STATUS OF THE GLC X-BAND POWER SOURCE R&D

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Abstract

In this paper, we summarize the R&D status of the X-band power source development for the GLC (Global Linear Collider, previously called JLC) project. Main emphases are on the latest achievements of the PPM klystrons and the development of the IGBT induction modulator. The pulse compression schemes and the optimisation of the tunnel layout for different configuration of the main linac are also discussed.

INTRODUCTION

The linear collider project in Japan, used to be called JLC (Japan Linear Collider), is now regarded as an Asian project promoted by the Asian Accelerator Community (ACFA). Addressing this major strategy change more clearly, the name of the project was recently changed to GLC (Global Linear Collider). The GLC/NLC design teams have been investigating the DLDS pulse compression system as a possible high efficiency option. However, the baseline pulse compression system was recently changed to the dual-moded SLED-II system to ensure a less expensive and faster demonstration of a full RF sub-unit [1]. In addition, the dual-moded SLED-II system is based on the single-moded SLED-II systems that have operated at the NLCTA for over five years, providing confidence in the design. The schematic configuration of the new RF power source unit together with accelerator structures is illustrated in Fig.1. A fundamental power source unit consists of one pair of periodic permanent magnet (PPM) focusing klystrons. The RF pulses from each klystron are 1.6σs in length and 75 MW in power. Then a time compression of the output pulses from klystrons is applied through a dual-moded SLED-II pulse compression system, which compresses the input RF pulse with a time compression factor of 1/4. This is accomplished by temporarily storing the RF power from klystrons within a pair of 29 m-long delay lines. A theoretical power gain is 3.3. With a 10% power loss in the waveguides, it results in a time-compressed pulse of 450 MW, 400 ns, as delivered to the entrance of accelerator structures. The output power from SLED-II feeds eight accelerator structures. Two dual tunnels, 14.1 km-long each, will accommodate the two main linacs. Figure 2 shows a conceptual view of the RF power source unit that is installed in the klystron tunnel, together with the accelerator structures in the accelerator tunnel.

The immediate goal of GLC/NLC is to satisfy the ILC-TRC requirements, which include tests of the RF power and energy handling capability of the dual-moded SLED-II pulse compression system at GLC/NLC design levels and the demonstration of the operation of PPM klystrons at the full repetition rate of 120Hz (NLC) or 150Hz (GLC). The GLC/NLC teams are currently working to fulfil these goals in 2003-2004.

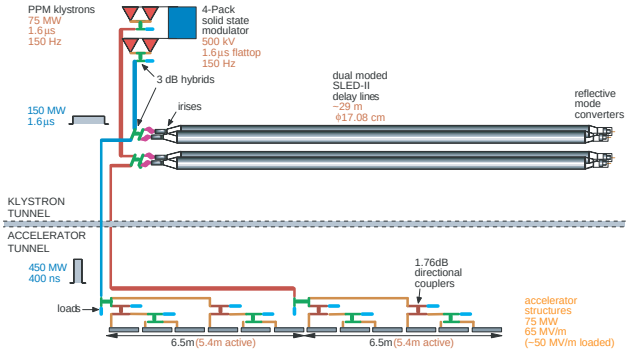

Figure 1: Schematic of GLC X-band linac RF unit.

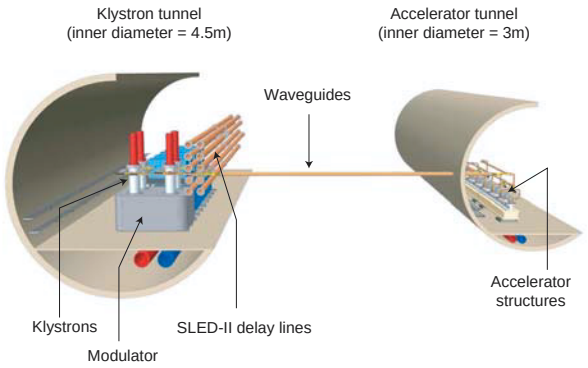

Figure 2: Main linac tunnels for GLC.

MODULATORS

The modulators for the main linacs of JLC are required to produce 1.6σs long, 500kV-260A pulses to each klystron with an efficiency of 80% at a repetition rate of 150 Hz. The line-type modulator, like those presently used for klystron testing at KEK, has some known deficiencies. The thyratron switch tube needs frequent tuning and has a limited lifetime of around 15,000 hours. The thyratron is a fast on switch, but is slow to back off. The overall efficiency of the modulator is 50-60% due to large losses in various components and relatively slow pulse rise and fall times as dictated by the pulse transformer with a high step-up ratio.

The solution to these problems adopted for GLC is to introduce semiconductor device as the switching device. The fast on-off Insulated Gate Bipolar Insulator (IGBT) solid-state switch is used as a power switch, and it is incorporated into an induction-linac type modulator design. The solid-state induction modulator [2] is basically a large stack of small pulse transformers. The primaries of the toroidal-cores are driven in parallel by a separate set (called cell) of IGBT switches and capacitors. While the individual primaries are operated at a relatively

low voltage (3.2 kV), because of their parallel operation a very high voltage, adequate for driving klystrons without any step-up transformers, is induced on the secondary.

Previously, so called the linear induction modulator design was adopted as the most suitable for the 8-pack DLDS configuration, where the toroidal cores are lined up on a straight line, and the transformer secondary (made of a straight HV-cable) runs through their center for a simpler insulation design. Following the recent change in the pulse compression scheme from the DLDS to SLED-II that requires only a pair of klystron for operation, we went through re-optimisation process of our modulator design for the 2-pack configuration and concluded that the 4-turn secondary is the best configuration.

In the new design, the toroidal cores are stacked on two stories, and the 4-turn secondary (made of copper tubes) windings are threaded through them as illustrated in Fig.3. A driver cell, including an IGBT switch and two capacitors on a printed circuit board, is designed as a plug-in module. It can be easily accessed and replaced in the field for fast maintenance. NLC has already built a 4-pack prototype with a 3-turn secondary, and has demonstrated a high efficiency of more than 80% and a pulse shape with fast rise and fall times of 200-300 ns.

In the present prototype design, one modulator powers two klystrons. It consists of 42 FINEMET cores and 84 IGBT drivers, including 5% spears for the waveform compensation. It is designed to produce a 1.6σs-long output pulse of 500kV-1060A with 80% efficiency. The electrical and mechanical designs are nearing completion, and a 2-pack prototype will be operating in fall of 2003.

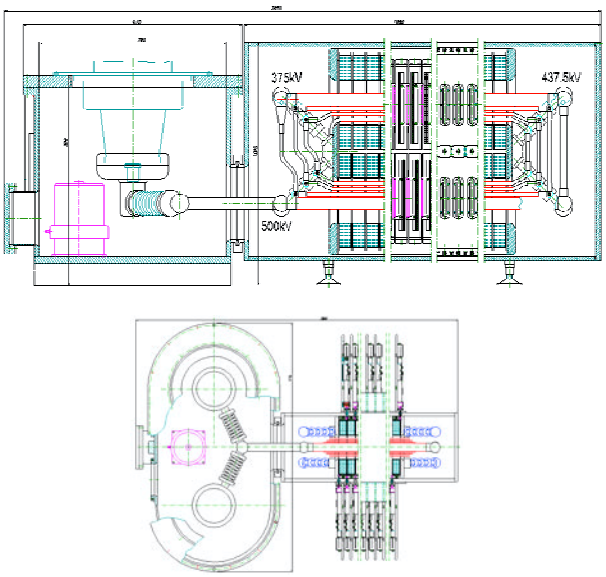

Figure 3: Side (top) and top (bottom) views of the IGBT induction modulator.

PPM KLYSTRONS

The X-band klystrons at GLC must produce 75 MW in 1.6σs pulses with 55% efficiency. The development of the X-band power sources has been one of the major goals for GLC/NLC R&D program. The actual R&D begun 15 years ago and has been much more difficult than initially anticipated. But now, the design is finally converging.

The power-consuming solenoid magnets cannot keep the operating cost manageable, and thus Periodic Permanent Magnet (PPM) klystrons are being developed which would consume no electric power for focusing, and would thus have a higher net efficiency. KEK carried out a two-year project with Toshiba to produce two PPM klystrons in two stages [3]. Figure 4 shows photos of the first two X-band PPM klystrons built in Japan, PPM-1 (left) and PPM-2 (right). The PPM-1 (later rebuilt as PPM-1.5) achieved 56 MW power with 50% efficiency at the standard 1.5σs pulse length. Neither oscillation of parasitic mode nor gun oscillation was observed. The electron beam transmission was found to be 100% when no RF signal was applied. However, since PPM-1 did not implement full features of body cooling, the repetition rate was limited at 25 Hz.

The second klystron (PPM-2) was also tested. The PPM introduced a full water-cooling system of the klystron body and the PPM stack. For a higher efficiency, some revisions of the resonant frequency of the penultimate cavity were made. The PPM-2 produced 73.2 MW at 500 kV for a 1.4σs pulse length. At 70 MW, the standard 1.5σs pulse was attained with an efficiency of 55%. The maximum efficiency reached 56%. The performance of the PPM-2 klystron is tabulated in Table 1. In respect of power, efficiency and pulse length, PPM-2 almost achieved the GLC specifications. The testing was terminated by the breakdown of the pulse transformer.

Figure 4: Photo of the first (PPM-1, right) and the second (PPM-2, left) PPM klystrons for GLC.

Table 1: Design parameters and actual performance of the PPM-2 klystron.

	Design	Achieved
Peak power (MW)	75	75.1
Efficiency (%)	55	56
Pulse length (σs)	1.5	1.5 (at 70MW) 1.4 (at 73.2MW)
Repetition rate (pps)	150	25

Following the success of those two klystrons, the development plan was expanded for the next two years. In JFY 2001, the PPM-3 klystron was built and high power tested. The main goal of this klystron was to achieve the high repetition operation (limited to 50 Hz by the specification of the modulator) to prove that the PPM klystron is ready for use at GLC. To this end, refining and remodelling of the water-cooling system and the RF windows were made. Two 2nd-harmonic cavities were also installed to increase the efficiency. The output power of 65 MW was attained at a 1.5σs pulse length with 53% efficiency, as summarized in Table 2. The PPM-3 klystron successfully doubled the repetition rate to 50Hz (limited by the modulator). The TRC Report addressed that "the Working Group considers the JLC-X PPM-2 klystron a proof of existence (although tested only at half the repetition rate)". The testing was terminated by the failure of the one of the output windows, though the window outperformed the any of previously made windows.

Table 2: Design parameters and actual performance of the PPM-3 klystron.

	Design	Achieved
Peak power (MW)	75	65
Efficiency (%)	55	53
Pulse length (σs)	1.5	1.5
Repetition rate (pps)	150	50

KEK is committed to trying its best to fulfil the TRC R2 requirement on PPM klystrons in 2003-2004. The remodelled PPM-2 with new windows was shipped to SLAC and its high power testing is under way. The aim is to satisfy the ILC-TRC requirement R2 that demands the demonstration of the operation at the full repetition rate of 120Hz (NLC) or 150Hz (GLC). The PPM-4 klystron, with an improved cooling system, is now under high power testing. The PPM-4 will be also shipped to SLAC for testing at 120Hz repetition rate after the conditioning at KEK is finished. The PPM-5 with further improved cooling system is being designed for completion in December 2003.

DUAL-MODED SLED-II

The SLED-II uses a pair of high-Q resonant delay lines as the temporary energy storage to produce flat output pulses. In the case of the single-moded SLED-II, when an output pulse length of 400 ns is required, as in the case of GLC, the natural length of the required delay lines would be 58m. This tends to result in a tunnel layout that is heavily crowded with many delay lines that are extending from neighboring klystron pairs. To address the space issue, a breakthrough concept of dual-moded SLED-II was invented for NLC at SLAC [4], and has been adopted for GLC as well. In this system, by using two modes in the delay lines, TE01 and TE02 modes, the delay lines, with a physical length of 29 m, can act as having an effective length of 58 m, adequate for producing 400 ns output pulses. The intrinsic efficiency of this dual-moded SLED-II pulse compression system is approximately 80%. In addition, by running the two pairs of delay lines, originating from two pairs of klystrons driven by a single modulator unit, into two opposite directions, a very nicely packed installation of the RF power sources can be realized. This is illustrated in Fig. 5. In this configuration, the number of parallel running delay lines will be limited to 10 at maximum, reduced from 18 in the nominal 8-pack configuration, and the delay lines are almost uniformly distributed through the linac. The working principle of the dual-moded SLED-II has been demonstrated in a low power testing by the US NLC group in 2002. Preparation work is under way for a high-power testing of the dual-moded SLED-II system in NLCTA at SLAC, as a joint (8-pack) project between the NLC and GLC groups, in order to fulfil the ILC-TRC requirements. In the first round of experiment in 2003, four 50 MW solenoid-focused klystrons, operating with 1.6σs pulse length, will be used. With this set-up a production of 600 MW in 400 ns pulses is expected. This will allow testing of many of the RF components at power levels higher by about 30% than what is needed for NLC/GLC. It is also planned, in late 2003 or early 2004, to use a pair of PPM klystrons as the power source for this SLED-II test station. KEK is participating in this 8-pack project by providing some SLED-II components. It was reported that the tapers used at the original dual-mode SLED-II delay lines may be a reason of measured degradation of the compression performance by a factor of 10%. KEK has designed alternate tapers for the dual-mode SLED-II delay lines to improve its performance and they are under fabrication. They will be shipped to SLAC to participate in the 8-pack project.

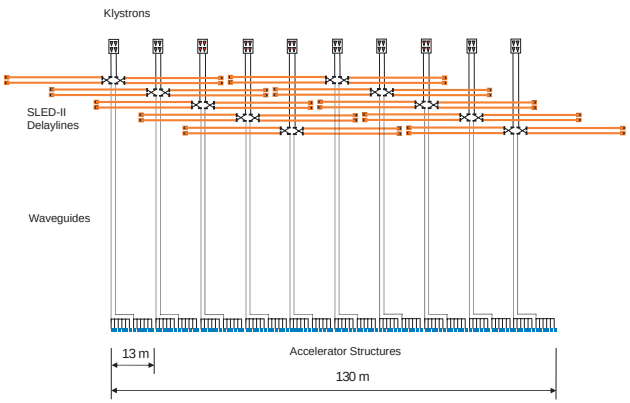

Figure 5: Optimised layout of SLED-II.

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