STATUS OF JLC X-BAND MAIN LINAC R&D

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Abstract

In this paper, we summarise the status of the X-band main linac R&D efforts for the JLC (Japan e^+e^- Linear Collider) project including the PPM klystron, the IGBT solid state modulator, the DLDS pulse distribution system, and the RF structure.

1 X-BAND MAIN LINAC

1.1 Klystron

The 0.5-TeV JLC project [1] requires about 1800 (/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[2]. The goal is to produce 50MW output power with efficiency>50% at 1.5 µs pulse length at the first klystron and then to advance to 75MW with efficiency=55% at the second one. Figure 1 shows photos of the PPM-1 (right) and PPM-2 (left) klystrons. The first PPM klystron and its revised version (PPM-1.5) have been tested, and they achieved 56MW power with 50% efficiency at the standard 1.5 µs pulse length. Neither oscillation of parasitic mode nor gun oscillation was observed. The particle transmission was found to be 100% when no RF signal is applied. The performances of PPM-1 and PPM-1.5 are tabulated in Table 1.

Figure 1: Photos of the PPM-1 (right) and PPM-2 (left) klystrons.

Table1: Design parameters and actual performance of the PPM-1 and PPM-1.5 klystrons.

	Design	Achieved
Peak power (MW)	>50	68
Efficiency (%)	>50	49.6
Pulse length (µs)	1.5	1.5 (at 56MW)
Micro-perveance	0.8	0.79
Repetition rate (pps)	50	5 (25Hz possible)

The second PPM klystron is currently under high-power testing. It has improved water cooling system of PPM circuit and the output cavity for 150Hz operation. The RF system was also revised for a higher efficiency. Up to date (June 6, 2001), the PPM-2 klystron produced 73.2MW at 1.4 µs pulse length and 70MW at 1.5 µs pulse length with the efficiency of 54.5%. The oscilloscope traces are shown in Fig. 2. The maximum efficiency reached 56% at the specified cathode voltage. The performance of PPM-2 klystron is tabulated in Table 2. Figure 3 shows the output power and the efficiency as a function of the cathode voltage. More details of measurement results are found in Ref. 3. The high-power testing will be continued to attain 75MW output power with the standard 1.5 µs pulse.

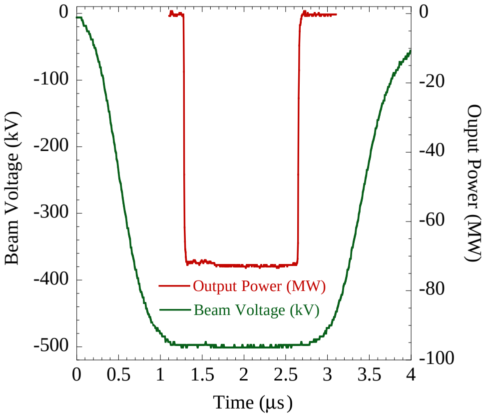

Figure 2: Oscilloscope traces of PPM-2 output pulses.

Table 2: Latest measurement results of performance of the PPM-2 klystron (June 6, 2001)

	Design	Achieved
Peak power (MW)	75	75.1
Efficiency (%)	55	56
Pulse length (µs)	1.5	1.5 (@70MW) 1.4 (@73.2MW)
Micro-perveance	0.8	0.79
Repetition rate (pps)	150	25

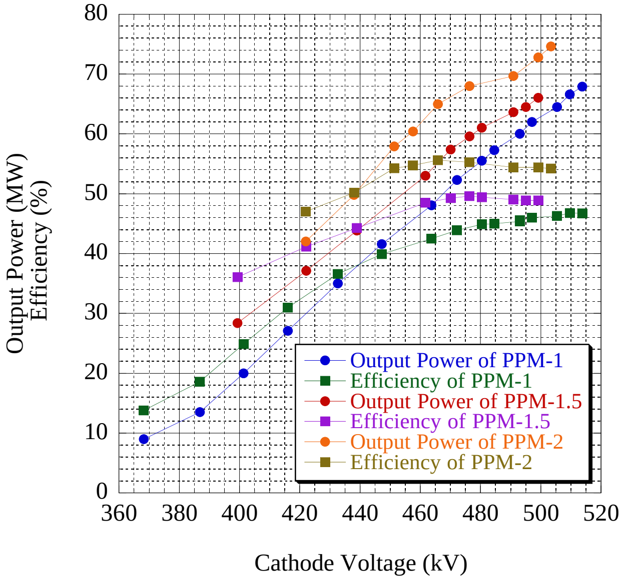

Figure 3: Output power and efficiency vs. cathode voltage at PPM-1, PPM-1.5 and PPM-2 klystrons

1.2 DLDS Pulse Distribution System

In the simplest DLDS (Delay Line Distribution System), illustrated in Fig.4, the RF power from two klystrons with independent phasing is combined through a 3-dB coupler. One output port of the 3-dB hybrid is connected, through low-loss waveguide, to a linac feed about one half of the compressed pulse width times the speed of light upstream of the klystrons; the other port is connected to a local feed. The first half of the input RF pulse of duration equal to the sum of the structure fills time and the bunch train time, is sent to the upstream feed through the delay. The second half of the RF pulse is fed into the linac close to the klystrons, without delay.

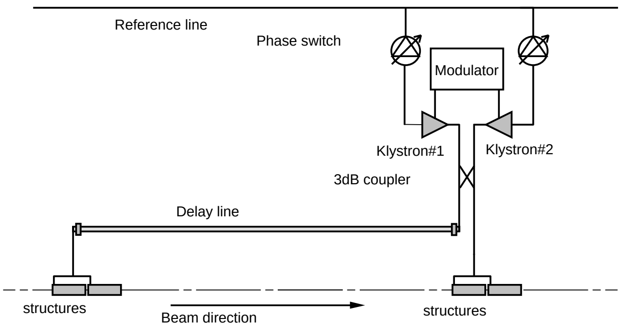

Figure 4: A schematic diagram of the simplest factor-2 DLDS.

The largest drawback of the original (single mode) DLDS is that it requires long waveguides: the maximum of 27 waveguides run together inside the linac tunnel. A conceptual improvement was proposed by SLAC to further reduce the length of waveguide system by multiplexing several low-loss RF modes in a same waveguide. Thus, the sub-pulses in the distribution waveguide are carried by different waveguide modes so that they can be extracted at designated locations according to their mode patterns. 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 [3]. Its scheme is illustrated in Fig.5. It consists of almost identical dual mode DLDS systems with long and short waveguide. The two propagation modes were chosen to be TE_{01} and TE_{02} modes from the results of the joint experiments with SLAC and BINP performed at KEK on a 55m long delay line assembled in the ATF linac tunnel [4]. In these experiments we measured the stability of various modes and their transmission losses over the 55m long pipe. The TE_{01} and TE_{02} modes were found to have the lowest transmission losses and they are less sensitivity to the pipe imperfection (no electric field at the surface of the pipe). This allows a looser tolerance for the pipe fabrication and the insertion of expansion joints to absorb the thermal expansion of the pipe without significantly increasing the transmission loss. KEK is now pursuing the TE_{01}/TE_{02} 2x2 DLDS scheme and we completed the design of all RF components. Their cold models will be tested soon.

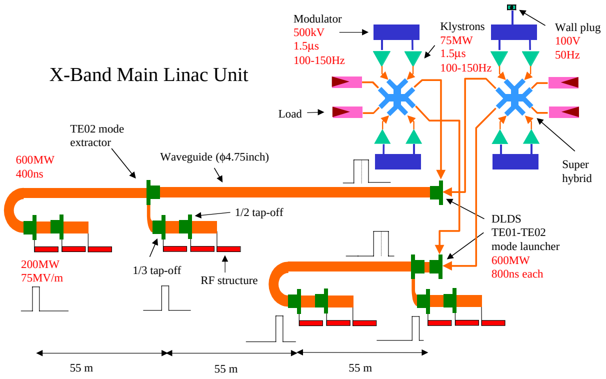

Figure 5: Schematic view of TE_{01}/TE_{02} 2x2 DLDS

1.3 Modulator

To improve the reliability of the modulator, KEK is now developing a new IGBT (Insulated Gate Bipolar Transistor) modulator as a two-year project. The main specifications of this modulator are tabulated in Table 3. The IGBT modulator diagram is illustrated in Fig. 6. It consists of a DC power supply, four modules of switching unit at 25kV, a pulse transformer with a ratio of 1:5, and a waveform compensation circuit. Each module contains 13 stacks of energy storage capacitors, IGBT switches and IGBT gate drivers, and it produces 25kV voltage in total. The four modules are connected in a series-parallel arrangement and turns on into the primary of a pulse transformer to produce 500kV-output pulse at 530A with a flattop width of 1.5µs. The individual IGBT has its own gate driver, which can control the output waveform to an arbitrary form. The diode network allows the isolation of faulted klystron load and protects the IGBT circuits from an over-current. Two prototypes of the modules, with three and ten stages for 6kV and 20kV output pulse each, were built and tested successfully. The entire system at full specifications with the waveform compensation circuit and the over-current protection circuit will be built and tested in spring 2002.

Table 3: The main specifications of this modulator.

Number of klystrons per modulator	2
Peak klystron voltage	500 kV
Total peak current	530 A
Pulse width	1.5 µs
Pulse top flatness	2 %
Energy efficiency	70 %
Repetition rate	100 Hz

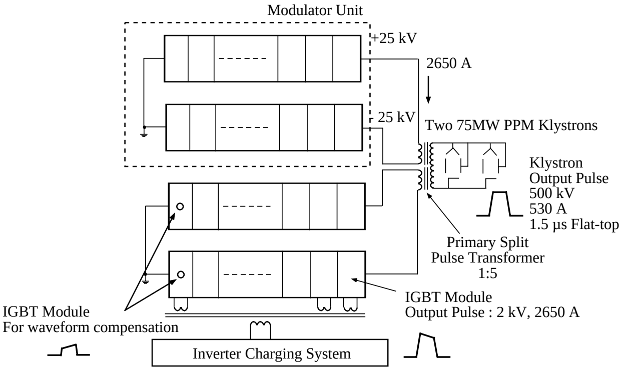

Figure 6: Diagram of the IGBT modulator.

1.4 RF Structure

The main requirement for JLC RF structures is to efficiently provide a 70MV/m-accelerating gradient to a beam, while controlling the short and long-range wakefields to preserve the very low emittance of the multi-bunch beams. In the past years, the various types of RF structures have been designed, built and tested in collaboration with SLAC. The latest design is called RDDS (Rounded Damped Detuned Structure) which not only detunes higher-harmonic modes out, but also aggressively damps them. Its first prototype was successfully built in 1999 and was tested for wakefield characteristics at the ASSET facility at SLAC in 2000. At KEK, much of attentions have been paid to the fabrication issues such as high-accuracy diamond cutting and the diffusion bonding of cells.

These structures are 1.8m long and the group velocity varies from 12% at the input end to 3% at the other end. During recent tests at high power, it was discovered that the net RF phase advance through the prototype structures had increased by roughly 20 degrees per 1000 hours of operation at gradient as low as 50MV/m. The microscopic examination uncovered significant electrical damage in the upstream cells. This has sharp contrast with earlier testing of the structures with lower group velocity (less than 5%) and shorter length, which showed no sign of degradation at the gradient of more than 80MV.

In the hope that a lower group velocity and a shorter length will help to reduce the damage, a series of structures with different lengths and group velocity profiles are being built and tested. All of the low group velocity structures (5%-3%) have reached gradient of more than 70MV/m and show minimum shift in phase advance. The processing voltage history is shown in Fig. 6. Based on these results, we are changing the design for JLC/NLC structures to have a peak group velocity of 3-5% and a length of 0.9m. This, however, demands the average iris size too small to meet short-range wakefield requirements. To increase the iris size, while keeping the group velocity low, the phase advance per cell should be increased to 150 degree from 120 degree.

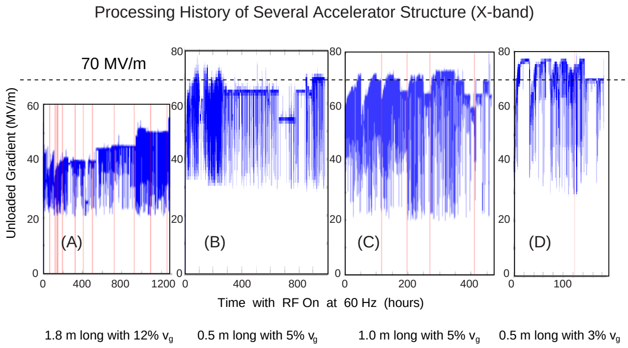

Figure 7: Processing voltage history for (a) 1.8m structure with the peak group velocity of 12%, (b) 0.5m structure with the peak group velocity of 5%, (c) 1m structure with the peak group velocity of 5%, (d) 0.5m structure with the peak group velocity of 3%. (Courtesy D. Burke, 2001)

2 CONCLUSIONS

The X-band R&D efforts are making steady and significant progresses in the last few years. As the critical step to the next stage of R&D, we are working for the three-year project to build a basic main linac unit (or its half-scaled version) by 2004 at KEK for testing of its functionality as system at high power.

3 REFERENCES

[1] "JLC Design Report Study", KEK Report 97-1, 1997.
[2] Y. H. Chin, et. al., " X-Band PPM Klystron Development For JLC", in Proc. of PAC2001.
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[4] S. Tantawi, et. al., "Evaluation of the TE(12) Mode in Circular Waveguide for Low-Loss, High-Power RF Transmission", Phys. Rev. ST Accel. Beams 3: 082001, 2000.