Proposal to adopt a single tunnel configuration for the ILC main linac

Submitted by ILC GDE Project Managers for consideration as a Baseline Change Request, 28 September, 2010.

Introduction

The proposal to adopt a single tunnel solution for the Main Linac technical systems remains essentially that outlined in the SB2009 report. The primary motivation was and remains a reduction in project cost due to the removal of the support tunnel for the Main Linac. (The service tunnel for the BDS remains.)The original proposal was based on the utilization of two novel schemes for the HLRF:

- Klystron Cluster System (KCS). KCS has been identified as a preferred solution for 'flat land' sites where surface access (buildings) is not restricted
- Distributed RF System (DRFS). DRFS has been identified as being the preferred solution for mountainous region where surface access (buildings) is severely limited.

It is acknowledged that both these schemes require R&D (briefly described below). Having both R&D programmes in parallel can be considered as risk-mitigation against one or other of them failing.

At the beginning of the cost-reduction studies (2008), the two primary obstacles to adoption of a single tunnel were identified as:

- safety egress
- operations and availability.

Both these issues were subsequently addressed, and the successful results reported in the SB2009 proposal (submitted December 2009). The conclusions were later accepted by both AAP and PAC.

The remaining identified issues were the technical feasibility and cost of the HLRF solutions upon which the single-tunnel proposal was based. Two components to successful adoption were identified:

- Definition of acceptance criteria for TD Phase R&D for successful demonstration of one or more of the novel HLRF schemes.
- Inclusion in the designs of a risk-mitigation strategy, whereby a fall-back to the RDR HLRF Technology solution could be adopted, should the R&D on DRSF or KCS not be considered successful. In this context, *RDR HLRF*

Technology is defined to mean the technology based on a 10 MW multi-beam klystron (MBK) and a local rectangular waveguide power distribution system directly feeding a few cryomodules.

Technical Issues with DRFS

The basic concept of the configuration (a feasibility demonstration) will be tested this year at S1-global. A DRFS klystron has been designed and two are on order. Preparation for the S1-global test has advanced the DRFS design in 2010, generating substantial progress since January. Technical issues that remain include an evaluation of cost effectiveness (a cost estimate is due in 2011), klystron MTBF (scaled from KEKB linac S-band klystron performance), and radiation sensitivity for tunnel hardware (to be updated based on both XFEL experience and further experimental studies). Significant progress on RF power overhead analysis has been made, which has impact on the number of klystrons and the AC power requirements. Additional power margin is required to accommodate the proposed *gradient spread*, which is summarized in a separate recommendation. (See DRFS overview, slide 9; 800 KW is 14% more power than foreseen in RDR.)

Technical Issues with KCS

Full field tests of prototypes of all critical KCS components will be performed within the TD Phase. The stored energy in the test waveguide, which could be deposited during a breakdown test, is expected to reach about $1/6^{th}$ of that available in a full ILC system discharge. A ten-meter section of waveguide and Co-axial Tap Off (CTO) prototypes have been successfully built and cold-tested in 2010. In addition, there was significant progress in understanding operational aspects. (For new estimates of the required overhead, see KCS Overview, slide 46. Neglecting RF power devoted to availability, 14% more power is needed). As above, some of this is to accommodate the proposed *gradient spread*, which is reviewed in a separate recommendation. Technical issues that remain include better understanding of the extrapolation of proposed tests to full system, quantification of system tolerances and assumptions (combiner etc.), and the development of an improved, detailed failure mode analysis.

RDR HLRF Technology Solution (back-up)

Two scenarios have been briefly studied for support of an RDR HLRF Technology solution in a single-tunnel:

1. 10MW MBK + Modulator in the single tunnel
2. XFEL-like solution with modulators (10% voltage) accessible in cryo refrigeration buildings/caverns, with long HV pulse-cables feeding 10MW MBKs (via a pulse transformer) in the single tunnel.

Both are considered technically feasible. (The latter is currently being constructed and will be operated at the European XFEL in 2014.)

For scenario 1: Early investigations show the tunnel diameter would need to increase to 6.5m from 5.7m. This represents an estimated 10% increase in cost/unit tunnel length compared with the proposed DRFS tunnel unit cost (~0.5% TPC) and is considered acceptable. (Note this cost increase is not the same in each region – 10% represents an average). Current availability simulations suggest an additional ~5% linac overhead is needed beyond that estimated for DRFS (see below and SB2009 proposal).

For scenario 2: Additional space for modulators in halls/caverns is required. Cost of ~3000 km of pulsed cable will be required. The tunnel cross-section will need to be reconfigured to accommodate the cables (cf XFEL design). Current availability simulations suggest an additional ~2.5% linac is needed(see below and see SB2009 proposal).

It is proposed that these RDR-like single-tunnel solutions be carried forward in parallel with the proposed baseline configurations (KCS, DRFS), in enough detail to support a cost estimate (incremental). This estimate, together with the scope of the re-design work necessary to adopt one of the scenarios, will be factored into the TDR Risk Assessment. The main R&D and AD&I effort will continue to pursue the preferred baseline solutions, KCS and DRFS. In order to reduce the number of scenarios to be supported, we propose to phase out one of the RDR HLRF Technology scenarios within the next six months.

Technical issues with RDR HLRF Technology option

We will follow EU XFEL developments closely during the TD Phase (and beyond) as this requires no additional ILC R&D resources. No specific ILC-related R&D is proposed at this time. Some AD&I activity (layout/design work) will be required for feasibility and cost analysis. The goal would be to allow a rapid adoption into the design and cost for the TDR if necessary.

Comments on Availability

Availability Task Force (AvTF) report (included as appendix in SB2009 proposal) concluded that a 10% linac overhead was required for an RDR HLRF Technology single-tunnel solution (RDR scenario 1), compared to 3.5% for KCS and 5% for DRFS. These estimates were based on 40kHr MTBF for MBK and 50kHr MTBF modulator. Scenario 2, the EU-XFEL like option that provides unrestricted access to the modulator, was not directly studied. We assume the additional overhead is required is reduced by a factor of two to 6.5% in this case (to be confirmed). The simulation (and assumptions) need review (work for the AvTF in TDP2). Higher MTBF is expected for the Marx modulator, now under development, which would affect scenario 1. Also, Toshiba quoted 100kHr for their MBK (needs review). We expect to be able to reduce the linac overhead required for the RDR HLRF Technology single-tunnel back-up solution.

In the AvTF report, the availability difference between KCS and DRFS was considered to be a small effect; either system was considered adequate. However, the additional 5% linac overhead, (beyond that suggested for DRFS), needed for the RDR HLRF Technology option was not deemed to be a small effect and additional study was suggested. The cost increment for the linac overhead will be evaluated using the same guidelines as used in the RDR.

CFS Solution for Single-Tunnel in a Mountainous Region (Japan)

Current site studies in Japan represent a significant step forward from 'conceptual/generic' sample site designs presented in the RDR. Analysis by experienced tunnel construction engineers have proposed the need for a pilot tunnel to reduced risk associated with the boring of the main accelerator tunnel. This pilot tunnel, while not considered mandatory for safety, could be beneficially incorporated into the accelerator tunnel emergency egress strategy. The single main tunnel concept is retained and houses all the linac technical components. The pilot tunnel will remain relatively 'basic', supporting only water drainage and emergency egress. The report on their analysis of a 'single tunnel scheme in a mountainous region' is available (paper copy).

Costing for the Asian CFS solution will not be available until the end of 2011.

Costs (General)

The cost reduction expected from this proposal is 2.0% (KCS) and 1.5% (DRFS) (SB2009). We will have an estimate of the cost of the single tunnel in a mountainous region in about one year. For RDR HLRF Technology scenario 2, assuming the tunnel diameter increase is roughly ½ of that needed for scenario 1, we estimate the proposal cost reduction to be 1.3%.

Reference: SB2009 Proposal Document

- Introduction to the single-tunnel solution (Section 2.2.2),
- Technical descriptions of the two HLRF variants KCS and DRFS (Section 4.6),
- Overview of the revision to the CFS design (Section 4.8.3)
- Cost study of the change (Section 5).
- Operational availability of the single-tunnel design (Appendix 1).

Reference: R & D Plan Release 5

- Distributed RF System (DRFS) test at S1-Global (Section 4.2.5)
- Klystron Cluster Scheme R&D (Section 4.5.3)
- Distributed RF System R&D (Section 4.5.4)

2010 technical presentations

- DRFS Overview
- KCS Overview

- Single-tunnel scheme for a mountainous site

Reference: RDR HLRF Technology back-up solution

- XFEL-like solution applied to ILC
- Singe-tunnel solution for a mountainous site
- Current XFEL single-tunnel design status

Reference Design Report (2007)

- Klystrons (Section 3.4 / pdf page 177) and Waveguide (Section 3.5/pdf page 181)

Peter Garbincius to provide cost information on request