DEVELOPMENT OF THE B-FACTORY LINAC 50-MW PULSE KLYSTRON

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Abstract

The B-Factory is a future plan, requiring an energy upgrade of the KEK linac from 2.5 GeV to 8.0 GeV. This paper describes the recent development of a 50-MW klystron for the PF-linac rf-source of the B-Factory. This tube is a modified version of the existing 30-MW tube, which produces 51 MW at a 310 kV beam voltage by optimizing the focusing magnetic field. In order to increase the reliability, the cathode diameter, the gun housing and the insulation ceramic-seal were enlarged. This tube was redesigned so as to have the same characteristics as the test results of 30-MW tubes at a higher applied voltage. Four prototype tubes have been manufactured; final test results showed that these new tubes produce an output power of more then 50 MW at 310 kV with an efficiency of 46%. Using these new tubes, an old focusing electromagnet was reused with only a slight change.

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]. This is to be achieved by using a combination of 59 klystrons, having an average output power of 41 MW (max. 46 MW), and SLAC-type rf compressors (SLED). In this plan, the peak power and pulse width from the modulators can be increased to 107 MW and 5.6 μs, respectively, by doubling the modulator PFN capacitance; also, the klystron rf power and pulse width increase to 46 MW and 4 μs, respectively[2]. In order to achieve this program, an upgrading of the klystron is being carried out. Because the modifications of linac will be conducted during an interval of machine operations for the photon factory, compatibility between the old and new system was aimed at while developing an rf source. We have found a solution in which both an upgraded 30-MW klystron and a newly designed 50-MW tube having almost the same size can be used.

Improvement of a 30-MW Klystron

The upgrading of existing 30-MW klystrons, especially those of the low-gradient type with a large curvature of the gun electrode and anode (PV3030A2) to reduce failures due to arcing in the gun region, is being carried out at KEK. A simulation analysis of the PV3030A2 using the FCI code[3] has suggested the possibility that it can produce more than 60 MW of output power at a 350 kV beam voltage with reasonable efficiency by optimizing the profile of the focusing magnetic field.

A tentative test of the 30-MW klystron up to a beam voltage of 300 kV was carried out with a low duty rate in order to prevent the tube from failures due to the high-voltage ceramic seal and the output window. At that level, a peak output power of 47.3 MW with a reasonable efficiency of 44% was obtained. After obtaining this test result we replaced the high-voltage ceramic seal with a larger one in order to increase the insulating length (PV3030A3). A test of this improved klystron was performed up to a beam voltage of 310 kV; a peak output power of 51.5 MW with an efficiency of 44% was obtained[4]. The test results showed that the maximum of the focusing magnetic field was about 1150 Gauss, exceeding the available maximum field of the permanent magnet presently used(see Fig. 1). In a test of the full duty rate using a PV3030A3, the temperature of the output window of the tube was measured; there was no problem. This window material is high-density pure alumina of 99.7% (HA997) and has a very low tanδ value. An X-ray shield of the PV3030A3 collector region was reinforced in a manner similar to the modified tube described in next chapter; some of the tubes have already been installed in the klystron gallery in order to test the SLED for the B-Factory project[5].

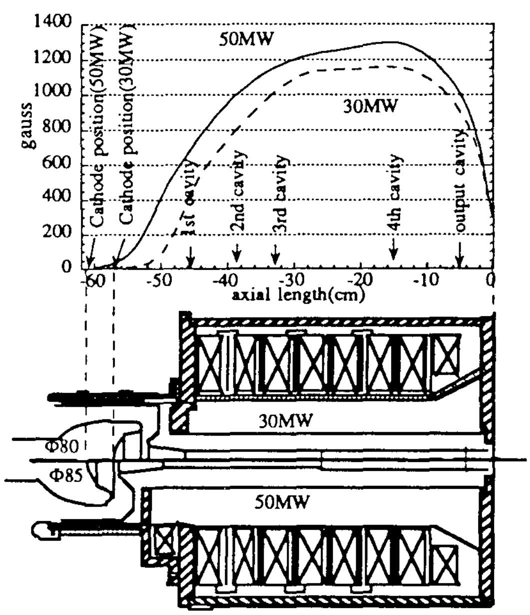

Fig. 1 Relation between the magnet and the tube.

Development of a 50-MW Klystron

Design

The improvement in the PV3030A3 klystron enables its application to the B-factory project. In order to increase the reliability, slight modifications of the PV3030A3 tube were attempted. The new tube design (50 MW tube) was performed at KEK while considering the following design concepts; (1)The rf interaction region (i.e., parameters of the cavities and the drift lengths) was kept the same as those of the PV3030A3 (therefore, it is the same as the SLAC XK-5 tube[6]). (2) The cathode diameter was enlarged from ϕ80 to ϕ85 in order to reduce the average pulse-current density from

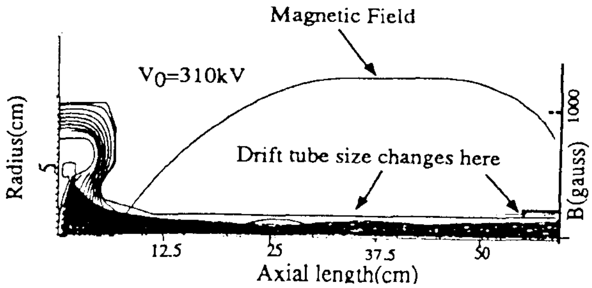

Fig. 2 Beam trajectory at V_0=310 kV.

the cathode. (3) The gun-electrode design was based on a low-gradient Pierce gun so as to reduce any arcing problem. (4) The high-voltage ceramic seal of the gun housing was enlarged so as to increase its capability to higher voltage applications up to a 350-kV operation. (5) The klystron outer dimension was determined considering that the main part of the focusing electromagnet has compatibility between the 30-MW tube and the 50-MW tube with only a slight change at the gun region of the tube. (6) The length from the anode to the 1st cavity was extended by 4 cm due to microwave considerations of the drift tube within the restriction of compatibility of the focusing magnet. (7) An X-ray shield was reinforced by making a large space between the collector and its outer spool.

Table 1 Gun-electrode design parameters. BFE means a beam focusing electrode.

Klystron	PV3030A2	PV3030A3	50MW	5045[6]
Applied Vol.(kV)	310	310	310	315
Cathode Dia.(mm)	80	80	85	90
High Vol. Seal	small	middle	large	
Anode(kV/mm)	23.5	23.5	21.4	17.5
BFE(kV/mm)	24.8	24.8	22.0	22.5

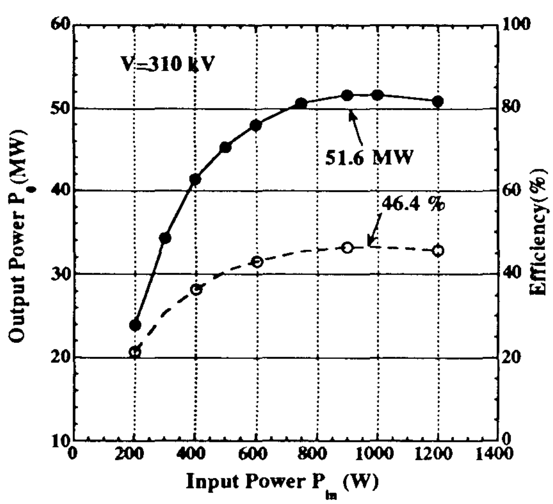

Fig. 3 Input-output power characteristics predicted by the FCI simulation code.

A simulation of the FCI code has predicted a similar result as that of the performances of PV3030A3 test. A comparison of cut-away views of the old and new tubes with the optimum magnetic field is shown in Fig. 1. Fig. 2 shows a beam trace from the gun to the collector without an rf input. This beam flow is a semi-confined flow, thus allowing a small magnetic flux of 30-40 Gauss on the cathode and the same condition as that of the 30-MW tube. Therefore, the beam trace is not completely laminar, but shows almost the same flow as that of the PV3030A3 tube. Table 1 shows the field gradient of this tube as well as other tube data. The FCI code prediction of the input to the output power characteristics is shown in Fig. 3; the saturated output power at 310 kV was 51.6 MW and the efficiency was about 46.4%. The gain was low because the code did not consider the drift-tube radius change (see Fig. 2). Considering the coupling coefficient at the input cavity and comparing the PV3030A3 simulation result with the test data, we could predict that saturation would be obtained at an input power of between 200-400W.

Test Result

Four new prototype tubes, which were ordered in September, 1993, to 2 Japanese manufacturers, have been completed and tested; the tube names are PV3050 (MELCO) and E3730 (Toshiba), respectively. The specifications for both tubes are the same: the same focusing magnet, X-ray shield and sockets must be mated with them. The rf windows and the high-voltage ceramic were designed by the manufacturers individually. The window of E3730 is of the long pill-box type. The shapes of the high-voltage ceramic are oval and conical in the PV3050 and the E3730, respectively. An output power of 50 MW and an efficiency of 45-46% were achieved at company tests; KEK tests are now in progress. So far, the characteristics of the four tubes vary slightly; the required voltage is higher than predicted (PV3030#1 and E3730#1) and the input power at the saturation point is larger than predicted (PV3050#1). Unstable operation was observed in the E3730#1. The nominal perveance is usually 2.1 $\mu A/V^{3/2}$, and the PV3050#2 has a higher perveance (2.18 $\mu A/V^{3/2}$). The results agreed with the design prediction. Fig. 4 shows the test result. A higher voltage application and a more complete evaluation of the tubes is scheduled for this year. We will order more 50-MW tubes this fiscal year. Fig. 5 shows pictures of the PV3030A3, PV3050 and E3730 tubes.

Socket Assembly for Upgrading Klystrons

The focusing electromagnet was slightly changed in accordance with the design concept of (3) mentioned above. The inner bore diameter of the main magnet was slightly enlarged and an X-ray shield inside was moved to the outer side. These modifications enable the tube outer diameter (i.e., the ceramic-seal diameter) to be enlarged. The auxiliary coil was replaced during a test of the 50-MW tube from the old-type iron cylinder, which was suitable for the PV3030A3 tube.

It is necessary to reinforce the existing pulse transformer, of which the step-up ratio is 1 : 12. These pulse transformers are operated without a core reset bias. Because they have large cores, they can be reused only by changing the step-up ratio to 1 : 13.5 and supplying a core-reset bias current to the primary windings. The insulating lengths of the pulse transformer have

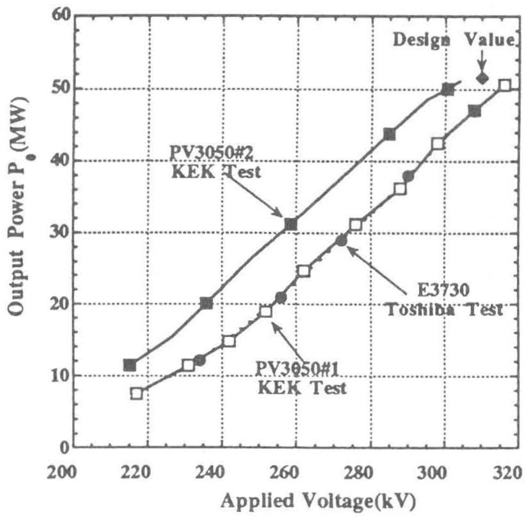

Fig. 4 Test results of prototype 50-MW klystrons.

been redesigned in order to withstand over 310 kV during operation[2]. The pulse-transformer oil tanks can also be reused without changing the outer dimensions. We currently use an extension adapter of 10 cm to increase the height of the tank for mounting new klystrons with longer ceramic insulators, though we also plan to use completely the same dimensions as the old ones by using a smaller heater transformer and corrugated high-voltage insulators in the tank. All other parts, such as the feeder sockets, cooling pipes and wave-form monitors are also being reused. The costs of these modifications are much less than that involved in introducing a new set of assemblies.

Conclusion

We have succeeded in outputting 50 MW from a 30-MW klystron and have modified it to a practically available tube. Further, we have redesigned the 50-MW tube so as to have a larger cathode and a high-voltage insulator in order to increase the reliability. The performance of the 50-MW tube agreed with the design simulations and achieved more than 50 MW and an efficiency of about 46%. We will search for even more optimization of these upgraded tubes. Some of the tubes have been already installed in the klystron gallery in order to test the SLED cavity and are also being used to investigate the operation condition of the SLED and the accelerator structure.

Reference

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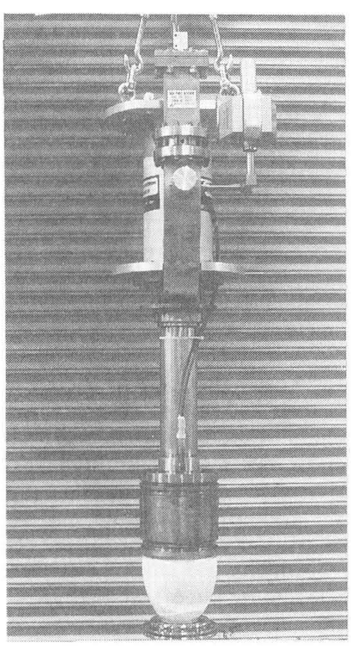

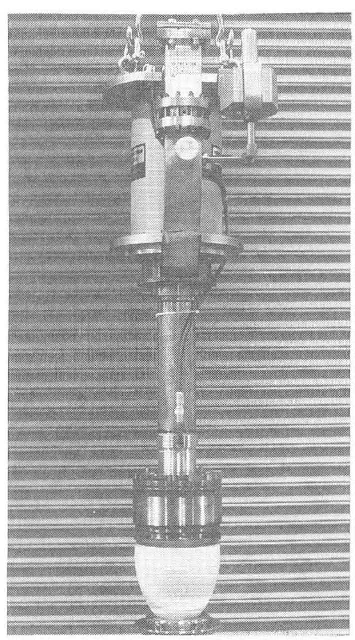

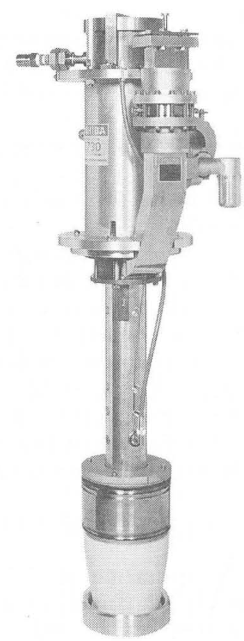

Fig. 5 Pictures of PV3030A3, PV3050 and E3730. (from left to right)