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BASELINE CONFIGURATION OF THE CRYOGENIC SYSTEM FOR THE INTERNATIONAL LINEAR COLLIDER

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The paper discusses the main constraints and boundary conditions and describes the baseline configuration of the International Linear Collider (ILC) cryogenic system. The cryogenic layout, architecture and the cooling principle are presented. The paper addresses a plan for study and development required to demonstrate and improve the performance, to reduce cost and to attain the desired reliability.

INTRODUCTION

Following a decision of the International Technology Recommendation Panel (ITRP) which has been endorsed by the International Committee on Future Accelerators (ICFA), a Global Design Effort (GDE) has been launched in 2005 to study a TeV scale electron-positron linear accelerator based on superconducting RF (SRF) technology and called the International Linear Collider (ILC). The ILC will accelerate and collide electrons and positrons and will consist of an electron source, a positron source, an electron damping ring, two positron damping rings, two “Ring To Main Linac” (RTML) sections, two main linacs and a beam delivery system. The main linacs which constitute the largest part of the project are composed of 1.3 GHz multi-cell SRF cavity modules and superconducting quadrupoles immersed in a saturated bath of superfluid helium at 2 K. The electron source includes a 5 GeV pre-accelerator. The positron source includes a 5 GeV booster, a superconducting undulator and a keep-alive system. The damping rings are composed of 650 MHz single-cell SRF cavity strings and superconducting wigglers operating at 4.2 K. The beam delivery system includes 3.9 GHz SRF “crab” cavities and final-focusing doublets operating at 4.5 K. In a first stage, two 11 km linacs will produce a center-of-mass energy of 500 GeV using an average accelerator cavity gradient of 31.5 MV/m. In a second stage, the center-of-mass energy could be upgraded to 1 TeV by extending the two linacs up to 20 km using average cavity gradient of 36 MV/m. Figure 1 shows the overall layout of the ILC linear collider. In the first stage

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about 2150 SRF cavity modules (all types) and 1140 superconducting magnets (all types) will be required.

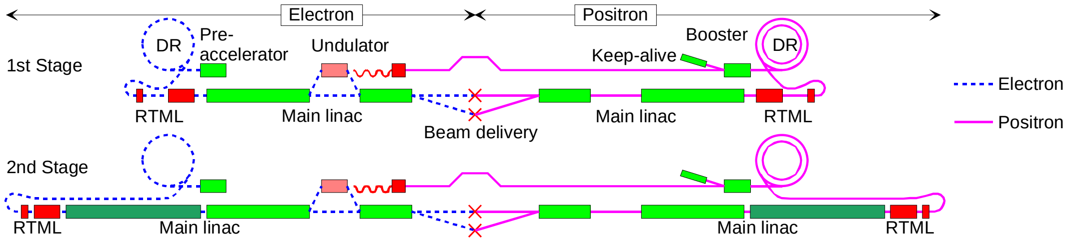

Figure 1 Overall layout of the ILC linear collider

MAIN CONSTRAINTS AND BOUNDARY CONDITIONS

As the ILC site is not defined yet, the cryogenic system must be able to accommodate different configurations of tunnel and civil works. The tunnel can follow the earth’s curvature or can be laser-straight with a maximum slope of up to 0.6 % creating large elevation differences. To avoid harmful instabilities, all fluid should ideally be transported over large distances in a mono-phase state. Local two-phase circulation of saturated liquid can be tolerated over limited lengths, within a controlled range of vapour quality. The tunnel can be shallow excavated, i.e. with depth of access shafts smaller than 30 m, allowing the installation of all the cryogenic above ground. The tunnel can also be more deeply excavated. In this case, certain components which must be close to the cryostat or which cannot be installed at ground level because of the hydrostatic head will have to be installed underground.

The ILC cryomodule cryostat is based on the TTF III design [1] which contains all the cryogenic pipework inside its vacuum enclosure. Three temperature levels are present: the 40-80 K level for thermal shielding and first heat intercept level; the 5-8 K level for thermal screening and second heat intercept level; and finally, the 2 K level for cooling of the superconducting devices.

CRYOGENIC LAYOUT AND ARCHITECTURE

In the first stage, each main linac will be divided in 5 cryo-units each of them containing 192 or 180 cryomodules resulting in cryo-unit lengths of 2.27 km and 2.13 km, respectively. Each cryo-unit will be cooled by a dedicated 2 K cryoplant [2]. Two of these cryoplants will be also used to cool half of the 1.2 km-length undulator in the electron main linac tunnel. Two additional 2 K cryoplants will be dedicated to cool the RTML and the pre-accelerator in the electron side, and the RTML, the booster and the keep-alive system in the positron side. Four 4.5 K cryoplants will be distributed in alcoves of each 6 km-long damping ring tunnel to cool the SRF cavities distributed in 4 locations and the wigglers in 8 locations. Figure 2 shows the layout of the ILC cryogenic system. In total, twelve 2 K and ten 4.5 K cryoplants will be needed in the first stage. Table 2 gives the distributed heat loads in the main linacs. Concerning the contingency, an uncertainty factor of 1.5 has been applied on the static heat inleaks and an overall overcapacity factor of 1.4 has been applied. Table 3 gives the required capacities of the cryoplants for the different area systems. The maximum required unit capacities equivalent at 4.5 K and at 2 K are compatible with the present state of the art already used for the Large Hadron Collider [3]. In the first phase, a total installed power equivalent to 254 kW at 4.5 K including 45 kW at 2 K corresponds to an unprecedented level of refrigeration.

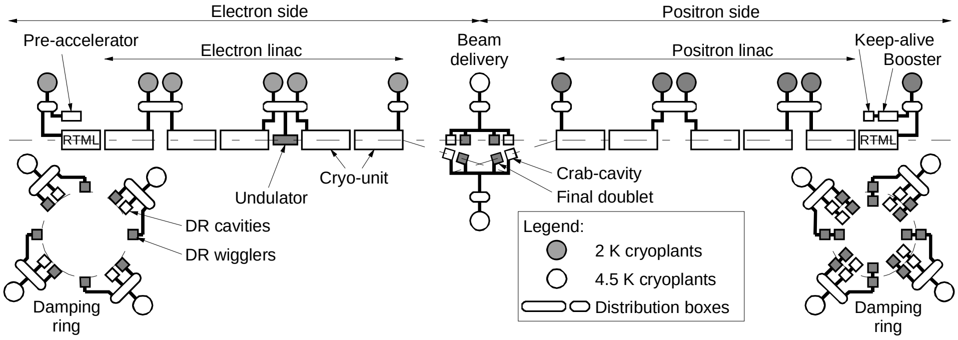

Figure 2 First-stage cryogenic layout

Table 2 Main linac distributed heat load [W/m]

Temperature level	40-80 K	5-8 K	2 K
Static heat inleaks	6.7	1.2	0.4
Dynamic heat load	8.9	0.4	0.7
Total without contingency	15.6	1.6	1.1
Total with contingency	26.5	3.1	1.8

Table 3 Cryoplant inventory and capacity requirement [kW]

System	Nb	Temperature level				Equivalent unit capacity @ 4.5 K
		40-80 K	5-8 K	4.5 K	2 K	
Main Linac and undulator	10	60	7.0	N/A	4.1	22
Electron RTML and pre-accelerator	1	25	2.9	N/A	1.7	9.2
Positron RTML, booster and keep-alive	1	26	3.0	N/A	1.8	9.5
e- damping ring	4	2.6	N/A	0.6	N/A	1.2
e+ damping ring	4	4.9	N/A	1.1	N/A	2.9
Beam delivery	2	2	N/A	0.6	N/A	0.7

COOLING PRINCIPLE

Series architecture is basically used in the cryo-unit cooling scheme. The 5 K heat intercepts and radiation screens are cooled in series at the 5-8 K temperature level; the 40 K heat intercepts and thermal shields are also cooled in series at the 40-80 K temperature level. The exception is the cavity cooling at 2 K for which a parallel architecture is implemented with the parallel cooling of cryo-strings resulting in operational flexibility. Consequently, each cryo-unit is sub-divided in 16 or 15 cryo-strings which correspond to the 142 m-length elementary block of the cryogenic refrigeration system. Figure 3 shows the cooling scheme of a cryo-string which contains 12 cryomodules. The cavities are immersed in baths of saturated superfluid helium gravity filled from a 2 K two-phase header. Saturated superfluid helium is flowing all along the two-phase header for filling the cavities and phase separators located at both ends of the two-phase header. The first phase separator is used to stabilize the saturated liquid produced during the final expansion. The second phase separator in used to recover the excess of liquid which is vaporized by a heater. At the interconnection of each cryomodule, the two-phase header is connected to the pumping return line.

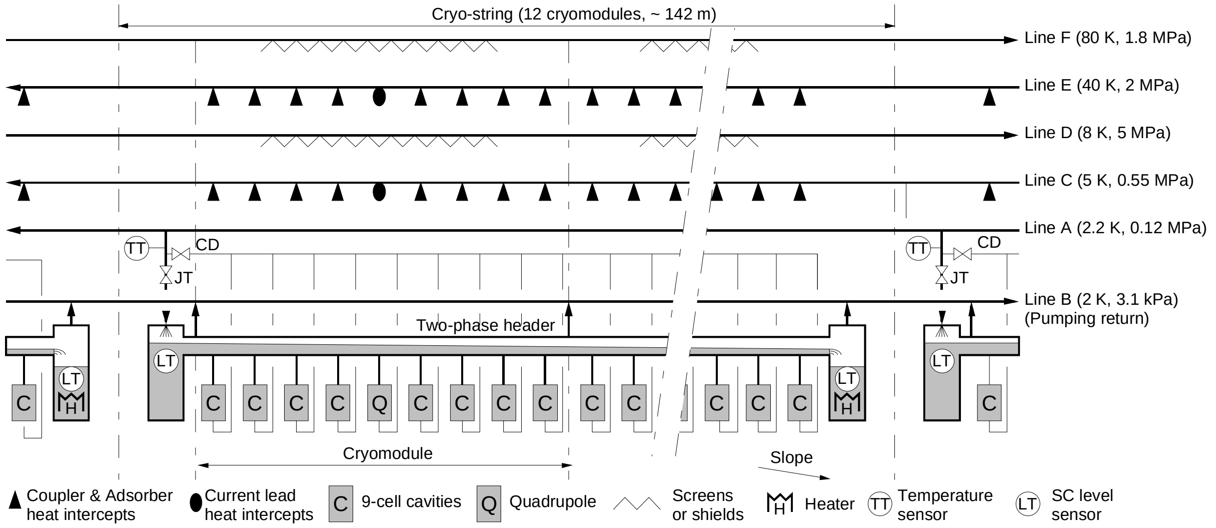

Figure 3 Cooling scheme of a cryo-string

STUDIES AND DEVELOPMENTS REQUIRED

In order to consolidate the technical choices of the baseline configuration, reduce the cost and improve the filling factor, operation availability and reliability, studies and developments are required on:

- smaller sub-sectorization to reduce the maintenance unit length,
- thermo-mechanical optimization of the cryomodule,
- mechanical stability of a cryo-string assembly,
- larger cryoplant to increase the cryo-unit length,
- two-phase superfluid helium flow pattern and cooling limitations with respect to slope and string length,
- efficient control strategies to limit the use of electrical heating during transient and steady-state operation.
- sub-cooling heat exchangers with capacity 10 times larger than the present state of the art.

CONCLUSION

The baseline configuration of the cryogenic system for the International Linear Collider has been defined. In total 22 cryoplants will be required in the first stage to cool the different area systems. A total equivalent installed capacity of 254 kW at 4.5 K corresponds to an unprecedented level. Some study and development will be required to validate the different technical choice, improve the reliability and reduce the cost.

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