BEATS

Workpackage 3

The X-ray Source

Magnet Specifications for Tender

D 3.4

July 2020

Funded by the EU's H2020 framework programme under grant agreement n°822535

PROJECT DETAILS

PROJECT ACRONYM
BEATS

PROJECT TITLE
BEAmline for Tomography at SESAME

GRANT AGREEMENT NO:
822535

THEME

START DATE
2019

DELIVERABLE DETAILS

WORK PACKAGE: 03

EXPECTED DATE: 31/07/2020

WORK PACKAGE TITLE: THE X-RAY SOURCE

DELIVERABLE TITLE: MAGNET SPECIFICATIONS FOR TENDER

WORK PACKAGE LEADER: INFN

DELIVERABLE DESCRIPTION: REPORT

DELIVERAVLE ID: D3.4

PERSON RESPONSIBLE FOR THE DELIVERABLE: J. CAMPMANY, A. GHIGO

NATURE

☒ R - Report ☐ P - Prototype ☐ D - Demonstrator ☐ O - Other

DISSEMINATION LEVEL

☒ P - Public
☐ PP - Restricted to other programme participants & EC:
☐ RE - Restricted to a group
☐ CO - Confidential, only for members of the consortium

REPORT DETAILS

VERSION: 2

DATE: 31/07/2020

NUMBER OF PAGES: 9

DELIVERABLE REPORT AUTHOR(S): J. CAMPMANY ET AL.

FOR MORE INFO PLEASE CONTACT: CAMPMANY@CELLS.ES

STATUS

☐ Template ☐ Draft
☒ Final ☒ Released to the EC

CONTENTS

INTRODUCTION

Work Package 3 of the H2020-funded project BEATS deals with the choice of a suitable x-ray source as well as its detailed design. This deliverable is the last in a series of three reports (the first two of which dealt with the choice and the detailed design of the source [2]) and concentrates on the technical specifications of the chosen design.

In a first step, BEATS' work package 3 studied three options identified as a photon source for BEATS: Concepts based on i) a super-bend design, ii) a multipole wiggler, and iii) a 3-pole wiggler (wavelength shifter) installed in a short straight section of SESAME's [1]. During the first year of the BEATS project, it was decided to install the third option. An optimised design was elaborated, that combines acceptable values of the perturbation of the machine optics with satisfying performance for the BEATS beamline.

In this report we briefly summarize the conceptual magnetic design of the 3T 3-pole wiggler chosen to be installed at SESAME for the BEATS beamline, followed by a detailed presentation of the technical specifications for magnets and iron to be used.

The main design constraints considered for the model were:

- Minimum gap: 11 mm
- Maximum field: ~3 T
- Magnetic length: < 1 m.
- Spectral range achieved with flux > 10^{10}photons / (s 0.1%bw mrad^2) between 20 and 50 keV.

THE CONCEPTUAL MODEL

A magnetic model for the 3-pole wiggler has been generated using the RADIA code, taking into account the parameters given in the introduction [3]. This model was then refined to reduce the decapole multipole and the attractive forces involved [2]. The resulting model is shown in Figure 1 below. The new model allows the use of permanent magnet blocks of relatively low remnant field (B_r = 1.28 T), still yielding a peak field of 3 T.

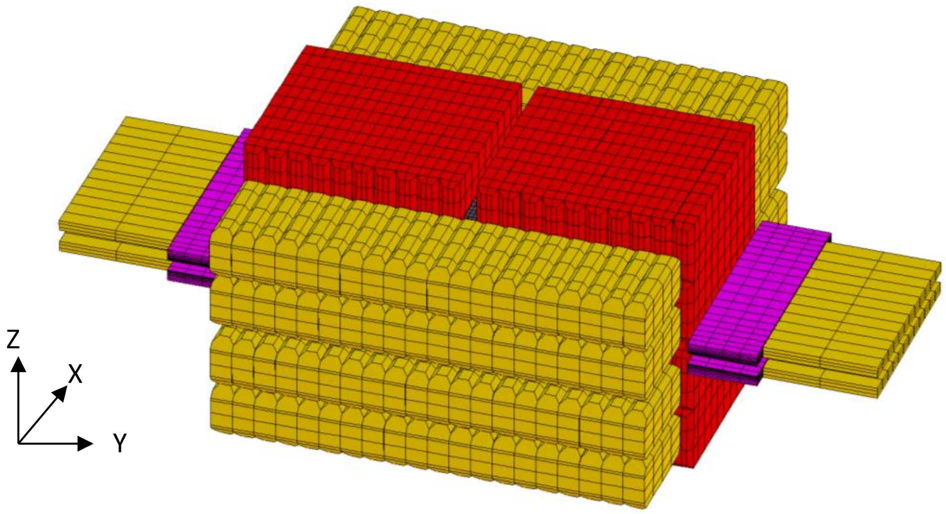

Figure 1. Axis definition and magnetic model generated by RADIA. Red and yellow parts are NdFeB magnets. Pink parts are the iron poles (there is another iron pole (grey) in the center). The overall length is 0.755 m, the overall width is 0.400 m, the overall height is 0.331 m and the minimum gap is 11 mm.

Figure 2 shows the field lines in the gap of the insertion device.

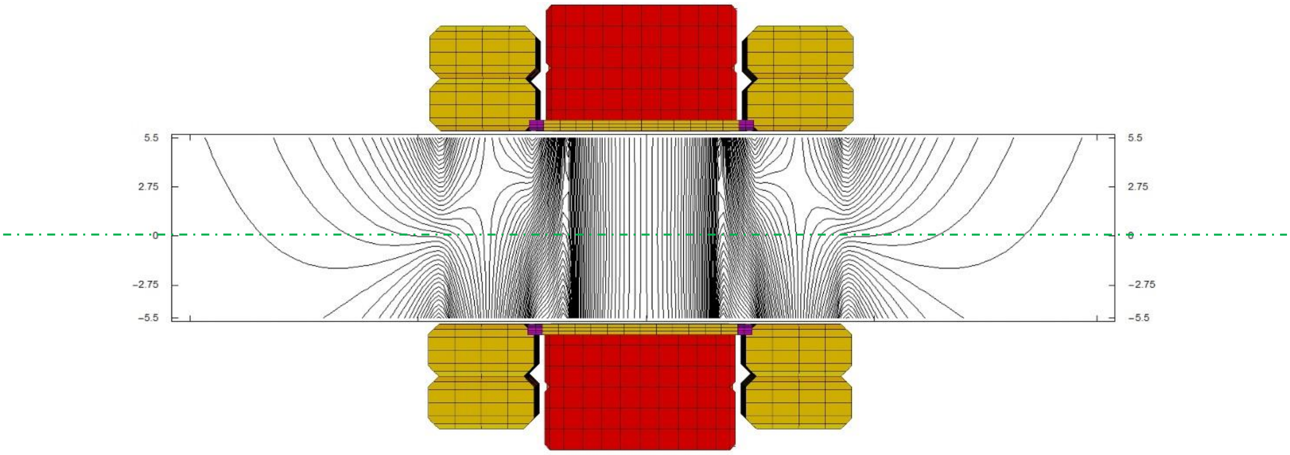

Figure 2. Magnetic field lines within the gap at longitudinal position Y=0.

In order to optimize the design, it was assumed that the mechanical tolerances of magnetic blocks and iron poles along the longitudinal axis are ±0.020 mm. This means that the void (also referred to as “air gap”) left between blocks and poles to allow tolerances should be 20 µm. (Figure 3).

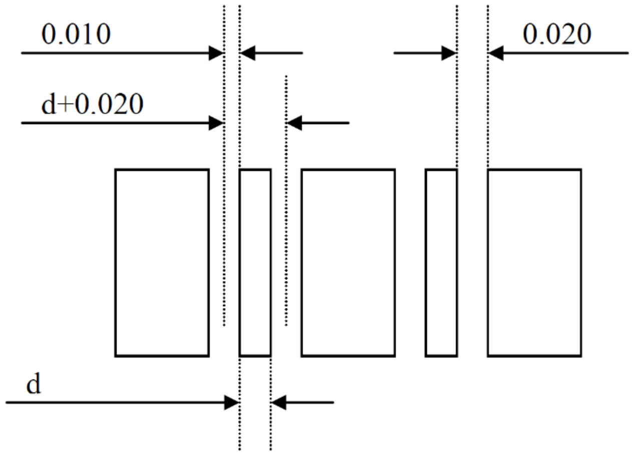

Figure 3. Schematics of pole / block arrangement and air gaps left for tolerances (measures in mm)

All permanent magnets are made of the same material and with a remnant field of B_r = 1.28 T
The magnetization orientation is shown in Figure 4 below.

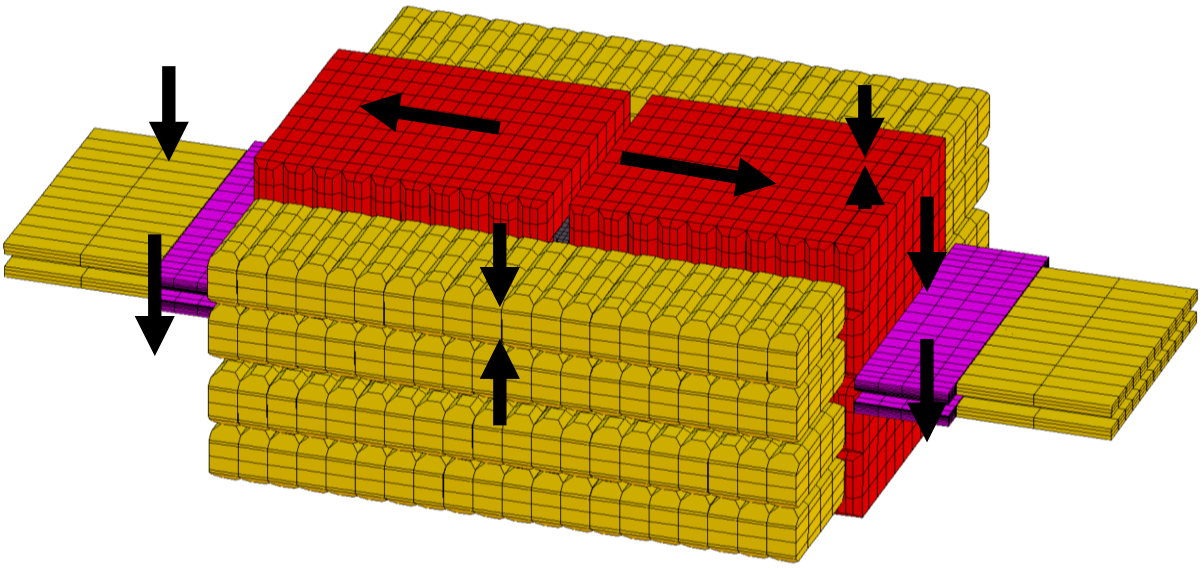

Figure 4. Magnetization directions in the assembly of 3PW.

The design has been optimized to obtain a low first field integral, low attractive force and low decapole contribution. Table 1 presents the longitudinal position and size of each block

Position (mm)	Magnetic structure	Length (mm)	B_r orientation
-377.5	Edge block	105	(0,0,-1) top and bottom
-272.5	Air gap	0.5	-
-272.0	Iron (permendur)	64	-
-208.0	Air gap	0.5	-
-207.5	10 magnetic blocks	200	(0,-1,0) top (0,1,0) bottom
-7.5	2 Side blocks	15	(1,0,0) and (-1,0,0)
-7.5	Iron (permendur)	15	-
7.5	10 magnetic blocks	200	(0,1,0) top (0,-1,0) bottom
207.5	Air gap	0.5	-
208.0	Iron (permendur)	64	-
272.0	Air gap	0.5	-
272.5	Edge block	105	(0,0,-1) top and bottom
377.5	End of device	-	-
-50.0	20 Lateral blocks	400	(0,0,±1) opposite top and bottom

Table 1. Description of the magnetic arrangement

The magnetic field along the longitudinal and the transversal axis is shown in Figure 5 and 6, respectively.

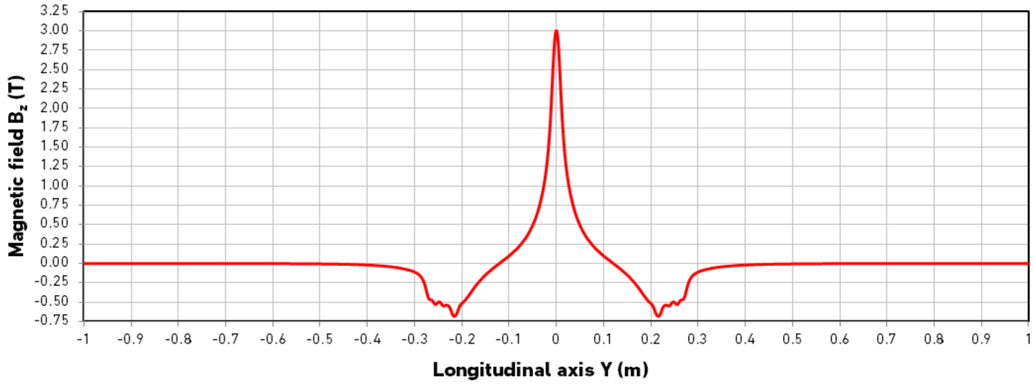

Figure 5. Magnetic field B_z on axis.

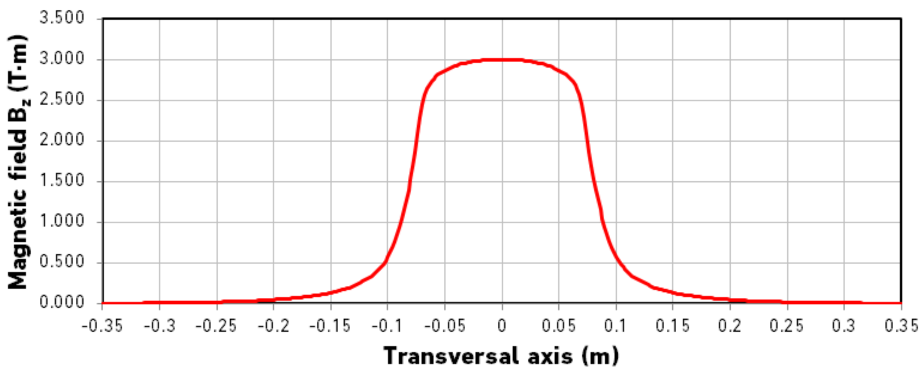

Figure 6. Magnetic field B_z along the transversal axis.

Figure 7 shows the field-map in the symmetry plane. The field reaches a peak value of 3.0025 T

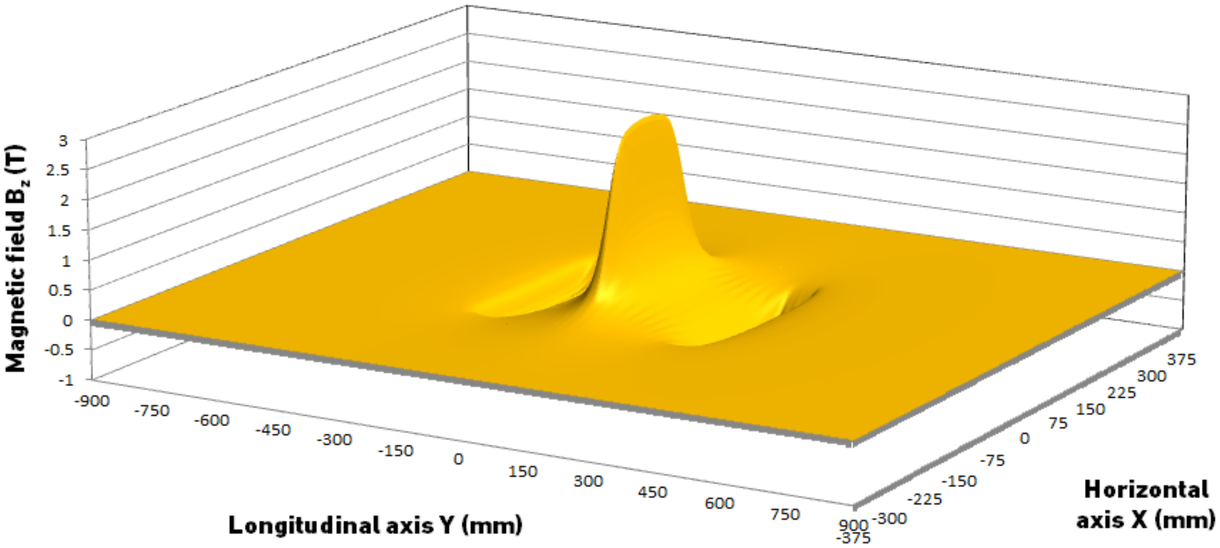

Figure 7. 3D Map of the vertical field B_z in the 3-pole wiggler.

The attractive force between the magnetic structures reaches its maximum of 1245 N at minimum gap (11mm).

THE SPECIFICATIONS:

Block Quantities

The 3-pole-wiggler consists of 88 magnets and 6 iron poles. It is advised to produce a 20% higher number of magnets to allow for tests and the reduction of errors due to inhomogeneity by block sorting. Table 3 summarizes the total quantities of each magnet type.

Magnet Geometry and Dimensioning Tolerances

Type	Quantity	Length (mm)	Width (mm)	Height (mm)	Tolerance (mm)
Central pole	2+2	15	150	80	0-0.020
Side blocks	4-2	15	150	120	0-0.020
Central Block	80+16	20	180	60	0-0.020
Edge Block	4+2	64	180	10	0-0.020
Edge Pole	4+2	105	180	10	0-0.020
Lateral Block	160+32	20	100	50	0-0.020

Table 3 Types and specifications of the magnet blocks

The specification includes magnet blocks of different shapes. The geometry and magnetization of each type of magnet block is given in Figures 8 to 12.

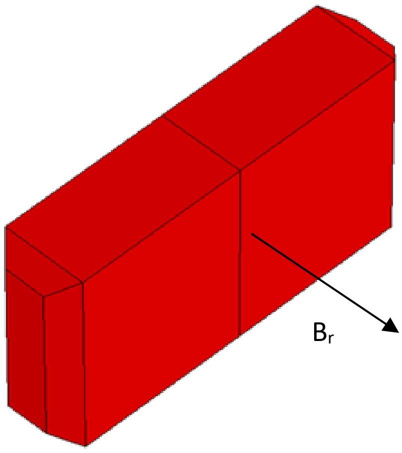

Figure 8. Main block. 180 mm wide, 60 mm high, 20 mm thick. Easy axis is oriented perpendicularly to width-height plane, as shown in the drawing. Edge cuts are 3 mm and 45º

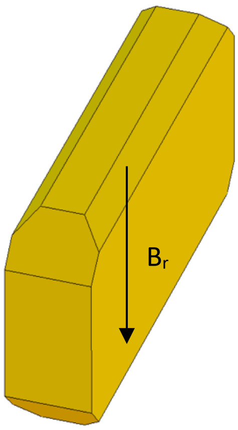

Figure 9. Lateral block, 100 mm wide, 50 mm high, 20 mm thick. Easy axis is perpendicular to thin upper side.

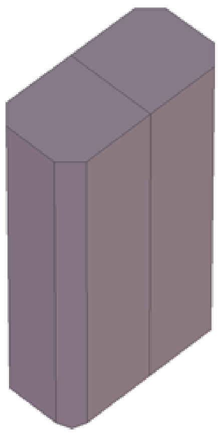

Figure 10. Central pole. 150 mm wide, 80 mm high, 15 mm long. Edge cuts are 3 mm and 45º

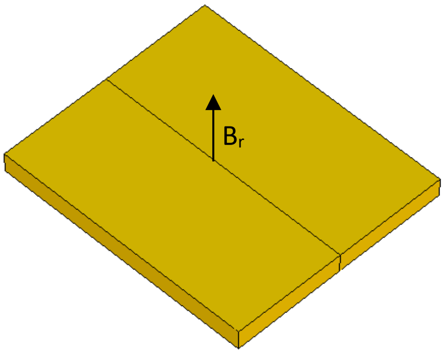

Figure 11. Edge block. 105 mm long, 180 mm wide and 10 mm thick. Easy axis perpendicular to length-width plane. Field should point towards opposite direction of the main structure field.

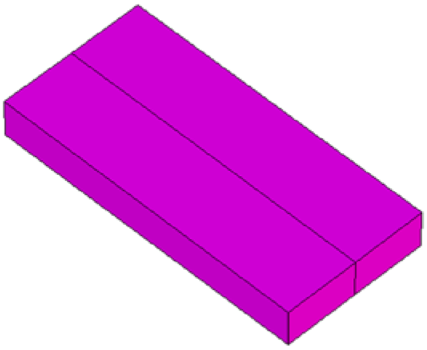

Figure 12. Edge pole. 64 mm long, 180 mm wide and 10 mm high

Taper Angle

While an error in the parallelism of the magnetic structure along the electron beam trajectory (see Figure 13) may have no effect on the emission properties, as the main emission is concentrated in the central magnetic pole, regarding mechanics and machine dynamics, however, a taper could damage the vacuum chamber of the storage ring and/or introduce unexpected effects into the beam dynamics. Therefore, we recommend to fix a tolerance for the taper angle of 0.5 mrad. Given that the attractive force changes with gap, the tolerance should apply at minimum gap.

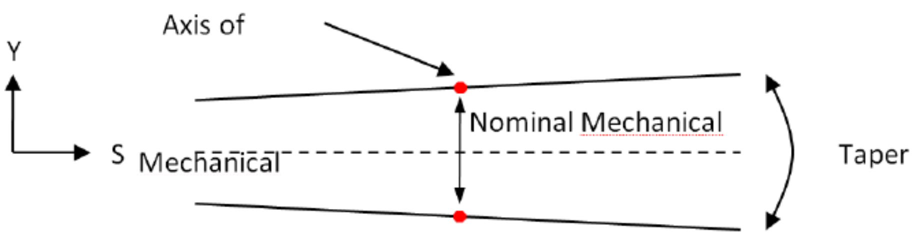

Figure 13. Schematic representation of taper. The S vector (the curvilinear longitudinal coordinate along the electron motion) points in the beam direction.

Roll Angle

It is assumed that the rotation of the individual beams about the S-axis is equal in magnitude but opposite in direction, as shown in Figure 14. The roll angle of the beam shall be defined better than 0.050 mrad in order to avoid additional multipolar components perturbing the electron beam dynamics.

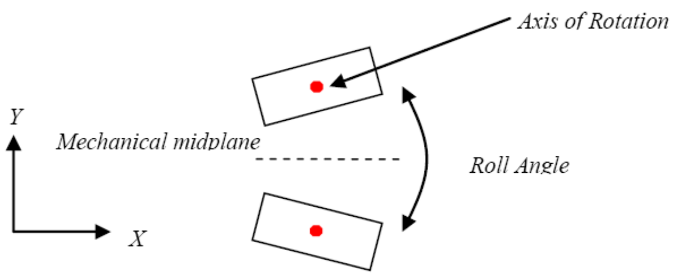

Figure 14: Schematic illustration of the roll angle. X is the horizontal transversal axis

Characteristics of the magnetic blocks

Manufacturing Process

At present, the method of transverse die pressing and application of the polarizing field in a direction perpendicular to the pressing direction produces blocks with the highest homogeneity and minimum error in the geometric alignment of the average dipole moment. The method of transverse die pressing shall be applied to all blocks such that the blocks achieve the highest remanence possible for the material specification whilst maintaining the specified material coercivity, minimum alignment error of the average dipole moment, and a maximum uniformity of the magnetic material.

Magnetic material

The magnetic structure is hybrid, the magnetic material is high grade NdFeB alloy with a remanent field of 1.28 T and a coercivity not less than 1250 kA/m. These values are obtained, for instance, by VACODYM 633 TP from Vacuumschmelze, or 40 UH from Kyma. Iron poles should be made of Permendur.

Magnet Identification

Each magnet shall be inscribed with a magnet identifier, followed by a serial number. The magnetization orientation must be inscribed on each magnet and must be clearly visible.

Remnant Strength of the Magnet Blocks

The material used for the magnet blocks will be NdFeB. The magnetic remanence shall be precisely parallel to their respective nominal easy axis for all types of blocks and not be less than 1.28 T.

Average Magnetization of Magnet Blocks

An open circuit model of the specified magnet block geometry on a B-H curve places the block not at H=0 but slightly off axis along the demagnetization curve. Therefore, the average dipole moment is expected to be less than the value of the remanence specified in section 9.4. The supplier shall confirm the theoretical average magnetization of each block. The theoretical average block magnetizations shall be the average minimum magnetization for each block. Based on a recoil permeability of 1.05, dB/dH and a magnetic remanence of 1.28 T, all blocks shall have an average magnetization no less than 1050 kA/m ($\mu_0 \cdot M > 1.28$ T)

Tolerance in Error of Magnetization Strength

Errors in the magnetic field resulting from errors in the magnetization of the magnet elements (hereinafter referred to as magnet blocks) act to perturb the uniformity of the electron orbit. A non-periodic orbit degrades the quality of the emission spectrum and disturbs the SR closed orbit.

From a set of manufactured magnet blocks the absolute difference in magnetization from block to block of a particular type shall be less than 1.5 % for the average of the set.

Tolerance in Error of the Magnetisation Direction

Each block shall have a magnetization vector that is parallel to the direction defined in their respective drawing. The maximum tolerable deviation angle is 1.5 degrees.

Intrinsic Coercivity

For this device the maximum coercive field has been calculated to be ~1028 $kA \cdot m^{-1}$, therefore we require the intrinsic coercivity of each magnet block shall not be less than 1050 kA/m at 20ºC. We therefore require the magnetic material to be in its linear region of the demagnetization curve and will not experience any irreversible losses during assembly and operation.

Segmentation of Permanent Magnet Blocks

The 3-pole wiggler should not be built by gluing individual magnet blocks. Mechanical clamps attaching the blocks and poles to holder are required.

Magnet Block Coating

All the magnet blocks should be coated with a material protecting them from scratches and erosion. Aluminium layer by vapour deposition, or other similar materials should be used. In any case, the coating thickness shall be less than or equal to but no greater than 0.010-0.015 mm. The coating thickness should be clearly mentioned in the offer. No observable surface defects will be tolerated (e.g. bubbles, holes, cracks, chips, loose particles, dog bones).

Magnet Block Cleaning

Considering the magnet production, the following steps will have to be respected:

- Before the coating, all the blocks shall be carefully degreased by using a cleaner and/or slightly etched by an acid (+ drying). The detailed process must be described by the manufacturer.
- For the magnetization process, the necessary tools shall be cleaned with a solvent, or the magnets will be kept in their polyethylene bags

After the magnet coating is applied, it must never get in contact with oil or grease. They must be handled with latex gloves to avoid touching with bare hands and leaving finger prints.

References

[1] J. Campmany, *Photon source for the BEATS beam line at SESAME. Options to be considered*, ALBA document AAD-IDBEATS-A-001.

[2] BEATS, Deliverable D3.1 and D3.2

[3] RADIA, by O. Chubar, P. Elleaume, J. Chavanne: open code for magnetic calculations: http://www.esrf.eu/Accelerators/Groups/InsertionDevices/Software/Radia