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MEMO ON THE ACCURACY TO BE OBTAINED FROM THE SURVEYING SYSTEM FOR LINING-UP THE MAGNET UNITS.

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1) Radial tolerance on the magnet units.

In all the calculations made on the closed orbit deviation it has been assumed that the equilibrium orbit inside the units can be aligned to the perfect circle within ± 0.5 mms. There are two tolerances involved in this alignment; one is the mechanical tolerance i.e. the accuracy with which the units can be set down arround the perfect circle, the other is the accuracy with which the equilibrium orbit can be measured inside each magnet unit. We will assume that the overall tolerance is divided equally between these two sorts of error i.e. the units are set down within ± 0.25 mms of a perfect circle and the equilibrium orbit position is known to within ± 0.25 mms with respect to the magnet unit.

The calculations assumed that the equilibrium orbit, inside each magnet unit (length about 5 metres) was perfect inside the unit and that at the end of each unit the equilibrium orbit was within ± 0.5 mms of the perfect circle. Applying now the assumption about splitting the tolerance equally between mechanical and magnetic errors we have that each unit is assumed to be perfect in itself and that the ends of each unit are within ± 0.25 mms of the perfect circle.

One obvious but unpractical way of achieving this tolerance would be to take a geodectic surveying tape and measure the ends of each unit from the centre of the machine. Such tapes have an accuracy of 1 part in 10^6 at best or 1 in 10^5 at the very worst. The radius of the machine is 70 metres so the ends of the sectors can be set to 0.07 mms at best or 0.7 mms at the worst. Taking an average tape therefore it seems quite possible to set the ends of each unit to ± 0.25 mms by this process. However there are about 100 such units and this means 200 length measurements which would take far too long.

The problem is therefore to find a rapid way of ensuring the above tolerances. One suggested method is to set up accurate marker stations near the final position of the perfect circle, these stations being measured from the centre of the machine either by tapes or using high grade theodolites and triangulation. The magnet units are then measured with respect to these marker stations rather than the centre of the machine. Although the number of setting operations are roughly the same all measurements are done inside the ring building from the marker stations once these stations, which can be small in number, have been measured from the centre of the machine. This method of setting up has the advantage that in case of the units becoming misaligned, due to some now unknown cause, after the initial setting up another survey can be taken without refering to the machine centre.

Calculations show that it is not necessary that the units lie on a perfect circle but a perfect ellipse would be just as suitable provided the major and minor axis are not different by more than, say, two or three centimetres. Furthermore the ellipse need not be quite an ellipse but can have smooth irregularities or bumps provided the bumps are not too big or too local. The depth of the bump or, putting it another way, the maximum deviation of the periphery from the perfect circle (or ellipse) depends on the bump length in the following approximate fashion, if we assume that the bump is a smooth sinusoidal excrescence.

Length of bump / Circumference	Peak deviation of bump from perfect circle
$\frac{1}{2}$	2 cms
$\frac{1}{4}$	$\frac{3}{4}$ cms
1/8	$\frac{1}{4}$ cms
1/16	$\frac{1}{4}$ cms

One conclusion that can be drawn from the calculations is that the setting up of the marker stations need not be very accurate perhaps only to about $\frac{1}{2}$ cms providing there are only a few marker stations and that there is a very accurate method for lining up the units with respect to the marker stations For instance if we imagine four marker stations, one at each 90° line, then they can be in error by $\frac{1}{2}$cms with very little effect on the closed orbit. But it is essential that the units lie on a smooth curve going through these four marker stations (or fixed distance from them) and all bumps near 1/8 to 1/16 circumference long should be avoided. Since the four marker stations are not in visual sight of each other due to the narrowness of the ring building, it will be necessary to set up sub-marker stations, perhaps eight in number, within the ring building very accurately measured from the four original marker stations. It should be possible to set up the units from this total of twelve marker stations. Whatever method is used to set up the sub-marker stations from the main marker stations must result in the sub-marker stations not being more than 1 to 2 mms away from the smoothest curve that can be drawn through the four main marker stations. And whatever method is evolved to set up the units must result in the ends of the units not being more than $\pm$ 0.25 mms away from the smoothest curve that can be drawn between all marker stations.

2) Vertical tolerance on the magnet units.

All that has been said above about the radial tolerances applies equally well to the vertical setting up of the units with the difference that no length measurements have to be taken to the centre of the machine, only height measurements. Thus we set up the four marker stations to within $\frac{1}{2}$ cms of a true plane. The sub-marker stations are then set up from the main marker stations to within 1 to 2 mms of the smoothest surface that can be arranged through the four marker stations. Finally the units are levelled to within $\pm$ 0.25 mms of the smoothest surface that can be arranged between all marker stations.

J.B. Adams
Geneva
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