# NEW DEVELOPMENTS OF A LASER ION SOURCE FOR ION SYNCHROTRONS

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*Abstract*

Laser Ion Sources (LIS) are well suited to filling synchrotron rings with highly charged ions of almost any element in a single turn injection mode. We report the first measurements of the LIS output parameters for $Pb^{27+}$ ions generated by the new 100 J/1 Hz Master Oscillator – Power Amplifier $CO_2$-laser system. A new LIS has been designed, built and tested at CERN, as an ion source for ITEP-TWAC accelerator/accumulator facility, and as a possible future source for an upgrade of the Large Hadron Collider (LHC) injector chain. The use of the LIS based on 100 J/1 Hz $CO_2$-laser together with the new ion LINAC, as injector for ITEP-TWAC project, is discussed.

## 100 J/1 HZ $CO_2$-LASER

A 100 J, 15÷30 ns $CO_2$-laser system has been developed, based on a Master Oscillator – Power Amplifier (MO-PA) configuration, which was designed and built as a driver for LIS during the last 5 years. In 2001 the laser was assembled and tested in free-running oscillator mode at ITEP (Moscow). In spring 2002 it was delivered, re-assembled and commissioned at CERN in both free-running oscillator and MO-PA modes. The results of the laser reliability and stability tests together with the first results of ion measurements are presented in this paper.

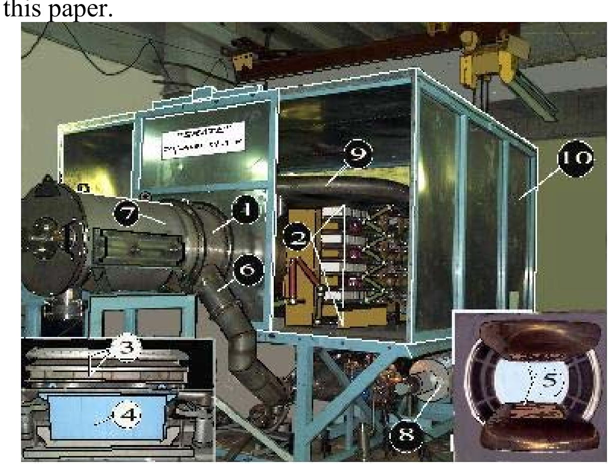


Figure1: Power Amplifier general scheme (1 – laser chamber, 2 – Marx generator for the main discharge, 3 – x-ray preionization module, 4 – e-gun Marx generator, 5 – profiled electrodes system, 6 – turbine driven gas loop, 7 – optical chamber, 8– gas mixture regenerator, 9 – guard electrode, 10 – screen).

1 Hz rep-rate and high reliability ($10^6$ shots without interventions) required by accelerators set strong constrains on the type of a $CO_2$-laser amplifier to be used. The large active volume and the considerably long life-time demanded, led to the choice of a self-sustained discharge with x-ray preionization for the excitation of the laser medium. The general scheme of the Power Amplifier (PA) is presented in Fig. 1. The main subsystems of the Power Amplifier (PA) are the laser chamber, gas loop with a fan, regenerator and two heat exchangers, electron gun with Ta foil x-ray converter, Marx generator for gas discharge and optical units.

### *Power Amplifier stability and reliability tests in free-running oscillator mode*

Stability and reliability of LIS strongly depends on stability and reliability of the laser used. For the first tests the Power Amplifier (PA) was converted to a free-running oscillator by installing of resonator mirrors on the axis of the PA. As is usual for free-running oscillator mode the laser pulse consists of the first peak with high intensity and the “tail” with low intensity. Results of the first peak power stability test are presented in Fig. 2 and Fig. 3. Shot-to-shot statistical fluctuations of the first peak laser power and pulse width (FWHM) were below ± 3%.

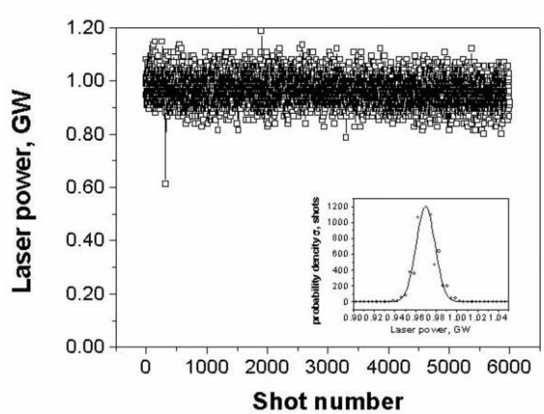


Figure 2: Shot-to-shot laser pulse power fluctuations in 1 Hz rep-rate free-running oscillator mode.

The longest uninterrupted operational time at 1 Hz rep-rate achieved was 3 hours, restricted by degradation of the regenerator and as a consequence the appearance of arcing during the main discharge. This may be solved by significantly increasing the active volume of the

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regenerator, from the present volume of 12 l, which should result in a longer operational time.

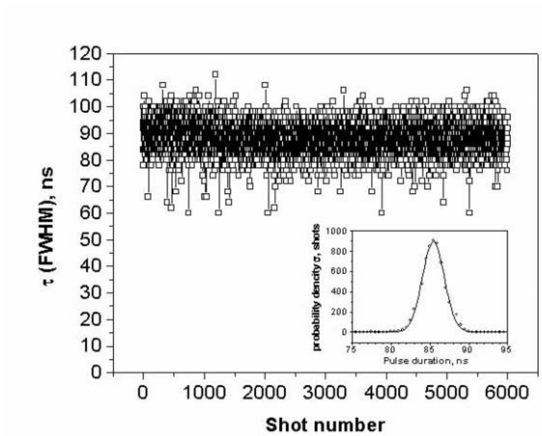


Figure 3: Shot-to-shot laser pulse width fluctuations in 1 Hz rep-rate free-running oscillator mode.

The correct screening and grounding of all PA elements and systems led to very low levels of radiated noise. The radiated noise measured just near the PA was below 10 mV/m [2]. This allows the laser to work safely in the environment of any accelerator electronic controls and to avoid problems regarding the measurements of low-level optical signals.

### *Master Oscillator – Power Amplifier stability and reliability tests*

The Master Oscillator – Power Amplifier (MO-PA) configuration has advantages in comparison with the free-running oscillator mode, providing higher efficiency of highly charged ion generation and allowing the adjustment of the laser pulse shape. The MO-PA laser optical scheme is presented in Fig. 4.

The Master Oscillator (MO) provides a single longitudinal and transverse mode laser pulse with an output energy of 150 mJ and a pulse duration of 75 ns with rep-rate up to 3 Hz. A detailed description of the MO can be found in [3].

Two $SF_6$ cells were installed between the MO and PA allowing adjustment of laser pulse width at the output of the PA in the range 25÷50 ns [4]. A 4-pass amplification scheme was used to obtain the shortest laser pulse with the highest output energy, but still avoiding self-lasing in the PA. The shortest laser pulse duration achieved was 23 ns.

Shot-to-shot statistical fluctuations of laser pulse amplitude and width (FWHM) were equal to ± 14% and to ± 9%. The longest 1 Hz rep-rate operational time achieved was equal to 1 hour 15 min and was also restricted by degradation of regenerator.

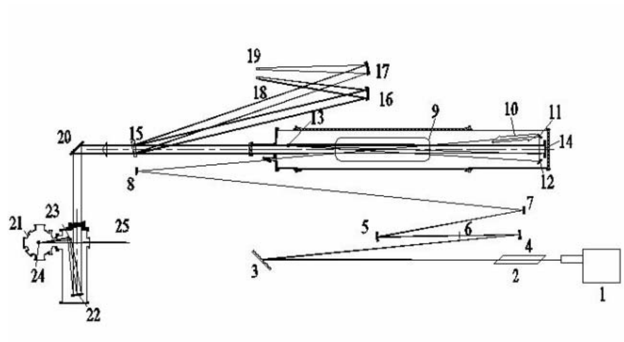

Figure 4: 4-pass optical scheme of MO - PA $CO_2$-laser: 1 - Master Oscillator (MO), 2,10 - absorber cells, 3 - grating , 4,5 – spatial filter optics, 6 - diaphragm of spatial filter, 7, 8, 11, 12, 20, 23 – flat mirrors, 9 - active volume of Power Amplifier (PA), 13 – convex mirror of telescope, 14 – concave focusing mirror of telescope, 15 - salt wedge laser beam splitter, 16, 17 – focusing mirrors, 18 - energy meter, 19 - laser pulse shape detector, 21 - vacuum chamber, 22 - focusing objective spherical mirror, 24 - target, 25 - expanding plasma.

A specially designed laser beam dump was installed at the output of PA during these tests to avoid reflections back to active volume of PA, avoiding damage of the optical elements of MO-PA laser system.

## FIRST RESULTS ON ION BEAM GENERATION, EXTRACTION AND MEASUREMENTS

The layout of the Laser Ion Source experiment at CERN is presented in Fig. 5.

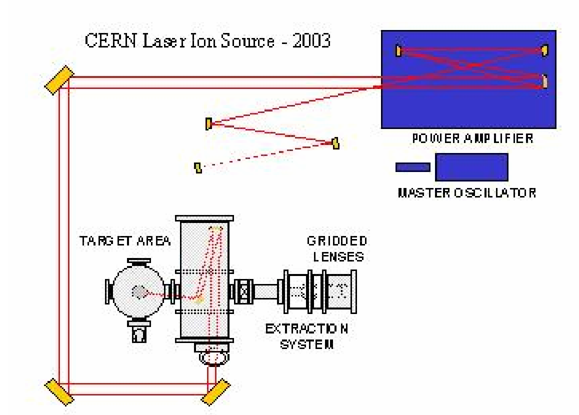


Figure 5. Layout of the Laser Ion Source experiment at CERN.

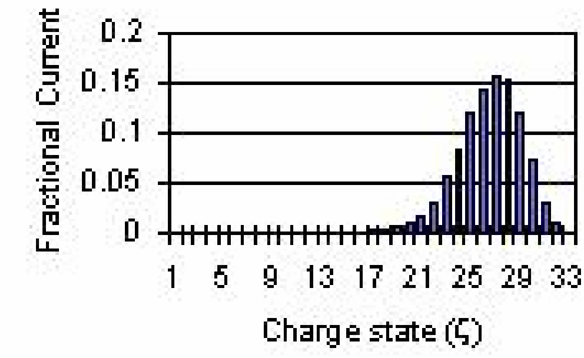


Figure 6: Charge state distribution of Pb ions for laser power density at the target $3\bullet10^{13}$ W/cm$^2$.

The charge state distribution of ions from the laser-produced plasma has been measured by an electrostatic analyzer; the total ion current with a Faraday cup with a suppression ring just after extraction and the emittance of extracted beam by a pepper pot with fast scintillator and CCD camera. Detailed description of these experimental methods can be found in [5].

It was shown that an ion beam can be extracted from laser produced-plasma without breakdowns for laser power density of $3\times10^{13}$ W/cm$^2$ (100 J/27 ns) and extraction voltage of 105 kV with 1 Hz rep-rate. The charge state distribution measured in the time window of existence of the most abundant charge state ($Pb^{27+}$ in our case) is presented in Fig. 6, where the current fraction of $Pb^{27+}$ is close to 16%. Using an extraction aperture of 24 mm and extraction voltage of 100 kV, the normalized rms emittance was found to be 0.2 mm•mrad for a total extracted current of about 20 mA.

During these tests we observed several instances of damage to the absorber cell (KCl) windows (10 in Fig. 4). Such damages were caused by reflections back from the target and laser-produced plasma to the active volume of the PA. The reflected laser pulse passing through the PA is amplified up to sufficient energy to damage optical elements of MO-PA laser system. Final inspection of all optical elements revealed that convex mirror of telescope was also damaged (13 in Fig. 4). Further optimisation of the optical scheme will be needed to avoid any damages to optical elements during target irradiation.

## LASER ION SOURCE DEVELOPMENT AND USE FOR ITEP-TWAC PROJECT

The LIS has been developed in a very close collaboration between ITEP, TRINITI and CERN. This first design was intended for use as the ion source for the Large Hadron Collider. However, in March 2003, CERN fixed the use of an ECR ion source coupled to the 4.2 MeV/nucleon Linac and a Low Energy Ion Ring (LEIR) [6]. Hence the LIS is now free for use as the source for the ITEP-TWAC project [7]. Therefore, the LIS has been moved to ITEP, where the research and development can now continue.

The source will be re-assembled in ITEP and the parameters of medium mass ion beams (Ti ÷ Ni) will be measured. Then a LIS based on the 100 J/1 Hz $CO_2$-laser will be used with a new high current injector [8] for the ITEP-TWAC project. Further technical improvements of the laser are required to significantly increase its reliability and provide conditions for wide usage for different applications.

## CONCLUSIONS

A 100 J/1 Hz MO-PA $CO_2$-laser system has been designed and built for the CERN LIS. Stable operation of the laser has been demonstrated during a few hours and has been restricted by the low efficiency of the regenerator. The first results of ion beam generation have been obtained, showing $Pb^{27+}$ to be the most abundant ions in the beam for laser power density of $3\bullet10^{13}$ W/cm$^2$ with a current fraction close to 16%. The ion beam has been extracted at 105 kV in 1 Hz rep-rate without vacuum problems or extraction system breakdowns. In the future LIS based on 100 J/1 Hz MO-PA $CO_2$-laser will be re-assembled, up-graded and used for ITEP-TWAC project.

## ACKNOWLEDGMENTS

This work has been supported by the European Community via the ISTC Project #495 and by Minatom of the Russian Federation.

Important contributions came from colleagues at CERN, Ch. Mastrostefano, B. Pincott, M. O'Neil; at ITEP, S. Savin, I. Roudskoy; and at TRINITI, S. Khomenko, V. Roerich, A. Stepanov.

The authors thank F. Szoncso for the measurements and suggestions to reduce of the PA radiated noise.

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