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ELECTRON-POSITRON LINEAR COLLIDER R&D PROGRAM AT KEK

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INTRODUCTION

It is generally recognized that the study of elementary particle interactions should be extended to the multi-TeV region for penetration of the frontier described by the Standard Model. This necessarily demands development of new accelerators, both hadron colliders and lepton colliders, of energies a few to tens of TeV. In Japan, the High Energy Committee, high energy scientist's organization in Japan, showed in 1986 the directions in which we should go after TRISTAN to pursue physics in the new energy frontier. Those are summarized as follows.

1. Immediate initiation of R&D efforts to investigate a possible construction of an electron-positron linear collider of the beam energy 0.5 - 1 TeV as a home-based facility.
2. Promotion of the international collaboration which will lead to the participation in experiments to be done by super-high energy hadron colliders as SSC and LHC.

Responding to this High Energy Committee's proposals, KEK has organized a group to do a coherent R&D work on the linear collider this year. The tasks imposed on this group are to make and execute an R&D program to determine the feasibility of a TeV class linear collider in approximately five years. It should be noted, however, that the R&D work required will be far beyond the scope of one institute and should be done in a frame of an international cooperative program.

OUTLINE OF THE R&D PROGRAM

In order to grasp technical difficulties inherent to TeV class linear colliders, we present in Table 1 the general parameters of a 0.5 TeV + 0.5 TeV linear collider which is tentatively designed. Investigations of those parameters generally specify areas which the present R&D program should encompass as follows.

1. Theoretical works on (a) system design including injection damping rings, linacs, and final focuses, and (b) beam dynamics such as beam-beam disruption, beamstrahlung, and instabilities of an intense bunch accelerated in linacs.
2. Development of high gradient accelerating structures which can attain the accelerating field higher than 100 MV/m in practical operations.
3. Development of high power sources of an output power larger than that presently realized by an order of magnitude.
4. Development of final focussing devices.
5. Investigation of ground motion and development of static and dynamic methods to install and align accelerator structures with an accuracy better than submicron meters.

A major experimental R&D program planned at KEK is to build a test accelerator facility as described below. The facility will be a multipurpose one and expected to offer means for developments of high gradient accelerating structure and high power RF sources as well as studies of interactions between beam and accelerating structures. In parallel with the experimental work, considerable efforts are also to be directed to design studies of not only a TeV class linear collider but also a fairly lower energy one. Construction of such a prototype accelerator might become necessary preceding the TeV one. At the moment no guidance exists as to the energy of the prototype. It will be influenced both by future progress of R&D works including the operation of SLC and by requirements of physicists, provided that the prototype will also be used to produce physics outputs.

Table 1 Parameters of a linear collider tentatively designed at KEK

Beam related parameters	
Beam energy, E_0	0.5 TeV
Luminosity, L	1×10^{33} cm^{-2}sec^{-1}
Beam power, P_b	7.5 MW/beam
Disruption parameter, D	0.45
Aspect ratio, σ_y^*/σ_x^*	1
Enhancement factor, H	5.7
Beamstrahlung parameter, δ_{cl}	0.1
Number of particles per bunch, N	4.8×10^{10}
Bunch frequency, f_B	2×10^3 sec^{-1}
Normalized emittance, $\gamma\varepsilon$	1.8×10^{-5} m·r
Final focus parameter, β^*	1 cm
Bunch length, σ_z^*	0.6 mm
Bunch radius, σ_r^*	0.43 μm
Linac parameters	
Length per linac, L_ℓ	5 km
RF frequency, f_{rf}	10 GHz
Accelerating gradient, G	100 MV/m
Attenuation parameter, τ	0.65
Filling time, T_f	140 ns
RF and structure efficiency, $\eta_{rf}\cdot\eta_s$	0.25
Energy extraction efficiency, η_b	0.06/bunch
Total wall plug power, P_{ac}	100 MW/linac

TEST ACCELERATOR FACILITY

Numerous new ideas on the linear collider have been proposed to solve such technical problems as mentioned above. On a relatively short time scale, however, the solutions should be sought among the fairly conventional approaches. As one of such approaches we are going to build a test accelerator facility as depicted in Fig. 1. The main ingredient of the facility is a 1 GeV S-band linac with an accelerating field as high as 0.1 GeV/m. The linac is about 10 m long and will be composed of three sections of a 3.3 m structure unit. For a conventional 2π/3-mode constant impedance structure with the beam aperture 22 mm in diameter, the group velocity would be approximately 0.011c and the shunt impedance 55 MΩ/m. Hence the required peak RF power per unit section would be 840 MW for the average accelerating gradient 0.1 GV/m. If we assume klystrons of output power exceeding 100 MW are available, eight such tubes should be employed for each unit. One of the candidates will be the SLAC 50/45 type 60 MW klystron which is expected to generate an output power of

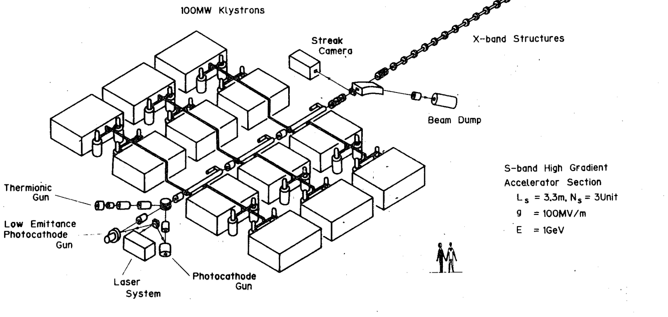

Fig. 1 KEK test accelerator facility.

about 100 MW for pulse width less than 1 μs. The output power from those eight tubes will be combined straight forwardly by a series of 3 dB hybrids. The input coupler of each structure will have two or four input ports for the sake of field symmetry on the beam axis and also to reduce the number of the 3 dB hybrids.

A high gradient S-band accelerating structure has already been tested at KEK.[1] The structure is composed of three regular cells and two coupler cells at each end and operated in the 2π/3 traveling wave mode. Main parameters of the regular section are summarized in Table 2. The structure was tested by inserting it in a resonant ring as shown in Fig. 2. The klystron output power of 30 MW with a pulse width 2 μs was fed into the ring through 6 dB coupler to give a maximum circulating power inside the ring of about 120 MW. After about five-hundreds hours of integrated microwave conditioning, an accelerating field gradient of 104.5 MV/m was stably achieved extending for more than ten hours. This was experimentally proved by measuring energy spectra of the field emitted electrons as shown in Fig. 3.

As illustrated in Fig. 1, we will install a long section of X-band structures to transmit electron bunches accelerated by the 1 GeV test linac. For the moment it is very difficult to say what frequency range will be best suited to TeV class linear colliders. Recent progress in the theoretical design studies, however, seems to show a preference of considerably higher frequencies than S-band, 10 GHz the lowest. In such a case, serious problems will arise from beam induced transverse wake fields, which scale as the third power of the operating frequency. Unless errors on jittering of the injected bunch position, misalignment of structures and Q-magnets etc. are minimized enough, effects of this wake would make stable transmission of a high current bunch extremely difficult. Therefore, with the present facility we plan to investigate a transverse emittance growth due to the wake by constructing a transmission line made of the X-band structures with a total length corresponding to several betatron wave lengths or 10 to 20 m.

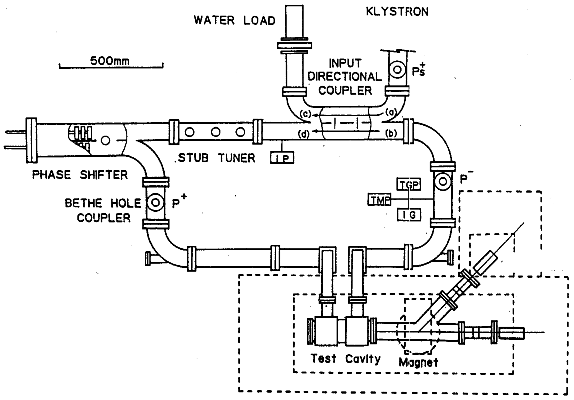

Fig. 2 Experimental set-up for high accelerating field generation.

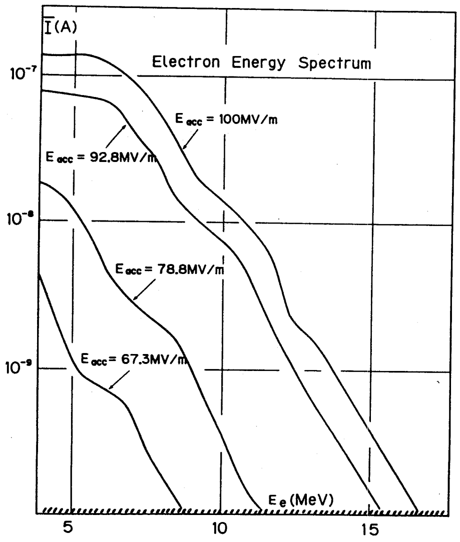

Fig. 3 Energy spectra of field emitted electrons for various accelerating field.

Table 2

Parameters of the accelerating structure

Phase shift/cell	2π/3
Structure length	17.5 cm
Beam hole diameter	1.6 cm
Cavity diameter	8.132 cm
Resonant frequency	2856.15 MHz
Q	13330
Shunt impedance	63.1 MΩ/m
Attenuation	0.7017 Neper/m
Group velocity	0.0032 c

With regard to the RF source, there is no available X-band high power tube. If we scale from the S-band case, to obtain an accelerating gradient of 0.1 GeV/m for the X-band structure will require an RF power of around 65 MW per 0.5 m long unit structure with a pulse width about 0.2 μs.

In the past few years, an experimental development of a lasertron is underway at KEK.[2] The purpose of this work are to study high RF power generation by lasertron and to investigate a possible application of the lasertron gun to a high current and low emittance electron source. Theoretical analyses show that compared with a conventional klystron the lasertron will have the potential merit of producing higher peak power with higher efficiency. The present lasertron has such a structure as drawn in Fig. 4 and is assembled together with a laser system, a modulator power supply, a coaxial cable to supply charge to the photocathode, and a beam collector as shown in Fig. 5. A cw mode-locked Nd:YAG laser produces a continuous train of 85 ps infrared optical pulses with 5.8 ns separation. After pulse modulated and waveform shaped, the output is converted by a second harmonic generator into green light of the wave length 532 nm, pulse width 60 ps, and optical power about 40 mJ. Then, a mirror system increases the frequency by a factor of 16 to form a 2856 MHz optical pulse train. A GaAs wafer with an active area of 20 mm in diameter is used as the photocathode. Its quantum efficiency is expected to be about 5 %. Results of the first experimental test of the present system are given in Fig. 6. The figure shows the beam current I and output RF power P_{rf} as a function of the accelerating voltage V. Below 50 kV, I exhibits a nor-

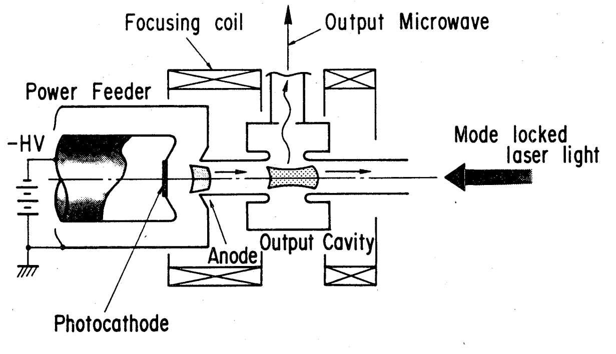

Fig. 4 A conceptual drawing of the lasertron.

mal behavior characteristic of a klystron. Above 50 kV, I is proportional to V and indicates a deviation from the normal diode characteristics. The maximum RF output power attained so far is about 80 kW with a peak current of 21 A and an applied pulsed high voltage of 150 kV. Efforts to improve the performance of the present system are in progress aiming at achieving an output power exceeding 1 MW.

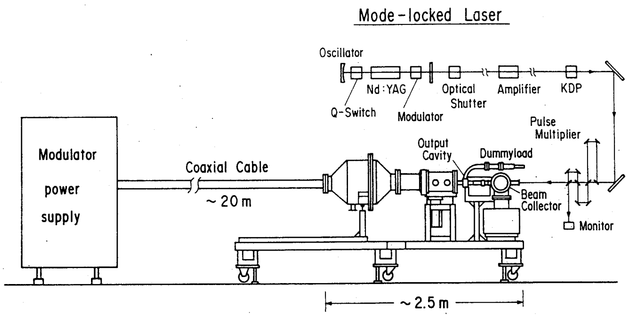

Fig. 5 Experimental arrangement of the KEK lasertron system.

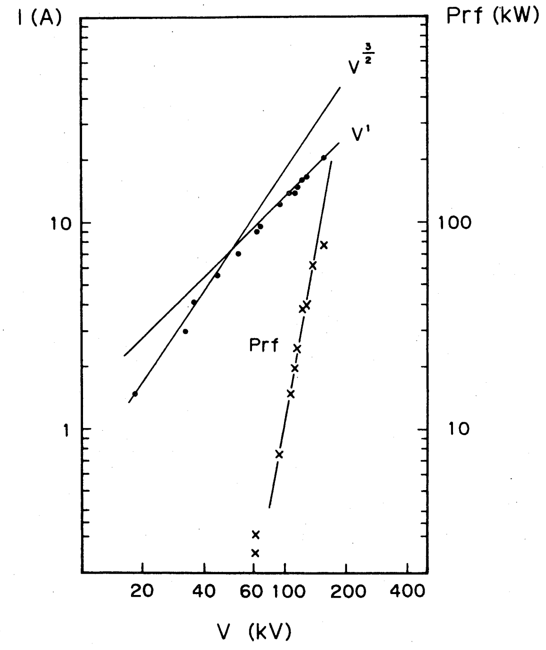

Fig. 6 Beam current and output RF power of the lasertron as a function of the accelerating voltage.

OBSERVATION OF A REGULAR GROUND TREMOR

In connection with problems of the fine beam alignment required for linear colliders, we have tried to measure a regular ground tremor in the KEK site. A system of high sensitivity seismometers was set at the depth of 100 m underground at the site boundary about 100 m away from a main public road. The stratum on which the seismometers were placed is a hard sand layer with an n-value larger than 100. The seismometer system consists of three units to measure vibration amplitudes in three directions, two in horizontal and one in vertical. Each unit has a sensitivity of better than 0.01 μm. The measurements were carried out through a week by using an automatic data recording system. Typical data measured are illustrated in Fig. 7 and 8. Figure 7 shows the tremor amplitudes in horizontal, North-South and East-West, and vertical, Up-Down, directions. Figure 8 shows frequency spectra of the tremor obtained by Fourier analysing the amplitude data. Case A and B denoted in the figures correspond to the data obtained in the night-time and day-time, respectively. As seen from Fig. 7, the peak to peak amplitudes of about 1 μm in the day-time are suppressed to about 0.2 μm in the night-time. Correspondingly, the frequency spectra of the day-time data contain far larger high frequency components than those of the night-time data indicating the dominant source of the ground tremor is vehicular traffic on the public road.

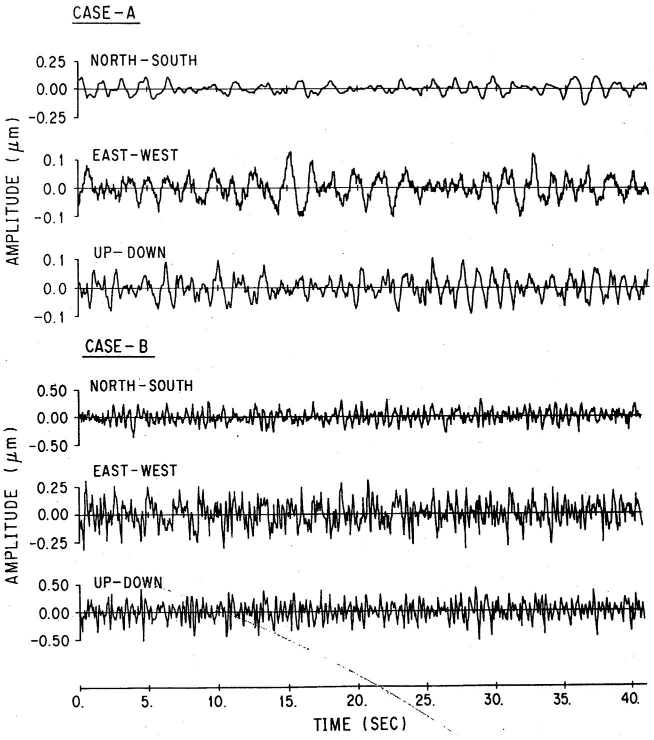

Fig. 7 Ground tremor amplitudes in horizontal, North-South and East-West, and vertical, Up-Down, directions. Case-A and B correspond to the data obtained in the night-time and the day-time, respectively.

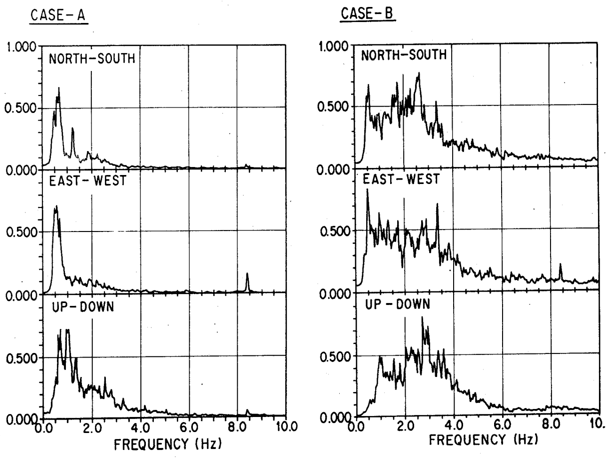

Fig. 8 Frequency spectra of the ground tremor as shown in Fig. 7.

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