Decay ring status / studies

Antoine CHANCÉ

CEA Saclay IRFU/SACM

2nd July 2008
Outline

1. Optics
2. Collimation in energy
3. Defects in the magnetic elements
4. Losses by $\beta$ decay
5. Conclusion
Outline

1. Optics
2. Collimation in energy
3. Defects in the magnetic elements
4. Losses by $\beta$ decay
5. Conclusion
## The decay ring

### Parameters for the decay ring

|                | $^6\text{He}^{2+}$ | $^{18}\text{Ne}^{10+}$ |
|----------------|---------------------|-------------------------|
| $\gamma$       | 100                 | 100                     |
| $B_\rho \ (\text{T.m})$ | 938                 | 563                     |
| $B_{dipole} \ (\text{T})$ | 6                   | 3.6                     |
| $\tau \ (\text{s})$ at rest | 0.8                 | 1.67                    |
| $N_{injected}$ (ions/batch) | $9.05 \times 10^{12}$ | $4.26 \times 10^{12}$ |
| $N_{stored}$ (ions/batch) | $9.71 \times 10^{13}$ | $7.40 \times 10^{13}$ |

Total length: 6911.5 m (SPS length). 
“Useful” length: 2468 m.

$\Rightarrow$ 36% of useful decays in the decay ring.
Space charge effects

|                      | Nominal values       | Recommended       |
|----------------------|----------------------|-------------------|
|                      | $^{6}\text{He}^{2+}$ | $^{18}\text{Ne}^{10+}$ | $^{18}\text{Ne}^{10+}$ |
| $\gamma$             | 100                  | 100               | 100               |
| Nb of ions/bunch     | $4.85 \times 10^{12}$| $3.70 \times 10^{12}$ | $3.70 \times 10^{12}$ |
| rms $\epsilon_x$ ($\pi$ mm.mrad) | 0.11                | 0.11              | 0.22              |
| rms $\epsilon_y$ ($\pi$ mm.mrad) | 0.06               | 0.06              | 0.22              |
| $\Delta \nu_x$       | -0.015               | -0.127            | -0.055            |
| $\Delta \nu_y$       | -0.024               | -0.201            | -0.063            |
| $\epsilon_x \frac{\partial \nu_x}{\epsilon_y \frac{\partial \nu_x}{\partial U_x}}$ | +0.003/+0.002 | +0.025/+0.014 | +0.010/+0.007 |
| $\epsilon_y \frac{\partial \nu_x}{\epsilon_x \frac{\partial \nu_y}{\partial U_y}}$ | +0.005/+0.003 | +0.038/+0.025 | +0.012/+0.007 |

For $^{6}\text{He}^{2+}$, the space charge effects are neglectable. For $^{18}\text{Ne}^{10+}$, the space charge effects are much stronger (higher charge number). The tune shift is very large and the beam will cross several resonances. A solution to handle the space charge effects would be to increase the rms emittance of the beam.
In order to maximize the flux going to the detector, we need:

- large betatron functions in the long straight sections (FODO lattices). The rms angle $\sqrt{\gamma_x \epsilon_x}$ must be low compared with $1/\gamma \approx 10$ mrad.

The injection system needs:

- a low $\beta_x$ and high dispersion insertion. This insertion is in one of the arcs: dispersive areas with low betatron functions and dipoles are already present.
- a collimation of the ions which are not accepted anymore in energy.

All injected ions are lost in the ring. We have to:

- extract the decay products when possible.
- restrict their deposition in the magnetic elements.
Optical functions of the decay ring

![Graph showing optical functions of the decay ring]

- Extraction Section
- Section Injection
- Matching Section
- FODO lattices
- Matching Section

\[ \sqrt{\beta_x}, \sqrt{\beta_y}, D_x \]

s(m)
Outline

1. Optics
2. Collimation in energy
3. Defects in the magnetic elements
4. Losses by $\beta$ decay
5. Conclusion
Principle of the “off momentum” injection

1. The stored beam is deviated by 4 kickers.
2. The entering beam is injected “off momentum” on its chromatic orbit.
3. The kickers are switched off. The injected beam stays on its chromatic orbit and runs under the septum blade.
4. The 2 beams are merged together by a specific RF program.
The stored beam is deviated by 4 kickers.
Principle of the “off momentum” injection

1. The stored beam is deviated by 4 kickers.
2. The entering beam is injected “off momentum” on its chromatic orbit.
Principle of the “off momentum” injection

1. The stored beam is deviated by 4 kickers.
2. The entering beam is injected “off momentum” on its chromatic orbit.
3. The kickers are switched off. The injected beam stays on its chromatic orbit and runs under the septum blade.
Principle of the “off momentum” injection

1. The stored beam is deviated by 4 kickers.
2. The entering beam is injected “off momentum” on its chromatic orbit.
3. The kickers are switched off. The injected beam stays on its chromatic orbit and runs under the septum blade.
4. The 2 beams are merged together by a specific RF program.
Beam evolution injection after injection

The RF merging program has been applied to an entering beam at $\delta = 5 \text{ permil}$ to simulate its evolution injection after injection.
Two loss sources have been identified:

1. Some ions of the injected beam are not in the capture bucket and form a halo around the beam.
2. Blow-up in the space ($l, \delta$) injection after injection. After 15-20 injections, the ions are not accepted anymore.

The survival of the beam after each step has been drawn:
Two loss sources have been identified:

1. Some ions of the injected beam are not in the capture bucket and form a halo around the beam.
2. Blow-up in the space $(l, \delta)$ injection after injection. After 15-20 injections, the ions are not accepted anymore.

The survival of the beam after each step has been drawn:
The energy collimation system

The mean power to collimate in the ring has been evaluated to $74 \text{ kW}$ for $^6\text{He}^{2+}$ and $248 \text{ kW}$ for $^{18}\text{Ne}^{10+}$. 

⇒ A two-step collimation system has been designed to perform the collimation in energy. It has been located in the long straight section which is not directed toward the detector.
Outline

1. Optics
2. Collimation in energy
3. Defects in the magnetic elements
4. Losses by $\beta$ decay
5. Conclusion
Random errors in the magnetic elements

| Defect type                  | rms value | units |
|------------------------------|-----------|-------|
| **DIPOLES**                  |           |       |
| $\frac{\Delta B}{B}$        | 0.1       | $10^{-3}$ |
| Horizontal misalignment      | 0.2       | mm    |
| Vertical misalignment        | 0.2       | mm    |
| Rotation error/s axis        | 0.1       | mrad  |
| **QUADRIPOLES**              |           |       |
| $\frac{\Delta B}{B}$        | 0.1       | $10^{-3}$ |
| Horizontal misalignment      | 0.2       | mm    |
| Vertical misalignment        | 0.2       | mm    |

The misalignment errors can be corrected by inserting 83/85 horizontal/vertical correctors with a maximum integrated field of 0.18 T.m in the decay ring. More precise values on these errors are needed.

Before correction:

After correction:
Dynamic aperture without any defect

The ions run a large number of turns before being lost. ⇒ The long term transverse stability must be considered. The chromaticity must be corrected to accept the injected beam in the decay ring.

Without any defect in the structure, the obtained dynamic aperture is very large with 6 sextupole families. The design of the dipoles at large aperture (±80 mm) cannot be perfect and multipole defects are unavoidable.

Neon case

\[
\sigma_x = \sqrt{\beta_x \epsilon_x} \approx 2 \text{ mm.}
\]
\[
\sigma_y = \sqrt{\beta_y \epsilon_y} \approx 0.9 \text{ mm.}
\]
\[
\epsilon_x = 0.22 \text{ mm.mrad.}
\]
\[
\epsilon_y = 0.22 \text{ mm.mrad.}
\]
Systematic multipole defects in the dipoles

C. Vollinger, E. Wildner

| Multipoles | \(b_n \left(10^{-4}\right)\) | \(K_nL = \frac{b_n\theta}{\beta^{n-1}} \left(m^{1-n}\right)\) |
|------------|-----------------|------------------|
| 1 (main field) | 10^4 | \(\theta = \frac{\pi}{186}\) rad |
| 3 | -1.68 | -0.00171 |
| 5 | 33.02 | 9.307 |
| 7 | -50.12 | -3924.5 |
| 9 | 29.58 | 643400 |

Neon case
\(\sigma_x = \sqrt{\beta_x \epsilon_x} \approx 2\) mm
\(\sigma_y = \sqrt{\beta_y \epsilon_y} \approx 0.9\) mm
- \(n = 5\)
- \(n = 7\)
- \(n = 9\)
- all multipoles

The dynamic aperture dramatically decreases in presence of the multipole defects in the dipoles.
Management of the defects in the dipoles

1. Several working points have been studied to compare their optical properties. The dynamic aperture is up to $6 \sigma$.

2. The coupling between the different planes is still important and could have an effect on the collimation efficiency.

3. A more precise estimation of the tolerances on the different multipolar defects (systematic + random) must be pursued.
1. Optics
2. Collimation in energy
3. Defects in the magnetic elements
4. Losses by $\beta$ decay
5. Conclusion
Losses due to the $\beta$ decays in the ring

The decay of the stored ions implies a continuous power loss with a mean value of:

$$P = 10.8 \text{ W/m for } ^{6}\text{He}^{2+}$$
$$P = 11.8 \text{ W/m for } ^{18}\text{Ne}^{10+}$$

The relative rigidity difference is:

$$\delta \approx -33\% \text{ for } ^{6}\text{He}^{2+} \quad \delta \approx +11\% \text{ for } ^{18}\text{Ne}^{10+}$$

The rigidity difference is too large to accept the decay products: they are lost after crossing a few dipoles.
⇒ Deposition maxima after the long straight sections: several tens of kilowatts! A dedicated extraction section is inserted at the arc entry.
⇒ The deposition inside the superconducting magnets must be low enough to avoid quenching.
Decay losses in the arcs

2 solutions are under study to handle the decay losses in the arcs:

The optics of the decay ring is very similar in both cases. The advantages of the open mid plane dipoles are:

1. The dipoles can be lengthened which decreases their magnetic field (5 T instead of 6 T).
2. The aperture is smaller (±50 mm against ±80 mm).
3. The structure needs less changes if other ions are used.
Results from BETA

In both cases, the differences with the second order are very low. According to BETA code, the average power lost in the dipoles is under 10 W/m. To improve the model and to verify these results, a simulation with ACCSIM and FLUKA was run by E. Wildner and F. W. Jones. By this way, a 3 D model has been realized.
Local Power Deposition, dipole coil, He

F. W. Jones et al, PAC’07, THPAN006

Peaks exceed recommended limit, $4.3 \text{ mW/cm}^3$ for dipoles. Quadrupoles are below limit.

BETA results:

Courtesy: Elena Wildner
Outline

1. Optics
2. Collimation in energy
3. Defects in the magnetic elements
4. Losses by $\beta$ decay
5. Conclusion
To sum up

Some solutions to handle the main problematics in the arcs have been proposed:

- Extraction section at the entry of the arcs.
To sum up

Some solutions to handle the main problematics in the arcs have been proposed:

- Extraction section at the entry of the arcs.
- Use of absorbers or open mid-plane dipoles in the arcs.
To sum up

Some solutions to handle the main problematics in the arcs have been proposed:

- Extraction section at the entry of the arcs.
- Use of absorbers or open mid-plane dipoles in the arcs.
- Realization of a dedicated injection section.
To sum up II

The specific RF program was developed too:

- Simulation of the merging of the injected and stored beams.
- Evaluation of the losses due to this system.
- A collimation system in energy was then defined.
An optics of the decay ring was then realized and its optical properties have been evaluated.

**Without any defects:**
The properties at the first and second orders are sufficient.

**With multipole defects in the dipoles:**
The dynamic aperture has to be enlarged.
⇒ An automatic optimization program of the dynamic aperture was written.
⇒ Several working points were tested in order to limit the effect of the multipolar resonances.
What can be done

- Simulate the transport of the beam in the collimation section. The interaction with the walls and the beam 6D distribution must be taken into account.
- Go on the study on the field defects in the magnetic elements and find some solutions to reduce their effects.
- Improve the simulations of energy deposition in the elements.
- Study the effect of the high intensities stored on the beam dynamics (beam loading, space charge, impedances, ...).
- Realize a lattice for the ions $^8B$ and $^8Li$ but we need parameters.