迴轉機械之振噪檢測研討會

機械運轉之動態穩定性與異常振動診斷

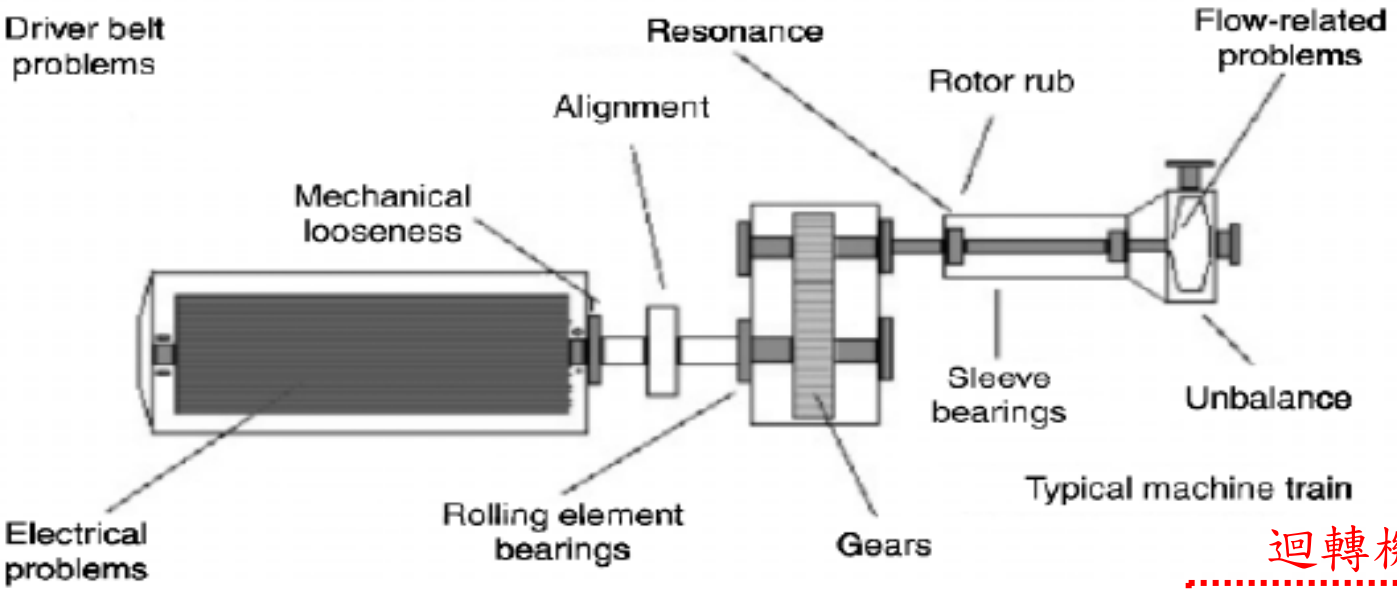
吳豐泰

逸奇科技

2011/6/29

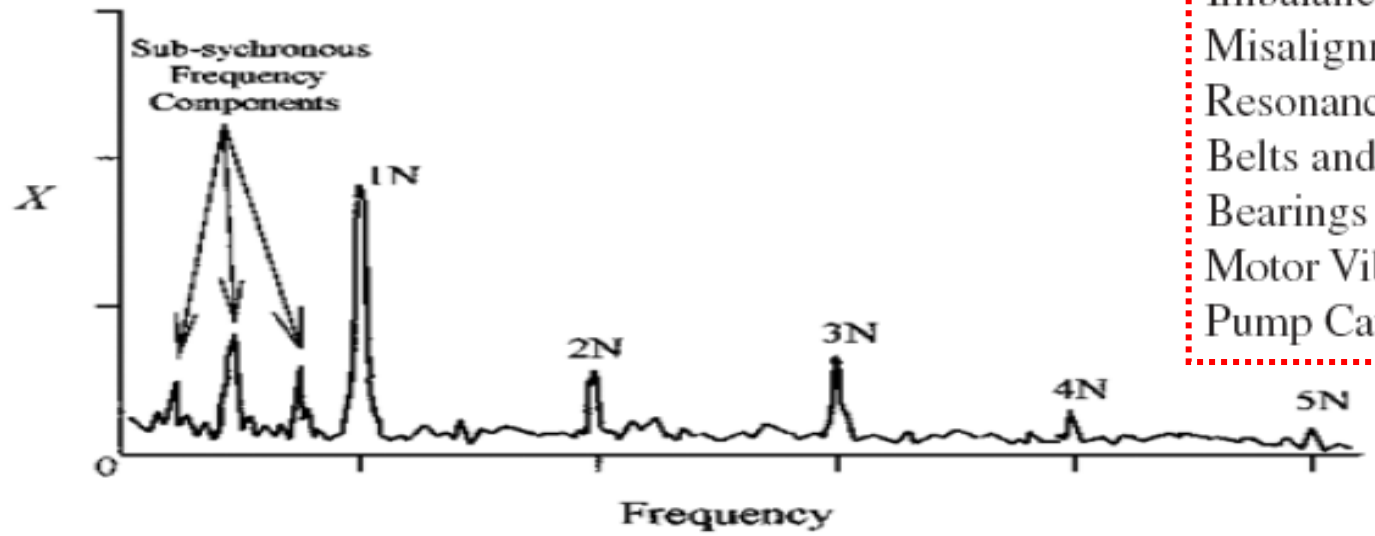
迴轉機械之振動頻譜

迴轉機械之傳動與典型振動頻譜

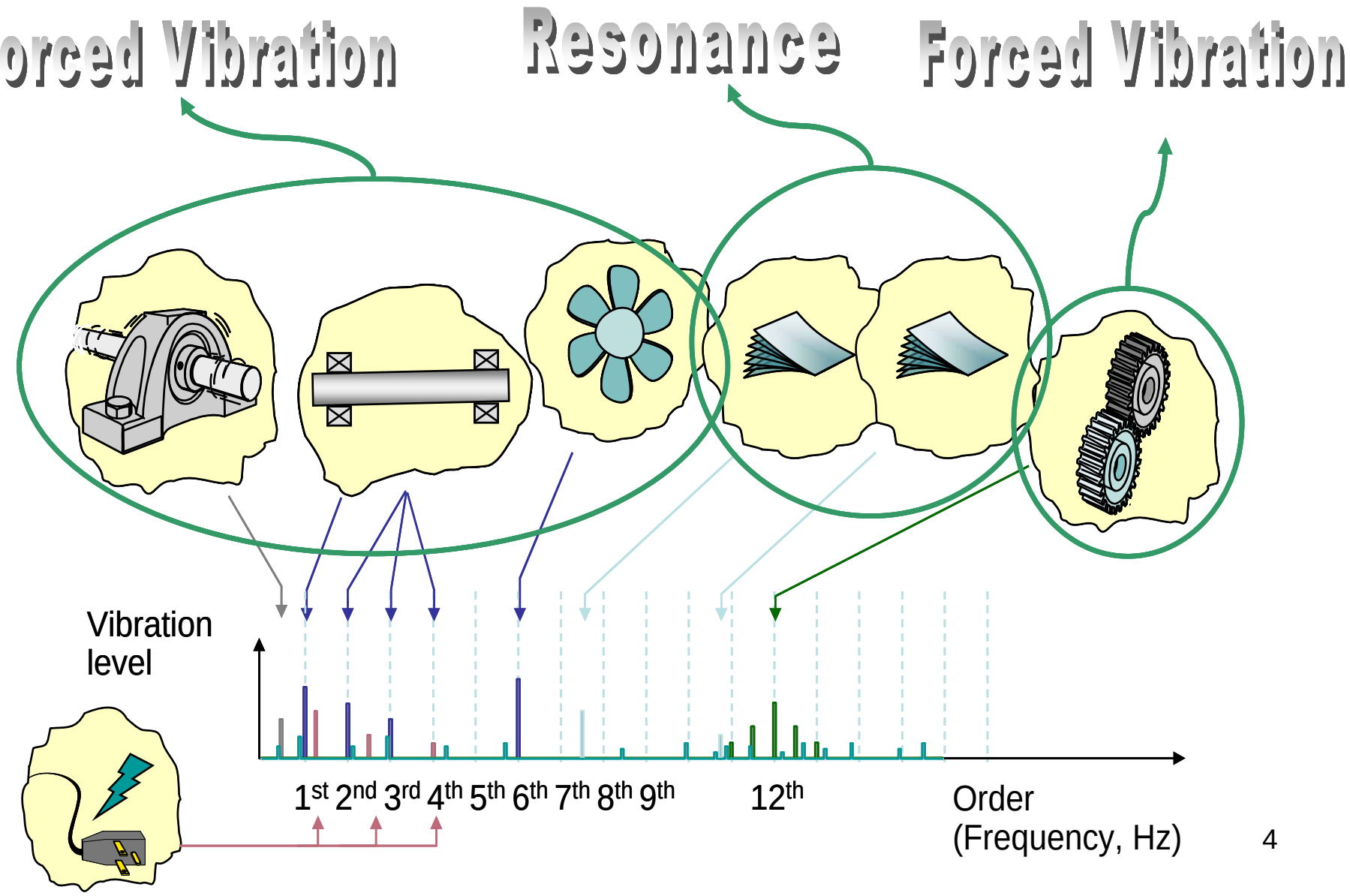


迴轉機械異常原因排序

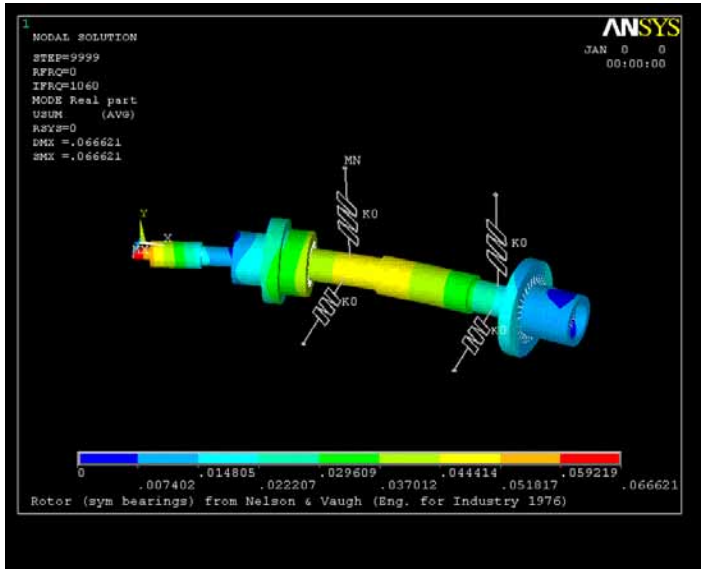
Imbalance	40%
Misalignment	30%
Resonance	20%
Belts and Pulleys	30%
Bearings	10%
Motor Vibration	8%
Pump Cavitation	5%

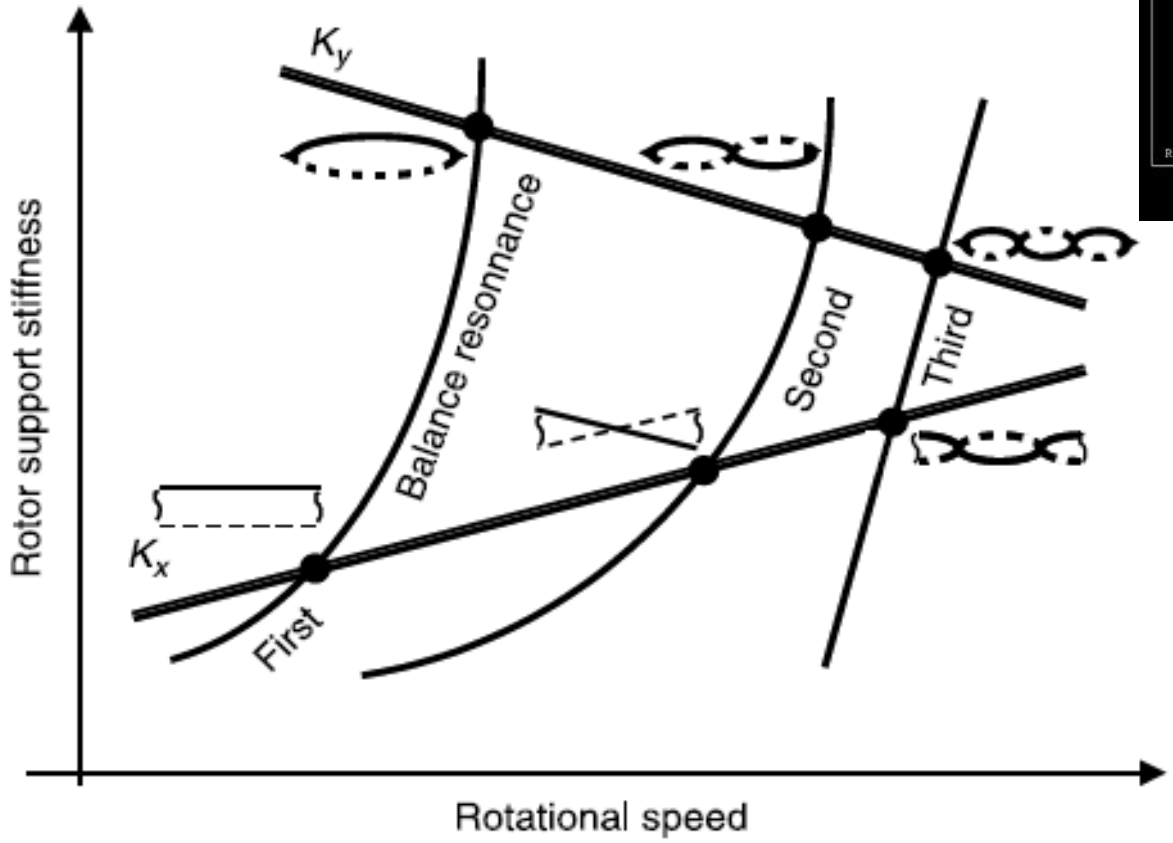


迴轉機械之轉速倍頻振動頻譜

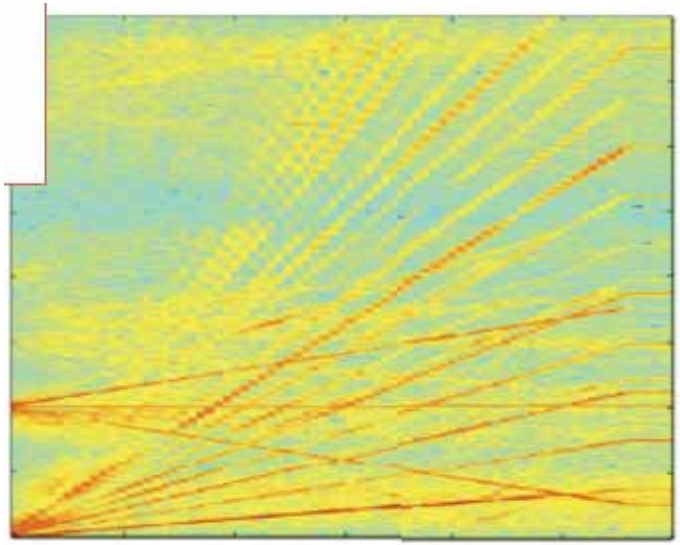


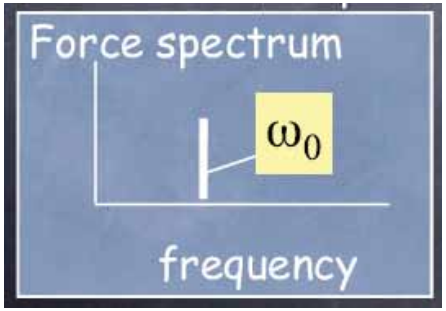
軸承剛性與主軸臨界轉速之關係

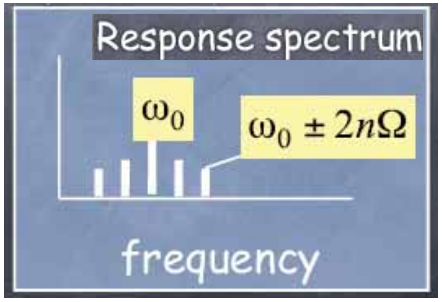


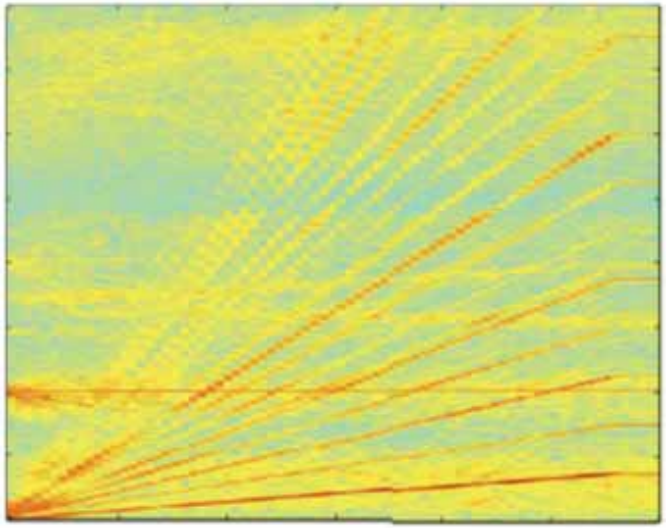


異常調變排除⇨主軸非對稱效應之校平衡

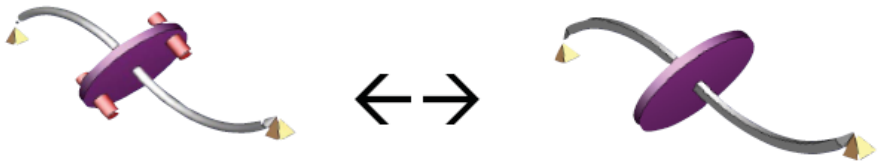








Asymmetric inertia ←→ anisotropic stiffness

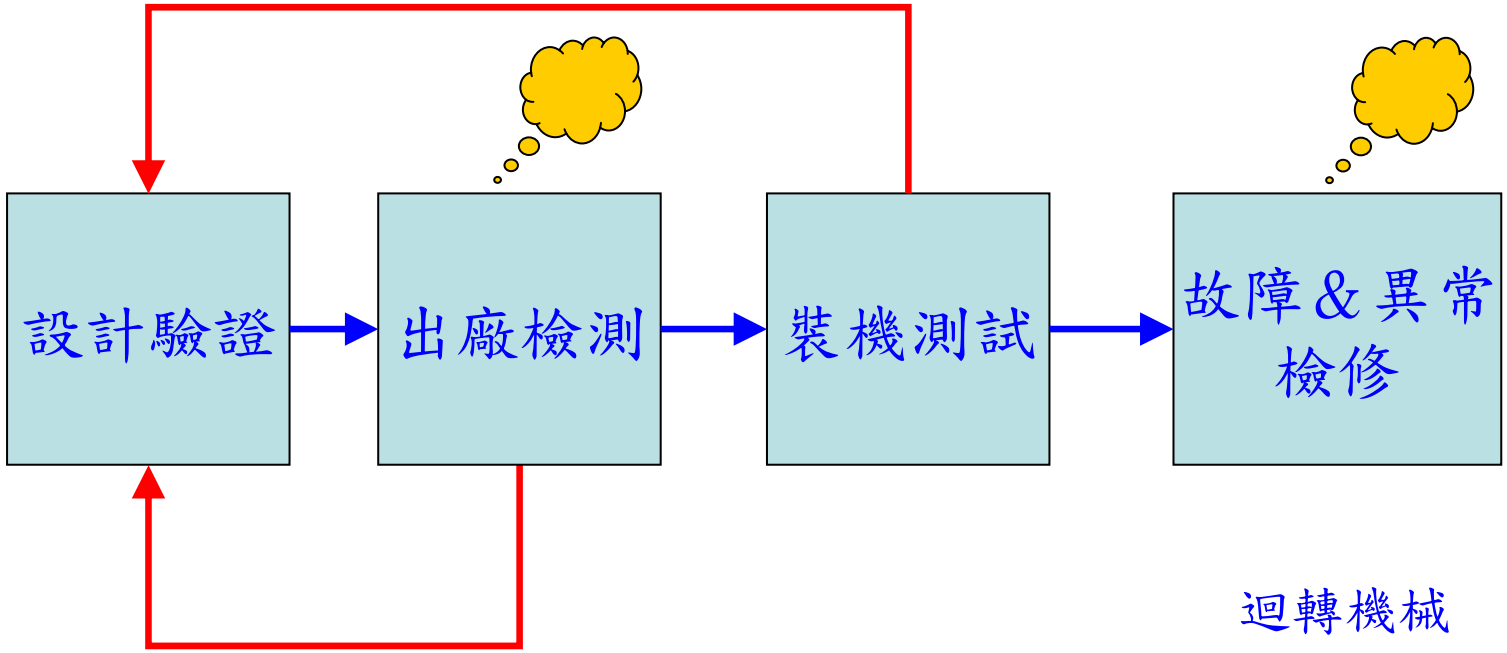


* for asynchronous detection purposes

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

PC-based檢測系統

Why振動噪音檢測？



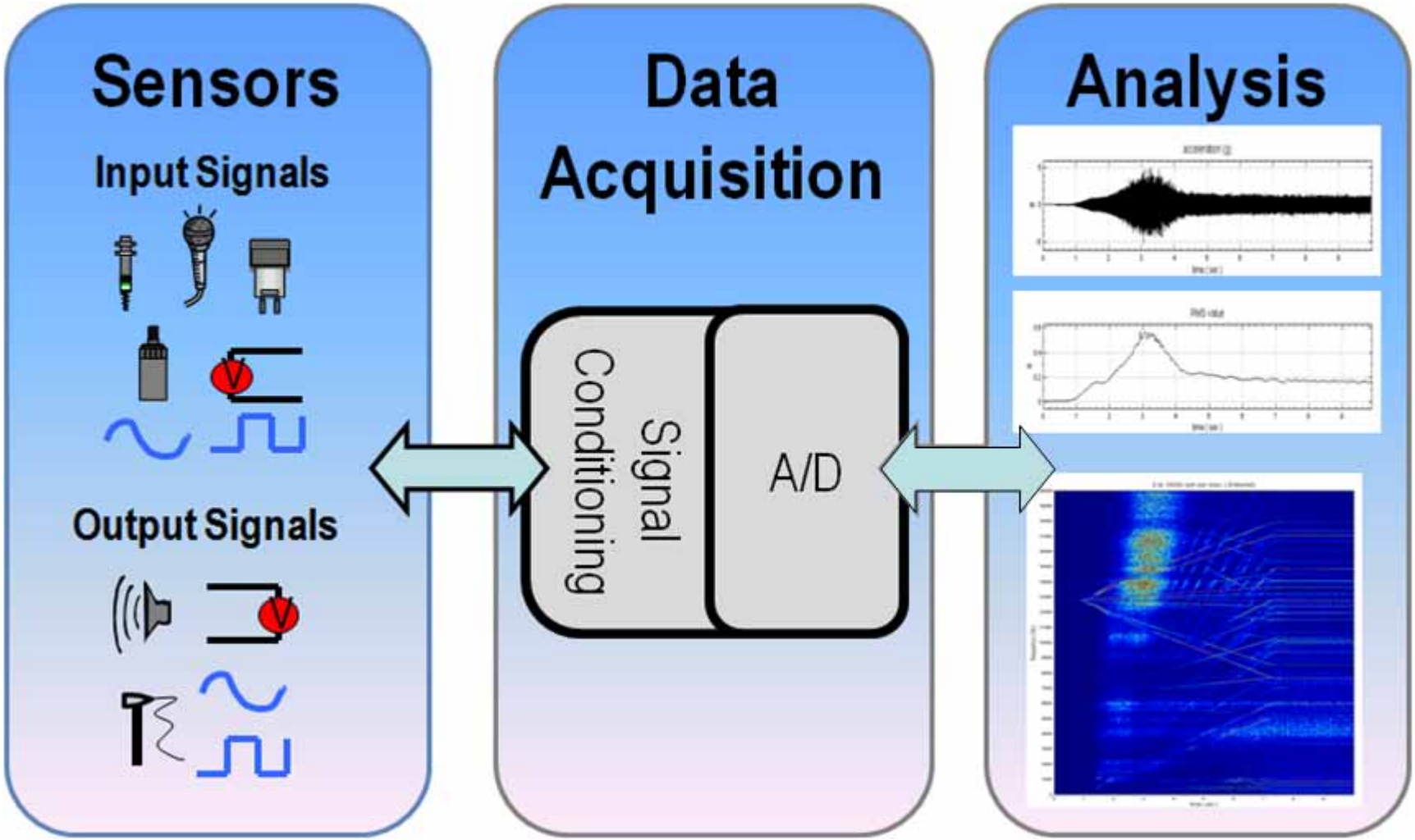
FEM模型
原型驗證
參數調測

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

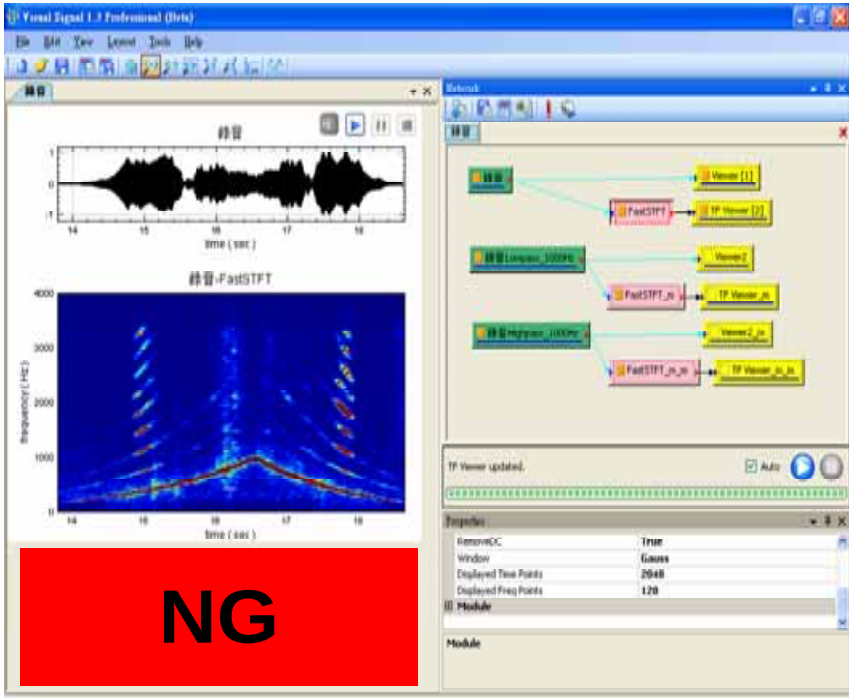
迴轉機械
主軸
齒輪
軸承
馬達

PC-based檢測流程



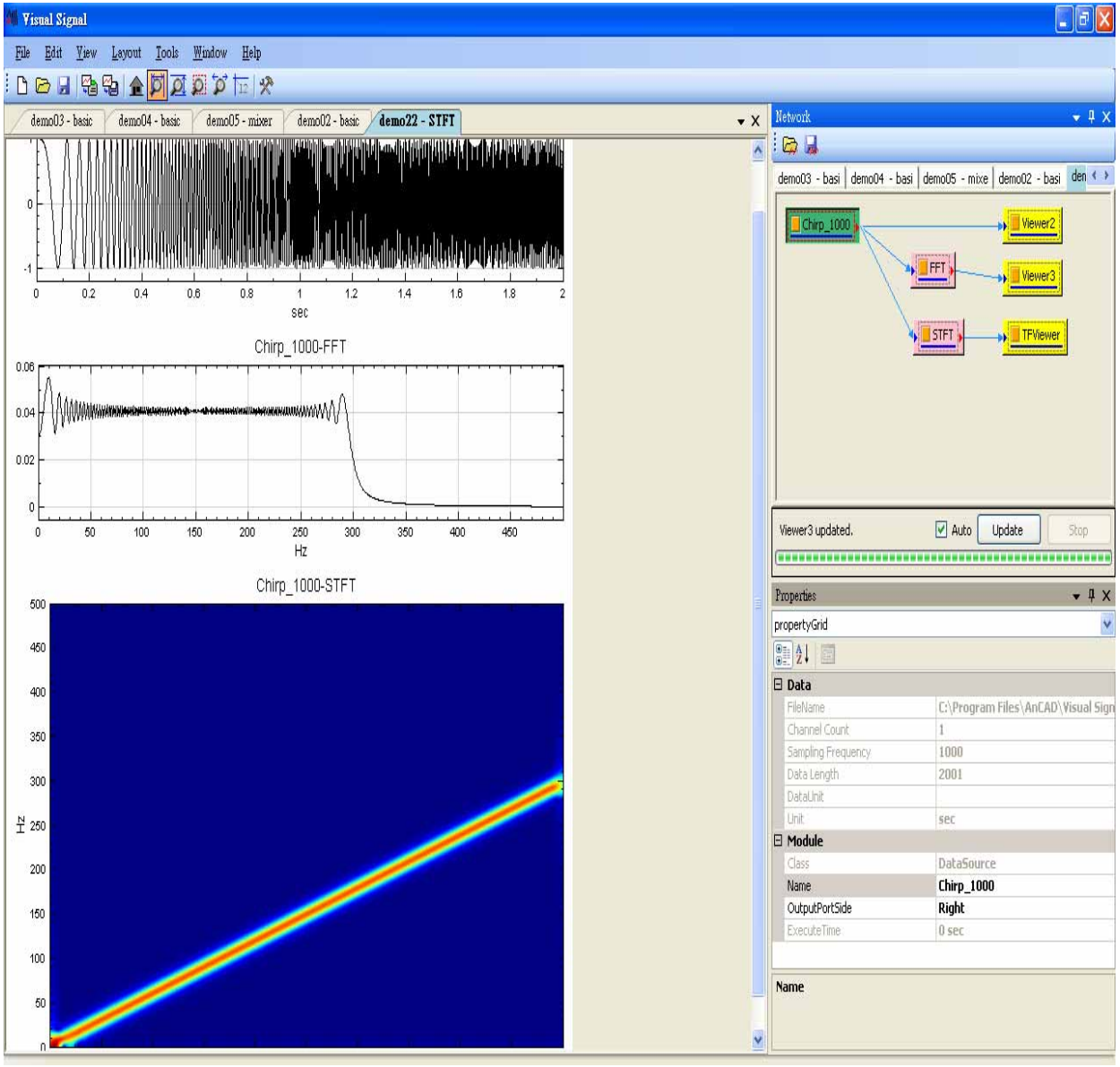
PC-based檢測系統架構

- 軟體
  - 檢測與監測操作平台(Visual Signal)
  - 資料擷取軟體(DAQ API)
  - 振動與噪音分析模組(SVM)



- 硬體
  - 資料擷取卡(NI DAQ)
  - 加速規
  - 麥克風
  - 轉速計
  - 熱電偶
  - …

Visual Signal：軟硬體整合平台



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

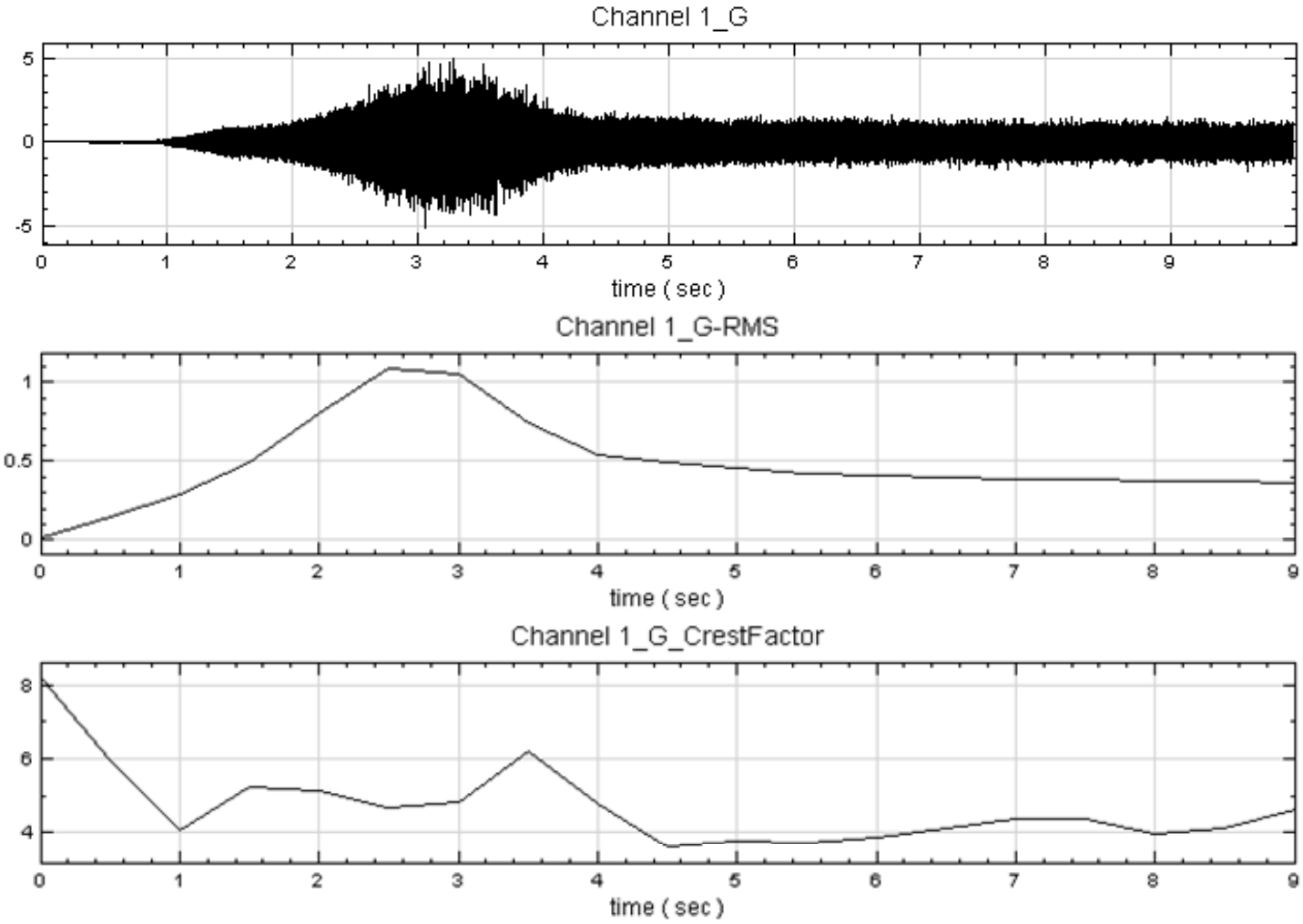
輸出

圖形
檔案
訊號產生器

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 by STFT
  Order Tracking by EnMorlet
- Bearing Analysis
  Bearing Defect
  Envelope Detection
- Cepstrum
- Scale…

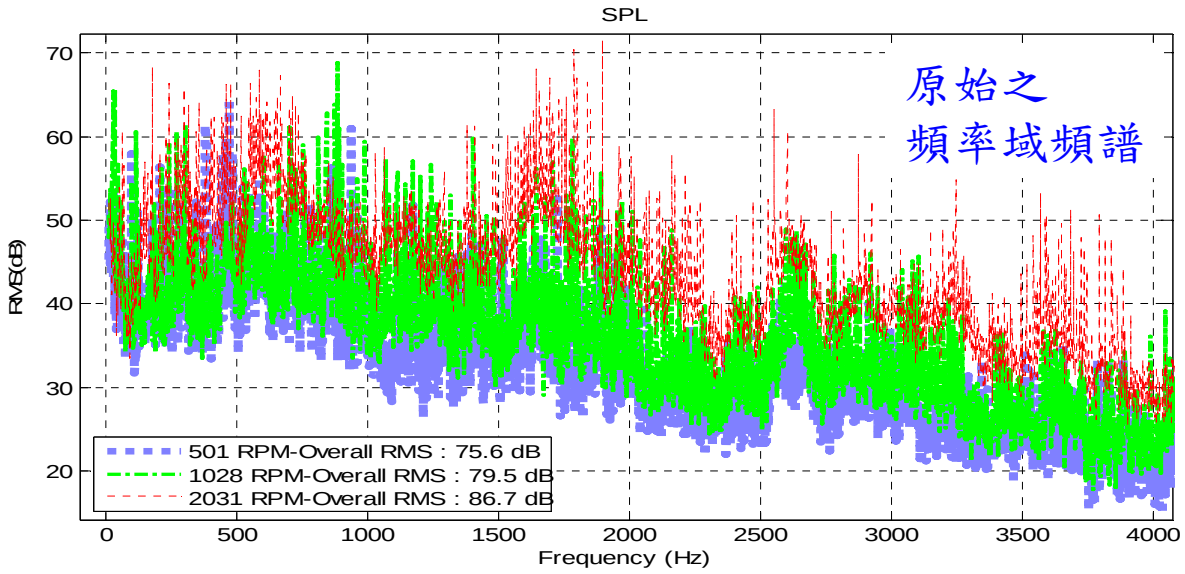
Vibration Level: RMS & Crest Factor

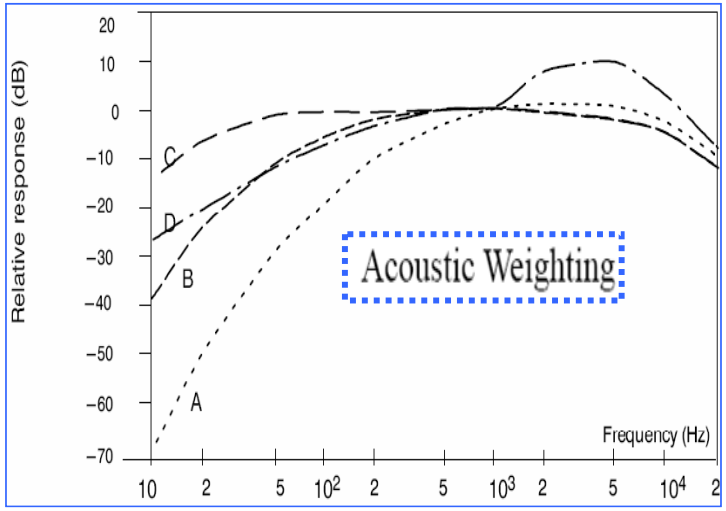


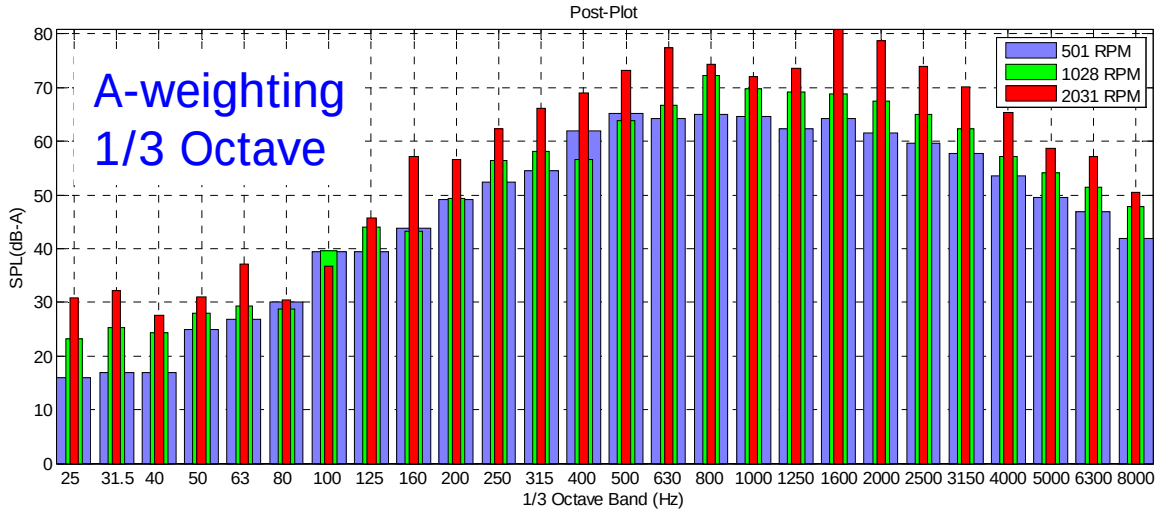
$$RMS = \sqrt{\frac{1}{T}\int_0^T a^2(t)\,dt}$$

$$CrestFactor = \frac{TruePeak}{RMS}$$

Sound Level: Weighting & Octave







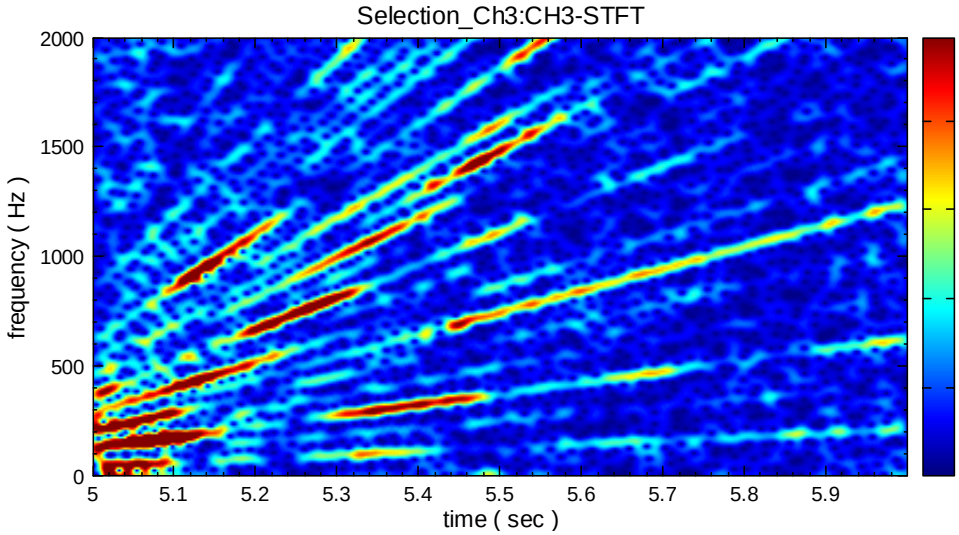
ThirdOctave：$\frac{1}{3}$八度音

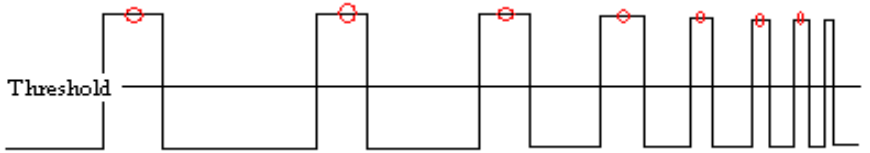
Octave：八度音

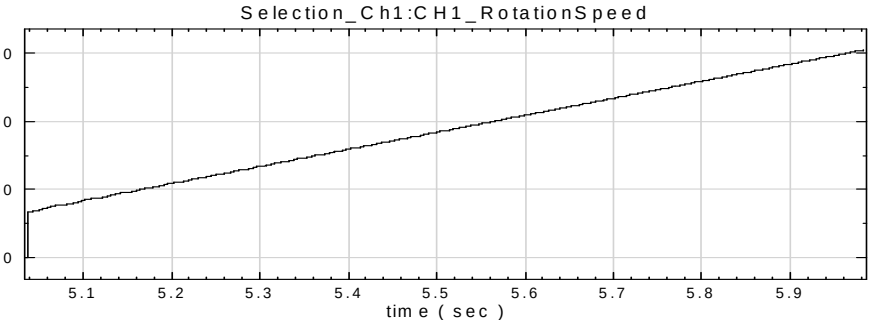
N_Octave：$\frac{1}{n}$八度音 $(n=\frac{1}{1},\frac{1}{3},\frac{1}{6},\frac{1}{12},\frac{1}{24})$

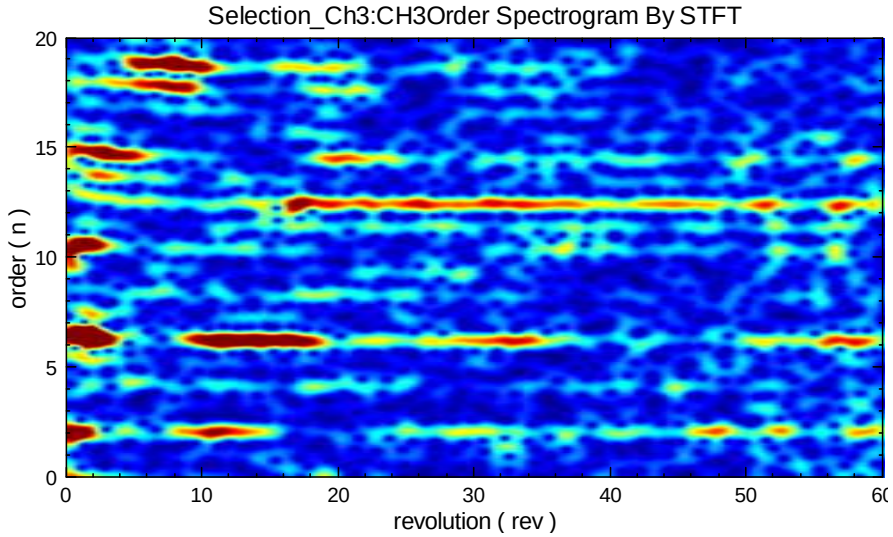
人耳效應

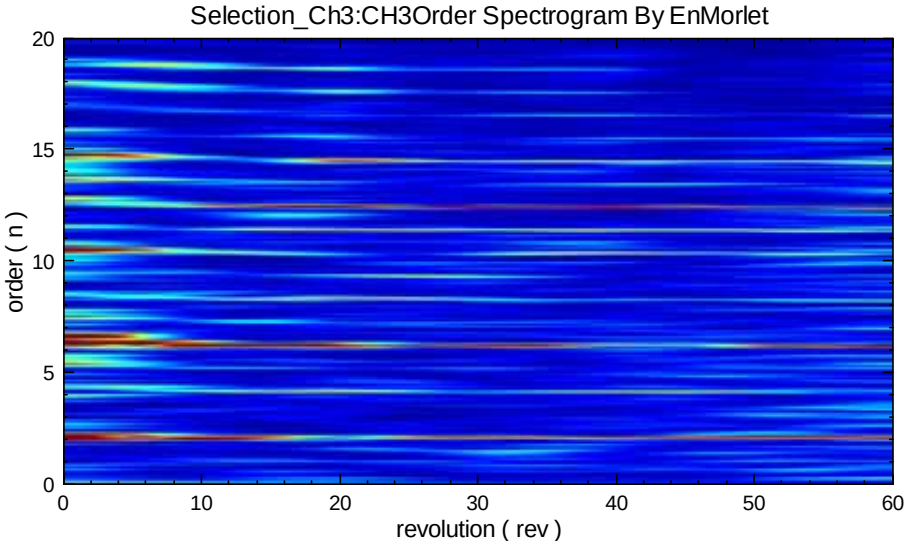
Order Tracking



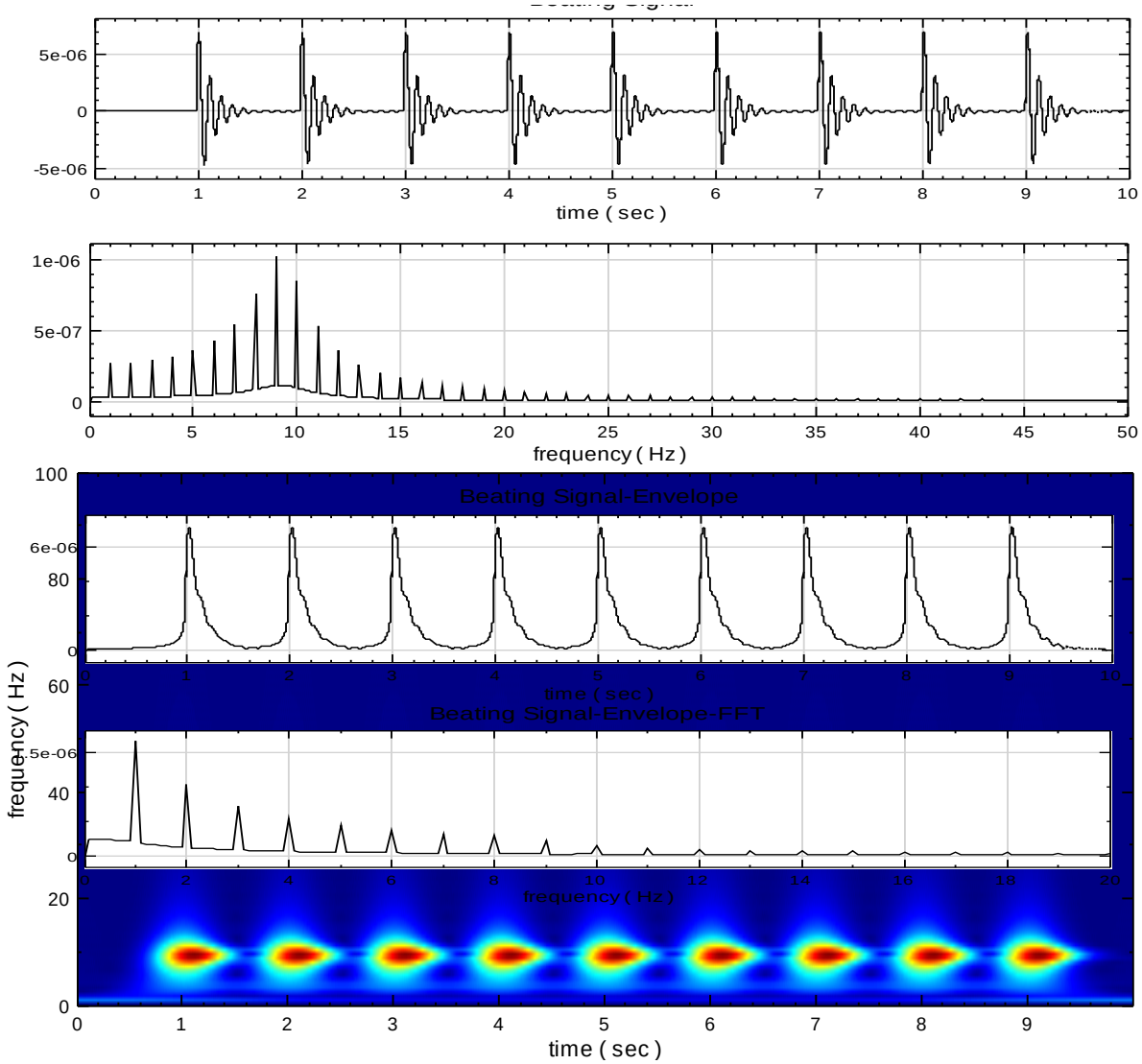


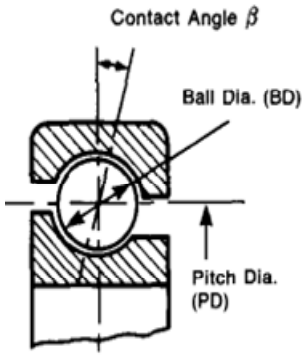






Bearing Analysis





n = number of balls or rollers

f_r = relative rev./s between inner and outer races

Impact Rates f(Hz) (assuming pure rolling motion)

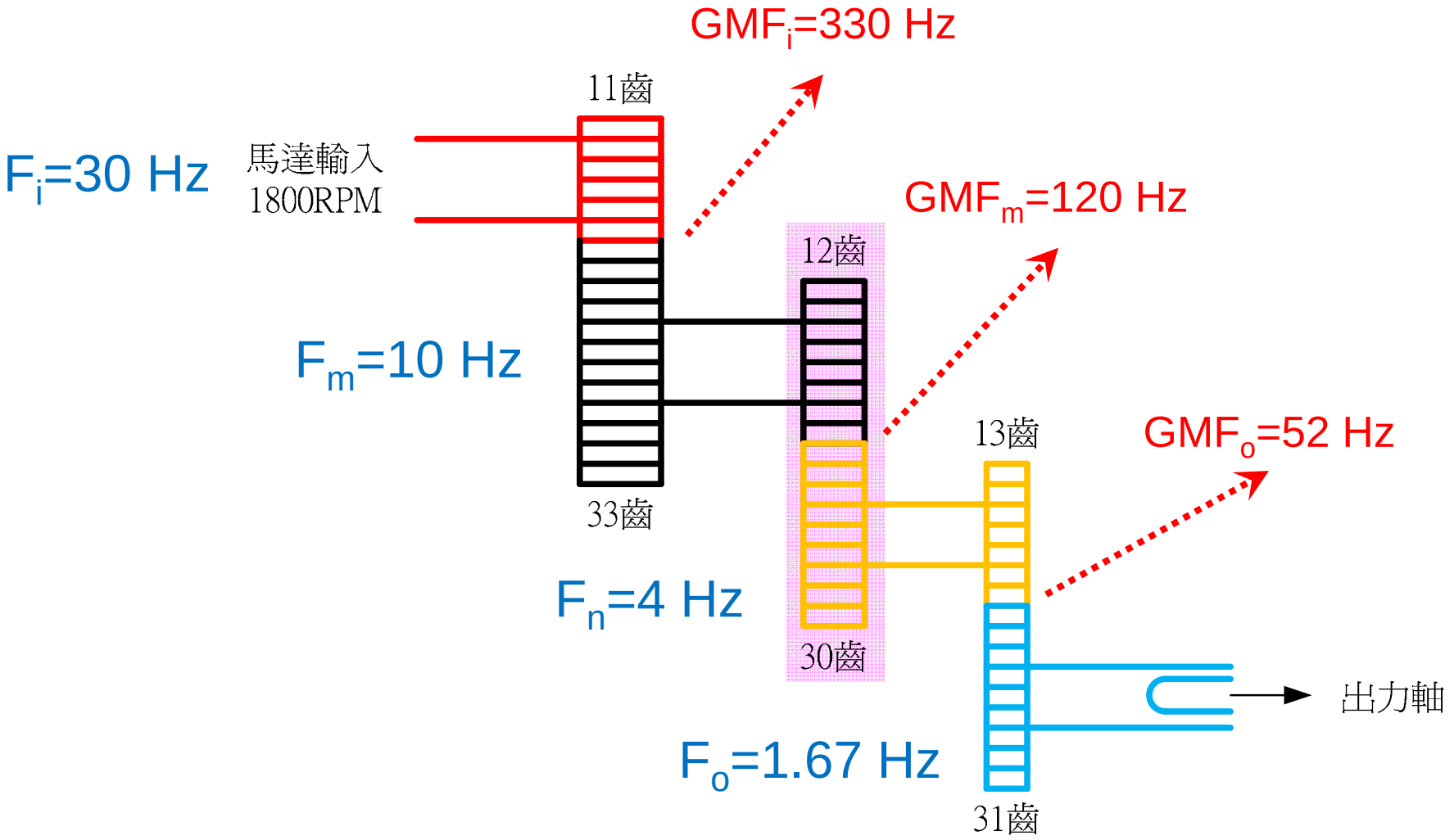
For Outer Race Defect: $f(Hz) = \frac{n}{2} f_r \left(1 - \frac{BD}{PD} \cos \beta\right)$

For Inner Race Defect: $f(Hz) = \frac{n}{2} f_r \left(1 + \frac{BD}{PD} \cos \beta\right)$

For a Ball Defect: $f\ (Hz) = \frac{PD}{BD} f_r \left[1 - \left(\frac{BD}{PD} \cos \beta\right)^2\right]$

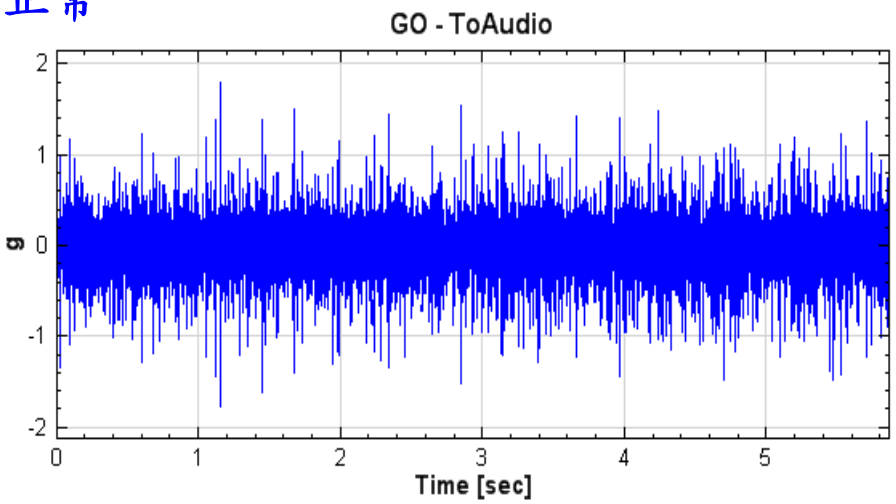
齒輪箱包絡頻譜分析

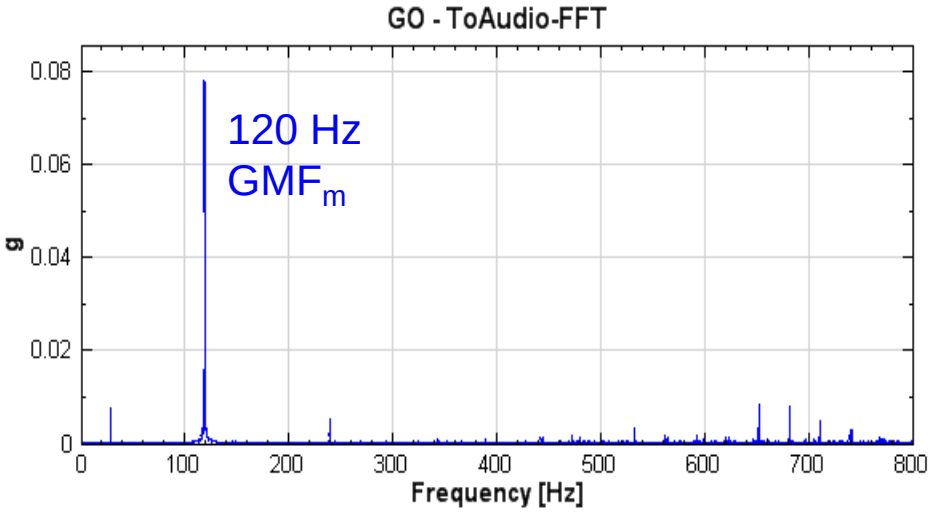
轉軸頻率與嚙合頻率


GMF$_i$=330 Hz
11齒
F$_i$=30 Hz
馬達輸入
1800RPM
GMF$_m$=120 Hz
12齒
F$_m$=10 Hz
13齒
GMF$_o$=52 Hz
33齒
F$_n$=4 Hz
30齒
出力軸
F$_o$=1.67 Hz
31齒

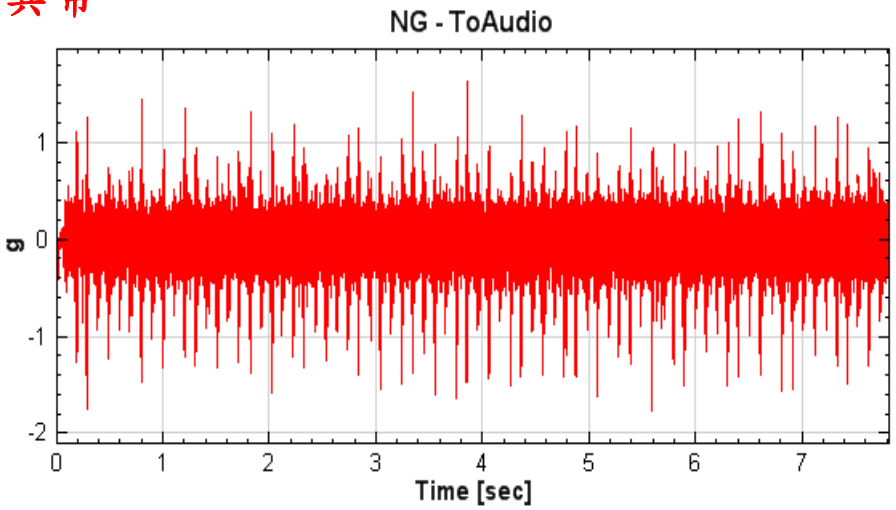
正常VS.異常齒輪箱振動訊號&頻譜

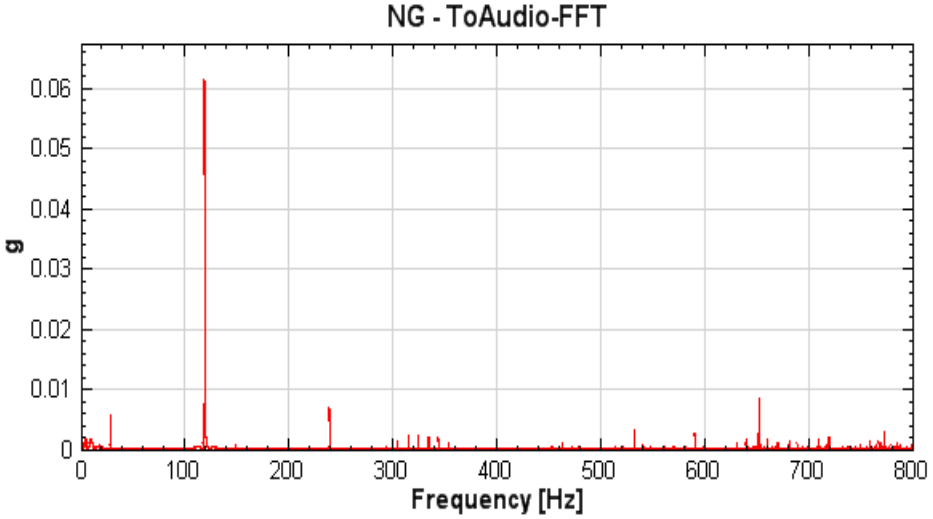
正常





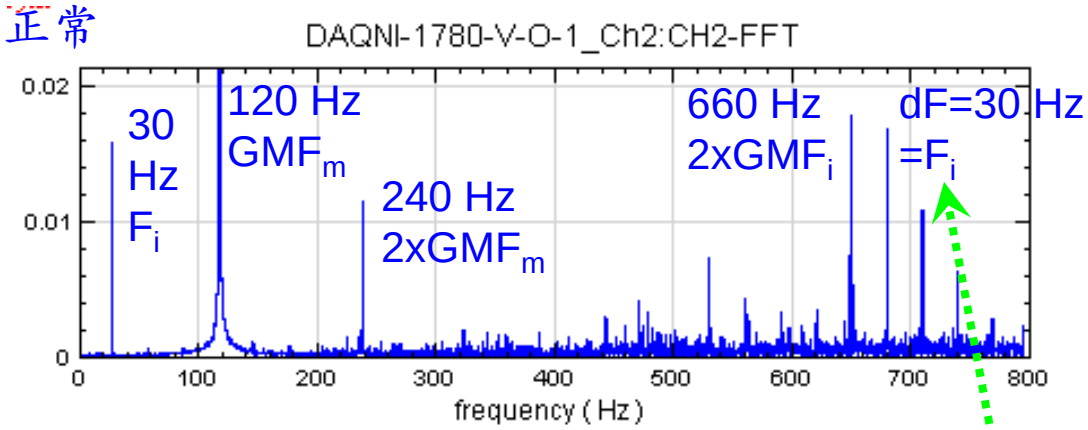
異常



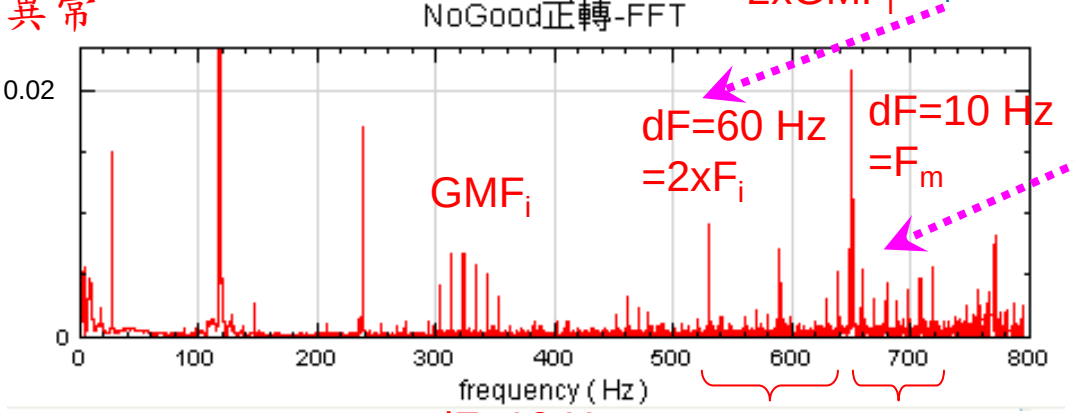


正常VS.異常齒輪箱振動訊號：頻譜比較(Zoom-in)

正常



異常



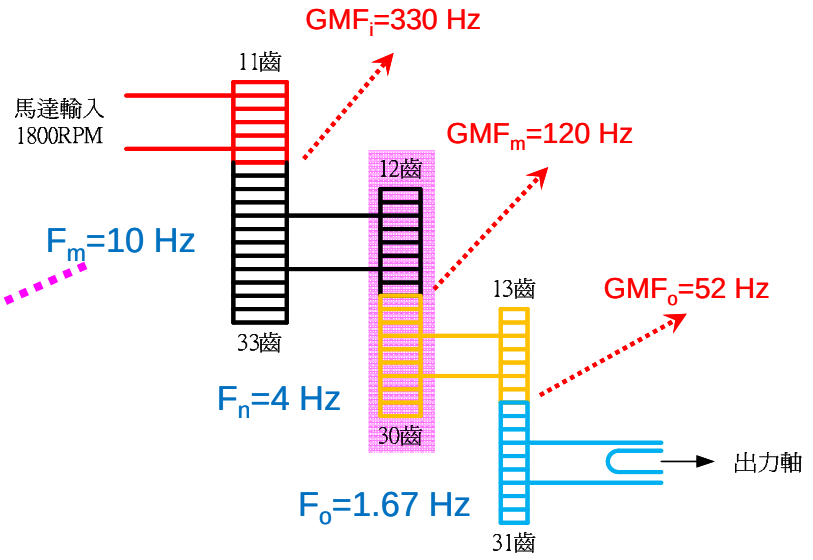
$2xGMF_i$ F_i=30 Hz

F_m=10 Hz

dF=10 Hz
$=F_m$

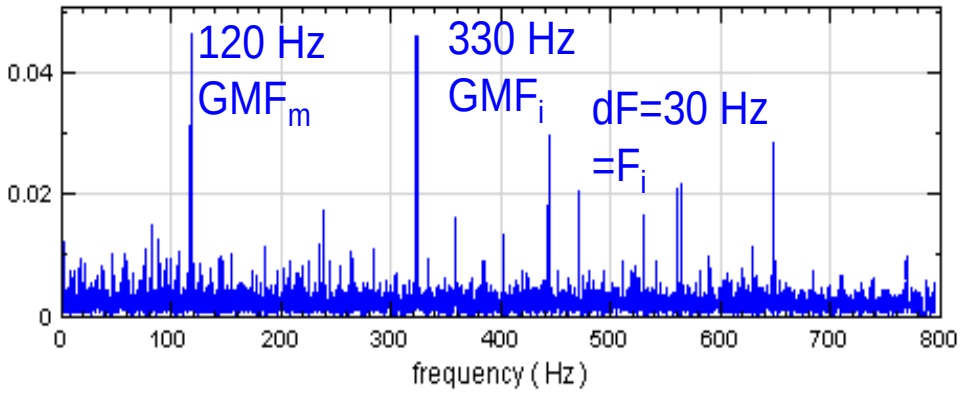
i軸鬆脫
不對心

m軸
偏心

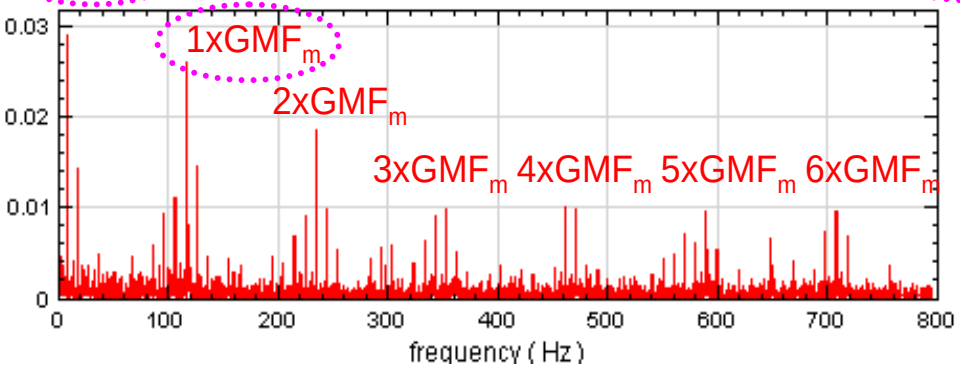


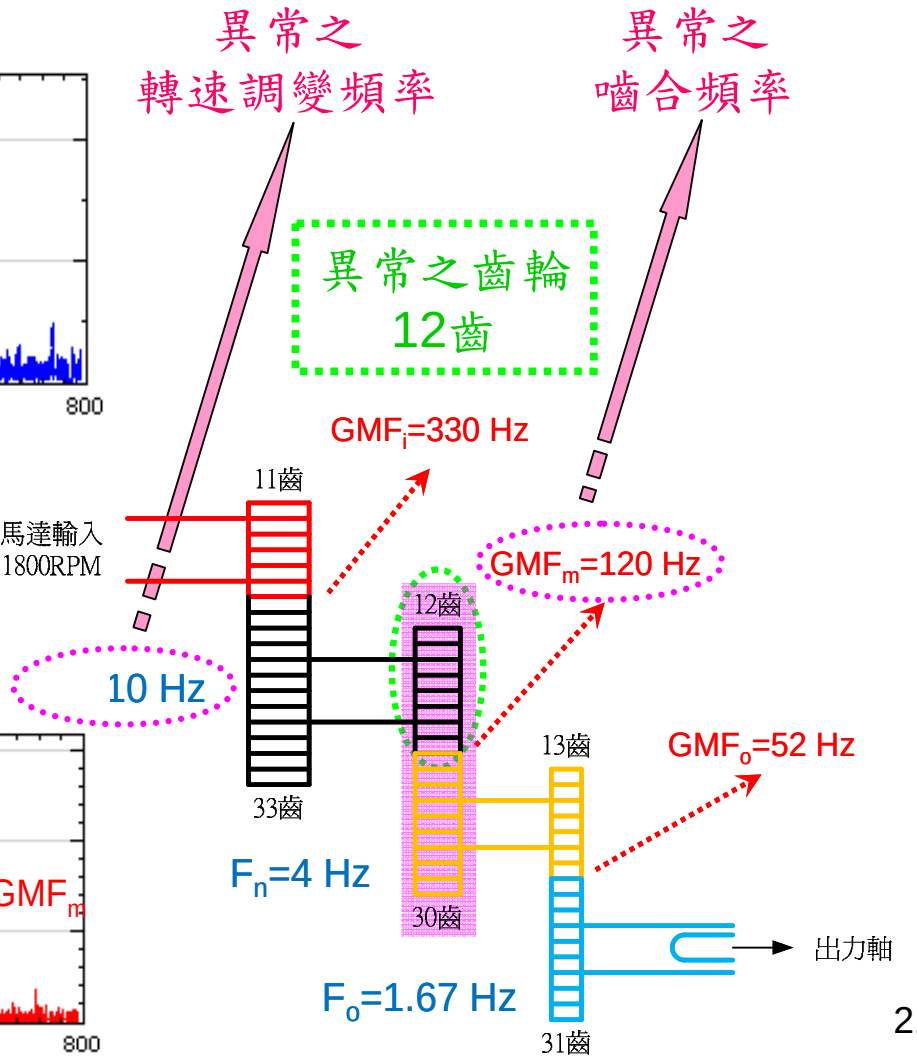
正常VS.異常齒輪箱振動訊號：包絡線頻譜

正常齒輪箱之包絡線頻譜



異常齒輪箱之包絡線頻譜

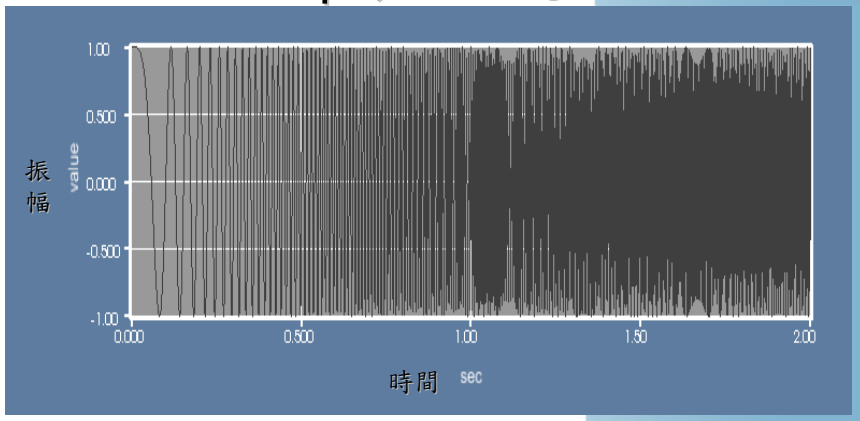




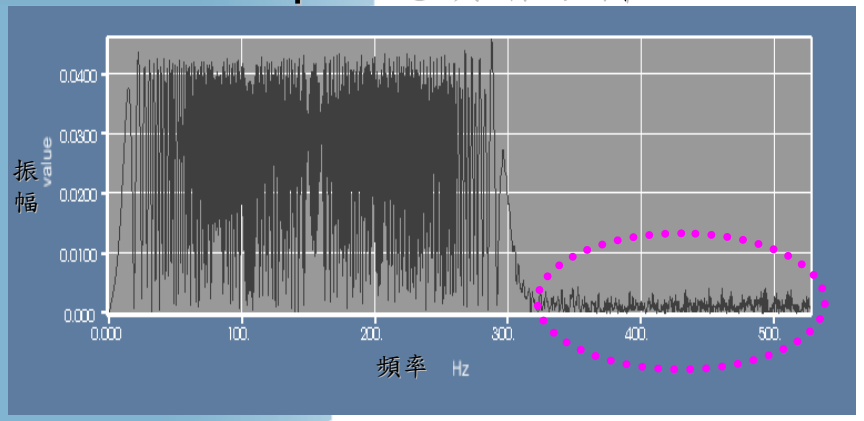
Time-Frequency Analysis (TFA)

Why高解析時頻分析? ⇨ 細微異常檢出

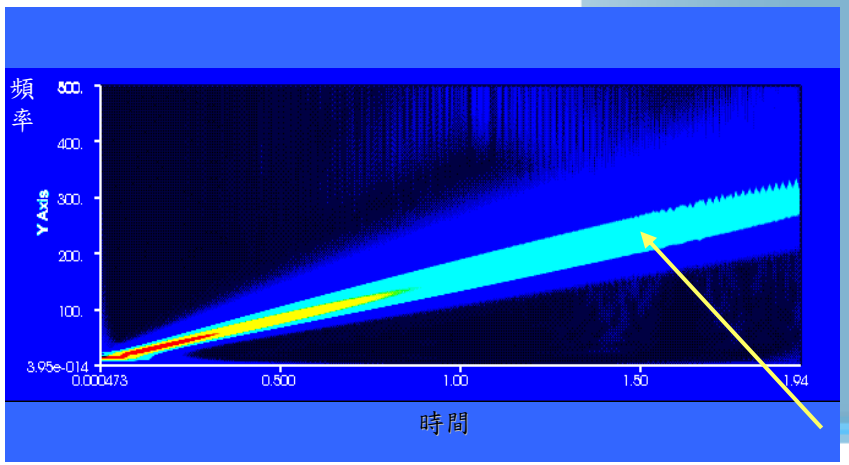
Chirp原始訊號



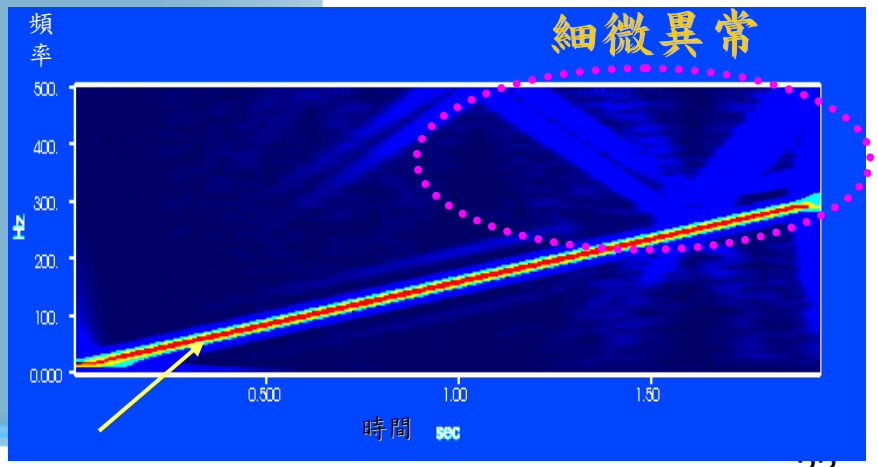
Chirp訊號頻譜分析



Morlet Transform時頻圖



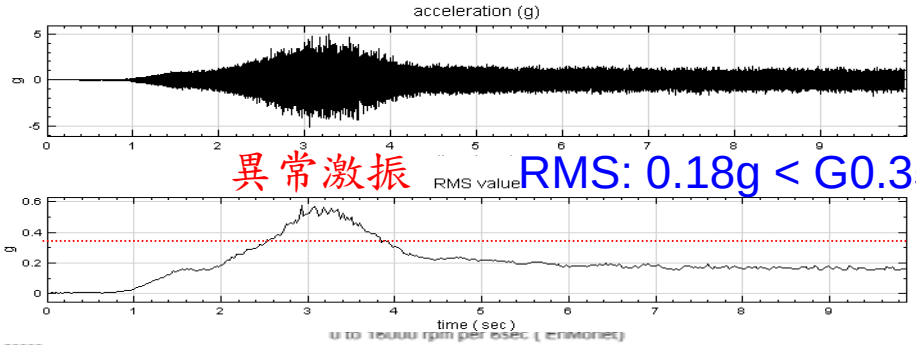
Enhanced Morlet Transform



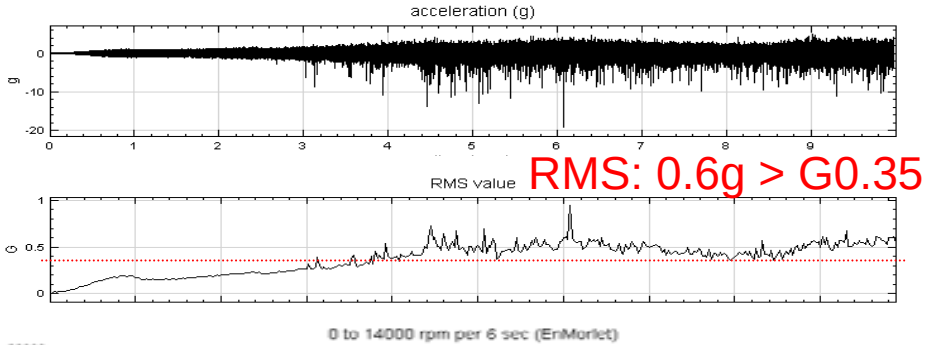
色彩表示其能量或振幅

Why變轉速時頻分析?

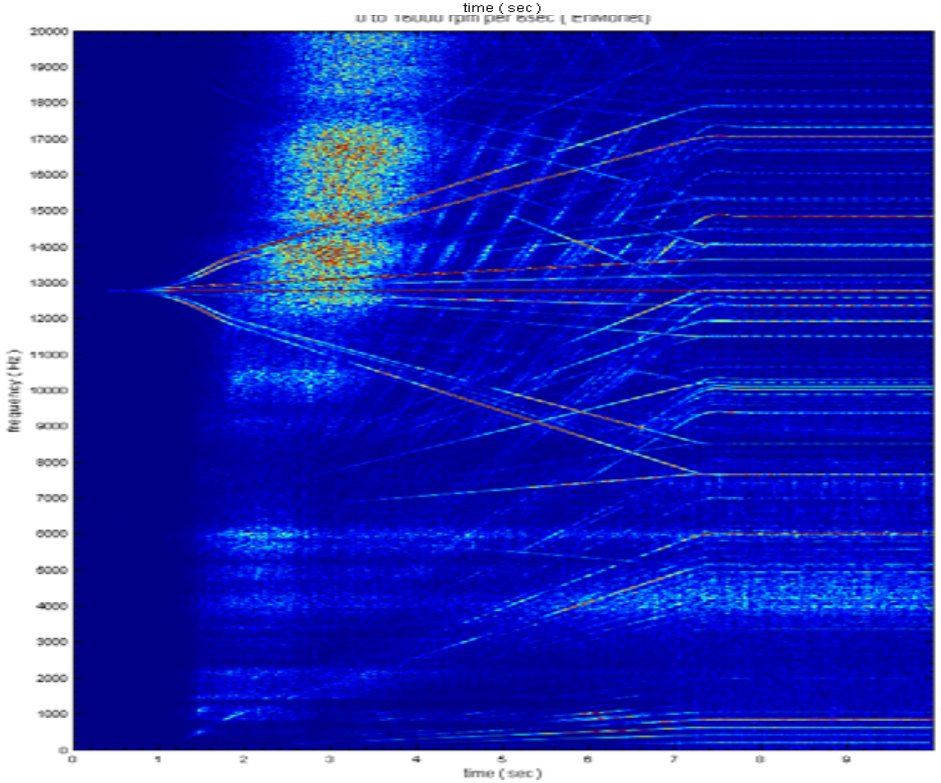
⇨轉速倍頻、共振頻段、異常激振、頻率調變

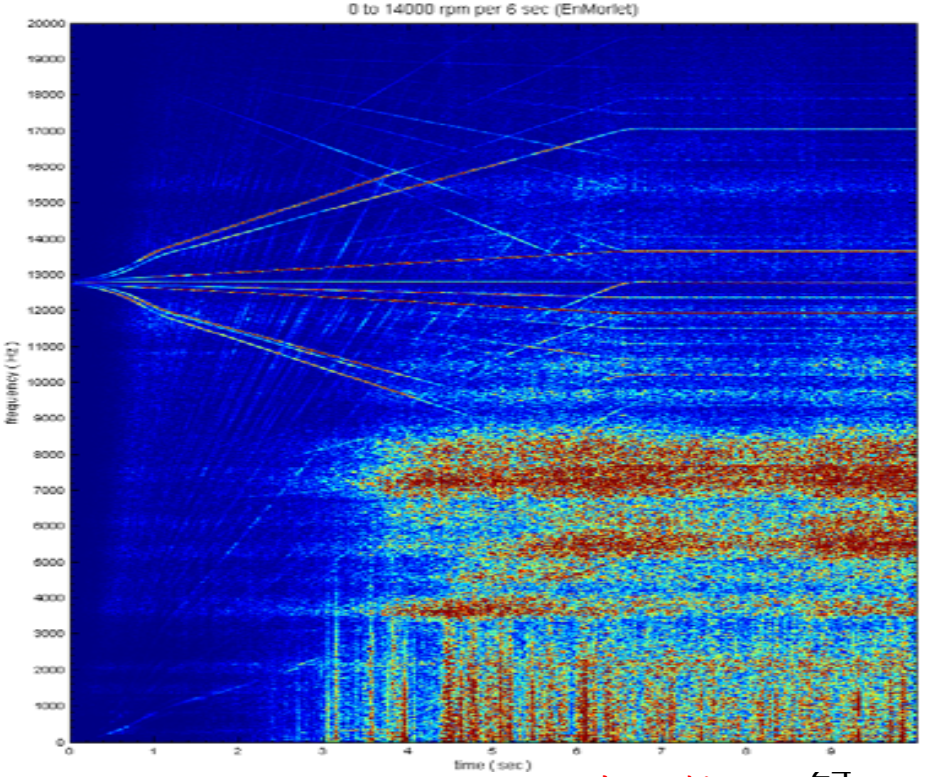


異常激振 RMS: 0.18g < G0.35



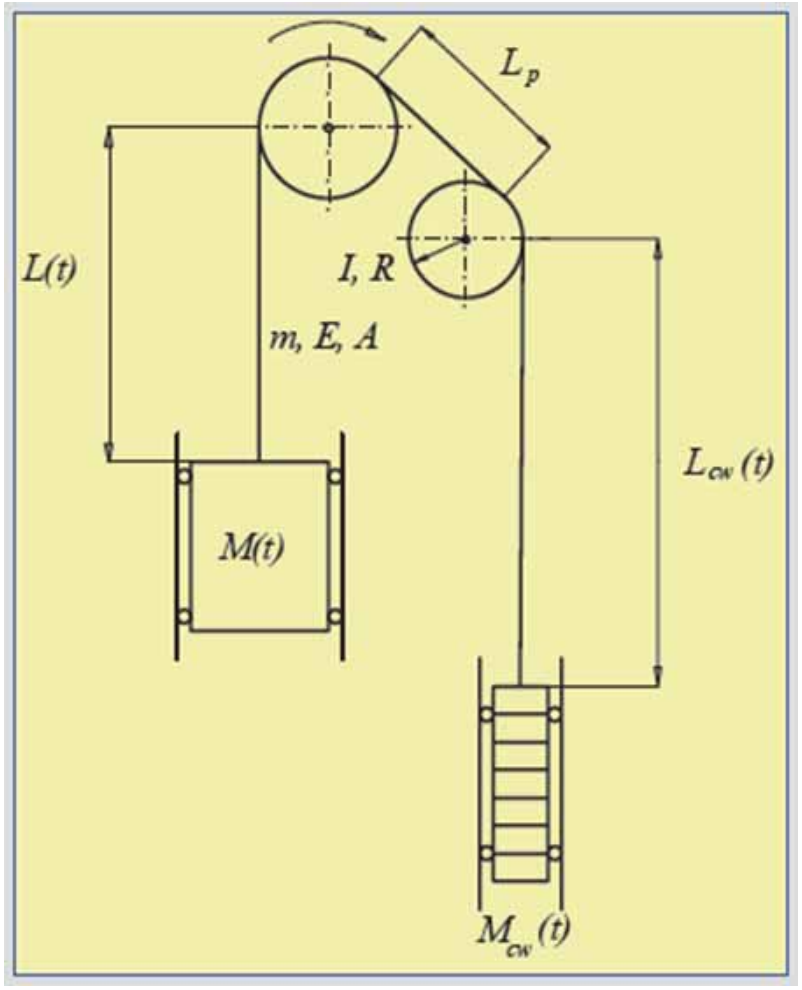
RMS: 0.6g > G0.35

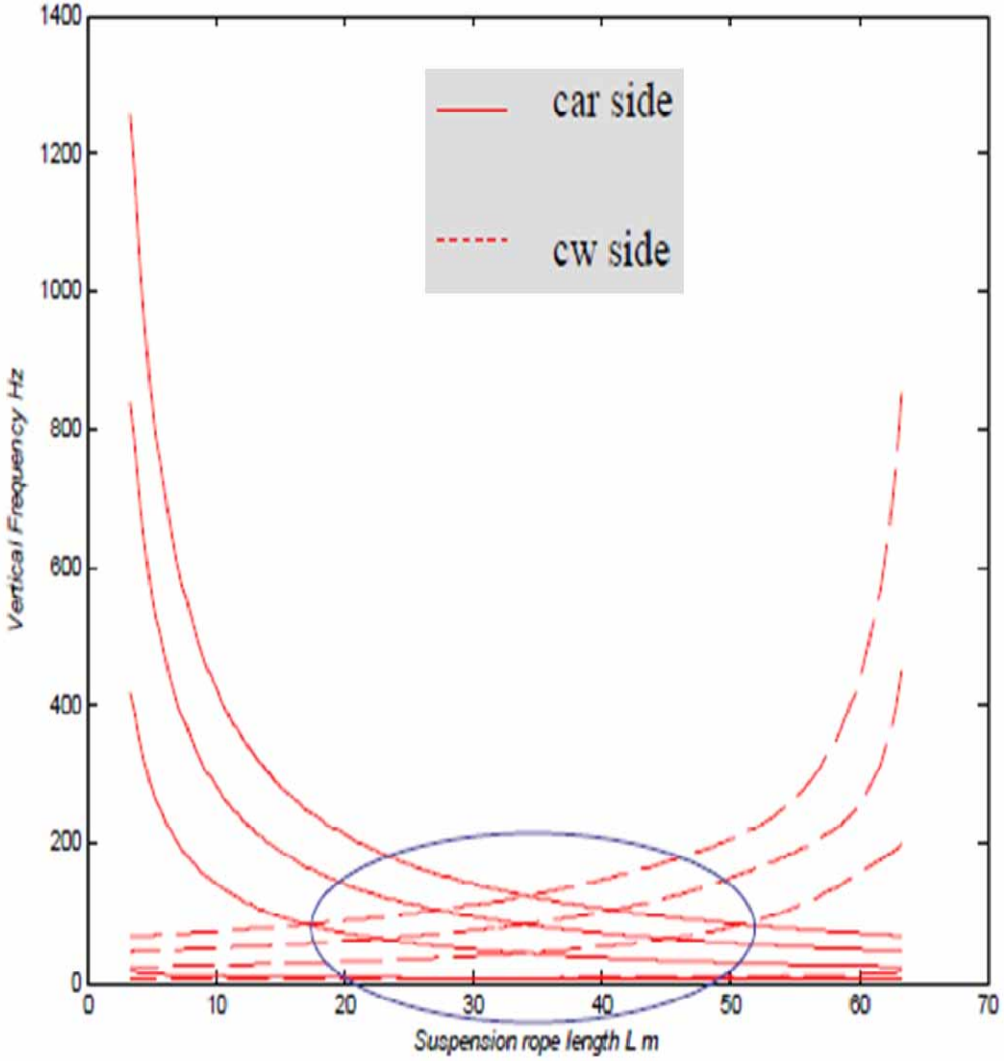




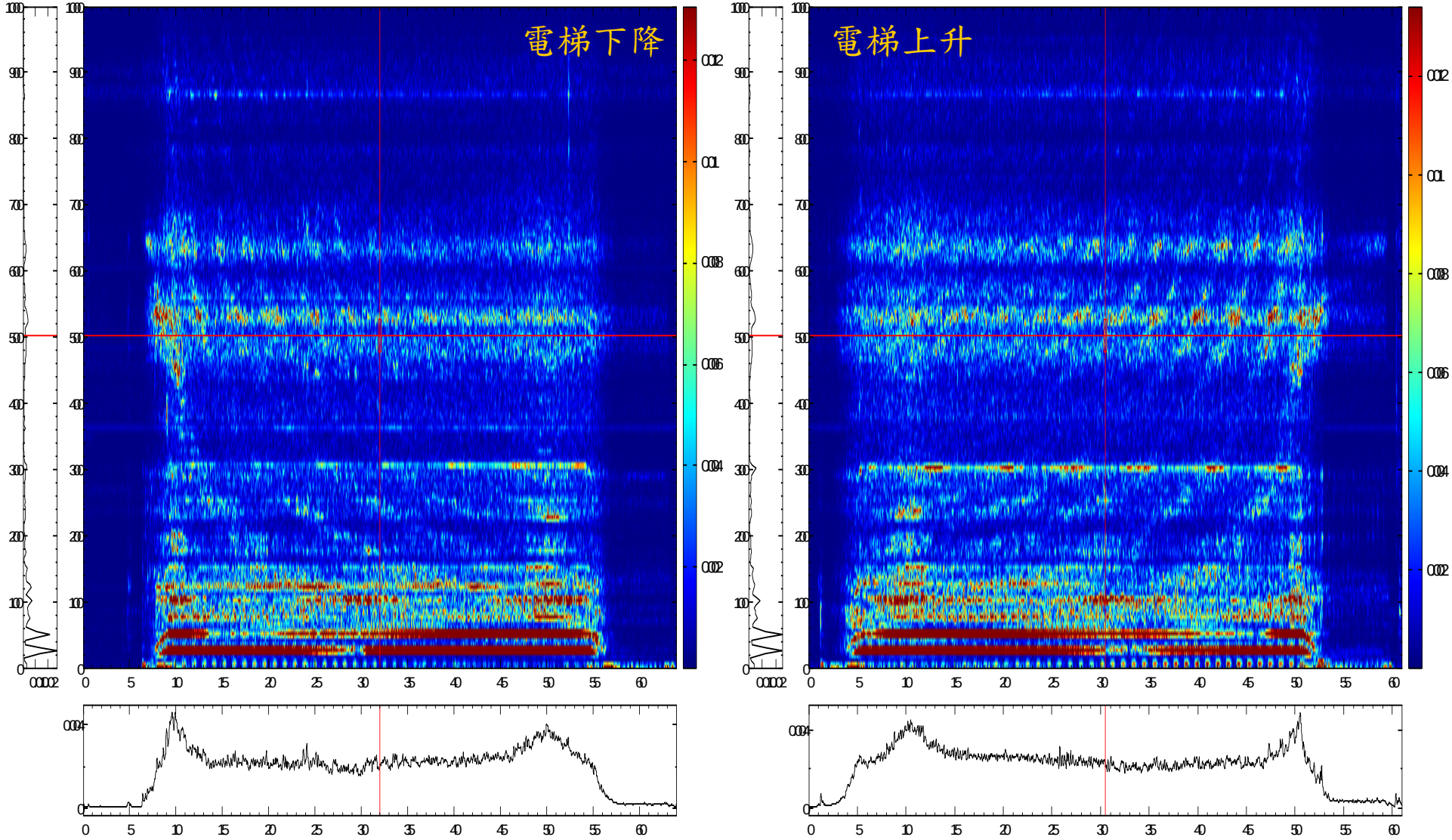
異常撞擊

電梯系統自然頻率


L_p
$L(t)$
I, R
m, E, A
$L_{cw}(t)$
$M(t)$
$M_{cw}(t)$

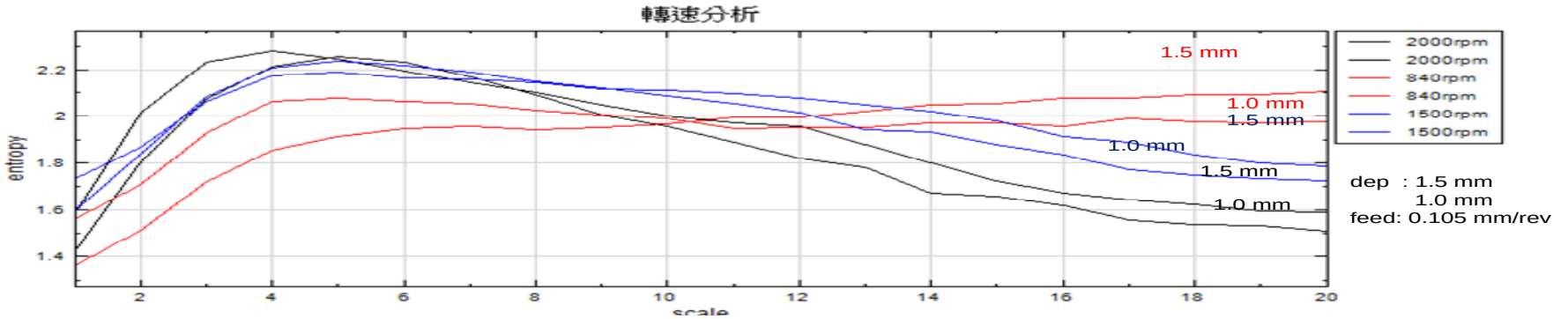

car side
cw side
Vertical Frequency Hz
Suspension rope length L m
0
200
400
600
800
1000
1200
1400
10
20
30
40
50
60
70

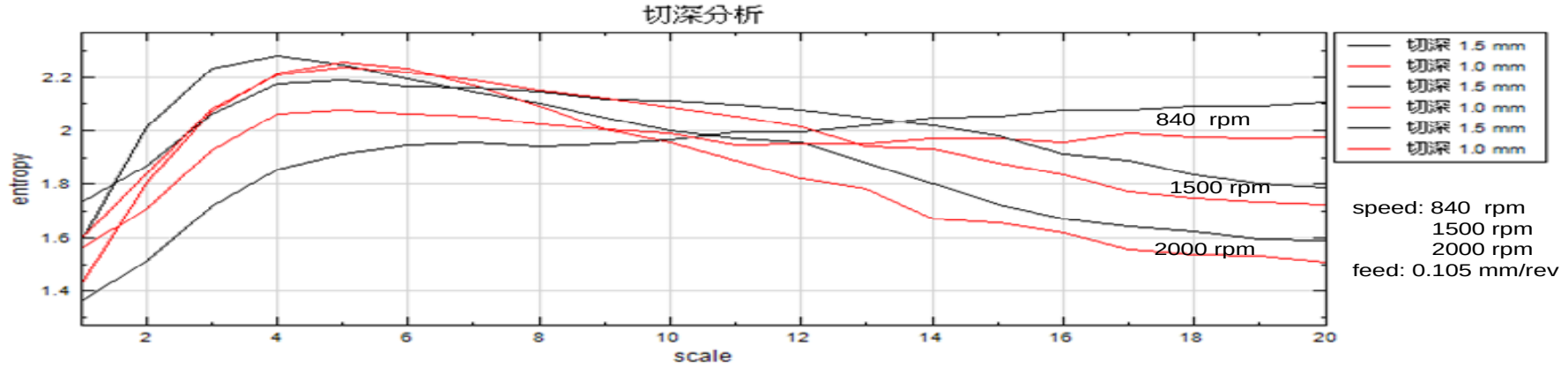
電梯系統振動時頻分析

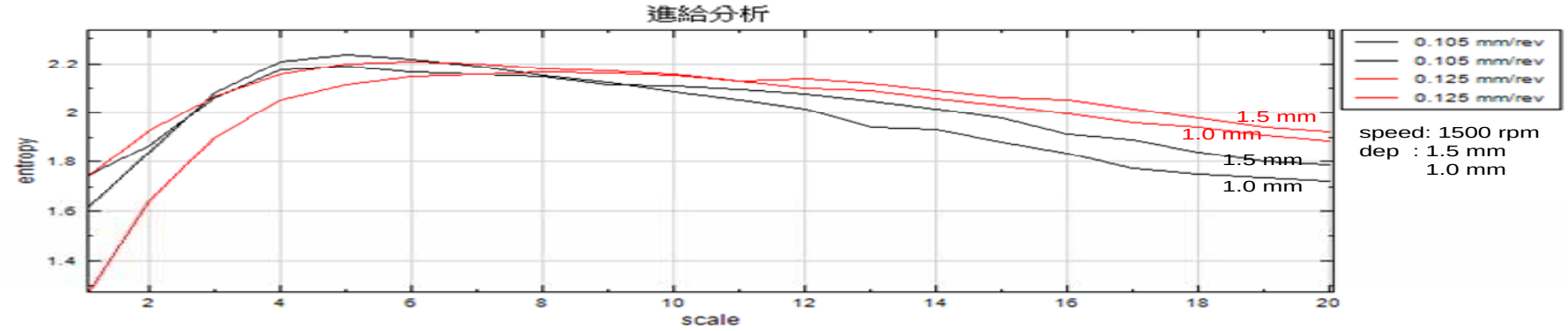


Multi-Scale Entropy (MSE)

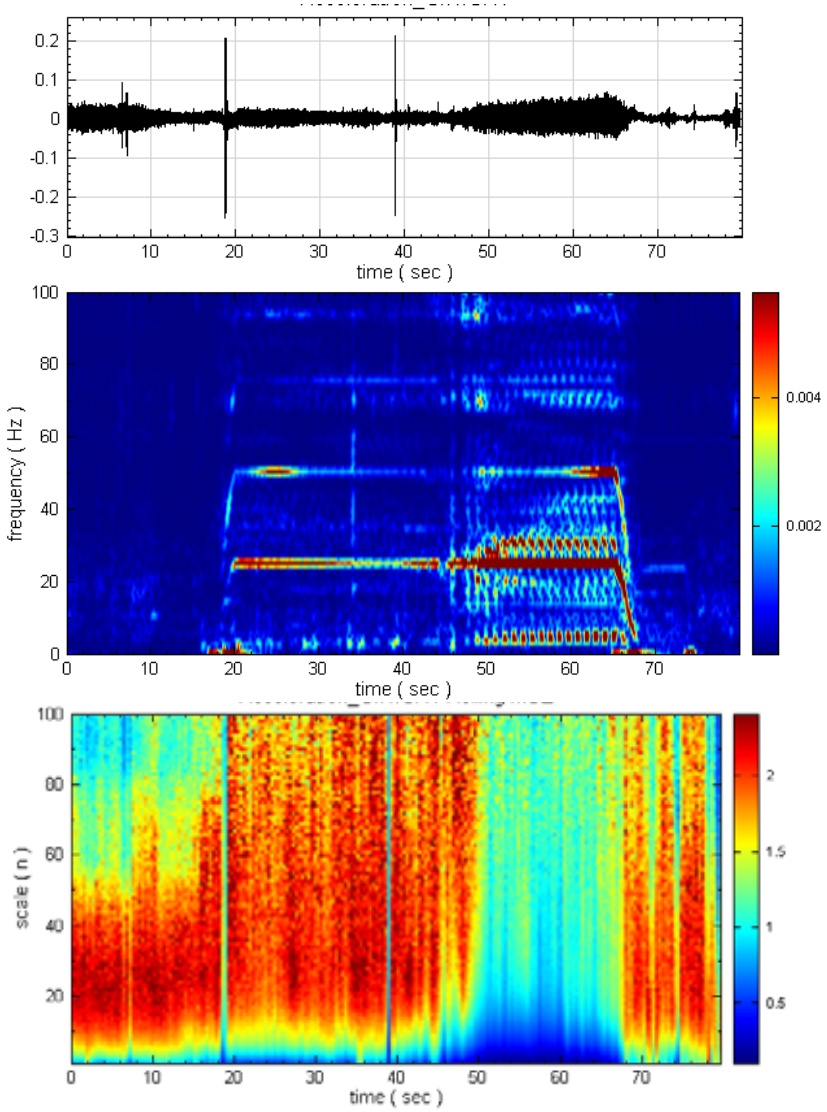
MSE：參數明顯度判別 ⇨ 轉速>切深>進給

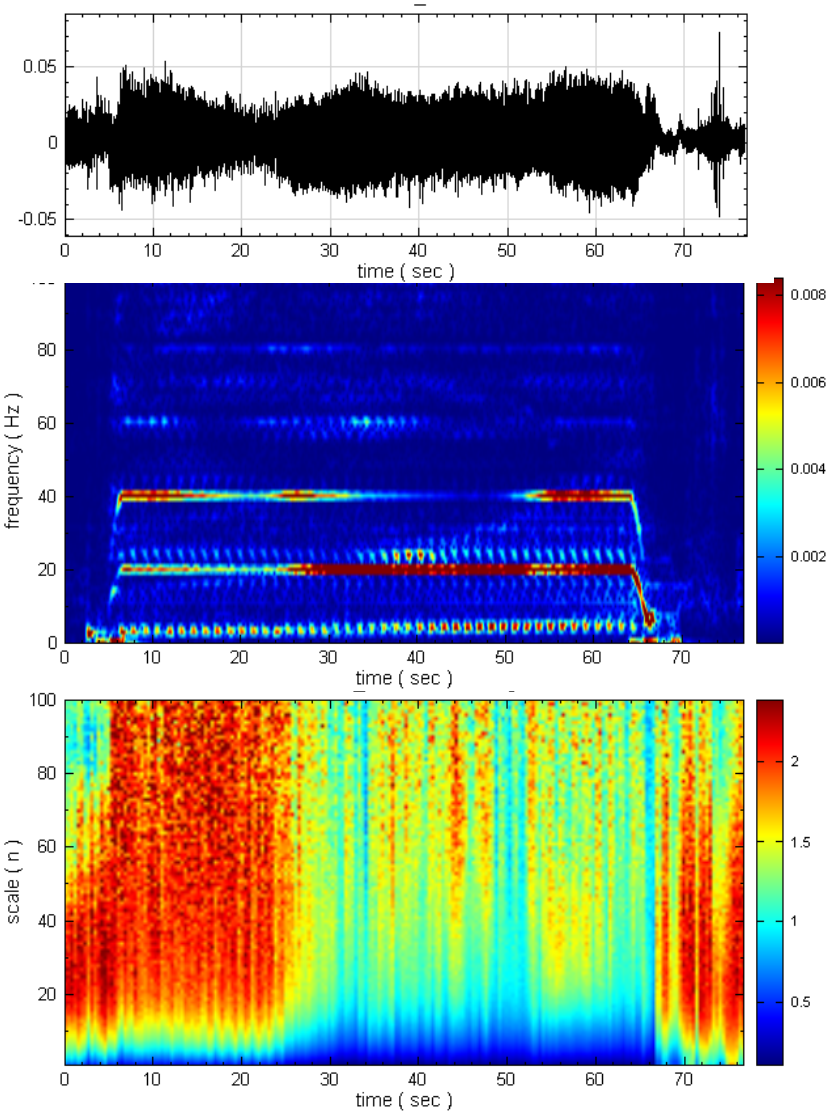






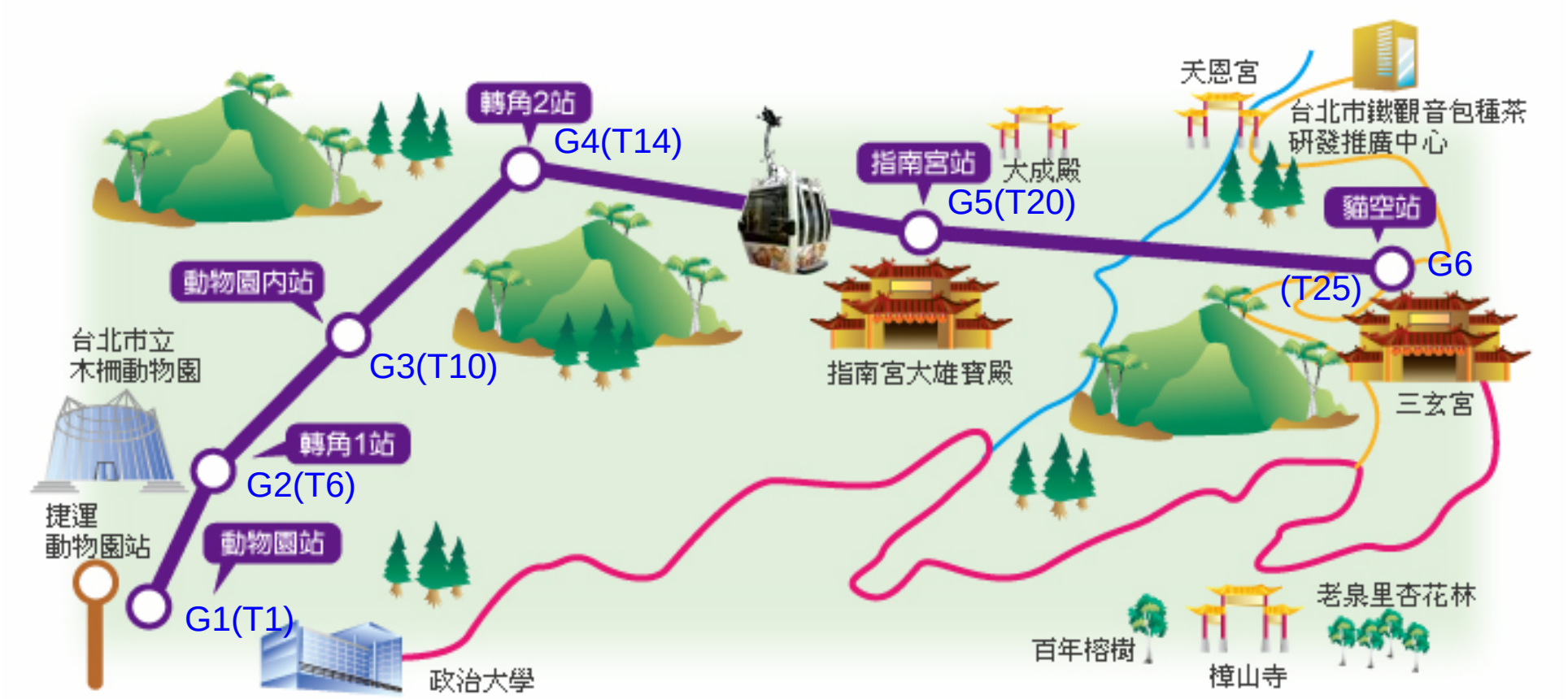
Rolling MSE：電梯振動



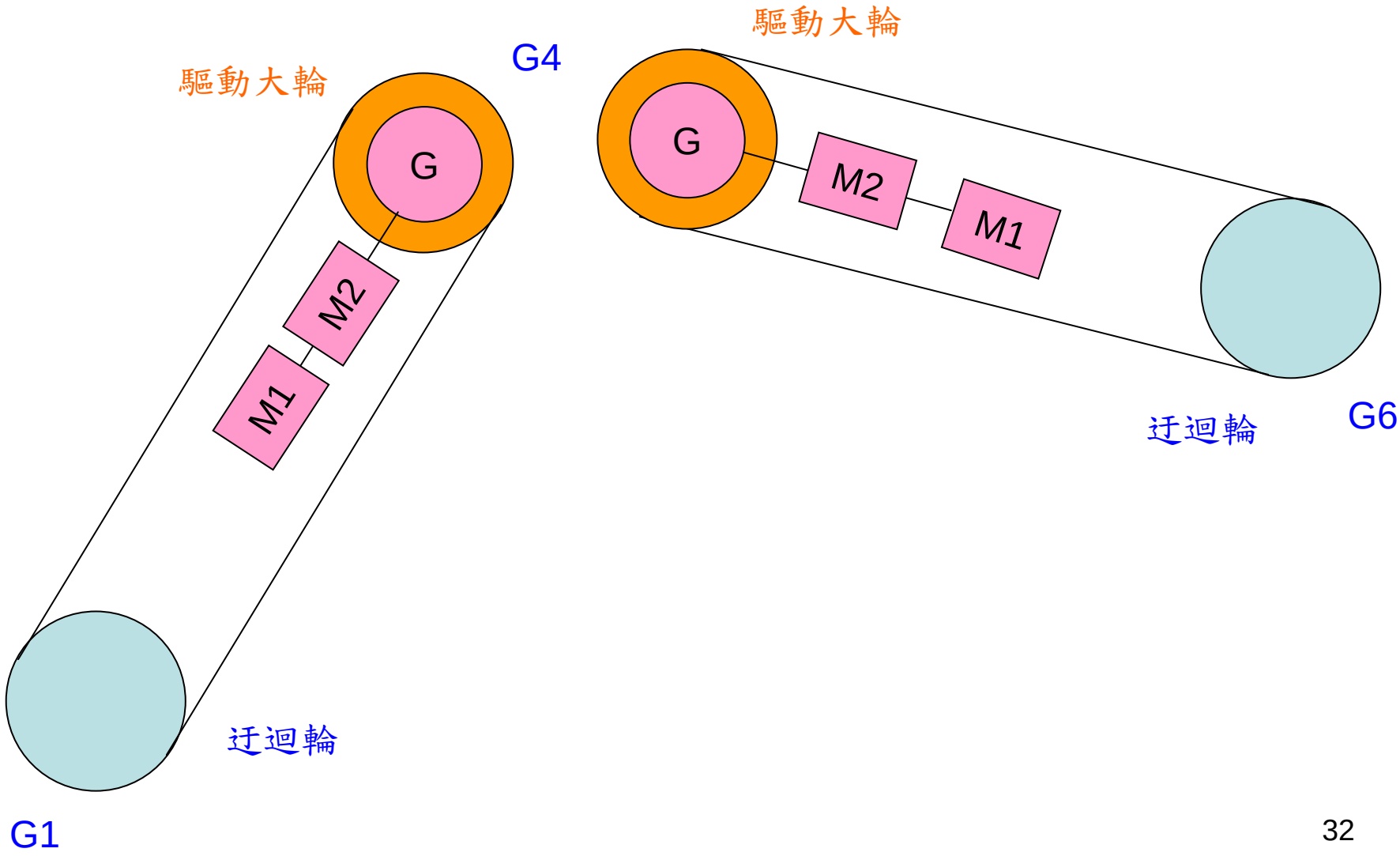


纜車之振噪檢測

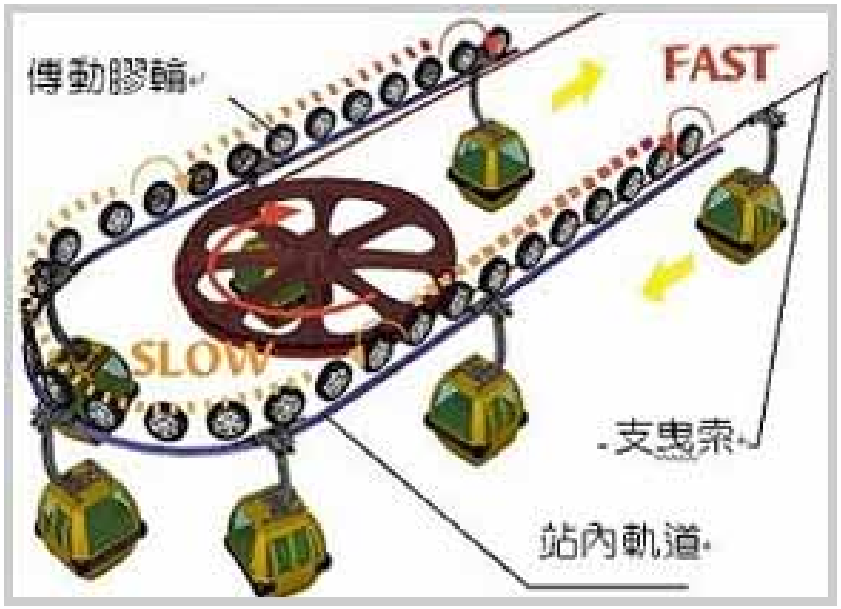
貓纜路線圖


轉角2站
G4(T14)
指南宮站
大成殿
G5(T20)
天恩宮
台北市鐵觀音包種茶
研發推廣中心
貓空站
G6
(T25)
動物園內站
台北市立
木柵動物園
G3(T10)
指南宮大雄寶殿
三玄宮
轉角1站
G2(T6)
捷運
動物園站
動物園站
G1(T1)
政治大學
百年榕樹
樟山寺
老泉里杏花林

纜車動力系統



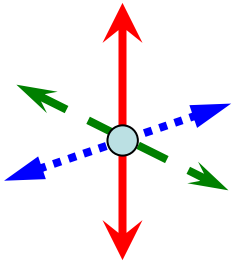
激振頻率 VS. 自然頻率⇨異常共振



驅動頻率： $\Omega_n = 2n(V_c/R_d),$

$n = 1, 2,$

- ✓轉動激振頻率
- ✓驅動驅動頻率
- ✓塔柱滾輪激振頻率
- ✓流體激勵頻率
- …



量測硬體設置

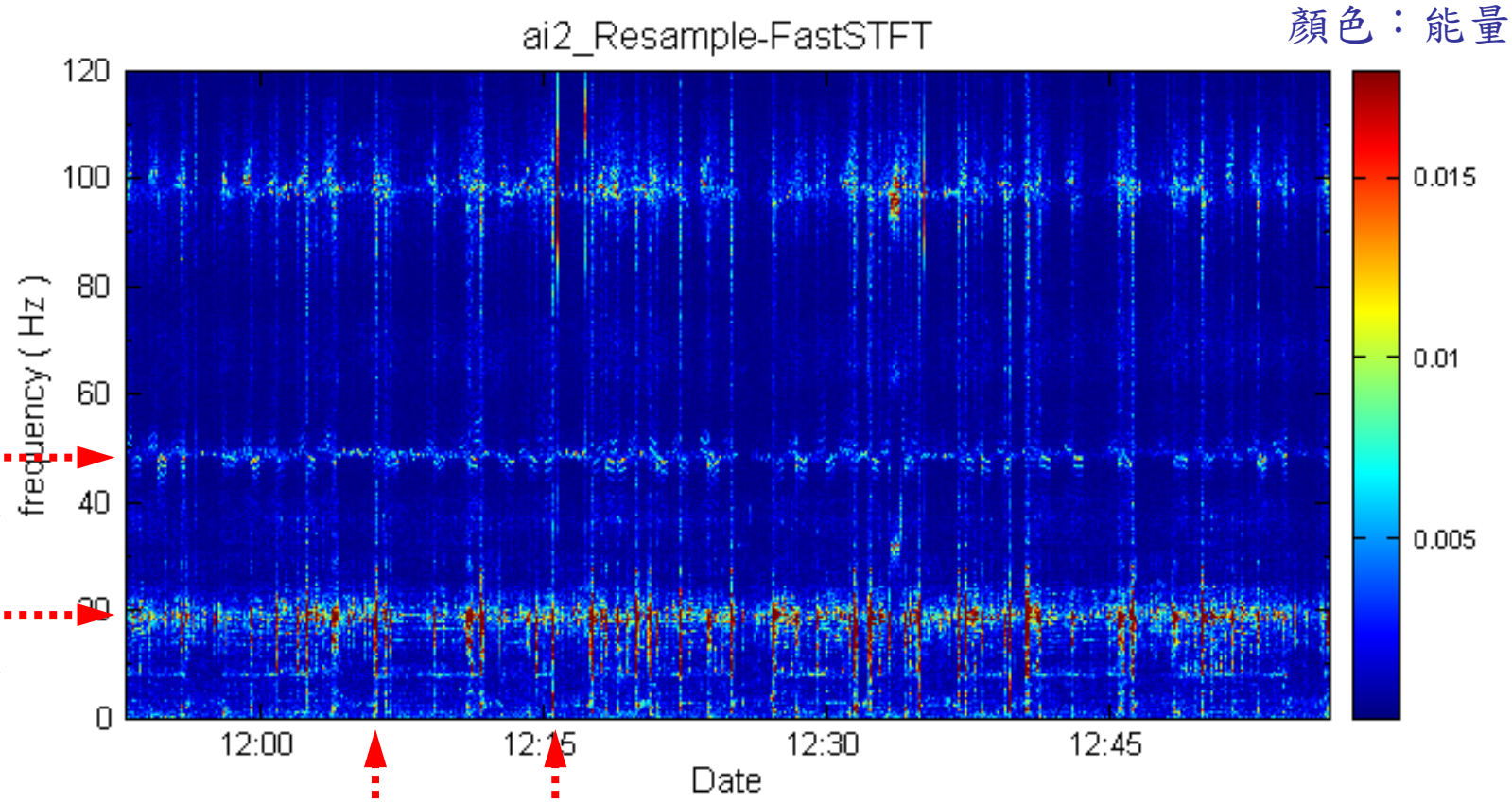
麥克風(車廂內)
量測乘客感受之噪音

加速規(車廂框架)
量測纜繩傳遞至車體之振動

加速規(車廂天花板)
量測發聲源之異常共振

訊號擷取卡＋筆記型電腦
將物理訊號數位化並儲存

時頻圖之物理含意



顏色：能量

縱軸：頻率

橫線：
外力激振頻率

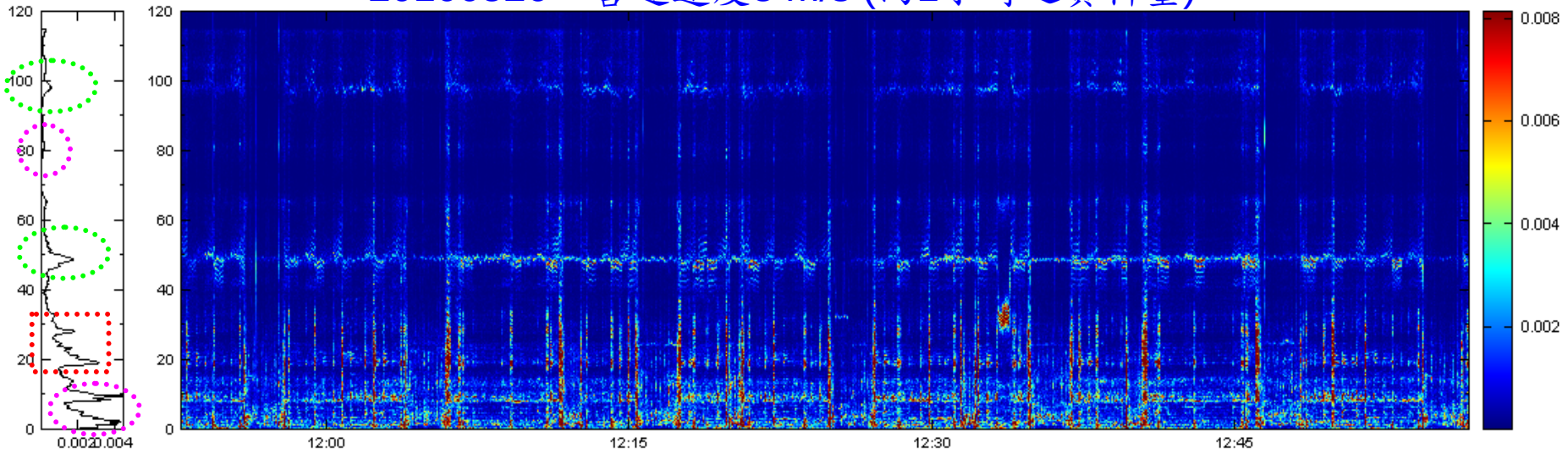
橫線：
系統自然頻率
（結構共振）

縱線：
衝擊事件時間點
(纜車通過索輪或進站)

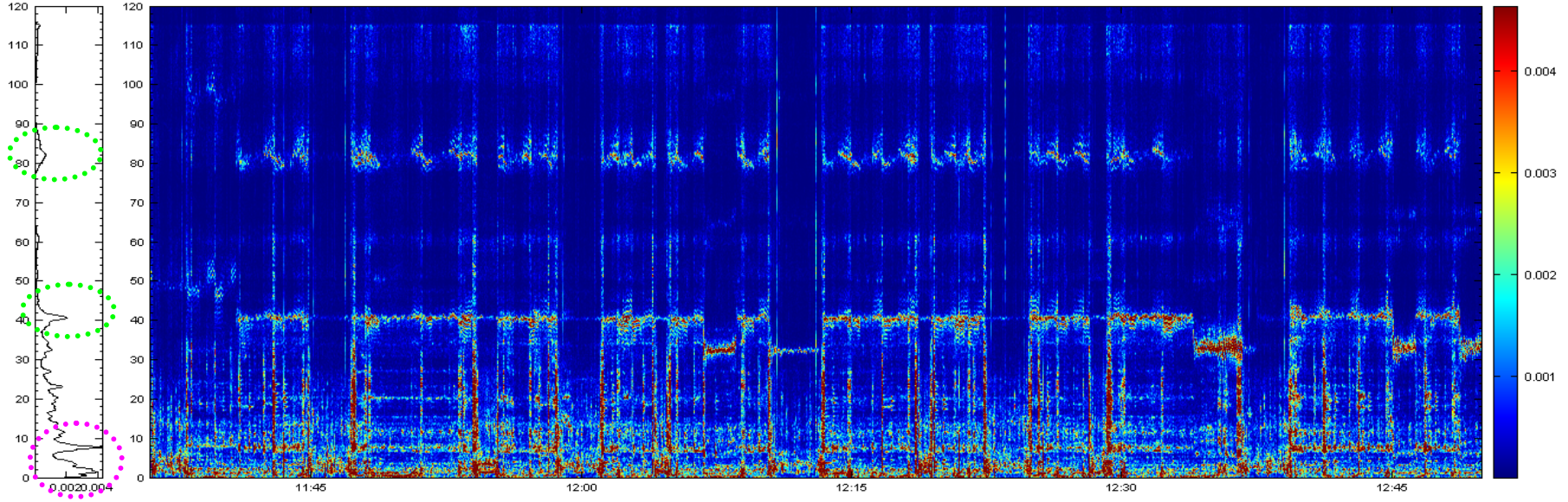
橫軸：時間

營運速度對系統穩定性之影響

20100526：營運速度3 m/s (約1小時之資料量)

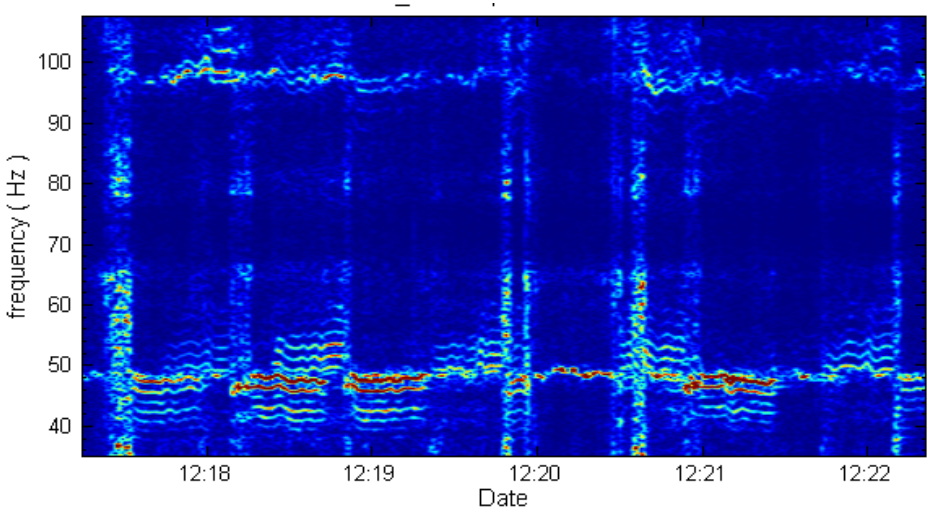


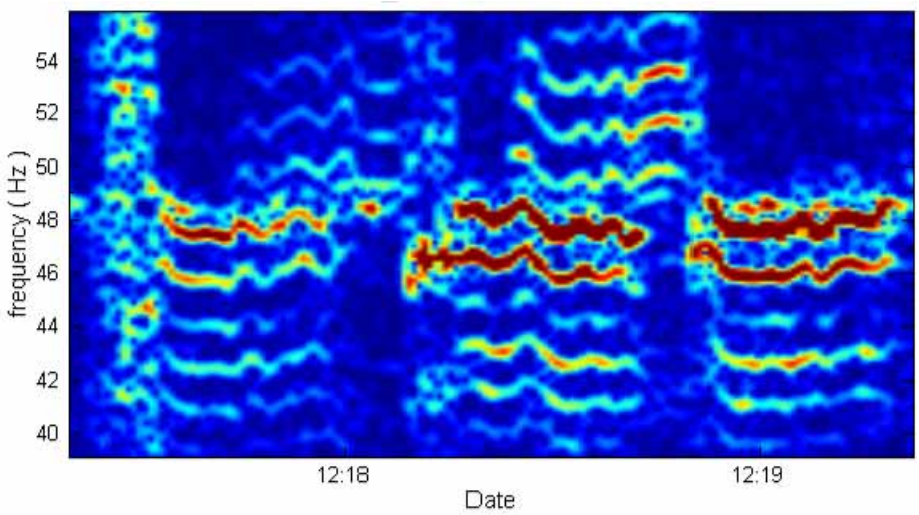
20100429：營運速度2.5 m/s（約1小時15分鐘之資料量）



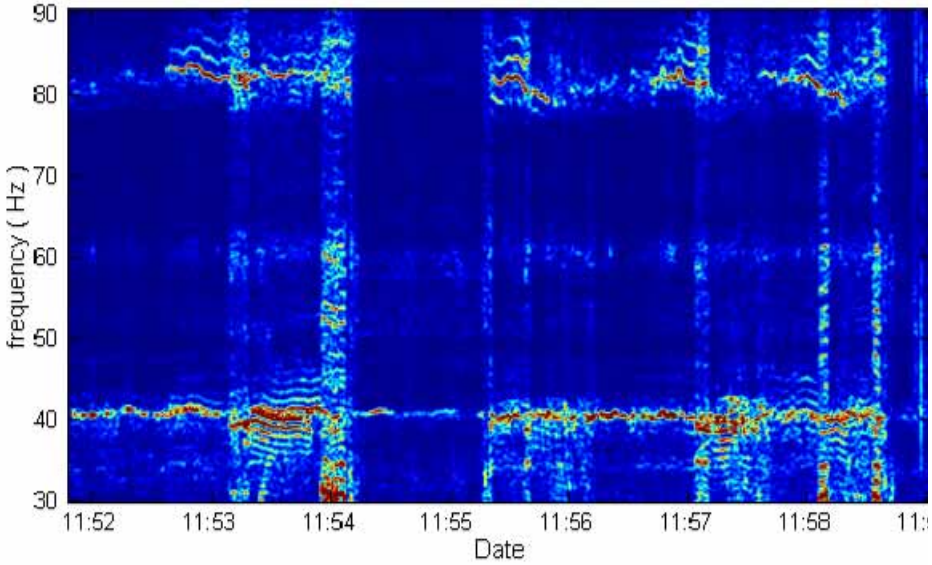
營運速度對系統穩定性之影響

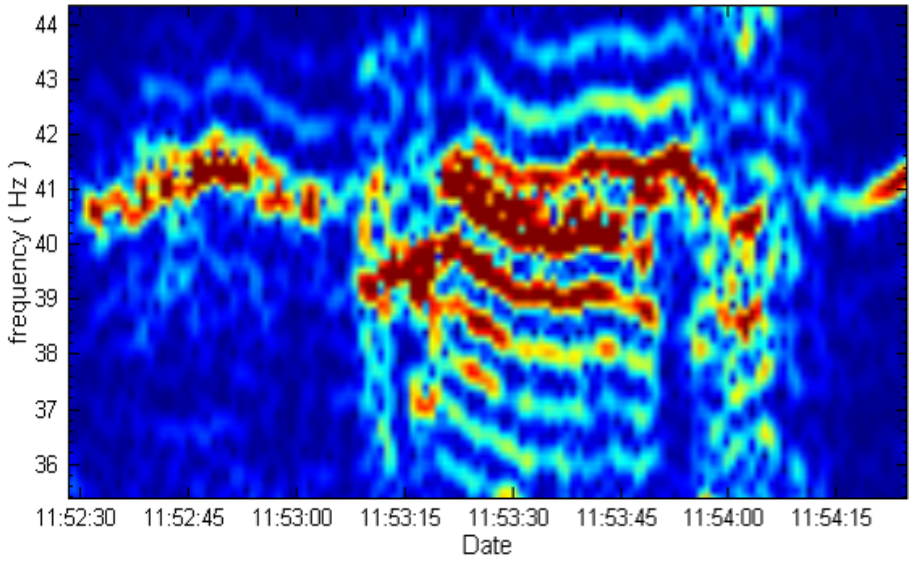
20100526：營運速度3 m/s





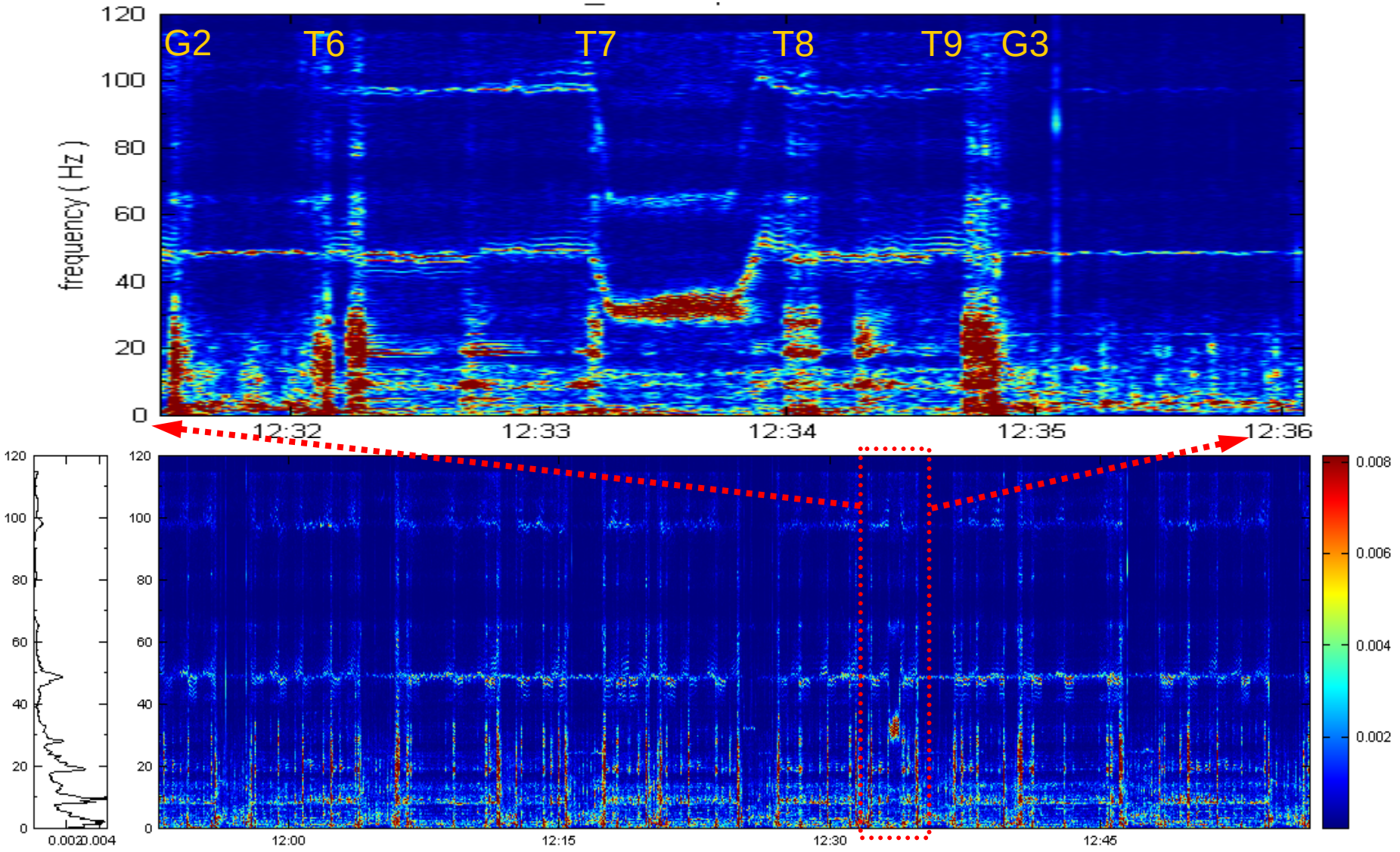
20100429：營運速度2.5 m/s





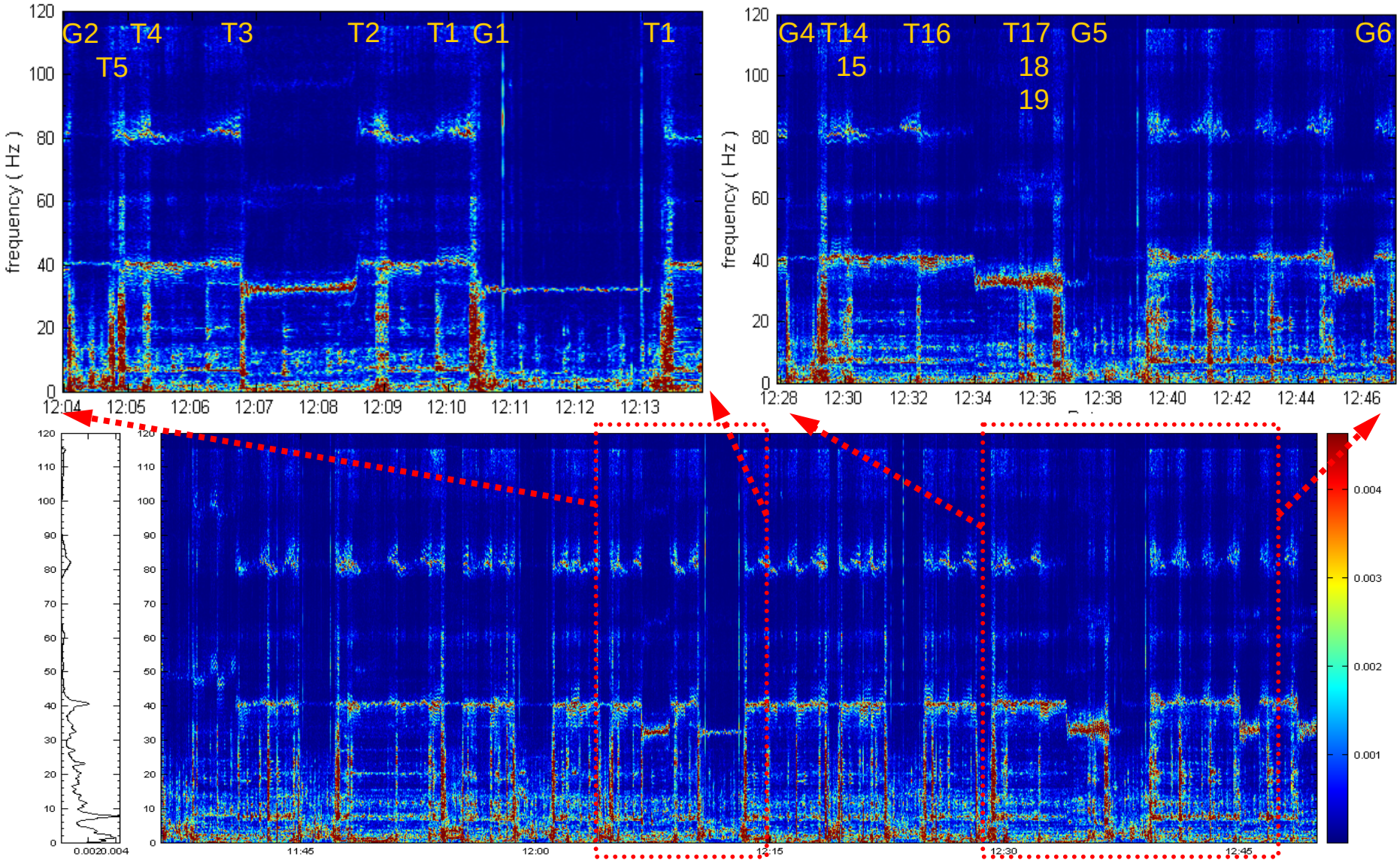
營運速度對系統穩定性之影響

20100526：營運速度3 m/s



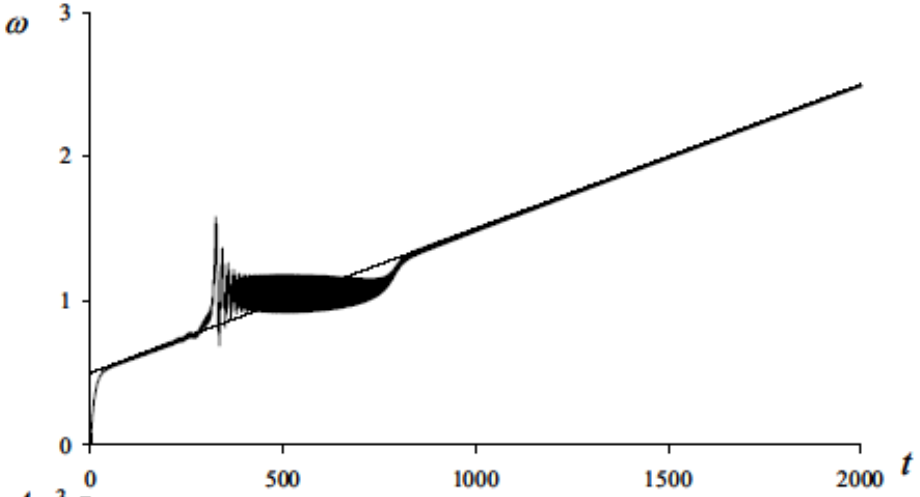
營運速度對系統穩定性之影響

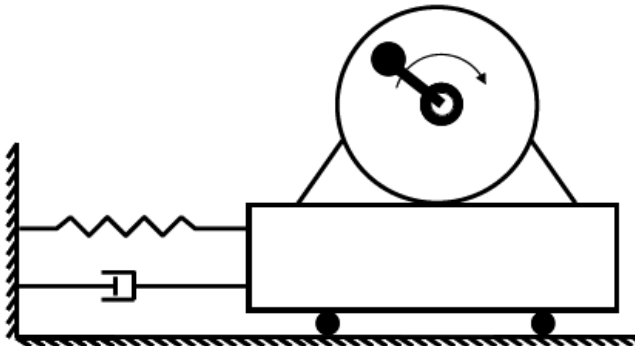
20100429：營運速度2.5 m/s

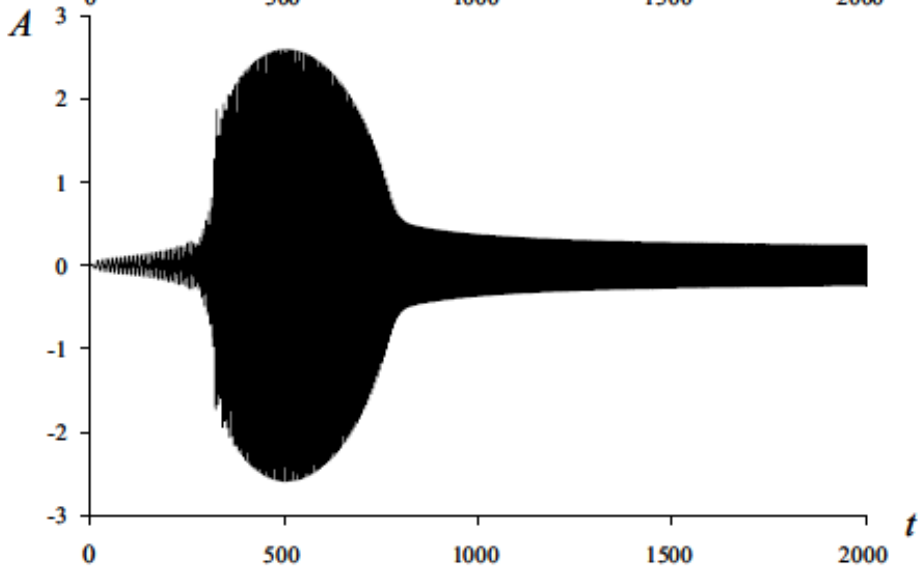


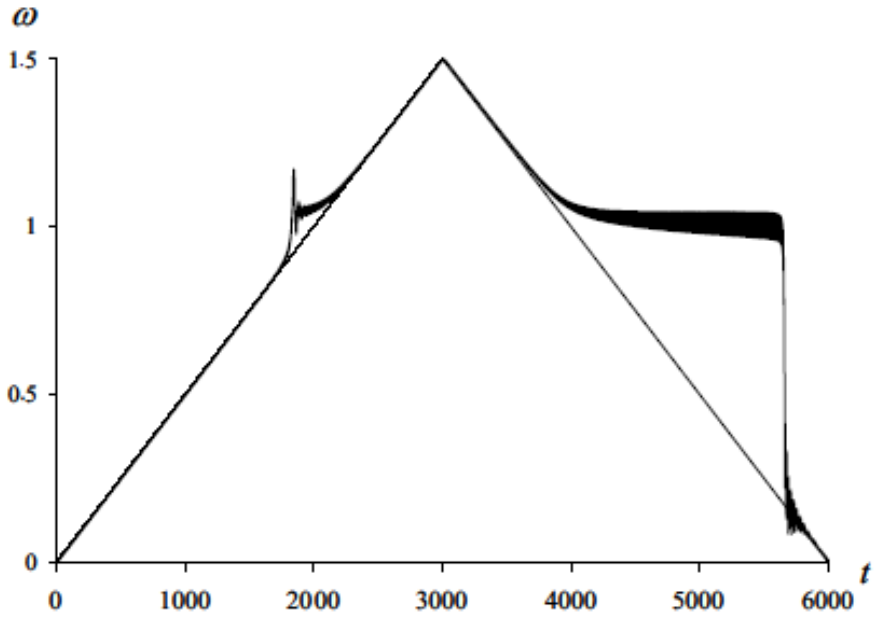
臨界轉速&共振頻率

非線性振動：暫態效應、鎖定共振

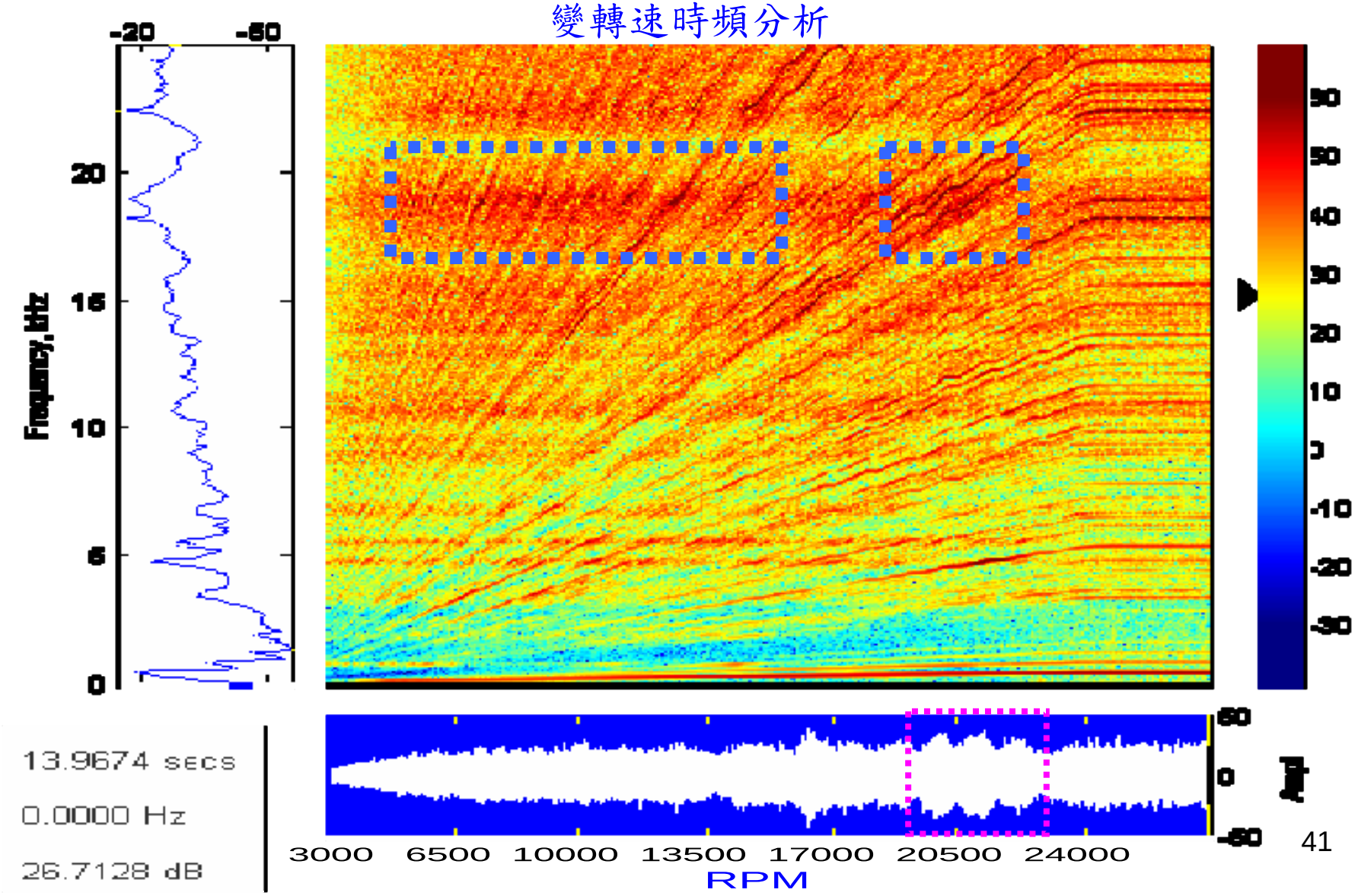






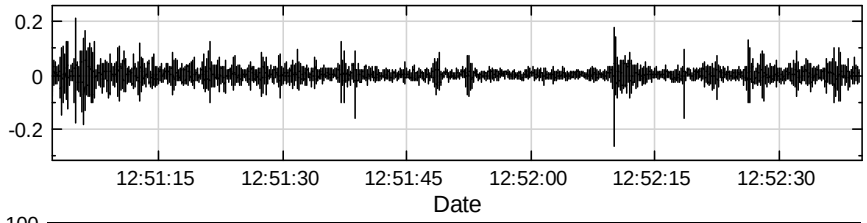


變轉速時頻分析：臨界轉速

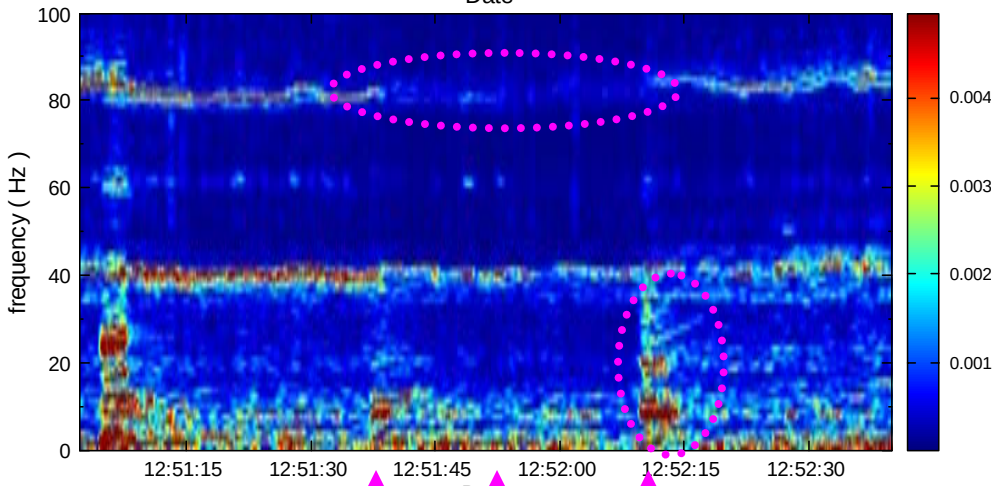


T24⇨T23

塔柱之間
纜車振動

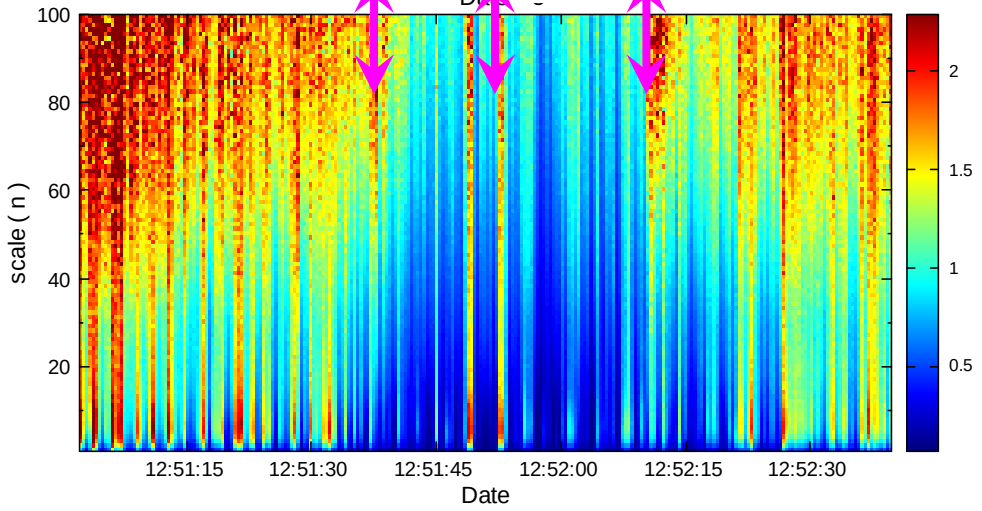


纜車振動
時頻圖



纜車振動
MSE

(軟體判別)



明顯異常
振動之紀
錄時間點

(人工判別)

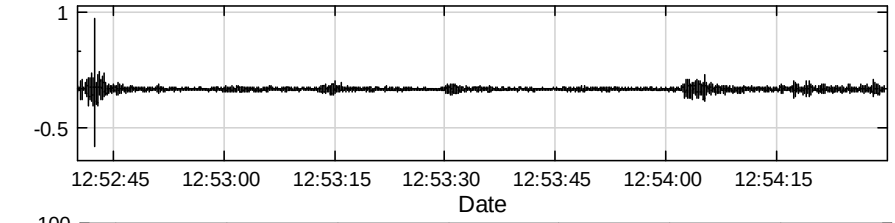
T23⇨T22

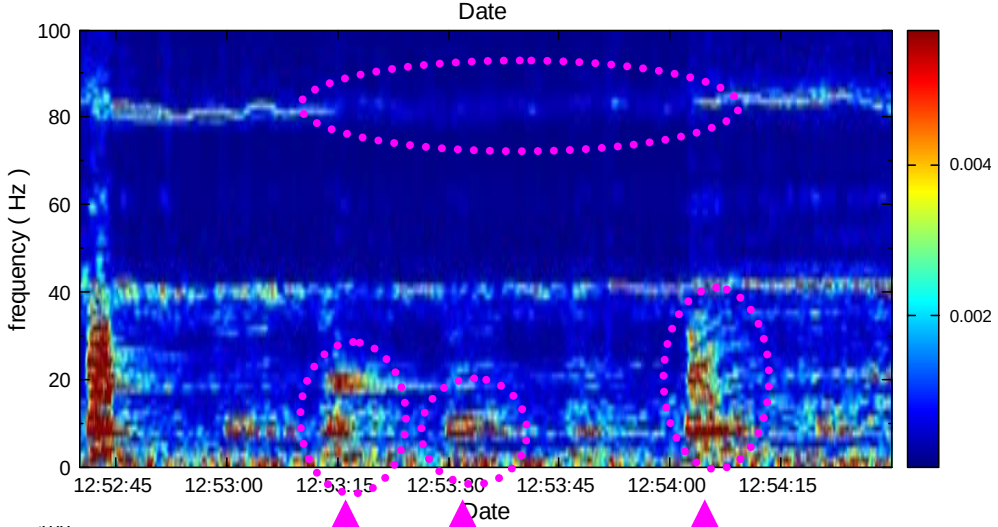
塔柱之間
纜車振動

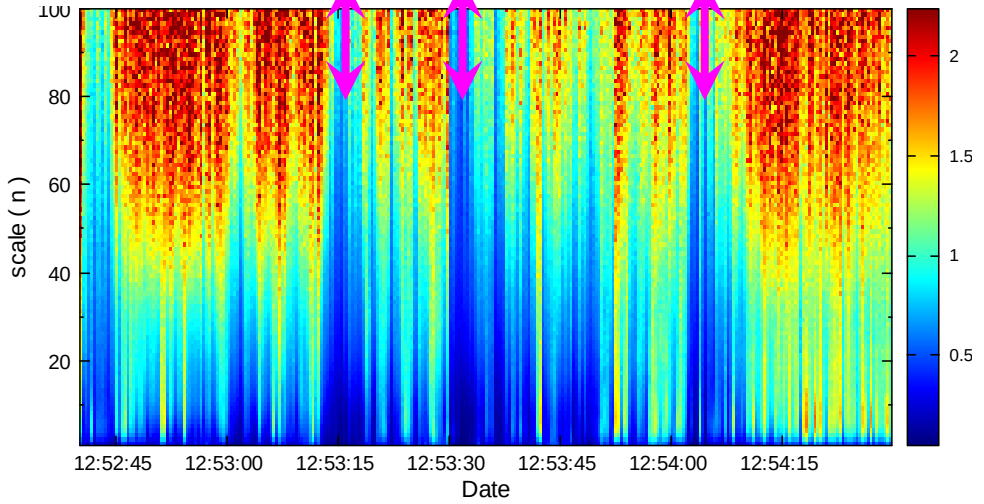
纜車振動
時頻圖

纜車振動
MSE

(軟體判別)





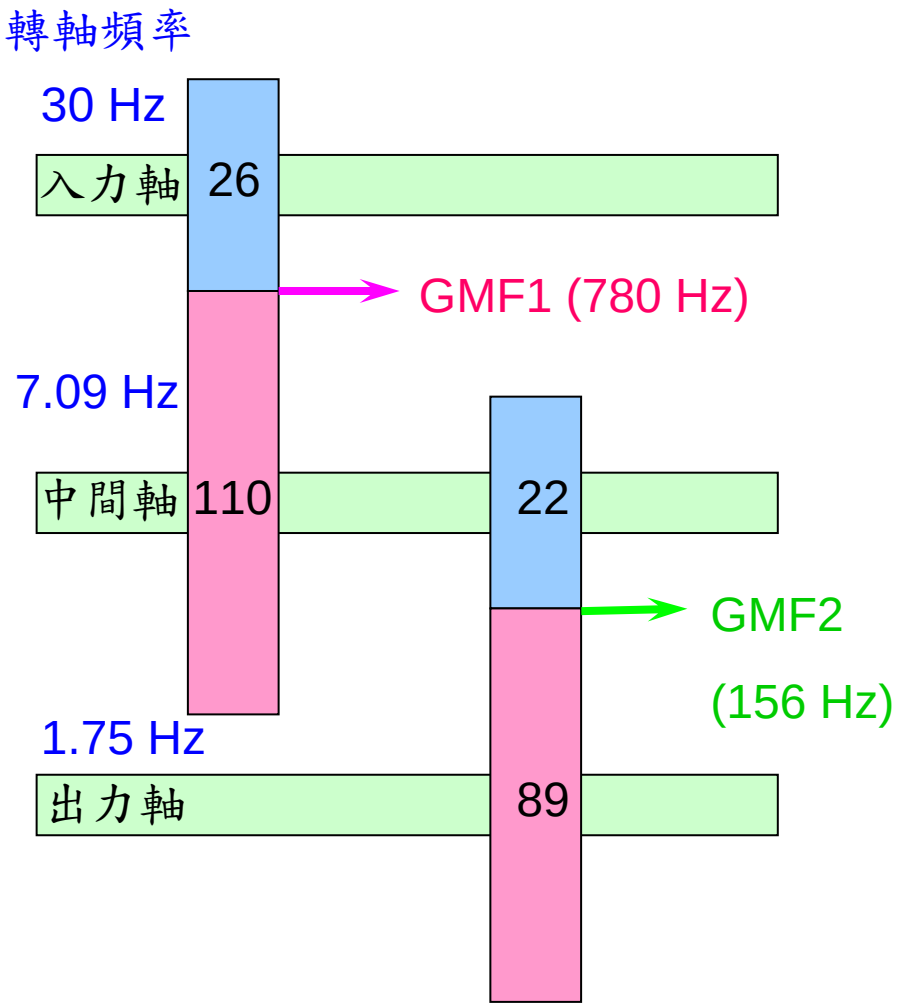


明顯異常
振動之紀
錄時間點

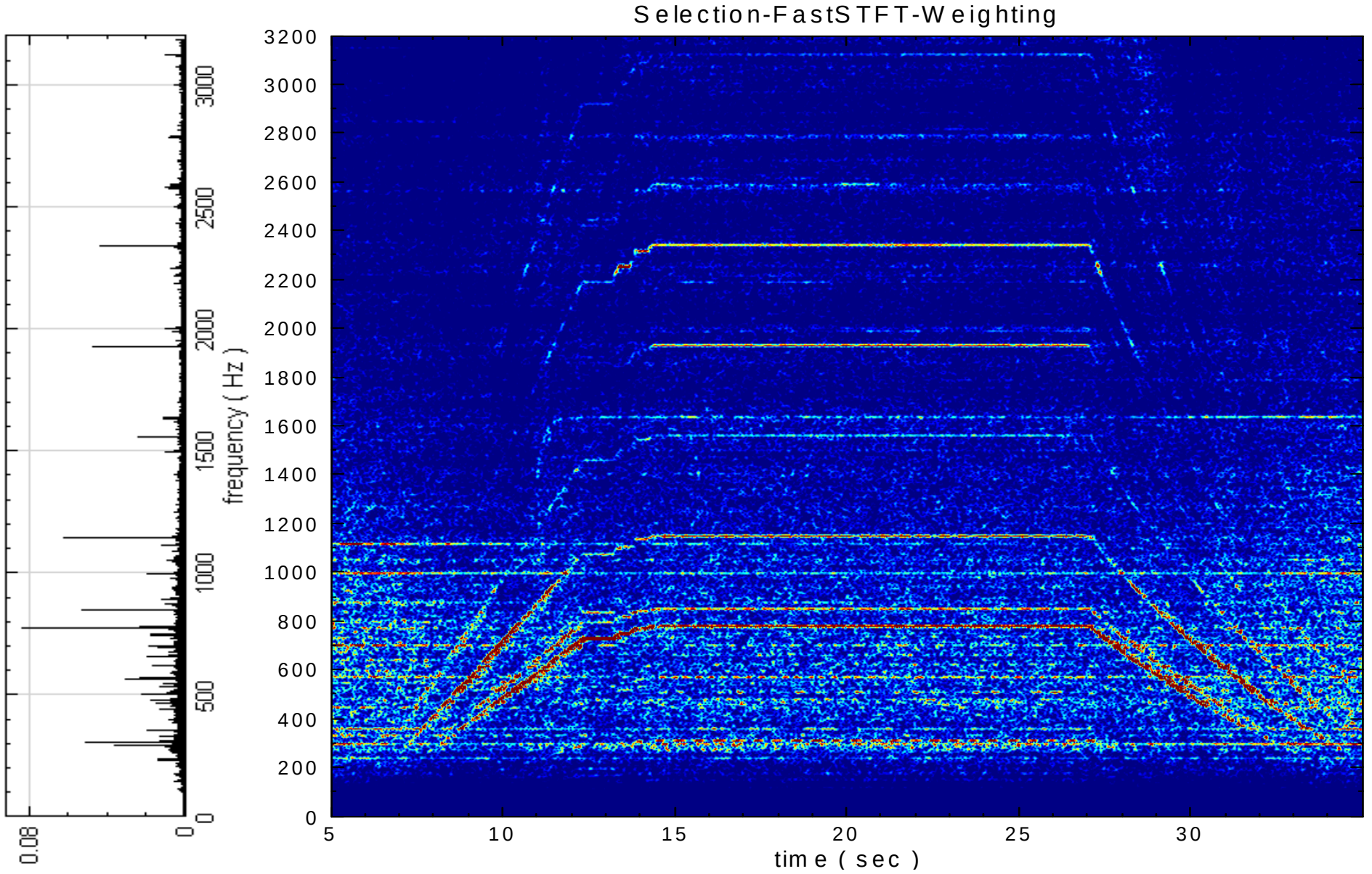
(人工判別)

電梯減速齒輪箱異音檢測

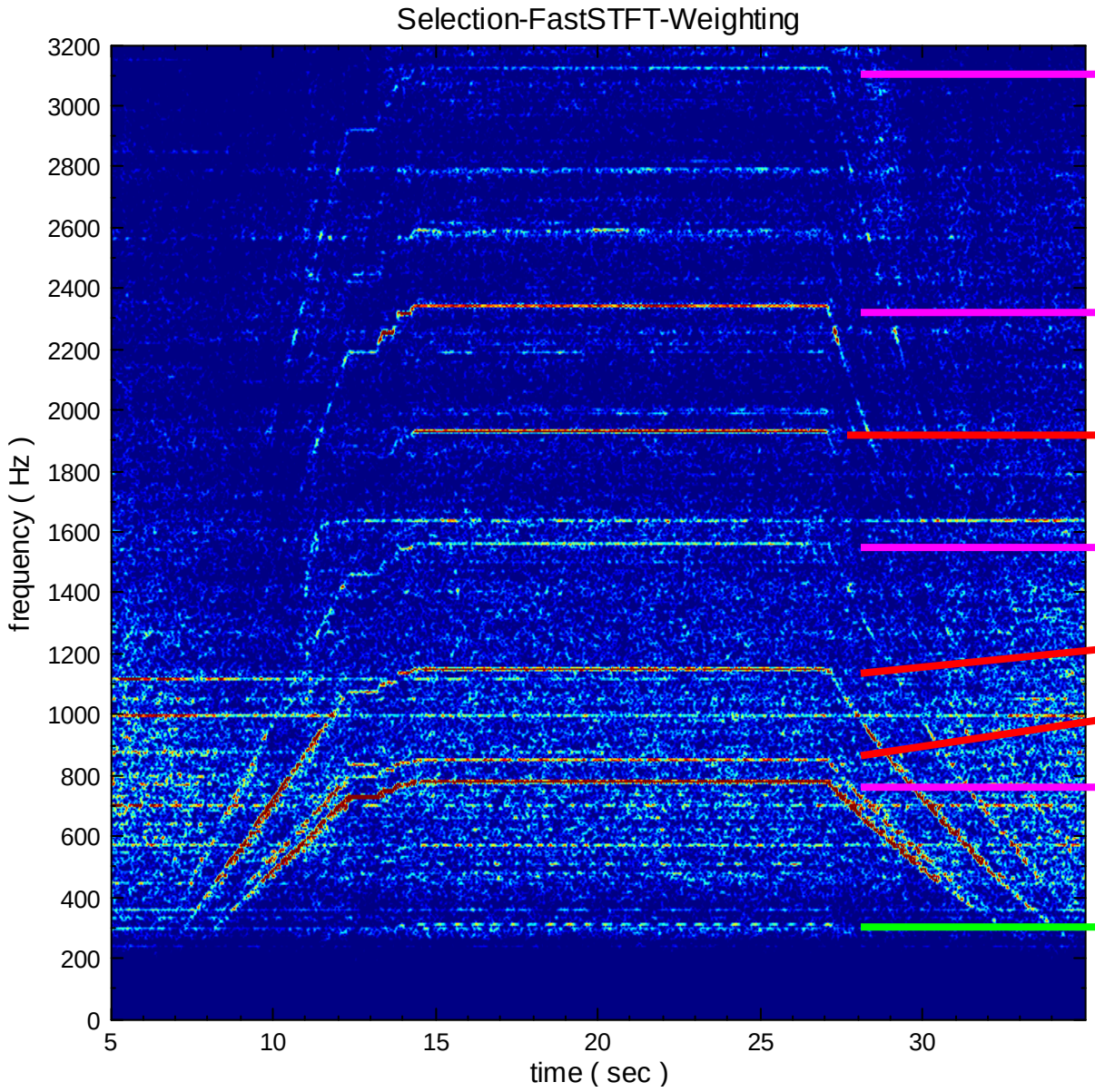
電源頻率60Hz-轉軸頻率及嚙合頻率



60Hz-正常生產運轉方向
聲音原始頻譜



60Hz-正常生產運轉方向
聲音A加權頻譜➔人耳感受



4xGMF1 (3120 Hz)

3xGMF1 (2340 Hz)

1930 Hz~2.5xGMF1
or (2x(30+7.09)x26)

2xGMF1 (1560 Hz)

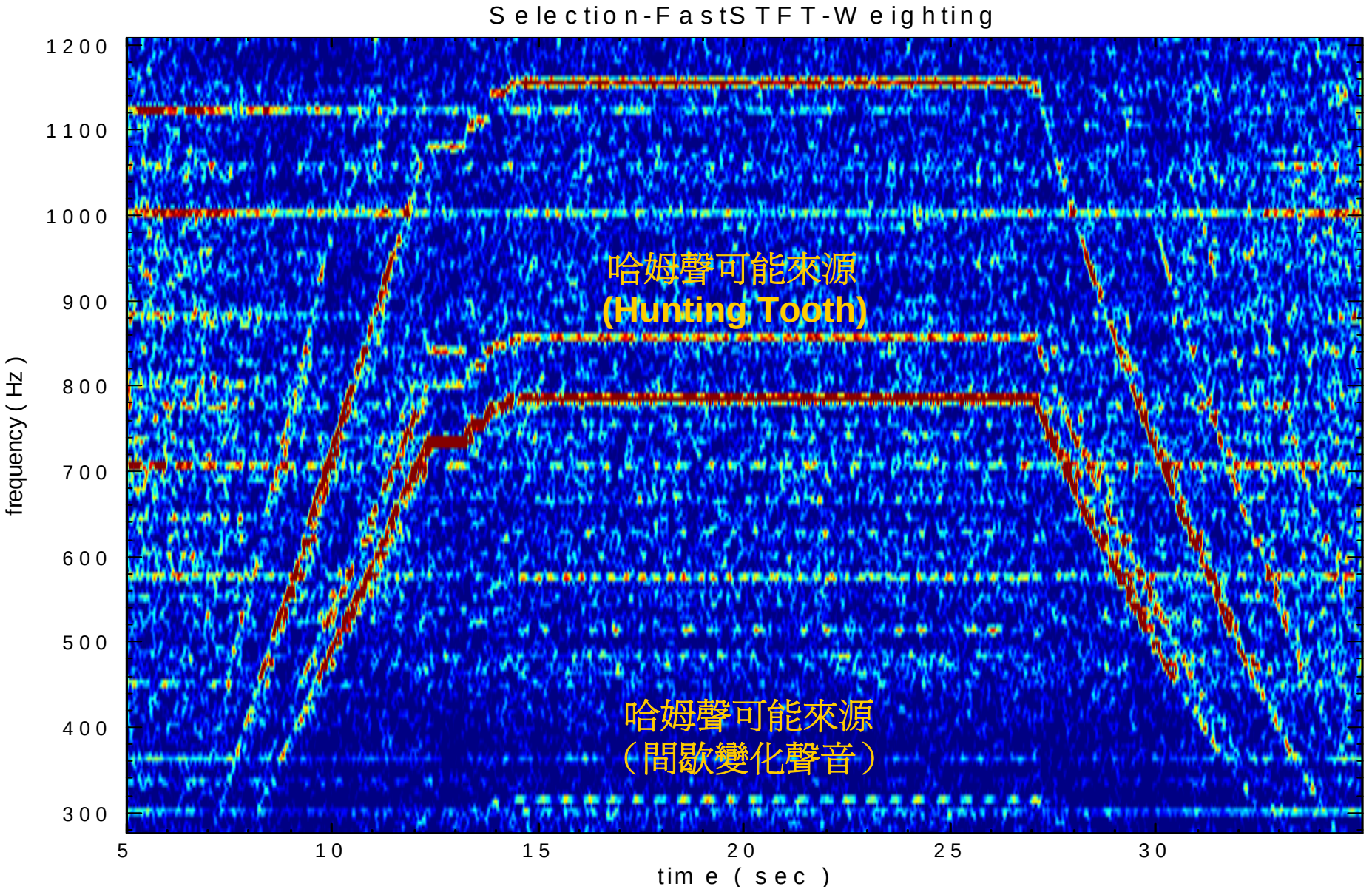
1150 Hz~1.5xGMF1

852 Hz (2x(30x7.09))

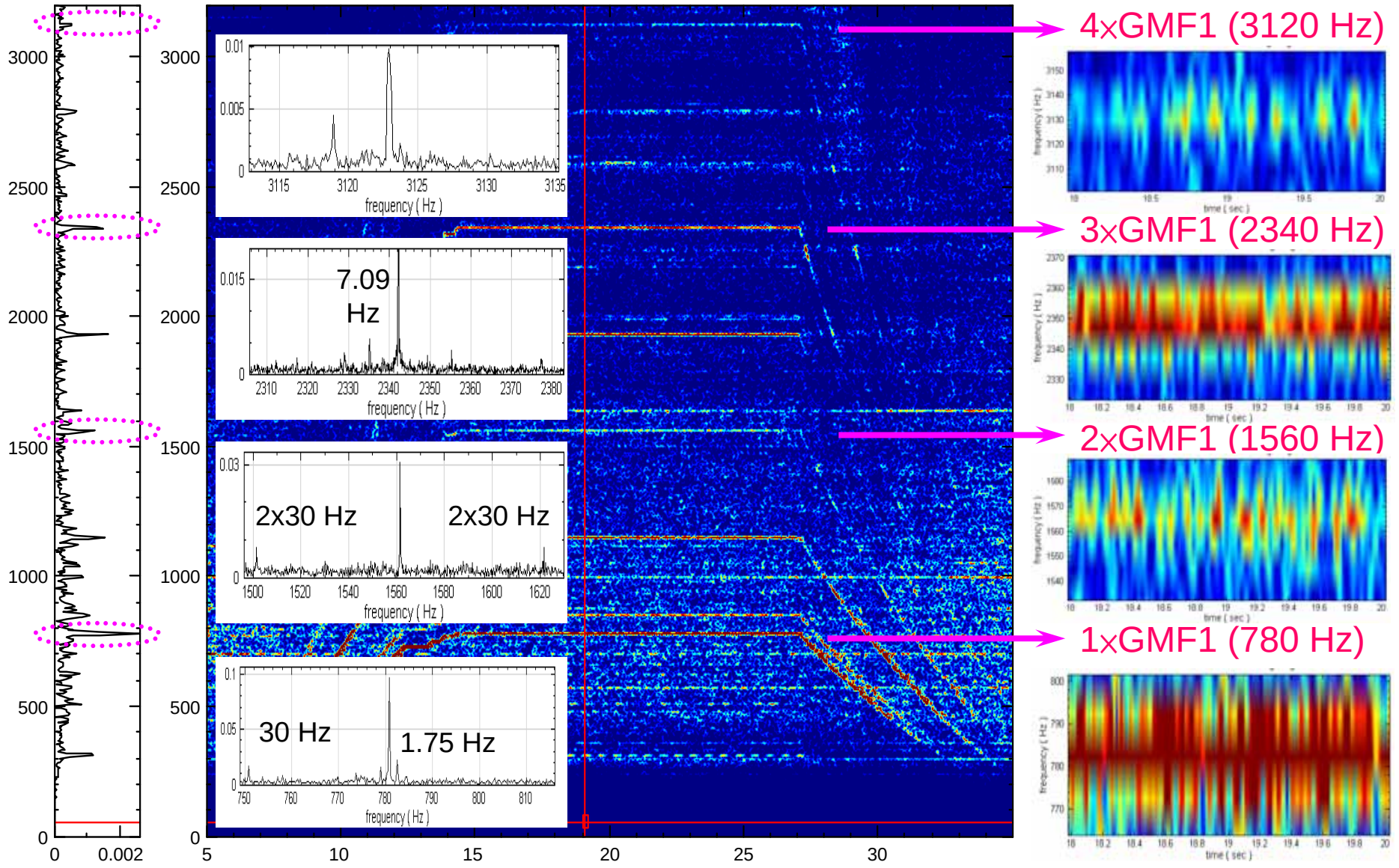
1xGMF1 (780 Hz)

2xGMF2 (312 Hz)

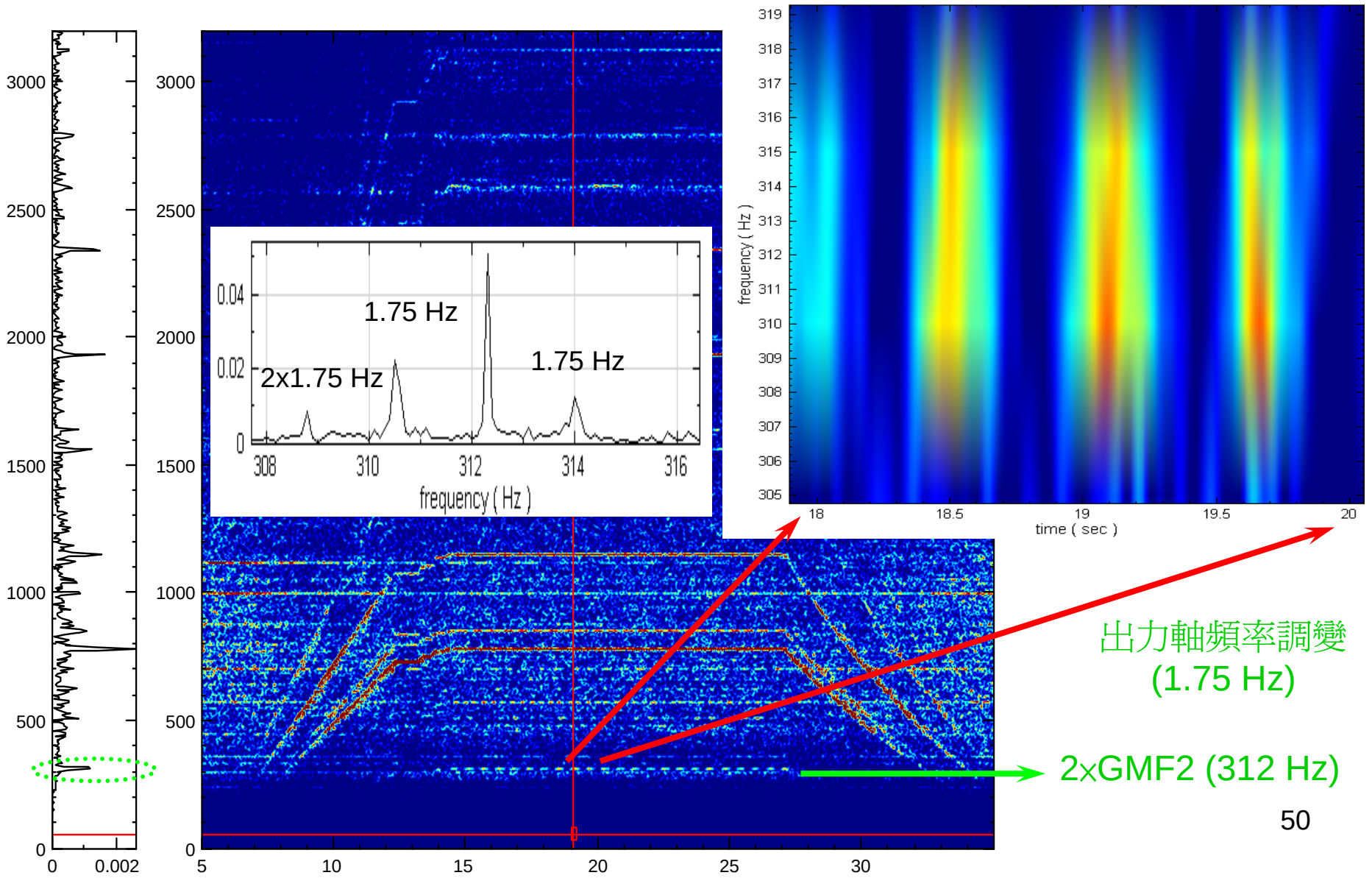
60Hz-正常生產運轉方向
聲音A加權頻譜➔低頻區域



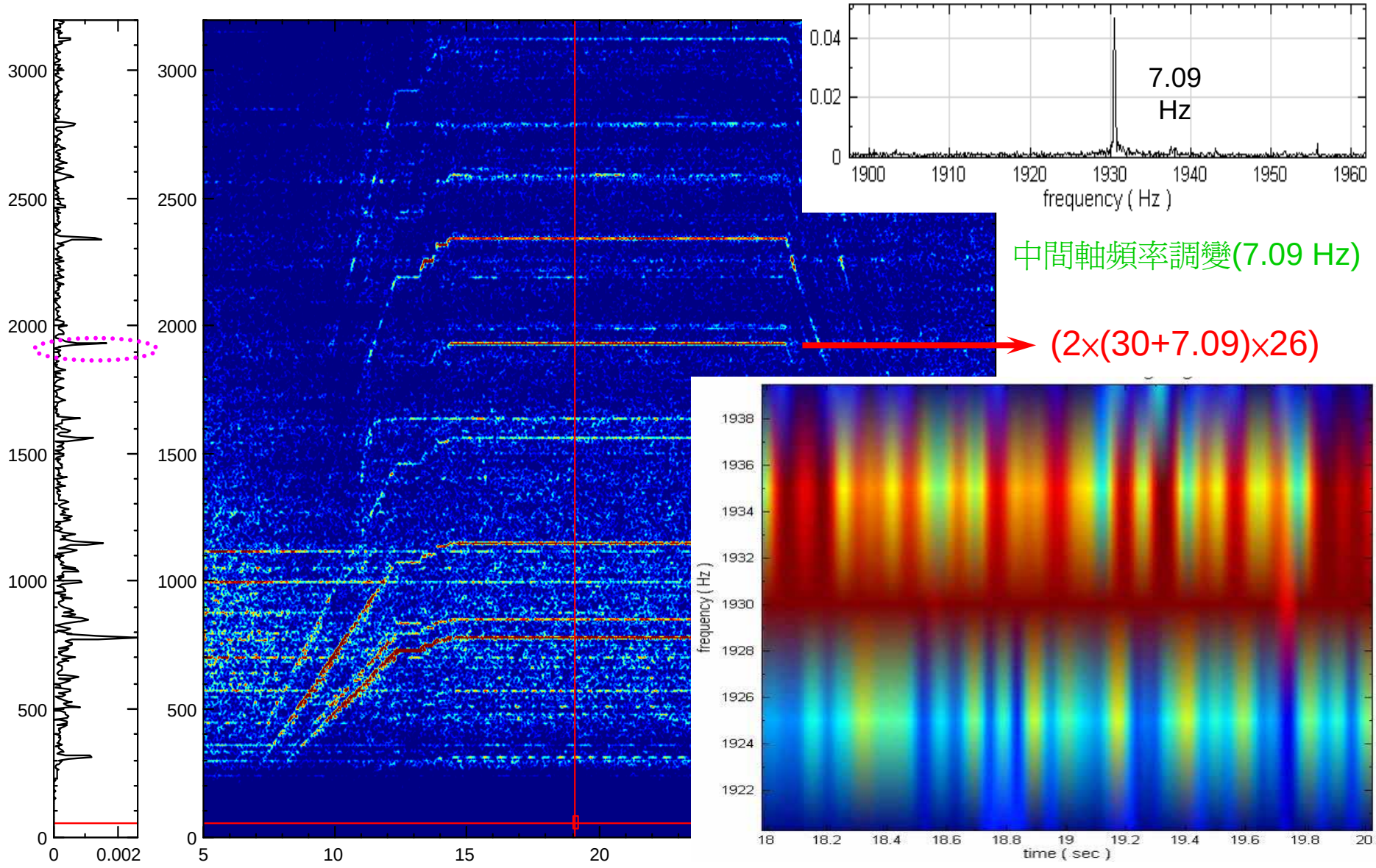
60Hz-正常生產運轉方向
入力軸與中間軸之嚙合頻率倍頻



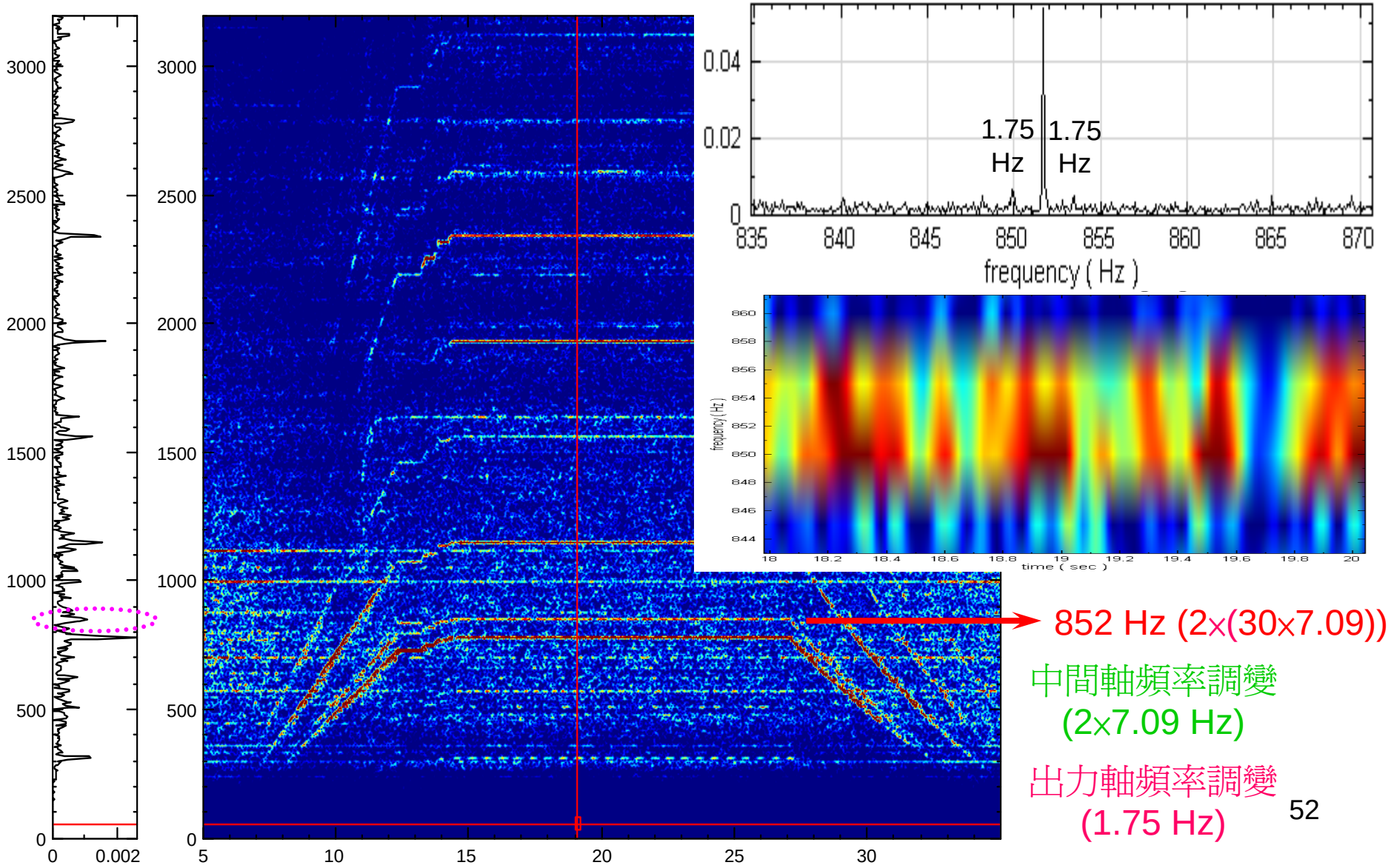
60Hz-正常生產運轉方向
中間軸與出力軸之嚙合頻率



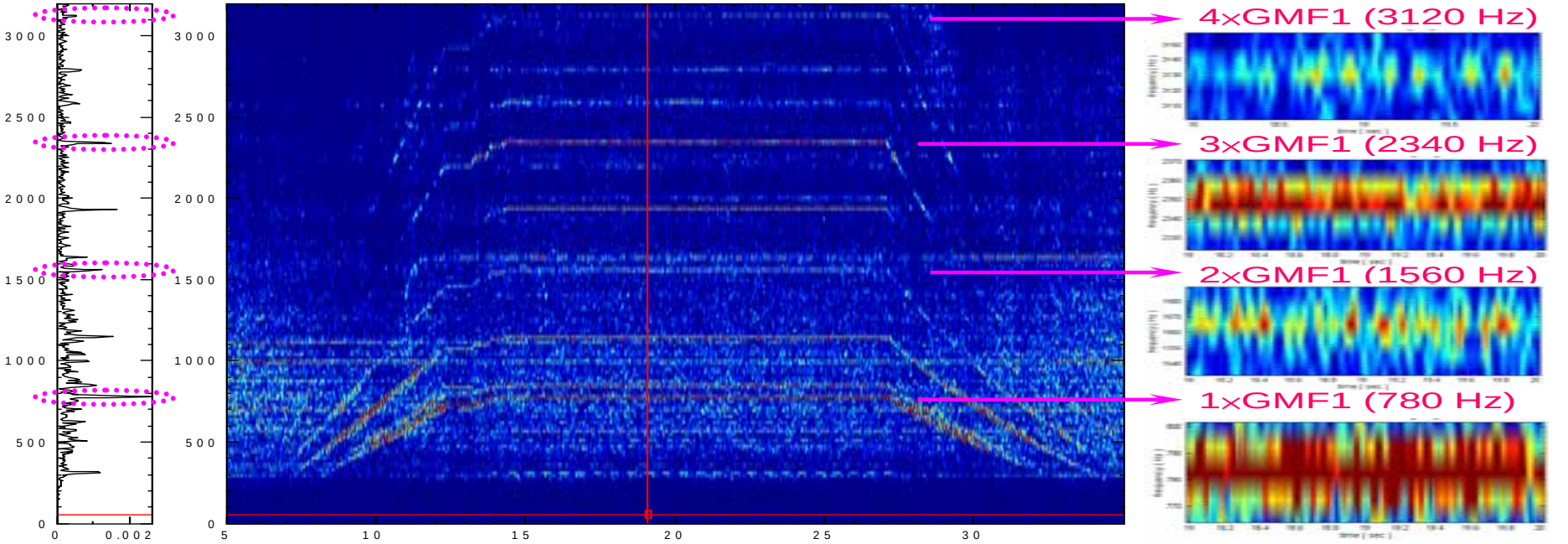
60Hz-正常生產運轉方向
其他問題頻率：Sum modulation 2倍頻

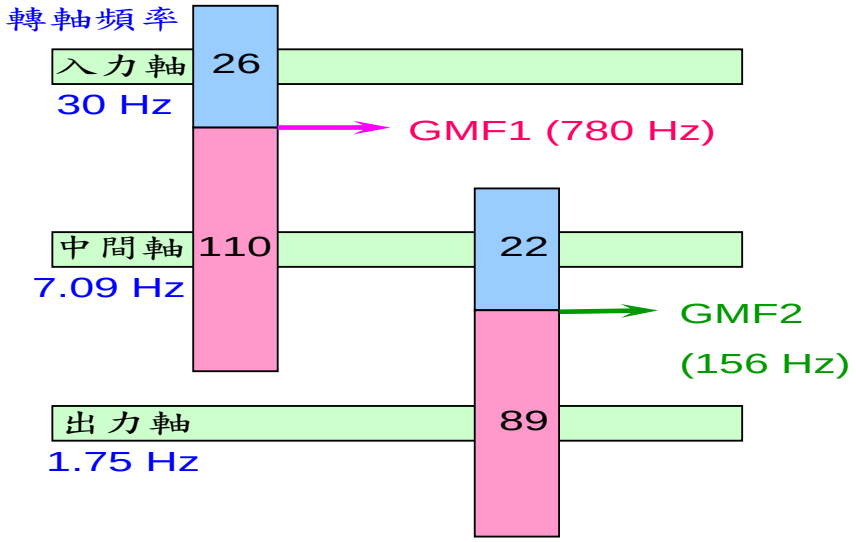


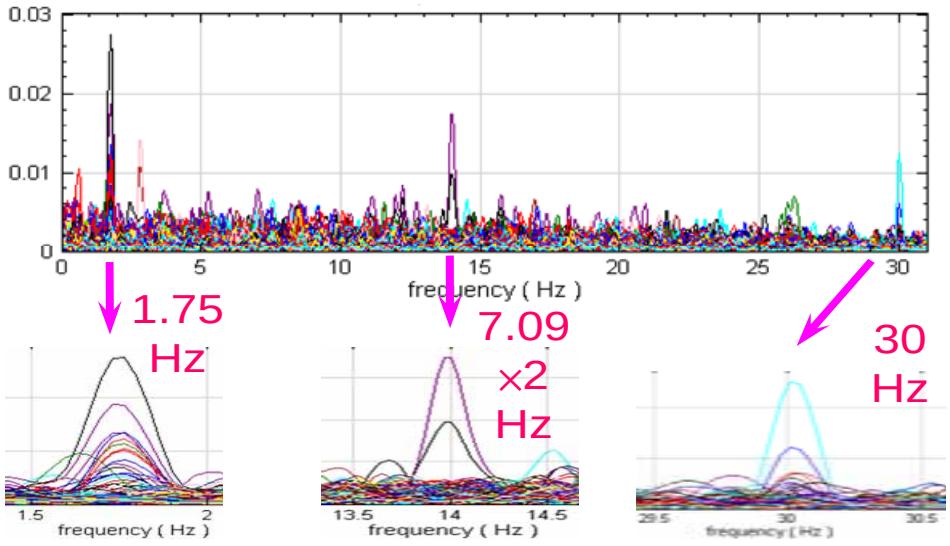
60Hz-正常生產運轉方向
其他問題頻率：Product modulation 2倍頻



嚙合頻率振幅不穩定之波動頻率分析



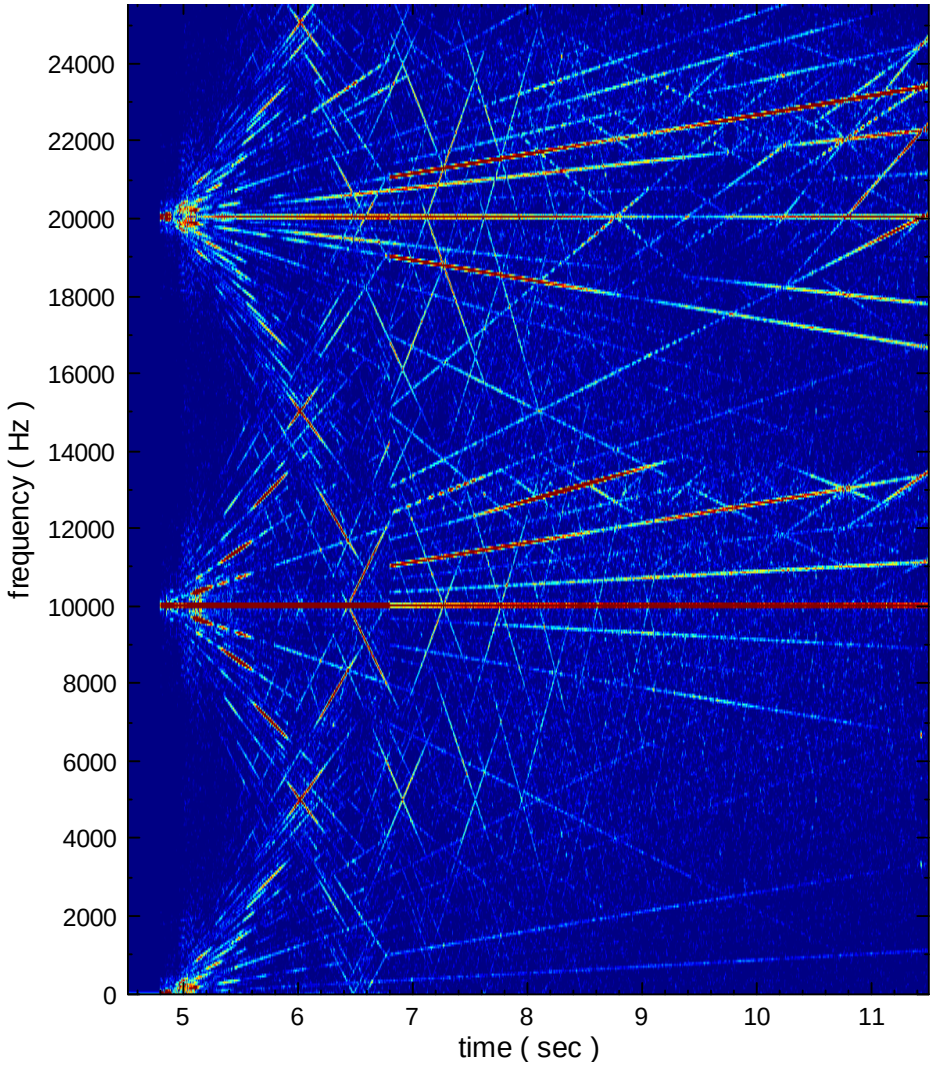




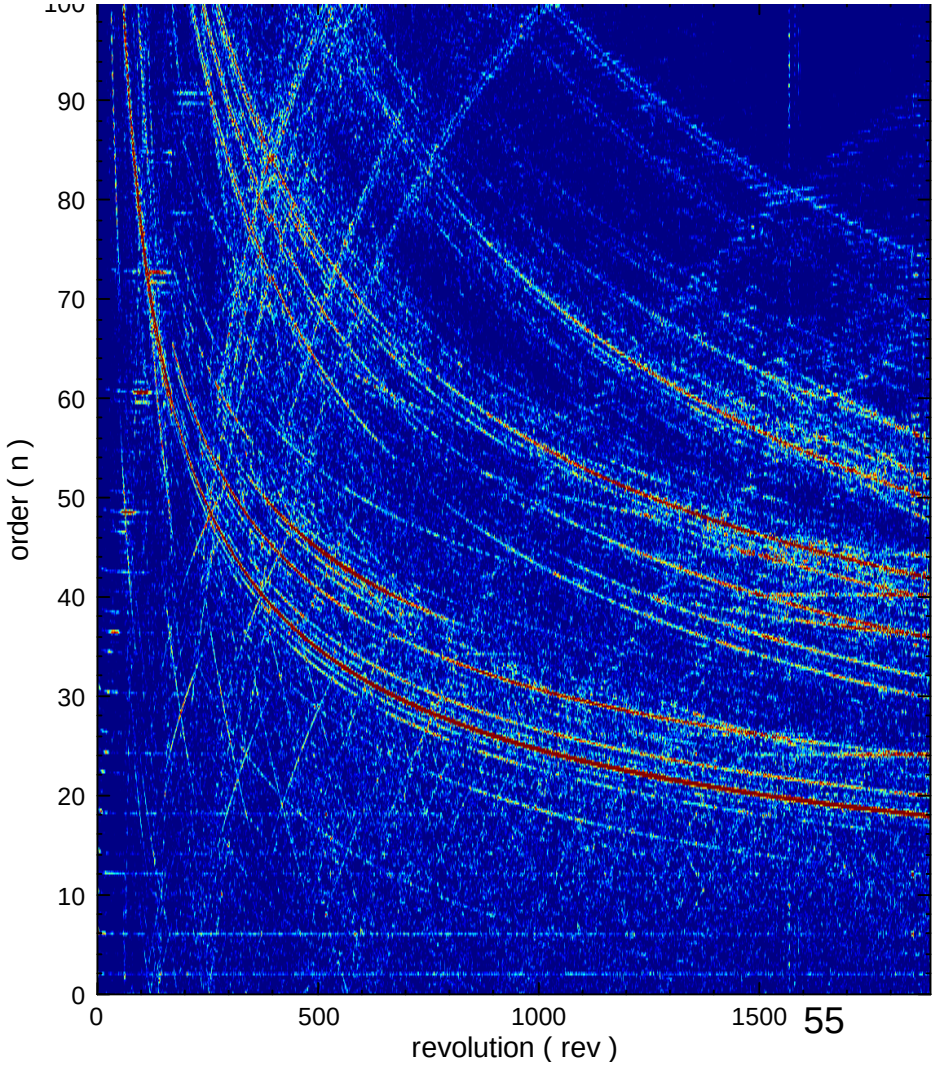
Visual Signal應用

主軸之動態特性檢測
轉速倍頻、共振頻段、異常激振、頻率調變

變轉速時頻分析

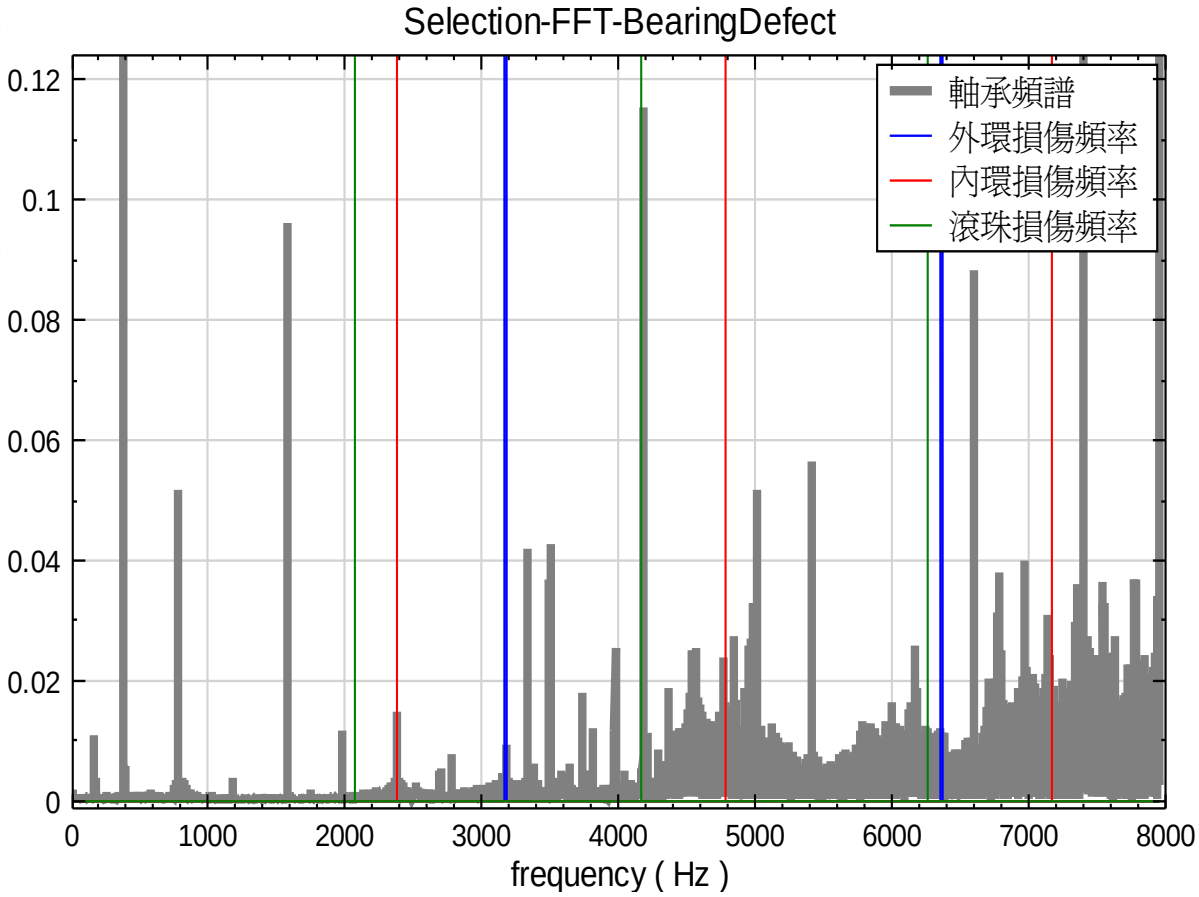


轉速階次分析



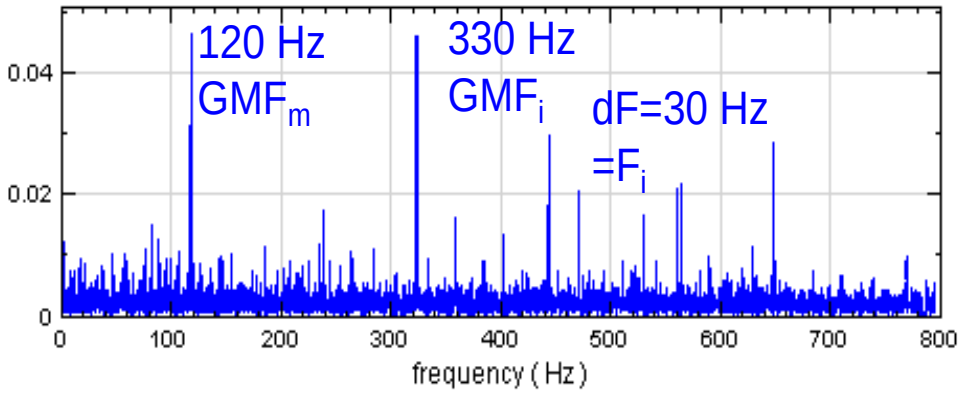
軸承之損壞特徵檢測
依據軸承規格自動計算內外環或滾珠損壞特徵頻率

特徵頻率	
內環損傷頻率	2392.9923728949975
外環損傷頻率	3184.6076271050019
滾珠損傷頻率	2089.5379498952088
參數	
轉速	398.4
軸承規格	
軸承平均直徑	42.5
接觸角	15
滾珠直徑	7.94
滾珠數量	14



變速齒輪箱之嚙合異常檢測
偏心、對心、鬆脫、背隙、磨損、斷齒

正常齒輪箱之包絡線頻譜



異常之
轉速調變頻率

異常之
嚙合頻率

異常之齒輪
12齒

GMF$_i$=330 Hz

F$_i$=30 Hz

馬達輸入
1800RPM

11齒

GMF$_m$=120 Hz

12齒

10 Hz

13齒

GMF$_o$=52 Hz

33齒

F$_n$=4 Hz

30齒

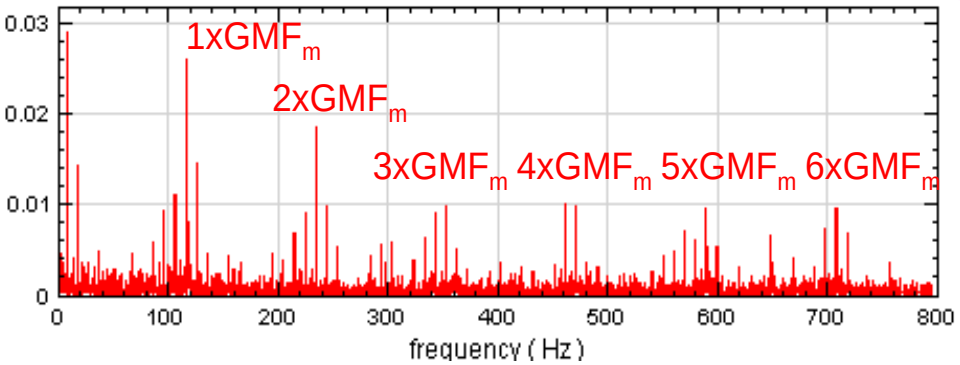
出力軸

F$_o$=1.67 Hz

31齒

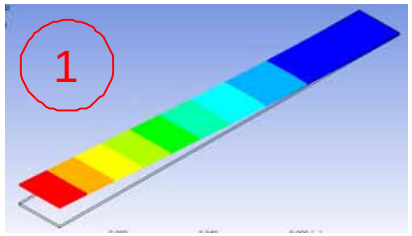
dF=10 Hz
=F$_m$

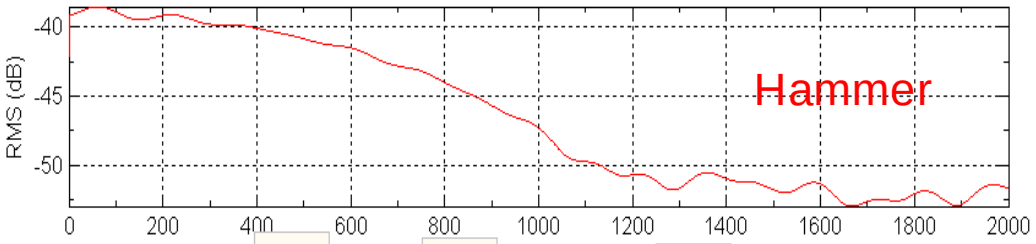
異常齒輪箱之包絡線頻譜

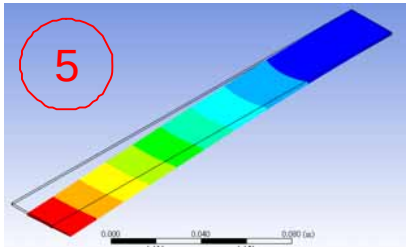


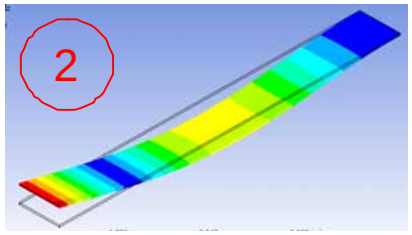
結構之自然頻率檢測

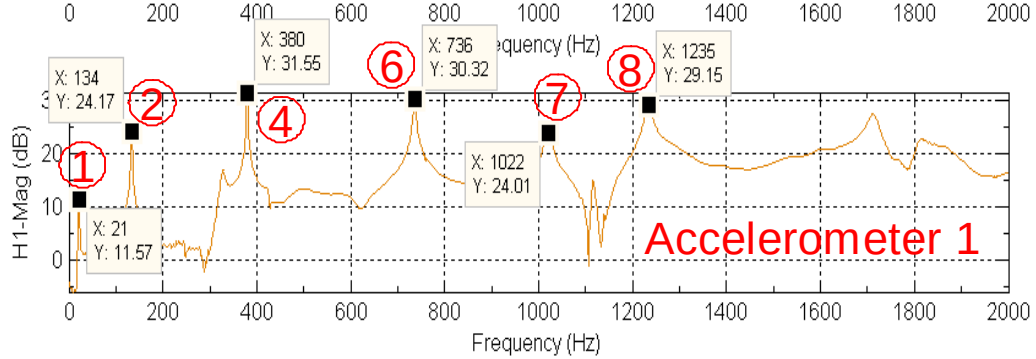
利用敲擊測試之自然頻率驗證有限元素分析之正確性

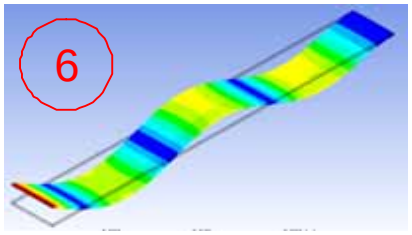


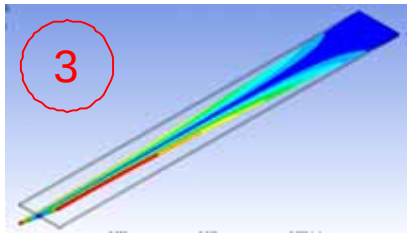


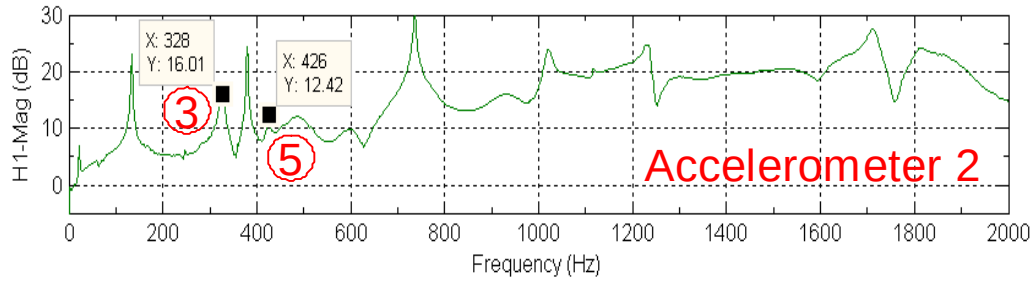


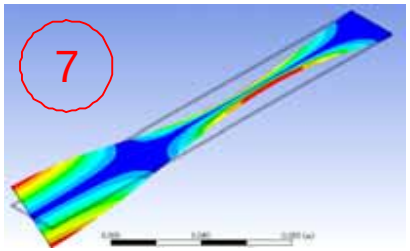


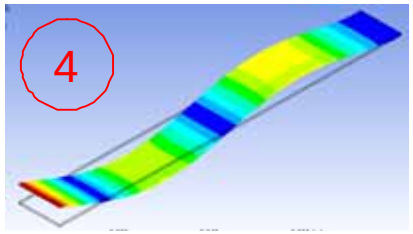


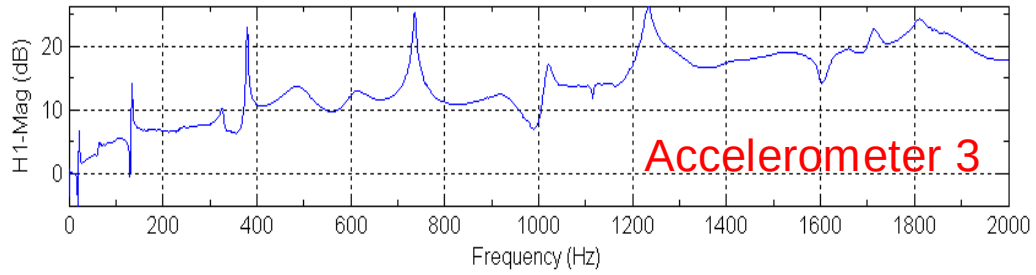


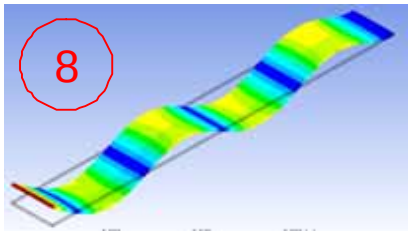








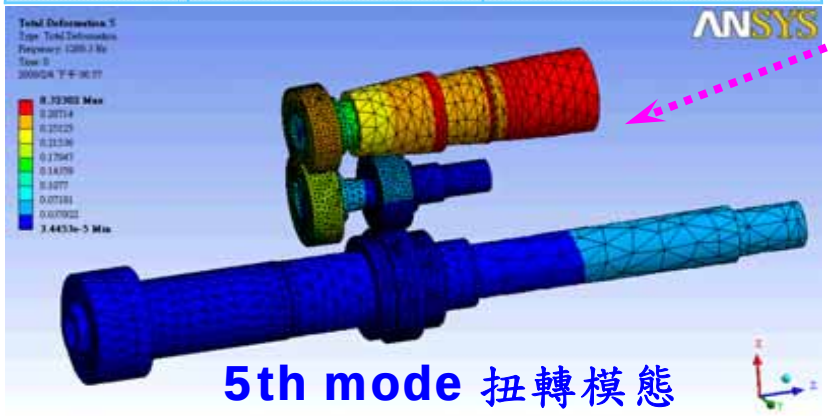




結構之自然頻率檢測
利用變轉速時頻驗證有限元素分析之正確性

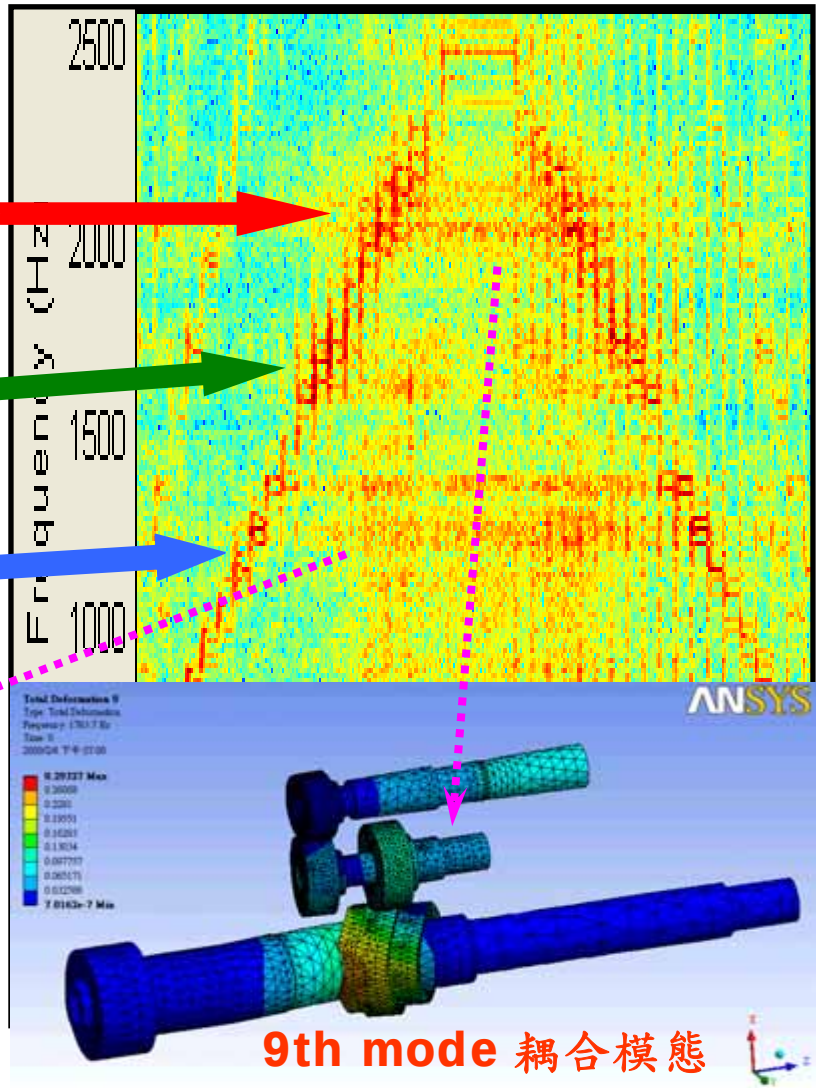
FEM模擬結果：

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



5th mode 扭轉模態

量測結果：

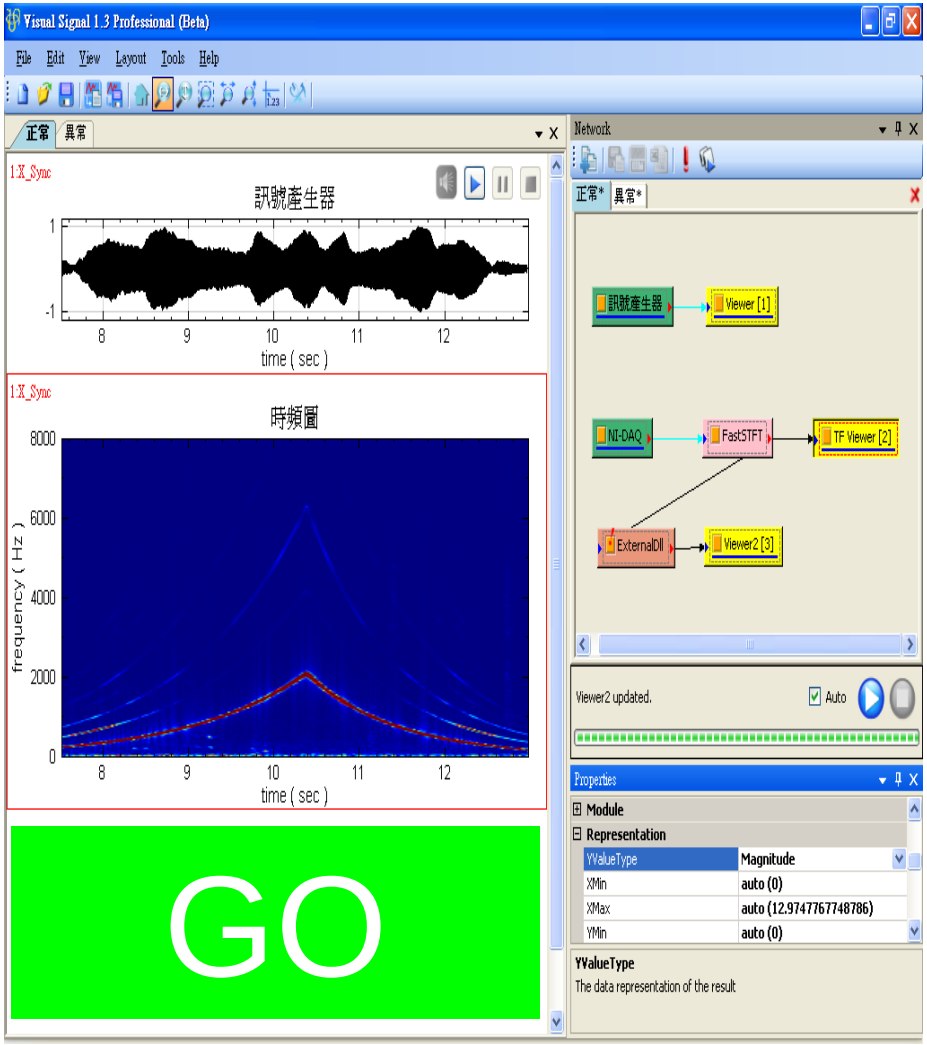


9th mode 耦合模態

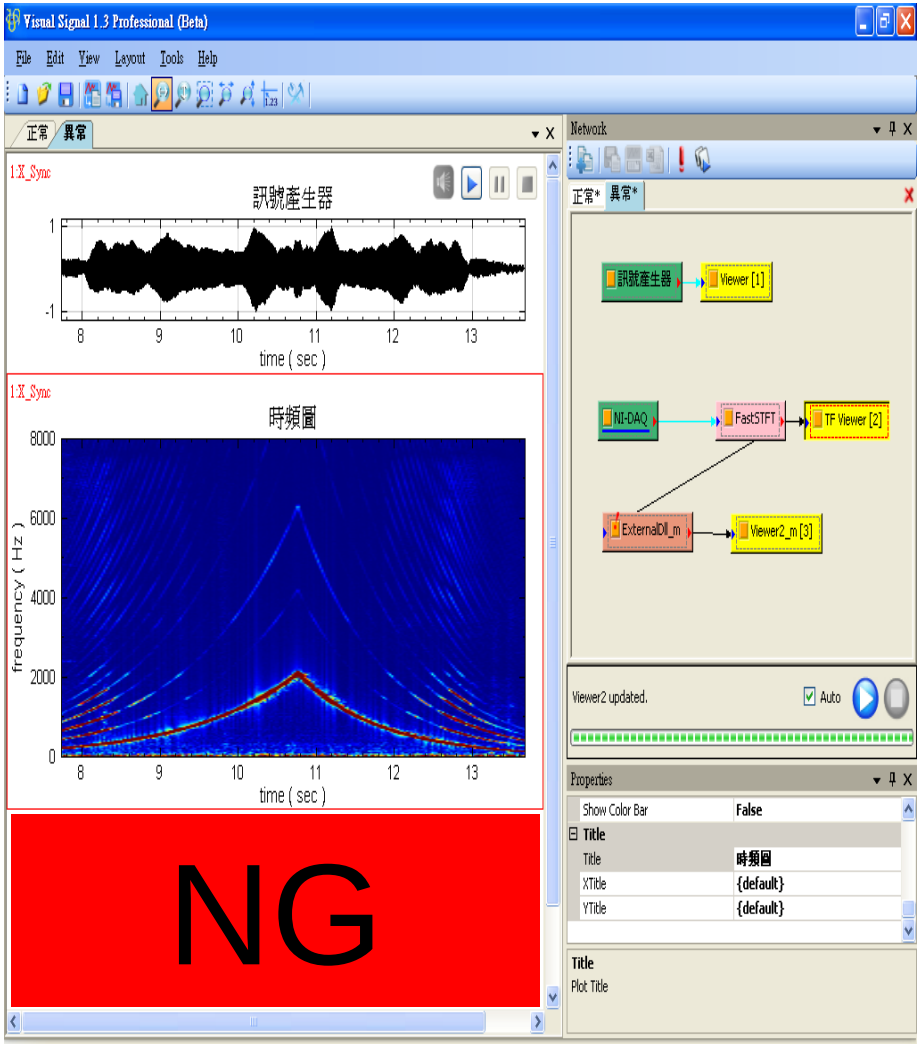
出廠之振噪品管檢測

客製化自動檢測流程、訊號產生器、客製化品管介面

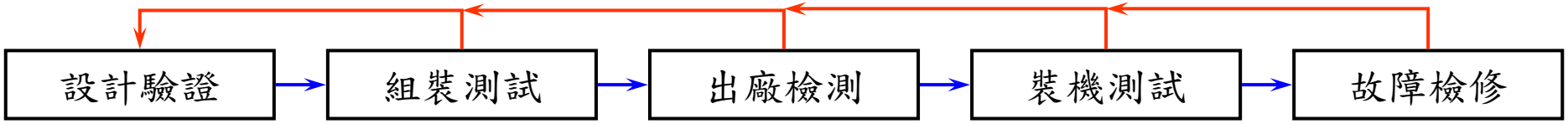
出廠異音檢測：合格



出廠異音檢測：不合格



Visual Signal 於各應用層面可檢測項目



◆SOP設計與驗證
◆有限元素模擬分析
◆振噪量測分析
◆模擬與量測比對

➢轉子/主軸
✓振動模態
✓靜態變形剛性
✓動態運轉剛性

➢軸承支撐剛性分析
✓軸承型式之選用
✓軸承位置之確認
✓軸承預壓之調測

◆SOP設計與驗證
◆振噪量測分析
◆動態精度檢測
◆高低轉速變形效應之檢測分析

➢轉子/主軸
✓動平衡測試
✓偏心測試
✓對心測試

➢軸承
✓對心測試
✓軸承預壓測試

◆SOP設計與驗證
◆振噪量測分析
◆QA/QC檢測報告
◆品保資料庫
◆生產履歷

➢轉速倍頻激振之檢測
➢轉子臨界轉速之檢測
➢轉子共振頻段檢測
➢轉子高低轉速之運轉振動等級檢測
➢熱機溫昇效應之檢測

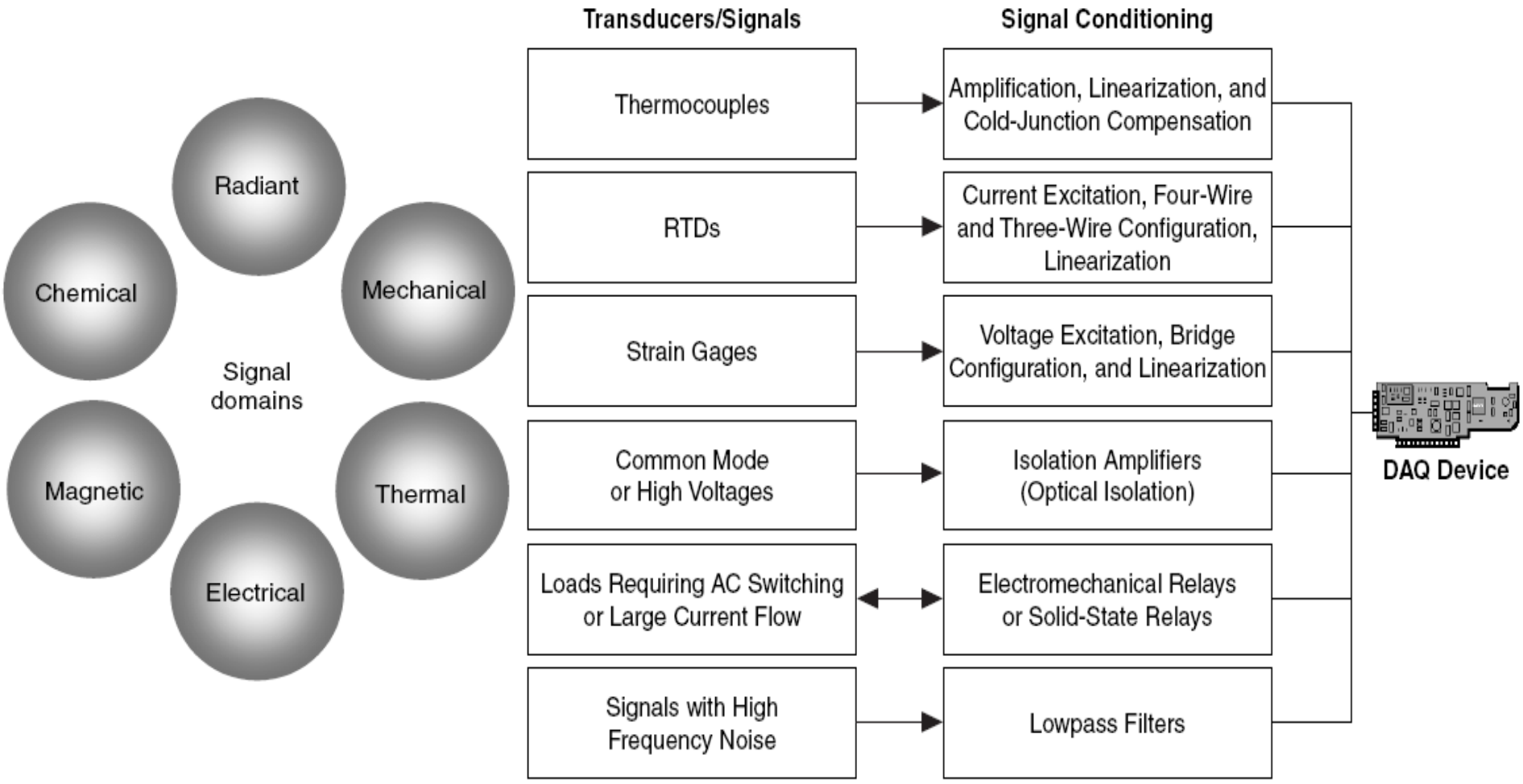
◆SOP設計與驗證
◆振噪量測分析
◆裝機負載檢測報告
◆整機操作頻率之測定
◆整機振動之來源鑑別與責任釐清

➢整機臨界轉速之檢測
➢整機共振頻段檢測
➢整機高低轉速之運轉振動等級檢測

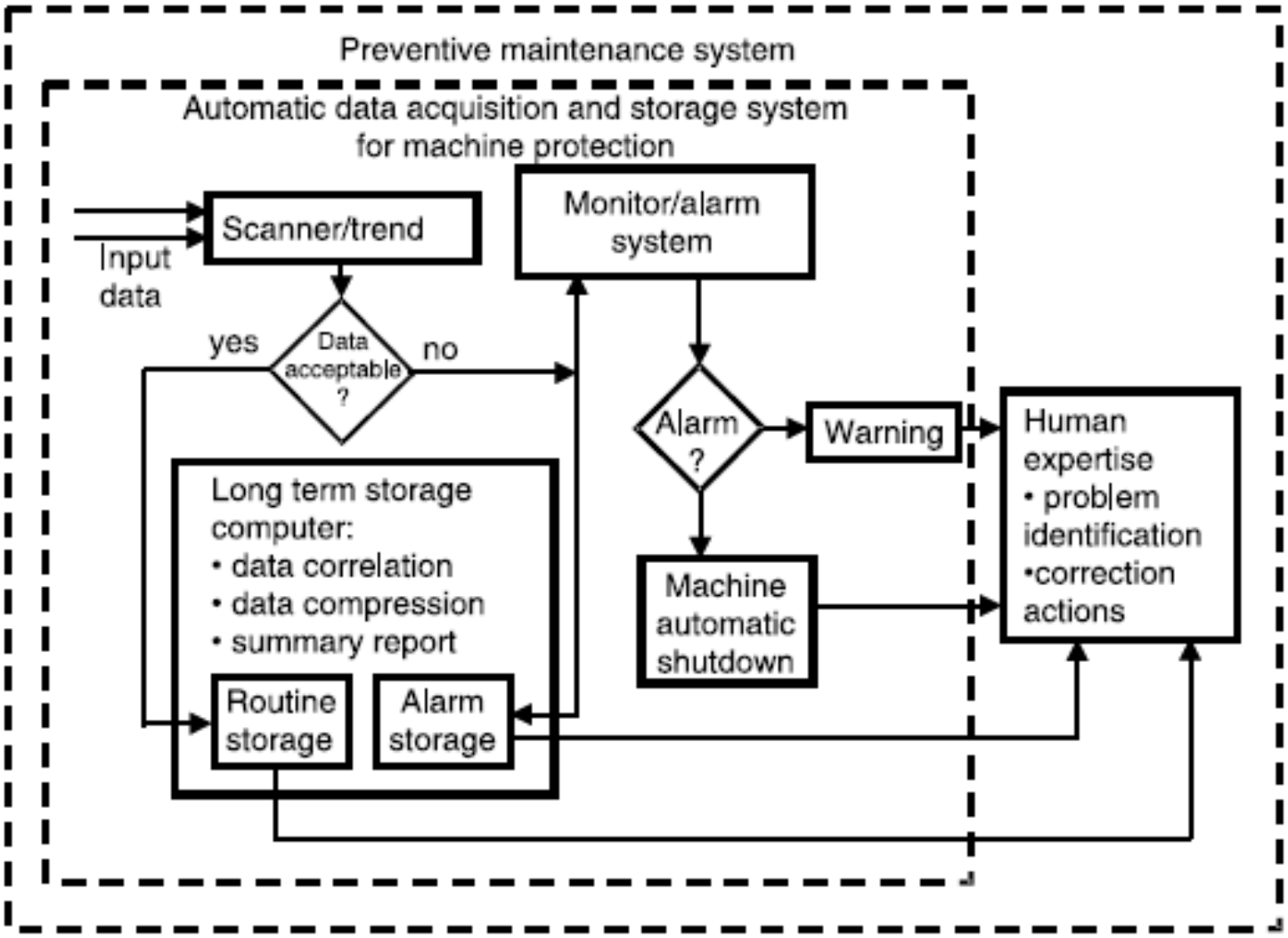
◆SOP設計與驗證
◆振噪量測分析
◆故障檢測報告

➢轉子異常檢修
➢軸承異常檢修
➢馬達異常檢修
➢齒輪箱異常檢修

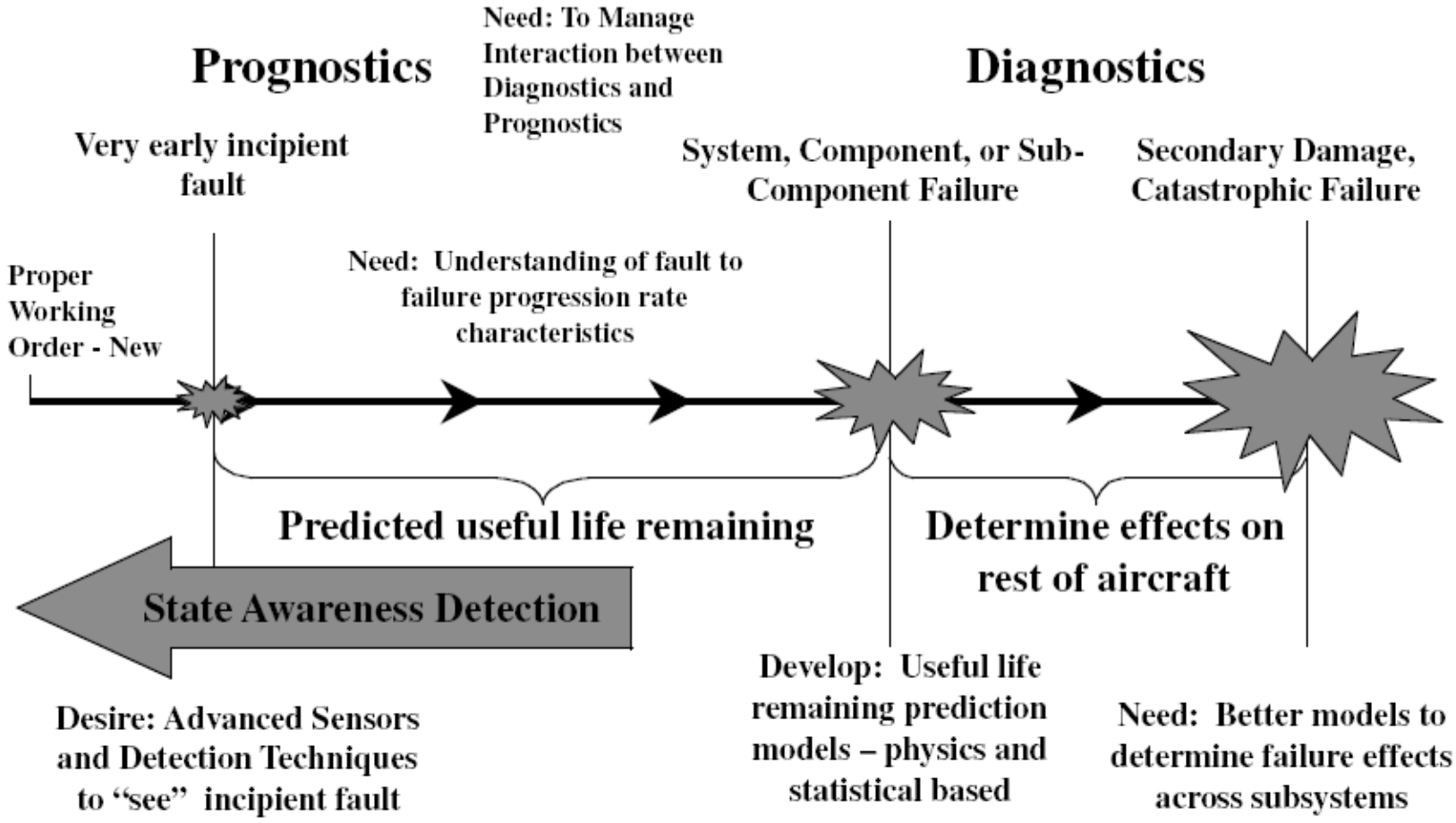
感測器擴充性：多物理場訊號擷取與整合



軟體擴充性：預防保養系統

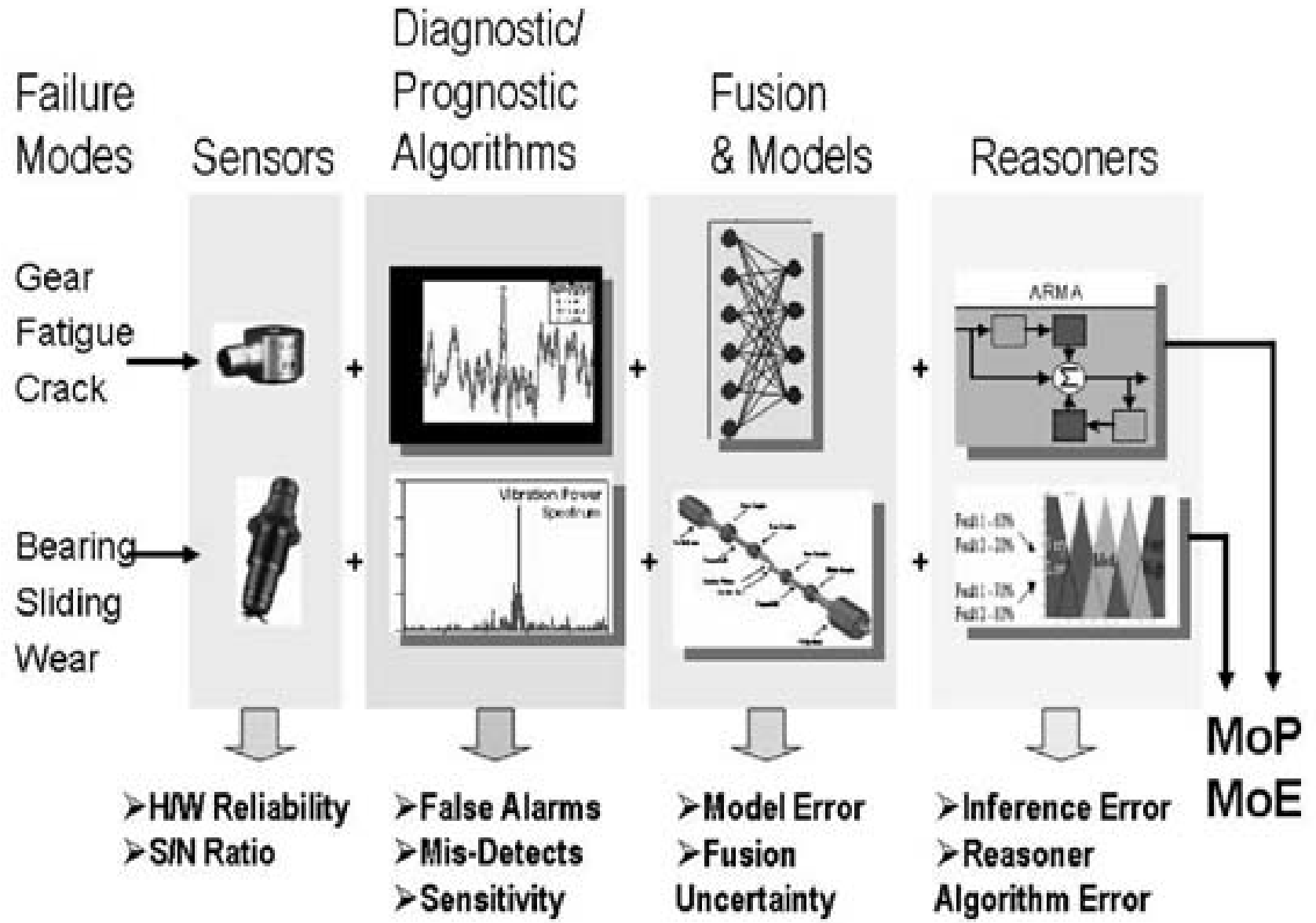


軟體擴充性：線上故障預知與診斷系統

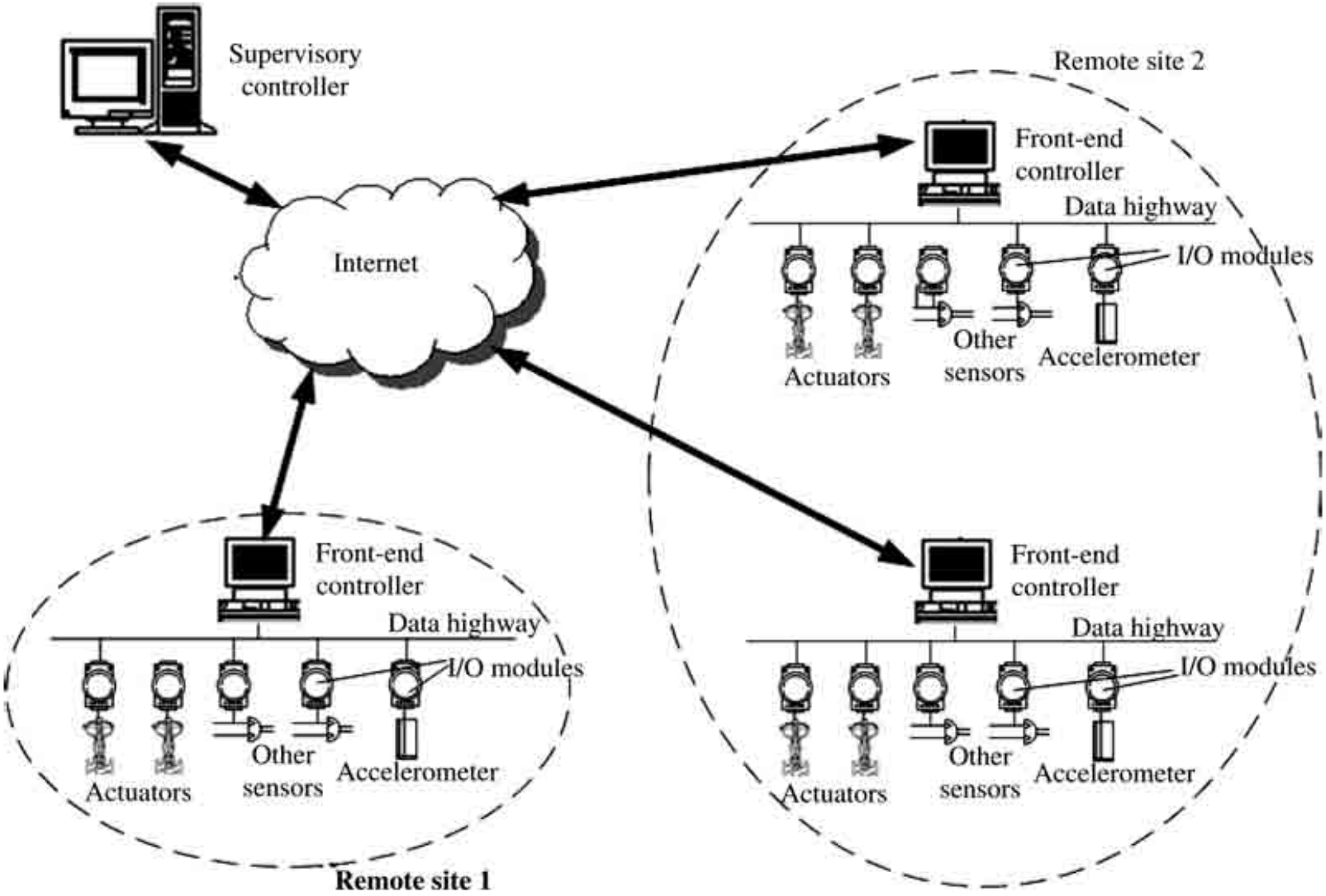


The Goal is To Detect "State Changes" as Far to the Left As Possible

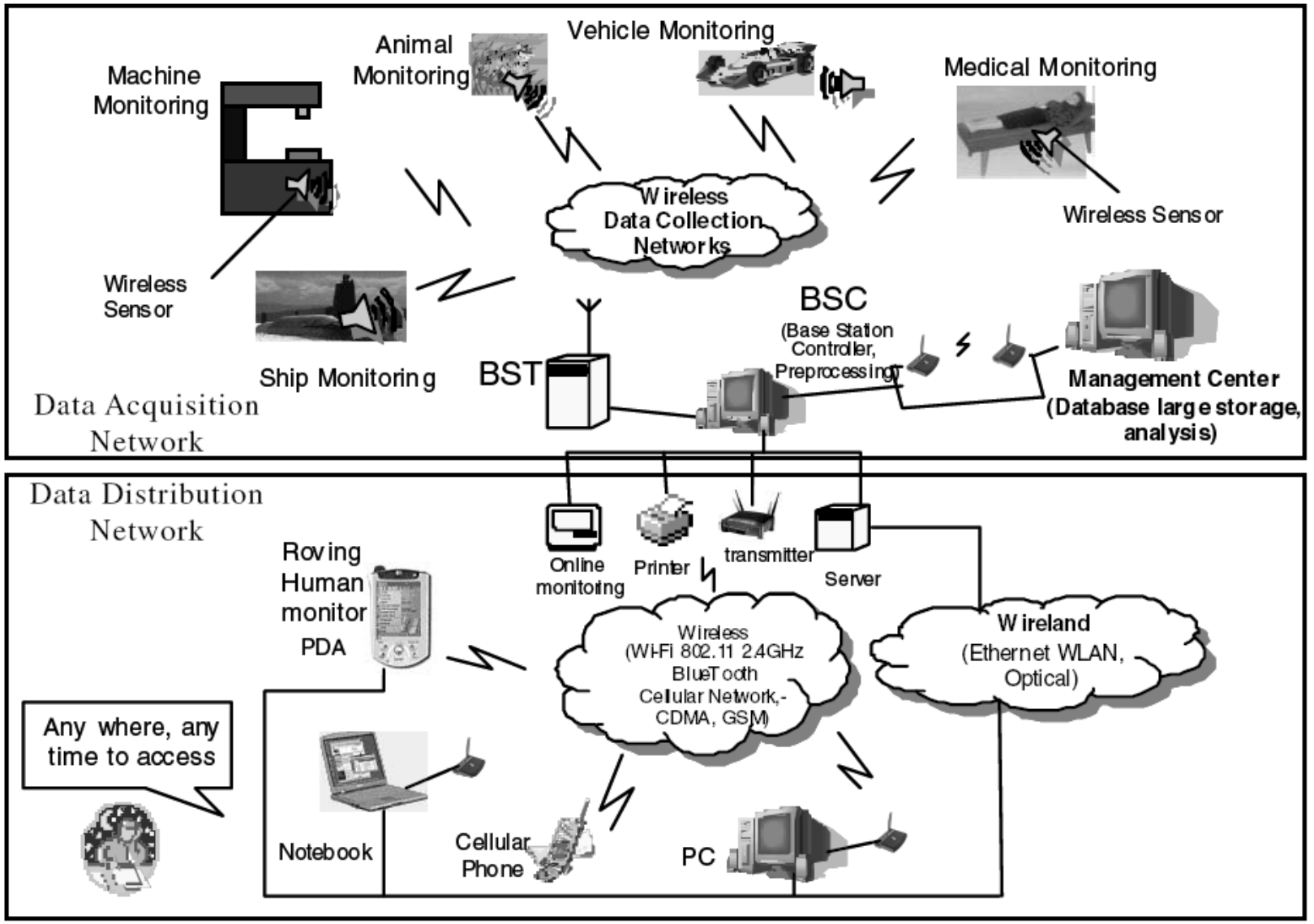
軟體擴充性：智慧型診斷系統



軟體擴充性：遠端監測與控制系統



軟體擴充性：資料庫建立與傳輸網路系統



Thank you!