Ion Clearing and Photoelectron Production in the 200 MeV SXLS Ring*

H. Halama and Eva Bozoki
Brookhaven National Laboratory
Upton, New York 11973

Abstract

The design of the SXLS clearing system and its behavior are presented. In normal 200 MeV operation, clearing electrode current is dominated by photoelectrons. Clearing electrodes appear essential only in several locations but not in the dipoles. The effect of clearing voltage on the tune and the beam profile is also discussed.

I. INTRODUCTION

The X-ray Lithography Source (XLS) offers a unique opportunity to study both ion clearing and photoelectron production since its energy can be ramped from 60 to 200 MeV which represents critical photon energy ϵ_c between 0.8 and 30 eV. The installed clearing electrodes collect not only positive ions produced by the circulating electron beam but also expel photoelectrons which are created in much larger quantities when clearing electrodes (CEs) are hit by synchrotron radiation. At $\epsilon_c = 0.8$ eV the photoelectron production decreases six orders of magnitude when compared to $\epsilon_c = 30$ eV and direct clearing (positive ion) current measurements become possible.

Only one other light source, namely Aladdin [1], having ϵ_c of 1.4 eV permits direct clearing current measurements. In higher energy machines CE current is almost entirely due to photons.

II. ION TRAPPING AND CLEARING

Despite a substantial amount of both theoretical and experimental work at various laboratories, this subject is still rather poorly understood and each machine seems to have its own peculiar behavior. In some cases, the entire circumference seems to require CEs for efficient clearing [1], while in others only one or a few CEs located in potential wells are sufficient [2].

In this paper we will not attempt to discuss the theory of ion trapping as it has been thoroughly covered by many authors. Rather, we will discuss our observations at the XLS in the hope of improving general understanding of clearing behavior. This investigation was primarily undertaken to test the design of the clearing system for the 700 MeV SXLS, in particular to determine whether CEs have to be installed in superconducting dipoles [3]. The present 200 MeV machine

is identical in all respects except that room temperature 1.1 T magnets will be replaced by 3.9 T superconducting magnets.
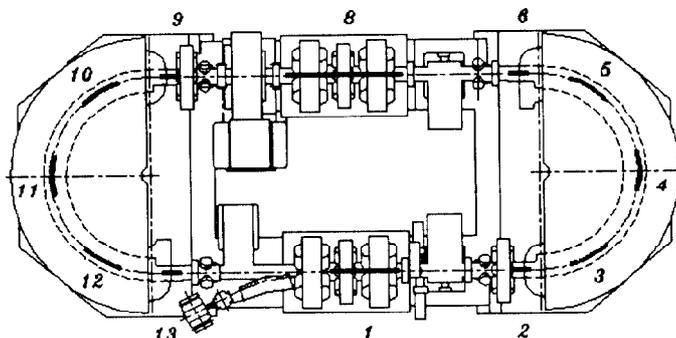
Fig. 1 Strip line clearing electrodes: width = 25 mm, $Z_o = 50$ Ω

Fig. 1 shows the schematic of the ring equipped with 12 dedicated strip lines which are used as clearing electrodes. In order to permit 5 kV operation we have investigated several termination schemes and have selected 50 Ω lossy coaxial cable (Capcon Corp) with the following attenuation: 5 db/m at 50 MHZ, 28 db/m at 220 MHZ and 80 db/m at 1 GHZ.

One side of the stripline is terminated with open circuited cable 1.2 m long. Measured reflected power is -20 dB for frequencies from 100 MHZ to 6 GHZ. High voltage is also applied through the same lossy cable. Thus each strip line is terminated on both ends with its characteristic impedance and is powered by a separate variable 5 kV supply to assess the relative effectiveness of each CE.

Since the injection energy into the SXLS is 200 MeV most tests are conducted at this energy. It is not surprising that almost all current, I, drawn by CEs is due to synchrotron radiation photons and is proportional to circulating current but independent of pressure. The highest I is recorded at locations of high photon flux (CE 4, 5, 11, 12). Applying ± 600 V to CE 4 yields normalized current/mA of beam current I = 1.6 uA/mA and 0.8 uA/mA, respectively. The lowest I < 1x10² uA/mA was measured at CE 2. If positive voltage is applied to CEs, the photo electrons created by photons incident on the vacuum chamber are collected. Negative voltage applied to CEs expels photoelectrons created by photons hitting CEs, thus producing current of the same polarity as that caused by positive ions.

Photoemission occurs only when the photon energy exceeds the potential barrier to the escape of an electron from

the metal which is given by its work function. In stainless steel this energy was determined to be ~ 10 eV, as shown in Fig. 2, where the flux of photons having energy higher than 10 eV is plotted vs. machine energy. X and O represent photoelectric yields for positively and negatively biased CEs, respectively.
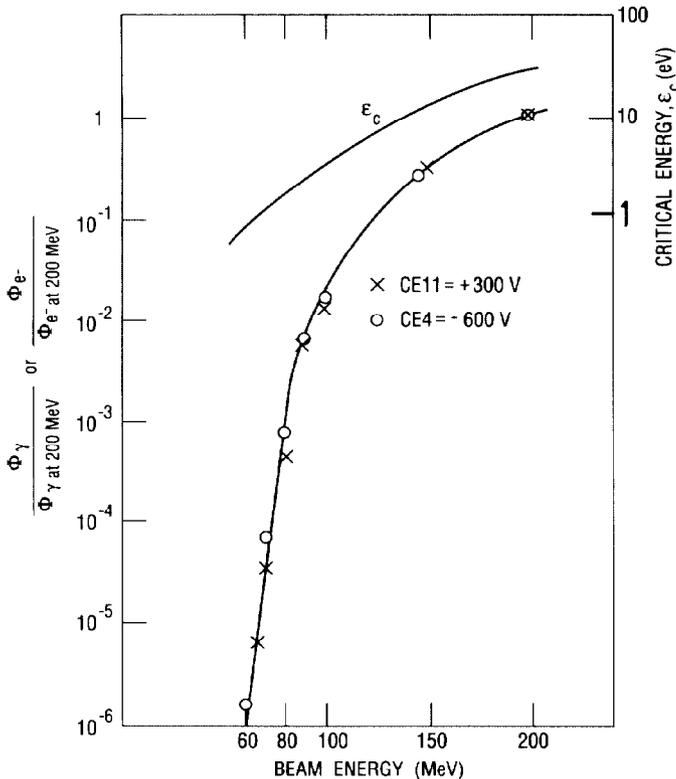
Fig. 2 Normalized photon and photoelectron flux

Photon flux in Fig. 2 decreases rapidly when the machine energy is lowered and true ion current measurements can be carried out at energies between 75 and 60 MeV which corresponds to ϵ_c of 1.5 and 0.8 eV. This current is both beam current and pressure dependent and was estimated to be 2 - 3 x 10 $^{-12}$ A/mA.m after about 10 ampere-hours of conditioning, which can be compared to 4 x 10^{-12} A/mA.m measured at Aladdin with ϵ_c = 1.3 eV.

In six runs, negligible effects on total CE current drawn by CEs 2, 6, 9 and 13 were observed when CEs 3, 4, 5, 10, 11 and 12 were switched on or off. It was therefore decided not to install them in the superconducting magnet vacuum chambers. In subsequent tune and beam profile measurements, they were shorted to ground through lossy cables and CE 1, 2, 6, 8, 9 and 13 were connected to a single variable power supply in the control room.

A good injection rate of 50-100 mA/min up to 150-200 mA is possible without clearing. Beyond this current, up to I ≈ 500 mA, V_c = 200-300 V clearing voltage is needed to maintain a good injection rate. On the few occasions when 900-980 mA were stored, V_c = 500V was used.

Methods of tune and profile measurement

Four strip lines arranged in quadrupole mode, were connected to a swept RF generator to provide either horizontal or vertical excitation of the beam. The beam response was picked up on one of the PUE's and analyzed by a spectrum analyzer. Due to horizontal-vertical coupling it is possible to simultaneously display and measure both the horizontal and the vertical tunes.

For beam profile measurements a video camera and a digitizer provided two dimensional particle density display [4]. The measurements were taken over a six week period and the degree of ion capture by the beam varied somewhat depending on the circumstances. In spite of the considerable spread of the individual data, the tunes and beam sizes averaged within 50-70 mA provide a good measure of the ion effects and are presented below.
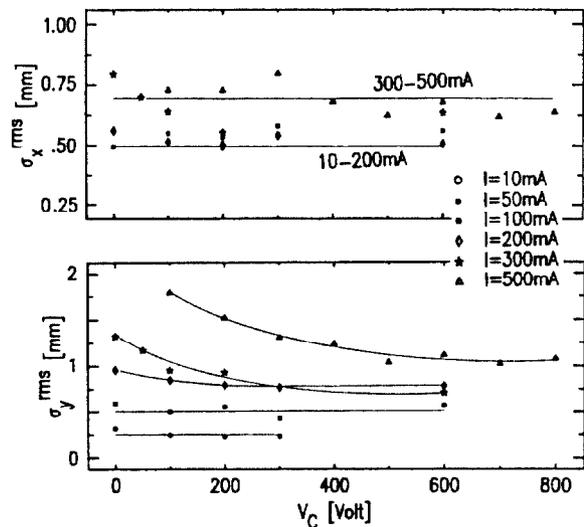
Figure 3 Averaged horizontal and vertical beam size vs. clearing voltage

Beam blow-up

At very low intensities (I ≈ 10 mA) Fig. 3 shows beam size with σ_x^{rms} ≈ .5mm and σ_y^{rms} ≈ .25 mm. The horizontal beam size is independent of the clearing voltage but exhibits a slight dependence on the beam current, .5-.6 mm and .6-.8 mm below and above I ≈ 250 mA, respectively.

The vertical beam size, on the other hand, shows both strong dependence on the beam current and on the clearing voltage. The.vertical rms beam size with no clearing grows from .32 to 1.33 mm as the current increases from 50 to 300 mA. 500 mA can be stored only with a minimum of 100 V clearing. The σ_y^{rms} vs. V_c curves run above each other; the larger the beam intensity, the higher the curves are situated.

The vertical beam blow-up due to ion capture is more pronounced at higher beam intensities $\Delta\sigma/\sigma$ ≤ 37% and 87% without clearing for I ≤ 200 mA and I = 300 mA, respectively. The same beam blow-up at I-500 mA with V_c = 100 V is 78%.

The effect of the ion capture on the vertical beam size can also be seen in a series of measurements in Fig. 4 performed under similar conditions during one six hour shift.

I≈100mA   I≈200mA   I≈500mA

INTENSITY (in arbitrary units)

$V_C = 0V$

$V_C = 100V$

$V_C = 200V$

0 2 4 6 8
Y mm $V_C = 300V$

$V_C = 600V$

0 2 4 6 8   0 2 4 6 8
Y mm   Y mm
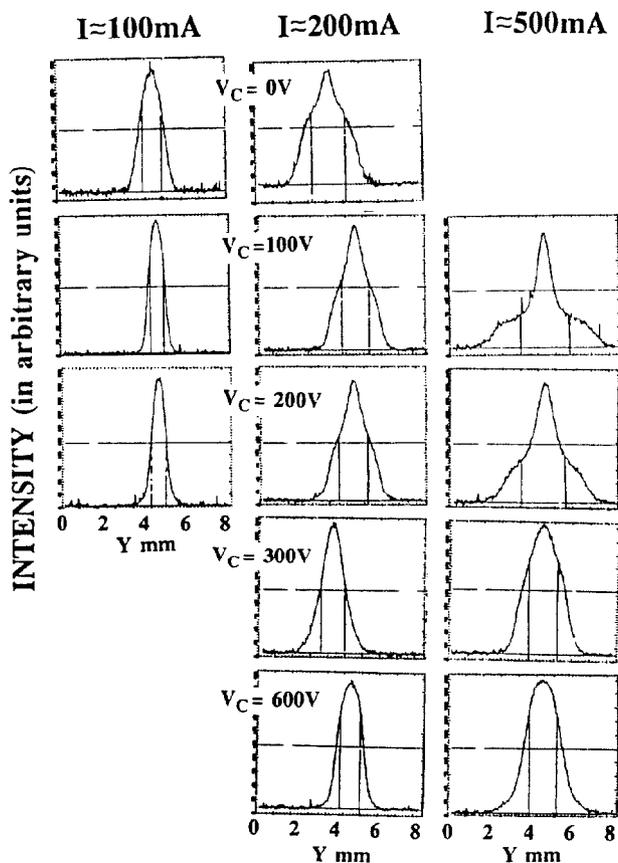
Figure 4   Vertical beam profiles Y at various beam currents,
I, and clearing voltage V_c

It is interesting to note, that the "uncleared" beam shows a more or less Gaussian "core" and a much wider "halo" around it.

Beatron tune.
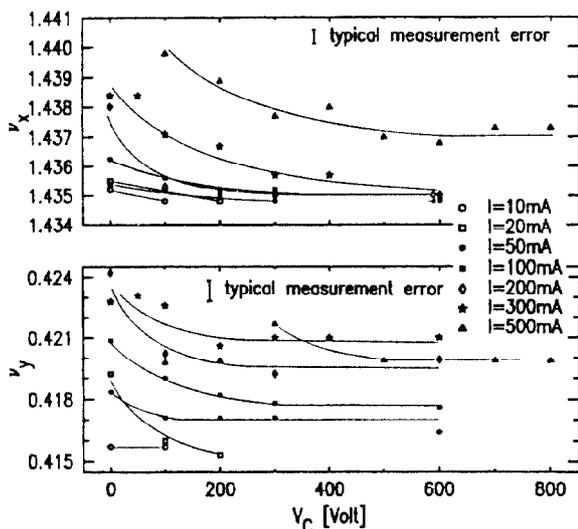
Figure 5   Averaged horizontal and vertical tune, as a function of clearing voltage at different stored beam intensities.

The horizontal and vertical tunes measured at very low beam intensity (I = 10 mA) were $v_x = 1.435$ and $v_y = 0.416$ with $\Delta v = \pm .0003$. With no clearing v_x starts to increase at I ≈ 100 mA and at I ≈ 300 has increased by $\Delta v = .0032$. At I ≈ 500 mA and $V_c = 100V$, $\Delta v = .0046$. The horizontal tune spread ($\Delta v \approx .001$) did not increase with either the beam current or the degree of ion capture.

Vertically we expect and measure a more significant vertical tune change. With no clearing the tune shift is $\Delta v = .005$ and .007 at I ≈ 100 and 300 mA, respectively. Comparing the measured tune shifts the neutralization factor is in the low a 10^{-2} range.

An interesting phenomenon not shown in Fig. 4 was observed. When the ions start to be removed, in most cases the vertical tune has, in addition to the higher value with large tune spread, a sharp line around the basic tune of $v_y = 4.157$.

Both the behavior of the horizontal and vertical tunes in Fig. 5 and the beam profiles in Figs. 3 and 4 indicate, that the effective clearing voltage needed to remove the ions and beyond which the tune or beam profiles, do not change, increased form $V_c = 100V$ at I ≈ 50 mA to $V_c = 500V$ at I ≈ 500 mA. This represents the minimum voltage necessary to compensate the beam self-field.[3]

III. CONCLUSIONS

Based on our investigations we draw the following conclusions:

1 - Clearing electrodes appear to be essential to reach high currents and to achieve small tune shifts, tune spreads and beam sizes.

2 - The number of CEs required and the magnitudes of voltage applied to them to achieve optimum beam conditions could not be determined due to large variations in day-to-day measurements.

3 - CEs 2, 6, 9 and 13 located in potential wells [3] are probably sufficient and at times good clearing was achieved with only one or two electrodes. CEs 3, 4, 5, 10 and 12 located in the dipoles [3] are not necessary, probably due to high ion velocities in magnetic fields.

4 - A programable power supply should be installed in the SXLS, since desired clearing voltage depends on injected current. High voltage during low energy injection is detremental.

IV ACKNOWLEDGMENTS

V. REFERENCES

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