THE GRENOBLE ECR AND SARA SYSTEM

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Introduction

SARA (Système Accélérateur Rhônes-Alpes) was presented at the last Conference on Cyclotrons at CAEN.

It is a two cyclotron accelerator ; the first one is a compact cyclotron (K = 88) which has been running since 1967, the second accelerator (K = 160) has four separated sectors. Its construction began in 1977, the first beam was accelerated in March 1982 at the nominal energy of 30 MeV/amu and the first physics experiment was completed in May 1982.

SARA has been routinely operated since September 1983 with the ECR MICROMAFIOS source designed by R. GELLER.

General description

SARA has already been described [1, 2] with more details, let us summarize a few points.

First cyclotron

Originally designed for light particles (up to 60 MeV protons), the operating range of this cyclotron has been extended to heavy ions by a PIG ion source, it was only able to accelerate ions from Li to Ar with energies from 8 MeV/amu to 3 MeV/amu respectively.

MAGNET	
Pole diameter	2.12 m
R extraction	.88 m
Gap = min.	.16 m
max.	.36 m
Average field	1.6 T
4 Spiral sectors	
11 Circular correcting coils	
4 Harmonic coils	
Weight	200 t
Max. power	270 KW
R.F.	
2 Dees 80°	
Frequency min.	10.7 MHz
Frequency max.	21 MHz
Tuning by moving panels	
Max. RF voltage	60 KV
Harmonics	1, 2, 3
EXTRACTION	
1 Electrostatic channel	
1 Magnetic channel	

Table 1 : First cyclotron characteristics.

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Second Cyclotron

Stripping of the ions by a carbon foil (50 $\mu g/cm^2$) proceeds on the beam transfer line. Stripped ions are injected at R = 900 mm in the SSC and accelerated up to the extraction radius at 2 110 mm. Thus the net energy gain is 5.6, and, since K = 160, the maximum energy for particles of $q/m = \frac{1}{2}$ is 40 MeV/amu.

This cyclotron has been designed for a nominal energy of 32 MeV/amu and particles of $q/m = \frac{1}{2}$, i.e. main magnets have been shimmed for this operating point with minimal currents in the trim coils.

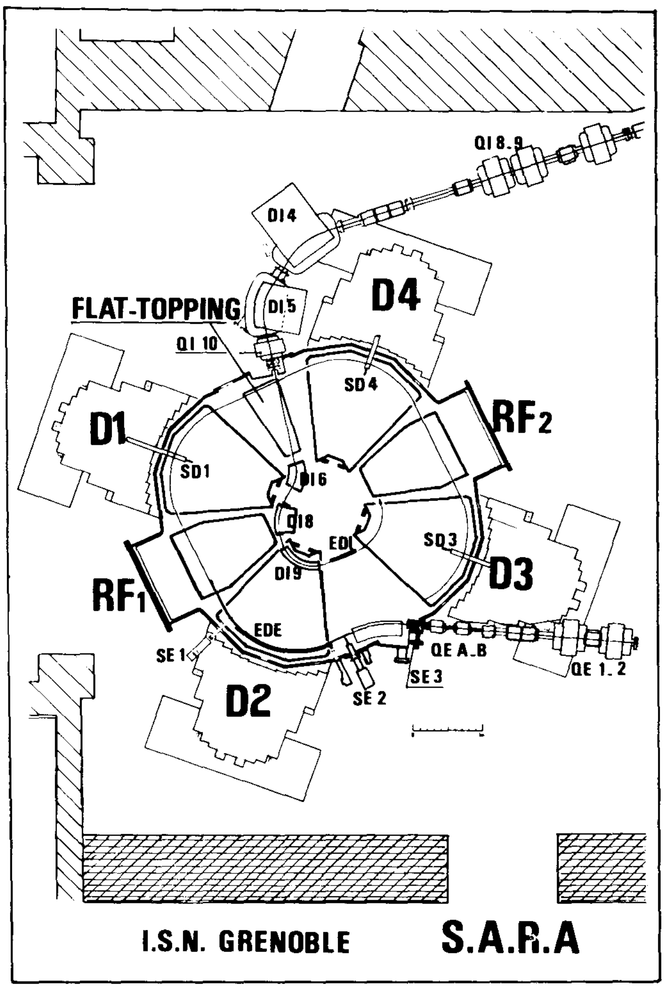

Figure 1 : SARA Second Cyclotron.

POST ACCELERATOR MAGNETS	
Sector angle	48°
Spiralisation	0°
Gap	60 mm
Nominal field (K = 160)	1.65 T
with	95 000 At
Maximum pole radius	2 280 mm
Trimming coils	15
Shimming : central slot	
Total weight (1 magnet)	100 t
MAIN RESONATORS	
Two vertical λ/4 lines	
Dee angle	34°
Frequency range	21-32 MHz
Maximum RF voltage	100 KV
Q factor	5 000
Phase regulation	.1°
Amplitude regulation	10^{-4}
Harmonics	4, 6
FLAT TOPPING RESONATOR	
Two vertical λ/4 lines	
Dee angle	13°
Frequency range	63-96 MHz
Maximum RF voltage	40 KV
Harmonics	12-18
INJECTION	
3 Magnetic channels	
1 Electrostatic channel	
EXTRACTION	
1 Electrostatic channel	
1 Magnetic channel	

Table 2 : Post-Accelerator magnets and resonators main characteristics.

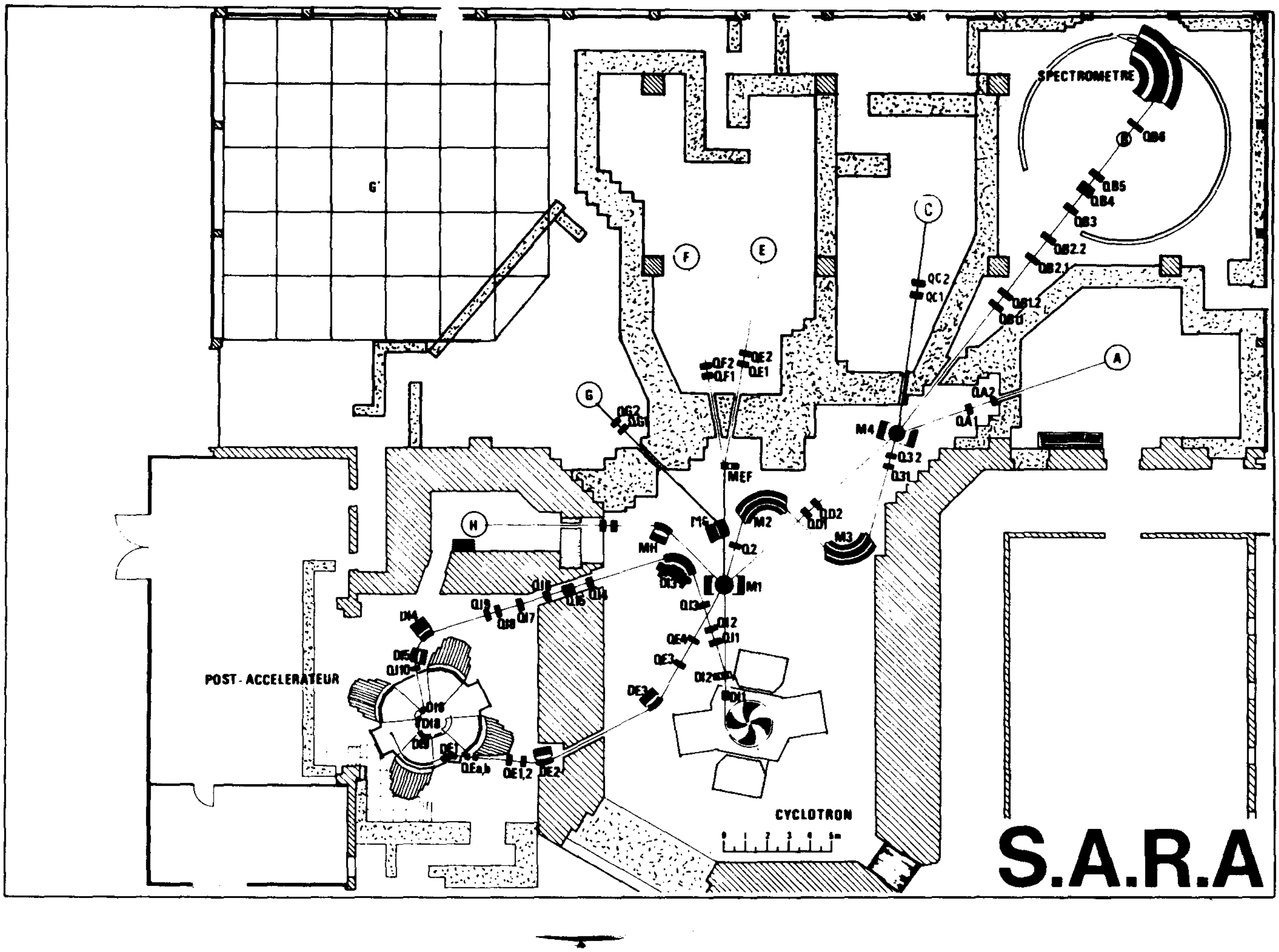

Figure 2 : SARA General lay-out with beam lines

Beam lines

No major change has been done on the beam lines (fig. 2) at the exit of the cyclotron. The main switching magnet M1 is fed either from the first cyclotron or from the extraction line of the Post-Accelerator ; in the latter case, a part of the beam line (Qi_1 ; Qi_2) is rotated so as to deliver the beam to the transfer system.

Originally, it was only possible to deliver the beam from the Post-Accelerator to 4 of 7 beam lines without any change. We are now improving the system so as to provide any SARA beam to any experimental area except the irradiation cave H ; the yokes of the analyzing magnets M2, M3 have been increased, and their power supplies improved, beam line G has been modified by installing a more powerful magnet.

The ECR source and coupling

The ECR source has extended the energy range of SARA (fig. 3).

It has been relatively easy to install the ECR source MICROMAFIOS [3] because the injector cyclotron was already equiped with an axial injection system (fig. 4) [4] which was used both for a polarized proton source and an external PIG ion source.

The latter source was removed in February 1983, MICROMAFIOS was installed during summer shutdown. After the first tests in September, and in view of the good results, it was decided to run it continuously, even though it was not our previous intention.

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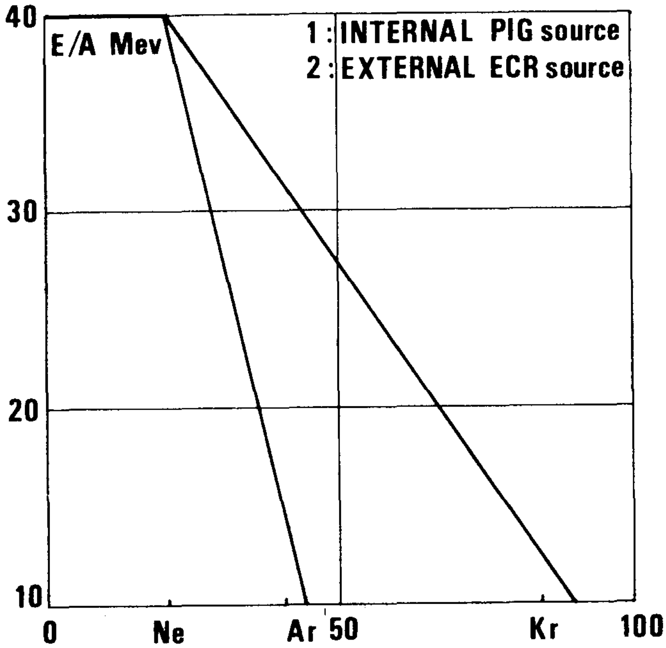

Figure 3 : Increase of the maximum energy of SARA with MICROMAFIOS.

	Currents		Efficency
	eµA	10^{12} Particule/s	
ECR source	10	16	
Accelerated 1st Cyclotron	3.7	5.8	37 %
Extracted	1.3	2	13 %
Stripped	1.3	1.16	7.2 %
Extracted SSC	.5	.45	2.8 %

Table 3 : Typical figures of electrical currents for a standard beam ($^{14}N^{4+}$ stripped to give $^{14}N^{7+}$ at 30 MeV/amu).

Particles	1st cyclotron			2nd cyclotron		
	Charge state	E MeV/amu	I extracted enA	Charge state	E MeV/amu	I extracted enA
^{20}Ne	6	5.25	1 200	10	30	97
^{32}S	8	5.25	220	15	30	30
^{35}Cl	9	5.1	140			
^{40}Ar	10	5.25	100	17	30	23
^{40}Ar	8	3.5	730	16	20	75

Table 4 : Some SARA beams with MICROMAFIOS. Beams of the following elements have been accelerated in the range 15-38 MeV/nucléon (^{12}C, ^{13}C, ^{14}N, ^{16}O, ^{19}F, ^{20}Ne, ^{22}Ne, ^{32}S, ^{35}Cl, ^{37}Cl, ^{40}Ar).

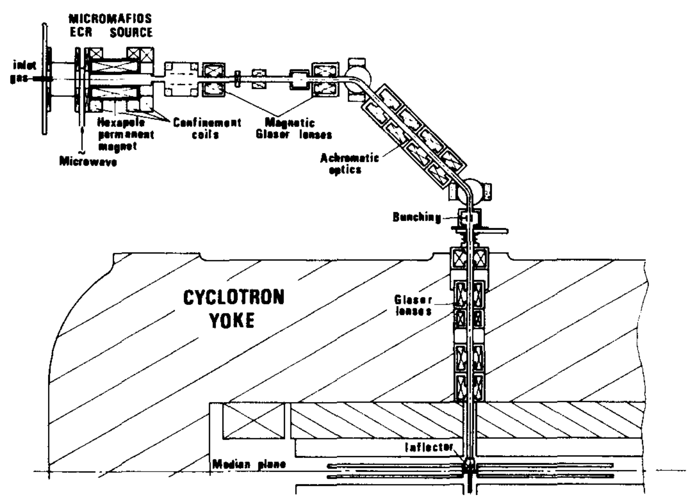

Figure 4 : ECR source and axial injection.

Operating conditions

Eight months of operation with MICROMAFIOS has convinced us of its simple and trouble-free operation. The source can be run continuously for weeks on end, no part is subject to wear and gas consumption is minimal. On this last point, since the gas flow is low (a few cc/hour) we were able to use the source without the need of the complex recovery system of the internal source and also with rare isotopes such as ^{13}C. Similarly we had no problems, with more or less corrosive gases (SO_2, SF_6, CCl_4), because of the small quantities involved and the good ionization efficiency.

Neither the currents in confinement coils nor the gas flow are critical and operation is drift-free during long term experiments.

Microwave power is presently limited to 1 KW peak. The duty cycle may be adjusted up to 100 %, the standard value is 90 %.

General operating condition

Set up of SARA

Set up time of SARA is comparatively short. This time-from the ECR source to the target - ranges from 2 hours, for a well known beam, up to 10 hours for a newly developped one.

For this last case the main difficulties are caused by the extraction of the first cyclotron and resulting uncertainties in the extraction radius and injection parameters, especially for harmonic 3 where trajectories are off-centered.

Reproducibility is noticeably better with MICROMAFIOS, certainly because of better positionning of the first orbit.

For the Post-Accelerator itself, reproducibility is good and we need not readjust trim coils once the beam is injected.

Efficiency for experiments

As operation is now continuous, time is no longer lost in changing the PIG source with all that implies. As a rule of thumb, total gain for experimental efficiency may be estimated at 25 %. Moreover, replacing the internal source was not straightforward and it often changed optical properties and energy, which frequently led to retune beam lines down to the scattering chamber.

Beam current measurements

Beam currents on intercepting probes and slits for the two machines and all beam lines are displayed on video monitor by 20 different menus dis - played related to sections of interest (i.e. injection, acceleration, analyzing system) gathering up to 15 simultaneous measurements. All this system is controlled by a Z80 micro-processor.

Emittance measurements

A micro-processor system for emittance measurements has been developped. It is composed of a moving slit (1 mm wide) followed 1 m downstream by a fixed 32 wire - 1 mm spaced - profile monitor. Results are directly displayed on a printer (fig. 5), values of currents are digitized from 0 to 256 and may be displayed on a 0 to 15 scale in hexadecimal in 4 ranges, giving a good resolution down to beams of a few nanoamperes. One emittance measurement lasts 1 minute, including printing.

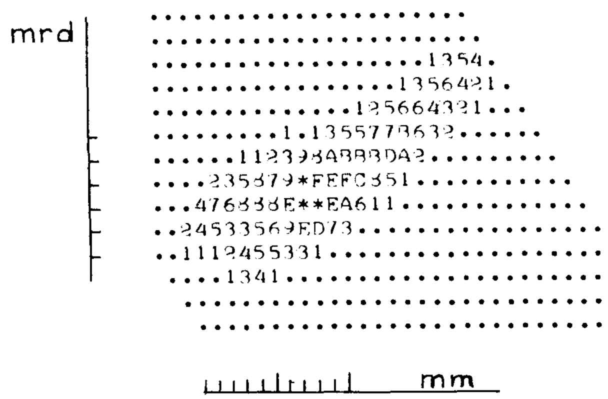

Figure 5 : Vertical emittance of 69 MeV $Neon^{4+}$ total intensity 140 nA.

Phase measurements

Eight capacitive phase probes are located in the free space of the SSC. Electronics are derived from those of GANIL [5] and GRONINGEN [6] (fig. 6). They are 12 cm by 12 cm copper plates located 4 cm above and below the median plane. After switching, the two signals are added and amplified 20 or 40 dB on a 50 Ω input amplifier. We then just extract the $A_1 \sin \varphi_1$ and $A_1 \cos \varphi_1$, first Fourier components of the signal at the repetition rate of the beam, i.e. at the RF frequency of the first machine. Because the RF frequency of the SSC is twice that of the first machine, related parasites are rejected.

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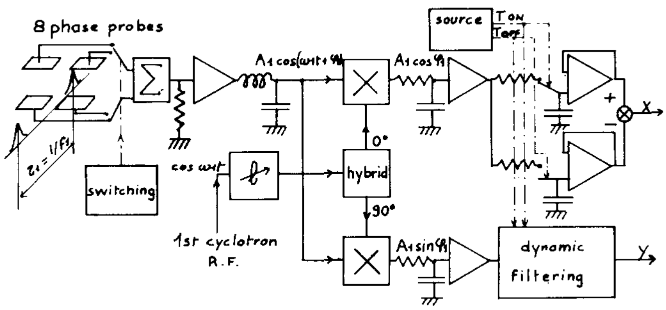

Figure 6 : Beam phase measurement diagram.

Moreover a dynamic filtering synchronous with ON and OFF periods of the source is used to remove the remaining components at the fundamental frequency.

At the moment, the $A_1 \sin \varphi_1$ and $A_1 \cos \varphi_1$ signals are displayed on an oscilloscope in the XY mode, but soon we will display simultaneously amplitude and phase (exactly tg φ) of the 8 probes on video screen using a special "menu" of the current measurement system.

Future developpements

Metallic ions

With the aim of producing metallic ions, we plan as a first step to perform experiments with our ECR source by the end of this year. On a 2 year basis we plan to devote a second ECR source to metallic ions. It will be placed outside the cyclotron vault and the first one too ; both will be equipped with an analyzing system connected to the injection so that one source may be developped whilst the other runs independently for beam production.

Flat-topping

The flat-topping system is working on the 3rd harmonic of the main resonators. It has been installed since 1983. Its operation has been delayed mainly because of lack of time for machine maintenance and developpement. A long time is necessary to increase the voltage on the dee in the presence of the magnetic field. At present , 20 KV can be obtained and some effects are noticeable on the separation of orbits but we have not yet obtained sufficient data to reach a definite conclusion.

Conclusion

The SARA accelerator has provided up to now 4 500 beam hours for physics taking into account a shut-down of 4.5 months due to major fault in the vacuum chamber of the first cyclotron. The beam time is allocated to experiments every six months by a scientific committee. For the past period the proposals have exceded the available beam time by a factor of two. The mean cost for electric power only is of the order of 600 FF per hour (∿ 70 US $).

As a general statement we can say that SARA provides good and reliable conditions for experiments. The ECR ion source has provided a very important improvement in performance and efficiency of experiments. Improvements in beam qualities and intensities are planned, the present limitation being essentially due to the first cyclotron.

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