Beam Instability Observations and Analysis at SOLEIL

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R. Nagaoka on behalf of the SOLEIL team
Outline:

1. Introduction
2. Multibunch Instabilities
3. Development of a Multibunch Tracking Code
4. Single Bunch Instabilities
5. Conclusion
Acknowledgement

to the People Who Specially Contributed to this Work:

Instability Measurements:
M.P. Level, M. Labat, M.E. Couprie, L. Cassinari, A. Loulergue, A. Nadji,
J.M. Filhol and the SOLEIL commissioning team members

Development of a Multibunch Tracking Code:
A. Rodriguez (student), Ph. Martinez, W. Bruns (GdfidL)

Development of a Transverse Bunch by Bunch Feedback System:
C. Mariette, R. Sreedharan, T. Nakamura (SPring-8), K. Kobayashi (SPring-8)
1. Introduction

SOLEIL is the French third generation light source ring commissioned in 2006 and starting its user operation this year.

<table>
<thead>
<tr>
<th>Energy [GeV]</th>
<th>2.75</th>
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</thead>
<tbody>
<tr>
<td>Circumference [m]</td>
<td>354.097</td>
</tr>
<tr>
<td>Nominal current [mA]</td>
<td>500, 8×12</td>
</tr>
<tr>
<td>Harmonic number</td>
<td>416</td>
</tr>
<tr>
<td>Betatron tunes $Q_H/Q_V$</td>
<td>18.2/10.3</td>
</tr>
</tbody>
</table>

Machine characteristics related to beam instability:
- Aims to achieve high average/bunch current
- Choice of relatively small vertical aperture ($b = 12.5$ mm) for the standard chamber
- Commissioned the machine equipped with ID low gap chambers ($b = 5$ & $7$ mm)
- About half of the ring NEG coated (Al vessels)
- Presence of in-vacuum IDs [presently 3, (full gap)$_{min} = 5$ mm ]
Impedance induced instability expected to be significant
- Evaluation/minimization of geometric impedance with 3 & 2D codes (GdfidL/ABCI)
- Evaluation of RW (resistive-wall) impedance ($\rho$, chamber cross section, thickness, layers)

| Object                          | Number | Loss factor | ($P$)500mA | $\Sigma|ZL/n|_{eff}$ | ($ZV)_{eff}$ | $\Sigma|\nabla^*ZV|_{eff}$ | ($ZH)_{eff}$ | $\Sigma|H^*(ZH)_{eff}$ |
|--------------------------------|--------|-------------|------------|----------------|--------------|----------------|--------------|----------------|
| Shielded bellows               | 176    | 8.72E-03    | 1.17       | 48.30          | (0.03 0.14)  | (52.8 246.4)  | (0.01 0.06)  | (15.8 112.6)  |
| Flange                         | 332    | 4.67E-04    | 0.12       | 11.65          | (0.00 0.01)  | ( 0.7 42.3)   | (0.00 0.01)  | ( 9.1 46.8)   |
| Dipole chamber                 | 32     | 1.64E-04    | 2.63E-03   | 0.48           | (0.00 0.00)  | ( 0.2 0.7)    | (0.00 0.03)  | ( 0.1 0.8)    |
| SOLEIL cavity                  | 1      | 2.20        | 1.55       | 9.30           | (0.29 0.44)  | ( 0.8 1.3)    | (0.17 0.44)  | ( 0.8 2.0)    |
| BPM                            | 120    | 3.31E-03    | 0.28       | 12.80          | (0.02 0.04)  | (22.4 37.2)   | (0.0 0.0)    | ( 0.0 0.0)    |
| Medium section tapers          | 10     | 1.76E-03    | 1.24E-02   | 9.31           | (1.35 3.41)  | (85.5 215.9)  | (0.01 0.56)  | ( 0.4 33.7)   |
| Long section tapers            | 3      | 7.32E-04    | 1.55E-03   | 1.52           | (0.43 1.13)  | (14.9 39.2)   | (0.00 0.24)  | ( 0.1 9.2)    |
| In-vacuum ID tapers            | 4      | 0.25        | 0.76       | 18.92          | (0.50 1.42)  | ( 6.0 17.0)   | (0.13 0.50)  | ( 9.4 36.0)   |
| SOLEIL cavity outer tapers     | 1      | 0.17        | 0.13       | 6.70           | (0.49 1.56)  | ( 2.6 8.3)    | (0.01 0.29)  | ( 0.0 1.6)    |
| Resistive-wall                 | -      | 7.31        | 5.17       | 85.50          | (21.8 101.5) | (135.2 743.5) | ( 7.1 51.7)  | (34.8 376.3)  |
| Injection zone                 | 1      | 1.86E-03    | 1.42E-03   | 0.09           | (0.00 0.01)  | ( 0.0 0.1)    | (0.10 0.72)  | ( 1.2 8.7)    |
| Pumping slots (at quadrupoles) | 128    | <1.0E-07    | <1.0E-07   | 0.01           | (0.00 0.00)  | ( 0.0 0.0)    | (0.00 0.00)  | ( 0.0 0.5)    |
| Total                          | -      | -           | 9.20       | 204.6          | -            | (321.1 1351.9)| -            | (71.7 628.2)  |

*(Impedance budget presented at EPAC2004)*
Instabilities (RW, TMCI, head-tail, microwave, bunch lengthening,…) estimated using time and frequency domain simulation codes.

Calculated impedance (GdfidL/ABCI) is decomposed into pure inductance & BBRs.

Original wake potentials are reconstructed with corresponding wake functions.

Total RW impedance is constructed from a data base of the ring.

Simulation codes read BB decomposition coefficients & RW data base to construct impedance and wake potentials.
2. Multibunch Instabilities

- Mixture of RW and ions induced instabilities in both V & H planes.
- No instability observed in the longitudinal plane (HOM free SOLEIL SC cavities).

- Ion-induced instability depends much on the beam filling
- \((l_{th})_V\) at low chromaticity in rather good agreement with prediction
- \((l_{th})_H\) much lower than expected

(\(\leftrightarrow\) Measured when beam dose was \(\sim\)20 A\(\cdot\)h)

- Characterization of instability in terms of beam spectra

\(\leftrightarrow\) "RW dominated"

"Ion-induced dominated"

(Observations in \(\frac{3}{4}\) filling)
- However, influence of ions on “RW dominated” cases not yet clear
- Stabilisation of $m=0$ occurs at chromaticity of ~0.2 in vertical
- As expected, shift of chromaticity excites higher-order head-tail modes
  $\rightarrow$ Bunch-by-bunch transverse feedback (TFB) used at zero chromaticity

$m=-1$ excitation
at 250 mA, $\xi_v=0.3$
in ¾ filling

◊ Recent analysis using TFB and its ADC data:

TFB is switched off temporarily over several milliseconds to follow the instability bunch by bunch
**Observations in ¾-th filling**

- **Oscillation amplitude**
- **Oscillation phase**
- **Beam spectra**

*Growth rate vs bunch*

*Averaged growth rate vs beam current*

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Diamond Dependence of the instability on the vacuum level:

- Average pressure is still improving as a function of beam dose (lowered by a factor of ~5 since early instability measurement)
- Vacuum level several times higher locally in in-vacuum IDs
- Recently, it became difficult to measure the threshold without beam loss (tail part)
  (Overall beam-ion interaction triggered RW instability & avoided beam losses?)

Courtesy C. Herbeaux
3. Development of a parallel-processed multibunch tracking code

- To analyze RW & Ions driven transverse multibunch instability.
- To be able to treat different beam fillings, incoherent tune spread, beam-ions interactions.

- Master stores CM motions of all bunches. Each child then takes into account long-range (RW) forces of all bunches over multiple turns.

- At SOLEIL, 1000 turn tracking of 138 bunches (1/3 filling) with 2000 particles/bunch:
  Takes ~ ¼ hour with 16 processors
3. Single Bunch Effects

- Mode detuning and TMCI threshold

### Comparison of impedance using

\[
\frac{df}{dl} = -\frac{\beta}{8\pi^{3/2}\sigma E/e} \cdot \Im(Z_{\perp})_{\text{eff}}
\]

(Horizontally, \(df/\beta dl\) is deduced as \(-f_0Qs/l_{th}\).)

<table>
<thead>
<tr>
<th></th>
<th>((df/\beta dl)_{\text{meas}})</th>
<th>(\beta \Im(Z_{\perp})_{\text{eff}})</th>
<th>(\beta \Im(Z_{\perp})_{\text{budget}})</th>
<th>(\text{ratio} \ (\text{meas}/\text{calc}))</th>
<th>((l_{\text{TMCI}})_{\text{meas}})</th>
<th>((l_{\text{TMCI}})_{\text{calc}})</th>
<th>(\text{ratio} \ (\text{calc}/\text{meas}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>-1.34</td>
<td>2.45</td>
<td>1.35</td>
<td>1.8</td>
<td>2.8</td>
<td>5.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Horizontal</td>
<td>-0.44</td>
<td>1.05</td>
<td>0.63</td>
<td>1.7</td>
<td>8.4</td>
<td>14.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>
- Bunch lengthening (streak camera)

- Synchronous phase shift (streak camera)

- Energy spread widening
  
  Both measurement and simulation show no substantial widening up to 20 mA

◊ Measured data seem to indicate that $\text{Im}Z$ is larger than expected by a factor of $\sim 2$ in all H, V and L planes.

◊ Measured $|Z/n|_{\text{eff}}$ is still less than 0.5 $\Omega$.  

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Could the ImZ discrepancy be due to roughness of the NEG coating?

- Reports exist that NEG coated Al chambers have granular surface roughness.
- Anomalous increase of ImZt observed at ELETTRA when NEG coated Al chambers installed.
  → For precaution NEG coating thickness reduced (1 → 0.5 μm) at SOLEIL

• Estimates using the roughness impedance theory:
  - G. Stupakov’s small angle model applied to the measured substrate → Δ(ImZ) negligible
  - K. Bane et al.’s model applied to a granular surface (a ∼1 μm) → Δ(ImZ) ~ discrepancy

However, NEG coating carried out for SOLEIL chambers did not degrade the roughness

→ The observed Δ(ImZ) should not be attributed to the roughness

Measured at the ESRF  
(bumps ∼μm)  
Courtesy T. Perron

SOLEIL extruded Al chamber  
(rms ∼0.3 μm)  
Courtesy SOLEIL’s Metrology Lab.

NEG coated SOLEIL extruded Al chamber  
Courtesy SAES Getters
4. Conclusion

- There appears to be a strong influence of beam-ion interactions on the multibunch, on top of impedance (RW) effects.

Better understanding of the dynamics is required for the good control of the beam instability.

Up to the present maximum current of 300 mA in 3/4th filling, TFB manages to keep the beam stable at zero chromaticity in both H & V planes.

- The origin of discrepancy on the broadband impedance (measured vs calculated) must be clarified