PS/Int.EA 59-6
16th June 1959

MEASUREMENTS ON THE SMALL DEFLECTING MAGNET.

SUMMARY : Tests have been made on a small magnet, which show that it is possible to obtain under d.c. conditions a stray field less than 1 o/o of the main field. The transition in the median plane from main field to stray field has been effected in about 1 millimeter. Under pulse conditions the stray field may be even less. Current densities of 50 A/mm^2 have been realised.

INTRODUCTION.

In accordance with the report on the slow ejection, CERN/PS-59-21, a small deflecting magnet has been constructed. The required kick strength is 2,5 m rad, equivalent with a flux of about 6000 gauss over 36 cm length of deflector for protons of 25 GeV. The magnet is intended to be used in pulsed operation. A peak current of 4800 A is required. Details of the construction are shown in Fig. 5. The C-shaped magnet is made up of twelve packets of araldited laminations and housed in a C-shaped water-cooled aluminium frame. The magnet has a single turn winding. The conductor (a) facing the beam is clamped onto the aluminium frame and keeps at the same time the steel packets in place. The current in this conductor is confined in the mid part, approximately equal to the gap height, by cutting slits from the sides every 5 mm. The slits form however, no obstruction for the developed heat to be transferred onto the aluminium frame. The return conductor (b) has brased onto it cooling fins every 3 cm, which poke through recesses in the steel packet and transfer the developed heat through clamped braided copper strips to the back of the aluminium frame. A back leg conductor (c) is provided for and intends to compensate for the stray field. The conductors are insulated from the frame by scotch tape.

The measuring programme involved the cooling condition, the homogeneity of the magnetic field in the gap and the stray field, under both d.c. and pulsed conditions.

II. COOLING.

The required pulse duration is 10 ms. Allowing for rise-time and tail of the pulse, an effective pulse duration of 30 ms is assumed. Since the repetition rate is one pulse every three seconds, the duty cycle of the magnet is 1 o/o. Therefore the same heat is developed by running the magnet continuously at 10 o/o of the peak value, i.e. 480 A. The copper section of either conductors was 10 x 1 mm^2 so that the continuous current density is about 50 A/mm^2. It appeared that the conductor facing the beam is adequately cooled: it became not more than hand warm. The conductor facing the yoke became about 100^{o}C, and although this is not excessive, we will increase the copper section for this conductor to 10 x 2 mm^2 and also improve somewhat on the heat transfer at the braided copper. The magnet has been run a short time at 1200 A d.c., but some soft soldered joints became undone (the soft soldering was necessary for easy exchange of the components, but in the final application hard soldering will be applied). In the pulsed operation the instantaneous temperature rise of the conductors work out as 45^{o}C. If the conductor (b) were made 10 x 2 mm^2 the instantaneous temperature rise would have been 11^{o}C. Although the system has not been tried out in vacuum, one could be confident that, with the moderate temperature rises encountered in air, the cooling will be satisfactory.

III. MAGNETIC FIELD IN THE GAP.

As pointed out in CERN/PS-59-21, 10 o/o fluctuations in the field could be tolerated. It will be appreciated that this requirement is easily met. However, in view of the more stringent conditions ruling the design of the large deflecting magnet, a brief survey of the field was made with a miniature Hall plate. This Hall plate was embedded in a ceramic rod of 2 mm outer diameter so that an area of 7 x 7 mm^2 could be scanned. Over this area the field appeared to be constant within the measuring error, estimated to be 2 o/o. Also noteworthy is that, if anything, the homogeneity improved while compensating for the stray field.

IV. STRAY FIELD.

a) d.c. conditions. A low stray field is required because the device allows only a few millimeters clearance between the conductor (a) and the circulating beam. A stray field lower than 1 o/o of the field in the gap, everywhere in the volume occupied by the circulating beam, seems low enough, because it would displace or blow-up the beam by an amount of the order of 0.025 m rad, which is small compared with the angular spread of 0.5m rad already present in the circulating beam. One would intuitively feel that the location and section of the outer conductor is more decisive for the stray field than the inner conductor. The latter extended nearly over the full height of the gap, only space was left for insulating tape and fitting clearance. The slits of the outer conductor were cut to leave the centre part slightly larger than the nominal gap height, with the intention to reduce the effective current path width in successive approximations.

We consider first the case that the effective width of the outer conductor is too large and that there exists an optimum width. Then, assuming that the system is linear, we may consider the actual current distribution as a super position of the optimum distribution plus a perturbation, the amount of which we wish to evaluate. Fig. 1 shows how to split the actual current distribution. We note that the integrated area of the actual and optimum distribution have to be equal, so that the distribution of the perturbation is known. If the difference of actual width and optimum width is small, we may approximate the effect of the perturbation as the magnetic field produced by two parallel current threads plus a surface current between the threads. The threads carry each a current Δ i in the same direction as the actual current, and are spaced by the height of the gap. The current sheet carries in total a current of 2 . Δi in the opposite direction.

Fig. 2 shows the field plot in the median plane, as it would be without iron. The influence of the perturbing current sheet is everywhere larger than that of the two perturbing wires, so that the stray field has the sign of the current sheet i.e. if the outer conductor is wider than the optimum width, the stray field has the same direction as the main field and visa versa. The presence of the iron yoke modifies the stray field picture somewhat. Noting that iron behaves as a mirror, the possible amplification amounts to a factor of two at the most. However, at infinitum the iron does nothing and also at the origin where the mirror effect is smallest. From the preceding we infer that the accuracy with which the conductor can be made and positioned relative to the magnetic circuit is a measure for this type of stray field:

$$\left(\frac{\Delta H}{H}\right)_{max} \approx \frac{\Delta a}{2a} \qquad (1)$$

Assuming that a mechanical accuracy of 0.1 mm can be maintained, the aim of a 1 o/o stray field is just about possible.

The low current (500 A) d.c. measurements confirmed the above assumptions. In Fig. 3 is shown the stray field (in the median plane) for three values of 2a : 10.5 ; 9.5 and 8.5 mm. W e note that in the latter case the slits are cut too deep and that the optimum value of 2a must be about 8.8 mm. This is appreciably less than the gap height of 10 mm so that apparently there is a considerable by-pass of current between the slits.

We consider now the effect of the compensating wire (c). If the wire is put parallel to the inner conductor its overall effect is the field produced by the current in the wire plus a current sheet located at the outer conductor, and visa versa. In either case the field of the wire alone, in the plane under consideration, can be neglected when compared with the field produced by the current sheet alone. The direction of the current in the latter coincides with the direction of the main current in situ. The correction thus produced is more penetrating than the correction obtained by adjusting the depth to which the slits are cut, because the effect is identical to the top curve of Fig. 2. Also here we find easily:

$$\left(\frac{\Delta H}{H}\right)_{max} \approx \frac{\Delta i}{i} \qquad (2)$$

This result was verified experimentally.

b) <u>pulsed conditions.</u> It may be expected that under pulsed conditions the aspect of the stray field changes appreciably. Nevertheless one may state that if the stray field is low under d.c. operation, it will be lower under pulsed operation, because the metallic housing screens off time varying fields to the outside. However, one should not use a heavy shielding indiscriminately, because a large d.c. stray field is a sure sign of inhomogeneous main field, moreover precious millimeters would be lost.

The current shape which could be realised with the present equipment is shown in Fig. (4a) i.e. peak current 3150 A to be reached 60 ms after switching on and total pulse duration including tail of 210 ms. The Hall voltage produced in the oscilloscope was roughly identical in shape with the current as shown on Fig. (4a), in so far as the measurement was done for 2a = 10.5 and 9.5 mm respectively. Also the peak value of the flux density vs distance followed reasonably close the measured flux under d.c. conditions as shown in Fig. (3). But with 2a = 8.5 mm the influence of the screening was better detectable. A typical shape of the Hall voltage is shown for a position close to the copper conductor, Fig. (4b), and at a distance of 5 mm, Fig. (4c). The largest value of the flux ever measured was in this case 7 gauss i.e. 0.2 o/o of the main field. However, the accuracy should not be estimated too high because of other disturbing effects.

Compensation with the back leg wire worked out favourably for 2a = 9.5 mm: for distances over 2 mm the largest flux ever measured was also 0.2 o/o of the main field.

Under actual pulsed conditions of 10 ms duration, the picture may change again. The experimental equipment is for the time being not available. However, the 1 o/o aim for the stray field is in all probability not too severe for practical realisation.

E. Braunersreuther

F. Krienen

/fv

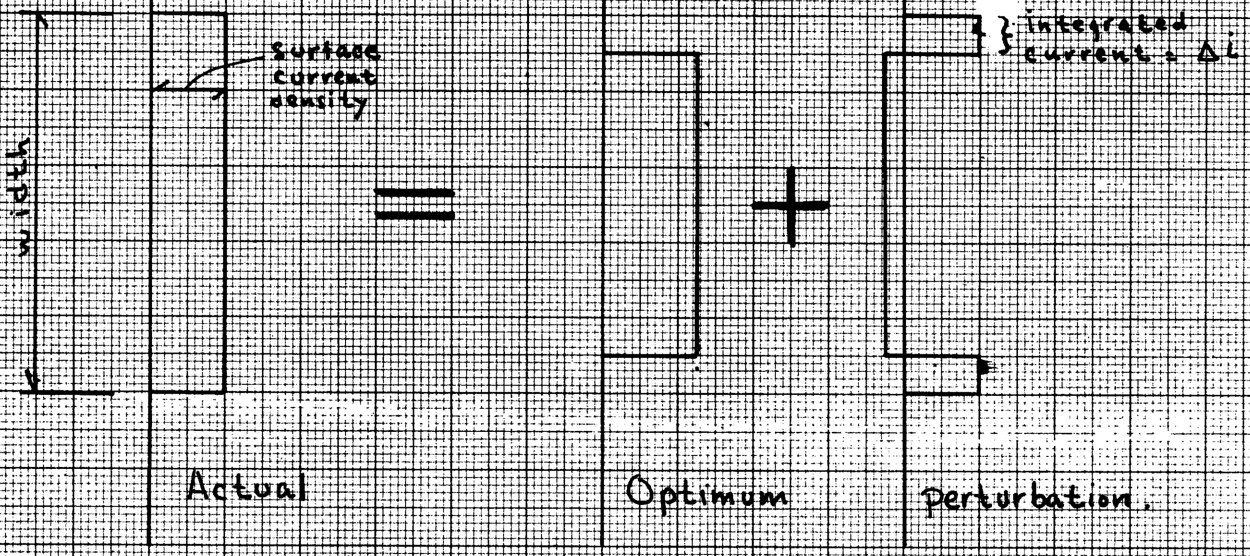


Fig 1 Current distribution

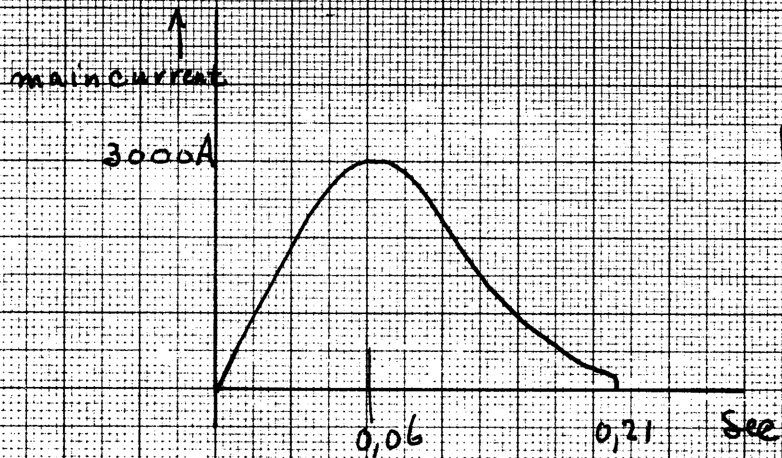


Fig 4a Current v time

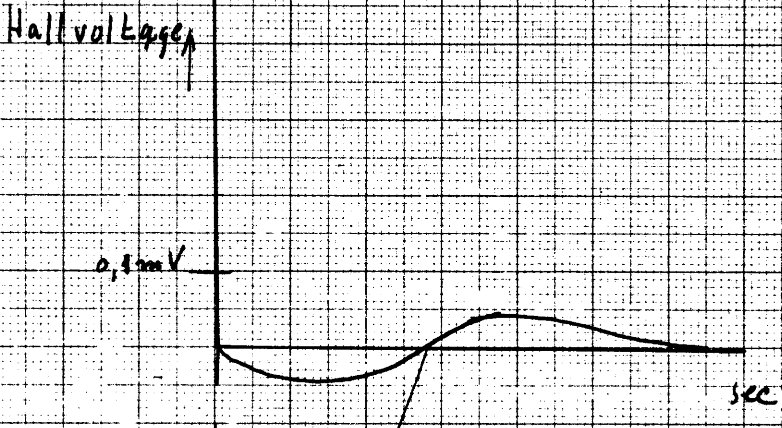


Fig 4b Hall voltage v. time.
(near the conductor
2a = 0,5 mm

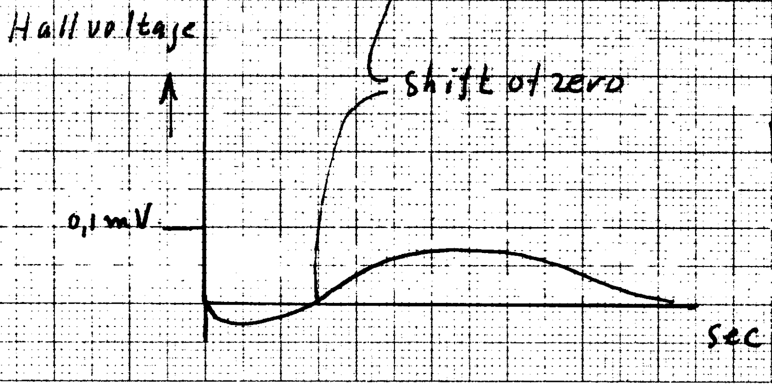
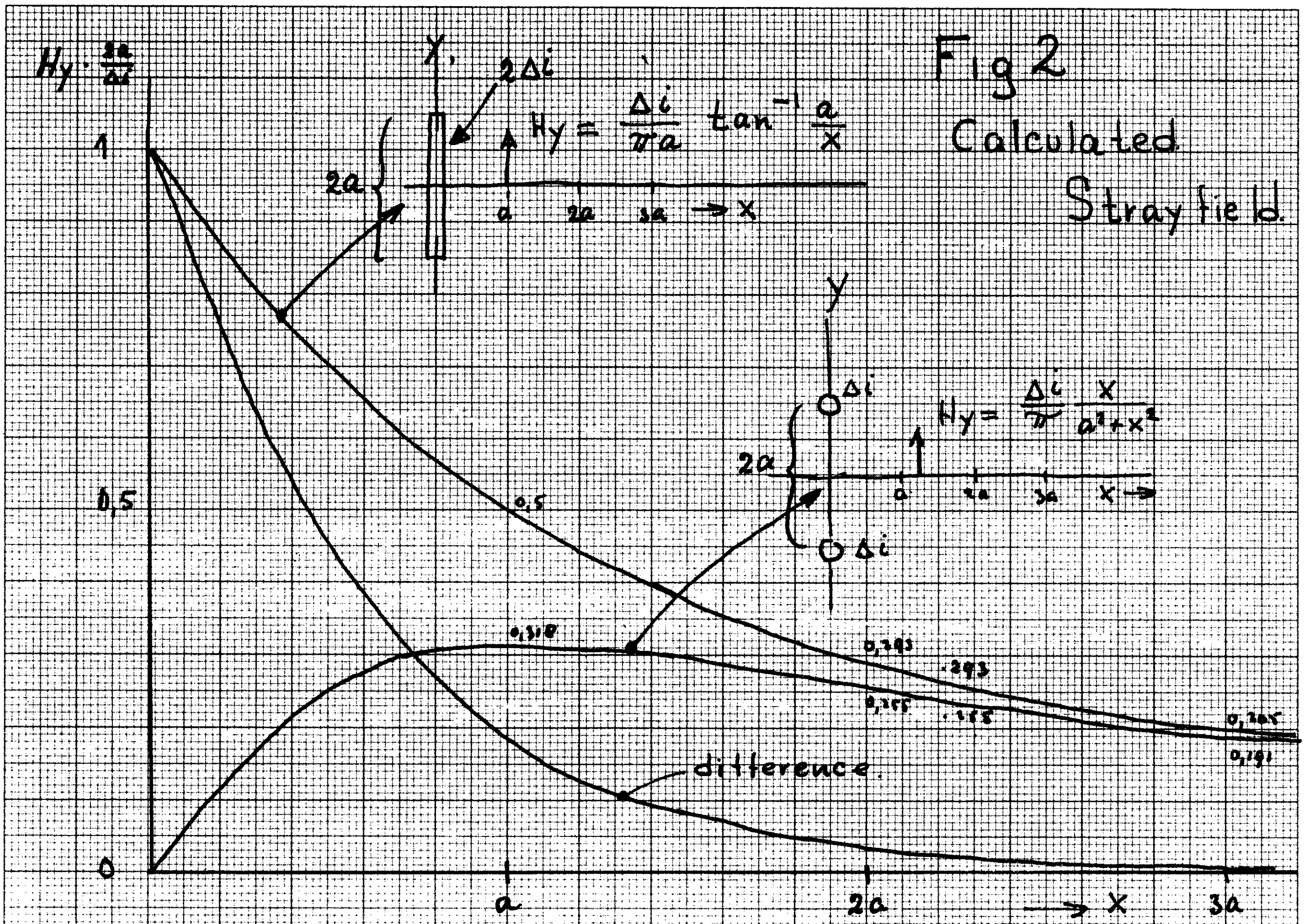
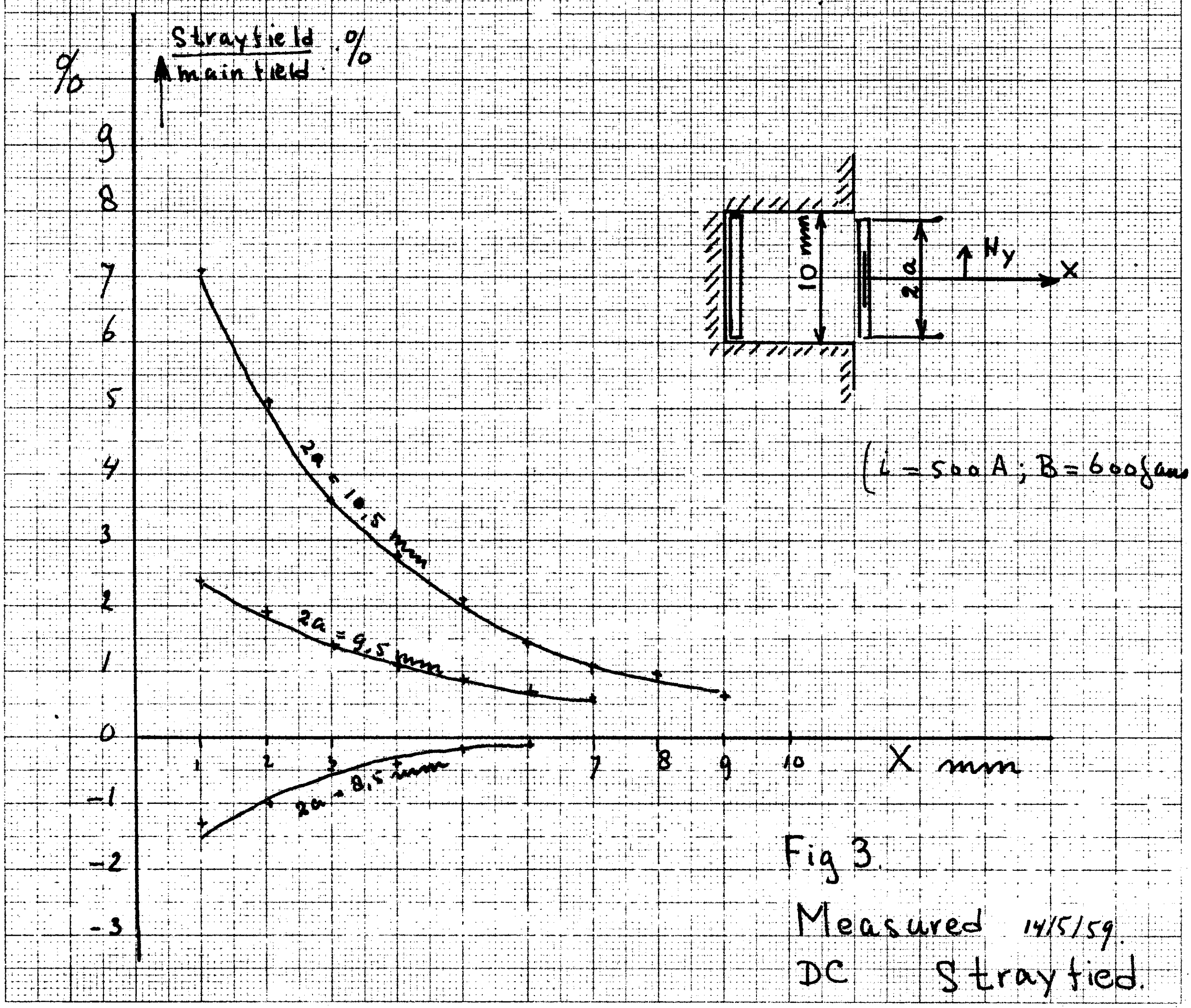


Fig 4c Hall voltage v. time
(5 mm from conductor)
2a = 0,5 mm.

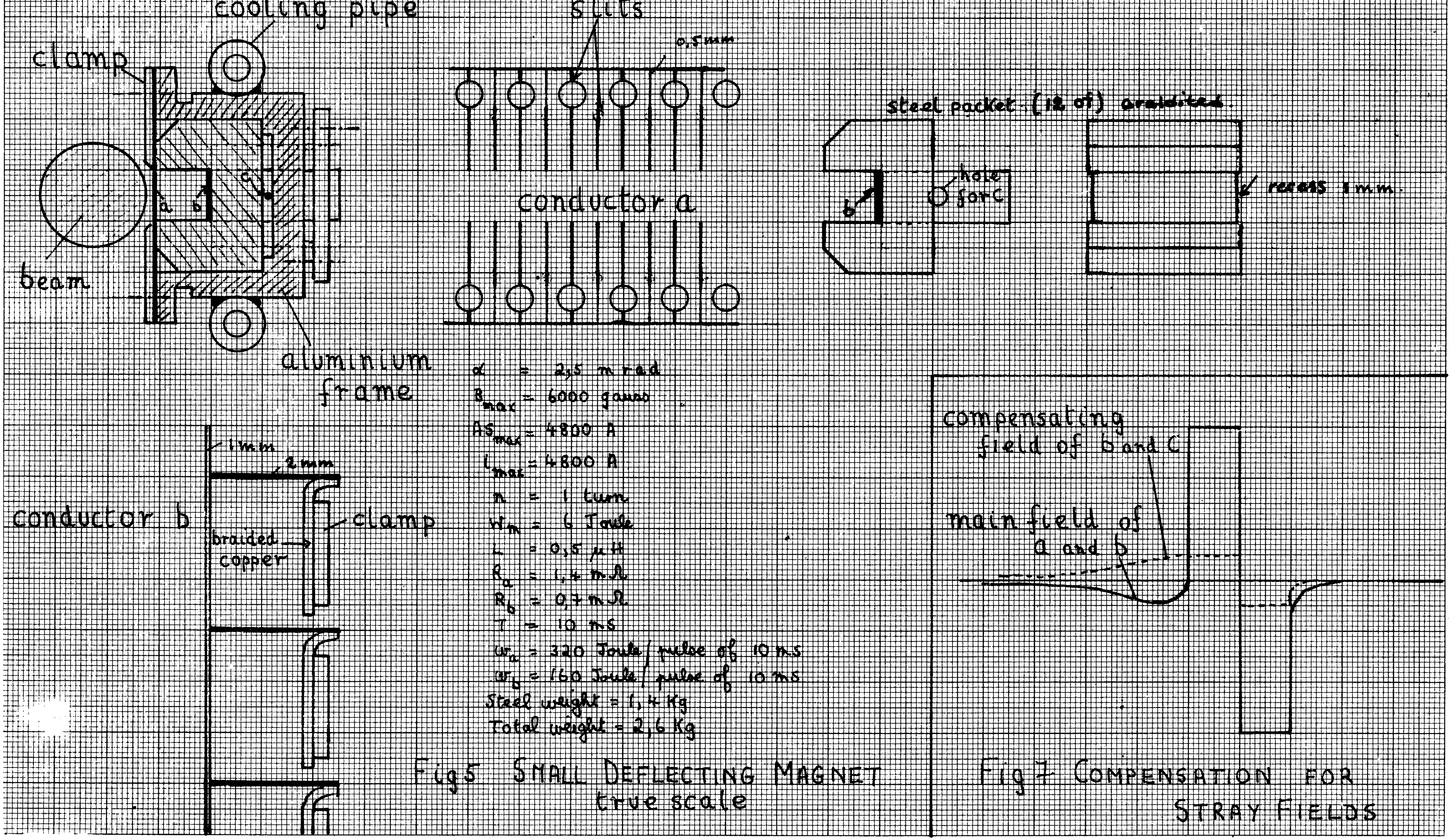




FK 23.

SIS. R59/421

3/3/59.



α = 2,5 m rad
B_{max} = 6000 gauss
AS_{max} = 4800 A
i_{max} = 4800 A
n = 1 turn
W_m = 6 Joule
L = 0,5 μH
R_a = 1,4 mΩ
R_b = 0,7 mΩ
T = 10 ms
w_a = 320 Joule / pulse of 10 ms
w_b = 160 Joule / pulse of 10 ms
Steel weight = 1,4 Kg
Total weight = 2,6 Kg

Fig 5 SMALL DEFLECTING MAGNET
true scale

Fig 7 COMPENSATION FOR STRAY FIELDS

SIS. R59/271

EA 59-3