BOEING 120 MeV RF LINAC INJECTOR DESIGN AND ACELERATOR PERFORMANCE COMPARISON WITH PARMELA

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INTRODUCTION

The injector for the Boeing 120 MeV L-band RF linac was designed to produce 400 Amp peak current electron beam pulses with minimal emittance growth. PARMELA [1], a mostly three-dimensional matrix ray trace code with a two-dimensional space charge model, was used to determine the optimum setting of the injector elements for tuning purposes. The injector model predictions were used to tune the injector with very good agreement between the model and the experiment.

Beam dynamics modeling from the gun through the sixth accelerating section was done with PARMELA, using experimental settings for the beamline elements. We observed excellent agreement between PARMELA predictions and experimental results.

INJECTOR SIMULATION

As shown in figure 1, the injector consists of a SLAC type thermionic gun, two subharmonic bunchers at 108 and 433 MHz separated by 120cm drift and a tapered phase velocity traveling wave buncher at 1300 MHz for longitudinal bunching to achieve high peak currents. The radial growth of the beam due to space charge and radial electric fields in the traveling wave buncher are controlled by the axial magnetic fields provided by the solenoids. The diagnostics consist of current monitors, pepper pot, profile screens, and a streak camera as shown in figure 1.

The injector design, originally, was done with ORBIT [2], the one dimensional longitudinal bunching code including space charge and OPTIC [3], one dimensional radial confinement code using the paraxial ray equation. This forced us to do the design in piece meal fashion and did not provide emittance information. Eventually the injector design was tested with PARMELA.

The PARMELA simulation was done from the gun to the end of the first accelerator section all in one piece. The code was run on the Cray with 1000 particles and 5 degrees of 1300 MHz time steps.

The simulation starts with a 5.5nc, 1.9ns FWHM, 1.6 cm diameter electron pulse at the cathode. The entire system thru the first accelerator section is optimized to deliver 5.5nc 10 ps FWHM .6 cm diameter beam at the entrance to the accelerator. The 108 MHz and 433 MHz bunchers are running at 40 kV and 35 kV respectively. The 1300 MHz buncher is powered by 11 MW and the cavity parameters are as shown in figure 1. The axial magnetic field varies from 90 gauss in the front end to 1300 gauss over the first three cavities of the TPV buncher where the beam is the most compressed both radially and longitudinally. From this point the field drops down to 1200 gauss up to the first accelerator and then tapers down to 700 gauss over the accelerator. The last solenoid is located at the end of the first accelerator section where the beam energy

1300 MHz buncher

Cavity	β	E, MV/m
1	0.55	5.9
2	0.66	6.9
3	0.78	7.9
4	1.00	16.3
5	1.00	15.8
6	1.00	15.3

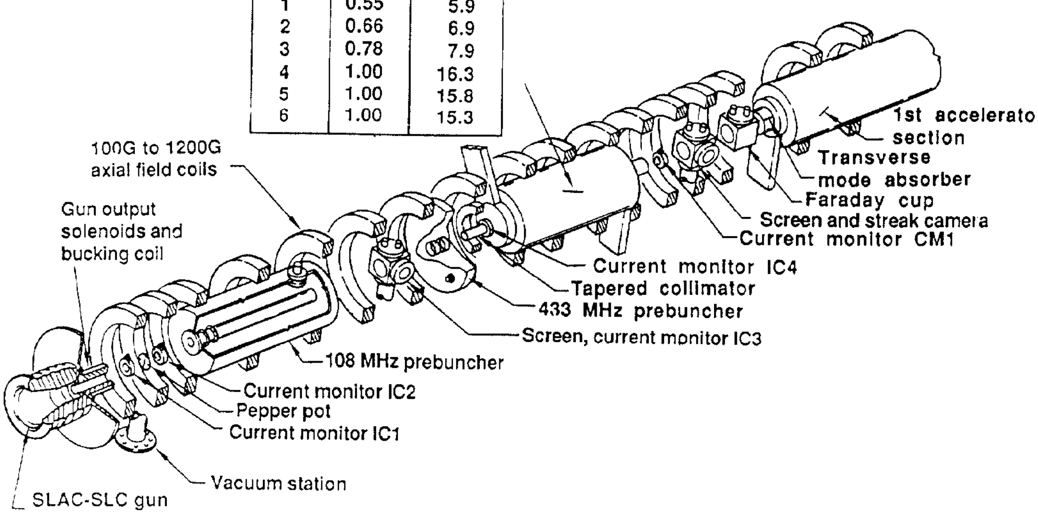

Figure 1. Double subharmonic injector

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is 20 MeV. After many PARMELA runs an optimized system of injector parameters were chosen to produce 100% charge transmission of 5.5 nc, at the entrance to the accelerator section. Of this 4.1 nc was within 10 ps pulse width. The beam diameter is .65 cm, the normalized emittance 40 pi-mm-mrad, energy is 2.5 MeV and the energy spread .8 MeV FWHM. PARGRAF, the graphics post processor for PARMELA is set up to produce beam parameter plots at each diagnostic station and some key points in the injector. Table 1 shows a summary of the modeling and experimental results.

Table 1. Injector to experiment comparison.

Location	Charge (nc)		Pulse Width FWHM (ns)		peak current (Amp)		Beam size (cm)	
	mod.	exp.	mod.	exp.	mod.	exp.	mod.	exp.
IC1	5.5	5.5	1.9	1.9	3	3	1.6	1.6
Pep Pot	5.5		1.9		3		1.6	1.6
IC2	5.5	5.5	2.0	1.9	3	3	1.6	
CA27	5.5		.43		10		1.9	1.6
IC4	5.5		.128		43		1.0	
Ent TPV	5.5		.149		40		0.6	
Ext TPV	5.5		.021		230		0.4	
CM1	5.5		.015		250		0.4	
SC1/Strk	5.5		.010	.014	320	414	0.5	0.5
FC	5.5	5.8	.010		350		0.4	
Ent Acc1	5.5		.010		410		0.65	

INJECTOR EXPERIMENTAL RESULTS TO PARMELA COMPARISON

The first experiment was to tune and make beam measurements in the injector. All the parameters except emittance and energy were measured. The code to measurement agreement is excellent.

The experiment started with setting the injector components to values predicted with PARMELA, then making slight adjustments to get the minimum pulse width and diameter at the streak camera station at the entrance to the first accelerator station. The solenoids were set to achieve an axial magnetic field profile as close to the PARMELA prediction as possible but we were limited by space and power supplies in the region from the TPV to the end of the first acceleration section. Figure 2. shows the comparison of the axial magnetic field achievable with the existing solenoid configuration to match the PARMELA prediction versus the field achieved in the experiment given the power supply limitations.

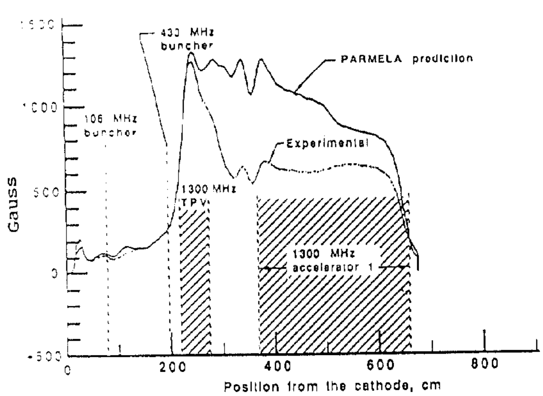

Figure 2. Axial magentic field

The pepper pot,screen combination shown in figure 3 was used to set the beam size at the entrance to the 108 MHz prebuncher. This was done by first turning off the 108 MHz buncher power, inserting the pepper pot and the screen in the beamline and adjusting AF1,2,3 to set the number of holes to 13, which corresponds to 1.6cm beam size as required by PARMELA. Interactive OPTIC is used to zero the axial magnetic field on the cathode using the bucking coil, AF1. The buncher powers were set to 7.5 KW and 4.8 KW respectively for the 108 and 433 MHz bunchers and 11MW for the TPV. At these powers the bunchers should produce the 40 and 35 KV fields respectively as required by PARMELA. Unfortunately the 433 MHz buncher multipactors at 4.8 KW and we had to adjust its power and the neighboring solenoids slightly to avoid multipactoring. The amplitude of the 108 MHz buncher and the phases of all the bunchers were tuned to deliver the minimum pulse width at the streak camera. The power level for the 108 and 433 MHz bunchers after tuning was completed was 8.3 and 6.0 KW respectively which corresponds to gap voltages of 42 and 39 KV. This is in excellent agreement with the model since 10 to 20% errors in power measurements are typical.

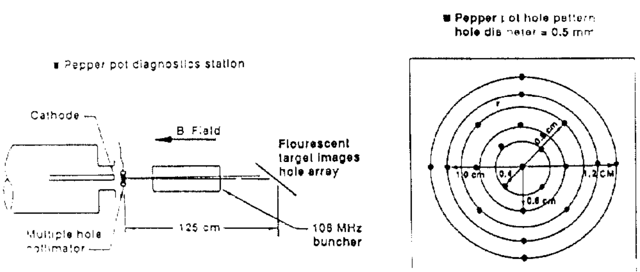

Figure 3. Pepper pot Screen cominati.on

The total charge was measured with a calibrated current monitor at the output of the gun to be 5.9 nc. The Faraday cup at the entrance to the first accelerator section measured 5.8nc, an agreement better than experimental error. Figure 4. shows 14 ps FWHM (410 Amp) at the streak camera screen at the entrance to the first accelerator. The code to experiment comparison is shown in table 1.

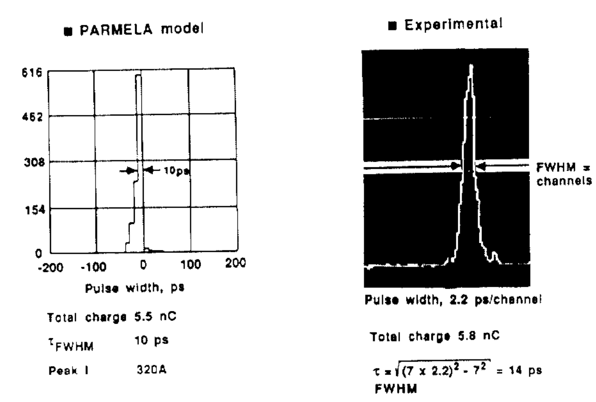

Figure 4. Micropulse structure after TPV buncher

ACCELERATOR EXPERIMENTAL RESULTS TO PARMELA COMPARISON

The purpose of the second experiment was to transport beam thru the entire machine down to the end of the straight ahead leg diagnostics station. At this station we can measure energy, energy spread, charge, position, spot size and the emittance. The experimental settings used in the accelerator elements were put into PARMELA to make a comparison between the model and the experimental results. The energy and energy spread predicted by PARMELA agreed very well with the measured values at 103.8 MeV plus or minus less than .5 MeV FW. Figure 5. shows that PARMELA is in very good agreement with the experiment for the charge transmission from the gun to the end of the sixth accelerator section. 3.5 nc out of the 5.5 nc of charge at the gun made it to the end of the sixth accelerator section and to the diagnostics station. The loss of charge is partly due to running more power in the 433MHz buncher and adjustment of the nearby solenoids to avoid multipactoring, deviating from what PARMELA simulations would require, and partly due to the lack of power to run the solenoids over the region from the exit of the TPV to end of The first accelerator as PARMELA would require. The latter problem was corrected since this experiment.

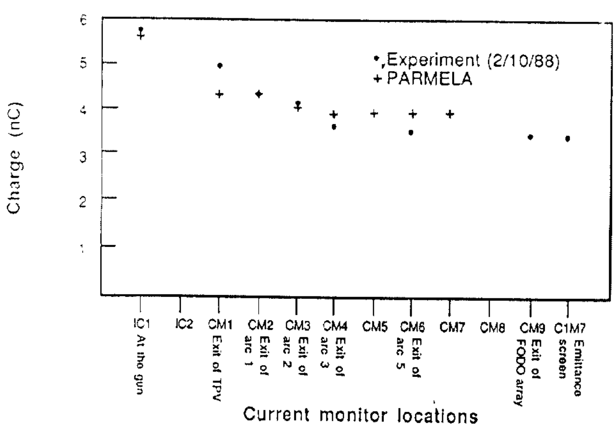

Figure 5. Micropulse charge transmission

Three emittance measurements were made in the X and Y planes. The measurements were made using the size vs - 1/f technique developed at SLAC (Ref 4). The beam phase space at the emittance triplet was varied for each set of measurements and unfortunately the phase space for the Y plane in the second measurement was not right and the data could only produce one leg of the hyperbola. Table 2 compares the predicted normalized emittance and brightness to the measured. PARMELA predicts a normalized emittance of 150 pi-mm-mrad for 90% of the charge, with peak current of about 350 Amps (3.5nc, about 10ps) at the end of accelerator 6. This translates to a brightness of 3.0E9 Amp/m2/rad2. The measured normalized emittance for the same amount of charge is 42 to 73 pi-mm-mrad about 1/3 to 1/2 the value predicted by the PARMELA simulation of the experiment. While we do not have a micropulse width measurement at the end of section 6 it is reasonable to assume that the pulse width is the same or less than that measured at the entrance to the first accelerator section and is somewhere between 10 and 14 ps. For a peak current of 350 Amps the measured brightness is between 4.0E10 and 1.3E10.

Table 2. Emittance and Brightness comparison

	I_p (Amp)	Plano	ϵ_N (π mm-mrad) 93%	$B = \frac{2 I_p}{\pi^2 \epsilon_N{}^2}\left(\frac{A}{m^2 \cdot rad^2}\right)$ 93%	
PARMELA Calculations	350	Hor.	150	3×10^9	3.5 nc
		Vert.	150	3×10^9	
12:25 P.M.	350	Hor.	64	1.7×10^{10}	3.5 nc
		Vert.	64	1.7×10^{10}	
4:55 P.M.	350		73	1.3×10^{10}	
			-	-	
8:00 P.M.	350	Hor.	57	2.2×10^{10}	
		Vert.	42	4×10^{10}	

2/10/88 Data Runs

CONCLUSION

The injector for the Boeing 120 MeV linac functions very close to its design parameters. PARMELA has been a useful tool for determining the injector tune parameters.

The PARMELA to experiment comparison on the accelerator shows very close agreement with the exception of the emittance which measures a factor of 2 to 3 better than the simulation prediction.

ACKNOWLEDGEMENTS

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