Cryogenic System of the ILC Central Region in a Japanese Mountain Site

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  – Option A Cold box move with detector
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Central region is mainly composed of four sections from the cryogenics point of view.

1. IR region (underground)
2. Compressor station (underground)
3. Damping ring section (underground)
4. Helium gas storage yard (surface or underground)

Baby sitter type helium storage (Liquid helium storage method) is now considered.
• Push-pull operation will be applied to two detectors (SiD, ILD)
• QD0s are installed in both detectors. (move with detector)
• QF1 and CC are installed in the accelerator tunnel (do not move with detector)
Cooling conditions

Today's presentation is focused on cryogenics for detectors and QD0.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>$T_{cool}$</th>
<th>$T_{shield}$</th>
<th>Coolant</th>
<th>$P_{inlet}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiD</td>
<td>4.5 K</td>
<td>70 K</td>
<td>2pHe (Two phase cooling)</td>
<td>150 kPa-abs</td>
</tr>
<tr>
<td>ILD</td>
<td>4.5 K</td>
<td>70 K</td>
<td>2pHe (Two phase cooling)</td>
<td>150 kPa-abs</td>
</tr>
<tr>
<td>QD0</td>
<td>1.8-1.9 K</td>
<td>4K &amp; 70 K</td>
<td>pressurized HeII (105 kPa)</td>
<td>110 kPa-abs</td>
</tr>
<tr>
<td>Crab cavity</td>
<td>1.8-1.9 K</td>
<td>4K &amp; 70 K</td>
<td>saturated HeII</td>
<td>1.68 kPa-abs</td>
</tr>
<tr>
<td>Damping ring</td>
<td>4.5 K</td>
<td>4K, 70 K</td>
<td>supercritical He (400 kPa)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Heat Load / Cold Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiD</td>
<td>800 W / 130 ton at 4.5 K, 800 W / 165 ton at 4.5 K</td>
</tr>
<tr>
<td>QD0</td>
<td>15 W / * ton at 1.8 K,</td>
</tr>
<tr>
<td>Crab cavity</td>
<td>20 W / * ton</td>
</tr>
<tr>
<td>Damping ring</td>
<td></td>
</tr>
</tbody>
</table>
How to cool down?

- **Three cold boxes** will be installed in experimental hall to cool down all superconducting equipment (detectors, QD0, QF1, CC).
  - One for CC + QF1 → Conventional Cryogenics
    CC and QF1 don’t move with detectors.
  - One for ILD + QD0
  - One for SiD + QD0

→ Some technical difficulties because of following two reasons.
   1. Push-pull Operation
   2. Vibration problem for final focusing magnet, QD0.

   Allowable vibration level is 50 nm within the 1 msec long ILC bunch train

Today’s Talk is about cryogenic system for Detectors and QD0.
Cryogenic System for push-pull

• Two cryogenic options for cooling down the detector and QD0 are proposed.
  – Option A : Cold box moves with detector.
  – Option B : Cold box doesn’t move with detector.
Option A (2D top-view)

- CBs are installed on a platform for cryogenic equipment (green area).
- Standard Flexible tubes for helium gas line, CL cooling line, 2K vacuum line and quench recovery line should be employed for push-pull.
Option A (3D view of experimental hall)

- Cold box (2.0 kW at 4.5 K)
- Distribution Box (DB)
- Cable chain for Flex tubes
- Rigid tubes
- Utility space (6th floor)
- Cable chain for Flex tubes
- Rigid tubes
Option A (Side view)

Standard flexible Helium gas supply and return line between cold box and compressor. He gas temperature is 300 K

TRT between distribution box and chimney port.

Busbar for detector

Chimney port

TRT between QD0 and 2K refrigerator (Rigid)

2 K refrigerator for QD0s

Platform for cryogenic equipment

TRTs between distribution box and 2K refrigerator (Rigid)
Cryo & Vacuum Block Diagram of Option B

- **COMP**
  - Comp cavern
  - Utility cavern
  - Platform for Cryogenics (pushpull)

- **Buffer tank**
  - Platform for Detector & QD0 (pushpull)

- **2K refrigerator**
  - To buffer tank (QRL)
  - 2K vacuum line
  - 2K p-He (4.5K)

- **Chimney**
  - CL port
  - 4.5K LHe
  - 2p-He (4.5K)
  - To buffer tank (QRL)

- **6F utility space**
  - CB
  - DB
  - 7K SHe, S&R
  - 300K GHe, Sup & Ret
  - 70K GHe, Sup, Ret
  - 4K LHe, Sup, Ret
  - 2K p-HeII, Sup, Ret
  - Current lead cooling (CL port)
  - Quench recovery line (QRL)
  - 2K vacuum line
  - flex TRTs and tubes

- **QD0**
  - To buffer tank (QRL)

- **Utility cavern**
  - Buffer tank
  - Chimney
  - 70K GHe for shield
  - 4.5K LHe

- **QRL**
  - To buffer tank

- **CL port**
  - To buffer tank

- **300K G-He gas, Sup & Ret**
- **4K LHe, Sup, Ret**
- **2K p-HeII, Sup, Ret**
- **Current lead cooling (CL port)**
- **Quench recovery line (QRL)**
- **2K vacuum line**
- **flex TRTs and tubes**
Option B (2D Top view)

- CBs are installed on a utility space.
- On the contrary, DB is located on the platform for cryogenic equipment (Green area).
- In this case, helium condition in the TRT between CB and DB is not liquid but supercritical (7K, 400 kPa-abs).
- By doing so, cold flexible TRTs with one in one structures (without 70 K shield) can be employed because phase transition from liquid to gas does not occur.
- As a result, bending diameter of flexible one in one TRT becomes small.
Flexible TRTs are installed in the cable chain located on the utility space
*SHe (7K, 400 kPa) is supplied to distribution box
*Liquid helium is generated by JT valve installed in a DB.

Rigid TRTs are located between Flex-TRTs and DB.

CB is located on the utility space.
Option B (Side View)

- Cable Chain for cold flex TRTs for pushpull. (Flexible TRTs are installed in the chain)
- Cold Box
- Power Supply
- Rigid Type TRT between Flex TRT and Distribution box.
  - TRT between distribution box and chimney port.
  - Busbar for detector
  - Chimney port
- Detector QD0
- Support post for QD0
- TRT between QD0 and 2K refrigerator (Rigid)
- 2K refrigerator for QD0s
- Helium gas supply and return line between compressor and cold box. (Rigid)
- Platform for cryogenic equipment
Flexible TRT for Option B

- Helium condition between CB and DB should be 7 K supercritical helium (not 4 K Liquid helium).
- By doing so, one in one type Flex TRT for supercritical He (SHe) can be applied between CB and DB.
- If DB is installed next to the CB (utility space), helium condition in flex TRT is 4K Liquid helium → In this case, not one in one but multi layer Flex TRT (above) should be employed.
  → Bending Dia. of multi-layer TRT is at least 5m.
- Therefore liquid helium Dewar (Distribution Box, DB) should be installed on the platform
Flex Tubes installed in a Cable Chain in the case of “Option A”

- All flex. Tube (TRT) are installed in the following cable chain.
- All flex tubes are single (standard flexible tube)

<table>
<thead>
<tr>
<th>No</th>
<th>Tube installed in the cable chain</th>
<th>Structure</th>
<th>Tube Dia. (mm)</th>
<th>Num</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300 K helium gas supply line between CB and COMP</td>
<td>Single</td>
<td>60.5 mm</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>300 K helium gas return line between CB and COMP</td>
<td>Single</td>
<td>200 mm</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Helium gas vacuum line for 2 K refrigerator (for saturated He II)</td>
<td>Single</td>
<td>150 mm</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Quench recovery line</td>
<td>Single</td>
<td>150 mm</td>
<td>1~2</td>
</tr>
<tr>
<td>5</td>
<td>Current lead cooling line</td>
<td>Single</td>
<td>30 mm</td>
<td>1</td>
</tr>
</tbody>
</table>

Total number of Flex tube = 5 ~ 6
### Flex Tube installed in a Cable Chain in the case of “Option B”

<table>
<thead>
<tr>
<th>Tube name installed in the cable chain</th>
<th>Structure</th>
<th>Tube Dia. (mm)</th>
<th>Num</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 7 K supercritical helium supply line</td>
<td>One in One</td>
<td>OD~70 mm</td>
<td>1</td>
</tr>
<tr>
<td>2 4 K – 7 K helium gas return line</td>
<td>One in One</td>
<td>OD~70 mm</td>
<td>1</td>
</tr>
<tr>
<td>3 70 K shield helium supply line</td>
<td>One in One</td>
<td>OD~70 mm</td>
<td>1</td>
</tr>
<tr>
<td>4 70 K shield helium return line</td>
<td>One in One</td>
<td>OD~70 mm</td>
<td>1</td>
</tr>
<tr>
<td>5 Helium gas vacuum line for 2 K refrigerator (for saturated He II)</td>
<td>One in One</td>
<td>OD~70 mm</td>
<td>2</td>
</tr>
<tr>
<td>6 Quench recovery line</td>
<td>Single</td>
<td>150 mm</td>
<td>1~2</td>
</tr>
<tr>
<td>7 Current lead cooling line</td>
<td>Single</td>
<td>60.5 mm</td>
<td>1</td>
</tr>
</tbody>
</table>

To determine the actual number of quench recovery line, we have to perform simulation of thermo fluid dynamics during the detector quench.
Vacuum pump operation strategy

- **Vacuum pumps for adiabatic vacuum layer**

  Vacuum pumps have only to be operated during precooling operation. Once temperature is less than around 70 K, vacuum pumps should be stopped because cryo-sorption effect occurs under the condition.

  Therefore vacuum pumps for adiabatic vacuum layer is not regarded as vibration source of QD0.

- **Vacuum pump for 2K refrigerator (to obtain saturated superfluid helium)**

  Vacuum pump to obtain saturated superfluid helium has to be operated continuously during steady state operation.

  From the view point of vibration, vacuum pump for 2 K refrigerator should be located on the utility space. (Detail research on vibration should be performed.)

*Appendix:* Heat load of QD0 is relatively small, 15 W at 1.8 K, therefore we don’t have to employ cold compressor.
Vibration Source

We have to consider various kinds of vibration described below.

♠ Mechanical vibration from compressor.
♠ Mechanical vibration from cold box.
♠ Mechanical vibration from vacuum pump.
  · Oscillation from electrical transformer
  · Oscillation due to cooling water
♠ Vibration due to fluid motion.
  · Bellows oscillation
  · Oscillation and instability due to two phase flow.
♠ Vibration due to thermal instability
  · Taconis oscillation
♠ Vibration due to ground (seismic oscillation)
QD0 vibration requirement

Allowable vibration level is 50 nm within the 1 msec long ILC bunch train.

- QD0 is supported by pillar and support tube.
- QD0 is supported independent of detector.

Vibration is transmitted through TRT and platform.

Therefore the platform for detector and TRT should be designed such that vibrations become minimum.
Vibration Reduction

- Especially Option A is disadvantage from the viewpoint of vibration.
- To reduce vibration of QD0, **platform for cryogenic equipment** should be prepared in addition to platform for detector. All equipment with vibration source should be installed on the platform for cryo-equipment.
- Vibration absorber such as D2052 should be employed between these two platforms.

⇒ it is necessary to research vibration of QD0 (We have to do!)
An example of vibration reduction method

- D2052 with Mn, Cu, Ni, Fe etc. has the high logarithmic decrement for vibration.
- As for one reduction method, D2052 is employed between each platform.
Conceptual Flow Diagram

Compressor Station

Buffer

HEX

Adsorber

T1
T2
T3
T4

70 K He gas shield ret.
70 K He gas shield sup.
7 K helium sup.
7 K helium ret.

Turbine cooler

Cold box for detector and QD0

Quench Recovery Line

Chimney for detector

Distribution Box

TRT

Detector (SiD or ILD)

QRV

2 K refrigerator

QRV: Quench Relief Valve
DP: Diffusion Pump for CB and 2.0 K refrigerator.
T1 - T4: Expansion Turbine (T4 : Supercritical Turbine)
There is one JT valve (isenthalpic expansion valve) to obtain saturated liquid helium of 4.5 K which is regarded as a heat exchanger.

There are three HEXes (heat exchangers) in the liquid helium dewar.

DB supplies coolant of 4.5 K helium to chimney and 2K refrigerator when 7 K supercritical helium from CB is directory passed through the HEXes.

The installation location of the distribution box should be same level as the top of the detector.
The chimney has mainly two functions.

- One is to cool down the current lead which is cooled by forced convection cooling. Required mass flow ~ 3 g/sec at 20 kA.
- The other is to supply the detector cooling channel with the two phase flow of HE. We can choose cooling scheme of thermo syphon cooling or forced convection by controlling the V1 and V2 valves.
• 2 K refrigerator has the dewar for saturated He II which is regarded as heat exchanger to perform transition from normal liquid helium (He I) to pressurized He II.

• Pressurized-He II can be obtained when the 4 K liquid helium from distribution box passes the heat exchangers HEX(2).

• The 2 K vacuum line also can be regarded as a kind of heat exchanger (HEX1). Therefore the temperature of liquid helium from distribution box becomes decreasing to around less than 3 K.
Which option is better?

<table>
<thead>
<tr>
<th></th>
<th>Option A</th>
<th>Option B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>&lt; From the view point of Push-pull&gt;</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Flexible tube for push-pull</td>
<td>Warm (single)</td>
<td>Cold (one in one)</td>
</tr>
<tr>
<td>Bending Dia. of Flex TRT</td>
<td>~ 2.0 m</td>
<td>~ 2.2 m</td>
</tr>
<tr>
<td>Total number of Flex tube for push-pull</td>
<td>5~6</td>
<td>8~9</td>
</tr>
<tr>
<td>Heat Load between CB and DB</td>
<td>1.25 W (L=5m)</td>
<td>20.5 W (L=50 m)</td>
</tr>
<tr>
<td>Repair and Reliability of multiple TRT (Cold TRT)</td>
<td>Low broken rate</td>
<td>Easy to replace (by employing Bayonet joint)</td>
</tr>
<tr>
<td><strong>&lt; From the view point of Vibration&gt;</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold box location</td>
<td>Platform</td>
<td>Utility space</td>
</tr>
<tr>
<td>Vibration of QD0</td>
<td>Disadvantage ??</td>
<td>Advantage ??</td>
</tr>
<tr>
<td><strong>&lt; From the view point of Cost &gt;</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Cost of Flex line for push-pull</td>
<td>1 (Flex tube + TRT from CB to DB)</td>
<td>4.2 (Flex and Rigid TRT from CB to DB)</td>
</tr>
<tr>
<td>Total Production cost of cryogenic system (per 1 detector system)</td>
<td>1</td>
<td>1.032</td>
</tr>
<tr>
<td><strong>Present Score</strong></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Conclusions

- Present score is almost same between Option A and Option B from the various viewpoint.

- Option A has high reliability for push-pull because multiple flexible TRT is not employed but has disadvantage from the viewpoint of vibration.

- Option B has low reliability for push-pull compared with Option A because a lot of flexible one in one TRT has to be employed but if one of the Flex TRT is broken we can easily replace back-up one by employing Flex TRT with bayonet joint. The degree of freedom to reduce vibration of QD0 becomes high compared with Option A because CB is installed on utility space which is independent of the detector platform.

- To determine the cryogenic system for push-pull, following additional researches has to be performed.
  - Studies on vibration reduction method
  - Quench simulation from the viewpoint of thermo-fluid dynamics.
How to obtain a cryogenic scenario?

- **Experimental and numerical researches on vibration of QD0 should be performed.**

  - **Experimental research**
    - The best way to clarify the vibration characteristics of QD0 is to fabricate prototype of QD0 with pillar and support tube and to measure the vibration.

  - **Numerical research**
    - Eigen value problem with respect to large size of matrix has to be solved numerically,
      \[ \hat{A} \left| \phi \right\rangle = \lambda \left| \phi \right\rangle \]
    - Multi step mode superposition method developed by Kubo is good from the view point of parallel & high speed computing.
    - By solving inverse problem, we can obtain optimal solution to reduce vibration of QD0.
Vibration investigation procedure

(Numerical Approach)
1. PSD of vibration source (CB, vacuum pump, PS) are measured.
2. Seismic oscillation with respect to site is also measured.
3. Eigen value problem is solved numerically by means of measured PSD.
   Measured PSD is given as an input condition.
4. Response function, $G$, can be obtained from numerical simulation.

(Measurement)
1. Prototype QD0 with support post and pillar is fabricated.
2. Artificial vibration is given to prototype QD0.
3. Output vibration amplitude is measured by means of three laser displacement meter.
4. We can obtain response function, $G$, from measurement result.
   
   \[ G \sim \frac{\text{PSD OUT}}{\text{PSD IN}} \]
5. We can also evaluate the validity of numerical simulation by comparison with measured $G$

(Research vibration reduction method)
1. After the confirmation of validity of numerical simulation,
   inverse analysis is performed to find optimal vibration reduction method.