MAGNETIC CHARACTERIZATION OF FEL-2 UNDULATORS FOR THE FERMI@ELETTRA FREE-ELECTRON LASER

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Abstract

Kyma Srl is the spin-off company of Sincrotrone Trieste, Elettra Laboratory, set up in 2007 together with the two industrial partners Cosylab d.d. and Euromisure SpA, in order to design and manufacture the undulators for the FERMI@Elettra project in Trieste, Italy.
The insertion devices for FEL-2 line, manufactured and characterized so far are the following: modulator, 3.2 m linearly polarized undulator, three 55.2 mm period APPLE-II variable polarization undulators, each 2.4 m long and six 34.8 mm period APPLE-II undulators also 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 full agreement with the design values.

This paper presents the most relevant changes in design from FEL-1 to FEL-2 beam lines and the results of the magnetic measurements carried out on all the above undulators.

FEL-2 BEAM LINE

The FEL-2 beam line at FERMI@Elettra consists in a first stage made of one linearly polarizing 100 mm period modulator and 2 elliptically polarizing radiators with period 55.2 mm, same as FEL-1 beam line. The second stage consists of one 55.2 mm period elliptically modulator and six 34.8 mm period elliptically polarized radiators.

Kyma has now fully completed the production, characterization and delivery of all undulators for the FERMI@Elettra Project.

UNDULATORS

Linearly polarized modulator

The linearly polarising modulator for the FEL-2 beam line has the same design characteristics as the modulator for the FEL-1 beam line. The period length is 100 mm with working gap from 12 mm to 35 mm..

Kyma has successfully finished and characterized this undulator. The magnetic characterization has showed results fully consistent with those obtained for the first modulator [1]. A small phase error was achieved with minimal shimming.

Virtual shimming was used only to correct trajectory kicks at the entrance and exit of the undulator.

The integrated field multipoles were in the specification already after the assembly process so no correction was necessary. Magic fingers were used only to fine tune the integrated field multipoles to a minimal levels.

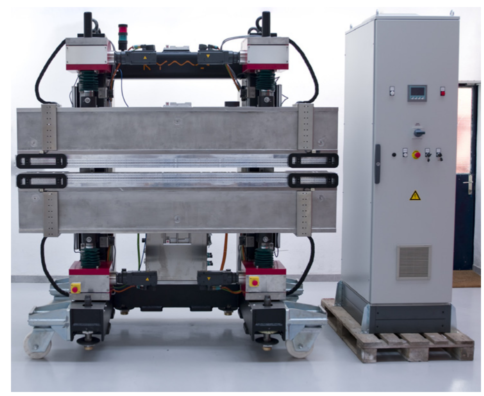

Figure 1: Finished modulator for the FEL-2 beam line, just before shipment to the FERMI@Elettra site.

Type EPUa undulators

Type EPUa undulators are of the same design as for the FEL-1 beam line. The three finished undulators show performances analogous to the undulators for the FEL-1 beam line [1], which were successfully installed and commissioned.
One aspect of particular interest was a shift dependent skew quadrupole, which is now believed to have origin in the micro mechanical movements of the horizontally polarized blocks [2]. Even if this effects in no way the performances of the FEL, it was worth to be fully investigated and understood.

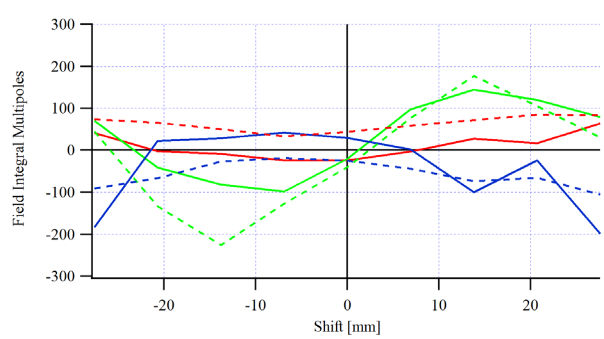

Figure 2: A measurement of the shift dependant integrated field multipoles for the EPUa#1. Measurement was done at minimum gap of 10 mm. Multipoles values drop quickly with the gap and drop down to correct values at gaps greater than 12 mm. Solid lines are normal components, dashed line are skew components. Red is dipole in Gcm, green quadrupole in G and blue sextupole in G/cm.

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The mechanical origin of the shift dependent integrated field multipoles prompted a new study of the forces on the single magnet blocks and of holder design.

Both forces on the single vertically and horizontally polarized magnet blocks were studied. From figure 3 it is evident, that the main force component is in the vertical direction. Vertically polarised blocks (Type A) are pressed into a holder while horizontally polarized blocks (Type B) are pulled out from the holder. In the second case only the corner clamps and the friction on the surfaces hold the magnet in places so it is much more susceptible to the lateral and horizontal displacements.

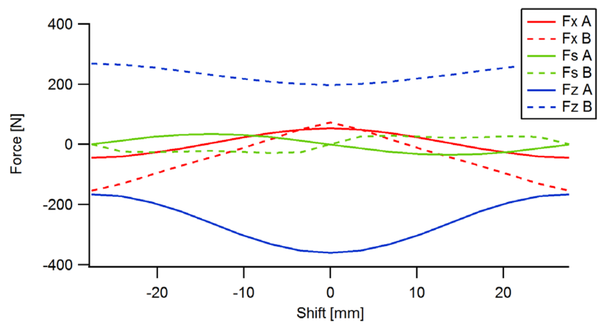

Figure 3: Analysis of the forces on a single magnet block. Forces shown were calculated with RADIA with a 4 period model including susceptibility of the magnetic material.

New Design for EPUb

The experience gained with the design and realization of the EPUs for FEL1, allowed for an even improved design of the undulators for the FEL2 line.

In first place the magnet block size was reduced to a 20 mm x 20 mm profile. This has divided the forces approximately in half for the EPUb design from EPUa. Figure 4 shows forces on the type A and type B blocks of EPUb.

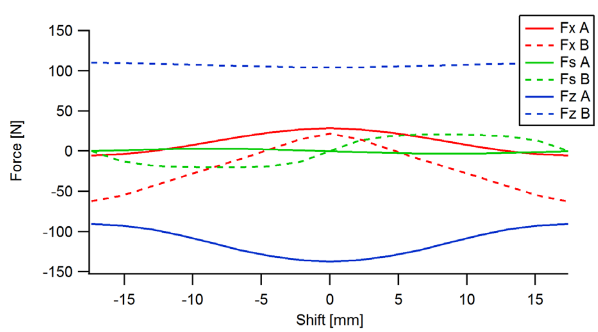

Figure 4: Magnetic forces in the vertically and horizontally polarised blocks of the EPUb. Forces shown were calculated with RADIA with a 4 period model including the susceptibility of the magnetic material.

Furthermore the magnet holder was redesigned to increase the stiffness and reduce the possibility of the magnet block movements.

Following figure shows a comparison of the old and new holder design. This new design has proved successful and the EPUb type undulator for the FEL-2 beam line show minimal change with the shift. Even at the minimum gap the integrated field multipoles are well below the specified limits.

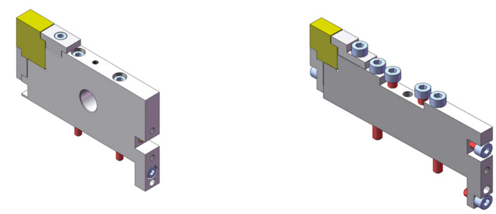

Figure 5: Old (left) and new (right) holder design. New holder ensures better stiffness to reduce the movements of the magnet blocks due to the changing magnetic forces.

Type EPUb Undulators.

The type EPUb undulators for the FEL-2 beam line at FERMI@ELETTRA have 68 periods with length of 34.8 mm. The operation gap of the undulator is from 10 mm to 35 mm.

Six of this type of undulator were successfully designed, manufactured and characterized at Kyma in the first quarter of 2011 and are now being delivered to the FERMI@Elettra site. All design parameters were fully met as can be seen in Table 1.

Table 1: Peak Field and Phase Error

Undulator		**Peak Field [T]**	**RMS Phase Error [°]**
EPUb#1	Ver. Field	0,746	4,2
	Per./4 shift	0.353 / 0.524	4,9
	Hor. Field	0,523	3,0
EPUb#2	Ver. Field	0,749	2,5
	Per./4 shift	0.353 / 0.524	4,0
	Hor. Field	0,523	2,9
EPUb#3	Ver. Field	0,745	3,7
	Per./4 shift	0.365 / 0.545	3,9
	Hor. Field	0,522	1,9
EPUb#4	Ver. Field	0,741	3,1
	Per./2 shift	0.367 / 0.538	2,0
	Hor. Field	0,52	3,4
EPUb#5	Ver. Field	0,741	3,2
	Per./4 shift	0.367 / 0.538	4,4
	Hor. Field	0,522	2,2
EPUb#6	Ver. Field	0,744	4,0
	Per./4 shift	0.367 / 0.541	4,8
	Hor. Field	0,523	3,9

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The new design of the magnet holder and the reduced size of magnetic blocks has showed to be important issue in the further improvement of undulator performances.

The shift dependent integrated field multipoles are reduced well within the design limits, as can be seen in figure 6. The largest change is in the normal sextupole does not originate in the mechanical movements but has magnetic origin.

The figure 6 below show an example of the shift dependent integrated field multiples for one the EPUb type undulators.

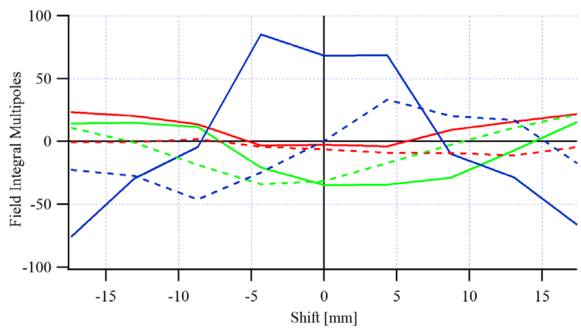

Figure 6: Shift dependent integrated field multipoles of the EPUb#2 undulator at minimum operational gap of 10 mm. All the multipoles are well within the specified limits of 100 G for quadrupoles and 100 G/cm for sextupoles. Solid lines are normal components, dashed line are skew components. Red is dipole in Gcm, green is quadrupole in G and blue sextupole in G/cm.

As can be see from the figure 6 the normal sextupole and dipole change with the shift is predicted from the RADIA model.

As it is now customary at Kyma none of the assembled undulators required any heavy shimming. Only on two undulators virtual shimming was used to fine tune the electron trajectory. Magic fingers are used (but not necessary) only to fine tune the integrated field multipoles and the entrance and exit trajectory kicks.

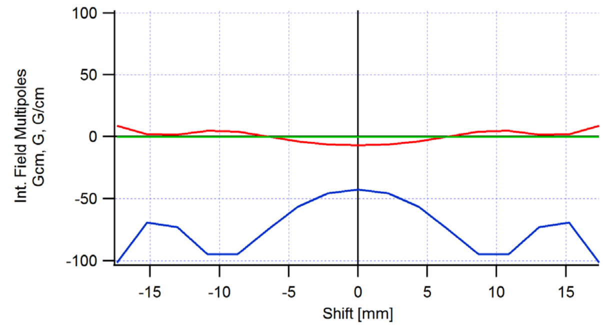

Figure 7: RADIA prediction of the shift dependent integrated filed multipoles due to the susceptibility of magnetic material in the end section. Red is dipole, green quadrupole and blue sextupole

CONCLUSIONS

Kyma has built with success all the undulator for the FERMI@Elettra project. All the undulators have performances in the specified limits, and the IDs for the FEL-1 free-electron laser have been successfully commissioned and are now in operation.

Kyma's design, manufacturing and characterization processes are well established and are able to handle even large scale production of insertion devices for FELs.

REFERENCES

[1] M. Kokole, T. Milharčič, G. Soregaroli, M. Tedeschi, M. Zambelli, B. Diviacco, "Magnetic Characterization of The FEL-1 Undulators for The FERMI@ELETTRA Free-Electron Laser", FEL'10, Malmö, 2010, THPC08, p. 664

[2] C. Kitegi et al., Development of the Short Period High Field Apple-II Undulator at SOLEIL", IPAC'10, Kyoto, 2010, WEPD008, p. 3099

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