ELECTRON BEAM CHARACTERISATION BY UNDULATOR RADIATION

Å. Andersson, M. Bässler, S. Butorin, M. Eriksson, R. Feifel, M. Georgsson and S. Werin
MAX-LAB, Lund, Sweden, M. Jurvansuu, Oulu University

Abstract

The electron beam in the storage ring MAX II has been analysed by deconvolution of recorded undulator spectra. The change in coupling between different optics have been measured and the energy spreads in various operation modes have also been deduced.

1 INTRODUCTION

The electron beam in MAX II [I] can be manipulated in several ways. In this work we wanted measure the coupling in the electron beam, and to see its influence on the radiation intensity. On the storage ring there are also high harmonic cavities for Landau damping installed [II]. When these are operated the energy spread of the electron beam is reduced. We wanted to measure this change in energy spread and also see the effect on the intensity of the undulator radiation.

As the width of the peaks in the undulator spectrum are strongly dependent of the behaviour in both size and energy distribution of the electron beam, the radiation is a good tool to measure these effects.

1.1 MAX-lab

MAX-lab [I] is a Swedish national laboratory for synchrotron radiation research and nuclear physics research. It operates three accelerators: a Racetrack microtron injector, a 550 MeV 2nd generation storage and pulse stretcher ring and the new 3rd generation 1.5 GeV storage ring MAX II.

1.2 Undulator I411

The undulator used in these measurements was the I411 on MAX II. It is a hybrid device built by VTT [III].

Table 1. Data for undulator I411

Period	60 mm
K_{max}	3.63
# of poles	87
Total length	2.65 m
Magnet gap	22 - 300 mm
Peak field	0.65 T
Type	Hybrid, taper

1.3 Beamline I411

The actual beamline components at station I411 are under construction but a set-up has been installed for first characterisation of the undulator [IV]. This experimental set-up consists mainly of a very versatile soft x-ray spectrometer, originally designed at Uppsala University for high resolution soft x-ray emission spectroscopy [V,VI].

2 BASIC IDEA

The idea behind this work is to use the sensitivity of the undulator radiation to changes in the electron beam characteristics. These can then be simulated and the actual changes can be extracted.

2.1 Theory

The wavelength of the undulator radiation is given by:

$$\lambda = \frac{\lambda_w}{2\gamma^2}\left(1 + \frac{K^2}{2} + \theta^2\gamma^2\right) \qquad \textbf{Eq. 1}$$

Where: λ is the wavelength of the radiation, λ_w the undulator period, γ the relativistic parameter, K the undulator strength and θ the angle to the electron beam axis.

The spectral width, or spread in wavelength, of a harmonic in the undulator spectrum is given by:

$$\frac{\Delta\lambda}{\lambda} \approx \sqrt{\left(\frac{\Delta\lambda}{\lambda}\right)^2_{Nat} + \left(\frac{\Delta\lambda}{\lambda}\right)^2_{Detector} + \left(\frac{\Delta\lambda}{\lambda}\right)^2_{Source} + \left(\frac{\Delta\lambda}{\lambda}\right)^2_{Energy} + \ldots} \qquad \textbf{Eq. 2}$$

Where the natural spread, or homogenous broadening, is

$$\left(\frac{\Delta\lambda}{\lambda}\right)_{Nat} = \frac{1}{kN}\bigg|_{FWHM} \qquad \textbf{Eq. 3}$$

Where k is the harmonic number and N the number of undulator periods.
The remaining factors, also called inhomogeneous broadening, are due to the detector, acceptance and resolution, and the source characteristics, distribution in energy, angle and space, plus magnetic errors in the undulator.

Finite numbers in electron beam size and divergence plus detector acceptance can be translated to angular errors and then inserted into:

$$\left(\frac{\Delta\lambda}{\lambda}\right)_{Angle} = \left.\frac{\gamma^2\theta^2}{1+\frac{K^2}{2}}\right|_{\approx FWHM} \qquad \textbf{Eq. 4}$$

An energy error in the electron beam translates by

$$\left(\frac{\Delta\lambda}{\lambda}\right)_{Energy} = \left.\frac{2\sigma_\gamma}{\gamma}\right|_{RMS} \approx \left.\frac{4.7\sigma_\gamma}{\gamma}\right|_{FWHM} \qquad \textbf{Eq. 5}$$

The broadening due to magnetic errors in the undulator can be estimated by using a code which uses the measured magnetic field of the undulator. The broadening due to the detector has, of course, to be analysed in each set up.

The aim with this method is to measure the width of the harmonics in the spectrum and from these data extract the energy spread and the beam size respectively. To do this it is important that all other contributions are as small as possible. The easiest way here is to do the analysis on a high harmonic, as the natural broadening will not dominate the results, use radiation only within a small aperture and a low emittance beam.

2.2 Simulations

To actually deduce the influence of the different sources the computer code UR [VII], which is capable of including both measured magnetic fields and energy spread, has been used. The theoretical expressions given above will only be useful for relative changes, as all details can not be introduced into this language.

3 MEASUREMENTS

The measurements are based on the calibrations made in [IV].

3.1 Coupling/decoupling

The coupling in MAX II is varied by moving the tunes of the machine closer or away from each other. The measurements were made on "zero current" to avoid broadening from energy spread. At this current the energy spread is the natural energy spread, around 0.07%. (see fig 1)

In the simulated curves of fig 1 the coupling is fitted to change from 0.6% to 50%. The precise form of the peaks is not reconstructed, but the deviations are similar in both coupled (wide peak) and decoupled (narrow peak) mode. The increase in intensity for decoupled operation is a factor 1.25.

3.2 Landau damping and energy spread

The high harmonic cavities for Landau damping do only operate at higher currents (above 70 mA) which also means that the energy spread has increased from the natural energy spread.

In the first spectrum (fig 2) the cavities are detuned and the energy spread should be the ordinary spread of high current operation. To fit the curves a spread of 0.4 % has been used in the simulations with good agreement.

When the Landau cavities are tuned in the energy spread goes down to 0.22 % according to fig. 3. The increase in

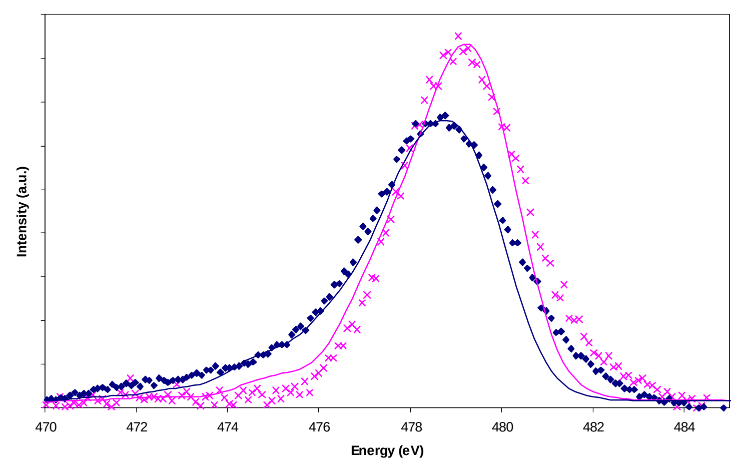

Figure 1: 8th harmonic at 24 mm gap. Coupled beam (wide peak) and uncoupled beam (narrow peak), Dots/crosses - measured, solid line - simulated.

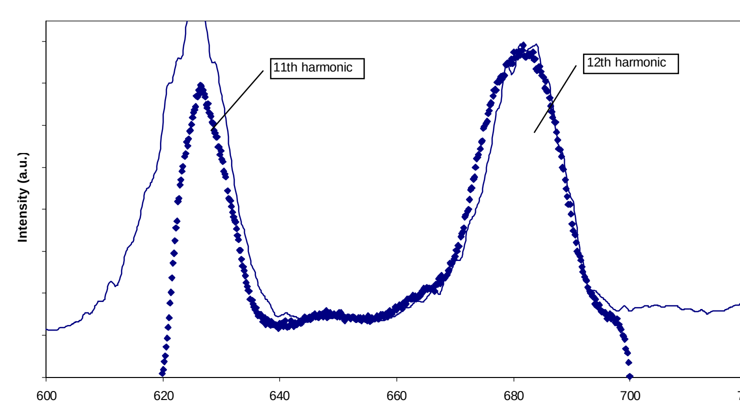

Figure 2: 11th and 12th harmonic at 23.5 mm gap. Landau cavities tuned out and energy spread 0.4 %. Dots - measured, solid line - simulated.

peak intensity (not deducible from the figures) is a factor 1.6.

4 SUMMARY

The conclusion from these measurements is that this method does perform very well while measuring the energy spreads at full current operation. The reason is that at these conditions the energy spread is the dominating factor for the undulator peak width. The coupling/decoupling is more difficult to measure by this method as the effects are smaller and several broadening mechanism have the same order of magnitude.

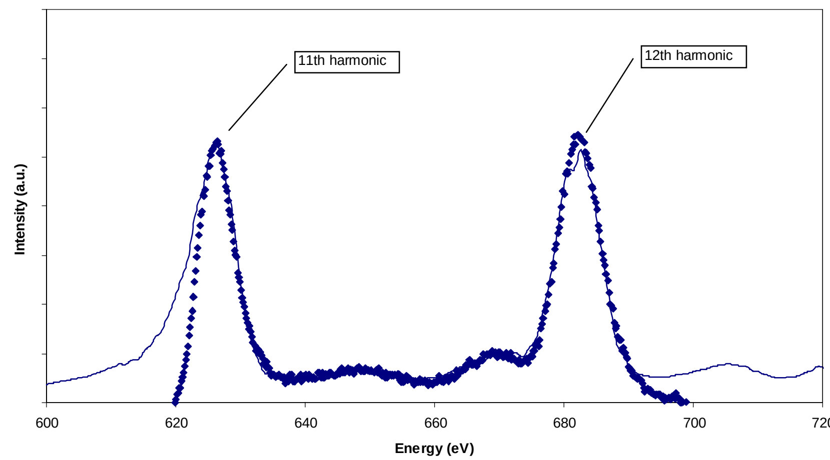

Figure 3: 11th and 12th harmonic at 23.5 mm gap with Landau cavities tuned in giving energy spread 0.22 %. Dots - measured, solid line - simulated.

The I411 is gaining a factor of 1.25 in peak intensity by the possibility of operating the machine at very low coupling (0.6%). On the other hand the price in lifetime has to be paid, and might not be worth it.

The high harmonic cavities for Landau damping are a well functioning device and do not only increase the lifetime of the machine, but do also improve the spectral characteristics of the undulators with an increase of 1.6 in peak intensity.

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