COMMISSIONING OF AN ACCELERATOR:
TOOLS AND MANAGEMENT

Amor NADJI
SOLEIL SYNCHROTRON

EPAC08, Genoa, Italy, 23rd – 27th June 2008
OUTLINE

- COMMISSIONING STRATEGY
- PRE-BEAM PREPARATION
- GETTING THE FIRST BEAM
- FIRST OPTICS STUDIES
- ROLE OF THE DIAGNOSTICS & CONTROLS
- TOP LESSONS
- CONCLUSIONS
In this talk, I will relate my own experience of the commissioning of **SOLEIL**, as well as some information collected from other accelerators recently or being commissioned, **DIAMOND, J PARC, LCLS, LHC, SNS, and SSRF**.

**AKNOWLEDGEMENTS**

R. Bailey (CERN), Z. Dai (SSRF), P. J. Emma (LCLS), J. D. Galambos and S. D. Henderson (SNS), R. Bartolini and, Vince Kempson (DIAMOND), and Tadashi Koseki (J-PARC, KEK).

SOLEIL accelerator physics group and J.-M. Filhol.
Commissioning: actions for checking and tuning an accelerator in order to meet its specifications.

After years of calculation, construction and tests.

Pressure to reach the goal as fast as possible BUT

Take time for a sound understanding of the accelerator functions and a safe operation of the equipment.

Definition of the Objectives, Organization of the Coordination and Preparation of the Tools.
The standard approach encloses 5 STAGES:

- Pre-Beam preparation
- Getting the first beam
- Beam-Based hardware and software checkout
- First optics studies
- High current intensity operation

Some commissioning considerations are specific to different types of accelerator.
**PRE-BEAM PREPARATION**

- Avoid (at any price) the commissioning with beam to be plagued by different technical problems.

  Clear aim to commission/fix/test everything that can be: before beam.

- A comprehensive and thorough **Hardware Commissioning**.

- Systems implicated include:
  - Survey / Alignment
  - Cooling
  - Vacuum
  - Cryogenics plant
  - Electrical connections
  - Magnets
  - Pulsed magnets
  - Power supplies
  - Machine protection
  - Safety interlocks
  - Timing system
  - Controls
  - Diagnostics
  - RF systems
Procedure and Documentation

- Design the procedures
- Evaluate the resources needed
- Build the necessary environment (documentation, test folders, analysis tools, logbooks)

LHC HWC Web Site: http://hcc.web.cern.ch/hcc/
Green stickers to validate the polarity of the magnet (SOLEIL)

Check the wiring (LHC)

Use of graphics for checking (LCLS)
Could only be revealed by the beam:

- Aperture limitations

- Polarity errors (if not identified during the control)
Lattice Modeling (1)

- A very accurate on-line optics modeling tested and ready for use before the start-up.

- Databases of the measured magnets used for a complete and trustworthy (non-)linear model.

- Good quality of magnetic measurements is then fundamental.

- Take into account: additional focusing effects coming from magnets fringing field, gradient due to curved trajectory in BM and difference between entrance and exit edge, magnetic fields overlap between neighboring magnets...
Lattice Modeling (2)

SOLEIL: optimized bare lattice  $v_x = 18.20$  $v_z = 10.30$

- Additional focusing effects deduced from magnetic measurements (Field mapping of 10 BM)
  - BM fringing field
    - $L = 0.1607$ m
    - $\Delta v_z = -7.6 \times 10^{-2}$
  - Gradient due to curved trajectory
    - $\Delta B/B = +2.2 \times 10^{-4}$ at $x = +20$ mm
    - $\Delta v_z = -8.5 \times 10^{-2}$
  - Difference between entrance and exit edges
    - $\Delta \theta = 0.3 \text{ mrad } (0.017^\circ)$
    - $\Delta v_z = +2.2 \times 10^{-3}$

Compensation:

The 10 quadrupole families are used to restore:

- Tunes
- Optical Function Symmetry
- Chromaticity shift
During the first days, the correction of the beam trajectory, the tune adjustment, and the variation of the chromaticities will rely on the model response matrices.

- facilitate the circulation of the first beam
- provide accurate snapshot input for off-line or on-line evaluation

Essential for the protection of the accelerator equipment.

Example: The highly destructive power of the LHC beam, operating mainly in a superconducting environment, places stringent demands on the beam parameter control.
GETTING THE FIRST BEAM

SSRF Storage Ring 5 first turns

transmission and number of turns improving after powering the sextupoles

SSRF

50 turns with sextupoles and RF OFF

SOLEIL

FCT

Stored beam

25/06/2008

Amor NADJI

EPAC08, Genoa, Italy
Unique, Exceptional, Historical, and highly emotional event!

DIAMOND

SOLEIL

SSRF
BEAM-BASED HARDWARE AND SOFTWARE CHECKOUT

- BPM offset measurements.
- BPM and Corrector polarity checking and calibration.
- Aperture scans.
- Orbit, current, radiation, instability,… interlocks.
- Machine protection validation.
- Optimizing and automating tune measurements.
- Calibration of the beam size measurement instrument.
- Calibrating the thresholds of the Beam Loss Monitors.
- Debugging and optimizing the main high level applications.
FIRST OPTICS STUDIES

Check and Correct the optics of the accelerator

- Beam Based Alignment
- Optimize RF frequency (circumference measurement)
- Response Matrices (orbit, tune, chromaticity)
- Beta functions at quadrupole locations and at BPMs
- Dispersion function
- Beam emittance and dimensions
- Betatron and synchrotron tunes
- Natural and corrected chromaticity

- Global and local coupling
- Momentum compaction factor
- Bunch length
- Energy spread
- Beam lifetime
- Momentum acceptance and dynamic aperture
- Effect of Insertion Devices
- …
LOCO code

- It is a (standard) tool for **restoring** the linear optics.

\[
\sum_{i,j} \frac{(M_{\text{exp},ij} - M_{\text{cal},ij})^2}{\sigma_i^2}
\]

is minimized in iterative process.

- Fits many parameters in an optics model, including quadrupole gradients, BPM and corrector calibrations.

- Constraints for large machines: the large number of BPMs and correctors, the available computer memory, and CPU time.

- A response matrix using 120 BPMs and 56 correctors in both planes takes typically 25 min at SOLEIL. 896 parameters are used in the fitting.
Some results after LOCO correction

Full coupled orbit response matrix.

< 0.3% rms
It is certain that excellent beam diagnostics make beam commissioning much easier. Ears and eyes in the control room.

Beam current: FCT (Turn by turn)

Beam behaviour: a visible light monitor

Beam dimensions: a pinhole camera
**Beam Loss monitors:**

![Beam Loss monitors graph]

**Kill the beam, acceptance:** Scrapers

![Scrapers diagram]

**Bunch length:** a streak camera

![Bunch length image]

**Longitudinal instabilities:** a streak camera

![Longitudinal instabilities image]
TURN-BY-TURN BPMS

- Successfully used for the setting of the Bending Magnet current and for the tuning of the first turn.
TURN-BY-TURN BPMS

- Allowed to understand quickly that some magnets were connected in the opposite direction, and helped investigate the location of obstacles in the beam path.
TURN-BY-TURN BPMS

- Allowed to understand quickly that some magnets were connected in the opposite direction, and helped investigate the location of obstacles in the beam path.

(2 quadupoles with inverted polarities)
TURN-BY-TURN BPMS

- Allowed to understand quickly that some magnets were connected in the opposite direction, and helped investigate the location of obstacles in the beam path.

(Courtesy of R. Bartolini (DIAMOND))
Obstacles in the vacuum vessels

- Problem of obstacle reducing the beam stay clear aperture
Obstacles in the vacuum vessels

- Problem of obstacle reducing the beam stay clear aperture

RF finger at 1.5 mm from the beam axis

Systematic bad mounting of RF Fingers in the short straight sections.
ROLE OF CONTROLS

A control system: « computing tool » dedicated to the implementation of distributed systems, heterogeneous and oriented control/command.

• Distributed Systems?
  The system components are geographically distributed on machines connected through a computing network

• Heterogeneous Systems?
  A coherent whole made from heterogeneous hardware and software

• Oriented Systems ctrl/command?
  Services adapted to a control system (storage, logging, alarms, …)

EPICS, TANGO and in-house built control systems.
At SOLEIL, TANGO was used very successfully at full scale from Linac to Beamlines.

Java, C++, Python

GNU/Linux, MS-Windows, Solaris
HIGH LEVEL APPLICATIONS

- SNS developed a Java high level application framework (XAL), which has been used also by J-PARC.

- Synchrotron light sources commissioning have benefited a lot from the Matlab Middle Layer applications.

Developed by
ALS and SSRL
Contribution
SOLEIL
MATLAB® Toolbox for Particle Accelerator Modeling
Accelerator Toolbox is a collection of tools to model particle accelerators and beam transport lines in MATLAB environment. It is being developed by the Accelerator Physics Group at Stanford Synchrotron Radiation Laboratory for the ongoing design and future operation needs of SPEAR3 Synchrotron Light Source.

Andrei Terebilo: www-ssrl.slac.stanford.edu/at/welcome.html
http://www.slac.stanford.edu/~terebilo/at/
Displaying Closed Orbit
Save/ Restore magnet setpoints
Vacuum System

- 239 flowmeters
- 70 gauges
- 201 ion pumps
- 95 valves
- 327 thermocouples

- Average pressure
- Global state of a cell
- Grouped command for closing all valves
Capacity to understand unexpected beam losses (postmortem systems, Machine Protection system)
Electronics logbook: machine (operation, vacuum, ID groups, BLs)

<table>
<thead>
<tr>
<th>Date</th>
<th>Sujet</th>
<th>Auteur</th>
<th>Accélérateur</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/06/06, 03:24</td>
<td>TOP-UP maison toutes les 10s avec 10 - 16 mA de 3H à 6H du matin</td>
<td>P. Lebasque, A. Louergue</td>
<td>Anneau</td>
<td>41</td>
</tr>
<tr>
<td>05/06/06, 03:24</td>
<td>Shift d'après-midi du 5 juin 2006</td>
<td>R. Nagaoka+J.C. Demard+P. Marchand + A. Louergue</td>
<td>Anneau</td>
<td>40</td>
</tr>
<tr>
<td>05/06/06, 08:23</td>
<td>session machine lundi 5 juin 2006 7h - 15h</td>
<td>A. Nadji, M. Level, P. Brunelle</td>
<td>Anneau</td>
<td>39</td>
</tr>
<tr>
<td>05/06/06, 05:12</td>
<td>shift 23h - 7h de dimanche 4 au lundi 5 juin</td>
<td>JM Filhol, MA Tordeux et Alex reste un peu</td>
<td>Anneau</td>
<td>38</td>
</tr>
<tr>
<td>04/06/06, 04:10</td>
<td>Shift 15h - 23h du 4 juin dimanche 2006</td>
<td>A. Louergue + R. Nagaoka</td>
<td>Anneau</td>
<td>37</td>
</tr>
<tr>
<td>04/06/06, 09:16</td>
<td>dimanche 4 juin: 7h - 15h</td>
<td>L. Nadolski, A. Madur</td>
<td>Anneau</td>
<td>36</td>
</tr>
<tr>
<td>03/06/06, 22:28</td>
<td>samedi soir</td>
<td>A. Nadji + JM. Filhol</td>
<td>Anneau</td>
<td>35</td>
</tr>
<tr>
<td>03/06/06, 18:47</td>
<td>18h30 - 23h samedi 3 juin: Correction orbite mode anneau, changement nombre d'onde</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/06/06, 16:54</td>
<td>shift 15h:18h samedi 3 juin: Correction orbite mode anneau, changement nombre d'onde</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/06/06, 11:04</td>
<td>shift 7h - 15h du samedi 3 juin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/06/06, 00:18</td>
<td>Continuation Session 2 (shift de nuit 02 juin vendredi - 03 juin samedi)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/06/06, 00:28</td>
<td>shift 15h-23h du vendredi 2 juin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/06/06, 00:54</td>
<td>Session machine 23h - 7h du jeudi 1 juin 2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/06/06, 19:59</td>
<td>shift 15h-23h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/06/06, 01:43</td>
<td>Session Machine 23h - 7h mercredi 31/05/06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/05/06, 23:18</td>
<td>fichier de bump d'Alex et Amor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/05/06, 19:24</td>
<td>session1 du protocole semaine 22 (continuation)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/05/06, 00:42</td>
<td>Shift de Nuit 30-31 mai 2006 (test de la radioprotection)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30/05/06, 18:37</td>
<td>démarrage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14/05/06, 16:01</td>
<td>Run machine dimanche 14 mai 2006</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A coordinator with a **central team** is generally in charge of leading the accelerator commissioning with beam.

For round the **operation**. (3 shifts of 8 hours per day)

Not restricted to accelerator physicists but has to include, since the early stages, representatives of the technical teams.

allows for interdisciplinary interactions to better identify and solve encountered problems
ORGANIZATION (2)

- **Necessary training**
  - Global view of main equipment operation
  - Radiation safety
  - High level applications
  - Other systems control software

- **Detailed plan**
  - Step by step
  - Necessary condition for each step
  - Goal for each step
  - Possible trouble in each step
  - Backup solution
  - Flexible
A detailed protocol for each shift.

Shift crews.

An overlap of a minimum of half an hour between two successive shift members.

Weekly commissioning meetings.

A meeting following each blocking point.

Reporting progress and problems to the wider community.
LTC Dec 14th: LHC commissioning organisation

Accelerator Systems
As required
Defined responsibilities

Accelerator system
Activity 1
Activity 2
Activity n

Activity 1
Activity 2
Activity n

Machine Coordinator
Weekly responsibility
3 needed

Commissioner
Scheduled shifts years 1,2
Pool of at least 7 needed

EIC
Scheduled shifts long term
7 needed

Operator
Scheduled shifts long term
7 needed

S. Redaelli 01.06
M. Gruwe 01.06
EIC3 07.06
EIC4 07.06
EIC5 01.07
EIC6 01.07
EIC7 01.07

EIC
EIC3 07.06
EIC4 07.06
EIC5 01.07
EIC6 01.07
EIC7 01.07

(E Courtesy of R. Bailey (LHC))
Don’t neglect Infrastructure!

SOLEIL: water cooling problem due to presence of resin balls blocking the magnet filters

⇒ Cooling repetitive interlocks

DIAMOND: water supply and quality problems ⇒ commissioning of the Booster at 700 MeV without any cooling water at all.

LHC: Delay due to problems in QRL.
TOP LESSONS (1)

• Keep the commissioning simple, and phase it.

• Wait for completion of installation and test of equipment before moving to the commissioning.

• Make sure first order simple functions work first.

• Allocate some time in between beam commissioning shifts to analyze data and modify software or hardware.

• The availability of more than one central team member on shifts (in addition to the operator) is very useful. This helps in communicating knowledge, and combining people’s skills and experiences to promote new ideas and approaches.
TOP LESSONS (2)

- A tool to easily save and restore machine settings for good tunes is imperative.

- It is important to carefully document in the Electronic log book all failures of equipment and their causes, to help associated colleagues to better understand the problems and their remedies.
CONCLUSIONS

- The most recent commissioning of accelerators have been performed in much shorter time than it used to be before.

- This is due to a careful preparation of the phase before the beam, a much more detailed, extensive, and accurate modeling and analysis, a robust control system, and an excellent set of diagnostics ready on day one.

- Additionally, as it is expected in any projects, the tremendous enthusiasm enables to overcome rapidly most of the difficulties that may arise.
CONCLUSIONS

The commissioning phase is a real team effort requiring great communications and very cooperative spirits.

Thank you for listening