Steam Turbine Blade Failure

Rajendra Zope
Umesh Choondassery
Qatar Chemical Company, QATAR

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ABSTRACT

The objective of this Case study is to share the Failure analysis of a steam turbine blades due to blade excitation aided by corrosion.

The blade failure was detected early by Company Vibration analyst in July 2006, when maximum shaft vibration had a step change from 9 Microns to 18 Microns Pk-Pk. (SET Points: Alarm at 58 and Trip at 72 Microns Pk-Pk).

This helped in arranging resources and plan a short shutdown of 8 days in March 2007 to replace the rotor.

The following slides explain the detailed failure analysis and corrective actions taken.

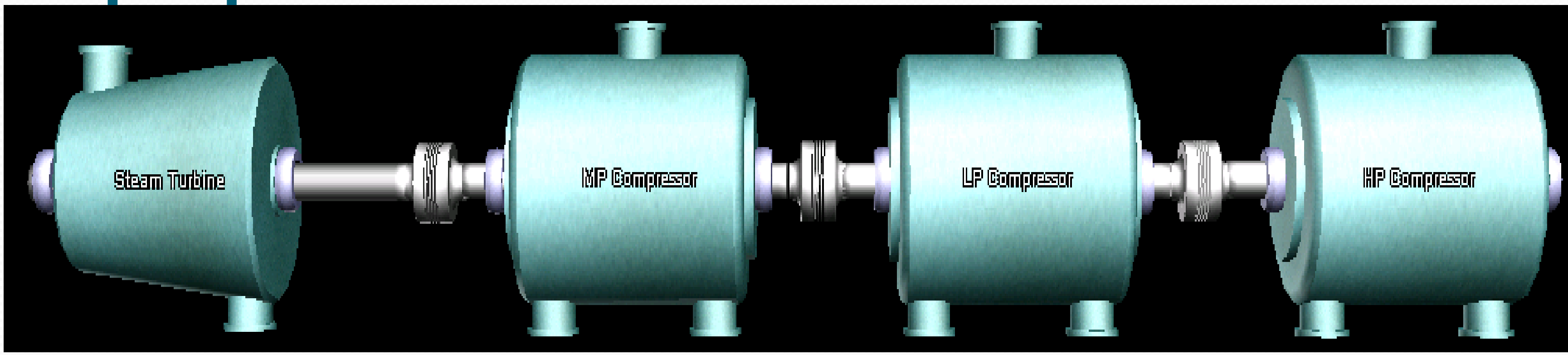
Event Timeline – Vibration Trends

July 2006 – First Step Change, Suspected Blade Failure.

Feb 2007 – Second Step change, Vibration reach 70% Alarm.

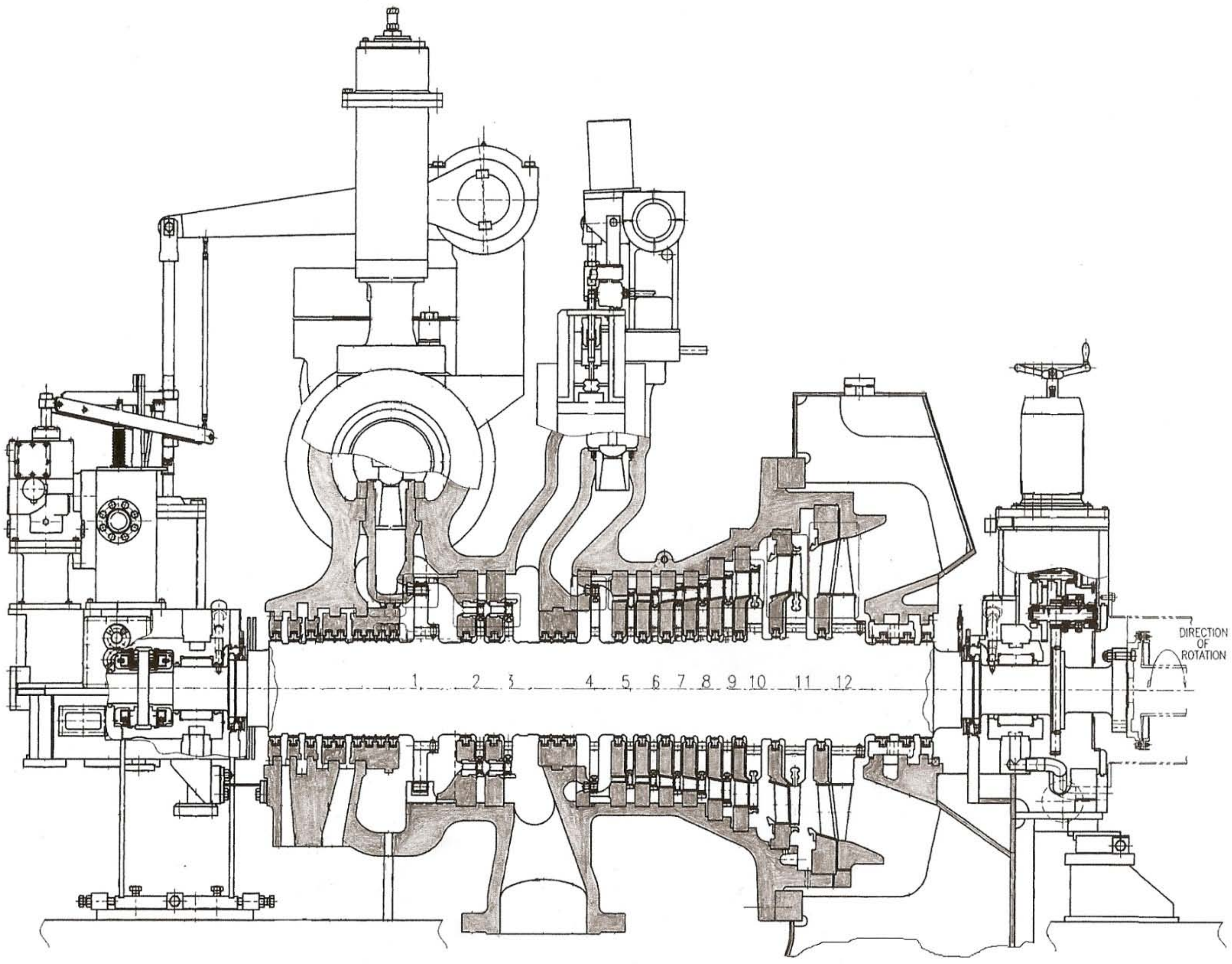
March 2007 – Planned shutdown and rotor replaced.

Equipment Data



	Turbine	
Media Handled	**Steam**	**Note:** This 12 stage turbine was commissioned in February 2003 and since then in continuous operation. Machine vibrations were smooth, right from commissioning (Maximum shaft vibration of 12 microns Pk-Pk.)
Capacity	26.5 MW	
Inlet Condition	103.5 kg/cm^2A, 493 °c, 190 T/Hr	
Outlet Condition	44 kg/cm^2A, 383°c-Extraction 102 mm HgA, 50°c-Condenser	

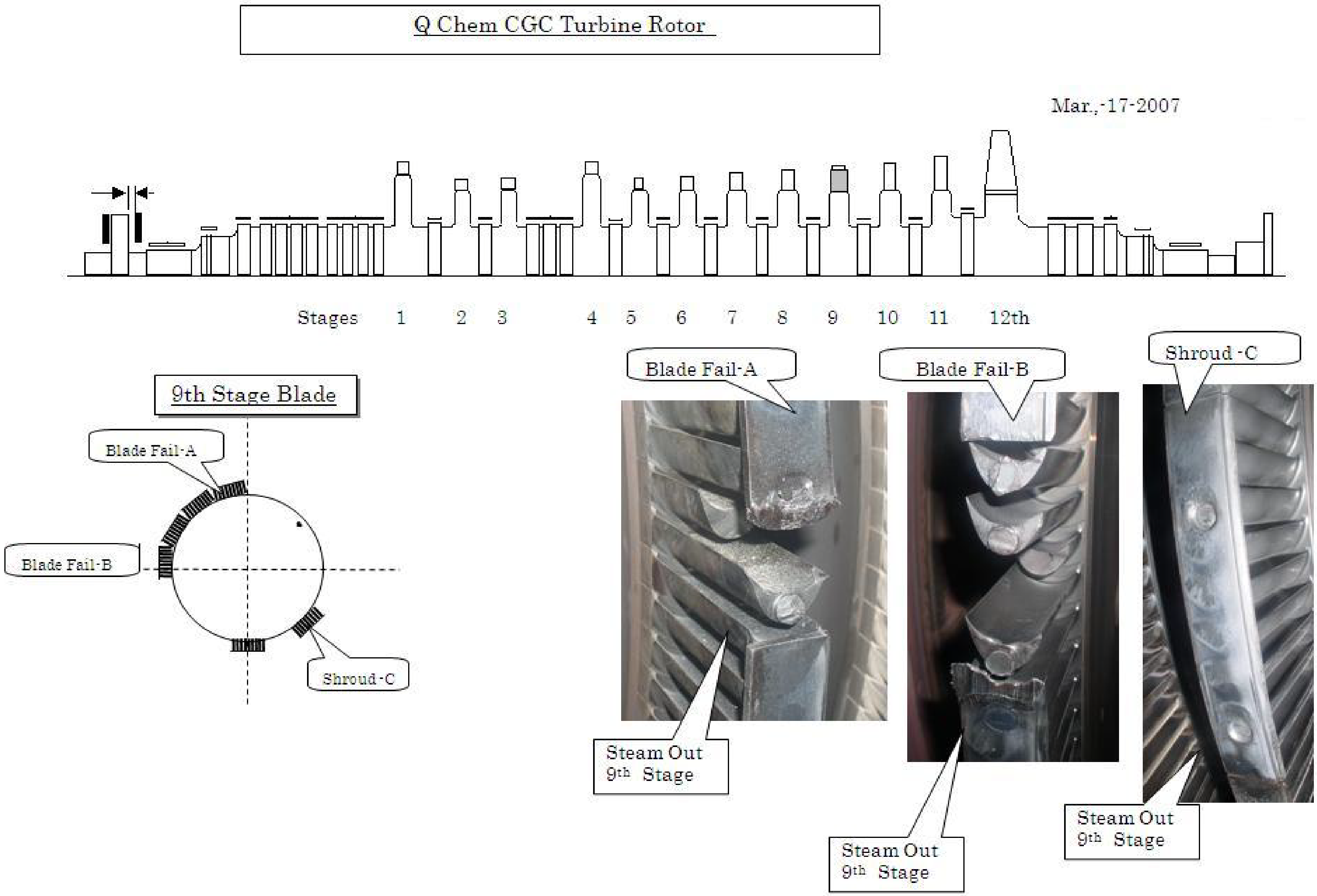
Turbine Cross section



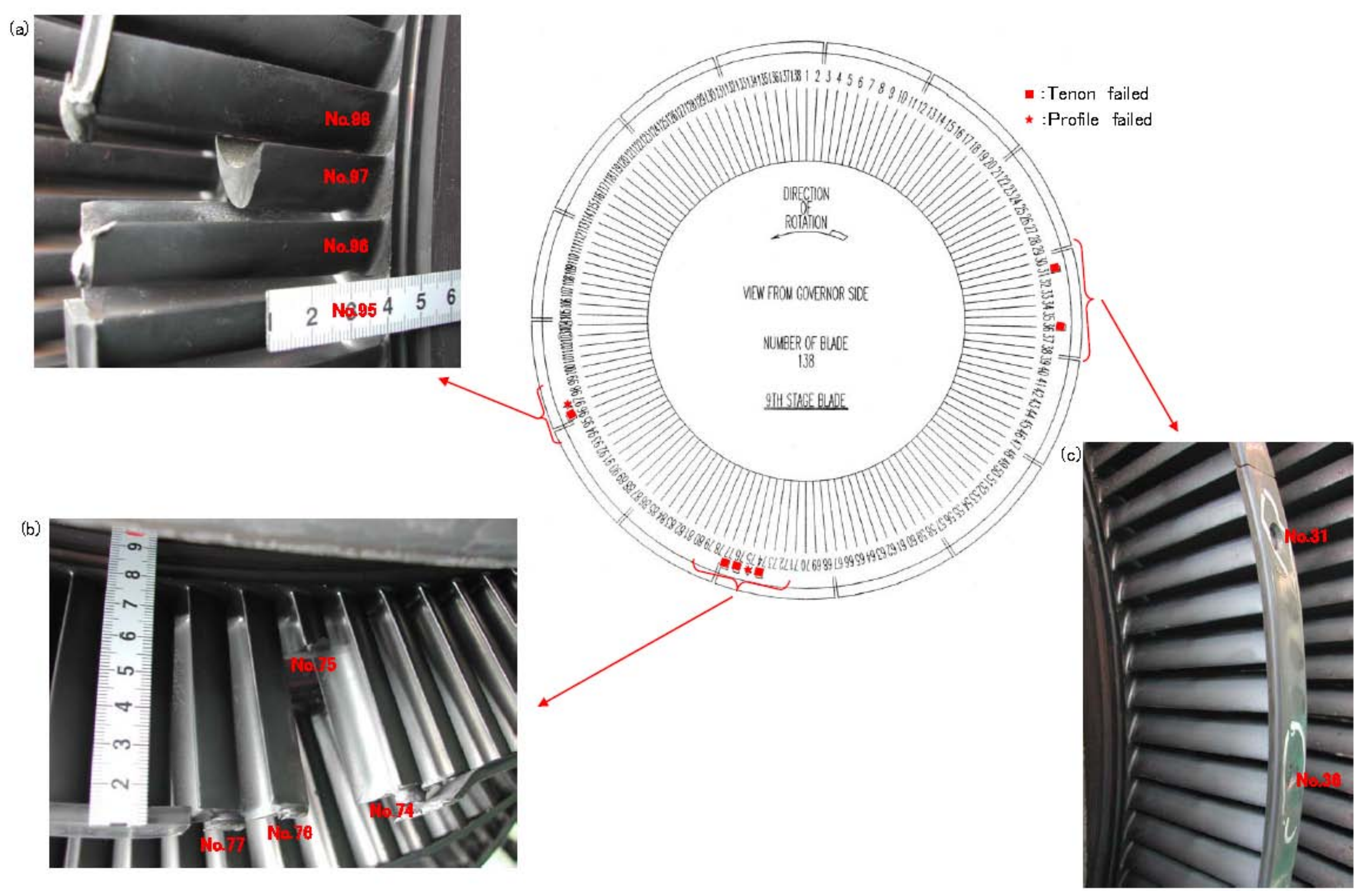
Visual Inspection of failed rotor

- Failure limited to 9th stage blades.
- 9th stage blades failed at 3 locations. Blade no 30~38, 68~77, 96~104.
- Surface and fracture surface of blades found black.
- Tenons found broken at 31,36,76,96
- Profile found broken at 75,97
- Shrouds were lost at 74,77,98
- Rub marks on blades 76, 96
- Some red deposits found on 2nd ~6th Stage blades
- Some white deposits found on 7th ~12th Stage blades.
- Inlet side of 10th stage blades show many dents.

Visual Inspection of failed rotor



STAGE 9 -BLADE FAILURE LOCATIONS

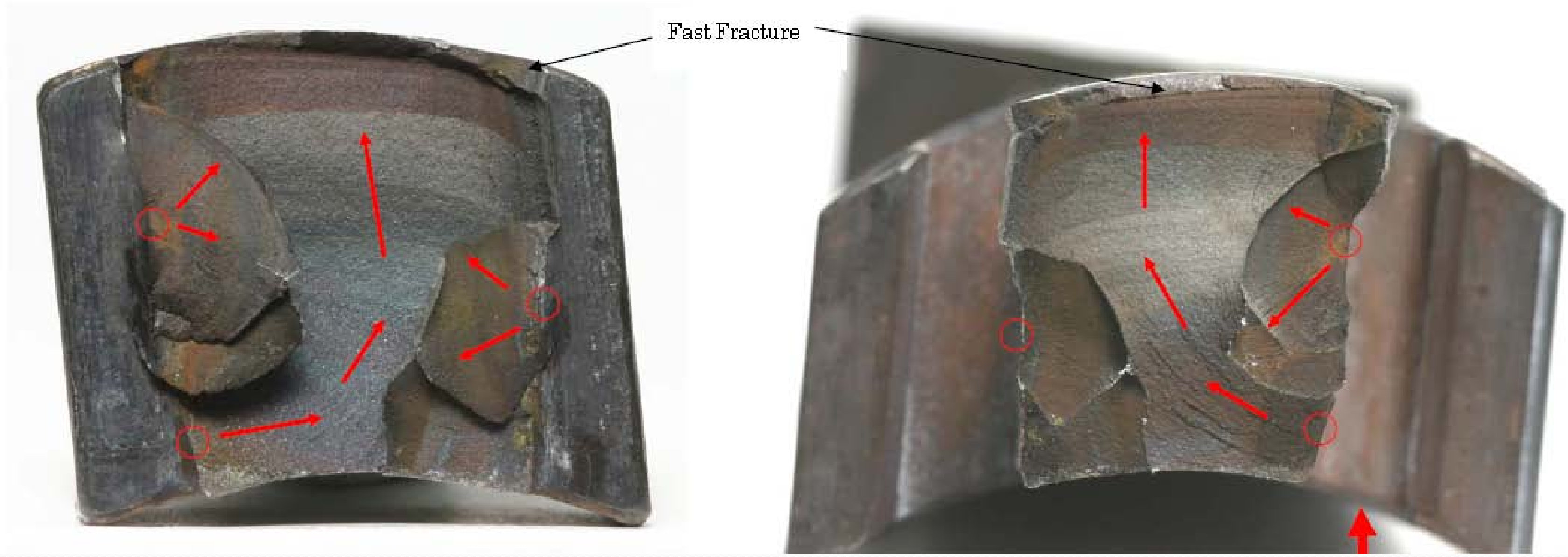


Failure condition of 9th stage blades

DETAILED INSPECTION- FRACTURE SURFACES

Blade Roots

- Magnetic particle tests were carried out at all 9th stage blade roots and cracks were observed at roots of blade Numbers 24,26,32 and 65.
- Beach mark pattern indicating fatigue fracture is seen in the fracture surfaces.

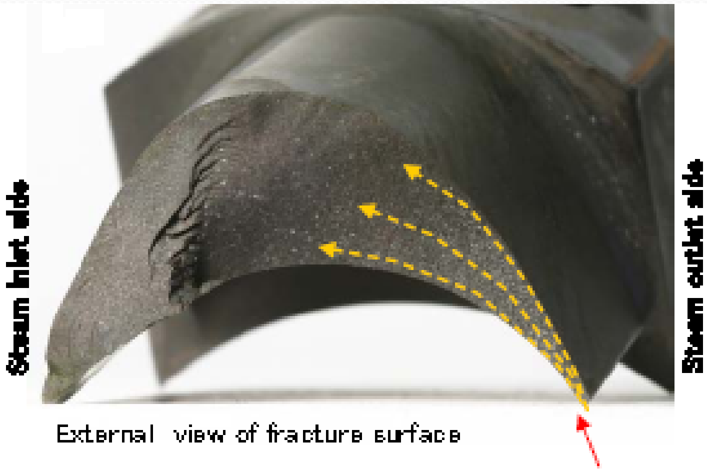


DETAILED INSPECTION- FRACTURE SURFACES

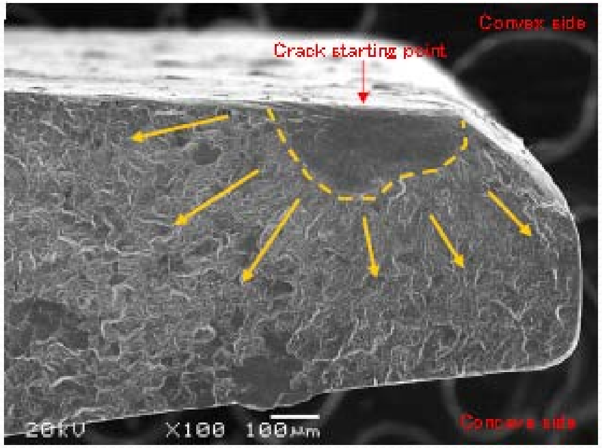
Profiles

- Sub surface cracks and corrosion pits are seen on tenons
- Fatigue crack initiated in the tenons at corrosion pits.
- Striation patterns of fatigue crack characteristic are observed at propagated area.

External view of No.75 failed blade



External view of fracture surface



DETAILED INSPECTION- FRACTURE SURFACES

Tenons

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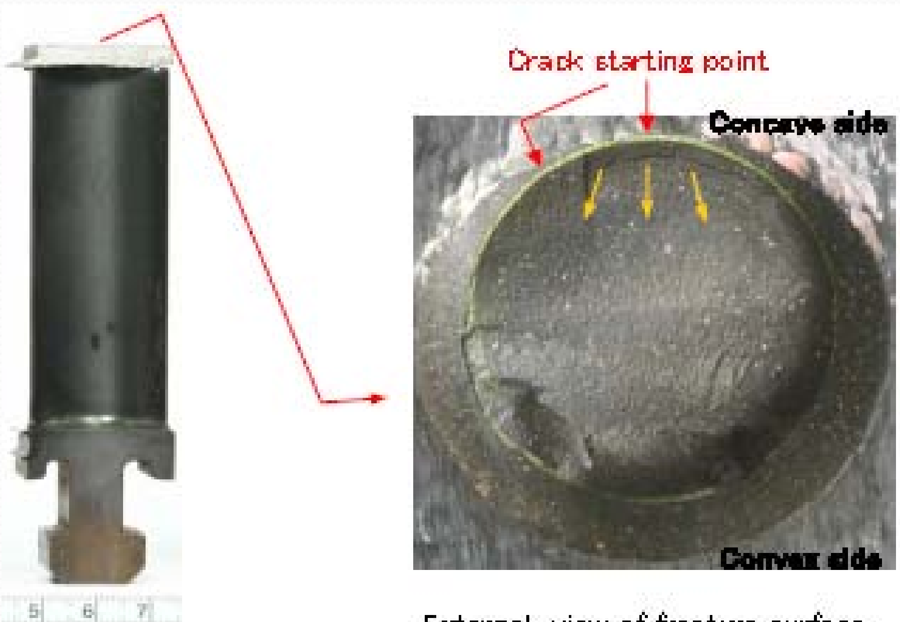
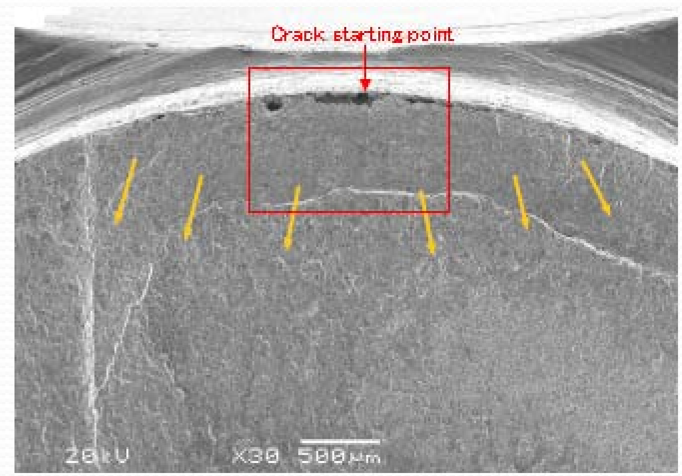
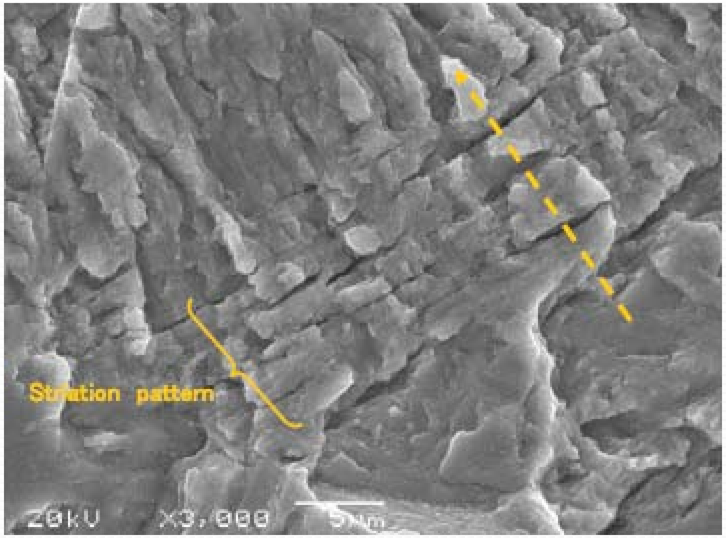


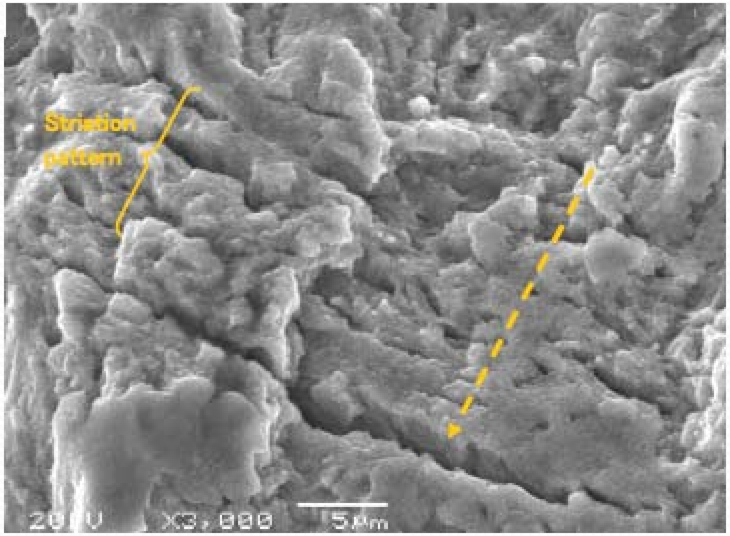
External view of fracture surface

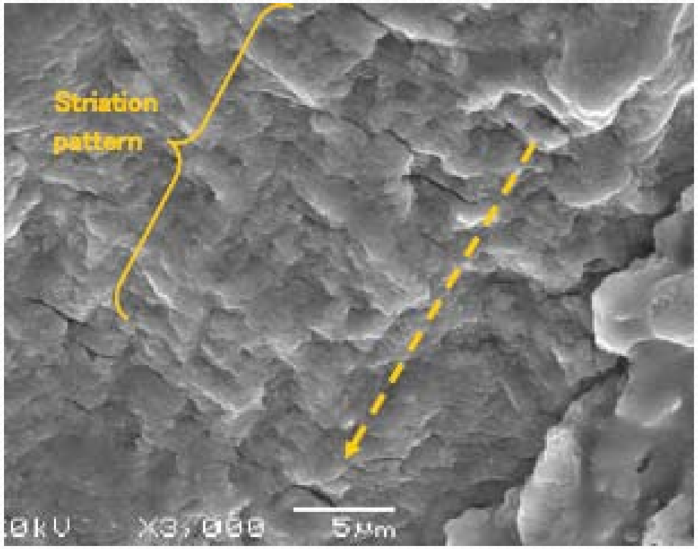


DETAILED INSPECTION- FRACTURE SURFACES

Striations associated with fatigue failure







Design Parameters – Stage 9

- Maximum allowable Chloride content in the steam is 2 PPB.
- 9th stage is subjected to 1.2 to 2.0% wet steam, temperature is close to saturated (127.6 C).
- There are 44 nozzles in the 9th stage diaphragm and 138 blades in the 9th stage rotor.
- Blade material is SS 410.
- Speed Range 4342 ~6513 RPM, Normal 6150RPM

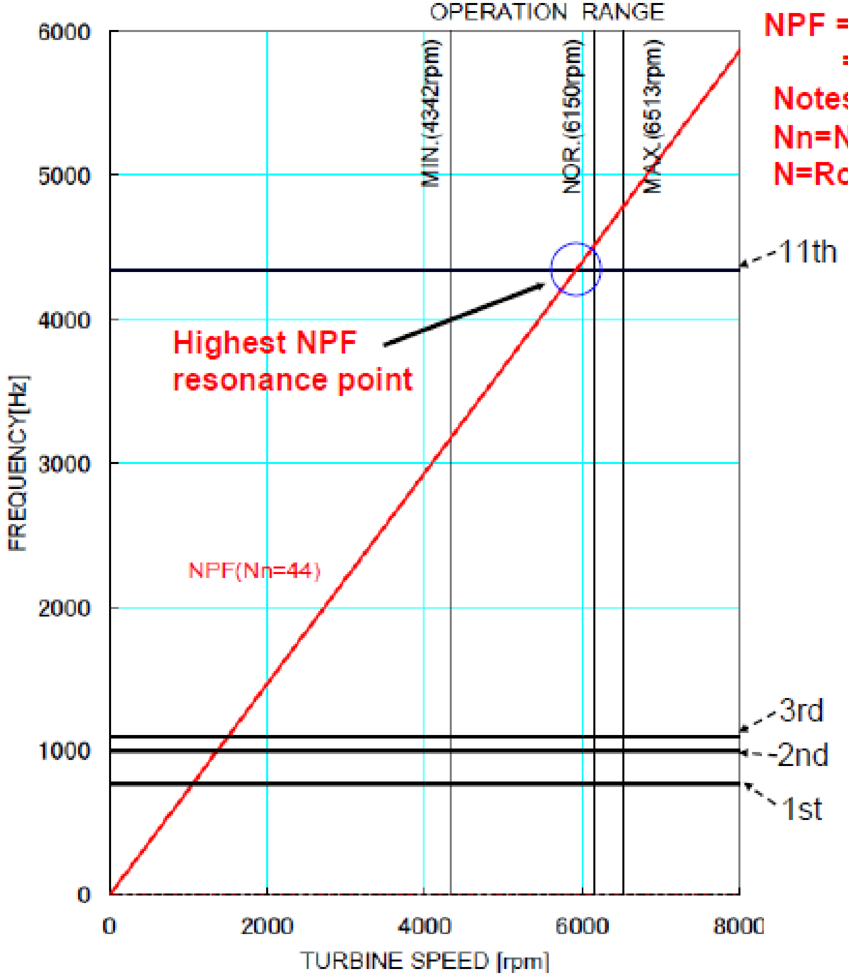
FAILURE ANALYSIS

- The blade pack and rotor disk were modelled to evaluate Natural frequency of blades.
- 11th mode of blade natural frequency has the highest resonance among all modes
- 11th mode of blade natural frequency (4334Hz) is in resonance with Nozzle pass frequency in the Operating range. (See Campbell Diagram)
- Highest resonant stresses at tenon 2.5 kgf/mm^2, profile 0.33 kgf/mm^2 and blade root 3.2 kgf/mm^2.
- Above resonant stresses are within design limit, but close to their boundaries.
- Corrosive environment lowered the fatigue limit of the material, causing the stresses to exceed the limits.

FAILURE ANALYSIS

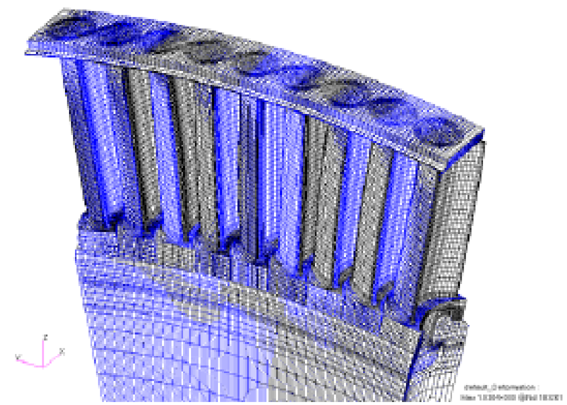
Campbell diagram

(NPF Resonance check of blade natural frequencv)



NPF = Nozzle Passing Frequency
= Nn × N /60

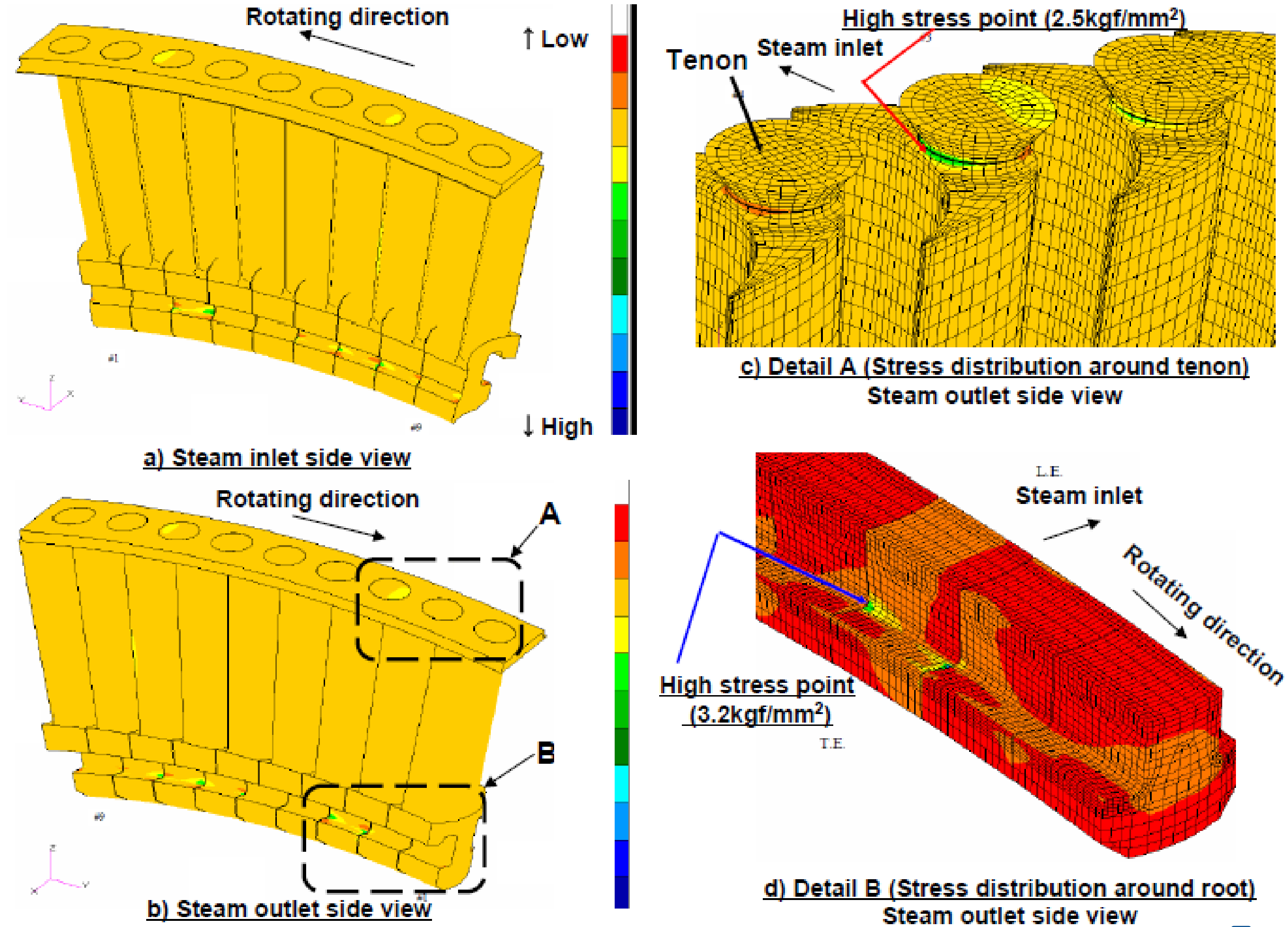
Notes;
Nn=Nozzle number
N=Rotating speed



11th blade natural frequency mode
(4334Hz)

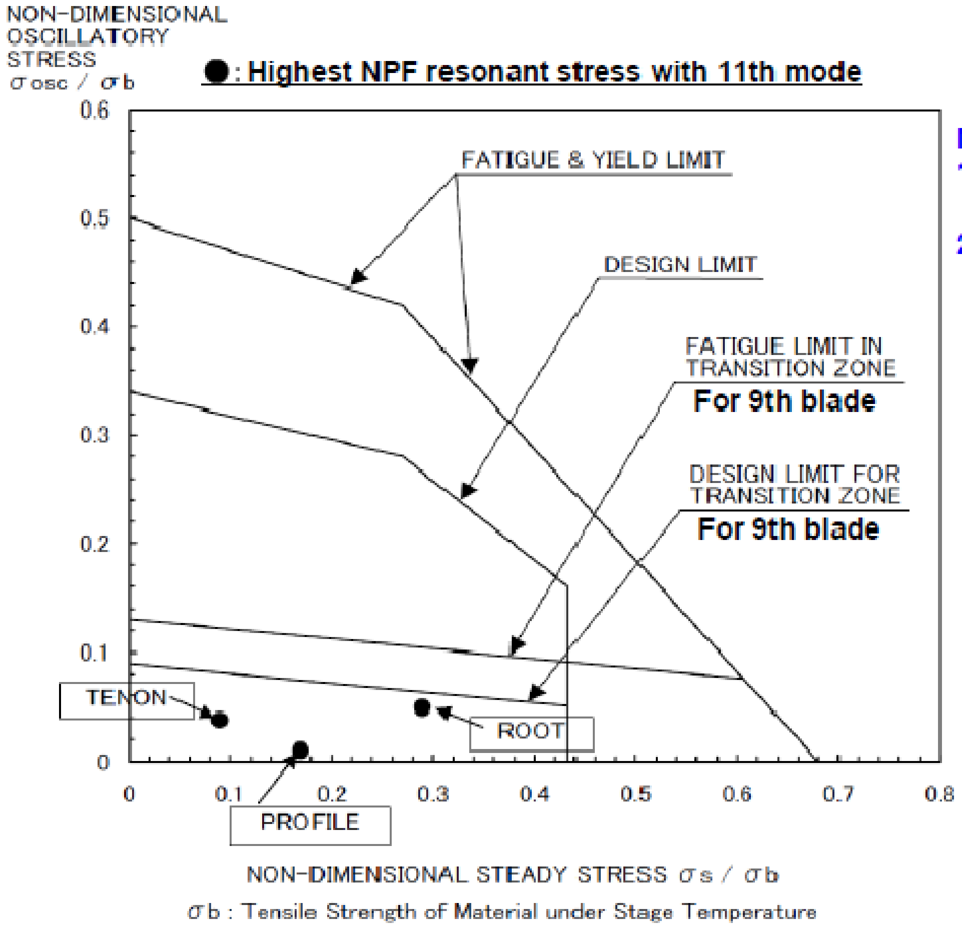
Resonance check of 9th stage blade by 3-D model analysis

FAILURE ANALYSIS



NPF resonant stress distribution of 11th mode

FAILURE ANALYSIS



a) Goodman diagram

Notes:
1)Definition of Transition zone
=Steam wetness 2 to 6%
2)Design steam wetness of 9th stage
= 1.2 to 2%

Highest resonant stress level
→Within design limit

Goodman diagram on 9th stage blade

FAILURE ANALYSIS - CONCLUSION

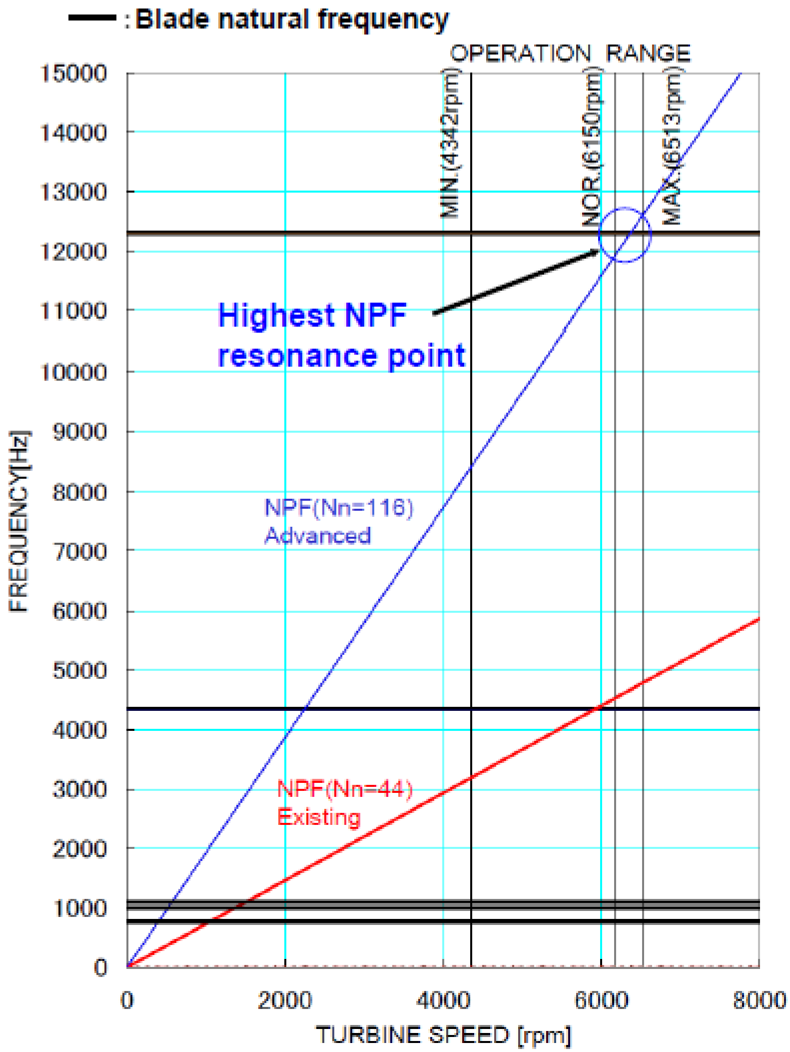
Failure of 9th stage blades is attributed to:

- Corrosion and pitting caused by presence of Chlorides .
- Higher stress due to existence of blade resonance at its 11th mode of natural frequency, excited by Nozzle Pass frequency in the operating range.

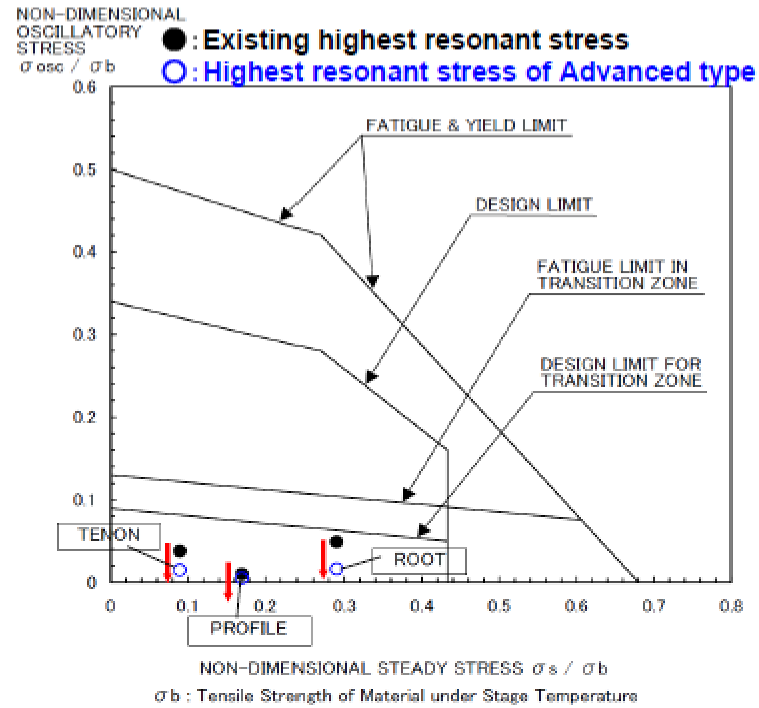
CORRECTIVE ACTION TAKEN

- Reduction in Chlorides.
  - Regular monitoring steam quality and maintaining chloride levels less than 2 PPB.
- Reduction in stress.
  - Increase number of 9^{th} stage nozzles from 44 to 116 to ensure that NPF is not exciting the blade resonance. This is found to reduce the highest NPF resonant stress by $1/3^{rd}$. (See Revised Campbell and Good man's Diagrams)
  - Increase Axial Clearance between nozzle and blades from 5.5 mm to 9.5 mm to reduce the stresses due to nozzle wake.

CORRECTIVE ACTION TAKEN



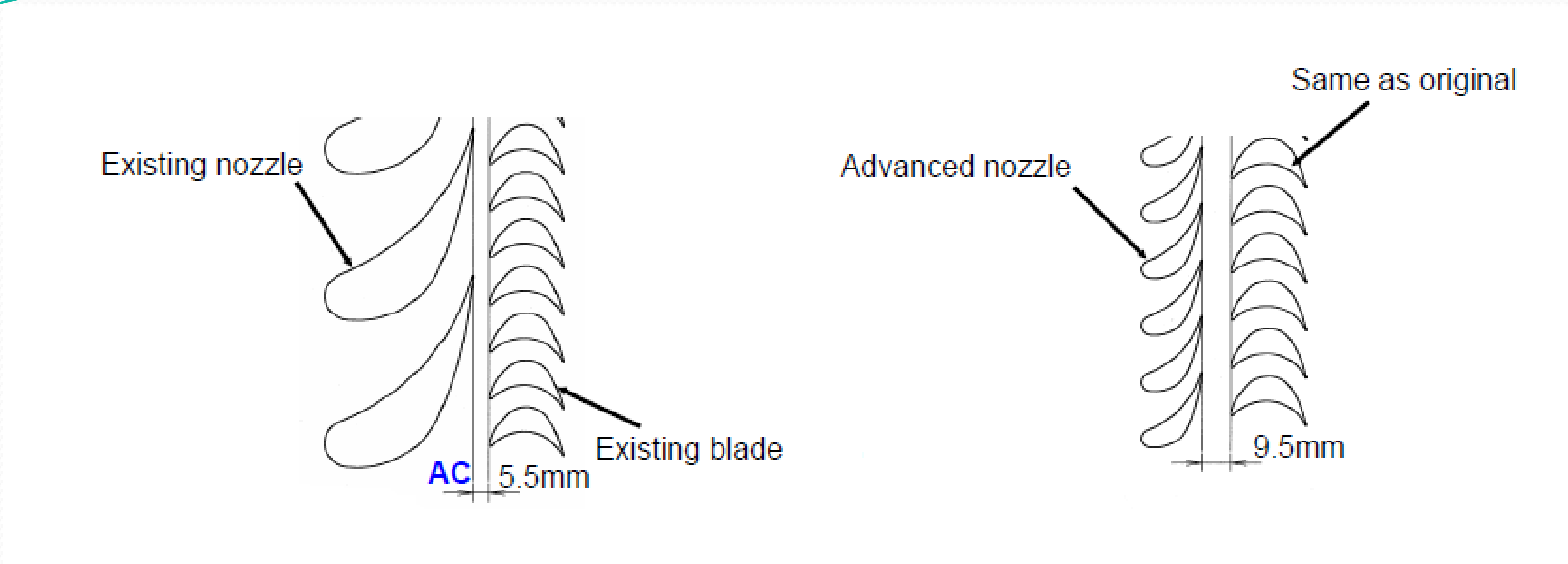
a) Campbell diagram



b) Goodman diagram

Campbell diagram & Goodman diagram on advanced type

CORRECTIVE ACTION TAKEN



Turbine rotor replaced in Mar'07.
Modified 9th stage diaphragm with 116 nozzles and increased axial clearance of 9.5 mm installed in Mar'08.

RELIABILITY PLAN

- Chlorides in Steam
  - Regular monitoring of Chlorides in steam and maintaining levels less than 2 PPB.
- Rotor inspection, planned in Jan'2012.

QUESTIONS?

THANK YOU