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DESIGN OF FRONT END AND A 3-POLE-WIGGLER AS A PHOTON SOURCE FOR BEATS BEAMLINE AT SESAME

J. Campmany, J. Marcos, ALBA-CELLS, Cerdanyola, Catalonia, Spain
I. Cudin, ELETTRA, Basovizza, Friül-Venecia Julia region, Italy
S. Guiducci, INFN, Frascati, Lazio region, Italy
G. Lori, M. Al-Nadjawi, M. Attal, SESAME, Allan, Al Balqa gov, Jordan
P. Van Vaerenbergh, ESRF, Grenoble, Isère Department, France

Abstract

BEATS is an international collaboration funded by EU under the Horizon 2020 program, aimed to design and construct a hard X-ray full-field tomography beamline to be installed at SESAME synchrotron in Jordan. In this paper we present the design of the photon source and of the front end that interfaces the beamline with the accelerator. The photon source will consist of an out-of-vacuum 3-pole wiggler with a peak field of 3 Tesla; the contract for its manufacturing has been awarded to Kyma.

INSERTION DEVICE REQUIREMENTS

BEATS is one of the new beamlines currently under construction at the 2.5 GeV synchrotron light facility SESAME in Jordan. The beamline will operate a hard X-ray micro tomography station allowing a wide range of applications, including high-resolution phase contrast tomography scans, rapid scans of dynamical phenomena at medium resolution, as well as low-dose applications (biomedical imaging and cultural heritage) [1].

From the point of view of the photon source, the main requirements were: (i) to shift the critical photon energy of the emitted X-ray spectrum considerably above the one for the existing storage ring (SR) dipoles (1.45 Tesla, $E_c = 6$ keV), (ii) to maximize the flux and brightness of the delivered photon beam, and (iii) to reduce as much as possible the SR modifications required in order to mitigate the impact of the source on the electron beam.

At an initial stage several options for the source were considered: a) a 3 Tesla superbend ($E_c = 12.5$ keV) replacing one of the SR dipoles, b) a 3 Tesla, $\lambda_w = 50$ mm period, 2.5 m-long multipole wiggler (MPW), c) a 3 Tesla 3-pole wiggler (3PW), with a strong central pole and two satellite poles to compensate the field integral.

All options were carefully analysed taking into account their impact on the accelerator at different levels: effect on the beam dynamics, required hardware modifications, associated services, etc. [2]. As a result of this investigation the 3PW option was finally selected. The superbend option was rejected due to the large accelerator adaptations that it would entail (modification of both the girder and the vacuum chamber together with the installation of two new quadrupoles), whilst the MPW option would most likely require a superconducting magnet, with the added complexity of the associated cryogenic system. Furthermore, a 3 Tesla 3PW can be realized using out-of-vacuum permanent magnet technology, and the resulting device can be easily fitted in one of SESAME's short straight sections, with a minimal impact on the technical systems of the facility.

ID DESIGN

Preliminary Design

A preliminary design of the 3PW based on a hybrid structure combining NdFeB permanent magnets and FeCo poles was developed using RADIA [3]. The main parameters of the magnetic structure are listed in Table 1, and the magnetic model is shown in Fig. 1.

Table 1: Main Parameters of BEATS Insertion Device

Device type	wavelength shifter
Magnetic configuration	Planar hybrid
Technology	Out vacuum
Number of poles	1 + 2
Magnetic minimum gap	11 mm
Gap range (magnetic)	11 mm to 30 mm
B_0 value at minimum gap	3T

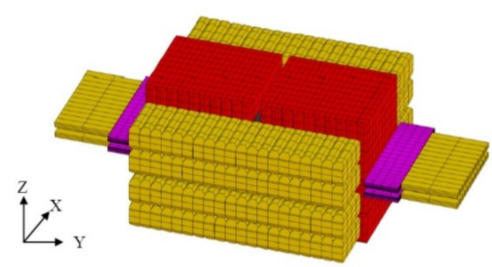

Figure 1: Preliminary magnetic model of BEATS 3PW generated by RADIA. Red and yellow parts are NdFeB magnets. The main iron poles are in the centre and edge poles to compensate the field integral are in pink. Side blocks have been introduced to compensate the large attractive force in the device.

The field profile generated by the device is shown in Fig. 2. A first version of the device with a main block/ central pole width of 90 mm/30 mm gave raise to very significant integrated multipoles (mainly sextupolar and decapolar terms). In order to reduce these components, the width of the main block and central pole was increased up to 180 and 150 mm, respectively, providing a reduction of the sextupolar term by a factor 100 and of the decapolar term by a factor 400.

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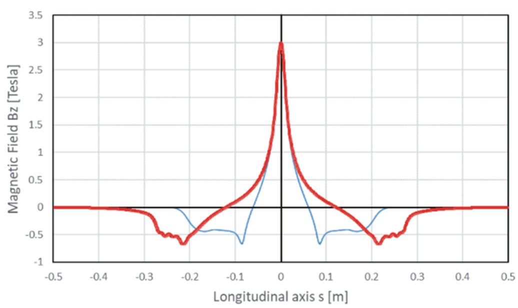

Figure 2: 3PW magnetic field along longitudinal axis, with the peak field of 3 T at the center of the device. Red line corresponds to the preliminary design, and blue line corresponds to the shortened design proposed by Kyma.

However, this widening of the device gave rise to a substantial increase of the magnetic forces, from ~7 kN up to 22.5 kN at the minimum gap of 11 mm. In order to alleviate these forces it was proposed to install a set of compensating magnets with opposite polarities at both sides of the device (yellows blocks in Fig. 1), which would allow to reduce the total force at 11 mm down to 1.2 kN.

The spectral flux delivered by the 3PW device through the user aperture of 1.8×0.4 mrad^2 obtained using the SPECTRA code [4] is shown in Fig. 3.

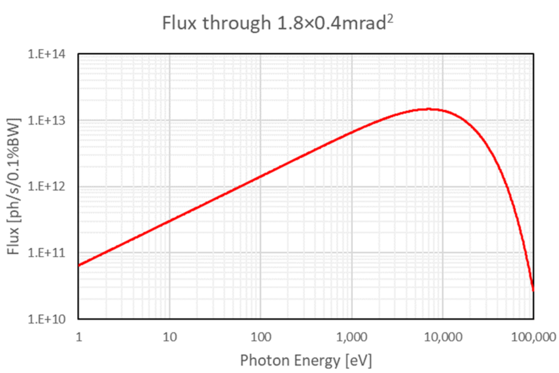

Figure 3: Emission spectrum of the 3-pole wiggler at minimum gap for an electron beam current of 200 mA.

Manufacturing

The manufacturing of the device was awarded to Kyma Srl (Trieste, Italy) on December 2020 and it is currently in its final design phase. The preliminary magnetic design has been modified in two main aspects: (i) the overall length of the device has been reduced from 755 mm down to 412 mm (see Fig. 2), leading to a reduction of magnetic material and associated forces; (ii) the compensation magnets have been removed from the design, due to the difficulty of integrating them into the assembly procedure. Despite this suppression, the shortening of the device by itself will result in a 30% reduction of the magnetic force at minimum gap, down to 15.5 kN, that will be handled by the mechanical support.

The magnetic structure proposed by Kyma is shown in Fig. 4. The final width of the main magnet has been increased by 5% (up to 190 mm) and the width of the central pole has been reduced by 25% (down to 110 mm) in order to leave space for the flux-concentrating lateral magnets (in orange in Fig. 4). The integrated multipoles, however, have been kept well within the requested limits.

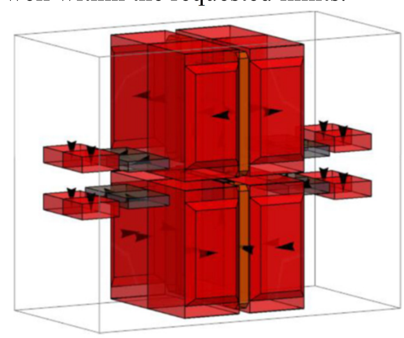

Figure 4: Final magnetic design of the 3PW developed by the manufacturing company. Red and orange pieces correspond to NdFeB magnets, and gray pieces to FeCo poles.

As for the materials, NdFeB 40UH grade ($B_r \geq 1.26$ T and $H_{cj} \geq 1900$ kA/m) has been selected for the magnet blocks and the pole pieces a FeCo alloy with properties comparable to Vacoflux50 will be used.

Figure 5 shows a view of the mechanical design developed by Kyma. It can be seen that two sets of correction coils at each end of the device for the active compensation of residual field integrals have been foreseen.

The 3PW device is expected to be delivered to SESAME on December 2021.

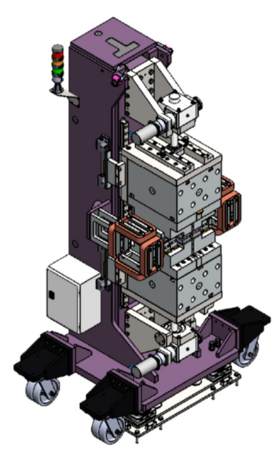

Figure 5: View of the complete design for the 3PW proposed by Kyma.

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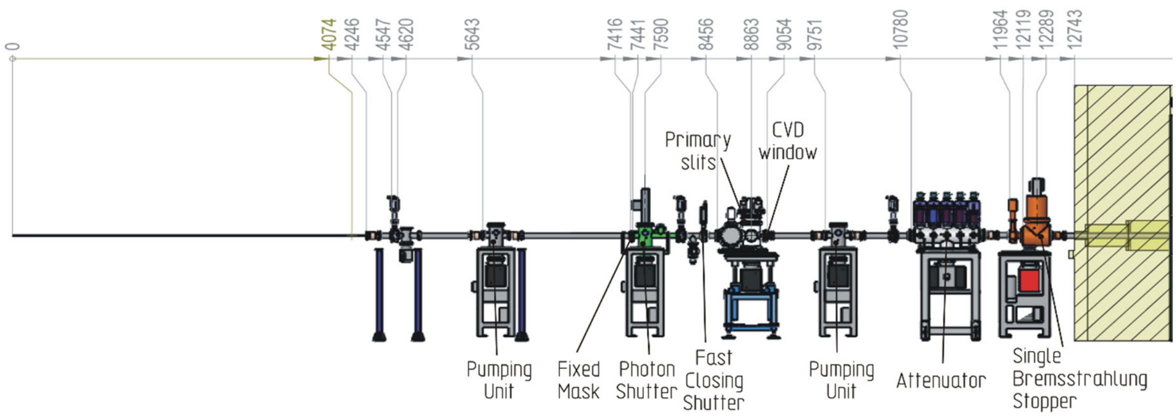

Figure 6: Layout of the FE for BEATS, with the distances from the 3PW source point indicated.

BEATS FRONT END

The total power (~1 kW @400 mA) and the peak power density (250 W/mrad^2 @400 mA) associated with the 3PW source are relatively small, similar to the values corresponding to SR dipoles of medium energy (2-3 GeV) 3rd generation light sources. Taking this into account, together with the requested user aperture of 1.8×0.4 mrad^2, the front end (FE) has been designed accordingly.

As a reference for the design we have taken the standard configuration for bending magnet FEs at ALBA [5], adapting it to the particularities of SESAME. The design includes: (i) a fixed mask to protect the downstream elements and to define the user aperture, (ii) a photon shutter, (iii) a fast closing valve triggered by gauges installed on the beamline side for protection of the accelerator's vacuum, (iv) a system of primary slits (refurbished from ID19 beamline at ESRF), (v) a set of beam attenuators with 5 independent axes, and (vi) a single-block Bremsstrahlung stopper. The layout of the FE is shown in Fig. 6. All power absorbing elements have been dimensioned to withstand the power delivered by a stored electron beam of up to 400 mA.

Most of the FE units are being manufactured by JJ X-ray A/S (Denmark), and will be delivered on April 2022.

CONCLUSION

A photon source for the new tomography beamline BEATS at SESAME has been designed and is currently under construction. The developed 3PW device will deliver the requested flux at high energies (above 20 keV) while at the same time enabling a smooth integration into SESAME's accelerator. BEATS beamline is expected to enter into operation by the end of 2022.

ACKNOWLEDGMENTS

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