Engineering Upgrades to DiPOLE-100 Laser System for the D100X Project

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Introduction

DiPOLE100 is a diode-pumped solid-state laser (DPSSL) system [1]. It utilises a cryogenic gas-cooled amplifier head containing multi-slab Yb:YAG gain media producing 1030 nm wavelength output with nanosecond pulses at a maximum energy of 100 J and a maximum repetition rate of 10 Hz.

D-100X is based on the DiPOLE100 Laser System commissioned in the HiLASE Facility in the Czech Republic during 2016. The D-100X project required significant modification to the overall layout of the DiPOLE100 Laser System, to enable compatibility with the available laboratory space in the High Energy Density (HED) Instrument at the European XFEL Facility in Hamburg, Germany.

Lessons learned from the design of the previous system were also incorporated where cost effective and operationally beneficial. These included improvements to the 100J amplifier head design, mirror mounts, routing of system services and improvements to the control systems, some of which are described below.

Configuration for D-100X

The DiPOLE100, 'HiLASE' laser system was designed in a straight line, 18m long by 3m wide. The available space in the HED Instrument laser hutch was constrained to only 5m x 11m. The layout of the DiPOLE100 Laser System had to be radically reduced without major modification to the proven laser multi-pass architecture, posing an engineering challenge. Re-configuration of the D-100X amplifier stages into a 'U' form was implemented by tailoring the layout to the space available in the HED Instrument, whilst minimising constraints imposed on operability and maintainability. (Fig 1)

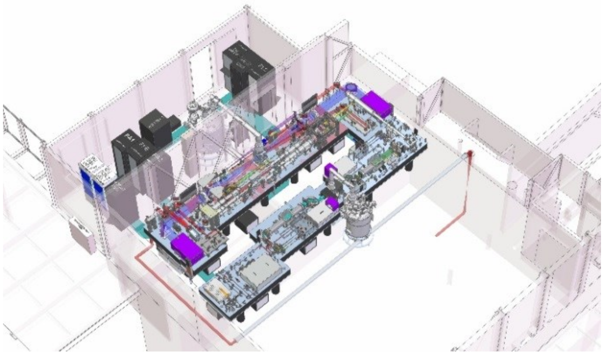

Figure 1: CAD model of the D-100X Laser System in the HED Instrument laser hutch at the European XFEL.

Whilst working access/egress space was reduced, the end client is very satisfied with the finalised layout.

The modification of the overall layout demanded re-design of:

- Beam transport sections of the laser system.
  - Front End to 10J
  - 10J to 100J
- Cryostat configurations

Services Updates

The HED end station was designed with a false floor within which services are routed. This was a major change to the HILASE system, which utilises overhead gantries and enclosure frameworks in which to route services.

Apertures introduced into the laser tables during design permit the routing of services to the table components directly from cable tray distribution networks located under the false floor. This maximizes available access for maintenance and operations.

Quick release couplings and connectors implemented between tables will minimize dismantling and packing, as well as ease installation at the HED Instrument. The length of cables and services are appropriate for installation at the European XFEL, allowing the entire system to be fully tested prior to shipment.

Modifications and Analysis of 100J Amplifier Head Design

The design of the two complex, cryogenically-cooled amplifiers is derived from the size and orientation requirements of the multi-pass laser beam as it passes along the laser chain.

The power amplifier head for the DiPOLE100 Laser System, as delivered to HILASE, had a maximum allowable working pressure (MAWP) of 11 bar. The required operating pressure at 150K was 10 bar, resulting in loss of helium during warm up to room temperature.

The amplifier head for the D-100X project underwent design modification to achieve a MAWP of 20 bar (10 bar at 150K), preserving the helium inventory during warm up. To achieve this involved complex finite element modelling and analysis of the amplifier head.

The modelling narrowed down a particular region of interest, that of the main body of the amplifier head where the sapphire window flanges affix. Analysis focused on an undesirable deflection that prevented window flanges from sealing above 12 bar within the design. Modifications were made to the construction of the amplifier head to reduce these deflections, reducing the risk of leakage at higher pressures. Figures 2 and 3 compare and contrast the deflections in the original and in the improved design.

These changes have reduced deflection in the critical region from 0.15 mm to 0.03 mm, a five-fold improvement in overall performance.

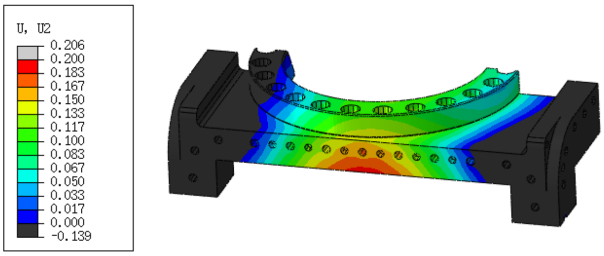

Figure 2: Deformation (mm) outwards in the direction of the sapphire window for the original amplifier head design for steady state operating conditions.

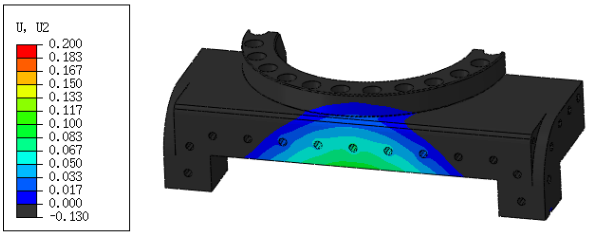

Figure 3: Deformation (mm) outwards in the direction of the sapphire window for the revised amplifier head design for steady state operating conditions.

Conclusions

Modifications to the DiPOLE100 Laser System design will facilitate installation of D-100X in the severely constrained European XFEL HED Instrument laser hutch, without constraining operability and maintainability.

In addition, modifications to the power amplifier head for D-100X will enhance performance and minimize the loss of helium during operation.

References

1. P.J. Phillips, S. Banerjee, P. Mason, T. Butcher, K. Ertel, M. De Vido, J. Smith, A. Lintern, S. Tomlinson, M. Tyldesley, C. Hernandez-Gomez, C. Edwards, J. Collier, ‘Frequency doubling experiments carried out on the DiPOLE-10 amplifier at CLF’, CLF Annual Report 2015/16