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HIGH-BRIGHTNESS PHOTOEMITTER DEVELOPMENT FOR ELECTRON ACCELERATOR INJECTORS*

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ABSTRACT

Free-electron-laser (FEL) oscillators require a train of high-brightness bunches. Conventional subharmonic bunchers are currently used with rf linacs to generate pulse trains, but the resulting dilution of the transverse phase space and lower beam brightness are unacceptable for high-performance FELs. Recent developments suggest that photoemitters of high quantum efficiency combined with rapid acceleration can produce pulse trains of higher brightness than has been achieved before.

DISCUSSION

The prospects for development of high-brightness photoemitters are good. First, the high peak current that a FEL requires has been demonstrated. Recently, a peak current of over 200 A has been demonstrated at the Thermo Electron Corporation, using a 1-cm^2 Cs_3Sb cathode, while at SLAC a current density of 180 A/cm^2 has been produced, using a GaAs photoemitter. Secondly, the average energy of the electrons produced is less than 1.0 eV--only a little more than the thermal energy of 0.1 eV typical of dispenser cathodes. Finally, there is a variety of negative-electron-affinity photoemitters available for which the work function is close to zero. This means that there is a reasonable chance of finding a material that can be used in the demanding environment of an accelerator injector.

At the Los Alamos National Laboratory, a program is under way to develop an rf gun based on a laser-illuminated photocathode in an rf cavity. A mode-locked laser is used to generate electron bunches less than 50 ps in duration and carrying a charge of up to 10 nC. The repetition rate is about 100 MHz. The photoemitter is placed on the end wall of an rf cavity in which longitudinal electric field is about 30 MV/m. The resulting rapid acceleration reduces the time in which space-charge forces can act to degrade the emittance.

Figure 1 shows the normalized transverse emittance of typical electron linacs using subharmonic or other conventional bunching schemes plotted against the peak bunch current in amperes. The goal for photoemitter rf guns is halfway (on a log scale) between current practice with typical linacs and the thermal limit for a bright photoemitter such as GaAs.

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The Los Alamos program is based on a high-quantum-yield photoemitter mounted in a 1300-MHz cavity. The vacuum pressure must be maintained at 10^{-10} torr or lower. The immediate objective of the program is to demonstrate the production of 200-A pulses at a repetition rate of 100 MHz and acceleration to an energy of 2 to 5 MeV with a transverse normalized emittance of about 10 to 30 π mm•mrad.

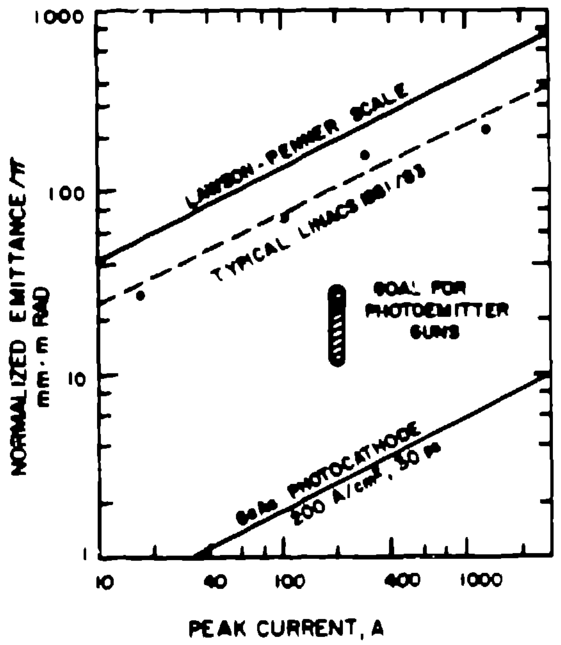

Fig. 1. Normalized transverse emittance vs peak electron current. Scope for possible improvement is indicated by the gap between the thermal limit of a bright GaAs photoemitter and the results obtained from typical linacs.

The transport and acceleration of intense electron bunches in the rf cavity is being simulated with aid of 2D, time-dependent codes. The MASK code is being used in a collaborative effort at SLAC, and the ISIS code is being used at Los Alamos. Figure 2 shows typical output from the code ISIS of the current profile near the photocathode and bunch outlines at two positions.

A conceptual design of an electron injector, an rf gun, and several high-gradient rf cavities is shown in Fig. 3. A magnet at the end of the injector linac deflects the electron beam so the pulsed laser beam can illuminate the photocathode through the linac bore hole.

The Los Alamos injector development program includes the study of a back-up scheme that retains the features of a bright emitter and rapid acceleration of the beam (Fig. 4). A LaB_6 thermionic emitter (with a current density of 200 A/cm^2) is placed in a bimodal cavity excited at 200 and 600 MHz to form pulses of about 1 ns width. The bunches are then rapidly accelerated in high-gradient 200-MHz cavities to an energy of 2 MeV or more. The required bunching to 50 ps is then accomplished with some form of magnetic compressor.

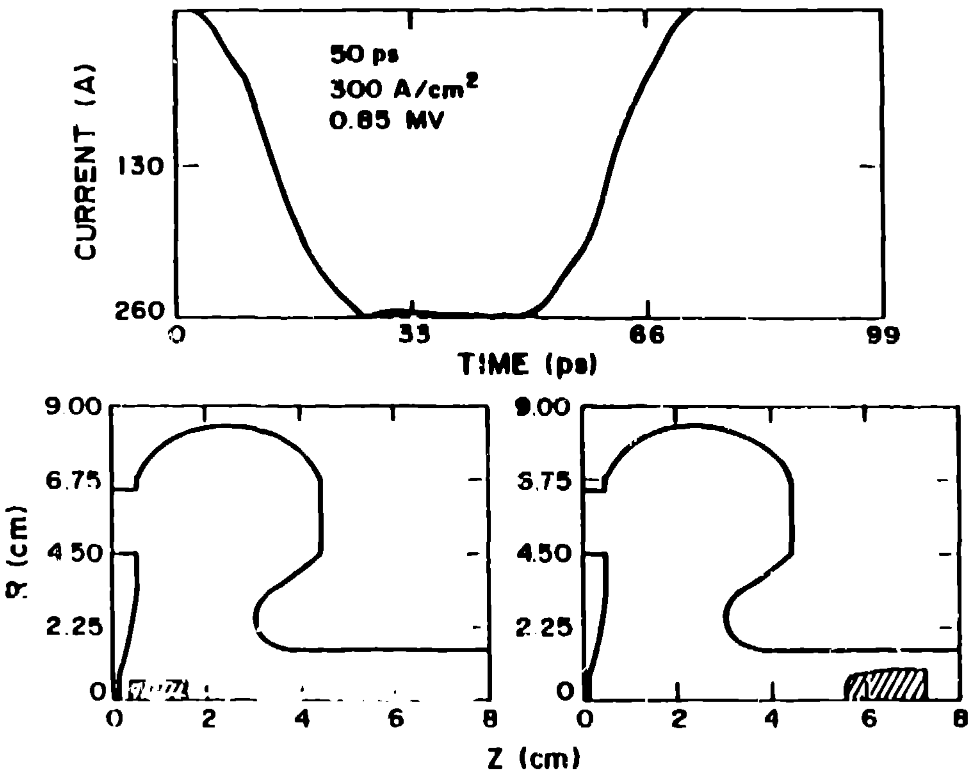

Fig. 2. Current profile and bunch profiles from the 2D, time-dependent code ISIS.

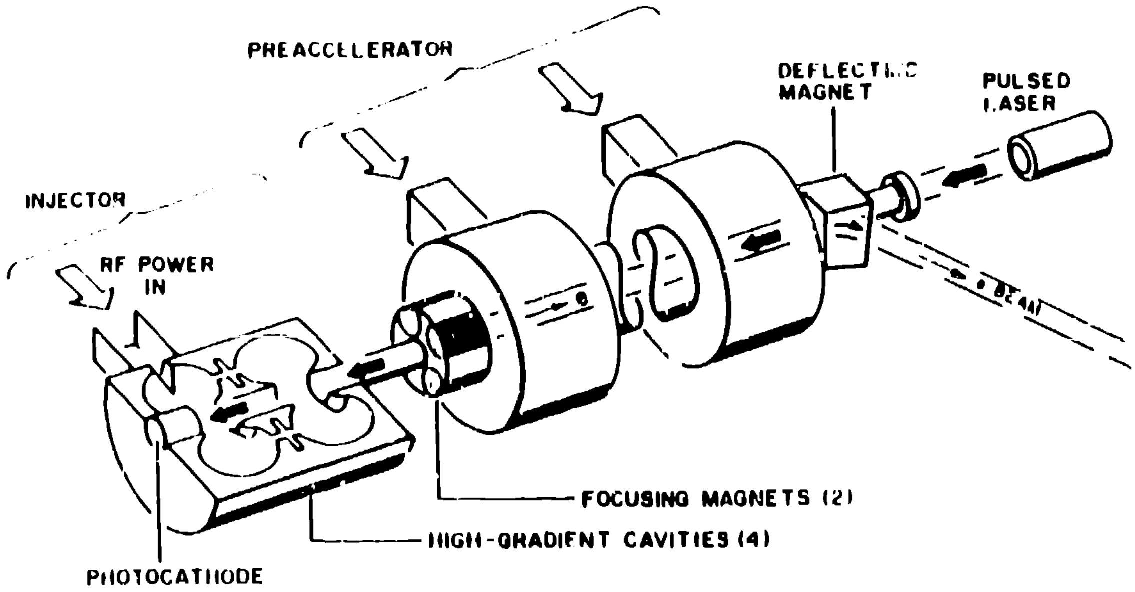

Fig. 3. Conceptual design of an electron injector based on the use of an rf-photocathode gun.

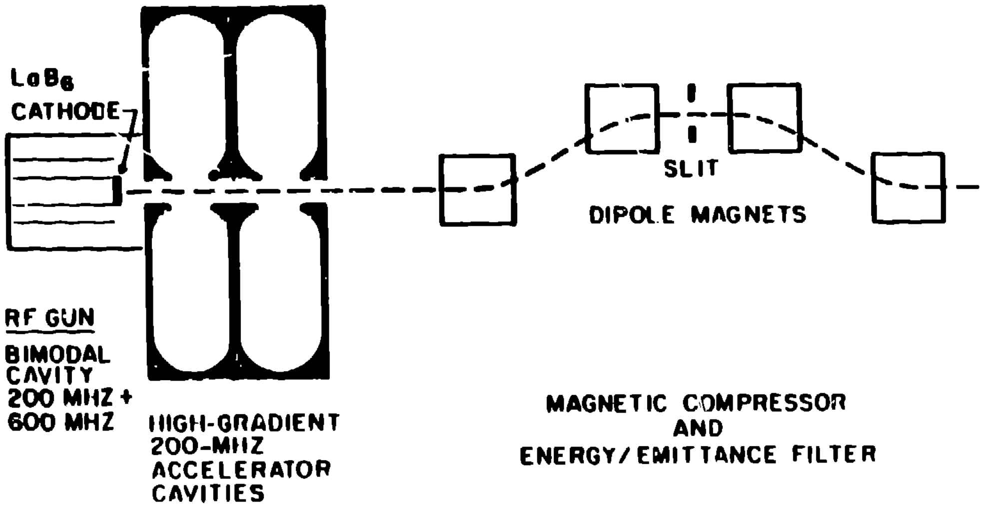

Fig. 4. Schematic diagram of back-up scheme based on a bright thermionic emitter and rapid acceleration of 1-ns bunches followed by magnetic compression.

ACKNOWLEDGMENT

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