Title
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EMITTANCE MEASUREMENTS ON AN ABERRATED CYLINDRICALLY SYMMETRICAL PROTON BEAM*

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Abstract

Four dimensional emittance measurements have been made on an aberrated cylindrically symmetric proton beam. These measurements indicate that even in the presence of non-linear effects that radial symmetry is maintained, and that most of the beam emittance occurs in the radial plane. The presence of magnetic field at the plasma cup has been observed to create a strong non-linearity when the beam is tightly focussed.

Introduction

A preliminary set of measurements has been made of the four dimensional emittance of the Bevatron pre-injector ion beam. These measurements have shown striking correlations which can be traced to the effects of magnetic field leakage at the source plasma cup, and aberrations in the pre-injector einzel lens. An optimum set of lens voltages has been empirically determined, that gives maximum phase space density. This set of parameters corresponds to minimum filamentation of the phase space. Both radial and angular aberrations have been observed.

Experimental Equipment: The experimental arrangement used is sketched in Fig. 1. Measurements were made on the Bevatron ion source test stand[1] using spare operating components. Tests were conducted at 110mA and an energy of 360KeV.

The emittance measurements were made using a rectangular array of holes spaced center to center a distance of 0.625cm. The hole diameter was 0.0508mm, and the hole thickness was 0.127mm. (The angular acceptance of a single hole was 0.8 radian.) A modified roll film camera was mounted 47cm from the rear of the slit plate. The camera was mounted on a pivot and could be swung out of the beam path against a grounded plate. A light shutter was mounted ahead of the slit plate, to prevent light from the ion source filament and discharge fogging the film. A beam torroid ahead of the slit plate and shutter was used to monitor the beam current. All measurements were made using a standard routine:

(1) The film (Dupont Type 116) was inserted into the system and the system pumped down.
(2) After operating pressure was attained the system was tuned up with the camera swung against the ground shield. During this tune up both the beam torroid and an auxiliary Faraday cup were used.
(3) After stable operation was attained the beam pulse was stopped, the camera swung into the beam and the shutters opened.
(4) One beam pulse was then allowed to pass through the system striking the emulsion.
(5) The camera was then swung against the ground sheet, and the film discharged for 2 minutes. The pre-injector beam was kept on to ensure stable operation.
(6) The film was then wound 2 framewidths, the parameter being studied varied, the beam turned off, and the exposure sequence repeated.

A total of 30 exposures could be obtained, during each run. Thus parameter studies could be made without disturbing the system operation.

Results: Using the method described above a series of runs were made of the effect of various parameters on the beam emittance. The Bevatron pre-injector is a system consisting of a duo-plasmatron, a Pierce extractor followed by an einzel lens and a 76cm 12 gap column. In operation, the einzel lens voltages were adjusted so that the beam is matched to the column, and a waste produced near the column exit. This matching requires that the beam enter the column with a large radius, and converging. The large (~3cm) radius required for matching combined with the low voltage of the einzel lens (~18kV) makes the system beam characteristics extremely sensitive to the einzel lens voltage (EI). In addition, there is a large leakage flux in the extractor region from the duo-plasmatron magnetic field, making this parameter extremely critical at high beam currents. Fig. 2 is typical of the patterns obtained. The tuning parameters were:

Extractor	40kV	Col	320kV
Focus	100kV	Current	110mA
E1	20kV	Energy	360kV
E2	40	Focusing magnets all off.	

The radial symmetry is striking with most of the beam emittance appearing in the RR' plane. The pattern produced by each pin hole has a complicated structure which we initially associated with the ion beam atomic and molecular constituents (the source produces 70% H^+, 29% H_2^+, ~1% H_3). In order to prove this we placed a transverse magnet field between the emittance plate and the film. The result is shown in Fig. 3. An examination of the dot patterns shows clear separation of the various species, with each species retaining the complete structure of the pattern. This is even true for the central pin hole with its interesting ring structure. Thus the structure observed is certainly to be associated with the system aberrations and not with the beam composition. Reference to the slit patterns of Fig. 2b and 3b also show the same phenomena. Another striking fact is the

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clear separation of aberrative effects obtained in 2a but not in 2b.

An examination of 2a, also indicates some angular effects near the beam axis. These effects can be correlated with the source magnetic field. Fig. 4 shows the result of changing the source magnetic field from 30A to 20A, holding the other parameters constant. There is a clear reduction in the angular widths observed in dot pattern, near the center of the beam. There is also an assymetry in the pattern which we have found to be caused by non-solenoidal components in the source pole field solenoid due to the insertion of cooling plates.

The results of varying the voltage on E1 is shown in Fig. 5, for a constant source magnetic field. Note the reduction in both radial and angular filamentation when the diameter of the beam is increased. It is of interest to examine the equations of motion, keeping in mind the patterns obtained above. Functionally the equation for RR' will have the form:

$$(1+r^2\theta'^2 + r'^2)r'' = kr + \Sigma A_n r^n - \frac{BIr}{R^2} - \frac{Dr_0^2}{r^3}$$

The first term on the right is that usually obtained when the paraxial equation is used, with no space charge; the second represents aberrations due to lens effects; the third space charge effects; and the fourth the angular momentun acquired by the beam if the plasma cup is inserted in a field. In this equation R is the beam envelope (only defined completely if D=0), r_0 is the initial radius of the beam at the emitting surface, and I is the total current in the beam. Both B and D are functions of n, the charge to mass ratio. The term associated with r" is obtained when one considers finite transverse velocity effects on the longitudinal (z) velocity.

Obviously if a beam with finite angular momentum is made to cross over only those particles born at $r_0 = 0$ can do so. All other particles receive a strong diverging force and tend to move away from the system axis. That is the presence of angular momentum imparted to the beam at the plasma surface by leakage flux separates the beam into two clases of particles. This we believe is the cause of the ring observed about the central dot, and the assymetries in θ on the patterns near the beam axis. All other aberrations should be radial, and this is certainly observed by us experimentally. In addition, a careful examination of the patterns obtained has led us to the conclusion that the phase space distribution of the beam is a strong function of the plasma cup configuration and the accelerating systems lens aberrations. In general, it is non-uniform and varies from a hollow distribution to a gaussian.

Conclusion: The use of four dimensional emmittance measuring techniques on an aberrated cylindrically symmetric beam permits separation of the aberrating components, and allows one to determine the source of aberrations.

Cylindrical beams have a "natural" phase space [2] of dimensions $(rr'^2\theta\ \theta')$, with most of the beam emittance appearing in the rr' plane. In understanding the formation of beams from plasma cups or emitting cathodes, it is important to measure the beam characteristics in an uncoupled coordinate system, otherwise it is not possible to separate out the effects of aberrations due both to radial and angular non-linearities. Finally, the presence of leakage flux from a source at the plasma surface constitutes a major disturbance because of the non-linear coupling between the radial and theta phase planes. If this coupling were zero, then the phase volume could be represented by a three dimensional space r r' (rθ').

References

1. Robert W. Allison et al, RSI Vol 32 1961.
2. M. J. Rhee et al, Studies of Electron Beams from a Febreton 705, Proc. IEEE, June 1971.

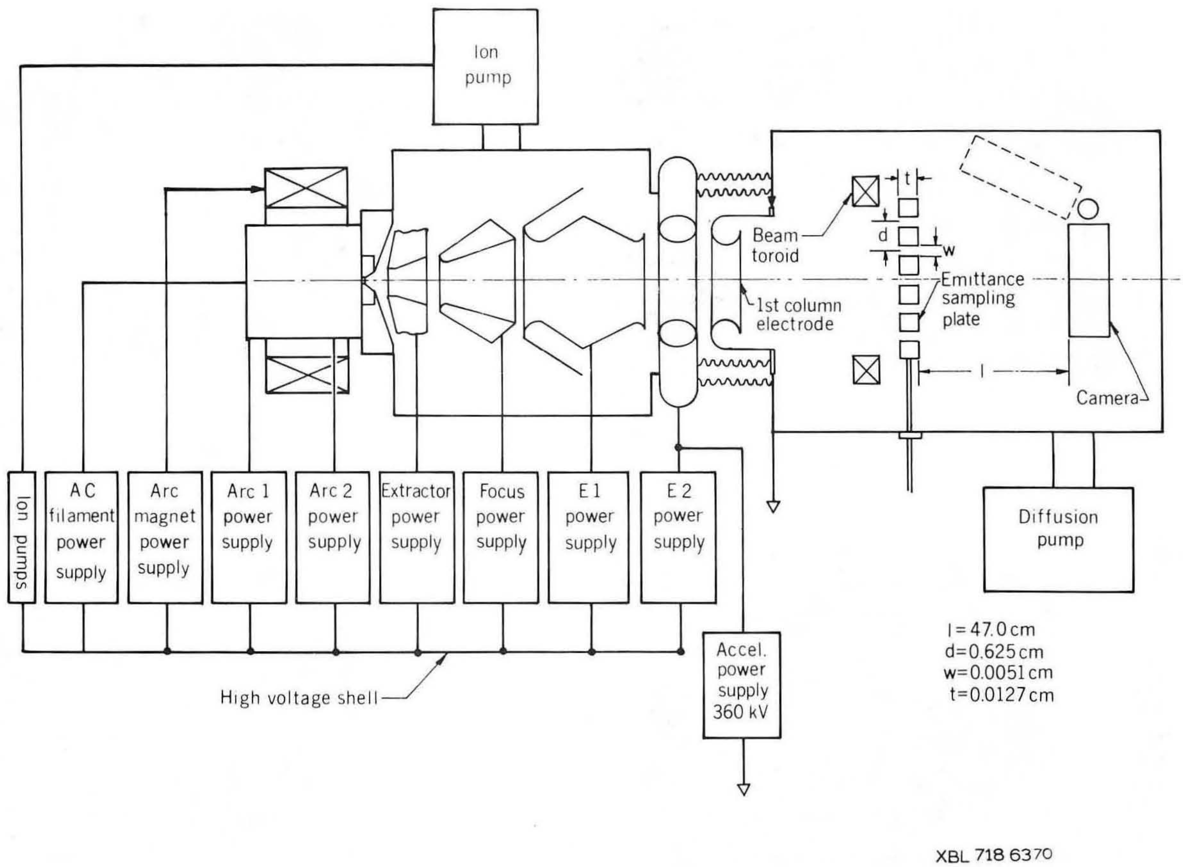
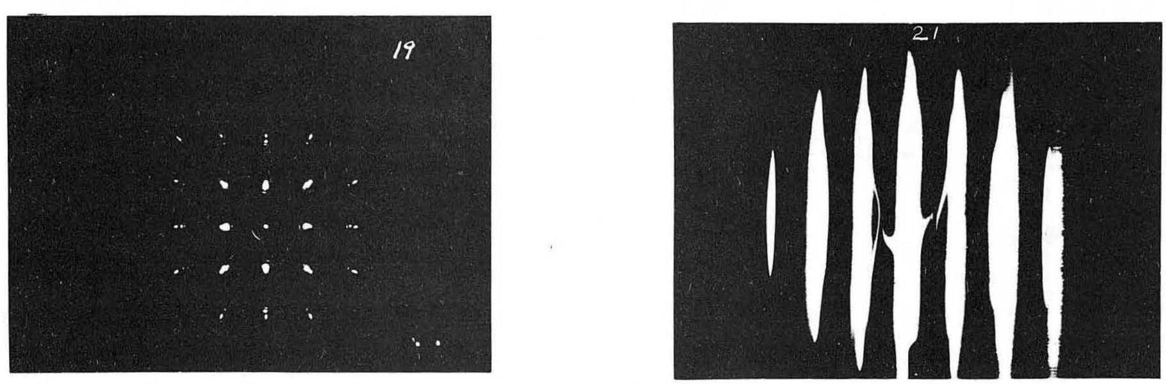


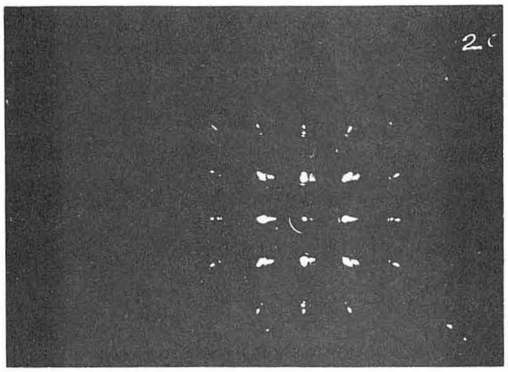
Fig. 1 - Experimental Set-Up



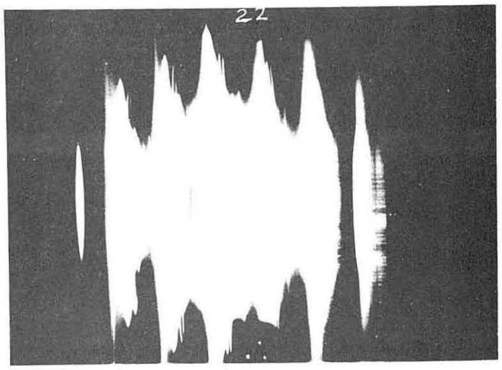
2a

2b

Fig. 2 - Comparison of four dimensional emittance pattern and conventional two-dimensional "slit" emittance measurement. Note striking radial symmetry Beam current 110mA, energy 360 eV, E1 20kV, source magnet 20A.

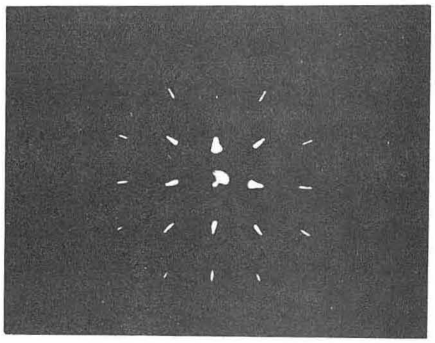


3a

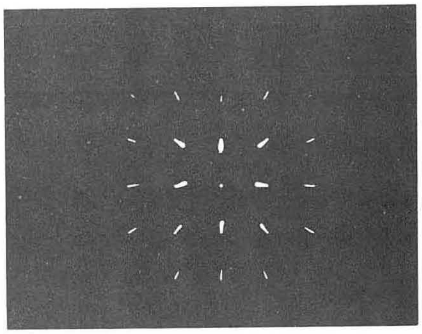


3b

Fig. 3 - Effect of transvers magnetic field on dot and list emittance patterns. Note that each molecular component retains the full aberration structure. All parameters are identical with Fig. 2.

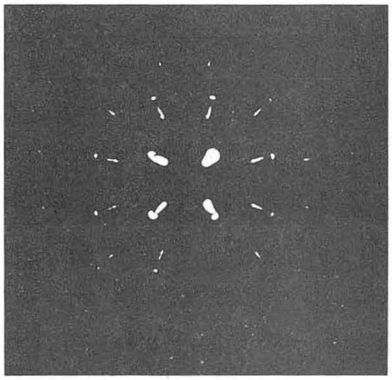


4a Source Magnet



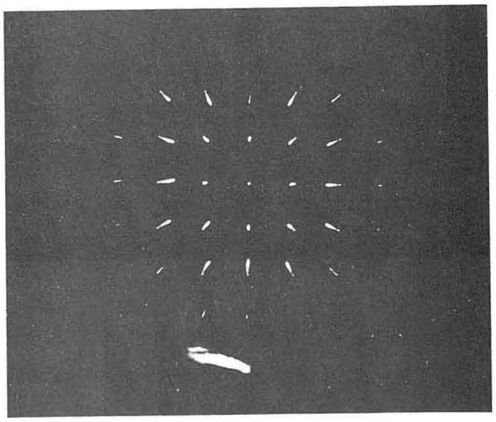
4b Source Magnet

Fig. 4 - Effect of charge of source magnet field on four dimensional emittance patterns. Note reduction in pattern width in θ with decrease in source field. Assymetry in pattern is due to aberration in source field. El = 20kV.



5a

El = 16kV



5b

El - 24kV

Fig. 5 - Effect of charge in El on dot pattern. Source magnet at 30A, all other parameters as in Fig. 2. Fig. 4a can also be included in this series. Note in Fig. 5a that plate was not aligned on central axis.

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