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ENGINEERING DESIGN OF THE INJECTOR LINAC FOR THE ADVANCED LIGHT SOURCE (ALS)*

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Introduction

The injection system for the ALS is designed to provide an electron beam of up to 400 mA at 1.5 GeV to the storage ring in a filling time of less than five minutes.[1] The 328 RF buckets in the storage ring can be filled with electrons in an arbitrary pattern. The injection system begins with an S-Band linac that provides 50 MeV electrons to the booster synchrotron for further acceleration to 1.5 GeV. The electron gun can be pulsed to give single and multi-bunch formats. An efficient subharmonic bunching system is used to compress the electron gun pulse to fit in a single S-Band bucket, thereby conserving charge and making the diagnostics of booster injection unambiguous.[2] A by-product of this bunching is flexibility for future FEL injection. Two disk-loaded accelerating waveguides that are independently powered complete the acceleration with modest field gradients. These two sections are fabricated using self-aligning precision-machined cups. Energy spread due to beam loading is compensated by a fast differential phase shift between the two accelerating sections.

TABLE 1. Performance Requirements of Linac

ELECTRON GUN		
Energy	[keV]	120
Single bunch mode		
Current	[A]	2.4
Pulse length	[ns]	2.5
Multi-bunch mode		
Current	[A]	1.0
Pulse length	[ns]	100
LINAC		
Energy	[MeV]	50
Repetition rate (max.)	[Hz]	10
Frequency	[MHz]	2997.924
Single bunch mode		
Intensity	[e]	1.3×10^{10}
Bunch length (rms)	[ps]	15
Multi-bunch mode		
Average current	[mA]	125
Pulse length	[ns]	100
Emittance (rms)	[π m-rad]	0.4×10^{-6}
Energy spread (rms)	[%]	0.4

Linac Construction and Layout

The layout, construction, and component complement of the linear accelerator are shown in Figure 1. The support girder structure is split into three parts. The first girder will be assembled well in advance of the S-Band sections to provide a Faraday Cup terminated test stand. The test stand will be used to evaluate the performance of the gun, subharmonic bunchers and diagnostics.

The Electron Gun Source

The triode gun of the linac employs a 1.0 cm^2 dispenser cathode which operates at a dc potential of -120 kV. Pulses with an intensity of 6.0 nC (i.e. 3.8×10^{10} electrons) and an emittance of less than 10×10^{-6} π m-rad can be delivered.

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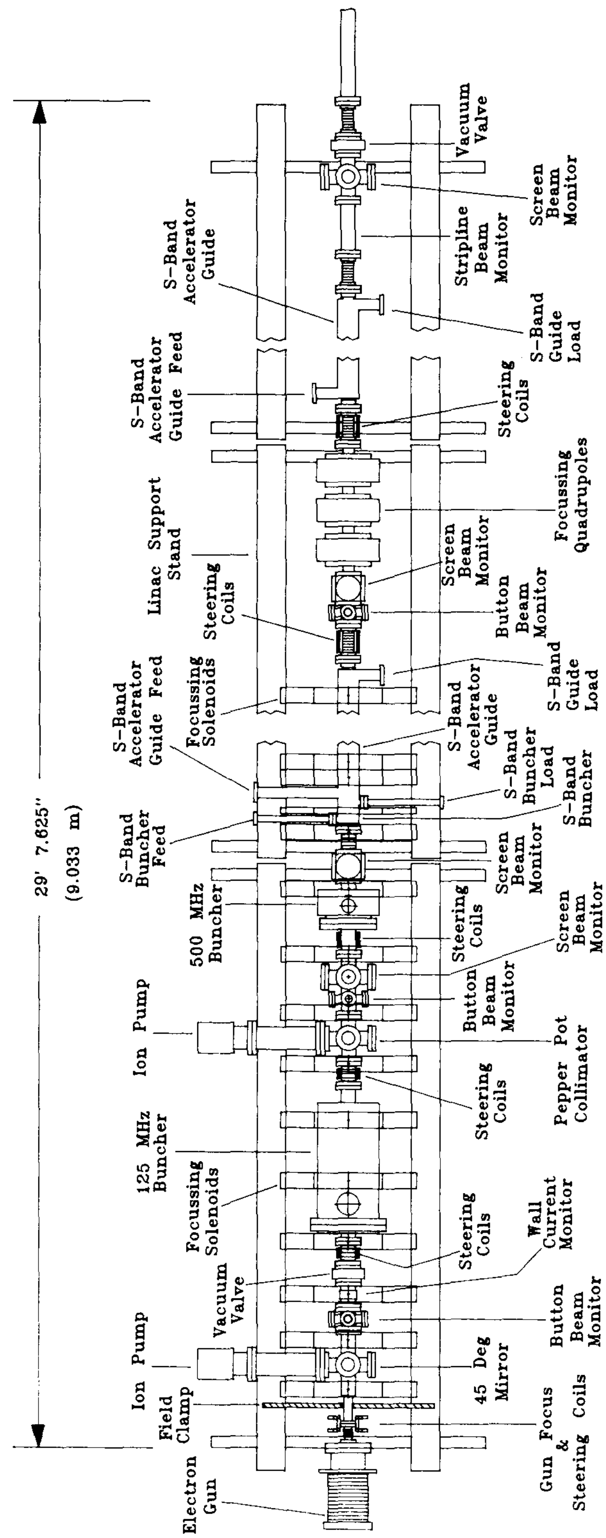

Figure 1. Linac Layout

A 125 MHz sine wave, divided down from the 500 MHz ALS master oscillator, is biased and clipped to form a continuous chain of 2.5 ns negative going pulses that are applied to the gun cathode. By applying a positive going gate pulse of from 12 ns to 150 ns to the grid any number of 2.5 ns beam pulses from 1 to 19 may be emitted at will.

The Subharmonic Bunchers

Each buncher employs quarter-wave stainless steel resonant cavities; in both cases the nose cone gap is 2 cm. The shunt impedance of the 125 MHz cavity is 186 kΩ and of the 500 MHz cavity 248 kΩ. The required gap voltage in both cases is 60 kV.

Amplifiers using commercial modules hybrided together and using 3 CPX 800 A7 tubes are employed for both systems. Pulse power levels up to 24 kW at 100 μs and 10 Hz are obtained giving an ample power margin. The design of the amplifier systems also provides for several hundred watts of long pulse or cw power. This feature allows for outgassing and multipactor conditioning of the cavities.

Provision has been made for temperature stabilization of the cavities to minimize phase drift of the gap RF voltage.

The S-Band Buncher

The buncher comprises four cavities (including the coupler) tuned to 2997.924 MHz in the $2\pi/3$ mode. The period is 25 mm, making the phase velocity equal to 0.75 times the velocity of light. A shunt impedance of approximately 38 MΩ/m indicates an axial field of 4.8 MV/m for an RF input power of 1 MW.

In order to minimize beam expansion and debunching, the buncher will be brazed directly to the first accelerator section, so that the intervening drift tube length is held to 22 mm.

Low-impedance waveguide feeds and special high-vacuum flanges are employed to allow close spacing of magnetic focussing coils in the buncher region.

The completed buncher is shown in Fig. 2.

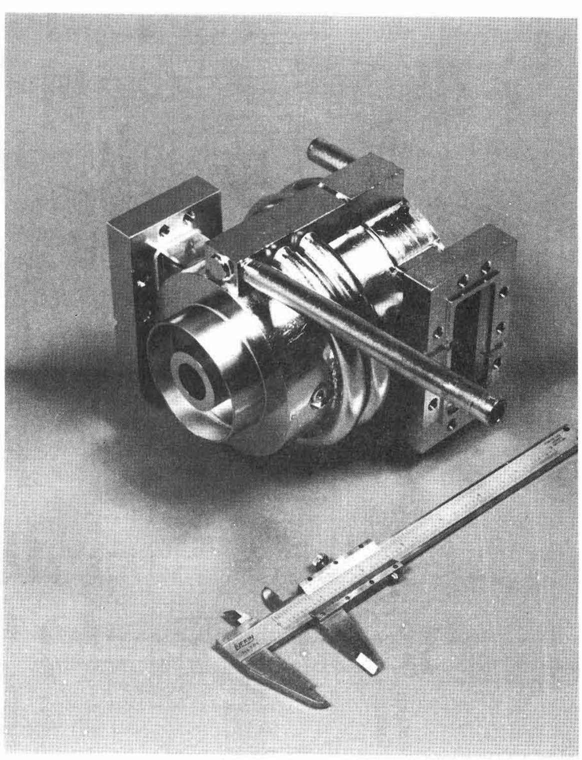

Figure 2. S-Band Buncher

The S-Band Accelerator Sections

There are two disk-loaded waveguide accelerator sections, each 60 cavities (2m) long. A constant-impedance design was selected for economy and simplicity. The principal parameters are given in Table 2.

TABLE 2. Accelerator Section Parameters

Iris aperture	[mm]	24
Cavity diameter	[mm]	79.25
Period	[mm]	33.33
Shunt impedance	[MΩ/m]	55.9
Normalized group velocity		0.0173
Attenuation constant	[Np]	0.262
Filling time	[ns]	325
Energy per section with 20 MW klystron power	[MeV]	28.7
Axial field in input cavity	[MV/m]	16.3
Beam loading at 125 mA	[MeV]	1.7

The accelerator sections are fabricated from precision-machined copper cups, which are stacked and brazed. Initially, sub-sections are brazed as shown in Fig. 3 (which also shows the buncher and a single cup). At this stage, the coupler matching is checked and pre-tuning is done on the cavities in the coupler sections. After this, the sub-sections are brazed together and the water cooling circuits are added, and the completed section is tuned.

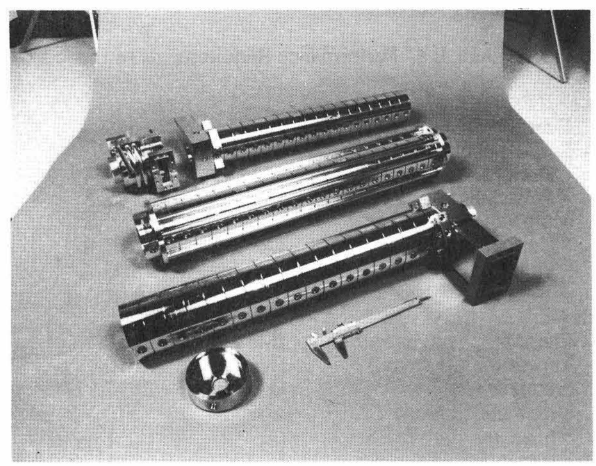

Figure 3. S-Band Buncher, Guide Sub-sections, and a Single Cup.

Diagnostics

Immediately following the electron gun output spool a 45° double sided optical mirror may be inserted into the beam tube. The mirror allows for visual and optical pyrometer inspections of the cathode surface. A laser beam may also be injected via the mirror for alignment checks.

Following the mirror facility, a wall current monitor displays the gun intensity pulse.

Situated between the subharmonic bunchers, a pepper pot collimator and fluorescent screen allow for emittance measurements.

Button type RF beam position monitors and further screens are strategically placed for beam position and size monitoring.

The final output monitor of the accelerator is a strip line device monitoring position, intensity, and pulse shape.

The Control System

The control system for the linac is integrated into the larger ALS system which uses a large number of small modules called intelligent local controllers (ILCs), multi-dropped on serial links. The linac uses 25 ILCs for controlling and monitoring all linac variables. Several are used as essential elements of feedback systems for the steering coil power supplies, the S-Band buncher high power phase and amplitude motor controllers, the beam loading compensation system, and the accelerating guide temperature controller.

Using a small portable control station the ILCs can be fully exercised, either in concert on the serial link or individually, for local control of the linac.

The Focus and Steering System

The main water cooled solenoid focus system is comprised of 22 identical 55 turn coils and one 22 turn coil. The coils have large internal diameters to facilitate access to enclosed components and to give clearance for longitudinal coil movements.

Commercial dc power supplies feed the coils in groups of three or four, thereby allowing further field shaping adjustments.

Focussing at 25 MeV between the accelerator guides is by means of three quadrupole magnets.

The steering coil power supplies are high quality stereo amplifiers with dc response. They will provide typically ±7 A at 30 V. the amplifiers are converted to stable constant current devices by feedback involving ILCs that are part of the control system. This approach which provides horizontal and vertical steering from each amplifier unit is more economic than normal commercial bipolar supplies.

The S-Band RF Drive System

A simplified schematic of the RF drive system is shown in Fig. 4. A 2997.924 MHz CW signal, derived from the ALS master oscillator and a x6 multiplier, passes through a phase-shifter and is divided into two drive paths, one for each klystron. Additional phase-shifters allow for beam loading compensation and phase adjustment between the two accelerator sections. Phase and amplitude detectors provide inputs to ILCs which control phase-shifters and attenuators to stabilize the operating parameters. Preamplification is provided by 800 W solid-state amplifiers. These amplifiers drive the input cavities of the klystrons. The two 25 MW klystrons provisioned are of established design.

A low duty cycle (1 μs at 1-10 Hz) allows considerable simplification of the klystron modulator design. A ten section transmission line with decoupled and individually variable inductors is used. The line is dc charged using a highly stable high voltage switching supply. Switching into the klystron pulse transformer is via the usual hydrogen thyratron. However, in this low duty case, a glass envelope tube can be used with economic advantage.

The klystron RF outputs are transmitted to the accelerator sections via temperature controlled evacuated waveguide. Power is coupled off the first klystron to drive the buncher. This power is transmitted through waveguide filled with pressurized nitrogen. The path contains a high-power attenuator and phase-shifter. Windows at each end isolate the nitrogen and vacuum systems.

Beam Loading Compensation

The beam loading on the accelerating waveguides for the longest (100 ns) linac pulse will result in an energy spread of about 4 percent between the beginning and end of the beam pulse if left uncorrected. This must be reduced so the energy spread lies within the acceptance (±1%) of the Booster.

To compensate for the energy spread a fast step phase change is made between the klystron drive chains for the two accelerating waveguides at the beginning of the beam pulse. This results in a power increase to the accelerating waveguides that reduces the energy spread to within acceptable limits. The phase step method allows the klystrons to be operated in a more stable saturated mode.[3]

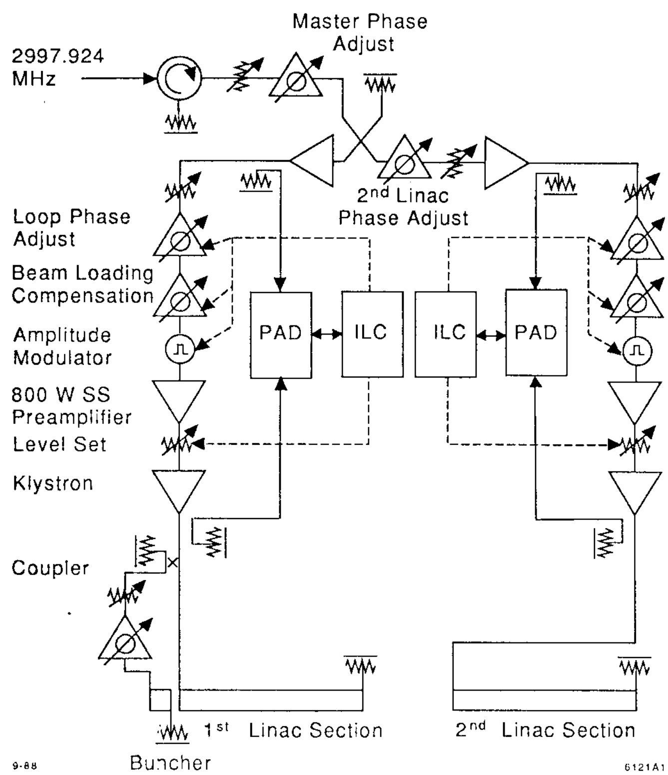

Figure 4. S-Band RF Drive System, Simplified Schematic.

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