LA-UR-16-27249
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Intended for: Report

Issued: 2016-09-22

Using superconducting undulator for enhanced imaging capabilities of MaRIE

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9/20/2016

MaRIE x-ray free electron laser (FEL) is envisioned to deliver a burst of closely spaced in time pulses for enabling the capability of studying the dynamic processes in a sample [1]. There is a large variety of materials of interest which dynamics will be studied. Most likely all these materials cannot be diagnosed using a single imaging technique. For example, techniques which can be applied to image polycrystalline metals will not be applicable to imaging amorphous materials due to lack of Brag refractions in such a media. On the other hand, amorphous media are not as dense as metals which allows one sampling them with a much softer radiation due to smaller scattering and absorption.

Sampling materials with a larger wavelength radiation has clear benefits compared to the shorter wavelength radiation. First, the interaction of materials with radiation is stronger at larger wavelengths. Second, the curvature of the Ewald sphere increases with the wavelength. That may allow recovering the 3D information about the object [2] which is not possible at smaller wavelengths. Finally, the soft x-ray optics is simpler and has higher TRL level compared to the hard x-ray optics. Having the capability of generating soft x-ray photons will be highly beneficial for MaRIE.

The wavelength of radiation in FELs can be reduced by reducing the energy of the electron beam which is used for lasing. The wavelength of FEL radiation is equal to

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + K^2/2\right), \qquad (1)$$

where λ_u is the undulator wavelength, γ is the beam energy and $K\sim 1$ is the dimensionless undulator parameter describing its strength. The upper limit of the FEL wavelength is determined by the lowest achievable energy in the accelerator. There is a practical limit on the lowest achievable electron energy in the accelerator and it is determined by the energy of the last bunch compressor. In this case the RF power in the last linac section is turned off and the bunch bypasses to the undulator hall. Reducing energy even further requires major changes in the operation of the machine and this option is not typically realized in modern FELs. The CD-0 pre-conceptual reference design assumes the last bunch compressor at 1 GeV and the final beam energy at 12 GeV. However, the latest studies indicate that this choice of parameters is not optimal and the final compressor will be probably placed at 2-3 GeV energy [3]. As a result, the lowest achievable x-ray photon energy in MaRIE will be limited to 1-2.5 keV. At the same time, there is a strong national demand on the coherent light sources in the soft x-ray region required by Chemistry, Material Science and Biology communities. This is precisely the motivation for upgrading the LCLS FEL and extending the photon energy down to 250 eV [4]. Such a capability will not be achievable in current MaRIE design.

The MaRIE capabilities in soft x-ray region can be extended by using the undulator with a larger wavelength. This option is expensive for conventional permanent magnet undulator since it would require an additional undulator. However, the undulator with an increased period can be realized using the superconducting undulator (SCU) technology which is currently under development and is at the pace of maturation [5]. The SCU is an electromagnet in which the magnetic field is generated the by current flowing along the superconducting wire. The current is high and the achievable magnetic field surpasses the magnetic field of the permanent magnets by about a factor of 2. The SCU technology has been suggested by the participants of the MaRIE-centric workshop for consideration in MaRIE design [6]. The direction of the magnetic field in the SCU is determined by the direction of the current flow in the superconducting wire. Introducing two separate wires in the SCU will allow doubling the undulator period when switching the direction of current in one of them (see Fig. 1). Each individual wire should generate the current in two neighbor magnets missing two magnet after that. At the same time, the direction of the magnetic fields in two neighbor magnets generated by the same wire should be opposite which implies different direction of winding in them.

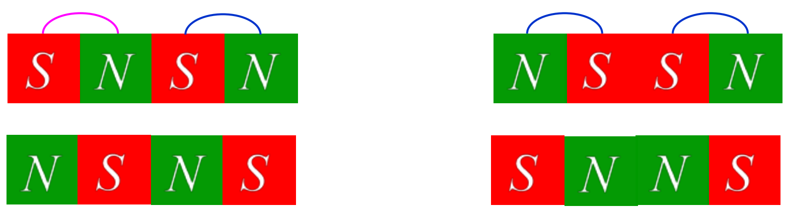

Figure 1. The schematics of the SCU with two independent wires. The polarity of half the magnets can be switch by switching the polarity of voltage in one wire allowing for doubling the SCU period.

Doubling the period in the SCU increases the undulator strength *K* by more than a factor of two due to a larger ratio of the undulator period to the undulator gap. As a result, the radiation wavelength generated in FEL increases by about a factor of 5 at the same beam energy as follows from Eq. (1) under assumption of the undulator parameter $K=1.216$ used in the MaRIE CD-0 reference design. Scaling of the main FEL parameters according to the 3D theory indicates that the number of generated photons increases by a factor of 2 in the double period SCU regime compared to the case of a single period SCU and reduced beam energy for reaching the same photon energy.

In summary, MaRIE capability can be largely enhanced using the superconducting undulator which has the capability of doubling its period. This technology will allow reaching the photon energy as low as *~200-500* eV. As a result, the MaRIE facility will have a broader photon energy range enabling a larger variety of experiments. The soft x-ray capability is more likely to achieve the 3D imaging of dynamic processes in noncrystal materials than the hard x-ray capability alone.

References

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