OPERATION OF THE KEK 2.5 GeV ELECTRON LINAC

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Summary

Construction of the KEK 2.5 GeV electron linac was completed at the end of January 1982 and the initial operation was started at the beginning of February 1982. A general description of the operational behavior of the linac since that time will be given. The goal of the linac performance was completely satisfied on March 16 with the measured value of 2.5 GeV at 55 mA. At the high current test, 2.5 μs 300 mA beam was obtained at 1.81 GeV. Scheduled operation of the linac for the Photon Factory 2.5 GeV storage ring was opened in June 1982 and injection into the TRISTAN accumulation ring has been continued since November 1983. Energy, energy spread and profile of the accelerated beam are stable. In addition, some of the technical developments concerning the linac will be reported.

Introduction

The KEK 2.5 GeV electron linac was constructed as an injector for the Photon Factory (PF) 2.5 GeV storage ring dedicated to the synchrotron radiation research[1] and for the electron positron collider TRISTAN[2] The general guiding principle for design of the linac was based on obtaining stable beam and on simplifying the structure to facilitate construction, operation and maintenance. Because of the linac is an injector for the two storage rings, high stability is required for the beam. In addition, high threshold for beam break up is desirable for such a long linac. To obtain the stable beam, high level of stabilization for the rf sources and the beam transport system is required. To reduce the beam break up effect, it is desirable that the accelerating field and the beam guiding field are as symmetrical as possible and the symmetrical thin beam passes through along the center axis of the whole system.

To realize above requirements,

1. Five types of semiconstant gradient high precision accelerator guides which have different HEM mode frequencies[3]
2. Rf couplers in which the field distribution is symmetrical[4]
3. Strong and symmetrical focusing system such as quadrupole triplets[3]
4. Well aligned structures over the whole length

were adopted.

To simplify the structure and to facilitate the construction of the linac, module system was widely introduced. The principal parameters of the linac are listed up in Table 1.

Table 1 General parameters of the 2.5 GeV linac

Energy (50 mA loaded)	
(Total rf power) 840 MW	2.5 GeV
1200 MW	3.0
Beam pulse length	1.5 ns ∿ 2.0 μs
Repetition rate	< 50 pps
Energy spread	< 0.5 %
Normalized emittance	< 10π cm·mrad
Accelerator guide (Main accelerator)	
Type of structure	TW. 5 type Semi-C.G.
Frequency (at 27°C)	2856 MHz
Length of accelerator guide	2 m (Including couplers)
Total number of guides	160
Length of acceleration unit	9.6 m
Number of acceleration units	40
Number of sectors	5
RF	
Peak power of klystron	30 MW (Max.)
Number of klystrons	41 (Including one klystron of Injector)
RF pulse length	3 μs
Injection system	
Type of gun	Triode
Gun voltage	- 100 kV
Number of acc. guides	2
Output energy	35 MeV (Max.)

The linac housing running south to north is located on the west side of KEK site and is connected with the PF storage ring and the TRISTAN rings as shown in Fig. 1.

The linac consists of a 35 MeV injection system, a main accelerator, a beam switching system, a central control system and a positron generator which is still under construction.

The main accelerator is divided into five sectors, each of which is composed of eight acceleration units and sector control system. One acceleration unit consists of four 2 m long accelerator guides mounted on a cylindrical supporting girder, a high power wave guide system, a high power klystron and its modulator with a controller. Vacuum manifold, cooling water pipes and two position sensitive targets for alignment are also mounted on the girder. The assembled acceleration units were transported into the tunnel and installed using a special trailar. The beam line over 450 m was aligned by a He-Ne laser beam and the position sensitive targets. In order to avoid the air turbulence, the alignment targets are placed in a vacuum pipe over the whole length. The alignment error was within 0.3 mm over the length[5]

In each acceleration unit, the rf power from the klystron is split and fed to the four accelerator guides. The phase lengths of the four waveguide branch lines were made so precisely that the phase shifters were omitted in the high power lines.

Operation of the Linac

Initial operation

As an assembling of the 2.5 GeV electron linac and the 2.5 GeV storage ring was almost completed at the end of January, 1982, initial operation of the linac was started at the beginning of February. Figure 2 shows a view from the injection side of the linac. The first beam was smoothly accelerated without any serious trouble and after 2.34 GeV, 57 mA (1.5 μs) beam was achieved on February 10, the linac beam was mainly used for injection into the storage ring. During this period, beam transmission of the linac was remarkably improved, and beam spill over the main accelerator was reduced to within several percent of the injected beam.

On March 11, 2.5 GeV, 31 mA beam was injected to the storage ring and the first 2.5 GeV, 6.2 mA beam was successfully stored. The goal of the linac, that is, 2.5 GeV, 50 mA beam was obtained on March 16 with the measured energy and beam current of 2.54 GeV and 55 mA respectively.

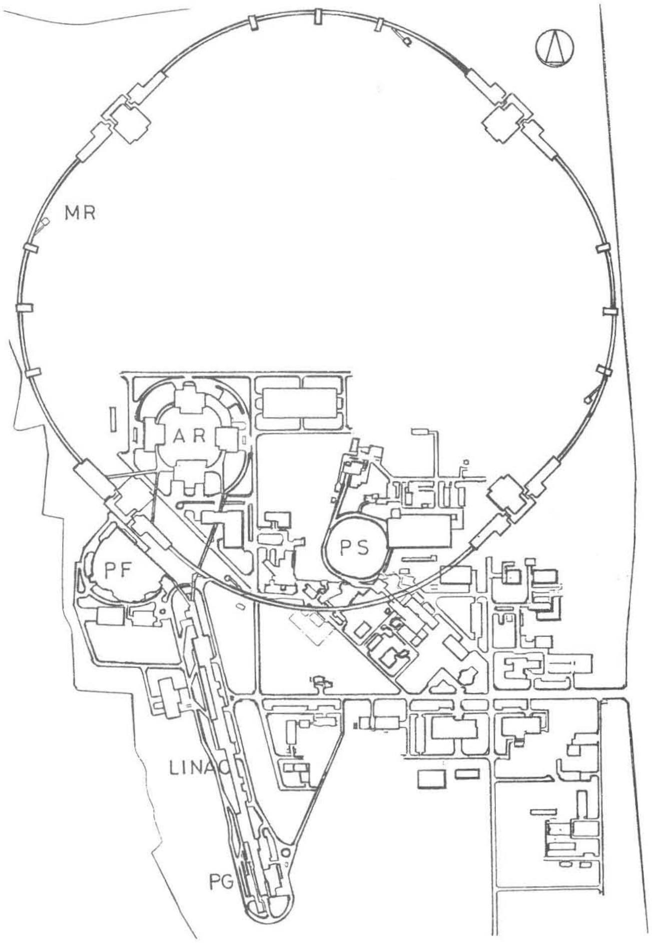

Fig. 1 Layout of the KEK Accelerators.

At the end of the initial run, the beam intensity of the linac was increased as high as possible and a beam of 300 mA was obtained at 1.81 GeV. The current of 2.5 μs, 300 mA was the beam blow up threshold of the linac for the initial operating condition.

Thus the initial overall operation of the Photon Factory accelerators and some of the experimental equipments was successfully completed on March 19, 1982 and the first scheduled operation of the machines for synchrotron radiation research was opened in June 1982.

After the initial operation, with the advance of fine tuning of the injection system, beam transport system and of the rf system, beam quality of the linac has been remarkably improved. Constant improvements in the control system have made routine operation of the linac more easy and simple than the initial operation.

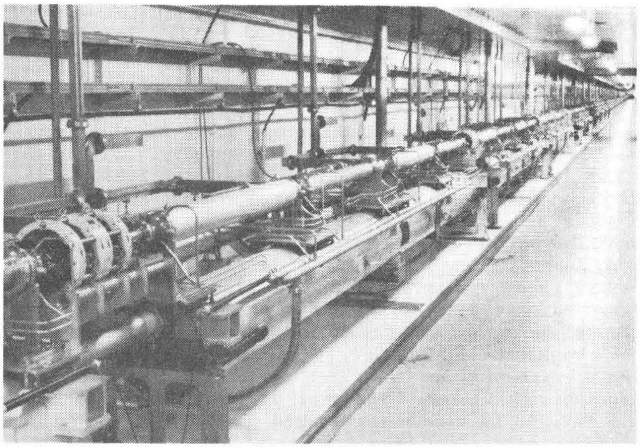

Fig. 2 View of the 2.5 GeV electron linac.

Operating performance

The injection system, the accelerator guides, the vacuum system, the beam transport system and the control system have been operated satisfactorily without any serious trouble. The rf system has been operated stably except occasional arcing in the high power klystrons. Stability of the beam energy in the long linac depends on the stabilities of the rf power and rf phase. During one week operation period, rf phase adjustments are unnecessary unless the high power klystron voltage is changed.

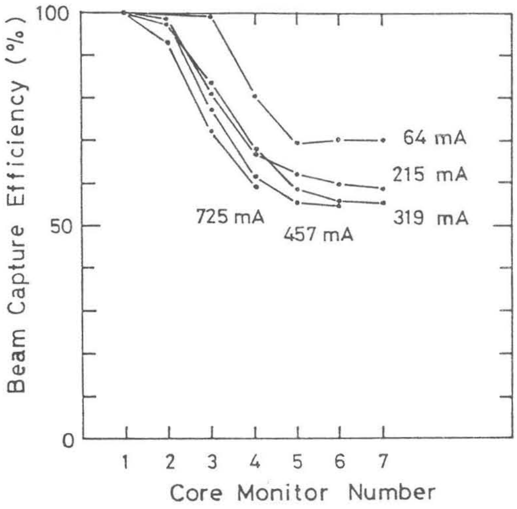

Fig. 3 Beam capture efficiency of the injection system.

A number of beam monitors; current transformers, fluorescent screens and ionization chambers distributed along the beam line facilitate the beam handling at the operation. Beam intensity is measured and monitored by 40 current transformers. Position and profile of the beam are monitored by 7 remote controlled fluorescent screens. For beam handling in the main accelerator, in addition to the current transformers, a beam loss monitor system using 40 ionization chambers are very efficient.

Figure 3 shows beam capture of the injection system. In a range up to hundreds mA of the beam current the capture efficiency is 60 to 70 percent. Beam bunch width was measured at the 500 MeV beam analyzer. Although the bunch width depends on the beam current and the rf phase adjustments, the minimum bunch width was 2 to 3 degrees up to 150 mA (Fig. 4).

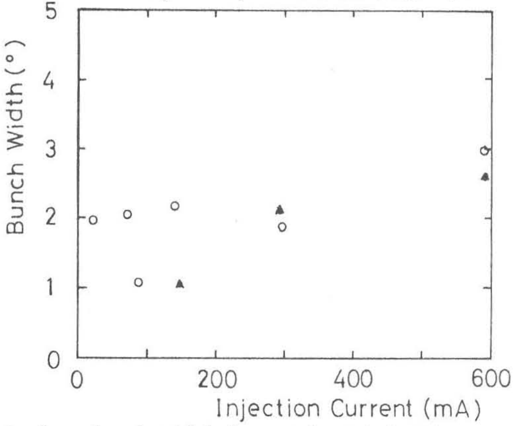

Fig. 4 Beam bunch width for various injection current.

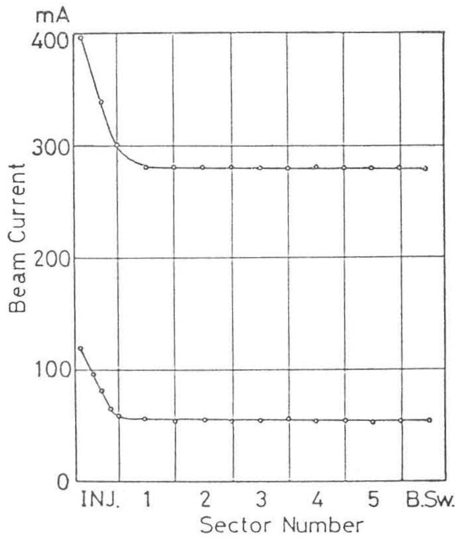

Fig. 5 Beam transmission of the linac.

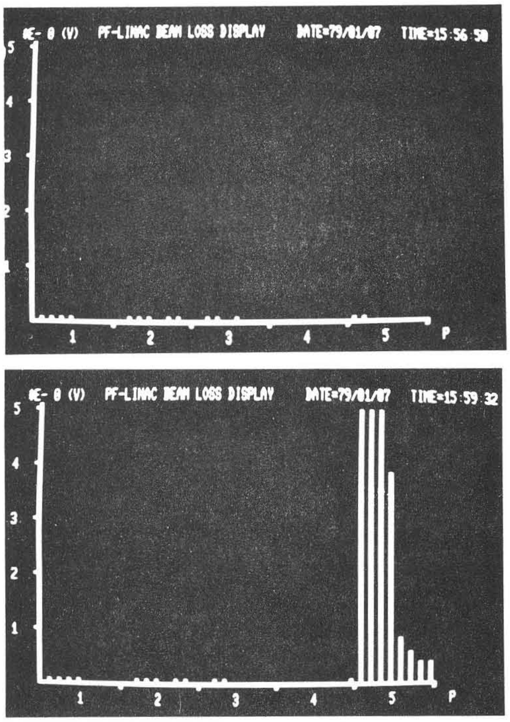

Fig. 6 Displays of the beam loss monitor.
Upper: After adjusting the linac.
Bottom: Fluorescent screen is inserted into the beam line at the end of the 4th sector.

Figure 5 shows beam transmission over the main accelerator. The positions and the rates of the beam spill along the main accelerator are displayed by the beam loss monitor system as shown in Fig. 6. Beam spill over the main accelerator is less than few percent. Beam profiles and beam positions at the sector ends are monitored by the fluorescent screens and ITV cameras. Two screen plates placed downstream of the linac have 4 mm diameter holes at their centers so as to observe axial displacement of the beam at "beam ON". The beam diameter is less than 5 mm and the most of the beam current passes through the screen holes. Figure 7 shows the beam current-beam energy relations. Beam break up threshold currents for 2.5 μs and 1.5 μs pulse beams are shown in the figure.

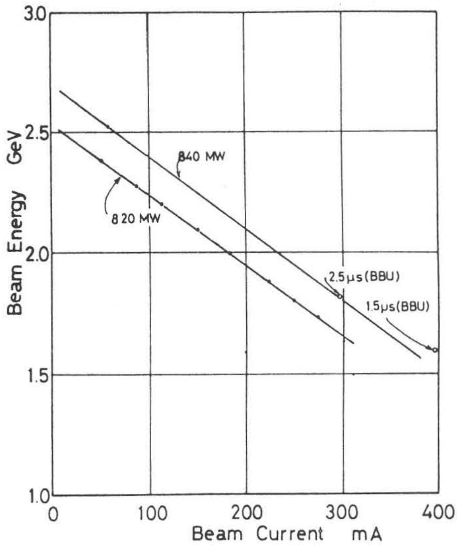

Fig. 7 Beam current-beam energy relations.

Measured energy spread is less than 0.5% for the 2.5 GeV, 1 ∿ 2 μs beam. However, for short pulse beams such as 1.5 ns, the energy spread decreases to 0.1%. Accurate emittance measurement in the electron linac is rather difficult compared with the proton linac because of the thin beams. The measured emittance was less than 30 πcm·mrad (normalized).

Injection into the storage rings

As the energy of the linac is same as the PF storage ring, injection and stacking of the beams in the PF ring have been carried out very easily. The PF ring is usually operated in a multi-bunch mode and occasionally operated in a single bunch mode. On the other hand, in the TRISTAN accumulation ring, the single bunch mode operation is usual. As the beam life time of the PF ring is increased to more than 10 hours, the injection for the PF ring is repeated every 8 hours. During the remaining time between the injections for the PF ring, the linac beam is used for the TRISTAN accumulation ring.

In order to stack a single bunch beam in the storage ring, synchronized injection of a very short pulse beam of which width is less than one period of the ring rf (500 MHz), is required. Although the routine operation of the PF ring is the multi-bunch mode, the stored beams filling up all of the rf backets (312) cause an instability due to the effect of ion-trapping. To reduce the instability, a partial fill mode (fill up 2/3 backets) operation is often efficient. For such an operation, the synchronized injection is also required.

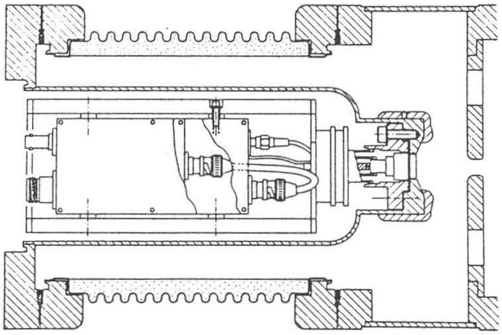

Fig. 8 Crosssection of the electron gun.

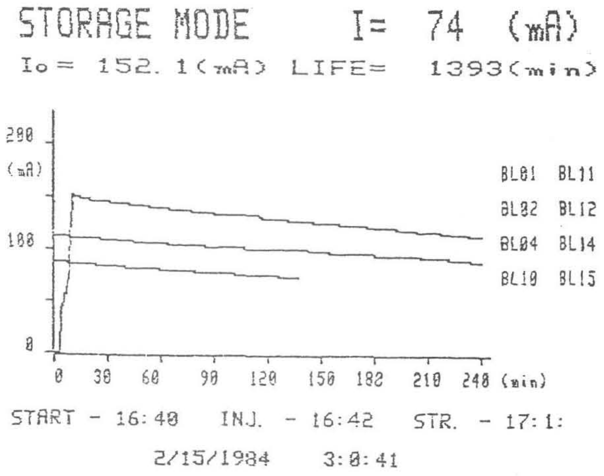

Fig. 9 Display of the PF storage ring operation.

To provide the long and/or short pulse beams for both of the rings, easy and smooth switchover of the beam pulse width is required.

For the purpose, the synchronized trigger[7] and the electron gun in which a module of the nanosecond grid pulser was installed, were developed. Figure 8 shows a section of the electron gun. The microsecond grid pulser is placed on the high voltage station of the gun and the microsecond pulse is transmitted through a coaxial cable which is connected in parallel with the out put of the nanosecond grid pulser through a low pass filter. Consequently, the μ-sec and n-sec pulses are remotely exchanged by switching of the trigger pulses for both of the pulses.

At present the injection energy is fixed at 2.5 GeV and the beam current is 30 mA to 50 mA. However, the repetition rate is decreased to 1 Hz. In such a condition, beam stacking rate of the PF ring is 1 ∿ 2 mA/pulse and this means the injection is finished in a few minutes. The rate is now limited by the tuning speed of the mechanical tuners of the rf cavities. Figure 9 shows a typical operating condition of the PF ring.

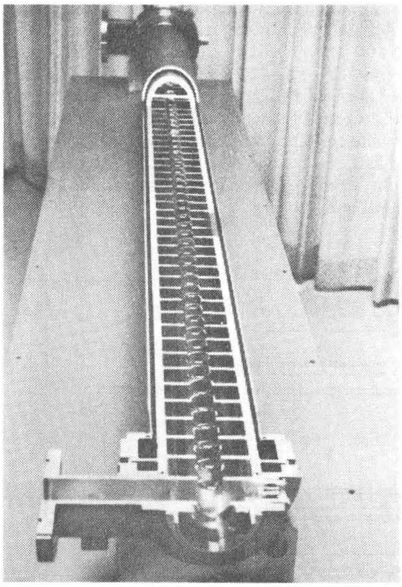

Fig. 10 Cutaway model of the accelerator guide made by an electroplating method.

Conclusion

Except for the high power klystrons, all of the 160 accelerator guides made by means of an electroplating method[8] (Fig. 10), the injection system, the beam transport system and the control system have been operated reliably without any serious trouble.

The rf system has been stably operated owing to the highly stabilized rf amplitude and phase and to the use of temperature compensated coaxial cables[9] The accelerated beams are stable, however, long term stability of the beams has been limited by occasional arcing in the high power klystrons and the beam has been interrupted for a few minutes whenever fault of the klystrons took place. The most serious trouble in the linac was high power klystron failure. In FY 1982, 10 klystrons had to be replaced. 6 of them were due to internal arcing and 3 of them were due to puncture of the ceramic rf window[10] (Fig. 11).

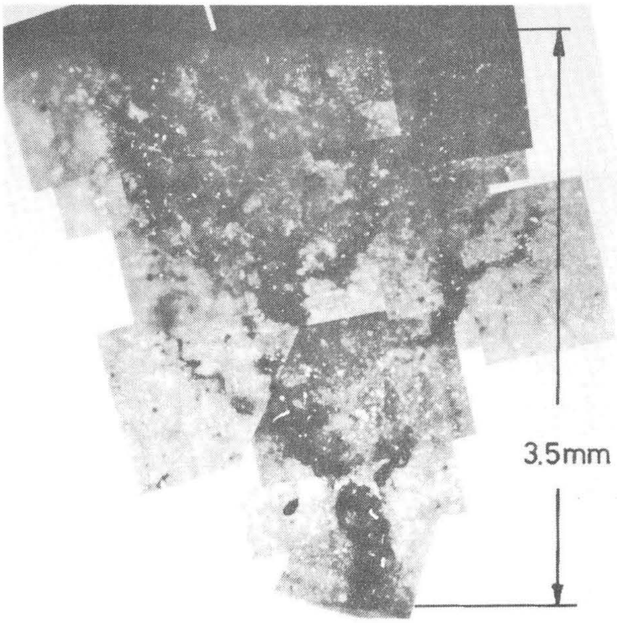

Fig. 11 Sectional view of the punctured window seramic.

The internal arcing is being cured by improvement of the klystron production process. At the end of FY 1983, fault rate of the klystrons were decreased by 30 percent compared with the rate in FY 1982. The puncture of the rf windows was remarkably reduced by change of the ceramic material and by slow down of the initial rf power up rate after replacement of the klystron. The studies on the rf window is now continued.

The pulse modulator of high power klystron is the most powerful noise source in the linac. In order to operate the machine reliably and to take accurate data, noise level around the controllers of all kinds of power supplies and the monitor-system must be reduced as low as possible.

A passive matching element consisting of a resister and a capacitor was added at the out put of the pulse forming network. Optical fiber cables were used for the communication lines interconnecting many linac-control processors. These are very efficient to reduce the large spike noise and to operate the linac reliably.

The rf coupler corrected the field and phase ditributions[4,11] was successful. Although all of the wave guide feeders connected to the accelerator guides are placed on the left hand side of the beam line, any dominant direction of the beam deflection has not been experienced. Figure 12 shows a typical distribution of the correction angles by the steering coils along the main accelerator.

Rf dummy load[4] made of ceramic type SiC was improved. By direct water cooling, the average rf power absorbed by the load was increased up to more than 1 kW without deteriorate the VSWR.

Figure 13 shows the new dummy load and Fig. 14 shows the result of the improvement for higher average power.

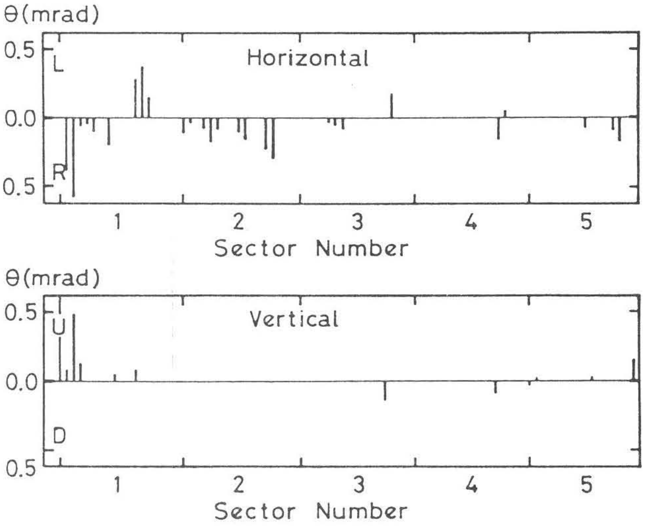

Fig. 12 Correction angles by the steering coils along the main accelerator.

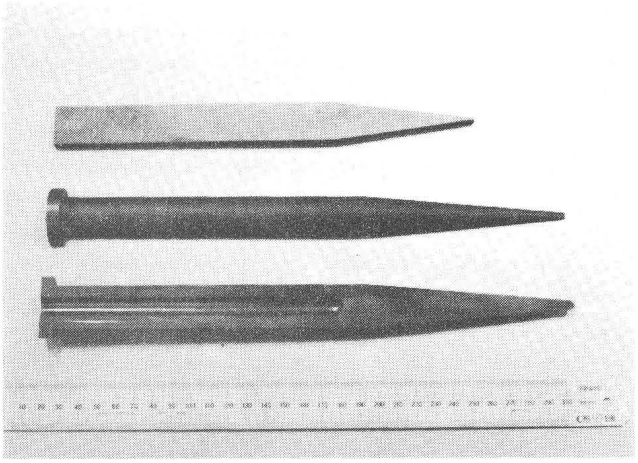

Fig. 13 SiC dummy loads.
Upper: Plate type load (old).
Middle: Water cooled cone type load (new).
Bottom: Sectional view of the new load.

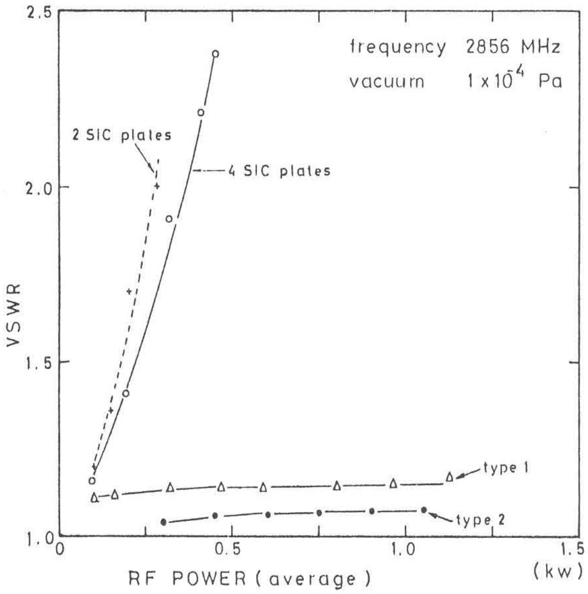

Fig. 14 Rf characteristics of the new and old type SiC dummy load.

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