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Emittance Measurements in Heavy Ion Transfer Line

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Subject Emittance Measurements in Heavy Ion Transfer Line

SUMMARY

Emittance measurements were made in Sections 12 (DC beam) and at the start of Section 21 (Pulsed beam). In each case, the beam was observed at a multiwire detector (harp) while the currents in one or more upstream quadrupoles were varied in such a way that the beam was seen to pass through a waist condition in both planes at the harp. Profile data were acquired and displayed by the program INSTRUMENT on the Apollo. Relevant parts of the data were saved in files that were later transferred to an IBM-PC for analysis and fitting. Following values of emittance (for 95.4% of the area under the profile, or 86.5% of distribution in phase-space) were found at the two locations:-

Section 12 (9 nA, DC)	Horizontal:	2.713π	mm-mrad
	Vertical:	1.683π	mm-mrad
Section 21 (70 μA, pulsed)	Horizontal:	2.037π	mm-mrad
	Vertical:	1.734π	mm-mrad

ANALYSIS OF PROFILE DATA

The data output by the INSTRUMENT program for a profile pair consists of X and Y coordinates (of the harp wires, relative to one of the central wires in each plane), the corresponding intensities and the mean and RMS values of X and Y. INSTRUMENT makes a measurement of offsets in each of the wire channels before the harp is inserted into the beam, and then subtracts these offsets from the actual digitiser readbacks once the harp is in the beam. It then subtracts the smallest resulting value from all channels, making all the finally reported intensities equal or exceed zero.

In some cases this treatment results in a situation where the profile has a number of outlying points with intensities of one or two least counts. These affect the RMS value to the point that it cannot be used as a measure of the profile width even though its shape is quite close to a Gaussian, as was the case with the pulsed beam measurements in section 21. This problem was dealt with by treating the intensity data as following:-

i) A value 0.00488 (equal to one least count of the digitiser) was subtracted from each profile ordinate.

ii) If the resulting value was less than 0.005, it was set to 0.

iii) Mean and RMS deviations of these profiles were determined, taking into account the correct wire spacing.

iv) Beam half-width was taken to be one RMS deviation. If the beam half-width is taken to be some multiple of the RMS deviation, the calculation need not be performed afresh; the new emittance equals that with one RMS half-width, times the square of the multilier. In particular, if we choose the half-width to be twice the RMS deviation (corresponding to 95.4% of the area under the Gaussian profile, or 86.5% of the beam with a bivariate normal distribution in phase-space) the emittance is 4 times the values reported in the tables below.

The validity of this method was established by plotting the treated profile data for Section 21 along with the plot of a Gaussian function having the same mean and standard deviation and an amplitude factor that made the two plots have the same maximum ordinates. For almost all the profiles, the two plots closely coincided.

EMITTANCE CALCULATION

To calculate the beam emittance we need to know the transfer matrices for the line between the reference point at which the emittance is desired and the harp at which the profile measurements are made. These matrices must be calculated for each of the different quadrupole currents used. Separate APL programs were written for each section, incorporating the correct line elements and appropriate quadrupole calibration factors. These programs generate transfer matrices for both planes for any number of different current settings (i.e., for any number of optical conditions).

These sets of transfer matrices are then used to obtain the three independent elements of the beam sigma matrix by a least-squares fit to the measured beam half-widths. The fitting is performed by a separate APL program that outputs the sigma matrix and emittance, beta, alpha and gamma parameters for each plane. As a separate check on the calculation, the sigma matrix at the reference point can be used to calculate the half-widths at the harp for each of the optical settings; the calculated half-widths are shown along with the measured ones for comparison.

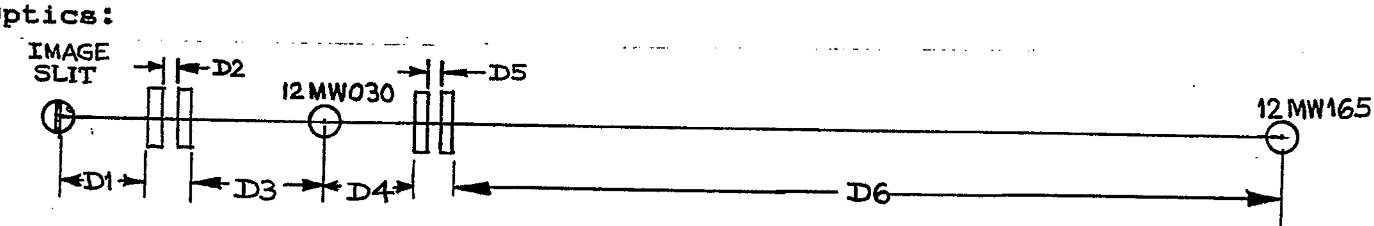
--------- SECTION 12 ---------------------------------------

Conditions:

Reference Point: Image Slit
Beam: O-16, charge +8
Kinetic energy: 112 MeV/ion

Observation Point: 12MW165
Mode: DC beam, 9 nA
Magnetic rigidity: 7.6314 kG-m

Optics:



Drift distance	D1 = 3.607	m
Drift distance	D2 = 0.255	m
Drift distance	D3 = 5.846	m
Drift distance	D4 = 3.908	m
Drift distance	D5 = 0.255	m
Drift distance	D6 = 36.424	m
Quadrupole effective length	L = 0.2025	m

Quadrupole calibration factors	12QH1	2.5019	kG/A-m
	12QV1	2.3831	kG/A-m
	12QV2	2.3755	kG/A-m
	12QH2	2.3915	kG/A-m

Results:

12QH1	12QV1	12QV2	12QH2	-----H-rad-----		-----V-rad-----	
----------	(Ampere)	---------		Meas. (mm)	Fitted (mm)	Meas. (mm)	Fitted (mm)
10	9.8	5.23	5.50	7.88	7.87	4.33	4.24
10	9.8	5.53	5.82	5.78	5.48	3.34	3.38
10	9.8	5.84	6.14	2.89	3.35	2.38	2.58
10	9.8	6.03	6.34	1.39	2.27	2.29	2.38
10	9.8	6.15	6.47	1.88	2.04	2.22	2.39
10	9.8	6.27	6.60	2.09	2.43	2.47	2.51
10	9.8	6.46	6.80	3.90	3.69	3.12	2.93
10	9.8	6.76	7.12	6.93	6.36	4.18	3.95
10	9.8	7.07	7.44	8.88	9.13	5.32	5.43

Sum of squared deviations: 1.64 mm^2 0.19 mm^2

These are consistent with errors of 0.5 mm and 0.2 mm in determination of beam widths in the horizontal and vertical planes, respectively.

Emittance parameters	HOR	VERT	
Emittance	0.67823	0.42070	mm-mrad
Beta	0.69340	7.20731	mm/mrad
Alpha	-0.76015	-3.51580	
Gamma	2.27548	1.85380	mrad/mm

Sigma matrices (SI units)

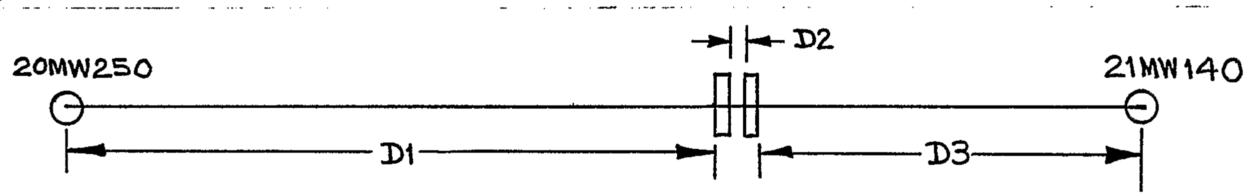
4.7029E-7	5.1555E-7	3.0321E-6	1.4791E-6
5.1555E-7	1.5433E-6	1.4791E-6	7.7989E-7

---------- SECTION 21 --

Conditions:

Reference Point: 20MW250 Observation Point: 21MW140
Beam: O-16, charge +8 Mode: Pulsed, 70 μA
Kinetic energy: 112 MeV/ion Magnetic rigidity: 7.6314 kG-m

Optics:



Drift distance	D1 = 28.283	m
Drift distance	D2 = 0.255	m
Drift distance	D3 = 16.393	m
Quadrupole effective length	L = 0.202	m
Quadrupole calibration factor	2.37275	kG/A-m

Results:

21QV1	21QH1	-----H-rad-----		-----V-rad-----	
--- (Ampere)---		Meas. (mm)	Fitted (mm)	Meas. (mm)	Fitted (mm)
6.90	6.98	2.53	2.48	2.83	2.85
7.06	7.13	2.17	2.19	2.20	2.18
7.21	7.28	1.80	1.85	1.67	1.65
7.36	7.43	1.46	1.53	1.23	1.17
7.51	7.58	1.20	1.23	0.87	0.87
7.66	7.73	1.09	1.01	0.89	0.96
7.81	7.88	1.02	0.93	1.29	1.38
7.95	8.03	1.09	1.05	1.84	1.82
8.10	8.17	1.27	1.25	2.56	2.51
8.25	8.32	1.53	1.58	3.14	3.16

Sum of squared deviations: 3.01E-2 mm^2 2.03E-2 mm^2

These are consistent with errors of less than 0.1 mm in determination of beam widths in both planes.

Emittance parameters	HOR	VERT	
Emittance	0.50937	0.43360	mm-mrad
Beta	9.39204	9.87228	mm/mrad
Alpha	-0.13560	-1.09968	
Gamma	0.10843	0.22379	mrad/mm

Sigma Matrices (SI units)

4.7841E-6	6.9071E-8	4.2806E-6	4.7682E-7
6.9071E-8	5.5232E-8	4.7682E-7	9.7035E-8

Calculated beam dimensions at Harp 20MW250

Size	2.1872E-3	mm	2.0690E-3	mm
Divergence	2.3501E-4	mrad	3.1150E-4	mrad