Visual Signal於迴轉機械之振噪檢測

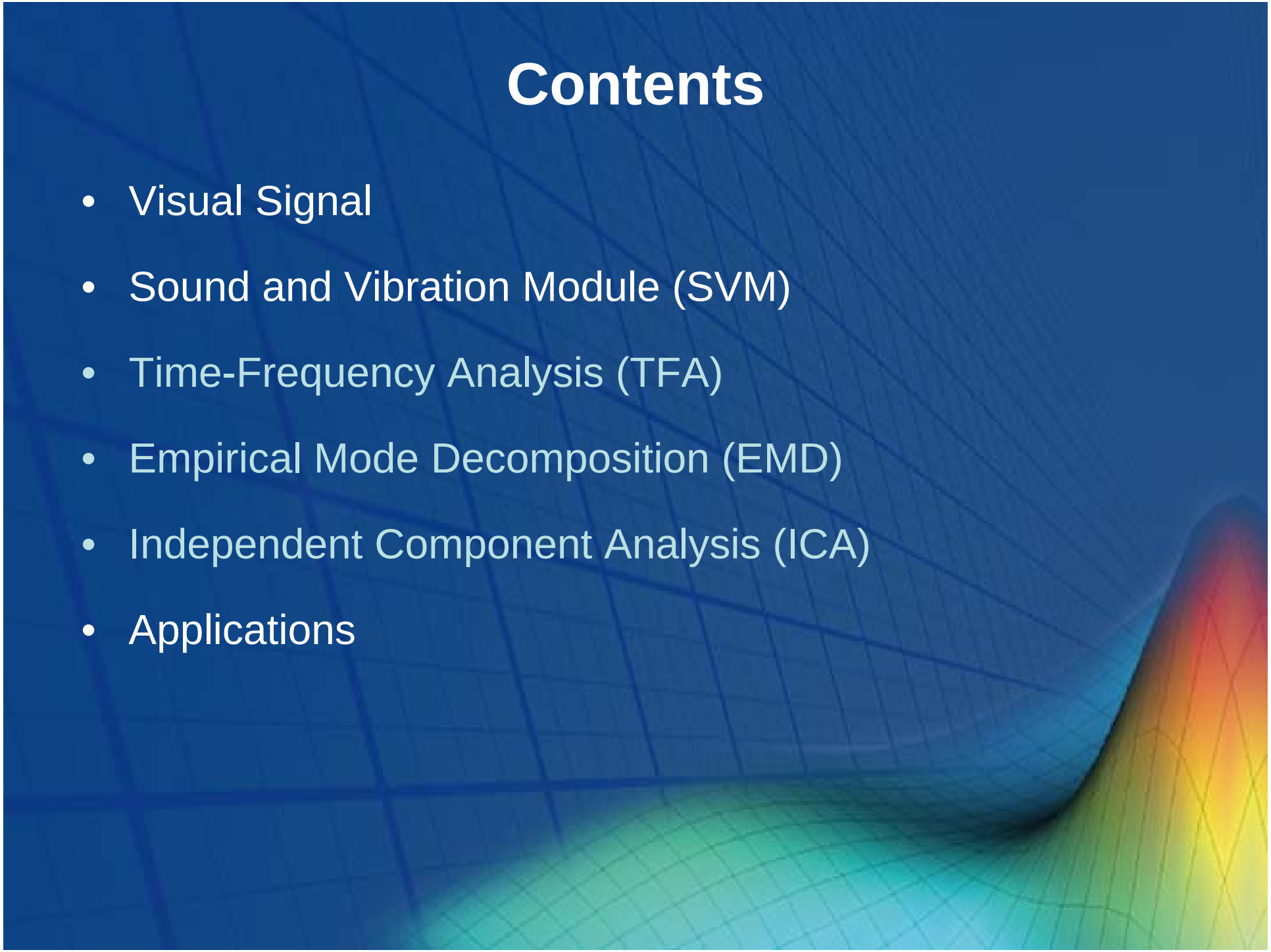
吳豐泰

逸奇科技

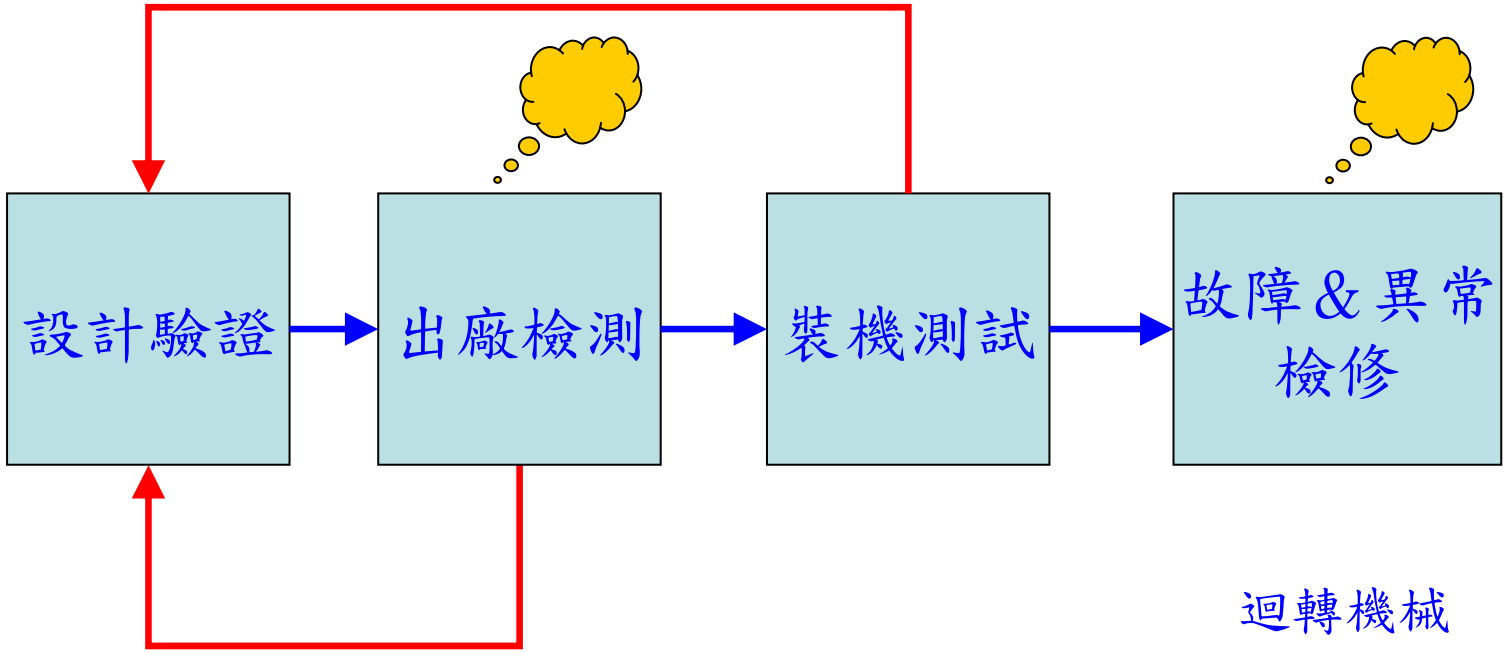
AnCAD

Contents

- Visual Signal
- Sound and Vibration Module (SVM)
- Time-Frequency Analysis (TFA)
- Empirical Mode Decomposition (EMD)
- Independent Component Analysis (ICA)
- Applications



Why振動噪音檢測？



FEM模型
原型驗證
參數調測

生產履歷：
製造&組裝
品保資料庫
臨界轉速

客戶機台
動態特性
操作頻率
臨界轉速

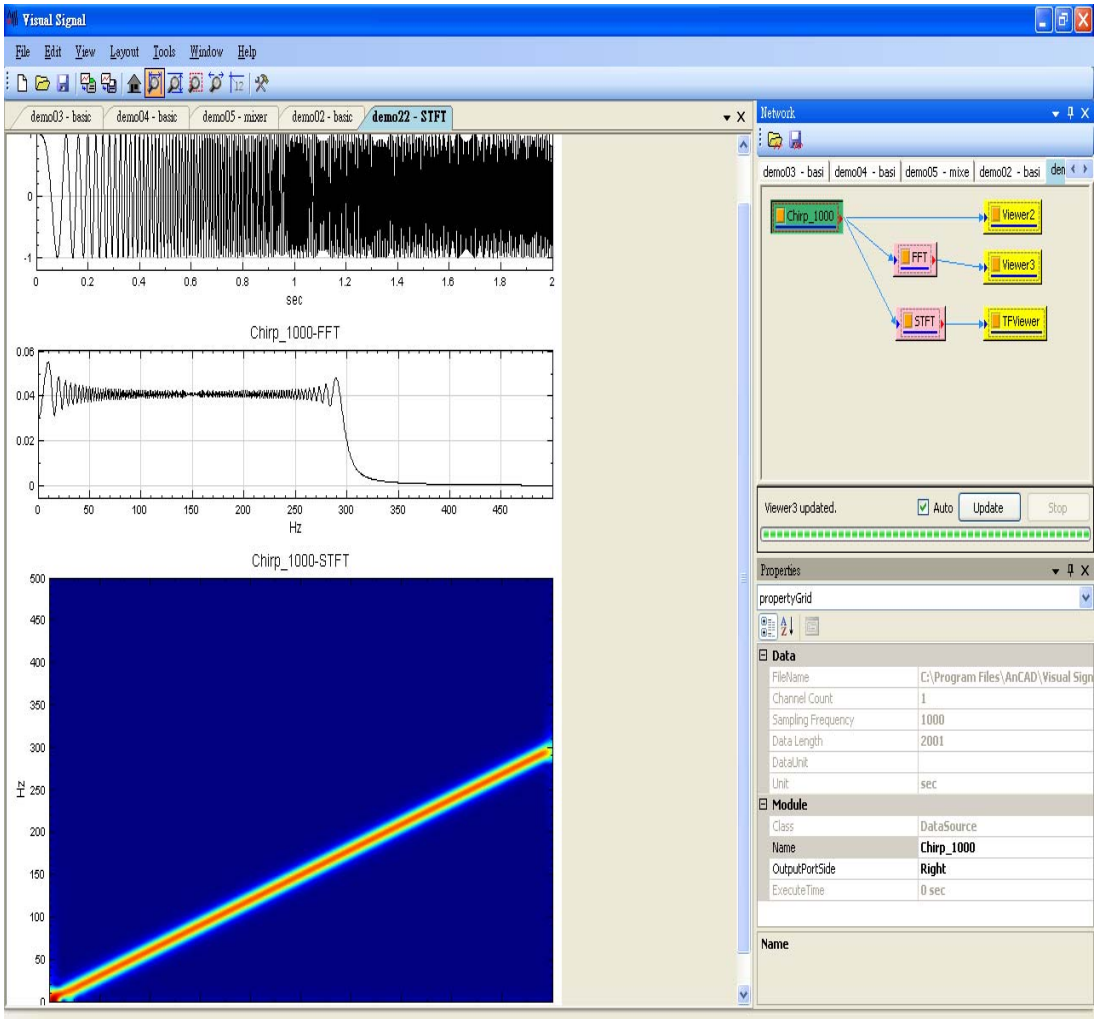
迴轉機械
主軸
齒輪
軸承
馬達

AnCAD

Why Visual Signal?

Visual Signal：軟硬體整合平台

- 專注於找出問題與解決問題，而非學習程式與訊號處理。



輸入
- 資料擷取硬體
- 檔案
- 使用者自建函數

分析
- 雜訊濾除
- 趨勢移除
- 時間域分析
- 頻率域分析
- 時頻分析
- 統計分析
- 矩陣與數學運算
- MATLAB, DLL

輸出
- 圖形
- 檔案
- 訊號產生器

AnCAD

Data Interface

- Input data format supported
  - Plain text (.txt)
  - VS internal (.tfa)
  - Sac reader (.sac)
  - Excel reader (.csv)
  - Sound/speech (.wav, mp3)
  - WFDB Reader (.hea)
  - Matlab (.mat)
- Exported data format
  - Excel (.csv)
  - Plain text (.txt)
  - VS internal (.tfa)
  - Sound/speech (.wav, mp3)
  - Matlab (.mat)

AnCAD

資料擷取卡選用：類型與介面

FIGURE 29.1 Examples of typical, computer-based data acquisition devices. Plug-in devices are also commonly available for USB, PCI, and PCI Express buses.

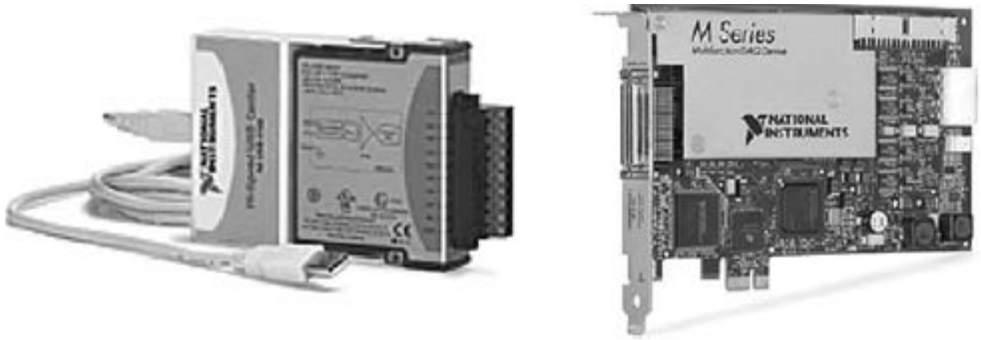


FIGURE 33.3 Examples of other measurement hardware choices for virtual instrumentation. On the left is a USB peripheral module and on the right, a PCI Express plug-in module.

AnCAD

資料擷取卡選用：可攜式、工業用、分散式

FIGURE 35.9 Portable PC-based data-logging system.

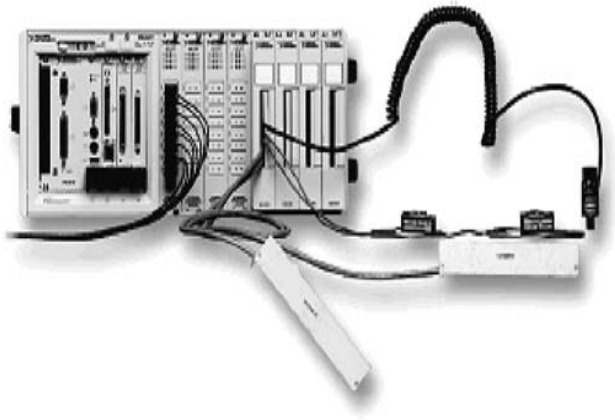


FIGURE 35.10 Rack-mount industrial PC-based data-logging system.

FIGURE 35.11 Examples of distributed data-logging systems.

AnCAD

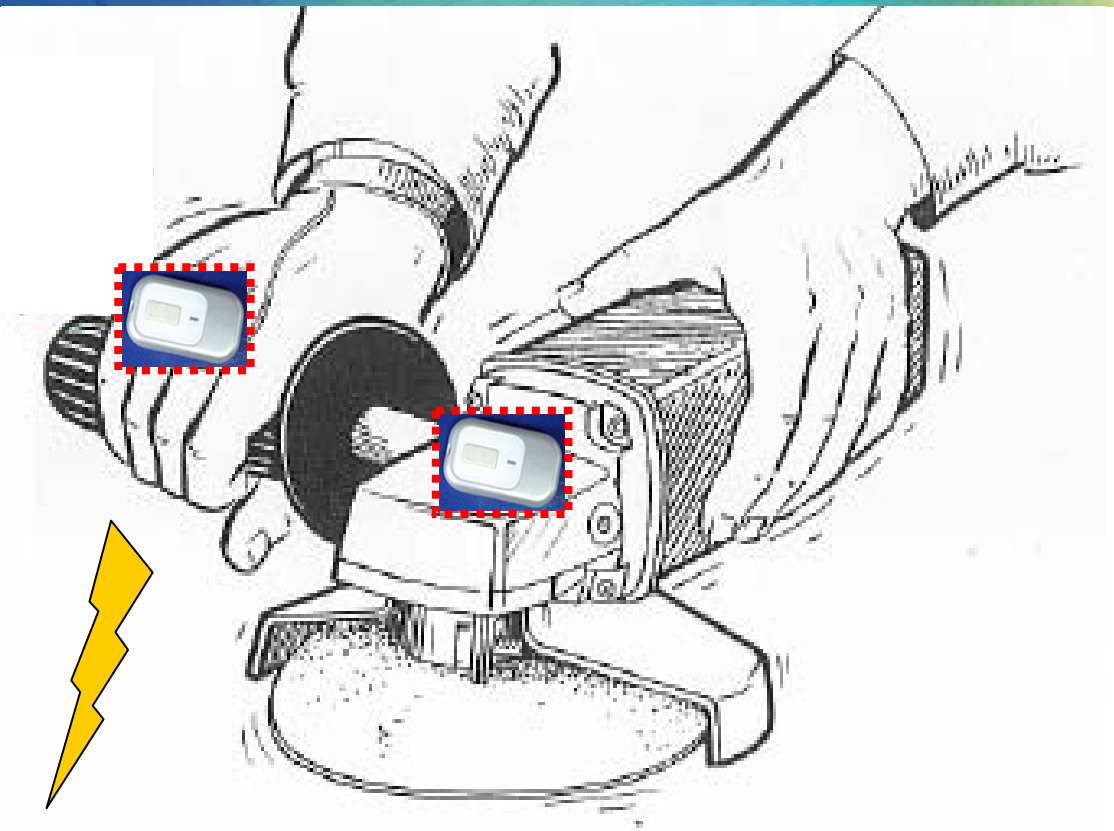
Wireless Vibration Analyzer

8通道：

✓MEMS三軸加速規

✓溫度

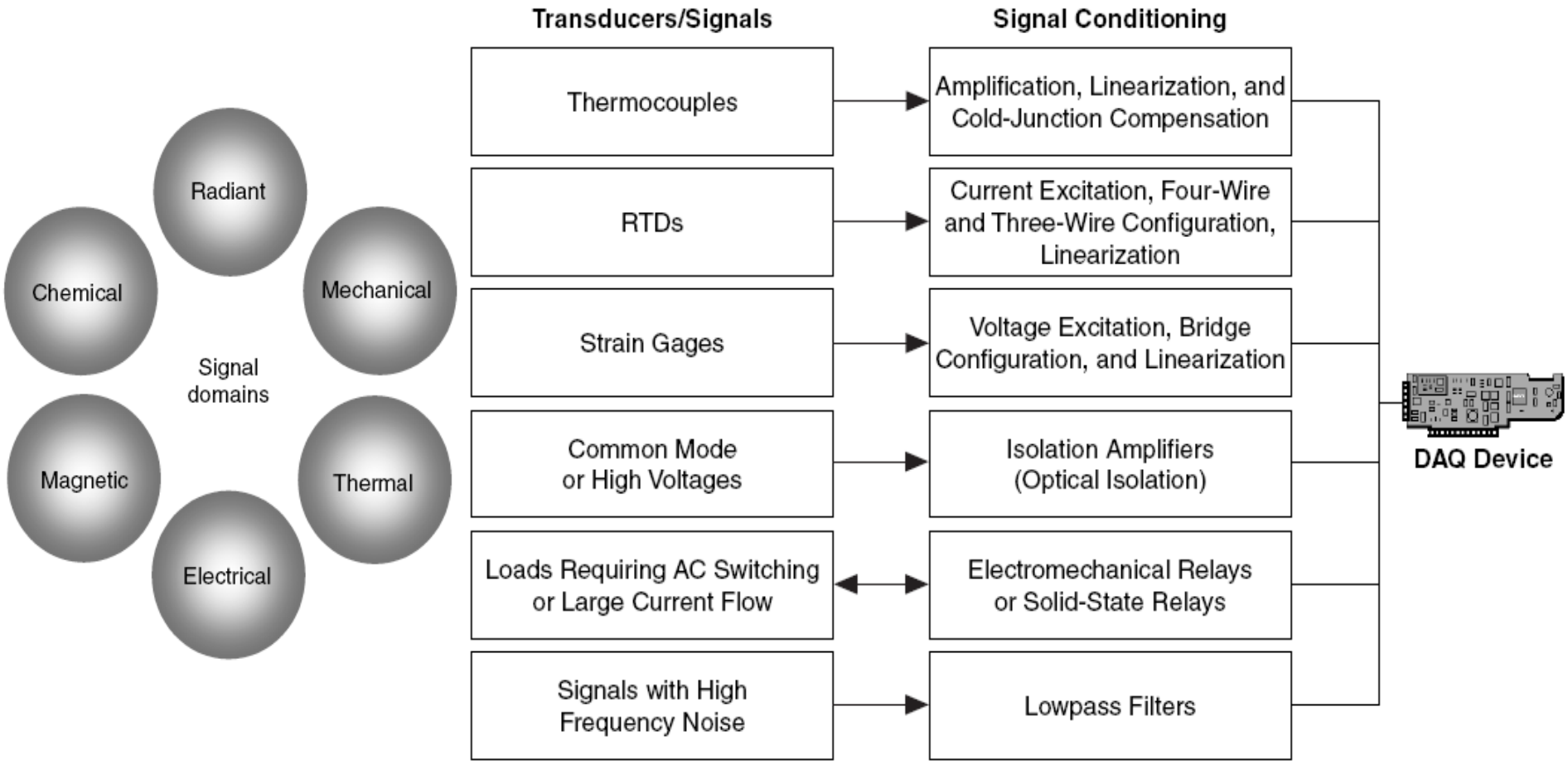
✓生理訊號



TD1A

Wireless

Why多物理場訊號擷取與整合?



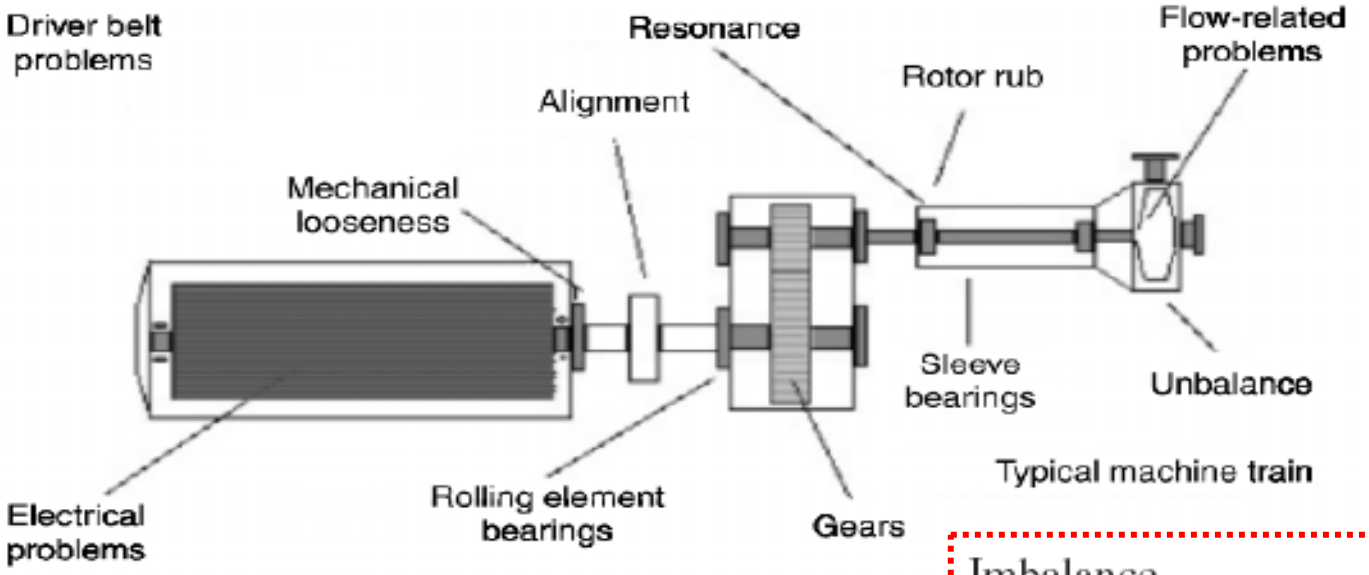
AnCAD

Why Sound and Vibration Module?

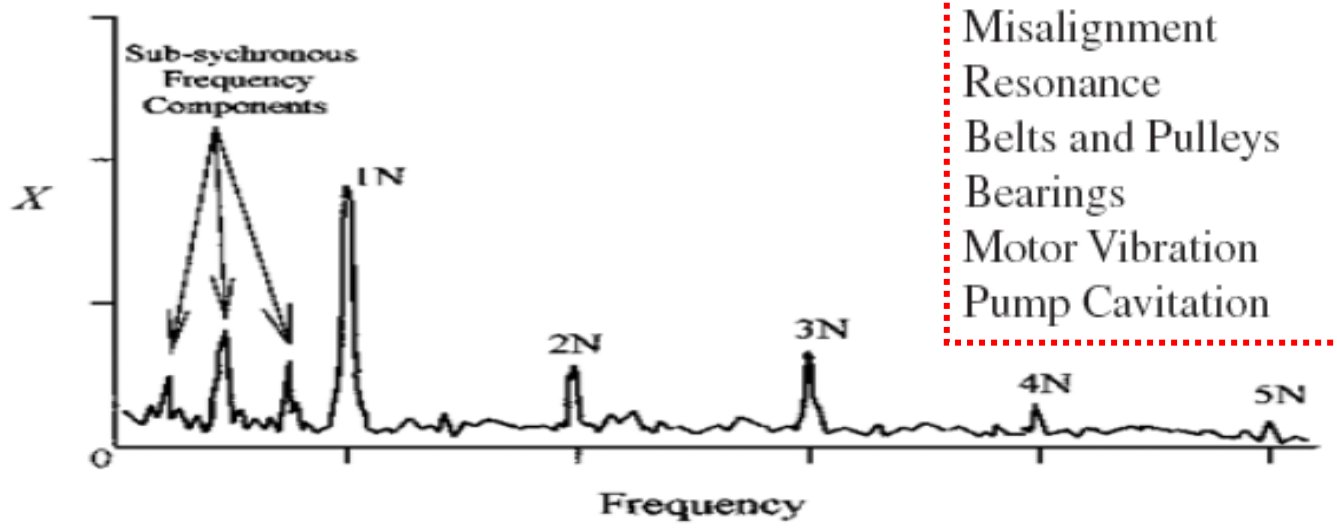
- Vibration Level
  RMS: RMS, Peak, Peak-to-Peak
  Crest Factor
  Peak : Max, Min, True Peak, True Peak-to-Peak
- Sound Level
  A, B, and C Weighting
  Octave
- Order Tracking
  Digital Tacho
  Order Tracking
  Order Tracking by STFT
- Bearing Analysis
  Bearing Defect
  Envelope Detection
- Cepstrum
- Scale…

AnCAD

迴轉機械之振動頻譜

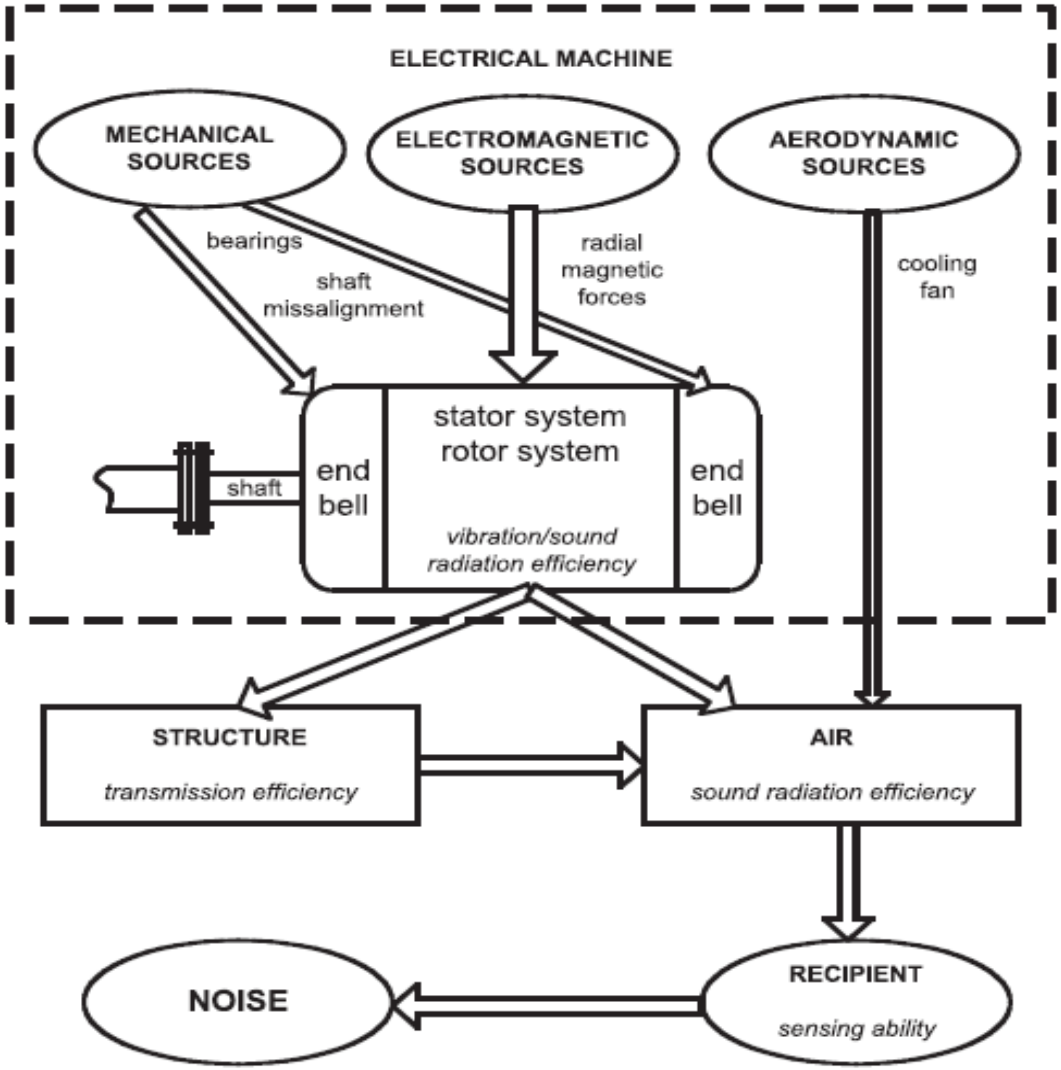


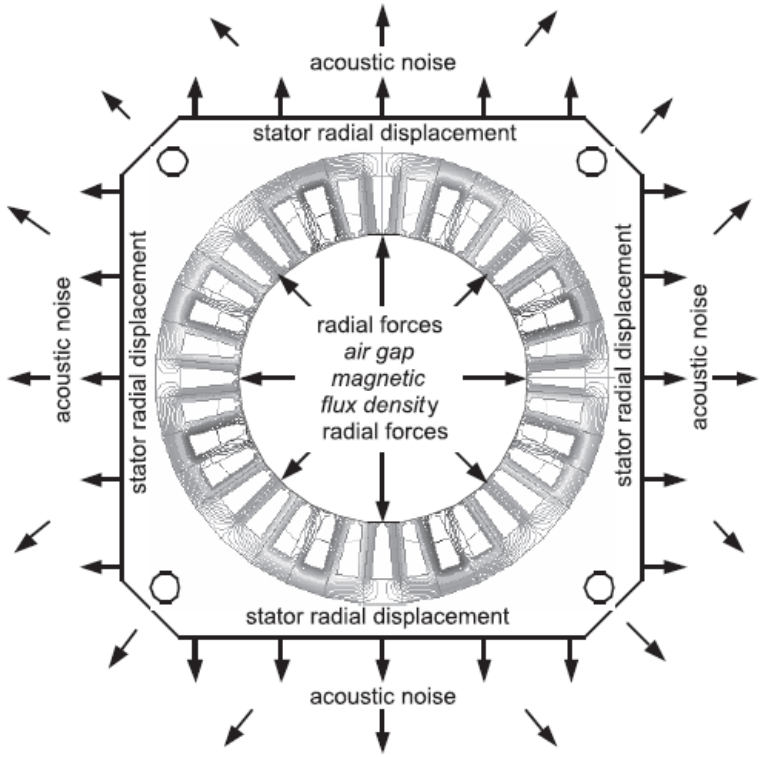
Imbalance	40%
Misalignment	30%
Resonance	20%
Belts and Pulleys	30%
Bearings	10%
Motor Vibration	8%
Pump Cavitation	5%



AnCAD

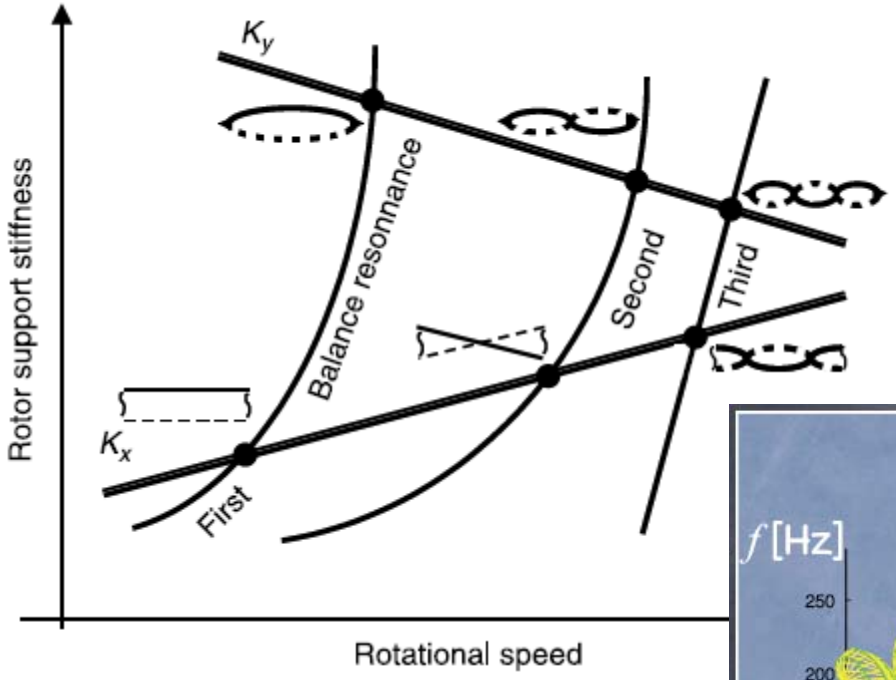
Vibration ⇔ Noise

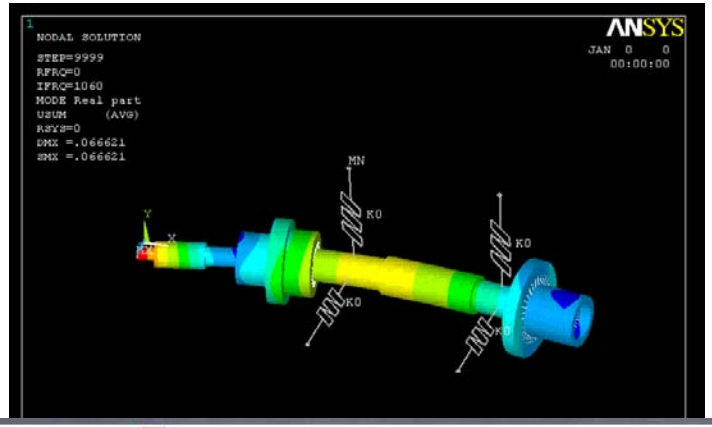


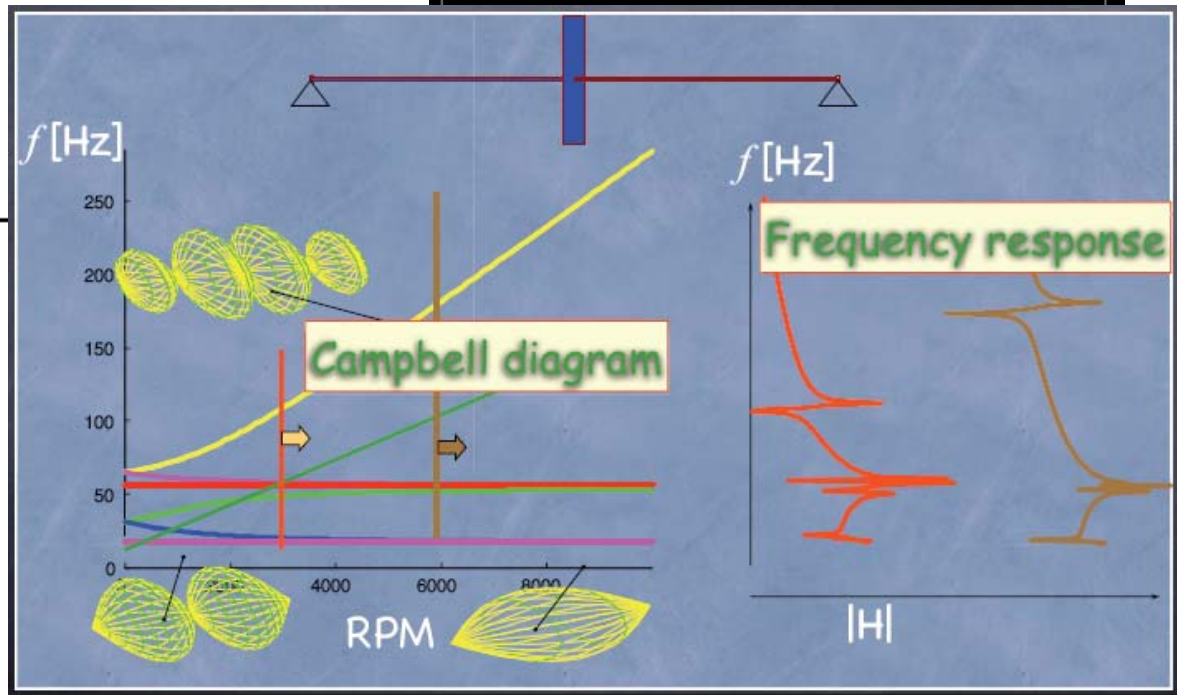


AnCAD

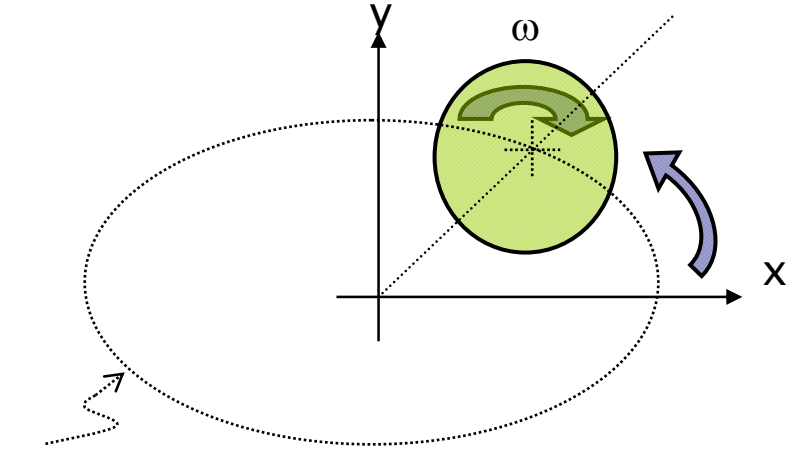
軸承剛性與主軸臨界轉速之關係





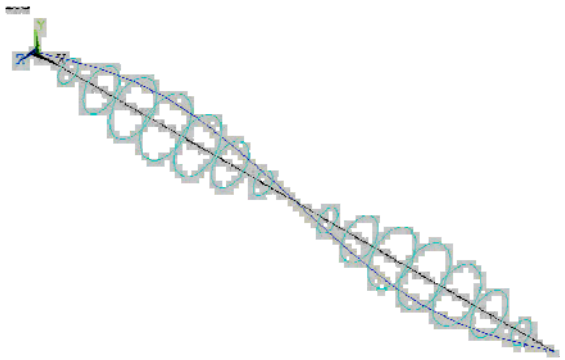


Campbell Diagram



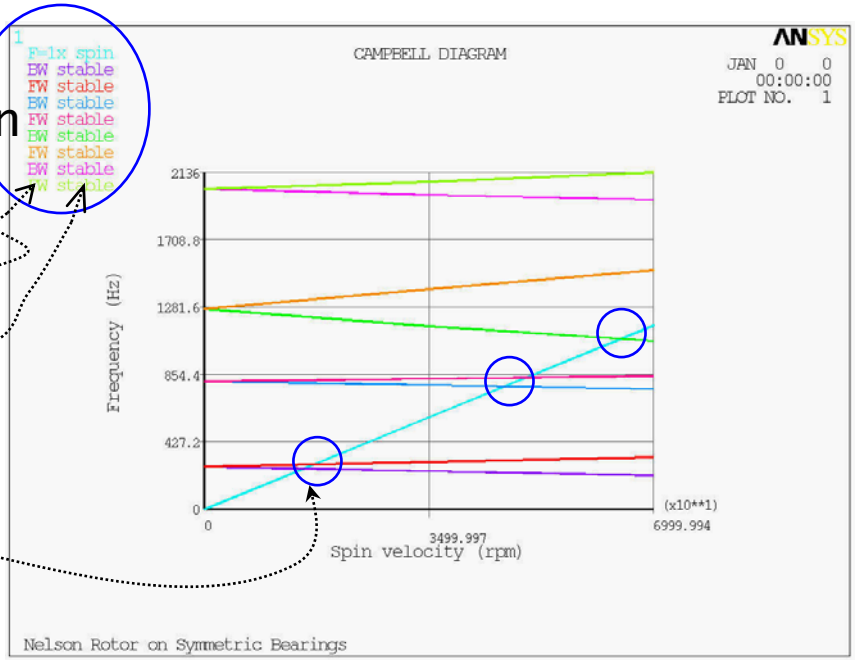
Elliptical whirl orbit

whirl motion



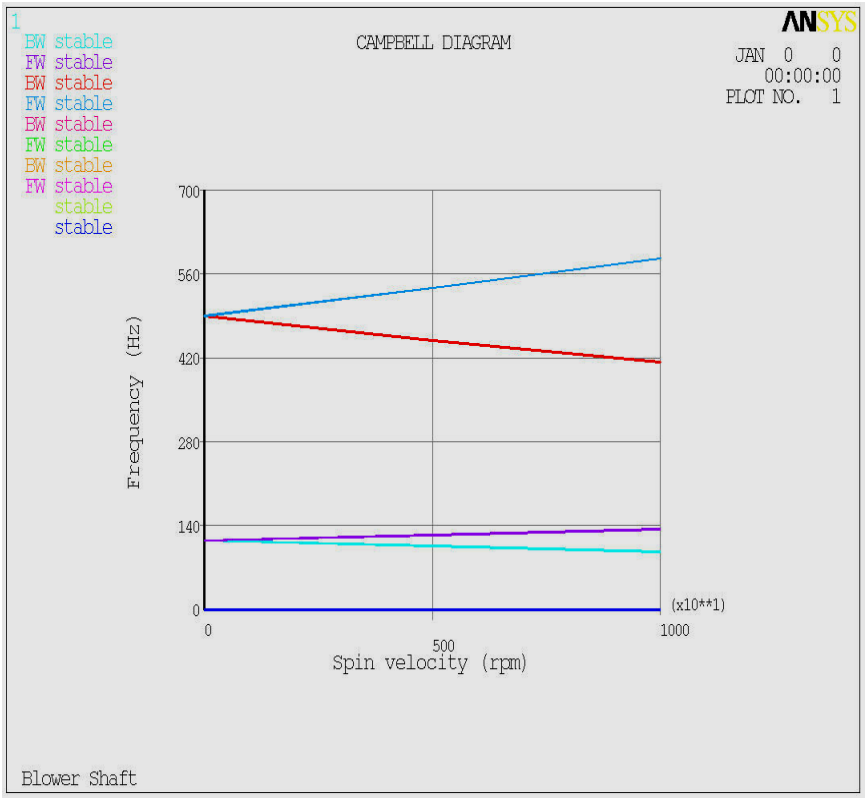
As frequencies split with increasing spin velocity, ANSYS identifies:

- forward (FW) and backward (BW) whirl
- stable / unstable operation
- critical speeds (PRCAMP)

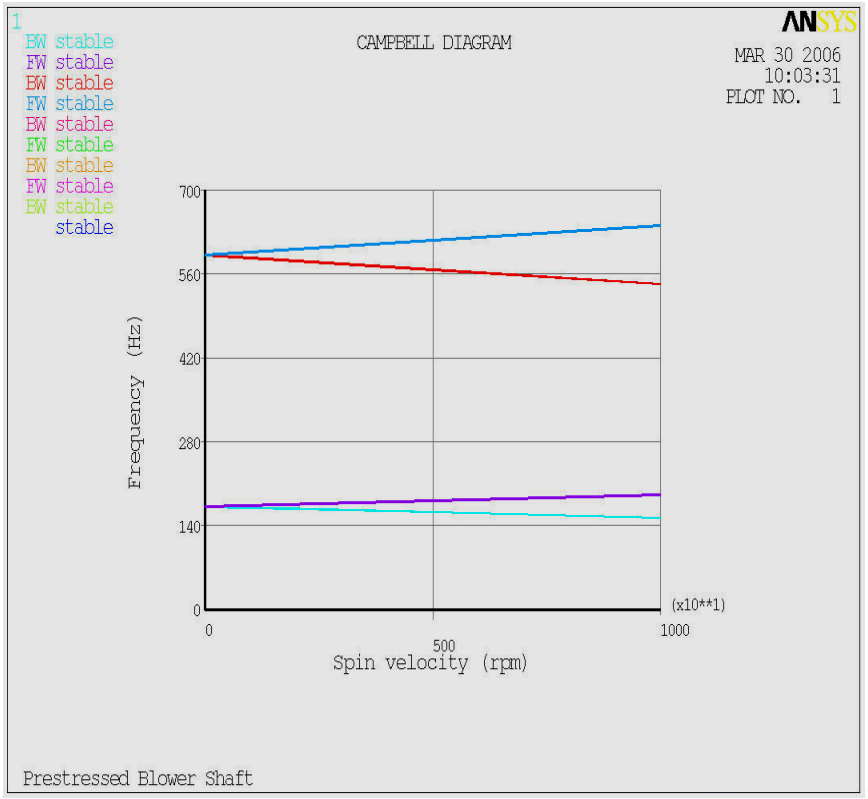


軸承剛性對自然頻率之影響

No prestress

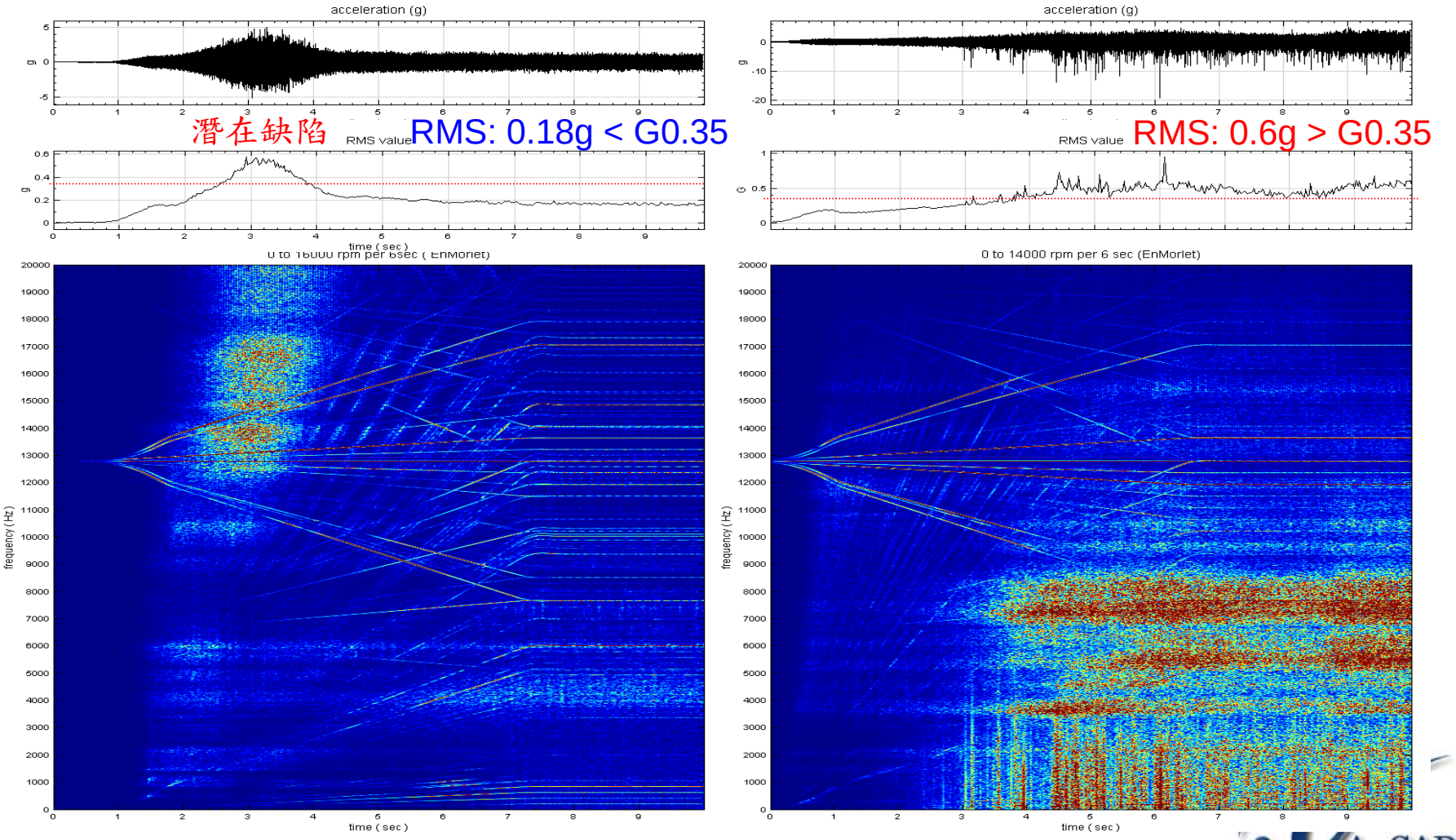


With thermal prestress



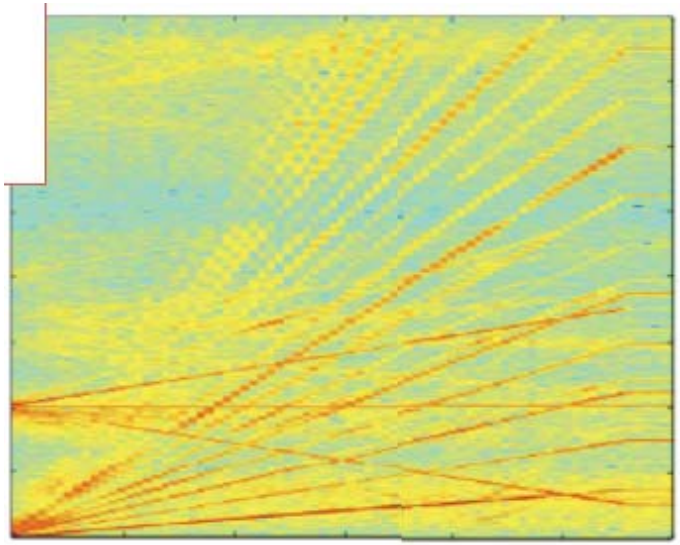
AnCAD

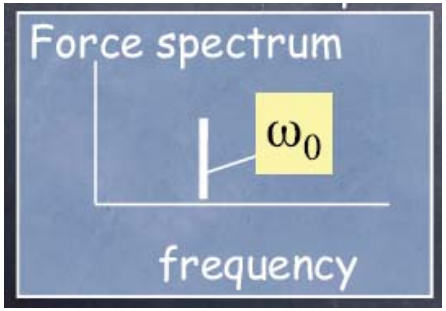
Why變轉速時頻分析? ⇨ 潛在缺陷檢出 故障排除

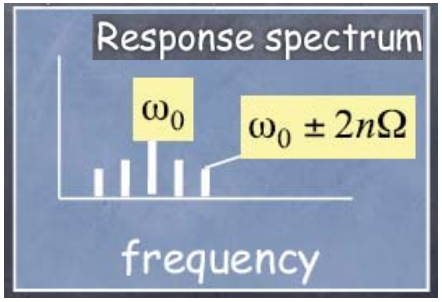


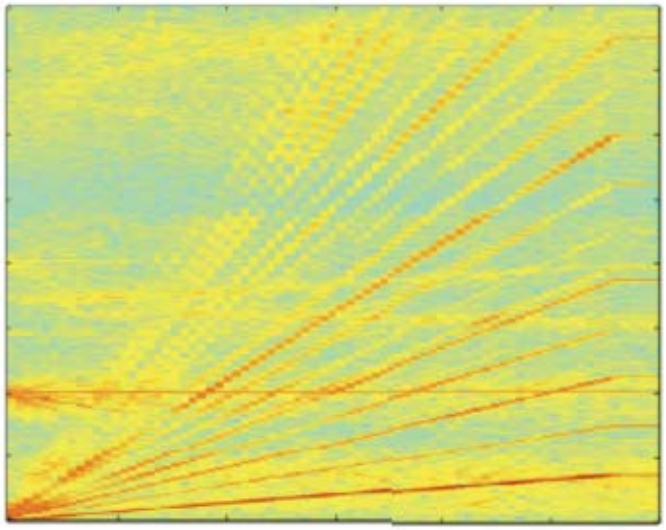
AnCAD

異常調變排除⇨主軸非對稱效應之校平衡

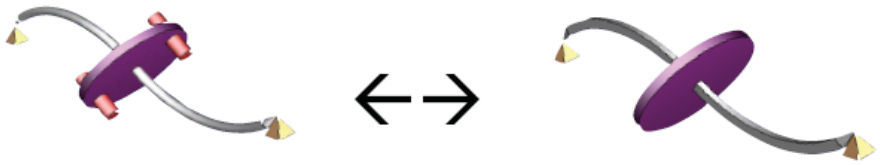








Asymmetric inertia ←→ anisotropic stiffness



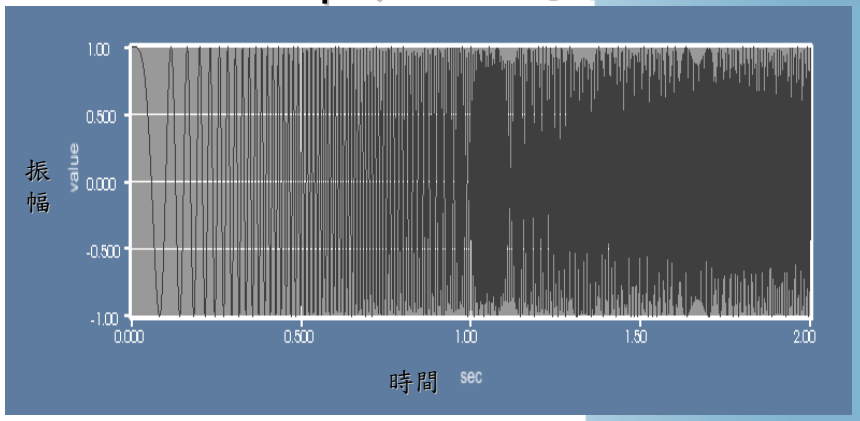
* for asynchronous detection purposes

- Force frequency ω
- Speed of rotation Ω
- Response frequencies ω, ω±2nΩ
- Resonance frequencies ω, ω±nΩ

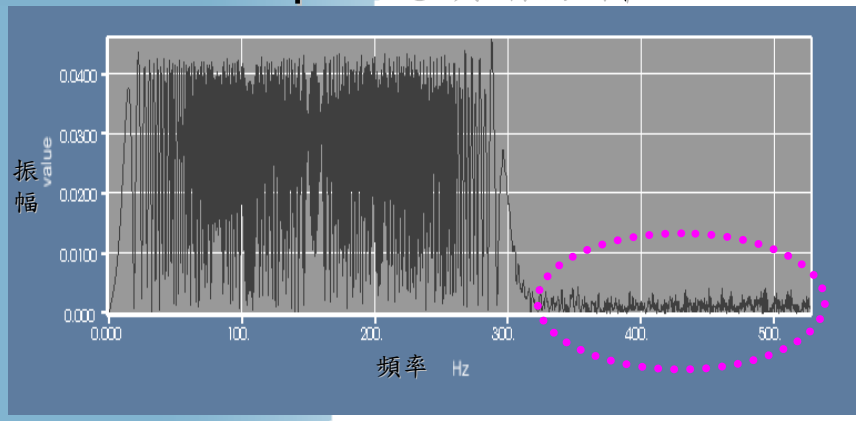
AnCAD

Why高解析時頻分析？⇨ 細微缺陷檢出

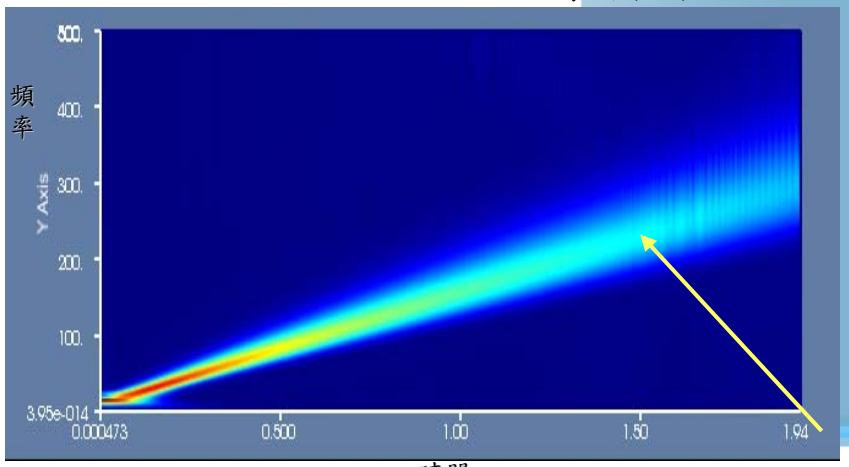
Chirp原始訊號



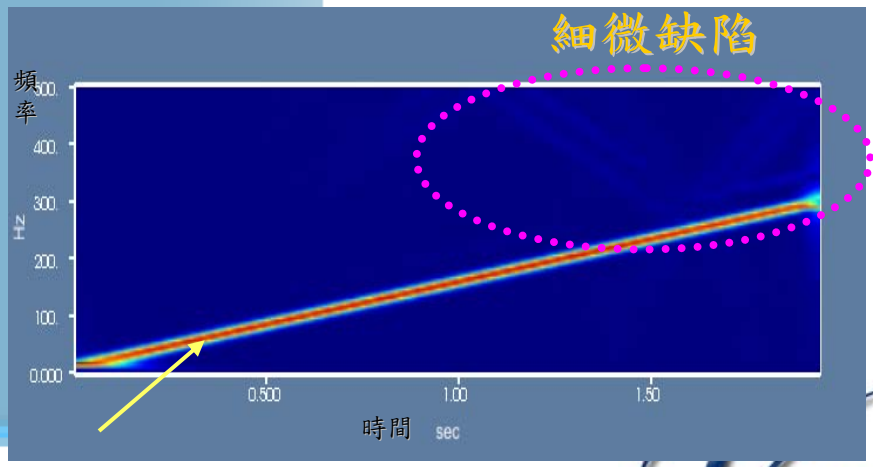
Chirp訊號頻譜分析



Morlet Transform時頻圖



Enhanced Morlet Transform

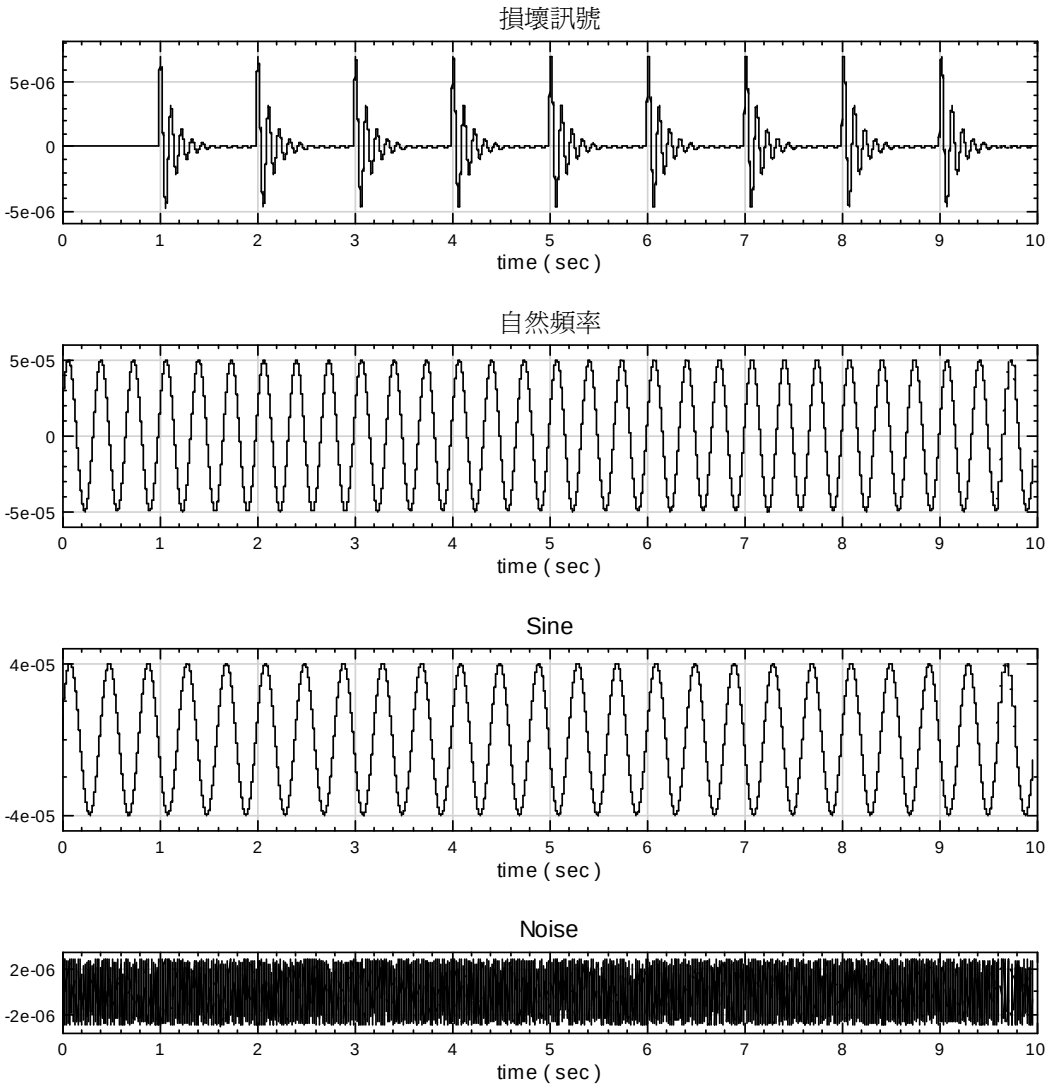


色彩表示其能量或振幅

AnCAD

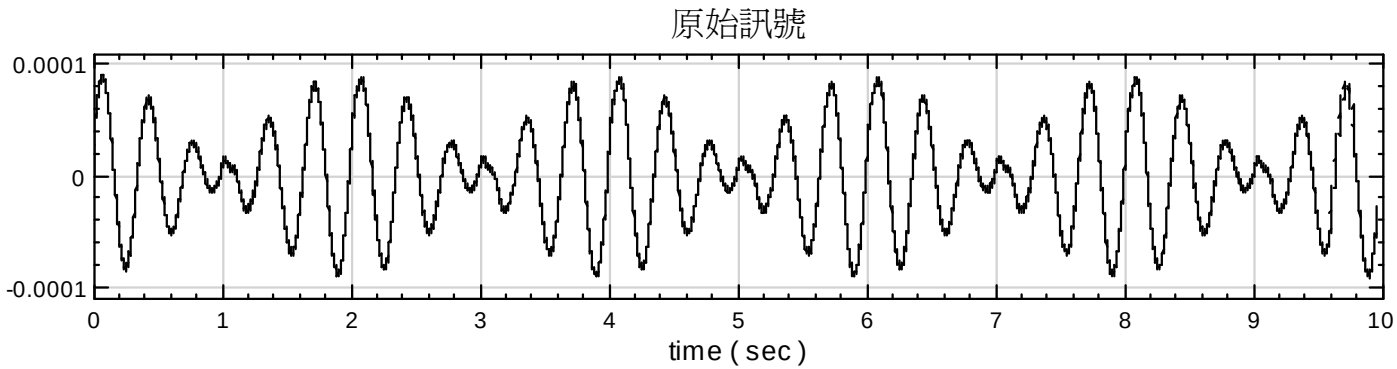
EMD

EMD 應用於微小損壞訊號偵測(1)

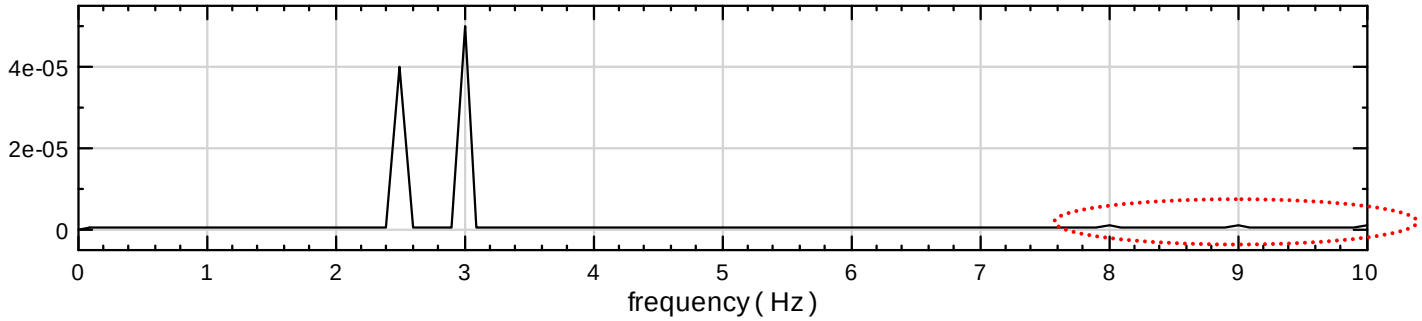


- 將四個訊號混合，作為原始加速規量測的訊號。
- 此模擬為驗證微小的損壞訊號會被機械共振頻率所覆蓋，無法偵測。

EMD 應用於微小損壞訊號偵測(2)

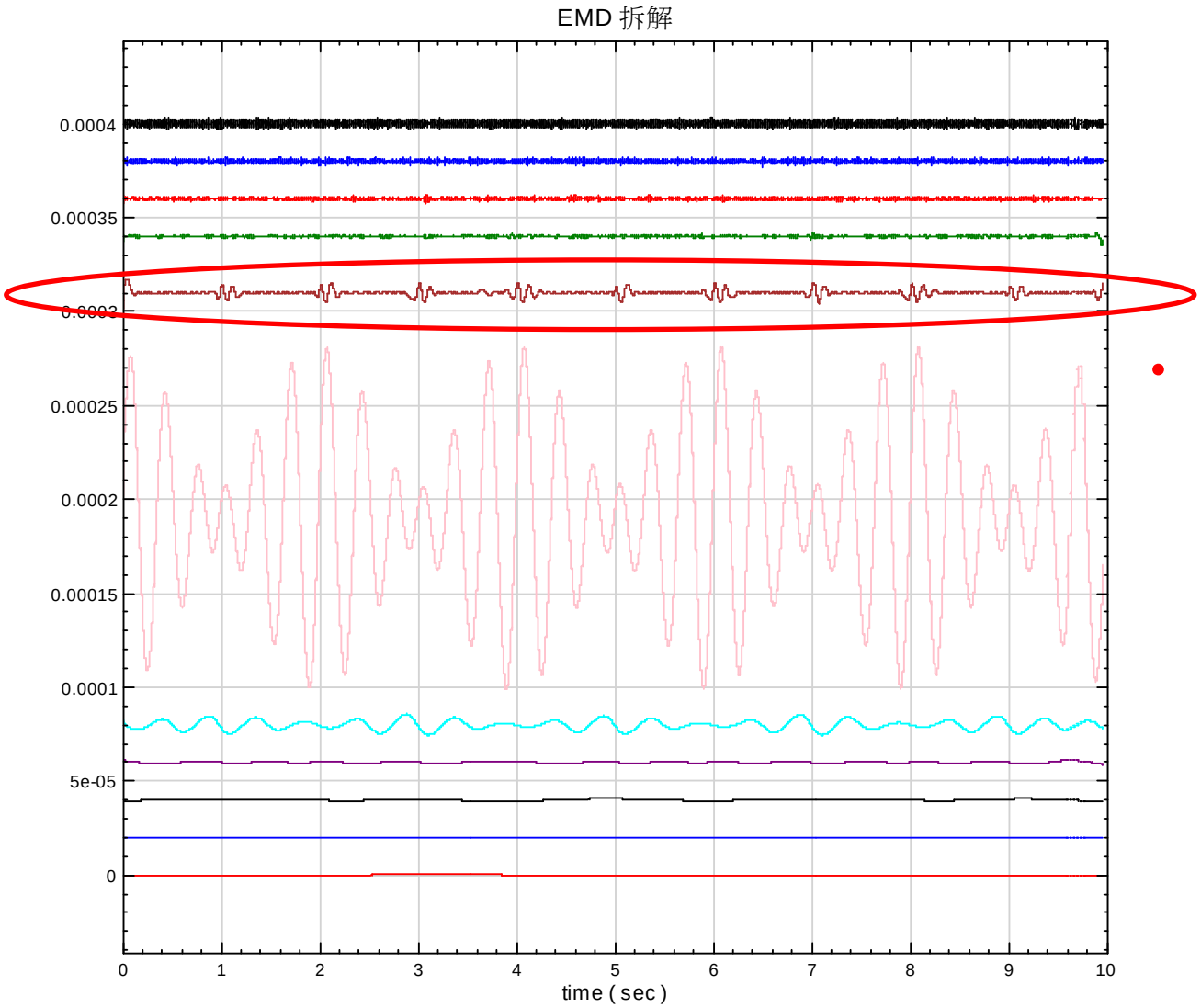


FFT



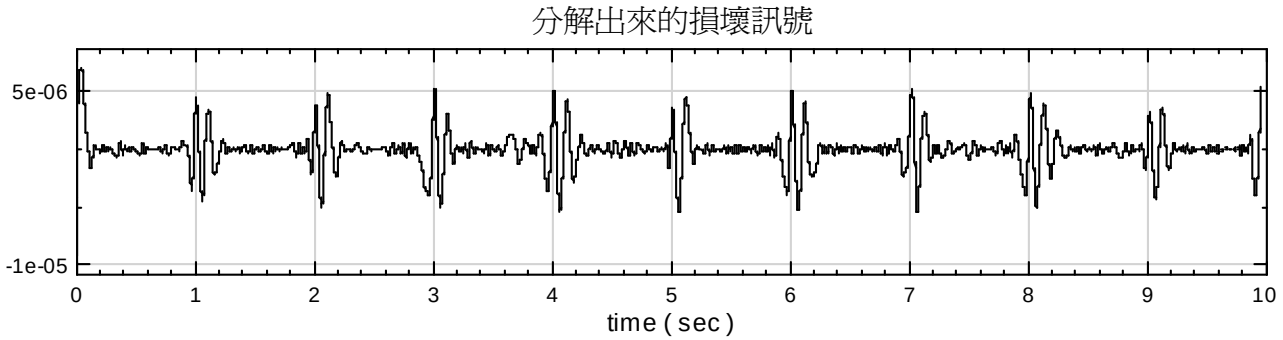
- 上圖為前述四訊號的合成結果，若是對其做傅立葉轉換，會得到下圖的傅立葉轉換頻譜圖。

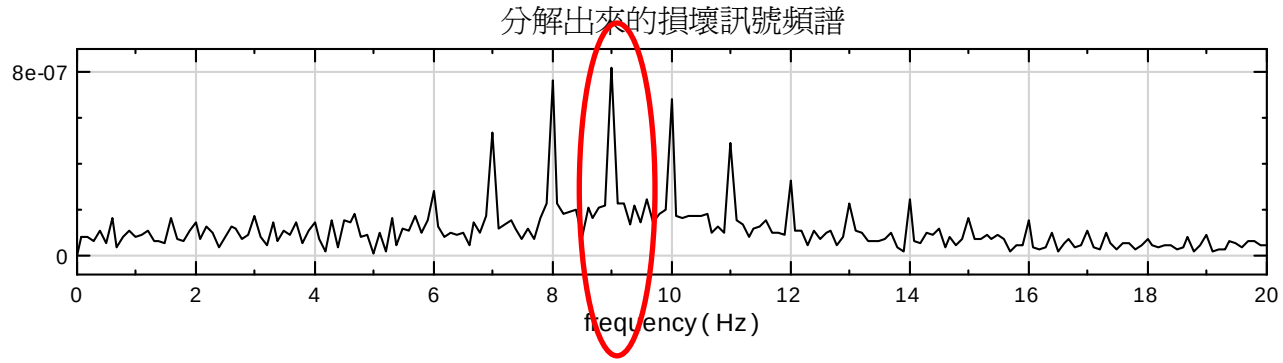
EMD 應用於微小損壞訊號偵測(3)

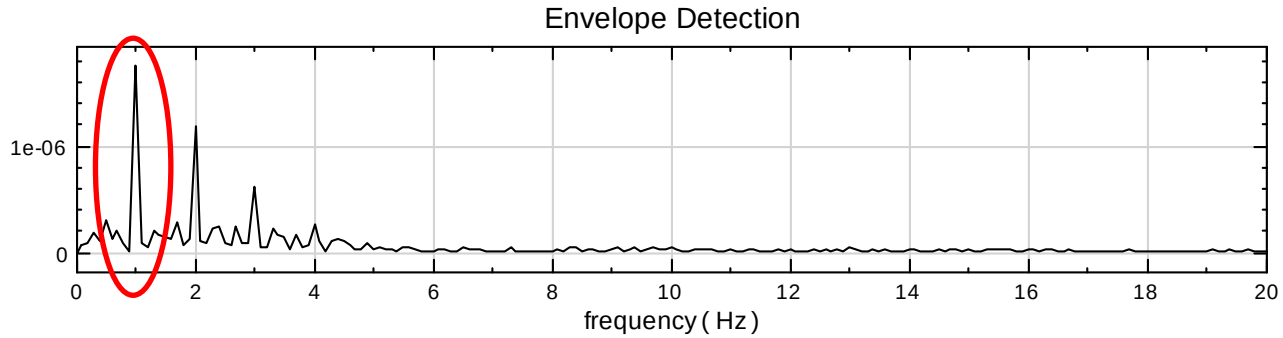


- 透過 Intermittency 的拆解，可以將損壞訊號拆解至單一子訊號中。

EMD 應用於微小損壞訊號偵測(4)

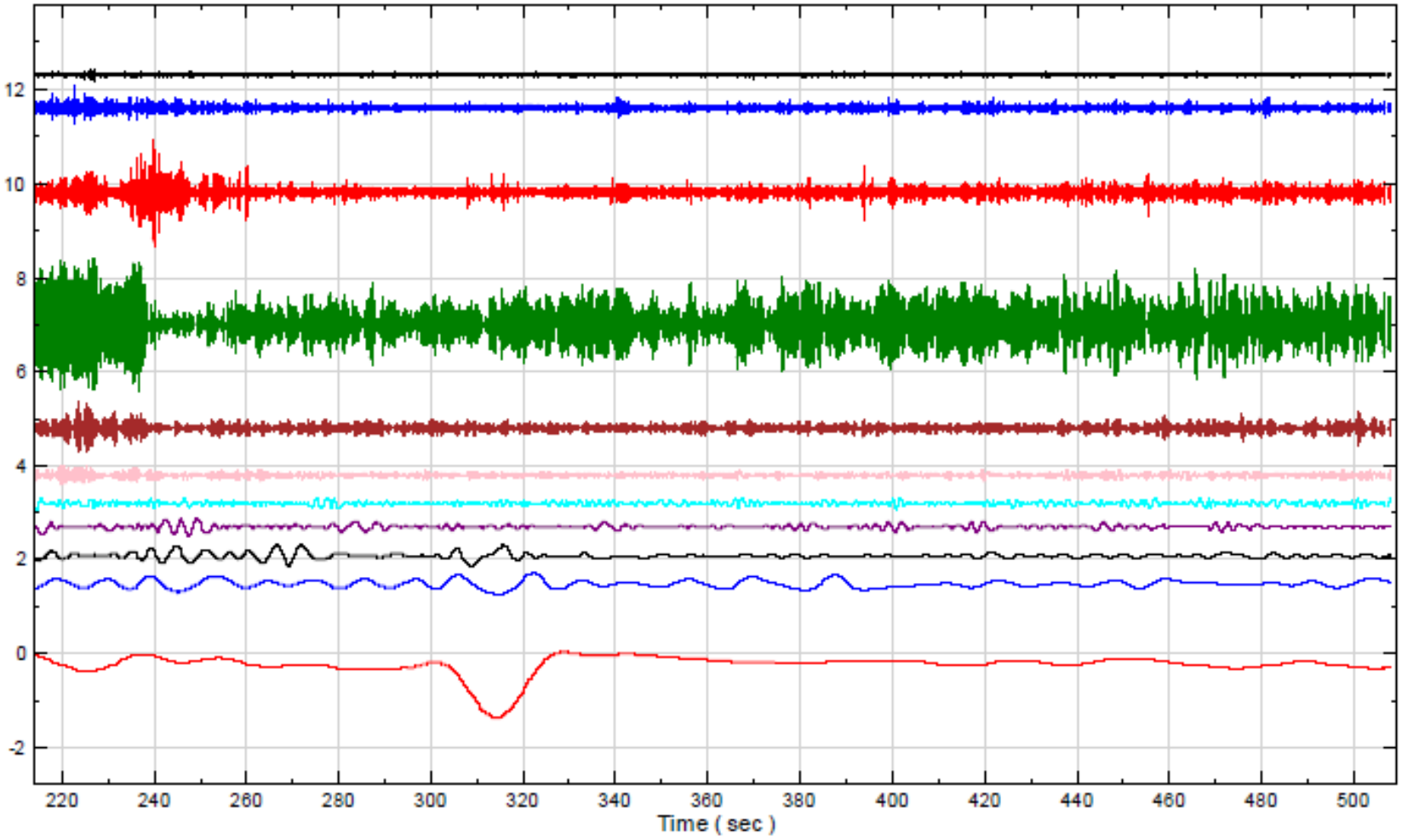






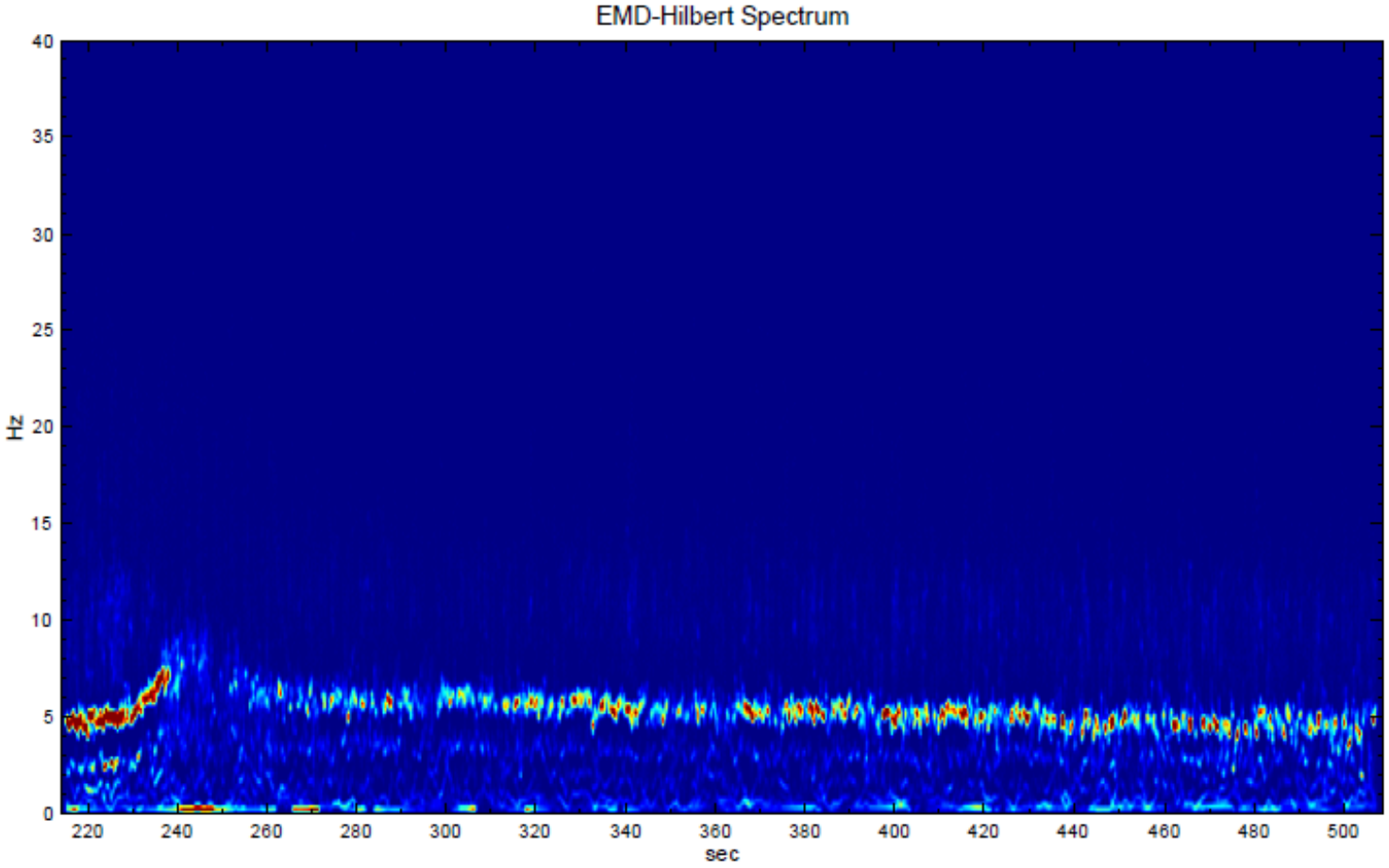
- 將拆解出來的損壞訊號做傅立葉轉換。
- 將該分解出的子訊號作 Envelope，再取其傅立葉頻譜。

Why EMD? ⇨ 時域拆解與濾波



AnCAD

EMD analysis: Hilbert spectrum

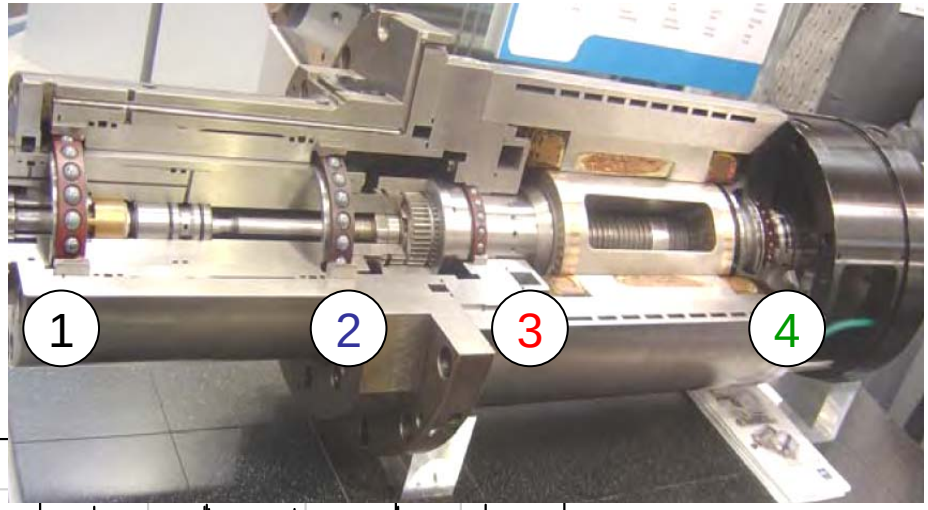


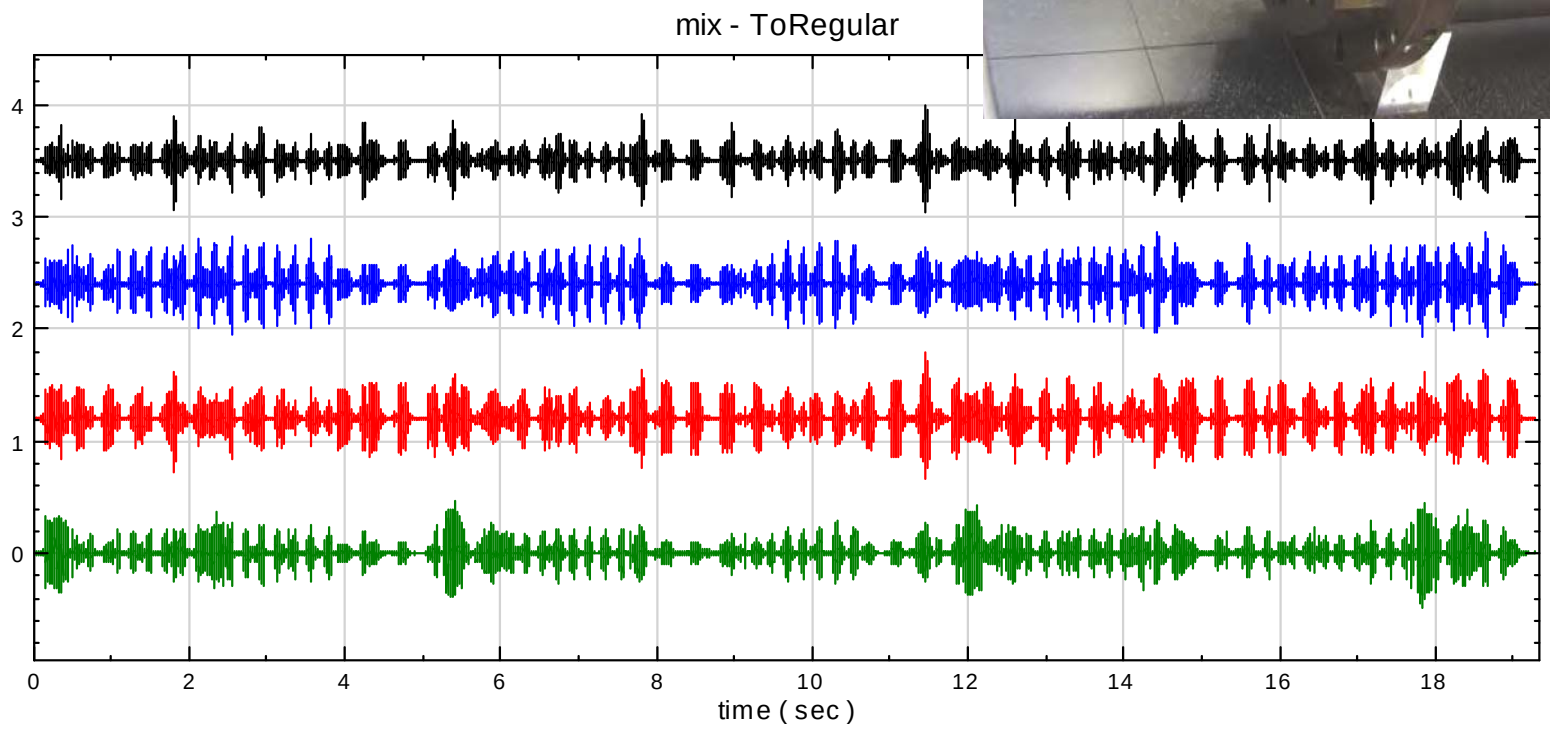
AnCAD

ICA

AnCAD

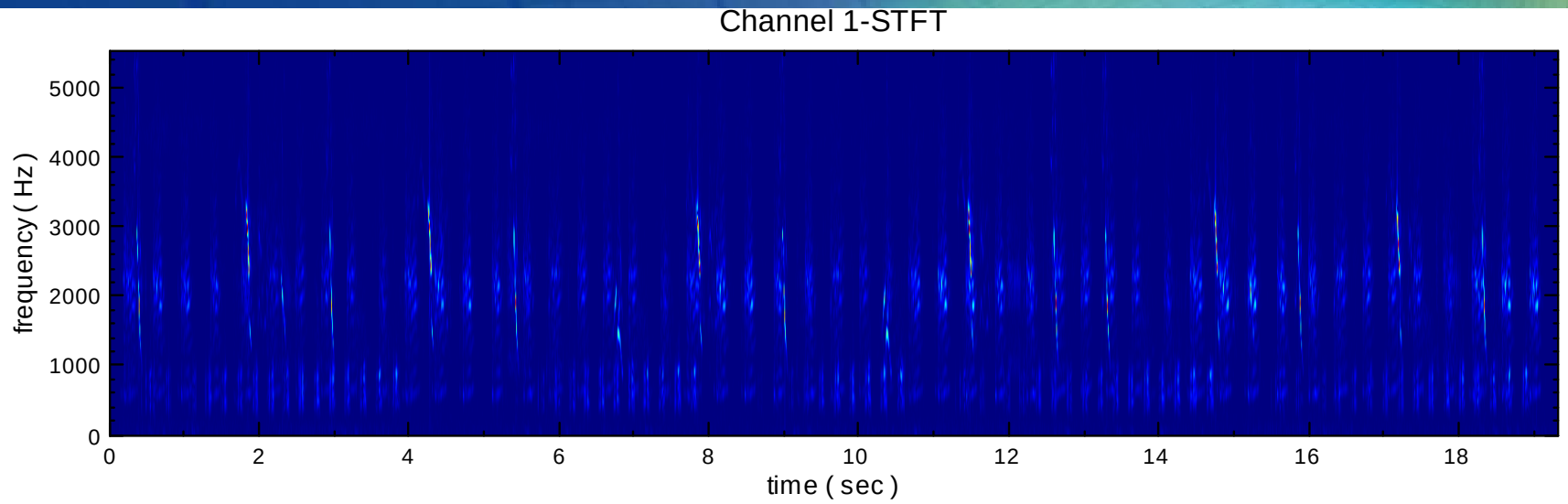
4個量測點之混合訊號

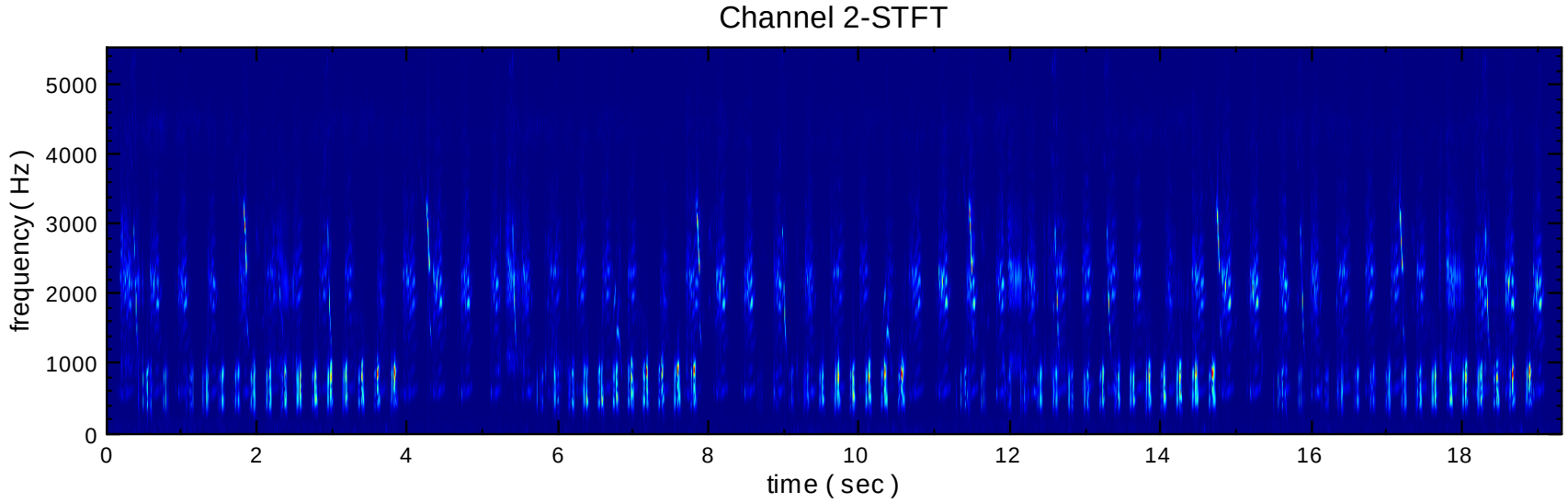




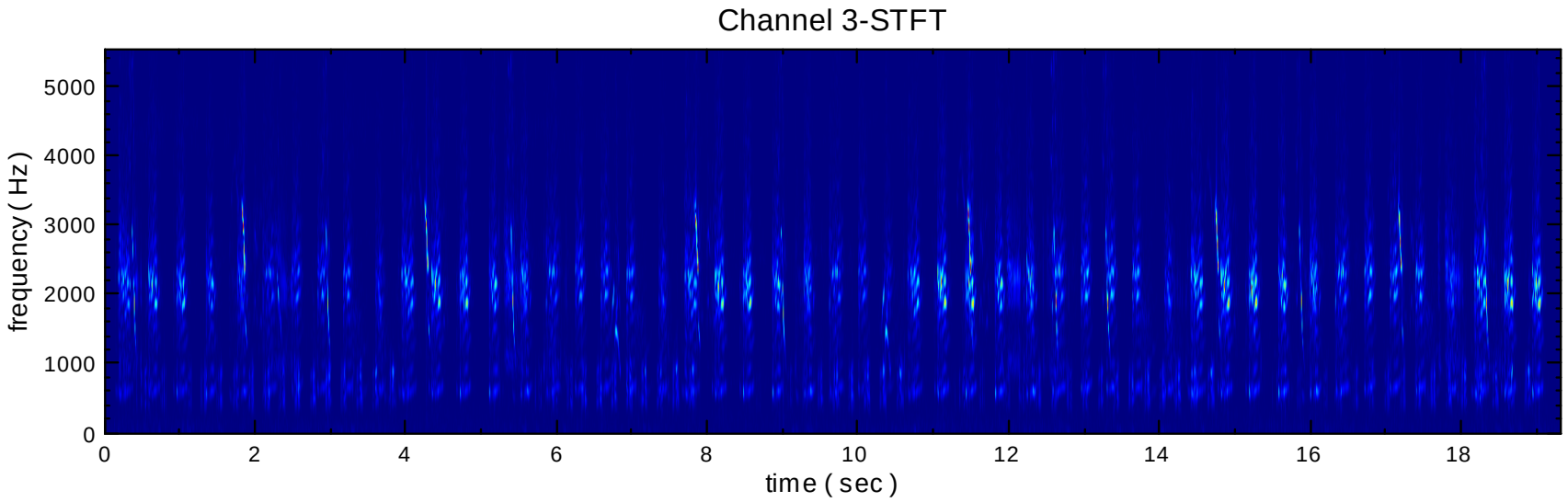
AnCAD

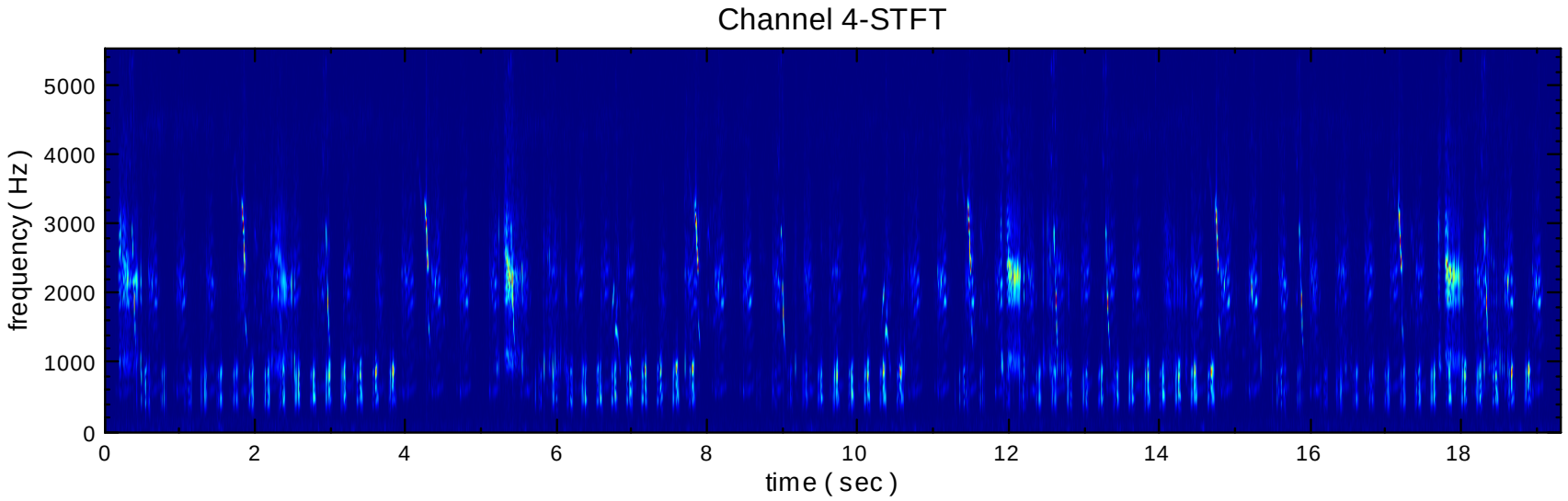
分離前之特徵：Channel 1 & 2



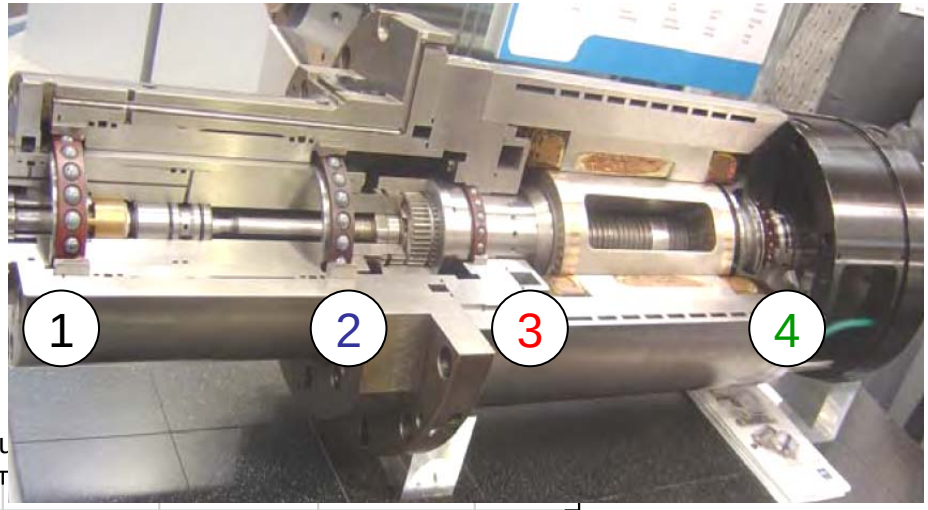


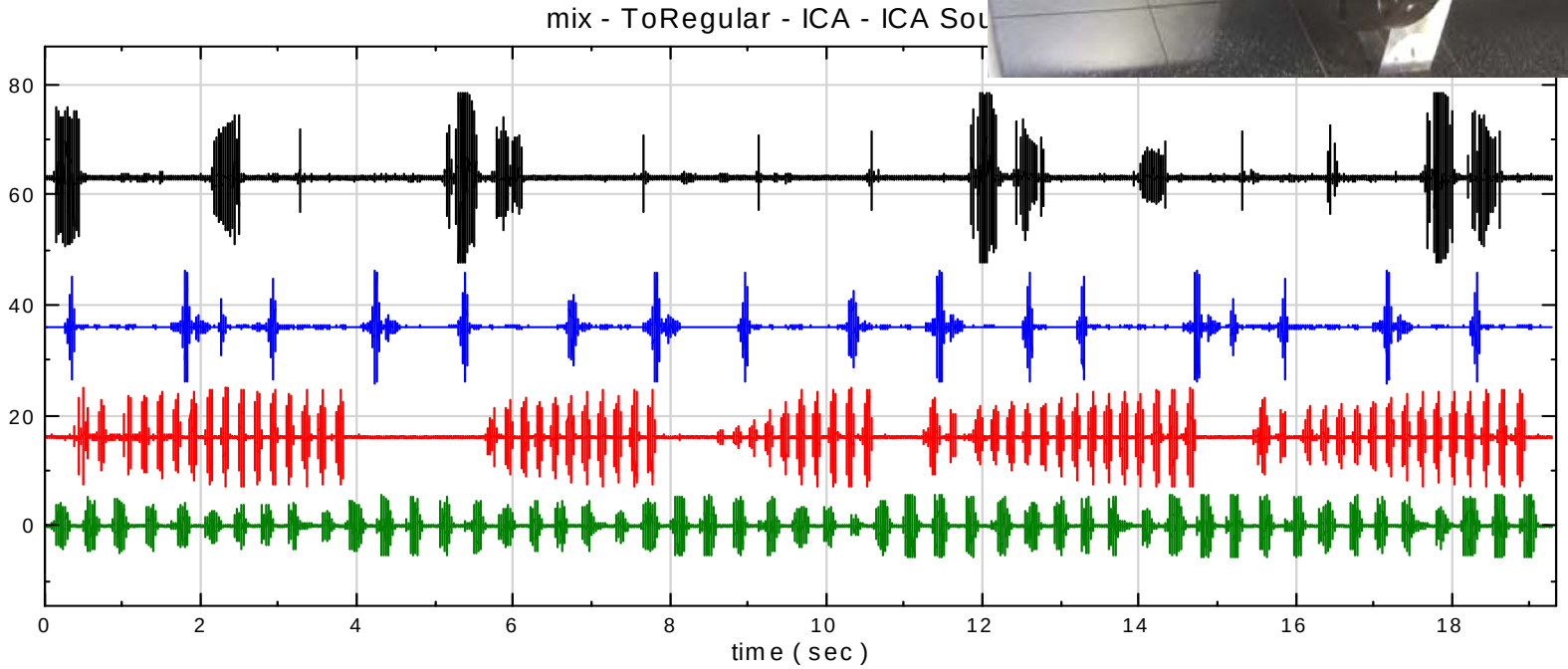
分離前之特徵：Channel 3 & 4





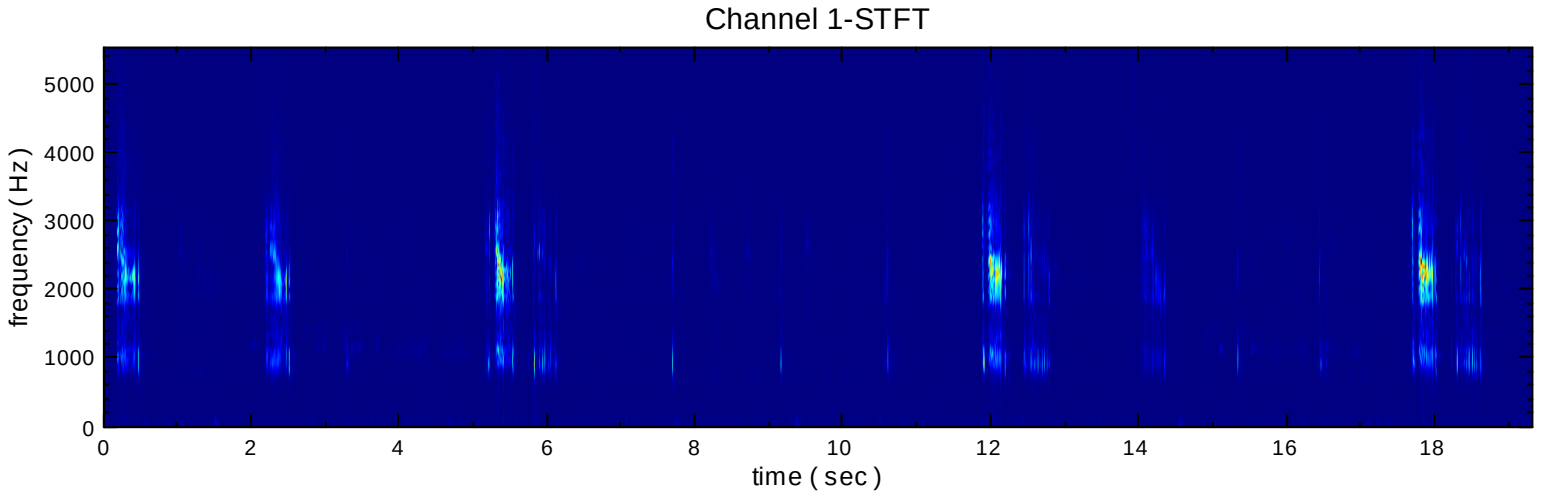
ICA分離 ⇨ 4個獨立振動源

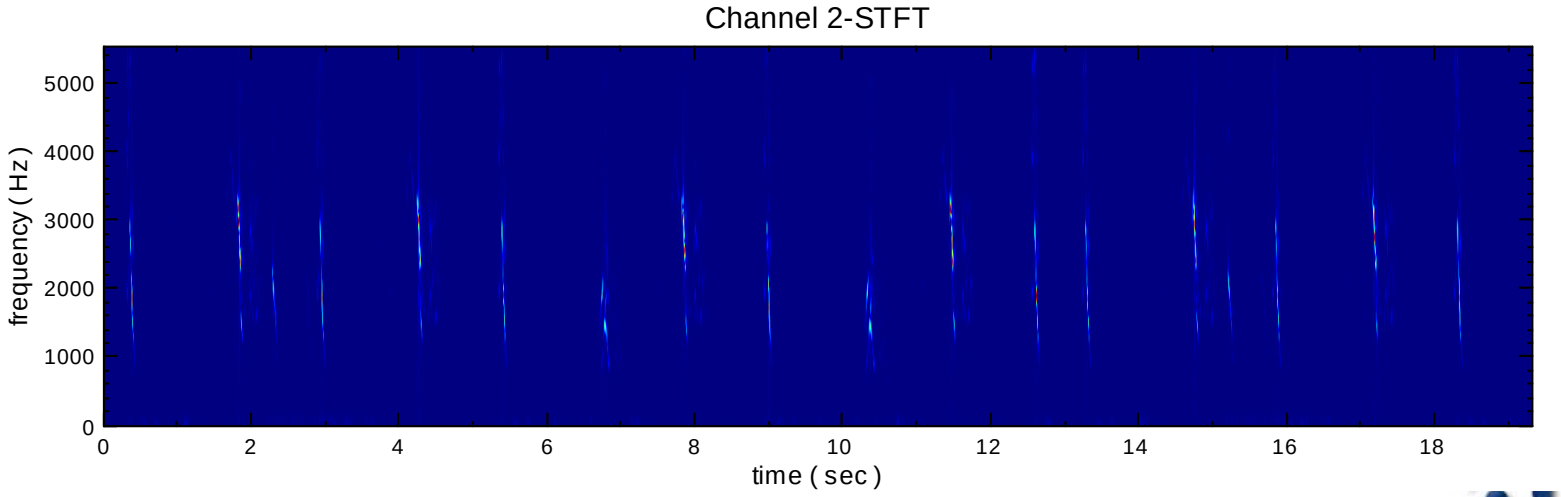




AnCAD

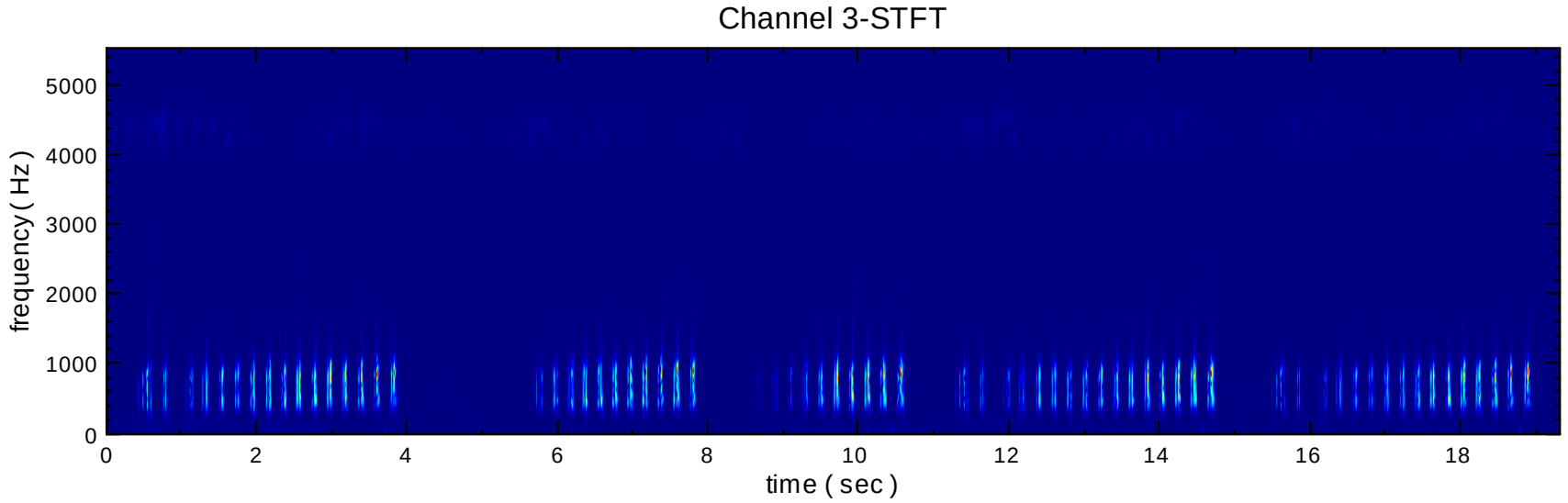
分離後之特徵：Channel 1 & 2

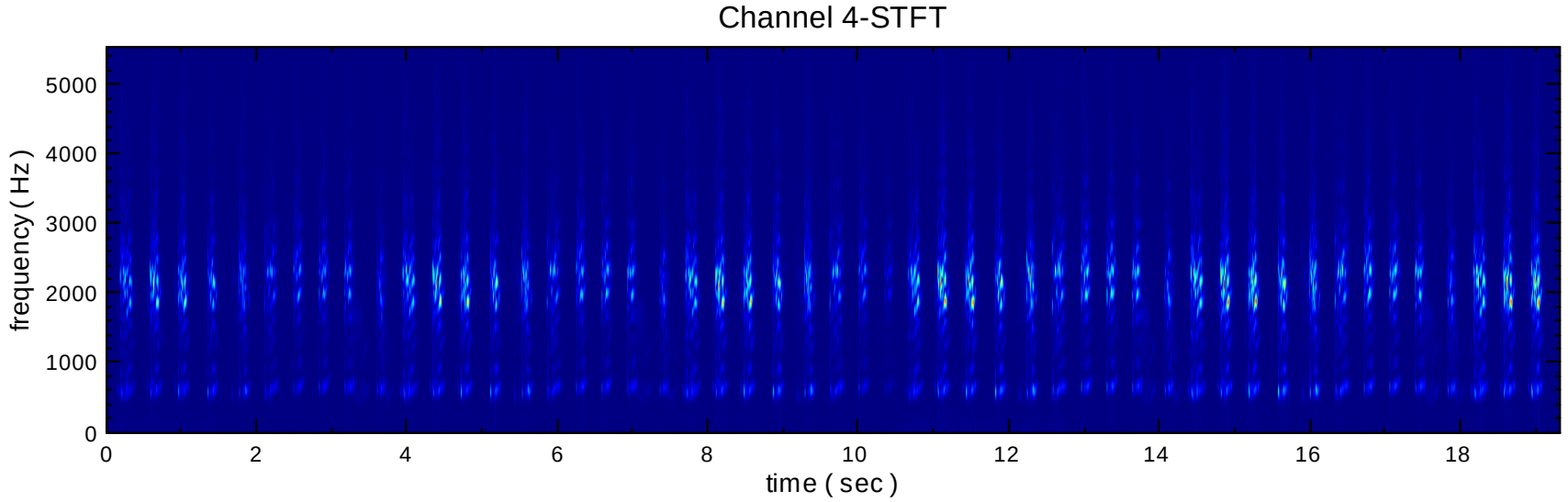




AnCAD

分離後之特徵：Channel 3 & 4





Applications

應用實例：系統整合平台

應變儀

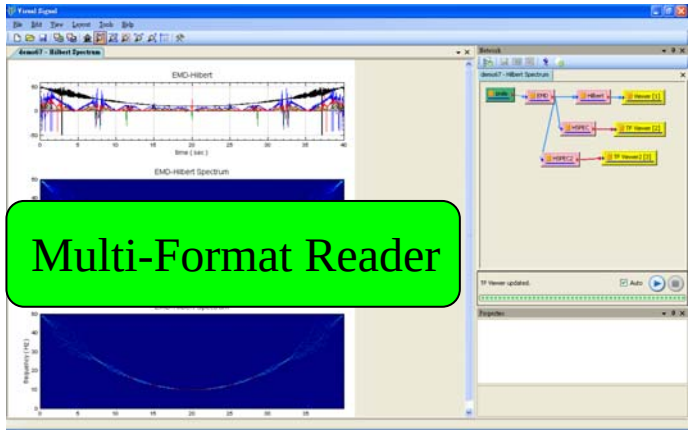
應變規
格式

振動儀

振動儀
格式

轉速計

轉速計
格式



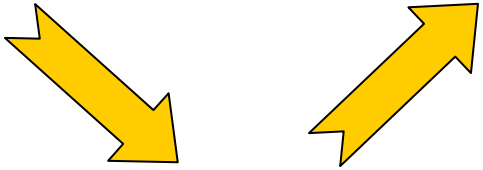
Visual Signal 分析

PC-based整合式主軸量測分析平台

- 受限於各儀器規定之檢測流程
- 關鍵檢測技術受制於國外儀器廠商

- 振動分析儀
- 平衡機
- 橫式動平機
- 溫昇跑合台
- 剛性檢測機

- 內藏式主軸
- 皮帶式主軸
- 直結式主軸



- 自訂檢測流程
- 自主開發關鍵檢測技術
- 系統整合與擴充之彈性高

PC-based整合式量測分析平台：

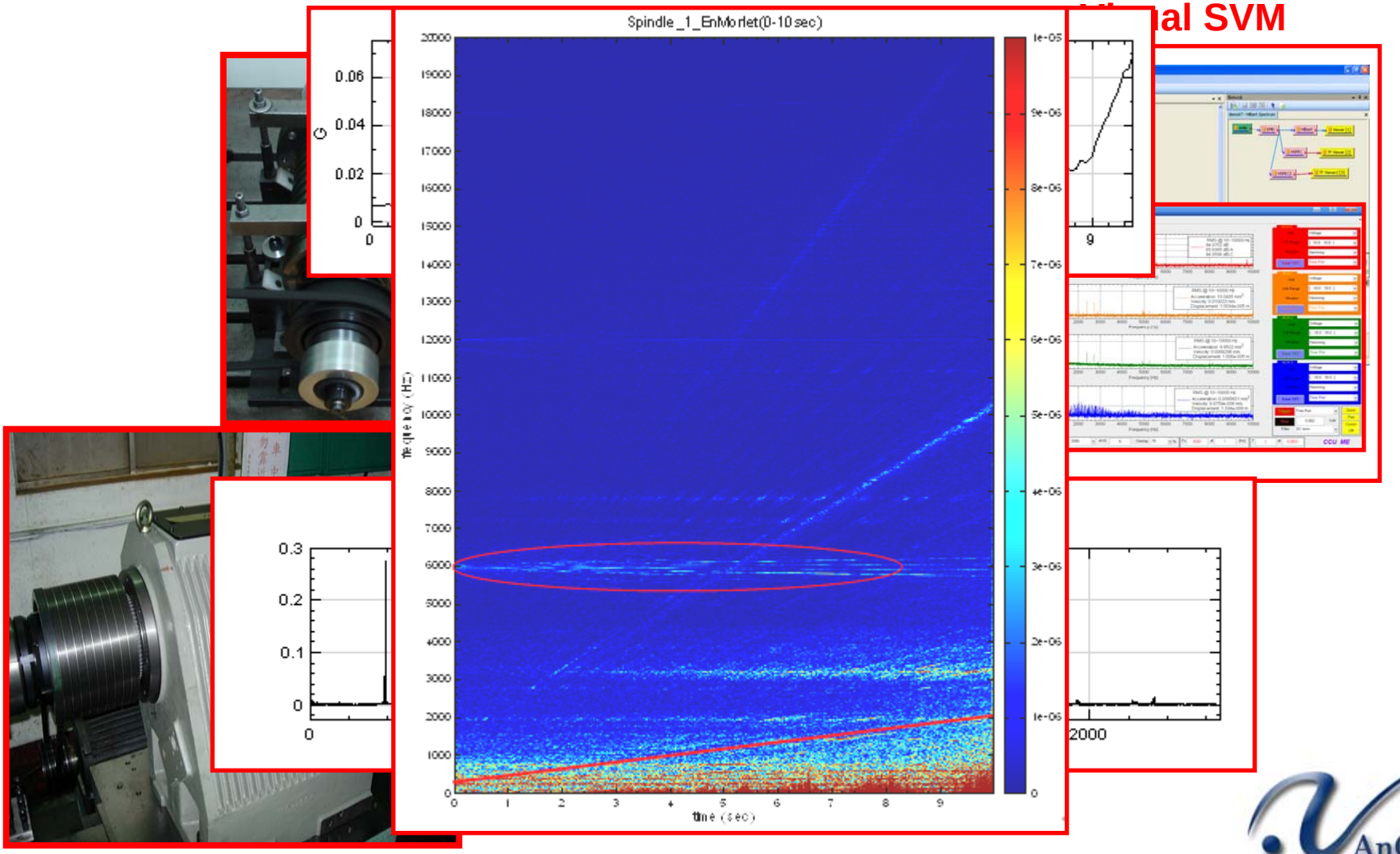
✓各式主軸之複合檢測平台

✓主軸品質檢測軟、硬體之整合

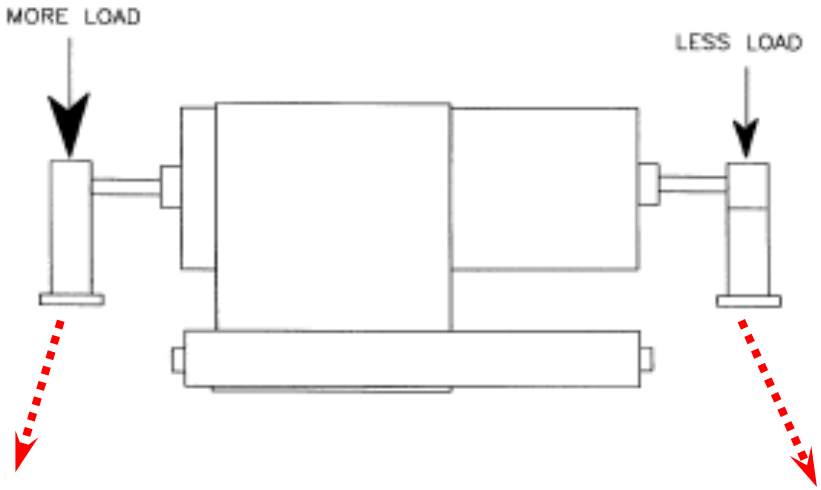
✓各式主軸故障特徵資料庫之建立

AnCAD

應用實例：主軸 QA 檢測系統

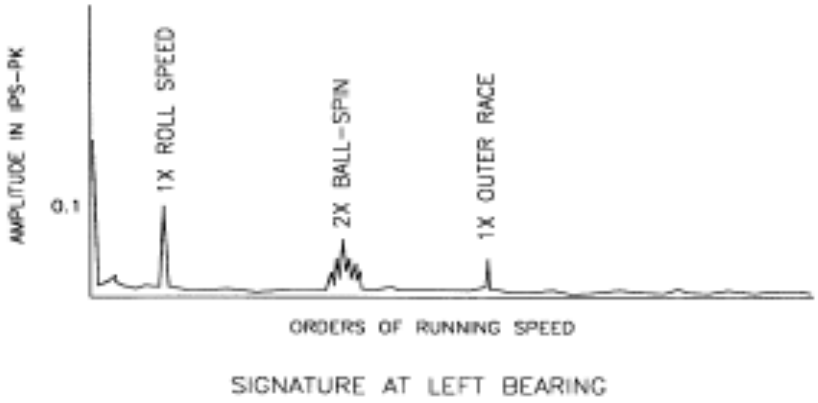


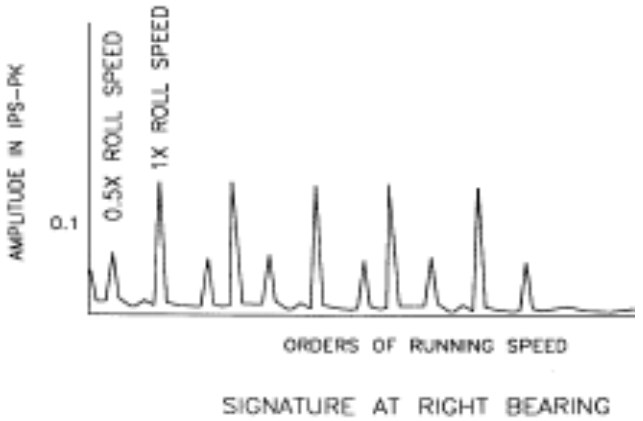
應用實例：主軸之軸承裝配檢測



受力較大：軸承相關之高頻振動

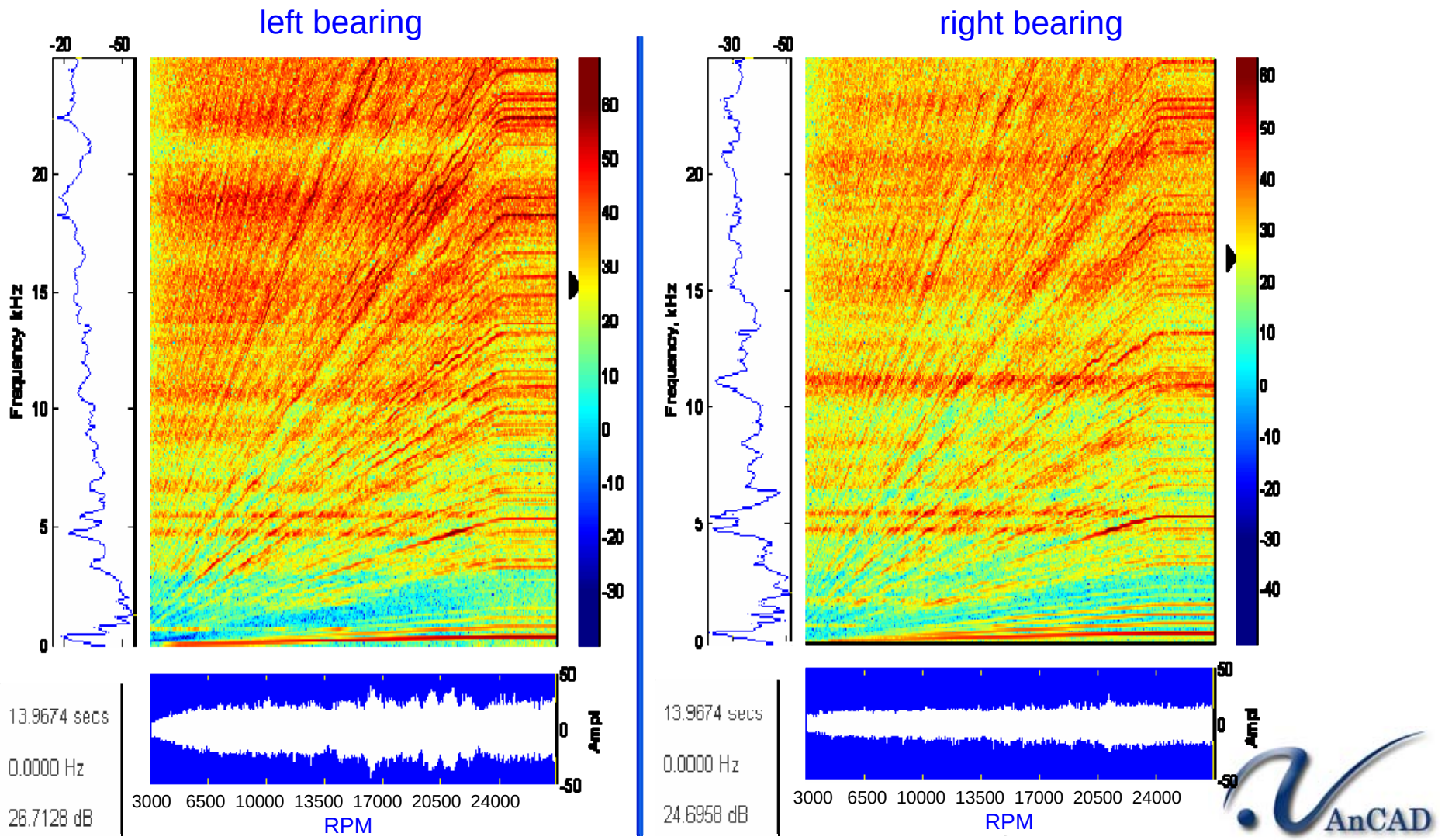
受力較小：轉速相關之低頻振動



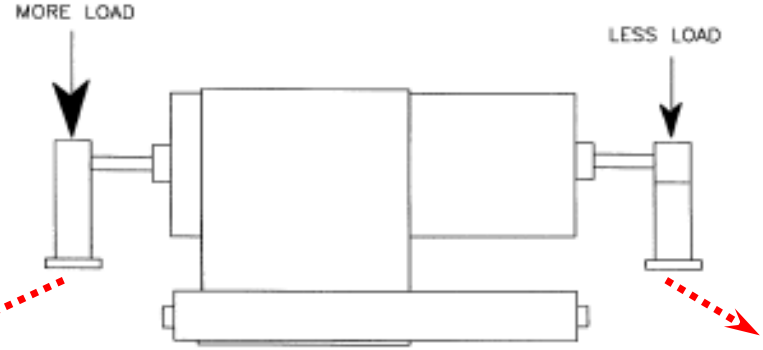


AnCAD

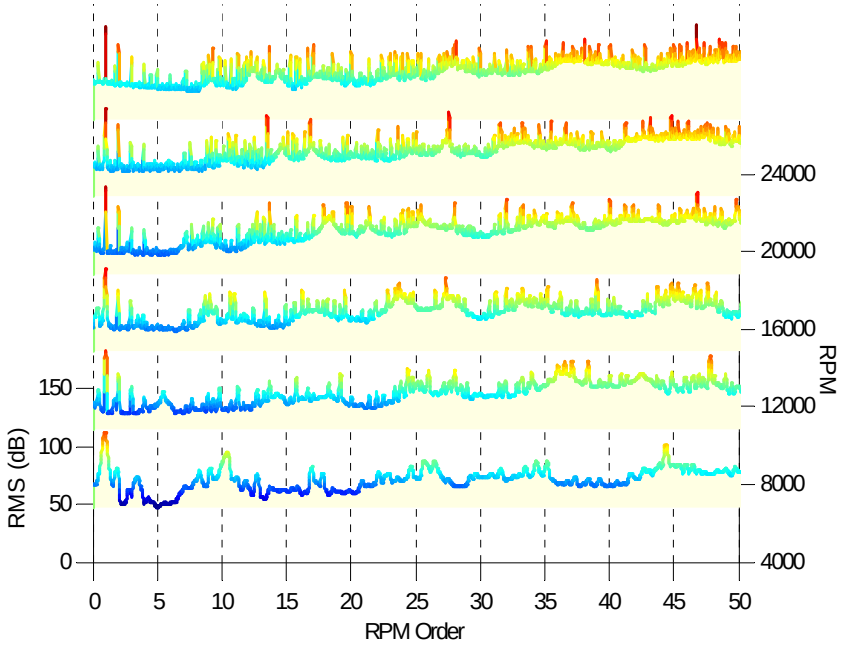
應用實例：主軸之變轉速時頻分析



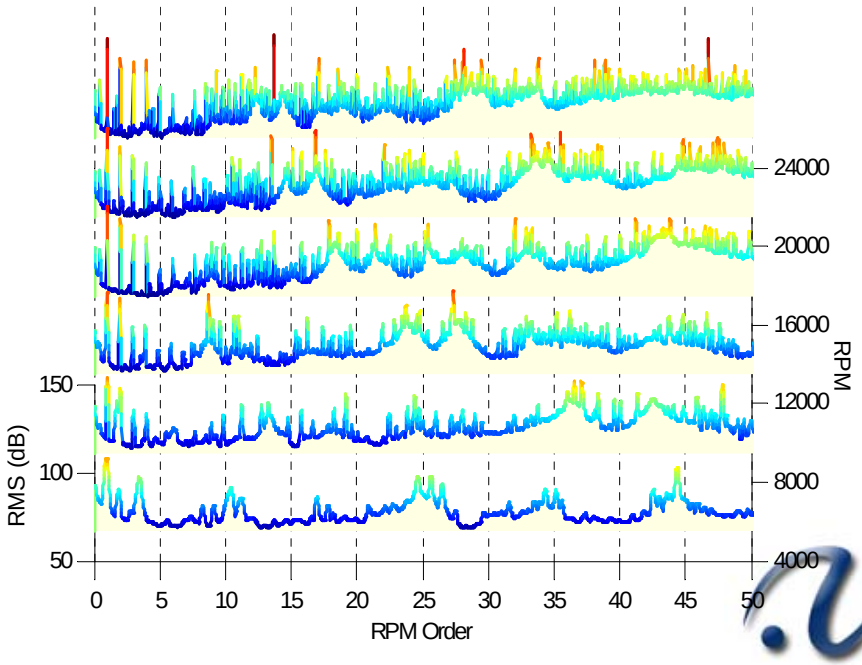
應用實例：主軸之異常轉速倍頻檢測–階次分析



受力較大：軸承相關之高頻振動

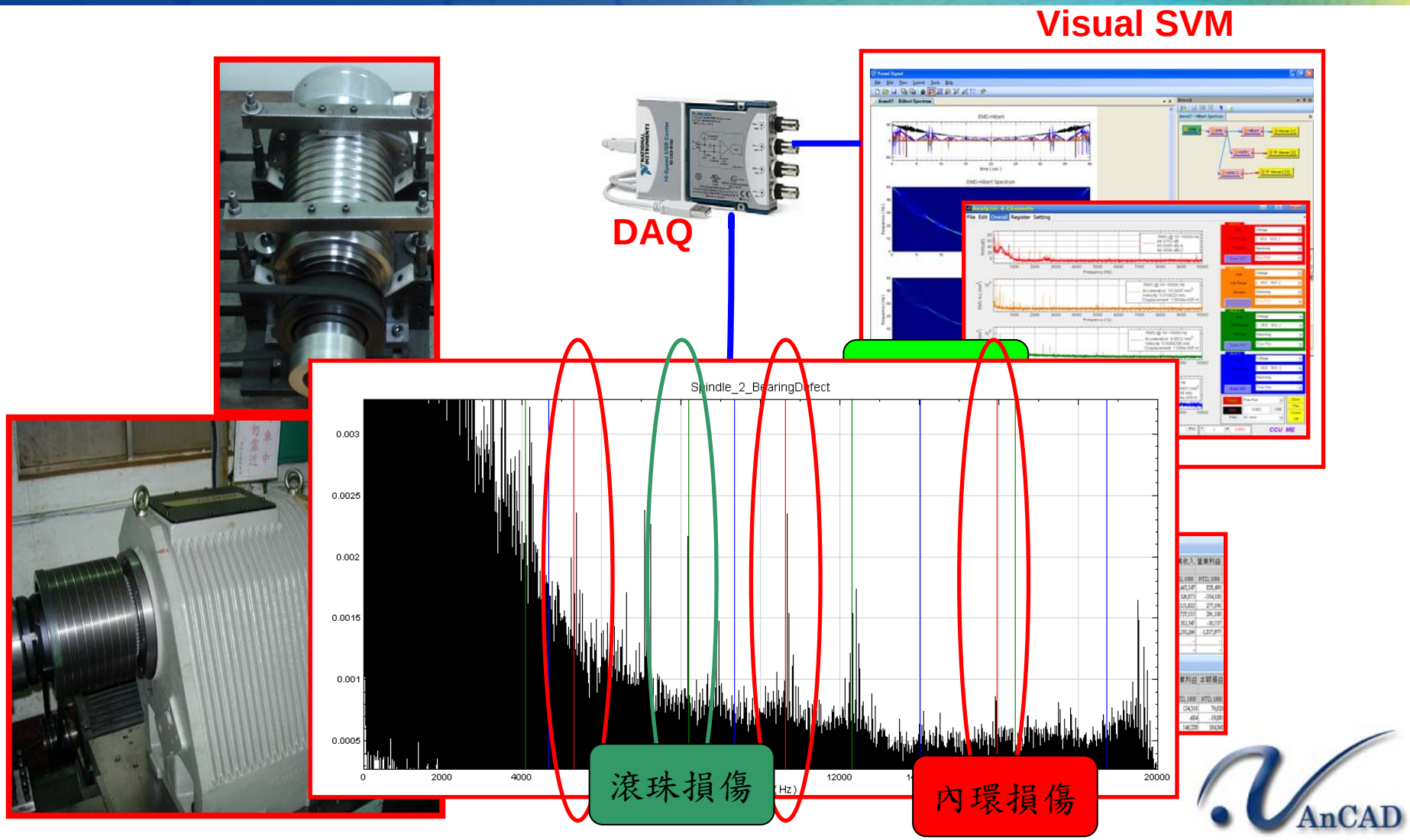


受力較小：轉速相關之低頻振動



AnCAD

應用實例：軸承損壞頻率特徵比對

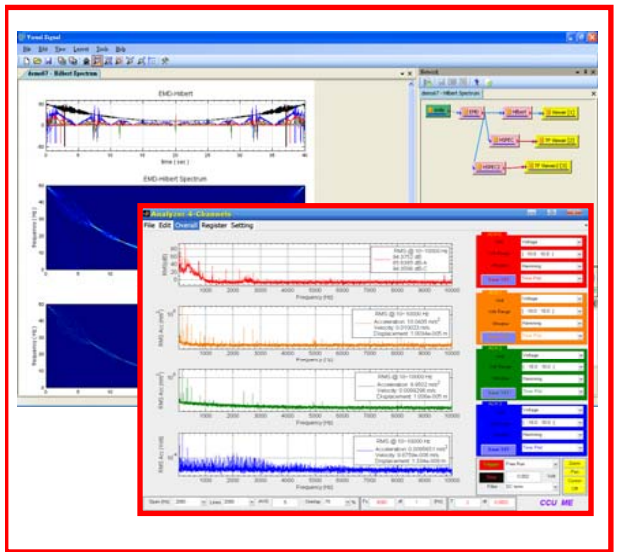


應用實例：齒輪箱異常檢測

Ch3: Acc. (m/s²)

Ch2: Acc. (m/s²)

NI DAQ



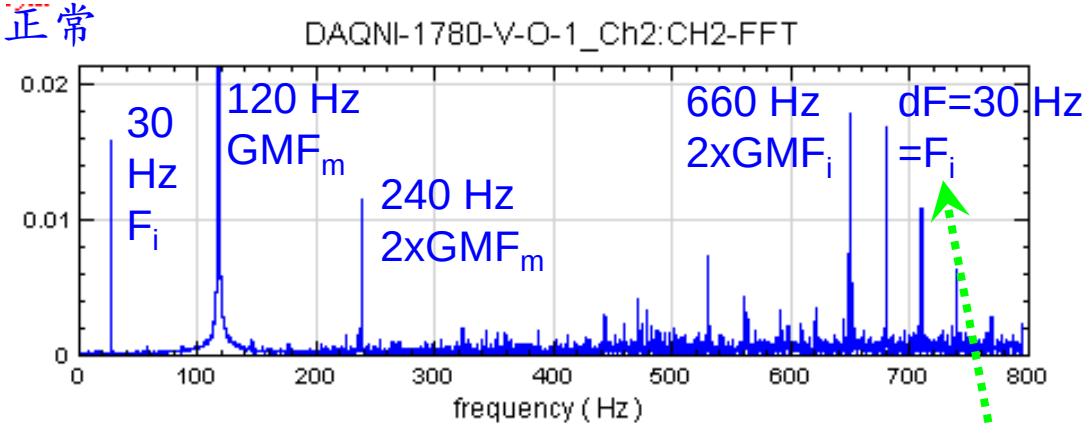
Ch1: Mic. (Pa)

聲壓　　轉速
加速度　溫度
位移　　扭力…

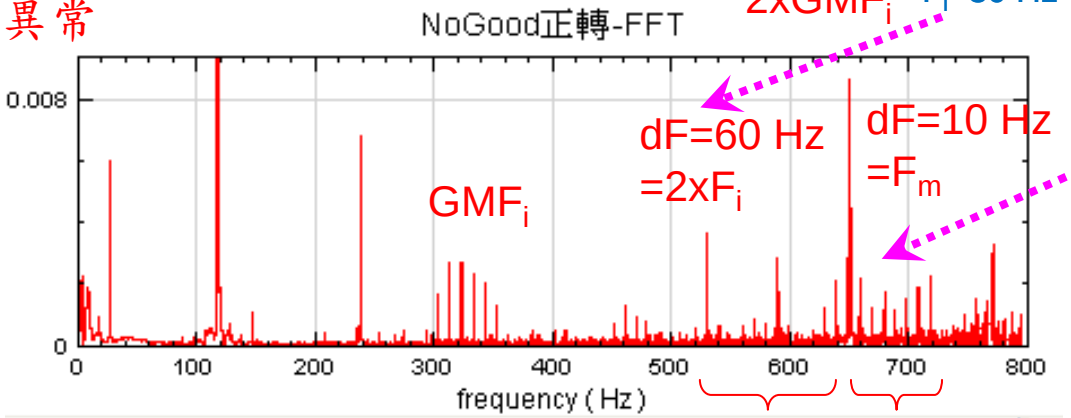
AnCAD

正常vs.異常齒輪箱振動訊號：頻譜比較

正常



異常



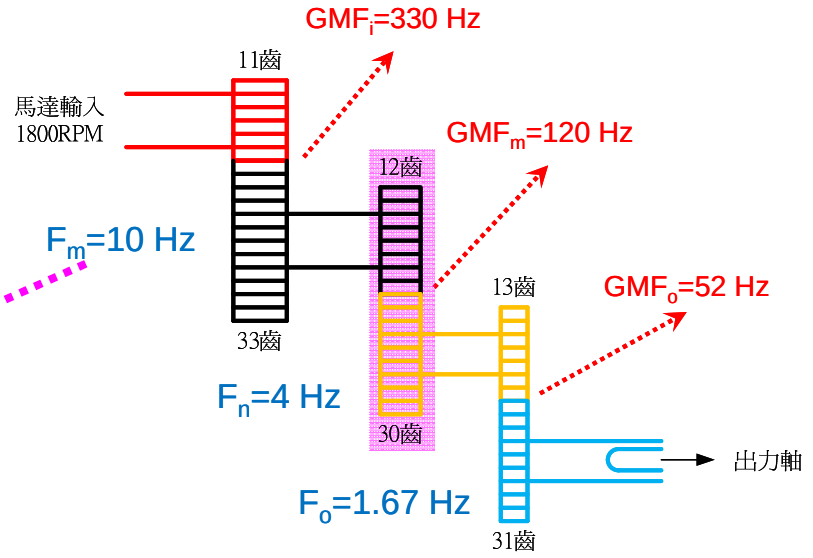
$2xGMF_i$ F_i=30 Hz

F_m=10 Hz

dF=10 Hz
$=F_m$

i軸鬆脫
不對心

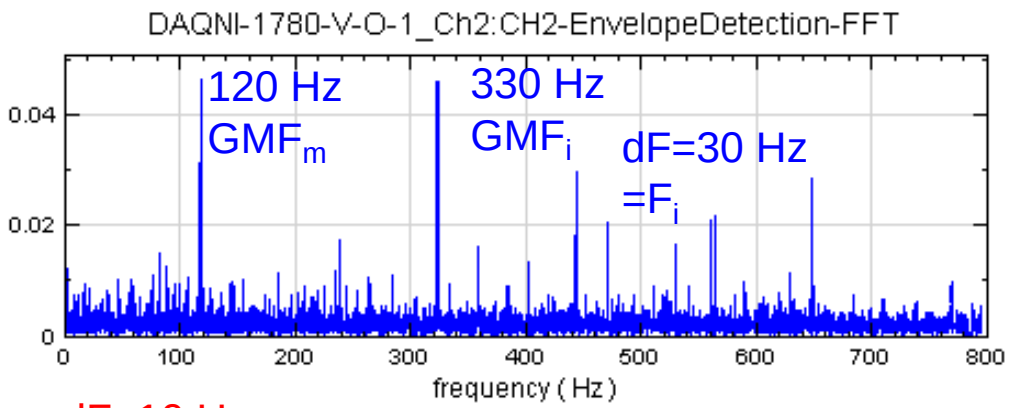
m軸
偏心

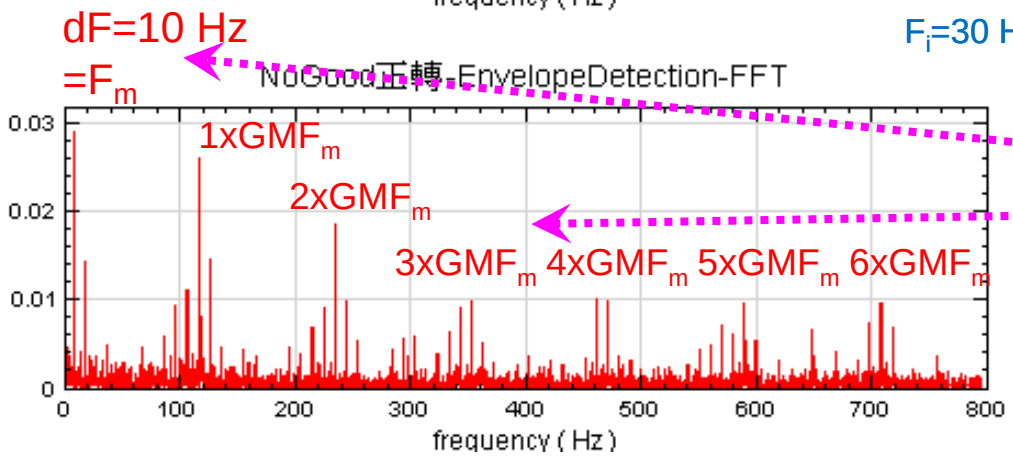


AnCAD

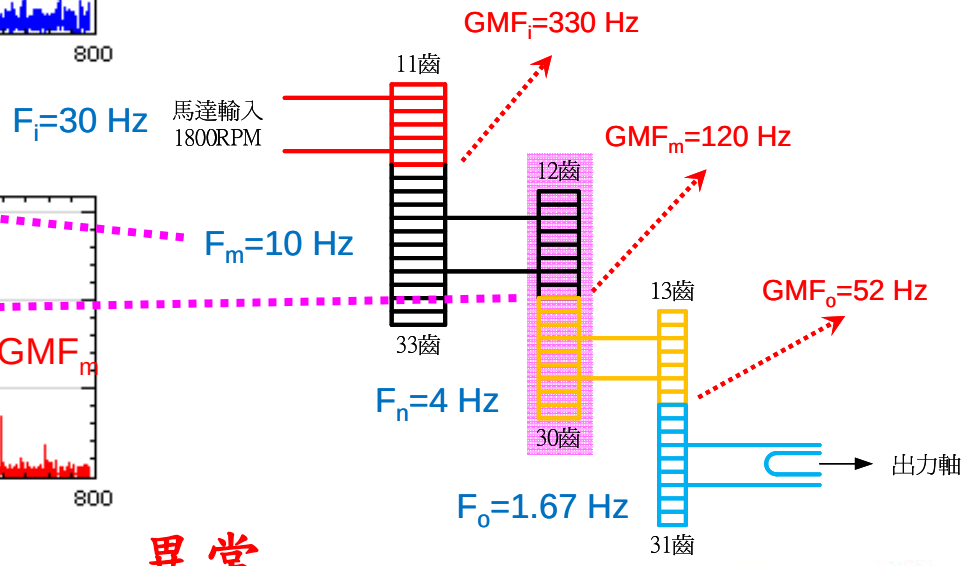
正常 VS. 異常齒輪箱：包絡線頻譜比較

正常





異常



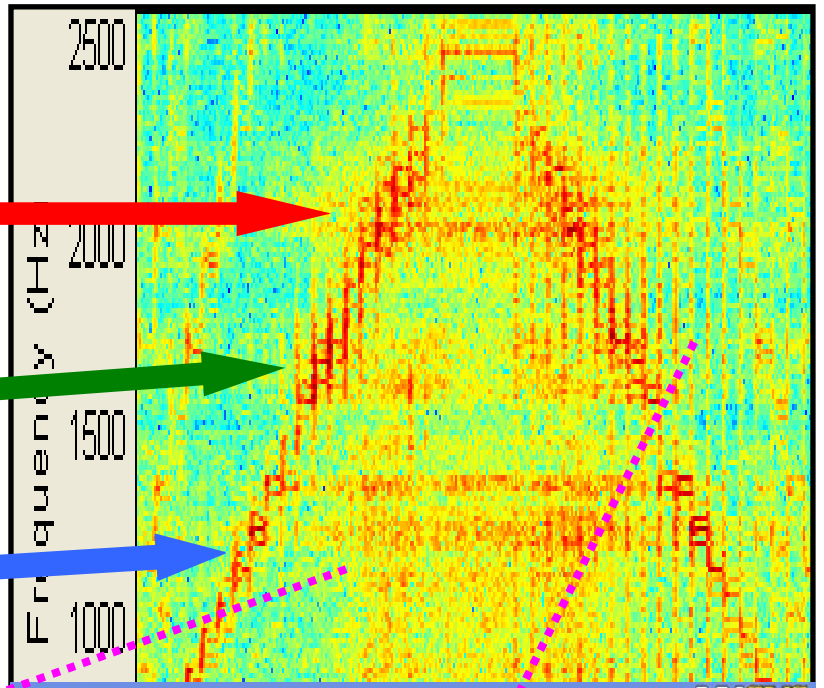
AnCAD

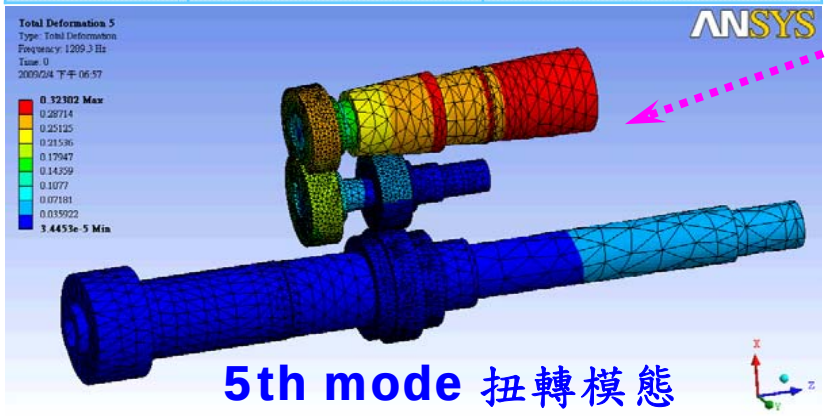
齒輪箱關鍵零組件FEM驗證：模擬⇔量測

FEM模擬結果：

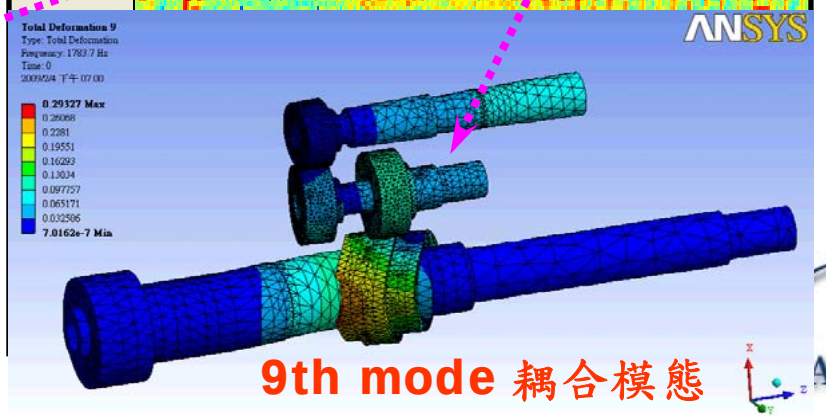
模態	模態形式	自然頻率 (Hz)
12	Coupling	2289
11	Coupling	2176
10	Coupling	2003
9	Coupling	1784
8	Torsion	1541
7	Bending	1421
6	Bending	1415
5	Torsion	1289

量測結果：





5th mode 扭轉模態



9th mode 耦合模態

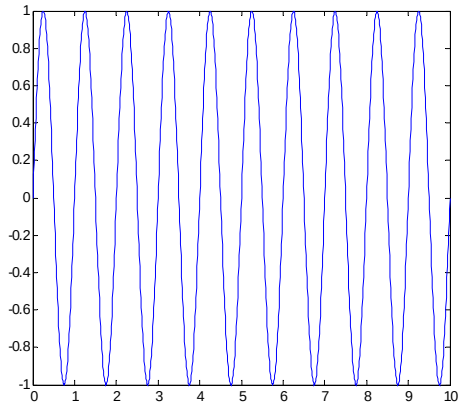
Thank you

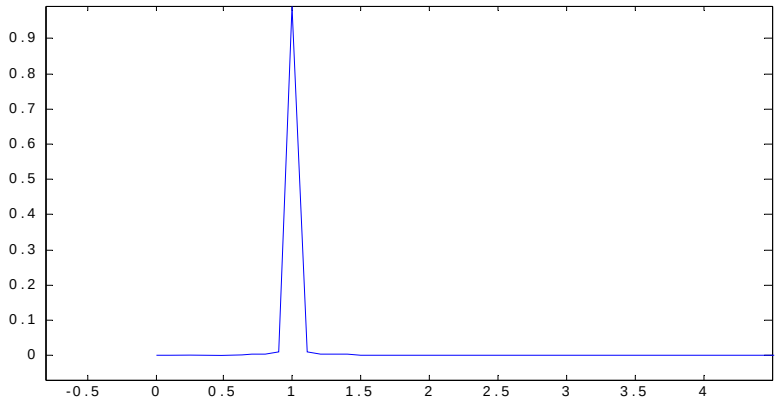
AnCAD

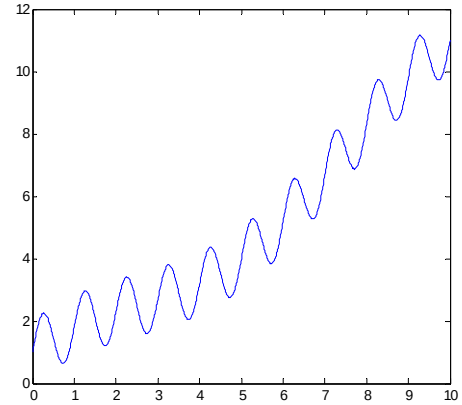
Removal of Non-Periodical Signal

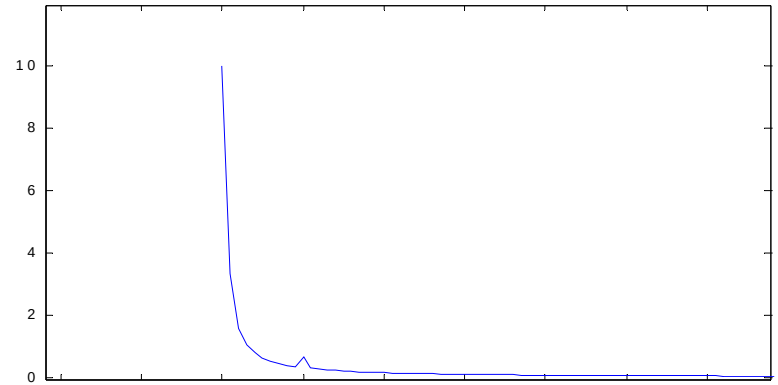
AnCAD

Containmanation of non-periodical Signal



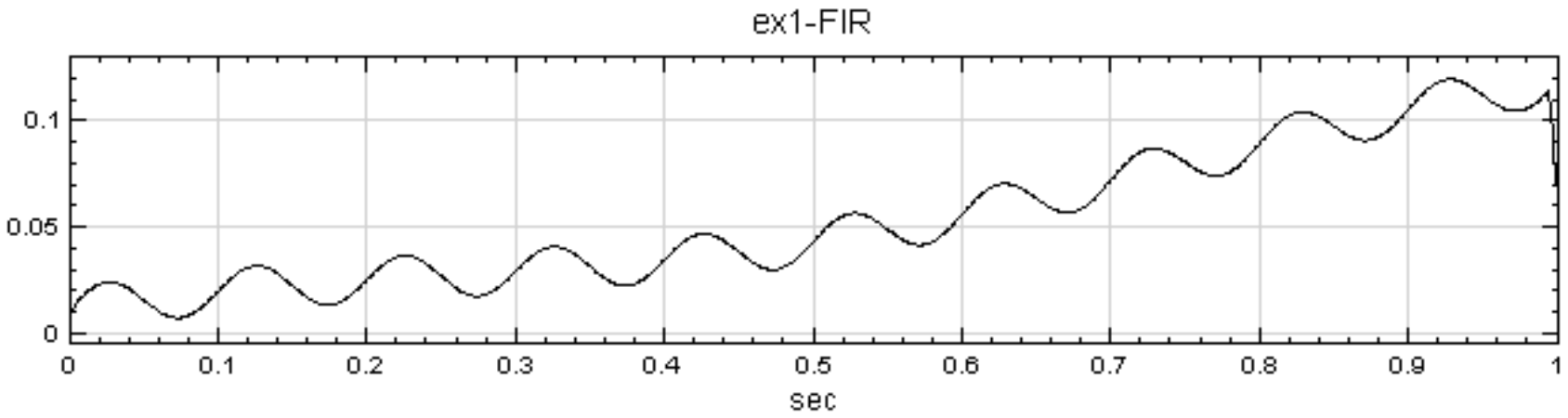


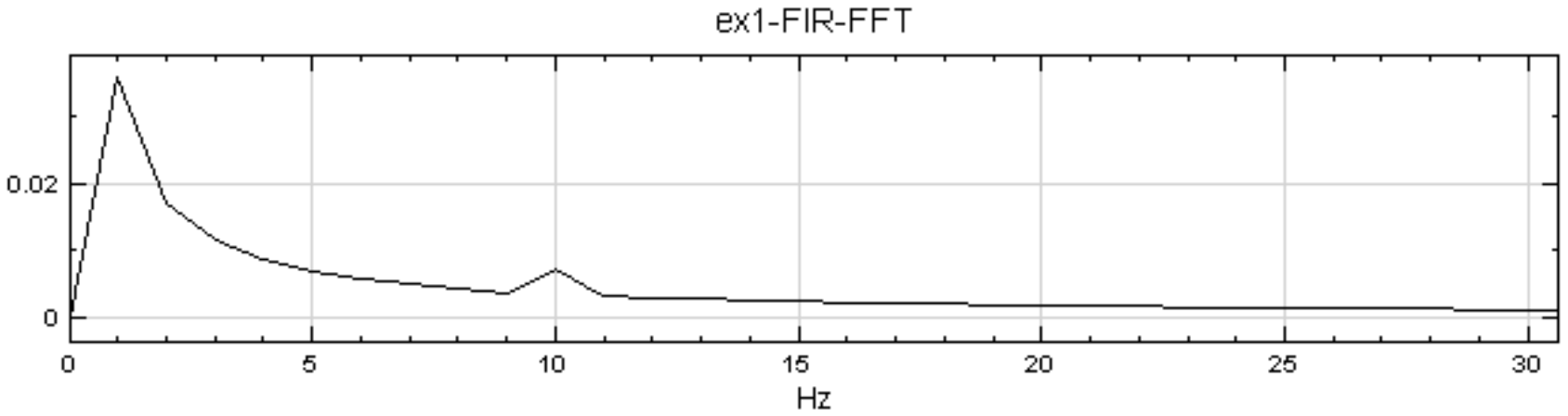




AnCAD

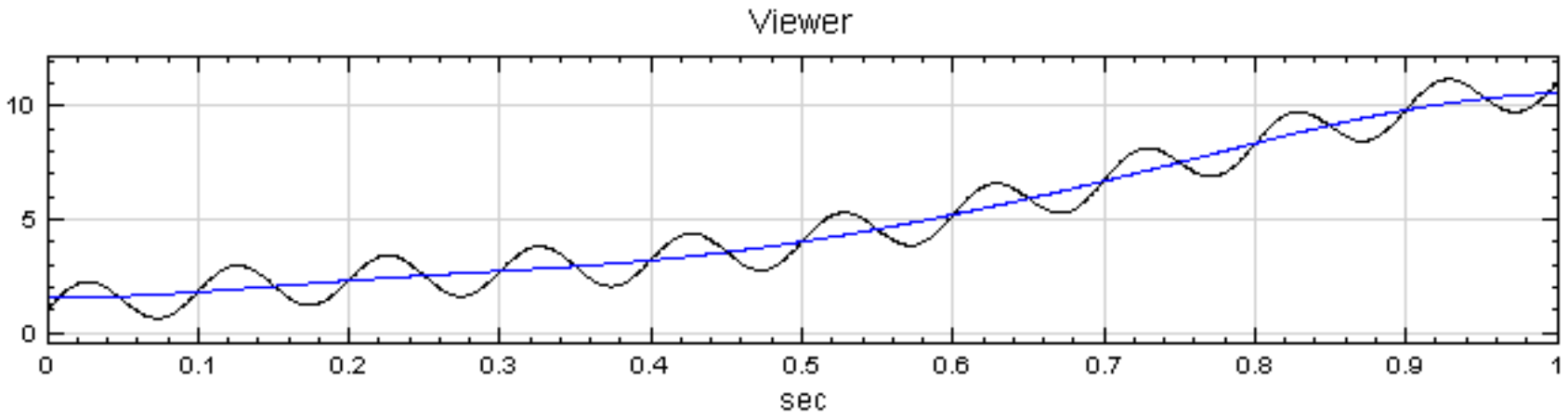
FIR Filter

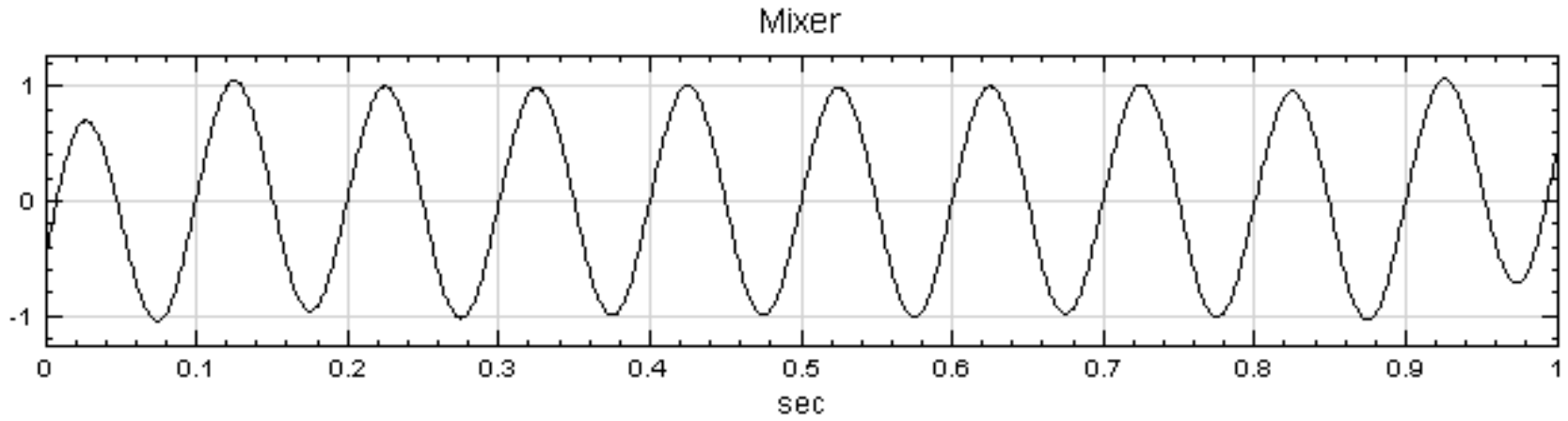




AnCAD

Iterative Gaussian Filter





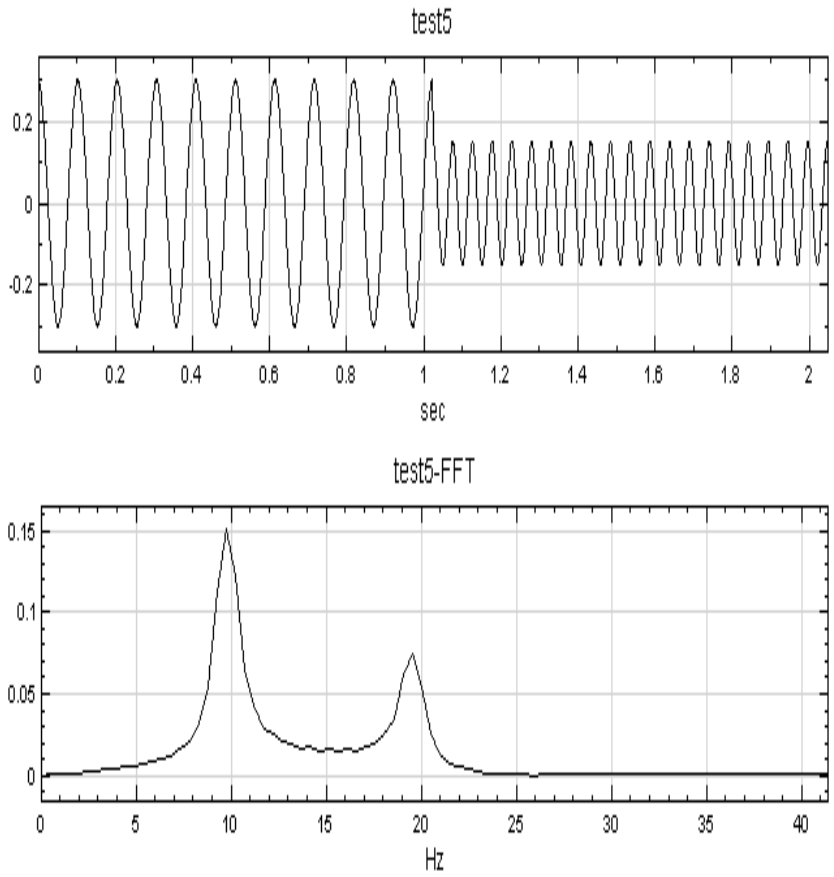
AnCAD

Why Time-Frequency Analysis (TFA)?

AnCAD

Is FFT good enough for you?

- With only FFT, we cannot see the frequency/amplitude change with time.

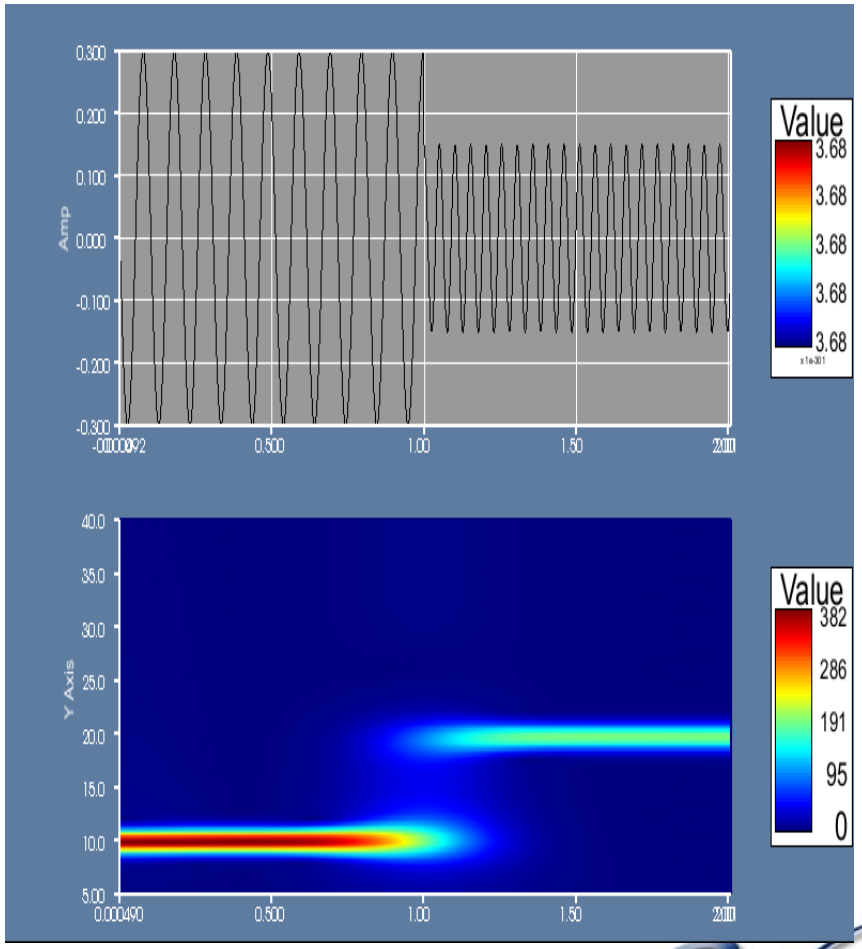


AnCAD

TF Plot: Change of frequency and amplitude

- Signal with abrupt change of frequency and amplitude

$$x(t) = \begin{cases} 0.30\cos(2\times 10\pi t) & ,0 \le t < 1 \\ 0.15\cos(2\times 20\pi t) & ,1 \le t < 2 \end{cases}$$



AnCAD

TFA in Visual Signal

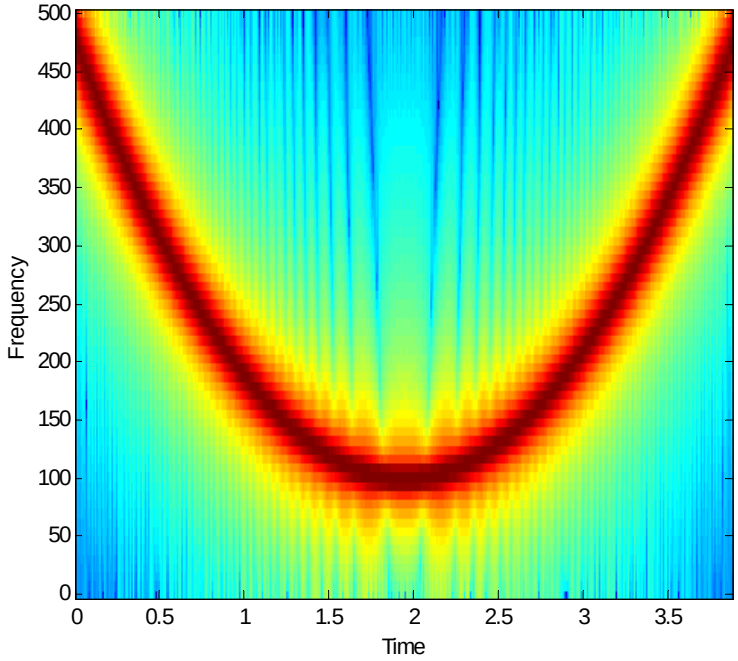
- Short-Term Fourier Transform (Spectrogram)
- Morlet Transform (Wavelet Transform)
- Enhanced Morlet Transform
- Hilbert Transform
- Hilbert-Huang Transform

AnCAD

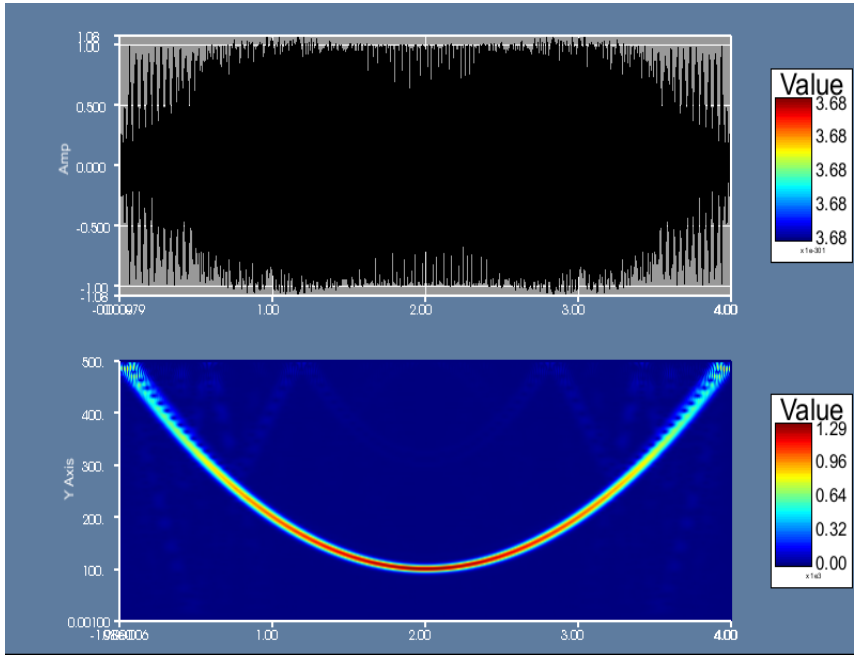
Enhanced Morlet Transform

AnCAD

Quadratic Chirp Signal



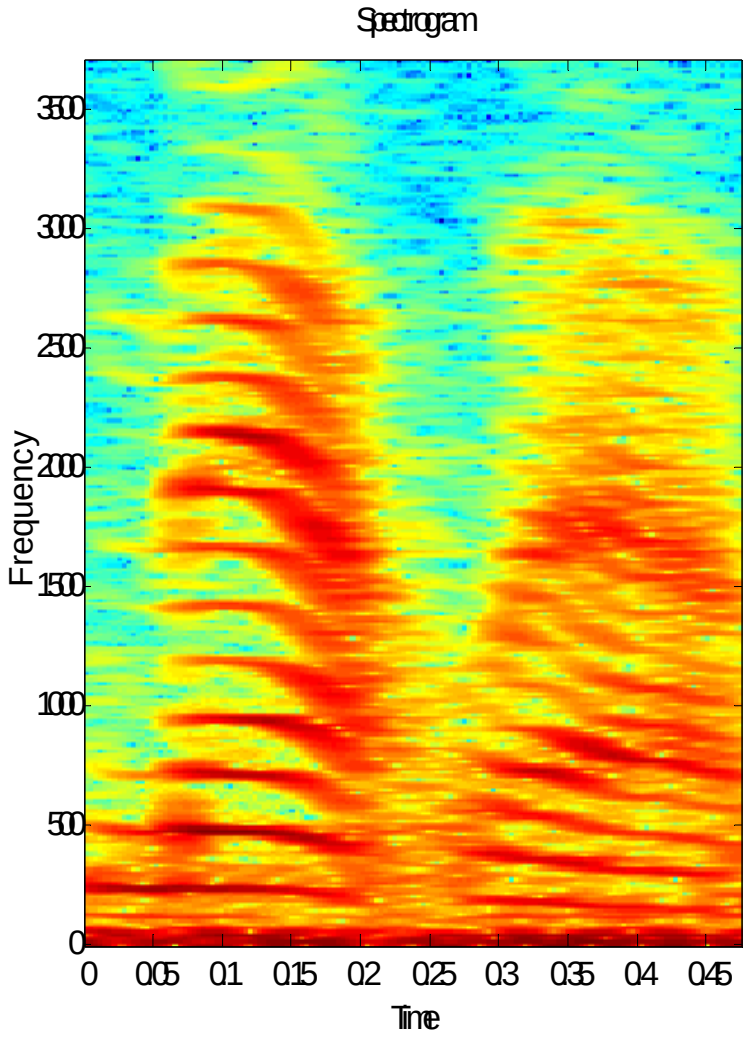
Spectrogram, MATLAB



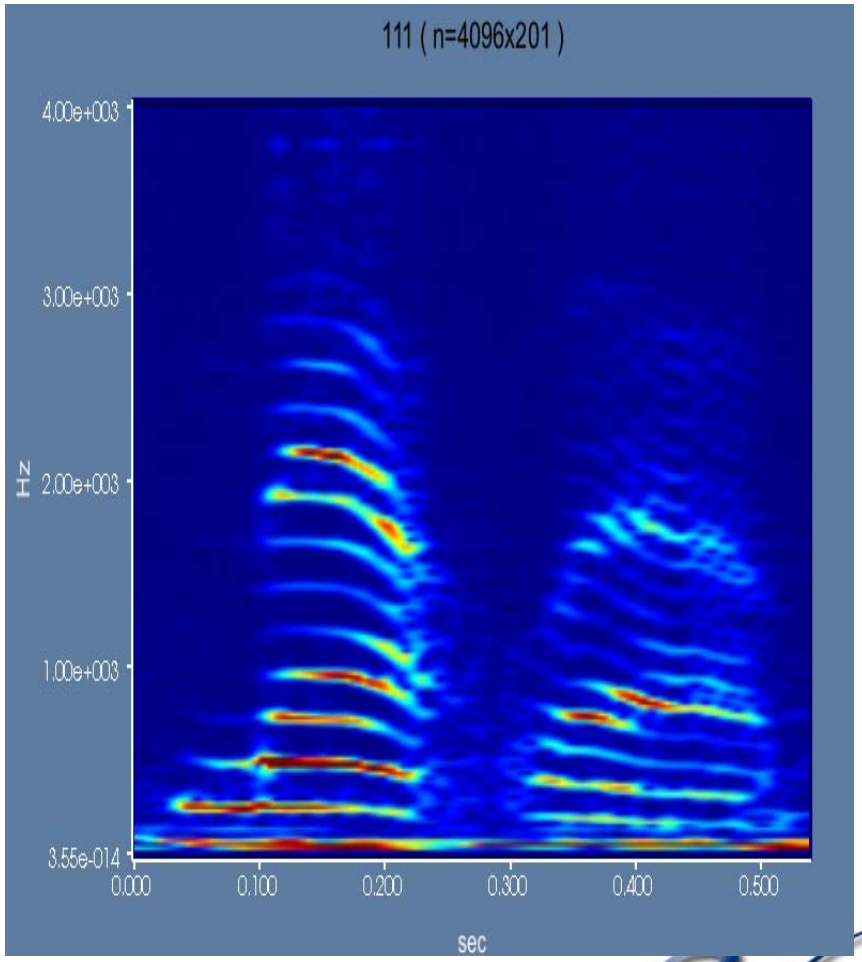
Morlet-Jeng, MATFOR

AnCAD

Voice “MATLAB”



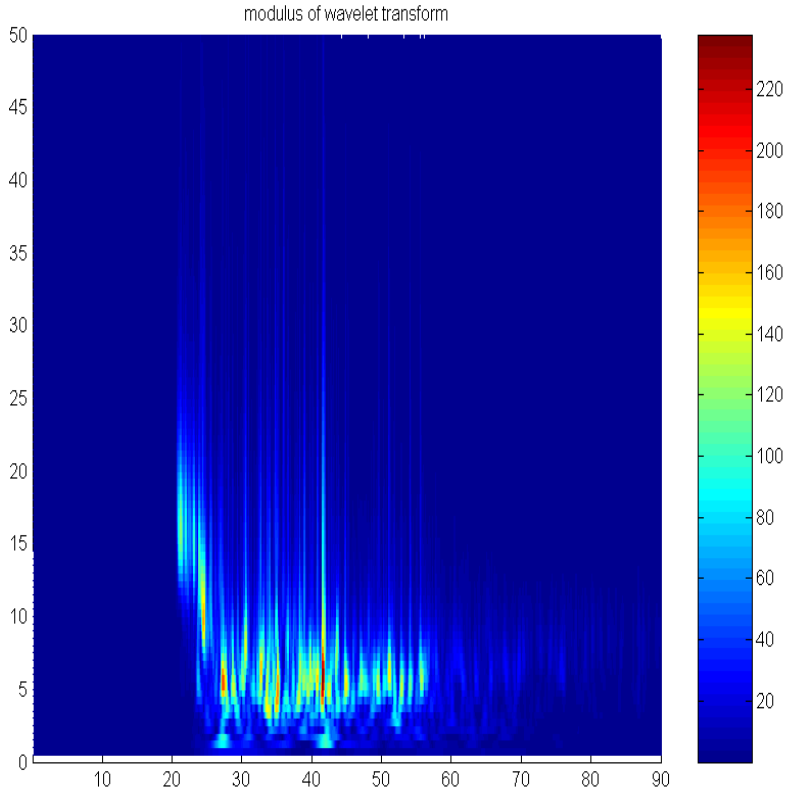
Spectrogram



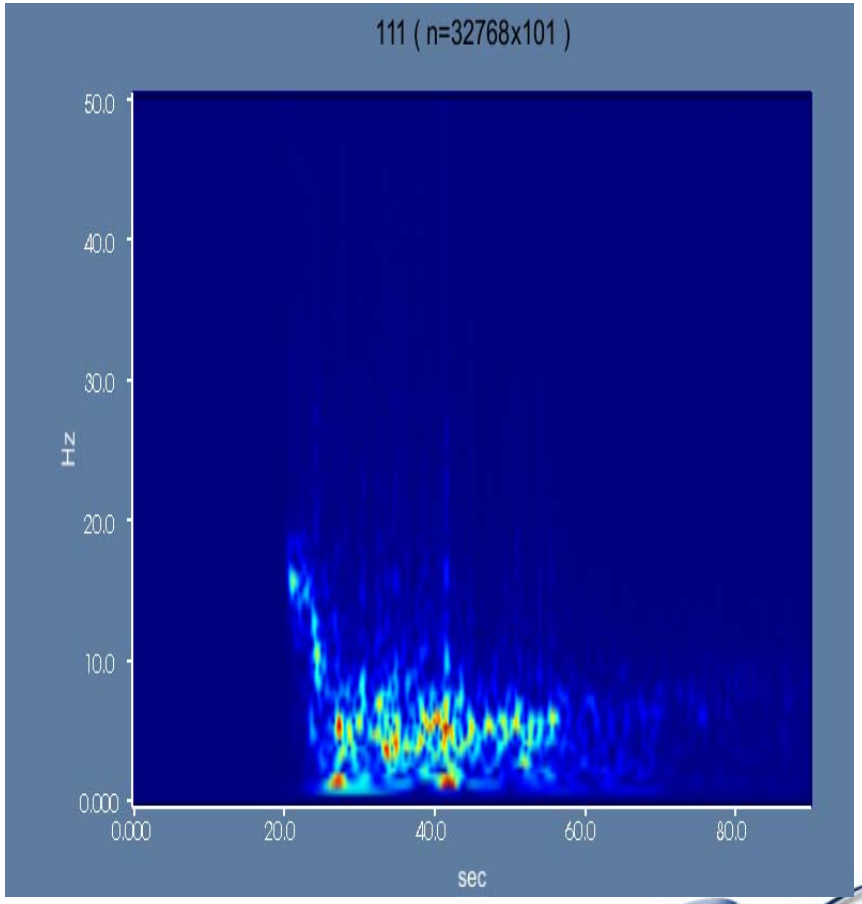
Morlet-Jeng Transform

AnCAD

Chi-Chi (921) Earthquake



Morlet Transform by MATLAB



Morlet-Jeng Transform

AnCAD

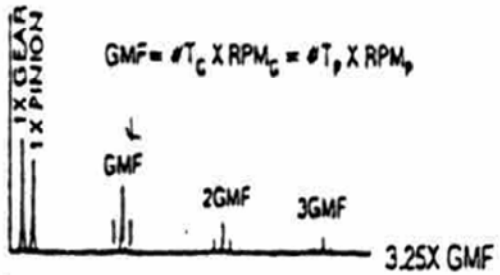
Time-Frequency Analysis Comparison

	Fourier Transform	STFT	Morlet / Enhanced Morlet	Hilbert Transform	HHT
Instantaneous frequency	n/a	distribution	distribution	Single value	Discrete values
Frequency change with time	no	yes	yes	yes	yes
Frequency resolution	good	ok	ok/good	good	good
Adaptive base	no	no	no	n/a	yes
Handling non-linear effect	n/a	no	no	yes	yes

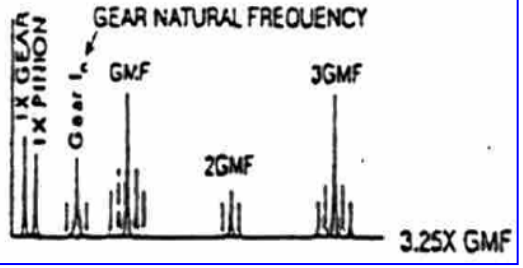
Why SVM? ➔異常檢測：齒輪振動頻譜

GEARS

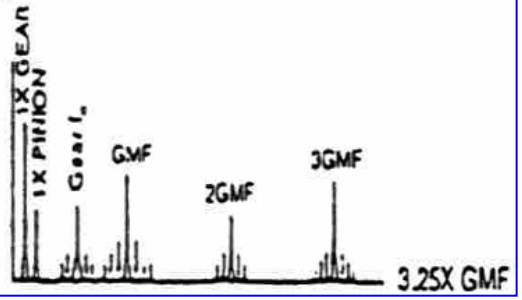
A. NORMAL SPECTRUM



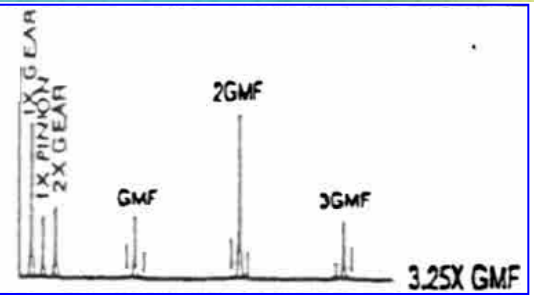
B. TOOTH WEAR



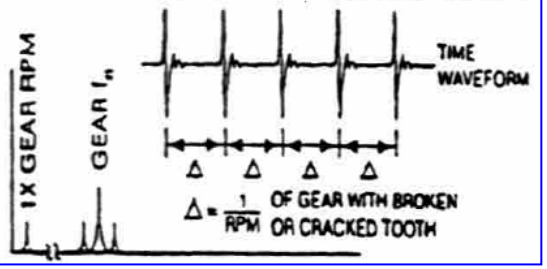
D. GEAR ECCENTRICITY AND BACKLASH



E. GEAR MISALIGNMENT

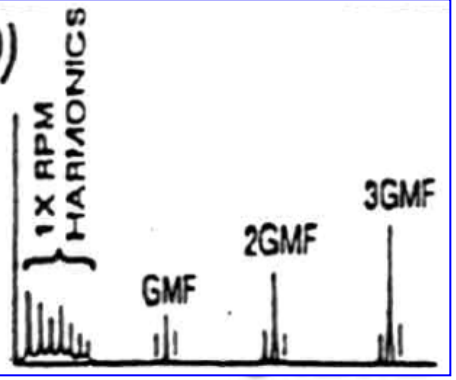


F. CRACKED/BROKEN TOOTH

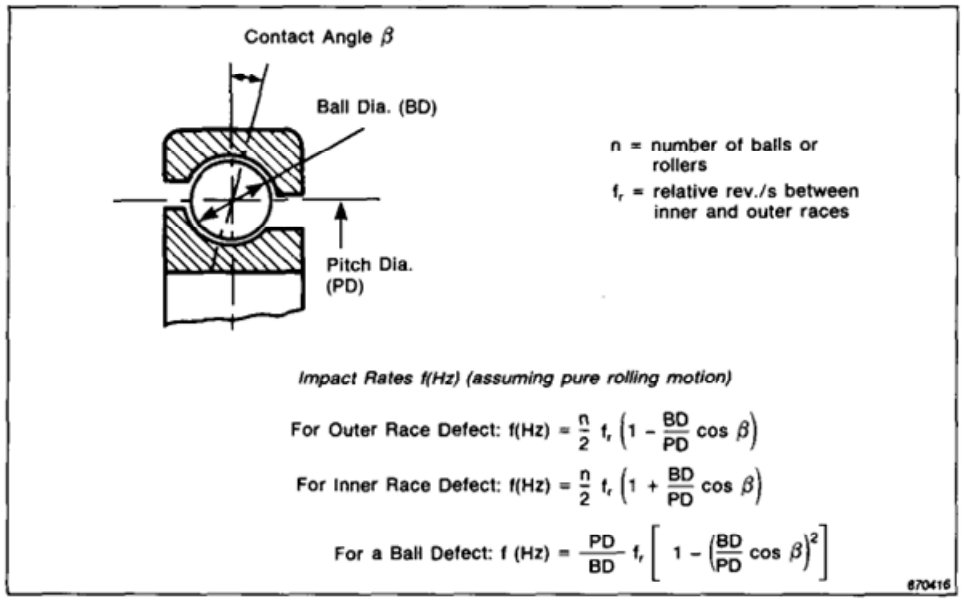


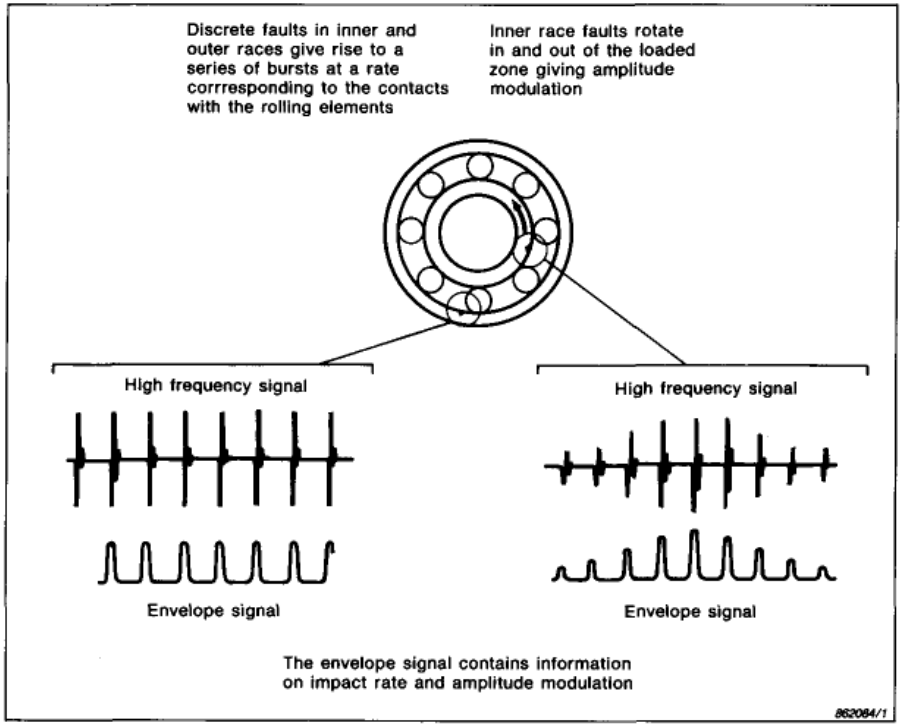
GEARS (CONTINUED)

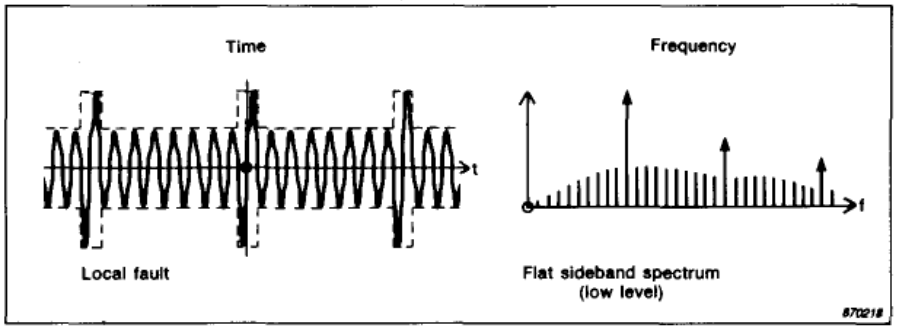
I. LOOSE BEARING FIT

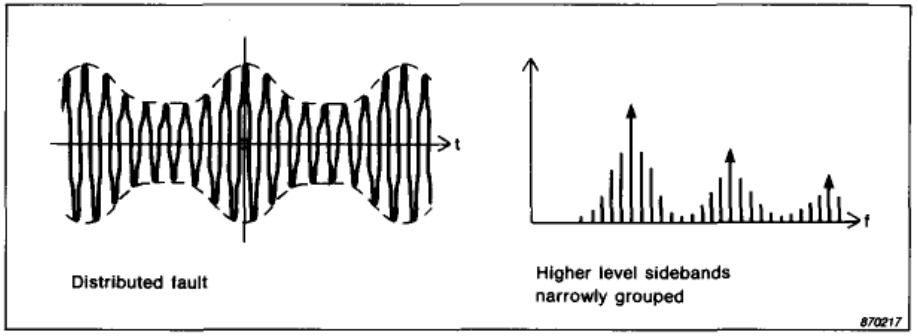


Why SVM? ➔異常檢測：軸承振動頻譜









Why SVM? ➔異常檢測：軸承磨損

$$BPFI = \frac{Nb}{2}\left(1 + \frac{Bd}{Pd}\cos\theta\right) \times \text{rpm}$$

$$BPFO = \frac{Nb}{2}\left(1 - \frac{Bd}{Pd}\cos\theta\right) \times \text{rpm}$$

$$FTF = \frac{1}{2}\left(1 - \frac{Bd}{Pd}\cos\theta\right) \times \text{rpm}$$

$$BSF = \frac{Pd}{2Bd}\left[1 - \left(\frac{Bd}{Pd}\right)^2 (\cos\theta)^2\right] \times \text{rpm}$$

Nb = Number of Balls or Rollers
Bd = Ball / Roller diameter (inch or mm)
Pd = Bearing pitch diameter (inch or mm)
θ = Contact angle in degrees

BPFI = Ball pass frequency – Inner
BPFO = Ball pass frequency – Outer
FTF = Fundamental train frequency (Cage)
BSF = Ball spin frequency (rolling element)

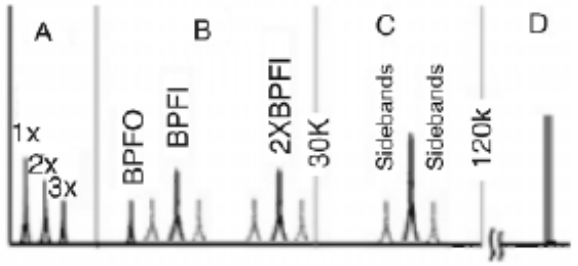


Figure 5.46
Wear is now clearly visible over the breadth of the bearing

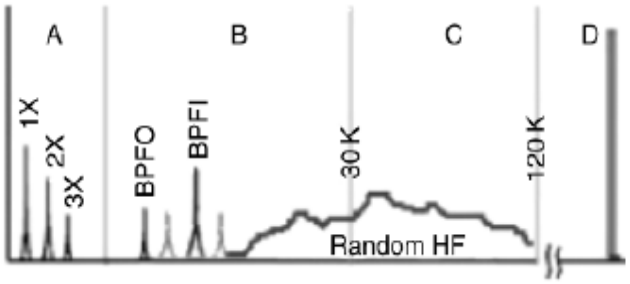
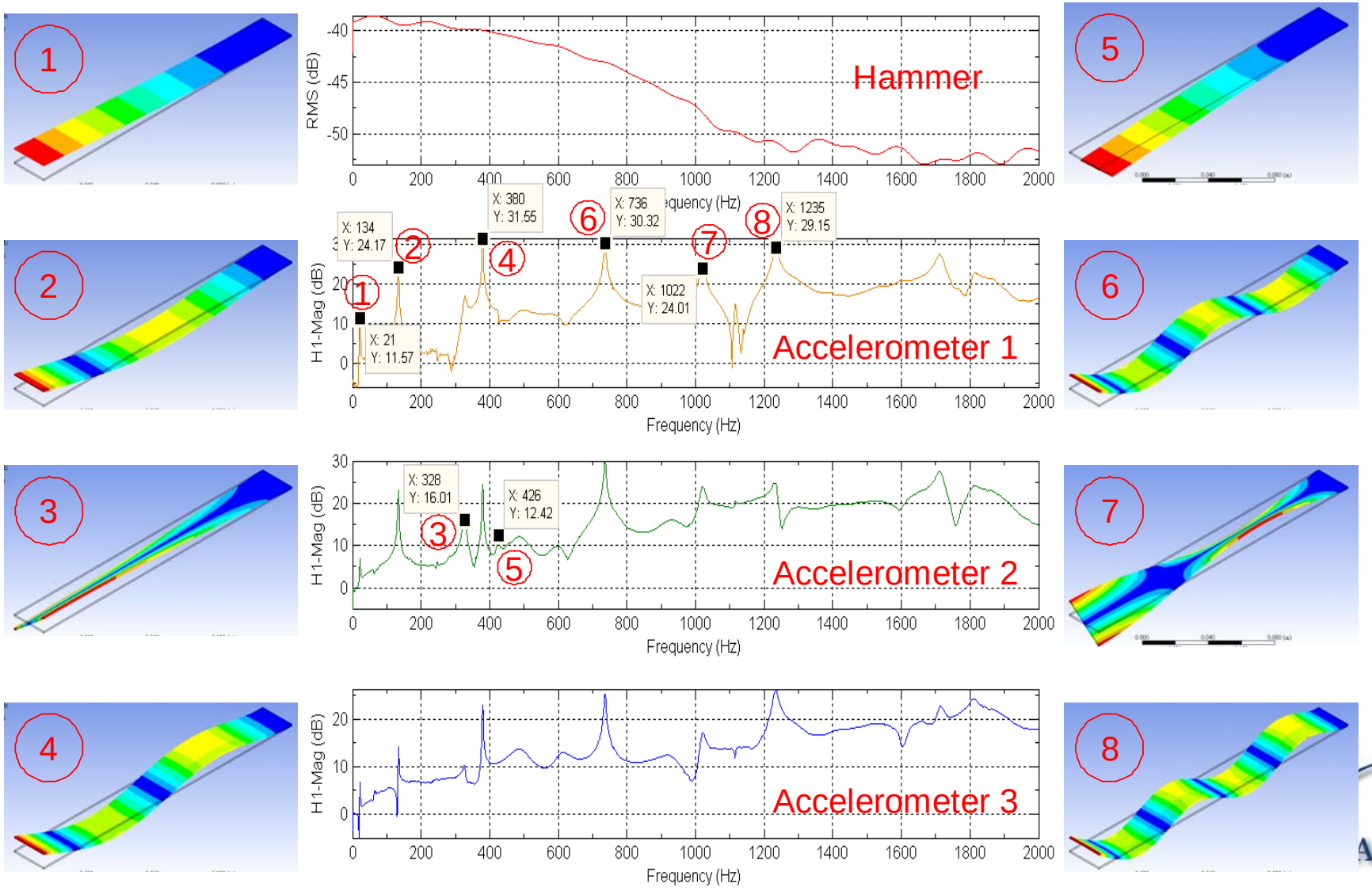


Figure 5.47
Severely damaged bearing in final stage of wear

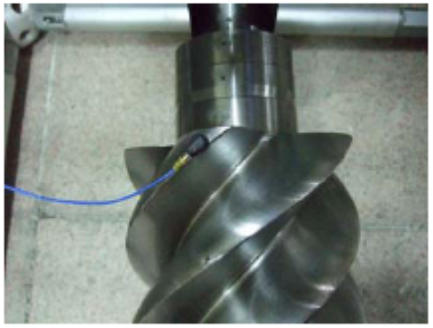
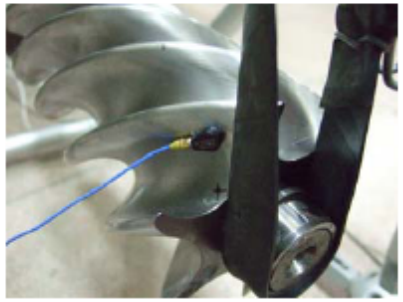
懸臂樑：Impact testing⇔FEM模態分析



懸臂樑：量測頻率與模擬結果比較➔修正數值模型

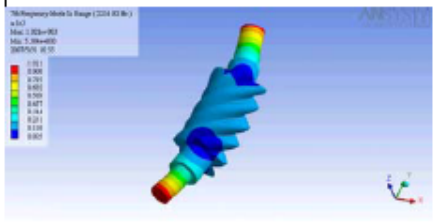
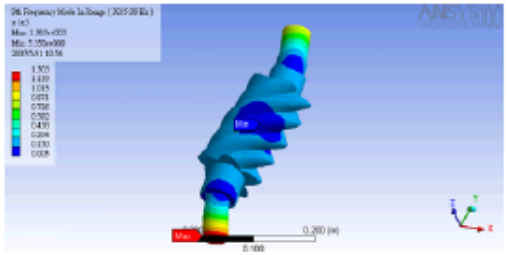
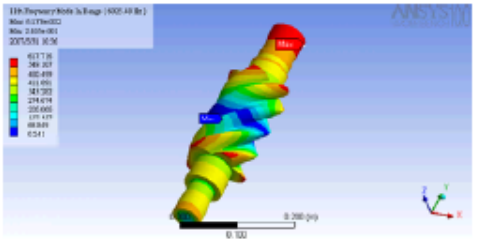
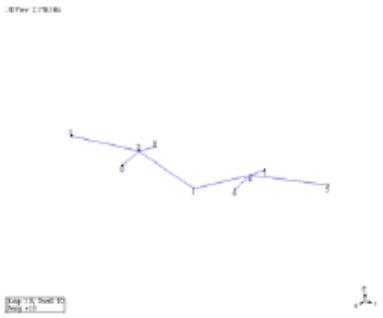
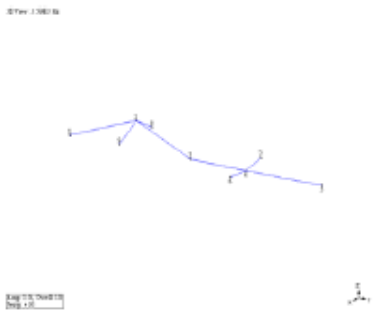
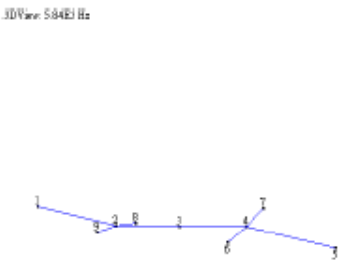
Mode	量測 頻率	原始 分析	差異 %	修正 分析	差異 %
1	21 Hz	23.071 Hz	**9.8619**	21.467 Hz	2.2238
2	134 Hz	144.5 Hz	**7.8358**	134.46 Hz	0.3433
3	328 Hz	367.6 Hz	**12.073**	347.76 Hz	6.0244
4	380 Hz	404.91 Hz	**6.5553**	376.78 Hz	-0.8474
5	426 Hz	459.16 Hz	**7.7840**	442.13 Hz	3.7864
6	736 Hz	794.75 Hz	**7.9823**	739.54 Hz	0.4810
7	1022 Hz	1111.4 Hz	**8.7476**	1051.2 Hz	2.8571
8	1235 Hz	1316.4 Hz	**6.5911**	1225.0 Hz	-0.8097

螺旋壓縮機轉子模態測試

	bending	torsion	extension
公轉子			
母轉子			

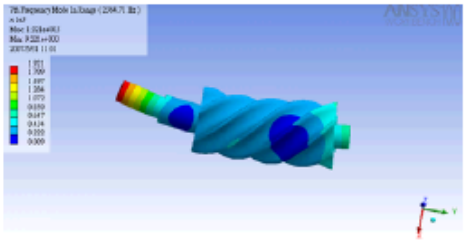
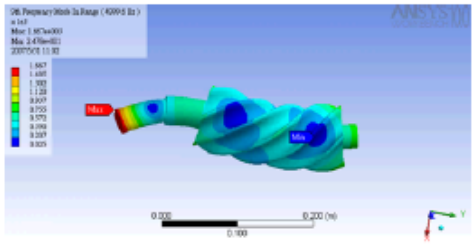
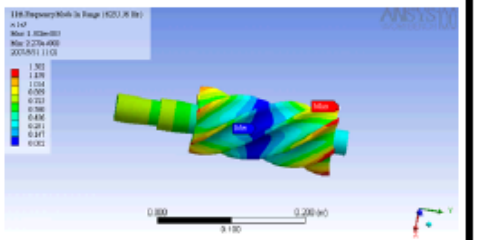
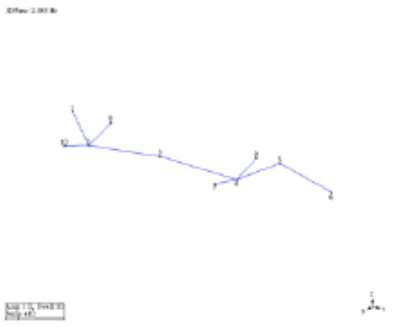
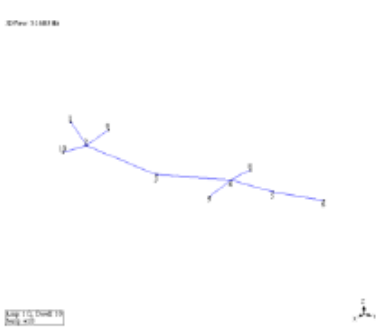
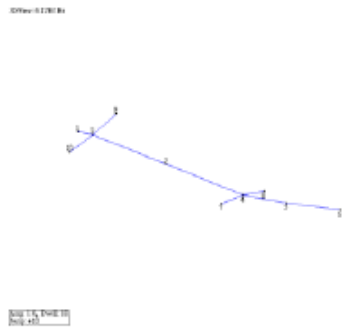
AnCAD

公轉子前三模態：量測⇔模擬

	第一模態(誤差2.8 %)	第二模態(6.41 %)	第三模態(3.07 %)
FEM 振型			
頻率	2234 Hz	3836 Hz	6025 Hz
量測 振型			
頻率	2170 Hz	3590 Hz	5840 Hz

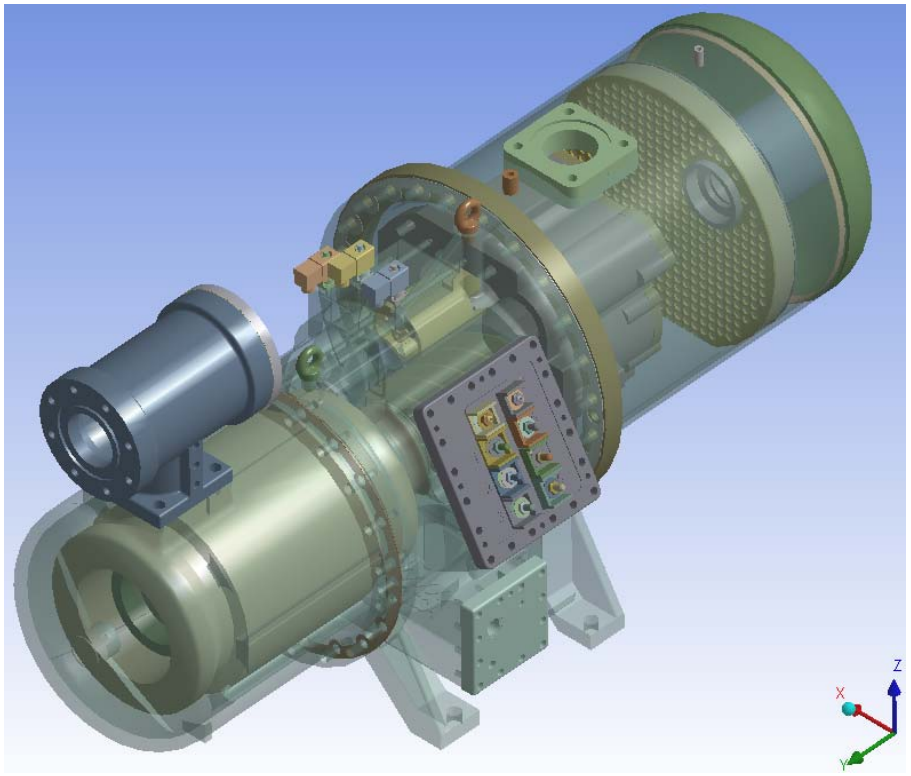
AnCAD

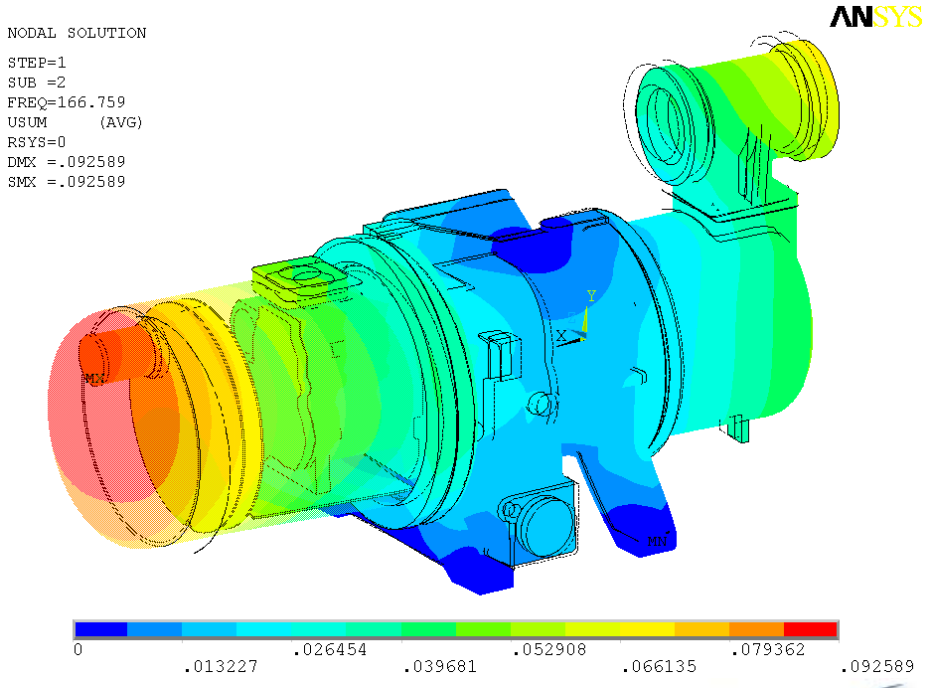
母轉子前三模態：量測⇔模擬

	第一模態(誤差2.75 %)	第二模態(誤差3.20 %)	第三模態(誤差1.33 %)
FEM 振型			
頻率	2365 Hz	5000 Hz	6253 Hz
量測 振型			
頻率	2300 Hz	5160 Hz	6170 Hz

AnCAD

螺旋壓縮機之整機模態與動態分析





AnCAD

迴轉機械 之振動與噪音檢測

逸奇科技

AnCAD

課程時間表

Day 1		Day 2		Day 3	
訊號時域、頻域、時頻分析		迴轉機械振動噪音檢測		專題：齒輪之振噪檢測	
8:00-9:00	專題演講	8:00-9:00	專題演講	8:00-9:00	專題演講
9:10-10:00	基本原理介紹	9:10-10:00	基本原理介紹	9:10-10:00	基本原理介紹
10:10-11:00	量測實例展示與解說	10:10-11:00	量測實例展示與解說	10:10-11:00	量測實例展示與解說
11:10-11:40	上機實作	11:10-11:40	上機實作	11:10-11:40	上機實作
11:40-12:00	討論	11:40-12:00	討論	11:40-12:00	討論
感測器選用與訊號擷取技術		專題：主軸之振噪檢測		專題：軸承之振噪檢測	
13:00-14:00	專題演講	13:00-14:00	專題演講	13:00-14:00	專題演講
14:10-15:00	基本原理介紹	14:10-15:00	基本原理介紹	14:10-15:00	基本原理介紹
15:10-16:00	量測實例展示與解說	15:10-16:00	量測實例展示與解說	15:10-16:00	量測實例展示與解說
16:10-16:40	上機實作	16:10-16:40	上機實作	16:10-16:40	上機實作
16:40-17:00	討論	16:40-17:00	討論	16:40-17:00	討論

課程宗旨

- 正確量測振動與噪音訊號
  (Hardware)
- 準確分析振噪訊號
  (Software)
- 正確解讀振噪訊號之頻譜特徵
  (Knowledge base)

參與學員之受益

- PC-based振噪檢測系統之建構技術
- 振噪量測感測器之選用關鍵
- 資料擷取卡之選用與設置技巧
- 迴轉機械之振噪檢測技術
- 迴轉機械振噪頻譜之解讀技巧
- 機械振動與異音之來源鑑別技術

課程主題

- 訊號時域、頻域、時頻分析
- 感測器選用與訊號擷取技術簡介
- 迴轉機械振動噪音檢測
- 專題：主軸之振噪檢測
- 專題：齒輪之振噪檢測
- 專題：軸承之振噪檢測

各主題架構

- 專題演講
- 基本原理介紹
- 量測實例展示與解說
- 上機實作
- 討論

訊號時域、頻域、時頻分析

- 專題演講
- 基本原理介紹：
  - ✓時序訊號分析
  - ✓頻譜分析
  - ✓時頻分析
- 量測實例展示與解說
- 上機實作
- 討論

感測器選用與訊號擷取技術

- 專題演講
- 基本原理介紹：
  - ✓加速規之頻率響應與安裝方式
  - ✓麥克風之頻率響應與方向性
  - ✓資料擷取卡
- 量測實例展示與解說
- 上機實作
- 討論

迴轉機械振動噪音檢測

- 專題演講
- 基本原理介紹：
  - ✓動不平衡之檢測
  - ✓角度、平行之軸不對心檢測
  - ✓組件鬆脫之檢測
  - ✓馬達異常之檢測
  - ✓皮帶異常之檢測
- 量測實例展示與解說
- 上機實作
- 討論

主軸之振噪檢測

- 專題演講
- 基本原理介紹：
  - ✓ 主軸臨界轉速之量測-變轉速時頻分析
  - ✓ 主軸裝配問題之檢測-偏心、對心、鬆脫
  - ✓ 主軸彎曲之檢測
  - ✓ 高低轉速對主軸動平衡之影響
- 量測實例展示與解說
- 上機實作
- 討論

齒輪之振噪檢測

- 專題演講
- 基本原理介紹：
  - ✓齒輪箱之異音檢測
  - ✓轉軸頻率與齒輪嚙合頻率之交互影響
  - ✓齒輪嚙合不對心之檢測
  - ✓齒輪背隙異常之檢測
  - ✓齒輪磨損之檢測
  - ✓齒輪斷齒之檢測
- 量測實例展示與解說
- 上機實作
- 討論

軸承之振噪檢測

- 專題演講
- 基本原理介紹：
  - ✓軸承剛性及預壓對主軸臨界轉速之影響
  - ✓軸承受力不均之檢測
  - ✓軸承外圈缺陷之檢測
  - ✓軸承滾珠缺陷之檢測
  - ✓軸承內圈缺陷之檢測
- 量測實例展示與解說
- 上機實作
- 討論