JLC R&D STATUS

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Abstract

In this paper, we summarise the status of the R&D efforts for the JLC (Japan e^+e^- Linear Collider) project including X-band main linacs and the ATF (Accelerator Test Facility). Main emphasis are on X-band PPM klystron development, and on recent progresses at ATF on the studies on production of low emittance beam and multi-bunch beam. The report on the C-band RF system development can be found in Ref.1.

1 X-BAND MAIN LINAC

1.1 Klystron

The 1-TeV JLC project [2] 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 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. 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.

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 maximum efficiency reached 56% at the specified cathode voltage. The performance of PPM-2 klystron is tabulated in Table 2. Figure 1 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.

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

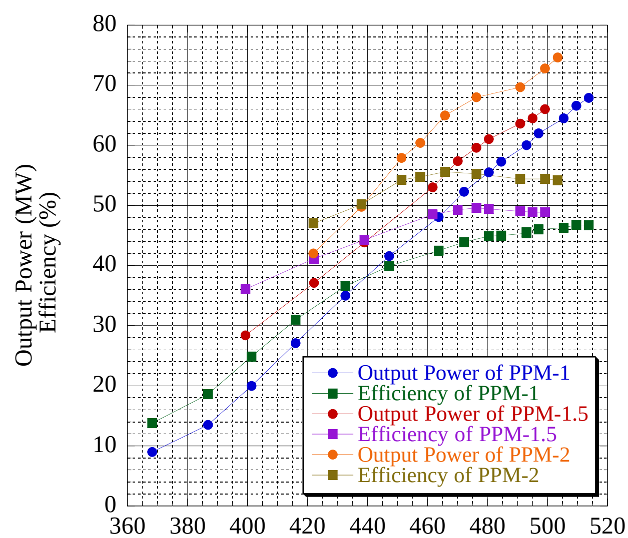

Figure 1: Output power and efficiency vs. cathode voltage at PPM-1, PPM-1.5 and PPM-2 klystrons

1.2 DLDS Pulse Distribution System

KEK is developing the multi-mode 2x2 DLDS (Delay Line Distribution System) to deliver RF power to four RF clusters [4]. Its scheme is illustrated in Fig.2. It consists of almost identical dual mode DLDS systems with long and short waveguide. In the initial design of the 2x2 DLDS, the TE_{01} and TE_{12} modes were chosen to be the propagation modes due to their theoretically small surface losses.on the waveguide. The critical issues in this scheme were the stability of linearly polarised TE_{12} mode and the actual loss in a long waveguide against the imperfection of the pipe shape and the surface condition. Meantime, the TE_{02} mode was conceived as an alternative choice against TE_{12} mode due to its small loss (3rd smallest) and 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. Joint experiments with SLAC and BINP were performed at KEK on a 55m long delay line assembled in the ATF linac tunnel [5]. The main findings of the experiments are;

1. The rotation of the TE_{12} mode is smaller than 1°.
2. The mode contamination in all modes is well below -20 dB before and after the transport line.
3. The power transmission losses over the 55m long pipe are approximately

TE_{01}	2% (theory: 1.7%)
TE_{02}	4% (theory: 3.2%)
TE_{12}	6% (theory: 2.5%)

As for the discrepancies between the theoretical losses and the measured ones, one can only conjecture that there are additional losses due to conversion to some TM modes, which were not measured by our mode analyser.

From these experiments, one can conclude that all the modes are well stable and their transmission losses are within tolerances. But, TE_{01} and TE_{02} modes are the best choices in terms of low loss, less sensitivity to the pipe imperfection and the simplicity of the system. 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.

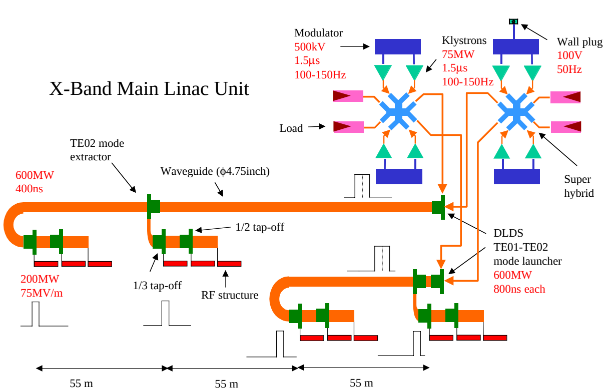

Figure 2: Schematic view of TE_{01}/TE_{02} 2x2 DLDS

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. 3. 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 2001.

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

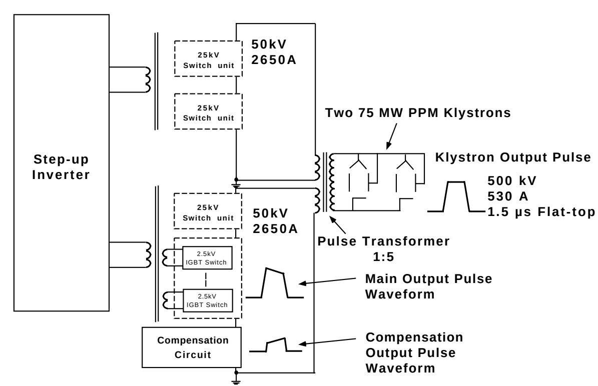

Figure 3: Diagram of the IGBT modulator.

1.4 RF Structure

The required features of the main linac structures are the good alignment of the constituent cells and the realisation of the design frequency distribution of the dipole modes in addition to the accelerating mode frequency tolerance [2]. These features have been realised by utilising the present-day high-accuracy diamond turning technology followed by the diffusion bonding process.

In order to keep the acceleration efficiency high under random frequency errors in accelerating mode, the random error tolerance was set at 3 MHz RMS. On the other hand, we set the tolerance of 5 degrees in the integrated phase advance error at any point along the structure. This requirement is equivalent to the systematic frequency tolerance of 0.1 MHz if the error is uniform over a structure. Even though this requirement seems very tight, it can be met with applying a feed-forward in some dimension of the cells of the later fabrication during the continuous fabrication of disks. From the fabrication of the disks for the first prototype RDDS (Rounded Damped Detuned Structure), we proved that the disks which satisfy the frequency requirements of both accelerating mode and dipole mode can be realised through a high-accuracy diamond turning machining with the help of a careful feed-forward technique.

2 ATF

The KEK/ATF consists of an S-band high gradient linac (Linac), a beam-transport line (BT), the damping ring (DR) and an extraction line (EXT). The pre-injector was completed in Aug. '93, when the development of multi-bunch beam-diagnostics started. In Nov. '95, we completed the high-gradient linac so that experiments on the acceleration of a multi-bunch beam and on the compensation of multi-bunch beam loading could be performed. After installation of the main hardware components, in Jan. '97 we started beam commissioning in the damping ring. In November 1997, we completed the extraction line for precise beam diagnostics. Presently, we are refining the beam-tuning techniques and a restabilizing the key machine components to supply the extremely small emittance beam stably into the extraction line. Since many beam instrumentation devices in the ATF turned out not to be sufficient for precise beam tuning and measurements, we are also upgrading each of the systems and are developing new diagnostics. For example, a laser wire and skew quadrupole magnet were installed near the end of JFY '99 to measure the tiny beam size in the ring and to control the tilt of the beam at the extraction line. Table 2 summarises the achieved accelerator performance of the ATF [6].

The purpose of the ATF is to generate beams with very small transverse and longitudinal emittances as required for future linear colliders. So far, a horizontal emittance of 1.4 ± 0.3 nm was measured with wire-scanners in the extraction line and with the horizontal spatial coherence using a SR interferometer. In addition, a vertical emittance of 15 ± 2.5 pm was measured with 5 wire scanners in the extraction line. Still much effort is needed in order to stably produce a beam with 10 pm vertical emittance at 1.3 GeV. A large number of beam studies conducted in the ATF Linac since JFY 1995 proved the soundness of the ±ΔF multi-bunch beam loading compensation scheme. The experiment demonstrating this scheme was conducted with 6×10^9 electrons/bunch and 20 bunches/train. The original multi-bunch energy spread of 5% from head to tail was corrected to within 0.6%.

3 REFERENCES

[1] H. Matsumoto, T. Shintake, et. al., "R&D status of the C-band RF-system development for e+e- Linear collider in Japan", KEK Preprint 99-83, 1999.

[2] "JLC Design Report Study", KEK Report 97-1, 1997.

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[4] J.Q. Wang, Y.H. Chin, et. al., " Study of RF Components for JLC 2x2 DLDS" in Proc. of PAC99, 1999, P.1058.

[5] 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.

[6] J.Urakawa, "Experimental results and technical research and development at ATF (KEK)", KEK Preprint 2000-67, 2000.

Table 4: Achieved and design parameters at ATF

Item	Achieved values	Design
ATF Linac Status		
Maximum Beam Energy	1.42GeV	& 1.54GeV
Maximum Gradient with Beam	28.7MeV/m	30MeV/m
Single Bunch Population	1.7×10^{10}	2×10^{10}
20 Multi-bunch Population	7.6×10^{10}	40×10^{10}
Bunch Spacing	2.8 ns	2.8 ns
Repetition Rate	12.5Hz	25Hz
Energy Spread (Full Width)	< 2.0% (90% beam)	<1% (90% beam)
Damping Ring Status		
Maximum Beam Energy	1.28GeV	1.54GeV
Circumference	138.6 ± 0.003m	138.6m
Momentum Compaction	0.00214	0.00214
Single Bunch Population	1.2×10^{10}	2×10^{10}
COD(peak to peak)	x≈2mm, y≈1mm	1mm
Bunch Length	≈6mm	5mm
Energy Spread	0.06%	0.08%
Horizontal Emittance	$(1.4\pm0.3) \times10^{-9}$ m	1.4×10^{-9} m
Vertical Emittance	$(1.5\pm0.25) \times10^{-11}$ m	1.0×10^{-11} m