JLC PROGRESS

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Abstract

The JLC is a linear collider project pursued in Japan by researchers centered around KEK. The R&D status for the JLC project is presented, with emphasis on recent results from ATF concerning studies of production of ultra-low emittance beams and from manufacturing research on X-band accelerator structures.

1 INTRODUCTION

Major elements of the current R&D activities for the JLC project[1] includes: development of polarized electron sources[2], experimental studies of a damping ring[3], development of X-band technologies as the main scheme for the main linacs, and C-band RF development as a backup technology for the main linacs[4].

Figure 1 shows a schematic diagram of JLC. The target center-of-mass energy is 250∼500 GeV in phase-I, and ∼1 TeV or higher in phase-II. Since 1998, through an R&D collaboration (International Study Group – ISG) which was formalized between KEK and SLAC[5], development of hardware elements for the X-band main linacs has been pursued based on the basic parameters common to both JLC and NLC[6]. Tables 1 and 2 give the most up-to-date basic machine parameters that have been chosen as a result of optimization process in ISG discussions.

Table 1: Partial list of representative JLC parameters as of April, 2000 [5], if the main linacs are built based on the X-band technology.

Item	Value	Unit
#Electrons / bunch	9.5×10^9	
#Bunches / train	95	
Bunch separation	2.8	ns
Train length	263.2	ns
RF frequency	11.424	GHz
RF wavelength	26.242	mm
Klystron peak power	75	MW
Length / cavity unit	1.8	m
a/λ	average 0.18	
Filling time	103	ns
Shunt impedance	90	MΩ/m
E_{acc}(no-load)	72	MV/m
E_{acc}(loaded)	56.7	MV/m
Normalized emittance	3.0×0.03 (Linac)	10^{-6}m.rad
	4.5×0.1 (IP)	10^{-6}m.rad
Bunch length	120	μm

Table 2: Representative JLC parameters (continued), if the main linacs are built based on the X-band technology. Parameters that would vary for $E_{\rm CM}$ =500 GeV and 1.0 TeV are shown.

$E_{\rm CM}$	500 GeV	1 TeV	
#cav/linac	2484	4968	
#klystrons/linac	1584	3312	
Length/linac	4.3	8.9	km
P(wall-plug)	94	191	MW
Rep. rate	120	120	Hz
$\beta_x^* \times \beta_y^*$	12×0.12	12×0.15	mm×mm
$\sigma_x^* \times \sigma_y^*$	330×4.9	235×3.9	nm × nm
$< -\Delta E/E >$ due to BSM	4.0	10.3	%
Lum. pinch enhancement	1.1	1.43	
Luminosity	7×10^{33}	13×10^{33}	cm^{-2}s^{-1}

This paper presents the R&D status of the JLC project, with strong focus on (i) the most recent results from ATF concerning studies of production of ultra-low emittance beams and (ii) manufacturing research on X-band accelerator structures.

2 ATF

The Accelerator Test Facility (ATF)[3] at KEK (see Figure 2) is a test bed for an upstream portion of JLC, which has to produce a train of ultra-low emittance bunches of electrons (and positrons). It includes a multi-bunch-capable electron source, a 1.54 GeV S-band linac, and a 1.54 GeV damping ring (DR) prototype.

A variety of studies were successfully conducted in 1994 through 1996 on acceleration of multi-bunch beam (up to 12 bunches, 2.8 ns bunch separation). The multi-bunch beam loading compensation scheme based on the RF frequency modulation of a small set of accelerating structures was successfully demonstrated.

Commissioning work of the ATF DR began in early 1997 with many participants from both inside and outside KEK. The accelerator has been operated in a single-bunch mode with the typical stored intensity of $\sim 1 \times 10^{10}$ electron/bunch or less at a repetition rate up to 1.56 Hz. Achieved and design parameters relevant to operation of ATF are summarized in Table 3. By Summer 1998, the horizontal beam emittance ϵ_x of $\sim1.4\times10^{-9}$m (i.e. $\gamma\epsilon_x \simeq 3.5\times10^{-6}$ m) was measured by using a group of wire scanners in the beam diagnostics section of the extraction line[7].

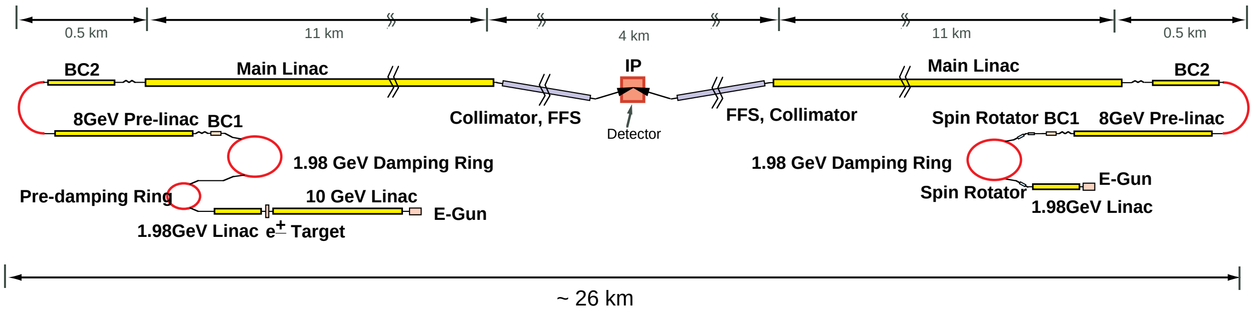

Figure 1: Schematic layout of JLC in its $E_{cm} = 1$ TeV configuration.

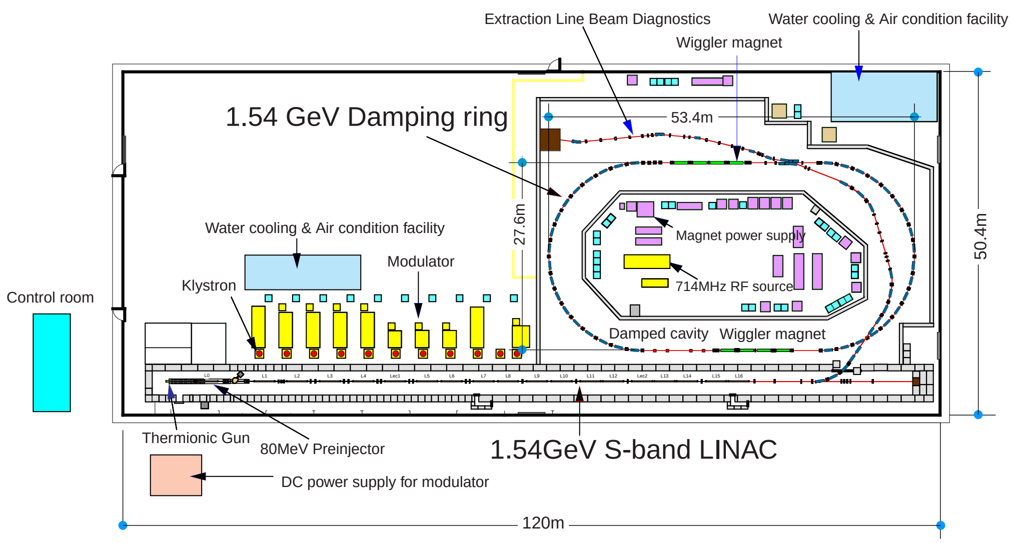

Figure 2: Layout of ATF – Accelerator Test Facility – at KEK.

Table 3: Achieved and design parameters at ATF.

Item	Achieved	Design	Unit
Linac Status			
Max. beam energy	1.42	1.54	GeV
Max. gradient with beam	28.7	30	MeV/m
Single bunch population	1.7×10^{10}	2×10^{10}	
Multi-bunch population	7.6×10^{10}	40×10^{10}	
Bunch spacing	2.8	2.8	ns
Repetition rate	12.5	25	Hz
Energy spread (full width)	$<$ 2.0 % (90% beam)	$<$ 1.0 % (90% beam)	
Damping Ring Status			
Max. beam energy	1.28	1.54	GeV
Circumference	138.6 ± 0.003	138.6	m
Momentum compaction	0.00214	0.00214	
Single bunch population	1.2×10^{10}	2×10^{10}	
COD (peak-to-peak)	$x \sim 2$, $y \sim 1$	1	mm
Bunch length	$\sim$6	5	mm
Energy spread	0.06 %	0.08 %	
Horizontal emittance	$(1.4\pm0.3)\times10^{-9}$	1.4×10^{-9}	m
Vertical emittance	$(1.5\pm0.25)\times10^{-11}$	1.0×10^{-11}	mm

The most recent set of measured horizontal and vertical emittance values[8], as of April, 2000, are shown in Figure 3.

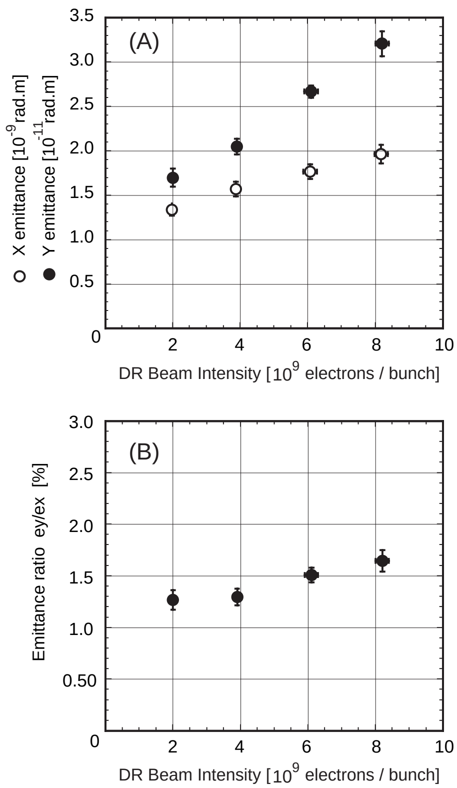

Figure 3: Measured values of (A) horizontal and vertical beam emittance (unnormalized) and their ratio (B) as function of bunch intensity from ATF.

Some of the development at ATF which are considered to play important roles in the progress of the achieved vertical emittance values are summarized as follows:

- Improved resolution ($\sim$20 μm) of single-shot BPM readout electronics.
- Improved understanding of the first order optics in the DR, and corrections introduced by using "fudge" factors for the field strength of quadrupole magnets and quadrupole field components of the combined-function bend magnets in the DR.
- Improved dispersion and orbit correction algorithm which are tuned to minimize the vertical dispersion ($\sim$ 5 mm) in the DR without overly upsetting the COD.
- Skew quadrupole magnet fields were introduced in the arc sections of the DR by using trim windings of sextupole magnets. They were used to minimize the cross-plane coupling by using the x-y coupling signals in the diagnostics of the first-order optics, as well as by using the tune difference ν_x-ν_y near the coupling resonance.
- Improved algorithm for the correction procedure for the vertical dispersion in the extraction line, where the wire scanner beam diagnostics instruments are situated.

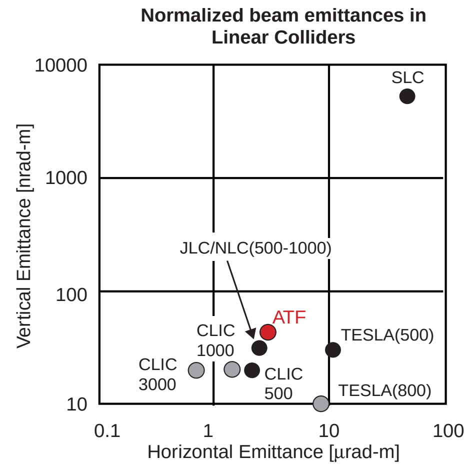

Figure 4: Normalized horizontal and vertical emittance values that have been achieved at SLAC and ATF, compared to what are required for injectors of next-generation linear colliders.

This result from ATF may be put in perspective as shown in Figure 4. It is seen that the beam emittance that is required for typical next-generation linear colliders, including JLC/NLC, is nearly achieved. However, a number of issues still remain to be investigated at ATF. For instance,

1. The beam emittance values so far considered the most reliable have been obtained by using wire scanners in the extraction line. These and measurements from synchrotron radiation (SR) monitor in the DR, which utilizes the interferometry, are not totally consistent. This is most likely due to effects of mechanical vibrations of the optical stands that are used for the SR monitor system, but it requires more studies.
2. There may be field errors in the magnetic components in the beam extraction line or at the beam extraction point. They might introduce x-y cross plane coupling and fictitious signals of the growth of the vertical beam emittance, which may not yet be accounted for in wire scanner measurements.
3. Observed growth of vertical emittance or the emittance ratio as shown in Figure 3 is found to have too strong a dependence on the bunch intensity, compared to existing model calculations of intra-beam scattering effects. It has not yet been resolved whether this is due to errors in measurements, inadequate set-up assumptions or true beam dynamics effects.

In addition, the reported emittance numbers from ATF are so far based only on single-bunch beam operations. After the Summer shutdown period, the beam operation of ATF is scheduled to resume in October, 2000. Preparation is currently under way for addressing the single-bunch emittance issues as well as multi-bunch operation of the ATF DR.

3 X-BAND ACCELERATING STRUCTURE

Development of X-band accelerating structure at KEK has been conducted in close collaboration with a group at SLAC. The accelerating structure studied is based on the damped-detuned concept [5]. The recent research focus at KEK has been on (i) fabrication of copper disks for the RDDS (Rounded Damped-Detuned) structure with a diamond-turning technique with ultra-high precision lathes, and (ii) their assembly into structure bodies by means of the diffusion bonding technique[5, 9]. They have been pursued in conjunction with development of better control of transverse wakefield and improved RF-to-beam efficiency.

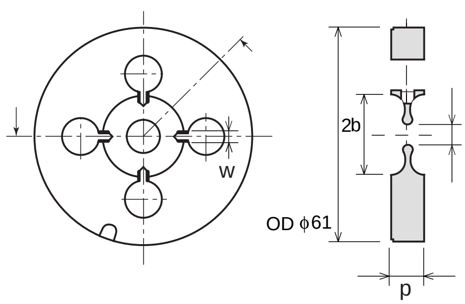

Figure 5: Schematic drawing of an RDDS disk.

Figure 5 shows a schematic drawing of the typical copper disk for the RDDS structure, whose first prototype (RDDS1) was successfully built in 1999 and was tested for wakefield characteristics at the ASSET facility of SLAC in 2000. The RDDS1 (1.8 m long) consists of 206 similar disks, each 61 mm in diameter and 8.737 mm in thickness.

During disk fabrication, much attentions have been paid to the temperature control of the lathe, positioning of the diamond cutting tool, and its motion. The radius of the cutting tool are pre-determined within 0.3 μm by machining an aluminum test hemisphere (ϕ60 mm) and by measuring the surface features with a roundness tester. Figure 6 shows a contour profile plot of a test RDDS disk that was measured with a CMM (Coordinate Measurement Machine) with contouring capability. The solid line shows the design shape, while the black dots show the measured shape, with the deviation from the nominal shape magnified by 200 times. The machined surface matched the design to within ± 1 μm. Other dimensional parameters such as the disk outer diameter, aperture radius $2a$, which are determined by the diamond turning, are found to have been done with similar precision.

In addition to mechanical quality control, careful measurements of the fundamental and first-order transverse

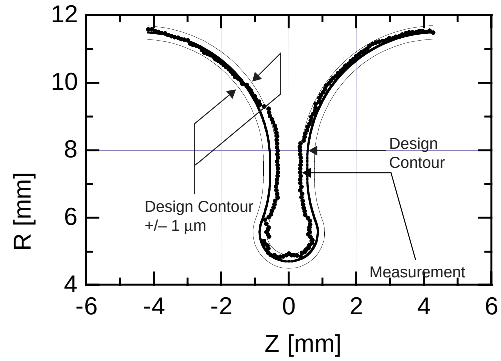

Figure 6: Contour profile plot of a test RDDS disk near the aperture opening part.

mode resonant frequencies of cells were performed for individual disks. As an example, Figure 7 shows the fundamental-mode frequencies, measured on a disk-stack setup (white circles). The disks are mostly fabricated in the order of the disk number. Figure 7 also shows the integrated phase error (broken line), expected from the measured deviation of the fundamental-mode frequencies. It is seen that by fine-adjusting the cell cavity size (denoted as $2b$ in Figure 7) based on the past trend of frequency errors, the total integrated phase error can be controlled with an extreme precision. Also, the first-order transverse mode frequencies of the fabricated disks have been found to have a smooth distribution within 0.4 to 0.6 MHz. Overall, the micron-level precision to which the disks are machined have been very successfully demonstrated.

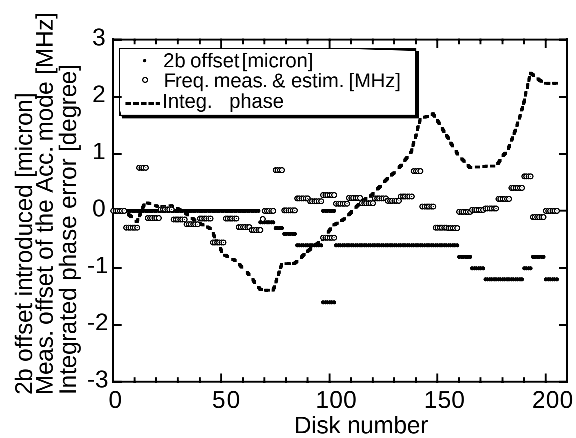

Figure 7: Fundamental mode frequencies, measured in a disk-stack setup, of RDDS1 disks.

The disks are then stacked on a precision V-block, where a disk-to-disk alignment of 1 μm or better is possible during stacking. A growth of the so-called “bookshelf” stack errors is prevented by monitoring the inclination angles of the surface of stacked disks with a two-axis autocollimator and by applying corrections during stacking.

Formation of the complete accelerating structure is made through (i) the diffusion bonding procedure of the copper disks that is conducted in two steps (prebonding and final bonding), and (ii) the brazing of external components such as cooling water tubing, fixtures for support frames, waveguides and flanges. It has been found repeatedly that the disk-to-disk alignment and the "bookshelving" error (of its absense thereof) of the disks are well maintained throughout the diffusion bonding process, which create vacuum-tight and mechanically strong enough disk-to-disk bonding junctions.

However, differential expansion of the ceramics endplate supports relative to the first and the last copper disks lead to a flaring of the structure ends during diffusion bonding. Similar deformation occurred on RDDS1 when a stainless steel manifold was installed on a mid portion of the structure during brazing. While the former error could be rectified later, the bonding techniques used in the assembly of X-band structures call for some improvements in the near future, in addition to studies of mass-production issues. Results from wakefield measurements of RDDS1 prototype are reported in a contribution submitted to this conference [9]. Also, issues pertaining to RF processing and high power operation of X-band accelerating structures at field gradient up to 70∼80 MV/m are being investigated[10].

4 OTHER ACTIVITIES ON THE X-BAND RF R&D

Development work is also under way[11] for: klystron modulators with semiconductor switching devices, construction of X-band high-power klystrons with periodic-permanent magnet (PPM) focusing, testing of the DLDS (Delay Line Distribution System) components (see Figure 8), development of X-band high-power RF windows[12]. Some of the efforts are carried out in collaboration with a group from Protvino branch of BINP, Russia, as well as with SLAC in the framework of the KEK-SLAC ISG.

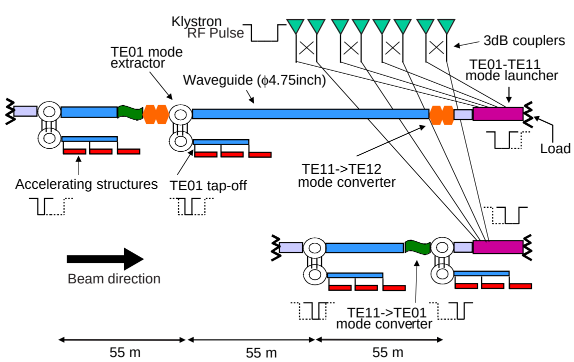

Figure 8: Schematic diagram of a DLDS concept where the RF power from 8 klystrons are divided and distributed to four clusters of accelerating structures situated along the linac.

A low-power testing of transmission of X-band RF through a long (∼50 m) waveguide as a proof-of-principle experiment of the DLDS concept was successfully conducted at KEK by a KEK-SLAC-Protvino collaboration in 1999. Another testing is planned for Fall, 2000. A high-power testing of Protvino-KEK RF windows have been successfully carried out at SLAC in late 1999 through early 2000. As of August, 2000, intense testing is being conducted on KEK site for a PPM klystron that was designed at KEK and built in collaboration with Japanese industry.

In a few years, when the basic R&D of these RF components, including the accelerating structures, becomes sufficiently mature, it is considered highly desirable to build a small part of the X-band linac, for instance a complete unit set of the RF system as shown in Figure 8. While its successful operation without any beam acceleration should already mark a major milestone, possible acceleration of low-emittance beams which would be hopefully available by that time from ATF would play a decisive role in showing the feasibility of JLC/NLC.

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