SATURNE II : PROPOSAL OF A RENOVATED PROTON FACILITY AT SACLAY

H. Bruck, J. -L. Laclare, G. Leleux
Section d'Optique Corpusculaire, Centre d'Etudes Nucléaires de Saclay
and the "GERMA" group*

Abstract.
The Saclay proton synchrotron Saturne will be transformed into a strong focusing machine to be used essentially for nuclear spectroscopy. The advantages of a circular machine for such a purpose are underlined. The shortcomings of weak focusing are analysed and essential parameters of the transformed machine are given.

1 - Generalities.

The Saclay proton synchrotron Saturne is 16 years old. But there are still long range programs for use of this machine in the field of nuclear physics, with heavier or polarized particles, for medical purposes, but mostly for proton nuclear spectroscopy.

For the latter purpose, a circular machine, even when compared to the Linac in Los Alamos, seems also attractive. It has less intensity but higher energy and less energy dispersion. Furthermore, the extraction mechanism analyses the energy, making therefore a separate energy analyser unnecessary.[1 2]

	$\bar{I}$	E_c	$\Delta p/p$ total	$\Delta p/p$ analysed
Los Alamos	$6.\ 10^{15}$	0. 8GeV	10^{-2}	----
Saturne II(expected)	$2.\ 5.\ 10^{12}$	2. 7GeV	$3.\ 10^{-4}$	10^{-4}

At present, the beam gets progressively unreliable with intensities approching $N_{acc} \longrightarrow 10^{12}$ accelerated protons, the horizontal emittance of the extracted beam being $(\mathscr{E}_x)_{ext} \sim 30\ \pi$ mrd. mm.

More particles in a much smaller emittance are expected from a modern machine.

It has been decided to renovate Saturne. Preliminary studies led to the recommandation to keep the present 20 MeV injector, the magnet power supply and the building, but to set up a new strong focusing, separated function magnet structure around the old magnet (fig. 1). Construction of this machine has started and will be completed in 1977. The cost is evaluated at 33. 6 10^6 french francs. The expected performance characteristics of the transformed machine are :

	(old machine) Saturne I	(new machine) Saturne II
E_c	3 GeV	2. 7 GeV
N_{acc} at 1 GeV	$\lesssim 10^{12}$	$2.\ 5\ 10^{12}$
T_c	3 sec	0. 9 sec
Δ	15 %	30 %
$\frac{dN_{ext}}{d\mathscr{E}_{x,ext}}$ x 5 π mrd. mm	$3.\ 10^{10}$	$2.\ 25\ 10^{12}$
$\left(\frac{\Delta p}{p}\right)_{ext}$	$2.\ 10^{-3}$	some 10^{-4}
for meaning of symbols see section 3.		

2 - Essential improvement factors.

Apparently the difficulties to get a reliable beam of high intensity in the present machine are related to resistive wall instabilities and to enlargement of the beam by betatron resonances.[3] The importance of these effects is inherent in the weak focusing principle : in order to get a beam steady with respect to transverse resistive instability, the betatron wave numbers ν_x and ν_z have to cover finite domaines $\delta\nu_{x,z} \gtrsim (\Delta\nu_{sc})_{x,z}$, where $\Delta\nu_{sc}$ is the space charge displacement of the wave numbers. Therefore with growing intensity the required values of $\delta\nu_x$ and $\delta\nu_z$ grow and cover a growing number of resonance lines.

Now, not only at given beam density, $\delta\nu_x$ and $\delta\nu_z$ are large in a weak focusing machine (because $\Delta\nu_{sc} \propto 1/\nu$), covering many resonance lines, but at given magnet field quality, the band width of these lines is also much larger than in a strong focusing machine.

In renovating Saturne, it therefore appears as most essential to introduce strong focusing with as high as possible wave numbers. A strong focusing separated function structure has been designed having betatron wave numbers $\nu_x \approx \nu_z \approx 3.6$, physical radius R= 16, 8m and long straight sections, each ~ 10m long as required for easy extraction (fig. 1).

* "Groupe d'Etude et de Réalisation de la Machine" in charge of future development and carrying the proposal into effect. This group comprises staff members of CEA and IN2P3 ; R. Vienet is in charge of this group.

Comparing the old machine to the new one at the same relative field errors $\langle\delta B'\rangle/B$; $\langle\delta B''\rangle/B$; $\langle\delta B'''\rangle/B$, the respective theoretical stop band width are reduced to 1/50 ; 1/6 ; 1/10.

Because of its higher wave numbers, this machine furthermore accelerates polarized protons without crossing low harmonic depolarizing resonances.[4]

Another essential improvement of performance characteristics will result from further reducing magnet field fluctuations.

Owing to strong and only slowly decreasing eddy currents inside the 10 mm thick iron sheets of the present magnet core, the field strength would be depressed at beginning of extraction flat top by $\Delta B/B \sim 10^{-2}$ with time constant $\tau \sim 1/10$ sec, whereas a field constant to at least 10^{-5} is required. This defect will be cured by an entirely new magnet, decided upon for various reasons and having sheet thickness of 1. 5 mm.

Furthermore, the ripple of the power supply is at present $\Delta I/I$ = some 10^{-3} during field rise and $\Delta I/I$ = some 10^{-4} during flat top, whereas ten times less must be achieved. The appropriate technology has not been decided upon yet. Use of the present magnet as a filter is contemplated .

3 - Parameters.

a) Orbit.

"Missing magnet" lattice.

Maximum kinetic energy(proton)	E_c = 2. 7 GeV
Physical radius	R = 16. 8 m
Magnet radius	ρ = 6. 34 m
4 long straight sections, each of length	L = 10. 3 m
Magnet field index	n = 0
Maximum quadrupole strength	$(G\ell)_F$ = 4. 12 T
	$(G\ell)_D$ = 4. 49 T
Betatron wave numbers	$\nu_x \approx \nu_z \approx 3.6$
Natural wave number dispersion	$k = d\ /(dp/p)$
	$k_x = -4.8$; $k_z = -4.8$
Orbit parameters	$(\beta_x)_M = 17.4$ m ; $(\beta_x)_m = 1.47$ m
	$(\beta_z)_M = 16.0$ m ; $(\beta_z)_m = 1.78$ m
Momentum compaction	$\alpha = 0.017$
Local momentum compaction	$Rg_M = 6.77$ m ; $Rg_m = -4.76$ m

b) Injection.

Energy(protons)	E_i = 20 MeV
Number of turns	n_i = 200
Injected number of particles	$N_i = 6.\ 10^{12}$
Space charge displacement at injection	$(\Delta\nu_{ce})_x = 0.17$
	$(\Delta\nu_{ce})_z = 0.17$
Emittances	$(\mathscr{E}_x)_i = 90\ \pi$ mrd. mm
	$(\mathscr{E}_z)_i = 200\ \pi$ mrd. mm
Energy dispersion	$(\Delta p/p)_i = \pm 8.\ 10^{-3}$
Maximum beam dimensions	$(x_M)_i = \pm 8.2$ cm ; $(z_M)_i = \pm 6.8$ cm

c) Acceleration.

Peak voltage	$\hat{V}_{RF}$ = 14 kV
Harmonic number	k_{RF} = 3
Speed of magnet field rise	$\dot{B} = 3.5\ T\ s^{-1}$
Number of accelerated particles	$N_{acc} = 2.5 \cdot 10^{12}$
Kinetic transition energy	$E_{c,tr}$ = 6. 36 GeV

d) Extraction (1 GeV)

Number of particles	$N_{ext} = 2.25 \cdot 10^{12}$
Emittances (total)	$(\mathscr{E}_x)_{ext} \leq 7\ \pi$ mrd. mm ; $(\mathscr{E}_z)_{ext} = 25\ \pi$ mrd. mm
Energy dispersion (total)	$(\Delta p/p)_{ext} \gtrsim \pm 1.5\ 10^{-4}$
Energy resolution	$(\Delta p/p)_{res} \simeq 10^{-4}$
Duration of one cycle	$T_c \approx 0.9$ sec
of flat top	$\tau \approx 0.3$ sec
Duty cycle	$\Delta \approx 30\ \%$

References.

1. R. Beurtey and J. Faure, Private communication.
2. H. Bruck, J. -L. Laclare and G. Leleux, General properties of slowly extracted beam, present proceedings.
3. J. Faure, G. Leleux and R. Vienet, Instabilities detected in Saturne, present proceedings.
4. J. Faure, A. Hilaire and R. Vienet, Acceleration of polarized protons in Saturne, Particle Accelerators 3 (1972) pp 225.