# DESIGN AND FABRICATION OF ARUPS U6 UNDULATOR AT PLS

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*Abstract*

Pohang Accelerator Laboratory(PAL) had developed and installed U6 undulator recently to utilize brilliant undulator radiation for ARUPS (Angle Resolved Ultraviolet Photoemission Spectroscopy) beamline at Pohang Light Source (PLS). The U6 is a hybrid type device with period of 6 cm, minimum gap of 18 mm, maximum flux density of 0.902 Tesla and total magnetic structure length of 1830 mm. The support locations and structure of an insertion device are optimized to achieve a minimum deflection due to the magnetic loads. A Finite Element Analysis (FEA) is performed to find out the amount of maximum deflection and optimal support positions on the backing beam. The optimized maximum deflection is estimated to be about 11.6 ㎛, while the deflection before any optimization is 48.8 ㎛. In this report, all the mechanical design, fabrication and assembly details of the PLS U6 undulator are described.

## INTRODUCTION

Pohang Light Source (PLS) is a 2.5GeV 3rd generation synchrotron light source [1]. The critical photon energy of the synchrotron radiation from bending magnet is about 5.48 keV at 2.5 GeV electron energy. U6 is designed for research on the electronic structure of solid surfaces and low dimensional nanostructures on surfaces. Using one sagittal focusing mirror and a specially designed chamber where a tube is passing through, brilliant UV and soft x-rays from two undulators can be efficiently delivered to the ARUPS system. The total energy resolution is about 10 meV at 20 eV photon energy.

The U6 consists of a magnetic structure, a support structure, and a drive and control system. Magnetic gap is adjusted by the drive system and the support structure, which includes the L-frame to support the magnetic structure. The L-frame structure is designed to allow for easy installation of the vacuum chamber and for easy magnetic field measurement. The U6 shown in figure 1 was designed with very rigid moment of inertia to length ratio resulting in minimum deflection. To reduce the deformation further, we designed and successfully implemented a Belleville washer springs system that counteracted the magnetic loads[2]. The compensation spring system will reduce the system friction, which gives better positional response from the drive system, reduced structure compression and no motor holding torque required at any magnetic gap. The drive system provides the gap adjustment mechanism to align the magnetic structure from gap 1.0 to 20.0 cm. The drive system includes two independent drive system in a standard structure. Each drive system is composed of step motor, gear reducer and absolutely rotary encoder. The positional accuracy is determined by two encoders attached on both ends of a ball screw. The measured gap repeatability is less than 7 ㎛. Five types of insertion device (U7, EPU6, U10, MPW14 and ARUPS U6) had been installed in the electron storage ring. The U6 described in this report is similar to other types of insertion device and built on the successful mechanical design concept, fabrication and assembly procedure

## MAGNETIC STRUCTURE

The hybrid magnetic configuration consists of permanent magnets and ferromagnetic poles (vanadium permendur) to concentrate the magnetic flux to the poles. This hybrid scheme gives a higher peak field compared to pure permanent magnet structures. Using Radia developed in ESRF, magnetic geometry analysis have been carried out to study the optimal magnetic geometry. In the final design, the maximum magnetic field is 0.902 Tesla. Multiple trim magnets at the ends of the undulator will be installed to decrease the transverse multipole components and to correct the field integrals. The main parameters of U6 are listed in Table 1, and the schematic geometry configuration of half period is shown in figure 2.

The basic block of the magnetic structure is a half-period pole assembly which consists of an aluminium keeper, a Vanadium Permendur pole and six Nd-Fe-B magnetized blocks.

Table 1: Main parameters of the U6 based on 2.5GeV beam energy and 250mA beam current

| Parameters | Value |
|---|---|
| Period length | 6 cm |
| Number of full field poles | 57 |
| Peak field | 0.902 Tesla |
| Total power | 1.452 kW |
| Device length | 1.83 m |
| Min. gap of magnetic structure | 18 mm |
| Max. gap speed | 10 mm/sec |
| Nominal gap speed | 5 mm/sec |
| Max. magnetic load | 2.4 Tons |
| Encoder type | Absolute rotating encoder |
| Encoder resolution | 1.3 ㎛ |
| Step motor | 2-phase stepper motor |
| Motor resolution | < 1 ㎛/step |

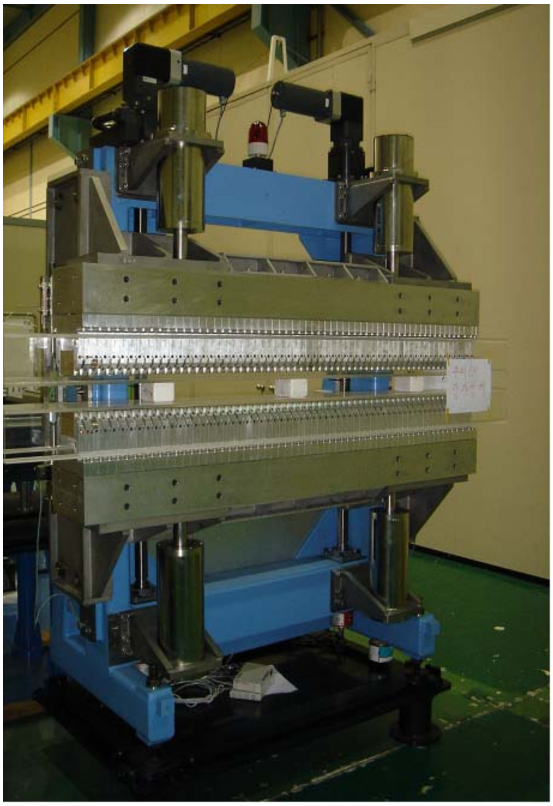

Figure 1: Photograph of ARUPS U6

The magnetic block has an average magnetization of 1.33 T and an intrinsic coercive force of 12.6 kOe. The variation of the magnetization ($M_z$) from block to block affects the pole-to-pole field error. Therefore, the block-to-block variation of the magnetization and the magnetization orientation error are limited to 1% and 1˚, respectively. Flatness of the block surfaces shall be within 0.025 mm for the two surfaces perpendicular to the direction of magnetization and perpendicularity of the block surfaces to each other shall be within 0.002 mm/mm.

## DESIGN AND FABRICATION OF SUPPPORT STRUCTURE

### *Deformation of backing beam*

The structural deformation of the backing beam depends on the pole gap. The backing beam is designed to support a maximum magnetic load of 2.4 metric tons at minimum gap. The support point for the backing beam is determined to achieve minimum deflection. The backing beam is analysed using ANSYS [3], including the complicated geometry structure. A solid geometry is adopted for the backing beam, including girder, which is fixed at ball screw and a linear motion guide. The backing beam material is aluminium A6061-T6, and the girder is non-magnetic stainless steel 316L. For the study of the worst case for the backing beam, 2.4 metric tons magnetic loads were applied for estimation of the backing

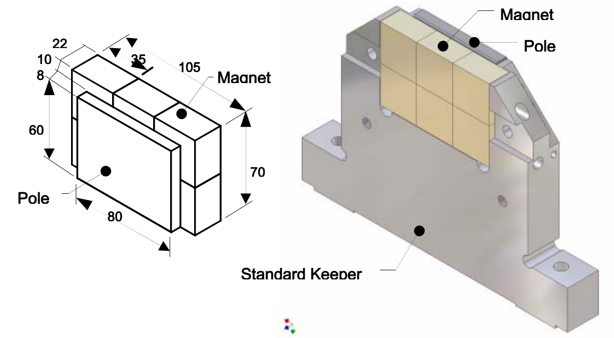


Figure 2: Geometry configuration of half period

beam deformation. ANSYS result for the backing beam in the vertical direction is shown in figure 3. The deformation of backing beam was analysed at no load, maximum magnetic load and maximum magnetic load with reaction force. The results are shown in figure 4. The minimum deformation at no load is 6 ㎛, and the maximum deformation at maximum magnetic load is 48.8 ㎛ in the vertical direction without any compensating reaction force. This exceeds the specification and we need a mechanism to reduce the deformations. To reduce the deformations, we apply a reaction force from the compensation spring. The profile of the reaction forces is varied to find the optimum design parameter of the reaction spring system. The optimum occurs when 90% of the magnetic load is counteracted by the compensation spring system. In that case, the minimum deformation is 11.60 ㎛ in the vertical direction, which meets our requirement. The deformation in the other two directions were negligible. The magnetic load compensation spring system will be provided for reacting the gap-dependent magnetic load. The magnetic load compensation spring system, as shown in Fig. 5, consists of several stacks of Belleville washers.

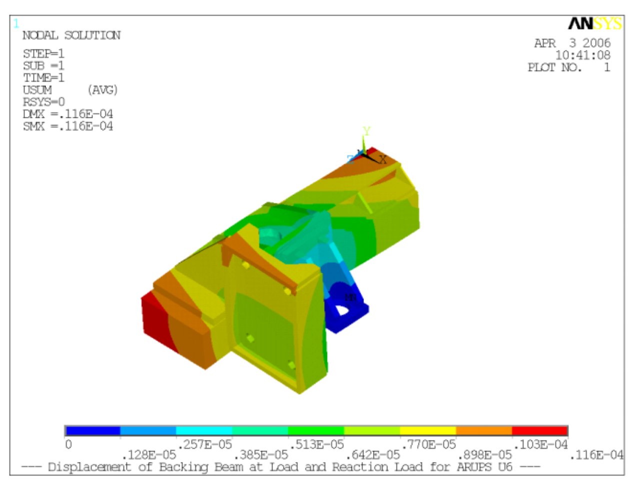


Figure 3: ANSYS result for the backing beam in the vertical (y) direction. The maximum deformation is about 11.60 ㎛ for 2.4 metric tons of magnetic load and reaction

force with magnetic load compensation spring system are applied.

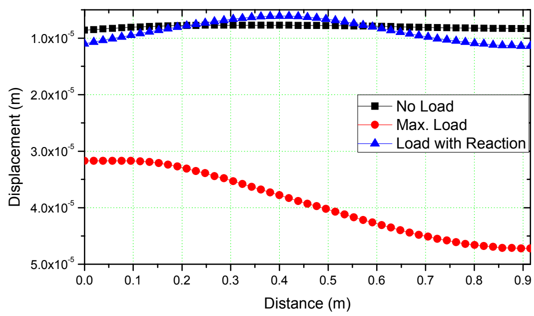


Figure 4: ANSYS results for the backing beam in the vertical (y) direction along Z-direction(beam pass) of backing beam at no load, maximum magnetic load and maximum magnetic load with reaction force.

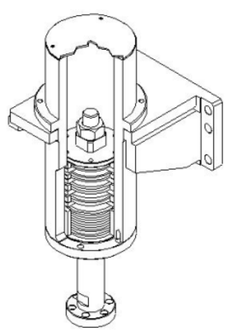

Figure 5: Design of magnetic load compensation spring system

### *Fabrication of magnetic structure*

The magnetic structure will incorporate the hybrid magnetic configuration consisting of Nd-Fe-B magnetic block, vanadium permendur pole and aluminium keeper. The vanadium permendur (Fe 49%, Co 49%, Va 2%) pole is machined, heat treated, and then precision machined to the final geometry. Each pole is pinned to its keeper. The magnetic block is bonded into the pole assembly. The half-period pole assemblies and the end-pole assemblies are bolted to the backing beam by using a milling machine and assembly-holding fixture. The variation of pole heights from the lower surface of the backing beam is controlled to be within 25 ㎛, and the pole-to-pole longitudinal positioning accuracy is limited to be within ±25 ㎛.

### *Drive and control system*

The drive and control system provides a gap adjustment mechanism to change the wiggler gap from 14 mm to 200 mm. Gap motion is achieved with a stepper motor, gear box, and left-handed & right-handed 5-mm-pitch ball screw at each side. The upper and the lower backing beams are attached to the ball screw and the load compensation spring system. The stepper motor is connected to a 20:1 reduction gear box unit. Two S106-250 stepping motors and AR-C absolute rotary encoders from Parker Co. are used to control the magnetic gap. The motor system has sufficient position accuracy to satisfy the specification. Test results show that the gap parallelism is better than ±5 ㎛ and that the gap reproducibility is better than 7 ㎛, both of which exceed the specifications of 10 ㎛.

## SUMMARY

PLS had developed 6 cm period ARUPS (Angle Resolved Ultraviolet Photoemission Spectroscopy) U6 for research on the electronic structure of solid surfaces and low dimensional nanostructures on surfaces. It features 0.902 Tesla, 57 poles at minimum magnetic gap of 18 mm. The maximum deflections of backing beams are estimated to be about 11.6 ㎛ with the compensation spring under magnetic load of 2.4 metric tons and gap reproducibility of structures are 7 ㎛. The assembly tolerance of backing beam is 25 ㎛ pole height and ±25 ㎛ distance of pole to pole.

## REFERENCES

[1] “PLS Conceptual Design Report”, Pohang Accelerator Laboratory,(1992)

[2] “U5.0 Undulator Conceptual Design Report” LBLPUB-5256, (November 1989).

[3] Program ANSYS, a product of Swanson Analysis System, Inc., is a commercial available 3D code by using finite element method.