壹、國外公務之內容與過程

一、目的

（一）、核四廠之汽機驅動飼水泵(Turbine Driven Reactor Feedwater Pump, TDRFP)依設備供應廠家日本三菱重工公司之分析結果，其共振頻率約為 2800RPM。此頻率落於奇異(GE)公司設計之 TDRFP 控制範圍(2000~5400RPM)內。經多次討論，本計畫之顧問公司石威(S&W)公司查詢相關電廠資料後，告知美國有 Peach Bottom、Hope Creek 、Susquehanna 三個核能電廠亦有上述情形。

（二）、依核四工程協調會議第 18 次會議決議事項第 3-1 項：汽機驅動飼水泵(TDRFP)設計 OVERSIZE 及共振頻率問題，由核四廠派運轉及儀控人員赴美國 Peach Bottom、Hope Creek 、Susquehanna 三個電廠瞭解其 TDRFP 相關之設計、運轉、控制等相關問題如何因應後，再討論處理。

出國期間自中華民國九十五年五月八日至九十五年五月二十一日，共計 14 天。

二、行程與工作項目

奉派至美國 Peach Bottom、Hope Creek 、Susquehanna 三個核能電廠瞭解其 TDRFP 相關之設計、運轉、控制等相關問題。為期 14 天，詳細行程及工作項目如下表：

起始日	迄止日	地點	工作內容
5/8	5/9	往程	台北-紐約-華盛頓 BWI 機場-Peach Bottom 電廠
5/10	5/12	Peach Bottom 電廠	與電廠人員討論 TDRFP 運轉與控制
5/13	5/15	Hope Creek 電廠	與電廠人員討論 TDRFP 運轉與控制
5/16	5/18	Susquehanna 電廠	與電廠人員討論 TDRFP 運轉與控制
5/19	5/21	返程	Susquehanna 電廠-紐約-台北

貳、執行過程與內容

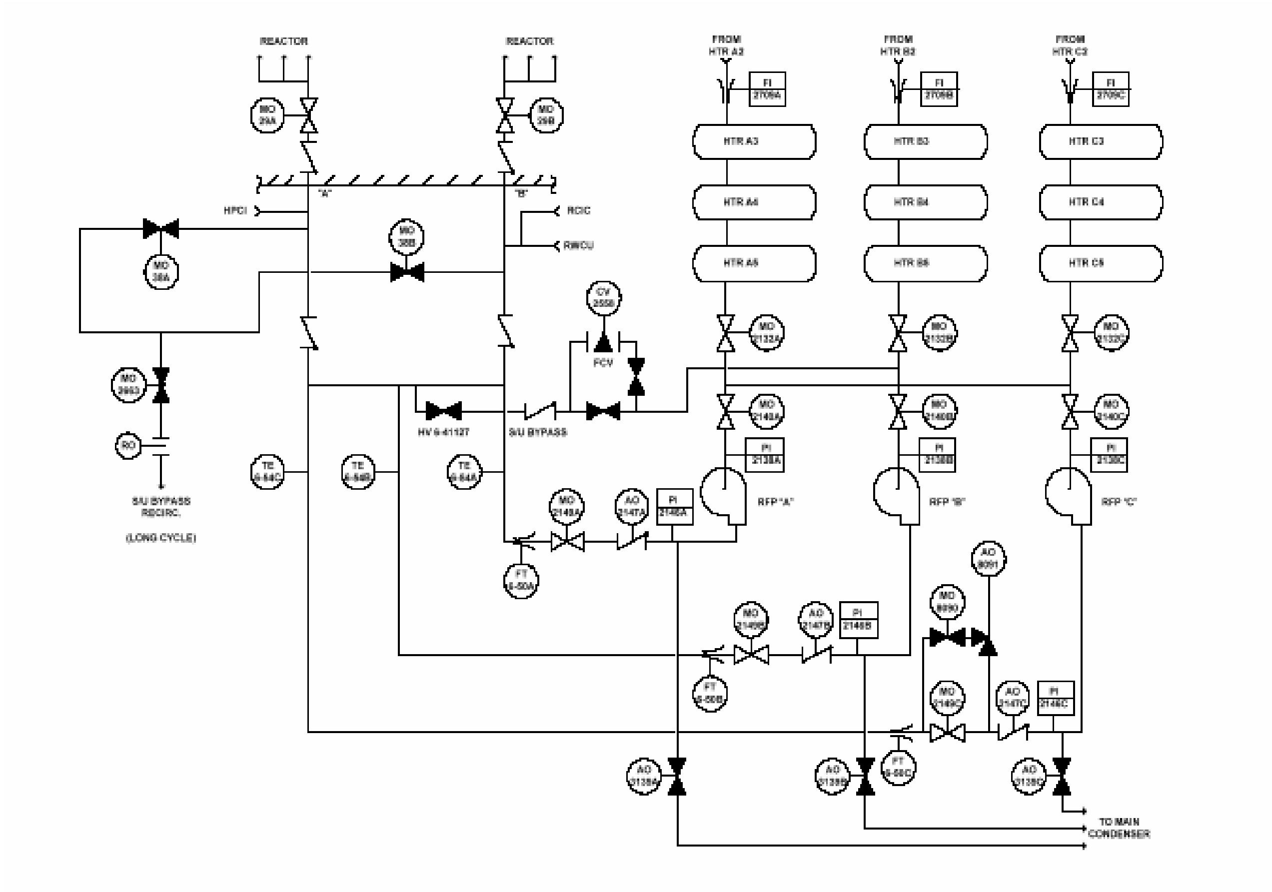
一、PEACH BOTTOM 電廠

(一)、Peach Bottom 電廠飼水系統概要

附表一 Peach Bottom 電廠飼水系統概要

	Peach Bottom 電廠	核四廠
熱功率	1112MWe	3926MWt
CP+CBP+TDRFP	3+0+3	4+4+3
MDRFP 台數	0	1
RFP 容量	40%	55%
最小流量閥開閉特性	全開/全關	可節流
最小流量閥開閉行程	45~90 秒	11 秒
共振區	2500~3000 rpm	2750~2850 rpm
LSS	2600~2900 rpm	1000 rpm(暫定)
HSS	5400 rpm	5400 rpm(暫定)
振動之正常值	< 1.5 mils	待測
振動之最大值	1.5 mils	待測
振動之警報值	3 mils	4 mils
振動之跳脫值	5 mils(高高警報，不跳脫)	5 mils

(二)、Peach Bottom 電廠和共振區相關之飼水操作



附圖一 Peach Bottom 電廠飼水控制系統簡圖

TDRFP 共振轉速限制區間設定為 2500~2900rpm，運轉控制區間則為 3000~5400rpm，所以在運轉控制區間無共振轉速問題。

第一台 TDRFP 投入使用時，利用最小流量閥之調節功能提升 TDRFP 轉速到共振轉速以上，第二及第三台 TDRFP 投入使用，則利用飼水泵出口閥的手動節流功能再加上開啟最小流量閥配合，先手動提升轉速(此時出口閥全關，最小流量閥全開)直到泵出口壓力比系統壓力大 60psig 以上，以保證可補水進入反應爐後，再利用出口閥的 BUMP OPEN 功能逐次開啟出口閥(每次按一秒鐘，共須操作約 70 次)，當出口閥全開後再將轉速控制切換為自動控制。最後才關閉最小流量閥。使用步驟說明如下：

A、第一台 TDRFP 投入使用步驟

1. TDRFP C 手動提升轉速至 LSS 以上，此時 TDRFP 出口閥全關，最小流量閥置於全開位置，反應爐水位由 Startup Control Valve 自動控制。
2. 繼續手動提升轉速直到出口壓力較系統壓力至少高 60psi，以確定可以補水至反應爐。當 Startup Control Valve 開度約 70~90%、轉速約為 3500~4500rpm 時，開始進行反應爐水位控制切換。
3. 手動按下出口閥開啟按鈕約一秒鐘後，按下 Hold 按鈕，觀察系統及反應爐水位是否穩定，此時 Startup Control Valve 應漸漸關小。
4. 持續步驟 3，直到 Startup Control Valve 開度約為 20~40%。
5 將飼水泵轉速控制改為 AUTO，Startup Control Valve 改為 MANUAL 控制。
6. 使用 BUMP OPEN 功能開啟出口閥並逐次關閉 Startup Control Valve，直到閥全關。
7. 關閉最小流量閥。

B、第二、三台 TDRFP 投入使用步驟

1. 手動提升 TDRFP A 或 B 台轉速至 LSS 以上，此時 TDRFP 出口閥全關，所有流量經最小流量閥打回冷凝器。
2. 繼續手動提升轉速直到出口壓力較系統壓力至少高 60~80psi，以確定可以補水至反應爐。
3. 手動按下出口閥開啟按鈕約一秒鐘後，按下 Hold 按鈕，觀察系統及反應爐水位是否穩定。此時出口流量應增加少許，原有運轉中 TDRFP 流量應減少。
4. 持續步驟 3，直到出口閥全開。

5. 調整個別 TDRFP 之轉速控制值，當其值與 Master Level Controller 誤差<5%，TDRFP 可設為 AUTO，接受 MLC 控制。

6. 關閉最小流量閥。

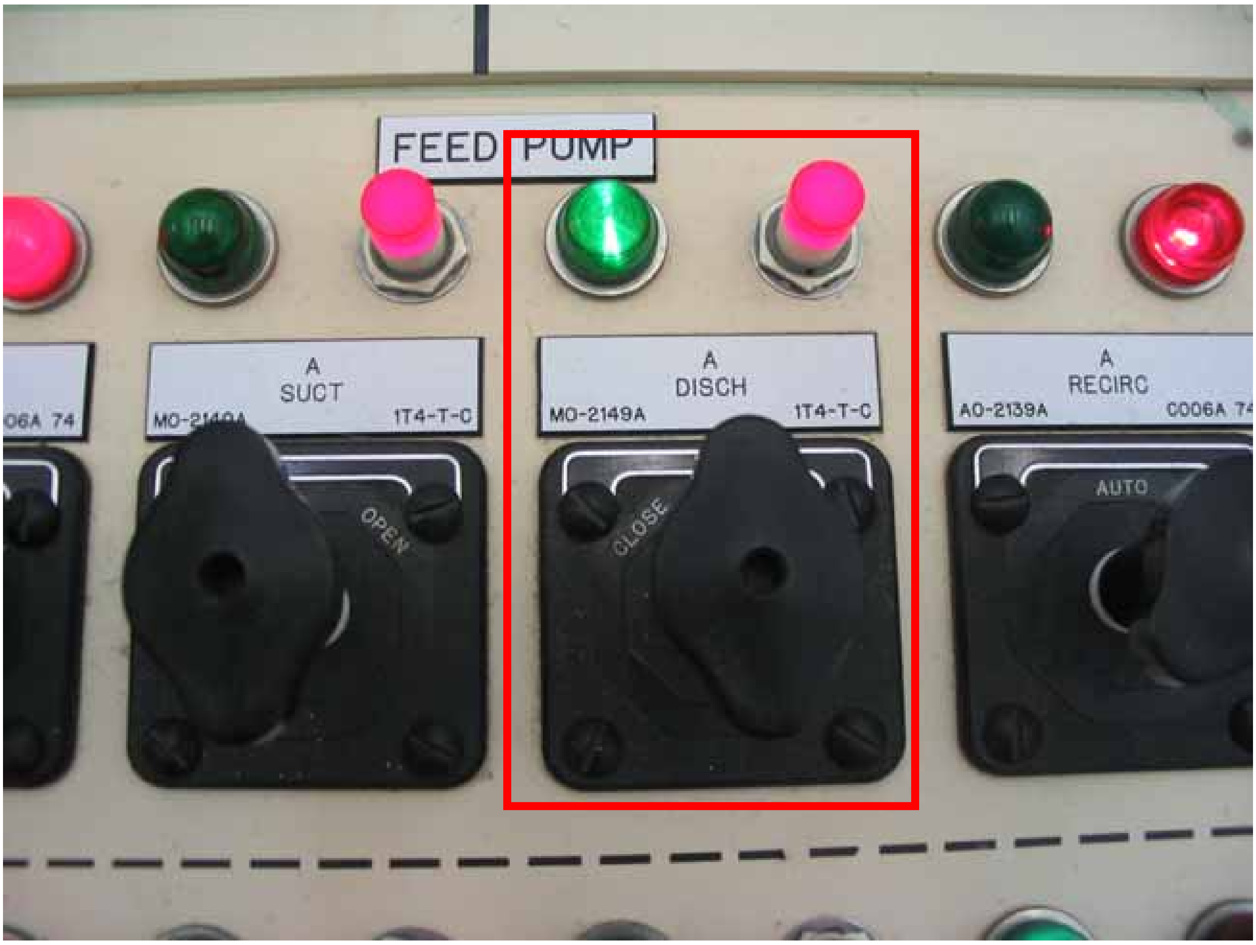
(三)、Peach Bottom 電廠的建議

1、建議在 TDRFP 出口閥增加 BUMP OPEN 的操作介面，以增加運轉彈性。

2、考慮增加最小流量閥的容量，利用增加最小流量，將 Critical Speed 移出 Control Band，避免運轉時的困擾。

3、建議 TDRFP 最小流量閥開啟/關閉行程要夠長。

4、上述操作利用模擬器驗證其可行性。



附圖二 Peach Bottom 電廠 TDRFP 出口閥具有 BUMP OPEN 功能

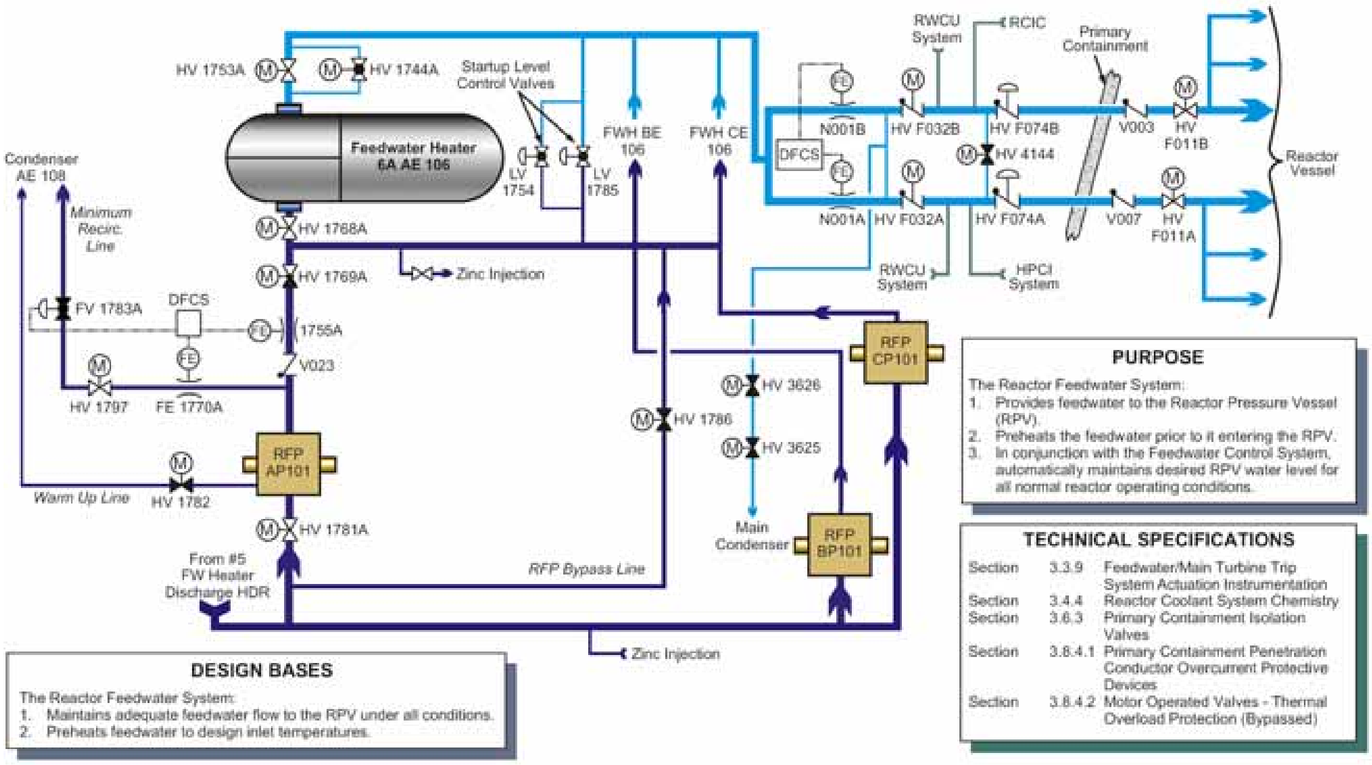
二、HOPE CREEK 電廠

(一)、Hope Creek 電廠飼水系統概要

附表二 Hope Creek 電廠飼水系統概要

	Hope Creek	核四廠
熱功率	3340 MWt	3926 MWt
CP+CBP+TDRFP	3+3+3	4+4+3
MDRFP 台數	0	1
RFP 容量	50%	55%
最小流量閥開閉特性	全開/全關	可節流
最小流量閥開閉行程	30 秒	11 秒
共振區	3250~3550 rpm	2750~2850 rpm
LSS	2500 rpm	1000 rpm(暫定)
HSS	5453 rpm	5400 rpm(暫定)
振動之正常值	<2 mils	待測
振動之最大值	3.5 mils	待測
振動之警報值	3 mils	4 mils
振動之跳脫值	5 mils(高高警報,不跳脫)	5 mils

（二）、Hope Creek 電廠和共振區相關之飼水操作



附圖三 Hope Creek 電廠飼水控制系統簡圖

TDRFP 的共振轉速限制區間約為 3250~3550rpm，控制運轉區則為 2500~5453rpm，所以在控制運轉區有共振轉速問題。

但依據該廠多年之運轉經驗，經過共振轉速限制區時，曾經發生的振動最高約 3.5mils(高振動警報設定為 3.0mils)，雖然會有高振動警報出現，但該廠認為此振動值仍在可接受範圍內，所以運轉人員只須注意此問題而不須處理。無自動跳脫功能，當振動過高(>5mils)運轉人員依異常操作程序書手動跳脫 TDRFP，但至目前為止尚無發生此狀況。

建議本廠充份利用現有 MDRFP 來越過共振區。於 15%負載時置第一台 TDRFP 自動水位控制後，仍保持 MDRFP 透過 LFCV 手動控制注水。機組依計畫升載直到第一台 TDRFP 轉速接近共振轉速前，再手動緩慢關閉 LFCV，

使第一台 TDRFP 轉速自動提升並越過共振區。參考附圖九-1 及附圖九-2 所示之操作示意圖。於 45%負載時，置第二台 TDRFP 手動控制並提升轉速，直到第一台 TDRFP 轉速自動調降並接近共振轉速前，即停止操作。機組依計畫升載直到兩台 TDRFP 的平均轉速已大於共振轉速後，再手動提升第二台 TDRFP 的轉速，如此第一台 TDRFP 轉速自動調降，最後兩台 TDRFP 可順利越過共振區。參考附圖十-1 及附圖十-2 所示之操作示意圖。

（三）、Hope Creek 電廠的建議

1、建議本廠充份利用現有MDRFP來越過共振區。

2、建議升載過程中任一台TDRFP僅越過共振區一次。

3、當TDRFP進行越過共振區的操作時，飼水總流量不能改變。

4、上述操作利用模擬器驗證其可行性

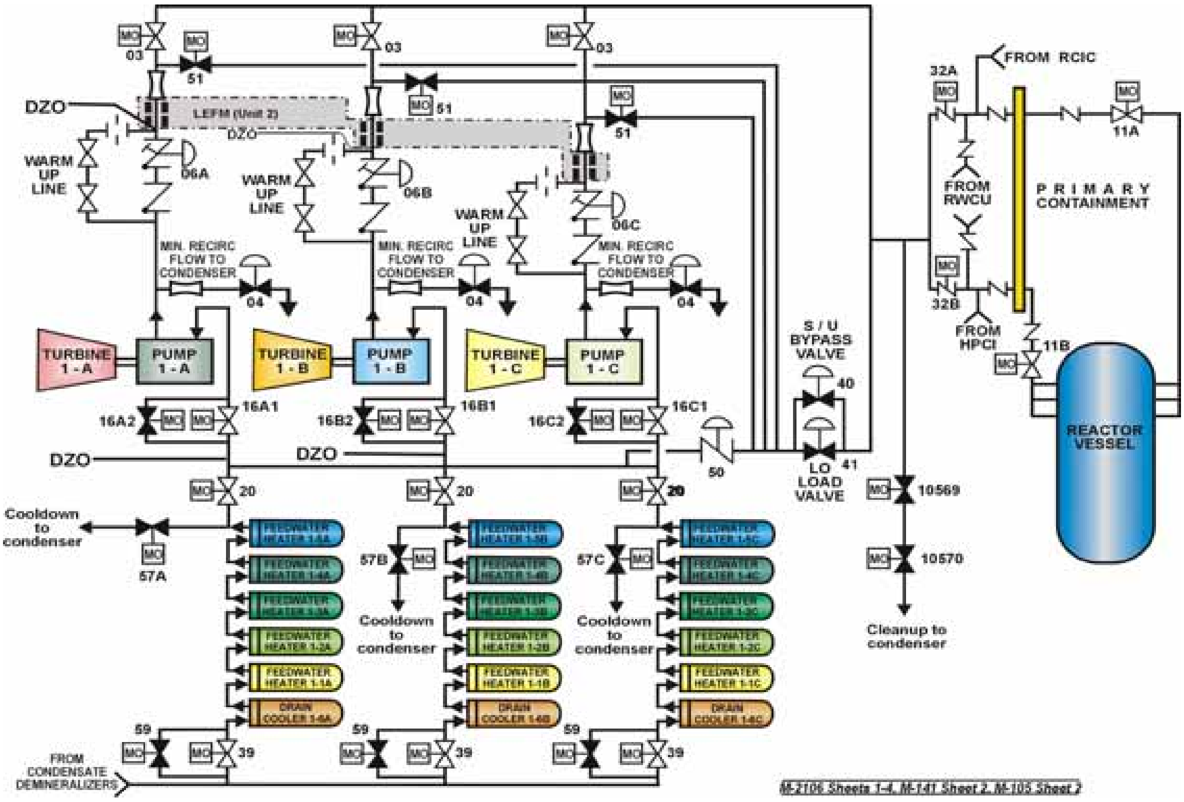
三、SUSQUEHANNA 電廠

(一)、Susquehanna 電廠飼水系統概要

附表三 Susquehanna 電廠飼水系統概要

	Susquehanna	核四廠
熱功率	3490 MWt	3926 MWt
CP+CBP+TDRFP	4+0+3	4+4+3
MDRFP 台數	0	1
RFP 容量	50%	55%
最小流量閥開閉特性	可節流	可節流
最小流量閥開閉行程	12~15 秒	11 秒
共振區	2800~3200 rpm	2750~2850 rpm
LSS	1500 rpm	1000 rpm(暫定)
HSS	5585 rpm	5400 rpm(暫定)
振動之正常值	<1 mils	待測
振動之最大值	~3 mils	待測
振動之警報值	3 mils	4 mils
振動之跳脫值	5 mils(高高警報，不跳脫)	5 mils

(二)、Susquehanna 電廠和共振區相關之飼水操作



附圖四 Susquehanna 電廠飼水控制系統簡圖

TDRFP 的共振轉速限制區間約為 2800~3200rpm，控制運轉區則為 1500~5585rpm，所以在控制運轉區有共振轉速問題。

但依據該廠多年之運轉經驗，經過共振轉速限制區時，未曾發生任何振動警報(高振動警報設定為 3.0mils)，所以運轉人員只須注意此問題而不須處理。無自動跳脫功能，當振動過高(>5mils)運轉人員依異常操作程序書手動跳脫 TDRFP，但至目前為止尚無發生此狀況。

建議本廠增加控制器 Bias 功能以增加運轉彈性，有關使用 Bias 的操作方法請參考附圖七-1~附圖七-5 所示之操作示意圖。

該廠特別說明在異常操作程序書中，若運轉 TDRFP 發生高振動問題(尚未達須手動跳脫 TDRFP 程度)時應採取以下方式處理：於單泵運轉時，利用

最小流量閥的開啟以增加流量使 TDRFP 轉速增加以越過共振區；於雙泵自動水位控制時，利用改變偏壓(BIAS)值，使雙泵運轉於不同轉速，高轉速者大於共振轉速，而低轉速者小於共振轉速。本方法可應用於 RIP RUNBACK/SCRRI 暫態時，改變偏壓(BIAS)值，使雙泵遠離共振轉速。參考附圖八之操作示意圖

（三）、Susquehanna 電廠的建議

1、建議本廠第一台 TDRFP 利用最小流量閥手動開啟越過共振區。

2、建議本廠第二台 TDRFP 利用 BIAS 控制越過共振區。

3、因暫態運轉而進入共振區時，利用 BIAS 控制離開共振區。

4、當 TDRFP 進行越過共振區的操作時，飼水總流量不能改變。

5、上述操作利用模擬器驗證其可行性。

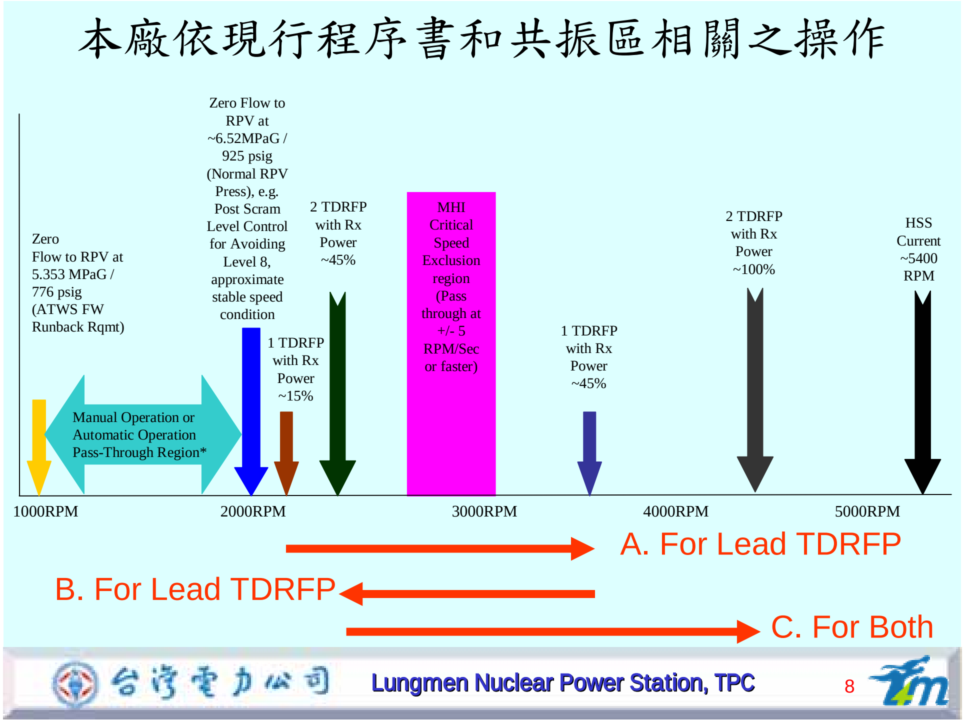
附圖五 Susquehanna 電廠控制器具有 BIAS 功能

附表四 核四廠與美國三個核能電廠飼水相關參數比較表

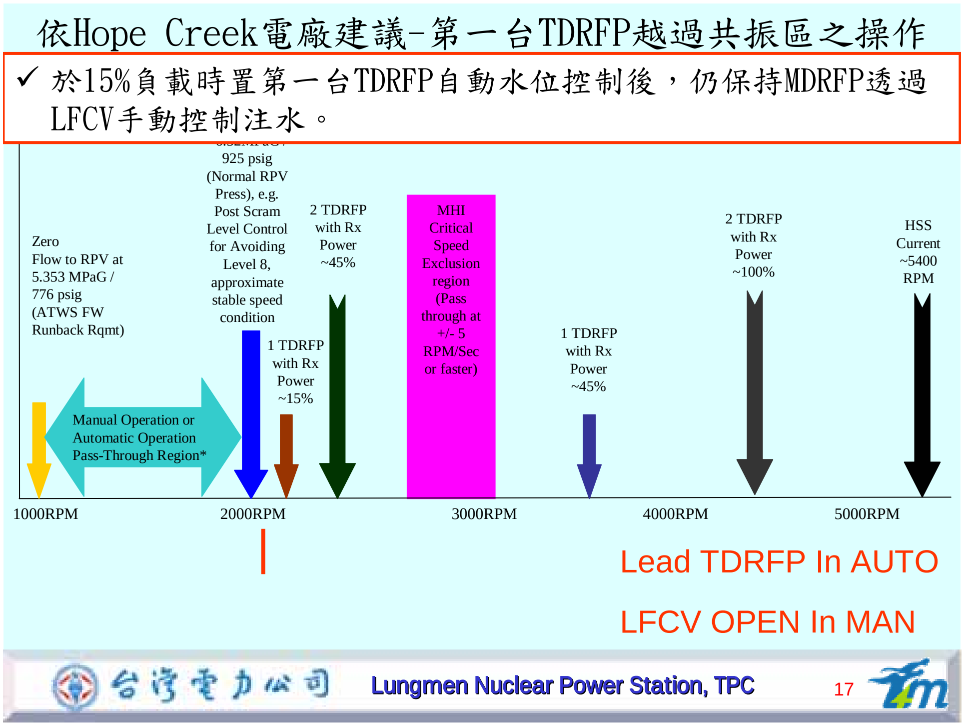
	PEACH BOTTOM	SUSQUEHANNA	HOPECREEK	核四廠
熱功率	1112 MWE	3490 MWT	3340 MWT	3926 MWT
CP+CBP+TDRFP+(MDRFP)	3+0+3+(0)	4+0+3+(0)	3+3+3+(0)	4+4+3+(1)
TDRFP 容量	40%	50%	50%	55%
最小流量閥開閉特性	全開/全關	可節流	全開/全關	可節流
最小流量閥之容量	33%RFP FLOW	40%RFP FLOW	--	32%RFP FLOW
最小流量閥開閉行程	45~90 秒	12~15 秒	30 秒	11 秒
出口閥特性	閘閥，可 BUMP OPEN	閘閥，全開/全關	閘閥，全開/全關	閘閥，全開/全關
共振區	2500~3000RPM	2800~3200RPM	3250~3550RPM	2750~2850 RPM
LSS	2600~2900RPM	1500RPM	2500RPM	1000RPM(暫定)
HSS	5400 RPM	5585 RPM	5453 RPM	5400RPM(暫定)
振動之正常值	<1.5MIL	<1MIL	<2 MILS	待測
振動之最大值	1.5 MIL	3 MILS	3.5 MILS	待測
振動之警報值	3 MIL	3 MILS	3 MILS	4 MILS
振動之跳脫值	5 MIL(已取消跳脫功能)	5MILS(已取消跳脫功能)	5 MILS(已取消跳脫功能)	5 MILS
飼水BIAS控制功能	無	有	無	無

附表五 美國三個核能電廠對本廠之建議

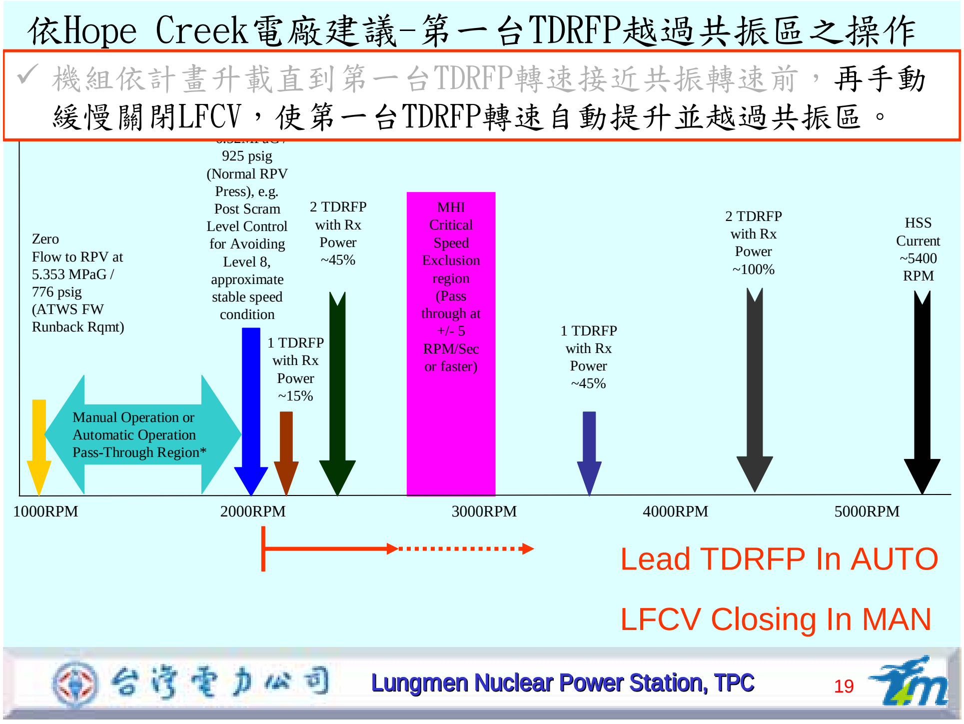
PEACH BOTTOM 的建議	SUSQUEHANNA 的建議	HOPE CREEK 的建議
建議本廠在 TDRFP 出口閥增加 BUMP OPEN 的操作介面，以增加運轉彈性。	建議本廠第一台 TDRFP 利用最小流量閥手動開啟越過共振區。	建議本廠充份利用現有 MDRFP 來越過共振區。
利用增加最小流量,將共振區移出運轉區,避免運轉時的困擾	建議本廠第二台 TDRFP 利用 BIAS 控制越過共振區。	建議升載過程中任一台 TDRFP 僅越過共振區一次。
建議 TDRFP 最小流量閥開啟/關閉行程要夠長。	因暫態運轉而進入共振區時,利用 BIAS 控制離開共振區	
	當 TDRFP 進行越過共振區的操作時，飼水總流量不能改變。	當 TDRFP 進行越過共振區的操作時，飼水總流量不能改變。
上述操作利用模擬器驗證其可行性	上述操作利用模擬器驗證其可行性	上述操作利用模擬器驗證其可行性



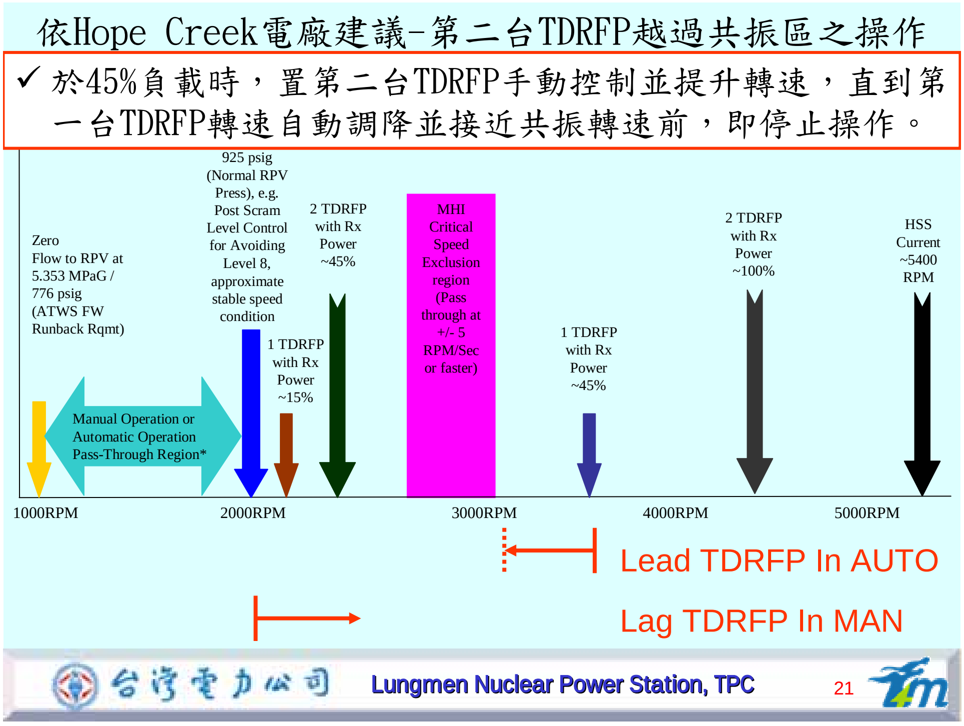
附圖六 本廠現行程序書須經過共振頻率區四次



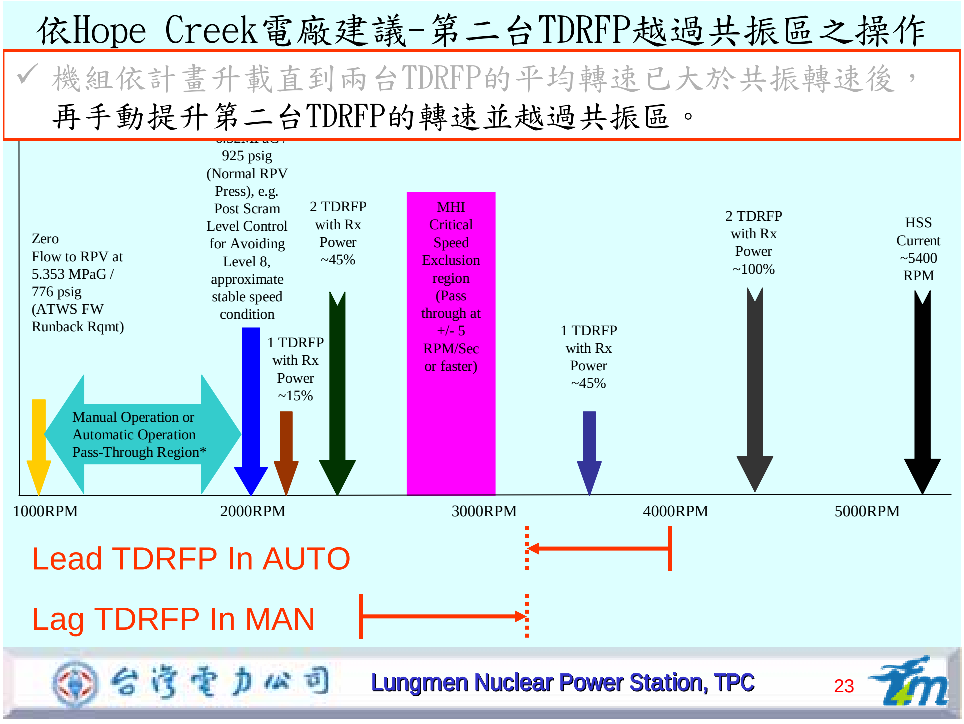
附圖七-1 於15%負載時，第一台 TDRFP 置於自動水位控制，MDRFP 仍經由 LFCV 手動補水



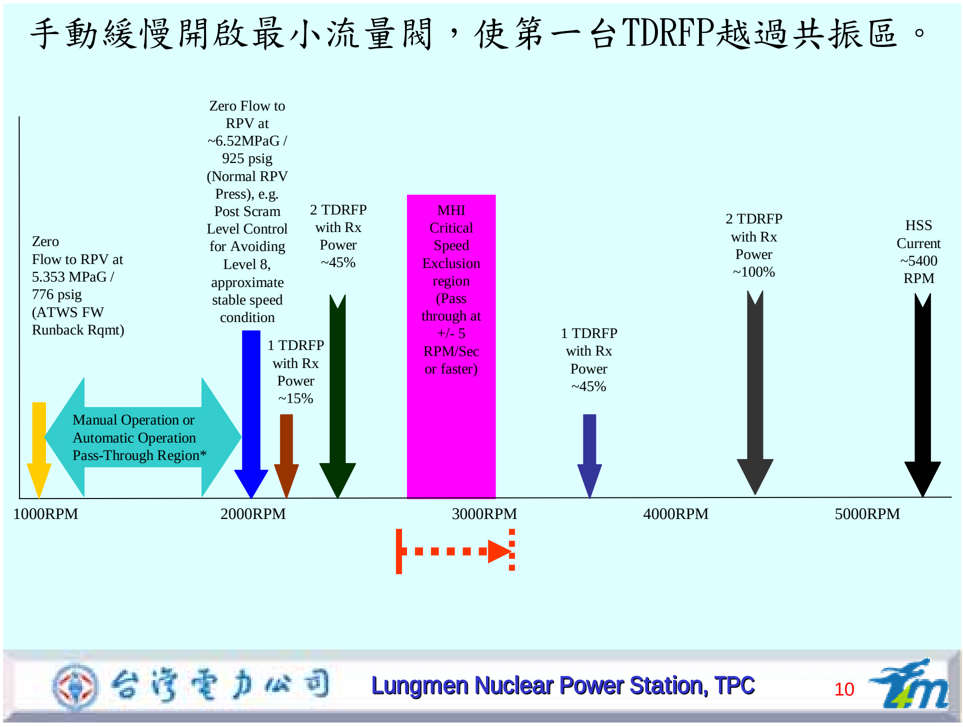
附圖七-2 接近共振轉速時，手動關閉 LFCV，使第一台 TDRFP 自動提升轉速越過共振區



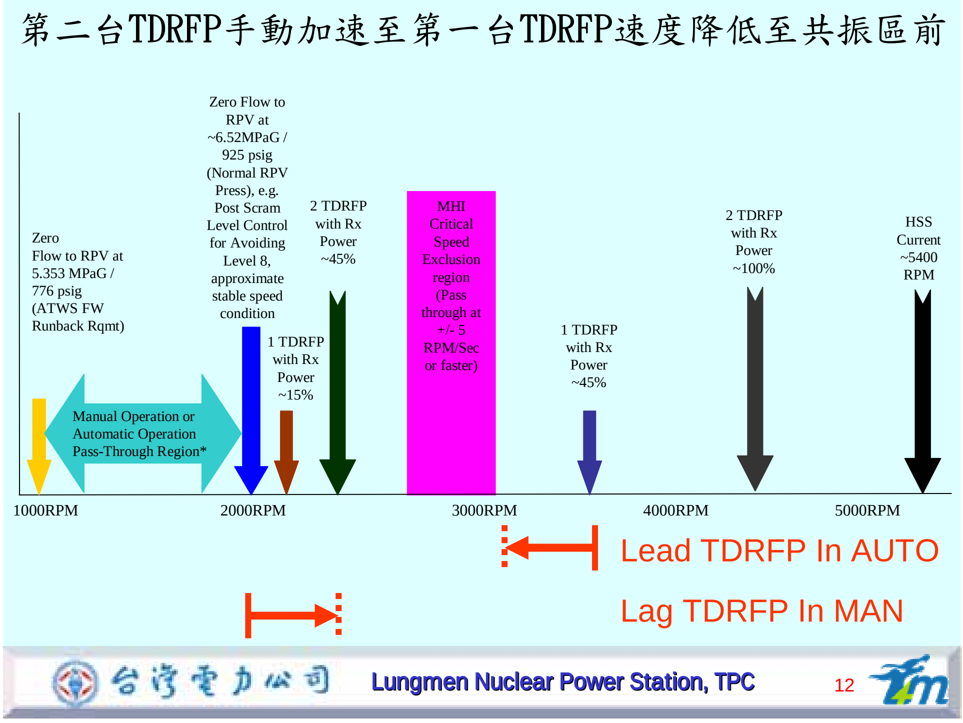
附圖八-1 45%負載時，手動提升第二台 TDRFP 轉速，使第一台 TDRFP 轉速自動降低至稍高於共振轉速



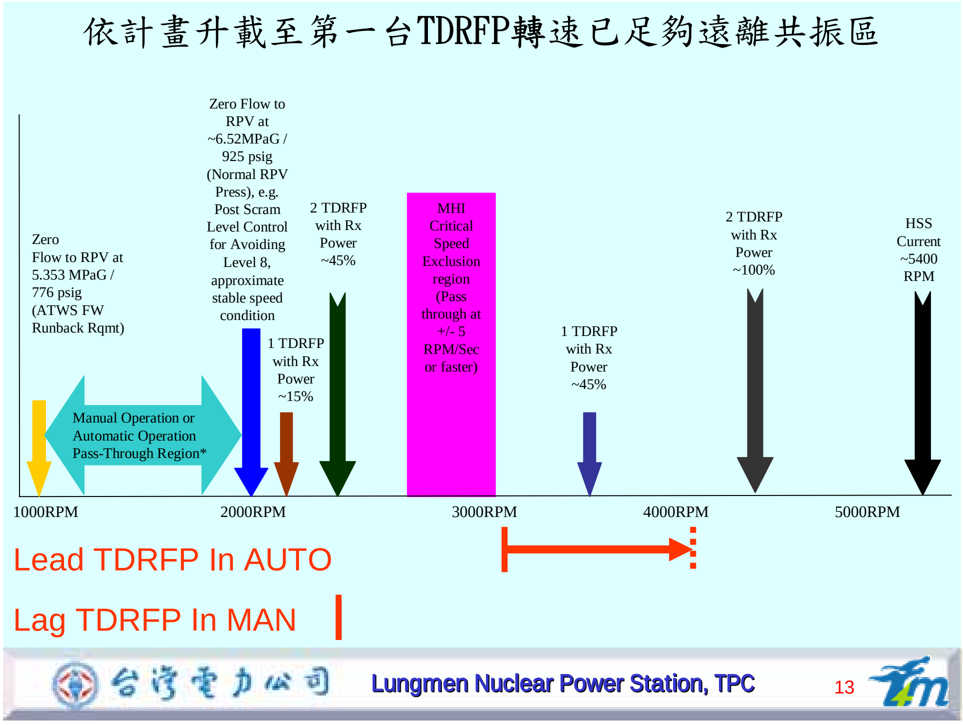
附圖八-2 依計畫提升功率直到平均轉速大於共振頻率，手動提升第二台 TDRFP 轉速使兩台 TDRFP 均大於共振頻率



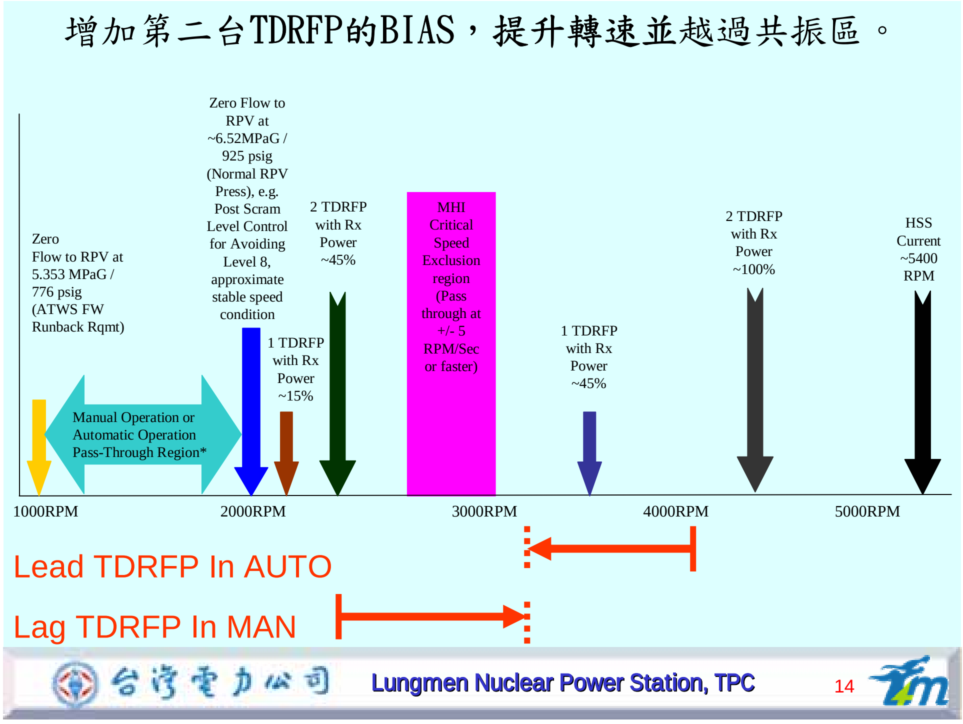
附圖九-1 手動開啟最小流量閥提升轉速使第一台 TDRFP 越過共振區



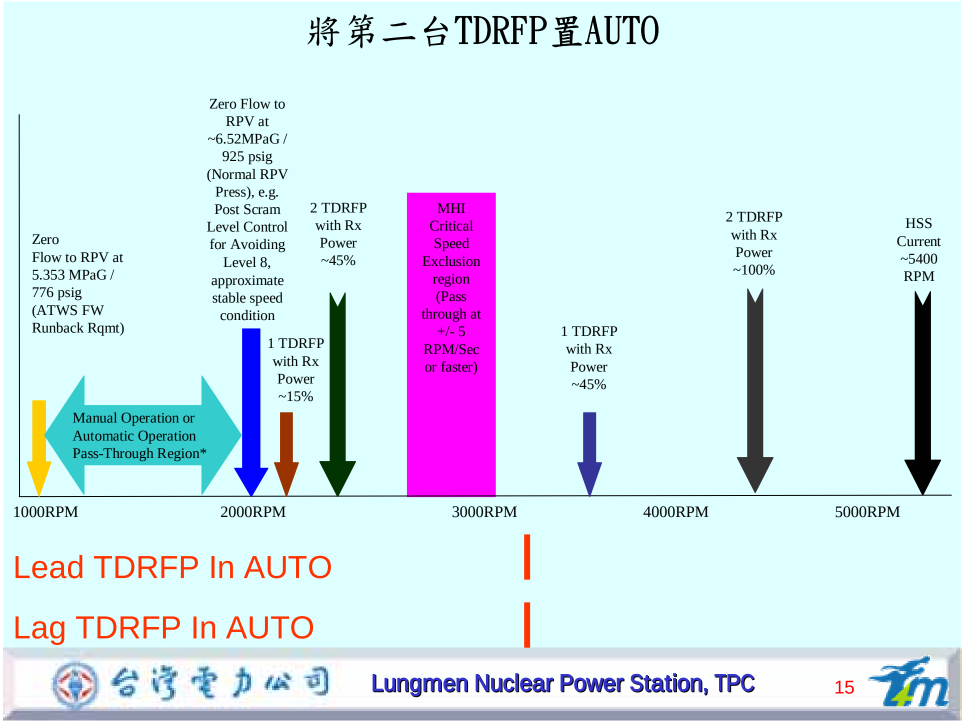
附圖九-2 第二台 TDRFP 手動加速，第一台 TDRFP 速度自動降低至稍高於共振頻率



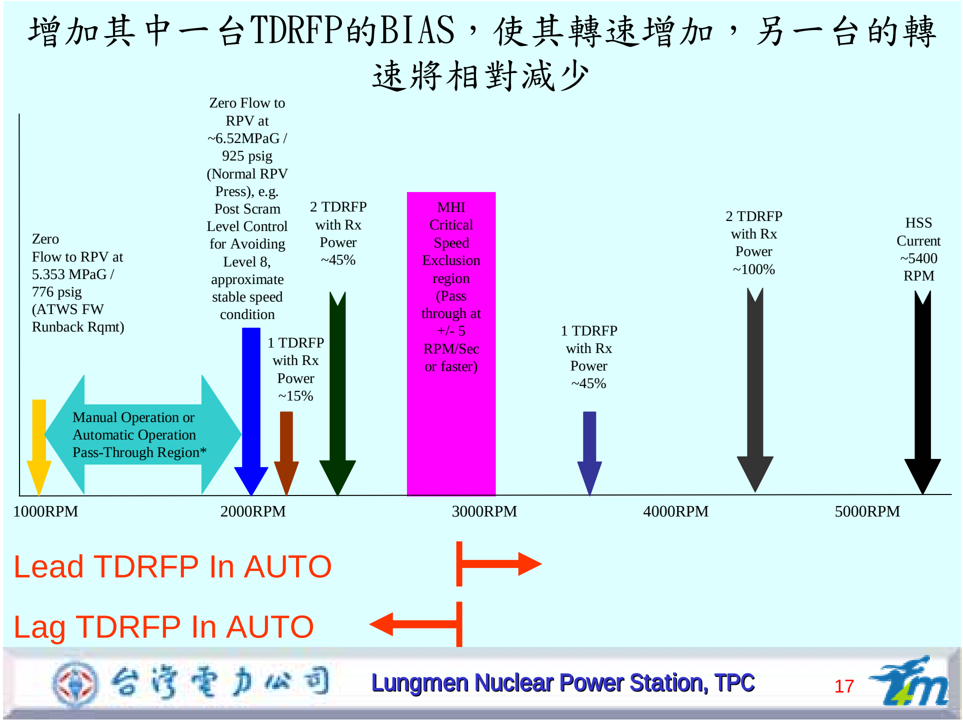
附圖九-3 依計畫升載至第一台 TDRFP 轉速已遠離共振區



附圖九-4 增加第二台 TDRFP 的 BIAS 設定提升轉速以越過共振區



附圖九-5 將第二台 TDRFP 置於 AUTO 完成操作



附圖十 遇暫態時，增加一台 TDRFP 的 BIAS 可將兩台 TDRFP 轉速移開共振區

參、國外公務之心得與感想

一、 本次拜訪的三個電廠 TDRFP 共振頻率都在運轉控制區附近,同時也都是在 STARTUP TEST 時才發現有此問題。其中 HOPE CREEK 及 SUSQUEHANNA 兩個電廠因為實際量測的振動值最多只稍高於警報設定點,廠方評估後認為可接受,所以具體作法只有在程序書中提醒運轉員勿停留於此區間而已,而不須採取特別的操作步驟。其中 SUSQUEHANNA 電廠另口頭提出如果振動過高超出可接受範圍,則要求運轉員參考異常操作程序書,利用 BIAS 功能將轉速移出共振頻率範圍。另一個電廠--PEACH BOTTOM 電廠則猜測其在共振頻率時實際量測的振動值可能超過可接受範圍,所以將 TDRFP 的控制範圍設為大於共振頻率,如此 TDRFP 在共振頻率區間不會 TAKE LOAD,即可避免運轉於共振頻率的問題,不過其操作程序亦因此變得非常煩雜。

二、 三個核能電廠均在 1980 年代以前商轉,因當年尚沒有相關規定,所以都沒有 AMPLIFICATION FACTOR 的設計/測試資料。不過 SUSQUEHANNA 電廠因其 TDRFP 有磨損(EROSION)問題,所以最近採購了 TDRFP 準備加以更換,其電廠機械工程師提供如附件一所示的 AMPLIFICATION FACTOR 資料,以其符合 API STANDARD 612 的 SEPARATION 要求,所以判定為可接受。因本廠為新建電廠應符合新法規,所以建議應向製造廠家 MHI 要求此資料。

三、 與 SUSQUEHANNA 電廠討論共振頻率區間運轉策略時,提到使用 CP 或 CBP 最小流量閥之開啟以提升再循環流量降低 TDRFP 進口

壓力的作法時，電廠模擬器講師提供 INPO 運轉經驗(OPERATION EXPERIENCE) OE20747 CONDENSATE SYSTEM DESIGN LIMITATIONS RESULT IN FEED PUMP TRIP AND SCRAM – BRUNSWICK(如附件三)的案例說明此法不可行,雖然本案歸納最直接原因是設計容量未確認，但最小流量閥之作用在保護 PUMP，若用以作其他控制功能將可能帶來無法預測的後果,依該講師訓練運轉員的經驗,建議電廠應避免此作法。

四、 依以往的運轉經驗,兩台以上 TDRFP 投入使用時,如果轉速差超過 200RPM 以上時，轉速較低的 TDRFP 將無法打水，所以一直以來的作法都是各台 TDRFP 轉速應差不多,即使升載期間亦是採取同樣作法。此行三個電廠不約而同均建議採用多台 TDRFP 不同轉速的運轉策略以越過共振頻率區間,因此可以採用的運轉策略就可以增加很多選擇。

五、 依討論結果單台 TDRFP 投入使用時,可使用開啟最小流量閥的方法提升轉速以越過共振頻率區間，第二、三台 TDRFP 投入使用時則可使用各種不同的運轉策略，不過共同點是此時發電量、飼水流量均應保持固定,然後再以一個手動控制,另一個自動控制補償的方式，以類似切換的方式越過共振頻率區間。

六、 三個電廠均建議所有的運轉策略均須經過模擬器驗證其可行性。

七、 SUSQUEHANNA 電廠依其運轉經驗建議本廠考慮增加最小流量閥開關時間,因其最小流量閥開關時間僅 12~15 秒,所以在飼水控制上主要的問題為最小流量閥開關會造成反應爐水位震盪。

八、 TDRFP 高振動自動跳脫功能，三個核能電廠均予以取消，改以程序書管制，若振動高於某設定值(5MILS OR HIGHER)則運轉員手動跳脫 TDRFP，如此可避免假信號造成 TDRFP 誤動作，因而造成反應爐不必要的暫態甚至可能引發急停。

九、 自三哩島事件後，各廠均有其自有之模擬器，模擬器的真實度均甚高，改善案設計完成後，須先經模擬器證明其功能符合後再進行施工。如有較重大的改善案，運轉員須先至模擬器體驗新的操作方式，待訓練完成後才能到機組正式運轉。故其模擬器不只是作為訓練之用，同時亦作為 DCR 改善可行性的檢驗。為配合這些訓練、研究、改善等多重目的，各廠訓練中心編制均超過五十人以上，SUSQUEHANNA 電廠甚至超過一百人。

肆、對公司之具體建議

一、 本次拜訪的三個電廠中有兩個電廠的 TDRFP 在共振頻率時，實際量測的振動值最多只稍高於警報設定點，所以具體作法只有在程序書中提醒運轉員勿停留於此區間而已，而不須採取特別的操作步驟。所以共振頻率時的振動不一定會高到無法接受。建議向製造廠家要求更進一步的設計/測試資料，例如 AMPLIFICATION FACTOR，如此可能不須作補救措施即可安全地通過共振頻率。

二、 善用飼水系統中的 MDRFP、LFCV、最小流量閥等設備的投入使用時機，以及使用自動/手動控制兩台 TDRFP，使其轉速高於或低於共振轉速等等之各種運轉策略，每一台 TDRFP 僅須經過共振區域一次，有效降低經過共振區的風險。各種運轉策略實際使用前必須先經過模擬器驗證其可行性。

三、 使用各種運轉策略都有一個前提：至少有一項控制設備要置於自動控制模式。另外經過共振區域時的操作是以類似切換的方式進行，如此可大幅降低停留在共振頻率區間的時間。

四、取消 TDRFP 高振動自動跳脫功能，改以程序書管制，若振動高於設定值(5MILS)則運轉員手動跳脫 TDRFP，如此可避免假信號造成 TDRFP 誤動作，因而造成反應爐不必要的暫態甚至可能引發急停。

五、以上建議供 TDRFP 共振頻率專案小組參考及討論使用。

附件一 由 SUSQUEHANNA 電廠提供的 AMPLIFICATION FACTOR 資料

Table 4-7

Response to Unbalance Results

Nominal Bearing Stiffness (Nom. Clearance)

Bearing Type	Radial Clear.	Preload Ratio
HP - Elliptical	0.0045	0.50
LP - Elliptical	0.0060	0.50

Oil supply temp - 120 F

	1st Horz	1st Vert	2nd Horz	2nd Vert
Critical Speed	1640	3360	3720	8350
Amplification Factor	6.1	6.3	3.1	3.1
Critical Speed Separation Margin				
- Required	15.0	15.0	5.0	15.0
- Calculated	58.4	14.7	5.0	59.0

Radial Displacement at Seals (in., o-p)

Mode		Second
- Seal Clearance	0.0100	0.0100
- Rotor Disp.	0.0019	0.0014
- API Limit	0.0075	0.0075

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Turbo Care

附件二 美國三個核電廠對本廠提問問題答覆總表

	Questionaire	Peach Bottom(5/10)	Susquehanna(5/16)	HopeCreek(5/18)
1a	Could you please make a brief description about your Feedwater system?	See P&ID	Ref. Training Text and Proc.	See 058-01 REACTOR FEEDWATER SYSTEM
1b	Please describe the Feedwater control mode transition during power ascension, also please provide the information like the amount of CP and TDRFP, the flow capacity and discharge head developed by these pumps etc..	CP: 600 psi Normal, 550 psi 100%power TDRFP: 650 psi rated	HSS: 110%	Primary CP: 150psi Secondary Cp: 650psi RFP: 1000psi
2a	Does your TDRFP has the critical speed in the control operation range? What is the critical speed of your TDRFP? What is the operating restrictive range of TDRFP defined in your procedure?	YES 2500~3000RPM LSS: 2600~2900 RPM (If Set, same all the time)	YES 2800~3200RPM	YES 3250~3550RPM
2b	Per your experience, when operating one, two, and three TDRFPs during restrictive critical speed range, what about the corresponding reactor thermal power would it be?	No RPV flow change when they pass thru critical speed	No idea, never pay attention to.	No idea, never pay attention to.
2c	How long will it take to pass the restriction range during power ascension?		hours	Minimize the time.

3	What is the strategy to minimize operating in the restricted range? Are there any assistant countermeasures like manually controlling the flow rate of minimum flow valve, or rapidly increasing the recirculation flow to ascend the reactor power ? please explain your method detailed if there are any.	unvalid	Go thru normally	Go thru normally
4a	When passing the restriction range is there any significant change in your system? How about the vibration amplitude increasing?	no any significant change	vibration alarm and recorder max. 3 mils in experience 1 mil for normal	max. 3.5 mils and cause alert alarm(3 mils)
4b	Are there any monitoring devices, like alarm or status indicator ,to alert the operator when TDRFP is operating in the restriction range?	high vib. Alarm No auto Trip	high vib. Alarm No auto Trip	alert : 3 mils danger : 5 mils No auto Trip
5	Are there any significant events impacting to the reactor normal operation due to the issue of critical speed of TDRFP ?	NO	NO	NO
6a	When did you know the condition of TDRFP critical speed?	Since plant design	Since plant design	Since plant design
6b	What methods have you ever tried to deviate the critical speed? How about the effects for these methods?	Test during start up; change the operation process	Startup test find the critical speed; just go through	Startup test find the critical speed; just go through

7	How was the LSS (Low Speed Stop) value generated in your plant? In our plant the LSS is defined as the speed which no flow of feedwater is found to RPV.	LSS 2600~2900rpm, just above restrictive range	LSS: 1500 rpm No requirement from ATWS FW Runback	LSS:2500rpm No requirement from ATWS FW Runback
8	What is the Amplification Factor (or Q Factor) of your TDRFP? According to the API Standard 612, normally the Amplification Factor should be less than 2.5 otherwise the oscillation will occur.	No Data, No Idea	No Data, No Idea the new purchase TDRFP Data is OK	No idea, but try to look for the data.
9	For the periodic maintenance of the TDRFP, did you have pay any special attention to the system. And do you have any experiences worth noting to us.	No	Pay a lot of attention on checking /monitoring the errosion Wearing is not much for bearing	No Every 6 years to overhaul Just a caution.
10	For your understanding of our system and base on your operation experiences of the system, do you have any suggestion to our case?	refer to the attachment	refer to the attachment	refer to the attachment

附件三 INPO OE20747

Date:05-26-2005

Subject:OE20747 - Condensate System Design Limitations result in Feed Pump Trip and Scram - Brunswick

ABSTRACT:

On April 9, 2005, Unit 2 was at 65% reactor power after completion of a refueling outage. The 2A reactor feed pump (RFP) was being removed from service to support Extended Power Up-Rate (EPUR) testing when a condensate transient resulted in a low suction pressure trip of the operating condensate booster pumps and the operating reactor feed pump. The reactor Scrammed on low RPV level while action was being taken to restore the Condensate and Feed system. The investigation determined that the Condensate system operating strategy in place at the time of the event was faulty in that the Steam Jet Air Ejector Condensate Recirculation Valve (CO-FV-49) was being operated to control Condensate pump (CP) discharge pressure without regard to CP flow. Use of this strategy resulted in a condensate system flow demand that exceeded the capabilities of the system. It was also identified that a flow limitation for the CP's had not existed prior to the EPUR system changes. When changes to the condensate and Feedwater system operating strategy were made, there was no established condensate flow limit to consider for revision.

REASON FOR MESSAGE:

This event shows the impact design changes can have on system operating strategies.

EVENT DATE:	April 9, 2005
UNIT NAME:	Brunswick Steam Electric Plant, Unit No. 2
NSSS/A-E:	GE/UE&C
DOCKET NO./LER NO.:	50-324
TURBINE MANUFACTURER:	GE

MAINTENANCE RULE APPLICABILITY: no

COMPONENT INFORMATION (AS APPLICABLE):

MANUFACTURER:	--
MODEL NUMBER:	--
PART NUMBER:	--

DESCRIPTION:

On April 9, 2005, Unit 2 was at 65% reactor power in reactor power ascension after completion of a refueling outage. Operations was in the process of removing the 2A RFP from service to support Extended Power Up-Rate (EPUR) testing when a condensate transient resulted in a loss of condensate pump (CP) discharge pressure and a loss of suction to the condensate booster pumps (CBP's) and the reactor feed pumps (RFP's). This resulted in a low suction pressure trip of the operating CBP's and 2B RFP. At the time of the transient, the 2A RFP speed had been reduced and the pump was no longer feeding the reactor pressure vessel (RPV). An attempt was made to restore the 2A RFP to service but the suction pressure to the pump had not yet been completely restored prior to the reactor tripping on low RPV level. The Operators were monitoring a decreasing reactor water level and had planned to insert a manual scram if the water level reached 171". However, an automatic scram (setpoint 168") occurred when the Control Room narrow range level indication, associated with the Digital Feedwater Controls, was reading 172"-173" (OE20748).

Prior to the event Unit 2 was in operation at 65% reactor power with 2 CP's, the 2 CBP's, the 2 HDP's, and both RFP's in service. The Steam Jet Air Ejector Condensate Recirculation Valve, CO-FV-49, was open approximately 55% to control CP discharge pressure in the 150-190 PSIG band, both RFP minimum flow valves were closed, and the Feed Water Recirculation to the Condenser, FW-FV-177 isolation valve was closed. No other pump minimum flow valves were open and no other pertinent plant activities were in progress at the time of the event. To support starting a third CP, the CO-FV-49 was adjusted to lower CP discharge header pressure. Per procedure the third CP start was to be performed to support the removal of the 2A RFP from service. The 2A RFP minimum flow valve was then opened and the 2A RFP speed was then lowered in manual. Observations indicated appropriate 2B RFP RPM and flow increases. Immediately after 2A RFP flow to the reactor was terminated, low pressure alarms were received at the CP discharge header, the CBP suction header, and at the RFP suction header. This resulted in a low suction pressure trip of the operating CBP's and 2B RFP. An attempt was made to restore the 2A RFP to service but the suction pressure to the pump had not yet been completely restored and the reactor tripped on low RPV level. The Reactor Operator had also ordered the Auxiliary Operator to close the CO-FV-49 but this did not result in system recovery rapidly enough to restore system pressure prior to the 2B RFP trip and reactor scram. No equipment deficiencies could be identified that contributed to this event. While there was some reported drifting of the CO-FV-49 just prior to the reactor scram this was later determined to most likely have been a result of automatic flow changes on the heater drain system. Static and dynamic testing performed after the scram recovery determined that the valve was operating properly.

The investigation determined that the loss of pressure at the CP discharge header was a result of the flow capacity of the CP suction piping. It was found that most limitations in the condensate operating procedures were based on system pressures and/or reactor power levels without regard to condensate system flow. This is an indirect and inexact method of controlling system flow. Flow through the CO-FV-49 was originally designed to be used as minimum flow control for the steam jet air ejector condensers. Many years ago the use of CO-FV-49 evolved into serving a dual purpose. The other use of this valve is for CP discharge header pressure control. The CO-FV-49 is able to direct as much as 13,600 GPM to the main condenser.

Normal lineup EPUR 100% CP flow is 17,400 GPM. At 65% power, this equates to approximately 11,300 GPM. At the time of the loss of pressure the CO-FV-49 was open 60% which resulted in an additional flow of approximately 9160 GPM. Since the 2A RFP was being removed from service, its associated minimum flow valve was open passing a flow estimated to be 3,800 GPM. This alignment resulted in a total CP flow demand of 24,260 GPM. This is equivalent to 139% of EPUR 100% condensate flow (24,260/17400).

Use of the CO-FV-49 can significantly increase the flow through the condensate system at the CPs and CP flow indication can only be monitored in the turbine building breezeway. The lack of indication was previously recognized as a weakness by engineering and operations in 2004. As a result, an engineering change was initiated to install various condensate/feedwater pressure and flow indications on the plant process computer.

Review of the CP performance curve indicates that, assuming no system losses, three pumps in parallel would deliver 27,000 GPM at 180 PSIG discharge pressure. This is sufficient to provide the necessary suction head and flow capability, through the SJAE and radwaste systems, to the CBP's to support operation well beyond rated EPUR 100% conditions. This demonstrates that the capacity of the CP's was not the cause of the loss of CP discharge pressure and that since pressure was lost as far upstream in the system as the CP discharge header, the condensate system piping and/or valves at or upstream of the CP discharge header is the flow limiting area of the system.

Since it is now known that the condensate system has flow limitations that were not defined in procedures, it can be further concluded that the procedural strategy for operation of the CO-FV-49, which was in place in the time period leading up to the event was flawed. The procedural focus for the operation of CO-FV-49 was on maintaining CP discharge pressure between 150 and 190 PSIG. At 65% power this resulted in the need to open the CO-FV-49 approximately 60% (9160 GPM to the main condenser) to regulate pressure, which resulted in a condensate flow rate exceeding the system capability. Operation of three CPs also contributed to this in that regulating pressure in the prescribed band required passing increased flow through the CO-FV-49.

During the investigation of the history of the condensate and feedwater operating strategy, it was discovered that a flow limitation for the CP's did not exist prior to the event and had never existed. When condensate system parameter changes were made, existing limits were identified and considered for revision. Since no flow limit existed for the CP's, no new flow limit was established.

It was recognized by the EPUR project personnel that the extensive modifications to the Condensate and Feedwater systems would lead to changes in the operating characteristics of the system (e.g. vibration, transient response). While such changes were likely, it is difficult to predict where in the effected systems they might occur without extensive dynamic analysis such as computer or scale modeling which is not generally performed on BOP systems. Consistent with normal practices, an extensive startup test program was implemented to evaluate system operation and response. The test program included inspections, data analysis, test hold points, and evaluation of any identified anomalies. The startup test program did not detect the flawed condensate system operating strategy as all pump alignments were tested at full power level flows (greater than 90%).

CAUSES:

Root Cause 1 – The Condensate system operating strategy in place at the time of the event was faulty in that the CO-FV-49 was being operated to control CP discharge pressure without regard to CP flow. Use of this strategy resulted in a condensate system flow demand that exceeded the capabilities of the system.

Root Cause 2 – A flow limitation for the CP's did not exist prior to the event and had never existed. When changes to the condensate and Feedwater system operating strategy were made, there was no established condensate flow limit to consider for revision.

Contributing Cause – Controls for CO-FV-49 and indication of CP flow are not available on the RTGB.

CORRECTIVE ACTIONS:

1. The Operating Procedures are being revised to include condensate pump flow limitations sufficient to ensure condensate pump cavitation or runout does not occur. A refined condensate operating strategy based on empirical data obtained during plant startups and shutdowns that include system flow limitations will be developed and incorporated into the appropriate procedures. This strategy should include guidance for operation with: two or three condensate pumps, Condensate Storage Tank condensate reject, Condensate Deep-bed Demineralizer rinse in progress, Final Feedwater Temperature Reduction, and Feedwater Heaters removed from service.
2. Controls for the CO-FV-49 and indication of condensate pump flow are to be installed in the Control Room.
3. Licensed Operator Continuing Training is to be conducted on this event including: the appropriate operating strategy and flow limitations of the condensate and Feedwater systems, and the missed opportunities to identify the flawed system operating strategy.
4. Engineering Support Personnel are to be trained on the cause of this event, and the missed opportunities to identify the flawed system operating strategy.

SAFETY SIGNIFICANCE:

The safety significance of this event is minimal. Reactor water level and pressure were quickly recovered and stabilized during the scram recovery. All control rods fully inserted and all safety systems responded as designed.