Proceedings of the Linear Accelerator Conference 1990, Albuquerque, New Mexico, USA

THE JAPAN LINEAR COLLIDER

Koji Takata
KEK, National Laboratory for High Energy Physics,
1-1 Oho, Tsukuba-shi, Ibaraki-ken 305, Japan

Abstract

Present status of R&D works for the proposed 1 TeV Japan Linear Collider is presented. Discussions are given about its major parameters. Summarized are high gradient experiments, X-band klystron development and accelerating structure studies at KEK. Test of the first X-band klystron with the designed output power 30 MW started and a peak power of about 10 MW has been achieved.

Introduction

The electron positron collision experiments at the energy frontier have been carried out solely with storage rings. In Japan the TRISTAN electron positron storage ring, which was commissioned November 1986, has been operated for physics experiments at the center of mass energy around 60 GeV with its highest value 64 GeV being attained in November 1989.[1] For the energy frontier physics in the 2000's, however, the center-of-mass energy is desired to be as high as 1 TeV. For such an energy range the only possible accelerator is the linear collider. In 1986 the Japan high energy physics community adopted the resolution to start R&D works for a 1 TeV linear collider in Japan, JLC (Japan Linear Collider), the construction of which is hoped to start in the end of 1990's.[2]

For a linear collider, the main electron and positron linacs extend colinearly, and accelerated electron and positron bunches collide each other at the median point. In order to enhance the luminosity, the cross section of a bunch is made as small as possible in each final focus section extending from the end of either linac to the collision point. At the entrance of the linacs, on the other hand, beam emittances are reduced to a minimum in a damping ring with a beam energy of about 1.5 GeV. The injector linac for the damping ring will be of a conventional type for each beam. For positrons, however, an electron linac with the energy being at least 10 GeV is necessary in order to convert electrons efficiently into positrons.

Since we started parameter designs for JLC in 1986, it has been our consistent policy that the main linac should be based on conventional linac technologies in which we have much experience. In particular, since the required acceleration gradient is as high as 100 MV/m, the RF power source is the key element in the JLC design. Hereupon we have been pursuing to push forward the well established klystron technologies to get very high power tubes. Regarding the RF frequency, a higher one is generally desirable because of, for instance, power saving. But we chose it at the X-band range which is not yet too high for fabrication of klystrons and disk loaded accelerating structures. Particularly it is 11.424 GHz, four times the SLAC frequency, since almost all of the conventional linacs are operated at the latter frequency and hence its integer multiple would be very convenient in the R&D works hereafter.

JLC Design

Figure 1 shows a schematic layout of JLC with its parameters listed up in Table 1.[3] The maximum luminosity would be 6.2 x $10^{33}cm^{-2}sec^{-1}$. Each linac operates at a repetition rate of 200 Hz. For a linac pulse 10 bunches are accelerated at the gradient 100 MV/m. The population per bunch is 1.0 x 10^{10} particles. The normalized emittances 3 x 10^{-6} rad.m and 3 x 10^{-8} rad.m for the horizontal direction and the vertical, respectively, are assumed to be the same as those achieved in the damping ring. The beam power 1.60 MW would be 9.3 % of the RF power for the accelerating structure. The overall length of the JLC system will be around 16 km. The interaction point and the damping ring complex will be located in the KEK site. The total wall plug power should not exceed the maximum available power at KEK of 200 MW.

We assume a flat beam with an aspect ratio of 166 at the interaction point (IP). The rms beam sizes will be as small as 230 nm horizontally and 1.4 nm vertically. The rms bunch length is 76 μm which is almost equal to the vertical beta function β_x^* 50 μm. In order to avoid the background problem at IP, the electron and positron bunches collide at a small horizontal angle of 6 mrad. This angle can be coped with in the final focusing section. Therefore the electron and positron linacs can be set in a straight tunnel, to a great simplicity of its construction. But a small loss of luminosity due to the finite angle crossing is not taken into account in the figure of Table 1. The beamstrahlung parameter $\Upsilon_{av.}$ is as small as 0.49 because of the large aspect ratio and a moderate energy loss δ due to beamstrahlung. Simulations suggest that the pair creation is concentrated within a very narrow cone in the forward direction and would cause no serious background problems.

The X-band main linac for each beam will consist of 900 eight-meter-long modules as shown in Figure 2.[4] In each module eight 70 cm long accelerating structures[5] are placed with a space of 1 m with focusing quads between them. The accelerating structure is assumed to be of a constant-impedance $2\pi/3$-mode traveling-wave type with 80 cells including the input and output couplers. With the iris radius 3.7 mm (a/λ = 0.14) and the disk thickness 2.0 mm, the computed Q value and shunt impedance are 6600 and 93 MΩ/m, respectively. With the group velocity being 2.5% of the light velocity, the filling time is 92 ns. The peak input power for the average gradient 100 MV/m becomes 120 MW. The bunch to bunch spacing is chosen to be 1.4 ns or 16 RF cycles and hence the bunch train length becomes 12.6 ns. In order to minimize the bunch to bunch energy spread due to the beam loading, some of the 900 modules are to be not completely filled with the RF pulse when the bunch train runs through.

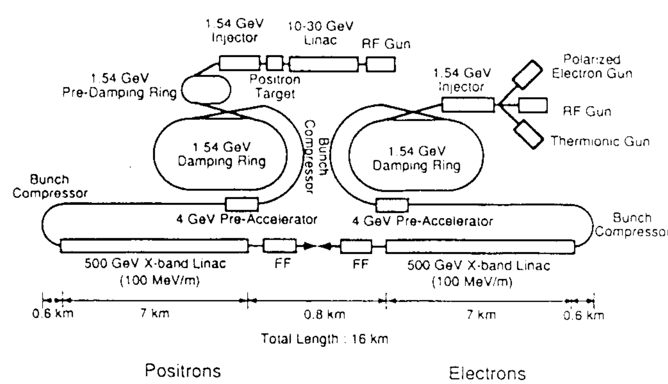

Fig. 1. Schematic layout of the JLC accelerator complex

TABLE 1
JLC Parameters

Global Parameters		
Beam energy	2E	500+500 GeV
Repetion frequency	f_{rep}	200 Hz
Number of particles/bunch	N	1.0×10^{10}
Number of bunches/RF pulse	N_b	10
Beam power per beam	P_b	1.60 MW
Normalized emittance	ε_{xn}	3×10^{-6} rad.m
	ε_{yn}	3×10^{-8} rad.m
Luminosity	L	$6.2\ \times10^{33}/\mathrm{cm}^2\mathrm{sec}$
Total accelerator length		16 km
Wall plug power		200 MW max
Beam-beam Interaction		
Rms beam size at IP	σ_x^*	230 nm
	σ_y^*	1.4 nm
Aspect Ratio	R	166
Rms bunch length	σ_z	76 µm
Beamstrahlung parameter	$\Upsilon_{av.}$	0.49
Average energy loss by beamstrahlung	δ	14 %
Crossing angle	θ	6 mrad
Final Focus System		
Beta function at IP	β_x^*	14 mm
	β_y^*	0.05 mm
Total length		365 m
Distance between the last quad and IP		1.0 m
Pole tip field of the last quad	B_t	1.4 T
Aperture of the last quad	2a	1.04 mm
Main Linac		
RF frequency	f_{rf}	11.424 GHz
Accelerating gradient	G	100 MV/m
Number of structures/beam		7,200
Structure length		70 cm
Number of cells/structure		80
Q value	Q	6,600
Shunt impedance	r	93 MΩ/m
RF power/structure	P_o	120 MW
Number of klystrons/beam		1,800
Accelerating mode		$2\pi/3$
Filling time	T_f	92 nsec
Iris radius	a	3.7 mm
Disk thickness	t	2.0 mm
Group velocity	v_g/c	0.025
Attenuation parameter	τ	0.50
Normalized elastance	s_0	0.70 Vm/pC
Extraction efficiency	η_{b1}	1.65 %/bunch
Bunch spacing	t_b	1.40 nsec
Beta function	$\beta(s)$	$3.0\sqrt{E/10\mathrm{GeV}}$ m
Damping Ring		
Energy		1.54 GeV
Number of paticles/bunch		1×10^{10}
Number of bunches /train		10
Number of trains		8
Bunch spacing	t_b	1.40 ns
Bunch train spacing		61 ns
Circumference	C	180 m
Transverse damping time	$\tau_{x,y}$	4.8 ms
RF frequency	f_{RF}	1.428 GHz
RF peak voltage	V_{RF}	1.0 MV
Wiggler field	B_{wig}	2.0 Tesla
Wiggler pitch	λ_{wig}	42.5 cm
Length of wigglers	L_{wig}	40 m
Equibrium emittance	ε_{xn}	3×10^{-6} rad.m
	ε_{yn}	3×10^{-8} rad.m
Equilibrium bunch length	σ_z	5.0 mm
Equilibrium energy spread	σ_ε	$0.79\ \times\ 10^{-3}$

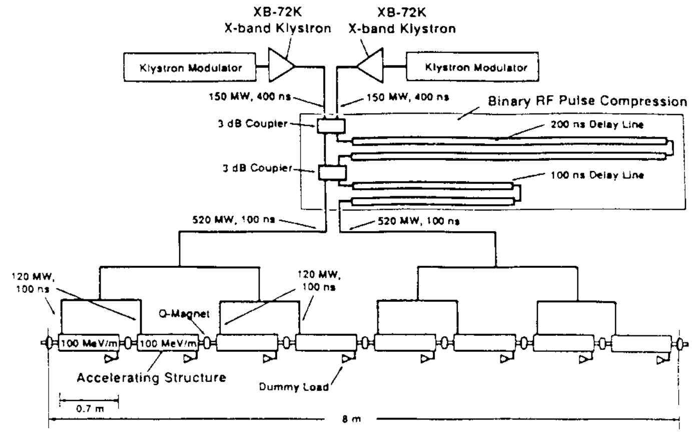

Fig.2. Unit module of X-band main linac

The single bunch longitudinal wake for the gradient 100 MV/m is expected to be -0.2% and -0.8% for the longitudinal position $-\sigma_z$ and σ_z respectively. The energy spread inside a bunch necessary for achieving the BNS damping[6] would be on the order of ± 0.5 %. We do not yet have, however, an accurate estimation of transverse wake field and hence are not able to determine the synchronous phase for the bunch. At any rate it would not deviate from the RF crest by more than ±10°.

For the multi-bunch acceleration we must solve the beam break up problem. In this case the dominant wake component would come from the TM_{110} mode. The wake potential due to a transversal offset of a preceding bunch induces also an offset for the trailing bunch. The value Δ of the latter relative to the former offset can be expressed as[7]

$$\Delta = \frac{\beta_0 e N}{G}\sqrt{\frac{E_f}{E_0}}\, W_0 \exp\left[-\frac{\omega_1 t_b}{2Q_1}\right] \qquad (1)$$

where E_0 is the injection energy (10 GeV), E_f the final energy (500 GeV), G the acceleration gradient (100 MV/m), N the number of particles per bunch ($1\ \times\ 10^{10}$) and the β_0 the beta-function at the injection energy (3.0 m) which we assume to be proportional to square root of the beam energy. For the TM_{110} wake we assume that W_0 is about $1\ \times\ 10^{17}$ V/C-m^2 as several numerical calculations show and ω_1 equal to $2\pi\ \times$ 16 GHz. Since the bunch spacing t_b is equal to 1.4 ns, substitution of the numerical values leads to

$$\Delta = 34 \exp\left[-\frac{70}{Q_1}\right] \qquad (2)$$

From this relation we see that the Q value of the TM_{110} mode Q_1 should be so low as 10 for $\Delta \ll 1$, while for $Q_1 = 20$, Δ is about 1. The damped cavity structure is, therefore, indispensable to suppressing the multi-bunch beam break up. Also it should be noted that for low frequency deflecting modes the wakes seem insensitive to the aperture radius a, contrary to the case of short range wakes.

For the RF power source we will employ two klystrons for each module as shown in Figure 2. The klystron named XB-72K, now in the designing stage, would generate a peak power of 150 MW in a 400 ns long pulse.[8] The output pulses from the paired klystrons will go through a two-stage pulse compression system[9] where the pulse length is compressed to 100 ns. Taking the waveguide loss into account we expect that the designed input power 120 MW would be available for each of eight accelerating structures. In order to improve the overall efficiency, we are considering a modulator incorporating magnetic switches with which rise and fall times as short as 100 ns would be enabled.

The 1.54 GeV damping ring will be a race-track type with two FODO arcs and two wiggler sections.[10] The circumferential length is 180 m and eight batches of ten bunch trains are stored with a spacing of 61 ns which is necessary for the rise and fall times of kicker magnets. The RF frequency 1.428 GHz is one eighth of the X-band frequency and the bunches in a train are placed in every two RF buckets. Wigglers of a total length of 40 m damps transverse betatron oscillations with a time constant of 4.8 msec to the equilibrium normalized emittances as shown in Table 1. The equilibrium rms bunch length σ_z and energy spread σ_ε are 5.0 mm and 0.79 x 10^{-3}, respectively. In order to increase the acceptance for the positron beam, we are considering the possible use of a pre-damping ring with a third circumference.

Accelerator Test Facility

In order to promote the R&D works for JLC, we have been establishing an accelerator test facility (ATF) in KEK. As a first step, a 1.54 GeV high gradient S-band linac is under construction. We will annex to it a test damping ring with which we will try to achieve the desired normalized emittances $\varepsilon_x/\varepsilon_y$ = 3.0 x 10^{-6} / 3.0 x 10^{-8} rad-m. The low emittance beam will be used to test the final focusing system. We also plan to construct a module of the X-band linac with which we will test the 100 MV/m acceleration using the 1.54 GeV linac beam. Novel techniques for electron and positron sources are also to be tested at ATF.

The S-band linac will consist of a 40 MeV injector and 1.5 GeV normal section. As an electron source we developed a 200 kV thermionic gun. It is to be followed by a subharmonic buncher operating at 714 MHz, a fourth of the S-band frequency, in order to get the 1.4 ns bunch spacing. The electrons will then be injected into a 1.5 m long conventional disk loaded structure. The 1.5 GeV linac will consist of twelve 3 m long disk loaded structures in which a gradient of 42 MV/m will be attained with six klystrons each generating 180 MW 1 µs pulses with the aid of the SLED system.[11]

With regard to the RF source, we had no reliable high-power S-band klystrons when we started the R&D works. Supported by the US and Japan scientific collaboration program, eight 5045 SLC klystrons[12] were delivered to KEK by SLAC. They can be operated at a rating of 100 MW output power for 1 µs pulses. Four modulators have already been set up and used for driving those tubes. We have obtained 200 MW 1 µs pulses in a single S-band waveguide line by combining the outputs of two tubes.

Besides constructing the linac, we are also undergoing tests of an S-band high gradient structure and development of X-band klystrons using the facility as described in the following sections.

S-band High Gradient Test

It is the key issue in R&D to successfully attain the high gradient 100 MV/m over a considerable length of the structure. Though tests should be carried out at the X-band frequency, there have been no high power X-band tubes available and hence experiments at KEK are restricted to only S-band structures.

Since the 30 MW klystron for the Photon Factory 2.5 GeV linac was the only available tube, an S-band resonant ring was employed to boost the peak travelling wave power. A five cell 2π/3 mode travelling wave structure was tested in this ring and it was possible to attain the gradient 100 MV/m.[13] But, since the active length including the coupler cells is only 17.5 cm and the RF power has scarcely a flat top in a resonant ring, it was desired that a much longer structure should be tested with a square pulse of a sufficient peak power and flat top.

As described above, however, the peak power 200 MW has become available by using the 5045 tubes. Hence we fabricated a constant gradient 66.5 cm long 2π/3 mode travelling wave structure in which the gradient 100 MV/m is to be attained for the 200 MW peak input power.[14, 15, 16] The iris diameter changes from 19.0 mm for the first cell to 15.9 mm for the last cell. The filling time is 430 ns. The disk thickness is 5.84 mm. According to Superfish calculations, the peak surface field of about 2.0 times the average acceleration gradient exists around the rounded iris. The structure is made of class-1 OFHC copper. Disks and cylinders were surface finished to the order of 0.02 µm except for the rounded iris where the roughness was one order of magnitude larger. They were brazed together with a 790°C silver alloy in a hydrogen furnace. The squeezing process for tuning the cells was carried out with a continuous flow of dry nitrogen gas inside the structure.

The experimental setup is shown in Figure 3. Since the survey of the field emission was the main purpose, faraday cups and current transformers were placed on each side of the structure. An energy analyzer was installed downstream. The conditioning started in July 1989 and continued until April 1990 when a ceramic pipe section for the current transformer cracked due to radiation damage. The integrated conditioning time was about 900 hours. The RF pulse was 1.0 µs long with a rise time of 100 ns. Its repetition rate was 25 Hz at first and then doubled. In the last stage the average gradient E_{acc} reached 92 MV/m, whereupon the peak input power was 160 MW. A considerable portion of the time was taken to improve the output coupler where breakdown occurred very often as radiation monitors and a current profile monitor suggested. It might be due to the fact that the surface finish of this area was not good enough at the initial tuning process. Application of inhomogeneous fields of about 200 gauss was very effective in speeding up the processing.

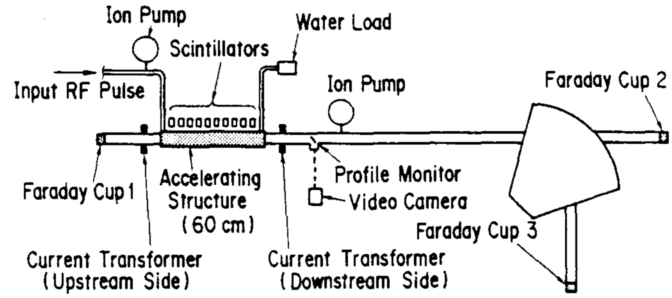

Fig. 3. Experimental set up for high gradient test of an S-band 66.5 cm long structure

The modified Fowler-Nordheim relation for the RF field is given by[17]

$$\ln\left[\frac{I}{E^{2.5}}\right] = -\frac{B\phi^{1.5}}{\beta E} + \text{constant} \qquad (3)$$

where I is the field emission in Amperes, E the peak surface RF field in V/m, β the enhancement factor, ϕ the metal work function in eV which is assumed here to be 4.65 eV of copper, and the numerical constant B is equal to 6.53×10^9.

The enhancement factor was around 90 for integrated conditioning hours from 200 to 400. But at the final stage where E reached 2.0 x 92 MV/m, β reduced to about 40. Beam acceleration was tried at acceleration gradients from 70 to 85 MV/m. At the 50 Hz repetition rate, 200 ns long beam pulses with peak currents up to 0.9 A were successfully accelerated. The beam energy spectra were consistent with the gradient calculated from the peak input power if we take into account the beam loading effect using the measured shunt impedance.

X-band Klystron

From many experiences about both S-band and UHF high power klystrons developed for the TRISTAN accelerator complex, we think that the most important is to get, for any kind of tube, a reliable electron gun which is stable and has a long life under high voltage operation. We therefore started at first fabrication of a diode tube named XB-50D[18] which has a somewhat small cathode diameter of 50 mm compared with the XB-72K tube. The designed voltage and perveance were 450 kV and 0.57 $\mu AV^{-3/2}$, respectively. For the cathode an iridium-coated barium-impregnated cathode was used. For the convenience sake, the gun electrodes were made compatible with the socket for the 5045 tubes at ATF.

The conditioning was carried out at a repetition rate of 2 Hz. It took 50 hours to reach the design voltage 450 kV. The perveance was 0.60 $\mu AV^{-3/2}$ for the cathode temperature 1020°C. The beam power was 81.5 MW. With further conditionings with 20 Hz pulses, the fault rate reduced to once per 8×10^4 pulses at the above voltage.

Employing the same gun configuration, we fabricated the first high power klystron XB-50K as shown in Figure 4.[19] The RF section was optimized by the 2.5D simulation code FCI.[20] It consists of five cavities with the drift section 8 mm indiameter between them, where an axial magnetic field of 4.5 kGauss is applied. The RF interaction length is 268 mm. The output cavity is of a pill box type 10.2 mm long and 17.2 mm in diameter with an interaction gap of 6 mm. It is coupled to the standard WR90 waveguide 22.9 mm wide and 10.2 mm high through a 9.8 mm wide inductive window. Those dimensions were determined with the codes Superfish and Mafia to obtain an optimized Q_{ext} 30. The FCI calculation gives an efficiency of 47 % or output power of 36 MW for this Q_{ext}. Though Qext larger than 40 would result in efficiencies better than 50 % as FCI simulations suggest, the surface field would be too high. Our design criterion for it was 100 MV/m, which correspond to Qext equal to 30. As the output window we chose a very simple design of a half wave-length ceramic block 4.45 mm thick with the same cross section as the waveguide. The VSWR is 1.01 at 11.4 GHz and its bandwidth at 1.05 is 90 MHz.

The conditioning of the first XB-50K tube was carried out at a repetion rate of 2 Hz. The voltage pulse width is about 2 µs, while the RF pulse width is 140 ns. After conditionings 15 hours long in total, the highest cathode voltage was 350 kV, when the tube suffered from cracks in the output window. The output power reached 11 MW with an efficiency of 27 % as shown in Fig.5. The perveance was 0.54 $\mu AV^{-3/2}$ which is close to the designed value 0.56 $\mu AV^{-3/2}$.

The XB-72K tube with the cathode diameter 72 mm is under design. According to FCI calculations, it will be operated at 600 kV with a perveance of 1.2 $\mu AV^{-3/2}$. With five cavities and drift tubes with a diameter of about 9.5 mm, 150 MW RF power is expected with an efficiency of 45 %. For the output cavity we will use a single gap pill box cavity without the nose cone to reduce the surface field gradient to 72 MV/m.[21]

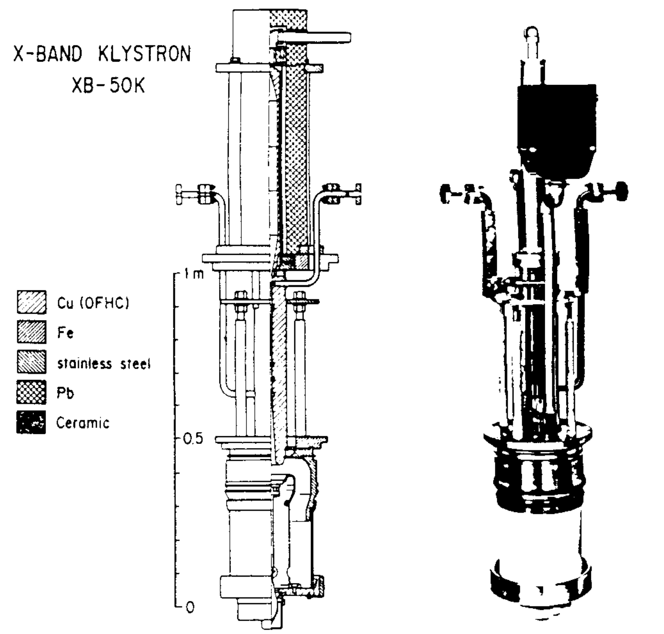

Fig. 4. First X-band klystron XB-50K

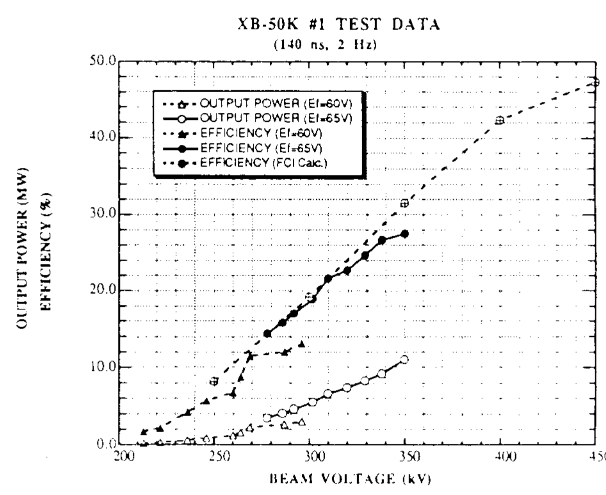

Fig.5 Conditioning of the XB-50K klystron

X-band Structure

R&D studies for X-band structures[22,23] have been covered two fields. One is to survey fabrication techniques for producing structures in the X-band scale. The other is to find damped structures with Q values on the order of 10 for deflecting modes by three dimensional calculations.

Machining tests were carried out for a cell unit scaled a fourth down from the conventional S-band disk loaded structure. It is a cuplike cylinder of 30 mm in the outer diameter and 21 mm in the inner with a 2.0 mm thick disk at an end. The disk has an aperture 6 mm in diameter with the edge rounded with a radius of

0.5 mm. Several pieces were fabricated by using a fairly good lathe. Machining accuracies for the cylindrical section were measured to be ±4 μm for the diameter dimensions and off-center within 3 μm. The outer disk surface of the cup had a flatness of 1 μm but the other side of the disk had deviations of about 5 μm. The surface roughness was on the order of 0.1 μm. Preliminary tests of brazing these pieces were also carried out.

Taking those results into consideration, we are designing an X-band structure for the high gradient test using the KB-50K klystron. It is a constant-impedance $2\pi/3$ mode 22 cell structure 19.25 cm long with the disk aperture diameter 6 mm. For an input power of 30 MW, an average gradient of 85 MV/m would be obtained with the attenuation parameter τ being about 0.33.

Calculations of damped structures have been carried out by use of Slater's formula[24] for the slots as shown in Figure 6. Two slots are cut in every other disk. The slot dimensions listed in the figure caption are the optimized ones for the TM_{110} mode. For modes with cell-to-cell phase shifts of 0 and π, the Q_{ext} values are as low as about 1 and 20, respectively. The latter is not yet low enough according to Equation 2 and additional slots may be necessary. For the accelerating mode, the slots would have a considerable amount of magnetic coupling and the dispersion relation should be carefully calculated. The Q value of the accelerating mode would be also a little go down since the slots so wide as shown in Figure 6 inevitably disturbs the cylindrically symmetric wall current.

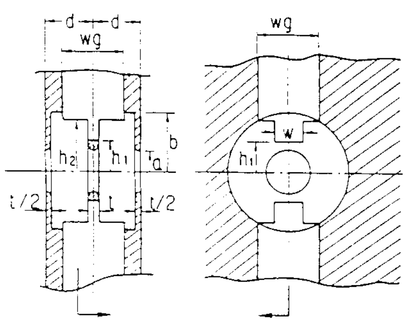

Fig. 6. X-band damped cavity calculation for the typical dimensions: cavity radius b=10.6mm, pitch d=8.75mm, aperture radius a=3.7mm, disk thickness t=2.0mm, slot heits h1=5.5mm and h2=9.0mm, slot width w=5.0mm, waveguide height/width wg=11.1mm.

Conclusions

Among many problems which should be solved by the R&D works, the key issues are the RF source and accelerating structure. As discussed above, the present status of their development are still far off from what is required for the JLC design. Particularly, if the RF source will not be fully developed, the JLC might be started with lower gradients 50 to 75 MV/m, contrary to the designed 100 MV/m acceleration. At any rate, we are stressing the klystron development most, since its test cycle usually takes much time. The other issue which should be seriously considered is to construct a test damping ring as early as possible in ATF. With low emittance beams generated by it, such urgent subjects as wake fields and beam monitors, for instance, will be experimentally pursued.

References

1. Y. Kimura, "The Performance of TRISTAN and Accelerator Development at KEK," presented at the Second European Particle Accelerator Conference, Nice, France, June 12 - 16, 1990.
2. Y. Kimura, K. Takata and M. Yoshioka, "Electron-positron Linear Collider R&D Program at KEK," Proceedings of the 1987 ICFA Seminar on Future Perspectives in High Energy Physics, Upton, USA, 1987, pp. 219.
3. K. Yokoya, "JLC Beam Dynamics," Proceedings of the First Workshop on Japan Linear Collider (JLC), KEK, October 24 - 25, 1989, pp. 26.
4. S. Takeda, "JLC Status," Presented at the Second International Workshop on Next-generation Linear Colliders, KEK, March 1990.
5. T. Higo, "X-band Accelerating Structure for Japan Linear Collider," Proceedings of this conference.
6. V. E. Balakin, A. V. Novokhatsky and V. P. Smirnov, "VLEPP: Transverse Beam Dynamics," Proceedings of 12th International Conference on High Energy Accelerators, Fermi Lab., August 1983.
7. K. Yokoya, private communication.
8. H. Mizuno and J. Odagiri, "X-band Klystron for Japan Linear Collider," Proceedings of this conference.
9. Z. D. Farkas, " Binary Power Multiplier," SLAC-PUB-3694, 1985.
10. J. Urakawa, "Preliminary Design of 1.54 GeV Damping Ring and Bunch Compressor for JLC," Proceedings of this conference.
11. Z. D. Farkas et al, "SLED: a Method of Doubling SLAC's Energy," SLAC-PUB-1453, 1974.
12. M. A. Allen et al, " Reliability and Lifetime Predictions of SLC Klystrons," SLAC-PUB-4863, March 1989.
13. H. Matsumoto et al, "RF Breakdown Studies on an S-band Disk Loaded Structure," Proceedings of the 1987 IEEE Particle Accelerator Conference, Washington, D.C., 1987, pp. 1654.
14. K. Takata, "Operational Experience of Superconducting and High Gradient RF Cavities," To be published, Proceedings of the 14th International Symposium on Discharges and Electrical Insulation in Vacuum, Santa Fe, USA, September 1990.
15. S. Takeda, "High Gradient Experiment by Accelerating Test Facility for Japan Linear Collider," Proceedings of this conference.
16. H. Matsumoto, "Experimental Study of the S-band High Gradient Linac," Proceedings of this conference.
17. G. A. Loew and J. W. Wang, "Field Emission and RF Breakdown in Copper Linac Structure," *Particle Accelerators*, 1990, Vol. 30, pp. 225.
18. H. Mizuno, J. Odagiri and T. Higo, "X-band Klystron Diode Test for Japan Linear Collider (JLC)," *Particle Accelerators*, 1990, Vol. 30, pp. 167, and also KEK Preprint 89-114, September 1989.
19. H. Mizuno, "RF Power Source for JLC," Proceedings of the First Workshop on Japan Linear Collider (JLC), KEK, October 24 - 25, 1989, pp. 76.
20. T. Shintake, "FCI- Field Charge Interaction Program for High Power Klystron Simulations," KEK Preprint 89-18, 1989.
21. T. Shintake, " High-Power Klystron Simulations using FCI - Field Charge Interaction Code," to be published on KEK report.
22. T. Higo, "Accelerating Structure," Proceedings of the First Workshop on Japan Linear Collider (JLC), KEK, October 24 - 25, 1989, pp. 91.
23. T. Higo, M. Takao et al, "X-band Accelerating Structure for Japan Linear Collider," Proceedings of this conference.
24. T. Kageyama, "A Simple Method Using MAFIA to Calculate External Q Values of Waveguide-Loaded Cavities," KEK Report 89-4.