BETATRON ACCELERATION
DURING EXTRACTION

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February 13th and 14th 1996
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There are (at least) 2 ways to control a resonant extraction during the "spill":
- sweep the resonance through the beam (by gradually changing the value of $Q_J$),
- accelerate the beam through the resonance.

The second method is better, because:
- the extracted beam central energy is fixed,
- all transverse parameters stay constant.

Acceleration can be done with:
- continuous wave RF, but $\Delta p/p$ is low, synchrotron oscillations can create problems and both high and low frequency structures are present in the extracted beam,
- phase displacement, but the process is not continuous,
- RF noise, but a lot of power is needed for spills of the order of a few hundreds of milliseconds,
- betatron acceleration, which works with debunched beam and is compatible with the phase displacement ripple reduction technique.
Principle of betatron acceleration

A magnetic flux $\Phi$ is created around the circulating beam with one or several magnetic circuits (torus). Just like in a transformer, a field $E$ appears inside, along the circumference, following the equation:

$$\int E \, ds = -\frac{d\Phi}{dt}$$

(1)

If $E$ is the mean electrical field over a revolution and $C$ is the orbit length, this writes:

$$d\Phi = C \, E \, dt$$

(2)

The increase of the particle momentum due to this electrical field is:

$$dp = Z_e E \, dt$$

(3)

where $Z_e$ is the particle charge.

From (2) and (3), we obtain:

$$dp = \frac{Z_e}{C} \, d\Phi$$

(4)

introducing the magnetic rigidity:

$$Bp = \frac{p}{Z_e}$$

(5)

and integrating along the time, we obtain the momentum increase due to the flux variation $\Delta\Phi$:

$$\frac{\Delta p}{p} = \frac{1}{CBp} \Delta \Phi$$

(6)

Sketch of installation

Application to TERA project (95'parameters)

If we want to accelerate by $\Delta p/p = 0.3 \%$, assuming $C = 80$ m, $Br = 6.3$ Tm (for high energy ions), then:

$$\frac{3}{1000} = \frac{\Delta p}{p} = \frac{1}{CBp} \Delta \Phi = \frac{1}{80 \times 6.3} \Delta \Phi$$

$\Delta \Phi \approx 1.5$ Tm

which can be done with a section of 0.5 m$^2$ of cheap iron, and a field varying from -1.5 T to +1.5 T.
Proposed characteristics (after M. Thivent, CERN PS and Heidelberg and Saclay equipments)

Magnetic torus (4 units):
- External diameter: 1000 mm
- Internal diameter: 160 mm
- Length: 300 mm
- Weight: 7200 Kg

Coil:
- Section: 2.5 mm²
- Number of turns: 50
- Resistance: 3 Ω
- Inductance: 10 mH

Power supply:
- Maximum current: 20 A
- Maximum voltage: 60 V

CONCLUSIONS

Accelerating the beam through resonance with betatron acceleration and use of low frequency ripple reduction with RF phase displacement seems to be the most attractive scheme: it offers a constant mean energy, a small Δp/p of the extracted beam and a good ripple rejection.

To accelerate by Δp/p = .3% (at 400 Mev/u for oxygen ions), the longitudinal space required is of the order of 1.5 m, the technology is simple and the price reasonable (as compared with RF acceleration).

References (thanks to D. Möhl):

An Induction Accelerator for the Heidelberg Test Storage Ring TSR, Ch. Ellert et al. MPIH-V31-1991

Le Betatron Injecteur de MIMAS, J.C. Clret 16 mars 1998