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TRANSVERSE EMITTANCE OF A 2.0-MeV RFQ BEAM WITH HIGH BRIGHTNESS*

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Summary

One major purpose of the accelerator test stand (ATS) is to see if particle simulation codes can correctly predict the output beam parameters of our radio-frequency quadrupole (RFQ) linac. By injecting a very bright 100-keV beam (100 mA, 0.02 π•cm•mrad) and comparing the measured output beam parameters with those predicted (using PARMTEQ), we can investigate PARMTEQ's performance in a high space-charge regime. PARMTEQ has successfully simulated the RFQ beam transmission and energy distribution; it is more difficult to simulate output transverse emittance. Transverse emittance is also difficult to measure because of the high-power-density beam. Special modification of our interceptive slit and collector equipment was required. This paper will compare measured transverse emittances with those predicted.

Introduction

A description of the ATS with its upgraded RFQ, improved source, and column has been presented earlier.[1] A diagram of ATS is given in Fig. 1. Using our present RFQ, we have measured its beam transmission and energy distribution as we varied the vane-tip voltage. The measurements[2] compared well with predictions based on the RFQ beam-dynamics code PARMTEQ. These measurements were done with input beams that were poorly matched to the RFQ. The narrow, highly convergent input beam, which is required by the RFQ, was impossible to obtain given the constraints of (1) a short low-energy beam-transport line (LEBT), which is required to minimize the emittance growth, and (2), a limited number of permanent-magnet quadrupoles (PMQs). To better match the beam to the RFQ, we constructed additional PMQs and included them in a redesign of the LEBT. A TRACE representation of our present LEBT is shown in Fig. 2; theoretically, with this LEBT we should obtain perfect matches. This design will be used for future studies of the RFQ performance as it accelerates low-emittance, well-matched beams.

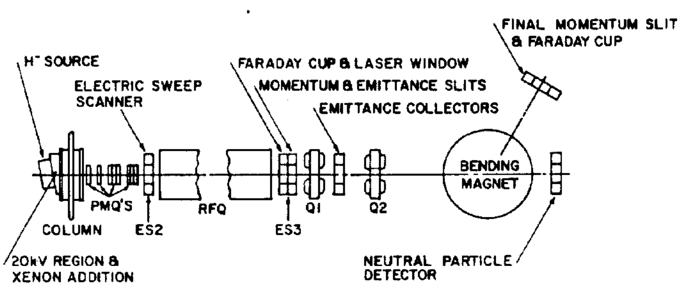

Fig. 1. Schematic of experimental arrangement.

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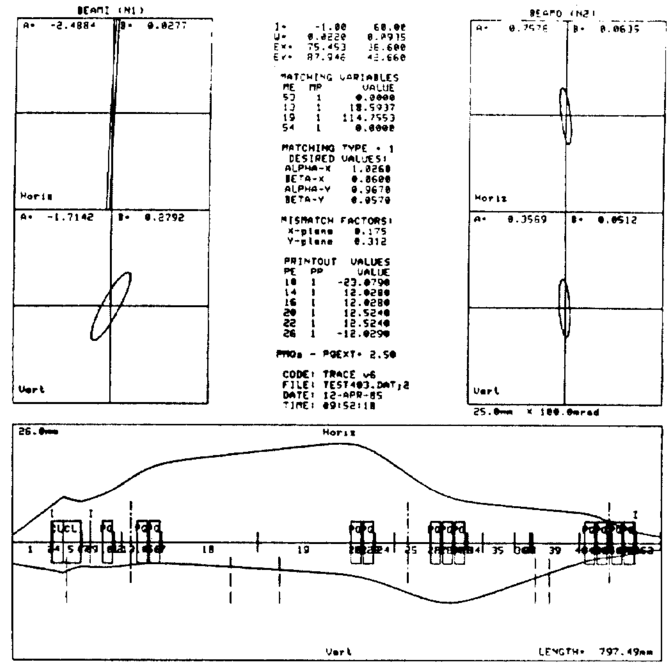

Fig. 2. TRACE beam-transport calculation showing mismatch of beam input to RFQ.

Using earlier configurations of our LEBT line, we have examined other performance characteristics such as the dependence of the output transverse and longitudinal emittance on vane-tip voltages and input beam emittance and match.

These measurements were difficult because the high-power-density RFQ beam destroys traditional diagnostic equipment. In addition, the longitudinal measurement of the micropulse required special techniques to observe this very short (full width is less than 400 ps) pulse. In this paper we present our studies on the transverse emittance of this RFQ. The longitudinal characteristics are the subject of another paper at this conference.[3]

Method

The goal of this experiment was to measure the RFQ input beam characteristics, its operating condition, and its output beam characteristics. The input beam current was measured with a Faraday cup placed just upstream of the RFQ entrance. The input-beam transverse emittance was measured with electric sweep scanners (labeled ES2 in Fig. 1). We iterated on the LEBT design by running the measured ellipse parameters backward through the TRACE model of the LEBT to its entrance. Again, using TRACE, we rematched this beam to the RFQ and obtained new PMQ positions that further improved the match. The ES2 measurements also served as input to a Monte Carlo code that generated a macroparticle distribution that was consistent with the measurements and that served as input to PARMTEQ.[2]

The RFQ power was monitored with one pick-up loop in the low-energy end of the RFQ and two pickups in the high-energy end. The output signals were rectified with calibrated crystals that supplied voltage signals proportional to the power in the RFQ. The proportionality constant K for each pickup was determined from comparing measured and predicted curves of transmission versus rf power.

The output current was measured with wideband pulse-current transformers. The output emittance was measured at ES3 in Fig. 1 using slit and "sandwich-type" collectors. The output beam power was 200-kW peak and was deposited in a 1.0- to 2.0-mm-radius spot on our emittance slit material. Because this power was dissipated within the first few mils of material, it quickly melted and eroded the metallic slits. We replaced our metallic slits with a modified LAMPF slit design, which used graphite inserts to define the slit. We tried pyrolytic graphite and a copper-loaded graphite whose heat conductivity was increased by the copper. Both types of graphite withstood the 2.0-MeV beam, but the copper in the copper-loaded graphite vaporized and caused breakdown in the RFQ structure. We decided to use pyrolytic graphite in spite of its lower structural strength. We also reduced the rf duty cycle to lessen the damage to the slits. This pyrolytic slit material has withstood numerous emittance runs without failure. We observed no effects on our measured H^- emittance when we biased our slits, whereas biasing the slits changed the emittance shape of the 750-keV LAMPF proton beam. We conclude that the thermal and secondary electrons, which are produced when the beam strikes the slit material, do not affect our H^- beam dynamics because they are removed from the beam by Coulomb repulsion. However, these electrons can affect the neutralization of a low-energy proton beam, its beam dynamics, and (hence) its apparent emittance. The energy of the output beam was monitored with our momentum spectrometer and was used to verify full acceleration by the RFQ.

Results

The following results were gained using four LEBT designs that were attempts to match the 96.5-keV input beam to the RFQ while maintaining a small input emittance. The four LEBTs were characterized by mismatch factors ranging between 1.17 and 2.52 in the x-plane and between 1.07 and 1.41 in the y-plane when compared to the input RFQ matched beam. Each LEBT design resulted in input beams that were quite different, having relative mismatch factors between 2.4 and 2.6 in the x-plane and 0.24 and 0.39 in the y-plane. The normalized emittance area for these input beams ranged between 0.015 and 0.036 π•cm•mrad. The different LEBT designs delivered 80 to 104 mA of current to the RFQ.

Figure 3 shows the measured and predicted transmission versus vane-tip voltage for two LEBT designs. We have plotted the percentage of maximum transmission in each case and the vane voltage V in percentage of design voltage V_0. The figure shows that the percentage transmission had the same dependence in both cases and agreed well with the PARMTEQ predictions. This good agreement also resulted in good agreement between the proportionality constants K as evaluated from the two cases. We do not know the cause of the slight discrepancy of the measured data with the PARMTEQ prediction in the region of the "knee" at the transmission plateau. The RFQ output current for these measurements was between 39 and 68 mA. The higher currents were obtained with smaller emittance input beams to the RFQ.

In Figs. 4 and 5 we show the locus of x- and y-ellipse parameters α and β as the vane-tip voltage

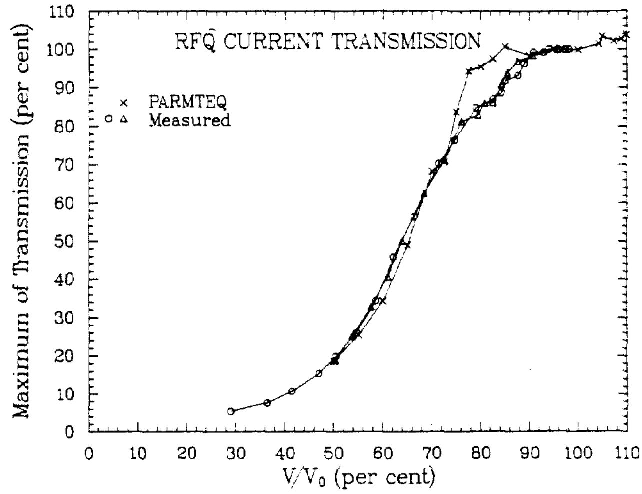

Fig. 3. Measured RFQ transmissions for several values of input mismatch (absolute transmissions are renormalized to 100%).

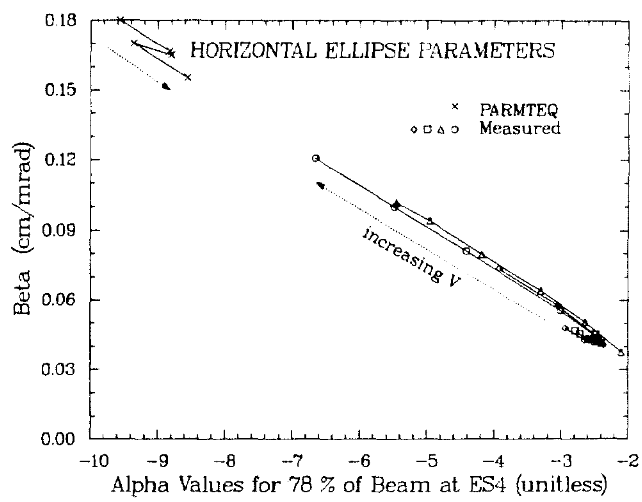

Fig. 4. Locus of ellipse parameters αx and βx as RFQ vane voltage is varied. Both measured and calculated values are shown.

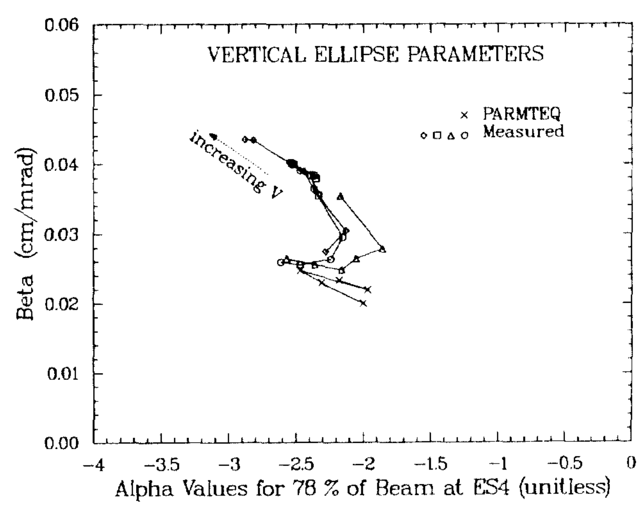

Fig. 5. Locus of ellipse parameters αx and βx as RFQ vane voltage is varied. Both measured and calculated values are shown.

was varied. Also plotted are the predicted ellipse values based on a PARMTEQ simulation. The locus of points for each of the four LEBT designs falls along the same line and shows a definite vane-voltage dependence. In fact, for each vane voltage, the RFQ output ellipse parameters are equal within measuring errors for each of the various LEBT designs and normally have relative mismatch factors less than 0.1. These values are small, compared to the mismatch factors between output beams with high and low vane voltages; the values of these factors are typically 0.7. The PARMTEQ simulation did not show the same vane-voltage dependence that was characteristic of the measured data. The mismatch factors between measured and predicted ellipse parameters at equal vane voltages varied between 0.13 and 1.05 in the x-plane and between 0.1 and 0.7 in the y-plane.

In Figs. 6 and 7 we show plots of unnormalized x- and y-emittance areas: both measured and predicted values are plotted versus vane voltage. We plot the

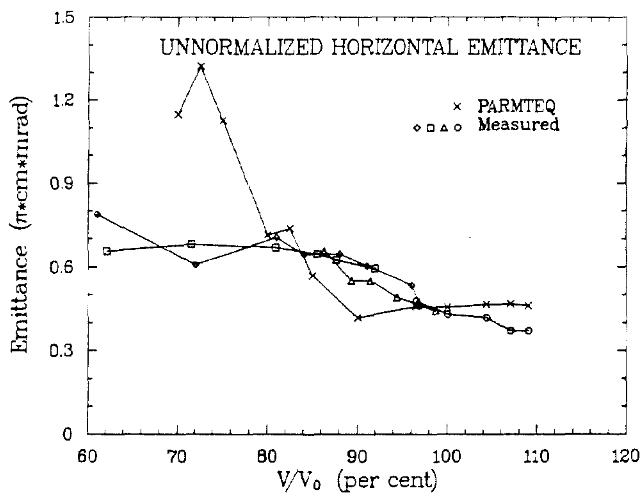

Fig. 6. Measured and predicted laboratory emittance areas as functions of RFQ vane voltage (horizontal plane).

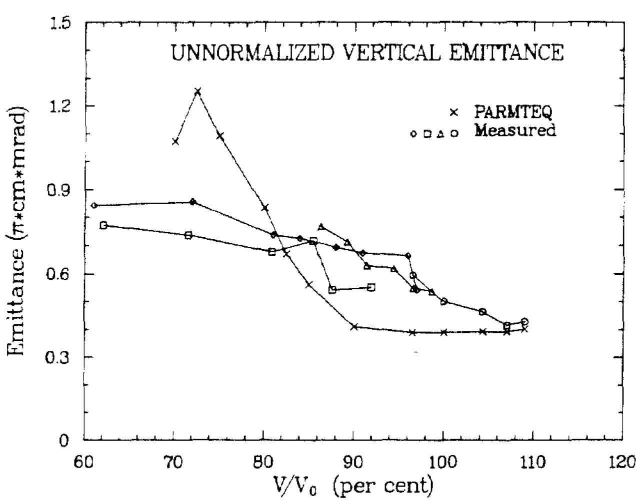

Fig. 7. Measured and predicted laboratory emittance areas as functions of RFQ vane voltage (vertical plane).

emittance area E that includes 39.4% of the beam. This value of E would be the rms emittance if the beam were Gaussian shaped. Although the data show considerable scatter, it is evident that for each LEBT line and input emittance, the value of E had a very similar, if not equal, dependence on the vane voltage. We attribute the raggedness of these plots to the uncertainty in determining the vane voltage and to the sensitivity of E to the background that is included as part of the total beam. We have examined some worse cases, which had an estimated 15% background. This background caused the value of E to increase by 25%. We are exploring ways to remove this background in the electronics and in the data-analysis software. Generally, the agreement between PARMTEQ predicted and the measured E versus vane voltage is not good. The steep rise in E at low vane voltages, as seen in PARMTEQ simulations, is not seen in the data.

Conclusions

We have observed that the amount of transmitted beam is a function of the input beam match but that the percentage transmission depends only on the vane voltage and not on the input beam match. We also find that the RFQ output emittance, for very different input beams, was only a function of vane voltage. The output emittance did not depend on beam current or input beam match. Our beams appear to have filled the acceptance of the RFQ, and what we observed at the exit of the RFQ was an aperture-dominated beam, which was transported by the transverse optics of the RFQ. This transverse focusing depended only on the RFQ vane voltage. This assumption implies that the output beam emittance will depend on the input match when the input beam emittance is sufficiently small and correctly shaped to avoid being scraped by the apertures in the RFQ.

Although the predictions of PARMTEQ are in good agreement with measured transmission and output-beam energy dependence on vane voltage, the predictions do not show the observed dependence of the transverse emittance on vane voltage. We are now exploring possible sources of these discrepancies.

Acknowledgments

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