COMMISSIONING 2 MEV COOLER IN COSY AND NOVOSIBIRSK

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Limits of the COSY stochastic cooling system

Cooling time ~ number of particles / bandwidth

- Luminosity: $\leq 10^{31} \text{ cm}^{-2} \text{s}^{-1}$
- Number of particles: $6 \times 10^{10}$
- Cluster target thickness: $10^{14} \text{ cm}^{-2}$

Requests for future COSY experiments

- Luminosity: $\geq 10^{32} \text{ cm}^{-2} \text{s}^{-1}$
- Number of particles: $6 \times 10^{10}$
- Pellet target thickness: $10^{16} \text{ cm}^{-2}$

Possible solutions

- Increase bandwidth of stochastic cooling
- Electron cooling up to maximum momentum

P=183.6 m, E=2880 MeV
Main feature of cooler COSY

1. Classical design with longitudinal magnetic field;
   - very wide range of the operation, the preferable smallest energy is 25 keV, it is injection energy;
2. Section-module principle of the design of the electrostatic accelerator;
   - each section contains the high-voltage module and coils of the magnetic field;
3. Possibility for on-line control of the quality of the magnetic field
   - in order to have high cooling rate;
4. Cascade transformer for power supply of the magnetic coils;
   - smooth longitudinal magnetic field along accelerated tube demands power to many coils;

5. Electron Collector with Wien Filter
   - in order to have small leakage current from the collector
6. “Magnetized” electron motion
7. “4-sectors” electron gun for diagnostics of the electron beam motion

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2 MeV Electron Cooler</th>
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</thead>
<tbody>
<tr>
<td>Energy Range</td>
<td>0.025 ... 2 MeV</td>
</tr>
<tr>
<td>Maximum Electron Current</td>
<td>1-3 A</td>
</tr>
<tr>
<td>Cathode Diameter</td>
<td>30 mm</td>
</tr>
<tr>
<td>Cooling section length</td>
<td>2.69 m</td>
</tr>
<tr>
<td>Toroid Radius</td>
<td>1.00 m</td>
</tr>
<tr>
<td>Magnetic field in the cooling section</td>
<td>0.5 ... 2 kG</td>
</tr>
<tr>
<td>Vacuum at Cooler</td>
<td>10^{-9} ... 10^{-10} mbar</td>
</tr>
<tr>
<td>Available Overall Length</td>
<td>6.39 m</td>
</tr>
</tbody>
</table>
3D design of COSY Cooler

- Collector gun
- Electrostatic Accelerator
- Electron beam
- Proton beam
- Cooling section
- Transport channel
3D design of Accelerating Column

Each section contains:
- high-voltage power supply +/- 30 kV;
- power supply of the coils of the magnetic field (2.5 A, 500 G);
- section of the cascade transformer for powering of all electronic components;

33 high-voltage section
Now in operation in COSY FZJ

Example of the long training regime in Novosibirsk. The electron current was about 200 mA. The electron energy was about 1 MeV. The total time of the training procedure is 6 day and night.
Possibility for on-line control of the quality of the magnetic field

According Parkhomchuk’s equation the cooling force strongly depends from the quality of the magnetic field in the cooling section.

Compass with gimbal suspension

Horizontal magnetic field in the cooling solenoid initially (curve 1) and after few iteration of coil adjustment (curve 2).

R.M.S. ripple of the magnetic force line was decreased from $6 \cdot 10^{-4}$ to $2 \cdot 10^{-5}$. 

measurement system
Cascade Transformer as Power Supply

Transformers section looks like accelerating tube:
- Transformers connected to series;
- Tube is alternation of the ceramic and metal rings (sections);
- Tube is filled by oil;
- Section has special spark-gaps;

PS generator
650V 60A 25 kHz

section 1
section 2
section 3
physics principle of operation of cascade transformer is combination of series and parallel resonances induced by the leakage inductance and compensative capacitances

- transfer constant on load resistor 20 Ohm is 0.9, the r.m.s. voltage 700 V corresponds to 25 kW of power

Series resonance curve

Distribution Power Along Accelerated Column
Wien Filter – try to catch electrons that run away from collector

Area with crossed electrical and magnetic fields compensated each other

\[ \vec{F'}_\perp = \vec{F}_\perp - c \vec{F}_\parallel \]

primary beam

\[ \vec{F'}_\perp = \vec{F}_\perp + c \vec{F}_\parallel \]

secondary beam

Motion of primary beam is red circle and motion of reflected beam is blue circle

The experimental recuperation coefficient is \( 10^{-5} - 10^{-6} \)
Исследование эффективности рекуперации при различных энергиях

30 кВ

150 кВ

200 кВ

1 МВ
The particle motion at a presence of a large magnetic field can be described as combination of the fast larmour oscillation and slow drift motion. In spite of the fact that, the adiabatic criteria isn’t satisfied the drift description of particle motion is correct. The reason is smallness of the transverse component of the magnetic field in comparison with the longitudinal component.

Transportation of the electron beam is also magnetized that has some features. The necessity to have the continuous magnetic field from gun to the collector is result of the operate range from 100 keV to 2 MeV.
To decrease heating of the beam after transition through a bend, the length of the bend should be equal to integer number of Larmor length. In such a case kick on entry to bend in compensated by kick on leaving.

The worst situation, which one should avoid, occurs when length of bend is equal to \( n + \frac{1}{2} \) of Larmor length. In such a case two kicks are added and resulting transverse velocity of electrons is very big from the point of view of cooling.

To adjust the optics for every energy is inconvenient. Another method was proposed for this system. The idea of the method is to change magnetic field in the cooler synchronously with beam energy. If magnetic sys was adjusted for 2 MeV electron beam then after the decreasing of energy for value \( U \), we must decrease magnetic field (longitudinal and transverse) in \( \alpha \) times where \( \alpha \) is equal to ratio of momentums for 2 MeV and for \( U \):

\[
\alpha = \frac{p_{2\text{MeV}}}{p_U}
\]
Matching section, non-adiabatic transition between the different value of the magnetic field

The special section with independent power supplies for forming proper profile the magnetic field

\[ B(z) = \frac{\gamma \beta}{e} c^2 k_N(z) = 2\frac{\gamma \beta}{e} c^2 \sqrt{\frac{1}{W^4} - \frac{W'}{W}} \]

Two place for optic compensation
Diagnostics of the shape of the electron beam

The combination of the constant and modulation voltage is applied to the electrodes.
Lengthy coils in longitudinal direction control the position of the center of Larmour rotation; Short coils control the amplitude of the Larmour oscillations.

Optic features of COSY cooler

- line17hor, line17ver, all bends—correctors of the beam shift
- line10—correctors of the beam kick
- Match and torbnd—correctors of the galloping of beam shape correction
- cool—convergence of ion and electron beams

Location of BPMs and magnetic elements of COSY coolers
Demonstration of the BPM and correctors working.
Scanning bend1 and bend2 magnets.
The simple verification of the diagnostic tools at electron energy 30 keV

At small value of the magnetic field the size of the electron beam is determined not only by the magnetic field but the anode value also

\[ \frac{r^2_{BPM}}{B_{gun}} = \]

Conservation of the magnetic flux

\[ B_{gun}r^2_{gun} = \]

Change shape of the electron beam by the potential of the control electrode

Pictures was done with wire probe
Effect of the short dipole corrector is combination of the shift of the center of electron beam with excitation of Larmour rotation.
Before cooling

Transverse cooling at 109 kV

Longitudinal cooling at 109 kV

Cooling
RF cooling with formation of very narrow ion beam

Cooling at 908 kV

600 s
Combine action of stochastic and electron cooling

Only stochastic
Stochastic+e-cooling

Electron energy 908 keV
Proton energy 1.66 Gev
Stochastic cooling vertical and horizontal
E-cool time 120 s
Stochastic cooling time 400 s
Beta function x/y 4m/3m

initial no longitudinal cool, after e-cooling
Macroscopic Larmour rotation is essential

edip kick=+2/0 A

Electron energy 315.85 keV
Jsol=225A=1275 G
cycle duration = 600 sec
Je=0.26 mA

\[ \lambda := \frac{\gamma \cdot 3 \cdot 511 \cdot 10^6}{B \cdot 300} \]
\[ \lambda = 1.697 \]

\[ \Delta := 0.02 \]
\[ \frac{\Delta}{\lambda} = 0.012 \]
Incline of the electron beam is essential too.

Electron energy 315.85 keV
\( J_{\text{sol}} = 225 \text{A} = 1275 \text{ G} \)
cycle duration = 600 sec
\( J_e = 0.3 \text{ mA} \)

\[
\frac{0.04}{125} = 3.2 \times 10^{-4}
\]
Horizontal size / 1 mm
Vertical size / 1 mm
Proton beam current / (0.1 mA)
Electron beam current / 100 mA
Time sec
The key problems of the electron cooler 2 MeV (modular approach of the accelerator column, the cascade transformer, the compass base probe located in the vacuum chamber, the design of the electron gun with 4-sectors control electrode) are experimentally verified during commissioning in Novosibirsk and Juelich.
- The strong surprises aren’t observed.
- The cooling experiments in COSY were started.
- The conception of magnetized cooling is useful until now

What is a next step of the cooling technique?