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APPLE II INSERTION DEVICES MADE AT MAX IV

A. Thiel, M. Ebbeni, H. Tarawneh, MAX IV Laboratory, Lund, Sweden

Abstract

At present five Apple II insertion devices were made and installed at MAX IV [1], three of them in the 1.5GeV-ring, and two in the 3GeV-ring. The assembly of the last one of a total number of six Apple II undulators made at MAX IV is currently going on. The undulators have period lengths of 48mm (two devices), 53mm, 58mm, 84mm and 95.2mm. The operational gap range of the 3GeV devices is between 11mm and 150mm, the range of the 1.5GeV devices is 14mm to 150mm. Structural analysis was applied to assure a minimum deflection of the main frame and the magnet array girders. The main frame is made of nodular cast iron, while the girders are made of aluminium alloy. In order to optimize the magnetic tuning the position of the magnet keepers can be adjusted by wedges. The undulators were fiducialized before the installation in the ring tunnel and were aligned in the straight section using their magnetic centre as reference. All MAX IV made undulators have three feet with vertical adjustment and separate horizontal adjusters. This paper describes the design, assembly, shimming and installation of the MAX IV Apple II devices in more detail.

OVERVIEW OF INSTALLED APPLE II

Three Apple II undulators (EPU: elliptically polarising undulator) are in place at the 1.5GeV-ring and two EPU's in the 3 GeV-ring. A sixth EPU is currently in assembly for the 3 GeV-ring. Table 1 shows the overview of the EPU's with some characteristic properties.

Table 1: Summary of Styles

	Beam-line	Period length	Inst. length	Magn. gap	K_{eff}
3 GeV	Hippie	53mm	4m	11mm	3.30
	Veritas	48mm	4m	11mm	3.30
	Softimax	48mm	4m	11mm	3.30
1.5 GeV	Bloch	84mm	2.6m	14mm	8.65
	FinEst	95.2mm	2.6m	14mm	10.40
	MAX peem	58mm	2.6m	14mm	4.95

These six undulators were manufactured at the MAX IV magnet laboratory between 2015 and 2018. The initial design bases on an EPU designed in collaboration with Bessy (HZB) [2].

MECHANICAL DESIGN FEATURES

Undulator Cast Frame

The backbone of MAX IV EPU's is the cast iron frame made of nodular cast iron EN-GJS-400-18-RT according to DIN EN1563. The material combines high strength and good machining properties with low deformation at present forces. The cast pattern of the frame was designed by the foundry based on the calculated magnet forces and estimated magnet array weight. Figure 1 shows the force pattern and Table 2 the allowable deformation.

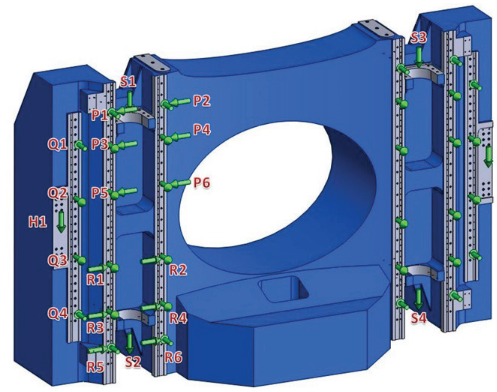

Figure 1: Force pattern on the EPU-model frame.

Table 2: Maximum Allowable Deformation

	Horizontal [mm]	Vertical [mm]
P-R		< 0.050
P1-P6 / R1-R6	< 0.015	
Q1-Q2 / Q3-Q4	< 0.010	
Q1-Q4	< 0.020	

The foundry's engineering team optimized the cast model respectively [3], also in regard of the manufacturing procedure. MAX IV used two standardized wooden cast patterns to cover the two different straight section lengths of the two storage rings. The cast frames have a weight of approximate 6.2t. Figure 2 shows the EPU53 cast frame during machining.

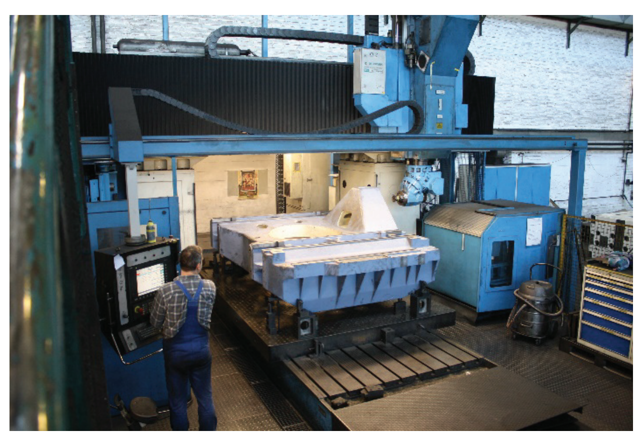

Figure 2: EPU53 cast frame during machining.

Undulator Feet Arrangement

The EPU's manufactured by MAX IV have three feet, which carry the entire weight. Three additional side adjusters take care of the horizontal alignment. The

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vertical feet are standard machinery feet with precise vertical adjustment based on wegdes. Bearings on the vertical feet allow the undulator to slide in the horizontal plane. This design separates the vertical and the horizontal alignments, which allows for smooth alignment in the ring tunnel saving tunnel access time. Figure 3 shows the vertical feet design.

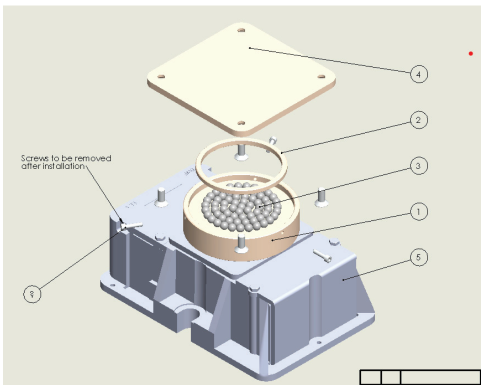

Figure 3: Feet for vertical adjustment.

A typical alignment of a MAX IV EPU takes about one hour, the most time in the ring is needed for the laser tracker to warm up (about 2…3 hours).

Magnet Keepers

Wedges realize the vertical position tuning of the MAX IV EPU magnet keepers. All magnet keepers are made of aluminium AW-6082. The wedges are made of copper alloy CW713 (2.0550). Two pins (CW614N) fix the position of each keeper on the respective subgirder. The position of the keeper on the wedge is defined by a M4 bolt, which is secured by a left hand threaded set screw, and a respective counter screw. The keeper is bolted down on the subgirder by a M8 screw. Each keeper holds a pair of magnets, horizontally and vertically magnetized. Figure 4 shows the explosion drawing of the magnet keeper assembly. Loctite 222 is used to secure all screws.

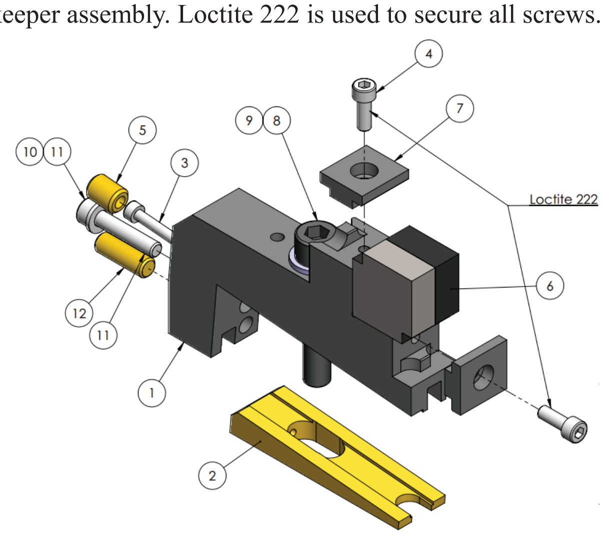

Figure 4: Dual magnet keeper of MAX IV EPU's.

The magnet keeper sees forces in all three axes and a respective torque in addition to the mounting force introduced by the screws. The individual magnet keeper of EPU95.2, the undulator with the longest period at MAX IV, sees a maximum horizontal force of 460N, a vertical force of 380N and a force of 440N in longitudinal direction at a gap of 14mm at different phase shifts. Figure 5 shows the corresponding calculated deformations in vertical direction.

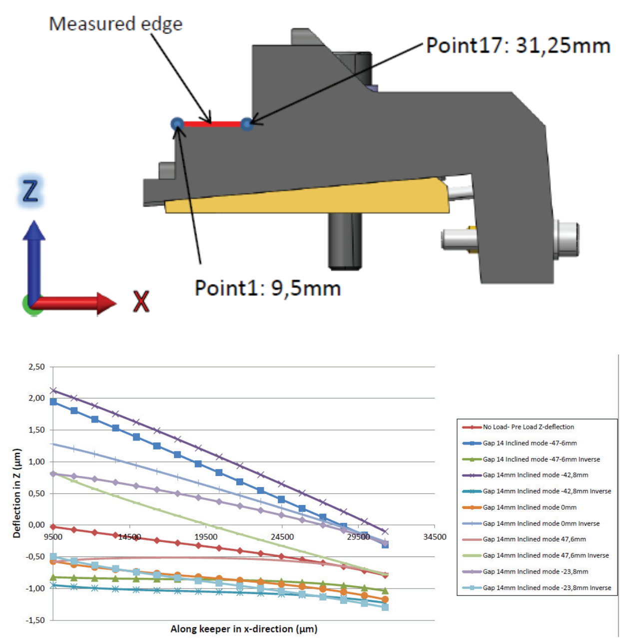

Figure 5: EPU95.2 magnet keeper vertical deflection.

According to the calculations the maximum deflection of the dual magnet keepers is below 3µm in all directions and all phases.

The assembly of the magnets on the keepers was done with the help of a mounting jig in order to have a reproducible placement of the magnets on the keepers. The jig, showed on Figure 6, can match to all magnet sizes used on MAX IV EPU's.

Figure 6: Magnet mounting jig.

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Girders

The magnet keepers sit on four subgirders, which themselves are mounted on two main girders as shown in Figure 7.

Figure 7: Main girder assembly.

The main girders deflect by the resulting magnet forces depending on gap distance and phase shift. The main design focus was to keep the vertical deflection of the main girder below 10μm under all conditions. There is no force balancing system on MAX IV EPU's. The deflection is limited by the cross section design of the main girder (400mm x 400mm). The girders are made of aluminium ACP5080. Figure 8 shows the calculated deformation in vertical direction of the main girder with subgirders in phase shift to realize inclined polarization.

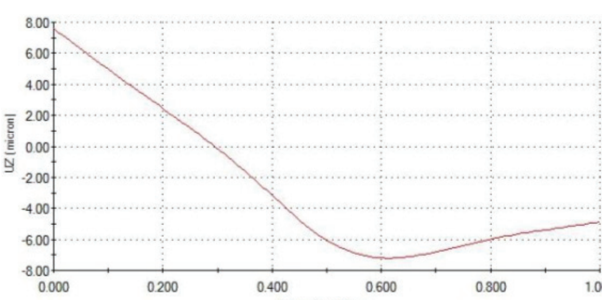

Figure 8: Vertical deflection of the main girder in inclined mode.

The maximum calculated vertical deflection due to magnetic force and weight is 7.5μm.

In operation the undulator gap deflects significantly more than that. The undulator gap is not only determined by the magnet forces and weight of the girders but also by the deflection and tolerances of the entire undulator structure. Adding up the tolerance chain of the main girder assembly of a 4m-EPU gives a number of 490μm. Adding the deformation induced by the magnet force the undulator gap might change by 500μm without motor motion. Thorough mechanical design can decrease that number. Still all MAX IV EPU's operate with linear encoders measuring the gap change and motors in closed loop in order to correct for the deformation and backlash of the mechanical system.

Magnetic Tuning

After the assembly is finished, all undulators are magnetically tuned (shimmed) at the MAX IV Hall probe and wire bench [4]. The device is released for installation in the ring tunnel when,

- the residual first integral error is below 100Gcm,
- the phase error (calculated with B2E code [5]) is below 5°
- the second integral error is below 20000Gcm^2.
- The device is measured at different gaps and phases.

A typical shimming campaign takes about 2 weeks for a 2.6m EPU, and 4 weeks for 4m EPU. The EPU's allow for all polarizations in between horizontal and vertical polarization. Measurements show, that all these modes become good enough in magnet field quality if successfully shimmed for horizontal and vertical mode. MAX IV EPU's are therefore shimmed at horizontal and vertical polarization mode at the respective minimum undulator gap.
Figure 9 shows the initially measured orbit of EPU84 before the start of the magnetic tuning.

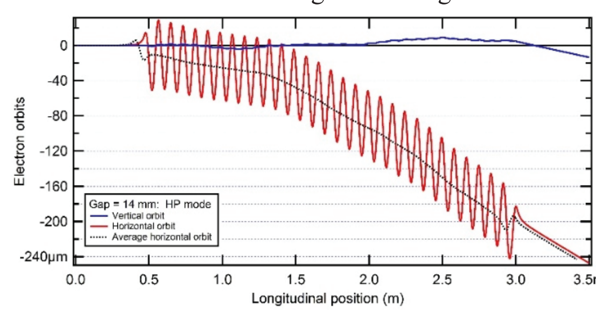

Figure 9: Measured orbit of EPU84 before shimming.

After 10 days of shimming the orbit was tuned as Figure 10 shows:

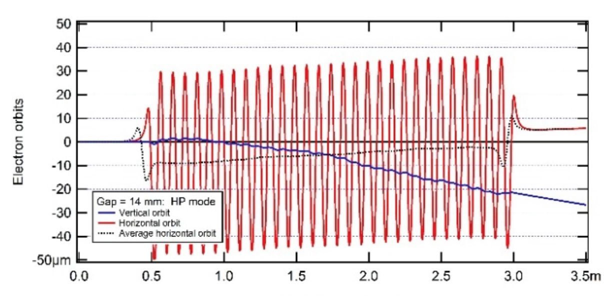

Figure 10: Measured orbit of EPU84 after 10 days shimming.

Figures 11 and 12 show the first and second integral in the horizontal plane after shimming.

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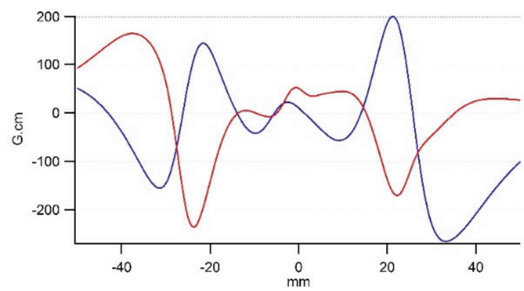

Figure 11: Measured first integral of EPU84 after shimming.

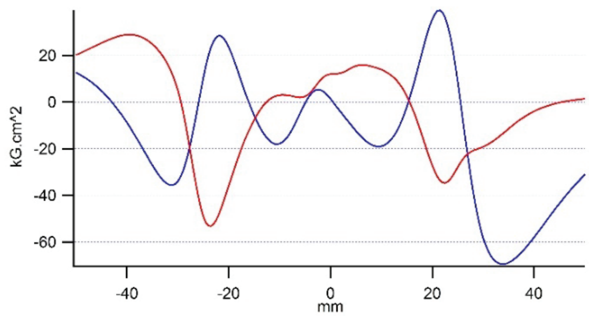

Figure 12: Measured second integral of EPU84 after shimming.

The measurements proof that the magnetic tuning with the wedge system assured the magnetic field quality, and allows for relatively quick shimming period for Apple II devices.

The measured field frequency in Figure 13 shows the achieved period length of 83.998mm of the assembled EPU84.

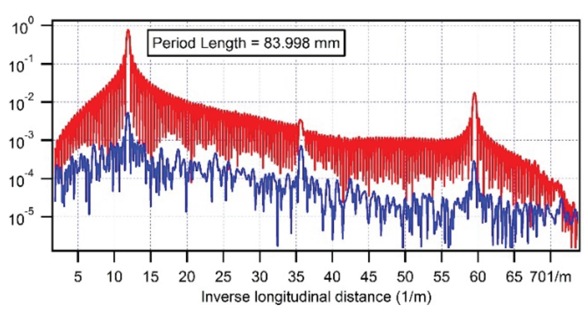

Figure 13: Measured magnet field frequency of EPU84.

Machine Protection

A possible damage of the straight vacuum chamber section is a major concern when operating Apple II devices in the storage ring. All EPU's installed at MAX IV have therefore a software limit, which prevents the user for commanding gap values outside the operation range. In addition, redundant limit and kill switches are mounted. The switches are adjusted in steps of 0.15mm below or above the operational limit and would stop the motion and activate the motor breaks. On top of this, all EPU's have a hard stop, a chunk of metal mounted in a way that the girders could not pass. The hard stops are adjusted to 0.3mm…0.4mm below or above the respective operation limit. A high precision tilt meter (Tuff Tilt 420, high gain version) mounted on each of the girders monitors any angular change of the respective girder position. Figure 14 shows the mounted tilt meter on EPU58.

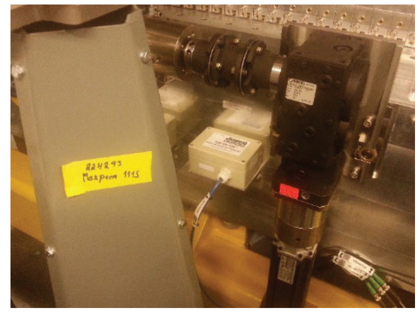

Figure 14: Mounted tilt meter.

An alarm would be triggered if the measured angle is outside the defined range. The EPU's girders are expected to operate without any taper. It turned out, that some of the tilt meters of installed EPU's triggered despite the fact they were not operated. The assumption is, that the tilt meters even measures the floor motion of the relatively fresh MAX IV concrete. That means, the tilt meter may also indicate a necessary realignment of the undulator.

CONCLUSION

Six EPU's have been built and characterized at MAX IV laboratory where of five are already installed in the two storage rings. The current design and work shop set up allows the manufacturing of Apple II undulators with magnetic and mechanical properties within specifications. All six EPU's were manufactured on time and budget.

There is still a lot of potential optimization to discover. Different magnet sorting and assembly procedures were tried. About twenty small design upgrades from the first to the last EPU already improved the mechanical behaviour and handling during assembly.

ACKNOWLEDGEMENT

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