LENDING COPY

B

DNPL EL/TM022.

ORBIT CORRECTION AT INJECTION

by

H. C. NEWNS

and

N. R. S. TAIT

National Institute for Research
in Nuclear Science,
Daresbury Nuclear Physics Laboratory.

November, 1964.

Orbit Correction at Injection

By

H.C. Newns and N.R.S. Tait.

1. Introduction

Imperfections in the synchrotron magnet system of NINA are expected to lead to radial distortions of the equilibrium orbit. These could lead to serious beam loss at injection. It is desirable to install dipole windings on the magnets to correct the distortions.

Maximum horizontal deviation from the ideal equilibrium orbit is expected in the radially focusing (F) magnet units. The ideal correcting system would allow separate and completely independent adjustment of the radial position of the equilibrium orbit at each F unit. A good approximation to this system can be obtained in several ways.

2. General Considerations

A localised distortion of the equilibrium orbit can be achieved by the application of equal magnetic field perturbations at two points on the orbit separated by half a betatron wavelength(1.) The orbit will be modified only in the region between the perturbations. With a Q-value of 5.25 and a magnet system consisting of twenty periods FoDO, the betatron phase change per magnet period is 94.5°. Thus in NINA the perturbations would be applied at positions separated by just less than two magnet periods.

In practice the perturbations must be applied over a finite length of orbit. This leads to a finite ripple on the orbit around the remainder of the magnet system. The ripple can be minimised by adjustment of the relative sizes of the perturbations or by the addition of a third perturbation. In all cases the effect on the equilibrium orbit of a given set of perturbations can be found by calculating the displacement of the orbit at a large number of points around the machine using transfer matrix methods.

3. Two Block Beam Bump System

The NINA magnet units consist of 9 full sized magnet blocks of azimuthal length 12.4" and two end blocks of length 6.2". The blocks are separated by wedge-shaped gaps. In the present discussion the blocks will be numbered 1-11 from the 'downstream' end of the magnet unit.

Suitable beam bump systems can be obtained using perturbations on only two blocks (fig. 1 (a)). The 3 x 3 transfer matrix for the system is calculated and the condition of zero equilibrium orbit displacement around the remainder of the magnet system is imposed. It is then possible to specify values of x_1, x_3 and t and to obtain solutions for y_1 y_3 and $\Delta B_1/\Delta B_3$

For a single block perturbation we want x_1 and x_3 to be 0.05, 0.15, etc. with $(y_1 - x_1) = (y_3 - x_3) = 0.1$. Exact solutions are not in general obtained but there is usually one with both $(y_1 - x_1)$ and $(y_3 - x_3) \sim 0.1$ and with $t \sim 0.6$. The effect of putting $(y_1 - x_1) = (y_3 - x_3) = 0.1$ can be found using the method described at the end of the last section.

A possible system was found for NINA with excitation on block 2 of magnet F_1 and block 10 of magnet F_3. Due to the limited space available between blocks for the accommodation of conductors, this system is only suitable for use at injection.

4. System using Complete Magnets

It is possible to apply the perturbations over the whole length of magnets F_1 and F_3, Fig. 1(b). If the two perturbations have the same magnitude ΔB_1, it is found necessary to apply a perturbation ΔB_2 at magnet F_2. The ratio $\Delta B_2/\Delta B_1$ can be found by a method suggested by T. J. Collins and illustrated for the present case in Fig. 1(d).

This system can be modified such that a perturbation $\frac{\Delta B_2}{t}$ is applied over fraction t of the magnet unit. The advantage of this is that a value

4. Continued

of t can be chosen such that the excitation currents are almost equal in all three windings. Equalising these currents simplifies power supply problems but leads to an increase in the orbit displacements around the remainder of the magnet ring. With t = 0.1 or 0.2 (corresponding to one or two block excitation) the increase in displacement is tolerable.

5. Comparison of the Systems for Orbit Correction at Injection

The two-block system has the advantage of simplicity. However the magnet blocks of the NINA magnets are separated by only 0.2-0.3 cm in the region of the back-legs and it would be difficult to accommodate the conductors for the relatively high currents required ($\sim$ 10 ampere turns/cm deflection at injection). Also the maximum ripple is very sensitive to $\Delta B_3/\Delta B_1$ as can be seen in the following table:

$\Delta B_3/\Delta B_1$	Max Ripple.
0.85	5.5%
0.90	1.5%
0.95	6.0%

The three magnet system only requires 1.2 ampere-turns/cm (at injection) on magnets F_1 and F_3, and is relatively insensitive to variations in the ratio $\Delta B_2/\Delta B_1$:

$\Delta B_2/\Delta B_1$	Max Ripple.
0.100	4.0%
0.157	0.006%
0.200	3.0%

The modification of this system using only one or two blocks of magnet F_2 has similar advantages:

$\Delta B_2/\Delta B_1$	Block Numbers	Max. Ripple.
1.0	5	3.5%

5. Continued

2.0	5	3.3%
1.0	6	3.5%
2.0	6	3.3%
0.5	5+6	3.5%
0.8	5+6	0.8%
1.0	5+6	3.3%

The magnitude of the ripple is found to be almost independent of the point of application of ΔB_2 while simple ratios $\Delta B_2 / \Delta B_1$ can be used. Thus $\Delta B_2 / \Delta B_1 = 0.5$ is obtained by passing the same current through two dipole windings, pole face windings for example, on F_1 and F_3 and through a single turn back-leg winding on F_2. Two turns of back-leg winding on F_2 would give $\Delta B_2 / \Delta B_1 = 1.0$. Finally, if a two block back-leg winding is in use we can obtain $\Delta B_2 / \Delta B_1 = 0.75$ by placing two turns on one block and one turn on the other.

The discussion of the last paragraph assumed that the magnet steel has infinite permeability. At injection fields this is not so, and some deviation from the calculated values of $\Delta B_2 / \Delta B_1$ may be expected as a result. Finite permeability of the magnet steel may also lead to some distortion of the field. Measurements made with a back leg winding on one block of the model F magnet indicated that $\Delta N/N$ is $\sim$ 1% for $\Delta B/B \sim 25\%$ at $B \sim 60$ gauss. This would have the greatest effect in the two block system where ΔB is large.

In conclusion, it appears that the system with two turn dipole windings on magnets F_1 and F_3 and a back-leg winding on blocks 6 and 7 of magnet F_2 is the most suitable for orbit correction at injection. There is considerable scope for optimising the ratio $\Delta B_2 / \Delta B_1$, while the current required is only 0.6 amps per cm. Fig. 2 shows the deflection of the equilibrium orbit as a function of azimuthal position for this system. The assymetry is due to the inequality in length of the two straight sections in each magnet period.

6. D-Unit Beam Bump System

If the system discussed in the last paragraph is applied to a triad of D-type magnet units, the displacement of the equilibrium orbit takes the form of Fig. 3. The current required is somewhat larger, being 1.8 amps per cm deflection in the first F magnet unit.

This system would be of considerable advantage in the correction of an orbit deviation which was in the same direction in several consecutive F magnets.

7. Method of Use.

The currents in the F-Unit systems will be set assuming that the systems are completely independent of each other. The optimum current setting for each system is taken to be the mean of the two settings at which the beam is just lost at the edges of the working region of the magnet aperture, all other systems being out of circuit. With an F-magnet aperture of 13 cms a minimum current of ± 7.8 A is required.

In the case of the D-Unit systems it is not possible to use this method as each system affects the orbit in two F units. The D systems can be used as a first correction using the F system currents as a basis for calculating the necessary D system currents to produce the same deflections. With the D systems in operation, the F systems are then re-set to give a second order correction, using the same method as before to determine the optimum current settings.

An alternative method of setting the currents is by calculation from the known position of the equilibrium orbit around the machine. In order to use this method on NINA a large number of beam position probes would be needed in order to determine the orbit position to the necessary accuracy.

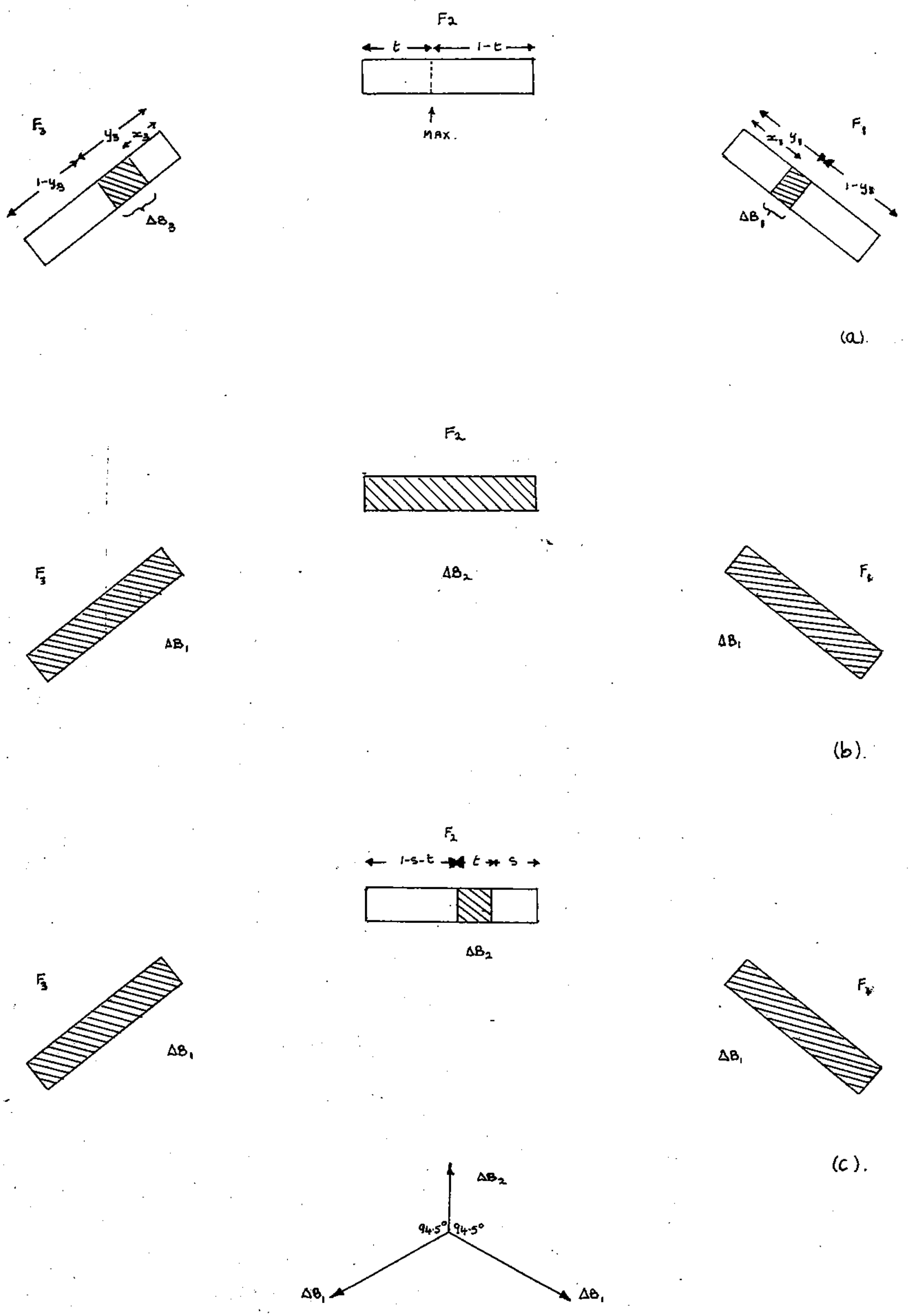
8. Practical Considerations

If a beam bump is to be provided at each F magnet unit it will be necessary to provide each F unit with two pairs of full length dipole windings and one back leg winding. One pair of dipole windings is already available - pole face windings D2 (see report EL/TM 16). The second pair will be added. The conductors will be of 1 mm diameter copper wire giving a total resistance for each beam bump system of 0.6 ohms at 40°C. The pole face windings will also be provided on the D units.

9. References

(1) H. Mieras et al. CEA-TM-128, Cambridge Electron Accelerator.

FIG. 1



$\Delta B = 2\Delta B \cos 85{\cdot}5^\circ$

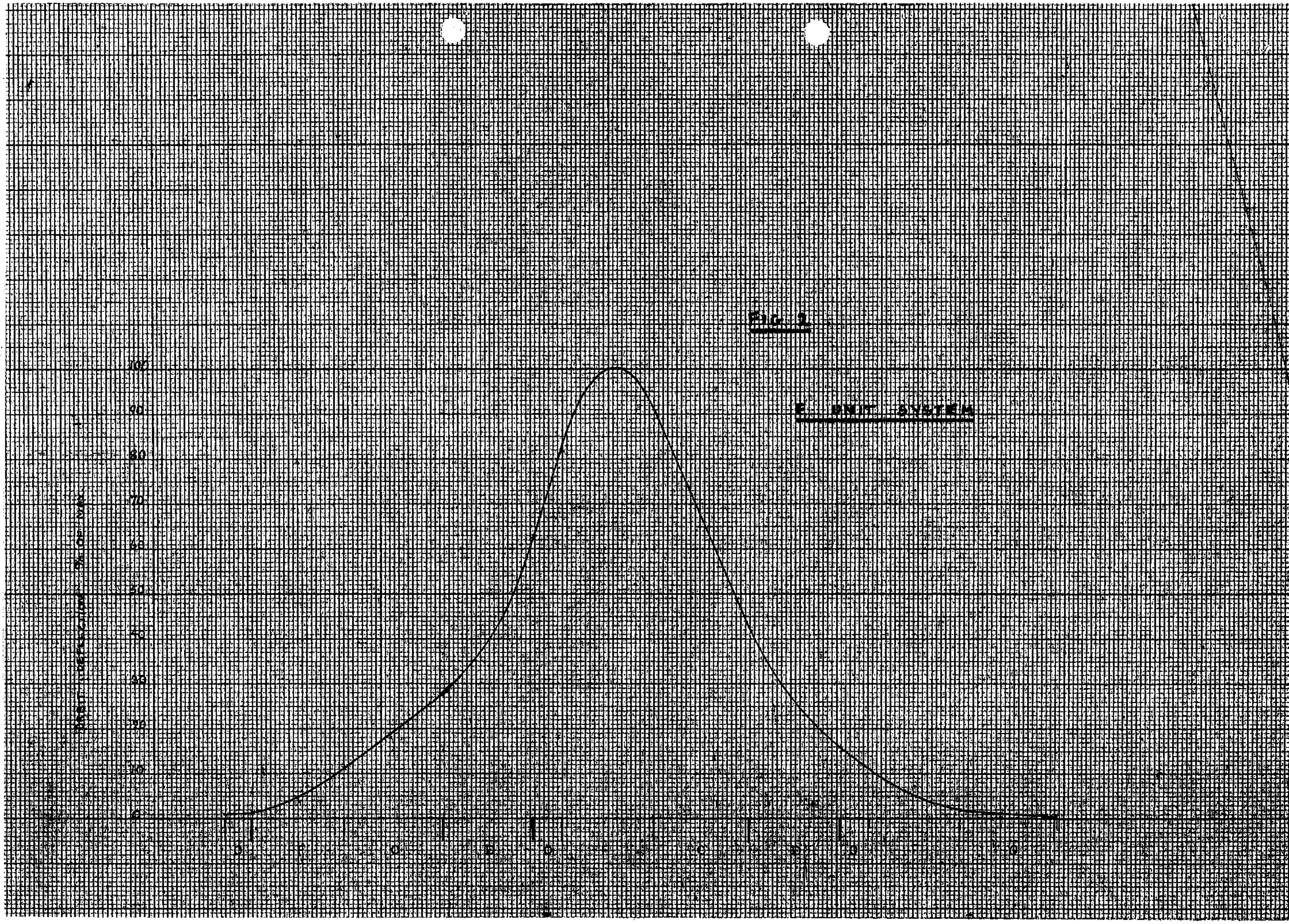


FIG. 2

E UNIT SYSTEM

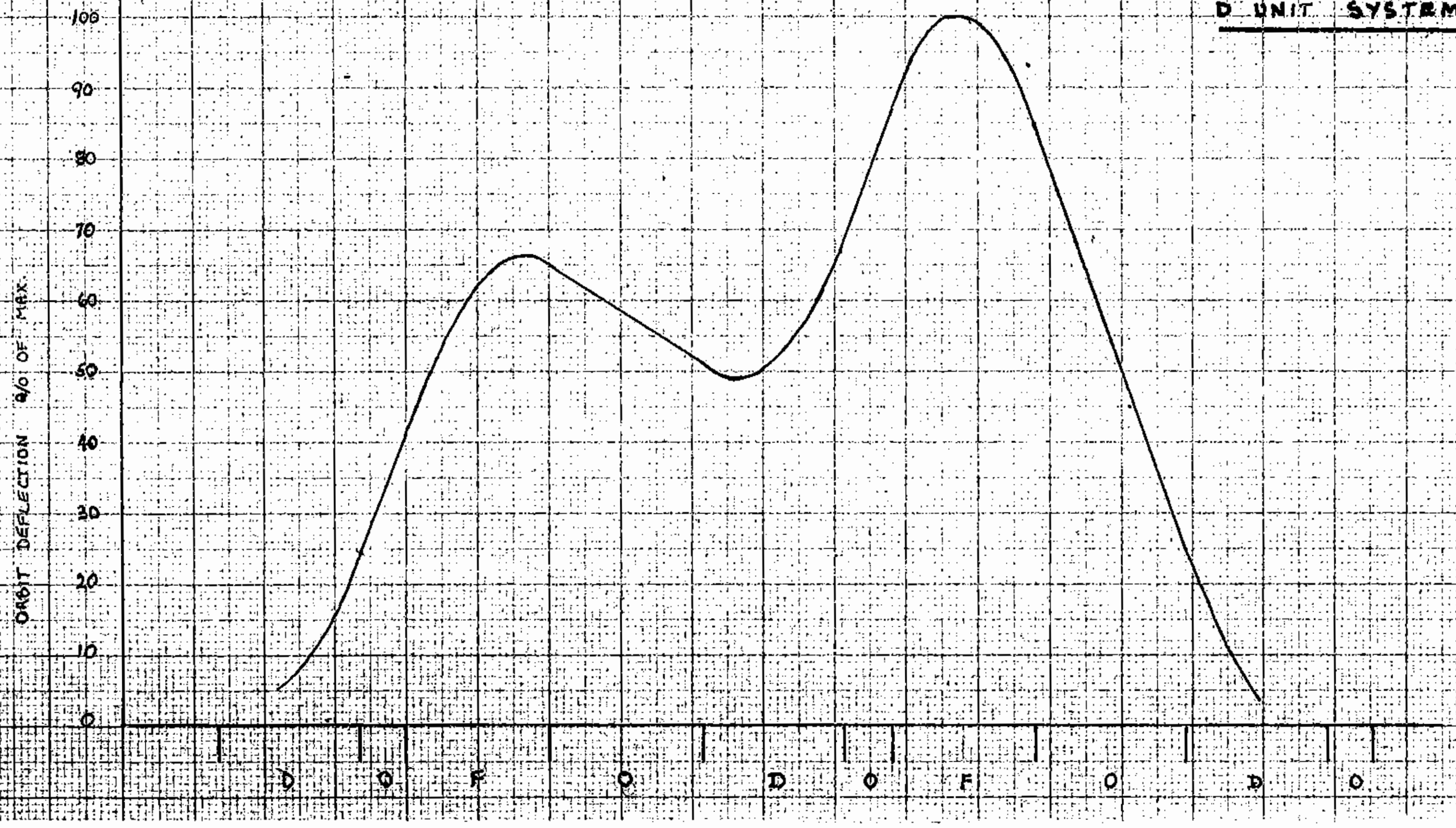


FIG 3

D UNIT SYSTEM