High-Gradient Acceleration Test Using a Resonant Ring

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Abstract

The high-gradient performance of the existing accelerator sections of the PF 2.5-GeV electron linac was investigated regarding the linac energy upgrade for the KEK B-Physics project. Though the field gradient is lower (8~10 MV/m) in the present operation, a maximum peak gradient of about 30 MV/m must be applied to the section in this upgrade.

In order to apply a higher gradient, a test was conducted in which high power from a 30-MW klystron was fed into one accelerator section instead of four accelerator sections fed under normal operation, as well as adding a resonant circuit to this section.

Introduction

A high-gradient accelerator test was carried out in order to prepare for an energy upgrade of the PF 2.5-GeV electron linac regarding the KEK B-Physics project (KEKB) which started this fiscal year. In the KEKB, the linac energy will be increased from 2.5 GeV to 8 GeV; this is a factor of 3.2 in energy. The energy upgrade will be performed by increasing both the peak rf power fed to the accelerator sections and the length of the linac. For increasing the peak rf power, the modulator power is to be increased by twice, and rf pulse compressors are to be employed. To increase the linac length, the upstream side of the linac is to be extended. In this upgrade, 228 two-meter accelerator sections are to be used; the energy gain of each section must be more than 40 MeV in order to stably provide an 8-GeV beam. By using rf compressors, an average electric field of 21 MV/m and a maximum of nearly 30 MV/m will be applied to these sections. Since tests for using an rf compressor are presently underway, a high-gradient test was first carried out using a resonant ring.

Accelerator Unit

The PF 2.5-GeV electron linac housing is a two-story building of about 500 m in length. The first floor was excavated to be an underground tunnel to include 40 regular accelerator units. One accelerator unit comprises four two-meter accelerator sections fed by a klystron. The accelerator section is an s-band $2\pi/3$-mode disk-loaded semi-constant gradient structure, which comprises 54 cells as well as input and output couplers. The disk hole diameter decreases in a stepwise fashion along the length of the accelerator section. The step size is 75 µm. In order to disperse HME_{11}-mode frequencies, all of the sections have been divided into five groups (type A~E) according to the different hole diameters of the first disk. Table 1 gives the characteristics of the accelerator section.

In the present acceleration unit, one 2856 MHz klystron feeds rf pulses of 30 MW (maximum peak power), 3 µsec (width) and 25 pps (repetition).

Table 1 Characteristics of the accelerator section.

Operation frequency	2856 MHz
Length of accelerator section	1889 mm
Phase shift per cavity	$2\pi/3$
Field attenuation ($\tau=\alpha l$)	0.302 ~ 0.368
Shunt impedance	57.238 ~58.298 MΩ/m
Group velocity (v_g/c)	0.0137 ~0.0113
Q	13200
Filling time	0.462 ~0.558 µsec
Disk hole diameter (2a)	24.920 ~19.400 mm
Operation temperature	30±0.2 °C

Resonant Ring

A resonant ring is often used to increase the peak rf power; it is especially effective in case that the insertion loss of the devise in the ring is low and the voltage transmission factor (T) is nearly unity. Figure 1 is an illustration of a resonant ring which includes an accelerator section. The rf from a klystron is introduced by a directional coupler; the power is accumulated in the ring whose electric length is tuned. The voltage multiplication factor is given by

$$M = C\left[\frac{1-\left(T\sqrt{1-C^2}\right)^n}{1-\left(T\sqrt{1-C^2}\right)}\right],$$

where C is the coupling coefficient, T the transmission factor, and n the number of superpositions. When n is sufficiently large, the maximum of M is obtained at

$$C \cong \sqrt{1-T^2}.$$

The accelerator section used in the test was a type of B; since the transmission factor was 0.728, the optimum coupling was 0.686 (-3.77 dB). For convenience, an existing -3dB coupler was used; nevertheless, the decrease in the multiplication was not very large against the optimum case. Based on the input rf pulse duration (3 µsec) and the filling time of the accelerator section (0.49 µsec), the power in the ring is expected to be superposed by five times, the expected multiplication factor is 1.40.

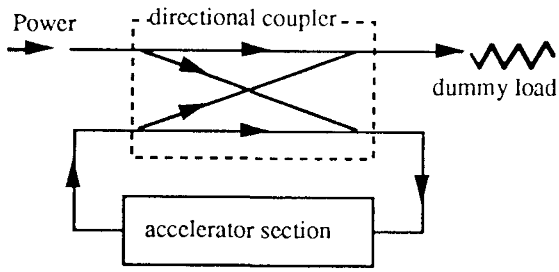

Fig. 1 Outline of a resonant ring which includes an accelerator section.

High-Gradient Acceleration Test

The First stage

Before using the resonant ring, the total power from one klystron was directly fed into one accelerator section by changing the rf-guide system. This test was carried out at the PF 2.5-GeV linac No.4-8 acceleration unit, which can usually be used on a standby basis for acceleration under 2.5-GeV operation. After rf processing, this unit was able to run at the maximum peak power at a pulse repetition rate of 50 pps without any significant problems concerning rf breakdown or the vacuum.

The acceleration energy was obtained from the difference between the maximum and minimum beam energies measured at a 2.5-GeV energy analyzing station by changing the rf phase from acceleration to deceleration. Thus, the energy gain of this unit was determined to be 19.6±1 MeV/m. The klystron output power was estimated to be about 24 MW, based on the shunt impedance of this acceleration section.

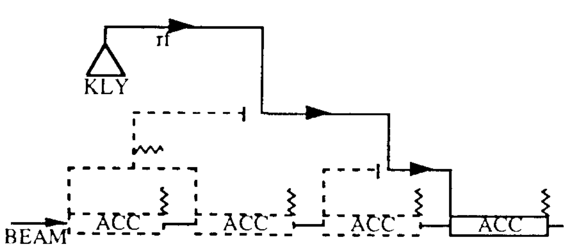

Fig. 2 The first high-gradient acceleration test at the accelerator section by changing the rf-guide system.

The second stage

After the first stage wsa completed, the waveguide system of the No.4-8 acceleration unit was changed so as to comprise a traveling-wave resonant ring with another 2-m accelerator section (Figure 3). This section had been in storage for six years after its past use; the waveguide was new. Because of a multipactoring discharge at the beginning, it took a little time to complete the conditioning. Before conducting high-power test, an attempt was made to determine the wavelength of the ring by a cold test. However, this was not sufficiently accurate to oftain a maximum multiplicaation in the high-power test, and there was a small gap between the operation frequency and the frequency of the maximum energy (386 kHz). Two pieces of short waveguide plates were therefore added after the first experiment.

The frequency gap was translated to a phase deviation using the relation

$$\delta\phi = \frac{2}{3}\pi \times \left(1 - \frac{c}{v_g}\right) \times \frac{\delta f}{f_0} \times \text{total cavity number}.$$

Thus, the optimum thickness of the phase-adjustment waveguide plate was determined and a maximum field was obtained during the high-power test. Figure 5 shows the waveform in the ring, observed through a Bethe-hole coupler. The rf power built up in five steps as described above. The measured energy gain was 28.6 MeV/m.

Table 2 Results of the high-gradient acceleration test with a 2-m accelerator section

	first stage	second stage
Acceleration energy (MeV)	37.0	54.1
Acceleration field (MV/m)	19.6	28.6
Fed rf power (MW)	24	30

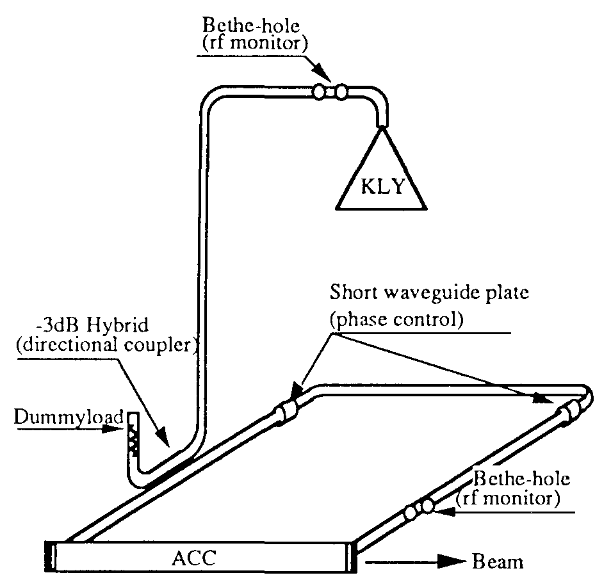

Fig. 3 Traveling-wave resonant ring with a 2-m accelerator section.

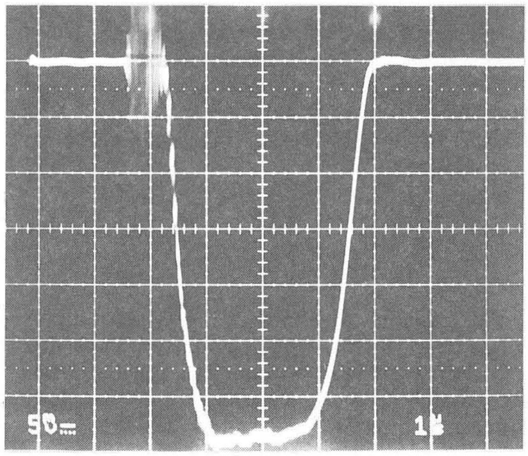

Fig. 4 Rf waveform out of the klystron. (1μs/div)

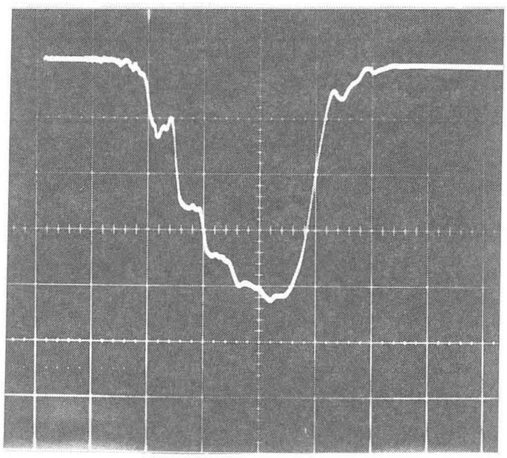

Fig. 5 An rf waveform building up in the accelerator section during a pulse. (1μs/div)

Conclusion

It has been proved that the existing accelerator section can be used under a high-gradient condition up to about 30 MV/m. However, the high-power performance issues regarding the total of 228 sections should be further studied by testing more sections. Due to the importance of this matter, an increase in the number of accelerator units with a high-power klystron and an rf compression is underway. A unit has been running at 23 MV/m since the winter of 1993; another unit was started this spring; three more units will be started this autumn. It has also been proved that an improvement in the vacuum is important for smooth conditioning of the accelerator section.

References

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