

First Prototype Undulator for the LCLS Project – Mechanical Design and Prototype Lessons

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Abstract

The design of a new hybrid-type undulator with a fixed gap of 6 mm, a period of 30 mm, and a length of 3.4 m is presented. The undulator line, consisting of 33 such units, is a critical part of the LCLS project, which is one step toward the design of a fourth-generation synchrotron radiation source. Magnetic tolerance of all 33 undulators, as well as the corresponding mechanical uniformity, is a major challenge. A ridged C-shape design with a titanium housing of 12" diameter was chosen to provide easy access to the gap area for magnetic measuring and tuning. Lessons learned while working with this prototype are critical for successful project execution. Assembly and tests results, as well as possible design changes, are presented.

Keywords: hybrid undulator, synchrotron radiation, SASE

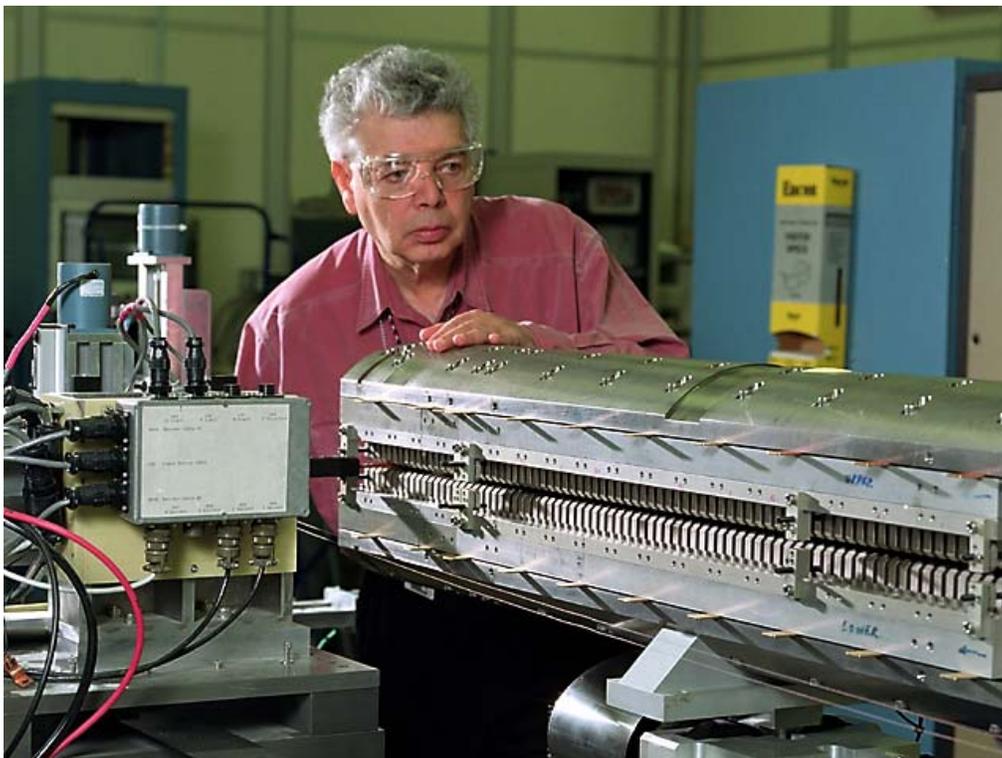


Fig.1 - LCLS prototype undulator on the magnet measuring stand.

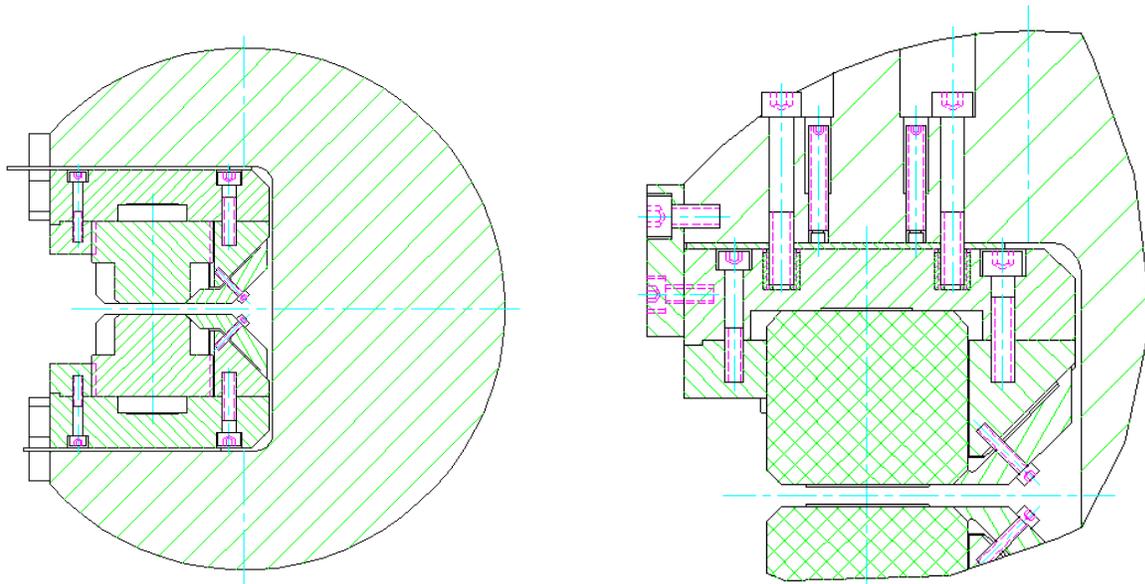


Fig.2 - LCLS prototype undulator cross section and details of the magnet structure.

A first prototype of the LCLS undulator was designed, manufactured and partially tested [1]. In Fig. 1, the undulator is shown on the magnetic measuring stand. The undulator cross section and magnetic structure are shown in Fig. 2. The major design features of this device are listed below:

1. Titanium housing made of a forged 12" bar.
2. Poles made of vanadium permendure with so called "wings."
3. The pole and magnet base is made of aluminum alloy that partially compensates for the changes in pole gap, as well as for the magnetization of the permanent magnets due to temperature change.
4. Only one clamp is used for each pole and magnet. Clamps are made of titanium.
5. Incremental shims and a "push-pull" screw can be used for the undulator gap adjustment.
6. Piezotranslators are used to precisely tune the field strength at both ends of the undulator (two on each end).
7. The outbound area is completely open for the side shim installation, where necessary, in order to tune the field strength along the undulator.
8. Side shims have six bars made of low-carbon steel. Each bar can be individually adjusted and locked in place.
9. Five camshaft movers are used for horizontal and vertical alignment of the undulator as a whole.

There were many lessons learned during the manufacture, assembly and first test of the prototype.

The titanium housing is quite expensive, but it is very rigid. The specifications for flatness and straightness along the whole length of the magnetic structure were achieved during fabrication (50 microns or better for each item).

Vanadium permendure poles were made with titanium wings. Titanium was chosen because it has almost the same thermal expansion coefficient as vanadium permendure. After complete assembly, the poles go through a final grinding process so the wings and pole piece have exactly the same thickness. This allows the wings to be inserted in the precisely machined aluminum base and clamped.

The initial intention, to use only one clamp for each pole, proved not to be the best choice. It allowed the poles to rotate slightly when the full magnetic force was applied thereby reducing the gap and creating cant. In an attempt to prevent this rotation, the clamping force was increased; however, this led to bending of the aluminum base (see Fig. 3). The decision was made to modify the design to use two clamps—one from each side of the pole. Only one clamp is still used to hold the magnets in place due to the fact that the magnetic forces push the magnets away from the gap and the tolerance for the magnet position is not very tight.

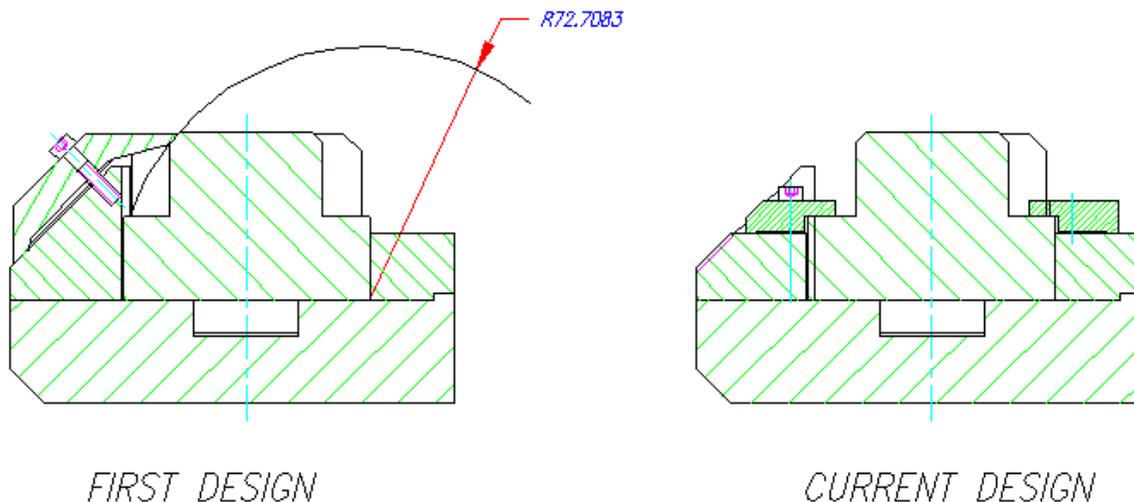


Fig. 3 - Different pole clamp options.

Initial tests showed that side shims with six bars change the peak field by almost 6%, which is much more than needed. Consequently, the number of the side bars was cut to four and remaining space was used to install the outboard side clamps.



Fig.4 - Cam shaft mover.

Both the “push-pull” screws and shims options for undulator gap adjustment were analyzed. Incremental shims are the preferred adjustment method because they make the whole structure more ridged and stable. For future work, the shims will be made of low carbon steel due to ease of fabrication and higher precision in thickness after grinding. In addition, precise nickel plating may be used to increase the shim thickness by an additional 2-4 microns. It has yet to be determined if relatively thin shims located roughly 80 mm away from the pole gap will have any impact on the magnetic performance of the undulator.

The cam shaft mover design is shown on the Fig. 4 and is similar to the design used to move for Swiss Light Source girders. To make the movers self aligned a double row spherical ball bearing was installed on each cam shaft. However, during the alignment procedure this ball bearing “travels” slightly causing movement jitter (see Fig. 5).

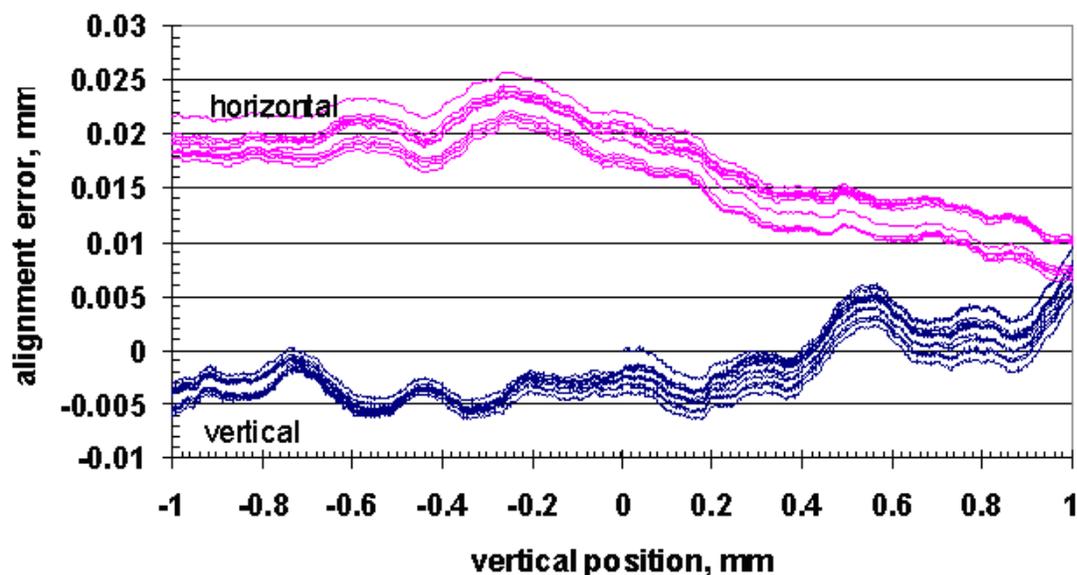


Fig.5 – Cam shaft mover test results.

Even with this jitter undulator positioning with an accuracy of better than 10 micron was achieved. During testing, it was discovered that it is beneficial to install a wire potentiometer on each shaft to locate the “zero” position [2]. This was added to the existing design with excellent results. The next step is to revise the design of the cam shaft movers to properly implement these findings. Also there is an intention to rotate the cam shaft movers 180° in the horizontal plane to keep motors shielded by the movers and gearboxes from radiation.

The piezo-translators for the gap adjustment weren't tested yet, and this job is still ahead.

A special procedure for the magnet certification was successfully implemented and tested [3], [4]. Magnets for the top and bottom jaws were panned in such a way as to produce the same field strength with a minimal variation. As a result the requirements to the mechanical tolerances of pole height became more restricting. Manufacturing specification of ± 10 microns was deemed inadequate, and a selective assembly procedure using the precise pole height measurements was implemented to decrease its influence on the field. Using this sorting technique, it was also possible to install a small outboard cant, which allowed measurement of the pole gap to an accuracy $\pm 2\sigma$ (see Fig. 6).

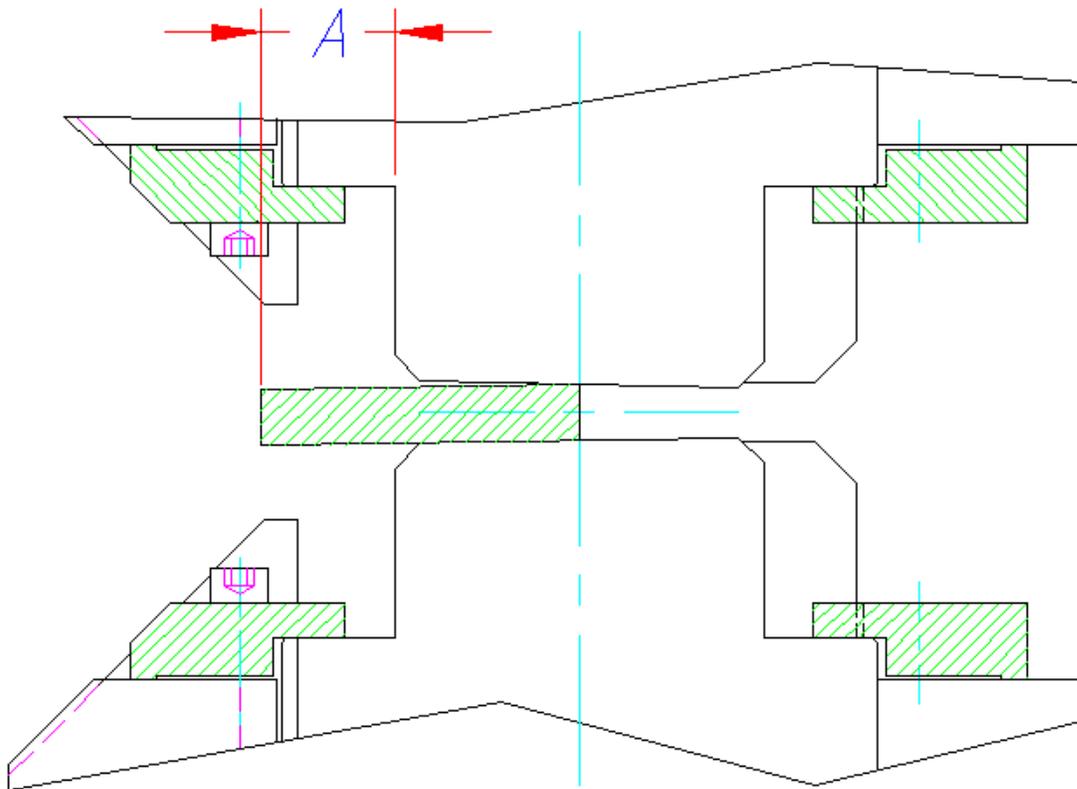


Fig6 - Precise measurement of the pole gap
("A" dimension shows the actual pole gap).

The fixture to assemble the top and bottom halves of the magnetic structure proved to be very well designed (Fig. 7). It allowed for an easy and convenient relative

alignment of both the top and bottom sections of the magnetic structure and placing them as a single unit into the housing.



Fig.7- Fixture for the Magnet Structure Halves Assembly

All necessary modifications to the two clamps design for each poles are completed. The prototype is assembled and is ready for the next set of magnetic measurements and tuning. The first set of magnetic measurements showed that even with the one side clamp for the poles we were able to achieve the trajectory straightness to within $\pm 2\sigma$ envelope. Future plans include mover redesign, piezo-translator testing (for the end gap adjustment) and preparation for the manufacturing of the second prototype. The second prototype will try to address the questions connected with the full-scale productions of the LCLS undulators – we have to make 33 of these!

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