ARABELLE 1550MWe units: 10 years of feedback experience in the EdF N4 nuclear power plants

Imech – Steam Turbine & Generator User Group
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Portsmouth, 06 September 2011
Agenda

Introduction – ARABELLE™: a proven and safe design

ARABELLE™: Steam Turbine feedback experience

Feedwater pumps feedback experience

ARABELLE™: Portfolio worldwide

Conclusion – ARABELLE™ today
ARABELLE™: a proven and safe design

**Features**
- Compact combined HP/IP module with single flow expansion
- Welded rotor technology
- Reduced weights and low stress levels
- Possibility to accommodate 4 LPs
- Mature family of last stage blades
- Fully adaptable steam path
- Reduced number of components

**Benefits**
- High performance
- High reliability & secure deliveries
- Adaptable to large outputs
- Proven design
- Safe and reliable design
- Adaptable to all reactors
- Low maintenance effort

Proven design perfectly suited to large output
ARABELLE™: a proven and safe design

- Nuclear reactor type: Areva PWR N4
- Turbine type, output: ARABELLE, 4 x 1’550 MW
- Turbogenerator type: GIGATOP 4-pole
- Steam parameters: Live steam 71 bar / 287°C
  Exhaust 55 mbar
- Customer: EDF (Electricité de France)
- Country: France
- City / region: Meuse / Vienne

- Schedule: order year 1992
  comm. year 2000
ARABELLE™: a proven and safe design

ARABELLE™ world largest operating steam turbine
>300’000 operating hours, 99.96% reliability

Alstom turbines are driving 30% of the world’s nuclear plants
ARABELLE™: a proven and safe design

- All 58 French operating units
  - 0.09% average FOR for last 15 Years, or 8 hours per Unit/Year

- 4 ARABELLE™ units in France
  - 0.04% average FOR or 3 hours per Unit/Year

Proven design perfectly suited to large output
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Steam Turbine Feedback Experience

- Impulse blading Technology 1500 rpm -1550MWe

- Combined HIP cylinder: HP single flow expansion from 71bar to 10bar IP single flow expansion (dry) to 3.3bar

- 3LP cylinders fed by steam at low temperature (151°C)

LP inlet: Dry steam close to saturation line
Steam Turbine Feedback Experience

- Double flow LP steam path
- Fillet weld fabricated diaphragms
- Carbon steel material on diaphragms rings (plate & casting)
- Chooz B1 2005 : Major LP1 overhaul
- Erosion on diaphragm #1 and flow separator
  - Channel
  - Pressure faces

Erosion on stage 1 diaphragms observed on LPs
Steam Turbine Feedback Experience

Flow Assisted Corrosion not retained:

- Short period of operation without second stage reheat
- Non homogeneity of erosion circumferentially
- LP inlet pipe drains to collect water
- Erosion discovered on all units

Water droplet erosion due to local condensation into LP inlets

- Condensation marks in inlet torus
- «Comets» in the inlet pipes

Root cause: Heat transfer through blocks connecting thermal shield and LP inlet pipes

Erosion due to generation of water droplets
Steam Turbine Feedback Experience

Welding repairs:

• Separator and diaphragm rings
• Austenitic deposit at half joint, pressure faces and steam channel
• Target to limit steam leakages and erosion propagation

Sealing joint:

• Diaphragm/separatpr grooves

Before repair

After repair
Steam Turbine Feedback Experience

Thermal shield:

- Additional labyrinth seals between thermal protection and pipe and joint covers between the different pieces of the screen to avoid steam leakages and thermal gradient.
- Boss used to maintain the screen onto the inlet pipe are capped to reduce the cold spots and water formation in the inlet pipes.

Diaphragm material:

- Low alloy rings on diaphragm #1.

Lessons learned
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Feedwater pumps feedback experience

The feed water pumps of the French Units 1550MWe are the most powerful feed water pumps for PWR:
- Each unit is equipped with 2 feedwater pumps, each able to supply 67% of the nominal flow (flow reserve) and without stand-by.
- The power of each pumps set is close to 17MWe

Main characteristics:
- Nominal flow: 4332t/h
- Nominal head: 871m
- Driving system: Turbine
- Speed: Adjustable
- Maximal speed: 4900rpm

Large operating range / High speed / High power density
Feedwater pumps feedback experience

- The partial load generates high fluctuations of the pressure, in particular at the outlet of the impeller.

The failure of the shroud of one impeller (Chooz B1) was not due to a fatigue issue but a manufacturing issue during the casting process.
Feedwater pumps feedback experience

The operation at very low flow generates also fluid deviation at the entry of the diffuser and cavitation even if the pressure is high.

Erosion due to long term operation at very low flow
Feedwater pumps feedback experience

• The good feedback experience after 10 years of operation of the N4 Units confirms the reliability of the Alstom feed water pumps.

• Alstom has developed new solutions, in particular new manufacturing processes, to increase the reliability for the worst operating conditions:
  - The impellers are now manufactured by Electrical Discharge Machining process
  - The diffuser could be manufactured also by Electrical Discharge Machining process followed by a shot peening to reduce the erosion by cavitation at low flow.

• These solutions are available for maintenance and new equipment products.
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ARABELLE™: Portfolio worldwide

Conclusion – ARABELLE™ today
ARABELLE™ portfolio worldwide

- **ARABELLE 1700**
  - 3 LP with 69" LSB
  - or 3 LP with 57" LSB

- **ARABELLE 1000**
  - 2 LP with 69" LSB
  - or 2 LP with 57" LSB
  - or 3 LP with 57" LSB

Fit all large nuclear reactors and vacuum conditions
From 900 MW to 1’800 MW

LSB: Last Stage Blade
ARABELLE™ Steam Turbine
For All Large Nuclear Power Plants

• Proven design for high performance
  - Design based on mature 1550 MW units
  - Single flow expansion for best performance
  - All 6 ARABELLE™ in operation today exceeded their guaranteed output level

• Fully adaptable steam path
  - Fit all large reactor types: PWR and BWR
  - From 900 MW to 1800 MW
  - For 50 Hz and 60 Hz grids
  - Fit all types of heat sink conditions
  - Well adapted for co-generation (DH, desalination)

• Optimum solution for any site cooling condition
  - 2, 3 or 4 LP modules can be fitted for best vacuum fit
  - 2 LSB sizes available for each frequency (50 Hz, 60Hz)
  - Proven LSB design: all those 4 LSB are in operation
ARABELLE™ Steam Turbine
Differentiators & Benefits

• Most compact, powerful and efficient turbine
  - Unique combined HP/IP module
  - Most efficient HP/IP single flow expansion
  - Largest LSB operating today

• Welded rotors for reliability and more secure delivery
  - High resistance to Stress Corrosion Cracking (SCC)
  - Excellent reliability in service, less inspections required
  - Smaller forgings available more rapidly, easier to forge

• Designed for ease of maintenance
  - Large spaces available for maintenance
  - IP-LP cross-under pipes
  - Easy adjustment of LPs thanks to independent structure
  - Compact arrangement with brush-less exciter
  - Less components to be maintained (valves, bladed rows)
ARABELLE™ Steam Turbine
LP Modules with Independent Structure

- Much reduced loads on foundation lead to savings
- Easy shaft-line alignment
- Constant load on LP inner casing eliminates vibrations due to condenser level or backpressure variations

30 to 50% concrete volume reduction for STG foundation
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Conclusion – ARABELLE™ today
ARABELLE™ today

- Over 300,000 OH of experience gained on N4
  - Turbines, turbo-generators and main feedwater pumps have behaved very well
    - It validates the fitness of the design for the purpose
- Potential for improvement has been noted in some areas
  - New technical solutions have been developed
    - This experience feedback collection and analysis is important to achieve maximum reliability and to reduce maintenance time
- Extended product portfolio is available
  - Developed to support all commercially proposed reactors
    - In Europe and worldwide
  - Fully leveraging from the improvement of knowledge gained thanks to the operational experience of N4
ARABELLE™ today

- The world largest steam turbine in operation & in construction
  - 4 units in commercial operation, 22 under construction
  - 300’000 Operating Hours with 99.96% Reliability

ARABELLE 1700

ARABELLE 1000

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<tr>
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<th>Units</th>
<th>Power (MW)</th>
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<td>+ Additional</td>
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ARABELLE™ today – Flamanville 3

- Nuclear reactor type: Areva PWR EPR
- Turbine type, output: ARABELLE 1700, 1 x 1’750 MW
- Turbogenerator type: GIGATOP 4-pole
- Steam parameters: Live steam 75 bar / 290°C
  Exhaust 46 mbar
- Customer: EDF (Electricité de France)
- Country: France
- City / region: Flamanville (Normandy)

- Schedule: order year 2006
  comm. year 2014
ARABELLE™ today – Ling Ao Phase II

- Nuclear reactor: PWR, CPR1000
- Turbine type, output: ARABELLE™ 1000, 2 x 1080 MW
- Turbo-generator type: GIGATOP 4-pole
- Steam parameters:
  - Live steam: 64 bar / 280°C
  - Exhaust: 56 mbar
- Customer: DEC for LDNPC
- Country: China
- City / state: Dapeng / Guang Dong
- Schedule:
  - Order year: 2005
  - Comm. year: 2010 (U3) and 2011 (U4)
ARABELLE™ today – Ling Ao Phase II

Ling Ao Phase II

- Proven design
- High reliability
- High efficiency
- Compact
- Adaptable to
  - any nuclear reactor
  - any cold end design

Synchronized in July 2010, ahead of schedule
Performance level met and above guarantee (U3 & U4)

Ling Ao 3, China - 1080 MW

Alstom nuclear technology is safe, efficient and reliable