RESULTS FROM THE ISIS RFQ TEST STAND

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Abstract

Results are described of studies on the LEBT matching section of the RFQ test stand at the Rutherford Appleton Laboratory. Comparisons are made between measurements on the beam line and theoretical predictions, and an assessment is presented of the extent to which the LEBT is successful in matching a beam with unequal transverse emittances from the ion source into the RFQ. In addition, the degree of space charge compensation present is evaluated, and its evolution with time during the beam pulse is described.

1 DESIGN OF LEBT

The ISIS RFQ design uses the standard ISIS penning H- ion source, which extracts at 18 kV through a 90° analysing magnet [1]. The beam is then accelerated across a second electrostatic gap to 35 keV, before being focussed by the solenoids into the RFQ. The LEBT was designed to match the unequal emittance ion source beam into the RFQ and balance the emittance in the process which was anticipated would give the best transmission. This balance occurs when the total field in the solenoids produces a rotation in the beam of $(2n+1)\pi/4$. If this is achieved it also couples two of the parameters enabling a full 4 parameter match to be achieved with 3 independent controls. Each of the solenoids also contains a crossed pair of steering dipoles, although only two sets are powered [2]. These are included to enable correction from misalignment of the beam path, when the bend magnet field and extractor volts are set at optimal levels for beam current. Diagnostic equipment is mounted between the

Fig 1 Picture of LEBT

second and third solenoids, this consists of two emittance scanners [3] and a scintillator, although to improve the vacuum in the system this has been replaced with an additional vacuum pump. There are current toroids at the exit of the ion source box, the entrance and exit of the RFQ. There is a repeat set of diagnostics after the RFQ on the test stand, which contains a further toroid at its exit.

2 COMPARISON OF MEASUREMENT TO MODELS

These comparisons were made somewhat more difficult as, at the time of writing, it had still not been possible to measure the raw emittance of the ion source. This is not possible on this test stand as the drift length through the first two solenoids is too large and the unfocussed beam has been clipped on the beam pipe before the emittance scanners are reached. Theoretically reverse field pairs and full rotation set-ups should give the initial emittance values, half rotation should interchange values. The other beam parameters can then be calculated by backtracking through the solenoids to get the initial values. However, the measured emittance does not remain constant when different field levels are used in reverse pairs as shown in Table 1.

Table 1 Attempt to evaluate initial emittance.

I sol 1	338.3	260	510	597.8
I sol 2	-338.3	-260	-510	-152.1
rotation	0	0	0	$\pi/4$
ε_x rms normalised	0.96	0.54	0.26	.45
α_x	1.85	2.3	-7.01	-3.98
β_x	0.44	3.01	0.95	0.82
ε_y rms normalised	0.40	0.35	0.36	0.72
α_y	3.93	1.62	-3.17	-2.54
β_y	1.09	2.84	0.42	0.60

There are three probable causes of error that lead to these problems. There is always a significant but relatively low level background signal, concurrent with the beam pulse, which is present and noisy throughout the scan. The most highly focused beams show aberrations, see fig 2. The beam from the ion source is larger than anticipated and in many of the evaluated set ups the edge of the beam is scraped on the beam pipe.

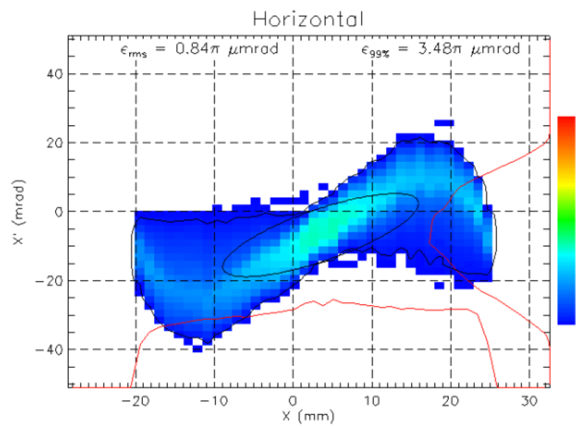


Fig 2 Beam showing aberrations

To establish a value for the initial beam parameters measured values were tracked back to the exit of the accelerating gap, the point at which measurements will be available from the ion source test stand. The success of this backtracking was evaluated by using the values in trace to calculate a new match, and then attempting to produce it on the test stand. Fig 3 shows, matched beam found empirically, the larger beam. It also shows an alternative smaller beam that matches. On the test stand a match transmitting more current was found very close to these settings.

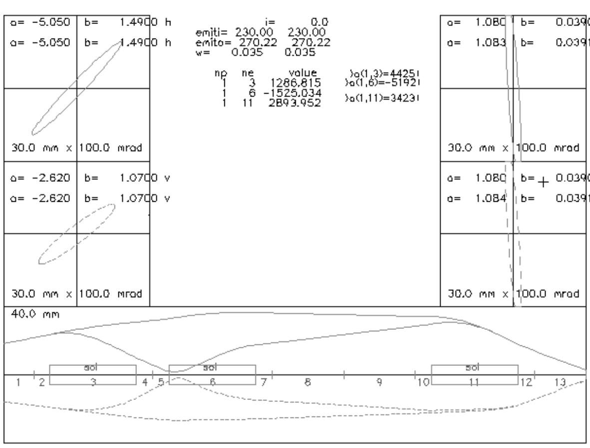


Fig3 Trace showing 2 matches for best estimate beam.

This was achieved by estimating the ellipse parameters from the plots rather than using the computer calculated values, which are affected by the low level signals throughout the phase space measured. Tracking back several of these settings, to give the most consistent value of initial parameters, enabled the effective length of the solenoids to be established, at 160 mm. This is somewhat shorter than expected from the theoretical calculations [2]. The estimated initial beam is then: -

ε_x rms 35 keV normalised = 0.55 π mm mrad,

α_x = -5.05, β_x = 1.49,

ε_y rms 35 keV normalised = 0.55 π mm mrad,

α_y = 2.62, β_y = 1.07

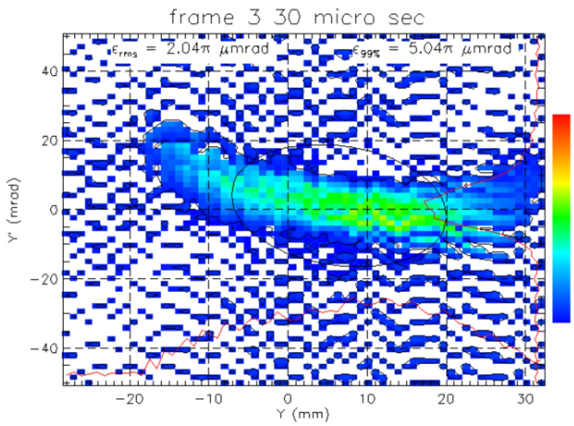
These values also have equal emittance, which is not correct, but putting in unequal values closer to those measured at the scanners does not produce consistent values for the initial beam. This work will needs to be repeated once a direct measurement of the ion source output beam parameters is available [4].

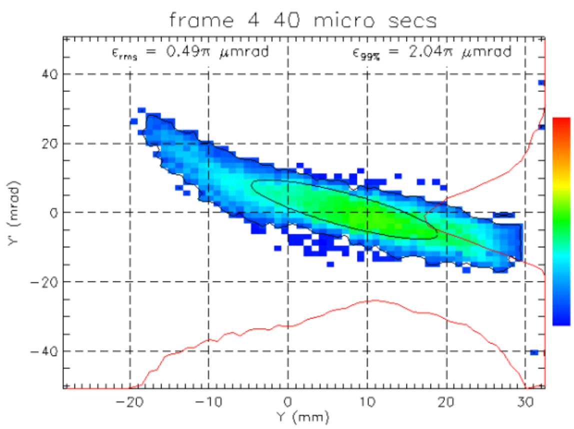
3 ASSESSMENT OF MATCH

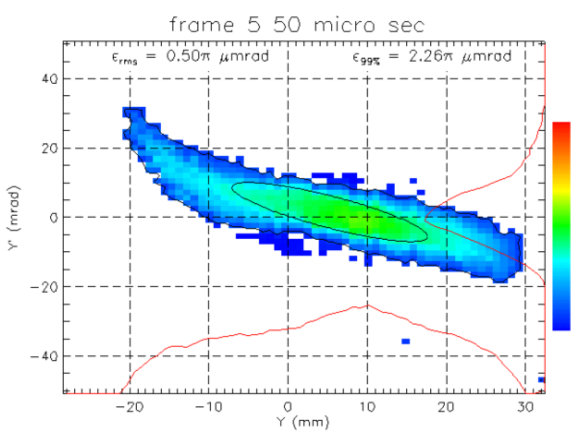
It is possible to produce a well matched beam into the RFQ, such that the transmission through the it is ~97%, 33 mA out for 34 mA in. However, this does not have the best transmission through the LEBT, only 66% at current pressures. An alternative match can be found which gives a greater output current from the RFQ, 36 mA. However, this is from an input beam of 40 mA i.e. 90% RFQ transmission, with ~80% LEBT transmission. Further settings of the LEBT that give 90% RFQ transmission have been found. The current measured in the first toroid is typically 50 mA, but the maximum through the second is 40 mA. The explanation for this loss has not yet been determined. The two most probable causes are the ion source beam is larger than was anticipated, or that stripping takes place in the background gas. The beam being sufficiently large to scrape on the beam pipe before the first solenoid could explain the inconsistencies in the backtracked values for the beam. Also stripping is clearly present as the loss was significantly reduced by substituting the scintillator for an additional vacuum pump. This reduced the pressure in the beam line from 3.5*10-5 mbar to 1.5*10-5 mbar. Design work is in progress to install a more efficient pump and recover the scintillator port. Depending on the exact values of the input beam parameters there are usually several matches calculated using trace, which vary in the total rotation put into the beam and whether a small waist is produced in the LEBT. So far only $\pi/4$ rotation settings have been studied as the system has been set up with the current to the second solenoid reversed. We have the option of changing this and looking at $3\pi/4$ rotations, which may have smaller beams on average, but more of the possible matches require fields that the solenoids cannot reach.

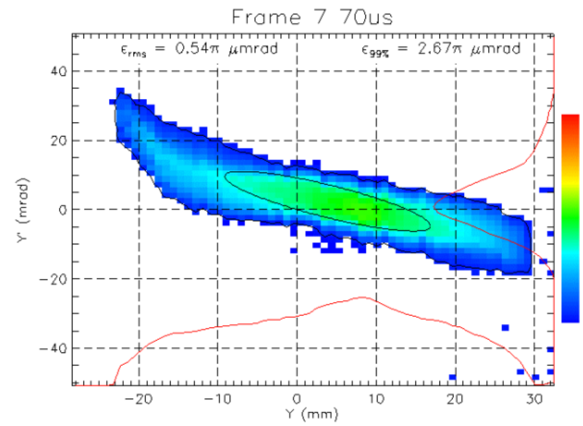
4 SPACE CHARGE

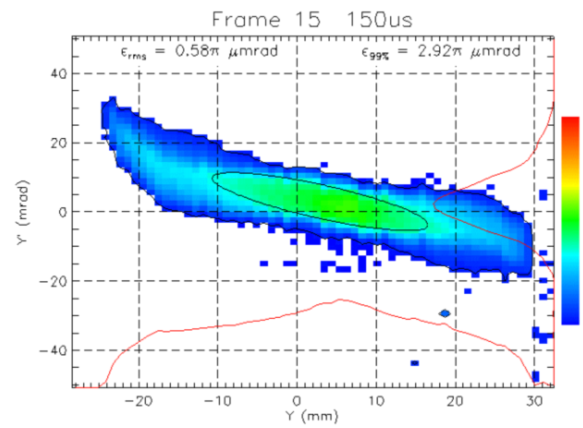
The bulk of the beam is space charge neutralised within the solenoid line. The only models which match are those that use total neutralisation. There is little evidence of variation along the length of the pulse, which suggests space charge neutralisation reaches a stable level as quickly as beam reaches full intensity in the first 30-50 µS of the pulse. The following series of plots show the development of the beam. There is no signal at the scanners until 30 µS after the trigger. Following this, the beam intensity grows rapidly and there is some change in the orientation of the beam over the next 30 µS, frame 3-5. After frame 7, there is very little change to the bulk of the beam.











Figs 4-8. Time evolution of a beam. Vertical Phase space

5 CONCLUSIONS

The agreement between the measured and modelled performance of the LEBT has been sufficient to find solenoid settings to match the beam to the RFQ, but due to the losses in the LEBT there is not an exact agreement. Measurements of the ion source output are needed to model the best way to reduce this loss. Judging by the transmission through the RFQ the LEBT is successful at matching the ion source beam into the RFQ. However, the extent of the inequality of its emittance has yet to be determined. There is a high degree of space charge neutralisation rapidly reached in the LEBT.

6 REFERENCES

[1] J.W.G.Thomason et al The ISIS RFQ ion source these proceedings.
[2] C.P.Bailey the ISIS ion source to RFQ match epac 98
[3] C.P.Bailey et al The ISIS RFQ emittance system these proceedings.
[4] J.W.G.Thomason Results from the ISIS ion source test stand. These proceedings.