STATUS OF THE X-BAND RF POWER SOURCE DEVELOPMENT FOR JLC

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Abstract

In this paper, we summarize the status of X-band RF power source development for the Japan Linear Collider (JLC) project. The periodic permanent magnet (PPM) klystrons are under development in the two-year/two-stage project with Toshiba. The goal is to produce 50MW output power at 1.5 μs pulse length at the first klystron and then to advance to 75MW at the second one. The high power testing of the first klystron is scheduled to start in July 2000. The multi-mode RF windows have been high power tested at KEK and SLAC. The window with smaller diameter (53mm) achieved a circulation power of 80MW with 1.5μs duration at 30Hz repetition. It was not destroyed during the testing. As for the modulator, the SI-thyristor solid state switches were tested successfully. KEK is developing the multi-mode 2x2 DLDS (Delay Line Distribution System) power distribution system, in which the stability of linearly polarized TE12 mode in a long (up to 160m) waveguide is the key for low loss power transport. The experiment was carried out successfully in the ATF linac tunnel in collaboration with SLAC using a specially installed 55m long waveguide. Details of these developments and measurement results are presented.

1 KLYSTRON

The 1-TeV JLC (Japan e^+e^- Linear Collider) project[1] requires about 3200 (/linac) klystrons operating at 75 MW output power with 1.5 μs pulse length. Periodic Permanent Magnet (PPM) klystrons are being developed to eliminate the expense and power requirements of the focusing solenoids. KEK has begun a two-year project with Toshiba to produce two PPM klystrons in two stages. The design parameters of those klystrons are shown in Table 1. The main emphasis of the Toshiba PPM-1 klystron is to test a new gun design and to study the design and manufacturing of the PPM circuit. For the first time in the X-band klystron development at KEK, stainless steel and Monel are being used for tube and cavity materials to damp possible RF oscillation modes. The design has been completed and most of the components were already manufactured. According to MAGIC simulations, the expected peak power exceeds the original design goal and reaches 70-75 MW with efficiency greater than 55%. Figure 1 shows the MAGIC simulation [2] of the beam in the output cavity region. The output power in this example is 74MW. The beam size is tunable between 2.3 mm and 3.3 mm by changing a combination of the bucking coil and matching coil currents. A critical issue for klystron performance is the actual dimension of the gun at operating temperature (so-called hot dimension). The PPM-1 hot dimension was estimated by the thermal code ANSYS (see Fig. 2). An actual measurement was conducted using a anode-like test fixture and a laser beam, showing a good agreement with the ANSYS calculation within 100μm. Figure 3 shows the entire PPM magnetic circuit to be used in the Toshiba PPM-1 klystron. Prototyping of the 4.5 period (13.5cm long) PPM circuit and the fabrication of this PPM circuit established the quality control method on the magnet pieces of 0.5%. Testing of the Toshiba PPM-1 is scheduled to start in early July 2000.

Table1: Main parameters of the Toshiba PPM-1 and PPM-2 klystrons.

	Toshiba PPM-1	Toshiba PPM-2
Peak power (MW)	>50	75
Beam voltage (kV)	480 - 500	480 - 500
Micro-perveance	0.8	0.8
Efficiency (%)	>50	60
Pulse length (μs)	1.5	1.5
Repetition rate (pps)	50	150
Bandwidth (MHz)	80 at -1 dB	80 at -1 dB
Cooling of PPM	Air	Water

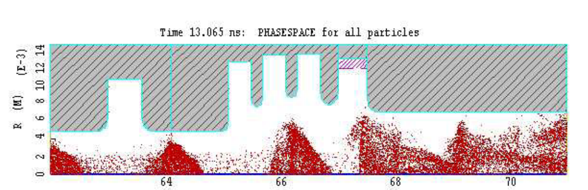


Figure 1: MAGIC simulation of Toshiba PPM-1 output cavity

The Toshiba PPM-2 klystron will incorporate experience and knowledge gained from the design and testing of Toshiba PPM-1. The main goals of the Toshiba PPM-2 are to manufacture a PPM klystron that meets the specifications of the JLC project and to refine the design and manufacturing process for future mass production. To meet these goals, the PPM-2 will have water cooling to allow a higher repetition rate and may use a clamp-on PPM stack for cheaper and easier production. A new high power multi-mode window, described in Section 2, will also be installed to support higher peak power and the full repetition rate. High power testing is scheduled to start in spring 2001.

Figure 2: The thermal calculation of Toshiba PPM-1 gun by ANSYS.

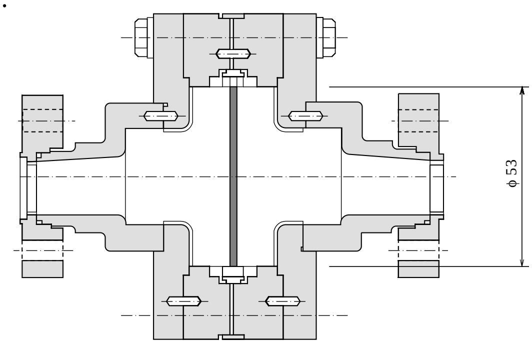
Figure 3: The entire PPM magnetic circuit

2 RF WINDOWS

New types of RF windows have been proposed by Kazakov and designed in collaboration between BINP and KEK[3]. The main feature of these is that the windows are operated in multi-mode. The combination of modes on the surface of the ceramic significantly reduces the electric and magnetic fields in the junction between the ceramic and the metal. In addition, a traveling wave configuration is used to reduce the field further. The windows have a simple shape for manufacturing and small overall dimensions, as shown in Fig. 4.

So far two types of high power windows at 11.424 GHz frequency have been fabricated. These windows have ceramic disks with a diameter of 53mm and 64mm. The basic characteristic of the mixed-mode window is that the electric field strength at the periphery of the ceramic disk is very weak, and this has been verified by a bead-pull method using a low power model. The window shows very small reflection (VSWR=1.04 for operating frequency) and wide bandwidth (260 MHz for VSWR less than 1.1). A high power model of the window was fabricated and tested in a resonant ring. The surface of the ceramic disk was coated with TiN (10 nm). A maximum circulating power of 81 MW with 300ns duration or 66 MW with 700 ns duration was achieved. The pulse repetition rate was 10 Hz. Light emission was observed for a power level of over 10 MW. The test was terminated due to lack of machine time and not because of RF discharge. Later, both windows with the diameter of 53mm and 64mm were shipped to SLAC for even higher power testing using combined power from two klystrons. The first window (53mm diameter) achieved a circulation power of 80MW with 1.5µs duration at 30Hz repetition. Although it was not destroyed and more testing will improve the performance, it was replaced by the second window with 64mm diameter due to lack of machine time. High power testing of the second window is still ongoing.

Figure 4: High power model of 53mm mixed-mode window.



3 DLDS PULSE COMPRESSION

Taking advantage of both the single mode and the multi-mode DLDS, a 2x2 DLDS was proposed at KEK to deliver RF power to four RF clusters. It consists of almost identical dual mode DLDS systems with long and short waveguide[4]. Only two modes TE_{01} and TE_{12} or TE_{11} are used in each waveguide to minimize the complication caused by handling of multi-modes in one waveguide, while still providing some of the benefit of multi-mode operation by considerably reducing the total length of waveguide. The critical issue in this scheme is the stability of linearly polarized TE_{12} mode in a long waveguide (that of TE_{01} mode has been well investigated at SLED-II). Joint experiments with SLAC were performed at KEK on a delay line assembled in the ATF linac tunnel. The typical setup is illustrated in Fig. 5. The transport line in our experiment was composed of eleven sections of a circular waveguide with a diameter of 12.065 cm. Each section was five meters long, for a total length of 55 meters. The sections were connected using a choked flange. This connection was designed to operate well for both the TE_{01} mode and the TE_{12} mode. The mode analyzer was installed at the end of the line to measure mode conversion due to this highly over-moded waveguide (102 modes can propagate in this guide.). The experimental findings can be summarized as follows:

1. The rotation of the TE_{12} mode is smaller than 1 degree. Furthermore, the level of the circularly polarized component in both cases is very small. Hence one can conclude that there is no significant mode cross polarization mixing.
2. The mode contamination in all modes is well below -20 dB before and after the transport line.

The overall level of the signal received is -0.37 dB, which indicates that approximately 8.5% of the input power has been lost. This cannot be accounted for by the losses in the two mode transducers and the arc-tapers (4.5%), the transmission line losses (theoretically 2.8%), plus mode conversion to TE_{14} mode (0.5%). One can only conjecture that there are additional losses due to conversion to some TM modes, which were not measured by our mode analyzer.

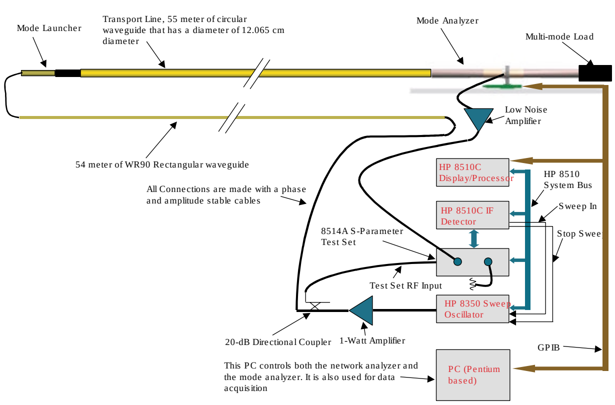


Figure 5: Experimental setup for TE_{12} mode transmission experiment.

4 MODULATOR

To improve the reliability of the modulator, KEK has developed a solid-state switch to replace the thyratron tubes[5]. The Static Induction SI-thyristor is suitable for the switch device because of its high-power handling and fast turn-on capability. KEK has investigated the NGK RT103N 4kV reverse conducting SI-thyristor (including freewheeling diode with press-pack ceramic housing. To evaluate the performance of this device, the fast turn-on characteristics of five stacked SI-thyristors connected in series were studied using a very low-inductance circuit. By using a coaxial structure, the residual inductance was successfully reduced to less than 136 nH. When an anode voltage of 15 kV was applied, a maximum peak current of 10 kA, dI/dt of 110 kA/µs, and switching time of 128ns were obtained. The switching time is the time required for the anode voltage to decrease to 10% of its maximum value. It was confirmed that the turn-on characteristics of the SI-thyristors are comparable to thyratrons.

Next, a 45kV solid-state switch was designed and built using the same devices. The switch uses a stack of 15 circuit card assemblies in series. Each circuit card assembly consists of a SI-thyristor, a resistor capacitor network and a gate-driving circuit. The trigger and DC power for each card were isolated from high voltage through ferrite core transformers. A photograph of the stack assembly is given in Fig. 6. The stacked devices are housed in a single cylindrical tank with a diameter of 300mm and a height of 550mm. The tank is filled with oil to insulate and cool the internal devices.

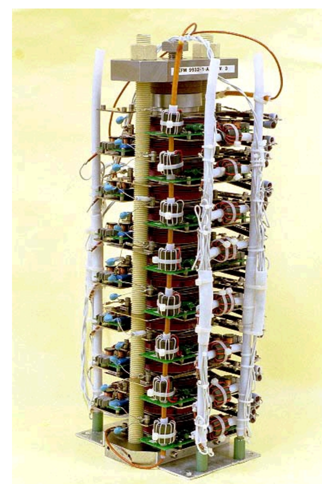


Figure 6: 45kV solid state switch.

The solid-state switch performance was investigated with a line-type 5045 klystron modulator at the KEK Accelerator Test Facility, ATF. The switch was successfully operated at 45kV and 6000A with a 6µs pulse-width at 25 Hz. The switch losses were measured by calorimetry and found to be 41 J/pulse at 45kV. This value corresponds to 5% of the total PFN stored energy, with about 90% of this loss dissipated in the devices themselves. Therefore, these switches still need to be improved to further reduce losses. However, it has been confirmed that the 45 kV Si thrystor-switch has a switching capability comparable to a thyratron.

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