THE STATUS OF UNK

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1. The Basic Characteristics

The project of UNK envisages the following aims. Construction of 3 TeV proton accelerator for fixed target experiments. This machine consists of the two stages: 400 GeV conventional magnet accelerator and 3 TeV superconducting acelerator. The 400 GeV accelerator will be used as a booster for 3 TeV ring. The design intensity of the proton beam is $6{\cdot}10^{14}$ ppp. This part of the project is realized now. Both rings are located in 5 m diameter tunnel.

In the past different options of the UNK collider have been discussed. Last May it has been decided to continue with proton-proton collider (0.4×3) TeV which could be realized soon after 3 TeV machine operated. The luminosity of $8{\cdot}10^{32}$ $cm^{-2}s^{-1}$ seems technically achievable. The final decision on the collider mode must be taken in fall of 1990.

The basic parameters of the 3 TeV UNK are listed in the following Table.

The main components of the machine are SC magnets. Total numbers of SC dipoles and quadrupoles are 2176 and 438 respectively.

2. Superconducting Magnets

Cold-iron 6 m long dipoles were chosen for UNK. Working field value is 5 T at 4.2 K. Figure 1 shows the cross-section of the UNK magnet.

In the first half of 1990 10 dipoles were produced by IHEP SC factory. The field exceeding 5 T is attained in the first quench. The maximum field

Parameter		UNK-1	UNK-2
Maximum energy	GeV	400	3000
Injection energy	GeV	65	400
Orbit length	m	20771.9	20771.9
Maximum field	T	0.67	5.0
Maximum injection field	T	0.108	0.67
Total cycle duration	s	120	120
Acceleration time	s	20	40
Harmonic number of accelerating field		13860	13860
Total amplitude of accelerating voltage	MV	7	12
Maximum energy gain per turn	MeV	2.1	4.5
Transition energy	GeV	42	42
Betatron frequency (without special section of lattice)		36.7	36.7
Total intensity		$6{\cdot}10^{14}$	$6{\cdot}10^{14}$
Mean intensity	s^{-1}	$5{\cdot}10^{12}$	$5{\cdot}10^{12}$
Invariant beam transverse emittance	mm*mrad	150	200
Invariant bunch longitudinal emittance	MeV*m/s	100	120

attained was 6.6 T at 4.3 K. The field reserve available allows one to ensure reliable operation of the dipoles at 4.4–4.6 K under ac and radiation heat releases.

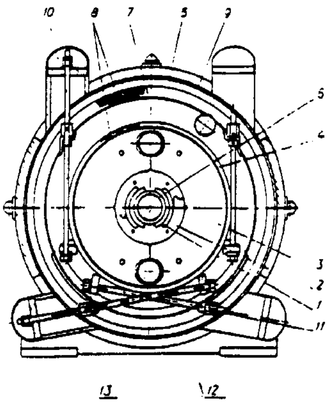

Fig. 1. Cross-sectional view of a superconducting dipole: 1 – coil, 2 – stainless steel collars; 3 – iron yoke, 4 – helium vessel, 5 – two-phase helium pipe, 6 – beam-pipe, 7 – nitrogen shield, 8 – superinsulation, 9 – vacuum vessel, 10 – suspensions, 11 – extension rods, 12 – single-phase helium channels, 13 – two-phase helium channel.

The ramp rate characteristics are satisfactory for both operating and emergency modes. The total measured losses per magnet (accelerator mode) are 11 W. The corresponding load on cryogenics is 35 kW and fits in the designed cryosystem.

In 1990 stand tests of the produced and newly constructed dipoles will be continued. Production rate of 1 dipole/week is expected by fall 1990.

In 1991 further increase of production rate must be achieved. All SC dipoles are to be constructed at IHEP.

3. Status of the UNK Construction

The tunneling of injection line (2470 m) has been completed, for ring tunnel 18.5 km of total length 20.7 km are completed, the first 400 m of the extracted beam line tunnel will be finished at the end of the year. More than 50% of the equipment for 400 GeV ring will be on the site to the end of 1990. Last fraction of this equipment (less than 25%) is expected in 1992. Installation of injection line will start in October 1990 and of main ring – in Spring 1991.

It is planned that the first principal milestone of the project – construction of 400 GeV accelerator – will be passed in 1993.

4. Experimental Program

Physics at fixed targets will benefit both from the high intensities and high energies of UNK extracted beams. The design proton intensity is $6{\cdot}10^{14}$ ppp, and $\sqrt{s}$ =75 GeV in comparison with 44 GeV at Tevatron. The principal physics goals are

—tests and measurements of the SM parameters,

—study of quark-gluon structure of hadrons,

—search for unexpected effects.

4.1. B-Physics

Threshold behaviour of the cross-section $\sigma(pp \to bX) \simeq 0.3\mu$b at UNK energies and the ratio $\sigma(pN \to b)/\sigma_{\rm inel} \simeq 3{\cdot}10^{-5}$ ensure one that in real experiment (MPS – Multiparticle Spectrometer) with account for trigger and other limitations a flux of beauties could be $10^7 - 10^8$ for a period of one year. In the case of dedicated experiment (CP-experiment) this value is estimated by 10^{10}. Variety of beams: protons (3000 GeV), photons (600 GeV) and hyperons (Σ^-, 2700 GeV) provide additional possibilites for experimentation.

4.2. Soft Hadron Physics and Gluons

This field is still waiting for clarification of many points and first of all for understanding of vacuum exchange mechanism. One of the promising proposals (GLUON) intends to investigate central production of gluonic states in exclusive reactions $h + N \to \eta + N + M^\circ, M^\circ \to \eta\eta, \eta'\eta, \eta'\eta'$, with $h = \pi^\pm, K^\pm, p^\pm$.

4.3. Spin Physics

Motivations for these studies are very strong especially with account for recent results at BNL, IHEP, CERN, FNAL.

Physics program includes:

—perturbatives QCD tests,

—study of spin dynamics at the constituent level,

—measurement of spin structure functions,

—search for new phenomena.

Jet target facility (NEPTUN) in Section 3 is under construction. This is the only experiment to be performed with use of internal 400 GeV beam. Later on it will be extended to 3000 GeV protons. Experiments with polarized beams and targets were also proposed (POLEX).

4.4. Spectroscopy (Heavy Quark Physics)

It is very promising to conduct at UNK the studies of gluonic states, the states with heavy (c, b) quark and s-quark and search for exotics. Creation of a hyperon (s-quark) beam is considered.

4.5. Neutrino Physics, Muons

It is expected that accuracies typical for hadron physics can be reached at UNK with neutrinos. Muon beam alongside of neutrino beam has been calculated. Its parameters are

$$E = 500 \div 2000 \text{ GeV} , \quad I > 10^8 \mu/\text{cycle}$$
$$\Delta p/p_0 < 10\% , \quad h\mu \leq 10^{-6} .$$

The most interesting part of the experimental program (TORS) with muons includes:

— precise test of QCD ($10 \leq Q^2 \leq 2000$ GeV) with impact on proof of α_s variation with Q^2 and search for "higher twist" effects,
— determination of Λ_{QCD} with an accuracy ~ 10 MeV,
— study of nucleon structure.

The basic characteristics of the beams are listed in the following Table.

Beam	Particles	Max. flux per 10^{13} protons	Momentum GeV/c	Comments
H1A	π^+	$2.1 \cdot 10^{11}$	1000	High intensity beam
	K^+	$2.3 \cdot 10^9$		
	π^-	$2.3 \cdot 10^9$		
	K^-	$7.8 \cdot 10^8$		
	e^-	$5.6 \cdot 10^8$		
H1B	π^+	$5.9 \cdot 10^9$	1000	Polarized proton beam
	K^+	$5.8 \cdot 10^8$		
	π^-	$5.0 \cdot 10^9$		
	K^-	$3.1 \cdot 10^8$		
	e^-	$3.8 \cdot 10^8$		
	$p_\uparrow$	$2.0 \cdot 10^8$	2000	Average polarization 30–45%
H2A	e^-	$4.0 \cdot 10^{10}$	300	High intensity electron beam
H2B	Σ^-	$1.6 \cdot 10^8$	2700	
H3	π^+	$9.4 \cdot 10^9$	1000	Medium intensity high resolution beam
	K^+	$9.3 \cdot 10^8$		
	π^-	$3.5 \cdot 10^9$		
	K^-	$2.2 \cdot 10^8$		
	e^-	$2.2 \cdot 10^8$	800	

STATUS AND PLANS FOR THE FERMILAB TEVATRON

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ABSTRACT

The Fermilab Tevatron is the world's highest energy accelerator system and the first large-scale superconducting synchrotron. Since Tevatron commissioning in July, 1983, the accelerator has operated in 1985, 1987 and 1990 with extracted beams of 800 GeV for fixed target physics; and in 1987, and 1988-89, with proton-antiproton colliding beams at a center-of-mass energy of 1800 GeV. This paper will review the current status of the Tevatron and the plans for its upgrades and future utilization.

Current Status

Approximately one year ago, the 1988-89 collider run[1)] of the Tevatron terminated with the delivery of almost 10 pb^{-1} of integrated luminosity to the CDF experiment. The peak initial luminosity achieved during the run exceeded $2x10^{30}/cm^2/sec$, more than twice the original design goal for the collider.

During the six month period following the run, a major repair program remedied a problem related to lead restraints in the ends of the superconducting dipoles in the Tevatron. Subsequently, the Tevatron was operated in fixed target mode (from February through August, 1990), and delivered an integrated intensity of about $1.85x10^{18}$ protons at 800 GeV to the experimental areas. The operational efficiency during the run was excellent, with many weeks over 70% efficient. Only one Tevatron dipole failed during the run; in contrast, during the 1987 run, the mean time between failures was about 6 weeks. Thus the repair of the lead restraint problem has indeed substantially improved the reliability of the Tevatron for fixed target operation.

*Operated by the Universities Research Association, Inc., under contract with the U.S. Department of Energy

The Fermilab III Upgrade Program

The Fermilab III program is a major initiative of the laboratory which includes a program of accelerator upgrades[2)], aimed at an increase by a factor of 50 in Tevatron collider luminosity over the original design. This is accomplished in a phased manner over the next five years; the program is designed to minimize the disruptions to the ongoing physics program during this period. Figure 1 shows the luminosity progression as a function of time, in terms of the initial luminosity which can be expected vs. calendar year through 1996. The text at the bottom of

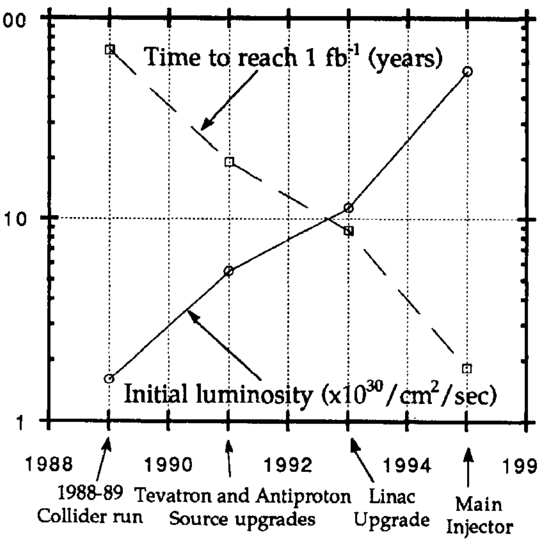

Figure 1: Fermilab III luminosity progression

the figure indicates the timing expected for each step in the upgrade.

Tevatron and Antiproton Source Upgrades

Significant improvements are being implemented in the Tevatron in preparation for the next collider run, which will begin in 1991. Two new low-β systems will be implemented: a new system at B0 to replace the old system used in the previous collider run, and a new system at D0 required by the advent of the D0 detector in 1991. The other major improvement for the Tevatron is a system of electrostatic separators which will separate the proton and antiproton beams everywhere except at the B0 and D0 interaction points. By reducing the number of beam-beam crossings with 6 bunches from 12 to 2, the beam-beam effects will be substantially reduced; these effects were a significant limitation to the luminosity in the last collider run.

In addition to improvements in the Tevatron, improvements have been implemented in the Antiproton Source. As shown in fig 1, the overall result of these improvements in the Antiproton Source and Tevatron is expected to be an increase in the initial luminosity to $>5\text{x}10^{30}/\text{cm}^2/\text{sec}$ for the collider run starting in 1991.

Additional improvements planned for the Tevatron for subsequent collider runs include an improved antiproton injection kicker, which will allow operation with up to 36 bunches, and a system of cold compressors in the Tevatron cryogenics system. The cold compressors will reduce the Tevatron operating temperature by about 0.5° K; this corresponds to an increase in the Tevatron energy from 900 GeV to above 1000 GeV.

Linac Upgrade

The Linac upgrade[3)] is a project to increase the Fermilab Linac energy from 200 MeV to 400 MeV by a replacement of the last four drift tube cavities in the present Linac with more efficient, higher gradient side-coupled cavities. This project is an approved line-item construction project, which started in October, 1989. The project is presently gearing up for full production of the required number of cavities. The schedule calls for installation of the new Linac cavities, and first operation at 400 MeV, in the fall of 1992. The motivation for this upgrade is to reduce the space-charge induced emittance growth presently suffered just after Booster injection at high intensities. The overall impact on collider initial luminosity, as shown in fig. 1, will be an increase to over $10^{31}/\text{cm}^2/\text{sec}$.

Main Injector

The principal limitation to the performance of the accelerator complex after the implementation of the Linac upgrade will be the Main Ring. This machine limits collider luminosity in a number of ways: the primary difficulties are its restricted transverse and longitudinal apertures, and its limited cycle rate. Additionally, the presence of the Main Ring beam in the vicinity of the collider detectors is a constant source of operational problems and dead time for the collider experiments.

The proposed solution to these problems is the Main Injector[4)]. This is a new 150 GeV synchrotron in a new tunnel, which replaces the Main Ring in all its functions. It will have a radius about half that of the present Main Ring, but will have adequate transverse and longitudinal acceptance to provide substantially increased proton intensities both to the

Antiproton Source for antiproton production, and to the Tevatron for collider operation. Moreover, it will be able to deliver intensities of 6×10^{13} protons/cycle to the Tevatron for fixed target operation. Finally, because it is in a separate tunnel from the Tevatron, it will allow 120 GeV test beams, and high intensity (3×10^{13}/cycle) 120 GeV production beams, to be delivered to the experimental areas year-round.

The overall impact of the Main Injector on collider performance is to increase both the proton and antiproton intensities sufficiently that the luminosity will exceed $5 \times 10^{31}/\mathrm{cm}^2/\mathrm{sec}$ (see fig. 1). The Main Injector project has been proposed to begin Oct. 1, 1991; if funded on the proposed schedule, it could be completed and operational by 1995.

Physics Reach of the Upgraded Tevatron Collider

In addition to the expectations for initial luminosity vs year, fig. 1 also displays another curve which shows the amount of calendar time (in years from the indicated date) required to reach an integrated luminosity of 1 fb^{-1}. This calculation folds in effects such as operational efficiency and luminosity lifetime, and is based on the experience of the 1988-89 collider run. It shows that within two years of operation after the Main Injector, the Tevatron collider could deliver 1 fb^{-1} of integrated luminosity. If the top quark had a mass of 250 GeV, this integrated luminosity would produce roughly 500 $\bar{t}t$ pairs. With detection efficiencies in the range of 5-10%, 25-50 top events would be seen, which would be enough to guarantee discovery. Since it is generally accepted that consistency with the Standard Model requires the top quark mass to be less than about 250 GeV, the absence of these top events would be direct evidence for a failure of the Standard Model.

Conclusion

The Fermilab Tevatron exceeded its design luminosity goal as a $\bar{p}p$ collider by more than a factor of 2 during the 1988-89 collider run; it has operated with excellent reliability during the present fixed target run. An upgrade program, called Fermilab III, has been initiated which will result ultimately in a 50-fold increase in the collider luminosity. This program, phased to provide a gradual increase in the luminosity over a period of 5 years, results in maximal utilization of the existing facilities for physics during this period. The major component of the upgrade is the Main Injector, a new 150 GeV synchrotron which will replace the Main Ring in all its functions. The upgrade will substantially benefit the Tevatron fixed-target program, and will provide a new source of high intensity 120 GeV beams at Fermilab. The result of the luminosity upgrade will be to provide integrated luminosities in excess of 1 fb^{-1} over a two-year period of operation following completion of the Main Injector. This will extend the mass reach for new physics by more than a factor of two. In particular, it will guarantee discovery of the top quark if its mass is within the range currently predicted by the Standard Model.

References

1. V. Bharadwaj, J. Crawford, R. Mau, "The 1988-89 Collider Run Summary", in *Particle Accelerators*, 26, pp. 167-172 (1990)

2. G. Dugan, "Tevatron Collider: Status and Prospects", *ibid.*, 26, pp. 121-130 (1990)

3. D. E. Young, R. J. Noble, "400 MeV Upgrade for the Fermilab Linac", *ibid.*, 26, pp. 205-210 (1990)

4. S. Holmes, R. Gerig, D.E. Johnson, "The Fermilab Main Injector", *ibid.*, 26, pp. 193-198 (1990)

TECHNOLOGICAL DEVELOPMENTS FOR LINEAR COLLIDERS

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ABSTRACT

Research and development work for TeV-class linear colliders is reviewed by referring to the 2nd International Workshop on Next Generation linear Colliders, which was held at KEK on March 28 – April 5, 1990. Discussed are generic designs of the linear colliders and possible approaches to the design goals.

INTRODUCTION

A linear collider is known to be an only machine to realize electron-positron collisions at energies beyond those covered by LEP. However the limited repetition rate of linear accelerators imposes very stringent requirements on particle densities at the collision point to achieve useful collision luminosities, and necessitates development of many new accelerator technologies. Presently the development work on linear colliders around the world is constantly reviewed through an international workshop which is held about once a year. The workshop, "International Workshop on Next Generation Linear Colliders", was first organized in 1988 at SLAC to discuss the research programs on linear colliders around the world, identify areas common or complementary in their goals, and advance these programs by collaboration. The following is a brief summary of the present linear collider R&D status based on the last workshop held at KEK on March 28 – April 5, 1990[1].

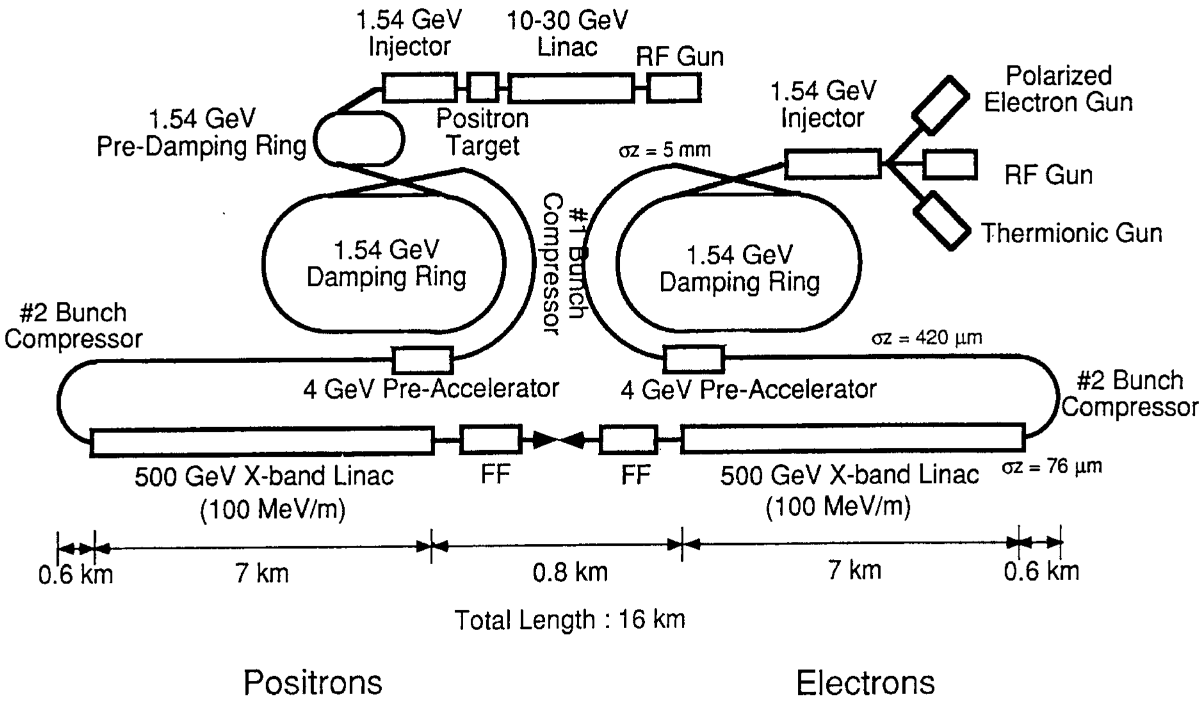

Fig. 1 A typical machine configuration of TeV-class linear colliders.

GENERIC MACHINE DESIGN

Extensive R&D efforts on linear colliders in the past few years are leading to a common machine configuration. Figure 1 illustrates a typical accelerator complex for TeV-class linear colliders. Its major subsystems are an injector complex, main linac, and final focus system. The injector complex consists of beam sources, injectors for damping rings, damping rings, pre-accelerators, and bunch compressors. The damping ring plays a role to reduce the emittances of the injected beams by factors of about 10^{-3} horizontally and 10^{-5} vertically. Its optimum energy is estimated to be 1.5 ~ 2 GeV. Parameters of the main linac and final focus system are listed in Table 1 for 0.5 – 2 TeV linear colliders proposed. It is commonly seen that flat beams are preferred to round ones, and beam sizes at the collision point have to be made as small as a few hundred nano-meters horizontally and a few nano-meters vertically to achieve luminosities of 10^{33} – 10^{34} $cm^{-2}\cdot s^{-1}$. In the case of the TESLA the requirements for the beam sizes are somewhat relaxed. The TESLA is a linear collider in which superconducting accelerating structures are used for the main linac. The superconducting structure has such advantages over the normal-conducting ones that it can tolerate a far larger duty factor and allow the operation at a lower RF frequency. The former is effective in resolving difficulties inherent to the design of the final focus system, and the latter relaxes the alignment and jitter tolerances for the structure which are required to avoid serious emittance growth due to wakefield generated in the structure by the beams. However the accelerating gradient presently attainable with the superconducting structure is fairly low (10 ~ 15 MeV/m) and construction cost of the machine is presumed to be very high. Therefore extensive R&D efforts for higher gradient and cost reduction will be needed before the TESLA will become realistic.

R&D STATUS

Requirements for the injector system are electron and positron production of about 10^{10} particles per bunch, emittance damping of beams at around 1.5 GeV to about 10^{-6} r·m horizontally and 10^{-8} r·m vertically in normalized unit in the damping ring, and bunch compression of the damped beams by a factor of about 10^{-2} to fit the

Table 1 Parameters of the 0.5 – 2 TeV linear colliders proposed.

	ILC or NLC (SLAC)	JLC (KEK)	VLEPP (INP)	CLIC (CERN)	S-BAND LC (DESY)	TESLA SC-LINAC
CM energy (TeV)	1	1	1	2	0.5	1
Luminosity ($cm^{-2}\cdot s^{-1}$)	3.9×10^{33}	6.2×10^{33}	10^{33}	1.1×10^{33}	1.9×10^{33}	5×10^{33}
Active length (km)	2 x 5.4	2 x 5	2 x 5	2 x 12.5	2 x 14.7	2 x 16.7
RF frequency (GHz)	11.4	11.4	14	30	3	1.5
Acc. gradient (MV/m)	93	100	100	80	17	30
Particles/bunch	1.6×10^{10}	1×10^{10}	1×10^{11}	5×10^{9}	7×10^{9}	6×10^{10}
Bunches/RF pulse	10	10	1	1	172	200
Rep. rate (Hz)	360	200	100	1690	50	15
RF pulse length (ns)	55	100	70	11	2800	0.8 ms
Wall plug power (MW)	196	200	100	70	99	234
Emittance: $\gamma\varepsilon_y$ (r·m)	3.5×10^{-8}	3×10^{-8}	6×10^{-8}	1×10^{-6}	6×10^{-8}	1×10^{-6}
$\gamma\varepsilon_x$ (r·m)	3.5×10^{-6}	3×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	2.5×10^{-5}
IP beam size: σ_y (nm)	3.1	1.4	10	12	7.8	58
σ_x (nm)	558	230	1000	60	192	554
Bunch length (μm)	70	76	700	200	200	1000

bunches to the phase acceptance of the main linac RF. These specifications are thought to be within the limit conventionally attainable, and the present R&D of the injector system is proceeding to an advanced design stage to discuss engineering optimization and prototype construction.

Key R&D elements of the main linac are high power RF sources and accelerating structures. It is very hard to specify the most optimum RF frequency and accelerating gradient of the main linac. These parameters are strongly affected by critical issues related to technical feasibility, beam dynamics, and construction cost. However, many pursuing TeV-class linear colliders with normal conducting structures believe that the RF frequency higher than about 10 GHz has to be chosen to limit the total wall plug power to a marginal amount, less than a few hundred megawatts, with the accelerating gradient of 50 ~ 100 MeV/m. As the high power RF source at the frequencies below about 15 GHz, a klystron tube seems to be most promising. Extensive R&D's are underway at SLAC and KEK for 11 GHz tubes and at INP-Novosibirsk/Protvino for 14 GHz tubes. The tubes fabricated have been tested to an RF power level of 50 ~ 70 MW, about half the design goal. For the CLIC, development of a new type of the high RF power source based on the two-beam scheme is in progress at CERN.

The accelerating structure for TeV-class linear colliders has to produce four to five times higher accelerating field than that attained in the present-day linacs, 15 – 20 MV/m. Many laboratories, SLAC, KEK, LAL-Orsay, and INP-Novosibirsk/Protvino, are undertaking developments of the high gradient structures. Recent experiments have proved that the copper structures fabricated with newly developed surface finishing techniques can sustain accelerating field higher than 100 MV/m at S-band. Test beams have also been accelerated successfully at the energy gradient reaching about 90 MeV/m in the short S-band prototype structures, although a dark current effect has been observed to become serious above about 70 MV/m. Another problem for beam acceleration with multi-bunches in the structure is excitation of higher order electromagnetic field modes leading to beam break-up. To avoid this effect, it is highly desirable to work out a structure which has very low external Q-values for dangerous higher order modes. This, so-called damped structure, is also being studied theoretically and experimentally.

The final focus system is one of the most critical of the linear collider. Its design parameters, as seen in Table 1, extend far beyond those attained in the SLC. The fundamental requirement is to achieve achromatic focusing with a demagnification factor of 1/300. To investigate feasibility of the final focus system experimentally, the Final Focus Test Beam facility (FFTB) is now under construction at SLAC in collaboration with R&D groups from SLAC, KEK, LAL-Orsay, DESY, and INS-Novosibirsk/ Protvino. The facility is to be built in the straight-ahead beam yard at the end of the 50 GeV linac, and is aimed to study the optics, alignment, and beam instrumentation required for focusing beams as thin as 60 nm. Its completion is foreseen in late 1992.

SUMMARY

As described above, the R&D work on the future linear colliders around the world has been making remarkable progress and getting at a stage of the advanced machine design beyond the conceptual one. In fact, many subsystems under the development for the beam sources, damping rings, high power RF sources, high gradient accelerating structures and final focus system are expected to nearly reach the design goal within two to three years. In addition to the FFTB at SLAC, also planned are construction of a number of test beam facilities, as Engineering Test Accelerator at SLAC, CLIC Test Facility at CERN, Test Facility at INP-Novosibirsk/Protvino, and Test Accelerator Facility at KEK. The R&D groups making the world-wide collaboration set their primary goal in completing a conceptual design to propose a next generation linear collider project by 1993 – 1994.

REFERENCE

1. *Proceedings of the 2nd International Workshop on Next Generation Linear Collider*, March 28 – April 5, 1990, KEK, KEK Internal 90-22.