Progress on PHELIX, a Petawatt High Energy Laser for Heavy-Ion Experiments

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Construction at the PHELIX laser project [1] continued during the year 2002. The major milestones reached this year are full operation of the amplifier cleaning procedures, testing of all high voltage components on hand and firing of amplifier heads fully equipped with flash lamps, compression of laser pulses form the short pulse front end, arrival of laser components form Lawrence Livermore National Laboratory (LLNL), testing on dielectric grating prototypes and design of the petawatt compressor, and completion of the specification and requirement sheet of the control system along with development and testing of many prototypes.

The short pulse front end was in 2002 in frequent operation and proofed itself reliable. The beam pointing and pulse stability has been improved by some small modification. The output reached over 60 mJ with a pulse stability of $\sigma = 1$ %. Most of the hardware components on the front ends – including delay generators, oscilloscopes, shot cameras, motors and the Verdi pump laser - have been connected to the control system in order to allow remote operation, which is for safety reasons required for full system shots.

A compressor was built to allow compression of 10 J laser pulses [2]. Laser pulse at 10 Hz, 60 mJ, and 7 nm bandwidth FWHM (full width at half maximum) were compressed to 350 fs FWHM as shown in Fig. 1. The pulses were measured using a single-shot autocorrelator setup (Fig. 1, left panel).

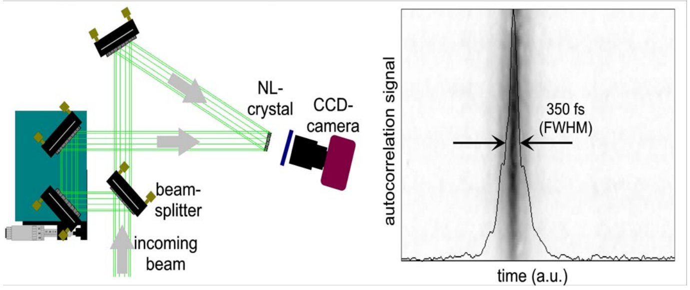

Figure 1.: Autocorrelation trace showing 350 fs compressed laser pulses and single-shot autocorrelator setup.

A 10 W Nd:YLF continuous wave alignment laser was taken in operation to allow for fast alignment of component without having the high intensity of a pulsed laser. With this laser the beam pointing form the front end to the experiments can later be verified before every full system shot.

Three laser heads of the preamplifier have been installed and aligned. Five telescopes with vacuum spatial filter have been put in place, tested and aligned. The laser heads have been fired with a small seed pulse from the short pulse front end.

Numerous mechanical modifications and additions are necessary to build the PHELIX main amplifier chain out of components obtained from Phebus (France) and Nova (USA). The main spatial filter had to be modified at the center section to allow injection of a preamplified pulse and to use the amplifiers in a folded double-pass configuration instead of the original single-pass linear chain. This modification was completed and the vacuum was successfully tested afterwards. The mirrors and mirror holders were after all not available items from LLNL and had to be purchased separately. A more compact type of mirror holder was already developed and tested in 2001 in collaboration with LULI, France, and were ordered for deliveries in 2002 and 2003. The beamline in the main amplifier is completely enclosed and filled with nitrogen to ensure that no dust or water vapor can settle on the optics. The housings around the mirrors and the pedestals under them along with about two dozen bellows and flanges to seal the main amplifier cavity airtight were constructed, built and delivered. After cleaning these parts the assembly of the laser cavity can continue, for which a movable flowbox was built, which ensures a class 100 cleanroom environment around the component to be installed. By successive assembly of the mirror housings, amplifiers and interstage bellows and tubes under this flowbox, the laser cavity can fulfill the required cleanness specifications.

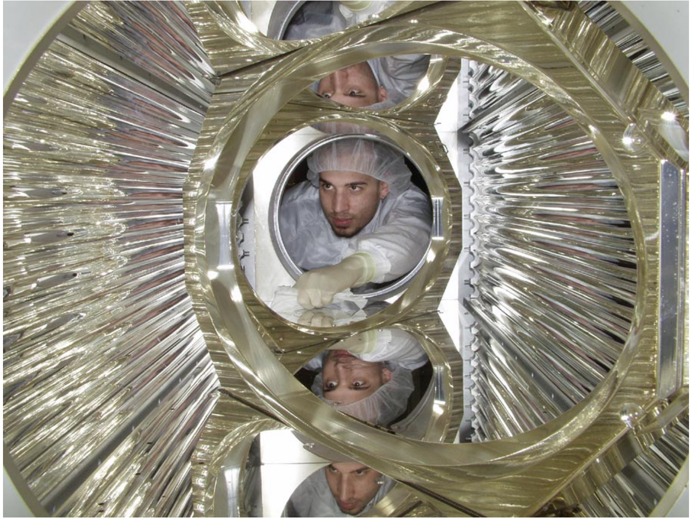

Figure 2.: PHELIX engineers clean an A315 amplifiers in preparation for the usage. Shown is the inside of the amplifier with two laser disk holders in the middle and flashlamp panels on the left and right. (Picture: G. Otto)

The preparation of all mechanical parts of the main laser amplifier is done in a separate class 100 cleanroom area inside the PHELIX building. For this a large hot water spray booth and a dishwasher for laser disk were taken in operation together with other cleaning equipment and verified for cleanness. The know-how of the amplifier cleaning procedures has been acquired by PHELIX engineers from Cilas, France, and through training of personal at LULI, France. In this procedure the laser amplifiers and other mechanical parts have to be taken completely apart. Every part is then verified to have less than two five-micron-size particles per square centimeter. For this verification the aging paint has to be taken of some components. One A315 laser amplifier was prepared to test the flash lamps. After the flashlamp tests two more amplifier were cleaned, equipped with tested flashlamp and inspected laser disk and put under nitrogen atmosphere to avoid oxidation of the silver surfaces and degrading of the phosphate laser glass.

The installation of the pulsed power system for the main amplifier proceeded during 2002 with the setup of the capacitor bank and with components tests. A preliminary control and safety system was developed to perform tests of the ignitron switches, the energy storage capacitors and the amplifier flash lamps. This control system allows the remote control of the power supply units, the dump system and a data acquisition system to monitor several current waveforms in parallel.

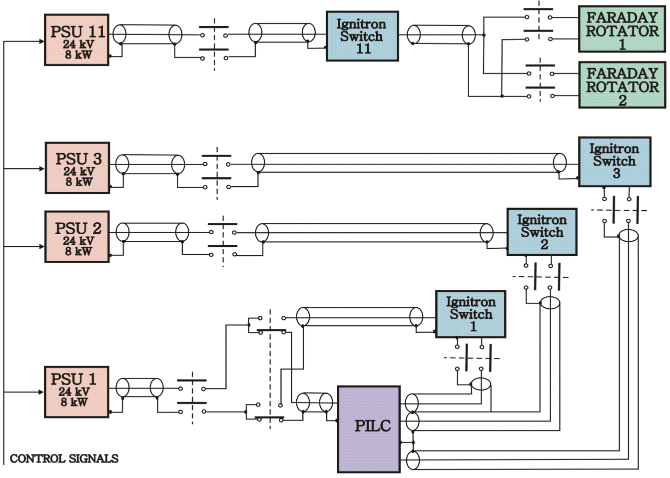

Fig. 3: Layout of the high voltage distribution and connection of the PILC circuitlamp test circuit.

For energy storage 52 µF capacitors manufactured by General Electric and Haefely with a nominal operating voltage of 22 kV are used. The 98 capacitors that were available during 2002 were tested with stepwise increasing voltages up to 20 kV by discharges into a 5Ω dummy load. Furthermore the internal leakage current of each capacitor was measured at a voltage of 20 kV. All capacitors passed the test except for two, which had a slightly different internal inductance.

To test the integrity of flash lamps and pulse forming networks (PFN) before a laser shot, a Pulsed Ionization Lamp Check (PILC) circuit will be used. This test circuit consists of a 52 µF capacitor and an ignitron (National Electronics, NL-2909). The integration of the PILC circuit into the high voltage distribution system is shown in Fig. 3. A high voltage relay connects the PILC capacitor to the high voltage terminal of the ignitron rack belonging to the amplifier under test. The capacitor is discharged in parallel through the ten PFNs and flashlamp pairs of the amplifier. The Rogowski coils in the ignitron rack are used to monitor the flash lamp currents. This allows a test of the circuit integrity with the low energy PILC pulse. The PILC circuit has been set up and is currently used for flash lamp tests. For the flashlamp tests a flash lamp panel with 10 lamps is installed in an amplifier housing in the laser bay and connected to the capacitor bank. After a successful PILC test the charging voltage is increased stepwise up to 20 kV and the current waveforms are recorded. A typical set of test curves is shown in Fig. 4.

RG 217 coaxial cables are used to connect the capacitor modules to the ignitron switches and to the flash lamps. In total about 10 km of high voltage cables are needed for the wiring of the capacitor bank. Care is taken that the cables do not touch grounded metallic structures to prevent arcing. The wiring is currently proceeding and will be finished early in 2003.

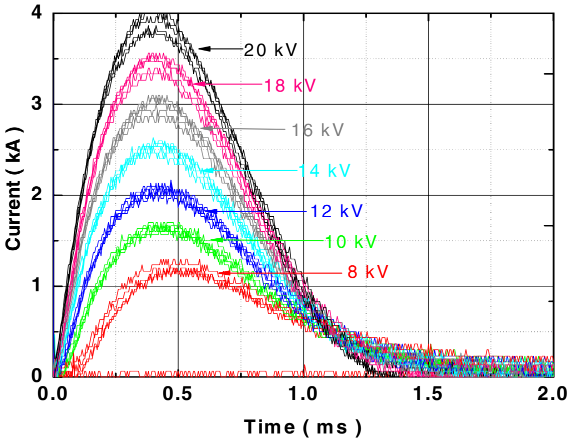

Fig. 4: Current waveforms for flash lamp tests with charging voltages between 8 and 20 kV

For experiments with the long pulse of PHELIX (1 kJ in 1 ns) the construction of the beamline to the target area and the reconstruction of the target area was started in 2002 to allow as soon as possible experiments on ion beam - plasma interaction.

The beamline itself will transport the laser beam over a distance of 70 m to the target from the PHELIX building to the area Z6 in the Experimental hall. Three massive mirror towers, one outside and two inside the Experimental hall, and a bridge to the PHELIX building to cover the telescope and to protect the beamline against wind and rain was installed. A 30 m long 1:1 telescope will be inserted to provide relay imaging for a good focusability and beam pointing stability. As mechanic stability is very important for the pointing of the beam, this was a key point for the construction of the mirror towers.

The current design allows two injections of the PHELIX beam, one perpendicular to the ion beam for hohlraum experiments and one under a 8° angle to the ion beam to produce homogenous plasmas for stopping power experiments. Due to the free space and experimental requirements both injections have a different final focusing system.

The target area Z6 was also reconstructed for the experiments with PHELIX. A new, bigger target chamber with a high precision target alignment system was installed, see Fig. 5. The ion beam line had to be partially reconstructed to clear space for the laser beam. The chamber is a sphere with 1 m diameter with numerous flanges for diagnostics, laser and ion beams. Inside the chamber is a thick threaded ring, which keeps its position during evacuation for precise aligned diagnostics. In 2002 all steel constructions of the beamline and the reconstruction of the target area has been finished. The installation of the optical components as well as the construction of the final focusing are still under work and will be finished in 2003. The characterization of the laser beam on target, synchronization to the Unilac and first experiments on stopping power are planned for this year.

In June 2002 the final contracts between the BMBF and the DoE (Department of Energy) were signed at GSI to clear the transport of the LLNL laser parts to PHELIX. It proved to be the fastest and least expensive to have PHELIX manpower at LLNL to dismantle the components from the NOVA laser, which has been shut down five years ago. Most electrical components had been stored outdoors for some time and will despite professional selection of the least deteriorated parts require significant overhaul and testing. The amplifiers, telescopes, midchain sensors and appropriate accessories were dismantled together with LLNL staff and prepared for shipment. Finally, five container with over 50 tons of laser components arrived in good condition at GSI. These parts are crucial for the completion of the laser.

The design phase of the PHELIX control system has been finished. The system is based on the control system framework developed at GSI [2], an object-oriented, multi-threaded, event driven and distributed system written with LabVIEW. The basic idea of the PHELIX control system is to provide capability for distributed computing in three software layers. The first layer is formed by front end computers, which are connected to the hardware to be controlled. The second layer consists of a central control PC that is providing SCADA/DSC functionality, data server capability and serves as communication interface between the front end and user interface layer. In 2002 the basic functionality of these two lower layers was defined and developed. The third software layer is responsible to give a convenient user access to control PHELIX. This layer will be given in form of graphical user interfaces (GUI), that represent~~s~~ the components of the laser. This GUI displays important system parameters and gives access to control the components of the laser.

Fig. 5: Shown is the new target chamber at Z6 below the last mirror tower. The ion beam form the UNILAC arrives from the right hand side, while the laser pulse arrives either form the top or from the top left.

Major components of the control system are close to the prototype state. The LabVIEW instrument driver required for the PHELIX hardware have been developed at GSI. The hardware that is used in the prototype state of the control system are oscilloscopes, arbitrary waveform generators, stepping motor controllers, FireWire (IEEE1394) CCD cameras, pulse and delay generators and specialized hardware components such as commercial lasers, laser power meters and high voltage equipment. A part of the PHELIX specific classes for the CS framework [3] were developed in close collaboration with the VAT [4]. A functional prototype of the PHELIX control system will be available in the first half of 2003.

Strict requirements have to be met concerning safety issues at PHELIX. Possible hazards are sources such as high voltage, laser light and scattered radiation and appropriate safety measures must be applied. In collaboration with GSI DVEE and the GSI safety department the requirements and layout for an interlock system were defined. Based on Beckhoff fieldbus components in combination with the Siemens access control and security system CERPAS the access to the building and the potentially hazardous areas in the building is controlled and restricted depending on the operational mode~~s~~ of PHELIX. The interlock system will be certified by the German VDE. In parallel to the commissioning of PHELIX, the interlock system is presently integrated into the control system software.

To obtain Petawatt laser pulses (500J in 500 fs) the technique of chirped pulse amplification [5] is used. For this a laser pulse is stretched in time by 4-5 orders of magnitude to reduce the peak intensity and avoid catastrophic damage in the laser glass during the amplification. After the pulse is amplified form nJ to kJ energy it is recompressed. Nonlinear dispersion, gain narrowing, imperfections of the optics and aberrations make it extremely difficult to reach the original pulse duration.

The critical element in the petawatt laser chain is the final grating, which must withstand full energy in short pulse duration and has typically a lower damage threshold than a high power dielectric mirror. Previous petawatt facilities at LLNL, JAERI and RAL use 1 m diameter gold coated gratings with a damage threshold of ~ 0.3 J/cm^2 at 1480 l/mm groove density. Tests done in 2002 on dielectric gratings show that the fluence can be doubled and the reflectivity could be increased and large gratings can be manufactured. This allowed us to order 485mm x 335m gratings for the PHELIX petawatt compressor with delivery is expected late in 2003.

A compact compressor is designed to pass a 21 x 30 cm rectangular laser beam with over 700 J input energy and 88% throughput. A group delay dispersion of 250 ps/nm can be compensated in a single pass compressor design with only 1.57m grating separation and a separation angle of 15°. The intensity loss due to spectral and energy clipping on the second grating and remaining spatial chirp is only 14 % and is compensated by the increased input energy on a completely filled first grating. The rectangular shape can be obtained by inserting a serrated aperture at the input of the double-pass amplifier, where the fluence is low and the beam has an image plane of a previous serrated aperture.

References

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