EJECTION FROM VARIOUS TYPES OF CPS STRAIGHT SECTIONS

1. Introduction

The single septum magnet (S) of each of the ejection schemes being installed at present is located in a long mid F straight section (no. 1). To avoid loss in optical quality of the ejected beam the beam position at the entrance of S should then not be further outside from the central orbit than about 3 cm [1]. This requires S to be moved for every machine cycle and, in the case of the slow resonant ejection, decreases the efficiency [2].

H.G. Hereward has recently proposed to review this situation in view of future schemes with the aim to keep S (and possibly the kicker magnet of the fast system) in a fixed position [3].

The following two possibilities have been studied somewhat more closely: (i) S in a mid D straight section (MD), (ii) half S (= S_1) in short mid F straight section (MF) and half S (= S_2) in subsequent short MD. Though there remain many other possibilities to be studied, the partial results are presented now because the writer will probably be unable to pursue this matter further for some time to come.

2. Ejection from mid D straight section

a) Effect of type of straight section

As pointed out previously [1], the ejected beam should avoid the aberrant region at the "narrow" gap (where the field gradient goes through zero) if its inherent optical qualities are to be preserved. As apparent from Fig. 1 (reproduced from [4]) this region is centred around $\Delta r = y \cong 125$ mm (depending on field level). On the other hand there exists a region centred around y ≅ 160 mm where the gradient is about constant. It was therefore thought interesting to attempt bringing out the beam roughly through the latter region. This could be done by deflecting the ejected beam either by 30 to 35 mrad in MF or by 17 to 21 mrad in MD *. A 35 mrad deflection at 28.4 GeV/c requires a bending strength of 3.3 Tm, e.g. 1.5 T x 2.2 m compared to about 2.0 Tm (e.g. 1.0 T x 2.0 m) for 21 mrad. On this account ejection from a standard long MF would appear to push S rather hard, whereas the situation for an MD looks reasonable under the conditions considered.

Two trajectories have been looked at in particular, no. ⑪ and ⑫ (see Table 1). The position of the septum is y = 35 to 40 mm and y = 45 to 50 mm for trajectories no. ⑪ and ⑫ from a short straight section respectively. In the first case the obstruction of the vacuum chamber as seen by the circulating beam is about the same as for the proposed septum position y = 46.5 to 51.5 mm in MF [3].

Table 1

Trajectories through $\frac{1}{2}$D $\frac{1}{2}$F unit

	Azimuth φ (mrad)	Traj. ⑪ y(mm)	Traj. ⑪ y'(mrad)	Traj. ⑫ y	Traj. ⑫ y'	Traj. ⑬ y	Traj. ⑬ y'
$\frac{1}{2}$D	0	72.0	21.0	70.0	17.0	53.0	3.5
	6	80.8	21.8	77.2	17.7	54.5	4.1
	12	90.4	23.9	85.1	19.7	56.5	5.5
	18	101.0	26.1	93.8	21.8	59.0	6.8
	24	112.5	28.7	103.5	24.2	62.2	8.2
	30	125.2	31.5	114.2	26.8	65.9	9.7
	35.02	136.7	34.0	124.0	29.1	69.6	11.0
$\frac{1}{2}$F	6	150.7	32.7	135.9	27.1	73.9	9.2
	12	164.4	32.4	146.9	25.6	77.4	7.4
	18	178.1	33.1	157.5	24.8	80.1	5.4
	24	192.4	34.6	169.0	24.9	81.9	3.5
	30	207.5	37.2	178.6	26.0	83.0	1.8
	35.02	220.8	37.8	188.0	26.4	83.7	1.7

* In the latter case the minimum gap to be avoided is about 2 m further away from the exit of S. As the ejected beam traverses first a region of field lower than at the central orbit relative bending is gained (compare e.g. trajectory no. ⑥ of ref. 1 with trajectory no. ⑪ given in Table 1 of the present note).

b) Standard long straight section

Using the same method as previously [1] the phase space diagrams for the vertical (V) and horizontal (H) planes have been worked out (Fig. 2). As will be seen on comparing the V diagram for (11) with that for trajectory (6) (Fig. 7 of reference 1, here partly reproduced in Fig. 3 for convenience) the reduction of the aberrations is seen to be quite considerable; a beam of 2 cm width at S along this trajectory could probably be accepted without any further corrections. The situation is less advantageous in H, where the beam would be strongly defocused. The divergence would reach a value of 5.8 mrad (Fig. 2) as compared to 1.2 mrad for trajectory (6). The total beam width would be 41 mm as compared to about 30 mm. Thus refocusing horizontally becomes imperative in the case of (11).

This additional focusing can be provided e.g. by a lens placed after the magnet unit in question or by shaping the profile of S similarly as shown in Fig. 8 of ref. 1). Assuming (arbitrarily) a gradient of 10%/cm, e.g. 30% field change over a radial aperture of 3 cm, the dashed H phase space diagram of Fig. 2 is obtained.

For a complete evaluation the trajectory through the subsequent magnet unit should of course also be considered. For this one must know whether the intermediate straight section is short or long (in case of a re-arrangement of the CPS magnet) and how much radial focusing is used. In any event no severe problems should arise from the optical point of view, because the beam leaves the first unit already at y = 220.8 mm and with an angle of 37.8 mrad.

c) Medium or short straight section

In view of the locations of the long MD in the CPS, the case just considered is somewhat less attractive for the East Area, though it might be discussed usefully for a further ejection scheme. In the East Area ejection from a short MD (no. 60) could however be of interest [3]. In this case the deflection angle is by necessity smaller and the beam displacement in the (shorter) S is less too. In order to get still beyond y = 115 mm or so at the entrance of the ½F unit, one has to start with S further to the outside and the minimum angle must be at least about 17 mrad (trajectory (12) in Table 1). At 28.4 GeV/c this deflection could be obtained e.g. with a field 1.5 T x 1.1 m or 1.0 T x 1.6 m (clearance between coil covers $\sim$ 1.10 m). While probably acceptable for a resonant slow extraction, (12) has the drawback for the fast ejection that the beam must be displaced further outwards than in the case of (11).

The V phase space diagram is shown in Fig. 4. Aberrations are somewhat worse than for (11), particularly for the inner trajectory, though still better than in the case of (6). The situation in H is practically the same as for (11).

3. Two stage system

a) Reasons for system

As the efficiency of the resonant slow ejection is roughly proportional to the thickness of the septum of S, it is clearly interesting to have as thin a septum as feasible *. Another consideration is that it is probably easier to free a short straight section than a long one. Combining the two arguments, one obtains a magnet with a bending strength of say 0.6 T x 1.1 m. The resulting deflection of about 7 mrad at 28.4 GeV/c will be sufficient to bring the beam a few centimetres further out in the subsequent straight section. The second stage can then have a septum of say, 3 cm, enabling one to get correspondingly higher bending strength such as 1.5 T x 1.1 m.

b) Choice of type of straight sections

Trajectory (13) (Table 1) pertains to a two stage system with an MD as the first one. While feasible, this possibility does not look very attractive, mainly because a large deflection is required in the subsequent MF. It may however be useful under certain circumstances e.g. to steer the ejected beam to a given location.

The alternative arrangement would appear to combine several advantages. Firstly, fast ejection from an MF leads to minimum kicker power. Secondly, at top momentum, full use can be made of the available bending strength of S_1 with-

* Increasing the efficiency by means of a larger amplitude growth per turn is limited by the CPS aperture and by the maximum acceptable beam width. Apart from the question of experimental physics requirements with respect to beam width, aberrations will of course make themselves felt the more strongly, the wider the beam.

out impairing the optical quality of the beam. Thirdly, the second stage would be in MD, where 17 mrad of bending are sufficient to bring the beam out completely

c) Particular case considered

The particular trajectory considered is shown in Table 2, (14A) being the part between S_1 and S_2 and (14B) the part following S_2 up to the beginning of the subsequent magnet unit. The septum of S_1 is assumed at y = 46 to 49 mm; beam width 20 (30) mm. It should be noticed that such a beam following this trajectory would clear the internal beam at S_2 by at least 30 mm and the yoke of a quadrupole located in the subsequent straight section by about 15 mm.

Table 2

Trajectory for two stage system

Traj. (14A) (after S_1)

	Azimuth φ (mrad)	y(mm)	y'(mrad)
½F	0	65.0	7
	6	67.9	6.8
	12	70.4	5.2
	18	72.2	3.5
	24	73.3	1.7
	30.1	73.7	- 0.1
	35.02	73.4	- 1.6
½D	6	73.0	0.1
	12	73.4	1.8
	18	74.6	3.6
	24	76.4	5.3
	30	79.1	7.3
	35.02	81.8	7.7

Traj. (14B) (after S_2)

	Azimuth φ (mrad)	y(mm)	y'(mrad)
½D	0	101.0	25.2
	6	111.6	26.2
	12	123.2	29.0
	18	136.1	32.1
	24	150.3	35.4
	30	165.9	39.0
	35.02	180.3	42.1
½F	6	198.4	44.0
	12	217.5	46.6
	18	237.8	50.0
	34	259.7	54.0
	30.1	283.5	58.5
	35.02	304.5	59.6
	0	370.1	59.6

(Beam equation for the case magnet units 57 and 58 :
$Y + 0.00902\ X + 1188.98 = 0$; this means that about 10 mrad inward bend are required to steer clear of the outer wall at the beginning of the East Target Area).

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* A two stage system of this general type has been proposed for an ejection into the (new) West Area[5] without considering however in detail the question of aberrations.

The phase space diagrams are shown in Fig. 5 and 6 respectively. Aberrations along (14A) are seen to be negligible. In contrast, they are marked along (14B) and in fact somewhat worse than for (12). This is probably due to the fact that in (12) a certain compensation of the sextupole field component takes place (see Fig. 1) while along (14B) the sextupole component is of the same sign all along. It is noted however that in the region -3 mm to +8 mm (from the central trajectory) the aberrrations are acceptable so that a fast ejected beam could probably be brought out without any further corrections.

In case of a wider beam, shimming of a magnet unit may be considered. This should be easier than in previous cases considered because (i) the beam is already quite far from the orbit, (ii) one could be guided by the better results obtained for (11).

In H the situation is more favourable than for (11). A quadrupole component in the field of S_2 (radially focusing) would still be an advantage though no longer a necessity. However, a quadrupole should then probably be provided as soon after the end of the $\frac{1}{2}$D $\frac{1}{2}$F unit as possible.

4. Situation in East Area

The fast ejection system to be provided in the East Area is to be used in conjunction with the r.f. separator for the CERN 2 m chamber. Less is known about the use of a slow ejected beam in that area though it has been considered for the muon beam [6]. A survey of the various possibilities discussed is given in Table 3. Obviously, the further use of an ejected beam should also be taken into account when considering the question from which straight section to eject. Broadly speaking, ejection from s.s. 61, 60 and 57/58 * would lead to beams following roughly the southern limit, the axis and the nothern limit of the East Target Area. Thus trajectory (14) which is among the more attractive ones from the narrower ejection point of view also looks interesting from the users' point of view. This all the more as it would provide an additional 20 m of length or so for a separated beam.

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* Ejection from 56 would probably not be entirely excluded; however, beam transport similar to that for the present fast beam would have to be provided to steer the beam clear of the wall of the ring.

Table 3

Comparison of various schemes involving septum magnet(s) in fixed position

Traj. No.	Location of septum magnet(s) (s.s.) (Example)	Length of straight section (m)	Radial position of septum (mm)	Deflection (mrad)	Bending strength at 28.4 GeV/c (T x m)	Radial beam centre pos. at beginning of subsequent s.s. (mm)	Angle with respect to circulating beam (mrad)	Comments
(6)	61	Standard long (2.5m between coil covers)	46.5-51.5 (49-51.5)	17.45	0.83x2.0	152.1	21.5	Needs correction[3)]
(11)	60	Standard long	35 - 40	21.0	1.0x2.0	220.8	37.8	Needs lengthening of s.s.
(12)	60	Intermediate (1.60m between coil covers)	40 - 45	17.0	1.0x1.6	138.0	26.4	Septum further outside
		Standard short (1.10m between c.c.)	40 - 45	17.0	1.5x1.07	188.0	26.4	
(14)	57	Standard short	46 - 49	7.0	0.62x1.07	81.8	7.7	Some correction ? Yoke of quadrupole extends to 275 mm
	+ 58	Standard short	40 - 70	17.5	1.55x1.07	304.5	59.6	

It is a pleasure to thank Dr. H.G. Hereward for several helpful discussions and comments, particularly on the evaluation of aberrations.

K.H. Reich

References

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6) A. Citron : Private communication.

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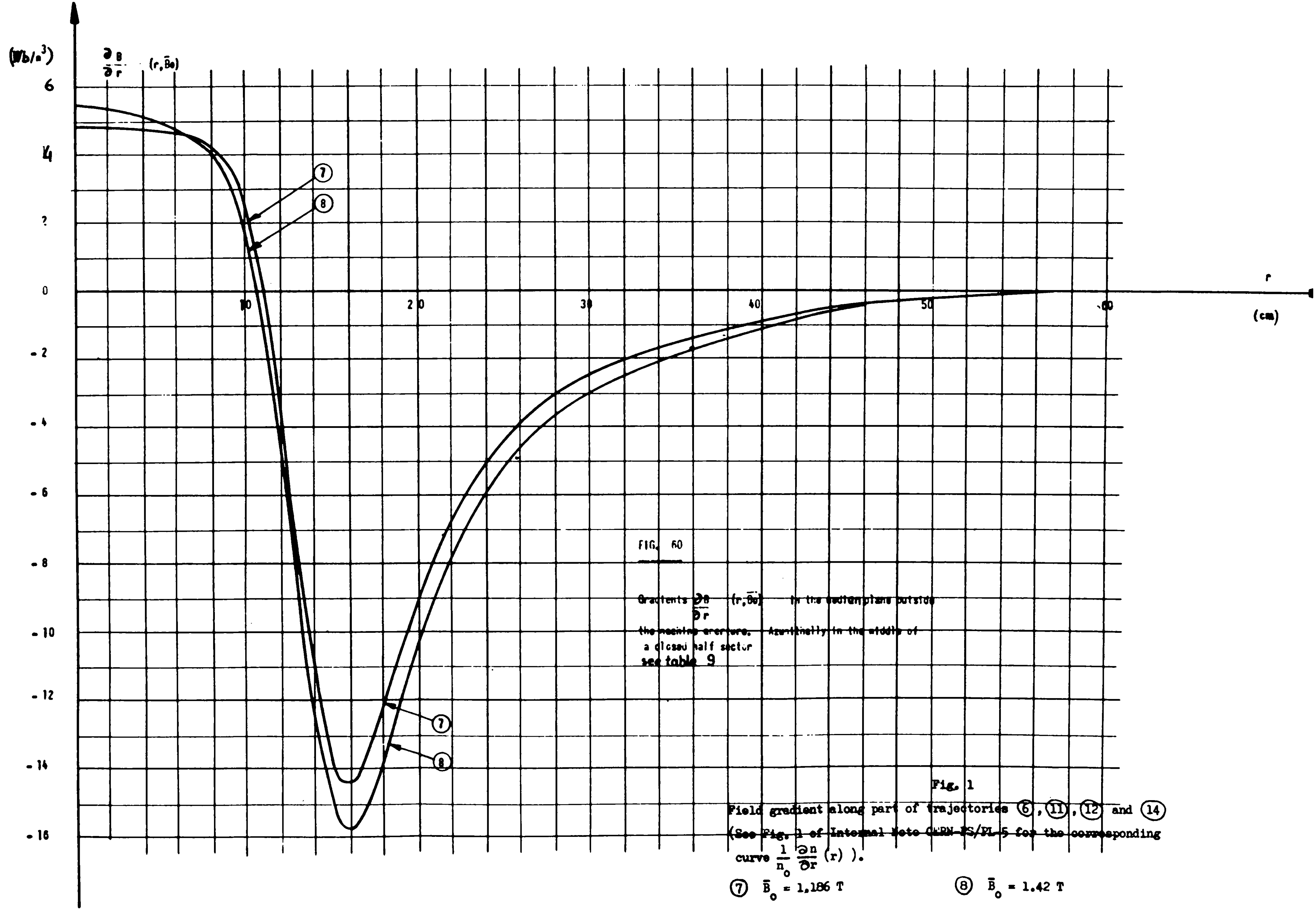

Fig. 1

Field gradient along part of trajectories (6), (11), (12) and (14)
(See Fig. 1 of Internal Note CERN-PS/PL-5 for the corresponding curve $\frac{1}{n_o} \frac{\partial n}{\partial r}(r)$).

(7) $\bar{B}_o$ = 1,186 T   (8) $\bar{B}_o$ = 1.42 T

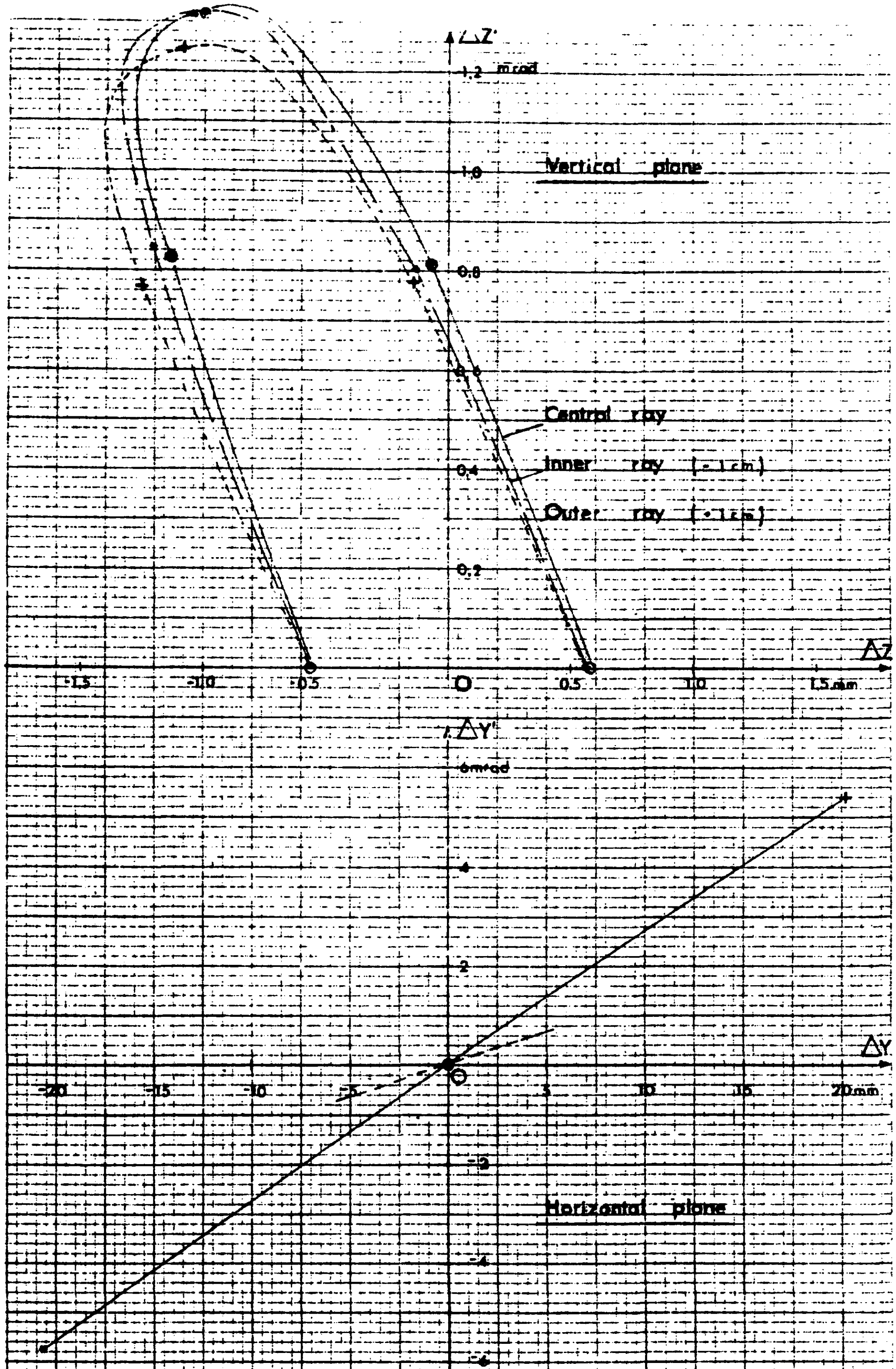

Fig. 2 Trajectory (11)

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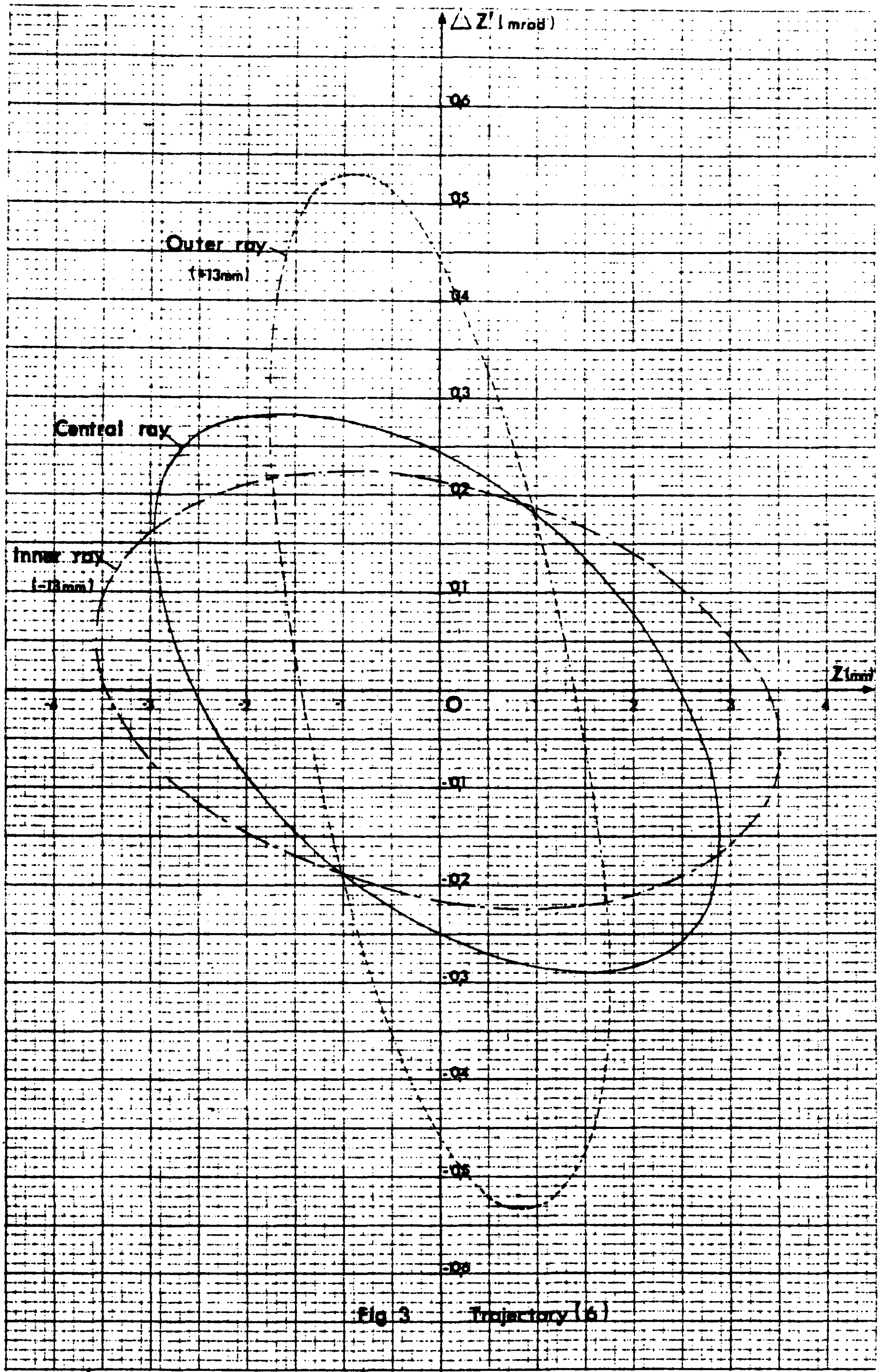

Fig 3 Trajectory (6)

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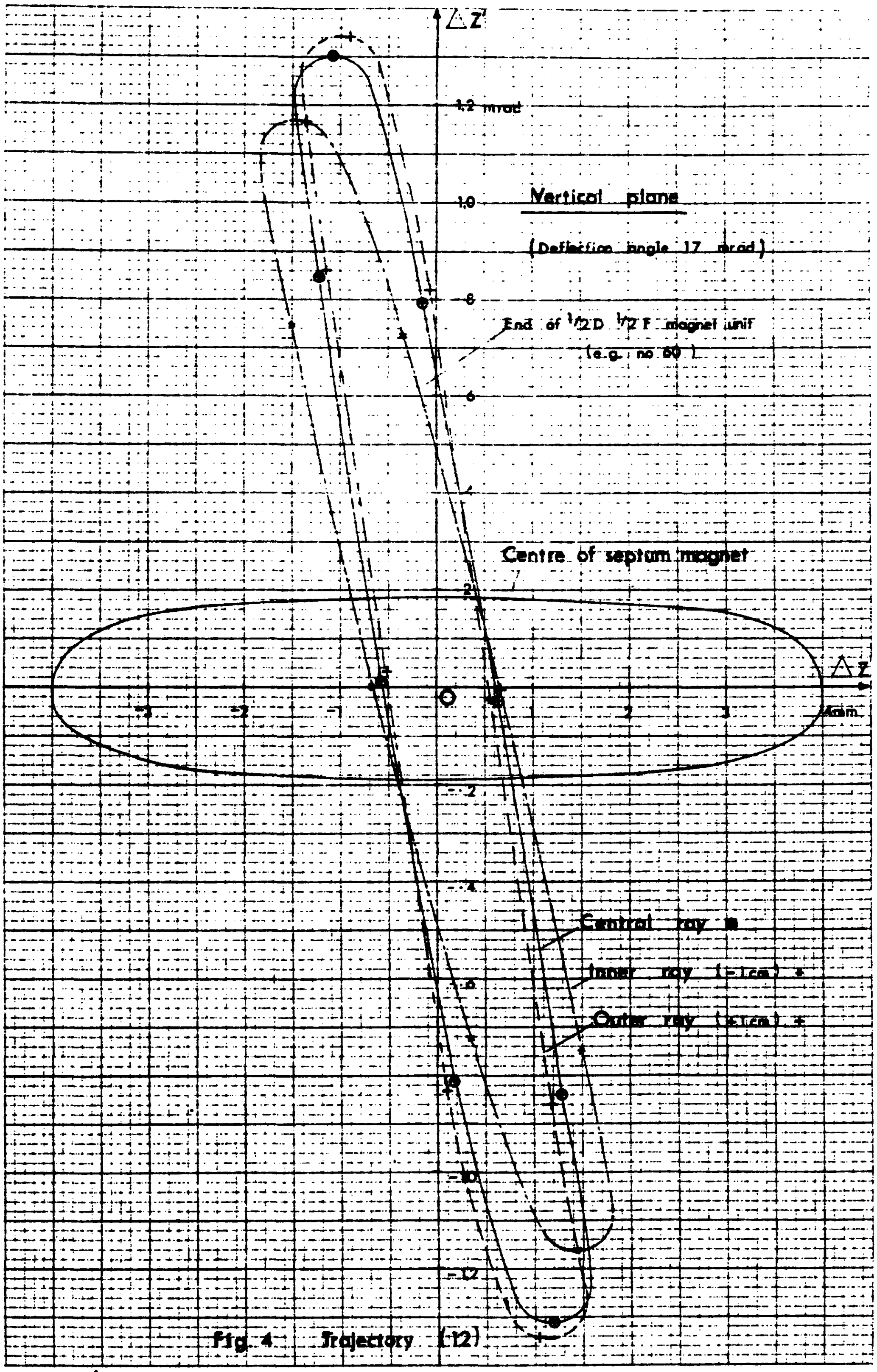

Fig. 4 Trajectory (12)

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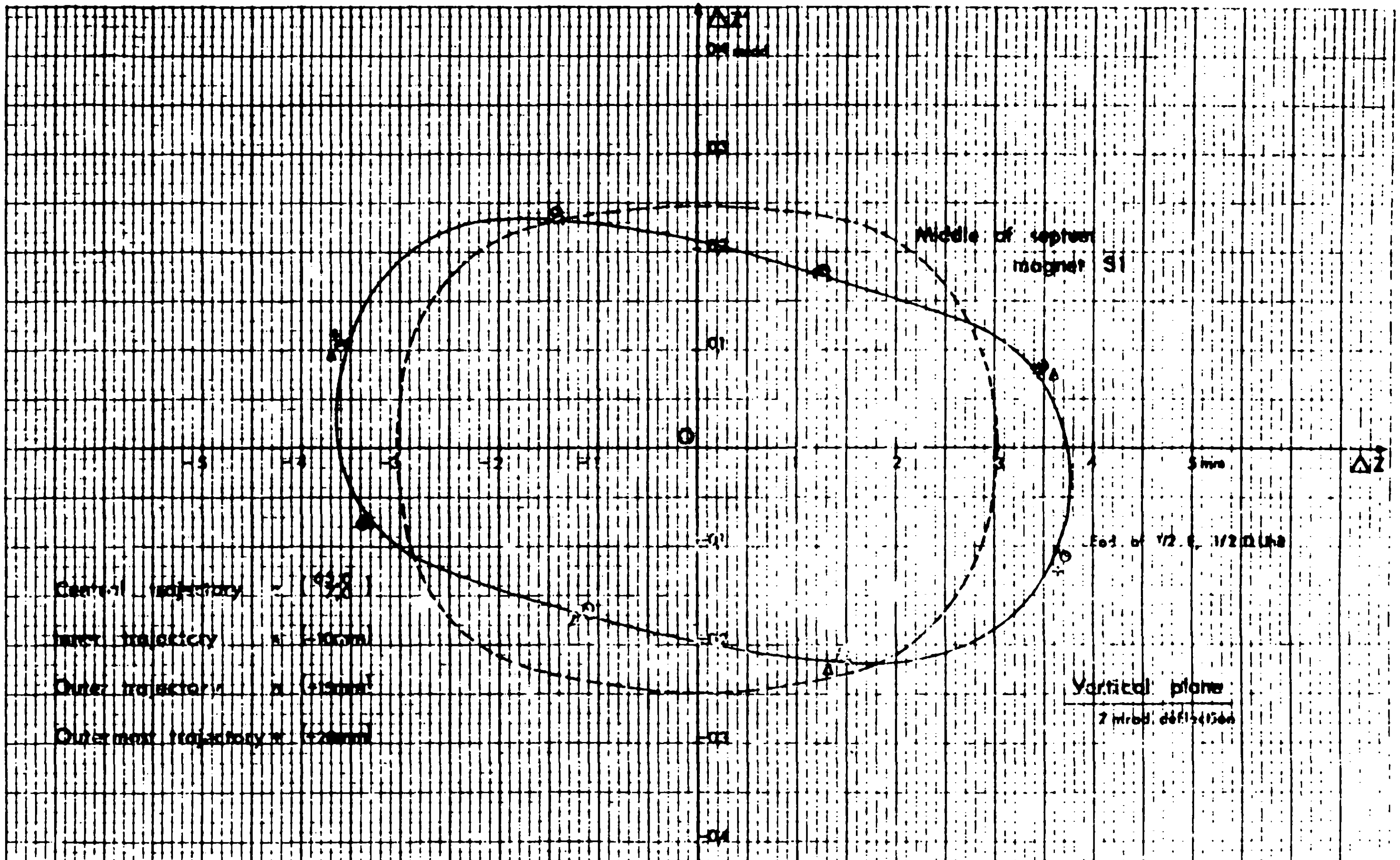

Fig 5 Trajectory (14A)

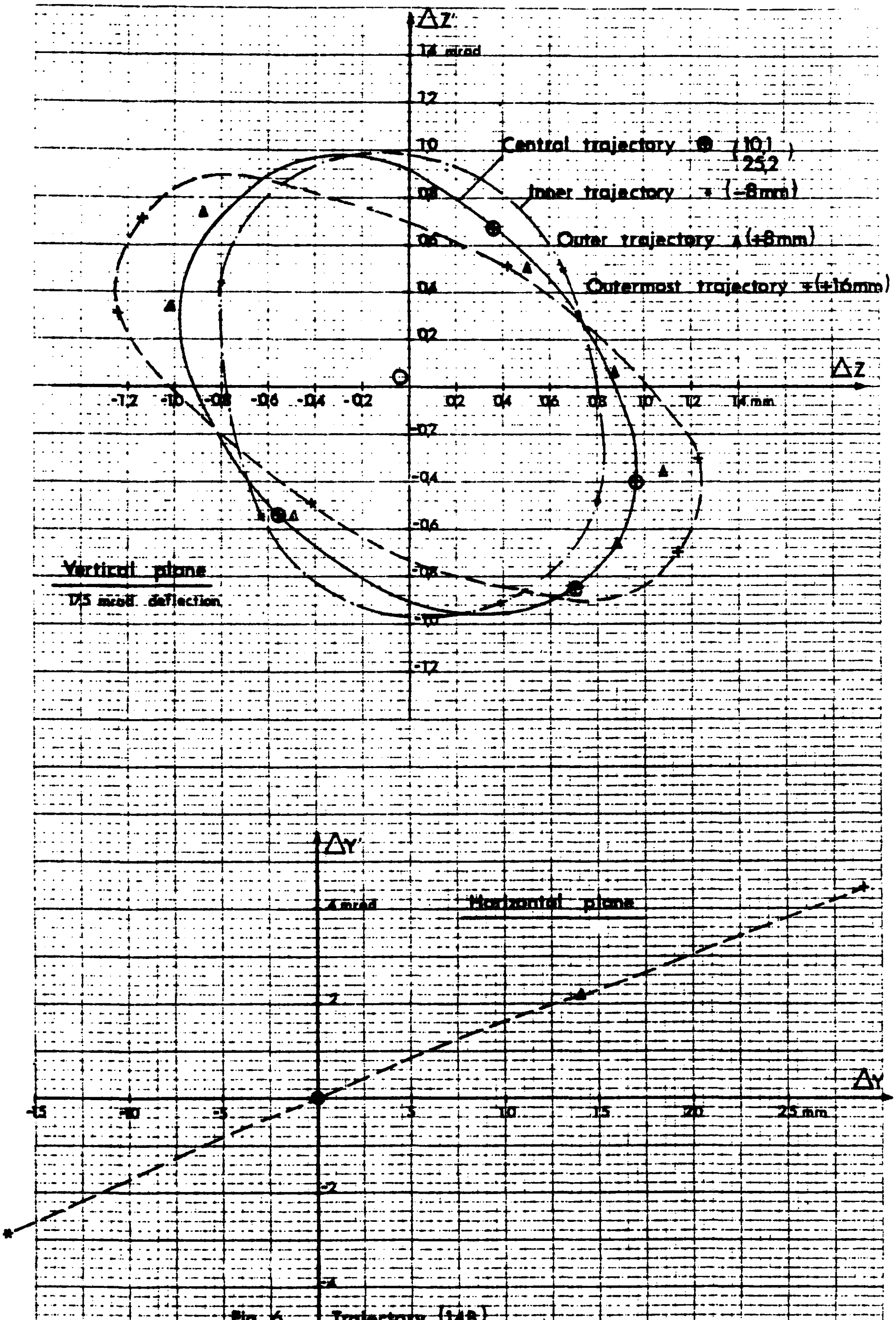

Fig 6 Trajectory (14B)