MAGNETIC CHARACTERIZATION OF THE FEL-1 UNDULATORS FOR THE FERMI@ELETTRA FREE-ELECTRON LASER

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Abstract

During 2009 and the first months of 2010, Kyma Srl, the spin-off company set-up by Sincrotrone Trieste, designed and realized all the insertion devices for the FEL-1 undulator chain at the FERMI@Elettra free-electron laser. The insertion devices manufactured and characterized so far are the following: The Laser Heater Undulator, a short, linearly polarized device, already installed in the FERMI linac. The Modulator, a 3.2 m long, linearly polarized undulator. The Radiator, made up of six APPLE-II variable polarization undulators, each 2.4 m long. All the above devices have been characterized, both from the mechanical and the magnetic point of view. The measured parameters are in good agreement with the design values. This paper presents the most relevant results of the magnetic measurements carried out on all the above undulators, and describes the characteristics and the performance of the dedicated equipment set-up and used for these measurements.

INTRODUCTION

Kyma Srl, and Kyma Tehnologija (its daughter company in Sežana, Slovenia) have recently completed the undulators of the FEL-1 chain for the FERMI@Elettra Project . This included the Laser Heater Undulator, LPU Modulator and six EPU radiators. All undulators are PPMs with NeBFe magnetic blocks. All undulators were successfully assembled and magnetically characterized and are all performing within required parameters. Laser Heater Undulator and LPU modulator are already installed in the FERMI@Elettra tunnel. The LPU and the EPUs #1 to #6 are now being installed.

FERMI @ Elettra

The FERMI@Elettra free-electron laser will use the APPLE-II undulators to produce variably polarized coherent photon beams. The FEL-1 undulator chain will consist in a LPU Modulator and 6 EPU radiators with PPM phase shifters in between.

The undulator mechanical structure was designed and manufactured by Kyma (Euromisure), and is an improved C shaped structure. The beams are made up by a complex structure of stainless steal, while the movable girders and magnet holder are made up of aluminium. The holder design was adopted and upgraded from a prototype [1] undulator developed at Elettra in the recent past.

LASER HEATER UNDULATOR

The Laser Heater Undulator (LHU) is a short length PPM linearly polarised undulator with 40 mm period length and 12 periods. It is operating at the 100 MeV electron beam energy at the start of the LINAC. This undulator was assembled directly from the optimization of the single block sequence into the complete undulator. It required some iron shimming and correction of the multipoles with the magic fingers. In both cases the simulated annealing optimization software was used. Figure 1 shows an electron beam trajectory and the phase error. The trajectory straightness is better than 15 micrometers, and the phase error is better than 5°, as required.

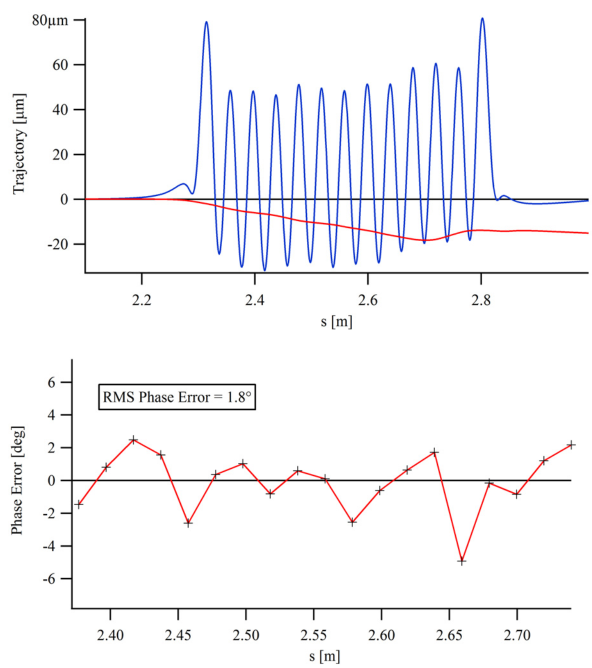

Figure 1: Leaser Heater Undulator electron beam trajectory and phase error at 24 mm gap. RMS phase error is 1.8°. Trajectory straightness is within 6 micrometers. Electron beam energy is 100 MeV.

MODULATOR

The LPU Modulator is the first undulator of the FEL-1 chain at FERMI@Elettra. It is a linearly polarised undulator with 100 mm period length and 30 periods. Its working gap is from 12 mm to 32 mm.

This undulator was the first undulator built at Kyma using the modular approach and in-house optimization software. M5 and M3 modules were used, consisting of 5 and 3 magnetic block respectively. The approach has proved to be successful since the LPU undulator required only minimal correction of the trajectory. Figure 2 shows the results at 20mm gap.

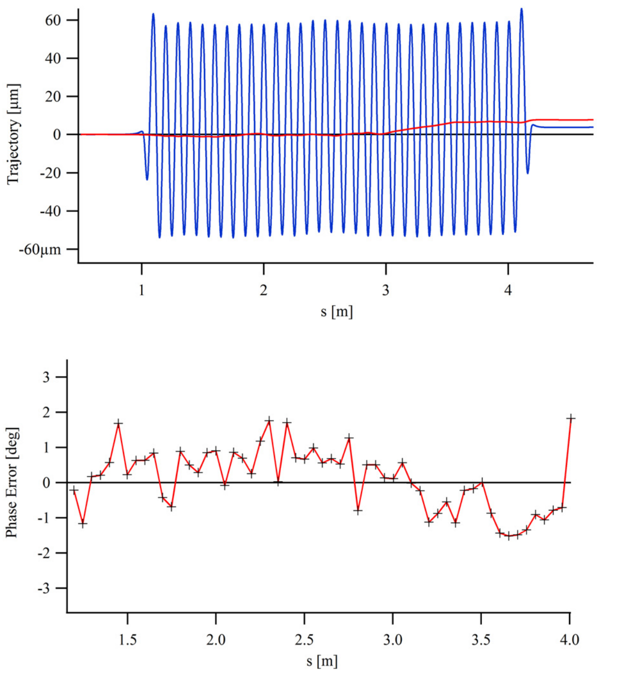

Figure 2: LPU Modulator; Electron beam trajectory and phase error at 1.2 GeV electron beam energy. Trajectory straightness is within 4 micrometers and phase error is 0.87°.

All parameters are within the specified limits. Phase error is less than 1°, trajectory straightness is better than 50 micrometers, integrate quadrupoless are less than 100 G and integrated sextupole within 100 G/cm.

RADIATORS

The six EPUs realized by Kyma met the required specifications. The modular stepwise approach to undulator assembly, with computer assisted optimization, has proved to be very successful since all the undulators required minimal virtual shimming and no phase shimming at all. Only two undulators required some degree of virtual shimming. Three undulators required dynamic shift dependent tapering, to correct for a moderate level of horizontal field taper.

Figure 3 shows the electron trajectory at minimum gap at no shift, 1/4 and 1/2 period shift for the EPU #3. This result was achieved without any virtual shimming, i.e. displacement of magnets.

In figure 3 the field integrals can be seen, which can be compensated with the external correction coils. The trajectory straightness is very good, maximum deviation from the straight line is less than 7 micrometers. The phase error is below 5 degrees. This results show that the modular approach [1] and the optimization aided assembly were very successful.

Three undulators did show shift dependent phase error due to the taper in horizontal field.

This error was compensated by dynamic tapering of the undulator beams with a good success. The result of this is the RMS phase error below 5 degrees for all undulators.

Figure 4 shows the phase error at the representative mid range gap versus the undulator shift, for all the undulators after the dynamic taper correction.

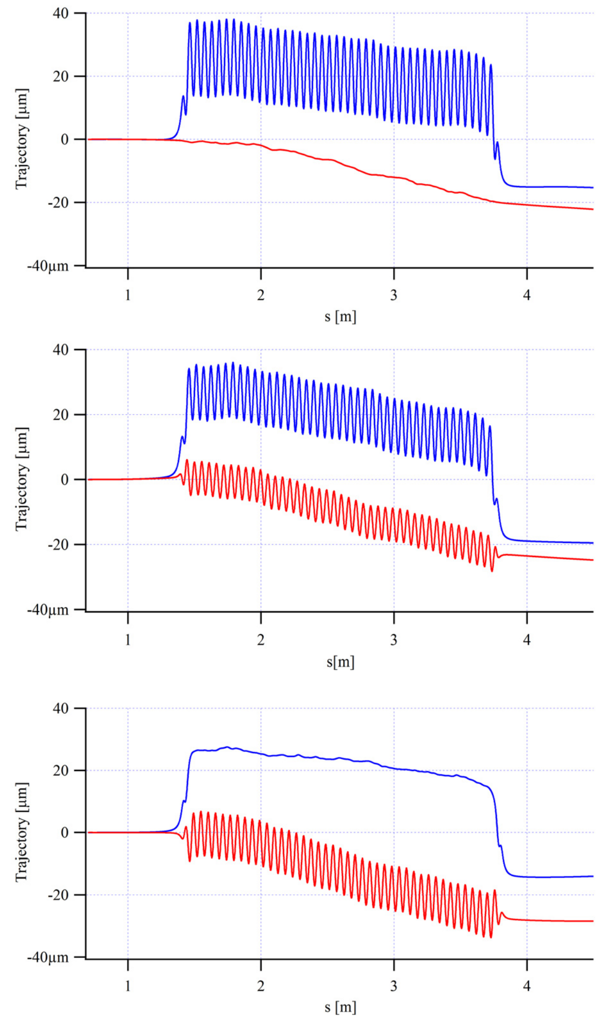

Figure 3: Electron beam trajectory for EPU 3 at 20 mm gap, for 0, 1/4 and 1/2 period shifts (top down). This trajectory was achieved by assembly optimization only, without any shimming. Vertical trajectory (red) and horizontal electron trajectories (blue) are shown.

The field integral multi-poles were adjusted by the use of correction magnets (magic fingers) at the extremities. The optimization software also allowed to correct the initially present first integrals in the termination. The software uses measurement data at three representative gaps; minimum gap, mid gap and maximum gap.

This approach gives a good correction at all gaps. Figure 5 shows a sample of the first horizontal and vertical field integrals for the EPU #6.

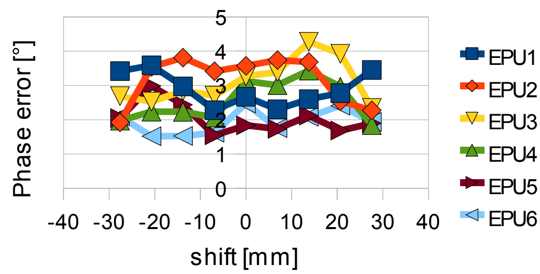

Figure 4: Shift dependency of phase error at 22 mm gap for all EPUs. Phase Error is within the specified limit of 5°. Just in three undulators it was necessary to compensate the shift dependency by dynamic tapering.

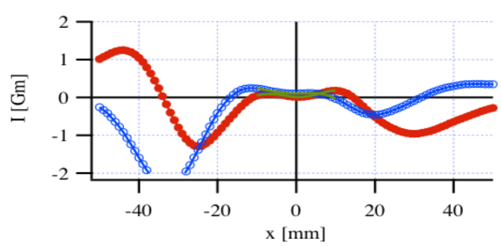

Figure 5: EPU #6 integrated field integrals at 0 shift and 10 mm gap. Normal field integral (blue) and skew field integral (red) are shown.

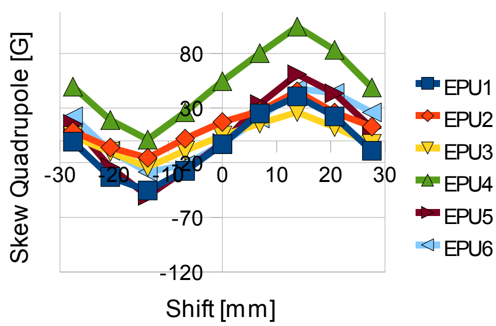

Figure 6: Shift dependent skew quadrupole at 22 mm gap. The dependency is present in all EPUs. Origin of this skew quadrupole is unknown, most probably due to micro movements as discussed in [3].

The field integrals do show a shift dependency, most notably and consistently the change in skew quadrupole. Figure 6 shows the shift dependency of the skew quadrupole at 20 mm gap. The shift dependency is expected to come from micro movements of the magnets blocks, as was noticed at the Advanced Light Source (ALS) [2] [3]. Even if this shift dependency is not very critical for the free-electron laser undulators, investigations are at present being carried out in order to better understand its origin and to further improve the performances of future undulators. In any case for FEL-1 undulators the skew quadrupole is also well within the specified limit for the gaps actually used at FERMI@Elettra.

A shift dependency of sextupoles has also been observed, which is varying from undulator to undulator.

AUTOMATION AND OPTIMIZATION SOFTWARE

To allow optimal production within short time, automated measurement, optimization and analysis procedures were developed. Each undulator is built through the following steps: magnet block characterization, optimization and assembling of magnet blocks into M5 and M3 modules with assistance of a genetic algorithm optimization, measurement of module field integrals with stretched wire, stepwise assembly assisted by genetic optimization algorithm, final characterization and reporting.

The optimization algorithms were developed in Java and are running as a server application with direct communication with the measurement bench, controlled by an Igor Pro application [4].

The two measurement benches available at Kyma facility are able to do the fully automatic measurements. The software is based on Igor Pro and B2E. The automated measurements application include control of the measurement bench, undulator movements, and current supply to the external correction coils. This allows a full automatic characterization of an EPU during one night. The procedures for automatic analysis can produce a full characterization report for and EPU in around one hour on a typical PC.

CONCLUSIONS

Kyma has successfully completed the production of the undulators for the FEL-1 chain at FERMI@Elettra. The undulators show a good performance and are all within the design specifications.

Kyma is therefore now recognized to be fully capable of large scale production of undulators for upcoming free-electron laser projects and synchrotron storage rings.

The in-house automation and optimization software allows for a very fast and precise manufacturing and characterization of both linear and elliptically polarised undulators.

At present the undulators for the FEL-2 chain at FERMI@ Elettra are being manufactured, two LPUs for the SuperESCA beam line at the Elettra storage ring have been successfully completed, and two other insertion devices for external Customers are presently in production.

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