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DO WE NEED A DEBUNCHER IN THE 200 MeV TRANSPORT SYSTEM?

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INTRODUCTION

Three years ago, Lloyd Smith[1] investigated the effect of longitudinal space charge forces on a drifting bunched beam between the linac and the booster, especially the increase of the momentum spread. He conjectured that "one might do as well (in reducing the final momentum spread) by manipulating the beam in the linac as by adding a separate cavity. . . . the present analysis suggests that in the 100 ma range it would only serve to make matters not quite as bad as they might otherwise be." Since that time, the linac has been found to be quite versatile and a number of "manipulations" have been tried successfully for reducing the momentum spread.[2]

The purpose of this note is to test Smith's conjecture by a numerical calculation which is slightly more elaborate than what he did and also to point out problems that must be solved before making the final decision. As such, this note should be treated as an interim report. A detailed investigation of space charge effects is in progress.[3]

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CALCULATIONS

With the same spirit as taken by L. Smith, only the linear part of the space charge force has been considered. An immediate advantage of this approximation is that one can describe the beam by its envelope (instead of tracing many individual particles). Two charge distributions have been used as a model of the (undoubtedly more complicated) real distribution.

(a) Cylindrical shape with the density uniform in radius but decreasing parabolically to zero at the ends of the bunch.[1] The linear term is an overestimate since the increase of the field along the axis is slower than a linear variation. The image charge on the perfectly conducting wall is assumed to be of the same longitudinal distribution as the bunch itself. In the linear approximation, the distribution is self-consistent.

(b) Ellipsoid with a uniform density.[4] This shape is not as realistic as the cylindrical one but the resulting space charge force is linear in all three directions. It has been shown by Bondarev and Vlasov[5] that the distribution is very nearly self-consistent. Only the linear term of the image effect is included in the calculation.

The calculation is one-dimensional with the beam of a constant circular transverse size although it is easy to solve three envelope equations simultaneously. It is felt that, in view of approximations made, the extension to a three-dimensional problem does not improve the result in a substantial manner.

RESULTS

The distance from the linac to the booster is 62 meters. The focusing system is composed of approximately 20 quadrupoles and 4 dipoles with the average transverse beam size of ~1 cm. With space charge effects, this may increase to ~1.2 cm. If needed, a debuncher (~2 m long) could be placed in the area which is ~40 m from the linac. The radius of the perfectly conducting wall is assumed to be 4 cm everywhere.

Results of the calculation are summarized in Figs. 1 and 2 and Table 1. Since there is no appreciable difference ($\lesssim$10%) between two results, one for the cylindrical shape and the other for the ellipsoid, only the former is presented. In Fig. 1, the longitudinal phase space area ($\Delta\phi$ - $\Delta p/p$) is assumed to be constant (1.0 π degree-%) so that the initial momentum spread is inversely proportional to the initial phase spread. In the actual operation of the linac, this may turn out to be difficult to realize, an increase of the phase spread not necessarily producing a decrease in the momentum spread (an effective dilution of the phase space area). In Fig. 2, the initial momentum spread is kept at $\pm 0.8 \times 10^{-3}$ so that the phase space area is proportional to the initial phase spread. In both figures, the ordinate is one-half of the total momentum spread ($\Delta p/p$) at the injection to the booster and the abscissa is the beam intensity. The design intensity is 65 mA ~ 70 mA. The final beam spread is ±25° ~ ±31° (or ±5.9 cm ~ ±7.3 cm) so that the neighboring bunches are still far away.

If rf buckets are not present in the booster when the beam is injected, the momentum spread may increase further while the beam is coasting in the booster. If one assumes that the present treatment is still meaningful in the booster, the calculation can be extended until each microbunch touches its immediate neighbors. This will take approximately 4 μsec (or 1.4 turns) after the injection. In Table 1, final momentum spreads are given when the beam intensity is 65 mA. Numbers under $(\Delta p/p)_I$ and $(\Delta p/p)_{II}$ are, respectively, without debuncher and with an ideal debuncher (i.e., no distortions in ($\Delta\phi$-$\Delta p/p$) phase space due to nonlinearity).

DISCUSSIONS

The importance of the initial phase spread is clearly shown in Figs. 1 and 2. If the phase space area is maintained, the final momentum spread at the injection can be reduced by better than 30% by stretching the initial bunch by 50% (see Fig. 1, Group A and Group C at 65 mA). Even when this stretching is not accompanied by the reduction in the initial $(\Delta p/p)$, the reduction in the final $(\Delta p/p)$ is 20% (see Fig. 2 at 65 mA). The effect of the beam size in the transverse direction is not very large (~10% reduction by expanding the radius from 1 cm to 1.5 cm).

If the beam is allowed to coast in the booster for a few microseconds before being captured, a debuncher is definitely useful (see Table 1). It should be noticed that, with a debuncher, the initial phase spread and the momentum spread are not important, the final $(\Delta p/p)$ being almost independent of them. The linac operation could be "sloppy" as far as the phase spread and the momentum spread of the output beam are concerned. The improvement by the use of a debuncher, on the other hand, is by no means drastic. One can achieve a similar result by stretching the beam initially and then capturing it as soon as it is injected into the booster.

The process of capturing the beam in the booster when the space charge effect is important is a complicated one and it has not been studied thoroughly. The laminated wall of the booster is far from perfectly conducting. Also several micro-bunches from the linac are captured in each rf bucket so that interactions with other bunches may become nonnegligible. Keeping in mind the limitation of the present analysis, one can only make the following conclusions:

(1) It is worthwhile spending time and effort in the manipulation of the linac. A thorough understanding of the effect of intertank phases on the output beam is essential. Possibility of using the last tank primarily for stretching the beam (rather than accelerating the beam) should be explored.

(2) The process of capturing the beam should commence as soon as the beam is injected to the booster. In connection with this, it is important to understand the space charge effect in the booster with and without rf.

(3) If it is decided to use a debuncher, the longitudinal quality of the linac output beam is relatively unimportant.

REFERENCES

1. Lloyd Smith, FN-146, May 9, 1968.

2. For example, D. Young, *et al.*, IEEE Transactions on Nuclear Science NS-18, No. 3, 517 (1971); S. Ohnuma, FN-227, April 10, 1971.

3. A.G. Ruggiero, private communication.

4. P.M. Lapostolle, CERN Report AR/Int. SG/65-15, July 15, 1965.

5. B.I. Bondarev and A.D. Vlasov, Plasma Physics (Journal of Nuclear Energy, Part C) 8, 599 (1966).

Table 1

MOMENTUM SPREAD WITH AND WITHOUT A DEBUNCHER

Current = 65 mA

Radius of the perfectly conducting wall = 4 cm

Average radius of the circular beam = a (cm)

Initial phase spread = $\pm\phi$ (degrees)

Initial momentum spread = $\pm\Delta p/p$ (%)

$\pm(\Delta p/p)_I$ = momentum spread of the beam drifted until the microbunch structure is lost (i.e., $\Delta\phi = \pm 180°$); without a debuncher

$\pm(\Delta p/p)_{II}$ = same as $(\Delta p/p)_I$; with an ideal debuncher placed at 40 m from the linac

a	$\Delta\phi$	$\Delta p/p$	$(\Delta p/p)_I$	$(\Delta p/p)_{II}$
1.0	10	0.1	0.201	0.133
1.25	10	0.1	0.190	0.128
1.5	10	0.1	0.181	0.124
1.0	12.5	0.08	0.177	0.135
1.25	12.5	0.08	0.168	0.130
1.5	12.5	0.08	0.160	0.126
1.0	15	0.067	0.160	0.133
1.25	15	0.067	0.152	0.128
1.5	15	0.067	0.144	0.123
1.0	10	0.08	0.192	0.134
1.25	10	0.08	0.180	0.130
1.5	10	0.08	0.171	0.125
1.0	15	0.08	0.166	0.135
1.25	15	0.08	0.158	0.129
1.5	15	0.08	0.151	0.125

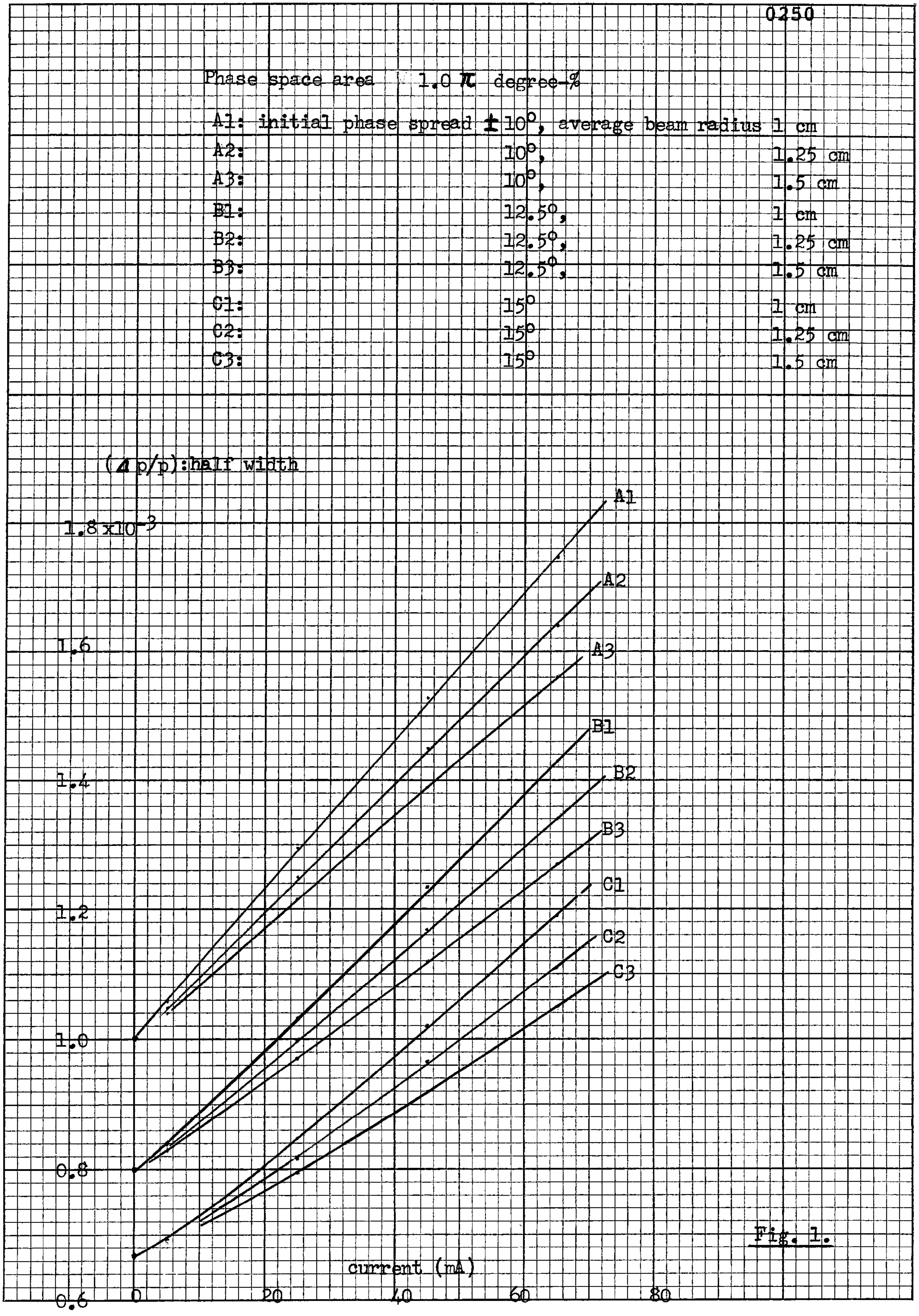
Phase space area 1.0 π degree-%
A1: initial phase spread ± 10°, average beam radius 1 cm
A2: 10°, 1.25 cm
A3: 10°, 1.5 cm
B1: 12.5°, 1 cm
B2: 12.5°, 1.25 cm
B3: 12.5°, 1.5 cm
C1: 15° 1 cm
C2: 15° 1.25 cm
C3: 15° 1.5 cm
(Δp/p): half width
1.8 x10^-3
1.6
1.4
1.2
1.0
0.8
0.6
A1
A2
A3
B1
B2
B3
C1
C2
C3
current (mA)
0
20
40
60
80

Fig. 1.

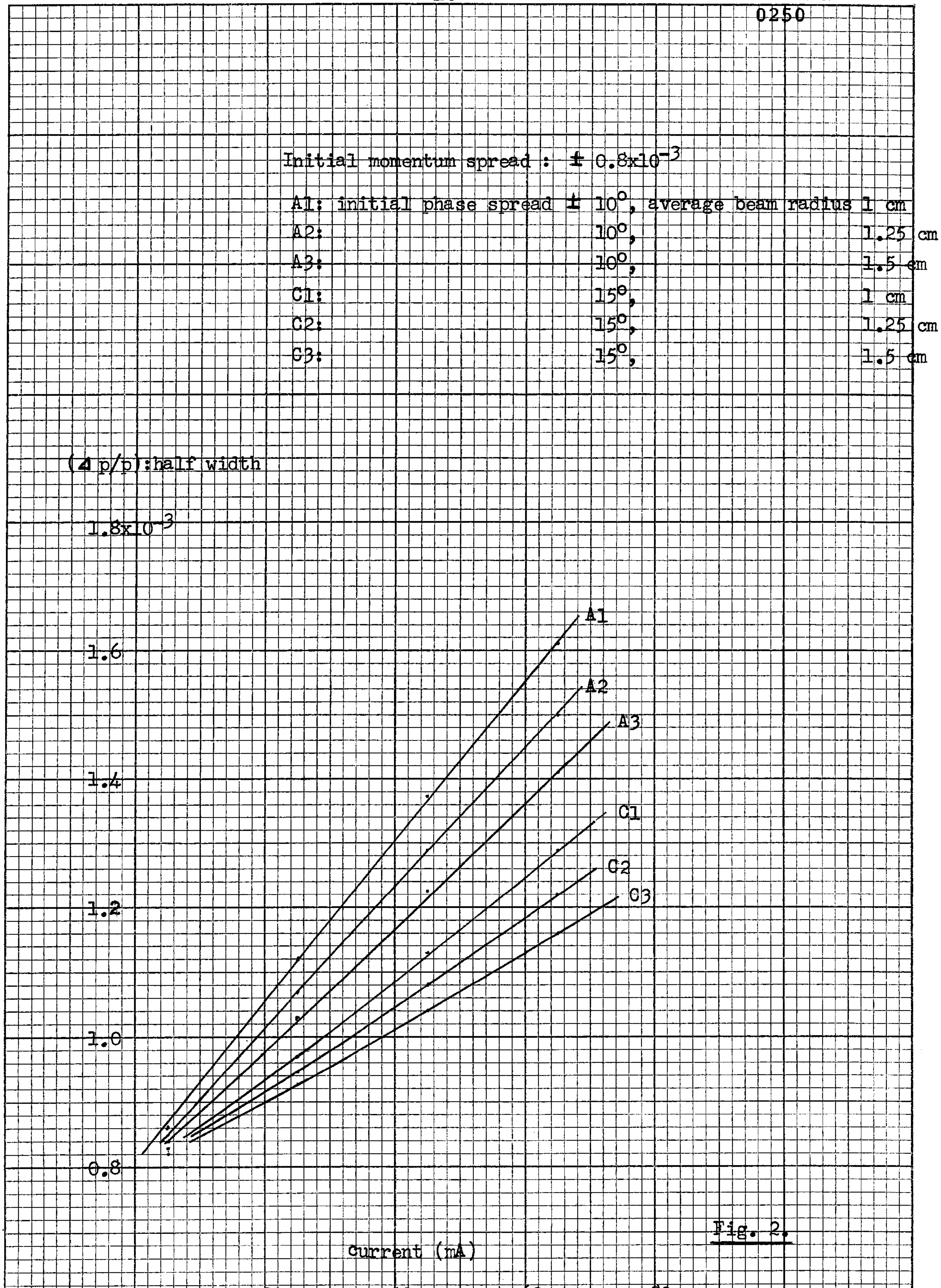
Initial momentum spread : ± 0.8x10^-3
A1: initial phase spread ± 10°, average beam radius 1 cm
A2: 10°, 1.25 cm
A3: 10°, 1.5 cm
C1: 15°, 1 cm
C2: 15°, 1.25 cm
C3: 15°, 1.5 cm
(Δ p/p):half width
1.8x10^-3
1.6
1.4
1.2
1.0
0.8
0.6
0
20
40
60
80
A1
A2
A3
C1
C2
C3
Current (mA)

Fig. 2.