Absorbers for beam dumping


FCC Week 2016
April 13th, 2016
Energy deposition in beam absorbers

This talk presents energy deposition studies for:

- Protection devices in the extraction region (for asynchronous beam dumps)
- Magnets/septa downstream of the protection devices
- Beam dump core

The energy increase from 7 TeV (LHC) to 50 TeV (FCC) is challenging:

- For a given transverse proton density, the peak energy density in absorber materials scales more than just with the ratio of beam energies
- In addition, beams are smaller compared to LHC if $\beta$-functions remain similar (smaller geometric emittance)

Figures: Energy density in 3 m-long Graphite ($1.83\,\text{g/cm}^3$) for one nominal proton bunch ($\sigma=400\mu\text{m}$), comparing HL-LHC (top) and FCC (bottom).
**Single bunch:** peak dose/temperature in CfC vs $\beta$-function

1 proton bunch, CfC (1.4 g/cm$^3$)

(Dispersion contribution to beam size neglected)

For small spot sizes could expect some (localized) material damage already from 1 bunch

$\rightarrow$ For small spot sizes could expect some (localized) material damage already from 1 bunch
Contents

1 Protection elements for asynchronous beam dumps

2 Beam dump

3 Conclusions
Protection elements for asynchronous beam dumps

- Need dedicated absorbers to protect septum and QD/downstream elements
  → see talk of B. Goddard

- Absorber requirements (like robustness and protection efficiency) have to be considered from the early stage of the extraction system/region design

- Peak energy density and stresses in absorber materials critically depend on:
  - transverse bunch size (i.e. local $\beta$-function)
  - the number of bunches impacting on the absorbers
  - transverse distance $\Delta x$ between bunches swept across the absorbers
  → acceptable load is a key factor for hardware, layout, optics decisions (see talk of W. Bartmann)

Illustration courtesy of B. Goddard.
## QD protection for asynchronous beam dumps

### LHC-like absorber for QD/collimation protection

- **Considered an LHC-like absorber:**
  - made of C blocks of different density
  - 9 meters long, 4 cm wide
  - complemented by shower absorber in front of QD

- **Optics and settings** (see talk of W. Bartmann):
  - $\beta \approx 2.5$ km ($\sigma \approx 320 \mu$m), absorber $9\sigma$ from beam

- **Studied 3 different failure scenarios:**
  - Nominal sweep asynchronous with abort gap
    - (5 bunches on absorber)
  - 5-module prefire + delayed retrigger of all other kickers
    - (6 bunches on absorber)
  - 10-module prefire + delayed retrigger of all other kickers
    - (9 bunches on absorber)

* 90 mm aperture (E. Todesco)
QD protection: energy deposition in C absorber

Nominal sweep (async.): 5-module prefire: 10-module prefire:

Load acceptable for 0/5-module prefire, stresses likely too high for 10-module prefire
Protection elements for asynchronous beam dumps

QD protection: energy deposition in QD coils

**Nominal sweep (async.):**

- **5-module prefire:**
- **10-module prefire:**

![Images showing transverse energy density in QD coils (J/cm³)](image)

Peak energy density (J/cm³) vs. Distance from the QD front (m)

- Effect of magnetic field

→ Energy deposition in coils somewhat high for 10-module prefire, but still acceptable

A. Lechner (FCC Week 2016)

April 13th, 2016
Septum protection for asynchronous beam dumps

- Considered an LHC-like absorber:
  - made of C blocks of different density
  - 9 meters long, 2.8 cm wide
  - Complemented by second absorber on the external side of the extraction channel

- Optics (see talk of W. Bartmann):
  - $\beta \approx 0.8 \text{ km} \ (\sigma \approx 180 \mu \text{m})$

- Asynchronous beam dumps:
  (input from L. Stoel, B. Goddard, W. Bartmann)
  - Nmb of bunches on absorber ($\sim 16$) similar for nominal sweep, 5- and 10-module prefire
  - Studied only nominal sweep
Septum protection: energy deposition in C absorber

**Nominal sweep (async.):** Transverse dose map in absorber (kJ/g)

- **Sweep**
- **Circulating beam**
- **Extracted beam**

**Peak dose (kJ/g) vs Depth (cm):**
- **CfC** 1.8 g/cm³
- **CfC** 1.4 g/cm³
- **CfC** 1.8 g/cm³

- Peak dose profile similar for 5- and 10-module prefire

→ **Stresses likely beyond material limits of absorber, would need somewhat faster sweep**

A. Lechner (FCC Week 2016)
Septum protection: energy deposition in coils, yoke, ...

LHC-like Lambertson septum (blade thickness: 18mm)

Coil: ~3 J/g

Blade: ~8 J/g

Vacuum chambers: 10 J/g

→ Energy deposition acceptable for septum
Contents

1 Protection elements for asynchronous beam dumps

2 Beam dump

3 Conclusions
Overlap of transverse shower tails:

- bunches need to be swept over dump front face in order to keep temperatures in core within reasonable limits (say below 1500°C)
- considering $\beta$-functions of a few km, neighbouring bunches need to be transversally separated by at least $d_{\text{min}} = 1.6-1.8$ mm (A. Lechner, FCC Week 2015)
- limited gain from larger $\beta$-functions (e.g. $d_{\text{min}} = 1.2-1.5$ mm for $\beta=100$ km)
- need a sweep path length of more than 20 meters! (LHC: 1.2 meters)
Spiral sweep pattern: importance of branch separation

Radial branch separation of 1.6 cm (bunch separation 2-2.6 mm) $\rightarrow T_{\text{max}} \approx 1850^\circ C$

Radial branch separation of 3.7 cm (bunch separation 2 mm) $\rightarrow T_{\text{max}} \approx 1550^\circ C$

Sweep patterns by F. Burkart

$\rightarrow$ overlap of neighbouring branches not negligible for a branch separation of a few cm

$\rightarrow$ matter of optimization between bunch and branch separation (and kicker parameters)
Spiral sweep pattern: optimized pattern

*Optimized pattern under consideration of achievable kicker parameters:* (see talk of T. Kramer and poster of D. Barna)

→ need a large dump cross section (diameter of 1.5m!)
Protection elements for asynchronous beam dumps

Beam dump

Conclusions
Conclusions

• The robustness of absorber/dump materials poses several constraints on the extraction system/extraction region design
  ◦ the transverse bunch size ($\sigma$) needs be at least a few 100$\mu$m
  ◦ the transverse distance between neighbouring bunches impacting on an absorber/dump needs to be of the order of mm

• Nevertheless, it seems within reach to design non-sacrificial protection absorbers for asynchronous beam dumps if
  ◦ $\beta$-functions are large at absorber locations ($\geq 1$km),
  ◦ the extraction kicker risetime is faster than in the LHC (1$\mu$sec),
  ◦ we have a long lever-arm between kicker and septa
    → see talk of W. Bartmann in this session

• Protection of magnets and septa seems to be less critical than the absorber material robustness
  ◦ protection elements of similar length as in the LHC ($\sim 10$ m)

• Dilution system design looks promising, but transverse dump dimension might be challenging (next: need to study consequences of dilution failures)