MAIN RESULTS OF THE SSC's MAGNETIC FIELD MAPPING AT GANIL

M. Barré, D. Bibet, A. Chabert, A. Daël, C. Eveillard, P. Lapostolle, J.F. Libin, M. Ohayon, Mrs. J. Sauret

GANIL (Grand Accélérateur National d'Ions Lourds) B.P. 5027 14021 CAEN Cédex (France)
Tel (31) 94 81 11 Telex : 170533 F

Abstract.- We briefly recall the magnetic configuration of the SSC's and give some indications on our magnetic field mapping system. Then, we present the general results together with the method we will use for setting a magnetic field pattern suitable for a given case of acceleration. We conclude with the results obtained for a particular case of acceleration in SSC 1.

1. Magnetic configuration of the SSC's and mapping system

1.1. Fig. 1 gives a schematic mid plane view of the magnetic elements of an SSC including injection and ejection devices.

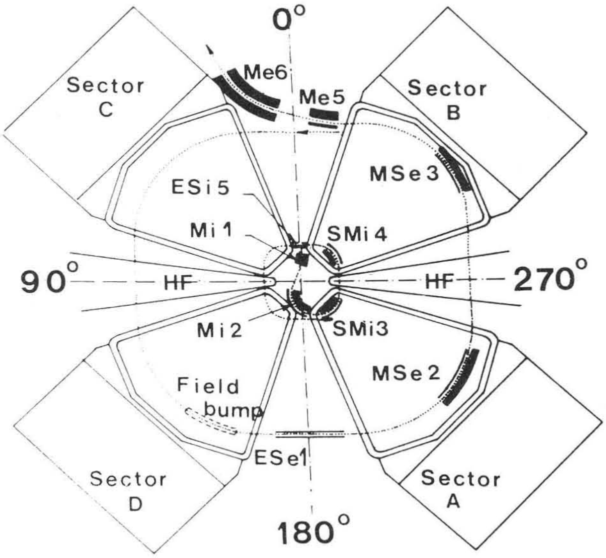

Fig. 1

The GANIL magnet was already presented at Bloomington in 1978 (^{1}) and technological problems solved during its construction are evocated in this conference (^{2}). Injection and ejection elements are also described in the same paper.
We just recall that the four sectors of our SSC's have approximately a 52° magnetic angle, pole profiles being used to obtain a $\bar{B}$ (r) roughly suited for acceleration at $\gamma \sim 1.014$ in SSC 1 and $\gamma \sim 1.054$ in SSC 2 at Bmax ∿ 16 kG. The trim-coils are enclosed in tight boxes screwed on each pole, and supplied either in series for the 4 sectors of one SSC or individually sector by sector : their actual pattern of connection and the power supply system being of course the results of our magnetic measurements.

1.II The magnetic field mapping system was described at Bloomington (^{1}).
Let us just mention the non magnetic pneumatically driven system we use : 90 temperature controlled hall probes are fixed along a radial arm (every 2 cm near injection and ejection and 4 cm elsewhere) extending between 740 and 3220 mm.
Measurements are performed every degree (32400 values for a 360° map are obtained in something like 4 hours). Precision is better than ± 1 Gauss on the whole range of field level (6.6 to 17.5 kG).
A Mitra 125 on line computer is used for data acquisition and pre-treatment and for arm displacement monitoring.

2. Main results from magnetic field mappings

B (I) curves of our magnets, problems related to cycling (required to get a reproductible field pattern at a given level) and to the adjustment of sectors at the same level, determination of trim-coils efficiency will not be presented here. Complete results concerning magnetic measurements are given in internal reports (^{3},^{4},^{5}).

2.I. General considerations :

During all our measurements we always observed to a very good approximation that if two given sets of currents in trim-coils, let say I_1^n and I_2^n add to the main field respectively the contribution ΔB_1 (r,θ) and ΔB_2 (r,θ), the set of currents $I_1^n + I_2^n$ gives ΔB_1 (r,θ) + ΔB_2 (r,θ). From this result, we decided to proceed in the following way to obtain a field pattern suitable for a given case of acceleration :

- due to the very good identity of the 4 sectors of one SSC, unperturbed by injection and ejection elements, we first establish a set of currents I_1^n for the n "isochronism coils" in series for the 4 sectors. This set of currents gives the contemplated isochronous B (r) law : § 2.II.
- injection and ejection elements affect each sector in a different way. Besides a shimming of these elements, we determine for each sector a set of currents I_c^m for the m "correcting coils" which cancels the remaining $\delta\vec{B}$(r) perturbation in each sector in such a way that we are again very close to the law $\bar{B}$(r) of the unperturbed sectors : § 2.III.
- if we need a given $\Delta\bar{B}$(r) perturbation in a given sector to obtain a special effect (phase compression, orbit centering or precession...) we determine the corresponding set of currents I_p^k to be introduced either in isochronism coils or in correcting coils.

The set of currents $I_i^n + I_c^m + I_p^k$ gives a $\bar{B}$(r) law very close to the contemplated one. The remaining refinements will have to be done from beam diagnostic results : § 3.
Moreover, from our results it appears that, even with the effects of the saturation (above 12 kG), it is sufficient to perform measurements at 6 "normalized" field levels (6.6 , 12, 14, 15, 16 and 17 kG) to obtain good enough results by linear interpolation for all the values depending on the field level.

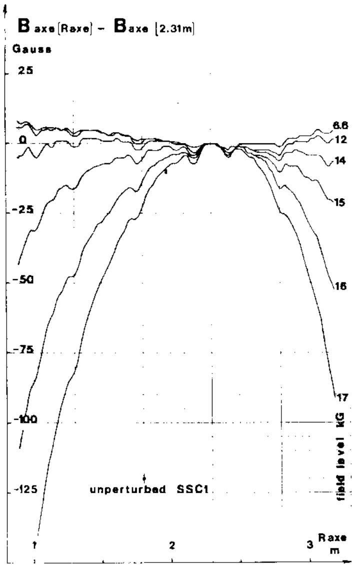

Fig. 2

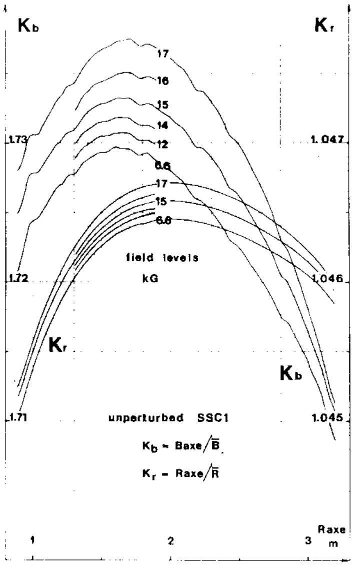

Fig. 3

2.II Unperturbed fields and method of isochronization :

Fig. 2 gives the curves B_{axis} (r_{axis}) for SSC 1 at the six normalized levels (mean values taken on the four sectors). We then determine on computer the non accelerated closed orbits in these 6 field maps and obtain for each orbit the two ratios $K_b = B_{axis}(r_{axis})/\bar{B}$ and $K_r = r_{axis}/\bar{r}$

Fig.3 gives K_b and K_r functions of r_{axis} for the six levels (case of SSC 1).

These 3 sets of curves describe the unperturbed SSC and are used to determine the I_i^n set of currents necessary for isochronization by the following formalism : for a given ion (Q,A,f_{rev}) to be accelerated at the fundamental frequency f_{rev}, we have on the orbit of mean radius $\bar{r}$:

$$\beta = 2\pi\bar{r}\, f_{rev}/c \text{ and } \bar{B}(\bar{r}) = (A\, m_o c^2/Q).\ \beta\gamma/(\bar{r}.c)$$

Using the two experimental ratios K_b and K_r, we obtain the value of isochronous field on the sector axis :

$$B^{iso}_{axis}\ (r_{axis}) = (A\, m_o c^2/Q).\ (2\pi f_{rev}/c^2).\gamma.K_b$$

with γ calculated from $\beta = (2\pi\ r_{axis}/K_r).(f_{rev}/c)$

The"isochronism" trim-coils contribution is thus given by : $\Delta B_{axis}\ (r_{axis}) = B^{iso}_{axis}\ (r_{axis}) - B_{axis}(r_{axis})$

and a small code gives the corresponding set of currents = I_i^n .

This method is good if K_b and K_r are the same for the unperturbed and the isochronous fields, that means if the non accelerated closed orbits are the same in the two fields : for SSC 1, the relativistic corrections being rather small (less than 100 G over the whole radial range) this is true, but for SSC 2 the corrections are as high as 400 G and we have to introduce on K_b and K_r a small experimental correcting factor depending on frequency and radius, for example :

$$K_{b(corr)} = K_{b(uncor)} \left[1 - 0.6\ (r_{axis} - 0.8)(1.1 - 0.26\ f_{rev})10^{-4}\right]$$

Results are very good as it can be seen on Fig. 4 (Ar^{+6} accelerated at f_{rev} = 1.93 MHz in CSS 1).

2.III. Perturbed fields, shimming and corrections : injection and ejection devices (Mi1, Mi2, SMi3, SMi4, MSe2, Mse3, Me5 and Me6) change the field by giving, compared to the unperturbed one, not only mean field errors $\delta\bar{B}$ but also components $\delta(\partial B/\partial r)$ and $\delta(\partial B/\partial\theta)$ which affect strongly the orbits.

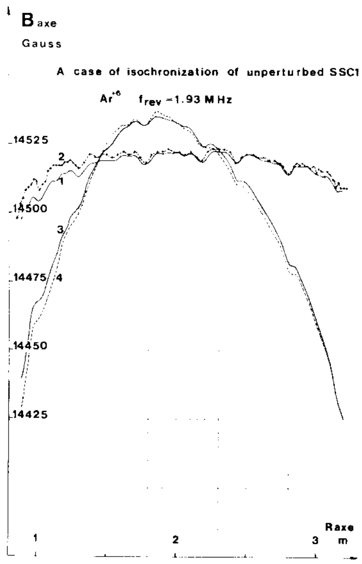

Fig. 4

Curve 1 : initial field as computed

Curve 2 : initial field as measured

Curve 3 : isochronous field as computed

Curve 4 : isochronous field as measured.

Fig. 5 shows for each sector of SSC 2 the effects of injection elements on the mean field (case $B_{max} \sim 16$ kG).

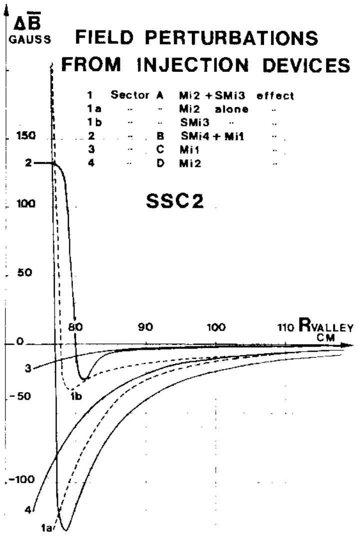

Fig. 5

We then decide to compensate the most perturbing elements, namely Mi2, SMi3 and Me5 as near as possible to the perturbation they introduce. To do that, we determine experimentally either local plate shimming (SSC 1) or a combination of plate shimming and pole profile modification (SSC 2).

Fig. 6 shows the compensation system of Mi2 and SMi3 in sector A1 of SSC 1.

After correction, it remains a residual perturbation which, if acceptable on gradients, has to be corrected in mean field. From measurements at the 6 levels, we know for each sector the $\delta\bar{B}$ to be corrected and we can interpolate at other levels. A small computer code gives the set of currents I_c^m which cancels the $\delta\bar{B}$.

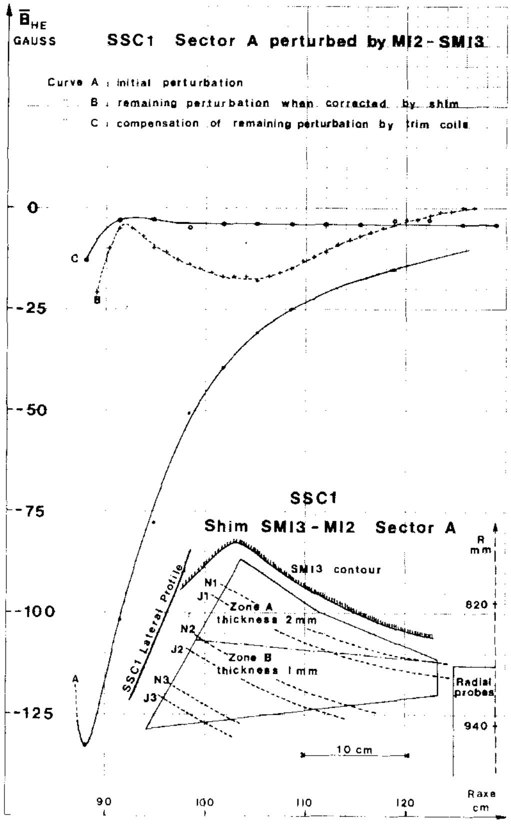

Fig. 6

2.IV. Introduction of special field patterns : either for phase compression mechanism, or to create an orbit precession (SSC 2)or to compensate HF effects (SSC 1 with h = 14)or to allow for orbit centering, we need special field pattern characterized by $\Delta\bar{B}p$ on a given sector : these perturbations are known (calculated to obtain the required effect) and we can therefore compute with our code the set of currents I_p^k.

2.V. Conclusion : determination of trim-coils connections and supplies.
From all our field mappings and simulations (around 250 maps) we were able to determine a system of connection and supply for our trim-coils allowing all the field settings we wish.

3. Application : magnetic field setting for a given case of acceleration

We present the results obtained for acceleration of C^{+2} at f_{rev} = 1.95 MHz in SSC 1 (h = 7, f_{HF}=13.65 MHz : highest energy of CSS 1).

3.I. Isochronization and corrections :
Into the computer are stored, for the 6 normalized field levels, measured values of :

- unperturbed B_{axis}, K_b, K_r, as functions of r_{axis} (mean values over the four sectors)
- remaining perturbations from injection and ejection elements $\delta\bar{B}$ as calculated on closed orbits for each sector .
- trim-coil configuration and trim-coil efficiency.

A.Q. f_{rev} being given, a general code determines first the required field level on the sector axis at a given r_{axis} (r_{axis}= 2.31m, a radius where there is no perturbation) and then interpolates between the 6 levels, thus giving B_{axis}, K_b, K_r, $\delta\bar{B}$ at the calculated level.

Using the method of § 2.II, we compute $\Delta\bar{B}_{axis}$ for isochronism, we know $\delta\bar{B}$: the code determines the sets of currents I_1^m , I_c^n .

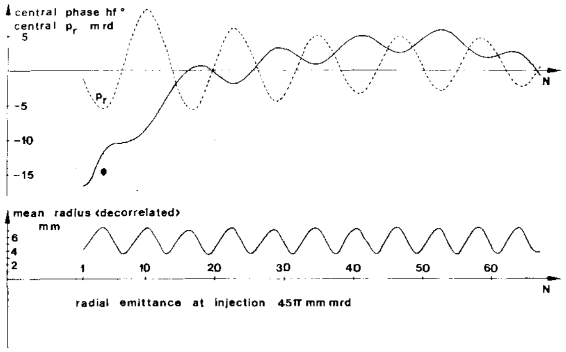

Fig. 7

After cycling of the magnet and having made the balancing of the 4 sectors, we introduce I_1^m and I_c^n and perform a 360° mapping of the resulting field. Main results are summarized on Fig. 7, which shows at azimuth $\theta = \pi/2$ the phase and radial momentum ($p_r = v_r / v$) of the central particle and the decorrelated beam radius versus turn number. The beam is not well centered (phase and p_r oscillations) nor well adapted in four dimensional phase space (Δr_{DC} oscillations) ; it would be possible to refine injection to reduce these oscillations, but anyway we can see from the central phase pattern that the resulting magnetic field is very good from the point of view of isochronism, except perhaps on the very first turns. Moreover, from the Δr_{DC} pattern, we can say that there is no unacceptable remaining field gradient perturbations or harmonic distorsion.

4. Conclusion.-

Magnetic configuration of the GANIL SSC's, including trim-coil system and correction of the perturbations of injection, ejection elements by shimming or pole profile tuning, is quite satisfactory. On another hand, the method we use to determine the trim-coil setting proves to be very attractive ; it gives very good results and needs only a few memory locations for its data, the code itself being very small and fast. Of course, beam experiments will be necessary to have definitive conclusions but it seems that no serious problems could appear with setting of magnetic fields.

References

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