COMMISSIONING & OPERATION OF SOLEIL.

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Abstract

The French 3rd generation synchrotron light source, SOLEIL, was successfully commissioned in 2006. A commissioning team of 20 persons composed of the machine physics group and people coming from different areas was constituted in the early stage. They shared their experience and their knowledge in the preparation of the different phases of the commissioning and in the analysis of the results. This organization allowed a fast progress of the commissioning (round clock operation) thanks to different ways to see and solve the encountered problems. The Linac and the Booster are now operational at their design performances. During the early phase of the Storage Ring [SR] commissioning, essential design parameters were reached very quickly even though the project incorporates some innovative techniques such as the use of dedicated superconducting RF cavities, solid state RF amplifiers, NEG coating for all straight parts of the storage ring vacuum vessel and new BPM electronics. The maximum current possible of 300 mA was reached within 8 weeks after a low 30 A.h accumulated dose. Out of the 24 beam lines programmed, 11 have already opened their front-ends. A total of **2927** hours of running time was achieved from January to July 2007. Beam availability was close to **93.8** %. The operation group is now complete with 8 fulltime operators. Part time operators complement them during users' shifts.

LINAC AND BOOSTER OPERATION

The **HELIOS** 100 MeV LINAC has been built by THALES and makes use of 2 accelerating sections donated by CERN [1]. The transfer line from the Linac to the Booster was built by SOLEIL. Its diagnostics enabled to fully characterize the Linac beam performances [2]. The first 100 MeV beam was produced on the first trial, on July 2nd, 2005 and was used to validate the radiological protections of the LINAC and Booster tunnels. In the Long Pulse Mode the LINAC produces a 300 ns long beam pulse modulated at 352MHz with a total charge of 9.3nC for a specified value of 8nC.

The 157 m long **Booster synchrotron** was designed and built by SOLEIL. It accelerates the 100 MeV Beam from the Linac up to the 2.75 GeV nominal energy of the Storage Ring (SR) and features a 150 nm.rad horizontal emittance at 2.75 GeV [3]. The magnets, arranged in a FODO lattice are ramped at 3 Hz, using 'SLS' type digitally controlled power supplies [4]. All pulsed magnetic equipment for both Booster and SR (septum magnets, kickers) were designed in house and their pulsers make use of solid state switches (**MOS** for the HV Booster kickers and IGBT's for HV SR kickers)[5]. A very flexible synchronization system enables to vary at will the filling pattern and injection frequency.

The first injection into the Booster was tried on July 23rd, 2005 and rapidly the 100 MeV beam was stored for up to 2 million turns. Due to conflict with the SR installation, the tests were resumed in October and then in May 2006, prior to the SR commissioning. The first energy ramping to 2.75 GeV was achieved on October 13th, 2005. Extraction from the Booster was performed very easily on May 8th, 2006, and the beam was guided along the transfer line up to the injection point of the Storage Ring. Now, the routinely achieved injection and extraction efficiencies are close to 100%.

BEAM COMMISSIONING IN THE STORAGE RING

The installation of all the components of the storage ring, including the first four insertion devices, was completed in May 2006. On May the 14th, the beam could be circulated for the first time over up to 9 turns without any orbit corrections, with magnet settings close to the theoretical values. As shown on figure 1, the beam went several times through the 10 mm small vertical aperture of the 10 insertion device chambers distributed along the ring.

Such a result underlines the quality of the magnetic measurements of the electro-magnets and of the alignment of all the equipment (magnets, girders, and vacuum vessels).

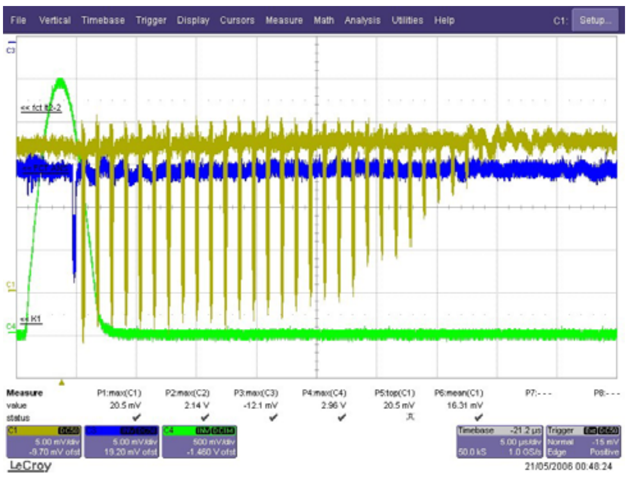

Fig.1: first successive turns achieved on day 1 without RF and with sextupoles OFF, as detected by the FCT.

The first trial to store beam was made on June 1st and after having fixed some equipment failures, a first beam (0.3 mA) was stored on June 2nd. The first accumulation (up to 8 mA) was performed on June 4th. The increase of the stored current progressed rapidly up to 300 mA after 8 weeks of effective beam tests. As of July 2007, the integrated current dose now reaches 259 A.h.

The conditioning of the vacuum vessels progressed quite well, with a reduction by more than a factor 100 on the normalized dynamic pressure (P/I) as shown on fig. 2.

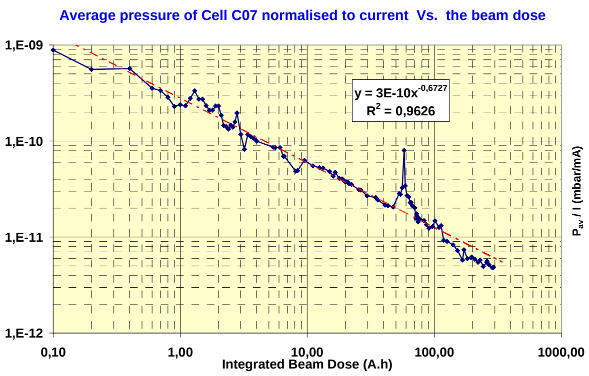

Fig.2: Average pressure of Cell C07 normalised to current vs integrated beam dose.

This good result clearly demonstrates the beneficial effect of the NEG coating on the aluminium chamber. This technology was never seen before on accelerators at such extensive use (up to 60% of the ring circumference).

2 innovations concern the RF system: A dedicated Superconducting cavities was developed via a CEA/CERN/SOLEIL collaboration. A 1st cryomodule enables alone operation up to 300 mA, and a 2nd cryomodule, which is being build by ACCEL, will enable to reach 500 mA. The 352 Mhz RF power is generated using 4x190 kW solid state RF amplifiers that are used for the first time in the world for such high power. Though few transistor failures (which doesn't stop the beam), the RF system (cavities, amplifier and cryogenics) is very reliable and only 3 beam trips were experienced during the 1st year of commissioning/operation, which is a very exceptional and unusual performance.

Specific and innovative insertion devices were developed such as 3 electromagnetic HU256 (10eV to 1000eV), a 10m long electromagnetic HU640 (5eV to 40eV), 3 permanent magnet HU80 APPLEII helical undulators, and 3 in-vacuum U20 planar undulators.

Despite the risks taken in the choice of new technologies, all achieved storage ring performances are quite close to the design parameters as shown in the following table.

Parameters	Design	Achieved as of June 2007
Eenergy (GeV)	2.75	2.74
RF frequency (MHz)	352.2	352.197
Betatron tunes	18.2 / 10.3	18.2009 / 10.2990
Natural chromaticities	-53 / -23	-53 / -19
Momentum compaction (α_1, α_2)	4.5 10^{-4}/ 4.6 10^{-3}	4.55 10^{-4}/ 4.30 10^{-3}
Emittance H (nm.rad)	3.73	3.70 ± 0.2
Energy spread	1.016 10^{-3}	1.0 10^{-3}
Coupling, εv/εh	<1%	0.3% without correction
Current multibunch mode (mA)	500	300
Average pressure at max current (mbar)	10^{-9}	3 10^{-9}
Beam lifetime (h)	16	9 @ 300mA / 22 @ 100mA
Single bunch current (mA)	12	20
Beam position stability, µm (H)	20 (rms)	3 ptp
Beam position stability, µm (V)	0.8 (rms)	2 ptp

In September 2006, 13th, the photons were delivered to a beamline (Diffabs) for the first time. Then 4 other beamlines opened were authorized to open their shutters before the end of the year. As of today 11 beamlines have already opened their front-end.

THE CONTROL ROOM

The control room, located in the centre of the Synchrotron building, is a large area (150 m^2) organised in 4 zones. Each of them has a different purpose:

- The first zone is the most important one with the "main desk". This area is devoted to the machine's operation and studies. That is the major place for operators
- A secondary desk corresponds to the second work area. It is mainly reserved for the development and deployment of the data-processing applications on the machine as well as monitoring of data for other groups (vacuum).
- Alarms concerned with safety of the site and monitoring of utilities (electricity, fluids) are centralised on 2 personal computers (PC) and are located in the third zone.
- Several cubicles accomodate some instrumentation as well as the Personal Safety System control panel, a video multiplexing system, a switching panel of analog signals coming from the equipments and the RF master clock.

Most of the computers in the control room are terminals running with Linux but some applications need PCs. 9 screens hanging on the walls and 4 oscilloscopes on the main desk are used for the diagnosis of injection in the different accelerators as well as the monitoring of various signals.

Fig.3: View of the main desk and cubicles.

OPERATION TEAM

During the shifts, within the operation group, 8 operators take their turns every 8 hours in order to ensure the presence of one of them in the control room 24h/24 and 7 days a week. This operator is assisted by 1 or 2 part-time operators who mainly come from the accelerator division. Before being ready to work in control room, they get training by the "machine physicists" on the general operation of the machine.

During shutdown, permanence in control room is ensured by an operator during the normal working hours.

Apart from the operation of the machine, the operators are implied in the result analysis and in the developments (software and equipment) enabling a better understanding and operation of the installation.

COORDINATION WITH THE USERS

An annual planning of machine operation organizes the sharing out of the beam time between the beam lines and the machine studies and fixes the shutdown periods. The detailed planning of each week is finalized during the weekly “Operation meeting”. A representative of the whole of the beam lines is also nominated every day to be the contact with the control room. In the same goal of interfacing, experimental hall coordinators will soon ensure support to the beamlines, working round the clock. Of course, the beam status and all important events are summarized in the “Machine Status” application which is seen by all the staff at every moment. This one is an on-line application delivering the main machine parameters and making it possible to the operators to broadcast short text messages.

The operation of closing and opening the front ends is performed by the users. Nevertheless, for security reasons, the first time, when beam lines open their front end, is always carried out from the control room. Concerning insertions control, for the moment all gaps and fields are changed from the control room at the request of the people on the beamlines.

THE ACQUISITION & CONTROL SYSTEM

The acquisition & control system in SOLEIL allows controlling equipments and subsets (Linac, Booster, storage ring, insertions and beam lines) and recovering generates data (experiments results, equipments information,…). It includes all the hardware and the software to be implemented since the electronic interfaces of the signals until graphic postings.

The system architecture is based around the TANGO framework. SOLEIL is the first accelerator using it as a full control system. TANGO is an evolution of TACO the in house developed control system of the ESRF. It is a software bus that permits to communicate between distributed applications thanks to a software interface called “Binding” (as shown on figure 4). This is the link between TANGO and the software applications that get all the tools permitting data processing, sequencing… The SOLEIL supervision layer is Global Screen (published by the company Ordinal Technologies). It brings high level functionalities necessary to make synoptic. Those are representing the essential machine control graphic interface for the operator. Besides Matlab is the expert application of machine configuration, The other software layers of supervision are Jive for configuration, Devicetree for supervision, ATKpanel for monitoring

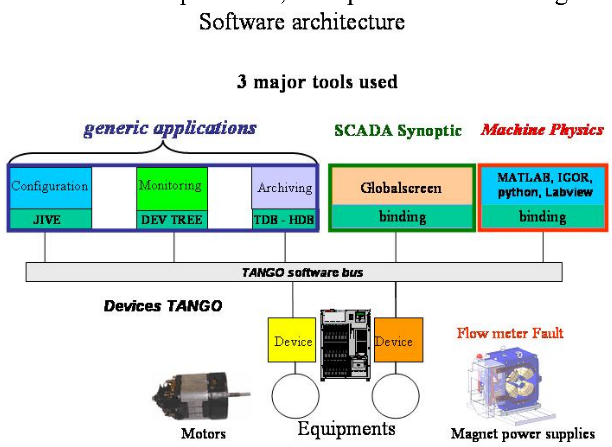

Fig.4: Tango architecture.

PILOTING & SURVEY

About 30 000 parameters to control or survey at Soleil including 6 000 main parameters. Of course, we can not display all at the same time. But the most relevant ones are permanently displayed on several screens.

Control applications have been developed in house using 2 major tools: the Matlab Middle Layer and GlobalScreen. Some of them are briefly quoted below.

Main Matlab based applications:

- Timing system application is a prototype that permits us to choose the filling patterns, save or restore timing setup.
- TL1/TL2 application is used to configure the corresponding transfer lines, save and restore settings, launch magnet cycling, measure emittance and energy spread.
- Booster application sets up, on the same named accelerator, Optics and power supplies, corrects orbit as well as it can measure online tune during ramping up. It saves and restores settings.
- Storage Ring application, like both last one, is used to adjust, save and restore optics and power supplies settings. But it has lot of other functions. Display,

correction, slow orbit feedback and bumps are few examples of what you can do about orbit. Other functions concerns BPM configuration and measuring, first turn, energy calibration, lattice symmetry restoration (LOCO), coupling correction, dynamics aperture measurement, frequency maps, tune, chromaticity, dispersion tuning, emittance and lifetime measurement…

GlobalSCREEN control applications:

For operation and easy to use (non expert) applications, a Java based industrial supervisor named GlobalSCREEN have been interfaced with TANGO.

- Application for Personal System Safety and Radiation monitors
- 2 applications for supervising each of the 2 transfer lines
- 2 applications for Booster and its RF system
- 7 applications for the storage ring supervision: power supplies and magnet survey, vacuum systems, interlock system, RF superconducting systems, beam line front-ends, insertion device control and diagnostics.

LabVIEW applications:

Using the efficient TANGO/LabVIEW binding, 3 LabVIEW applications are used to control the visible Synchrotron Radiation Monitor, the Pinhole system and to measure the tunes. The following picture (figure 5) shows the tunes measurement

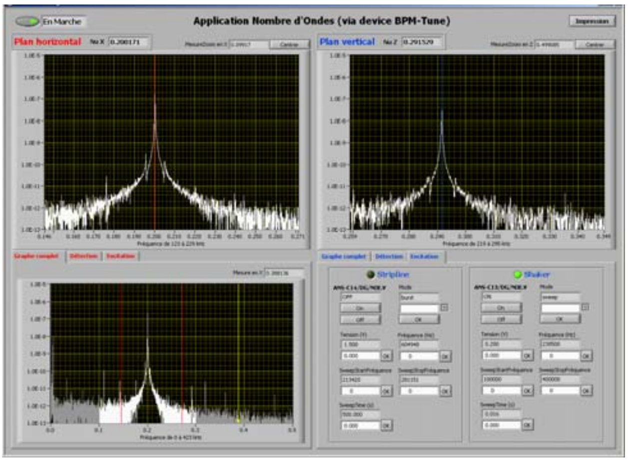

Fig.5: Tunes application.

A 4th LabVIEW software was developed by Thales to control the Linac. But this one does not use the TANGO/LabVIEW binding even though some gateways exist.

The main survey applications:

- ATKTrend and DeviceTREE are monitoring applications which are used to display real time curve from any machine parameters. Permitting us to follow some parameters evolution like beam source positions, vacuum, temperatures or gamma radiations for examples.
- Waiting for a centralized alarms device called "alarm diary" we made some pythons programs to know the state of most storage ring facilities. We also have a Global Screen application software called "Alarm Survey" that shows the state of each equipment family (if one device is not working properly the application displays the state corresponding colour on the equipment family).
- All global Screen synoptic are used to check the well running machine
- The Machine Status application shows the essential storage ring parameters like current attendance, average pressure, orbit values, betatron tunes, lifetime, filling mode, front-end states, beam delivering time and other as you can appreciate on the figure 6.
- In order to raise the attention of the operation team, major events, such as beam losses, trigger a message on a voice synthesiser.
- Interlocks trigger to kill the beam by interlocking some equipments when some wrong values go on some machine equipments like gamma monitors or vacuum facilities. Another example is when the orbit goes out of range (1mm on Z and 10mm on X). So, after beam troubleshooting, we can check interlocks with a dedicated GlobalSCREEN application.

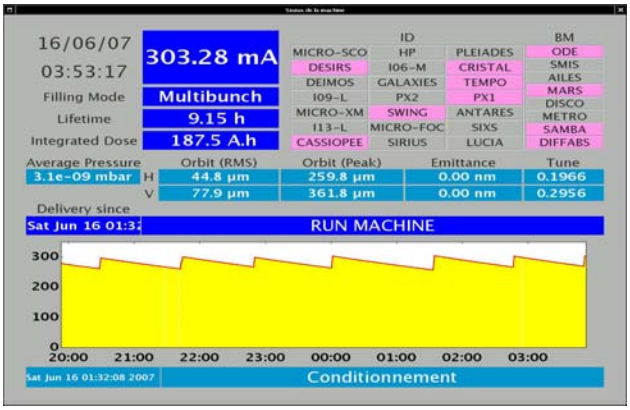

Fig.6: Machine status.

THE MACHINE FOLLOW-UP

Operators document all new delivered beams, beam losses, breakdowns, notices and report them on both, hand-writing and electronic logbook (figure 7). They write on a second book called "beam book" all beam events (new refill, beam losses, etc…), beam characteristics, commissioning team experiments, insertions gap changes and beam line communicated events. Another electronic book for beam line running time only is completed by operators, as the "beam book", in order to inform in real time the source division about machine operation. Statistics are automatically made at each run end from the electronic logbook.

Most of facilities parameters are archived in 2 data bases, the Historic Data Base and the Temporary Data Base. The first one, the HDB, conserves permanently the data but does not allow saving them down to 10 seconds. The second one, the TDB, save data during 3 days max but permit us to save 1 point every 100ms.

Sometimes, beam loss reason is not understood. To help us investigate we can call back the last 14 000 turns BPM measurements. That is the “BPM post mortem”. The same functionality is being process according to the RF equipments

Fig.7: Electronic logbook.

BALANCE-SHEET

Distribution of the operation time (except programmed interventions)	Operating hours	Breakdowns time with beam impact	Available beam time	Injection time with preparation of experiments
	hours	%	%	%
July to December 2006	1396 h	11,0	83,5	5,5
RUN-1 2007 Machine and beam lines	590 h	10,0	86,0	4,0
RUN-1 2007 Beam lines	156 h	5,0	91,0	4,0
RUN-2 2007 Machine and beam lines	624 h	4,0	93,0	3,0
RUN-2 2007 Beam lines	295,5 h	2,5	95,0	2,5
RUN-3 2007 Machine and beam lines	568 h	6,4	91,3	2,3
RUN-3 2007 Beam lines	349 h	3,3	95,6	1,1
RUN-4 2007 Machine and beam lines	618 h	6,9	90,6	2,5
RUN-4 2007 Beam lines	380,5 h	7,2	91,5	1,3
RUN-5 2007 Machine and beam lines	527 h	3,2	94,6	2,2
RUN-5 2007 Beam lines	339,5 h	3,3	94,3	2,4

CONCLUSION AND MAIN OBJECTIVES FOR EARLY 2008

The SOLEIL accelerator complex is now fully operational. The transition from the commissioning phase to the operation phase went smoothly, thanks to:

1. The strong implication and participation of the operation group during the commissioning of the machine.
2. Significant efforts from the machine physics groups and from the different groups in charge of equipment to transfer their knowledge to the operation crew.

The machine availability already reached 93.8 % over the 1521 hours of beam time delivered to the beamlines during the first 7 months of 2007. We are now aiming at increasing further this availability.

The next objectives set-up for 2008 are:

- 500mA operation (with second cryomodule)
- Preparation for top-up operation
- Single bunch and 8 bunches operation
- Secure beam stability with many insertion devices
- Increase beam availability.

[1] A. Setty et al, Commissioning of the 100 MeV Preinjector HELIOS for the SOLEIL Synchrotron, these proceedings

[2] M.A. Tordeux et al, Metrology for the beam emittance measurement of the SOLEIL injector, these proceedings

[3] A. Loulergue, Commissioning of the SOLEIL booster, these proceedings

[4] P. Gros et al, The 3Hz Power Supplies of the SOLEIL Booster, these proceedings

[5] P. Lebasque et al, Fast kicker systems for the SOLEIL Booster injection and extraction, with full solid-state pulsed power supplies, these proceedings

J.M. Filhol, Overview of the Status of the Soleil Project, EPAC'06, Edinburgh

A. Nadji, Commissionning and Performance of Soleil, PAC’07, Albuquerque

P. Betinelli-Deck, A. Buteau, L.S Nadolski, Status of Soleil Control System, EPAC'06, Edinburgh

L.S. Nadolski, Control Applications for Soleil Commissioning and operation, EPAC'06, Edinburgh

TANGO: **T**ACO **N**ext **G**eneration **O**bject

TACO: **T**elescope and **A**ccelerator **C**ontrolled with **O**bject

ESRF: **E**uropean **S**ynchrotron **R**adiation **F**acility

CERN : the European Organization for Nuclear Research