Upgrade of the PF Linac Rf Source for the KEK B-Factory

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Abstract

An upgrade of the PF linac microwave source is required to reach an acceleration energy of 8 GeV in the PF linac as an injector for the KEK B-Factory. This paper describes the upgrade methods of the modulators, klystrons and sub-boosters. By doubling the modulator pfn capacitance, the peak power and pulse width from the modulators can be increased to 107 MW and 5.6 μs, and the klystron rf power and pulse width increase to 46 MW and 4 μs, respectively. By adopting rf pulse compression using a SLED, we can obtain an energy gain of 160 MeV per klystron.

I. INTRODUCTION

An upgrade of the PF linac in order to increase the acceleration energy from 2.5 to 8 GeV is now in progress [1]. In the rf source, the rf power and pulse width from the klystrons will be increased from 27 MW (max. 33 MW) and 2 μs to 41 MW (max. 46 MW) and 4 μs, respectively. In addition to these, the peak power of the rf pulse will be increased with the SLAC type of rf compressors (SLED). The multiplication factor of the energy gain that is effectively evaluated by our 2-m-long structures is about 2. With these upgrades, we can obtain a voltage gain of 160 MV per one acceleration unit comprising one klystron and 4 structures [2].

In the PF 2.5-GeV linac, there are 48 units, including 2 injector units for electron and positron beams. All of these units must be upgraded, and, further, several new units must be fabricated and added in order to achieve 8-GeV acceleration during practical operation.

II. UPGRADE OF EXISTING SYSTEM

We decided to double the capacitance of the pfn capacitors with the same charging voltage, so that we can keep our upgrade cost within limits, and then make it easy to reuse as many parts of the existing system as possible [3]. By doubling the capacitors and assuming the output pulse width, most of the main parameters of the rf system can be clearly determined. Table 1 summarizes the main parameters of the upgraded system together with the existing system for a comparison, where the pulse widths of the modulator output voltage and klystron output power are 5.6 μs and 4 μs, respectively. These pulse widths are not optimum for the maximum energy gain when using the SLED (Q_0 = 100,000) for our structures ($T_{f\,average}$ = 0.5 μs). They are chosen to be rather long in order to reduce the peak voltage and to avoid any size or cost increase in the klystrons along with the associated parts.

The main components that we must modify or replace in accordance with doubling the pfn capacitors are summarized as follows:

1. Modulator: Replacement of the type of transformers used to supply twice the current to the pfn, and extension of the pfn cabinet for adding 20 capacitors.

2. Pulse transformer: Changing of the primary and secondary windings in order to increase the secondary voltage, and providing a new core bias in order to compensate for a higher voltage swing and a wider pulse duration.

3. Klystron: Replacing with newly-designed 50 MW klystrons and focusing magnets.

4. Sub-booster: Moving the installed location from the middle to the beginning of each sector for timing the rf pulse to the beam pulse, and replacing with newly-designed 50 kW klystrons.

5. Waveguide: Installation of pulse compressors (SLED), and addition of ion pumps for improving the vacuum adjacent to the rf windows.

Table 1 Comparison of the existing and upgraded rf

		Existing	Upgraded
Modulator			
pfn charging voltage	kV	45	45
pfn total capacitance	μF	0.3	0.6
energy stored in pfn	J	300	600
pulse repetition rate	pps	50	50
pfn impedance	Ω	6.4	4.7
pulse width	μs	3.5	5.6
pulse output voltage	kV	22.5	22.5
pulse output power	MW	80	107
Pulse transformer			
step-up ratio		1:12	1:13.5
2nd. voltage × width	Vs	0.95	1.7
core bias		none	necessary
Klystron			
beam voltage	kV	270	304
beam current	A	295	352
rf power peak	MW	33	46
rf power average	kW	3.3	9.2
rf pulse width	μs	2	4
Pulse compression		none	SLED
multiplication factor		1	~2
Energy gain / unit	MeV	65	~160

A. Modulator

The two times increase in the pfn capacitors with the same charging voltage as in the existing pfn requires a new IVR, a rectifier transformer, a filter choke and a charging choke. The rectifier diodes and the hold-off diodes, however, do not need to be changed, due to the sufficient margin for higher current flowing. There are two oil tanks: one is for a rectifier transformer, rectifier diodes and a filter choke; the other is for a charging choke and hold-off diodes. These can be reused by adopting water cooling. This reuse of tanks has the great advantage in that the existing (except for the pfn) cabinets and wiring can be left and reused as they are. To keep the same charging time as that of the existing modulators, the inductance of the charging choke is decreased to half of the existing one in accordance with the double capacitance of the pfn.

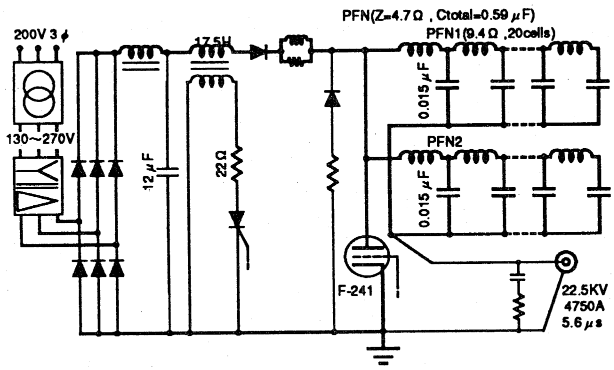

Figure 1. Circuit diagram of the upgraded modulator.

The insulator plate for mounting the pfn capacitors has been extended from 87 cm wide and 114 cm high (20 capacitors) to 89 cm wide and 210 cm high (40 capacitors). The enclosing cabinet has therefore been extended 80 cm in height (Figure 3). Forty capacitors (0.0147 μF each) are placed in four vertical lines on the plate, and the two lines of 20 capacitors are alternatively connected by 20 inductors (0.33 μH). There are thus two pfn's with 20 cells. In this arrangement, we can obtain smooth flat top pulses without the peaks or dips caused by the pfn structure (Figure 2). The thyratrons (ITT F-175's) which have been used in existing modulators, will be exchanged with ITT F-241's, because of a high fault rate, a short life, and the narrow and unstable range of the allowable reservoir voltage.

B. Pulse Transformer

From the relation between the modulator output voltage and the required klystron voltage, the step-up ratio of the pulse transformers becomes 1:13.5. The Vτ value (secondary voltage × pulse width), which determines the cross-section area of the iron core and turns of the secondary winding necessary to be unsaturated, increases from 0.95 V·s (270 kV × 3.5 μs) to 1.7 V·s (305 kV × 5.6 μs). However, because the existing pulse

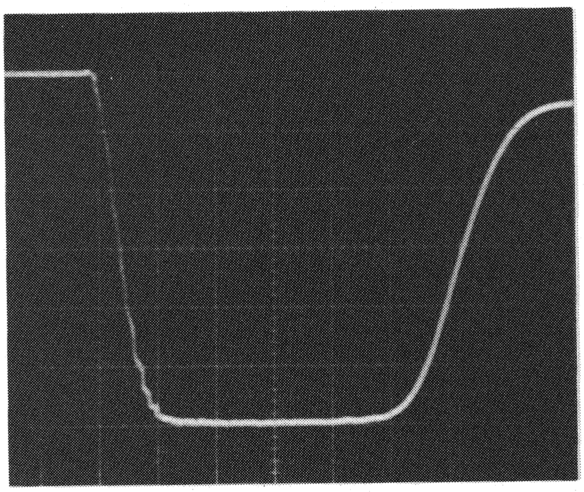

Figure 2. Pulse shape of the klystron cathode voltage (300 kV). Horizontal scale: 1 μs/div.

transformers have large cores, the cores can be reused only by supplying the core bias current to the primary windings. The distance between the cores and the corona rings of the secondary windings is maintained to be more than 3.3 mm, so that the pulse transformer can withstand over 310 kV during operation.

Pulse-transformer oil tanks can also be reused because there has been no change in their overall size. However, they require extension adapter tanks (10 cm high) for mounting new klystrons with long gun insulators (described in *C. Klystron*, see Figure 3). All other parts, such as the feeder sockets, cooling pipes, klystron socket and heater transformer, and waveform monitors, are also reused as they are.

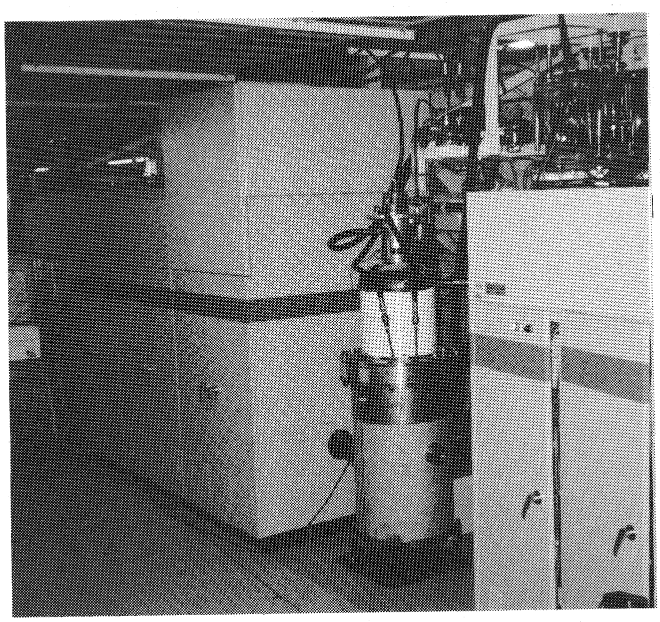

Figure 3. Overall view of #4-6. The modulator and pulse transformer tank have been upgraded.

C. Klystron

The klystron rf power and pulse width obtained by a modulator upgrade have a maximum of 46 MW and 4 μs, respectively, as shown in Table 1. The available klystrons that fulfill our specifications and have already been used in other linacs are the SLAC-5045 and the Toshiba-E3712. Although both of the klystrons can produce pulses with more than 60 MW at 350 kV of cathode voltage, since they have a large body, 6 cavities and two parallel rf windows, they require large and expensive peripheral components, such as a focusing magnet, a power supply and a socket tank. The existing klystrons, which had been developed based on the SLAC XK-5, have a standard size and structure as a 30-MW class tube. To examine the maximum capabilities, we enlarged the gun insulator to be able to withstand a higher pulse voltage [4]. From tests using the upgraded modulator and an electromagnet, we found that this tube has the capability of producing over 50 MW pulses at 310 kV of cathode voltage without any efficiency reduction, even though a higher focusing field is required.

If we adopt this XK-5-based, standard-size klystron, which was improved for high voltage use, we can reuse most of the parts of the existing klystron stations, including the waveguides, resulting in a saving in the upgrade cost. However, the increase in the focusing field requires a new electromagnet and power supply, because the permanent magnets used in our existing system cannot produce a required field of more than 1.1 kG. Furthermore, the 20% increase in the cathode peak current may cause problems regarding the cathode life necessary for practical long-range operation. Based on these facts, we decided to enlarge the cathode diameter (from 80 mm to 85 mm) and the gun outer diameter (from 190 mm to 205 mm), and to adopt a new electromagnet having a bore of 205 mm. This new type of klystron is now being designed at KEK. The general design parameters are given in Table 2. The rf power is increased up to 10%, compared to the maximum operated values given in Table 1.

Table 3 New 50 MW klystron

		existing (PV-3030)	50 MW
beam voltage	kV	270	315
beam current	A	295	370
beam power	MW	80	117
beam pulse width	μs	3.5	5.5
repetition rate	Hz	50	
rf output power peak	MW	33	50
rf output power ave.	kW	3.3	10
rf pulse width	μs	2	4
efficiency	%	41	43
perveance	$\mu A/V^{3/2}$	2.1	
overall length	mm	1317	<1400
number on cavity		5	

The rf window is a key point for developing the 50 MW klystron. From our studies on high-power rf windows using a resonant ring, we have adopted a conventional pill-box type. The window disk is of high density, voidless, and highly pure alumina ceramics (HA-997, 85 mm in diameter), surface of which is coated with a TiN film. To be more endurable for high-power, long-period use, it is important to develop better environing conditions on the disk surface: dust free and high vacuum. We thus equip an ion pump (20 ℓ/s) to a waveguide between a klystron and a SLED, and isolate its vacuum from the remaining waveguides by another rf window.

D. Sub-booster

The rf drive pulse, which is modulated with a 180° phase reverse in timing appropriate for SLED-mode operation, is generated by a sub-booster, and is distributed to 8 klystrons of each sector. For adjusting the timing of the rf pulse to the beam pulse, we must move the sub-boosters that have been installed at the middle of each sector to the beginning of the sector. In this case, the rf power required for driving 8 klystrons increases from 20 kW (two parallel 10 kW klystrons, Thomson TH-2436) to 36 kW, because the cable length for four downstream-installed klydtrons becomes long by half of one sector length. A new sub-booster klystron and a focusing electromagnet are now being fabricated, and will be tested in the Autumn of 1993. The maximum power is designed to be 50 kW at a cathode voltage of 25 kV. The sub-booster modulator will be upgraded by replacing the HV dc power supply and improving the modulator unit.

III. PROGRESS OF RF UPGRADE

Two main modulators was upgraded in 1992; one is used for a SLED test in # 4-6 accelerator unit; the other is used for klystron tests in the klystron test hall. We are preparing to produce two new modulators, and to upgrade 8 modulators and one sub-booster. Two new klystrons will be delivered by the end of the 1993 fiscal year. In parallel with these upgrades, we are testing upgraded components, including the SLED's and accelerating structures, in order to understand their maximum capability and reliability.

IV. REFERENCES

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[4] S. Fukuda et al., "Upgrade of an RF Source of the Linac for B-Factory Project", ibid.