The ELETTRA 3.5 T Superconducting Wiggler: assembling, installation and test results

D. Zangrando
<table>
<thead>
<tr>
<th>Operating Parameters</th>
<th>0.75 to 1.0 GeV</th>
<th>2.0 GeV</th>
<th>2.4 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection energy</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Final energy</td>
<td>320 mA (τ = 8 hrs)</td>
<td>140 mA (τ = 26 hrs)</td>
<td></td>
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<tr>
<td>Starting current</td>
<td>100 mA (τ = 33 hrs)</td>
<td>72 mA (τ = 52 hrs)</td>
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<tr>
<td>New Injection after 24 hours</td>
<td></td>
<td></td>
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</tbody>
</table>

**2002 Operating Time**

- Total Hours: 6216
- User Hours: 4704
- Machine Hours: 1512

- 25% User time at 2.4 GeV
- 75% User time at 2.0 GeV

3 EU sections
4 Pl.Un.
1 EEW
1 Hy.Wig
1 F8
1 SCW

D. Zangrando
### ELETTRA Insertion Devices

**First ID installation:** September 1993

<table>
<thead>
<tr>
<th>ID</th>
<th>type</th>
<th>sectio</th>
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<th>Nper</th>
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<td>100</td>
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<tr>
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<td>U8.0</td>
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<td>19</td>
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<td>EU4.8</td>
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<td>EU7.7</td>
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<td>EU6.0</td>
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<td>17</td>
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<td>FEU</td>
<td>PM/Figure-8</td>
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<td>ShortID</td>
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<td>-</td>
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**Most recent installation:** March 2003
## ELETTRA Insertion Devices

### SUPERCONDUCTING UNDULATORS & WIGGLERS
ESRF, Grenoble, Monday 30th June - Tuesday 1st July 2003

<table>
<thead>
<tr>
<th>Type</th>
<th>Section</th>
<th>Installation</th>
<th>N. period</th>
<th>Period length</th>
<th>K</th>
<th>Energy</th>
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<td>20-1000 eV</td>
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<tr>
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<td>Kh=5.9</td>
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<td>35-1600 eV</td>
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<td>10-25 keV</td>
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<td>giu-01</td>
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<td></td>
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</table>
SCW in storage ring
SCHEDULE

• Order : Dec. 2000 - Budker Institute of Nuclear Physics (BINP)

• Prototype tested in June 2001 (9 poles)

• Final Design Review : November 2001

• Factory Acceptance Test : August 2002

• Transportation (2-3 weeks): September 2002 (about 7200 km, by dedicated truck)

• Assembling at ST: September-October 2002 (2 weeks)

• Site Acceptance Test: October 2002 (1 week)

• Installation: October 2002 (28 October – 1 November)

• Commissioning started: November 2002

• Liner replacement : November 2003
The multipole superconducting wiggler, constructed by Budker Institute of Novosibirsk, was designed to produce a high flux and brightness source in the 10-25 keV range for the second Diffraction beamline (XRD-II)

**Main Parameters:**

- Critical photon energy at 2 GeV (keV) 9.3
- Total radiated power at 2 GeV, 100 mA (kW) 4.6
- Working temperature (K) 4.2
- Maximum field on beam axis:
  - Central 45 poles (T) 3.5
  - Side 2-nd and 48-s poles (T) 2.8
  - Side 1-st and 49-s poles (T) 1
- Pole gap (mm) 16.5
- Period length (mm) 64
- Stored energy (kJ) 240
- Total weight of cooled parts (Kg) 1000

D. Zangrando
A factor of 3 (14) higher flux will be produced compared to the permanent magnet wiggler of the existing Diffraction beamline (XRD) at 12.5 keV (25 KeV).

An advantage of a SCW compared to a perm.magn.device (W14) is the shorter length $\rightarrow$ smaller source sizes.
LHe TL
(LHe flux ~400 l/h)
installed in Sept.2002

SCW rack and PS

Space available for SCW : 2.5 m
Inside the stainless steel vacuum chamber that is part of liquid helium vessel is installed a cold copper liner (20 K), with an internal vertical aperture of 10.7 mm, designed to absorb the thermal load from scattered photons and r.f. heating (reduce heat flux to the helium chamber).
Length ~2 m
480 Slots: 15x1 mm

D. Zangrando
Wiggler magnetic system

Magnetic field is produced by 98 NbTi coils (wire diameter 0.92 mm, 8600 filaments, critical current 380 A)

Design carried out to obtain a magnetic field of 3.5 T, keeping the magnetic field period as short as possible (64 mm)

The shape of the central pole is *elliptical* with axes 140 mm and 7 mm.

Two power supplies is used to feed the central and side coils, in order to control the field integral (Ic=288A, Is=210A, for T=3.54 T)

Each superconducting section of the wiggler is protected by shunts with a resistance of 0.1 Ohm and cold diodes to prevent the coils from damage during a quench.

The ARMCO iron yoke is used to return the magnetic flux and to support the coils. The length of the magnet iron yoke is 1700 mm.

The coils are pre-stressed by a special bandaging system, consisting of 8 longitudinal bronze screwed rods (to avoid movement of the wire forming the coils under the action of magnetic field)

*D. Zangrando*
Wiggler magnetic system

BINP, Novosibirsk

The ELETTRA 3.5 T Super Conducting Wiggler (16)
LHe vessel

LHe vessel with inside the magnets Capacity 620 l, working volume 300 l

High Tc current leads connected to the magnet

The ELETTRA 3.5 T Super Conducting Wiggler (17)
Cryogenic system

Two cryo-coolers are used for cooling 60 K and 20 K shields (and the liner)

Two recondensers are used for recondensing LHe inside of the cryostat and cooling 60 K shield.
Cryogenic system

**Recondenser:** 2 Leybold Coolpower 4.2GM
Refrigeration Capacity
First Stage  45W @ 50 K, Max.
Second Stage  1 W @ 4.2 K, Max.
Minimum Temperature Second Stage: 3.2 K (No Load)

**Coolers:** 2 Leybold Coolpower 130
Refrigeration Capacity
First Stage  115W @ 77 K Max.
Second Stage  15 W @ 20 K Max.
Min. Temp. Second Stage: 9 K (NoLoad)
Support system

- Vacuum insulation \( \sim 10^{-8} \) mbar (measured)
- Special kevlar strips are used to support the LHe vessel
Liner

1. All dimensions are for reference only.
2. Hsg cup channel with liner channel, any steps at place of joints are not allowed.
Special elliptical adapter with “spring finger” contacts is used for smooth transition from SCW vacuum chamber to SR vacuum chamber.

D. Zangrando
Mode of operation

• **Power mode (PWM):** the 2 power supply (Danfysik power supplies, model 883, 400 A, 10V) are connected to the magnet.

  **Power Supplies Stability measured by Sincrotrone Trieste**
  
  < 5 ppm @ 24 Hours at 3.5 T (estimated orbit stability not worse than 1 µm)

• **Persistent mode (PRM):** there are 2 persistent switches that can close the 2 circuits and the power supplies are disconnected form the magnet:

  There is a redistribution of the currents inside the 2 circuits due to the strong inductance and non zero resistance:

<table>
<thead>
<tr>
<th>Field [T]</th>
<th>Decay time</th>
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<tbody>
<tr>
<td>1.5</td>
<td>4.4 Year</td>
</tr>
<tr>
<td>3.5</td>
<td>77 Days</td>
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</table>

<table>
<thead>
<tr>
<th>Field [T]</th>
<th>$\Delta I_1$</th>
<th>$\Delta I_2$</th>
<th>$\Delta (I_2-I_1)$ [mA/h]</th>
<th>$\Delta B/B$ in 1 hours</th>
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<tbody>
<tr>
<td>1.5</td>
<td>14,5</td>
<td>-33</td>
<td>-47,5</td>
<td>-2,6·10⁻⁵</td>
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<tr>
<td>2.5</td>
<td>-14,4</td>
<td>-42</td>
<td>-27,6</td>
<td>-1,3·10⁻⁴</td>
</tr>
<tr>
<td>3</td>
<td>-135,6</td>
<td>+85,2</td>
<td>+221</td>
<td>-2,4·10⁻⁴</td>
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<td>3.5</td>
<td>-522</td>
<td>+522</td>
<td>+1050</td>
<td>-5,4·10⁻⁴</td>
</tr>
</tbody>
</table>

  **The field integral variation (measured) in persistent mode at 3.2 T:**
  
  3 G*cm/min in hor. plane
  
  <10 G*cm/min (???) in vert. plane (measured, magn.meas.)

  **These meas. were not repeated with e-beam, because at 3.5 T there is the risk of quench if operate in PRM without FLUX pump!!!**

_D. Zangrando_  

The ELETTRA 3.5 T Super Conducting Wiggler (23)
To compensate the redistribution of currents: **FLUX PUMP**.

- However it is not possible to keep *simultaneously* first field integral to zero and field constant

Higher priority is to keep **first field integral variation** = 0 (vs. time)

Mag. Field vs. time (12 hours), at 3.5 T, Flux pump ON, 
(ΔB~100 G in 12 h), corresponding to

\[ \Delta B / B = 2.4 \times 10^{-4} \text{ per hour (} \tau = 175 \text{ days)} \]
Maximum field achieved after few quenches: 3.62 T (FAT, Novosibirsk)

---

Quench (demonstration) at 3.67 T,
at Elettra (SAT)
(80-100 LHe)

The magnet is again ready for operation after 30 minutes

4 quenches have been produced after wiggler assembling at the ELETTRA site.

(Wednesday, 9 October 2002 at 4 pm)
2. Peak-Peak magn. field variation : 1% (rms) at 3.5 T:

Factory Acceptance Test results (BINP)

B=0.6 T

1.86
1.2
-0.78
-2.1

B=3.5 T

1.25
0.68
0.12
-1.01

45 poles
Vert. Magn Field at 3.5 T

Angle at 2 GeV, calculated from magn.measurements

Calculated Electron trajectory at 2 GeV

D. Zangrando
Factory Acceptance Test results (BINP)

\[ \frac{B_y(X=0) - B_y(X=-10 \, \text{mm})}{B_y(X=0)} \times 100 \]

Transverse field variation along the SCW, for hor. displacement x=±10 mm at B=3.5 T

- 0.62 %
- 0.65 %
- 0.65 %
- 0.60 %

D. Zangrande

The ELETTRA 3.5 T Super Conducting Wiggler (28)
Sextupole component at 3.5 Tesla (calculated from magnetic measurements carried out at Novosibirsk)

At 0.6 T: sextupole: 10T/m²
Factory Acceptance Test results (BINP)

Horizontal first field integral (G*cm) vs. transverse position (mm) at different field level

D. Zangrando  
The ELETTRA 3.5 T Super Conducting Wiggler (30)
Factory Acceptance Test results

Vertical first field integral (G*cm) vs. transverse position (mm) at different field level

1 T
3.0 T

X Offset

Vert integral

Field 1T
Field 3T
Hor. and vertical second field integral (G*cm²) vs. at different field level at x=0

D. Zangrando
Factory Acceptance Test results

Residual magnetic field after quench

Residual magnetic field after slow ramping down

10 Gauss

30 G

45 Gauss

10 Gauss

7 Gauss

30 Gauss

9

D. Zangrando

The ELETTRA 3.5 T Super Conducting Wiggler (33)
Insulation Vacuum:
Insulating vacuum provided by ion pump better than 1-10⁻⁷ mbar

Cooling down of the wiggler
To cool down from room temperature to 90K, it was used about 700 liters of LN (70-80 hours) 400 liters of LHe to cool down to 4K during 3-5 hours.

Magnetic Field Ramping up and down time:
Time of **ramping up** with orbit, inside 100 microns (at 2 GeV, from magnetic measurements) is about 4 minutes 30 second. This time could be decreased down to 3.5 minutes by increasing current speed for B>1.5 Tesla (to be tested with beam).

Time of **ramping down** with (without) orbit control ~100 microns is about 8 (4.4) minutes
It was installed in the storage ring with a vertical misalignment of about 2 mm, caused by an extra force of about 700 kg on the magnet vessel created after pumping the insulating chamber (not been taken into account at the design stage).

With a vertical misalignment of 2 mm, 20 mA beam dump generated a quench!!!
Closed orbit distortion, with the SCW set in persistent mode at 3.5 T:

Max. variation in an hour of operation (with feedback off):

<table>
<thead>
<tr>
<th></th>
<th>position</th>
<th>angle</th>
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</thead>
<tbody>
<tr>
<td>Hor.</td>
<td>20 µm</td>
<td>1 µrad</td>
</tr>
<tr>
<td>Vert.</td>
<td>2 µm</td>
<td>5 µrad</td>
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</tbody>
</table>

(but it also include thermal drift, etc.)

In the horizontal plane the measured tune shift is 0.003 (at 3.5 T, as expected)
**Liquid helium consumption during acceptance test (at Elettra)**

LHe consumption (l/h) \quad B (T)

<table>
<thead>
<tr>
<th>LHe consumption (l/h)</th>
<th>B (T)</th>
</tr>
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<tbody>
<tr>
<td>0.85-0.9</td>
<td>3.5 (power mode)</td>
</tr>
<tr>
<td>0.4-0.6</td>
<td>3.5 (persistent mode)</td>
</tr>
<tr>
<td>1.7</td>
<td>0 -3.5 (ramping field)</td>
</tr>
</tbody>
</table>

**LHe consumption measured in storage ring and NO BEAM**

Liquid He consumption at 3.5 T with SCW in Storage Ring and I_beam = 0 mA

B=3.5 T
In order to overcome this anomalous consumption, which is believed to be due to the beam interaction with the liner slots, the liner itself will be removed next November and replaced with a modified version.
Liner temperatures vs. beam current

2.4 GeV, with NO LHE inside, recondensors OFF, coolers ON

temperaure [K]  E_beam current [mA]

Typical variation 4 K

D. Zangrando
2.0 GeV, with NO LHE inside, recondensors OFF, coolers ON

Temperatures vs. beam current

Typical variation 7-8 K

D. Zangrando