The ESS Cryomodules

2012 December, 5th
Christine Darve

Cryomodules Lead Engineer
Outlines

ESS accelerator context for a Globe of Science and Innovation
- Main parameters and milestones
- Cryomodule stakeholders

Cryomodule strategy
- Functions and constraints
- Technology Demonstrators
- Spoke cavities technologies
- Elliptical cavities technologies
The ESS philosophy

- **Vision & Raison d’etre:** Science for Society

- **Mission:**
  - Design, construct and operate the world’s leading neutron source
  - Manage the company business

- **Core Values:**
  - Excellence; Openness; Sustainability

- **ESS philosophy:**
  - “Greenfield thinking on a greenfield site”

Goal: to deliver first neutrons before this decade is out

→ Goal oriented project
Superconducting Proton Linear Accelerator (500 m)
- 2.5 GeV Proton Energy
- 50 mA (2 mA) peak (average) proton current
- 357 kJ/pulse
- 2.86 msec pulse length
- 14 Hz pulse frequency
- 71.4 msec periods between pulses
- 5MW proton beam power

Single Target Station
- Rotating Tungsten, helium cooled
- 22 instruments
- High reliability, low losses
## ESS Accelerator context

### The Goal for WP4 and WP5
- From design, procurement to test of spoke, high-beta and medium-beta elliptical:
  - Technology demonstrators
  - Series cavity packages
  - Series cryomodule packages

### The Planning

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<td>Q4</td>
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- First access to Upgrade space (test stand) (g)
- Beam license available (g)
- Cryo-plant buildings for test stand ready (g)
  - Full access to Accelerator Building (gallery and tunnel) (g)
  - Target building access (g)
  - Target Cryopanl commissioned (g)
  - Normal conducting beam commissioning starts
  - 80 MeV protons available

- Super conducting beam commissioning starts
- Medium Beta systems ready
- Spoke systems ready
- 630 MeV Protons available
- High Beta systems ready
- First Proton to Target (g)
- End of Construction (ACCSYS)

### The People

- Pierre Bosland
- Guillaume Devanz
- Sebastien Bousson
- David McGinnis
- Steve Peggs
- Cristina Oyon
- Romuald Duperrier
- Mats Lindroos
- Soren Pape-Møller
- Roger Ruber
- David McGinnis
- IFN
- INFN
- INFN Catania
- INTeG
- IPN Orsay
- CEA Saclay

### Work Package (work areas)

1. Management Coordination – ESS AB (Mats Lindroos)
2. Accelerator Science – ESS AB (Steve Peggs)
3. Infrastructure Services – now ESS AB!
4. SCRF Spoke cavities – IPN, Orsay (Sebastien Bousson)
5. SCRF Elliptical cavities – CEA, Saclay (Guillaume Devanz)
6. Front End and NC linac – INFN, Catania (Santo Gammino)
7. Beam transport, NC magnets and Power Supplies – Århus University (Søren Pape-Møller)
8. RF Systems – ESS AB (Dave McGinnis)
9. P2B: Test stands – Uppsala University (Roger Ruber)
98% of the accelerator is superconducting

### Table: Accelerator Specifications

<table>
<thead>
<tr>
<th>Section</th>
<th>Number of modules</th>
<th>Frequency MHz</th>
<th>Input energy MeV</th>
<th>Cavs. per module</th>
<th>Cavs. per sector</th>
<th>Module length m</th>
<th>Sector length m</th>
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<tbody>
<tr>
<td>Spoke</td>
<td>14</td>
<td>352.21</td>
<td>79</td>
<td>2</td>
<td>28</td>
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<td>Medium-beta</td>
<td>15</td>
<td>704.42</td>
<td>201</td>
<td>4</td>
<td>60</td>
<td>5.6</td>
<td>113.8</td>
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<tr>
<td>High-beta</td>
<td>30</td>
<td>704.42</td>
<td>623</td>
<td>4</td>
<td>120</td>
<td>6.7</td>
<td>227.9</td>
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<tr>
<td>Total</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td>208</td>
<td>6.7</td>
<td>400.16</td>
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### Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
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<tbody>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>2.5</td>
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<tr>
<td>Current</td>
<td>mA</td>
<td>50</td>
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<tr>
<td>Pulse length</td>
<td>ms</td>
<td>2.86</td>
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<td>Pulse repetition frequency</td>
<td>Hz</td>
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<td>Average power</td>
<td>MW</td>
<td>5</td>
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<tr>
<td>Peak power</td>
<td>MW</td>
<td>125</td>
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Cryomodule stakeholders - Interfaces

- ESS cold linac integrators (e.g. cryogenics, vacuum, conventional facilities)
- Safety team
- Cryomodule designers
- Cavity package designers
- Control and instrumentation teams
- Component assembly teams
- Test teams
- ESS system engineer
- Survey experts
- Toolings
- Transport

Cryogenic distribution

Beam Diagnostic

Beam Optics

Vacuum

Radio-frequency
Outlines

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Cryomodule Functions

→ Cavity package (incl. SRF cavity, Ti helium tank, cold tuning system, and fundamental power coupler)

→ Cryomodule package:
  - The supporting and mechanical systems that interface the cavity packages in the test area than in the tunnel
  - The vacuum vessel, thermal and magnetic shieldings that insulate the cavity packages from the ambient condition
  - The cryogenic distribution (hydraulic circuits, jumper connection) that interfaces the cavity packages with the cryogenic valve box (CTL, cryoplant)
  - The instrumentation, control valves and the safety devices

- Technology demonstrators to proof the series production technologies
- Cavity package
- Cryomodule package

- Design to complete following the Accelerator Design Update (ADU phase)
- Procurement
  - Product Breakdown Structure, materials
- Conditioning and Assembly
  - Power coupler conditioning, surface processing, clean room and hall assembly
- Test with cryogenics and RF environment
- Tunnel installation
- Commissioning
- Operation
Constraints

Integrated hazards due to operating environment:
- Radiation environment (high intensity proton beam)
- Cryogenic temperature: 2 K (Helium II), cryogenic vessel, pressure vessel
- Sub atmospheric condition (31 mbar saturated), leak-tightness
- Magnetic environment (14 mGauss)

Main challenges:
- Quality: science and innovative using the SRF cavities
- Quantity: 208 cavities and 59 cryomodules
- Short project time scale
- Limited budget
- Series to ease and enable industrialization process

Staged Approach:
- 630 MeV protons to target 3Q 2019
- Staged to nominal power will occur in 3 shutdowns in 2020-2022
Standards and Safety Culture

Engineering standards
- CEN, European Committee for standardization
- SIS, Swedish Standard Institute
- ISO, International Organization for standardization
  → e.g. European Directive 97/23/CE; EN ISO 4126, PED
  → ESS guidelines for pressure vessel modeled after FNAL, CERN expertise

Radio-Protection and Rad-hard equipment
- As low as reasonable achievable (ALARA)
- Passive and active safety measures (safety barrier)
- Personnel Protection System, Machine Protection System (IEC 61508)

Risk analysis and reliability study

Safety reviews

Quality Assurance
ESS Radiation Safety - Time Schedule

2012-04-01 → 2014-01-01

Radiation Protection Act
- PSAR (Preliminary Safety Analysis Report)
- Application

Environmental Code
- EIA (Environmental Impact Assessment)
- Application

Planning & Building Act
- Consultation Proposal
- Public Display
- Local Plan
- Appeals
- Come into force
- Building Application (ESS)

SSM (Swedish Radiation Safety Authority)
- Permit to construct

EC (Environmental Court)
- Court Hearing
- Construction and Operation Permit

LM (Lund Municipality)
- Building Permit

Courtesy of Peter Jacobsson - Head of ESS safety
Table 4.14: Heat load distribution per cryomodule (4.5 K equivalent).

<table>
<thead>
<tr>
<th>Heat load 4.5 K equivalent, W</th>
<th>Static</th>
<th>Dynamic</th>
<th>Beam losses</th>
<th>Total</th>
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<tr>
<td>Spoke resonator</td>
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<td>18.0</td>
<td>8.7</td>
<td>44.2</td>
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<tr>
<td>Medium-beta</td>
<td>27.0</td>
<td>67.3</td>
<td>17.1</td>
<td>111.3</td>
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<tr>
<td>High-beta</td>
<td>29.4</td>
<td>82.0</td>
<td>20.1</td>
<td>131.5</td>
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<tr>
<td>Linac sub-totals</td>
<td>1530</td>
<td>3722</td>
<td>981</td>
<td>6233</td>
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</table>

Table 4.15: Static heat load distribution for each temperature levels.

<table>
<thead>
<tr>
<th>Sector</th>
<th>2 K W</th>
<th>5 K W</th>
<th>50 K W</th>
<th>4.5 K equivalent W</th>
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<tbody>
<tr>
<td>Spoke resonator</td>
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<td>na</td>
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<tr>
<td>Medium Beta</td>
<td>6.7</td>
<td>1.5</td>
<td>75.0</td>
<td>26.9</td>
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<tr>
<td>High Beta</td>
<td>7.5</td>
<td>1.5</td>
<td>75.8</td>
<td>29.4</td>
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</table>

Figure 4.67: Load distribution (static, dynamic and beam losses)
Cryomodule instrumentation

* Instrumentation function
  Monitoring
  Control
  Interlock
  Alarms

* Expected categories
  • temperature transmitter: Cernox and PT100
  • vacuum gauge
  • pressure gauge
  • level gage
  • control valve
  * flowmeter
  * pick up coil
  * heaters
Tunnel integration
Cavity Cryomodule Technology Demonstrators

→ One Technology Demonstrator per cavity family to validate:

- **Fabrication and industrialization** of the cryomodule:
e.g. cleaning, tooling, assy procedures, QA;

- **The performance of the RF design:**
e.g. characterize the cavity RF signature; validate RF results obtained in vertical cryostat;

- **The performance of the thermal and vacuum design:**
e.g. cool-down rate, operating conditions; heat loads; cooling scheme efficiency, leak tightness;

- **The performance of the mechanical design:** e.g. MAWP, stability, alignment;

- **The safe operation** of the cryomodules:
e.g. process variables, control loops, operating modes, relieving system and interlock;

- **Training:** e.g. to assemble, to operate.
Spoke cavity string and cryomodule package

Technical design results:
- Position coupler
- Supporting system
- Thermal shielding
- Magnetic shielding

Spoke cryomodule overall dimensions

Position cavity string during cryostating step

Cavity string and its cooled magnetic shielding
Spoke cavity string and cryomodule package
Elliptical cavity string and cryomodule package

<table>
<thead>
<tr>
<th>Section</th>
<th>Total number of Modules</th>
<th>Cavity package frequency [MHz]</th>
<th>Cavity count per module</th>
<th>Cavity count per sector</th>
<th>Cryo-module length [m]</th>
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<td>Spoke</td>
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- Elliptical Cavities Cryomodule Technology Demonstrator results by the end of 2015 → start pre-series
Elliptical cavity cryomodule design

Space frame stress analysis and material choice

Figure 4.118: Cross section of the cryomodule
Conclusion

The ESS cryomodules to validate innovation applied to the next generation of accelerators

• Challenging schedule for a green field neutron source

• Effective and expertise thanks to European collaborations
EXTRA slides
Cryomodule Break Down Structure and Interface

Cryomodule

SRF Cavity Package
- SRF cavity (spoke or elliptical) in helium tank
- Cold tuning system
- Fundamental Power Coupler
- HOM Couplers
- Diagnostic Inst. & Valves
- Safety equipment

Beam pipe
Supporting system
Alignment system
Thermal shielding
Cryo-distribution Lines
Magnetic shielding
Coupler cooling Sys.
Diagnostic Inst. & Valves
Safety equipment

Tunnel
- Beam pipe
- Corrector magnet
- Vacuum station
- Instrum., BPM etc.
- Ext. supporting system
- Waveguide and RF eq.
- Control system eq.
- Cryo valve box
- Jumper connection
- Safety equipment
Current development
Elliptical cryomodule – flow process