R&D OF X-BAND LINACS FOR JLC: PRESENT STATUS

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Abstract

PPM klystrons nearly satisfying JLC specifications have been developed. A unique RF distribution system DLDS is making a satisfactory progress. A prototype IGBT modulator is under fabrication. Linac structures with v_g/c = 5% or less seem promising for operation at Eacc = 75 MV/m.

1 JLC LINAC SYSTEM [1]

JLC is an e+e- collider for Ecm from around 500 GeV to 1 TeV. The X-band linacs for electron and positron beams are the dominant part of the JLC accelerator complex about 27 km long as shown in Fig. 1.

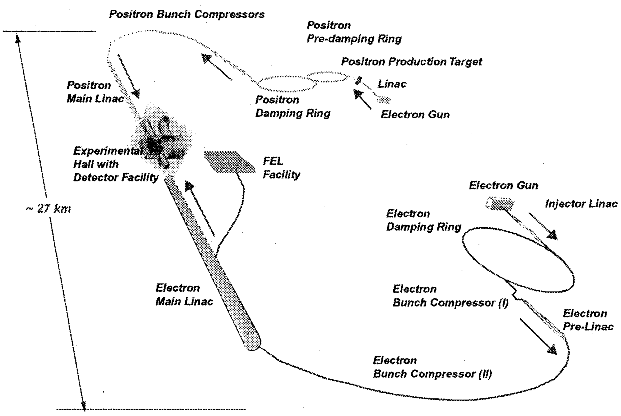

Figure 1: JLC Accelerator Complex

Each linac comprises 2484 travelling wave (TW) structures of 1.8 m in length operating at 11.424 GHz, 4 times the popular S-band frequency, 2856 MHz. The 2484 TW structures are grouped into 23 RF sectors. At each sector, 108 TW structures are driven by 72 klystrons via a unique power distribution system DLDS (delay-line distribution system). The 72 klystrons are further grouped into 9 sub-groups. The output powers from each sub-group's 8 klystrons are, after being combined and divided by the DLDS waveguides, fed into 12 TW structures. Hence, we will call each sector comprising 9 sub-groups as a "nonet." One nonet extends as long as 225 m, as its layout is shown in Fig. 2.

While each klystron produces 75 MW, 1.5 μs peak power, each TW structure receives 200 MW, 0.375 μs (= 1.5/4 μs) peak powers to produce an unloaded accelerating gradient of 72 MV/m.

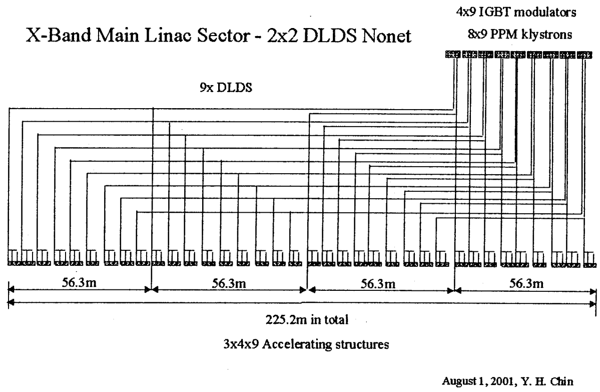

Figure 2: A DLDS Nonet of the Main Linac

2 RF POWER SOURCE [2]

2.1 Klystron

The 75 MW klystrons are of a PPM (periodic permanent magnet) focused type, with a micro-perveance of 0.78. Their main features are:

- The output cavity has a 5-cell structure optimised for a maximum DC-to-RF power conversion efficiency, minimising the surface field gradients.
- Except for the output cavity, all RF cavities together with drift tubes have stainless-steel liner to damp higher order modes.
- The output cavity has two output ports, which are aligned at 150° rather than 180° to damp the degenerated TM11 deflecting modes.
- The permanent magnets are made of a Nd-Fe-B tertiary alloy, which generate about 2.5 kG axial fields at a half pitch of 15 mm.

The development has been carried out in two stages. The first tube was designed without water-cooling channels, since it would complicate the magnetic field design. After confirming the test results of the first tube, we proceeded to the second tube with the cooling channels that would allow a high duty operation at a repetition rate of the JLC specification: 100 to 150 Hz.

The Table 1 summarises the design specifications and achieved values as of July 2001.

Table 1: #2 PPM Tube Results

	Spec.	Achieved
Output Power (MW)	75	73
Pulse Width (μs)	1.5	1.4
Rep. Rate (Hz)	100 - 150	3.6
Efficiency (%)	55	53

2. 2 DLDS

In one subgroup of the nonet (Fig. 2), the 8 klystrons are formed into 4 pairs. The phases of the 1.5-μs output pulse are coded either with 0° or 180° for each of 0.375-μs time slices. The coding, however, are different among the 4 pairs, so that the powers combined with magic-T's appear sequentially at 4 different ports in 600 MW, 0.375 μs pulses. Those pulses are transmitted through two circular waveguides 12 cm in diameter 225 m at the longest.

The pulses are launched into the waveguides in the transmission modes of TE01 and TE02, which have small attenuation and low rate of mode conversion due to possible waveguide deformations. The pulses are tapped off at extractors that select only one transmission mode at each point.

Proof-of-principle tests at low power levels have already been carried out in the KEK ATF linac tunnel. High power waveguide components are now in production.

2.3 Modulators

The klystrons need 500 kV or slightly higher pulse voltages to produce 75 MW. A thyratron switched modulator of a Blumlein type PFN has been used to test X-band klystrons at KEK. An IGBT switched modulator, however, is under development.

The IGBT's would have 10 times longer life and less jitters than thyratrons. Both KEK and SLAC are developing IGBT modulators, but the circuit designs are slightly different. Each IGBT unit drives the pulse transformer independently with 2 kV pulses in the SLAC design. In case of the KEK design, they are connected in series to produce about 100 kV primary pulses for a 1:5 transformer.

In preliminary tests using 10 IGBT units, we obtained 20 kV, 2 kA, 1.5 μs pulses. We are preparing a 52 IGBT-unit switch to produce 100 kV primary pulses for a 1:5 transformer.

Studies are under way for improving the pulse transformer in order to obtain faster rise times and robustness against breakdowns at the load.

3 ACCELERATING STRUCTURES

Development of X-band accelerating structures has been carried out as joint efforts between KEK and SLAC for over 5 years. What we have developed is damped-detuned structures (DDS) in which every cell has small slots to damp high order modes and has different dimensions to detune them. Cell types have evolved from a conventional pillbox to a round-corner one (RDDS: Rounded DDS) to improve the shunt impedance. KEK has been responsible for fabrication, including high-precision machining of oxygen-free high-conductivity (OFHC) cells and their diffusion bonding, without using any brazing alloys. Then the final assembly and wake-field tests are performed are at SLAC.

Most of the structures have been of a conventional $2\pi/3$ travelling wave (TW) type (cell pitch = 8.75 mm), except for a few ones for recent high gradient studies, which are either of a $5\pi/6$ TW or of a SW type. The aperture diameter 2a ranges typically from 11 mm to 8mm with the corresponding v_g/c from 12% to 3%. The length is typically 1.8 m, comprising 206 cells. Peak input powers needed for an average accelerating gradient of 75 MV/m are around 250 MW.

3.1 RDDS

The conventional flat disk of DDS's was modified to a rounded one as shown in Fig. 3. This was to improve the shunt impedance by about 15%. Hence, for a given shunt impedance, we are able to have a larger aperture which reduces higher-order mode wakes.

The cells were diamond-turned with dimensional tolerances around 1 to 2 μm in summer of 1999. The RF quality checks revealed that the frequency control was on the order of 1 MHz. The diffusion bonding was done in spring of 2000.

At the ASSET facility of SLAC, transverse wake fields were measured in summer of 2000. The result was in good agreement with numerical simulation including known dimensional errors as shown in Fig.4.

3. 2 Fabrication Technologies [3]

OFHC copper cylinders of class 1 grade are supplied by Hitachi-Densen. They are annealed at 500°C in a nitrogen furnace for about 2 hours after an initial rough machining.

Ultra-high precision finishing with a surface roughness below 50 nm is then carried out with a diamond turning machine whose operating temperatures are controlled within ±0.5°C. Unit cells thus machined are then cleansed with acetone and ozonized pure water.

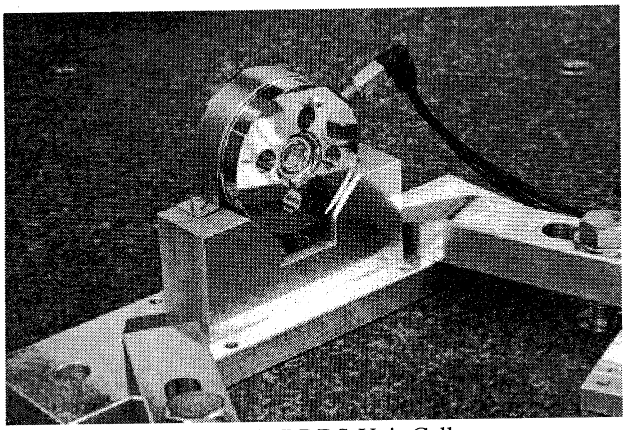

Figure 3: RDDS Unit Cell

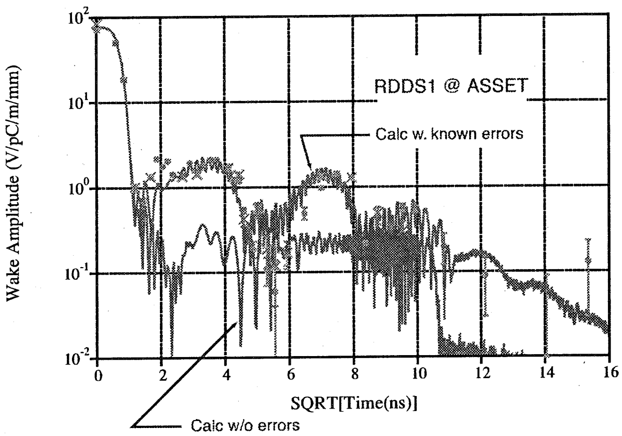

Figure 4: Calculated and Observed Transverse Wakes

The diffusion bonding is done at 890°C for about 4 hours in a vacuum furnace. The structure then is brazed together with couplers and cooling pipes in a hydrogen furnace.

3.3 High Gradient Tests [4]

High gradient tests are executed with 60 Hz, 100 - 240 ns pulses at the NLCTA facility at SLAC. The concern in the test is surface damages on the cell surface by RF breakdowns during the processing. A measure of quantifying the damage is a change per processing hour of the net RF phase advance through a structure.

For a series of DDS structures, the phase change rate was observed to be roughly 20° per 1000 hours even at gradients as low as 50 MV/m, although nearly 100 MV/m gradients can easily be attained for shorter structures such as a single cell. Many pits with diameters around 10 μm were actually observed in microscopical examination.

One critical parameter for the damage may be the energy input at a breakdown point, which is larger for a structure with a larger v_g. Hence, several structures with $v_g/c = 5\%$ or lower have been under test since last year. For these low-v_g structures, gradients around 70 MV/m have been achieved. A comparison of processing for structures of different v_g's is shown in Fig.5.

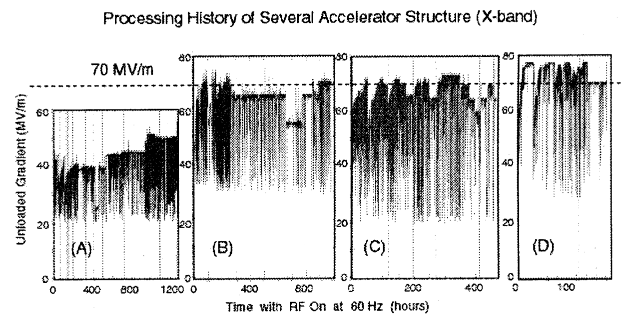

Figure 5: Processing Results: (A) v_g/c= 12%, 1.8 m tube, 1200 hrs, (B) v_g/c= 5%, 0.5 m tube, 1000hrs, (C) v_g/c= 5%, 1 m tube, 450 hrs, (D) v_g/c= 3%, 0.5 m tube, 200 hrs.

In the case (D) in Fig.5, breakdown points are rather concentrated around the input coupler. Therefore, the maximum gradient would be further increased if the coupler design is revised so that it has a lower effective v_g.

Another important factor that may affect the maximum attainable gradient is the surface finish/treatment of the structure. Sample tests are under way at Saitama University particularly with respect to various cleansing methods of copper surfaces.

4 CONCLUSIONS

The above results have attained through close and active international collaborations, particularly with the SLAC NLC team and also with the BINP Protvino team. This R&D style will be furthered in near future.

For the structure high-power tests, which are so far solely carried out at SLAC, KEK is going to build its own facility incorporating the presently developing PPM klystrons, DLDS waveguides, and the IGBT modulator.

5 REFERENCE

[1] N. Toge et al, ISG Progress Report, KEK Report 2007-7/SLAC R-559, April 2000.
[2] Y. H. Chin, this conference.
[3] Proceedings of the 2nd KEK Mechanical Engineering Workshop, KEK proceedings 2001-12, June 2001.
[4] C. Adolphsen, T. Higo et al, PAC 2001