CERN PS LASER ION SOURCE DEVELOPMENT

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Abstract

CERN, together with ITEP and TRINITI (Russia), is developing a CO_2 laser ion source. The key design parameters are: 1.4×10^{10} ions of Pb^{25+} in a pulse of 5.5 μs, with a 4-rms emittance of 0.2×10^{-6} rad m, working at a repetition rate of 1 Hz. This device is considered as one candidate source for LHC heavy ion operation. The status of the laser development, the experimental set-up of the source consisting of the target area and its illumination, the plasma expansion area and extraction, beam transport and ion pre-acceleration by an RFQ, will be given.

1 INTRODUCTION

In 1996 a laser ion source with beam transport (LEBT) and RFQ came into operation. This system was designed for multi-charge, heavy (A ≈ 200) ion currents >50 mA, charge states around 25+ [Fig. 1], [1]. The source generated 8 mA of Ta20+, 28% were transported into the aperture of the RFQ. A coarsely matched beam was accelerated by the RFQ to 100 keV/u. A current of 1 to 2 mA of Ta20+ was obtained, starting an intense effort to improve this result [2].

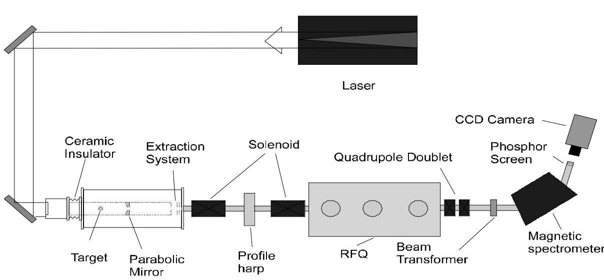

Figure 1: Scheme of the CERN Laser Ion Source

2 WORK AT THE SOURCE

2.1 Matching of Plasma Density and Extraction

The border between plasma and extracted ions together with the electric fields of the extraction electrodes and beam space-charge define the optics. Matching of the plasma and extraction is reached if the beam is smoothly focused to the LEBT. The current (I) of a Faraday cup with an aperture of 30 mm, was measured as function of extraction voltage (U), 300 mm after extraction. The current density of ions in the plasma was varied by changing the target to extraction distance for laser energies of 6 and 30 J. Figure 2 shows a measurement, $I = I(U)$, at 30 J. Two areas can be identified, current increasing with U and a flat-top, separated by a "knee-voltage", U_k. For a charge-state of 20+ and an atomic number of 181, the relation $U_k = 0.45\times10^6\times I^{2/3}$ is found. U_k gives the source working point.

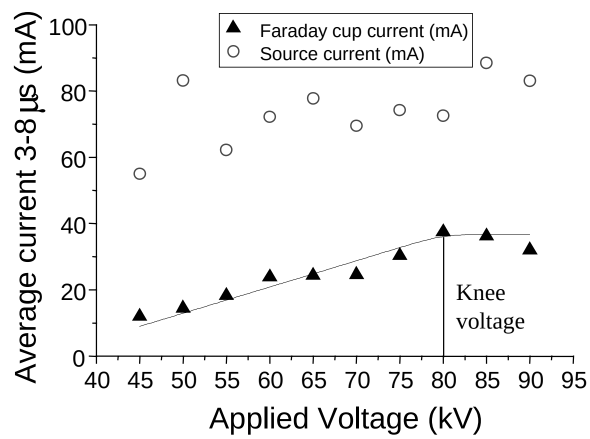

Figure 2: Characteristics of Current Transmission and Source Potential

2.2 Emittance Measurements

Figure 3 shows the emittance as function of extraction aperture ϕ at a density from 8 to 12 mA/cm^2, U = 60 kV. The distance between the extraction electrodes and the apertures was kept equal. It was observed that during the beam pulse, the orientation of the phase space ellipse changes (Fig. 4) and different shaping of the source outlet electrode led to different emittances. For the present extraction geometry and a source current of 60 to 80 mA, one finds for the ensemble of about 10 charge-states, around Ta20+ at 7 keV/u, a total 4rms-emittance of 300 mrad mm, normalized 1.2×10^{-6} rad m, a value which requires improvement. At 7 keV/u, measurements of the emittance using a multi-slit and phosphor screen at high currents suffer from space-charge effects. More reliable measurements of emittance can be expected at 100 keV/u, after the RFQ.

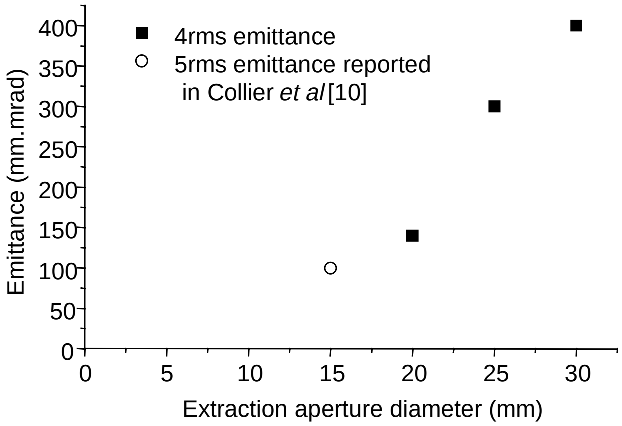

Figure 3: Emittance as a Function of Extraction Aperture

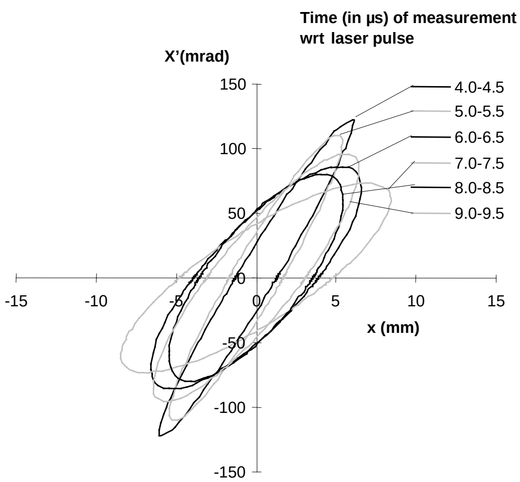

Figure 4: Emittance as a Function of Time

configuration		param.	96	Fall 98 [8]	Fall 98 [9]
ϕ FC = 30	1 sol	R30	33/58 = 57%	44/77 = 57%	
	2 sol	R30	26/58 = 45%	33/63 = 52%	
ϕ FC = 6.5	1 sol	R6.5		17/69 = 25%	17/63 = 27 % (18)
		T6.5		40%	43% (50)
		A6.5		5/80 = 6%	7/70 = 10 % (5)
		Y		11%	16% (20)
	2 sol	R6.5	10/60 = 17%	13/76 = 17 % (13), ((11))	
		T6.5	28%	28% (30), ((40))	
		A6.5		6/81 = 7 % (3), ((4))	
		Y		12% (11), ((11))	
remarks			transfer from source to outlet of RFQ 12%	good alignement	
				plasma/extraction matched	
				d=100 for 1 sol, d = 192 for	d = 30
			EF = 1.66, U = 60	EF = 1.66, U = 80	EF = 1.6, U = 60
Legend	Rab : I ab Faraday Cup / I source [%]				Y : Yield = A6.5 * EF [%]
	T6.5 : R6.5 * EF [%]				U : Extraction voltage [kV]
	A6.5 : I through double aperture / I source [%]				ϕFC : Faraday Cup aperture [mm]
	d : image distance from solenoid [mm]				I : Average current [mA]
	EF : Enhancement Factor allows for the change of charge states distribution at transport				

Table 1: Transfer Rates and Yields of Solenoid LEBTs

3 WORK ON THE LEBT

3.1 Magnetic LEBT, Experiments and Numerical Simulations

To improve transmission, alignment facilities for the solenoids were up-graded from 1D to 3D. In some experiments the LEBT was reduced to a single solenoid line, as beam simulations [3] suggested a strong improvement of the transfer rate. The best transmission rate which could be obtained was 43%. However the best particle yield was only 16%, when a double aperture device was inserted at RFQ position, simulating RFQ acceptance.

The programs PATH [4], CPO [4] and KOBRA3 [4] have been used. The latter treats magnetic and electrostatic elements or fields and it allows the introduction of electrons. Simulations included the study of a LEBT with super-conducting (sc) solenoids.

3.2 Results

Experimental and numerical results are summarised in Table 1. Simulations for warm solenoids are given in single parenthesis and for sc solenoids in double parenthesis. None of the configurations (whether tried out in an experiment or simulated with our different programs) led to a yield (particles in the xx′yy′ acceptance of the RFQ) above 20 %. The reason is the strong non linear space charge effect from the “chained” focal points in a beam of ions of different charge states, leading to strong emittance blow-up (>2, in some cases 8 times), intrinsic to all solenoids. In the beam, ring structures were observed in the transverse plane (Fig. 5).

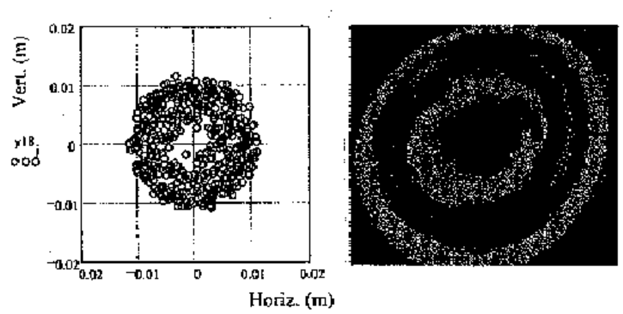

Figure 5: Ring Structures, Simulation and Experiment

3.3 Electro-static LEBT with Grids (GEL)

The GEL has been designed at CERN [5] and manufactured by INR, Moscow. Due to the lack of charge separation, strong non-linear space-charge effects should not appear and one expects high transfer rates compared to solenoid LEBTs. The mechanical layout of the GEL is shown in Fig. 6.

The result from beam simulations for an extracted beam of 60 mA , and an input emittance of 320 mrad mm, is shown in Fig. 7. Simulations give emittance growth <1.5, current transfer >50 %, a yield of 35 %. Experiments have started recently. An average current of 40 mA (for solenoid LEBTs it was 17 mA, see Table 1) has been observed in the Faraday cup of ϕ = 6.5 mm. The source current was then 70 mA. Inserting the double aperture device gave a yield of 30 %. Near the focal plane, emittance measurements confirmed the predicted low emittance growth.

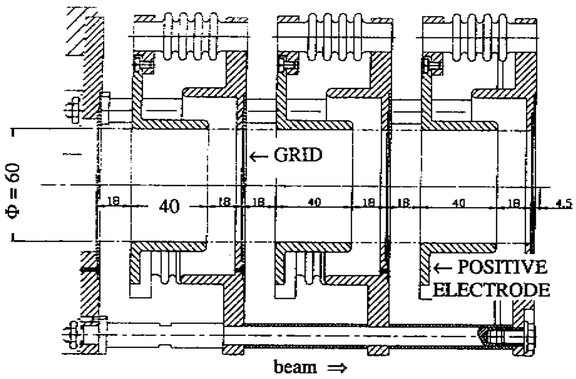

Figure 6: Mechanical Lay-out of the GEL

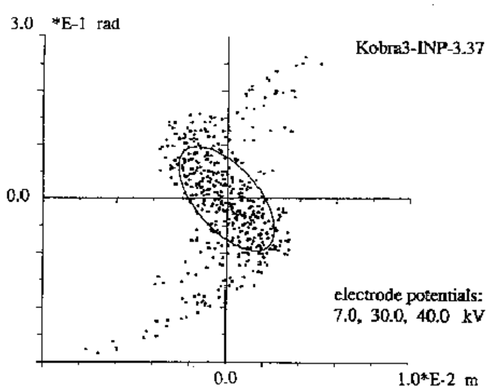

Figure 7: GEL Beam Simulations

4 LASER DEVELOPMENTS

4.1 Work at TRINITI, ITEP

In 1995, experiments with CO_2 laser oscillators of 30 J (CERN) and 80 to 130 J (TRINITI) suggested that a 100 J laser system, consisting of a master-oscillator and power-amplifier (MO/PA) should provide more than 10^{10} ions of Pb25+ within 6 μsec [6]. A master-oscillator was built by ITEP and TRINITI in 1996 and run in at CERN. It produces single transverse mode, single longitudinal mode pulses of 150 mJ in 60 to 70 ns at 3 Hz. The realisation of a 100 J laser amplifier with 1 Hz repetition rate [7] started in December 1997. This is a joint project of ITEP and TRINITI, supported by an ISTC grant. The amplifier will be delivered to CERN by the end of 2000. The first phase of the project included the characterisation of the ion yield to define the final laser parameters. Many configurations, 13 to 65 J, at pulse-lengths of 15 to 80 ns, have been run. Ion yields were measured and scaled to the 100 J energy level according to ion beam pulse length and current density at extraction. Extrapolating from a system, running at 13 J and 20 ns leads, with a power density of 8×10^{13} W/cm^2 at the target, to 1.3×10^{10} Pb25+.

4.2 Work at CERN

The 30 J laser delivers one pulse per 30 sec. To get hands-on experience with a 1 Hz system, a low level 1 Hz oscillator has been converted to an amplifier for the master-oscillator pulses. It provides 2 J of energy. This energy is sufficient to study LEBT performances at high currents, with light elements such as Al.

5 NEXT STEPS

The RFQ will be re-installed, together with the electro-static LEBT. Effort will be invested in the reduction of the source emittance if the results, obtained at 6 to 7 keV/u, are confirmed by measurements at 100 keV/u. Shaping of the extraction electrodes and modulation of extraction voltage may help. Immediate acceleration of the ions after extraction, to reduce space charge effects at transport and matching of the beam to the RFQ, is under study.

6 REFERENCES

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