Fifteen Years Operation Experiences of TLS Vacuum System

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(on behalf of Vacuum Group)

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Taiwan Light Source (TLS)

- 1993 – Operation 1.3 GeV
- 1996 – Ramping to 1.5 GeV
- 2000 – 1.5 GeV Full Energy Injection (200 mA)
- 2004 – Operation with Superconducting RF Cavity
- 2005 – Top-up Injection at 300 mA

- ¾ Circumference – 120 m
- ¾ Critical Energy – 2.14 keV
- ¾ Natural Emittance – 25 nm rad
- ¾ Average Pressure (200 mA) – 0.68 nTorr
- ¾ Accumulated Dose > 8000 Ah
- ¾ Life Time – 10 h

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Hsinchu Science Park
Vacuum System for TLS

[Diagram showing various components of a synchrotron radiation facility, including SRF, SC Wiggler, BM, Undulator, SR, Front End, SGV, NEG, SIP, Vacuum Chambers, and Electron Storage Ring.]
## Four stages of operation of TLS in 1993 ~ 2008 (15 years)

<table>
<thead>
<tr>
<th>Years of Stages</th>
<th>E(GeV)/ I(mA)</th>
<th>Accumulated Beam Dose (Ah)</th>
<th>Insertion Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) 1993~1994 Commissioning</td>
<td>1.3 / 200</td>
<td>167</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>U5 (03/1997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>EPU5.6 (03/1997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>U9 (06/1998)</td>
</tr>
<tr>
<td>(iii) 1999~2005 1.5 GeV New SC Wigglers</td>
<td>1.5 / 200</td>
<td>8840</td>
<td>SWLS (04/2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SW6 (12/2003)</td>
</tr>
<tr>
<td>(iv) 2006~2008 SRF, IASW6 (on Top-up)</td>
<td>1.5 / 300</td>
<td>14765</td>
<td>IASW6 (01/2006)</td>
</tr>
</tbody>
</table>
Roadmap / Accumulated Beam Dose (1993.07 ~ 2008.12)

- Top-up 1.5 GeV 300 mA

15.5 years
12/31/2008
07/01/1993
167 Ah
3004 Ah
8840 Ah
14765 Ah

(i) 167 Ah
(ii) 3004 Ah
(iii) 8840 Ah
(iv) 14765 Ah
dP/I (Pa/mA) vs. Beam Dose

Top-up

1.3 GeV
200 mA
Install ID-CH
W20
Install ID-CH
EPU5.6 + U5

1.5 GeV
200 mA
Install ID-CH
U9
Install
New FE

15.5 years

Install ID
SWLS
Install ID
SW6
Replace new
Kicker Chambers
Install
SRF Cavity

Replace ID
IASW6

1.5 GeV
300 mA

07/01/1993

YEAR/MONTH

1993/07
1994/07
1995/07
1996/07
1997/07
1998/07
1999/07
2000/07
2001/07
2002/07
2003/07
2004/07
2005/07
2006/07
2007/07
2008/07
12/31/2008

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dP/I (Pa/mA) vs. Beam Dose

Installation of New Insertion Devices

- W20 (1995)
- EPU,U5 (1997)
- SWLS (2002)
- IASW (2006)
- U9 (1998)
- SW6 (2003)
- SRF (2004)

Average Pressure/Beam Current (Pa/mA)

- 6.7×10⁻⁹ Pa/mA
- 1.7×10⁻¹⁰ Pa/mA
- 1.1×10⁻¹⁰ Pa/mA

Beam Dose (A h)

- 14765 Ah 2008/12

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I \cdot \tau \text{ (mAh)} \text{ vs. Beam Dose}
I · τ (mAh) vs. Beam Dose

Installation of New Insertion Devices:
- W20 (1995)
- EPU, U5 (1997)
- SWLS (2002)
- IASW (2006)

- U9 (1998)
- SW6 (2003)

- SRF (2004)

6.2 hours at 300 mA

10 hours at 200 mA

14765 Ah
2008/12
(i) Commissioning

- 1993/07 ~ 1994/07 (~ 1 year)
- Beam Dose ~ 167 Ah
- dP/I ~ 1 nPa/mA
Beam cleaning to reduce the PSD yields

Pressure rise per beam current and Desorption coefficient in B-ch ($\eta_B$) during beam cleaning.

TMP pumps were useful for removing the large amount of PSD outgas during the commissioning.

Desorption coefficient at S-ch ($\eta_S$) and B-ch ($\eta_B$)

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Residual Gases of PSD from TLS

Major PSD Outgas:

H₂ (93%) > CO (4.4%) > CO₂ (1.2%)
> CH₄ (0.5%) ~ H₂O (0.5%)
(ii) Installation of new ID and FE

- 1994/07 ~ 1999/07 (~ 5 year)
- Beam Dose ~ 3004 Ah
- dP/I ~ 0.17 nPa/mA
Aluminum Alloys (Al) Vacuum Chambers for the Storage Ring

B-Chamber
• CNC machining in pure alcohol
• Distributed Ionization Pump
• TIG welding in clean room

S-Chamber
• Al Extrusion
• Chemical cleaning by acid
• TIG welding in clean room

ID-Chamber
• Surface finishing by CNC machining after TIG welding
# Specifications for the ID Chambers

<table>
<thead>
<tr>
<th>Name of Straight Section</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>R5</th>
<th>R6</th>
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</thead>
<tbody>
<tr>
<td>Name of Insertion Device</td>
<td>SWLS</td>
<td>EPU5.6</td>
<td>U5</td>
<td>SW6</td>
<td>W20</td>
<td>U9</td>
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<tr>
<td>Minimum Pole Gap (mm)</td>
<td>55 mm</td>
<td>18 mm</td>
<td>18 mm</td>
<td>18 mm</td>
<td>22.5 mm</td>
<td>18 mm</td>
</tr>
<tr>
<td>Length of ID (m)</td>
<td>0.835 m</td>
<td>3.9 m</td>
<td>3.9 m</td>
<td>1.405 m</td>
<td>3.1 m</td>
<td>4.5 m</td>
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<tr>
<td>Length of ID Chamber (m)</td>
<td>0.84 m</td>
<td>4.16 m</td>
<td>4.16 m</td>
<td>1.4 m</td>
<td>3.16 m</td>
<td>4.76 m</td>
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<tr>
<td>Outside Vertical Height (mm)</td>
<td>28 mm</td>
<td>17 mm</td>
<td>17 mm</td>
<td>13.4</td>
<td>21.5 mm</td>
<td>17 mm</td>
</tr>
<tr>
<td>Inside Vertical Height (mm)</td>
<td>20 mm</td>
<td>13 mm</td>
<td>13 mm</td>
<td>11</td>
<td>17.5 mm</td>
<td>13 mm</td>
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<tr>
<td>Inside Horizontal Width (mm)</td>
<td>100 mm</td>
<td>80 mm</td>
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<td></td>
<td></td>
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<tr>
<td>Material of ID Chamber</td>
<td>Aluminum Alloys (A6063T5)</td>
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<tr>
<td>Machining of ID Chamber</td>
<td>Extrusion</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Outside Surface Finishing</td>
<td>CNC Machining (in Ethanol)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Flatness after Surface Finishing</td>
<td>&lt; ±0.2 mm</td>
<td>&lt; ±0.2 mm</td>
<td>&lt; ±0.2 mm</td>
<td>&lt; ±0.2 mm</td>
<td>&lt; ±0.2 mm</td>
<td>&lt; ±0.2 mm</td>
</tr>
<tr>
<td>Cooling Channel</td>
<td>NA</td>
<td>Outboard</td>
<td>Outboard</td>
<td>NA</td>
<td>Both Sides</td>
<td>Outboard</td>
</tr>
<tr>
<td>Pump inside ID Chamber</td>
<td>NA</td>
<td>Strip Type NEG (ST707)</td>
<td>NA</td>
<td>Strip Type NEG (ST707)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of NEG Pump</td>
<td>NA</td>
<td>3.54 m</td>
<td>3.54 m</td>
<td>NA</td>
<td>2.62 m</td>
<td>4.14 m</td>
</tr>
</tbody>
</table>
W20 Vacuum Chamber

Strip-type NEG pump

Al Chamber – manufacturing processes
1. Extrusion of the pipe
2. Machining the welding edges and cooling edges
3. Chemical cleaning by acid
4. TIG welding the supporting pads, cooling joints, tapers, and flanges
5. Surface finishing by CNC machining in ethanol
6. Insert NEG strip assemblies and feedthroughs
14 mm prototype U5 Chamber

Operation in March ~ June, 1996

Good vacuum has been achieved in two days of beam cleaning
The pressure of 14 mm U5 chamber has been improved efficiently by the beam cleaning in two days. However, the beam lifetime is still limited due to the smaller dynamical aperture.

ANSYS Simulation and Measurement
The measured 0.3 mm deformation on upper and lower surfaces near the beam center is similar with the simulated result.

Fig. 4. The product of the electron beam current $I$ and the beam lifetime $\tau$ vs the accumulated beam dose from 1 March to 3 March.

Good vacuum has been achieved in two days of beam cleaning
The pressure of 14 mm U5 chamber has been improved efficiently by the beam cleaning in two days. However, the beam lifetime is still limited due to the smaller dynamical aperture.

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EPU5.6, U5 Vacuum Chambers

Cross section of ID chamber

ID chamber assembly

NEG strip assembly

1997 March

4.16 m

13 mm

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U9 Vacuum Chamber

Pressure rise (dP/I) near U9 chamber is ~50 times higher than that of U5 & EPU5.6 chambers.

Current × Lifetime (I × τ) after installing the U9 chamber is similar with that of U5 & EPU5.6.

Highest pressure $1 \times 10^{-9}$ Torr in the storage ring addresses near U9 chamber.
Most of the vacuum problems caused by the baking during maintenance in the Tunnel.
Mass spectrum near a B-chamber shows CxFy contamination from the O-ring sealed Beam Line gate Valve (BLV). The O-ring had stuck on the wall of BLV due to over baking, hit by synchrotron light and broken, and released the CxFy outgas. All the BLV’s have been replaced by all metal ones.
High Temperature Baking Problems

A feedthrough of the ion pump was broken due to high voltage sparking when degassing during the baking. Number of times for switching the IP on are reduced to < 3 times.
Problem of Over Heating

A photon aperture, horizontally installed in a front end, was melt down due to insufficient water cooling. Each loop of cooling water pipes for the absorbers or masks should connect the flow rate meter and link to the interlock system.
An O-ring for a turbo-molecular pump located near the extraction septum chamber of 1.5 GeV booster synchrotron was damaged after high dosage rate irradiation. The pumps with O-ring contained has been removed from high dosage area after using.
(iii) Installation of SC Wigglers

- 1999/07 ~ 2005/12 (~ 6.5 year)
- Beam Dose ~ 8840 Ah
- dP/I ~ 0.11 nPa/mA
SWLS Vacuum Chamber

SWLS beam duct

The SR light emitted from SWLS (6T), with 130 mrad photon span and 9 mm offset, will hit on the downstream kicker ceramic chamber.

**ANSYS Thermal Analysis**
330°C hot spot near Cu cold head cover of absorber with upstream pre-absorber (5.3 T)

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SWLS operating at 5.3 T

Pressure rise
(dP/I) for IG2 and Pavg. Pavg/I reaches $5 \times 10^{-12}$ Torr/mA at 50 Ah beam dose.

Current $\times$ Lifetime ($I \times \tau$) reaches 10 hours at 200 mA at 50 Ah beam dose.

Temperature rise near SWLS and downstream kicker chamber. T1 ~ T4 represent the temperature near both sides of taper and flange downstream the SWLS, while T5, T6 and T7, T8 near upstream and downstream of kicker chamber respectively.

Beam Dose

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Aluminum Beam Duct for SW6

*Al Beam duct*
1. Length: 1.1 m
2. Inner width: 80 mm
3. Inner height: 11 mm
4. Outer height: 13 mm
5. Operating temperature: 100 K
6. Higher thermal conductivity
7. Lower emissivity

Leakage Check
Flatness Check
Bimetal LN$_2$ Test
(1) Al Beam duct
(2) Al / S.S. Bimetal Adaptor
(3) S.S. Taper

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SW6 Vacuum Chamber Welding

TIG Welding for Al beam duct

Commissioning of TLS with SW6 is successful. (April 2004)
In-Achromat Superconducting Wiggler (IASW6)
Oil-free manufacturing process for Al Bending chambers provides high reliability

1) NC Machining with Ethyl Alcohol
2) Dimension Check After Machining
3) Surface Cleaning
4) DIP Installation
5) Welding in Clean Room
6) Deformation Check After Welding
7) Leak Test
8) Pre-assembly In Lab
9) Installation in the Tunnel
Assembly, Welding and Testing (at NSRRC) for the B-Chamber
TLS Improvement (I) (1997-2002)

Improvement on Utility systems

- Orbit Fluctuation (um)
- Orbit Drift (x10 um)
- Failure Time (x100 hr)
- Temperature Fluctuation (x0.2 deg C)

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ID Div.

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TLS Improvement (II) (2002-2005)

Improvement on Noise and Stabilities of Monitors

- Pin hole detector stability improved
- AC line voltage regulated
- PS-Q4 noise reduced
- e-BPM noise reduced (<1 μm rms)
- SRF cavity & transverse F/B

(Time)

- Oct. 2002: 0.30
- Nov. 2002: 0.12%
- Jan. 2003: 0.08%
- Feb. 2003: 0.06%
- April 2005: 0.05%

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Top-up Injection at 300 mA
(routine operation before Dec. 2005)

Beam current
$I = 300 \text{ mA}$

Life time
$\tau > 5.5 \text{ h}$

Variation of Photon flux
$\Delta I / I < 0.1\%$

Average Pressure
$P < 0.65 \text{ nTorr}$
Top-up Test
(Constant Flux & Temperature)

Outlet cooling water temperature

Chamber’s temperature

(Top-up Mode) (Decay Mode)
(iv) Raise the Beam Current and Top-up Operation

- 2006/01 ~ 2008/12 (~ 3 year)
- Beam Dose ~ 14765 Ah
- dP/I ~ 0.17 nPa/mA
- Beam current increased to 300 mA
Top-up injection at 300 mA routinely

- Operation status of the weeks: 02/26 (Tuesday) – 03/03 (Monday)

1. User availability

\[ I = 300 \text{ mA} \]
\[ \tau = 3.5 \text{ h} \]
Fluctuation of photon flux $(dI/I) < 0.05\%$

2. $dI/I$ statistics:

$\text{Total average ratio is } 99.869\%$
- Tues 024(100.00\%)
- Wed 024(100.00\%)
- Thu 024(100.00\%)
- Fri 024(100.00\%)
- Sat 024(100.00\%)
- Sun 024(100.00\%)

By Y.C. Liu
(Op. Gr.)

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dI/I < 0.1 % available at > 95% of Operational User Beam Time

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Injection efficiency > 80%

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Scheduled time delivered to the Users

> 98%

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Failure Analysis in 2005-2008
Vacuum trip < 1.4 events per 4 years

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Noise pickup to the gauge

The readings of the ion gauge near a kicker pulsed magnet were instantly changed and hung due to the noise pickup during kicker firing. It has been solved by wrapping the gauge sensor with EM shielded clothes and the cable with Al foil. The grounding of the chamber is isolated from that of pulsed magnets.
It has been found the irregular temperature rise near the Sector Gate Valve (SGV) when beam current is raised higher than 360 mA.
The SGV (VAT 47 Series) installed in the TLS storage ring

1. The irregular temperature rise (\( > 68 \, ^\circ \text{C} \)) on SGV at beam current \( > 360 \, \text{mA} \) can not be explained by irradiation heating from upstream synchrotron light which keeps the temperature of SGV stable (\( \sim 32 \, ^\circ \text{C} \)) at 300 mA.

2. The possible reason of irregular temperature rise might come from the higher impedance of RF shielding structure caused by the operation parameters of beam.
X-ray Photographs of SGV

- SGV fully opened
- SGV not fully opened
- RF fingers extended
- RF fingers shrink
R3SGV2 (RF fingers slightly deformed)
Conclusions

1. The TLS vacuum system is getting reliable after 15 years operation.
2. Aluminum beam ducts illustrate good performance for TLS.
3. TMP pumps for PSD beam cleaning at commissioning is efficient.
4. Gas load to the IP and NEG after beam cleaning is significantly reduced which keep the getter materials fresh and longer life time.
5. Non-metal sealed valves are not adequate for high reliable light source.
6. In-situ baking not only causes the problems of damage the vacuum components or positional shift due to thermal expansion, but also leave the heavy work loads and long time for the maintenance inside the tunnel. It is better to complete the baking for the vacuum components outside the tunnel and assure the good ultrahigh vacuum qualities being achieved, then using the super-dry N₂ purging and super-dry ambient air shower exposing system and procedure for the installation of UHV components to avoid the in-situ baking inside the tunnel.

Thanks for your attention!