Contamination prevention measures when installing the SRILAC cryomodules to a 40-years-old dirty beam line

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Overview of SRILAC

- CW heavy-ion linac at RIKEN Nishina Center
- 10 SC-QWRs arranged into 3 cryomodules
- 4.5 K operation
- RT Q-magnets are used as focusing elements
- Differential pumping systems
- Constructed by 2019
- First beam: Jan 28th, 2020

### Design parameters of SC-QWR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency [MHz]</td>
<td>73.0</td>
</tr>
<tr>
<td>Duty [%]</td>
<td>100</td>
</tr>
<tr>
<td>$\beta_{\text{opt}}$</td>
<td>0.078</td>
</tr>
<tr>
<td>Aperture [mm]</td>
<td>$\phi_{40}$</td>
</tr>
<tr>
<td>$G$ [Ω]</td>
<td>22.4</td>
</tr>
<tr>
<td>$R_{\text{sh}}/Q_0$ [Ω]</td>
<td>579</td>
</tr>
<tr>
<td>$Q_0$</td>
<td>$1.0 \times 10^9$</td>
</tr>
<tr>
<td>$P_0$ [W]</td>
<td>8</td>
</tr>
<tr>
<td>$V_{\text{acc}}$ [MV] at $E_{\text{acc}} = 6.75$ MV/m, $\beta = 0.078$</td>
<td>2.16</td>
</tr>
<tr>
<td>$E_{\text{acc}}$ [MV/m]</td>
<td>6.75</td>
</tr>
<tr>
<td>$E_{\text{peak}}/E_{\text{acc}}$</td>
<td>6.2</td>
</tr>
<tr>
<td>$B_{\text{peak}}/E_{\text{acc}}$ [mT/(MV/m)]</td>
<td>9.6</td>
</tr>
</tbody>
</table>
Installation of SRILAC cryomodules to existing beam line

Contamination prevention measures
- Reinforcement of vacuum pumps
- Differential pumping system
- Fast closing valves
- Cleaning of the existing beamline
  → Targeting coarse dust reduction
- Clean connection of warm sections
  → To prevent submicron particle contamination

New installation of SRILAC cryomodules & beamline in 2019

RIKEN Heavy-Ion Linac (RILAC) Facility
Cleaning of HEBT

Cleaning on site in radiation controlled area for dipole magnets where the beam duct cannot be removed

- Inspection with fiber scope

- Alcohol wipes (Ethanol)

- Air blow – dust collector

Visible dusts are carefully removed one by one viewing with fiber scope

Performed by Japan environment research CO. LTD.
Example for dipole beam duct

Before

After
Cleaning of HEBT

Cleaning for dipole magnets where the beam duct can be removed in other radiation controlled area at RIKEN

- High-pressure rinsing with ultra pure water
- Drying by hot air blower with HEPA filter
Pictures of contaminant in HEBT

Example for dipole beam duct

Before

After

Traces of fiber scope
Pictures of contaminant in HEBT

Example for diagnostic chamber

Before

After

Further removed one by one
Analysis of particles by electron probe micro analyzer

Silver particulates

Golden particulates

Stainless steel

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt. (%)</th>
<th>Atom(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>40.998</td>
<td>68.8998</td>
</tr>
<tr>
<td>Si</td>
<td>1.171</td>
<td>1.1219</td>
</tr>
<tr>
<td>Cr</td>
<td>19.564</td>
<td>10.1225</td>
</tr>
<tr>
<td>Fe</td>
<td>41.344</td>
<td>19.9168</td>
</tr>
<tr>
<td>Total</td>
<td>103.017</td>
<td>100.0000</td>
</tr>
</tbody>
</table>

Brass

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt. (%)</th>
<th>Atom(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>2.698</td>
<td>10.2162</td>
</tr>
<tr>
<td>Fe</td>
<td>1.919</td>
<td>2.0811</td>
</tr>
<tr>
<td>Cu</td>
<td>83.899</td>
<td>79.9209</td>
</tr>
<tr>
<td>Zn</td>
<td>8.397</td>
<td>7.7817</td>
</tr>
<tr>
<td>Total</td>
<td>96.853</td>
<td>100.0000</td>
</tr>
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</table>
Cleaning of booster cavity

By a vacuum cleaner and alcohol wipe

Rf contact scraped shavings (copper & silver)

Occasional cleaning after start of beam operation (2021)
Connection of warm sections in situ

Following clean connections were required:
- Vacuum pumping stations of cryomodules (for beam vacuum)
- Slow leak and pumping system for clean work
- Beam ducts between cryomodules
- Beam ducts between cryomodule and differential pumping stations

CF flanges and SDC clean bolts were used for each connection in warm section (Beam ducts, vacuum pumping systems)

Slow leak and pumping system using MFC & diffuser
→ Argon gas was used for pressurization

SDC clean bolt
(316L stainless steel + plasma surface hardening)
→ Low particle generation and anti-seizing

Connection of vacuum pumping systems

Enclosed each section by local clean booth with standard aluminum frames and antistatic-vinyl sheets

One side of Stand KOACH pair was used for FFU

Open clean system "KOACH"
https://www.koken-ltd.co.jp/english/product/clean/super/

KOACH C900-F (Stand KOACH)
ISO class 1 super clean area: W900 mm × H700 mm × L1800～2300 mm
→ One side of pair: L900～1800 mm
Connection of beam ducts and installation of Q magnets

Beam duct was connected before quadrupole magnets installation

Beam duct connection

Connection completed

Installation of lower half of Q-mag.

Mounting of upper half of Q-mag.
Degree of contamination

- Degradation of CM2 performance is mainly due to an impact of SC06 coupler-window-break

- No significant performance degradation of CM1 and CM3 was observed after the connection of warm sections

- X-ray emissions were gradually increasing in the CM1 and CM3 with operation, however, the performance degradation has been recovered by a pulse conditioning so far

- It seems to be preventing the contamination of metallic coarse particles from old beam line
Summary

Three cryomodules of the SRILAC were installed in the 40-years-old dirty beam line

Cleaning of existing beam line and clean connection using a local clean booth were performed

The contamination of coarse particles could have been prevented by cleaning the existing beam line