SR2004 Design Your Own Undulator

QUESTIONS

Question 1.

A beamline is required for soft condensed matter experiments on the future Diamond Light Source (DLS) storage ring. The beamline will need to be continuously tuneable over the photon energy range 3.6 – 20 keV.

For DLS the relevant parameters are: E = 3GeV, and I_{av} = 0.3Amps.

The options for the beamline undulator are:

1. An 'out of vacuum' device using the high remanent field (B_r = 1.3T) permanent magnet material NdFeB. The minimum gap is 15mm, and the max device length that can be accommodated is 4m.
2. An 'in-vacuum' device using the lower remanent field (B_r = 1.03T), but more radiation resistant permanent magnet material Sm_2Co_{17}. The minimum gap for this type of device is 7mm, with the possibility of extending this to 5mm in the future (once the effect on the machine is understood). The maximum device length that can be accommodated is 2m (due to the proximity of the magnet arrays to the electron beam).

The expected r.m.s. magnet phase errors expected will be $\Delta\phi = 3.0°$ for both cases.

The beam line designer needs to choose the most appropriate undulator technology, and the parameters K_{max} and λ_u, to give the highest flux over the specified range. To assist in this, fig.1 shows the maximum K value that can be reached at each value of λ_u for the different undulator technologies (i.e. at min magnetic gap).

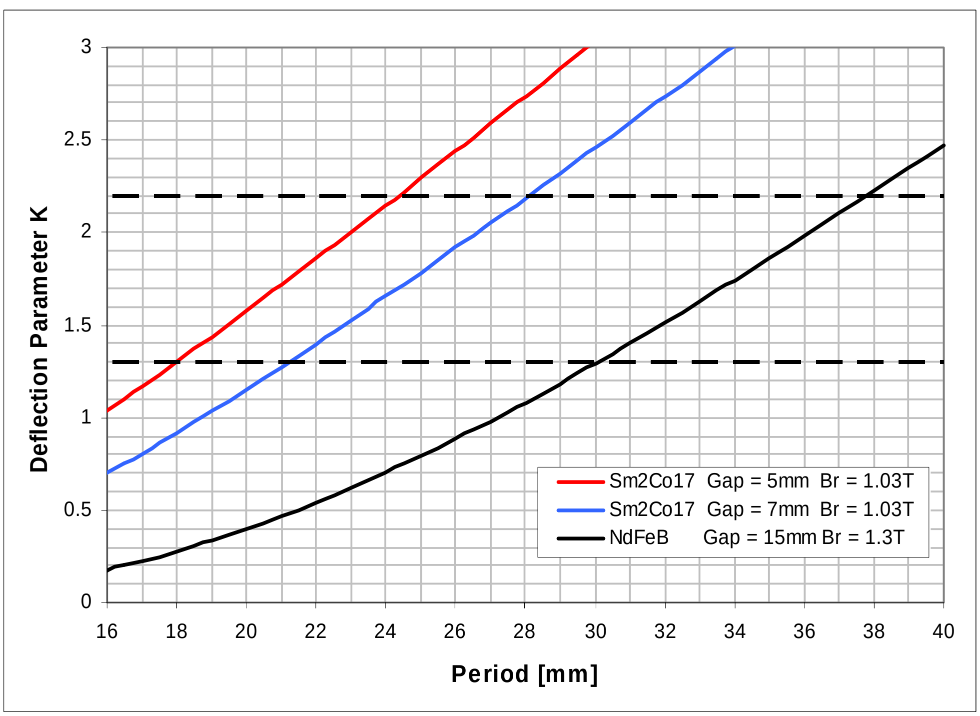

Figure 1: Undulator Technology Magnetic Performance.

The tunability of a source is determined by K_{max}. For $K_{max} \geq 1.3$ (lower dotted line) overlap is reached between the 3rd and 5th harmonics (and all adjacent harmonics above the 5th). For $K_{max} \geq 2.2$ (upper dotted line) overlap is reached over all adjacent harmonics.

Fig.3 gives the lowest photon energies (i.e. obtained at K_{max}) attainable on the 3rd harmonic for the out of vacuum and in vacuum technologies.

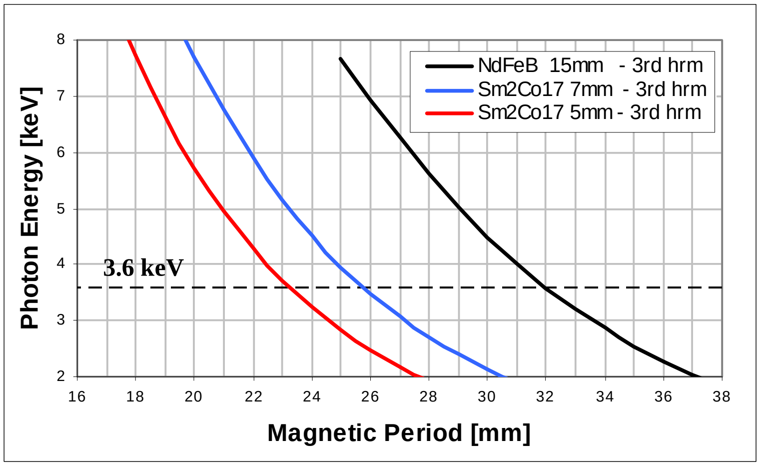

Figure 2: Minimum Photon energy vs λ_u for NdFeB and Sm_2Co_{17} Magnets.

The performance of the proposed devices is assessed over the following energy ranges:

Low Photon Energy Range:

i. Design an out of vacuum undulator (i.e. find the K_{max} and λ_u values) that is continuously tuneable from the 3rd harmonic and above.

ii. Can this device be used to reach 3.6keV on the 3rd Harmonic? If not, what parameter can you change to enable you to still reach down to 3.6 keV, whilst keeping $K_{max} \geq 1.3$? What value does this parameter, and K_{max}, now take? Estimate the flux obtained on the 3rd harmonic from this device at 3.6 keV.

iii. Next, design an in vacuum undulator, assuming a 7mm min gap, that can achieve full tunability from the 3rd harmonic onwards, whilst still reaching 3.6 keV on the 3rd harmonic. Estimate the flux obtained on the 3rd harmonic from this device at 3.6 keV.

iv. Which design would you recommend if the beamline was to be optimised for low photon energies? Does the in vacuum technology offer any advantage at this photon energy?

High Photon Energy Range:

i. For your in-vacuum and out of vacuum designs, deduce the harmonic you would need to use in order to reach the 20 keV upper energy limit, and estimate the flux you would obtain. (Hint: calculate the photon energy of the first harmonic at K_{max}). What are the effects of magnet errors at this energy for each device?

ii. Which design would you recommend if the beamline was to be optimised for high photon energies? Would there be an advantage to using the smaller gap for the in-vacuum device?

Question 2.

A beamline designer wishes to compare the output from a possible DLS undulator with that from a DLS bending magnet, in order to select the most appropriate radiation source for protein crystallography experiments. The experiments require a high flux output at the Selenium edge which occurs at a photon energy of 12.6 keV (λ_r = 0.98Å). The undulator (U21) chosen for comparison has the parameters K=1.1062, λ_u = 21mm and N = 95 (2m long).

For this beamline, the undulator radiation acceptance angle will be 100x50 μrad (Horizontal x Vertical). For the dipole source, all of the vertical flux will be accepted, with a 0.5mrad acceptance in the horizontal plane. DLS has an electron energy of 3GeV, and a bending magnet field strength of 1.4T.

i. Calculate the critical energy, ε_c, of a DLS dipole source.

ii. Estimate the total flux obtained from the dipole, through the specified acceptance angle at 12.60 keV.

iii. Calculate the 'on axis' photon energy of the 1^{st} harmonic of U21.

iv. What electron energy would you require in order to reach 12.6 keV on the first Harmonic? Since this energy is not available to us, suggest how we could still reach 12.6 keV using the U21 device on our 3GeV machine?

v. Calculate the on axis photon energy of the 5^{th} harmonic of U21. Repeat this for the point at the centre of the top edge of the aperture (i.e. at θ = 25urad).

vi. To reach the peak flux output on any harmonic, you have to 'detune' or lower the photon energy from the on axis value (this is done via the monochromator). For the 5^{th} harmonic of U21, at which photon energy will the peak output be reached?

vii. Estimate the flux output at 12.6 keV for U21. Is the undulator aperture large enough to allow the radiation cone at the peak energy to be transmitted? (Hint: use your answer to part v.)

viii. What is the ratio of the flux output for the undulator and the dipole source at 12.6 keV? Which would therefore make the most appropriate source for the beamline experiments.

ix. Undulators are designed so that K can easily be varied up to a max value determined by the magnet technology. U21 could be operated with K=1.5862. Calculate the on axis photon energy of U21 on the 7^{th} harmonic for K=1.5862. Compare the peak flux output with these parameters with that obtained for the original device parameters. Is it better to operate on the 5^{th} or 7^{th} harmonic?