FERMI@elettra COLLIMATORS*

S. Ferry†, C. Bontoiu, P. Craievich, S. Di Mitri, E. Karantzoulis
Sincrotrone, Trieste, Italy

Abstract

To avoid damages on permanent magnets by the electrons, collimators will be installed in FERMI@elettra. Their dimensions and shape are defined through the beam optics and the wake fields induced while GEANT simulations are performed to determine their absorption efficiency and thermal load for both normal operating conditions and in case of miss-steering. The design, the simulations and the expected performance of the collimators are presented and discussed.

INTRODUCTION

The permanent magnets of the insertion devices can be damaged by GeV electron beam. To avoid this, collimators are essential to protect the undulator modules from dark current and halo electrons.

Collimators play the role of longitudinal and transverse phase space filters in order to stop or to deviate particles which can be lost in the undulator modules. Collimators are of two types : geometric and energy collimator. Geometric ones catch particles of large beta amplitudes in dispersion free regions. Energy collimators are placed in large dispersion region to catch off-energy particles, usually in the dog-leg structure. Factors like beam energy and power, wakefields, optics, available space in the linac, are taken into account to define the characteristics of the collimators.

REQUIREMENTS

Aperture

For undulator protection the collimator must completely shadow the undulator beam pipe in terms of position and angular divergence, so that no particle can hit the undulator vacuum chamber. The clearance of the collimated beam Δx_{bsc} to the inner surface of the undulator vacuum chamber should be at least 20% of the undulator beam pipe height (half gap $g_{\rm half} = 3.5$ mm, therefore $\Delta x_{bsc} = 0.7$ mm). The upper limit for the collimator acceptance a_{coll} is given by:

$$a_{coll} \leq \frac{(g_{\rm half} - \Delta x_{bsc})^2}{2\,\beta_{und}} = 0.196\,\mu\text{m.rad} \qquad (1)$$

where $\beta_{und} = 20$ m is the maximum betatron function in the undulator chain. For a given betatron function at the collimator the absorber radius is :

$$R_{coll} = \sqrt{a_{coll}\,\beta_{coll}}. \qquad (2)$$

It is 1.4 mm for a betatron function of 10 m. For practical use and to avoid an important contribution from the collimator wake field, a minimum radius of 2 mm is chosen [2]. This is equivalent to a collimator acceptance of 0.4 μm.rad or, alternatively, to a betatron function at the collimator of 20 m. The rms beam size σ at 1.2 GeV is approximately 100 μm. Thus, for halo removal the collimation is set to 20 σ, horizontally and vertically.

The bending angle in the dog-leg is 3°. The dispersion function at the collimator location is about 3 cm, so for a 2 mm collimator radius, the energy cut is ±6.7% .

Collimator Material

High Z component such as Tungsten (W) have a high absorbing power (radiation length $\mathcal{L} \sim 0.5$ cm). Unfortunately, it is classified as "Highly susceptible to activation" [5], it can be easily activated by an electron beam, and will produced radioactive isotopes. Aluminum (Al) or graphite (C) are much less susceptible, the first is classiffied as "Relatively insusceptible to activation", the second is not classified. Radiation length for these 2 materials are much longer: $\mathcal{L}_{\rm Al} \sim 9$ cm, $\mathcal{L}_{\rm C} \sim 20$ cm which means collimators must be long and wide, eventually longer and wider than the available space on the transfer line. As an alternative, copper is a material "Moderately susceptible to activation", with a radiation length $\mathcal{L}_{\rm Cu} \sim 1.5$ cm. Copper is not damaged at temperature up to 200°.

Collimator Shape

Collimators may have various shapes. In the ideal case, collimators are composed of two parts: the spoiler (or scrapper) and the absorber. The spoiler is generally 2 or 3 radiation length where a large part of the undesirated electrons interacts and produces cascades of lower energy particles. It catches the denser and the most energetic part of the halo so it has to be short not to heat up. The cascade particles are then interacting more efficiently in the absorber. This absorber is usually of the order of ten radiation lengths. With varying aperture, two sets of these have to be used to collimate in both transversal planes. In addition, two collimation systems have to be placed at $\pi/2$ phase advance one another.

Unfortunately this ideal scheme is also space consumming. At FERMI, to minimise the space allocated for the collimators, they are chosen cylindric with a fixed aperture, so both planes are taken care of simultaneously . Moreover,

* The work was supported in part by the Italian Ministry of University and Research under grants FIRB-RBAP045JF2 and FIRB-RBAP06AWK3.
† sophie.ferry@elettra.trieste.it

the spoiler absorber scheme is abandonned for a one piece which will have to work as a spoiler and an absorber together. Two collimators should be placed at a $\pi/2$ phase advance. For geometric collimation, in the FERMI case, the second energy collimator is doubled: one for each FEL lines. In total 5 collimators are necessary for the transfer line.

To minimise the effect of the wakefields, tapers are added in the profile shape of the collimators similar to the ones sketched in references [3] [4]. Figure 1 shows the provided four different collimation possibilities : no collimation (the hole is as the vacuum chamber), defined collimation (step-in at 10 mm diameter followed by tapers with an inclination $\leq 1°$down to the 4 mm diameter hole), and 2 intermediate collimations (the same than the defined one with a step in at 12 mm and a hole diameter of 6 mm, and a 8 mm hole with tapers but no step-in).

At a 4 mm diameter the collimator protects 50% of the inner undulator chamber acceptance. As an optimal value would be $\geq$ 100%, 2 additionnal collimators of the same type are foreseen for the linac, at lower energy (300 MeV) after the bunch compressor.

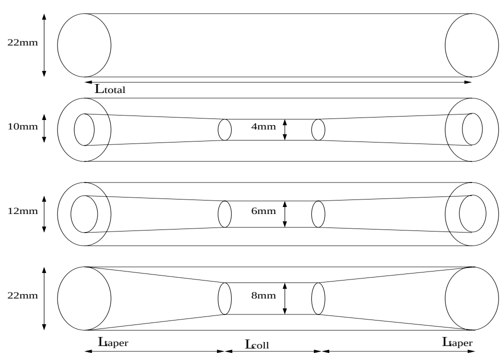

Figure 1: FERMI@elettra collimator design. $L_{\text{total}} = 45.5$ cm, $L_{\text{taper}} = 18.5$ cm , $L_{\text{coll}} = 8.5$ cm.

Wakefields In order to confirm that the internal profile of the collimators do not create strong wakefields, three different profiles were simulated with ABCi code [6] . It showed that the most suitable choice is the step-in + taper scheme. The results of the simulation are presented in table 1. Longitudinally, the maximum energy spread is of the order of the FEL tolerance for the RMS energy chirp at the machine end. Works are in progress to compensate it with off-crest RF phasing, without affecting the final beam quality. Transversally, the maximum kick is within the tolerance limits.

SIMULATION

Halo

Halo and dark current are not very well known and depend on the gun of each facility. The halo source is mainly the bunch compressor, but also wakefield tails, mismatch and mis-steered beam and coulomb scattering can be source of halo. Dark current is mainly created in the gun (field emission from the photocathode). A large part of the produced dark current is picked up by the acceleration section, but also lost in the gun cavity, and in further elements. In the end ~0.02% of the initial dark current (which is comparable to the beam itself) enters the linac. Off energy particles and energy tails in the bunch compressor are also creating dark current. A way to describe together the halo and the dark current is to use the Courant-Snyder ellipse, with a larger sigma, extending up to the vaccum chamber. Dark current and halo (together called halo) are transported by the linac around the beam core. Halo electrons can be considered of the same energy than the beam, and represent a proportion of ~1% the beam energy.

To avoid biaises and take into account any possible form of halo, in the Geant simulations, various distributions of halo electrons were tested.

Table 1: Maximum (peak to peak) wakefield potential created in the narrowest diameter of the collimator bloc, using a $\sigma = 50$ μm gaussian distribution bunch. The corresponding effect are calculated for the FERMI@elettra nominal beam : 1.2 GeV, 1 nC, transversally at 1 mm off-center.

Long.	600 V/pC	$\Delta E/E \leq 10^{-3}$
Trans.	4000 V/pC/m	$\Delta\theta \leq 3\mu$rad

Collimator Dimension

Starting from the shape figure 1 for the internal profile, with the halo simulated as described, the external dimensions were scaled in order to define the most adequate dimensions. The scaling was done either in length either in width (thickness of the walls) keeping the internal profile unchanged. The considered variables are : percentage of absorbed energy, percentage of stopped electrons, escaping particles in a 20°cone downstream the collimator and the temperature rise. The evolution of these variables with the input parameters are rather slow above a given dimension threshold. This threshold gives the most suitable dimensions. Each hole is surround by 4 radiation lengths of copper at minimum (6 cm) so the hole center to edge distance is 7.5 cm and the hole center to hole center is 3 cm.
For space issues, the collimators will be slightly smaller (4% in length, the final dimensions are indicated figure 1) without loosing much of their efficiency.

Energy Deposition, Particle Yield

Simulated electrons are sent onto the collimator with an enery of 1.5 GeV. Some part of their energy is deposited into the material. In the worse simulated case (with a $1/r$ primary halo electron radial distribution) more than 90% of the primary halo electrons are stopped, more than 85% of the primary energy is absorbed (respectively 95% and 90%

with a uniform radial distribution). In average 1.35 GeV of the primary particle is absorbed, and more than 90% of the primary electrons lose at least 1 GeV. The energy distribution of the exiting electrons has a large spread starting from the electron rest energy up to their inital energy (1.5GeV). In average these electrons energy is 100 MeV in the worse simulated cases, and more than 90% of them have a lower energy.

From the deposited energy one can estimate the temperature rise. Details of this estimation is presented in [1]. In normal conditions of operation, with a bunch charge of 1 nC and assuming 1% of it in the halo, the temperature rise is negligeable. Figure 2 shows the temperature rise profile for one specific halo assumption.

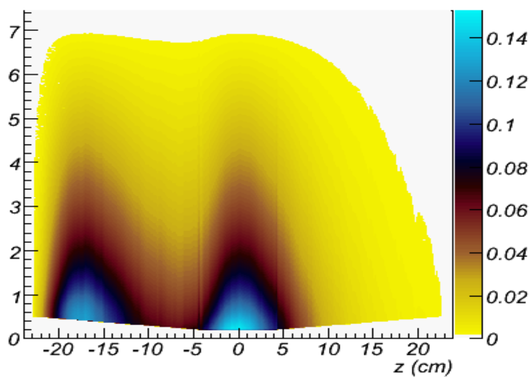

Figure 2: Temperature rise profile in °C for 1 case of halo distribution simulation.

Another concern is the exiting secondary particles created inside the collimator. Geant simulation allows to characterize the particles produced in the collimators in energy and momentum. Figure 3 shows the angular distribution of exiting secondaries. Above 2 MeV, 90% of leptons are going forward, 8% in a perpendicular direction and 2% backwards. Neutrons do not have a privileged direction.

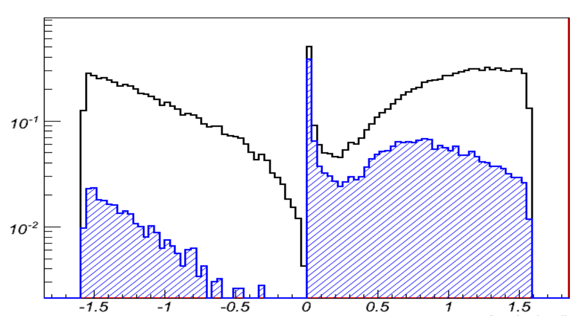

Figure 3: Angular distribution of the secondary particles created in the collimator and exiting it, normalized to 1 electron. The blue dashed histogram is for secondaries with energy above 2 MeV. All particles are included, but neutrons represent less than 1% of the number of particles.

MISSTEERING

In case of miss-steering, the beam core can impinge on the collimator. This is like a direct hit of the beam onto a piece of copper. The simulation of the geometry is then simplified to a box of copper. The beam is simulated as the nominal one, with the minimum emittance ϵ =0.8 μm.rad, and beta function $\beta_{x,y} = 10$ m. At maximum, the temperature elevation can reach 75°. Copper withstand such a heat without problems, nevertheless cooling is required and is added to the design.

CONCLUSION

The collimator design has been defined based on all the above mentioned aspects (optics, wakefields, Geant simulations). For saving space 'fixed hole' configuration has been adopted with 4 differents dimensions and profiles. To minimize alignment problems an 'in series' configuration of the holes has been chosen. In fact the FERMI@elettra collimators will resemble a beam stopper with four holes as shown figure 4.

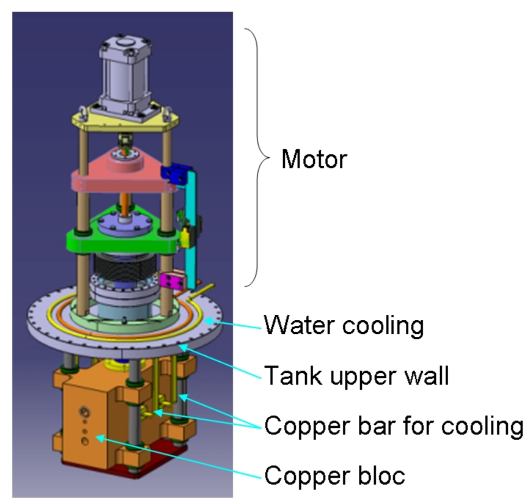

Figure 4: Collimator design.

REFERENCES

[1] S.Ferry, E. Karantzoulis, *FERMI@elettra beam dump.* These proceedings.

[2] S. Di Mitri, *Optics Design for the FERMI@elettra Collimation System*, Internal Notes (2008)

[3] T. Kamps, *Collimation System for the Bessy FEL* Proceeding of the 2004 FEL Conference, (2004) 381-384

[4] I. Zagorodnov, T. Weiland, M. Dohlus, M. Korfer, *Near-wall wakefields for optimized geometry of TTF2 collimator* TESLA Report 2003-23 (2003)

[5] W.P. Swanson, IAEA *Radiological Safety Aspects of the Operation of Electron Linear Accelerators* (1979)

[6] `http://abci.kek.jp/abci.htm`