USE OF SLEDS FOR HIGH-GRADIENT ACCELERATION

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Abstract

A SLED-type pulse compressor is under testing for the linac upgrade for the KEK B-factory. We adopted a SLED having dual coupling holes, developed by the JLC group at KEK. The SLED cavities work in the TE015 mode and have a Q value of 100,000. The allowable errors in manufacturing and tuning the SLED are discussed in order to ensure low VSWR and high energy-gain multiplication. RF power of more than 40 MW was fed into the first prototype SLED, and an energy gain of 23.7 MeV/m was obtained. The energy multiplication factor was 1.89 on the average.

Introduction

The B-physics project at KEK (KEKB) started this year (1994). The PF electron linac, which will be an injector for KEKB collider rings, will have its energy upgraded from 2.5 to 8 GeV by increasing both the RF power and the total accelerator length[1].

The upgrade of the RF source will be carried out as follows. The present klystron modulators will be upgraded[2] in order to increase the output power and to extend high-voltage pulse width up to 4 μs on its flat top. The present 30-MW Klystrons will be replaced by a new 50-MW type which is under development[3]. An RF-pulse compressor, such as a SLED, will be installed in every high-power RF sources, except for three sources which require severe phase and amplitude control. Accompanying the upgrade mentioned above, the RF drive system will be improved and intelligent control systems will be introduced in each high-power RF amplifier.

Two types of RF-pulse compressors are now under investigation:

- SLED[4] type having two standing-wave cavities and a 3-dB hybrid coupler.
- Traveling-wave type of resonant ring[5].

Two prototype SLEDs have already been installed in the present linac in order to evaluate the performance of the SLED and to find any problems involving the high-power RF sources. The second prototype is a SLED improved according to experience obtained with the first one. The next three SLEDs are installed this summer. Basic development of the traveling-wave type has almost been completed and a high-power test of the first prototype will be carried out this year.

Design of SLED

The basic design of the SLED was made by the JLC group[6]. This SLED comprises a T-shape 3-dB hybrid coupler and two cylindrical cavities. Both ends of a horizontal bar of the T are input/output ports, respectively. The cavities have two coupling holes on one end plate of each cavity and are combined with the vertical bar of the T-shape coupler. This cavity resonates in the TE015 mode (2856MHz) and has a cavity Q value of 100,000. The drive microwaves have a pulse width of 4 μs at maximum. These specifications and our typical accelerator guide give a maximum energy-gain multiplication factor of 2.01 at a coupling coefficient $\beta = 6.4$ (Fig. 1 and 2).

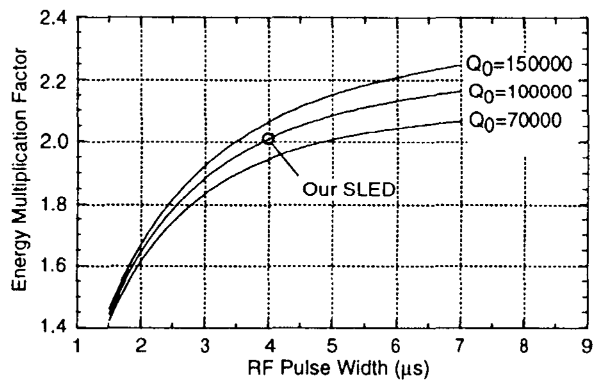

Fig. 1 Energy multiplication factor as a function of the RF pulse width and the cavity Q value.

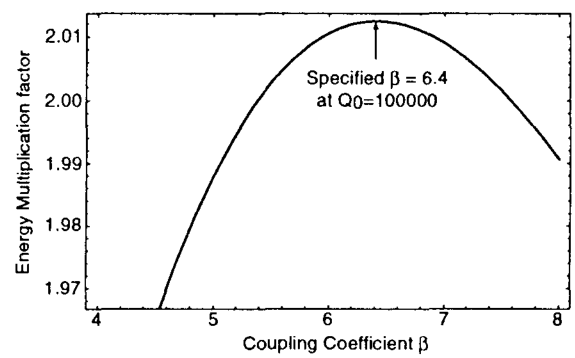

Fig. 2 Energy multiplication factor as a function of the coupling coefficient β.

Each cavity of the SLED has a precision frequency tuner with 2-kHz resolution, at their end plates. The cavities are also equipped with detuners in order to disable the SLED operation. The detuner of the second prototype SLED comprises a long thin needle made of a stainless-steel pipe, a permanent magnet at the root of the needle and seven solenoids wound around a cylinder which supports the needle in it. A control circuit sequentially and quickly switches the solenoids to slide the needle into (or out of) the cavity.

Multiplication and VSWR

The performance of the SLED cavity depends on the following three characteristic values: the resonant frequency

(f_0), the unloaded Q (Q_0) and the coupling coefficient (β). The deviation in these values from the specification decreases the energy multiplication. Any difference in these values of both cavities increases the VSWR. The later two values, Q_0 and β, are not very significant, since any possible errors in them do not cause a loss of more than 0.2% of the specified multiplication factor and do not give the VSWR greater than 1.1. The first one (f_0), however, must be precisely adjusted. If the loss of energy multiplication has to be less than 0.5%, we should adjust the frequency tuners to within an error of ± 15 kHz (Fig. 3). Figure 4 shows that a specification of VSWR < 1.2 requires one to tune the cavities to within an accuracy of f_0 ± 18 kHz.

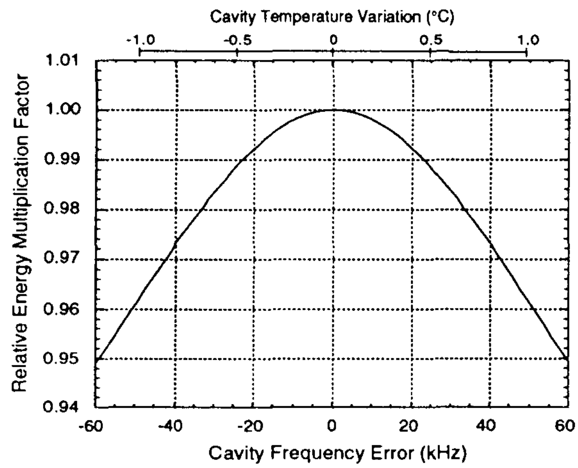

Fig. 3 Relative energy multiplication factor as a function of the frequency error and temperature variation.

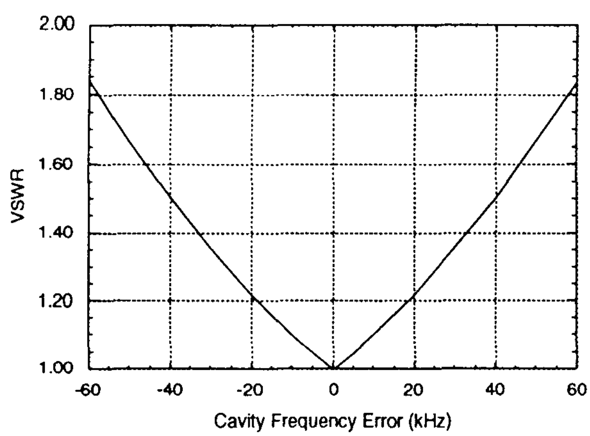

Fig. 4 VSWR as a function of the frequency difference of the SLED cavities.

The temperature drift of the cavity may greatly affect the resonant frequency. If we want to minimize the temperature dependence of the multiplication factor, the cavity frequency has to be adjusted as precisely as possible (Fig. 3). The temperature of the cooling water for the SLEDs and the accelerator guides is controlled at 30 ± 0.1 °C at the present linac. This small drift may cause a frequency variation of ± 5 kHz and can finally result in a beam energy drift of about ± 0.1% at maximum when the resonant frequencies are adjusted with errors of ± 5 kHz.

Under practical operation of the SLED, the finite response time of the microwave components decreases the multiplication. Figure 5 illustrates an example in which the rise time of the RF pulse and the phase-switching time are 100 ns and 200 ns, respectively. In this case, the energy multiplication loses about 3% of its value. The narrow bandpass characteristics of the accelerator guides also make the response time slower, however, this effect has not been well examined yet.

The 3 dB coupler also contributes to the VSWR of the SLED. According to the present specification, coupling loss = 3 ± 0.05 dB, VSWR is not greater than 1.1.

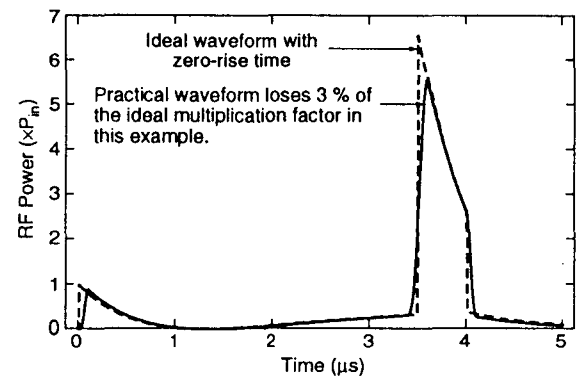

Fig. 5 RF pulses emitted from a SLED. The wave forms are obtained by solving the equation numerically.

RF-drive system (sub-booster)

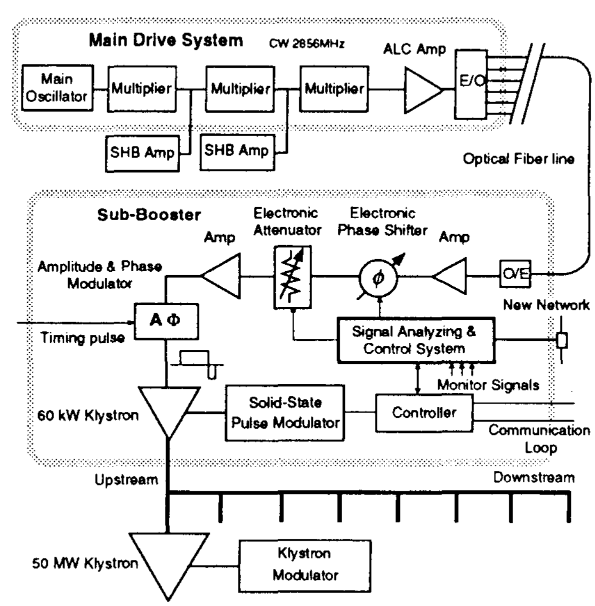

Fig. 6 New drive system for the KEKB.

The present Rf-drive system of the linac, which feeds RF signals to the high-power klystrons, comprises a main drive system and six sub-boosters. The main drive system generates 2856-MHz CW signals by multiplying a 119-MHz fundamental signal, and transmits them by optical fibers. The sub-booster receives the optical signal and drives two 10 kW klystrons.

In order to adopt an RF-pulse compressor, such as a SLED, we plan to upgrade the drive system as follows (Fig. 6):

- Install fast phase and amplitude modulators in every sub-booster for SLED operation.
- Move the sub-booster station from the present position (center of a sector holding 8 high-power klystrons) to the head of the sector. Thus timing of the accelerating RF pulses can be optimized and then the beam energy can be subsequently maximized.
- The above mentioned modification requires the development of a new 60-kW klystron which can drive eight 50-MW klystrons.
- Replace the switching tubes of the pulse power supplies with solid-state switches (35 kV, 8A) for higher reliability.
- Replace the present mechanical attenuators and phase shifters with electronic ones.

High-power RF source

Figure 7 represents an improved high-power RF source which will be adopted for the KEKB project. Amplitude/phase modulated RF pulses of about 1.2 kW are fed into the RF source. A 50-MW klystron, which is under development, will take the place of the present 30-MW one. The present modulator and a klystron socket will be upgraded to generate high-voltage pulses with a 4-μs flat top, which will drive the new klystron. A new electronic attenuator will be equipped instead of the present mechanical one, which is not remote-controllable.

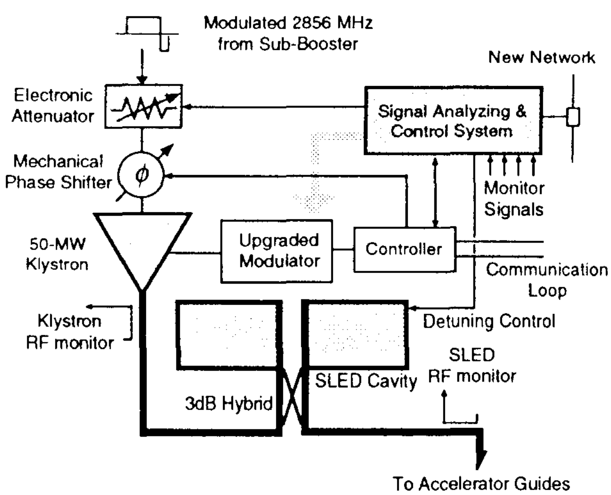

Fig. 7 Schematic diagram of the high-power RF source.

A signal-analyzing and control system will be newly installed in order to control the RF source more precisely than the present controller. For a good understanding of the linac condition it is very important to quickly detect any problem or symptom concerning some trouble of the RF system, such as a defect in an RF-wave form or variations in the vacuum of the wave guides. Therefore, this system will continuously take monitor signals from the modulator and the SLED into its computer. The computer will analyze the data and diagnose any problem of the RF source, when it occurs. A similar intelligent system will be installed in the sub-booster stations.

Beam-acceleration test

The first prototype SLED was installed in the number 4-6 unit and has been operated. The second one has already installed, but is not yet being operated yet. Table 1 shows the last results of beam-acceleration tests with the first SLED. The wave forms of the RF pulses from the SLED are illustrated in Fig. 8. The klystron is also the first prototype of the 50-MW klystron. The obtained energy gain per unit was 179 MeV, and this value is greater than 160 MeV, which is the specification for the KEKB.

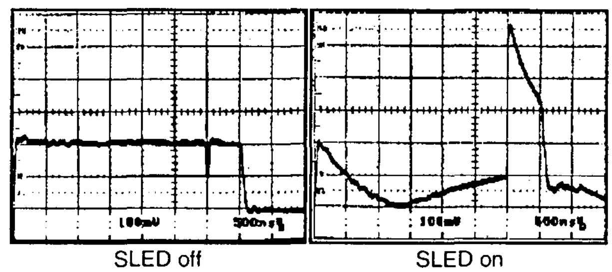

Fig. 8 RF-pulse wave forms observed at an output port of the SLED.

Table 1
Results of beam-acceleration tests with the SLED

RF power (MW)	SLED	Energy gain (MeV)	Field (MV/m)	Multiplication
38±3	OFF	87±4	11.5±0.5	
	ON	164±4	21.7±0.5	1.88±0.1
48±4	OFF	97±4	12.8±0.5	
	ON	179±4	23.7±0.5	1.85±0.1

RF pulse width = 3.5 μs.
RF power was calculated from the measured energy gain.
Field is an averaged value.
Theoretical multiplication factor is 1.96.

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