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BOOSTER INFLECTOR SPECIFICATIONS

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BOOSTER INFLECTOR SPECIFICATIONS

BOOSTER TECHNICAL NOTE
NO. 159

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Booster Inflector Specifications

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1 Location and Radius of Curvature

1.1 Given Information

Based on Frank Karl's measurements and calculations [3], the distance, $d + a$, and angle, θ, shown in Figure 1 are:

$$d + a = 66.937\,\text{inches} = 1.70020\,\text{meters}, \tag{1}$$

$$\theta = 14^\circ\, 59'\, 57.6'' = 14.99933^\circ. \tag{2}$$

1.2 Some Algebra

Refering to Figure 1, the distance of the trajectory from the beam center line at the exit of the inflector is b_1, and the angle of the trajectory with respect to the beam center line at this point is ϕ. The distance from the trajectory at the inflector exit to the upstream steel face of quad QHC4 is d. We shall, for the moment, consider b_1, ϕ, and d to be variables and calculate other parameters in Figure 1 in terms of these parameters.

The point (x_0, y_0) shown in Figure 1 is the center of curvature of the heavy ion trajectory in the inflector. It is defined by the intersection of lines $y = -m_1 x - b_1$ and $y = m_2 x - b_2$. The slopes of these lines are

$$m_1 = \cot\phi, \quad m_2 = \cot\theta. \tag{3}$$

The point $(x_1, y_1) = (0, -b_1)$ is the location of the trajectory at the exit of the inflector.

The point (x_2, y_2) is the location of the trajectory at the entrance of the inflector and is the intersection of lines $y = -(x-a)/m_2$ and $y = m_2 x - b_2$. Thus we have

$$R_1 = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2} = x_0\sqrt{1 + m_1^2}, \tag{4}$$

$$R_2 = \sqrt{(x_2 - x_0)^2 + (y_2 - y_0)^2} = (x_2 - x_0)\sqrt{1 + m_2^2}, \tag{5}$$

and

$$x_0 = \left(\frac{b_2 - b_1}{m_1 + m_2}\right), \quad x_2 = \left(\frac{m_2 b_2 + a}{1 + m_2^2}\right). \tag{6}$$

Now since we require the trajectory to be a circular arc we must have

$$R_1 = R_2 = R. \tag{7}$$

Using (3–6) in (7) we then find

$$b_2 = \frac{a \sin\theta \sin(\phi + \theta) + b_1(\sin\phi + \sin\theta)}{\sin\theta - \sin\theta\cos(\phi + \theta)}, \tag{8}$$

$$x_0 = \frac{\sin\phi \sin\theta}{\sin(\phi + \theta)}(b_2 - b_1), \tag{9}$$

$$x_2 = b_2 \cos\theta \sin\theta + a \sin^2\theta, \tag{10}$$

$$R = \frac{\sin\theta}{\sin(\phi + \theta)}(b_2 - b_1). \tag{11}$$

1.3 Position and Angle of E.O. at Inflector Exit

On page 4 of Reference 1 it is shown that the position and angle of the bumped equilibrium orbit at a distance $d_1 = 30$ cm upstream of the upstream steel face of quad QHC4 are given by

$$X_0 = -7.738\,\theta_k, \quad X_0' = -1.232\,\theta_k \tag{12}$$

where X_0 is given in meters and θ_k is given in radians. Given these relations we must find θ_k such that the bumped orbit has position $X = -b_1$ at the inflector exit. Since the space between QVC3 and QHC4 is a drift, we have

$$X_0 = X + X_0'(d - d_1) = -b_1 + X_0'(d - d_1). \tag{13}$$

Inserting equations (12) and solving for θ_k we find

$$\theta_k = \frac{b_1}{7.738 - 1.232(d - d_1)}. \tag{14}$$

In order for the heavy ion trajectory at the exit of the inflector to be tangent to the bumped orbit we must also have

$$\sin\phi = -X_0'. \tag{15}$$

1.4 Some Numbers

To insure that the radius of curvature, R, is not too small (which is necessary to keep the inflector voltage down), and to insure that beam injection occurs as close as possible to the horizontal beta maximum, the distance, d, from the exit of the inflector to the upstream steel face of quad QHC4 must be as small as possible. This requires eliminating the dipole corrector package upstream of quad QHC4 and shortening the bellows there. If this is done, then V. Badea finds that d should be no shorter than $35.000 - 8.375 = 26.625$ inches. We therefore take $d = 26.625$ inches (0.67628 meters) and hence $a = (d + a) - d = 40.312$ inches (1.02392 meters).

We also require that the inflector septum be outside the booster's limiting aperture, which is 2.0 inches (50.8 mm) at the horizontal beta maximum of 13.9 meters. Since the horizontal beta at the inflector exit is 10.9 meters, the septum must be at least $(10.9/13.9)^{1/2}(2.0) = 1.77$ inches (45.0 mm) from the beam centerline. Allowing a margin of 2.5 mm we therefore take the septum to be 47.5 mm from the beam centerline.

The nominal trajectory of the heavy ions in the inflector will be 8.5 mm from the septum, which coincides with the center of the 17.0 mm gap between the septum and cathode. Allowing 1.0 mm for the septum thickness, we therefore take $b_1 = 47.5 + 1.0 + 8.5 = 57.0$ mm. (Y. Y. Lee points out that in order to fill as much of the available phase space as possible, the incoming beam should be as close to the septum as possible without scraping it. Modeling by S. Y. Lee then indicates that the incoming beam should be 5.0 mm from the septum, which is 3.5 mm to the inside of the nominal trajectory. We plan to use correction dipoles upstream of the inflector to move the beam 3.5 mm to the inside of the nominal trajectory.)

Using these results in equation (14) we find $\theta_k = 7.836 \times 10^{-3}$, and hence $X_0' = 9.654 \times 10^{-3}$, $\phi = 9.654$ mrad. This means that at the upstream face of quad QHC4 the bumped orbit is 63.5 mm (2.50 inches) from the beam centerline.

Now using

$$b_1 = 57.0\,\text{mm}, \quad \phi = 9.654\,\text{mrad}, \quad a = 1.02392\,\text{meters} \tag{16}$$

in equations (8–11) we find

$$R = 8.74123\,\text{meters}, \quad L = R(\phi + \theta) = 2.37274\,\text{meters} \tag{17}$$

$$x_0 = 0.08439\,\text{meters}, \quad y_0 = -8.79783\,\text{meters} \tag{18}$$

$$x_2 = 2.34669\,\text{meters}, \quad y_2 = -0.35442\,\text{meters}. \tag{19}$$

2 Voltage Requirement

Let V and $D = 1.7$ cm be the potential difference and distance between the septum and the cathode of the inflector. Then in order for an ion with charge eQ and mass m to move with speed $c\beta$ along a circular arc of radius R, we must have

$$\frac{mc^2\gamma\beta^2}{R} = \frac{eQV}{D}. \tag{20}$$

Thus the required inflector voltage is given by

$$eV = \frac{D}{QR}mc^2\gamma\beta^2 \approx \frac{D}{QR}mc^2\beta^2. \tag{21}$$

Now, as discussed in Reference 2, we have

$$\frac{1}{2}mc^2\beta^2 \approx (1 + Q_t)eV_t, \tag{22}$$

where V_t is the Tandem (MP7) voltage and Q_t is the most probable charge state for ions after stripping inside the Tandem.

Putting (22) in (21) we then find

$$V \approx \frac{2D(1 + Q_t)}{QR}V_t. \tag{23}$$

Thus, using $D = 1.7$ cm, $R = 8.74123$ m, and $V_t = 15$ MV in (23) we find

$$V \approx 58.3\,(1 + Q_t)/Q \text{ kV}. \tag{24}$$

A. Soukas believes that this voltage requirement does not pose any serious power supply or cable problems.

(Note that the gap, D, between septum and cathode of the inflector has been reduced from the original design value of 2.0 cm to 1.7 cm. This was suggested by Y. Y. Lee as way to lower the voltage requirement. He does not believe this reduction in the horizontal aperture of the inflector poses any aperture problems. Experience has shown that a 2.0 cm gap is adequate for the inflector currently used to inject heavy ions into the AGS. Here one matches the incoming beam to the AGS acceptance which has a horizontal beta of 19.0 meters at the inflector exit. In the booster the horizontal beta at the inflector exit is 10.9 meters so that in princple one only needs a $(10.9/19.0)^{1/2}(2.0) = 1.5$ cm gap to match the incoming beam to the Booster acceptance.)

3 References

1. S. Y. Lee, Booster Injection Scenarios and Orbit Bump Requirements, AGS Booster Technical Note No. 155, December 18, 1989.

2. R. Thomas, Voltage Required on the Booster Electrostatic Septum, Memo to A. Soukas, January 30, 1990.

3. F. Karl, Memo, January 30, 1990.

Booster Electrostatic Inflector

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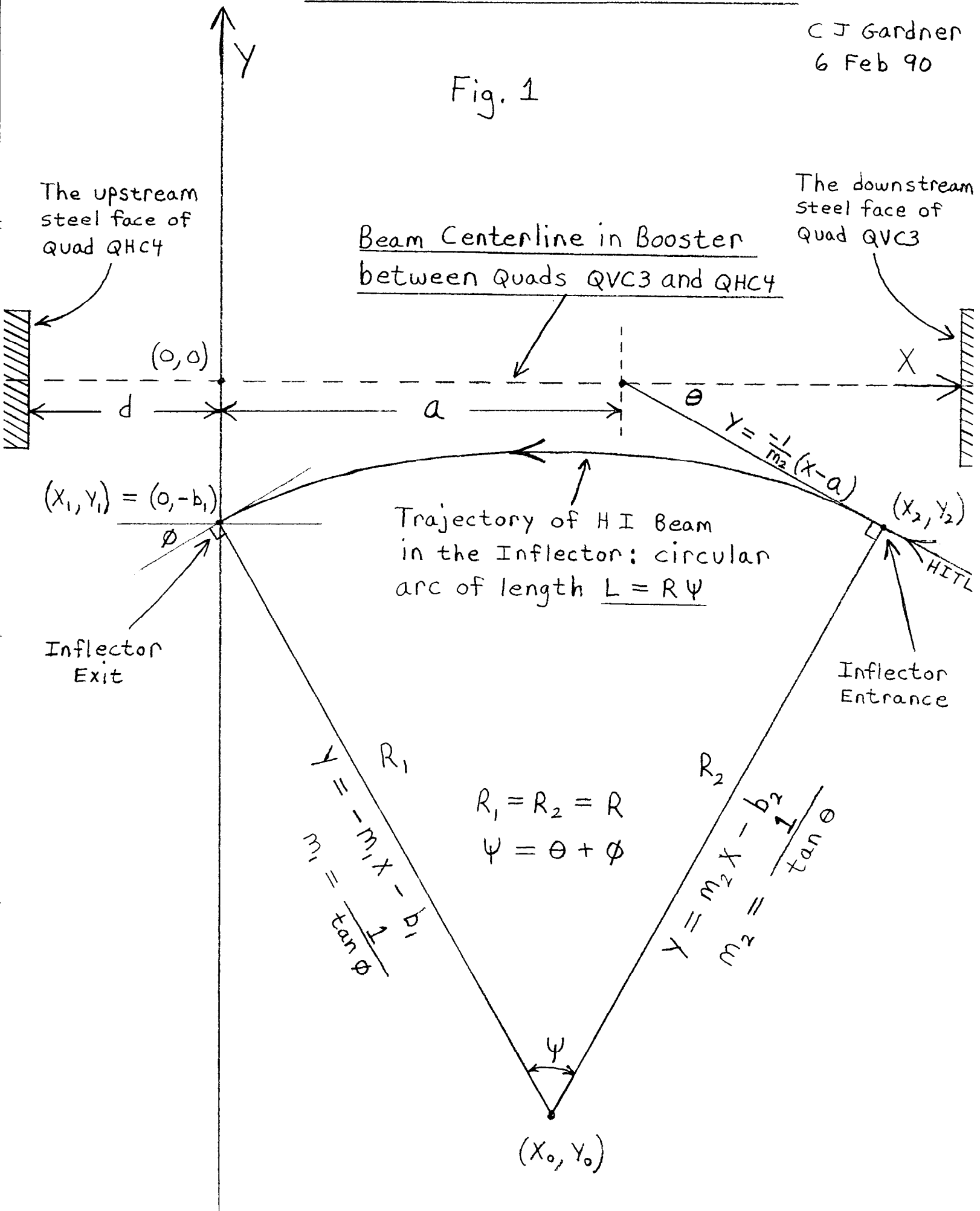
6 Feb 90

Fig. 1



Inflector Detail

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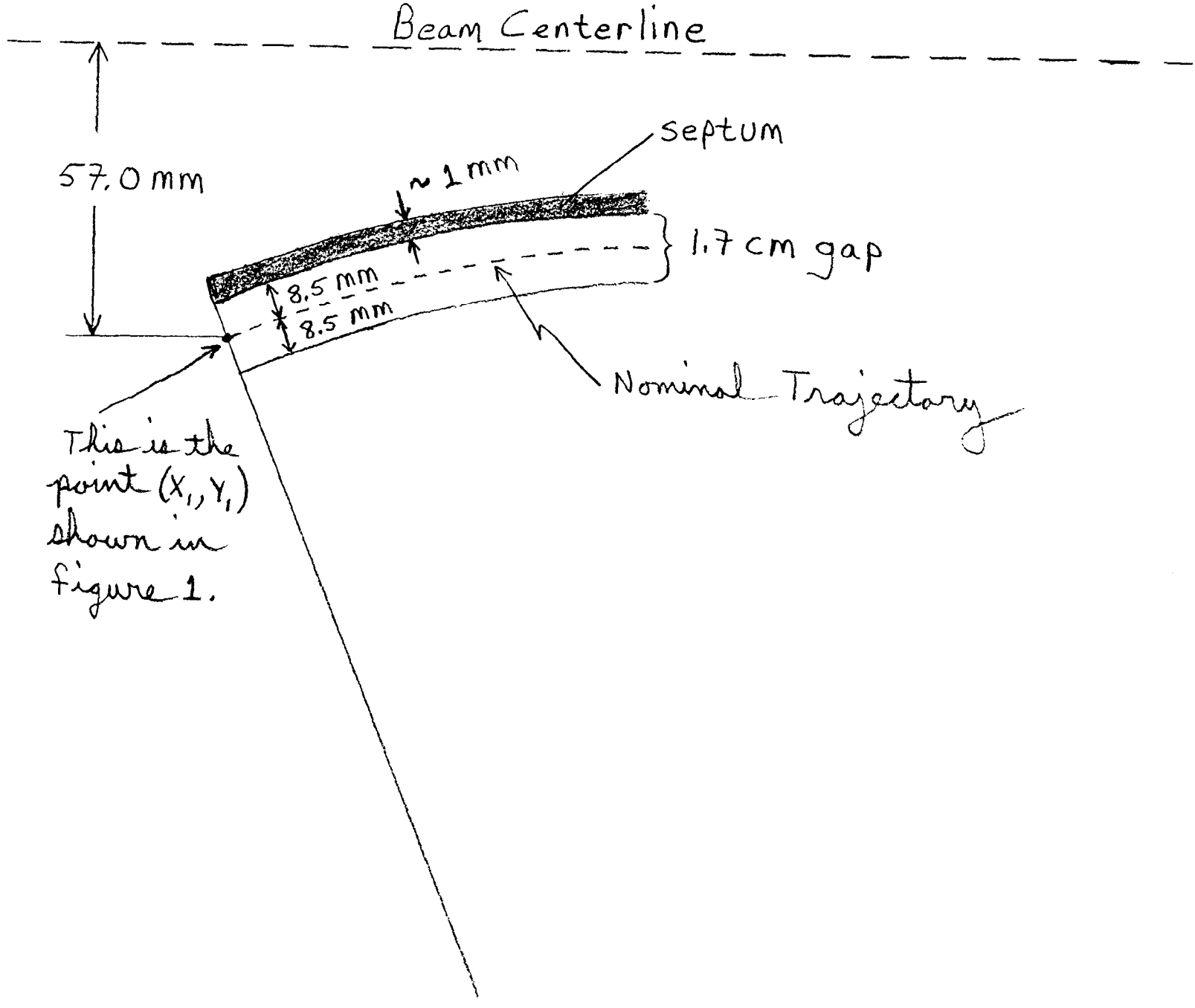
26 Feb 90



Booster Electrostatic Inflector

Entrance and Exit Detail

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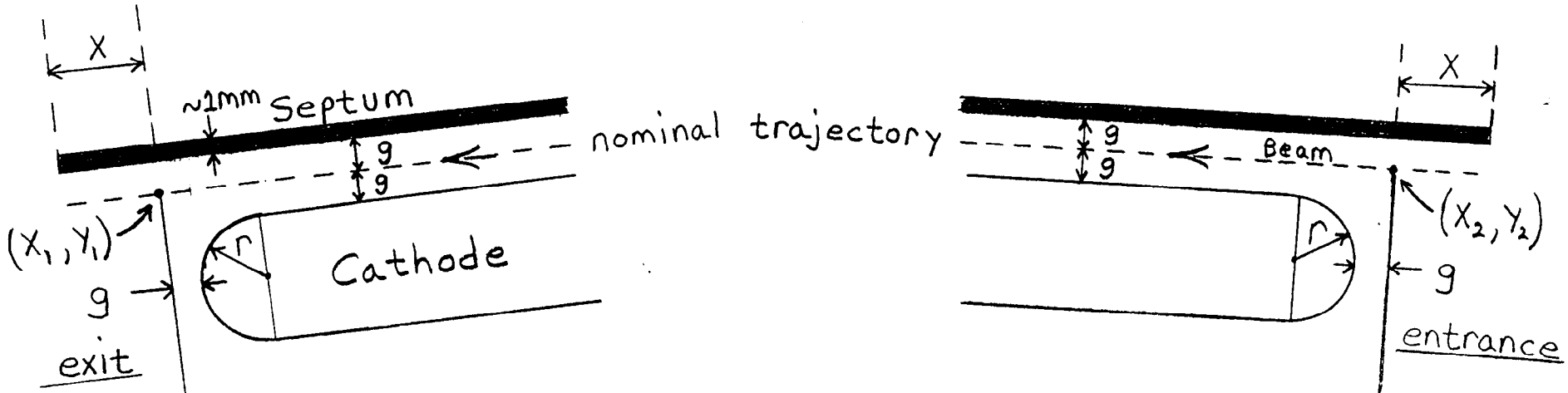
12 June 90



$g = 8.5$ mm

$r = 0.375$ in

$X = 17.0$ mm

The points (X_1, Y_1) and (X_2, Y_2) are as defined in Reference 1.

Ref 1 : C J Gardner, 'Booster Inflector Specifications', Booster Tech. Note, 26 Feb 90.