

# NOVEL MAGNET PRODUCTION TECHNIQUE USED FOR AN ELLIPTICALLY POLARIZING UNDULATOR

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## Abstract

A common problem for elliptically polarizing undulators (EPUs) is that the magnetic forces give a mechanical deflection in the magnet holder construction when changing the undulator phase. Gluing horizontally and vertically magnetized blocks together can increase the mechanical stability of the magnet holders. The gluing process of pairs of magnetized magnet blocks is time-consuming, expensive and difficult to carry out with high positional precision. A novel magnet production technique has been developed where un-magnetized pairs of blocks are glued together before magnetization. The large number of parts, the time for assembly, and the cost of the EPU can be reduced with the novel magnet production technique. The novel magnet production method has been used for a 2.6 m long EPU of APPLE-II type, which has been built in-house at the MAX IV Laboratory. The frame for the EPU is made of cast iron in order to get a small mechanical deformation when changing phase in the inclined mode. The paper includes detailed descriptions of the novel magnet production technique, including measurements of the magnetization, and the new EPU.

## INTRODUCTION

Elliptically polarizing undulators (EPUs) of APPLE-II-type consist of permanent magnets, which are arranged in 4 rows mounted on 4 sub-girders, the sub-girders are then mounted in one upper and one lower pair on two girders that can be moved vertically in order to adjust the gap of the EPU. The two rows on each girder can be moved relative to each other in order to change the polarization of the emitted radiation from the undulator. There are 2 types of magnets needed in an EPU: V-type magnets giving a field that is perpendicular to the direction of travel of the electron beam in the accelerator and H-type magnets giving a field that is parallel to the direction of travel of the electron beam. In a standard production sequence, the magnets are manufactured as individuals, mechanically characterized, magnetized, and finally magnetically characterized.

Large forces act on the magnets and the force distribution changes drastically when the polarization is changed in the EPU. This has several consequences. A few of them are:

- The magnets must be rigidly fixed in the nonmagnetic magnet holders by clamps and glue.
- The magnetic forces acting on the individual magnet blocks can give a mechanical deformation and also mechanical hysteresis in the magnet holders when chang-

ing the undulator phase, which results in phase dependent multipoles in the EPU.

- The mechanical frame and other parts of the EPU must be very stiff to withstand the magnetic forces.
- The gap and the phase position of the sub-girders must be continuously monitored and regulated by the motion control system of the EPU.

The magnetic forces on a pair of magnets that is glued together is smaller than the forces acting on individual magnets as can be seen in Figure 1. The magnet holder for a glued pair is wider and more stable than a magnet holder for a single magnet. Another benefit is that the number of magnet holders in the EPU is reduced by a factor of 2 when magnets are glued together into pairs.

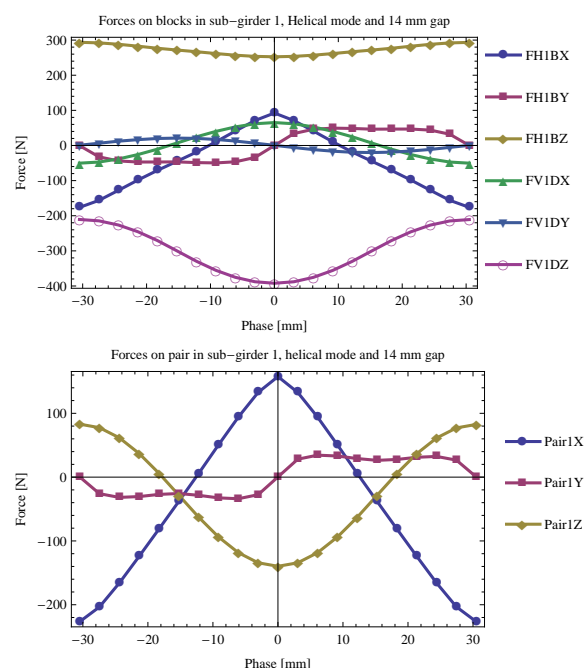


Figure 1: Forces acting on individual blocks (upper plot) and glued pairs (lower plot) in EPU61 at 14 mm gap assuming a remanence of 1.28 T. The forces FH1BX, FH1BY, and FH1BZ are the forces acting on a horizontally polarized block and FV1DX, FV1DY, and FV1DZ are the forces acting on a vertically polarized block. Pair1X, Pair1Y, and Pair1Z are the forces acting on a glued pair.

## NOVEL PRODUCTION TECHNIQUE

The novel magnet production technique consist of:

- Machine the permanent magnets to an intermediate dimension for the planes that are not used for the gluing process.
- Glue vertically and horizontally polarized magnets together as pairs before magnetization.
- Make the final grinding of the outer surfaces to their final dimensions.
- Magnetize them as pairs with a stronger magnetization field than usual at a  $45^\circ$  angle to their preferred direction.

The benefits with the novel magnet production technique are that the magnetic forces on pair is lower than for individual magnets, the magnet holder can be made wider and more stable, the number of magnet holders in the EPU is reduced by a factor of 2, and the geometric accuracy is increased since the final machining is done after gluing.

The novel magnet production technique with glued pairs has been used for the 352 pairs of magnets produced for EPU61. The blocks were made from transverse die-pressed NdFeB permanent magnet material with a remanence ( $B_r$ ) of at least 1.25 T and an intrinsic coercivity ( $H_{CJ}$ ) of at least 25 kOe. The cross section of the blocks is  $30 \times 30 \text{ mm}^2$  and there is a 5 mm quadratic cutout in two corners for the clamps holding the magnets. The thickness of a single magnet block is  $15.20 (+0, -0.05) \text{ mm}$  and the thickness of a glued pair is  $30.40 (+0, -0.10) \text{ mm}$ . The glue has a thickness of approximately 0.05 mm. Figure 2 shows a photo of glued pairs of magnets. The large flat surfaces transverse to the accelerator beam direction was ground before the gluing process. The final grinding step in the production, giving the mechanical dimensions of the glued pair parallel to the undulator axis, was made after gluing. For the magnetization in pairs, the magnets were placed in a keeper which holds them at  $45^\circ$  to their preferred direction. The magnetization was done in a special coil capable of supplying 7.0 Tesla magnetizing field, giving a field component of 4.9 T parallel to the easy axis in the two blocks.

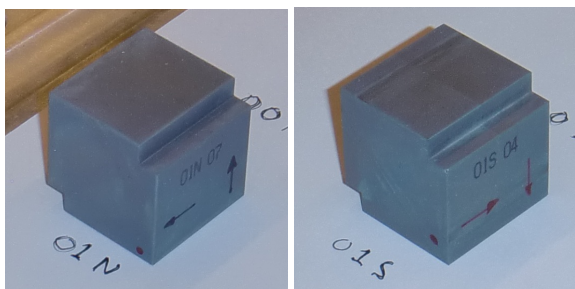


Figure 2: Photo of glued pairs of magnets with different directions of magnetization for the EPU61.

## THE ELLIPTICALLY POLARIZING UNDULATOR EPU61

The novel magnet production technique has been used for the 2.6 m long elliptically polarizing undulator of APPLE-II type called EPU61, which has been built in-house at MAX-lab. An illustration of EPU61 is shown in Figure 3. The period length is 61 mm, the minimum gap is 14 mm, and there are 83 full size poles in EPU61.

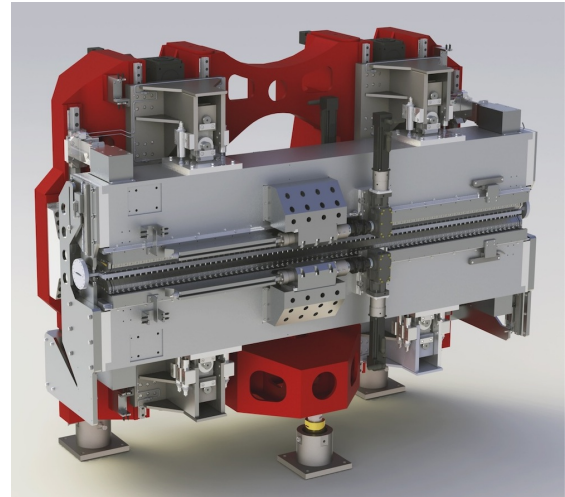


Figure 3: A computer rendered illustration of EPU61.

The concept with a cast iron frame, separate guiding rails and flexor plates has been used for EPU61. This concept has earlier been used for undulators both at BESSY II and PETRA III [1]. The magnet holders have wedges for adjusting the vertical position and there are set-screws to adjust the horizontal position to allow for a rapid and precise adjustment of the transverse magnet position during assembly and shimming. A similar concept has also been used for an EPU produced at Shanghai Synchrotron Radiation Facility [5]. The control system consists of 8 servo motors and 8 encoders. 4 encoders and 4 servo motors are used for controlling the gap. The gap is measured by 2 encoders at the ends of the EPU in line with the stored beam and 2 encoders are used for measure the position of the lower girder with respect to the bottom of the frame [2], see Figure 3. 4 encoders and 4 servo motors are used for controlling the phase position of the 4 sub-girders. The gap and phase position is continuously measured and regulated by the control system.

The end section design is based on the guidelines found in [4] and the end sections end with a horizontally polarized block. The magnetic modeling work has been done with Radia [3].

The sorting of the magnets was based on stretched wire measurements of the field integrals of the glued pairs instead of Helmholtz coil measurements of the total dipole moment.

The shimming was carried out at a gap of 16.5 mm. The shimming was carried out by moving glued pairs and also end section blocks vertically and horizontally. Shims of soft

magnetic material was not used. The measured field integrals after shimming are shown in Figure 4. The measured first field integrals and multipoles are well within the specifications in the good field region  $|X| < 10$  mm and phase dependent multipoles are not present. A maximum second field integral of  $12000 \text{ Gcm}^2$  is found in the positive circular mode, which can be compensated for with air coils having an integrated strength of  $0.5 \text{ Gm}$ . The rms phase error at  $16.5 \text{ mm}$  gap for planar and vertical mode the rms phase error is maximum  $2.1^\circ$ . For the  $45^\circ$  inclined mode the rms phase error is larger as can be seen in Figure 5.

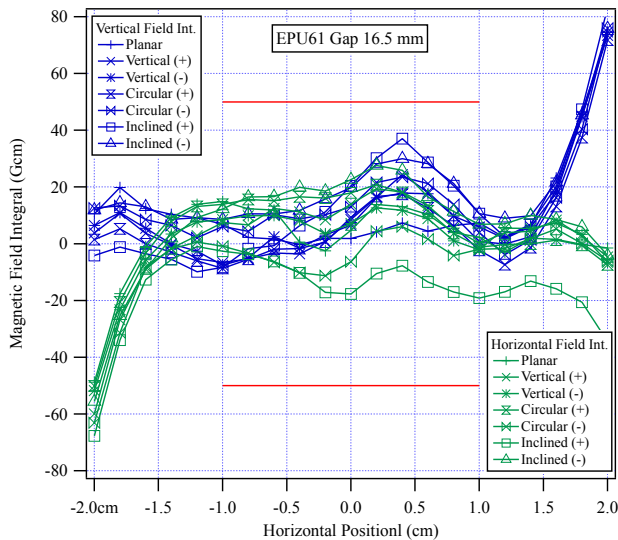


Figure 4: Measured field integrals after shimming of the EPU61.

## CONCLUSIONS

A novel magnet technology of gluing horizontally and vertically polarize magnets together before magnetization has been developed and the technology has shown to work well for a  $2.6 \text{ m}$  long elliptically polarizing undulatory with  $61 \text{ mm}$  period length called EPU61. The number of parts in the undulator is reduced by using glued pairs of magnets. The reduced forces on a glued pair compared to individual blocks combined with the wider magnet holder for a pair compared magnet holders for individual blocks have reduced the problem with phase dependent multipoles in the EPU61 to negligible levels.

## ACKNOWLEDGEMENT

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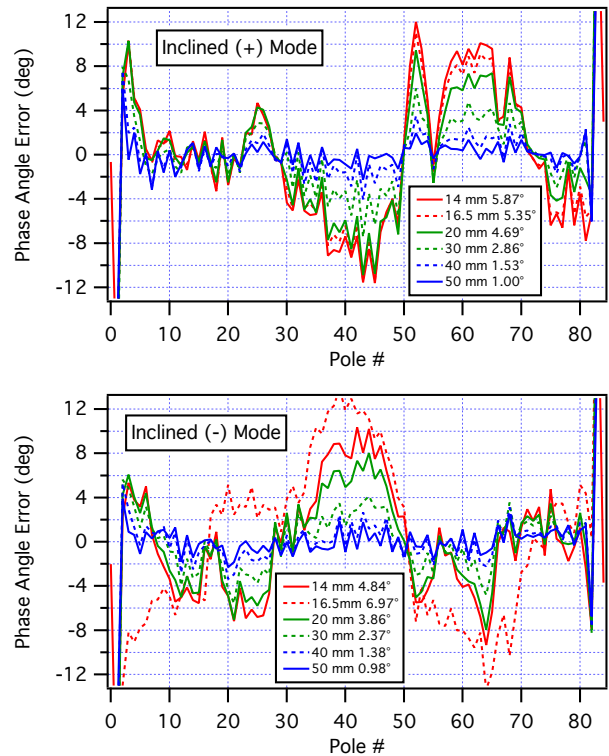


Figure 5: Measured phase error of the EPU61 in inclined mode after compensation for the second field integrals. The rms phase error has been calculated in the inclined plane and it has been calculated over 79 poles.

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