SSC Radio-Frequency-Quadrupole Beam: Comparison of Experimental and Simulated Results*

F.W. Guy, J.W. Hurd, D.Raparia, K. Saadatmand, W.A. Whittenberg
Superconducting Super Collider Laboratory
2550 Beckleymeade Avenue, Dallas, Texas 75237

Abstract

Simulations of the SSC RFQ output beam, run on the RFQ multiparticle code PARMTEQ, are compared with measurements from the SSC linac injector system. Some simulated RFQ input beams are generated from experimental observations of the output beams of the SSC einzel-lens Low Energy Beam Transport (LEBT) that focuses the beam from the ion source into the RFQ; this is the first LEBT to be tested with the RFQ.

I. INTRODUCTION

Now that operation of the SSC RFQ has begun [1], experimental beam output data from this machine can be compared to beam-dynamics simulation results from the PARMTEQ multiparticle code. These comparisons are important in the preliminary setup of the RFQ and its diagnostics and are used extensively to establish whether the RFQ is operating as expected. They can establish credibility for simulations of current RFQ operating conditions, and by extension, to simulations of other operating conditions or input beams; for instance in error studies [2]. Finally, they can be used to verify, and if necessary to adjust, simulated RFQ beam outputs to accurately represent the RFQ output beam for simulations of downstream components of the SSC Linac.

II. CALCULATIONS

The RFQ simulation code used in these calculations is derived from the Los Alamos National Laboratory VAX version of the PARMTEQ particle-following code [3]. The LANL code was modified at the SSC to allow input from a file of particle coordinates, to use an eight-term expansion of vane field potential [4] rather than the original two-term potential, to produce specialized outputs and to run on UNIX. A special version of the resulting SSCL code was further modified to investigate the effect of 3-D space-charge and image-charge effects, because these have been shown to result in decreased simulated beam transmission in some RFQs [5]. This version of the code was adapted to the SSCL Hypercube multi-processor computer because of its long running time.

The nominal input beam used in the RFQ design [4] was a matched 4-D waterbag of 30 mA with $\varepsilon_{rms,n}$=0.2 π mm-mrad. Test runs with the SSCL version of PARMTEQ gave virtually the same results with this beam as were obtained at LANL, 95% transmission and unchanged normalized emittance. The 3-D space-charge, image-charge version produced slightly higher transmission but within statistical error and we consider the results to be essentially identical.

Many parameter study simulations (such as error studies) have been run at LANL and SSC with the nominal design beam in the course of design and analysis. We now have recent experimental LEBT output beam data that can be used in simulations [6]. Files of particle coordinates are generated by random sampling from experimental slit-and-collector data files. These coordinate files are used for input to simulation codes and for plotting in the same format as simulation code output for easier comparison.

Simulated RFQ output particles were transported through the RFQ fringe field and drifted to the slit position of the slit-and-collector (22 cm) or the wire position of the bunch shape monitor (15 cm) by the particle-following code PARMILA [7]. There is a vertical (y) waist in the beam about 8 cm from the RFQ output with an x-y aspect ratio of more than 3 to 1, therefore a 3-D space-charge subroutine was used.

III. RESULTS

A. Input Beam

An einzel-lens LEBT is presently being used to focus and steer the volume ion source output beam into the RFQ. Slit-and-collector emittance data was taken at the output of the LEBT with the einzel lens focusing and steering voltages adjusted to give the best apparent match of the central beam Twiss parameters to the RFQ input acceptance. This is the input beam that was used in the simulations reported in this paper. The resulting experimental distributions are shown in Fig. 1 with the nominal input beam ellipse.

After the LEBT was mated to the RFQ and the RFQ was turned on, LEBT focusing and steering voltages were adjusted by hand to the settings that gave the highest beam transmission through the RFQ. Beam transmission was found to be quite sensitive to LEBT voltages (set using analog meters), therefore the RFQ input distribution used for the calculations in this paper may be somewhat different from that measured at the LEBT output. Input current for the simulations was 30 mA; measurements were made at approximately the same or perhaps slightly higher current.

Simulations were also done with an input beam derived from earlier measurements on a previous, slightly different, version of the source-LEBT combination. Simulated RFQ transmission of that beam was significantly better, up to 65%. We believe the difference in the input beams is due primarily to dissimilar settings of the focusing and steering electrodes rather than to the mechanical differences of the devices. As time permits, we intend to remove the present source-LEBT from the RFQ and more completely characterize the LEBT output beam with variations in focusing and steering. These measurements will provide data for further simulations.

* Operated by the University Research Association, Inc. for the U.S. Department of Energy, under contract No. DE-AC35-89ER40486.

0-7803-1203-1/93$03.00 © 1993 IEEE

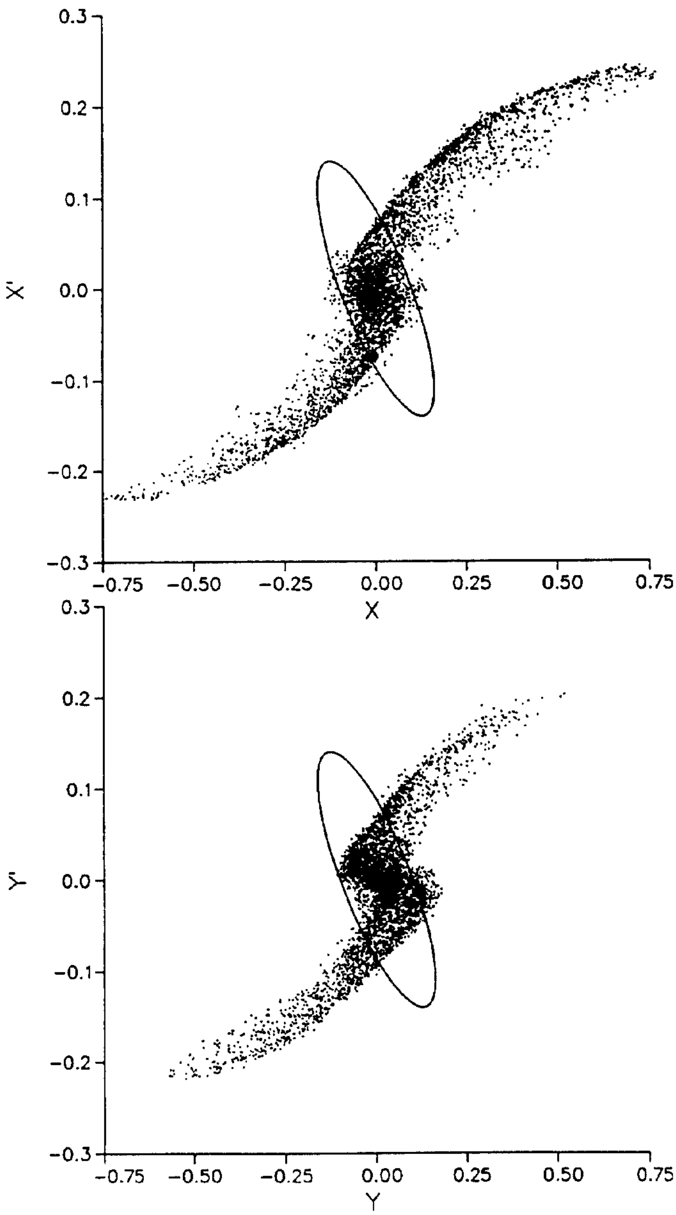

Figure 1. Experimental particle distributions (in cm and mrad) from the einzel lens LEBT. The design specification beam emittance ellipse is shown.

b. Output Beam: Transverse

In Figs. 2 and 3, y-y' particle plots of simulated and measured output beams at the slit position are shown. The y- projection was chosen because it is more compact than the x-projection. Emittance ellipses of equivalent uniform beams ($5 * \varepsilon_{rms}$) are shown for measured and simulated beams. Table I gives beam parameters. As can be seen, Twiss parameters are similar but transmitted current and emittances are larger for the measured beam. This may be a result of differences in the RFQ input beam between the LEBT measurements at the LEBT output and that used for the RFQ measurements.

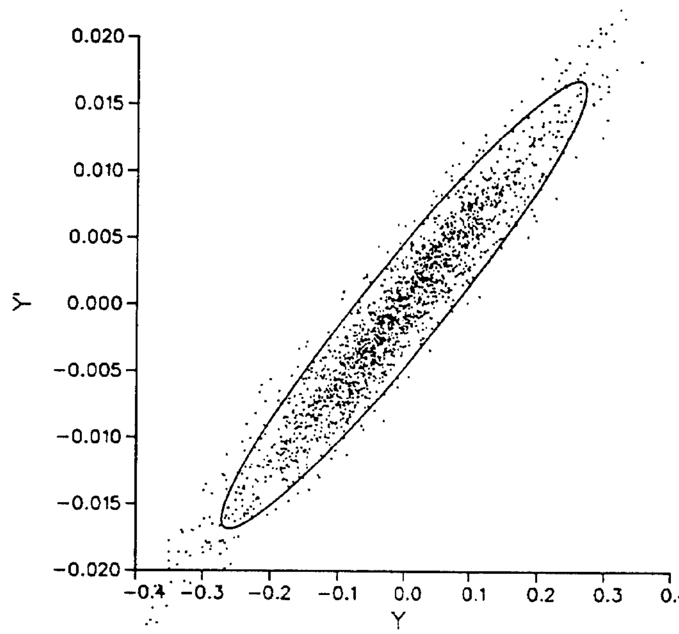

Figure 2. Transverse (y-y') particle plot in cm and mrad of simulated output beams at the slit position.

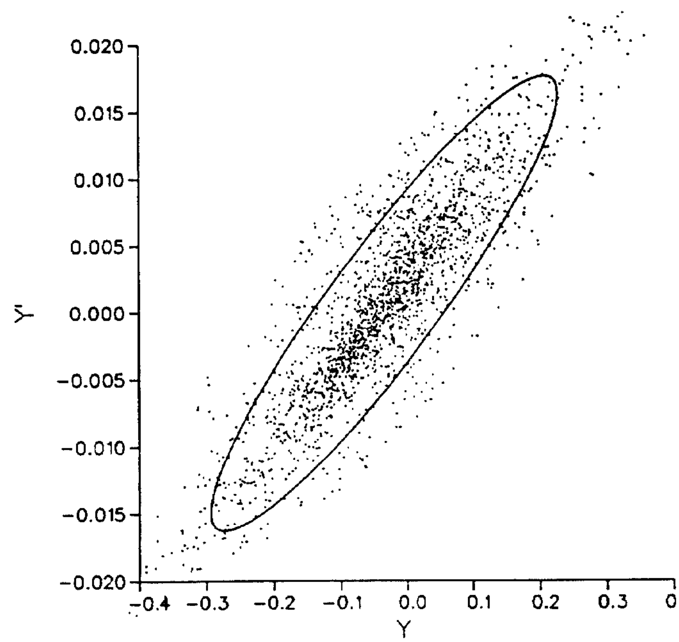

Figure 3. Transverse (y-y') particle plot (in cm and mrad) of measured output beam at the slit position.

TABLE I.

SIMULATED AND MEASURED BEAM PARAMETERS

	Alpha	Beta, mm/π−mrad	Emittance, π−mm-mrad (rms-norm.)	Current, mA
Simulated x	-8.65	2.53	0.172	11.7
y	-3.43	0.58	0.187	
Measured x	-10.5	3.00	0.247	16
y	-2.39	0.40	0.249	16

B. Output Beam: Longitudinal

The longitudinal profile of the simulated beam bunch for a full-current beam is compared with data from the bunch shape monitor in Ref. [8] and shows qualitatively good agreement, with a smooth shape. Bunch shape monitor measurements were also taken with the LEBT defocused to reduce beam current to a small value below the range of the RFQ output toroid. At this low current, the bunch length monitor was easily able to resolve a good signal, as shown in Fig. 4. It contained much more structure than the high-current beam signal.

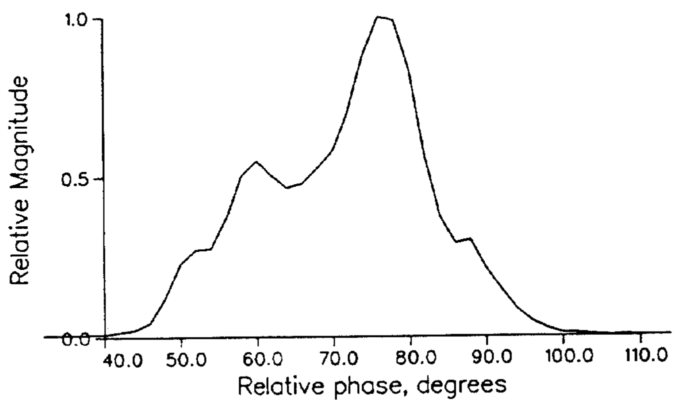

Figure 4. Measured longitudinal phase signal from the bunch shape monitor.

A simulation was done with the experimental RFQ input particle distribution with input current reduced to 1 mA. About half of this current was transmitted through the RFQ. After the drift the longitudinal distribution is shown in Fig. 5.

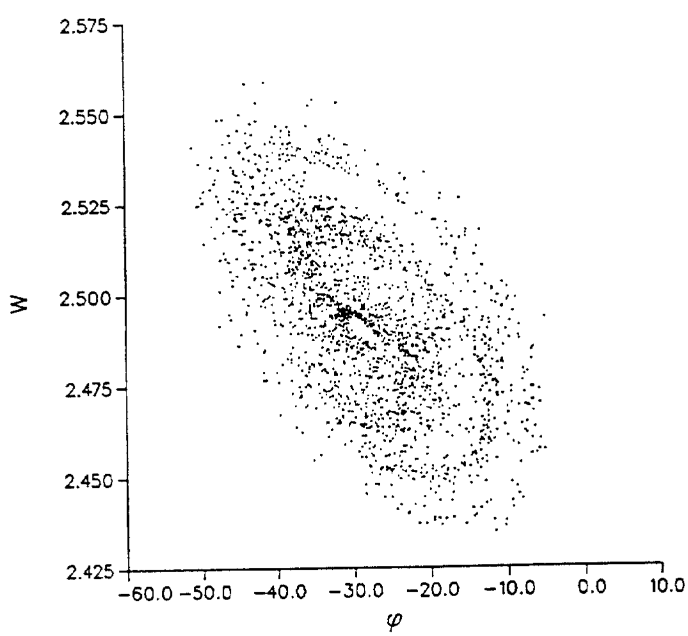

Figure 5. Longitudinal particle plot in phase and energy of simulated RFQ output beam at bunch shape monitor.

It is clearly evident that for the very-low-current case, structure is produced in the RFQ output longitudinal phase distribution by "wrap-around" of the initial monoenergetic beam in the RFQ bucket. This structure is destroyed by space-charge effects if beam current is more than a few milliamperes. The details of the phase distribution of the RFQ output beam are influenced by the input beam distribution and current, and by the RFQ vane voltage, of which only the vane voltage was known with any certainty. A comparison of the detailed structure of the measured vs. simulated low-current beams is likely to be unproductive until actual conditions can be better determined. Nevertheless it is interesting that the bunch shape monitor can be used for such a comparison.

IV. CONCLUSIONS

These preliminary comparisons between measured and simulated output data for the SSC RFQ show remarkably good agreement for an accelerator in the early stages of commissioning. However, much work needs to be done with detailed measurements and corresponding computer runs to investigate the parameter range of this source-LEBT-RFQ combination and to prepare for commissioning of downstream linac components.

The SSC plans to test the Helical ElectroStatic Quadrupole (HESQ) [9] in the near future, and this will provide an opportunity to use measured HESQ LEBT outputs in RFQ simulations.

V. ACKNOWLEDGEMENT

The authors thank K. Crandall of AccSys Corporation for his guidance and advice, and J. Hebert and J. Lenz of the SSCL Linac Group for their help and cooperation.

VI. REFERENCES

[1] K. Saadatmand et. al., "Performance of the SSC LINAC Injector," these Proceedings.

[2] D. Raparia et. al., "Error and Tolerance Studies for the SSC Linac," these proceedings.

[3] K.R. Crandall, "PARMTEQ—A Beam-Dynamics Code for the RFQ Linear Accelerator," *AIP Conference Proceedings 177, Linear Accelerator and Beam Optics Codes*, La Jolla Institute, pp. 22-28 (1988).

[4] T.S. Bhatia et.al., "Beam Dynamics Design of an RFQ for the SSC Laboratory," *Proc. 1991 IEEE Particle Accelerator Conference*, Vol. 3, pp. 1884-1886.

[5] F.W. Guy, "Three-Dimensional Space Charge and Image Charge Effects in Radio-Frequency-Quadrupole Accelerators," *Proc. 1991 IEEE Particle Accelerator Conference*, Vol. 5, pp. 3032-3034.

[6] J. Lenz et. al., "Comparison of Experimental and Simulated Results for the SSC LEBT," these proceedings.

[7] G.P. Boicourt, "PARMILA — An Overview," *AIP Conference Proceedings 177, Linear Accelerator and Beam Optics Codes*, La Jolla Institute, pp1-21 (1988); Los Alamos National Laboratory Report LA-UR-88-1544.

[8] J.W. Hurd et.al., "Bunch Shape Monitor for SSCL Linac," these Proceedings.

[9] D. Raparia, "Beam Dynamics of the Low Energy Beam Transport and Radio Frequency Quadrupole," Ph.D. Thesis, University of Houston, Houston, TX (1990).