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ANALYSIS OF THE DEUTERON DISTRIBUTION EMERGING FROM THE FMIT RFQ*

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Summary

Knowledge of the properties of the input beam is necessary for evaluating losses in a drift-tube linac (DTL). The FMIT (Fusion Materials Irradiation Test Facility) accelerator will use a Radio-Frequency Quadrupole (RFQ) structure as the first accelerator stage that feeds a drift-tube section. As the first step in evaluating beam spill in the drift-tube section and output transport, we studied the properties of the beam exiting the RFQ. An RFQ, because of its electric-field focusing, allows particles of any energy to pass through its structure. Thus, its output is essentially different from the output of an accelerator that uses strong focusing magnets. The study presents surfaces giving the number of particles as a function of position in various planes of phase space. Two PARMILA codes were used: a standard longitudinal position dependent code, and a time dependent code. The codes give slightly different answers.

Introduction

The FMIT accelerator[1] has stringent limits on the allowed beam spill in the drift-tube section and the High-Energy Beam Transport (HEBT). The beam spill in the critical sections mainly will be determined by the properties of the beam emerging from the RFQ[2] that feeds the drift-tube linac.

Of primary interest is the identification of those beam regions that give rise to particles that will be lost in the drift-tube section. We expect that such particles will be characterized by having either a single extreme in one of the six phase-space dimensions or a relative extreme in one of the two-dimensional phase planes. Thus, low energy by itself is enough to cause a particle to be lost, but the wrong combination of phase and energy also will result in loss. This should explain our interest in six-dimensional beam properties.

Method

The design of the FMIT RFQ is described in another paper presented at this meeting.[2]

Computer simulations of beams from the FMIT RFQ were made, using two particle-dynamics codes: PARMTEQ B and PARMTEQ C. PARMTEQ B is a code in which the independent variable is the axial position (Z) in the accelerator and will be referred to as the Z-code. PARMTEQ C uses time as the variable of integration and will be referred to as the T-code. The use of two codes gives us two slightly different models of reality, because slightly different formulations are forced by the use of different independent variables.

The electrical focusing in RFQs allows particles of all energies to traverse the accelerator. The number of low-energy particles lost from, or not captured in the bucket, may be small; therefore, considerable effort was made to use enough particles to get reasonable statistics. The results presented below are based on individual runs, with the initial number of particles set at more than 42 000.

The beams emerging from the RFQ were analyzed in several ways. Histograms were made of the distributions of the particles in each of the six dimensions of phase space. Three-dimensional surfaces, showing the particle distributions in various two-dimensional phase planes, were made by sorting the particles into rectangular bins in the desired planes. Standard rms methods were used to calculate emittances and the Courant-Snyder beam parameters.

Table I gives the properties of the beam's transverse input and output. The emittances are normalized and in units of cm-mrad, and are to be multiplied by π to obtain an emittance area. The α's are unitless and the β's have units of cm/rad. The output beam includes all particles leaving the RFQ, even those well out of the bucket in energy.

Results

Table I

Transverse Properties of RFQ Input and Output Beam

	α_x	β_y	ϵ_x	α_y	β_y	ϵ_y
Input to RFQ						
90%	3.68	31.7	0.07	3.62	31.5	0.07
100%	3.67	31.8	0.10	3.65	31.7	0.10
Output from RFQ						
Z-Code						
90%	5.05	126.0	0.18	-4.99	117.5	0.15
100%	2.42	61.4	101.18	-2.17	51.3	146.56
T-Code						
90%	3.91	110.7	0.21	-4.66	96.3	0.18
100%	0.81	24.7	93.86	-0.78	20.0	75.26

The transverse surfaces characterizing the beam emerging from the FMIT RFQ do not show noticeable differences between the T- and Z-codes. Surfaces of x-x' and y-y' are shown in Figs. 1 and 2; both appear to be roughly elliptical, with the particle density

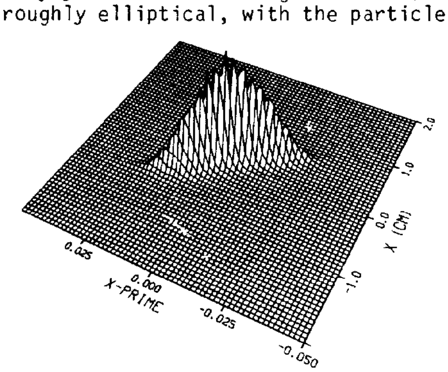

Fig. 1. The x-x' surface of the beam at the exit of the RFQ. (T-code)

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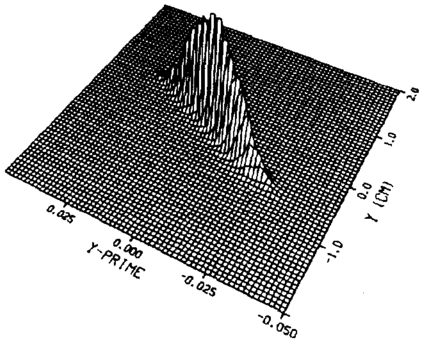

Fig. 2. The y-y' surface of the beam at the exit of the RFQ. (T-code)

falling off along the major axis, in what appears to be a roughly Gaussian manner. Along the minor axis, the fall-off seems more sudden. Histograms of the beam in the four transverse coordinates tend to confirm these observations about the x-x' and y -y' surfaces.

The beam distribution in physical transverse space is shown in Fig. 3. The RFQ ends at the point in the cell where the beam is nearly round. The "mountain" is quite symmetrical and the only unusual feature is the presence of a "lava steeple" in the center of the crater. The "steeple" appears in both T- and Z-code computations and seems to be characteristic, because it also appears in the output of other RFQ's.

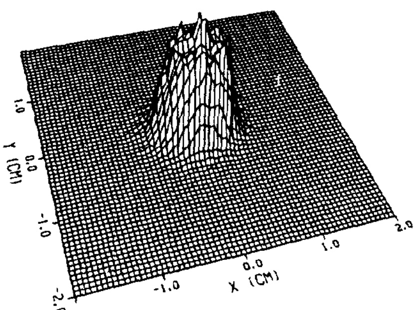

Fig. 3. The x-y surface of the beam at the exit of the RFQ. (T-code)

Longitudinally, the agreement between the two codes is not as satisfactory. Two views of the ϕ-W surface produced by the T-code are shown in Figs. 4 and 5. The design values for the output phase and energy are -30° and 2.0 MeV. Figures 6 and 7 show the ϕ-W surface produced by the Z-code.

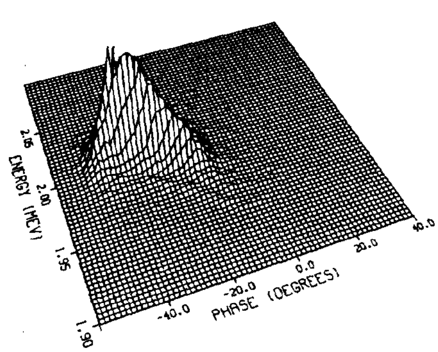

Fig. 4. The ϕ-W surface of the RFQ beam produced by the T-code.

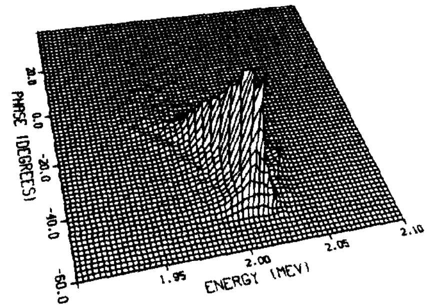

Fig. 5. Same surface as Fig. 4, but viewed from another angle.

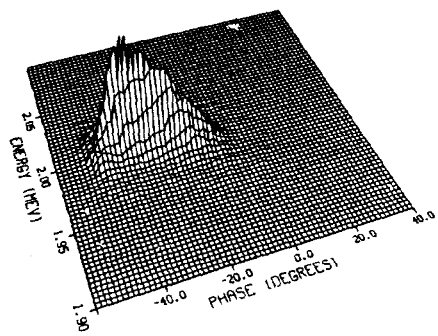

Fig. 6. ϕ-W surface of the RFQ beam produced by the Z-code. Compare with Fig. 4.

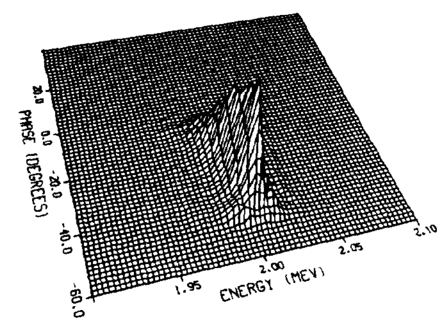

Fig. 7. Surface of Fig. 6 viewed from another angle. Compare with Fig. 5.

These surfaces do not show the entire extent of the beam. The full beam contains a 360° phase spread, and an energy spread from 0.03 MeV to 2.09 MeV. The surfaces shown contain about 97.8% of the output beam for the T-code and about 99.2% for the Z-code.

The Z-code ϕ-W surface seems to have an almost rectangular boundary. The ϕ-W surface produced by the T-code is more fishlike, having a tail projecting toward the low-energy and positive phase.

The low-energy portion in the T-code run is substantially greater than for the Z-code run. This is evident from a comparison of the logarithmic histograms shown in Figs. 8 and 9.

In these simulations, all particles exiting the RFQ were within the transverse acceptance of the DTL. Particles with energies below 1.9 MeV are

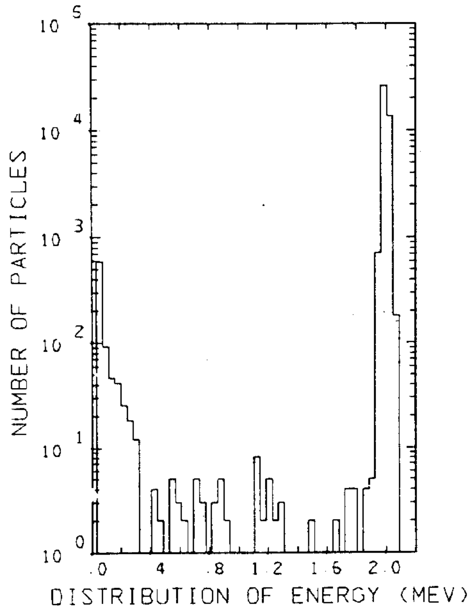

Fig. 8. Logarithmic histogram of the energy distribution exiting the RFQ. T-code calculation. The low-energy tail (< 1.85 MeV) contains 2.2% of total beam.

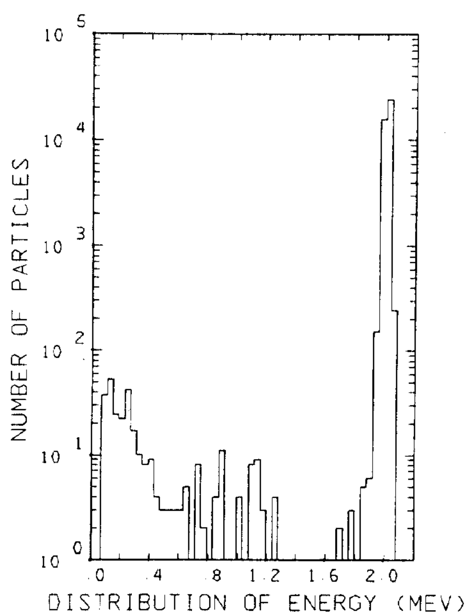

Fig. 9. Logarithmic histogram of the beam energy distribution exiting the RFQ. Z-code calculation. Low-energy tail (< 1.85 MeV) amounts to 0.8% of the total beam.

almost entirely responsible for the numerically observed losses in the FMIT DTL section, when RFQ calculated input is used. Therefore, the differences shown in Figs. 8 and 9 are of considerable importance in designing the DTL portion to accommodate the power deposited by the lost portion of the beam. The extreme low-energy portion of the beam (below 0.1 MeV) amounts to about 1.0% of the output beam for the T-code and to less than 0.1% for the Z-code. Except for the effect on the low-energy performance losses, the code differences have negligible impact on the DTL. In simulations, no particle lost in the DTL has had energy greater than 4 MeV.

Summary and Conclusions

The output beam of the FMIT RFQ appears to exhibit the expected behavior in the transverse coordinates of phase-space. In the longitudinal coordinates ϕ-W, the two dynamics codes give somewhat different results. At present, we cannot fully explain these differences. Two known causes are:

1. The space-charge impulses are applied at different longitudinal positions.
2. The reinjection of particles more than $\pm\pi$ in phase from ϕ_s back into the bunch are handled differently.

We know that the cores of the bunches are quite similar. We are actively investigating the code differences and believe that greater understanding will result from comparisons of the two codes.

References

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2. R. Stokes, T. Wangler, and K. Crandall, "The Radio Frequency Quadrupole: A New Linear Accelerator," Paper A-4, this Conference.