Upgrade of an RF Source of the Linac for the B-Factory Project

S.Fukuda, S.Anami, Y.Saito, S.Michizono, K.Nakao and I.Sato
National Laboratory for High Energy Physics (KEK)
Oho-1, Tsukuba, Ibaraki, 305 Japan

ABSTRACT

The B-Factory project is a future plan at KEK requiring an energy upgrade of the KEK linac from 2.5 GeV to 8.0 GeV. This paper describes an upgrade plan and recent progress concerning the rf source. A test to increase the rf power using the existing 30-MW klystron is being carried out and an output power of 51.5 MW has been obtained by increasing the beam voltage up to 310 kV while optimizing the focusing magnetic field. Tests using a 60-MW klystron are also planned. The choice between upgrading of the present klystron and the use of a 60-MW klystron depends on the pulse-compression system to be adopted. The most efficient way regarding costs is being surveyed in order to use the existing components, such as the focusing magnet and the pulse transformer with only slight changes.

I. INTRODUCTION

An energy upgrade of the linac for the KEK B-Factory project has recently been proposed. The B-Factory rings will be nominally operated at 8.0 GeV(e^-)x3.5 GeV(e^+). It requires an energy upgrade of the linac from 2.5 GeV to 8.0 GeV for the direct injection of the beams to the rings. The energy upgrade of the linac is planned along with a power increase of the klystron and a suitable pulse compression.

There are two candidates as the pulse-compression system; a traveling-wave resonant ring in the accelerating structure (TWRR) and a SLED system [1]. We have already developed and tested both systems, which are being installed in the linac to evaluate their performance [2].

Specifications of a high-power klystron depend on the type of the pulse-compression system. Table 1 shows the parameters of rf sources for a TWRR case and two SLED cases with different pulse widths[3]. The parameters in Table 1 are introduced with the assumption that one-pulse output energy from a modulator is twice as large as in the present system. Since the beam energy in this Table is calculated based on the present 40 klystron units, it is necessary to add several units for 8.0-GeV acceleration. The required klystrons are 60-MW klystrons for the TWRR case and 46-MW klystrons for the SLED case if a pulse width is chosen to be 4 μsec.

II. THE REINFORCEMENT OF A MODULATOR

Two pulse modulators are to be reinforced based on the plan given in Table 1. They are installed in the klystron test hall and the klystron gallery to test klystrons. The main parts which were replaced in the modulator are IVR's, charging choke transformers, PFN's and thyratrons. Particularly the PFN connected with two 20-section PFN units in parallel is adopted in order to produce a pulse of a 4 μsec width. The modulator in the klystron gallery has been operated to study the total performance of an rf system including SLED cavities[4].

Table 1. Possible Plans for B-Factory RF Source

	Unit	Present	TWRR	SLED-3	SLED-4
Modulator					
pulse energy	J	84x3.5	84x3.5x2	<=	<=
peak power	MW	84	155	131	101
width	μs	3.5	3.8	4.5	5.5
voltage	kV	22.5	<=	<=	<=
PFN impedance	Ω	6	3.3	3.9	4.7
Pulse transformer					
step-up ratio		12	15.7	14.6	13.5
V·t	MV·μs	0.95	1.3	1.5	1.7
Klystron					
beam voltage	kV	270	352	329	304
beam current	A	295	439	397	352
beam power	MW	84	155	131	107
rf width	μs	<2.0	2.3	3.0	4.0
rf peak max.	MW	(36)	67	56	46
rf peak av.	MW	26	60	51	41
Beam Energy					
mult. factor		1	1.34	1.88	2.0
e energy/40 units	GeV	>2.5	5.6	7.3	7.0

III. HIGH POWER KLYSTRON

The currently available S-band klystrons and their characteristics are listed in Table 2. A Toshiba E3712 klystron and a SLAC 5045 klystron have been excluded since their large size does not fit our existing system

A 60-MW klystron required in the TWRR case is being developed by two Japanese tube companies independently; both have succeeded in producing 60 MW as stated in Table 2 and shown in Figure 1. The single output window is adopted in both tubes. These tubes will be tested in our facility in June with the collaboration of the companies. Their focusing electromagnet and pulse transformer with a step-up ratio of 1:15.5 for 350 kV operation were designed and manufactured.

The upgrading of the existing 30-MW klystrons is being developed at KEK. We have been using 48 30-MW klystrons for the 2.5-GeV acceleration of e^-/e^+ beams (V_0=265 kV, P_0=33 MW rating). Several tubes are the low-gradient type with a large curvature of the gun electrode and anode in order to reduce failures due to the arcing in the cathode region (PV3030A2) [5]. A simulation analysis of the PV3030A2 with the FCI code [6] suggested the possibility that it can produce more than 60 MW of an output power at a 350 kV beam voltage with reasonable efficiency. From this simulation

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Table 2. Various Candidate Tubes for the KEK B-Factory Project

Vendor	Type	Voltage (kV)	Current (A)	Rep. (pps)	Pulse Width (µs)	Output Power (MW)	Efficiency (%)	Average Power (kW)	Total Length (m)	Running Data	Comment
Toshiba	E3712	400	482	(54)	6.7	80	43	18	1.9	JLCx2 Pohang	Double windows
SLAC	5045	350	414	180	3.5	67	46	42	1.7	SLACx240 KEK-Test	Double windows
Toshiba	E3726	347	380	50	2.0	62	47	6.2	1.7	Toshiba Prototype	Single window
MELCO	PV 3060	347	440	20	2.0	62.4	41	2.5	1.5	MELCO Prototype	Single window
MELCO	PV-3030A2	265	300	50	3.5	33	42	5.8	1.3	KEKx49	Low Gradient Single window
KEK-Test	PV-3030A2	310	370	50	4.0	51.5	44	10.2	1.3	KEK- Test	Under developing Large High Vol. Seal

the characteristics of the tube were found to strongly depend on the focusing magnetic field near to the output cavity region [7]. A tentative test of the 30-MW klystron up to a beam voltage of 300 kV was carried out with a low duty rate to prevent the tube from failures due to a high voltage ceramic seal and an output window. At that level a peak power of 47.3 MW with a reasonable efficiency of 44% was obtained. The focusing magnetic field was varied in order to keep the beam loss in the drift tube small by measuring the water temperature rise at the output cavity region. After obtained this test result, we replaced a high-voltage ceramic-seal with a larger one in order to increase the insulating length .

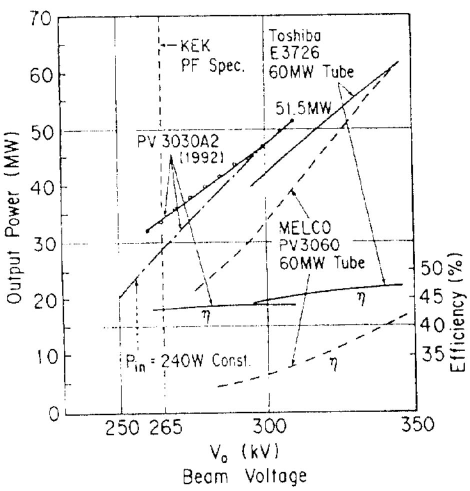

Fig.1 The output characteristics of the PV3030A2 klystron and the 60-MW tubes.

A second test was performed using this improved klystron up to a beam voltage of 310 kV. At this level a peak output power of 51.5 MW with an efficiency of 44% was obtained under the condition of a repetition rate of 30 pps, a beam pulse width of 5.5 µsec and an rf pulse width of 4 µsec. The limit was set by the modulator of the test stand. These test results are shown in Figure 1. Figure 2 shows the output power characteristics with the variation of the focusing magnetic field. Figure 3 shows the output waveforms of the beam pulse and the rf. In this test the temperature of the output window of the klystron was measured; 22 °C of the temperature rise was observed at P_0=46 MW, 4 µsec, 40 pps conditions. The temperature rise changes linearly to the average output power. It was found out that the window worked normally up to that rating. This window material is a high-density pure alumina of 99.7% (HA997) and has a very low tanδ value. Recently, the failures of the klystron output window that uses another material have been observed, therefore the reliability of the tube window seems to be a key point regarding klystron performance. The evaluation of the window performance will be continued by operating it in the klystron gallery, where the evaluation of a SLED system is performed at the same time.

The application of a higher beam voltage than 310 kV is being planned in order to study the maximum capability of this tube in June using a newly-developed modulator and pulse-transformer. In the future a slight modification of the gun of the tube might be necessary since the average pulse current density of the cathode reaches 8A/cm^2.

IV. FOCUSING MAGNET AND PULSE TRANSFORMER

There are 41 permanent magnets and 7 electromagnets which are currently in use as focusing magnets of the klystrons [8]. The test results previously mentioned show that the maximum of the focusing magnetic field is about 1150 G. This exceeds the available maximum field of the permanent magnets presently used. The existing electromagnets are possible to be used. We can expect the low manufacturing costs for these magnets, since their sizes are small comparing with the focusing magnets for 60-MW klystrons. Figure 4 gives a size comparison with other focusing magnets to mate the tubes listed in Table 2.

It is necessary to reinforce the existing pulse transformer of which step-up ratio is 1 : 12. These pulse transformers are operated without a core reset bias. Therefore, the size of the cores has been chosen to be larger compared with the other pulse transformers that are operated at 270 kV [8] . We are changing the windings of the primary and secondary slightly to obtain a step-up ratio of 1 :13.5. We reuse the same cores, so that the size of the primary winding frame must be made smaller in order to increase the insulating space between the

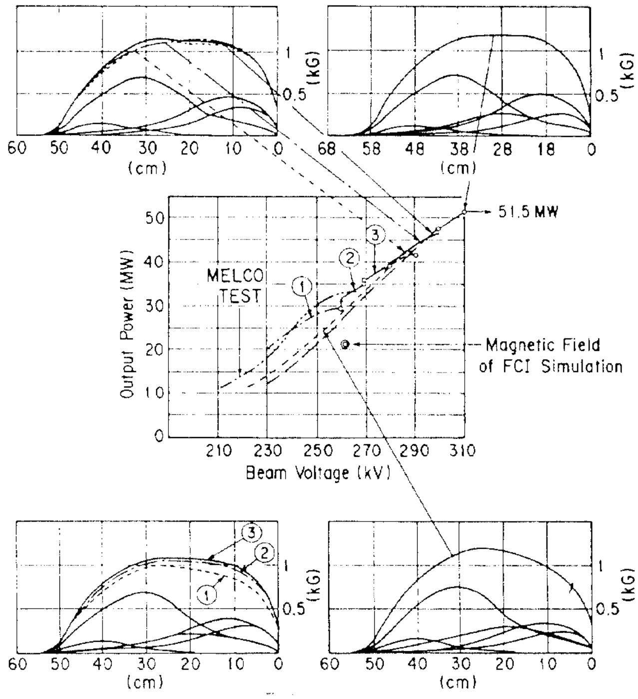

Fig.2 The output power of the PV3030A2 with the variation of the focusing magnetic field.

primary winding and the secondary winding. The overall size of the pulse transformer is not changed ,therefore the pulse-transformer oil tank can also be reused by adding a height-extension flange. A capability of more than 330 kV voltage operation is expected due to these modifications. Operation of this pulse transformer with a suitable core reset bias has already been performed successfully. The cost to modify this pulse transformer is about one third of the price of a newly manufactured one.

V. FUTURE WORK

A survey of the possible upgrade plans for the rf source of the B-Factory project will be continued this year. The final specifications of the rf systems will then be determined. Running data to evaluate the reliability will be accumulated by installing them in the klystron gallery and being used for routine operation.

The evaluation of 60-MW klystrons and the higher voltage operation of a PV3030A2 tube will be carried out in the near future. A window study and the necessary modification of the PV3030A2 will also be continued.

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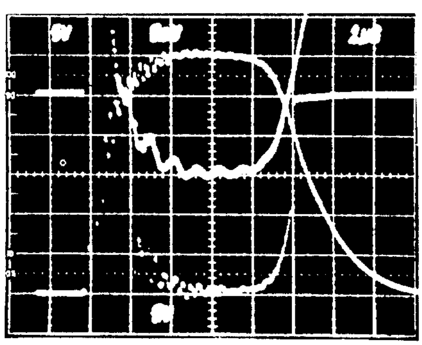

Fig.3 Beam current pulse(top trace), beam voltage pulse(middle),and rf pulse(bottom) shape at 300 kV. (time scale 1μsec/div.)

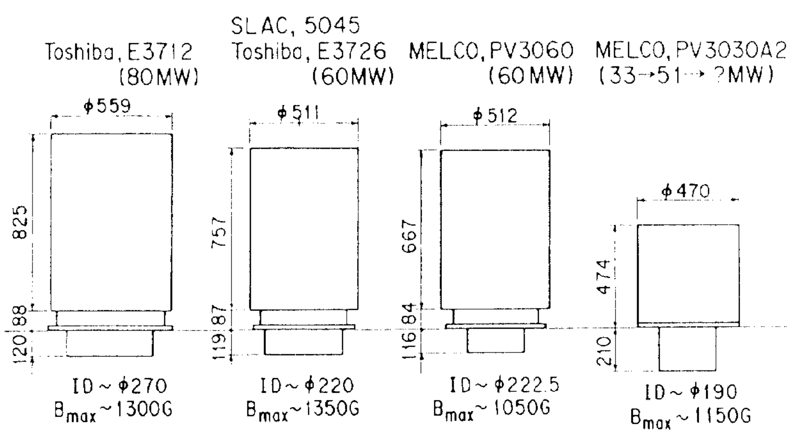

Fig.4 Various sizes of the focusing magnets.