DISTRIBUTED RF SCHEME (DRFS) - NEWLY PROPOSED HLRF SCHEME FOR ILC

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Abstract

The Baseline Conceptual Design (BCD) of the superconducting ILC main linac (ML) assumes 2 tunnels and the reference design report (RDR) based on that. However due to the high cost of construction, a single tunnel proposal has been developed. Two supporting plans, the klystron cluster scheme (KCS) and the distributed RF scheme (DRFS) are under intensive study by the ILC global design effort (GDE). In this report, we present the details of the DRFS configuration. We also discuss the availability and a maintenance plan. Critical items and the demonstration plan for the DRFS are also described.

INTRODUCTION

The BCD of the ILC has been based on the 2-tunnel plan since ITRP recommended the technical choice of ILC to be superconducting. Thereafter, through extensive design effort, a maintenance scheme, associated availability considerations and a cost evaluation have been performed and subsequently reported in the RDR[1]. The high estimated cost forced us to consider other schemes, such as a single tunnel scheme. There are several variants of a single tunnel plan: (1) a EU-XFEL (DESY) like plan, (2) a shallow tunnel plan having a klystron gallery on the surface, (3) the klystron cluster scheme (KCS), and (4) the distributed RF system (DRFS). Among these, the last two schemes have been promoted and discussed as the most likely candidates. Along with other technical revisions to the ILC plan, these last two schemes were described in the report of SB2009 [2]. In Figure 1, main proposed schemes are summarized showing a comparison of various features.

In KCS, all equipment to generate the L-band RF power is situated in surface buildings rather than in the underground tunnel. RF waveguides are implemented to connect the power sources outside the tunnel and the cavities inside the tunnel. Power from 35 10MW multibeam klystrons (MBK) is combined into an overmoded circular waveguide, brought into and along the linac +/- 1.3km, and finally delivered to each RDR RF unit, (10 MW to each). One unit of KCS feeds power to about 832 super-conducting (SC) cavities.

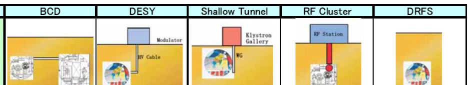
	BCD	DESY	Shallow Tunnel	RF Cluster	DRFS
Scheme					
Deep/Shallow	Deep	Middle	Shallow	Middle	Deep
Civil Cost	High	Middle	Shallow tunnel cost	?	Cheep
Cooling Cost	○	◎	◎	◎	○
Heat source	Heat source of RF in the tunnel	Modulator on the surface	Heat source of RF on the surface	Heat source of RF on the surface	Heat source of RF in the tunnel
Site Dependence	OK	Japan Mountain Site	Dubna OK Japan ?	Japan -> longer WG	OK
LLRF handling	○	○	○	△	◎
Vector Sum	26 cav. Vector Sum	26 cav. Vector Sum	26 cav. Vector Sum	780 cav. Vector Sum	1 to 1
Redundancy	○	○	○	△	◎
Kly Failure Impact	26 Cavity Stop	26 Cavity Stop	26 Cavity Stop Easy Klystron Replace	Easy Klystron Replace	Scattered failure section
Other Issues		Long HV Cable		Long Vacuum WG System	Very Simple Configuration
R&D Cost	○	○	○	△	◎
Test Facility	3 Cryomodule/26 Cavity= 1 RF unit	3 Cryomodule/26 Cavity= 1 RF unit	3 Cryomodule/26 Cavity= 1 RF unit	Difficult to evaluate one minimum unit	Very small system
Total Cost					

Figure 1: Comparison among BCD plan and several proposed single tunnel plans.

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The DRFS, alternatively, has all the equipment to generate the RF power situated inside the underground tunnel, together with the RF waveguide. It is a complete self-contained single tunnel plan. Every RF source is comprised of a small 800kW klystron that feeds power to two or four cavities depending which of two power options is adopted. DRFS is described in detail in this paper.

GENERAL DESCRIPTION OF DRFS

System Description

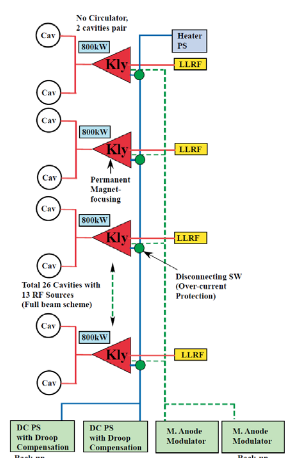

Figure 2: DRFS system.

In the BCD, a 10MW Multi Beam Klystron feeds power to 26 SC cavities. The ILC Main linac has 560 RF units with about 14560 SC cavities. Since RF power is pulsed, power is reflected back from the cavity at the pulse rising time and pulse falling time. If, instead, one klystron feeds power to two SC cavities with the correct phase difference, it is possible to cancel the reflected power. Therefore, the basic DRFS employs an 800kW klystron feeding the power to two SC cavities. In DRFS 7280 800kW klystrons are used. This klystron is a modulated-anode type klystron and the cathode is connected to a DC power supply. The modulation anode (MA) is connected to a MA modulator and the klystron beam is pulse modulated. The energy needed for the pulsed power is supplied by a DC power supply. This configuration is cost effective and allows easy expansion. Many facilities, such as J-Parc, use this scheme. Figure 2 shows the schematic drawing of the DRFS. The basic plan employs a DC power supply and a MA Modulator, which supply a DC high voltage and a pulse modulation to 13 MA klystrons feeding 26 SC cavities, which correspond

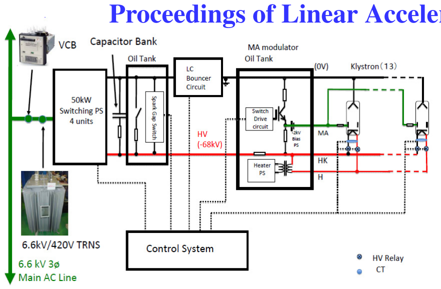

Figure 3: Block diagram of the HLRF circuit.

to one RDR RF unit. In order to realize high reliability, every two RDR units are linked to a backup unit, which will be designed and implemented to be "swappable". Each of the power and voltage distribution circuits will have high-voltage switches or relays to take them offline when an over current failure is detected. The filament power supply is common for 13 klystrons and this has an impact on estimated availability. Permanent magnet focusing is employed to reduce failures and eliminate the power supply for solenoid coil. The block diagram of the high level RF (HLRF) circuit is shown in Figure 3. The power distribution system (PDS) is relatively simple and includes: directional couplers, flexible wave guides, a fixed phase shifter and power dividers. In order to reduce cost, a circulator is not used in the PDS, which requires cavity sorting and grouping to cavities with similar loaded Q (Ql) and RF power (Pk) requirements. The reflected power is expected to be cancelled out. Table 1 shows the main system parameters.

Table 1: Specification Parameters for the DRFS

Klystron	Frequency	1.3	GHz
	Peak Power	800	kW
	Average Power Output	8.00	kW
	RF pulse width	1.5	ms
	Repitition Rate	5	Hz
	Efficiency	60	%
	Saturated Gain		
	Cathode voltage	65.8	kV
	Cathode current	20.3	A
	Perveance(Beam@65.8k	1.2	micro Perv
	(Gun@54.4 kV)	1.56	micro Perv
	Life Time	120,000	hours
	# in 3 cryomodule	13	
	Focusing	Permanent magnet	
	Type of Klystron	Modulated Anode Type	
DC Power supply per 3 cryomodules			
	# of klystron (3 cryomod	13	
	Max Voltage	71.5	kV
	Peak Pulse Current	264	A
	Average Current	2.67	A
	Output Power	177	kW
	Pulse width	2.2	ms
	Repitition Rate	5	Hz
	Voltage Sag	<1	%
	Capacitor	26	mF
Bouncer Circuit			
	Capacitance	260	mF
	Inductance	4.9	mH
M. Anode Modulator			
	Anode Voltage	54.4	kV
	Anode Bias Voltage	-2	kV

Hardware Installation Layout for DRFS

After considering various layout schemes, we settled on the tunnel scheme shown in Figure 4. The tunnel diameter is 5.7m and the cryomodules are installed on the floor. High level RF (HLRF) and other related components are installed in the opposite side of the tunnel which lies behind a radiation shield wall. In this component area, 6.6kV electricity with vacuum circuit breaker (VCB), DC power supply, MA modulator, 13 DRFS klystrons, control and LLRF racks, and backup modules are installed. RF power is transferred from klystron to cryomodule through a waveguide chase-way in the floor. The central passage is used to install cryomodules and it facilitates the exchange of failed components. The central passage includes a 0.5m wide egress space that allows a person to escape from unexpected disaster, even during installation. There is an exhaust channel space in the ceiling that can be used if a helium leak accident occurs.

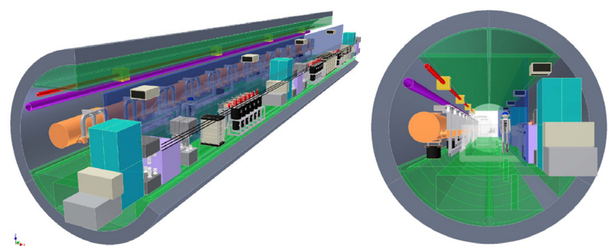

Figure 4: Tunnel layout. Left: bird's eye view and right: cross sectional view.

Upgrade Pass from the Initial Scale-Down Plan to Baseline Plan

In order to reduce initial construction costs, a cost saving plan for the initial stage is considered in the SB2009 document. In this cost saving plan, two scenarios are considered. One is the same energy as RDR but the beam current is half (4.5mA). This is called low power option. Another is half the energy of RDR, with a beam current of 4.5mA, but the repetition rate is double that of the RDR (10pps). This is to be used for low energy operation. In order to prepare for these two scenarios, initial layouts of the construction and upgrade path have been considered. In both scenarios, the number of HLRF components is half the nominal in order to save the cost. In this case, an 800kW klystron feeds power to 4 SC cavities and the PDS configuration differs from the baseline design, requiring an extra power divider. For the low energy option, an applied voltage to the klystrons is low, corresponding to half the power of the RDR, but repetition rate is double that of the RDR. In order to keep the total electric efficiency, special adjustment of the

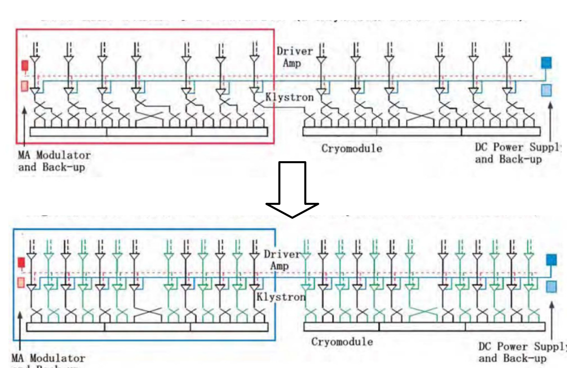

Figure 5: Upgrade pass from low power option to baseline layout.

klystron is required so the klystron efficiency is not decreased. In order to keep the klystron efficiency nominal in the lower voltage application, the micro-perveance of the MA klystron is changed from 1.2 to 0.8 by changing voltage ratio of MA electrode and cathode electrode, therefore by changing the resistor's dividing ratio of MA modulator. At the same time, the Q_{ext} of klystron output cavity is changed by inserting an iris in the PDS. Fortunately these modifications are possible done without a serious design change. In Figure 5, upgrade path from the low power option to the baseline layout is shown.

Availability and Maintainability

Since all components are installed in the single tunnel in DRFS, any failures that interrupt operation should be minimized, and great care for the availability has been considered in system design. Therefore the mean time between failures, (MTBF), of the main components which possibly affect to the beam operation is evaluated. For the roughly 8000 DRFS klystrons, an MTBF of 110,000 hrs has been assumed, based on the operational experience of the injector linac at KEK. With 5khr operation hours per year, 325 ILC tubes are expected to fail on average, corresponding to 4.5% of the total. If the energy overhead of the ML is more than that, the replacement of failed klystrons can wait for the long annual shut down. Since overhead is expected to be around 3%, klystron replacements would be take place during two shut downs a year. For the DC power supply and the MA modulator, which have MTBF much lower than that of the klystrons, a back-up dc power supply and an MA modulator are introduced in every two RDR units as redundancy. We considered other availability issues, and after completing the failure analysis described in SB2009, the allowable unscheduled downtime for reasonable energy overhead was obtained in DRFS.

As part of the availability study, a maintenance scenario was developed and required human resources and time were estimated and determined to be a manageable level for human resources and time.

LLRF for DRFS

The DRFS klystron feeds power to a small number of SC cavities. Compared to the RDR and KCS, the operability is good when a SC cavity quenches or deteriorates because a quick switch from deteriorated one to spare one can be done by LLRF control. At present, variety of cavity gradients, 31.5MV/m +-20%, is to be accepted. This means in practice that cavity gradients will vary from 25MV/m to 38MV/m. In DRFS, cavity matching is required since no circulators are used. Usually 20% of LLRF feed back overhead is assumed to use the linear region for the output power vs. input power characteristics. For driving 38MV/m cavities by adopting the cavity grouping, we will be limited to a small overhead of only 10%. We propose the DRFS system without any variable power tap-off, but if cavity deterioration after installation happens frequently, we will need to introduce a variable power divider to optimize the system.

Concern about the Radiation Damage

There are grave concerns about radiation damage to the key components since all components are installed in the tunnel. Since the EU-XFEL at DESY has a similar configuration, they have evaluated and reported this radiation effect against the key components, and proposed to have a shield combining 10cm heavy concrete and 1cm lead [3]. So we introduced a radiation shield wall having the same thickness as that. It will be necessary to watch and learn from the operation of XFEL, but at the same time, we have a plan to evaluate this effect, especially for the effect against the semiconductor SW which is believed to be low radiation durability. If extra shield is necessary, evaluation is mandatory.

R&D AND DEMONSTRATION OF DRFS

There are lot of R&D items to complete the DRFS design, and it is necessary to show the feasibility by constructing at least one DRFS RF unit. At KEK, the S1 global test, a plan to evaluate SC cavity gradient with an international collaboration is underway. By the end of 2010, two units of DRFS are to be constructed and demonstrated. One DC power supply and an MA modulator will drive two MA klystrons. Figure 6 shows the layout of the DRFS in S1 global project.

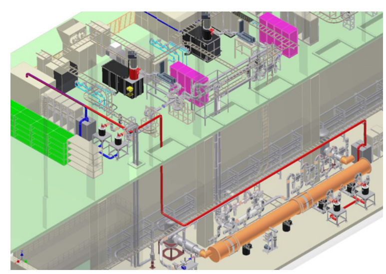

Figure 6: Layout of DRFS on S1 global.

SUMMARY

One of the ILC single tunnel plans, DRFS system is described in detail in this presentation. The conceptual design is finished and a more detailed technical design has been performed. Furthermore, a feasibility study including availability, operability and maintainability will be studied. A demonstration of DRFS is planned in 2010 showing a realistic DRFS configuration.

REFERENCES

[1] ILC Reference Design Report- Accelerator, 2007, http://www.linearcollider.org/cns/?pid=1000437.

[2] SB2009 Proposal Document, Rel. 1.1, 2009, http:// ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edm sid =D000 00 000900425.

[3] B. Mukherjee, et. al.,"Efficiency testing of shielding materials for XEFL using the radiation fields produced at FLASH", TESLA-FEL 2008-06.