Superconducting RF cavity system production for particle accelerators in scientific and industrial applications

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RI Research Instruments GmbH, Germany

- Mid 80’ies  Activities started at Interatom/Siemens
- 1994 – 2007  ACCEL Instruments GmbH (Management buyout)
- 2007 – 2009  ACCEL is 100% daughter of Varian Medical Systems
- 2009 – today  RI Research Instruments GmbH (51% owned by Bruker EST)

- **About 180 employees, 30% engineering & project management, 60 % manufacturing**
- Located in Bergisch Gladbach, a town 20 km away from the center of Cologne

Worldwide renowned as “Advanced technology engineering and manufacturing specialist”
Markets:
• Big Science
• Medical/ Particle Therapy
• Energy/ Nuclear (incl. Fusion, ADS, Transmutation)
• Advanced Technology Industry (incl. Life Science, Semiconductor)
In house manufacturing capabilities

On about 6000 m², we have a very deep manufacturing capability and are producing key components of our products in house

- Forming, milling and turning
- Certified welding and brazing
  - Electron beam welding
  - Vacuum and induction brazing
  - TIG welding
- Electro-chemical and physical and surface preparation and coating
- Heat treatments
- Clean room assembly
- State-of-the-art test facilities
  - RF measurements
  - Vacuum and Cryogenics
  - Dimensional inspection
- System integration
- ISO 9001 certification

From built to print manufacturing up to turn key system delivery with guaranteed performance
RI is working in parallel on 80 projects with contract values above 100 k€ each

Superconducting RF business: contributes about 25% of turnover of RI
Delivered SRF cavities

RI is world leading company in manufacturing SRF cavities

In total more than 1500 SRF cavities produced at our premises within the last 30 years.
European XFEL Superconducting Linac

The European X-ray laser project XFEL
Planning status October, 2003

key components of linac:
800 superconducting RF cavities, 800 RF couplers
RI contribution to the E-XFEL project

<table>
<thead>
<tr>
<th>420 Nb 9 cell cavities (1.3 GHz)</th>
<th>670 RF couplers (consortium with TED)</th>
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</thead>
<tbody>
<tr>
<td><strong>Manufacturing</strong></td>
<td><strong>Surface preparation</strong></td>
</tr>
<tr>
<td>Forming Nb sheets</td>
<td>Electro-polishing</td>
</tr>
<tr>
<td>Turning, milling</td>
<td>High pressure rinsing</td>
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<tr>
<td>Acid treatment (BCP)</td>
<td>Vacuum anneal (800 C)</td>
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<tr>
<td>Electron beam welding</td>
<td>ISO 4 clean room assembly</td>
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<tr>
<td>RF control</td>
<td>RF tuning</td>
</tr>
<tr>
<td>Vacuum control</td>
<td>Titanium He-vessel welding</td>
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</tbody>
</table>

Qualification testing at/by DESY  ➔ Qualification testing at/by LAL
Module assembly at CEA (company Alsyom, France)
Module testing at/by DESY  ➔ Installation into XFEL tunnel
Order for 420 received in September 2010 from DESY
Series production from Mid 2012 - Mid 2015 (3 years)
Achieved a production rate of up to 180 cavities per year, 0.7 cavities each working day

2 shifts (06:00 – 22:00) at 5 working days, Saturday used to accelerate the schedule

Resources (Occupation):
- 5 turning machines (75 %)
- 1 press (10 %)
- 1 milling machine (30 %)
- 2 EB welding machines (75 %)
- 1 RF control place (20 %)
- 3 dimensional control spaces (60 %)
- 1 BCP barrel (75 %)
- 2 metal working place (60 %)
- 1 leak checker (70%)  
- 1 grinding place (50%)

Challenges:
- shape accuracy (0.2 mm) of cells
- constant output of cavities

EB welding:
- very stable, almost no errors

RI had large experience in producing SRF cavities through the last 20 years
XFEL cavity manufacturing impressions

- End tubes, HOM couplers
- Metrological inspection of dumbbells
- Dumbbells and stiffening rings, welded dumbbells
The EXFEL Cavities had to be delivered to DESY ready for cold RF tests.

Sophisticated surface treatment was applied to the SRF cavities in order to generate a dust free and clean surface layer inside the cavity needed for cavity operation at highest accelerating gradients and quality factors.

The treatment steps (the XFEL-recipe) to generate such high performance cavity surface was developed within a 15 years long R&D phase at DESY and other various world leading SRF labs.

The cavity treatment according to the XFEL recipe requires erection of special Infrastructure (electro-polishing plant, ISO4 clean room, all metal vacuum annealing furnace, etc).

Technology transfer of the XFEL recipe to RI was done by DESY and INFN experts within a trustful and cooperative partnership.
Infrastructure for surface preparation

- Electro-polishing plant
- Buffered chemical polishing plant
- 800 C annealing furnace
- 120 C baking station
- TIG welding and pressure testing of titanium helium vessel
- 120 m² ISO 4 clean room with high pressure water rinsing stations, special vacuum pumping system
RI cleanroom for XFEL cavities
47 of 420 cavities of RI EXFEL cavity production exceeding 40 MV/m
More than half of the 420 cavities exceeded 35 MV/m
Average accelerating gradient of all RI cavities was 33 MV/m (RMS 6.5 MV/m)
Ongoing and future SRF cavity series production for scientific application

- After XFEL, the series production of almost identical LCLS-II cavities has started and is ongoing until Mid 2017
- Infrastructure can be easily adopted to allow quarter-wave (QWR), half-wave (HWR), or other kind of elliptical cavities for future projects like ESS in Lund, Sweden or RISP at IBS, South Korea.
- The aim of RI is, to deliver those cavities ready for cold RF test like it was done for the EXFEL project

First LCLS-II cavities ready to ship

Prototype QWR für IBS RISP project in cleanroom, at high pressure water rinse (HPR) and 120 C bake
ILC cavity production

- ILC needs 18,000 EXFEL type SRF cavities in total for 500 GeV
- 6,000 cavities to be produced in the three regions Asia, Americas and Europe each
- 2 production sites in each region: 3,000 cavities per production site
- 7.5 years series production: 400 cavities per year, each site
- Doubling the working time per week by going from 2 shift at 5 days to 3 shifts at 7 days and with some minor modification, RI would be able to produce with the currently installed EXFEL infrastructure about 400 cavities per year
- RI almost achieved the ILC design parameters already during EXFEL production
Delivered SRF accelerator modules

- LEP
- 500 MHz (storage rings)
- 1.3 GHz (linac)
500 MHz accelerator modules

Technology transfer from Cornell University, USA

2000: 2 SRF modules for NSRRC, Taiwan
2000: 2 SRF modules for CORNELL, USA
2000: 2 SRF modules for CLS, Canada
2003: 3 SRF modules for DLS, Great Britain
2005: 3 SRF modules for SSRF, PR China
2010: 3 SRF modules for PAL, Korea
2012: 1 SRF module for DLS, Great Britain

- Cavity production and cavity surface preparation
- Cavity vertical test
- Coupler production and conditioning
- Ferrite style HOM loads
- Module assembly
- Installation on customer site
- Commissioning, guarantee on cavity voltage and Q
- Valve boxes and transfer lines
- SRF Electronics
- Interlock and data acquisition system
Factory testing, shipping, installation
Twin Cavity Accelerator Module
as Turn-Key System for FEL and ERL Application

• RI has produced in 2006 already 2 such modules to Daresbury
• 2 Modules for Ankara University (2016)
• 2 Modules for Mainz University (2017)

License Agreement on the Twin Cavity
Module with FZ Rossendorf

Target Values (cw operation):
Eacc > 15 MV/m @ Cavity Q > 1 E10
Prf > 8 kW per Coupler

String assembly recently done with consultation/review of DESY experts
Future SRF module production

- The XFEL module production was performed by industry (Alsyom) using infrastructure at CEA, France
- Investment in infrastructure for module assembly (clean room, tooling) is lower than the investment in infrastructure for cavity surface preparation
- Shipping of SRF modules can be done
- **SRF module production technology could be transferred completely to industry**

Outlook for ILC:

- ILC needs 2,250 XFEL like modules, 750 per region, 375 per production site
- The XFEL module assembly infrastructure at CEA allows assembly of 1 module every week (50 per year) in one shift 5 working days operation.
- With 2 such production sites in each region (Asia, Americas, Europe), 100 modules would be assembled per year, the ILC production would be finished in 7.5 years.
SRF modules for Industrial application

SRF technology might be the choice for future industrial application of accelerators:

• EUV light source for lithography (ERL or FEL)

• Driver (linac) for an accelerator driven system (ADS) or accelerator driven sub-critical nuclear reactor

Each such machine would need about 40 (EUV) up to 160 (ADS) SRF cavities housed in 10 to 50 SRF modules

For both applications SRF modules are required operating in cw mode with highest reliability
For a fast and economic SRF module production for a industrial application like ADS or EUV light source a collaboration between institute and industry could be best and as follows:

<table>
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<th>Task</th>
<th>Performed at</th>
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<tbody>
<tr>
<td>Design in view of reliable operation</td>
<td>Industry (consultation from institute)</td>
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<tr>
<td>Manufacturing of cavities</td>
<td>Industry</td>
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<tr>
<td>Manufacturing of couplers</td>
<td>Industry</td>
</tr>
<tr>
<td>Surface preparation of cavities and couplers</td>
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<tr>
<td>Test of cavities and couplers</td>
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<td>Assembly of SRF modules</td>
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<td>Installation and commissioning of SRF modules</td>
<td>Industry</td>
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The cold testing of cavities and SRF modules in industry would need large investment in cryo-plant, RF power sources and test bunkers and should/could be done after the SRF technology has break through for industrial application.
Summary

• High performance SRF cavity production ready for cold RF test and at large numbers is already available in industry

• SRF module assembly feasible to be carried out completely in industry

• Collaboration between institute and industry proven to work for challenging scientific projects using SRF and could be extended for first industrial application using SRF technology