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BEAM TRANSPORT AND MATCHING FOR EXPERIMENTS WITH A 2 MEV CESIUM BEAM

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Lawrence Berkeley Laboratory
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A. A. Garren

October 1979

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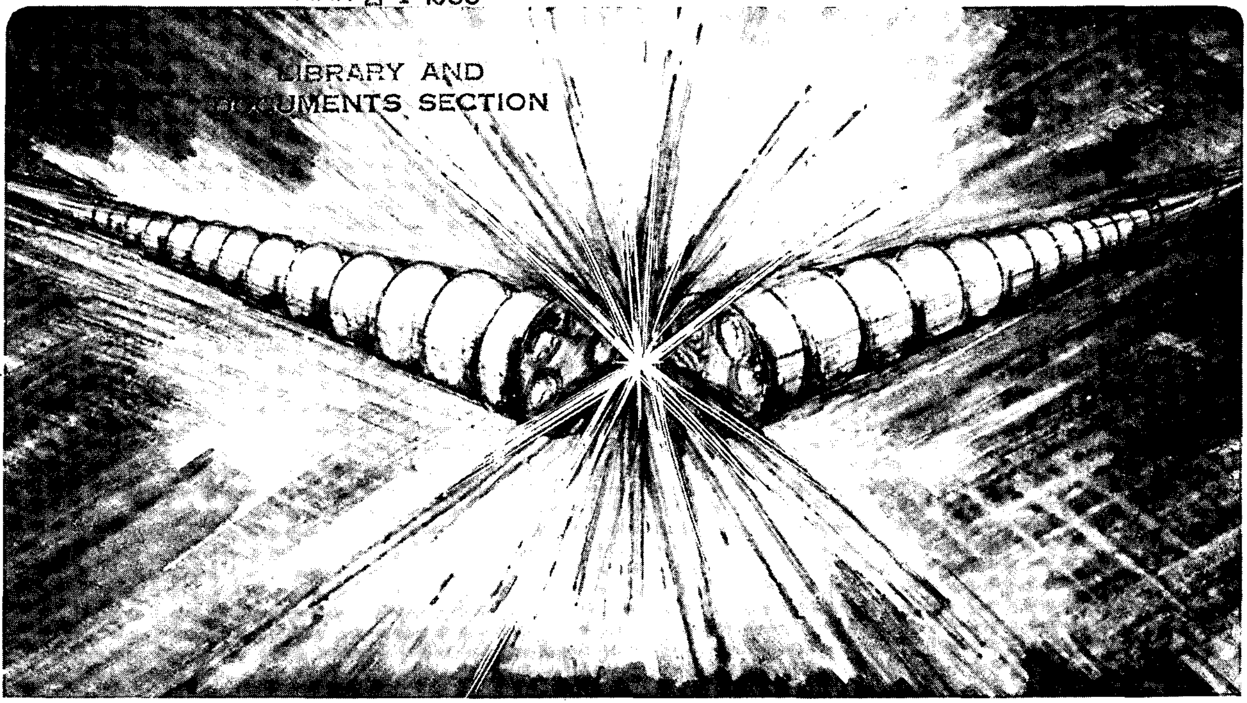

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A. A. Garren
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BEAM TRANSPORT AND MATCHING FOR EXPERIMENTS WITH A 2 MEV CESIUM BEAM

Introduction

Following acceleration of a Cesium beam to 2 MeV by a drift-tube structure, beam properties in a transport line will be studied. It is also proposed to accelerate the beam through a few induction modules. Calculations intended to aid the design of this complex are described in this note.

Beam Line

A schematic diagram of the proposed system is shown in Fig. 1. The beam enters the beam line at point 0 from the drift-tube accelerator left of the figure, and traverses the beam line which is made up of four sections:

1. A section of five 12" bore quadrupoles (designated 12QN24 in the Bevatron Handbook) for matching the round beam from the drift-tubes into the periodic lattice.
2. A section made up in six 'doublet' cells C with structure LL QF L QD using 8" bore quadrupoles (8QB16).
3. A section for matching the beam between the doublet cells C and the following 'FODO' cells C', made up of two 8" and two 12" quadrupoles.
4. A section of six induction modules with 10.4" bore quadrupoles comprising three cells with structure OFOD.

Sections 1, 2, 3 use quadrupoles presently available as Bevatron equipment.

Objectives

Initially sections 1 and 2 only will be used to study, for example, the dependence of stability of beams transported through periodic focusing structures on the tune or phase advance per cell, and its depression due to space charge. Theoretical work[1] suggests that for long transport lines the best strategy is to use zero current tune $\mu_o = 60^\circ$, and limit the current so that the actual tune μ is not depressed below 24°. For the beam parameters tabulated in the next section, the quadrupoles available are too small in diameter to transmit the beam with $\mu_o = 60^\circ$, so this case will have to be studied at lower current and voltage.

The emphasis of the present study is to establish the feasibility of transporting the full 1 Ampere, 2 MeV, Cesium beam expected from the drift-tube accelerating structure through the complete beam line, sections 1-4. For this purpose higher tune values may be used, since the line is too short for instabilities to cause large amplitude growth.

Beam Parameters

The calculations assumed the following beam specifications:

Particle	Cs	
Charge State	q	1
Atomic Weight	A	133
Current	I	1 Ampere
Energy, Kinetic	T	2 MeV
Charge parameter*	Q	.005234
Initial beam radius	r	.08 m
Initial beam divergence	r'	0
Emittance, normalized	$E_N\pi$	$10^{-5}\pi$ m-rad
Emittance, unnormalized	$E\pi$	$.001765\pi$ m-rad

[1] Comparison of Instability Theory with Simulation Results, L. J. Laslett, L. Smith, and I. Haber. Proceedings of HIF Workshop, Argonne, Sept. 19-26.

$$* \quad Q = \frac{4r_p}{ec} \frac{qI}{A(\beta\gamma)^3} = 1.278\times10^{-7} \frac{qI}{A(\beta\gamma)^3}$$

Periodic Lattice Sections

The first periodic section is made of 'doublet' cells C which consist of a drift space and a quadrupole doublet. The true and effective dimensions are given in Fig. 2. These are based on the Bevatron Handbook and measurements by E. Hoyer.

The following calculations are performed using the SYNCH computer program:

1. The quadrupole gradients and beta-functions that correspond to a specified zero-current tune μ_o are calculated.
2. The periodic horizontal and vertical envelopes and tunes are calculated for the specified charge Q and emittance E, using the KV equations:

$$\frac{d^2A_{x,y}}{ds^2} + K_{x,y}A_{x,y} - \frac{E^2}{A_{x,y}^3} - \frac{Q}{A_{x,y}(A_x+A_y)} = 0, \qquad K_{x,y} = \pm\frac{1}{BP}\frac{dB_y}{dx}$$

The results are shown in Table 1 for different values of μ_o.

Since these quadrupoles have a radius of 0.102m, we have chosen μ_o=90 A_{max}=0.087, so that there is ample clearance. There is less in the matching sections. Since these clearances tend to scale together, a beam that may traverse the cells adjusted to lower tunes might not get through the matching sections. However, if the current were lowered, smaller μ_o values would be feasible. These considerations would be modified if larger bore quadrupoles were used, in the cells or matching sections.

Another calculation was made for emittance 1/10 as great. The reduction of beam size is only about 10%, but the single particle tune μ is much more depressed.

The same calculations were performed on the FODO cells C' of the induction modules. In this case, the phase $\mu_o=100^o$ was adopted, giving beam size of 0.122m in the 0.132 m radius quadrupoles.

TABLE I - Phase Advance, Beam Size, and Gradients vs Zero Current Phase Advance μ_0 in cells C and C' for 2 MeV Cs^{+1} beam at 1 Amp. Q=.005234

		μ	Amax	Amin	μ	Amax	gradient
	μ_0	($E_N = 10^{-5}$ m-rad)			($E_N = 10^{-6}$ m-rad)		
'Doublet' Cells C	60°	23.15°	.1056 m	.0669m	2.71°	.0904 m	8.348 T/M
	70	30.05	.0968	.0570			9.583
	80	37.35	.0909	.0496			10.746
	90	44.92	.0868	.0439			11.830
	100	52.62	.0840	.0393			12.825
'FODO' Cells C'	60°	16.03°	.1601	.0999			3.878
	70	21.22	.1453	.0840			4.451
	80	26.86	.1348	.0721			4.991
	90	32.83	.1273	.0629			5.493
	100	38.99	.1217	.0556	4.57°	.1114 m	5.953

First Matching Section

We wish to transport the beam from an assumed 8 cm radius waist at the entrance, position 0, to position 1 at the entrance of the doublet cells, so that it is matched to the cells there. In this way the beam envelope will be periodic and have the smallest size possible in the cells. The four conditions, that A_x, A_x', A_y, A_y' of the envelope have the characteristic values of the cells, requires four independent quadrupoles. A fifth proves necessary to limit the beam size in this section.

Efforts were made to do all or part of the matching with 8 inch bore quadrupoles, but this proved infeasible. It can be done by using 12 inch bore 24 inch long quadrupoles, with gradients well within limits, though the beam just fits in Q2 and Q3. (See Table II). More clearance might be afforded with shorter, and/or larger bore magnets.

These calculations were also done using SYNCH, which links integration of the KV equations with an optimizing program to fit specified constraints. The program is used in the same way as for normal transport matching calculations on beams without space charge.

Second Matching Section

A second section is needed to match the beam between the periodic section with cells C and those with cells C'. Four quadrupoles suffice, the first two are 8" bore, the last two 12" bore quadrupoles.

Complete Beam Line

The complete proposed beam line is specified by the dimensions in Fig. 2 and the gradients in Table II. A tracking run with SYNCH through the complete line verifies the matching - the beam is periodic in the cells. The maximum displacements are shown in Table II.

The system calculated requires eleven distinct gradients. If less are used, the current transportable will be reduced.

Acknowledgements

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Table II - Gradients and Maximum Beam Displacements

		Gradient kg/inch	Gradient Limit kg/inch	Max Beam Disp.(cm)	Quadrupole Radius(cm)
Q1		0.634	2.2	11.3	15.2
Q2		1.452	2.2	14.8	15.2
Q3		-1.675	2.2	14.8	15.2
Q4		1.640	2.2	9.4	15.2
Q5		-1.585	2.2	9.5	15.2
QF	six	3.005	3.6	8.7	10.2
QD	cells	-3.005	3.6	8.7	10.2
QF9		2.820	3.6	8.8	10.2
QD9		-2.722	3.6	8.3	10.2
QF10		1.648	2.2	10.9	15.2
QD10		-1.538	2.2	12.6	15.2
F	three	1.512	1.5	12.2	13.2
D	cells	-1.512	1.5	12.2	13.2

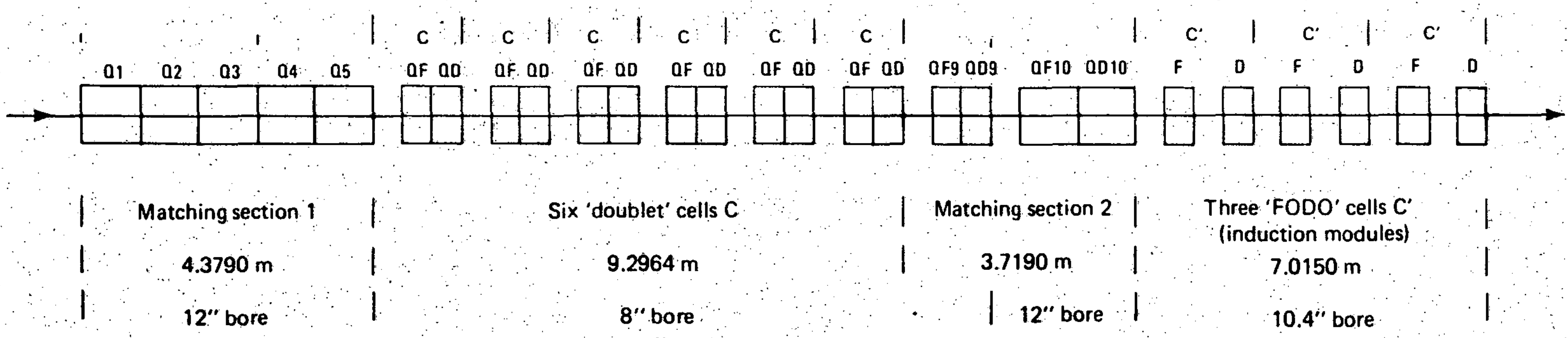

Fig. 1. Proposed Transport Line

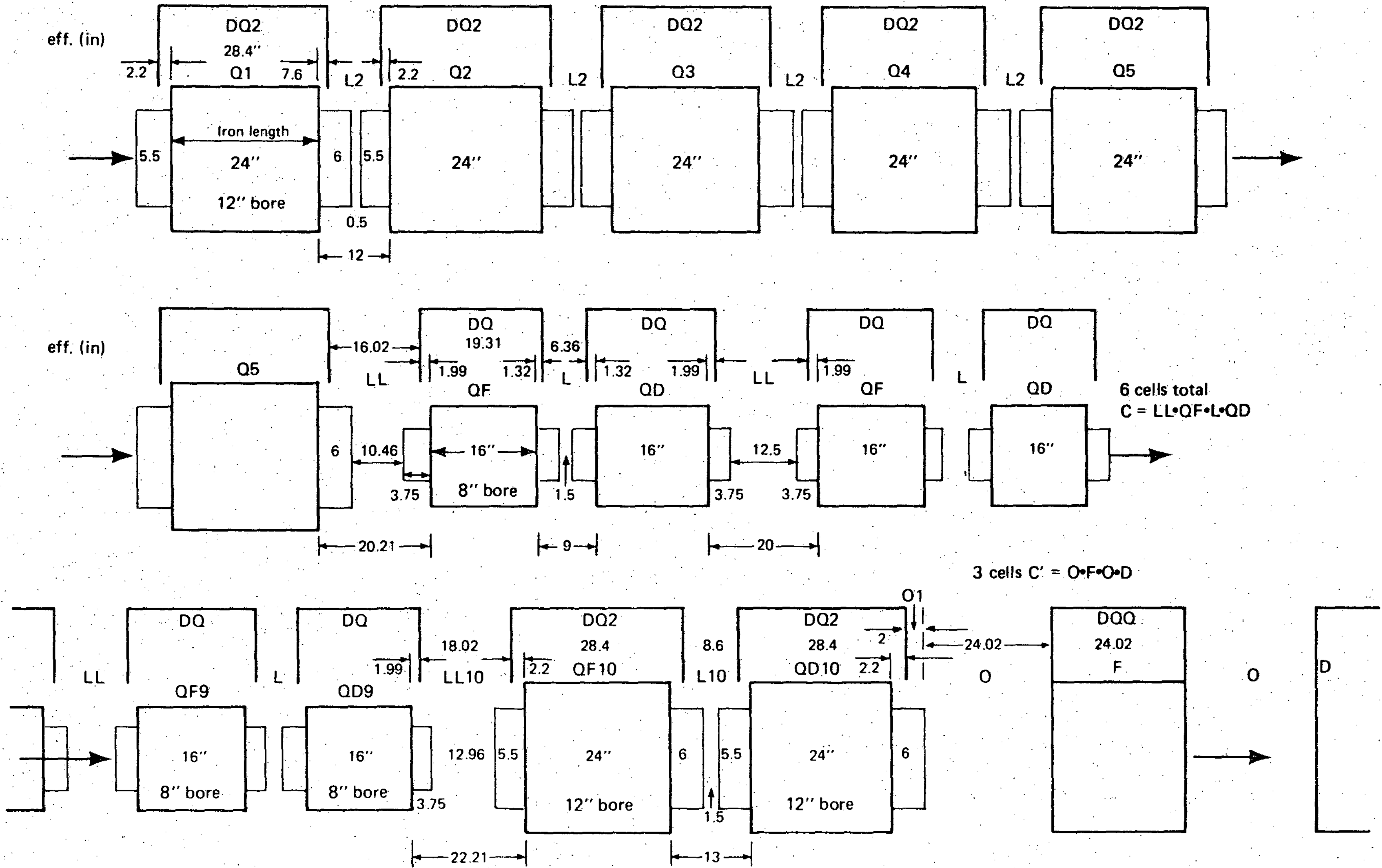

Fig. 2. Dimensions - overall, iron, and effective

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