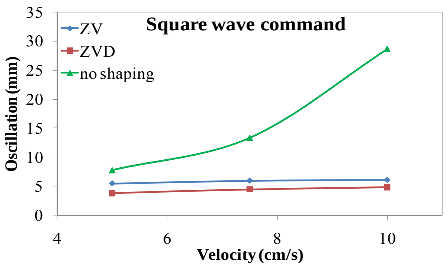
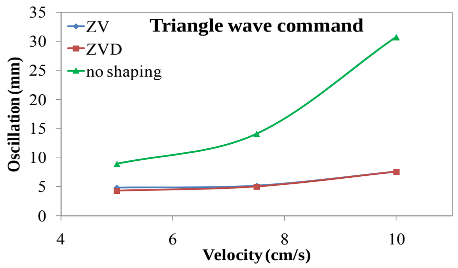
不同行進速度之減振效果比較

- 未加任何輸入修正法之振動量遠大於ZV法與ZVD法之振動量，且在行進速度變快時，振動量有明顯增大的趨勢。
  - 振幅約在8mm~30mm之間





- ZV法及ZVD法皆能保持一定程度的振動抑制效果
  - 振幅約在4mm~7.5mm之間

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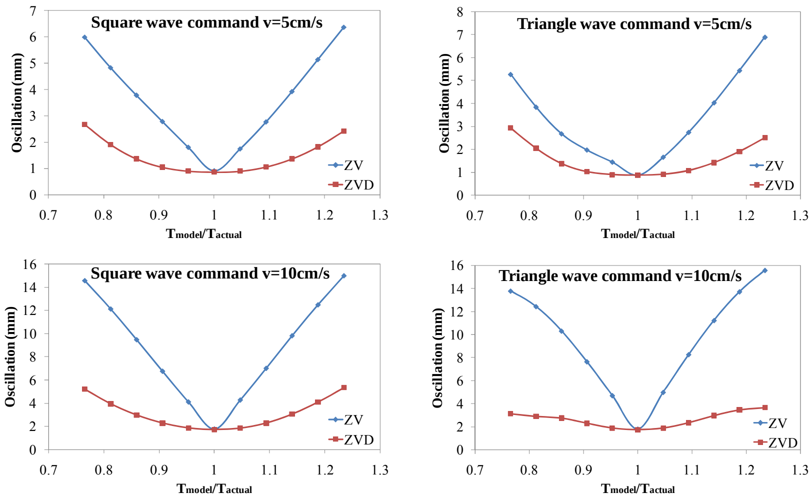
敏感度曲線



- ZV法所須的rising time較短
- ZVD法較ZV法具更高的強健性

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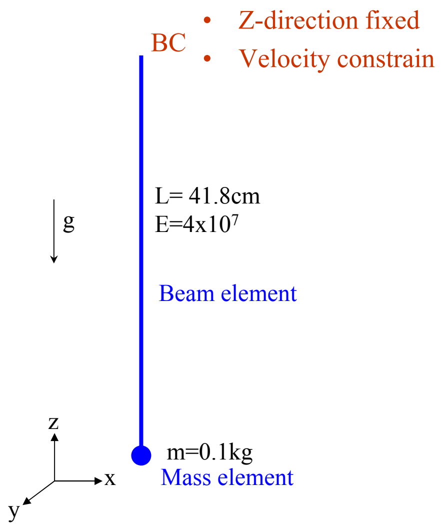
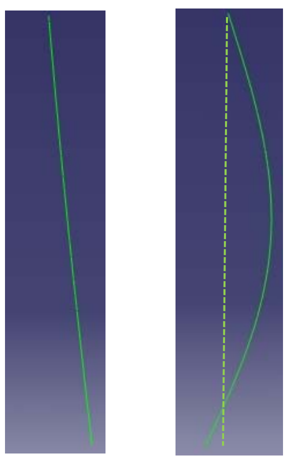
FEM simulation – Flexible beam

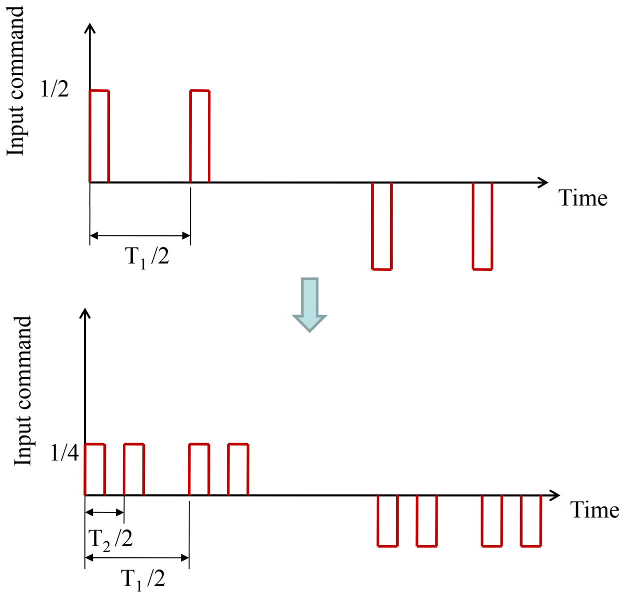




Mode 1&2
0.84957Hz

Mode 3&4
3.1779Hz

ZV-ZV shaping



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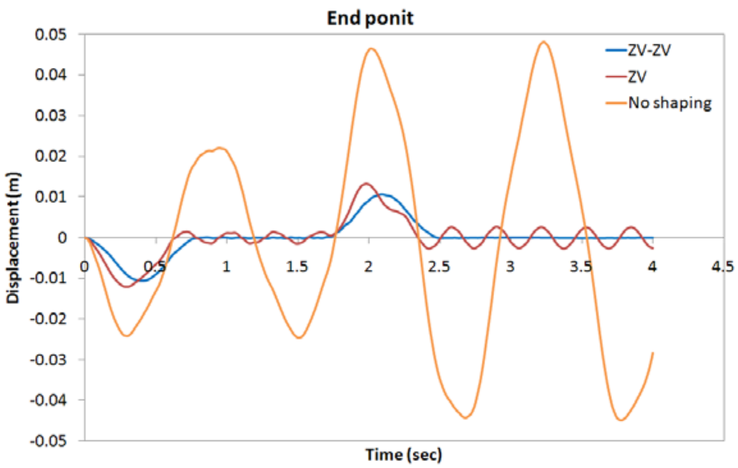
下端質點振動量



- ZV-ZV shaping 可將第二模態振動幾乎完全消除

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成大機械

Case Study V: 光碟機結構噪音量測

- Feb 2003 – Dec 2003
- Sponsored by 廣明光電
- Performed by 陳冠宇 (專題生, 台大機械所 2006畢業)

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System Dynamics Lab. For Mechatornics and Microsystems

CD-DOM (top view)

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Experimental setup (front view)

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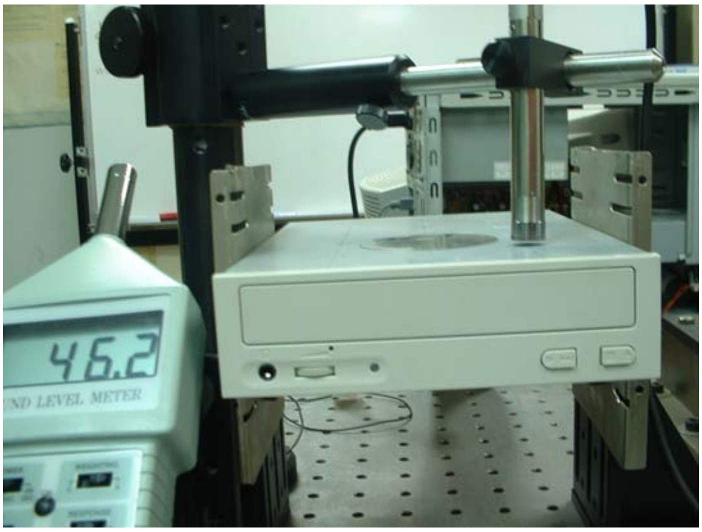
Experimental setup (front view)



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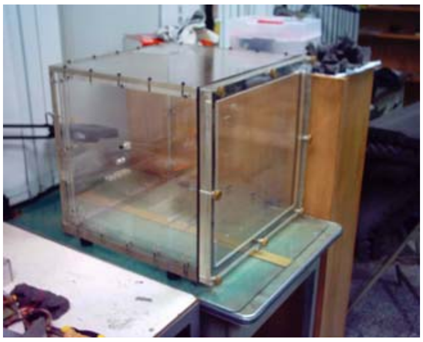
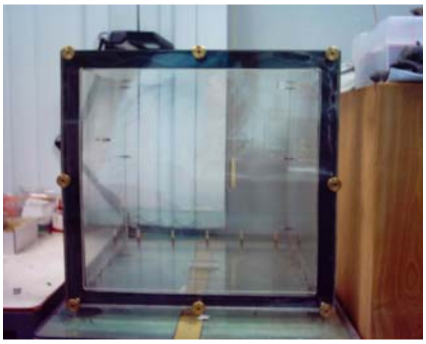
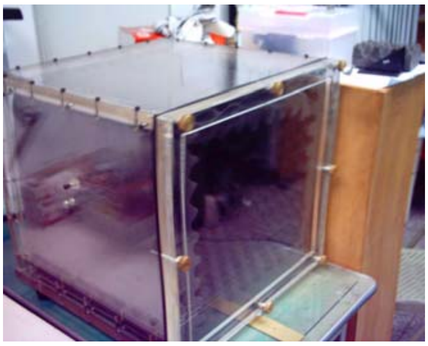
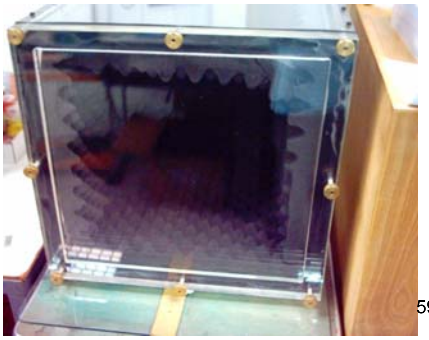

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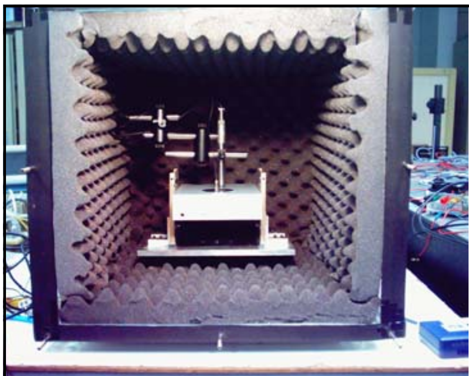
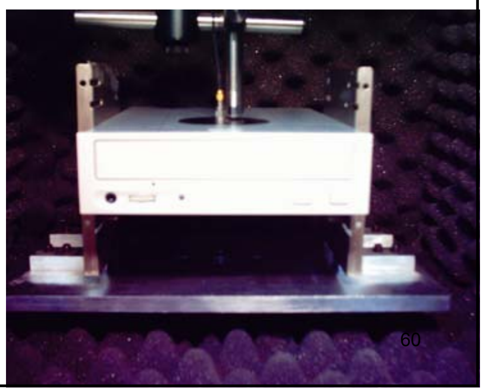


實驗設備



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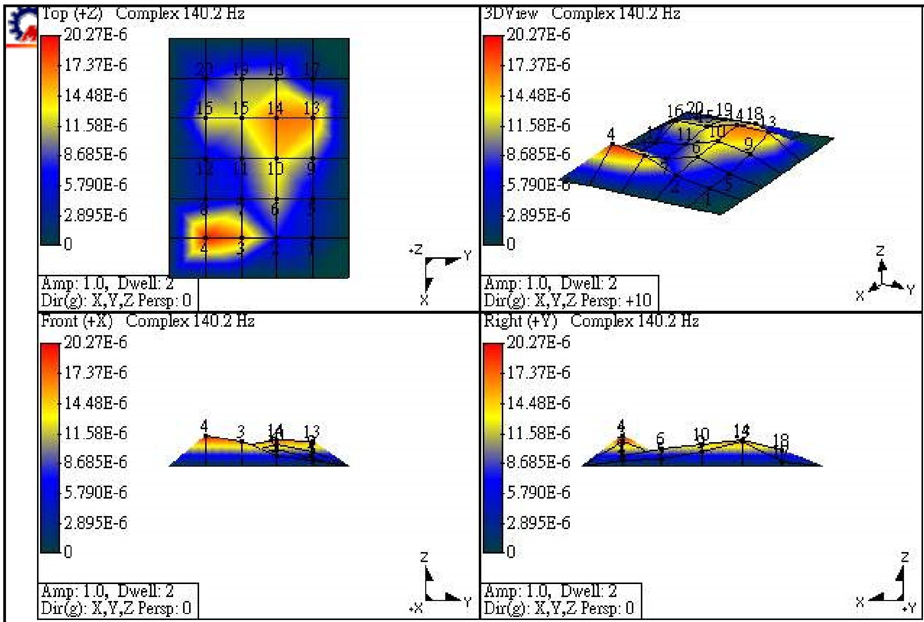

加速規量測偏振片9000RPM

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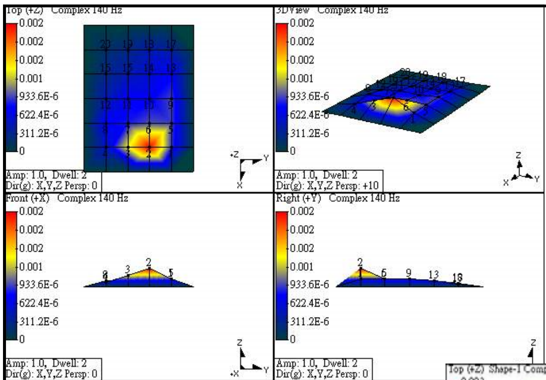
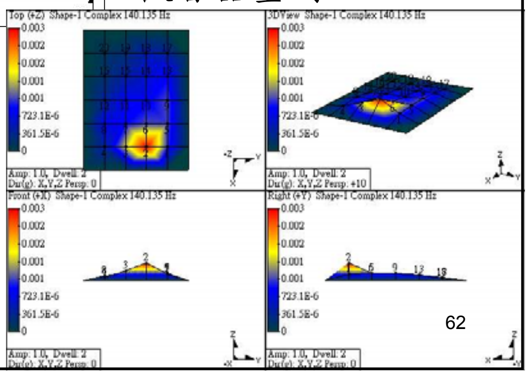
System Dynamics Lab. For Mechatornics and Microsystems



微音器量測 140Hz

微音器量測偏振片

9000RPM



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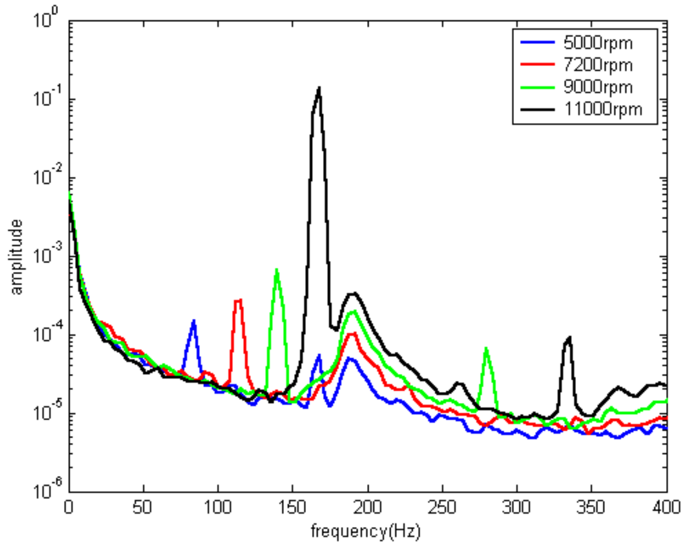
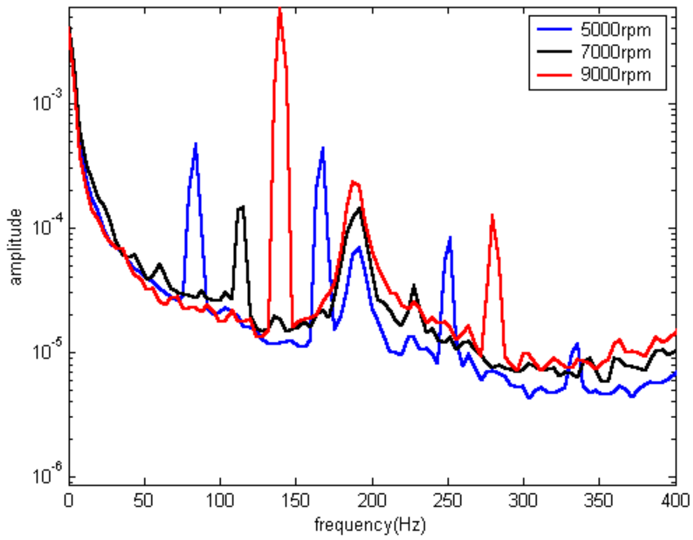
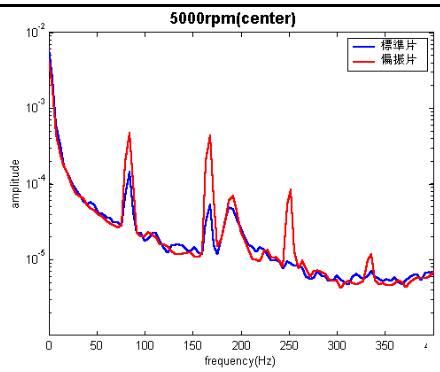


加速規量測 標準片

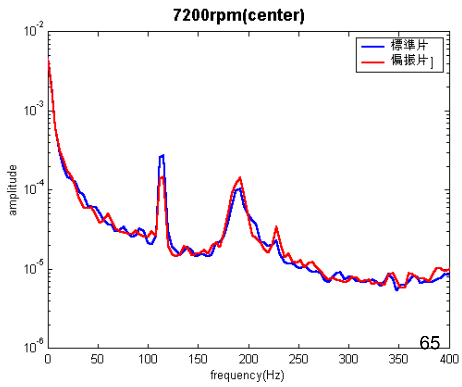


加速規量測 偏振片



加速規量測

加速規量測



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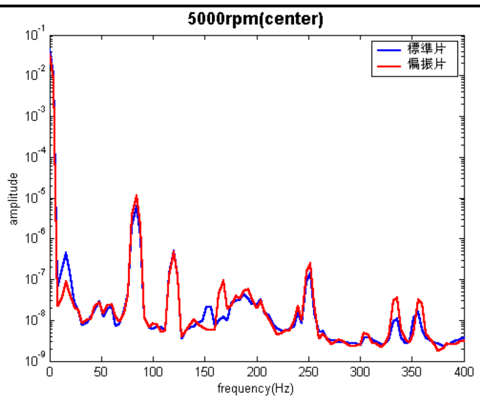
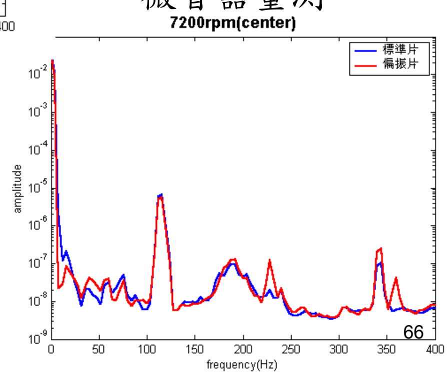


微音器量測

微音器量測



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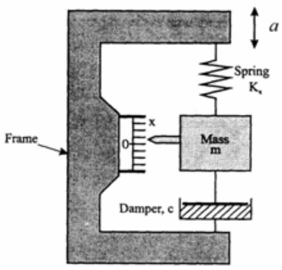
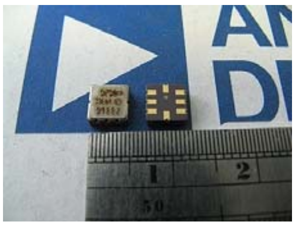
Case Study VI (慣性導航問題)

- July 2006 –
- Sponsored by ITRI and NSC
- Performed by 林韋澄 (專題生, 機研所研究生, 2009畢)

Accelerometer

- Detect acceleration
- Acceleration -> velocity ->displacement





MEMS Accelerometer

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MEMS Accelerometer

- for positioning
  - Small size
  - Low cost
  - Low power consume
  - Very portable
  - Self-contained device
    - Need no external electromagnetic signals
  - Signal drift problem

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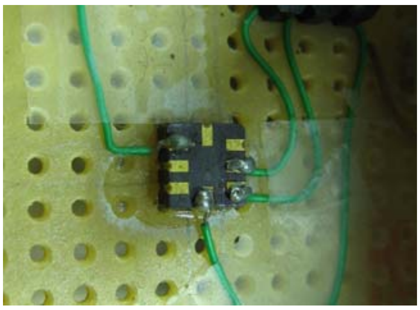
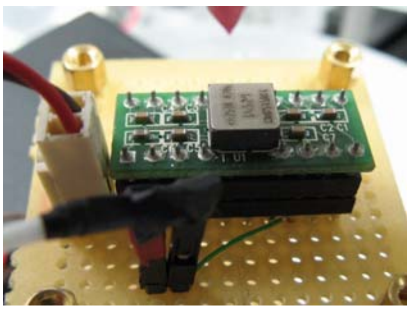
INS Hardware



2-axis Accelerometer



gyroscope

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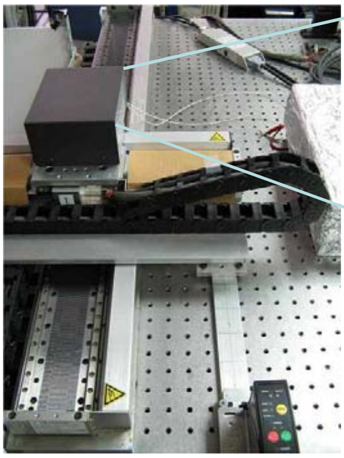
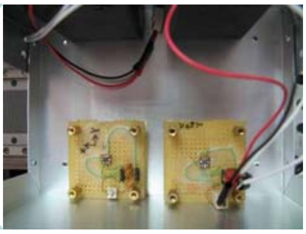
INS Hardware

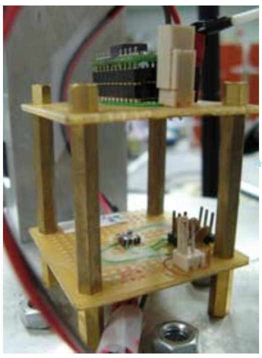


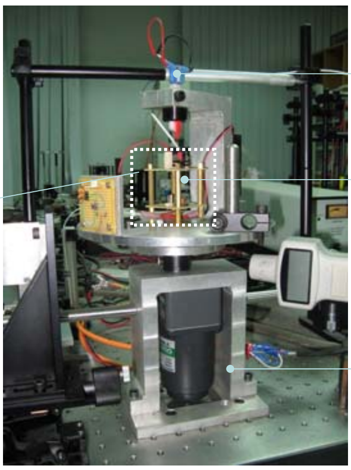


Accelerometer

Laser for position detect

INS Hardware





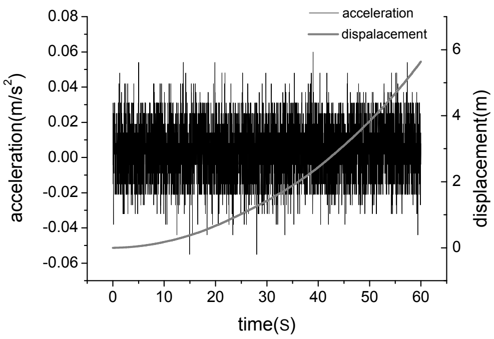
Rotational connector

Acc.meter & Gyro

Motor

Signal drift problem

- Accelerometer at static state 1 min
- Displacement shows almost 6m
  - Signal drifting error



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anti signal drifting

- Method
  - Re-calibration
  - Fuzzy logic filter
  - Velocity zero update

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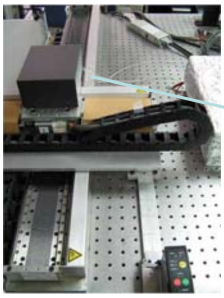
Experiment

- Accelerometer on linear motor
  - 40cm back and forth

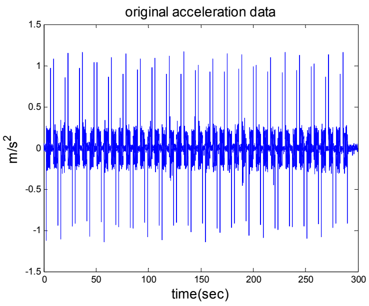


Accelerometer

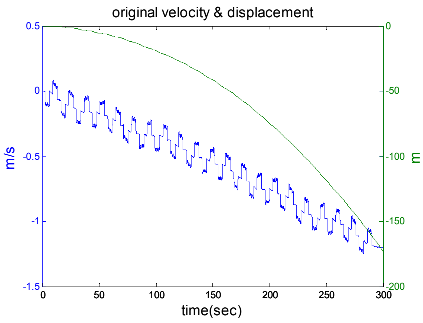
75 75

Experiment result

- Original data



Acceleration signal



Velocity & displacement

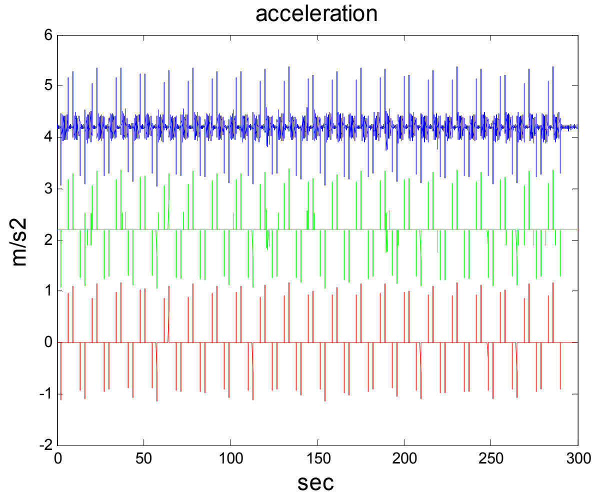
76 76

Experiment result (acceleration)

recalibration

Fuzzy logic I
Remove noise
(Noise range : 0.3 set zero)

Fuzzy logic II
remove peak noise



77
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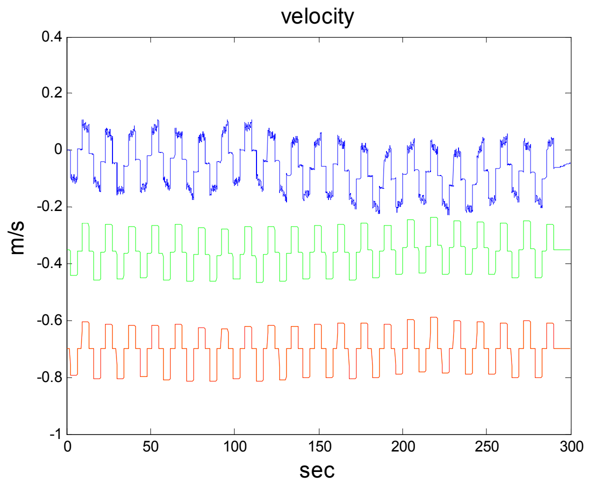
Experiment result (velocity)

1: only recalibration

2: 1+fuzzy logic

3: 2+ ZUP



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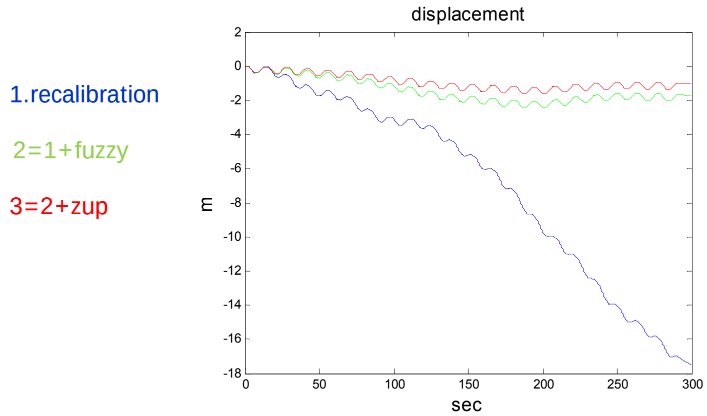
Experiment result (displacement)



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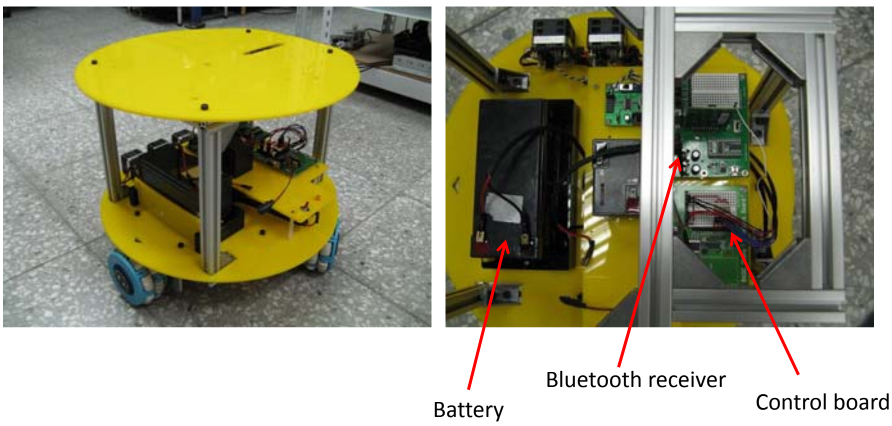
INS Hardware



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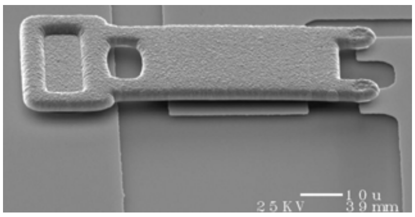
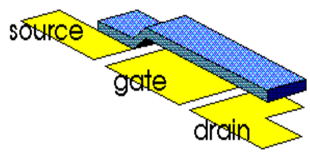
Case Study VII (Longevity of Contact Switches)

- 2004 – 2008
- Sponsored by NSC
- Perfomed by 歐廣順 (機械所博士 2008)

Switches

- RF contact switch
  - 藉由靜電制動而使得機械結構產生 Pull-In 現象因而控制信號傳輸之開放或是閉合
  - 無線通訊，振盪電路，以及信號處理



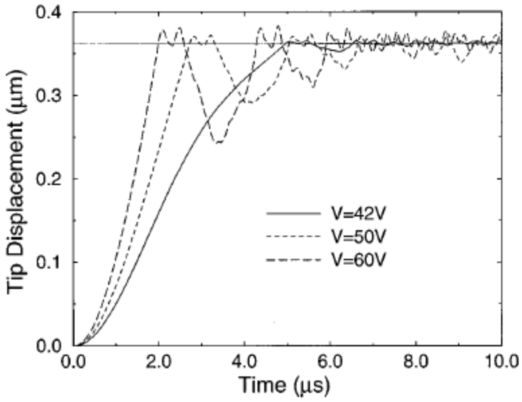


[Zavracky et. al., 1997]

RF contact switch作動與設計需求

- 作動反應
  - 需經歷數次撞擊
- 結構動態設計需求
  - 作動反應快
    - 較高的驅動電壓
  - 安定時間短
  - 可靠度與壽命長

典型RF contact switch 作動反應

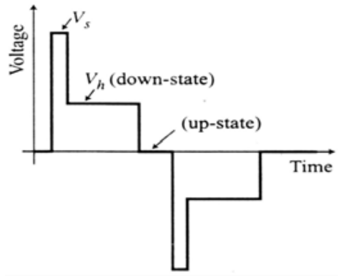


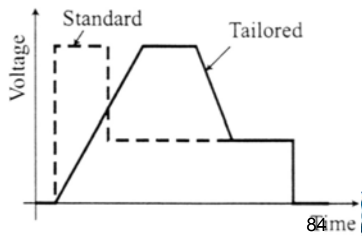
[McCarthy et. al., 2002]

導入控制的方法應可達到設計需求

輸入波形與元件壽命之關係

- 實驗上證實藉由修正的輸入波形，可大幅提昇 MEMS 可變電容器壽命[Rebeiz,2003]
  - 尚無相關理論
- Rebeiz 提出認為有助於提昇 RF contact switch壽命與可靠度之修正輸入波形[Rebeiz,2003]
  - 尚無實驗之證實





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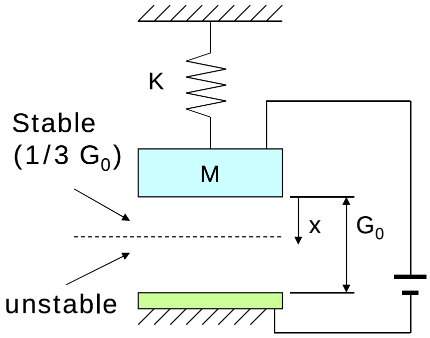
輸入修正波形之運用

- 非線性輸入修正波形 [尹瑞豐,2004]
  - 以能量守衡為出發
  - 在穩定區內的快速定位有良好的效果
  - 不能適用RF contact switch
    - 主要作動在非穩定區內



RF switch 的作動可視為一種定位

應可依輸入波形的精神出發，發展相關的輸入波形

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研究目標

- 發展適合 RF contact switch 使用之輸入修正波形
  - 能有效的減少contact force
  - 藉由減少contact force來增加RF switch 的壽命
- 改善RF switch 的性能
  - 減少每次作動所需的碰撞次數

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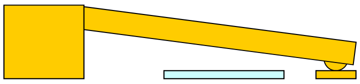
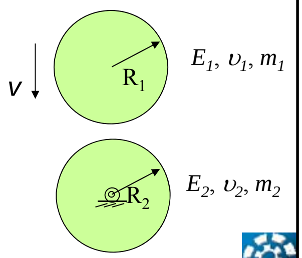
接觸力分析

- 當接觸瞬間，接觸力= 靜電力 - 彈簧力+撞擊力



- Hertz dynamic contact theory

$$p_0 = \frac{3}{2\pi}\left(\frac{4E^*}{3R^{3/4}}\right)^{4/5}\left(\frac{5}{4}Mv^2\right)^{1/5}$$



$$\frac{1}{E^*} = \frac{1-\upsilon_1^2}{E_1} + \frac{1-\upsilon_2^2}{E_2} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \quad \frac{1}{M} = \frac{1}{m_1} + \frac{1}{m_2}$$

當 v → 0 => 撞擊力→ 0

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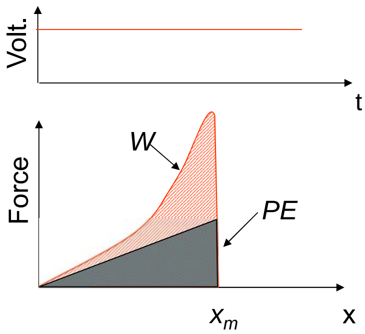
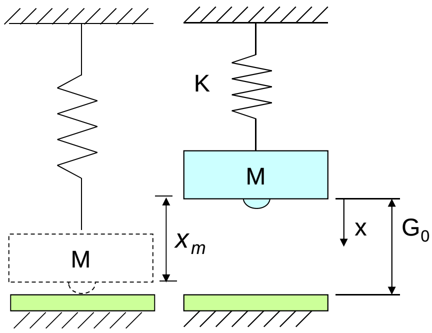
輸入波形理論推導(I)

- 能量守衡

$$KE + PE = W$$

v → 0 => KE → 0 => PE = W





尋找中繼點停止電壓施加

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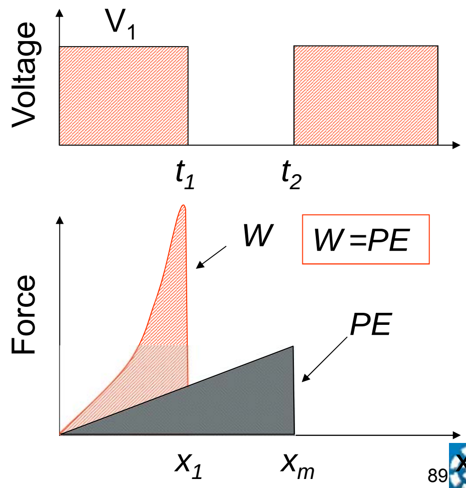
輸入波形理論推導(II)

$$\frac{1}{2}kx^2 = \int_0^x \frac{H}{(G_0 - x)^2}dx$$

$$H = \frac{A\varepsilon_0}{2}V^2$$

中繼點位置

$$x_1 = \frac{G_0^2 k x_m^2}{2H_1 + G_0 k x_m^2}$$



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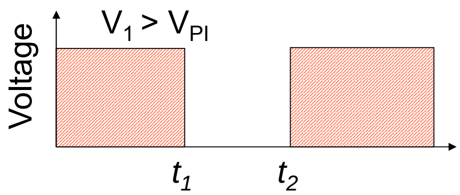
輸入波形理論推導(III)

$$v = \frac{dx}{dt} = \sqrt{\frac{2}{m}(W - PE)}$$

$$T = \int dt = \int (\frac{2}{m}(W - PE))^{-\frac{1}{2}}dx$$

$$t_1 = \int_0^{x_1} (\frac{2}{m}(W - PE))^{-\frac{1}{2}}dx$$

$$t_2 = t_1 + \int_{x_1}^{x_m} (\frac{2}{m}(W\Big|_{\substack{x=x_1\\H=H_1}} - PE))^{-\frac{1}{2}}dx$$



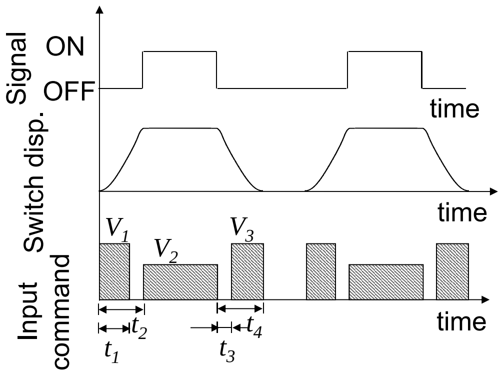
訊號切換與輸入波形的對應

$$t_1 = \int_0^{x_1} \left(\frac{2}{m}(W - PE)\right)^{-\frac{1}{2}} dx$$

$$t_2 = t_1 + \int_{x_1}^{x_m} \left(\frac{2}{m}\left(W\Big|_{\substack{x=x_1 \\ H=H_1}} - PE\right)\right)^{-\frac{1}{2}} dx$$

$$t_3 = t_2 - t_1$$

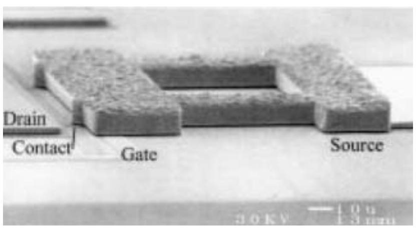
$$t_4 = t_2$$

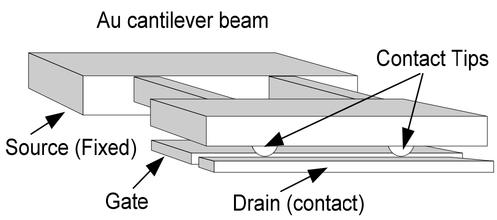


釋放與接觸所需的輸入修正波型參數相同

範例介紹

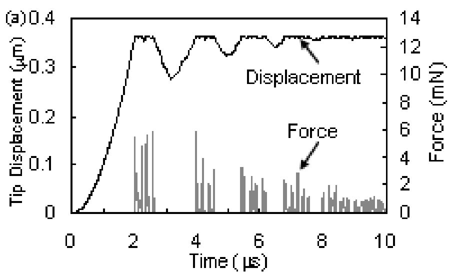
- McCarthy RF MEMS Switch [*J. MEMS*, 2002]



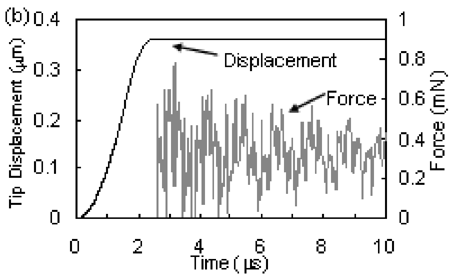


模擬結果

Step input



Shaping input



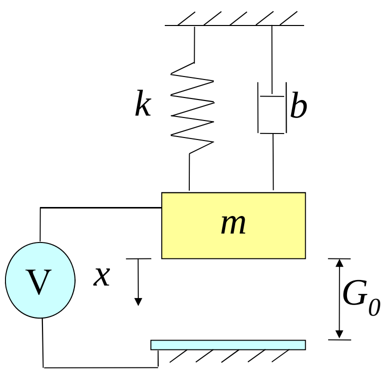
Max. contact force ~6mN

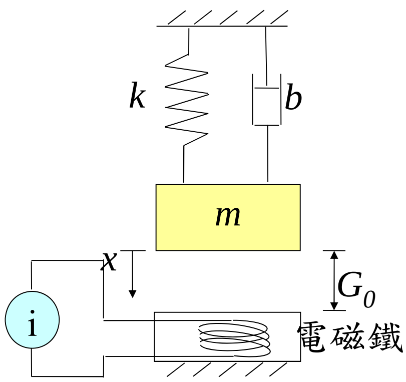
Max. contact force ~0.8mN

約減少7.5倍的contact force

安定時間縮短

等效系統實驗驗證





$$m\ddot{x}+b\dot{x}+kx=\frac{\varepsilon_0 A}{2}\left(\frac{V}{G_0-x}\right)^2$$

$$m\ddot{x}+b\dot{x}+kx=C_{EM}\left(\frac{i}{G_0-x}\right)^2$$

用電磁力等效靜電力進行實驗

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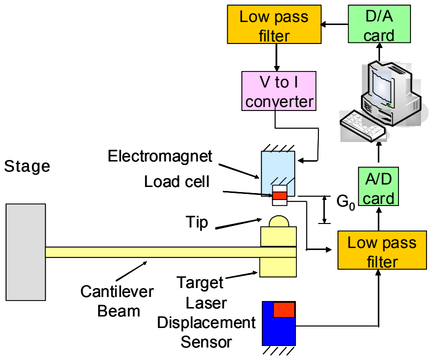
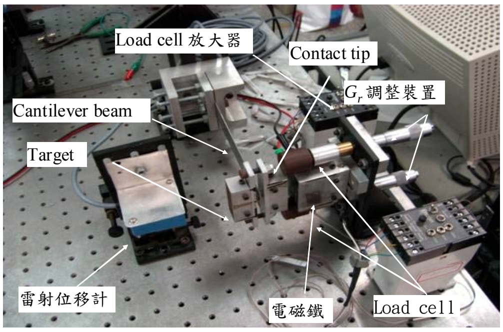
實驗架設示意





可方便的獲得Contact force 與動態反應
為較佳的輸入波形的發展與驗證平台

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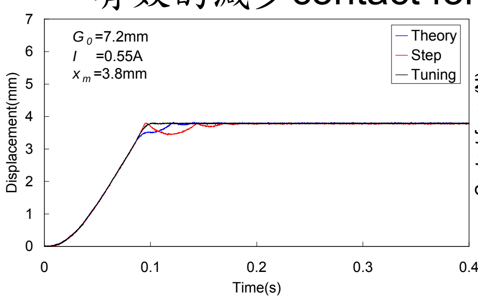
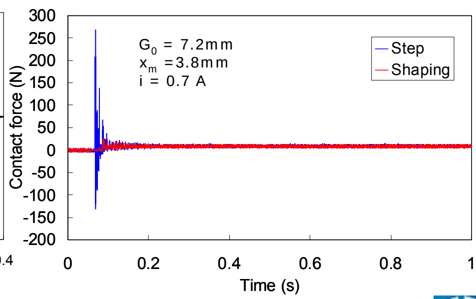
實驗結果(I)

- 理論部份阻尼影響未納入分析考量內
  - 藉由 Online tuning 補償
- 縮減安定時間與撞擊次數
- 有效的減少contact force





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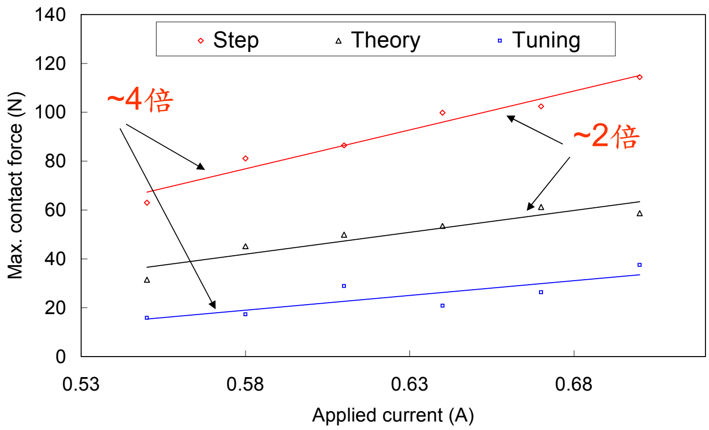
實驗結果(II)



有效的減少contact force

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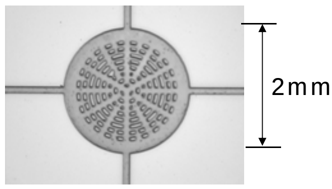
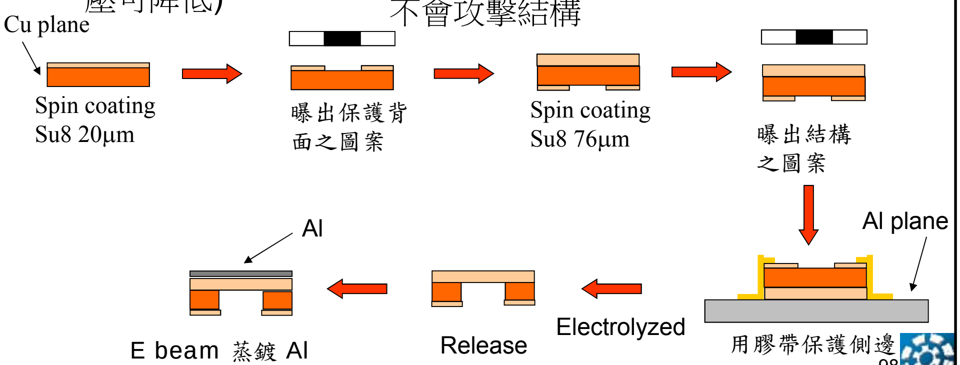
Specimen fabrication

- 選用光阻當結構
  - 製程較為簡易
  - 製程成本較低
  - 剛性低 (驅動電壓可降低)
- 選用Cu 當基板
  - 配合電解可快速釋放結構
  - 使用的電解液不會攻擊結構





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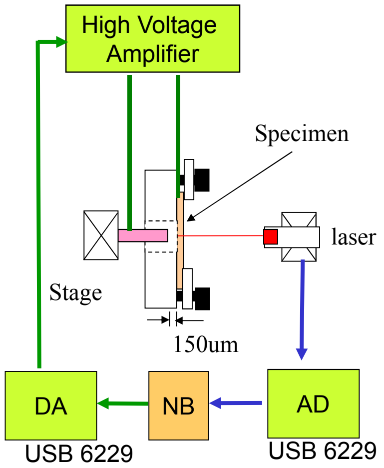
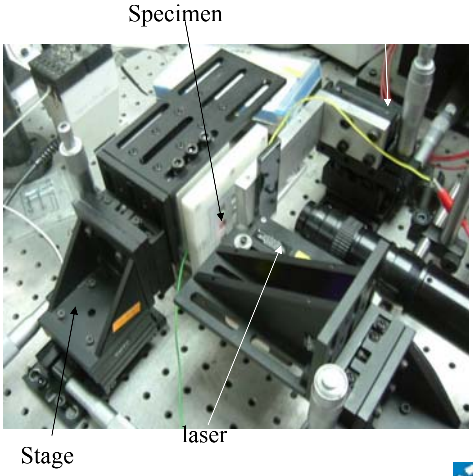
實驗架設





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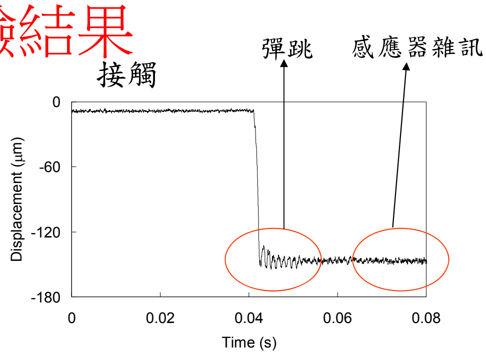
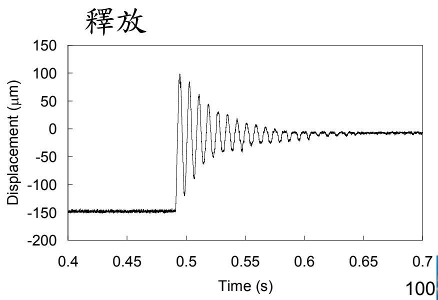
實驗結果

- 接觸時
  - 結構有彈跳的形況發生
  - 但感測器精度不夠不易觀察
- 釋放時
  - 可明顯觀察到振動的情形

由理論推導，釋放與接觸所需的輸入修正波型參數相同

=>以釋放的過程作為驗證





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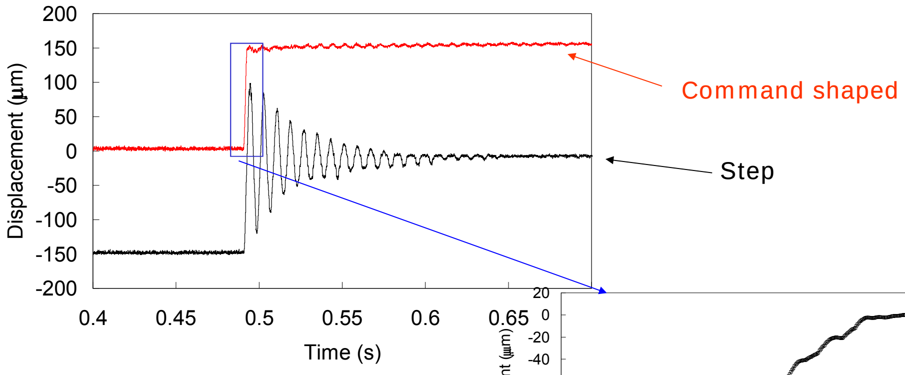
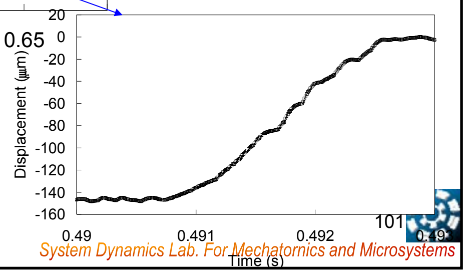
輸入修正之結果





可有效抑制結構釋放後之振動

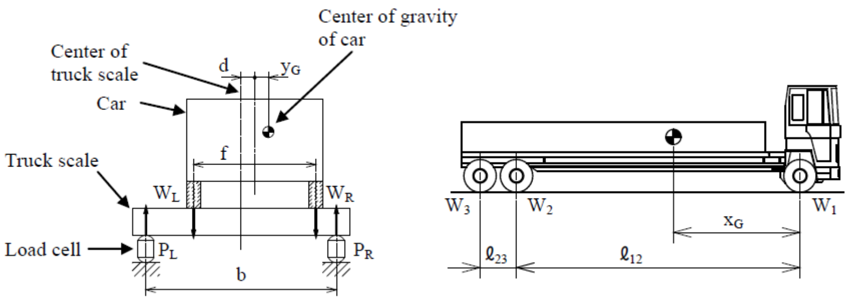
Case VIII Some results from SICE 2011

- Center of gravity measurement w/ Truck scale
  - Y. Mikata et al, SICE 2011

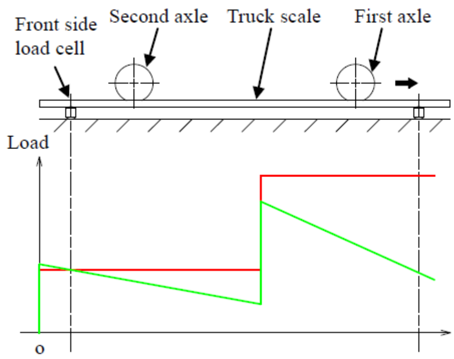
Center of Gravity Measurement

- Truck accidents
  - Inadequate position of CG after loading
  - How to find CG?
- Truck scale
  - Originally, peak only the total mass
  - Now, try to identify the CG of truck after loading

Schematic Plots



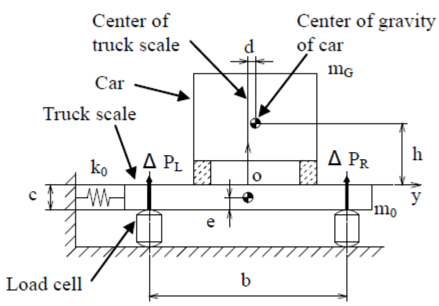
Length Direction



$$x_G = \frac{\ell_{12} W_2 + (\ell_{12} + \ell_{23}) W_3}{W_1 + W_2 + W_3}$$

$$y_G = \frac{f}{2} \times \frac{W_R - W_L}{W_R + W_L}$$

Vertical Direction



$$h = \frac{1}{m_0 \ddot{y}_0 + k_0 y_0} \left\{ m_0 e \ddot{y}_0 + \frac{m_G \left(\frac{b}{2} - d \right) + m_0 \frac{b}{2}}{m_0 + m_G} \Delta P - b \Delta P_R \right\} - c \qquad (5)$$

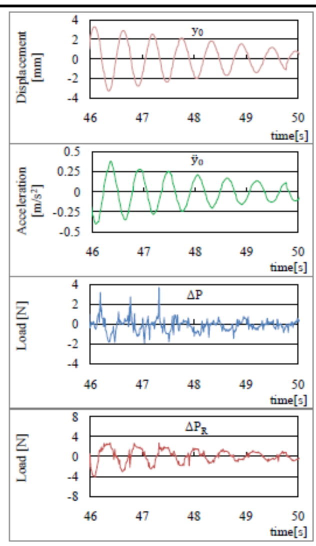
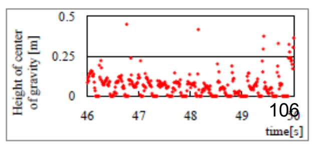


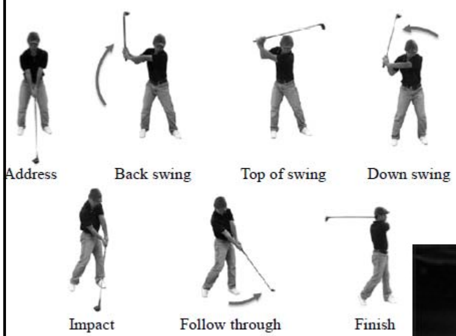
Fig.6 Waveform of each signal about pattern 1

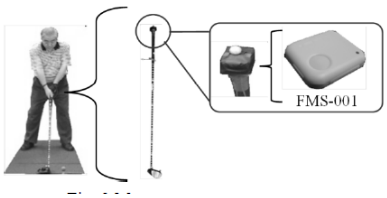


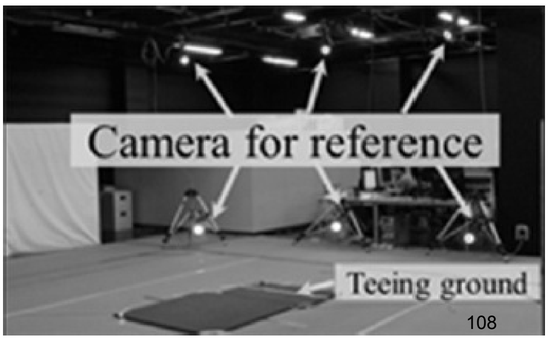
Motion Measurements

- Golf swing
  - H. Negoro et al, Hosei Univ., SICE 2011
- Bowing swing
  - K. Kimua et al, Hosei Univ., SICE 2011

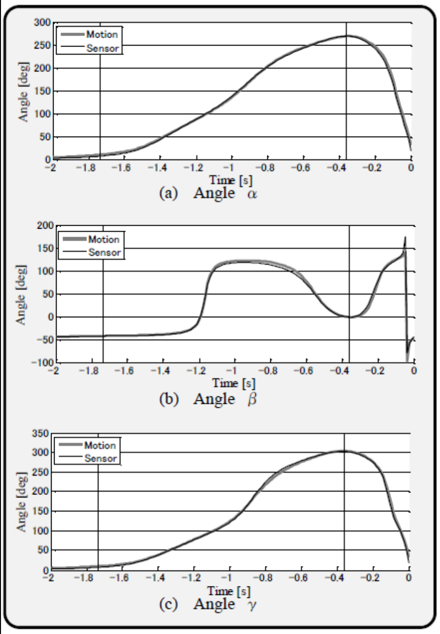
Golf Swing



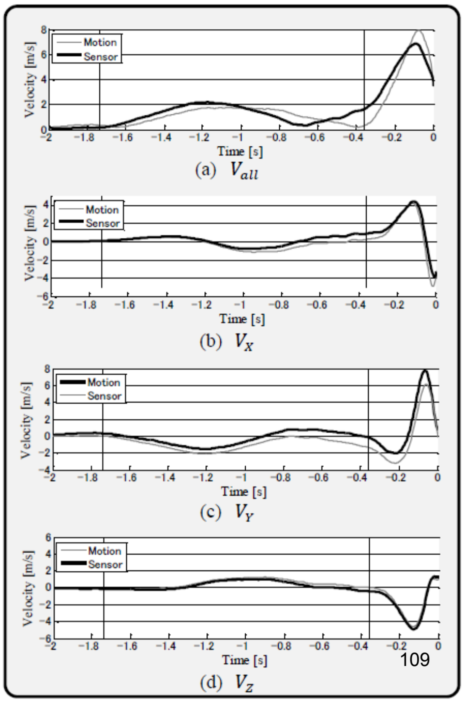




Results



(a) Angle α
(b) Angle β
(c) Angle γ



(a) V_{all}
(b) V_X
(c) V_Y
(d) V_Z

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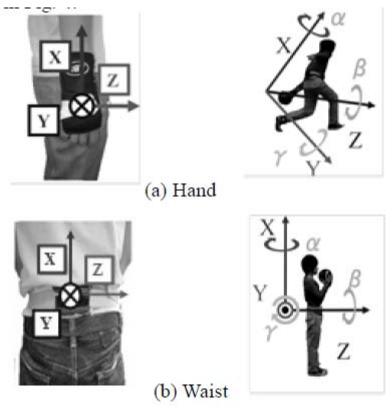
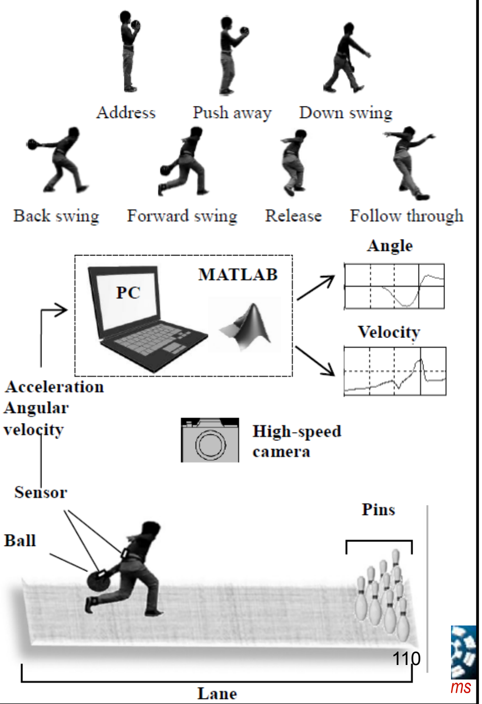
Bowling Swing



(a) Hand
(b) Waist



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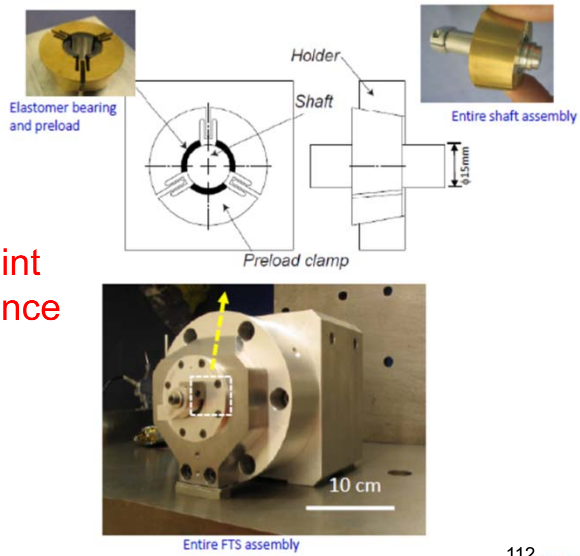
Case IX: Elastomer Testing System

- Mr. A. Barton (MIT ME, now at XEROX)
- Prof. D. Trumper (MIT ME)
- Prof. K-S Chen

- A system for characterization the frequency-dependent stiffness of elastomer is designed
  - For rubber bearing design
  - For precision instrumentations

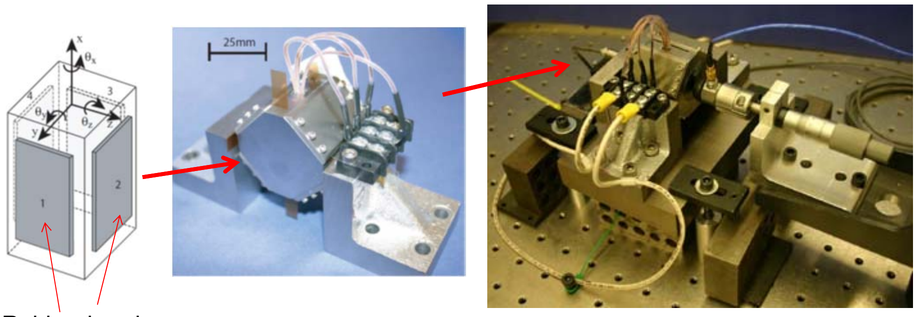
Example: FTS Servo

Elastomer bearings provide radial constraint while provide compliance for rotating motion



[Barton, 2005]

Example: Nano-positioner

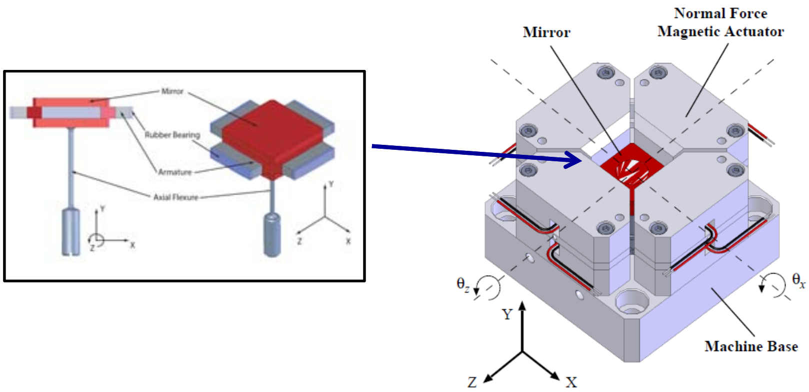


Rubber bearings

Elastomers provide compliance in x-direction and constraints for the rest five degrees of freedoms

[Cuff, 2006]

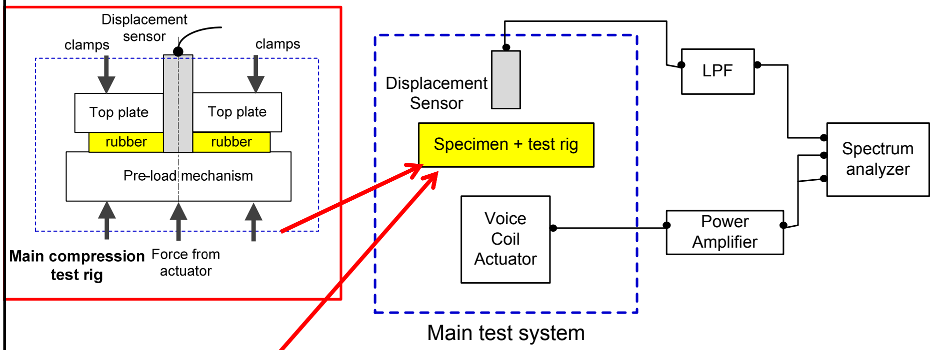
Example: Fast Steering Mirrors

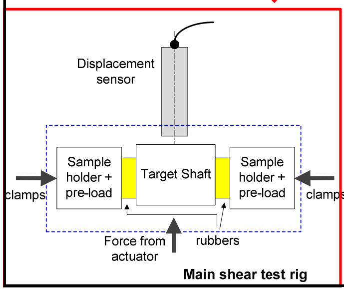


Rubber bearing provides compliances for θ_x and θ_z motion and constrains the rest of DOFs

[Kulk, 2007]

Functional Diagram





Major sub-components:

Specimen and holders: compression / shear

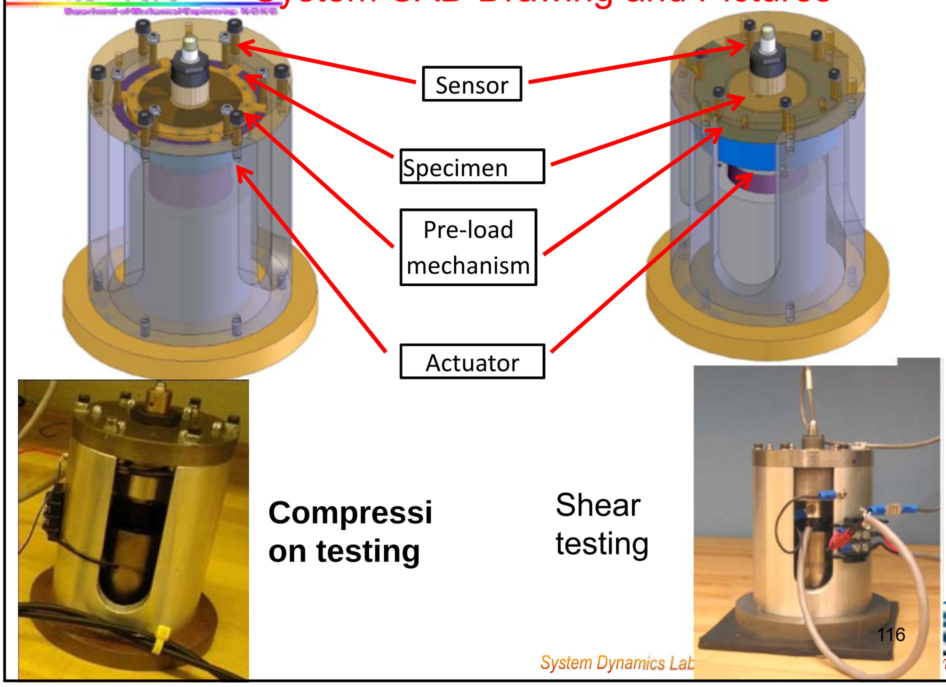
Actuator: voice coil

Sensor: Capacitive probes

Processing: Differential amplifier + Spectrum analyzer

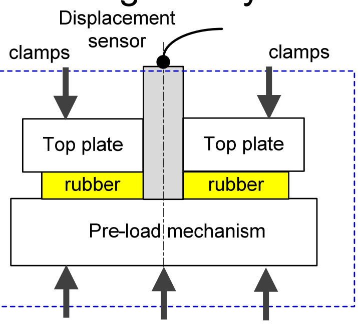
Modular design approach !!

System CAD Drawing and Pictures



Compression Rig

- Perform rubber compression test
  - Essentially a sample holder and a connecter between actuating and sensing sub-systems

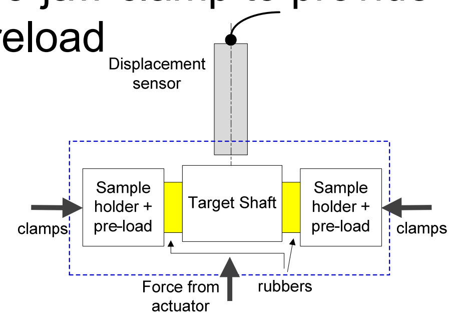


Main compression test rig

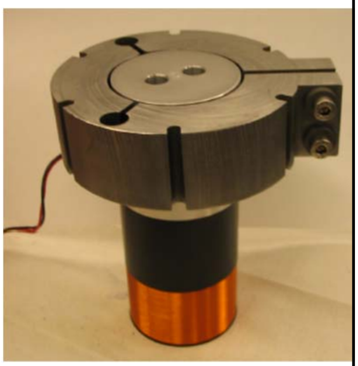
Compression rig assembly

Shear Test Rig

- Perform shear testing of sheet rubber
- A target shaft to provide shear loading
- A 3-jaw clamp to provide preload



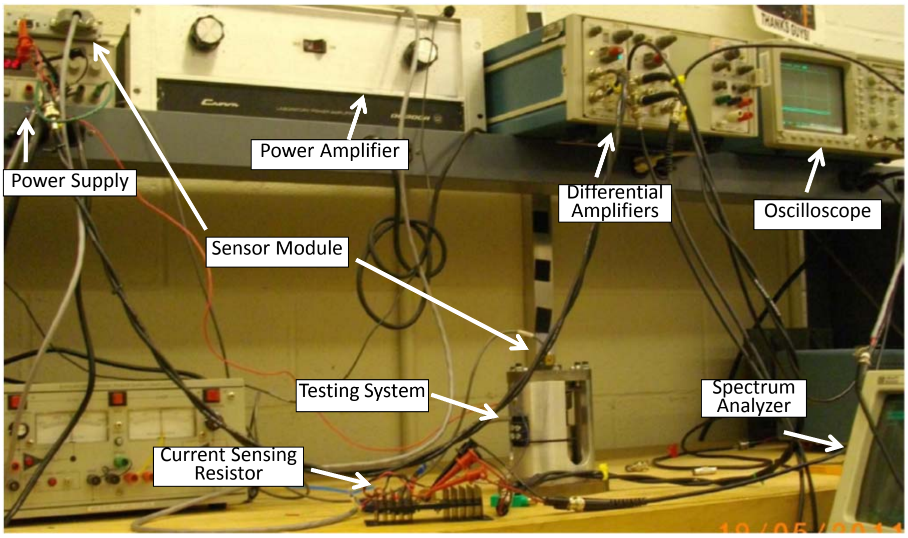
Main shear test rig



Shear test rig assembly

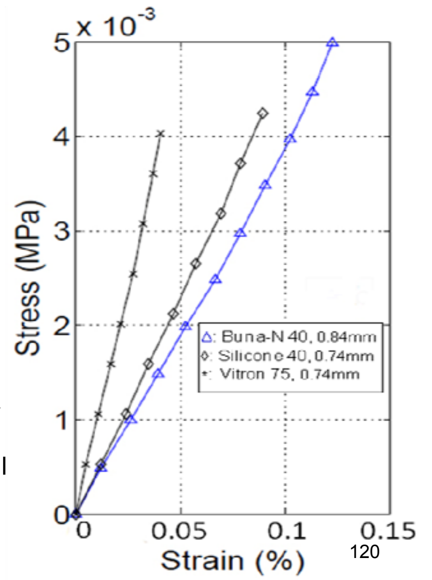
Target shaft & specimens

Overall Test System Setup

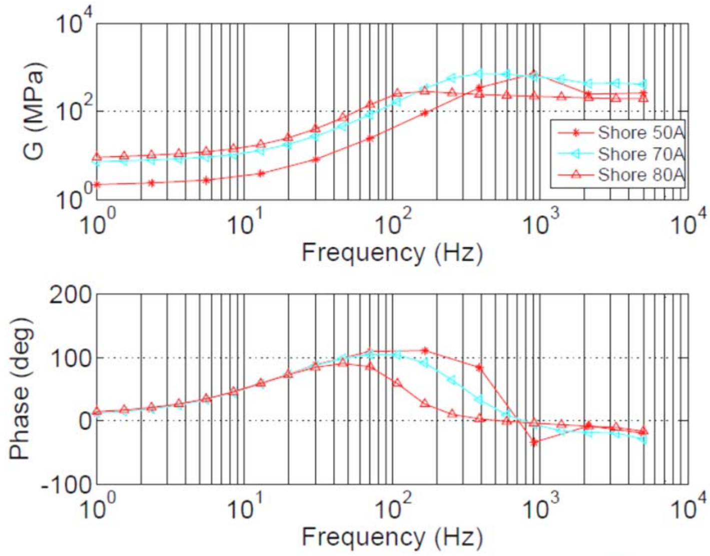


Compression Test (I)
Static Compression Modulus

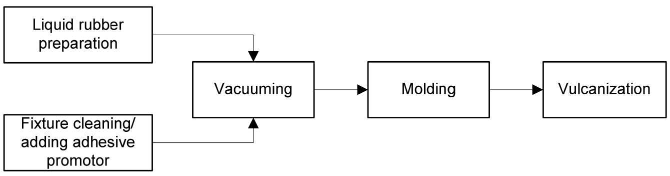
- Tests are in small stress/strain region
- Stress/strain curves essentially linear
- Compression modulus = slope of the stress/strain curves
- At larger strain level, the curves become nonlinear
  - Agrees with general rubber bearing characteristics

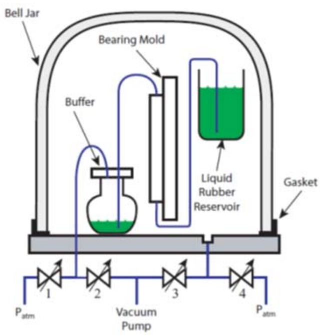


Shear Test: Complex Shear Modulus

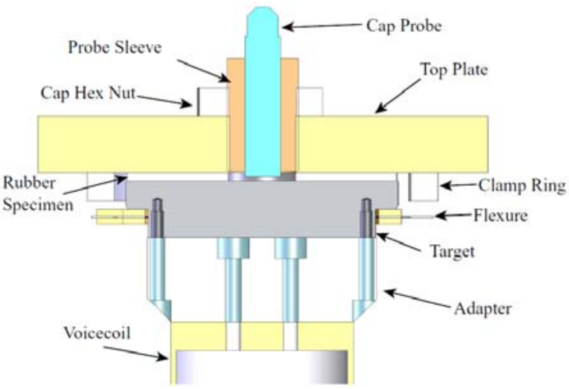


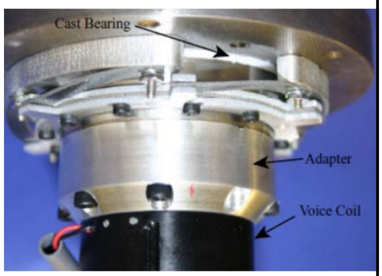
Casting Process





Casting Results





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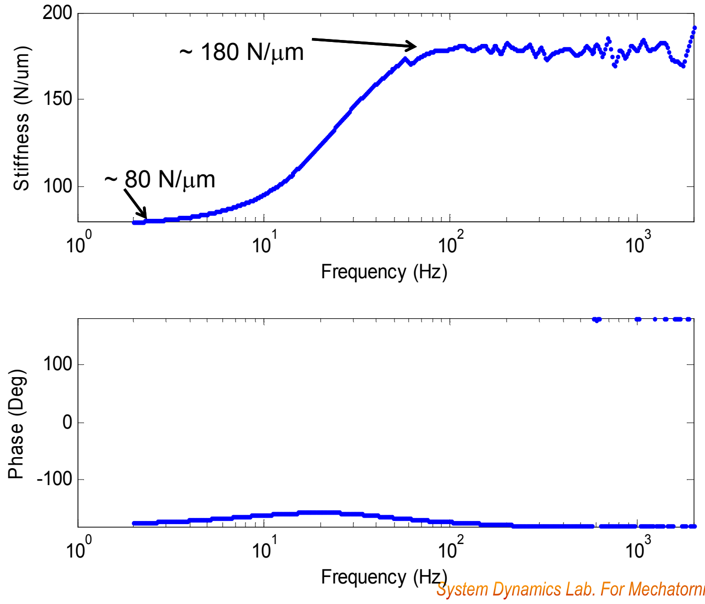
Casting Rubber Test: Complex Compression Modulus



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Case X:
National Cheng Kung University School Bell Research Project

T. Chia and Y.-S. You

in associate with

Prof. C. H. Chue, Prof. T.-S. Yang
Prof. H. T. Lee, Prof. K.-S. Chen
Prof. T.-C. Chiu

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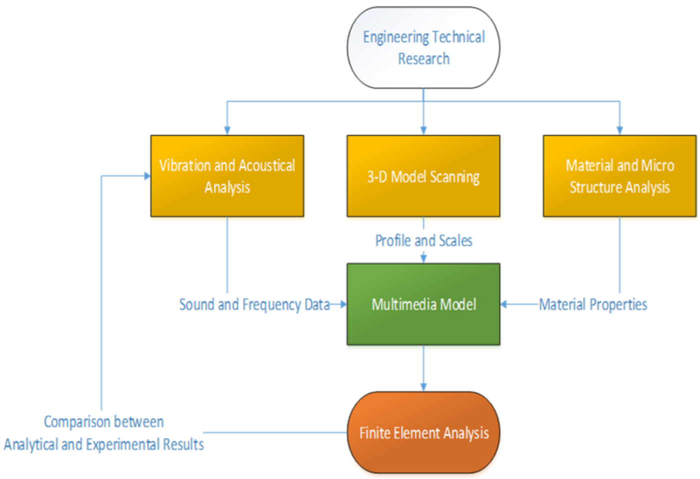
Project Structure



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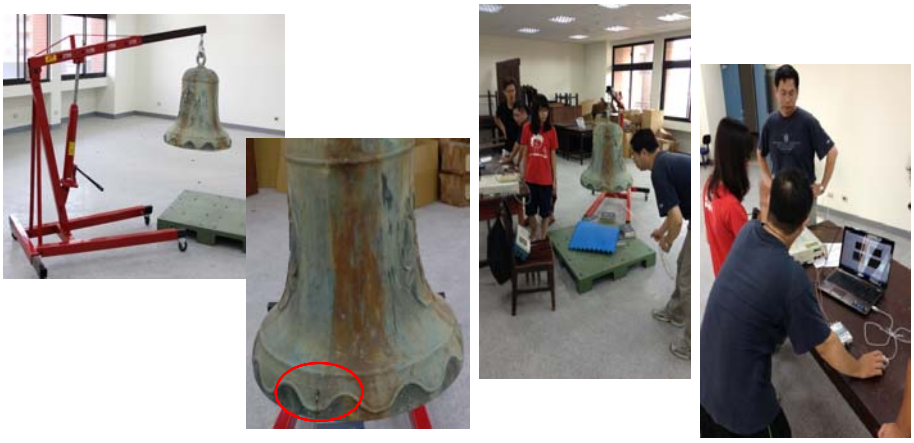
Vibration and Acoustical Analysis



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無響室實驗

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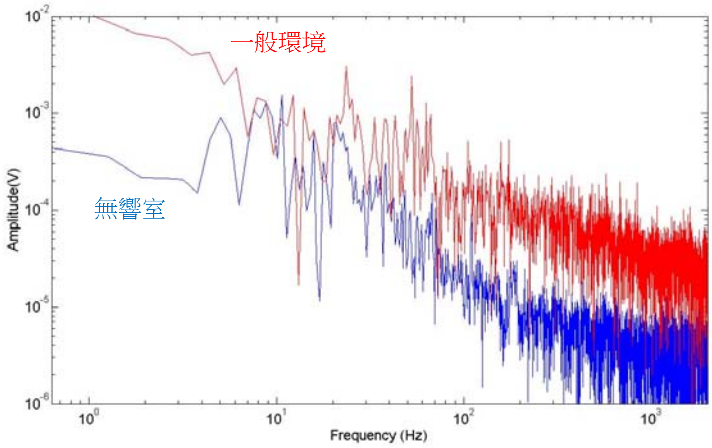
無響室 Background Noise



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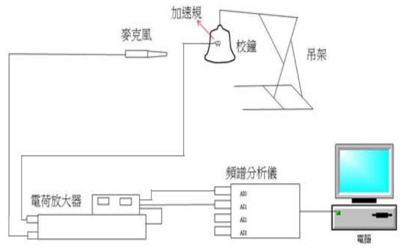
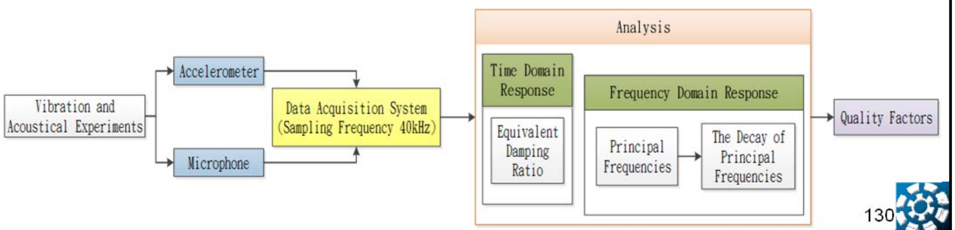
Experiment Process

1. Using microphone and accelerometer to record and measure the bell's sound and vibration characteristics.
2. Using FFT to get the frequency spectrum by using spectrum analyzer or computer programs (LabView, Matlab).





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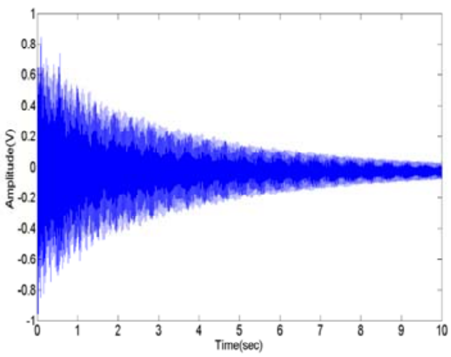
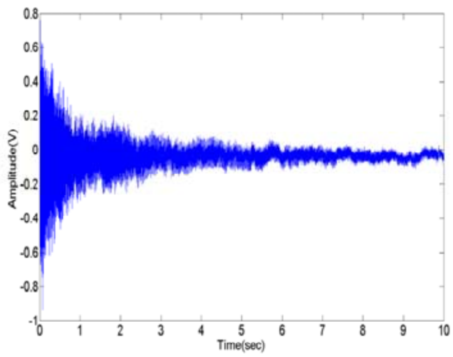
Accelerometer position

Time Domain Response

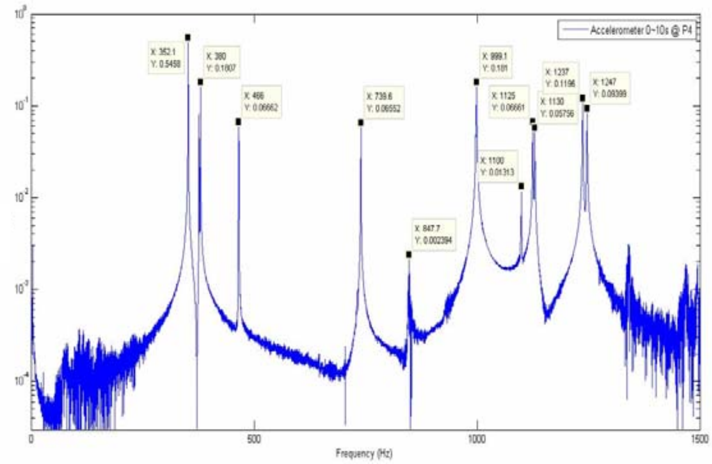




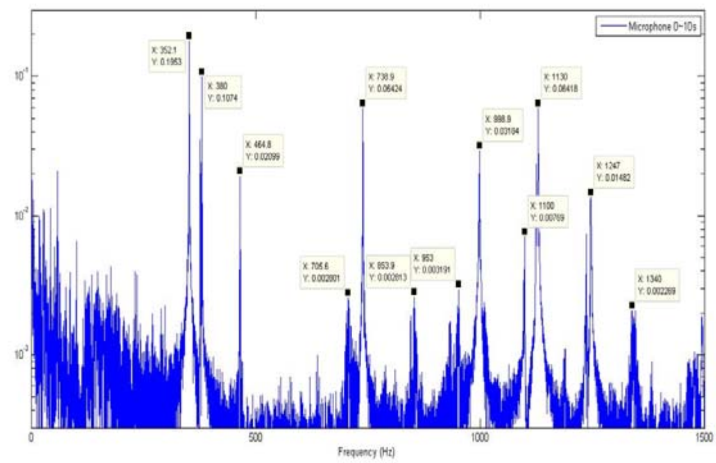
- Accelerometer Time Domain Response

Microphone Time Domain Response

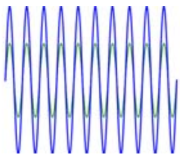
Accelerometer Spectrum

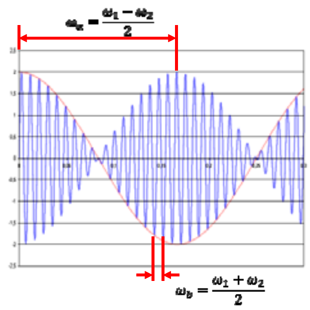


Microphone Spectrum



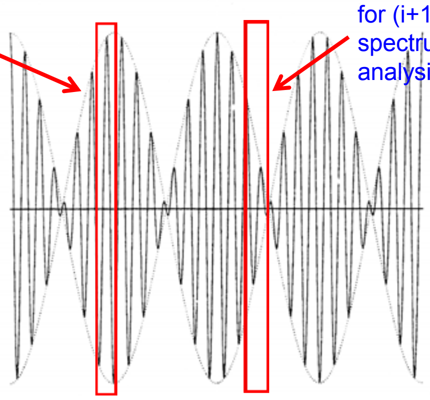
Beating Phenomenon





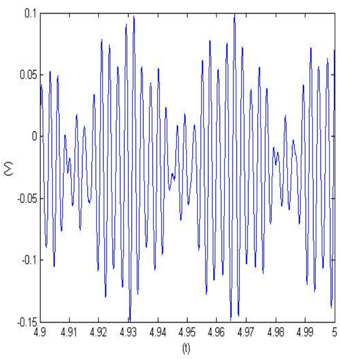
Signal used for ith spectrum analysis

Signal used for (i+1)th spectrum analysis

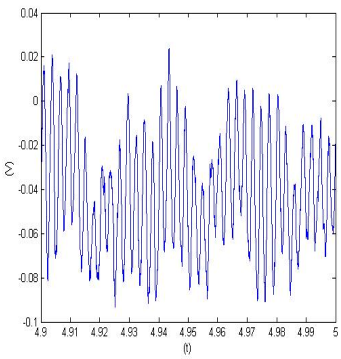


Two sinusoidal signals with close frequencies → beating → results in signal strength variation

Warble of Bell



Accelerometer

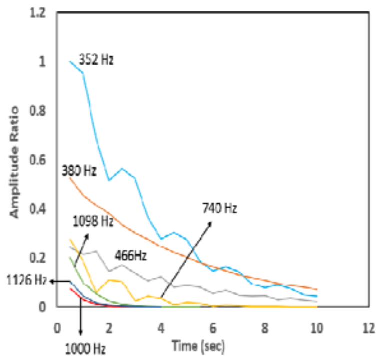


Microphone

Pure Partials

Warble

Decay of Spectrum Strength of Specified Frequencies



Accelerom
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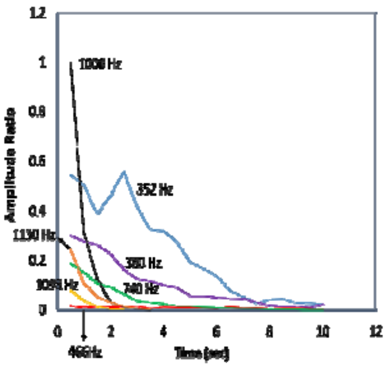
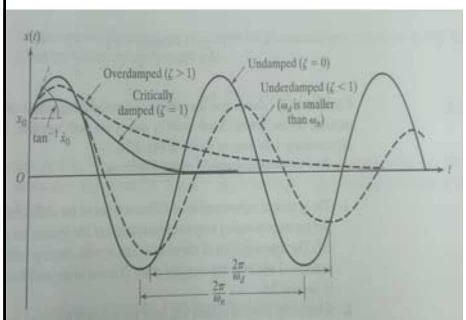


Microphone

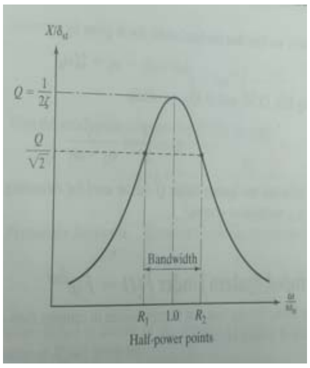
Damping Ratio



	shoulder	sound-bow	Bells
350 Hz	2.25E-04	1.34E-04	2.19E-04
380 Hz	2.07E-04	1.24E-04	2.02E-04
466 Hz	1.69E-04	1.01E-04	1.65E-04
740 Hz	1.07E-04	6.35E-04	1.04E-04

Quality Factor

$$Q \simeq \frac{1}{2\zeta} \simeq \frac{\omega_n}{\omega_2 - \omega_1}$$



	shoulder	sound-bow	Bells
350 Hz	2.22E+03	3.72E+03	2.28E+03
380 Hz	2.41E+03	4.04E+03	2.47E+03
466 Hz	2.96E+03	4.96E+03	3.03E+03
740 Hz	4.69E+03	7.87E+02	4.82E+03

整合振動抑制與3D 列印結構研究

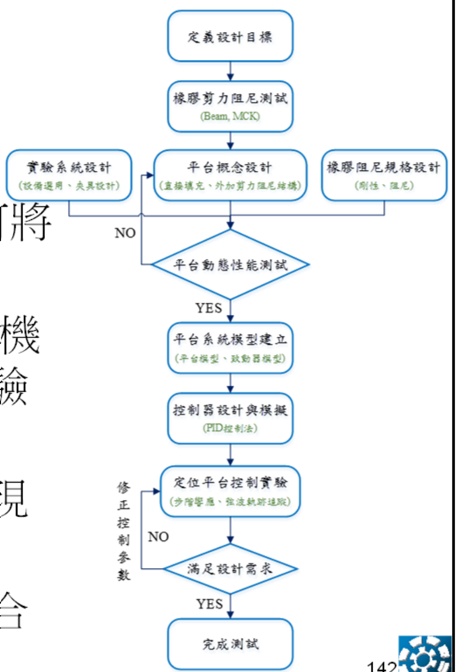
- Graduate student: Y-S You (2016)

Abstract

- 以3D列印製作較複雜的幾何外型來達到撓性定位平台之輕量化，
- 為了加強平台的動態表現，引入剪力阻尼的減振策略，對撓性平台之重點部位設計孔隙流道填入橡膠材料，達到提升材料阻尼之性能。

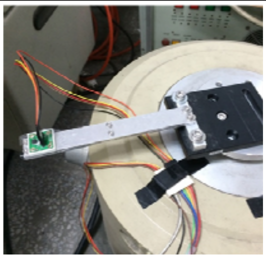
Introduction

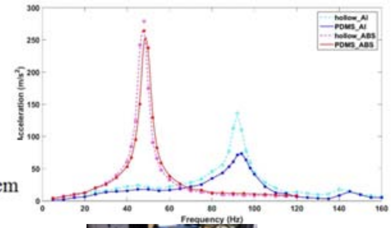
- 本研究根據研究流程, 可將重點分成下列數項:
- 結合3D列印與剪力阻尼機制之阻尼能力分析與實驗研究
- 撓性定位平台之設計實現以及動態測試
- 撓性定位平台之機電整合以及控制性能評估

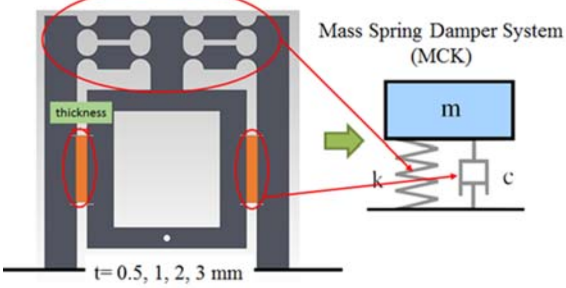


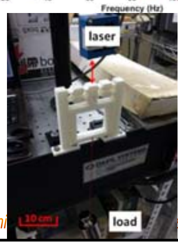
結合3D列印與剪力阻尼機制之阻尼能力分析與實驗:

1. 設計金屬剪力阻尼機構, 以實驗檢測其阻尼增強能力
2. 根據(1)的結論, 設計結合3D列印與剪力阻尼之機構, 測試期阻尼增強性能





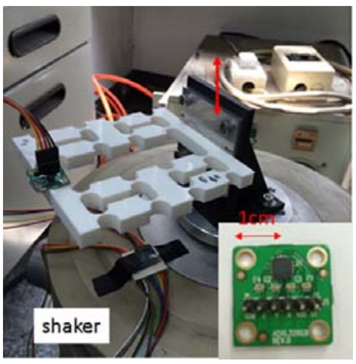


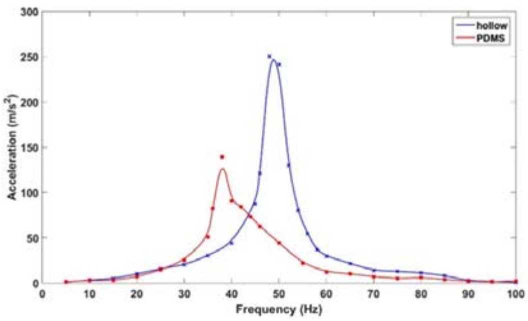


3DP Stage Design and Characterization

撓性定位平台之設計實現以及動態測試:

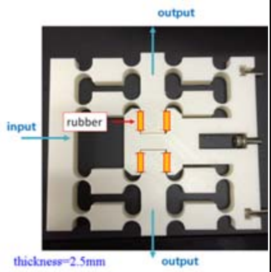
1. 以掃頻方式, 探求結構之阻尼增強效果
2. 設計參數實驗, 探討主要的阻尼控制機制

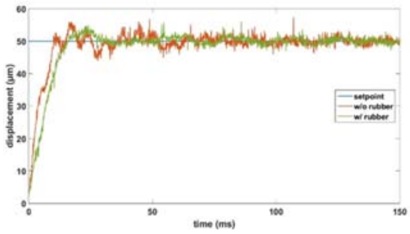


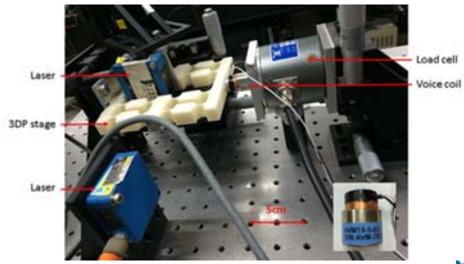


3DP Stage Positioning Control

- 結合音圈馬達，雷射位移探針，以及 FPGA 即時控制系統，實現平台定位控制系統
- 分別對原始平台以及阻尼增強平台進行步階與弦波軌跡追蹤控制，檢視其定位效果
- 結果顯示含剪力阻尼系統,其穩態變異較少，頻寬亦較寬，未來採用金屬3D列印設計平台，此阻尼增強結構應可做出更優異之性能改善







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