STATUS REPORT OF SARA

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ABSTRACT

Recent improvements to SARA are described. Three years operation with two ECR sources and their developments are presented. Differences between flux measurements of the 4 sectors of the second cyclotron show the need to uncouple the trim coils currents of the sectors.

1 - INTRODUCTION

S.A.R.A. (Système-Accélérateur Rhône-Alpes)[1-2] is a two cyclotron accelerator designed to accelerate heavy ions up to 40 MeV/u up to calcium, the maximum energy decreasing to 10 MeV/u for xenon. The first cyclotron with a K of 84MeV, originally devoted to light ions was rebuilt in 1987 for heavy ions. After stripping the beam is injected into a separated sector cyclotron of K = 160 MeV.

2 - OPERATION

Table I presents the statistics of operation for the last two years. 96 beams have been delivered in 1990 and 130 in 1991. Typical total setting up times for a new beam are four hours for one cyclotron and nine hours for the two machines.

In 1991, the breakdown time increased sharply because of a field dependent vacuum leak on the lower pole D_1 of the post-accelerator. Limitation of the magnetic field and injection of a sealing compound on the O ring allowed limited operation till the winter shutdown. A complete dismantling showed noticeable vertical movements of the yokes attributed to displacements of the concrete floor of the vault and a deep crack in the O ring.

Precise levelling of the yokes has been achieved for the whole machine and optical markers have been added to critical points of the poles for precise control.

Year		Total time	Tuning	On target	Develo-pment	Break-down
1990	hours	3632	438	2651	200	343
	%	100	12	73	5,5	9,4
1991	hours	4352	392	2912	312	736
	%	100	9	67	7	17

Table 1 - Operation of SARA

3 - AXIAL INJECTION LINE

Since 1989, an axial injection line for two ECR sources equips SARA. This 18 m long line has an 11 m long section in which a periodic focusing is ensured by 13 lattices of electrostatic lenses[3]. The rather low voltage (-8 to -15 KV) on these electrodes and the good cryogenic vacuum (2.10^{-9} torr) were important factors in maintaining high reliability over the last three years.

The overall transmission from the source to the center of the cyclotron is of the order of 75 %, the losses are due to some mismatching between the first 8 m straight section and the 3 m section leading to the yoke. The decentring of the central trajectory is attributed to the mechanical misalignement of the electrostatic lenses[4]. This causes oscillations of the trajectories that may subsequently cross regions of the lenses where aberrations are no longer negligible.

The possibility of rapid commutation of the two sources is very useful for simultaneous development on the source not used in injection, for quick change in case of failure, and also for preparing one source before changing the accelerated beam.

4 - ECR SOURCES

SARA was one of the first cyclotrons equipped with ECR ion sources . MINIMAFIOS built by R. GELLER[5] has been operating at SARA since 1983. In 1989, FERROMAFIOS was installed together with the new injection line. In 1991, it has been replaced by CAPRICE[6]. Table 2 and 3 show the ion yields of these sources.

Charge state	5	6	7	8	9	10	11	12	13	14	15	Feed
^{19}F	7	0,3										SF_6
^{20}Ne	80	24	11									Ne
^{27}Al	3	2,5	6,3	9,3								Al_2O_3
^{28}Si			11	9	2,5							SiH_4
^{32}S	21	10		20	7							SH_2
^{35}Cl				23	11	1,1	0,3					CCl_4
^{40}Ar			20	22	13	10	2,5					Ar
^{40}Ca				8,5	10	12	15	2	0,6			Ca
^{48}Ti						10	8		1,8			Ti
^{56}Fe							5,5	2,4	2,6			Fe
^{58}Ni							2		3,2	4	0,8	NiO
^{84}Kr							8	5	4	1		Kr

Table 2 - Intensities from MINIMAFIOS (electrical µA)

Charge state	9	10	11	12	13	14	15	16	17	18	Feed
^{32}S	15	7									SH_2
^{40}Ar			8	3,6							Ar
^{40}Ca			20	3							Ca
^{63}Cu		12	9								Cu
^{80}Se						1,6	1,3	1			SeH_2
^{84}Kr					5,7	10	8,6	6,8	3,3	1,1	Kr
^{86}Kr					1,3	2,5					Kr

Table 3 - Intensities from CAPRICE (electrical µA)

Metallic ions

MINIMAFIOS has been used for metallic ions with the insertion method, and a lot of long runs (two weeks) have been completed with calcium and aluminium. The sample (pure metal or oxide) is introduced close to the ECR surface and is driven by a stepping motor for precise control of its position and its advance rate. In our case, introduction 4 mm off-axis gives better results. With this method, the position of the sample and its speed are strongly coupled with the currents in the confinement coils that define the ECR surface, and to the microware power, all these parameters modify the temperature of the sample and its vaporization rate.

Some control is obtained by modifying heat exchanges with the supporting rod. Low vaporization temperature samples like calcium need to be supported on rather good heat conductors and refractory samples (Al_2O_3, NiO,...) have to be held with smaller diameter supports.

The pollution of the chamber by metal evaporated in excess is important, it reduces the efficiency of the source for subsequent runs and renders careful cleaning of the source indispensable.

Metallic ion development has begun on CAPRICE, using a small oven similar to that of GANIL[7]. First results on calcium at 800° C show the advantages over the insertion technique : ion yields are greater, the sample consumption is of the order of a few tenths mg per hour, the stability is good and the tuning is easier because the temperature of the sample is controlled independently of its position and of the magnetic confinement. Copper and nickel are currently under development.

5 - INCREASING THE TIME BETWEEN BEAM BURSTS

The radio frequency range of the first cyclotron is 10.5 to 16.5 MHz and the harmonic numbers are 2 and 3, the second cyclotron runs at twice this frequency and the harmonic numbers are 4 and 6 respectively. Time separation between these bursts corresponds to the first acceleration frequency and lies in the range from 60 to 100 ns and this time is too short for precise time-of-flight measurements.

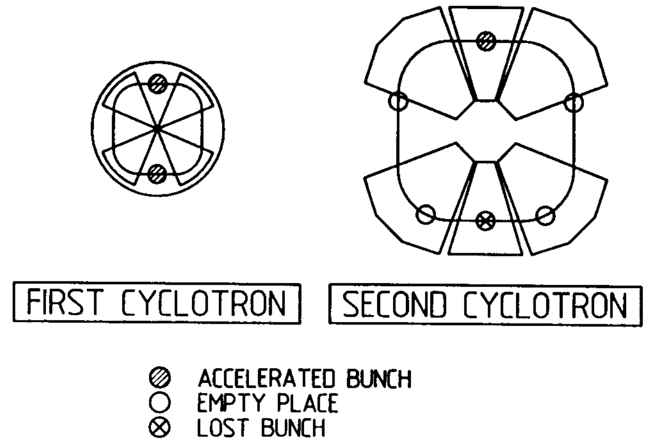

Figure 1 - Schematic view of the beam bursts with the 1st cyclotron in harmonic 2 and the 2nd in harmonic 5 for Neon 6^+ at 30 MeV/u.

When the first cyclotron is running in harmonic number 2, two beam bursts lie on the same turn, 180° apart. The second cyclotron RF is twice that frequency, in harmonic 4, four possible places are available for acceleration on each turn, only two of which are occupied by bursts, each 180° apart. By running the post-accelerator at different harmonic numbers, it is possible to extend time separation up to 300 ns.

If the harmonic number becomes 5, it would be possible to accelerate five bursts, but just one of the two injected bursts is accelerated, the other falls just between two places and is lost (Fig. 1). So one burst remains per turn ; beam burst separation has doubled. In the same way, with the first cyclotron in harmonic 3, and the second in harmonic 5 or 7, according to the frequency, one burst out of three is kept, original separation is multiplied by three. In this way, time separation between bursts ranges from 160 to 280 ns.

6 - MAGNETIC FLUX MEASUREMENTS

6.1 - Motivation and method

The orbits in the second cyclotron are frequently off-centred at intermediate radii even when the early orbits are well centred. This would seem to indicate that the magnetic fields in the four sectors are unequal. Individual adjustement of the field of each sector was not sufficient and indicated that the shapes of the field maps were different. Moreover the influence of the injection magnets in the center region is not known precisely. Hence it was decided to undertake magnetic measurements of the four sectors with the machine nearly completely assembled (without the resonators) to obtain more accurate information on their differences.

The measurement of a field map point by point posed too many practical problems. A global method was more appropriate in our case, so we chose the measurement of variations of magnetic flux generated by the poles when a large coil, in the form of boomerang, moves by defined steps along the sector radius (Fig. 2).

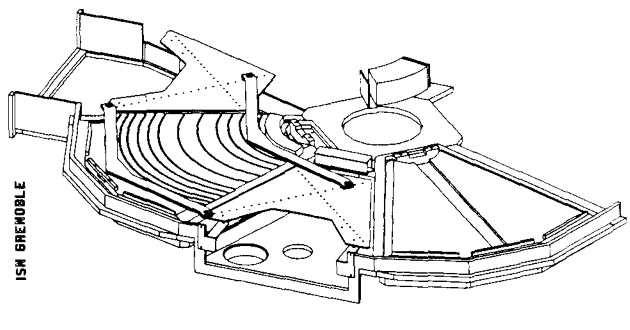

Figure 2 - Magnetic flux measurements. The coil is shown in two extreme positions on the pole of sector D_2.

Integrating the voltage of the coil gives the measurement of the flux variation between two positions.

$$\int_{t_1}^{t_2} V_{coil}(t)\, dt = -\Delta\phi_{i,\, i+1}$$

if the coil is moved from radial position i at time t_1 to i+1 at time t_2.

The coil was wound on a glass fiber epoxy material core form that was placed in a box of the same material

The angle betwen the two straight parts of the 1600 turn coil was a compromise chosen to cover no more than two trim coils from the center to outer radius (close to the trajectories). The coil was radially displaced in 60 mm radial steps between holes precisely drilled on templates previously centered on the magnetic structure, 23 holes defined 22 measurements. The radial extent of the coil is also close to 60 mm. Each step corresponds to a variation of 27 cm^2 in the surface of the poles seen by the coil so a nearly constant flux variation had to be integrated for each field level, improving the precision of measurements.

The displacement of the coil was manual ; one person at each extremity slid it on a teflon plate between 2 radial positions. Precise positionning at the drilled holes was obtained by dowel pins with compensation for backlash. Each movement was made in a period slightly less than the 20 s integration time, and these measurements of $\Delta\phi$ were sandwiched between dummy measurements which were used to correct for drifts in the integrator and to detect eventual parasites.

The apparatus used was a Metrolab PDI 5025 integrating voltmeter connected to a PC for logging and sequencing of the operations.

Measurements were made on each pole at 4 field levels and NMR probes in regions of "flat" magnetic field normalized the measurements and compensated drifts of the four sectors (Fig. 3).

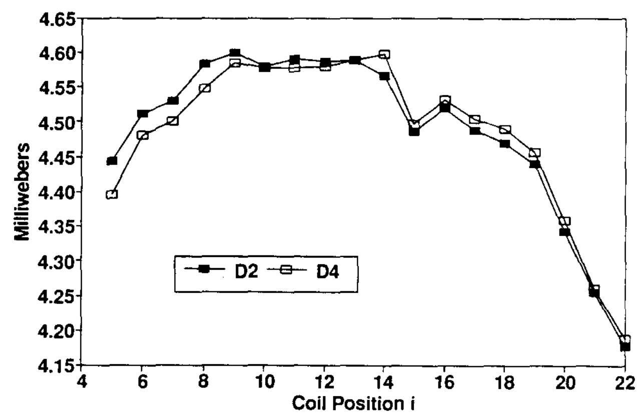

Figure 3 - Magnetic flux variation when the coil is moved from position i to i+1, for sectors D_2 and D_4 at a nominal field of 1.0 T.

It was difficult to maintain the coil at a constant temperature, but a rough stabilization of the cyclotron vault was installed, giving a variation of ± 0.4° C. Since the surface thermal expansion of glass fiber of the support is 8.10^{-5} per degree, this led to an error of ± 3.10^{-5} on the flux.

Tests of the measurements showed that after cycling the magnetic field and reinstalling the coil in a sector, a reproducibility of ± 3.10^{-4} was obtained ; this figure is limited by mechanical problems.

6.2 - The exploitation of the measurements

The field maps of the sector D_4, previously measured with Hall probes, were used as references to calculate the flux seen by the coil in each of its 23 positions. This calculation was done by summing the elementary fluxes at each point of the field map, no interpolations were used.

Using the experimental measurements of the variations of flux of each sector with respect to those of D_4 we calculate a small correction for each of the coil positions. For instance, for the sector D_2

$$\delta_i = \Delta\phi^{exp}_{i,\, i+1}(D_3) - \Delta\phi^{exp}_{i,\, i+1}(D_4) \qquad (1)$$

where $\Delta\phi^{exp}_{i,\, i+1}$ is the variation in magnetic flux measured when the coil is moved from position i to position i+1, defined above.

Our first aim is to produce a field map which represents the sector D_3. The first step is to use these values of δ_i (of the order of 10^{-5} Weber) to estimate the effective magnetic flux in D_2.

Since no absolute measurements of flux were made we suppose that there is one point where the actual flux is equal to the flux calculated in our reference field map. We call this point p the pivot.

$$\phi_p = \phi_p^{calc} \tag{2}$$

We can consider that for positions p + j, j = 1, ... (23 - p), the flux through the coil i :

$$\phi_{p+j} = \phi_{p+j}^{calc} + \sum_{i=0}^{i=j-1} \delta_{p+i} \tag{3}$$

Whereas for positions p - j, j = 1, ... p - 1

$$\phi_{p-j} = \phi_{p-j}^{calc} - \sum_{i=1}^{i=j} \delta_{p-i} \tag{4}$$

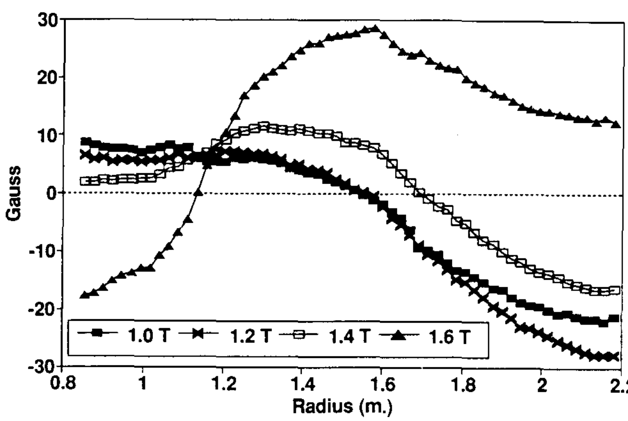

Figure 4 - Differences between mean magnetic fields of sectors D_2 and D_4, at four levels.

Thus to obtain the map for D_2, all the points in the reference field map $B(\theta,r)$ of the D_4 sector which lie under the coil in position i must be corrected by a factor.

$$F_i = \frac{\phi_i}{\phi_i^{calc}}$$

where ϕ_i is given by equation (3) or equation (4) (Fig. 4). D1 and D_3 are treated in the same way.

Our final aim is to obtain three sectors identical to D_4. Standard calculations of the trim coils, comparing these corrected maps to that of D_4, determine the currents needed to obtain identical magnetic fields in the four magnets. The 15 trim coils of the four sectors that are at presently serially fed will have to be decoupled. Further studies will indicate the number of individual coils to be fed separately or corrected either by an electronic shunt or by a power supply connected in parallel.

7 - VACUUM SYSTEM

7.1 - The automation of the vacuum system

The automation of the vacuum system that began with the injection line has been completed.The pumps, valves and pressure gauges of the entire machine, from the ions sources to the target chambers, are interfaced to several industrial programmable controllers. These controllers are ideal for surveillance, and can also supervise a sequence of operations following a single command. They are connected to a P.C. by a serial bus (RS485).

The application interface consists of 8 pages of synoptics which are colour graphics representing the geographic position and state of each element (Fig. 5). The operator interacts with the system uniquely with the mouse, by "clicking" on a virtual button. All commands and changes of state are logged on an on-line printer.

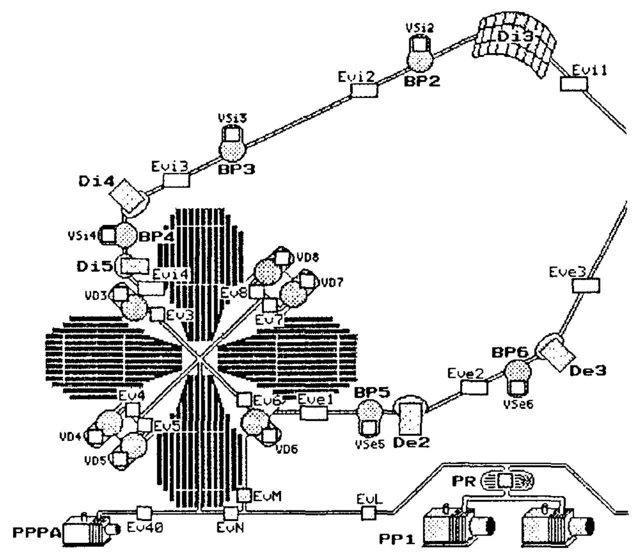

Figure 5 - Partial view of the synoptic of the vacuum system.

This system is proving to be reliable, flexible, and "user-friendly".

7.2 - Cryogenic pumping

Pumping the 3.5 m^3 vacuum chamber of the second cyclotron was ensured by 6 oil diffusion pumps with cold traps, 2 pumps being placed in each resonator, and one in the free sector.

Eight years experience showed that undetected failures in the cooling of the cold traps and troubles in the old control system led to important oil pollutions of the resonators. This reduced the maximum dee voltage and polluted the electrostatic inflectors, particularly at the extraction, that had to be frequently removed for cleaning.

Six cryogenic pumps (CTI, CT 320) with a pumping speed of 3000 l/s for air have replaced the oil diffusion pumps and are controlled by the automation system described above. RF voltages of 60 KV have been quickly obtained after cleaning the resonators.The large pumping speed for water vapor insures short pumping times after opening the chamber and quick resuming of the operation.

8 - FUTURE DEVELOPMENT

The project PIAFE[4)] of accelerating fission products coming from the I.L.L. high flux reactor requires the transport of singly charged radioactive ions, injection into an ECR source for multiple ionization to typical q/m of 0.15 and acceleration by S.A.R.A. Extraction at a continuously variable radius in the second cyclotron could permit variation of energy from 4 to 10 MeV/u.

9 - ACKNOWLEGMENTS

We are greathly, indebted to Mrs TKATCHENKO (CEN Saclay) for helful discussion about field measurements.

10 - REFERENCES

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