SINGLE BUNCH INJECTION SYSTEM FOR AN ELECTRON STORAGE RING USING AN RF PHOTOINJECTOR *

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Abstract
RF photoinjectors have gained acceptance as the source of choice for high-brightness electron accelerators, but have been quite expensive to build and difficult to operate. In this paper we describe the successful operation of an inexpensive, simple and reliable rf photoinjector suitable for single bunch injection into storage rings.

1. INTRODUCTION

For optimum storage ring FEL and Compton backscatter performance on the Duke Storage Ring, we require that the electrons be injected to specified ring rf buckets and no others at up to 1nC per bunch [1].

The Duke Ring operates with a bucket spacing of 5.5 ns. For clean injection, i.e. no spill-over into adjacent buckets, we require a system which has the following features:

- Delivery of beam only during injection with seamless and rapid switching between injection and non-injection mode
- The sum of the full pulse width of the injected beam plus any timing jitter be less than 5 ns
- Capable of being upgraded to 1 nC per pulse.
- Use the existing thermionic rf gun system
- Be easy to operate, reliable and inexpensive

Traditionally such requirements are met by using pulsed electromagnetic kickers [2]. A conventional rf photoinjector with a picosecond mode-locked and frequency multiplied drive-laser [3] could not satisfy the last of the requirements and therefore is unacceptable. Nothing precludes the use an inexpensive, longer-pulse laser in conjunction with a buncher and momentum selector [4]. A 337-nm, TEA nitrogen laser appears to be a suitable candidate. The Duke rf gun [5] previously had a conventional drive laser [6], and so has a port suitable for drive-laser injection, and a LaB_6 cathode of know quantum efficiency. Nitrogen lasers are commercially available for approximately $7000 which can produce 100-μJ of 337-nm light in sub-ns long pulses with sub-ns timing jitter [7].

This system differs from conventional rf photoinjectors a number of ways. Because the drive-laser pulse (600 ps FWHM) is longer than the linac rf period (350 ps for a 2.856 GHz system), there is no pre-bunching of the beam by the laser. Therefore a buncher/momentum filter α-magnet is required after the gun. In this way the system acts like a thermionic rf gun system with enhanced electron emission from the cathode. The system produces a 1-ns macro-bunch of three linac microbunches. The system operates in a single macro-bunch per rf macropulse mode. Unlike conventional drive lasers, no up-conversion of the photon energy is required, because the fundamental emission is at 377 nm.

2. DRIVE LASER

The nitrogen laser is a self contained system which is straightforward to operate. Details of the laser specifications are given in Table 1.

Model	Laser Photonics LN203C
Spectral output (nm)	337.1
Spectral Bandwidth (nm)	0.1
Pulse width (ps, FWHM)	600
Energy per pulse (μJ)	100
Amplitude stability (%)	1
Peak Power (kW)	167
Rep. Rate (max) (Hz)	50
Command timing jitter (ns)	<1
Beam dimensions at laser (mm)	5 x 3
Beam divergence (mrad)	6 x 2
Nitrogen flow rate (STD l/s)	0.016
Laser Dimensions (cm)	71 X 21 x 13

Table1: Drive-laser specification

Apart from AC power, safety interlocks and standard TTL trigger, only a source of dry nitrogen is required. The boil-off from a 500-litre liquid nitrogen Dewar is sufficient for several weeks of laser operation .

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3. SYSTEM CONFIGURATION

The laser was installed within 1 m of the gun so that optical transport would be as simple as possible. The optical transport consisted of a pair of alignment apertures, a 30 cm focal length lens, and two turning flats. The laser beam was focused on the 2-mm diameter single crystal LaB_6 cathode at an incident angle of 45°.

All the lenses and the vacuum window are uncoated glass, and the mirrors are front surface aluminum. Measurements of the electron beam current were made using a fast wall current monitor at the end of the linac at an energy of 270 MeV. The linac is a standard SLAC type traveling-wave linac [8]

4. SYSTEM PERFORMANCE

A summary of the system performance is given in Table 2 . A typical macro-bunch profile is shown in fig.1. The resolution of the signal analyzer was not sufficient to resolve the individual linac micropulses.

RF Macropulse length (μs)	2
Nominal injection energy (MeV)	270
E-beam macropulse length (ns FWHM)	1
Energy spread (macropulse)(%)	0.2
Energy jitter (%)	< 0.1%
Ratio of charge desired ring bucket to neighboring buckets	<0.001
Macropulse rep. rate (Hz)	2

Table 2. Performance of single bunch injection system

The LaB_6 cathode can be operated in a pure thermionic mode, a laser switched photoemission mode, or in a combined mode. A single laser pulse produced a macro-bunch of three linac micropulses. We operated with one macro-bunch in each 2-μs rf macropulse. The macro-bunch pulse duration was short enough that beam loading was not an issue. Therefore, the accelerator was tuned using the thermionic emission set at a very low level. In the photoemission mode, the temperature of the cathode was heated to approximately 1250 K, just below the threshold for significant thermionic emission.

Fig. 2 shows the charge per bunch emitted vs. cathode temperature in both the thermionic mode and the photoelectric mode. The cathode temperature was measured using a hot-wire optical pyrometer [9]. The temperature readings are corrected for the emissivity of LaB_6. With the cathode temperature at the threshold of thermionic emission, the charge per pulse was 0.09 nC. The pulse FWHM was < 1ns. The overall timing jitter of the electron beam relative to the ring rf timing was approximately 2 ns. Therefore the combined pulse length and timing jitter of the injected electron pulse had a full range of 3.5 ns, meeting the specification of < 5 ns combined pulse length and jitter, and resulting in reliable single-pulse injection and stacking.

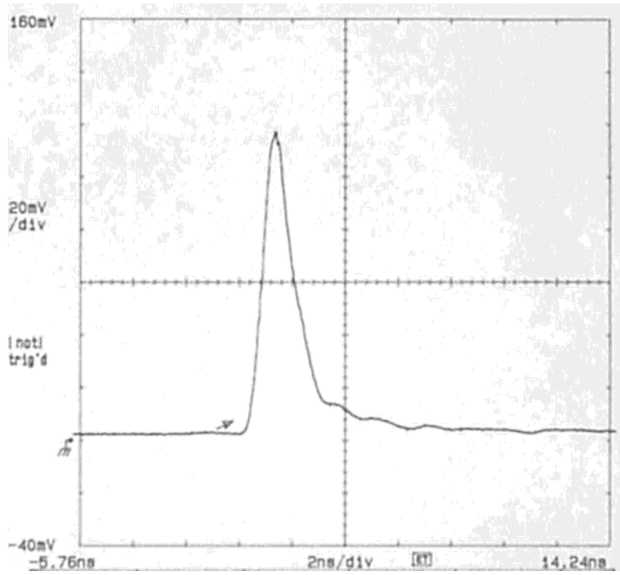

Fig. 1. Electron beam pulse profile as measured on the fast wall current monitor. The measured FWHM is 1 ns.

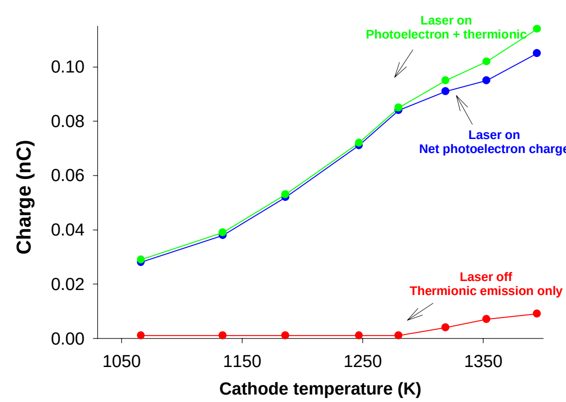

Fig. 2 Charge per bunch versus cathode temperature

5. ESTIMATE OF LaB_6 CATHODE QUANTUM EFFICIENCY

As is evident from fig. 2, we observe as others have [10,11], that the photoemission from the cathode is a function of the applied cathode heater power. When the heater power is lowered the electron current dropped at a rate much slower than the rate of drop of the cathode temperature. On removal of power from the cathode heater, the initial rate of drop in temperature is approximately 250 K/s. The characteristic time for the drop in emitted current is on the order of 10 minutes. We conclude from this that at lower temperatures the cathode was subject to significant contamination because of poor vacuum. The gun is operated at a pressure in the low 10^{-8} torr range. At this pressure, a monolayer will form on the surface in a few minutes (if a sticking factor of unity is assumed).

We did not attempt to measure the quantum efficiency of the cathode directly. We have estimated quantum efficiency of the LaB_6 cathode by using the measured photoelectron current transported to the end of the linac and the known transport efficiency of the linac in the standard thermionic cathode mode. The quantum efficiency (QE) of the LaB_6 cathode is estimated using the following equation:

$$QE = \frac{C_m}{\eta_p \eta_G \eta_\alpha N_p e}$$

where C_m is the measured charge per pulse at the end of the linac; η_p is the efficiency of photon transport from the laser to the cathode; η_G is the gun efficiency (i.e. fraction of the time that the drive laser can produce electrons which are accelerated out of the gun) [11]; η_α is the efficiency of transport of electrons through the α-magnet to the end of the accelerator; and N_p is the number of photons per pulse striking the cathode; and e is the electronic charge. We estimate $\eta_p \approx 0.3$; $\eta_G \approx 0.25$, $\eta_\alpha \approx 0.25$, $N_p = 1.7 \times 10^{14}$.

Fig. 3 shows the inferred quantum efficiency versus cathode temperature. The data for the quantum efficiency represent the stable, equilibrium values at a given cathode temperature. Asakawa et al [12] have reported LaB_6 quantum efficiency data measured at 355 nm from 300-1273 K. For comparison, these data are shown in fig. 3 in the temperature region where they overlap with our data.

6. CONCLUSION

We have demonstrated that a TEA nitrogen laser can provide a simple and reliable method of generating electron pulses for a single bunch injection system. Further plans for improvement of the system include the replacement of the existing optics with UV-grade anti-reflection coated elements, and the procurement of a laser with greater pulse energy, with the goal of achieving 1 nC per macro-bunch.

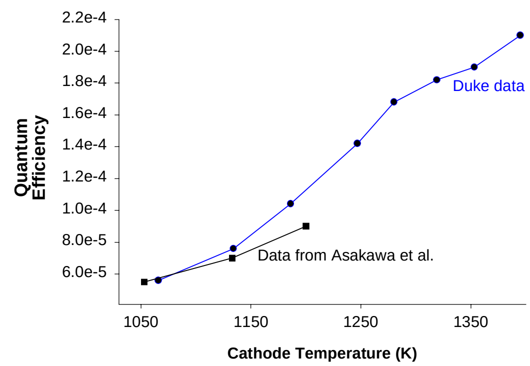

Fig. 3 Inferred quantum efficiency for the LaB_6 cathode versus cathode temperature. Duke data at 337 nm, Asakawa data at 355 nm

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. V.N Litvinenko, et al. *Unique features of the OK-4/Duke storage ring XUV FEL and monochromatic gamma-ray source,* these proceedings
2. Yokoyama, etal., Nuclr. Instr. and Meth. A 341, 367 (1994)
3. P.G. O'Shea, *Nuclr. Inst.s and Meth A*, **358**, 36, (1995).
4. C.B. McKee and B. Hooper, Duke FEL memorandum “Long Pulse photocathode”, unpublished (1993)
5. G.A. Westerskow and J.M.J. Madey, Laser and Particle Beams, vol. 2, part 2, 223 (1984)
6. M. Curtin et al. Nuclr. Instr. and Meth. A296, 127 (1990)}.
7. Laser Photonics, Inc, 12351 Research Parkway, Orlando FL 32626
8. P.G. O’Shea et al., Proceedings of the 1995 Particle Accelerator Conference, 1090 (1996)
9. Microtherm model, manufactured by Pyrometer Instrument Company, 234 Industrial Parkway, Northvale NJ 07647
10. D. J. Banford, M. H. Bakshi, and D. A.G. Deacon, Nuclr. Instr. and Meth. A318, 377 (1992).
11. C.B. McKee, Ph.D Dissertation, Duke University, unpublished (1994)
12. M. Asakawa et al., Nuclr. Instr. and Meth. A331, 302 (1993)}.