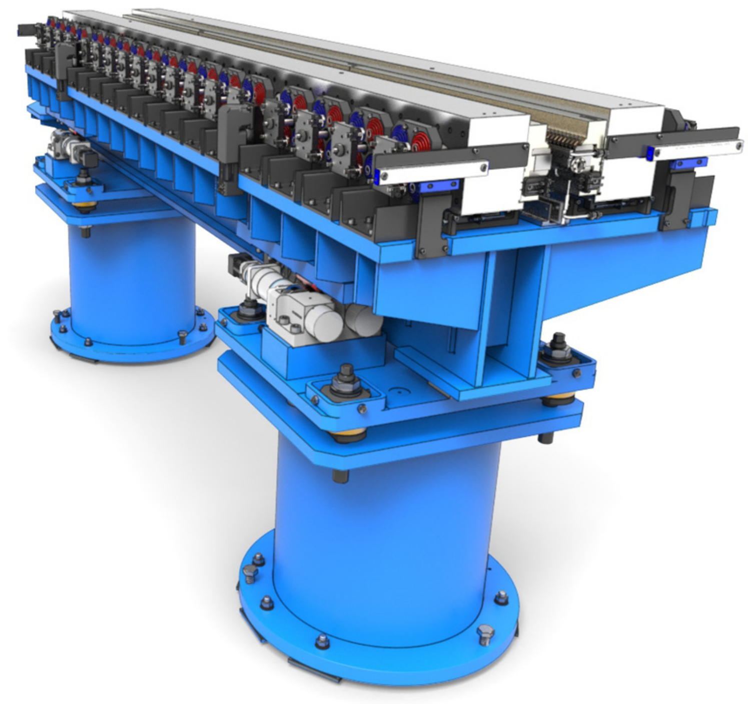
HORIZONTAL-GAP VERTICALLY-POLARIZING UNDULATOR (HGVPU) DESIGN CHALLENGES & RESOLUTIONS



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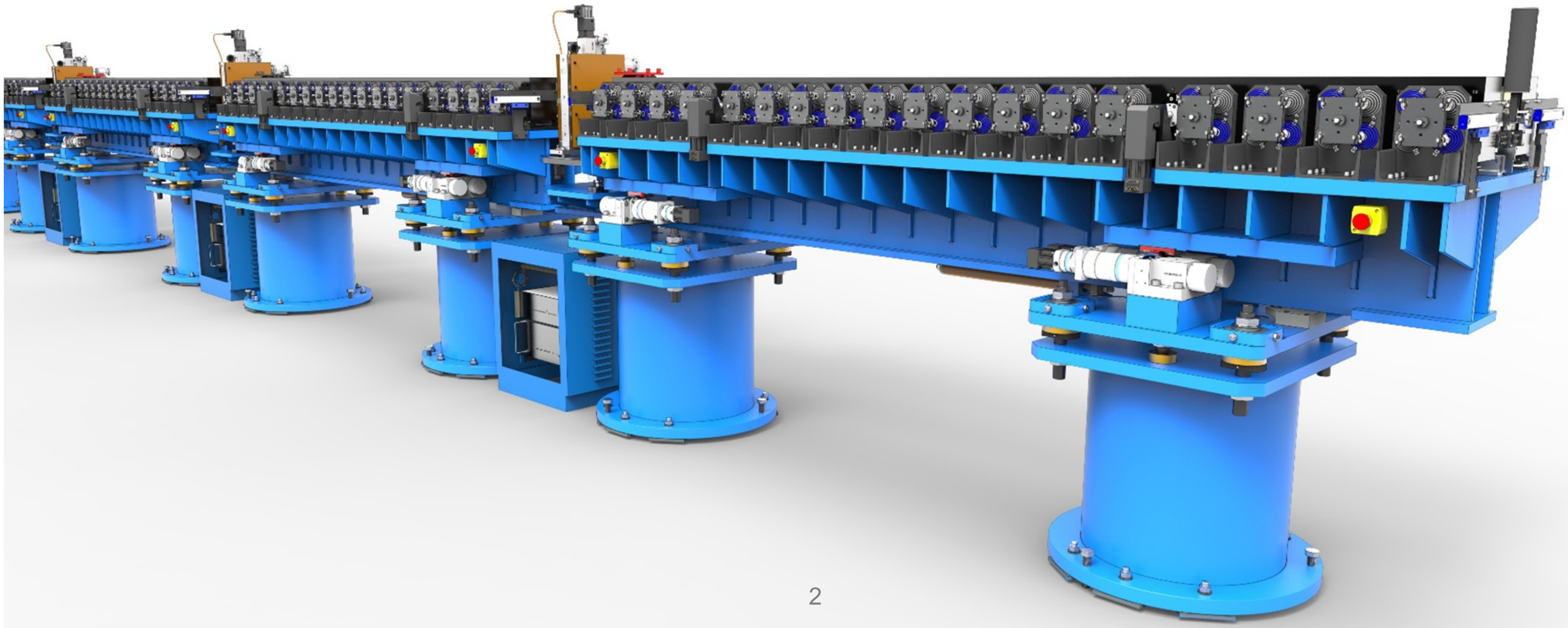
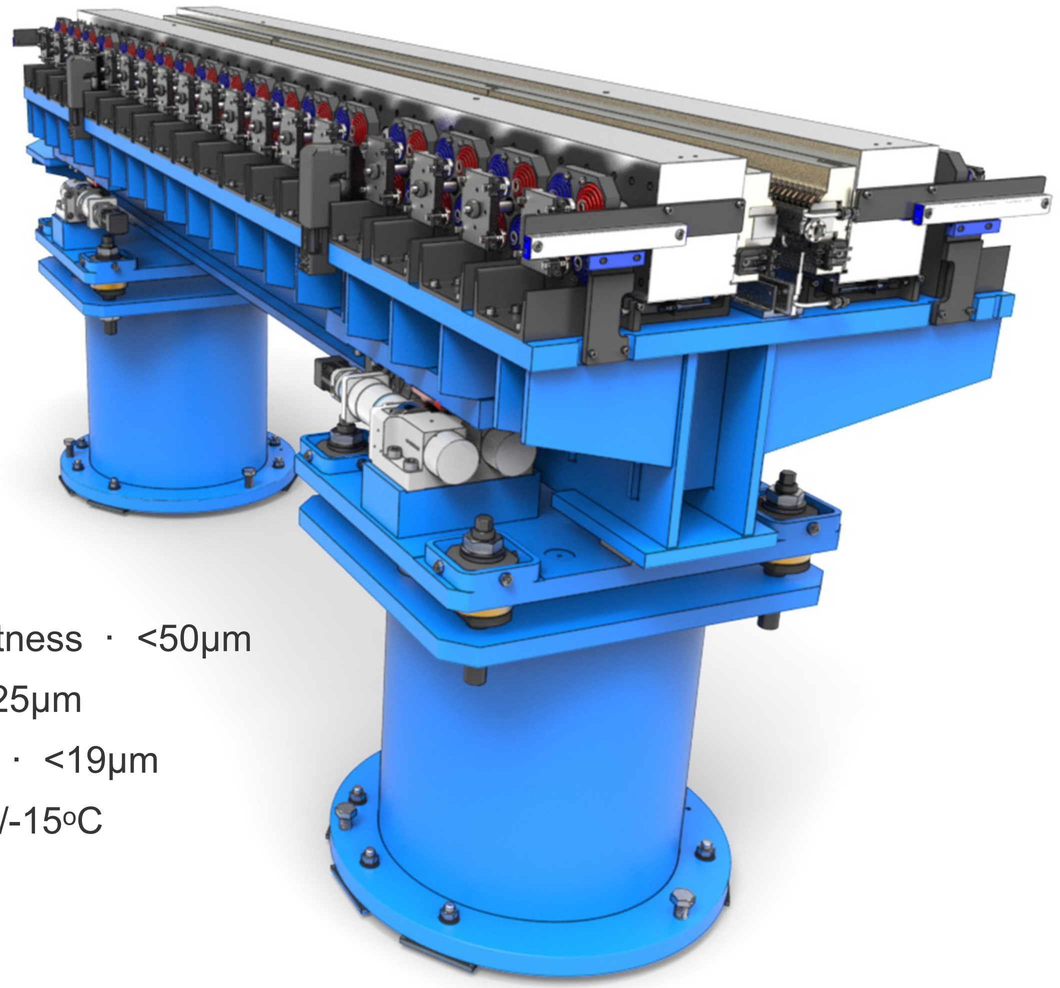
INTRODUCTION

- The Horizontal-Gap Vertically-Polarizing Undulator (HGVPU) is a compact, innovative, variable-gap insertion device developed by Argonne National Laboratory for the LCLS-II HXR beamline at SLAC.
- Vertically-Polarized X-Rays are preferred as they greatly simplify downstream beamline optics.
- A full sized 3.4-meter-long prototype has been built and fully tested meeting all LCLS-II undulator specifications.
- The HGVPU also utilizes the existing LCLS-I support and motion system along with other existing equipment and infrastructure, thus lowering overall cost and installation downtime.
- 32 undulator segments will be required for the final installation.



TECHNICAL REQUIREMENTS

From Physics Requirement Document LCLSII-3.2-PDR-0038-R0

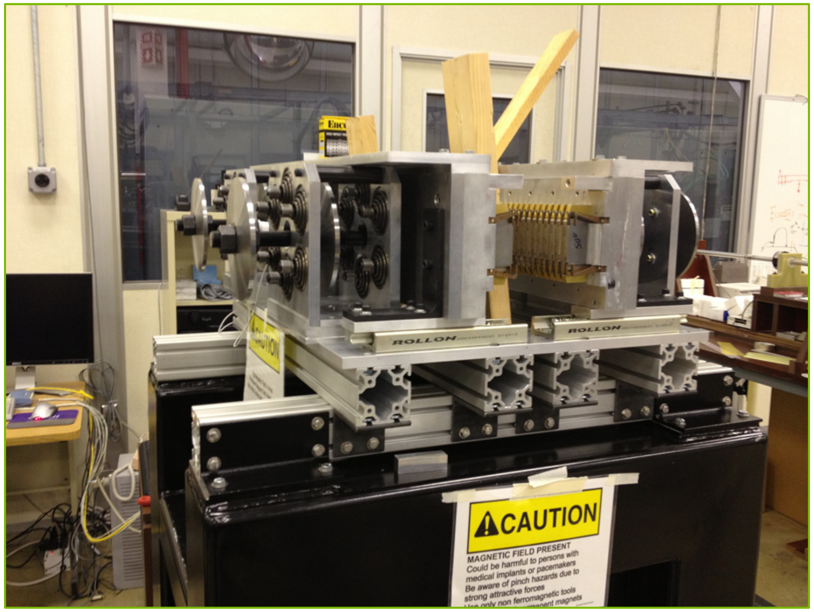


- Period · 26mm
- Segment Length · 3.4m
- Number of Segments · 32
- Operating Gap · 7-20mm
- Maximum Gap · 200mm
- Horizontal (X) Magnet Array Straightness · <50μm
- Longitudinal (Z) Pole Alignment · <25μm
- Total Strongback Deflection Change · <19μm
- Mechanical Thermal Stability · 20+/-15°C
- Tapering Capability · TBD

PROJECT BACKGROUND

Prior to full length prototype

- Two smaller prototypes were previously built to explore the spring compensation scheme, which provided valuable insight into the dynamics of this device.
- Many of our ideas and assumptions had been tested and validated.
- All of these ‘lessons learned’ would be employed in a final full-length prototype design.
- Funding for a full length prototype was approved in March-2015.

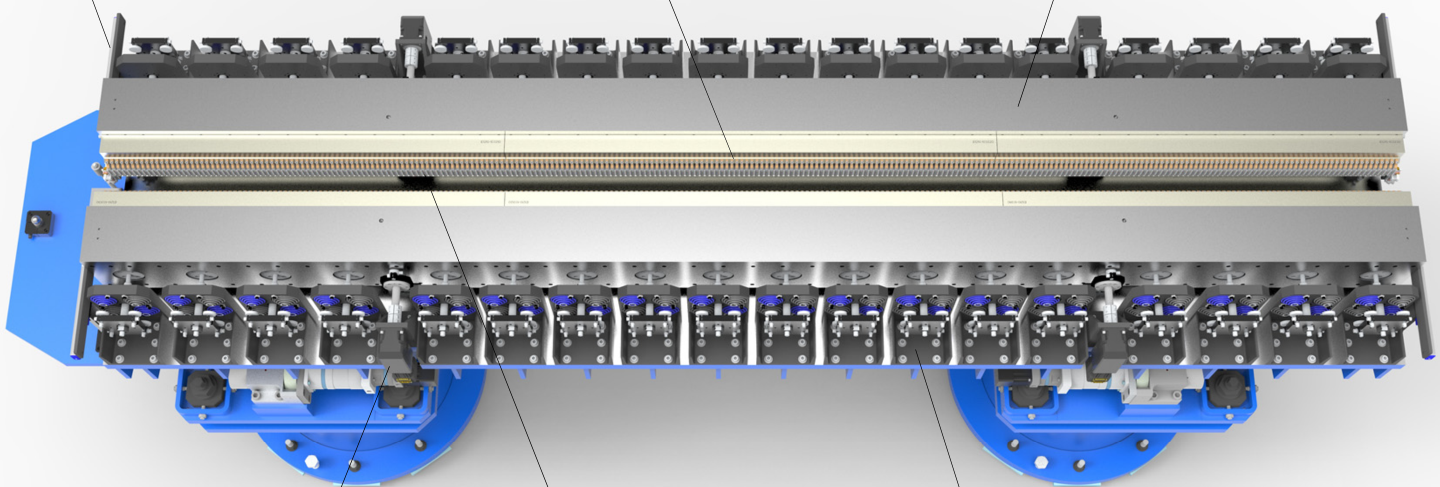


0.8 Meter-Long Prototype

3.0 Meter-Long Prototype

DESIGN OVERVIEW

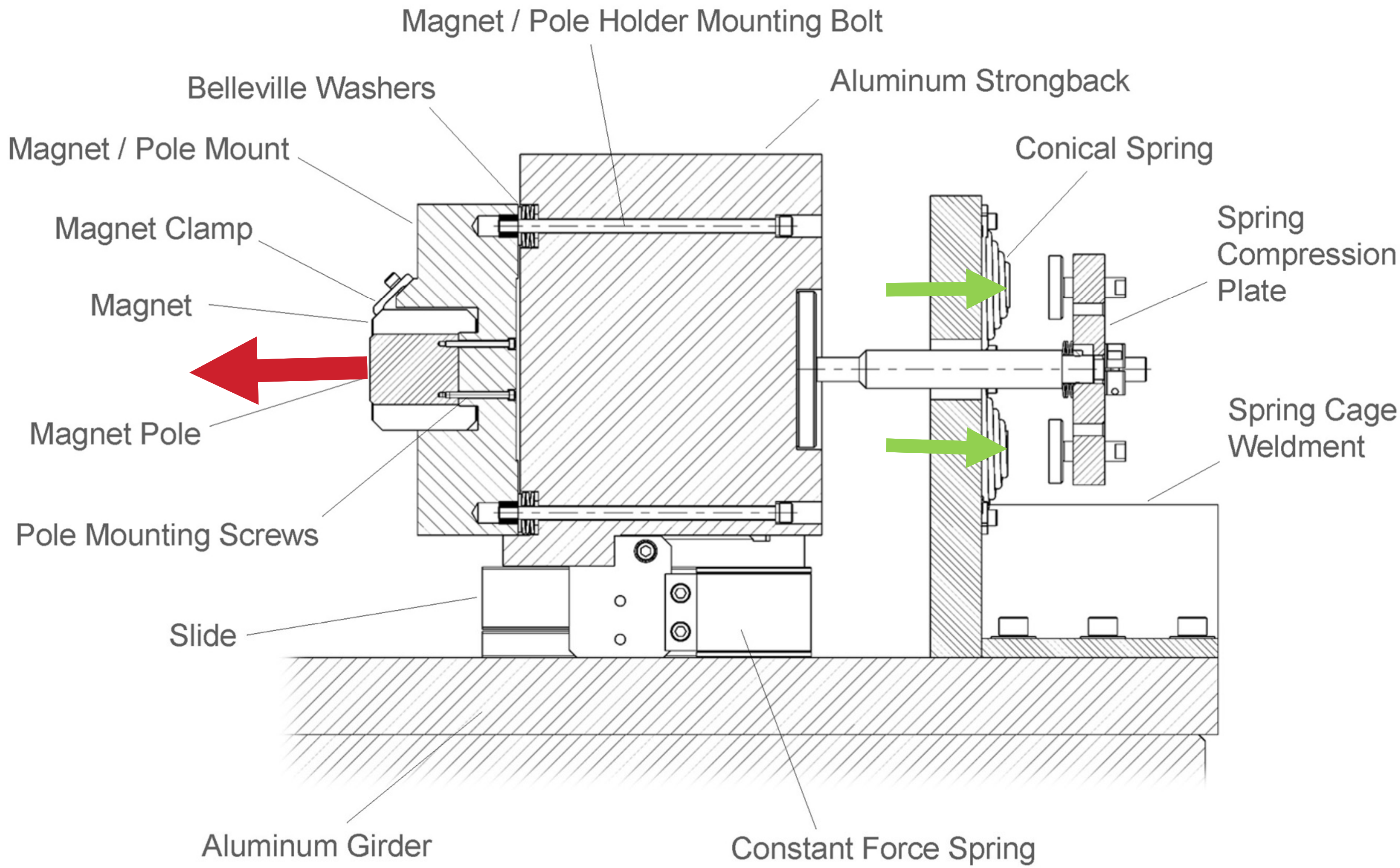
Gap Separation Mechanism



Attractive magnetic forces, roughly 6000 lbs. at minimum gap, are compensated for by an array of conical springs. These springs are designed to exhibit non-linear spring characteristics that can be closely tuned to match the force curve exerted by the magnetic field, thereby minimizing the overall deflection of the strongbacks and load on the actuators.

DESIGN OVERVIEW

Spring Compensation System

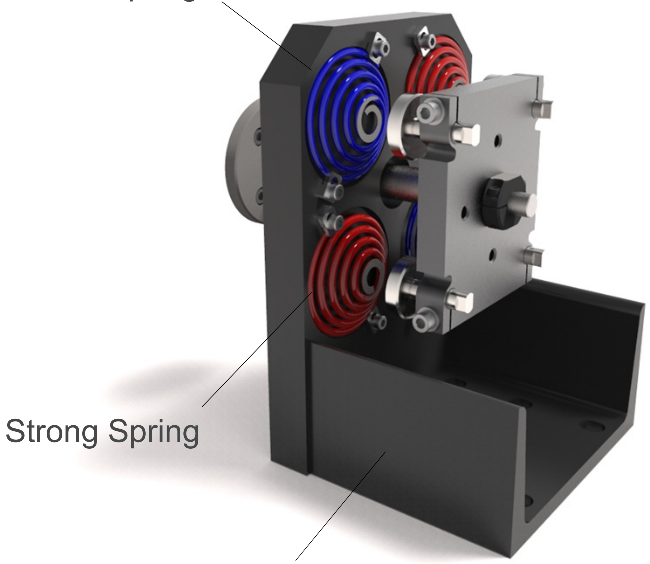


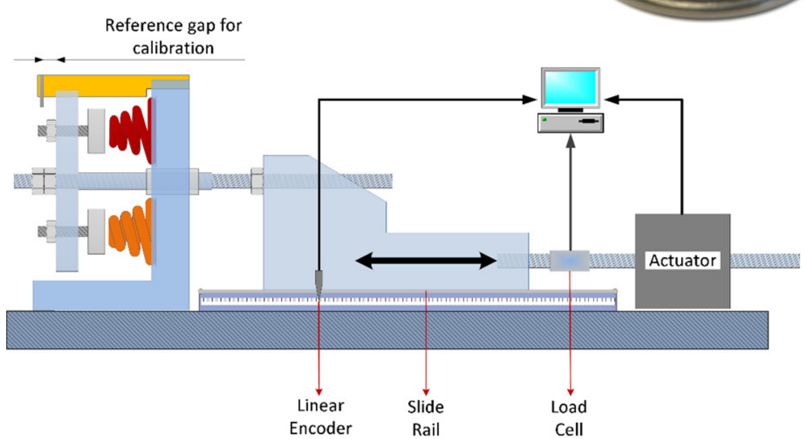
Section view for reference only. Details not necessarily in same plane.

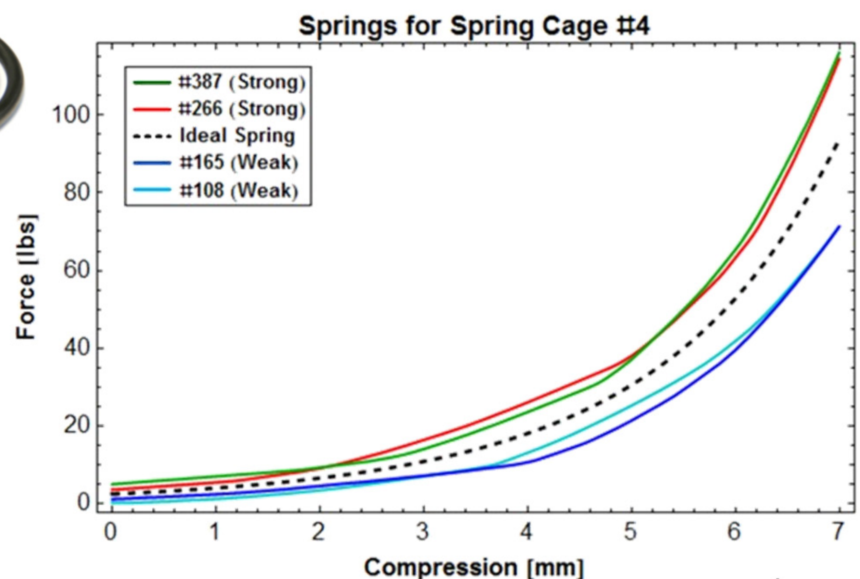
MECHANICAL DESIGN

Spring Cage Calibration and Installation

- Two types of springs, strong and weak, are measured, sorted to combined to approximate ideal spring curve
- Springs are installed in opposing strong/weak pairs onto spring cage bracket.
- Spring cage assembly is tuned via spring cage buttons using measurement data from individual springs.
- Compression plate is locked at a gap of 30mm for transfer to undulator.
- Spring cages are assembled onto gap separation mechanism one at a time while monitoring gap encoders.



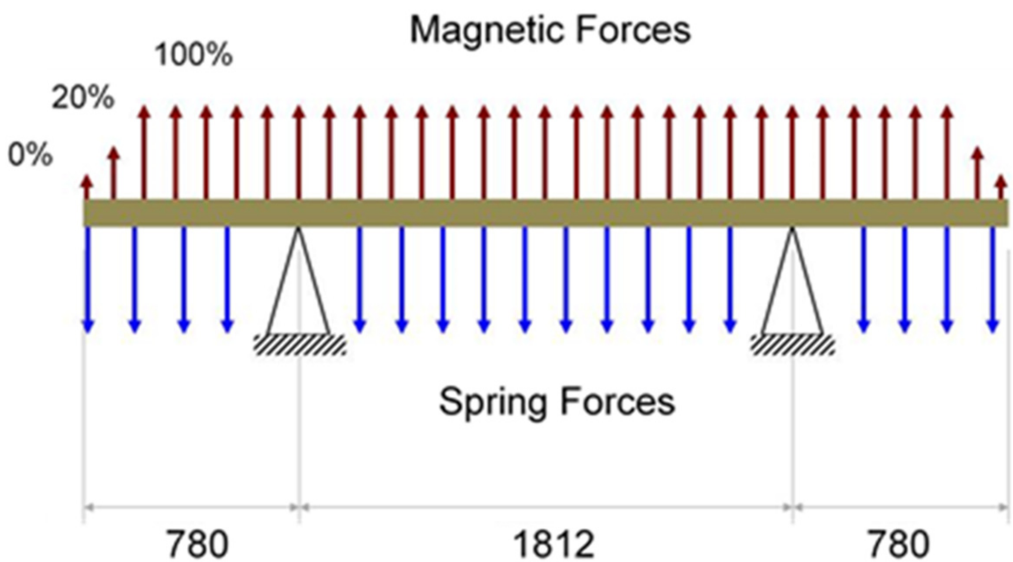




MECHANICAL DESIGN

Strongback Straightness and Actuator Position

In a perfectly balanced system, the spring forces would have the same force curve as the magnetic forces and would be equally spread across the length of the undulator. The beam would have zero deflection, and the actuators could, in theory, be mounted anywhere along the length of the strongback.



However:

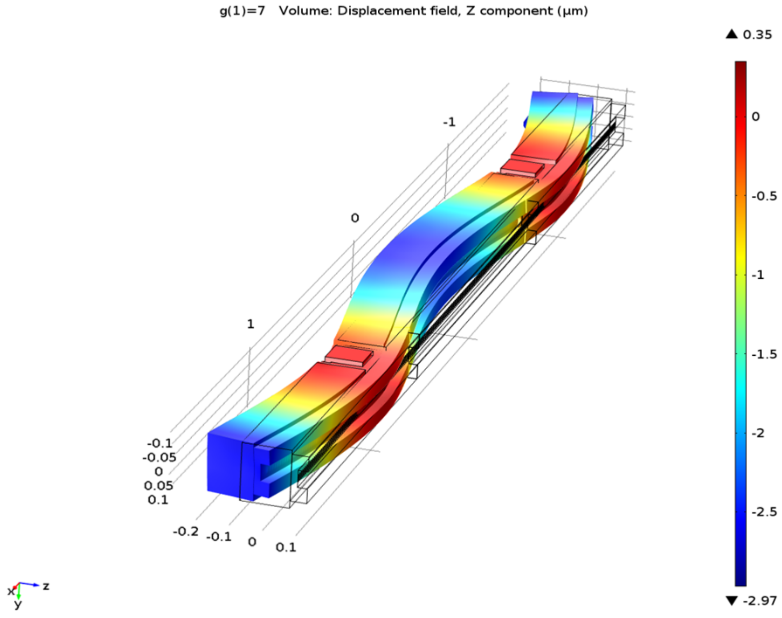
- Magnetic force is evenly distributed across 260 poles with slightly lower field strength at the end poles
- Corresponding number of spring cage limited to 18 due to space constraints
- Position and space to accommodate the actuators has to be considered

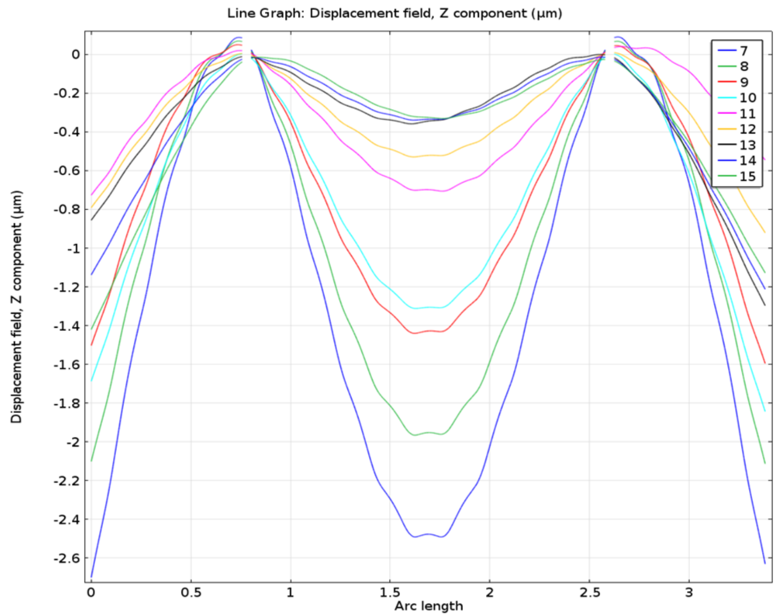
After many arguments and iterations, the final configuration shown in the free-body diagram was chosen.

MECHANICAL DESIGN

FEA Simulation

- Actual spring forces applied from measured data (Data for 8 and 14mm gaps interpolated)
- Magnetic forces derived from magnetic design
- Beam loading analysis run in COMSOL
- Analysis run for 7-15 mm gaps
- Maximum simulated strongback deflection of <3μm (gap variation of 6μm) corresponding to a gap of 7mm
- Minimum requirement of 19μm

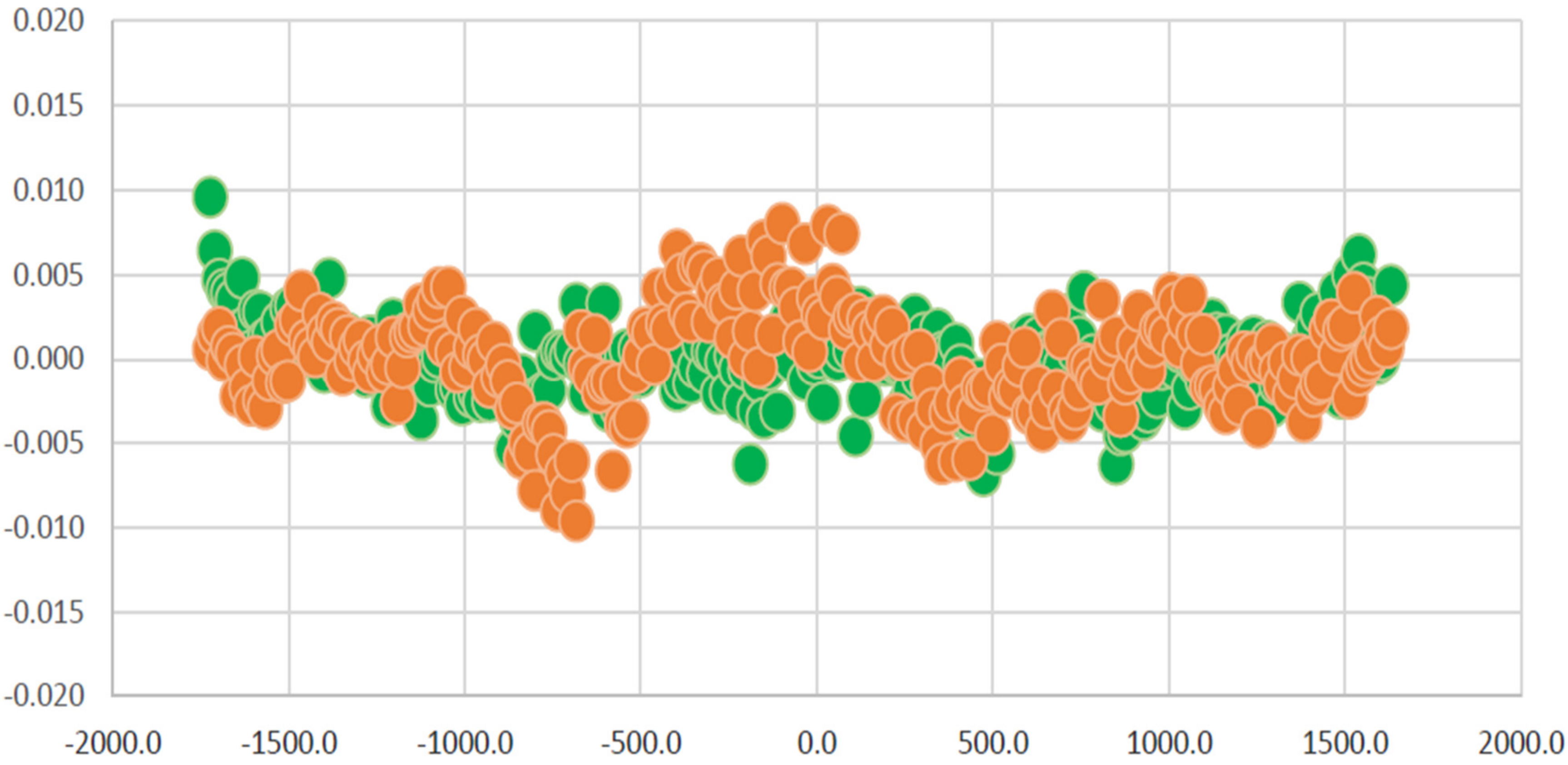




MECHANICAL DESIGN

Measured Results

Jaw Profile at 7.2mm

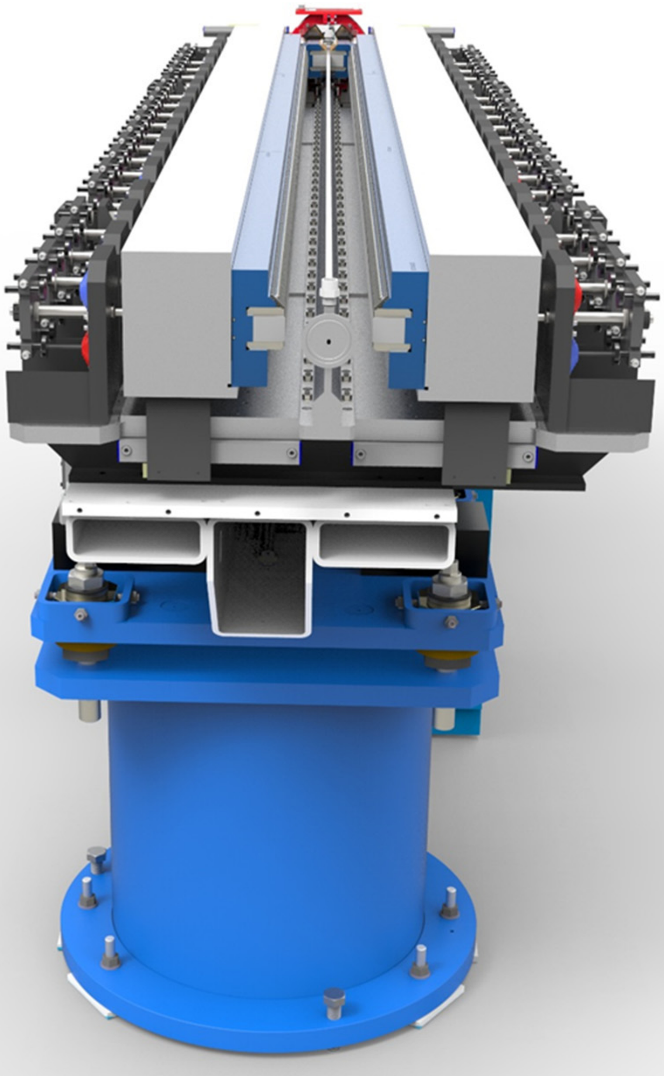


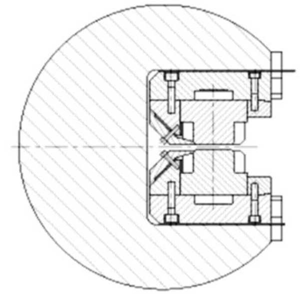
MECHANICAL DESIGN

Girder Optimization

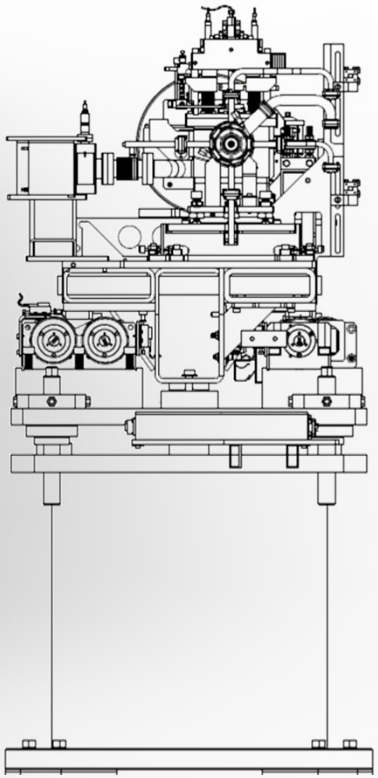
The original LCLS steel girder works but is not ideal for use with the HGVPU.

- Elevation of the girder top surface is around 3.5 inches too short requiring an array of spacers
- Beam centerline is offset on the girder requiring cantilevered support
- Combined weight of the new gap-separation mechanism, base plate, and spacers increased the overall weight of the undulator by roughly 1500lbs
- Dissimilar thermal expansion coefficients of the steel girder and the aluminium magnet jaws



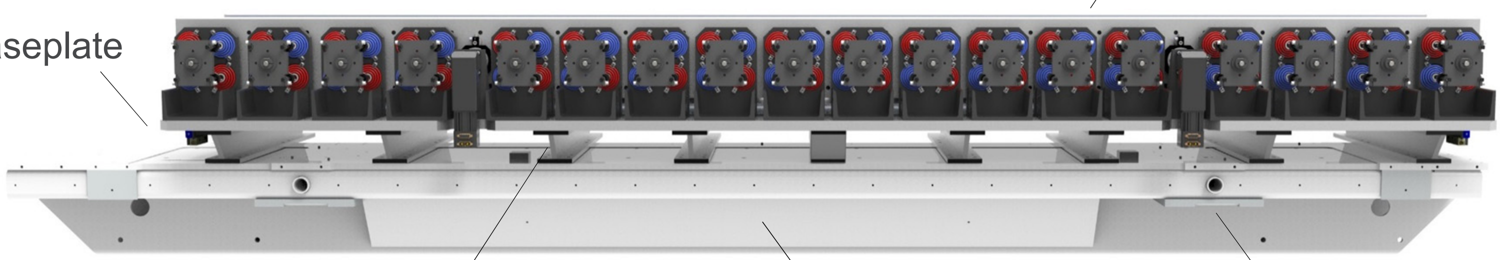


LCLS-I Cross-Section

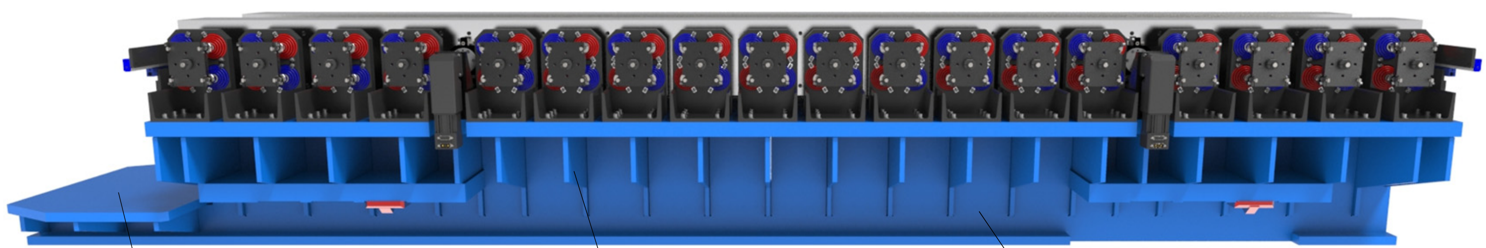


MECHANICAL DESIGN

Optimized Girder



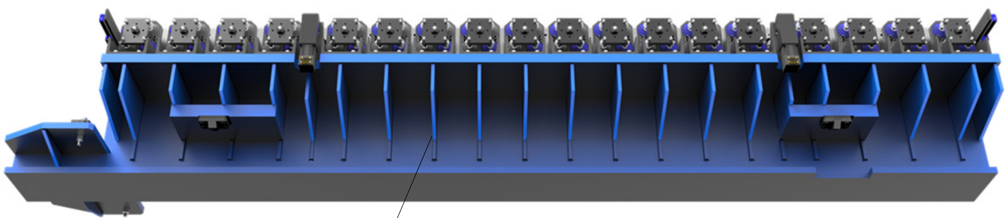
- Original Steel Girder



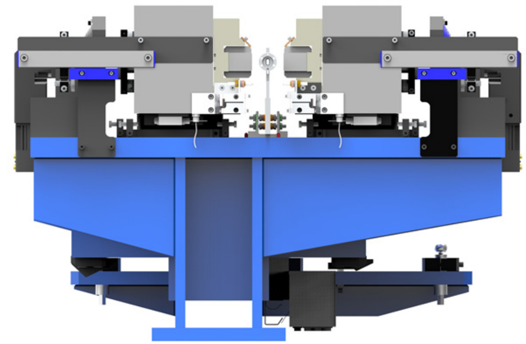
- Optimized Aluminum Girder - Taller, eliminating the need for spacers and separate baseplate. The girder is reinforced at each spring cage where the loads are concentrated and shares same interface locations to cam movers. It's also powder coated to match the support pedestals.

MECHANICAL DESIGN

Girder Design Features

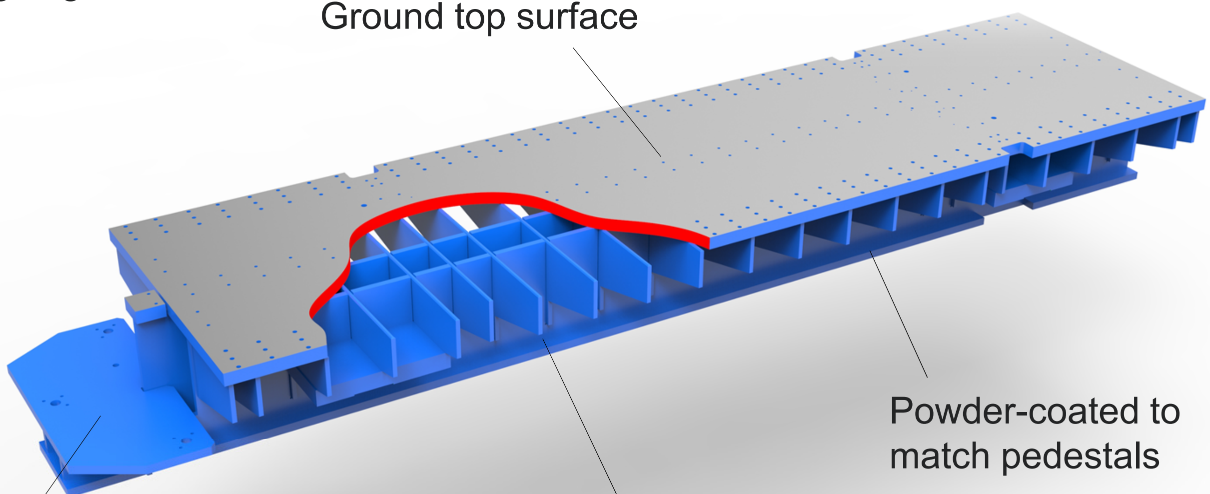


Ribs centered on spring cages



Asymmetric Design

Ground top surface



Powder-coated to match pedestals

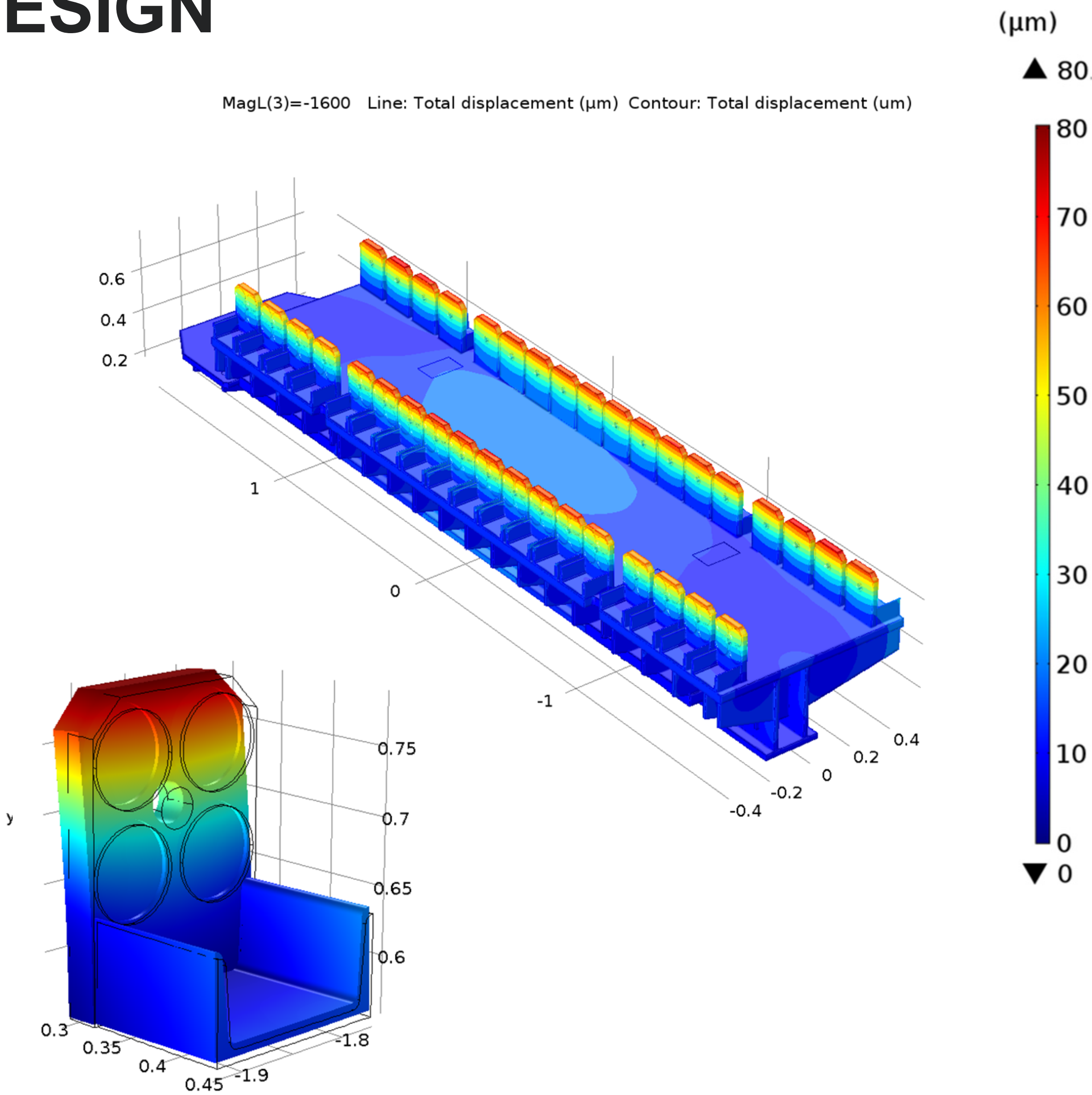
Shelf for interspace assembly

Welded waffle construction

MECHANICAL DESIGN

Girder Analysis

- Surface profile plot shown for girder deflection
- Maximum deflection in baseplate is about 12 microns which occurs slightly off centerline
- A maximum deflection of 80 microns occurs at tip of spring cages. (This deflection is however compensated for in the spring cage calibration)



CONCLUSION

As with any project, typical time constraints, cost constraints, and space constrains all had to be balanced and compromises were made. The end result however produced a very robust device that lead to the HGVPU being chosen as the baseline for the LCLS-II project hard x-ray beamline.

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