Injection Systems for Synchrotron Light Sources

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Primary authors : Dr. VOGEL, Hanspeter (RI Research Instruments GmbH)

Co-authors :

Presenter : Dr. VOGEL, Hanspeter (RI Research Instruments GmbH)
RI Research Instruments GmbH
Contribution to the II Mexican Workshop on Accelerator Physics: A Light Source

Hanspeter Vogel
RI Research Instruments GmbH
Content

Injection Systems for Synchrotron Light Sources

RF Accelerating Systems for Synchrotron Light Sources

- Overview on RI Research Instruments/ACCEL Instruments history and background
- Overview on RI activities in accelerator technology
- Injection systems for Synchrotron Light Sources
  - Sources and Linear Accelerators
  - Booster Rings
- RF Accelerating Systems for Synchrotron Light Sources
  - room temperature RF
  - superconducting RF
- Summary
  - Industrial capabilities to supply subsystems for synchrotron Light Sources
  - Requirements for the Synchrotron Light Source in case of industrial supplies
RI Research Instruments GmbH

Advanced Technology Equipment and Turn-Key System Supplier for Research, Industry and Medical worldwide

Linear Accelerators
RF Cavities, Couplers, Auxiliaries
Superconducting Accelerator Modules
Electron and Ion Sources
Beam Diagnostic Elements and Particle Beamlines
Accelerator Equipment for Particle Therapy
Specialized Manufacturing Projects

A former activity of ACCEL Instruments GmbH

51% of shares by Bruker ASC, Inc.

Management holding a significant equity stake of the company
Overview on RI’s company history

1970:
Interatom GmbH, 100% owned by Siemens, about 2000 people
Research Nuclear Power plant development

1989:
Siemens, about 2000 people
Research Nuclear Power plant development

1993
ACCEL Instruments GmbH (Staff developed 30 → 270 p)
RF cavities and special products
Optical beam lines
Superconducting magnets
Proton therapy

2007
ACCEL Instruments GmbH owned by Varian Medical Systems
RF cavities and special products
Optical beam lines
Superconducting magnets
Proton therapy

2009
RI Research Instruments GmbH
51% Bruker
RF cavities and special products
90 people

BASC GmbH
100% Bruker
Optical beam lines and SC magnets

Varian Proton Therapy GmbH
100% Varian Medical Systems
Proton therapy business
BEST (Bruker Energy and Supercon Technology)

Bruker EST Corp
Billerica, USA

Hydrostatic Extrusions Ltd.
Perth, Scotland, UK

Cuponal, tolling

Bruker EAS GmbH
Hanau, Germany
LTS and PIT wire: MRI, NMR, FTMS

Bruker HTS GmbH
Alzenau, Germany
1G and 2G HTS Superconductors

Bruker Advanced SuperCon GmbH: Supercon Magnets & Devices; Beamlines
Bergisch-Gladbach, Germany
HTS Supercon Devices, New Magnet Types, Beamline Projects, EUV and XAM Technologies

RI GmbH: Accelerators & Special Products
Bergisch-Gladbach, 45% investment by RI GmbH management
Project business & Specialized Manufacturing for Accelerators, Fusion research/ITER, VMS
Company Organisation

Operational Safety
S. Bauer

Managing Directors
Dr. M. Peiniger
Dr. B. Präuße
Secretary
H. Lohmar

Technical Management
H. Vogel

Quality Management
B. Gège

Business
SC RF, Cryogenics, Clean Surfaces
Dr. M. Pekeler
Marketing
Sales
Engineering
Project Management

Business
NC RF, Accelerator Systems, Special Products
Dr. C. Piel
Marketing
Sales
Engineering
Project Management

Technology, Development, Project Engineering
OEM VMS
Dr. P. vom Stein
Technology
Development
Design
Supply, Service
Varian PT

Manufacturing
S. Bauer
Manufacturing Logistics/
Dimensional Control
Turning
Milling
Electrical
Surface Treatment
Joining Technology
Assembly

Finance
T. Börner
Accounting
Financial
Project Management
Human Resources
IT/Systems
Core Competences and Markets

Technologies
- RF, Accelerator
- Superconductivity
- Cryogenics
- Vacuum
- Intgr. System Control
- Specialized Manufacturing
- Surface Treatment
- System Integration

Products / Services
- Linear Accelerators,
- RF Cavities, Couplers
- SRF Accelerator Modules
- Electron and Ion Sources
- Beam Diagnostic Elements
- Particle Beamlines
- Precision Manuf. Components

Markets
- Fundamental Physics
- Applied Research
- Medical/ Particle Therapy
- Energy/ Nuclear
- Advanced Technology Industry
  Including:
  Inspection,
  Solar,
  Live Science

Quality Management according to DIN EN ISO 9001:2000, KTA

World Map of Customers and Partners in Fundamental and Applied Research (not complete)
RI scope: **Engineering <> Manufacturing <> System Integration**

![Diagram of X-FEL coupler with labels for various components such as position sensor, waveguide to coax transition, etc.]

![Graph showing energy gain per cavity in MeV with different colors for Protons and Deutrons.]

- 6 Cavities $E_{max} = 0.09$
- 42 Cavities $E_{max} = 0.15$

$\phi_{opt} = -30^\circ$

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RI scope: Engineering <-> **Manufacturing** <-> System Integration
RI scope: Engineering <> Manufacturing <> System Integration
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- **Overview on RI activities in accelerator technology**
- Injection systems for Synchrotron Light Sources
  - Sources and Linear Accelerators
  - Booster Rings
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Overview on RI activities in accelerator technology

Superconducting RF

We manufactured e.g. 360 CEBAF, 109 SNS and more than 100 ILC Type Cavities

(Technology Transfer DESY, JLAB, Cornell, University Wuppertal)
Superconducting cavities – CEBAF upgrade cavities

86 pieces 1.5 GHz 7-cell cavities contracted in July 2009.

Scope includes material procurement, manufacturing, bulk chemistry and RF tuning (fundamental mode and HOM couplers).

First article to be delivered in June 2010, last cavity to be delivered middle of 2011 (current planning last cavity November 2010).

First cavities tested at Jefferson Lab with accelerating gradients in the range of 40 MV/m
Superconducting RF Accelerator Modules

Technology Transfer from CERN and Cornell

LEP 200 Nb/Cu, 352 MHz

3rd harmonic, 1500 MHz Landau Module for BESSY (Inhouse Development)
40 MeV Superconducting linear accelerator for Protons and Deuterons based on Half Wave Resonators
SRF Cavities, Prototyping

CH-Mode Cavity for Ion-acceleration (Design: Univ. Frankfurt)
Superconducting Linear Accelerators for FEL/ERL Applications and the Future ILC

SRF Accelerator Module for the future 4GLS X-Ray Source in UK (License Agreement with FZ Rossendorf)

SRF Cavities and Modules for the future projects X-FEL/DESY (800 Units) in Hamburg und ILC (20000 Units)

Delivery on Sept. 09, 2005, to FNAL for ILC

RI is the World’s leading Company in SRF Technology

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Overview on RI activities in accelerator technology
normalconducting RF

CCL Modules for SNS in Oak Ridge/USA

Complete CCL-Module during RF Test at RI

CCL Linac at SNS

We manufactured, assembled, aligned and rf
tuned 4 CCL Modules as a Special Equipment Supplier
(\textit{Co-operation} with LANL)
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3rd Generation Light Source Injector Linac

design, manufacture, installation, operation by RI:
Gun, Bunching System, Focussing System, Accelerating Sections, RF-supply,
vacuum-, control-system,
Turn-Key S-Band Electron Linear Accelerators for Synchrotron Light Sources and Medical Applications

Delivered:
- SLS/PSI, CH 100 MeV
- DLS, UK 100 MeV
- ASP, Australia 100 MeV
- PTB, Germany 0.5-50 MeV

In Production:
- Taiwan Light Source 150 MeV
- Uni Nijmegen 15 MeV
- NSLS-II. Brookhaven National Lab) 200 MeV

Technology Transfer from DESY (Dortmund Univ.)
License Agreement on S-Band Lin. Collider Components with DESY
S-Band Structures for injection linacs

Parameter:

- mode 2p/3
- frequency 2.9983 GHz
- length 5.2 m
- no. of cells including absorber cells: 150 + 6
- shunt imp. 51 MW/m
- Q 14000
- filling time 0.74 ms
Electron Injection Linacs for Synchrotron Light Sources

Swiss Light Source 100 MeV Linac

Diamond Light Source 100 MeV Linac
## Electron Injection Linacs for Synchrotron Light Sources, detailed parameters

<table>
<thead>
<tr>
<th>Project (year)</th>
<th>Energy</th>
<th>Pulse structure / repetition rate</th>
<th>Charge</th>
<th>Emittance (1σ) / energy spread (rms)</th>
</tr>
</thead>
</table>
| Swiss Light Source (2000) | 100 MeV | a) Single bunch < 1 ns / 10 Hz  
                      b) Multi bunch 200 – 900 ns, 2 ns bunch spacing / 10 Hz | a) > 1.5 nC  
                      b) > 1.5 nC total | $\varepsilon_n < 50 \, \pi \cdot \text{mm} \cdot \text{mrad}$ /  
                      $\sigma_E/E < 0.5 \%$ |
| Diamond Light Source (2005) | 100 MeV | a) Single bunch < 1 ns / 5 Hz  
                      b) Multi bunch 300 – 1000 ns, 2 ns bunch spacing / 5 Hz | a) > 1.5 nC  
                      b) > 3.0 nC total | $\varepsilon_n < 50 \, \pi \cdot \text{mm} \cdot \text{mrad}$ /  
                      $\sigma_E/E < 0.5 \%$ |
| Australian Synchrotron Project (2006) | 100 MeV | a) Single bunch < 1 ns / 5 Hz  
                      b) Multi bunch 150 ns, 2 ns bunch spacing / 5 Hz | a) > 0.3 nC  
                      b) > 3.1 nC total | $\varepsilon_n < 50 \, \pi \cdot \text{mm} \cdot \text{mrad}$ /  
                      $\sigma_E/E < 0.5 \%$ |
## Electron Injection Linacs for Synchrotron Light Sources (under construction)

<table>
<thead>
<tr>
<th>Project (year)</th>
<th>Energy</th>
<th>Pulse structure / repetition rate</th>
<th>Charge</th>
<th>Emittance (1σ) / energy spread (rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taiwan Photon Source (2011)</td>
<td>150 MeV</td>
<td>a) Single bunch &lt; 1 ns / 5 Hz</td>
<td>a) &gt; 1.5 nC</td>
<td>$\varepsilon_n &lt; 50 , \pi \cdot \text{mm} \cdot \text{mrad}$ / $\sigma_E/E &lt; 0.5 %$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Multi bunch 200 – 1000 ns, 2 ns bunch spacing / 5 Hz</td>
<td>b) &gt; 5.0 nC</td>
<td></td>
</tr>
<tr>
<td>NSLS II / BNL (2012)</td>
<td>200 MeV</td>
<td>a) <strong>Bursts of single bunches</strong>, $n \cdot 2$ ns bunch spacing / 10 Hz</td>
<td>a) &gt; 0.5 nC/bunch</td>
<td>$\varepsilon_n &lt; 15 , \pi \cdot \text{mm} \cdot \text{mrad}$ / $\sigma_E/E &lt; 0.5 %$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Multi bunch 160 – 300 ns, $n \cdot 2$ ns bunch spacing / 10 Hz</td>
<td>b) &gt; 15 nC total</td>
<td></td>
</tr>
</tbody>
</table>
Electron Source / Pulse Structure

Electron source 90 keV
Single bunch: $\text{FWHM} < 1\text{ ns}$
Peak current: $> 3\text{ A}$
Multi bunch: $0.1\text{ }\mu\text{s} \text{ to } 10\text{ }\mu\text{s}$
Grid modulation: $500\text{ MHz}$
Repetition rate: up to $100\text{ Hz}$

single bunch:
$<1\text{ ns}$
$10\text{ ms} \text{ to } \text{several seconds}$

multi bunch with $500\text{ MHz}$ modulation:
$2\text{ ns}$
$100\text{ ns} \text{ to } \text{several } \mu\text{s}$

single bunch bursts and multi bunch with flexible bunch pattern (NSLS II 200MeV Linac)

$\text{current}$
$\text{time}$
$\text{time}$
$\text{current}$
$\text{time}$
Electron Injection Linacs for Special Applications

<table>
<thead>
<tr>
<th>Project (year)</th>
<th>Energy</th>
<th>Pulse structure / repetition rate</th>
<th>Charge</th>
<th>Emittance (1σ) / energy spread (rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTB Germany (2009)</td>
<td>Range 0.5 MeV – 50 MeV</td>
<td>Multi bunch 3 µs, 333 ps bunch spacing / 100 Hz</td>
<td>Up to 400 nC per macro pulse</td>
<td>$\varepsilon_n &lt; 50 \pi \cdot \text{mm} \cdot \text{mrad}$ / $\sigma_{\varepsilon/E} &lt; 0.1 %$</td>
</tr>
<tr>
<td>FLARE IR-FEL driver Netherland (2011)</td>
<td>Range 10 MeV – 15 MeV</td>
<td>Multi bunch 10 µs, 333 ps bunch spacing / 10 Hz</td>
<td>&gt; 0.2 nC per bunch, 6000 nC per macro pulse</td>
<td>$\varepsilon_n &lt; 50 \pi \cdot \text{mm} \cdot \text{mrad}$ / $\sigma_{\varepsilon/E} &lt; 0.3 %$</td>
</tr>
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</table>
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500 MHz Five Cell Cavities for Boosters

500 MHz Five Cell cavities used at DESY, Hamburg and in a number of booster rings:

- DIAMOND Light Source
- Canadian Light Source
- Australian Synchrotron Project
- Shanghai Light Source

Complete with power coupler, tuner, vacuum system, low power rf, vacuum baked, ready for high power operation.
A complete injection system consisting out of a 100 MeV Linac and a complete booster ring including our 500 MHz rf cavity has been designed, built and delivered to the Australian Synchrotron Project (ASP).
RI is partnering with other companies or institutes experienced in magnet and circular accelerators.
**Lattice:**

**Booster circumference:**

**Injection energy:**

**Peak energy:**

**Beam current (multi bunch train):**

**Combined function**

- Booster circumference: 130m
- Injection energy: 100 MeV
- Peak energy: 3.0 GeV
- Beam current (multi bunch train): 5 mA

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**DANFYSIK - Accelerator systems**

**Australian Synchrotron Project – 2004-2006**

100 MeV Linac, LEBT, 3.0 GeV Synchrotron, HEBT
Conclusions on injection systems

1. Electron Linear Accelerators (linacs) as injectors for Synchrotron Light Sources are available in various variants. All linacs delivered so far are based on the same principles and well proven components, nevertheless individual parameters (energy, puls patterns, etc.) have been realized with every project and we are ready to be flexible for future projects.

2. Booster rings are based on a reliable 5cell cavity, designed by DESY. Such cavities may still be available at DESY. When building a booster possibilities for realization may vary from complete in house (customer) solutions to turn-key industrial supplied solutions.
Content (continued, second talk)

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Several concepts for HOM free or HOM damped nc cavities are existing

PEP (476 MHz)
ASP (500 MHz)
BESSY (500 MHz): applied in Willy Wien
CELLS: a further developed BEESY design applied at CELLS
ESRF (350 MHz), a scaled version of the BESSY/CELLS concept
(not mentioning other concepts with lower frequencies)

Principles of nc vs. sc HOM damping
The HOM free 500 MHz cavity developed by BESSY

Table 2: Fundamental Mode Performance Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shunt impedance</td>
<td>3.4 MΩ</td>
</tr>
<tr>
<td>Quality factor</td>
<td>29600</td>
</tr>
<tr>
<td>Coupling (adjustable)</td>
<td>0.1 - 8</td>
</tr>
<tr>
<td>Cavity power / rf-voltage reached</td>
<td>40 kW / 520 kV</td>
</tr>
<tr>
<td>expected with modifications</td>
<td>80 kW / 735 kV</td>
</tr>
<tr>
<td>expected without gaps</td>
<td>100 kW / 825 kV</td>
</tr>
</tbody>
</table>

Ref.: E. Weirether, EPAC 2008, THXM03, Patent by BESSY
The HOM free 500 MHz cavity developed by BESSY

Status:
One cavity operating at the German Metrology Light Source (Willy Wien, Berlin) at 520 kV (40 kW)
6 cavities produced with design modifications for CELLS (Spain).

Based on the performance of the Willy Wien cavity and the first tested cavity for CELLS improvements at the HOM waveguide connection have been implemented and successfully tested (end of 2008).
(825 kV and 100 kW)
HOM damped cavities for CELLS, Spain

CELLS is operating 6 cavities in the storage ring (+1 ‘hot spare’)

\[ F_0 = 500 \text{MHz} \]

\[ U_{\text{acc}} = 825 \text{ kV} \]

\[ P = 100 \text{ kW} \ (80 \text{ kW rf power}) \]

Cavities have been fully equipped (power couplers, tuner, vacuum), low power rf tests (fundamental mode, coupling factors) and vacuum-baked ready for high power test at CELLS.
ESRF is planning an upgrade of their storage ring rf by replacing 5 cell cavities with HOM-damped single cell cavities.

The design is similar to the CELLS/BESSY design at 352 MHz.

Prototypes are under fabrication for delivery in early 2011 and subsequent high power testing.
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Cornell modules (500 MHz): technology transfer to ACCEL

In 1999 Cornell University and ACCEL agreed on a technology transfer of the 500 MHz SRF module. Technology developed for CESR II.

NSRRC had decided to use the Cornell modules in their Light Source and were looking for an industrial supplier that could deliver the modules as a turn key system including valve boxes, transfer lines and SRF electronics.

The following contracts have been concluded meanwhile, making this technology transfer most successful:

- **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, China
- **2010**: 2 SRF Modules for the Pohang Light Source upgrade
- **2011**: 2 (3) SRF Modules are planned for NSLS II at Brookhaven

In total 14 SRF modules delivered, under construction
Cornell modules (500 MHz): technology transfer to ACCEL/RI

Main Components:

- srf cavity
- power coupler
- HOM loads (at room temperature)
- Cryostat, cryo system
- vacuum system
- control system (RF, cryo)
Turn key Cornell style SRF modules

Scope can cover

- Cavity production
- Surface preparation
- Vertical test
- Coupler production
- Coupler conditioning
- HOM loads
- Module assembly
- Installation
- Commissioning
- Valve boxes
- Transfer lines
- SRF Electronics
- Interlock and data acquisition system
- LLRF

Module performance:
\[ V_{\text{acc}} > 2 \text{ MV}, \quad Q_0 > 5 \times 10^8 \]

is the basis for cryoplant layout
Cavity preparation for vertical test at RI

Closed loop BCP

Assembly in clean room

Packing and shipping for vertical test

HPR
Bulk Nb Cavity preparation and test results

Preparation is done at RI Research Instruments as follows:

- Degreasing
- Buffered chemical polishing (1:1:2), in closed loop chemistry, acid actively cooled to temperatures below 15 °C
- Water Rising > 17 MWcm
- High pressure water rinsing (100 bar)
- Drying by pumping
- Assembly in class 100 clean room

- All test results achieved in consecutive preparations / tests
- All field values limited by available RF power

Cavities are accepted after cold test for module assembly with $E_{acc}$ at 2.5 MV and $Q_0 > 1 \times 10^9$
**Waveguide Window conditioning**

Windows cleaned, assembled and baked at RI
Shipped to Cornell or other research labs for RF conditioning by RI technicians, customer participation welcome.
Windows are accepted for module assembly with:
- 250 kWatt cw operation
- 120 kWatt cw operation full reflection
Factory acceptance test with valve box and SRF electronics
Overseas transport
Installation and taking into operation at customers site, here the SSRF storage Ring (Shanghai)
Main panel for cryogenic operation
(a control system example)
Commissioning of SRF modules on site

Commissioning of a SRF module takes normally about 4-6 weeks

First week: Unpacking, Installation into the storage ring, alignment
Second week: Pumpdown and leak check
Third week: Connection to the interfaces: cryoplant, RF plant, LLRF, control system
Fourth week: Cooldown, check of cryogenic performance and interlock check
Fifth week: RF conditioning and RF test

Requirements from customer side:

• Water supply ready
• Commissioning of RF plant finished
• Some helping hands during module installation
• Alignment group for installation
• Cryogenic plant commissioned
• Low power RF equipment like network analyzer, power meter for RF calibration
• Training of RF operators during commissioning and acceptance test

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Conclusions on storage ring RF (1)

1. superconducting rf systems are available from Industry based on proven designs like CORNELL Modules and 500 MHz modules from KEK (Japan) applied in a number of storage rings as shown here in this presentation plus KEK (Japan), IHEP (Beijing, China), New Taiwan Light Source

2. Proven designs and working room temperature rf systems are available from industry also in various applications like BESSY/CELLS design, ASP design, MaxLab (Sweden), ESRF (France, 352 MHz), NSLS (Brazil), Poland, etc.
Conclusions on storage ring RF (2)

1. For sc systems we deliver “turn-key” modules with cavities tested to specification and power handling capability shown for the rf window in a high power testing (as well as other parameters like tuning, coupling, vacuum, thermal properties). The final testing of the completed srf module requires the cryogenic and rf supplies of the customers installation.

2. For nc systems we deliver rf cavity systems complete with auxiliaries and low power measurements performed (frequency, tuning range, coupling etc.). High Power RF Testing to be discussed with partners (DESY...) or finally performed with the customers installation.
Industrial Supplies / User provided Infrastructure

Summary of possible industrial supplies and required infrastructure:
nc storage ring rf

<table>
<thead>
<tr>
<th>Supplier</th>
<th>User</th>
</tr>
</thead>
<tbody>
<tr>
<td>rf cavity: fully equipped with</td>
<td>high power rf supplies and distribution</td>
</tr>
<tr>
<td>• power/window</td>
<td>• cooling water and other utilities</td>
</tr>
<tr>
<td>• tuner, field probe</td>
<td>• technicians experience in rf and vacuum</td>
</tr>
<tr>
<td>• HOM dampers</td>
<td></td>
</tr>
<tr>
<td>• vacuum systems</td>
<td></td>
</tr>
<tr>
<td>• vacuum baked</td>
<td></td>
</tr>
<tr>
<td>• low power rf</td>
<td></td>
</tr>
</tbody>
</table>
## Industrial Supplies / User provided Infrastructure

Summary of possible industrial supplies and required infrastructure: superconducting storage ring rf

<table>
<thead>
<tr>
<th>Supplier</th>
<th>User</th>
</tr>
</thead>
<tbody>
<tr>
<td>srf accelerating module fully equipped with</td>
<td>high power rf supplies and distribution</td>
</tr>
<tr>
<td>• cavity, tested separately before integration</td>
<td>• cryogenic plant and distribution (transfer lines)</td>
</tr>
<tr>
<td>• rf window tested separately before integration</td>
<td>• utilities</td>
</tr>
<tr>
<td>• module leak-checked at cryogenic temperature</td>
<td>• technicians experience in srf cryogenic operations, vacuum rf</td>
</tr>
<tr>
<td>• valve box for distribution and control of cryoliquids</td>
<td></td>
</tr>
</tbody>
</table>
**Industrial Supplies / User provided Infrastructure**

Summary of possible industrial supplies and required infrastructure: injection systems

Supplier

- turn key linear accelerator with guaranteed parameters to be agreed with customer
- turn key linac
- alternative: turn key injection system

User

- beam transport systems
- kicker systems
- infrastructure
- utilities
Industrial Supplies: support in design

To reflect the Pohang Light Source upgrade requirements two options have been discussed:
sc option: 2 Modules in operation, one spare
operating gradient: 1.5 MeV (moderate)
power to beam: 270 kW per coupler (limit)
total rf power needed: app. 0.5 MW
nc option: 6 cavity systems in operation, one “hot” spare
operating gradient 500 keV (moderate)
power to cavity and beam: app. 130 kW per coupler (limit)
total RF Power needed: app. 0.8 MW

Design Requirements for PLS 3.0 SRF Cavity

Budget Information:*1

sc option: 4.5 Mill €
nc option: 2.5 Mill €

*1 subject to escalation, scope of supplies, fees, and commercial/contractual conditions, 2010 cost factors

<table>
<thead>
<tr>
<th>Bending Radius [m]</th>
<th>BM radiation loss [keV]</th>
<th>ID radiation loss [keV]</th>
<th>Gap Voltage [MV]</th>
<th>Total RF power @ 3 GeV, 400 mA [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3 (PLS3.0)</td>
<td>1137.3</td>
<td>213.3</td>
<td>3</td>
<td>540</td>
</tr>
<tr>
<td>10</td>
<td>716.5</td>
<td>213.3</td>
<td>3</td>
<td>372</td>
</tr>
<tr>
<td>15</td>
<td>477.7</td>
<td>213.3</td>
<td>3</td>
<td>272</td>
</tr>
</tbody>
</table>

• PLS 3.0;
  - Energy: 3.0 GeV
  - Current: 400 mA

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RI Research Instruments GmbH

- Advanced technologies, turnkey systems
- Project management, engineering and manufacturing
- Integrated system control, software
- Highly motivated, qualified people
- Project oriented, integrative, flexible
- Intensive, multinational cooperations
- Global player in an expanding worldwide business

We would be happy to serve with all our management, engineering and manufacturing capabilities and know-how for our valued worldwide customers.

Thank you for your attention
RI Research Instruments GmbH

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