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STATUS REPORT IN REJUVENATING SATURNE AND FUTURE ASPECTS

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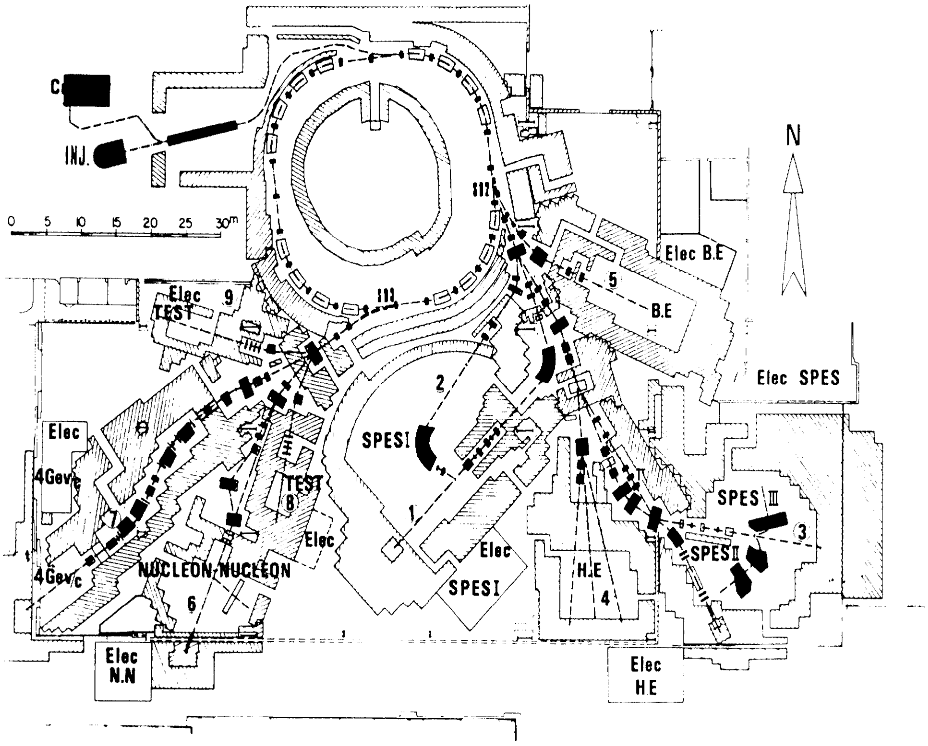

Figure 1 - SATURNE II General lay out.

INTRODUCTION

Several papers (1,2) have already been published about Saturne II Synchrotron renewal project. Let us recall that we have kept the 20 MeV linac injector in the same place; the building facilities and the main power supply have been kept too. All of these added some constraints to the conception of the project. Scores to be reached are the following ones :

- 2.10^{12} particles (protons),
- extracted beam optical qualities required for the fine nuclear spectrometry,
  - horizontal emittance 1 GeV = 8 π mm.mrd
  - instantaneous momentum spread $\sim \pm 2\ 10^{-4}$
- two extraction channels with the possibility of beam sharing on successive pulses or inside the same pulse,
- fast and flexible tuning,
- large range of particles available from H^+ up to heavy ions like Argon, as also polarized protons and deuterons.

At the scheduled time, by the end of July, the first proton was accelerated and the first beam appeared at the end of November. Since then, the beam has been delivered to nuclear physics spectrometry. Meanwhile the qualities have been measured. This paper will give the performances of the accelerator as well as the programs to come.

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This low intensity performance is far below our design goal 2.10^{12} ppp. A few machine development runs have shown that the machine is capable to achieve such a goal. We have already injected and trapped more than 2.10^{12} across the coupling resonance, when the ring is tuned to $\nu_x = 3{,}63$, $\nu_z = 3{,}71$ (Fig3). The first obvious difficulty was to maintain the beam as it overlapped $\nu_z = 11/3$. This could be easily avoided, for the ring is fully equipped with correction dipolar and non linear lenses which have not been turned on yet.

The other difficulty is the presence of a strong longitudinal instability.

At the very beginning, a couple motion of individual bunch center of mass was developing a short time after trapping and lasted until by the end of the cycle. The three bunches were moving by more than one bunch length with $2\pi/3$ or $4\pi/3$ phase shift from bunch to bunch, which was leading to a severe intensity limitation. At most, 5.10^{11} ppp could be accelerated with a large longitudinal blow up. Bad connections between the different points of the vacuum chamber were hold responsible for the instability and replaced. As a net result, the coupled bunch motion has disappeared during acceleration. While the RF is changing, it makes synchronism between bunches and environment hard to be maintained for long. But the instability reapears by the end of the cycle and develops on the flat top until the RF is off. The bunch pattern is no longer reproducible. It may be a pure dipole mode for one run (Fig4) and may turn to a pure quadripole mode for the run after, which makes investigation difficult.

We are not hopeless of reducing the longitudinal impedance but, in parallel, feed back corrections are being considered.

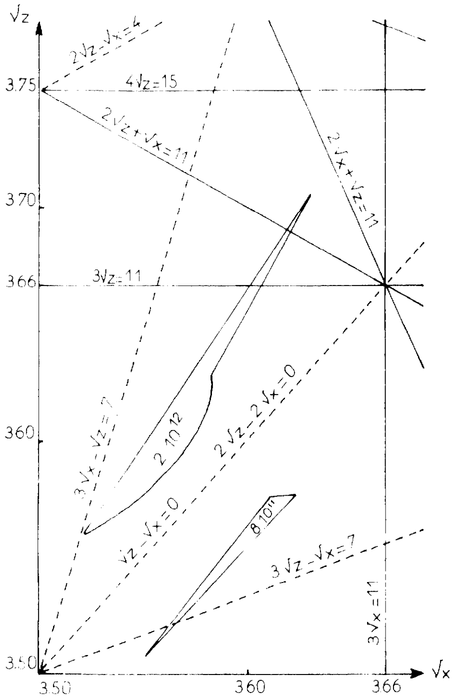

Figure 3 - Working point excursion due to space charge and energy variation at injection.

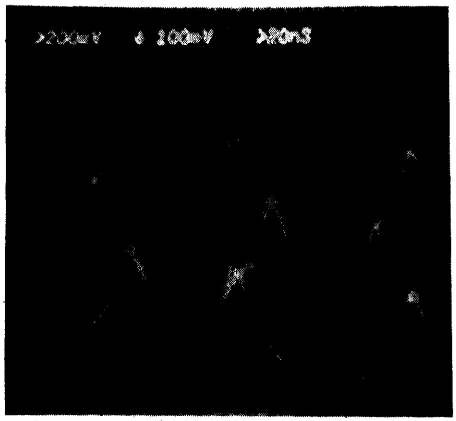

Figure 4 - Coherent longitudinal oscillations of the three buckets

BEAM EXTRACTION SYSTEM

The beam is extracted from Saturne by using a third integer resonance system. The beam blow up is controlled by sextupoles and the particles are pushed into the resonance region (ν_x varying with $\frac{\delta P}{P}$) by betatron acceleration performed by a magnetic flux variation in 10 tons core (named "Gephyrotron"). In order to reduce the necessary flux excursion throughout extraction, we reduce the circulating beam energy spread by decreasing the efficient RF voltage at the beginning of the flat top. In this way, extracted particles energy is constant all along the extraction process whitout modulation of the intensity at accelerating RF frequency. The value of K_h ($K_h = \delta\nu_x / \frac{\delta P}{P}$) is tuned so as to adjust extracted beam emittance and instantaneous energy spread values. (9)

Extracted beam characteristics have not yet reached their theoritical values, but the following results are very promising :

Horizontal emittance and energy spread

Measurements for 4.10^{11} circulating beam, $K_h = -10$ and 1 GeV extraction energy are :

	Theory	Measured
E_x (mm.mrd)	8π	10π
$\frac{\delta P}{P}$	$\pm 2.10^{-4}$	$\pm 3.10^{-4}$

As theory predicts (9), these values are directly connected with stored beam emittance that proves to be too large from injection as shown in experimental results (Fig.5). We estimate a 3 emittance enlargement factor.

We have therefore to keep the beam closer to the inflector throughout injection, which involves a very accurate tuning of injection beam line. The necessary beam diagnostic devices will be started up shortly.

Efficiency

Instead of the expected efficiency (80%), we have measured 55% efficiency. Studies are undertaken to understand this point.

TECHNICAL ASPECT OF THE ACCELERATOR

The 20 MeV injector has not been modified concerning beam optical characteristics (3) but it has been deeply transformed to improve reliability : RF power supply, tank adaptation, computer controls ...

Due to the expansion of the new ring in the hall and the linac location, the injection line is composed of four successive deviations. As the injection is a multiturn one (200 turns), the beam energy varies during the process, thereby each deviation is treated as an achromatic section. A 80 kV electrostatic inflector is the last part of the line and a special attention has been given to it in order to withstand the voltage during the 300 µs pulse length injected beam.

The thin corrugated vacuum chamber is treated with a high vacuum technology technique. A 2.10^{-7} torr average pressure is reached with low pumping speed. Each quadripole and dipole of the separated function accelerator has been magnetically tested and shimmed to obtain the high required tolerances :

$$(<\frac{\Delta B}{B}> \; <10^{-4} \text{ or } <\frac{\Delta G}{G}> \; <10^{-3}) \quad (4)$$

The RF cavities loaded with high permeability ferrites allow a 10 frequency variation factor (5). High thermic losses in ferrites (~ 2 W/cm^3) are evacuated by means of a cooling system.

We have made a special effort to control the beam :

In the injection line : a lot of control devices not yet fully operating, give us the possibility to measure intensity, position, emittance and energy spread, in order to tune the linac or adjust line parameters, so that the injected beam matches the synchrotron acceptance. A 1µs beam delivered by a chopper, provides: injection qualities, test losses, during the first turn and time life.

In the ring : The betatron oscillation wave number ν_x or ν_z can be measured (6) with a good accuracy ($\pm 2.10^{-3}$) on purpose to follow beam trip inside (ν_x,ν_z) diagram. These wave numbers can be adjusted by independant auxiliary power supplies.

- vertical and horizontal beam position is measured inside each focusing quadripole with ± 1 mm accuracy (7) in relation with dipolar correcting circuit.
- additional multipolar correcting magnets provide up to octupolar magnetic fields at low energy
- several intensity measurements systems (induction electrodes (13), injected beam current transformer) are set up.
- the lack of special foundations and inhomogeneity of the ground leads us to put every dipole and quadripole on an adjustable support. The quadripoles are remotely and separately movable.

In this way, we are able to minimize closed orbit distorsion and to correct resonance effects.

All these measurements (400 machine parameters) are handled by two coupled 224 k memories MITRA 125 computers (8). The data acquisitions from the injector, the main ring and the extraction are connected by means of 10 Camac crate-controllers, external memories and various adaptation sub-systems. Particular functions are handled by mini-computers (JCAM 10, MICRAL), microprocessor (TI9900) and PB6 programable automation. A program library allows operators, from independant control units, built around HP 2648A CRT displays, to know and control the beam and machine parameters. One can use for that purpose a general control program (COMCO) associated with a parameter standard notation system and shaft encoder hardware. In that way, it is possible to adjust a type of operating process from the display and to save the parameter values necessary for status, in the computer memories. Finally, an operation watching program group increases intervention easiness and velocity in case of failure of machine or remote-control system.

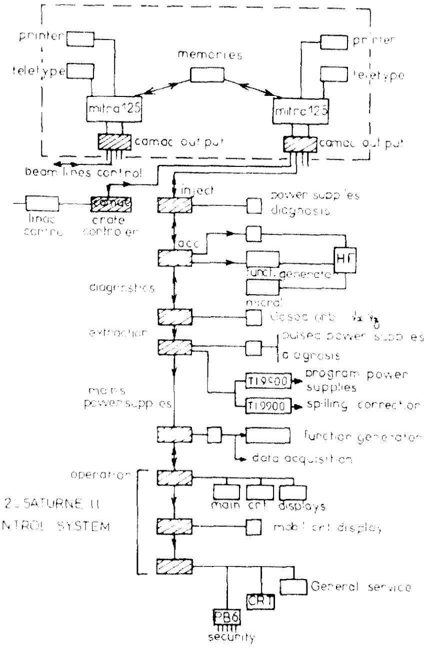

FIG 2 . SATURNE II CONTROL SYSTEM

BEAM INTENSITY PERFORMANCES

The uncorrected closed orbit is rather constant all along the cycle and mainly due to misalignment. The maximum deviation was originally 5 mm in either plane. It now reaches 10 mm owing to a slight sinking of the ground. Injection and trapping efficiencies have been measured and are in good agreement with expectations. We started working for physics almost immediately after the first beam and since then we have been running a low intensity beam most of the time. The injected 5.10^{11} pp intensity is reduced on purpose to ensure a minimum emittance blow up around $\nu_x = 3,64$ $\nu_z = 3,61$, just below the extraction tuning $\nu_x = 11/3$.

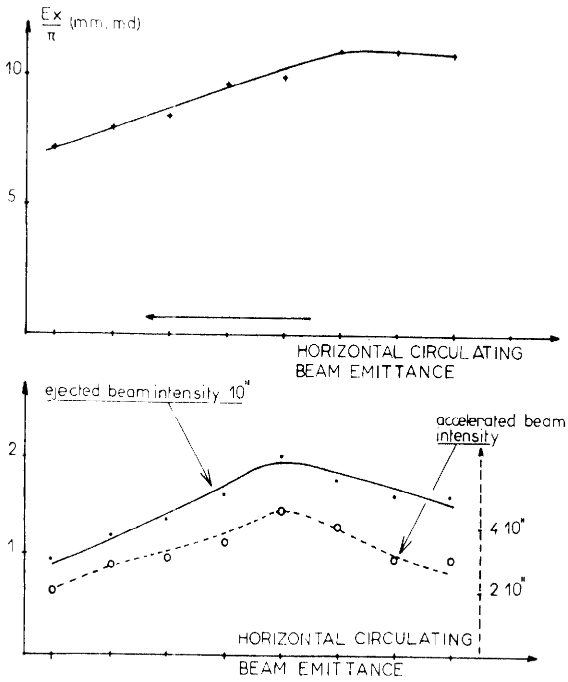

FIG 5 – EXTRACTED BEAM INTENSITY AND EMITTANCE VARIATION VERSUS CIRCULATING BEAM EMITTANCE

Spill modulation

The modulation is mainly due to main power supply ripple. For example, at 70 Hz frequency $\frac{\Delta I}{I}$ must be less than 10^{-6}. We can correct it in two ways :

- power supply regulation. The flat top filter can afford presently $\frac{\Delta I}{I} = 10^{-4}$. The situation can be improved by a factor 15, and in a few months, this regulation will be set up.
- correcting by compensation : If we modulate νx at the same frequency with the right phase and amplitude, we are able to compensate this effect. The frequencies can be predicted as harmonics of 50 Hz or 70 Hz and the Fig.6 shows spill (correcting device on and off).

We would prefer to use the first means because we have to optimize the compensation device each time we change power supply working mode.

Beam extracted channels

The two beam extraction systems are available. One of them has been operated so far. The second one will be in operation in June. The close orbit of Saturne is distorted at the end of acceleration by field variation in three main dipole magnets, located apart of each straight section. Each bump can be tuned separately for the two straight sections, and by relative tuning we will be able to share the extracted beam between the two channels.

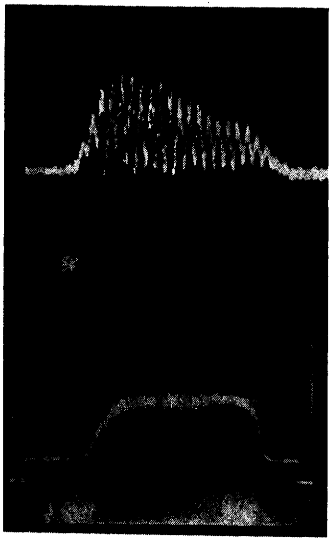

Figure 6 - EJECTED BEAM SPILL OUT

Structure correcting device a) ON
b) OFF

HEAVY IONS AND POLARIZED BEAM FACILITIES

At the very starting of the reconstruction of Saturne, rather strong a request for heavy ions ($\lesssim$A 40) and polarized particle (p,d) beam appeared. Cryebis (10) is the name of a new preinjector (designed in 1976) able to provide 200 KeV/nucleon beams to the linac (completely stripped ions). So far, the source itself has been tested and the results obtained : $5.10^9 N^{7+}$ and $3.10^9 (Ar^{18+}, Ar^{17+}$ mixed) particles per pulse, are very encouraging.

The polarized proton or deuteron beam will be obtained from the same ion source fed by an atomic jet (Glavish or Saclay type). Polarized protons are injected at 5 MeV, polarized deuterons or heavy ions at 5 MeV nucleons. The whole transparency between Cryebis and physicist experiment is quite low ($\sim$3%). After Saturne vacuum improvement (a few 10^{-8} torr), we hope to shoot 10^8 particles on the target.

In order to improve this score by a factor 10 for heavy ions and a factor 50 for polarized beams, a new project is under development (not yet funded). It is a new preinjector, a storage ring, named Mimas, (11) fed by successive pulses (5 or 10) injected directely from Cryebis. After stacking, particles are accelerated up to 5 MeV/nucleon. Extraction from Mimas and injection to Saturne will be performed by means of fast kickers and the necessary vacuum in Mimas has to be better than 10^{-10} torr.

In addition, contrary to linac, Mimas allows non completely stripped ion acceleration (for example Kr^{34+} already produced by Cryebis). As far as polarized protons are concerned we have to face depolarization effects throughout acceleration. Detailed calculations are given in a companion paper (12). It is quite interesting to notice that our strong focusing structure should be very efficient for polarized beam acceleration. Fig.7 shows the Mimas setting up

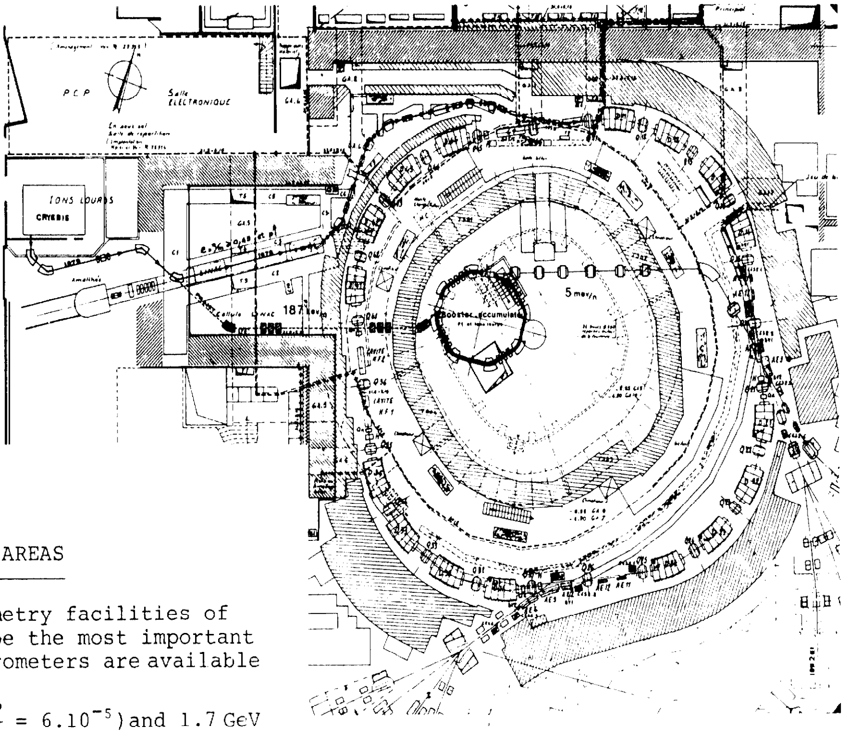

Figure 7 -
MIMAS project setting up inside Saturne ring.

EXPERIMENTAL AREAS

Nuclear physic spectrometry facilities of Saturne Laboratory will be the most important in the world. Four spectrometers are available or under completion :

SPES 1 High resolution($\frac{\delta P}{P} = 6.10^{-5}$) and 1.7 GeV maximum analysed momentum

SPES 4 Extrapoled from SPES 1, 4GeV/c maximum analysed momentum

SPES 3 Large solid angle (10^{-2}stradian) and large instantaneous analysed momentum range(0.6 GeV/c up to 1.4 GeV/c). In order to reduce focal length to a reasonable size (2,4 meters), it is designed for 3 T.

SPES 2 Is a reduced version of SPES 3(.75 GeV/c and 35% momentum range).

SPES 1 has been operated with old Saturne. User's complaints against beam properties gave us the list of qualities we have to achieve to rejuvenate Saturne. Therefore, it has been the first judge for the beam.

SPES 2 is presently working at CERN.

SPES 3 and SPES 4 are under construction.

Nucleon-nucleon reaction type are on the way with some devices like :

- cryogenic solenoïd for spin orientation,
- frozen target,
- all kind of measuring facility related to polarized beam,

Approximatively 4 or 5 extra beams will be used for :

- 3 dimensional radiography
- astrophysics equipment study
- radiobiology
- TPC
- π coherent production
- heavy ions specific studies.

Finally, we can notice a so called "cross-jet" experiment. An atomic polarized jet intersects the circulating beam in the machine : all during the acceleration nucleon-nucleon, diffusion parameters measurements are performed.

CONCLUDING REMARKS

This paper has described the main characteristics of the new Saturne 3 GeV proton Synchrotron and its performances during the first months of operation.

Considering the goals we had to achieve, (i.e. rejuvenating an old machine) and the first results obtained on physicist target at the time scheduled (10 times the number of particles in the same emittance as the old machine !), we are very satisfied more especially as we know that we can still increase the performances as far as particles intensity and extracted beam qualities are concerned. Three GeV energy and 2.10^{12} beam intensity are scheduled for next July.

REFERENCES

(1) H.Bruck and all."Proposal of renovated proton facility at Saclay" IX Conf. High Energy Acc. STANDFORD 74
(2) R.Vienet "Birth and next futur of Saturne" DUBNA 78
(3) P.Chamouard-M.Olivier "Improvement in the 20MeV beam Brightness at Saturne" CHALK RIVER Sept. 1976.
(4) JP.Pénicaud "Design and magnetic measurements of the new magnets for the Saclay proton synch." CHIGAGO 77
(5) C.Fougeron "RF system for Saturne II" CHIGAGO 77
(6) L.Degueurce "Measurements of the ν value in Saturne"
(7) A.Nakach "System of close orbit correction in Saturne"
(8) JL.Hamel "Beam lines controls system Sat.II" CHIGAGO 77
(9) H.Bruck, G.Leleux, JL.Laclare "Extected energy in the extracted beam of Saturne II" STANFORD 74
(10) J.Arianer, A.Cabrespine "Cryebis a miltipurpose EBIS for the Synchrotron Saturne II" This conf. (D2)
(11) J.Faure, J.L.Laclare, G.Leleux, M.Olivier, A.Ropert "Project of low energy accumulator-injector for Saturne II" This conference (G.35)
(12) E.Groruc, JL.Laclare "Crossing of depolarisation resonances in strongly modulated structures" This Conf. G17
(13) A.Nakach "System of pick up electrodes" int.report