MHI's Steam Generator Operating Experience with Tube Vibration and Wear

February 7, 2013

Dr. Hitoshi Kaguchi

Project Director

Nuclear Plant Production Division

Mitsubishi Heavy Industries, Ltd.

MHI's SG Operating Experience

- ***MHI fabricated 116 SGs***
  - ***94 SGs for Japanese PWR plants***
  - ***22 SGs for Overseas PWR plants***
    - ***6 SGs for US PWR plants***
- ***MHI's tube vibration and wear OE (Pre-2012)***
  - ***Early Instances of tube wear at Anti-Vibration Bar (AVB) ('80s – '90s)***
  - ***Tube Rupture at Mihama Unit 2 due to Fluid-elastic Instability (FEI) (1991)***

Pre-2012 MHI's Tube Vibration and Wear OE

Tube-to-AVB Wear

- ***Early fluid induced vibration wear at AVBs***
  - ***Large tube-to-AVB gaps: over 10 mils***
  - ***Corrective Measures: Smaller design gaps in later SGs (~3 mils)***
- ***Replaced existing AVBs with expandable AVBs in field for 13 plants (36 SGs) in Japan***

  (also performed by other vendors on similar SGs in the USA)

Pre-2012 MHI's Tube Vibration and Wear OE

Mihama-2 1991 Tube Rupture

- ***Tube rupture due to Out-of-Plane FEI occurred after 19 years of operation***
  - ***Improper AVB insertion during fabrication***
  - ***Sludge accumulation at tube support plate reduced damping***
- ***Corrective measures:***
  - ***Tighter control of AVB design and fabrication***
  - ***R&D with large scale tests and development of advanced ECT***
  - ***Implemented new design guidelines to prevent fluid induced vibration***

2012 In-Plane Fluid Elastic Instability at SONGS RSGs

- ***SONGS RSGs are the largest SGs fabricated by MHI***
- ***Design based on established design practices, applicable industry codes, and customer design specifications***
  - ***Tightest gap control to minimize wear: 2 mils at cold (zero gap at operation)***
  - ***Tube stability ratio demonstrated acceptable via conservative evaluation in accordance with industry practice***

2012 In-Plane Fluid Elastic Instability at SONGS RSGs

- ***In-plane FEI at SONGS is the first occurrence within the Industry***
- ***First evidence that in-plane FEI conditions could be achieved in operating SGs***
- ***Where in-plane FEI occurred, it was caused by the combination of***
  - ***High Steam Quality (Dry steam)***
  - ***High Flow Velocity***
  - ***Low contact forces between AVBs and tubes***

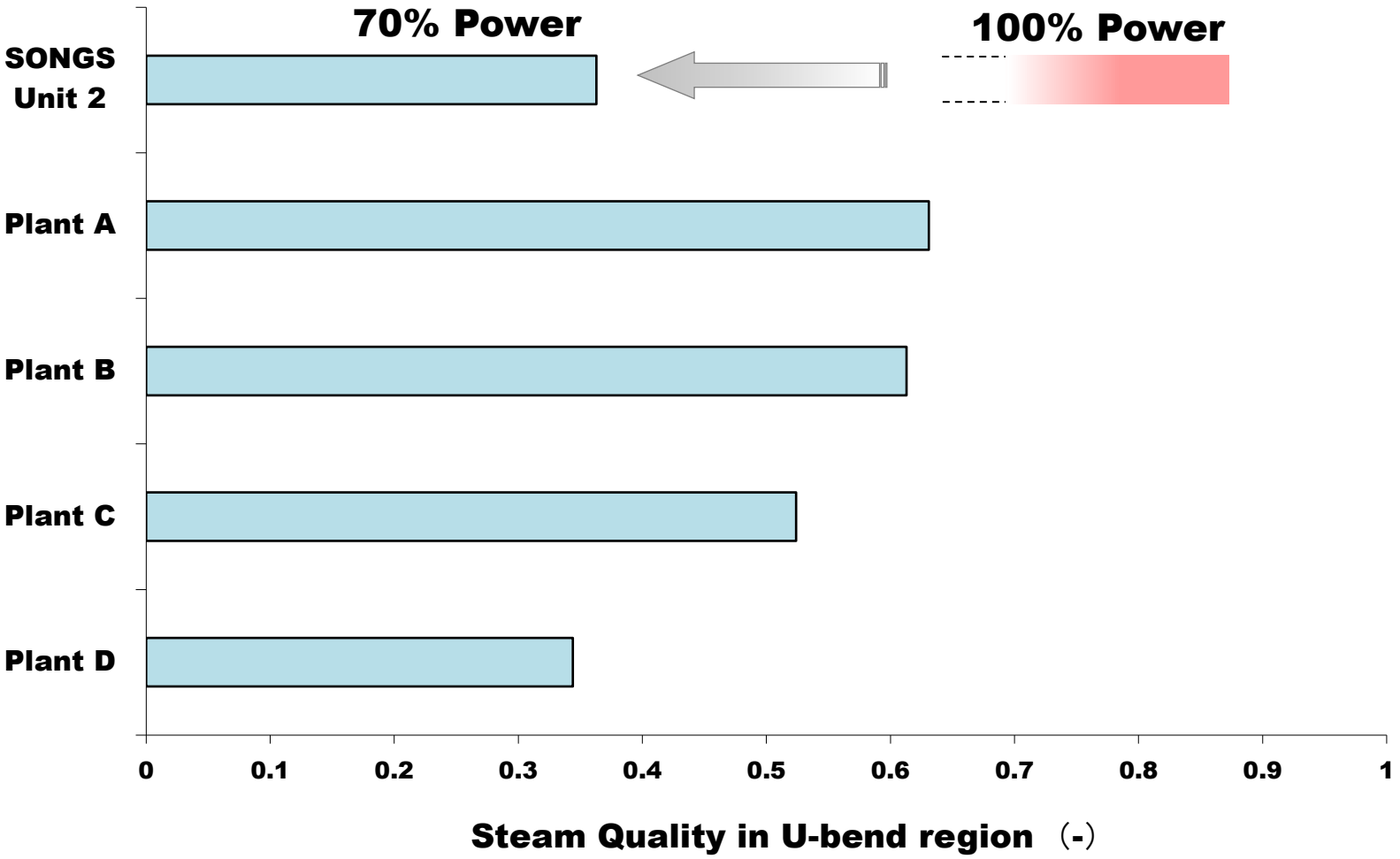
Differences in tube-to-tube wear in Units 2 and 3

- ***Fabrication process improvements in Unit 3 after Unit 2 RSGs***
- ***More uniform AVB gap control in Unit 3 resulted in half or less of the contact forces at Unit 2, based on current 3-D analysis***
- ***Unit 2 AVB supports are more effective***

Contact Force Analysis including all components

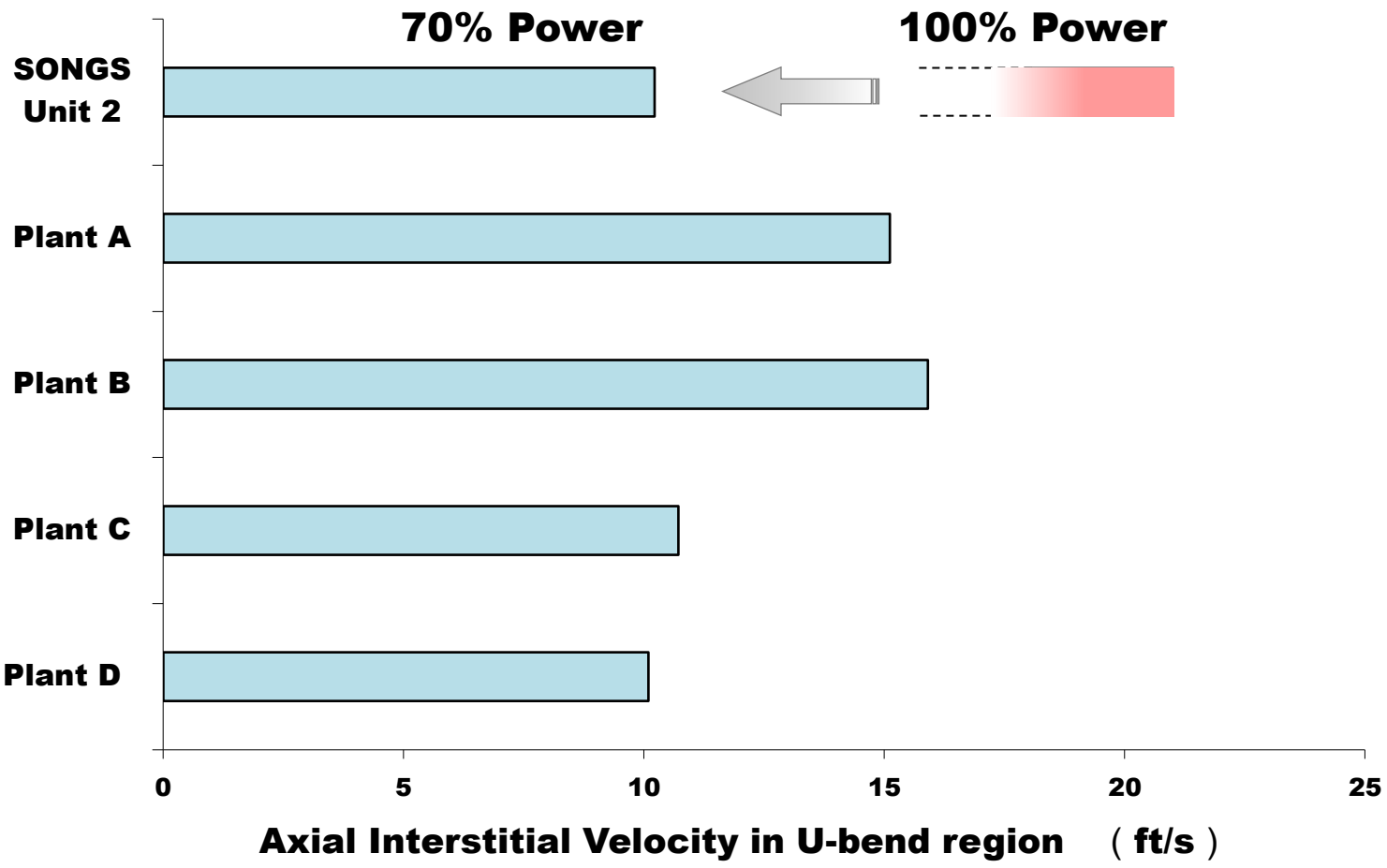
Potential Countermeasures for In-plane FEI at SONGS Unit 2

Reduced power operation improves steam quality (wetter steam)



Potential Countermeasures for In-plane FEI at SONGS Unit 2

Reduced power operation improves flow velocity (lower velocity)



Conclusions

- ***In-plane FEI at SONGS is the first occurrence within the Industry***
- ***MHI has identified the technical cause of tube wear from in-plane FEI***
- ***In-plane FEI can be prevented by***
  - ***reduced steam quality,***
  - ***reduced flow velocity, and/or***
  - ***greater contact forces between AVBs and tubes***

  in susceptible tube bundle regions

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END