PERFORMANCE OF THE RF-SOURCE FOR THE KEKB LINAC

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Abstract

The KEKB project, which requires an energy upgrade of the KEK linac from 2.5 GeV to 8.0 GeV, started in 1994, and has been progressing. About fifty 50-MW high-power klystrons (including equivalent 40-MW tubes) have been produced and tested. Twenty-eight of them have already been installed in the klystron gallery. We also obtained more than 60-MW rf peak power with a reasonable efficiency from this 50-MW tube. The klystron assemblies, including the magnets and pulse transformers, have been operated with no problems. In order to operate the SLEDs, we have also developed a sub-booster klystron, a driver klystron which produces more than 60-kW peak power for 8 high-power klystrons. Two of them have been successfully operated in the klystron gallery. We have started SLED operation at 2 sectors (sectors #4 and #5) and are accumulating data concerning the SLED and accelerated beams. We now describe this performance of the rf-source for the KEKB linac.

Introduction

An upgrade of the PF linac in order to increase the acceleration energy from 2.5 to 8 GeV, by using a combination of 59 klystrons having an average output power of 41 MW (max. 46 MW) and SLAC-type rf compressors (SLED) is now in progress[1]. We have achieved progress concerning the sub-booster klystron, the driver klystron, and feeding to 8 high-power klystrons, since it is necessary to change the driving scheme (shown in Fig. 1) in order to use the SLED operation with proper timing. In this modification, more than 40 kW of output power is required from the sub-booster klystron by taking account of the transmission losses. We had manufactured 5 tubes, including a prototype; 2 tubes have already been set in the gallery in order to test the SLED operation. Installation of the high-power tubes is proceeding on schedule. Twenty-eight tubes have already installed to the gallery, and 12 tubes are being operated under the SLED mode. Those tubes are operated during an injection to the PF ring and AR (Accumulating ring) for the SOR experiment users. Some of the high-power tubes are being operated at 335 kV to 350 kV, and have succeeded in outputting more than 60 MW. They are expected to be used at the unit just after the positron target position, where high-gradient acceleration is desirable.

Sub-booster Klystron Development

For the KEKB energy upgrade project, new 50-MW klystrons have been developed. In order to feed a drive power to these 8 high-power tubes, which are operated with SLED cavities, a 60-kW sub-booster klystron (SBK) is required. Since there are no commercial tubes which satisfy our specifications, this tube has been designed at KEK, and manufactured under the collaboration of KEK and MHI (Mitsubishi Heavy Industry Co.)[2]. The specifications for the sub-booster klystron are

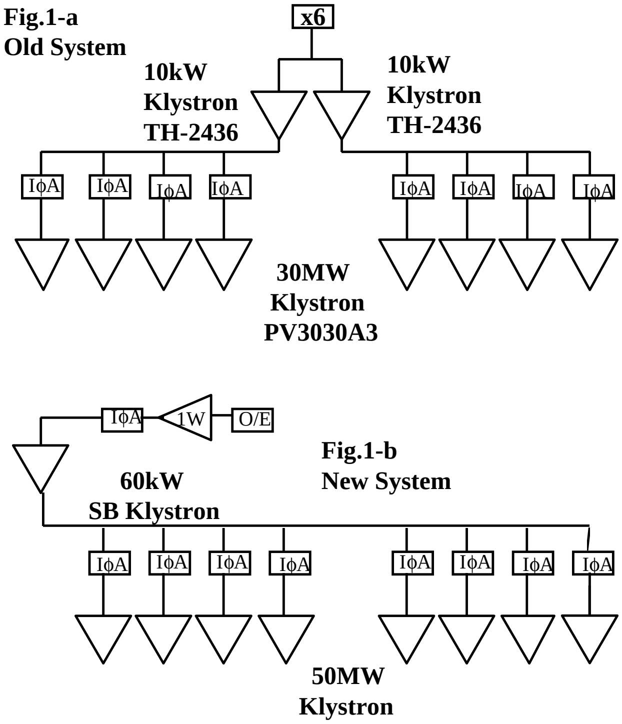

Fig. 1. Comparison between the old and new driving systems.

the collaboration of KEK and MHI (Mitsubishi Heavy Industry Co.)[2]. The specifications for the sub-booster klystron are given in the table 1.

We have been using two 10-kW tubes of Thomson CSF (TH2436) in parallel in each sector, as shown in Fig. 1a[3]. The different points between the old TH2436 tube and the new SBK-tube are as follows: (1) Electromagnet focusing has been adopted instead of permanent magnet focusing. (2) The tuning frequencies for the each klystron cavity are fixed, since our purpose of this tube is limited. The new tube has 6 cavities, while the old tube has 4. These modifications enable us to obtain a high gain. (3) The new tube has an integrated ion pump. (4) Water cooling is adopted in order to stabilize the operation performance. (5) The input power feeder is set vertically to make the inside bore diameter of the magnet small. (7) The output waveguide is a coaxial 39D-type waveguide and the output waveguide flange type is BFX-39D, which is popular in Japan (Old type is EIA-39D standard.) (8) An Ir-coated dispenser cathode of 1 inch diameter is adopted instead of the oxide cathode based on a life consideration. (6) Our tube configuration is partly based on the design of the SLAC sub-booster klystron, especially concerning item (5). [4]

The basic design of the tube is fulfilled in KEK and some manufacturing processes: for instance, as the cathode processing, baking-and-evacuation of the tube and pinching off

Table 1. Specification of SBK

item	unit	specification
Peak pulse voltage	kV	25.0
Peak pulse current	A	7.91
Microperv	$\mu A/V^{3/2}$	2.0
Pulse width(rf)	μsec	4.0
Pulse width(beam)	μsec	>6.0
Repetition	pps	50
Peak RF power	kW	>60
Average RF power	W	12
Efficiency	%	>30
Gain	dB	57
Input power	mW	120
Total length	mm	about 690
Electric gun	BI Cathode	
Focusing magnet	Electromagnet	
Cooling	Water cooling	
Ion Pump	1 *l* /sec integrated ion pump	
Cavity number	6	
Output Waveguide	39D Coaxial Waveguide	
Output Flange	BFX-39D standard	

were first demonstrated at KEK. A proto-type tube was manufactured in FY94. In FY95 it was tested and a 60-kW output power was obtained at a beam voltage of 25 kV, which was supplied by the newly developed SBK-modulator using a semiconductor switching device. In FY95 three tubes were ordered and two were tested. These tubes were installed at the klystron gallery in order to evaluate the SLED operations, and have operated satisfactorily. We need 8 sub-booster klystrons for KEKB-project. Up to now, we could achieve an output power of around 60 kW, while the efficiency is about 30%.

Status of High Power Klystron

Test and Installation in the Gallery

As previously reported[5, 6], we have been developing 2 types of high-power klystrons for this project: one is an improved type of an old 30-MW tube by enlarging the high-voltage ceramic-seal; the other is an improved one by using a larger cathode and larger high-voltage seal. PV3030A3 (MELCO; Mitsubishi Electric Company) and E3728 (Toshiba) are the former types of tubes and PV3050 (MELCO) and E3730 (Toshiba) are the latter types. Both types have abilities to produce more than 50 MW of output power at 310-kV applied voltage. The focusing electromagnet has compatibility between these two types with only a slight change at the gun region of the tube.

An output power of 50 MW and an efficiency of 45-46% were achieved on the average in the 50-MW tubes. The saturation point is located at 250-300 W at the input power on an average (a gain of around 53 dB is achieved). The typical performances of the 50-MW tubes are shown in Figs. 2 and 3. Our tubes have a single window and cooling structures are set on the upper and lower waveguides of the windows. The window material of our tube is high-density pure alumina of 99.7% (HA997: NGK) and has a very low tanδ value[7]. The evaluation after running in the gallery is satisfactory.

We have already purchased 50 tubes, including both types. Performance tests of 27 tubes have been finished and the tubes have been installed in the klystron gallery. During the first stage of tube development, some instabilities and arcing problems were observed in the Toshiba 50-MW tubes, which were completely solved by changing the cathode processing of the manufacturing process. Another type of instability and poor gain problems were observed in the MELCO tubes. These were solved by changing the structures inside the tube so as to prevent any distortion of the cavity during the manufacturing process.

60-MW test using the 50-MW klystron

Performances at an applied voltage higher than 310 kV have been of interest since the FCI[8] calculation predicted an output power of 70 MW at the 350-kV beam voltage. This test has been attempted using a prototype tube (PV3050#2) as a tentative low-duty test; a 64-MW output power was observed with an efficiency of about 42%; the performance has strongly depended on the magnetic-field distribution near to the output-cavity region, as predicted by FCI. Furthermore, the E3730 tube produced a 60-MW output power at 331 kV beam voltage and rf pulse width of 2 μs with an efficiency of 47% at a factory test. These output power level are highest when using single output windows. We have been planning that this tube operation mode will be used at the #2-1 unit, which is located just after the positron-conversion target, since high-gradient acceleration is required.

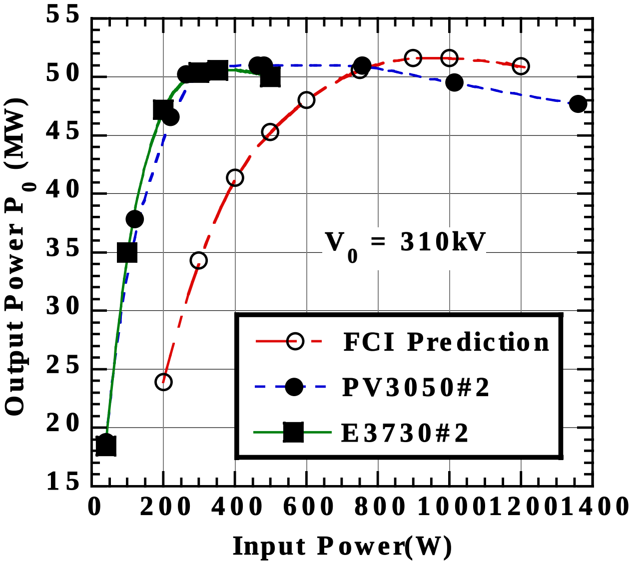

Fig. 2. Input -output power characteristics predicted by the FCI and those of two 50-MW tube performances.

Design and Status of the Socket Assembly

The final design of the pulse transformer is such that the step-up ratio has been changed to be 1 : 13.56; there are 7 primary turns and 95 secondary turns. This is an bifiller auto-winding type; a core reset bias is applied. More detail descriptions are given in reference [6]. We have newly developed corrugated high-voltage insulators made from epoxy material to support the klystron heater transformer, which is at a high-voltage potential. The heater transformer has been redesigned, and the final thickness is half that of the old one. Owing to these design changes, we can continue using the same oil tanks and same configurations, including the waveguide ports. A feeder section inside of the tank comprises a knife-switch-type connector made by Multi-contact Co., which enables it to be easily disconnected. The capacitive divider, used as a voltage monitor, has been replaced from the Pearson-Inc. type to the Stangenes-Inc. type for higher voltage applications of up to 350 kV. Two small-size current transformers are set in a tank circuit instead of the old home-made one; one is used for the current monitor and the other for a dedicated application of an interlock signal. So far, we have experienced no troubles up to around 320 kV in full duty and 350 kV under in lower duty. For the 350-kV application it is necessary to use a pulse-transformer with a step-up ratio of 1:15; this approach is being prepared

Forty-nine electromagnets have been manufactured up to FY95, including 2 types of magnets. Both types can be easily changed from one type to another by replacing the iron skirts and coil part. Thirty-two pulse-transformer assemblies have been modified from the old type to a new type by rewinding the pulse-transformer windings and adding pulse-circuits components. Since machine operation has been continued during the construction periods, the reformation schedule for the pulse transformer is the most tightest part.

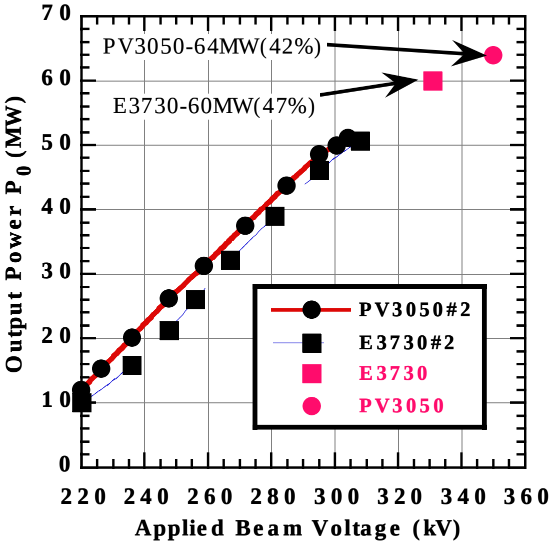

Fig. 3. Output-power characteristics as a function of the applied beam voltage

SLED Operation in the Gallery

Up to the FY95, 12 SLEDs have been installed in the gallery, and more 13 SLEDs are being installed during the summer shut-down period of 1996. Two sub-booster klystrons were installed in sectors #4 and #5; complete mode operation of the SLED has been carried out. In these sectors, conditioning of the upgraded high-power units is proceeding, and such processing data as discharging and the time dependence of the processing etc. have been analyzed. The averaged energy gain and energy-multiplication factor of the developed units in operation is 163 MeV/unit and 1.93, respectively[9].

The performances of the two sub-booster klystrons have so far been satisfactory. However, the tube efficiency is around the 30%, and the optimum focusing-magnetic field is quite different from the design field. It was found that a weak parasite oscillation exists under some conditions. It might be necessary to check the magnetic field, especially near to the cathode region. So far an output power of about 60 kW is sufficient for each high-power klystron to work at the saturation point, while 10 kW from the previous TH2436 tube was short for saturation-point operation for some poor-gain tubes. It is not clear that the some unstable operation of the SBK affects the SLED's operation or not.

A long processing time was necessary for some special unit up to the specified value. The main task for us will be to investigate what kind of the causes prevent full processing. This summer we will install another 2 sub-booster klystrons in the sectors #2 and #3, and we will also start operating in the SLED's mode there.

Conclusion

We are progressing satisfactorily regarding high-power klystron testing and installation in the klystron gallery. Purchasing the tubes and focusing electromagnets is on schedule. The final design of the pulse-transformer assembly has been fixed, and also continuously modified. The sub-booster klystrons, which are inevitable for our SLED's operation, are being developed and evaluated in the klystron gallery. Since FY95, the useful processing data have been accumulated by the SLED's operation of the sectors #5 and #4. These kinds of studies will be continued after this summer shut-down; roughly half of the construction will be completed.

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