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UCRL-85060
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CONF-810314--84

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This paper was prepared for submittal to
the
Particle Accelerator Conference
Washington, D.C.
March 11-13, 1981

March 4, 1981

Lawrence Livermore Laboratory

DESIGN AND PERFORMANCE OF THE 1.5 MV INJECTOR FOR FXR*

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Abstract

The new flash x-ray machine (FXR) at LLNL is scheduled for completion in late 1981. This is a 54 module, linear induction accelerator, designed to deliver 500 Roentgen at 1 m as *bremsstrahlung* from a 20 MeV, 4 kA, 60 ns pulsed electron beam. The 1.5 MV, cold cathode injector makes use of six accelerator modules as voltage sources. High voltage testing of the accelerator modules and their associated pulse forming lines and Marx banks has been completed, and beam tests of the complete injector assembly are in progress. Design information and preliminary test results are presented.

Introduction

The FXR linear induction accelerator is expected to produce bremsstrahlung from a 4 kA, 20 MeV, 60 ns electron beam pulse that will deposit a flash x-ray dose of 500 Roentgen at one meter from the production target. This will improve the radiographic capability at LLNL by nearly an order of magnitude, thereby allowing improved experimental validation of the computational models that are used in nuclear weapons design. The modular construction of FXR allows later expansion that should provide still greater enhancement of the available radiation dose.

The cold cathode injector uses six induction modules as power sources that are essentially identical to the 48 accelerator modules used in the remainder of the machine. The high voltage performance and the reliability of one four-module tandem arrangement was tested extensively in a series of 10^5 shots at 400 kV per module. Beam tests on the injector are still in progress. The entire machine is expected to be completed in September 1981. This paper will summarize the basic design considerations and the validating test results on the injector assembly, including the pulsed power conditioning, the diode design, and initial results of the beam tests. For the electron optics design, extensive use was made of computer simulation; these details are covered in a companion paper (Ref. 1).

Injector Design

The injector contains six induction modules in series to generate the 1.5 MV diode potential. A photograph of the injector assembly is shown in Fig. 1, and Fig. 2 gives a schematic of the arrangement. The voltage contributions of four modules, at 250 kV each, are summed along the cathode stem as it threads through the four units, and similarly two more power modules contribute to the potential appearing at the tip of the hollow anode stem. The anode aperture is closed off with fine (60 lpi) tungsten mesh, approximating a planar-diode geometry for the central portion of the beam. The cathode (Fig. 3) is a 90 mm dia., convex, spherical cap to which has been brazed a 50 turn spiral of 0.03 mm tantalum foil, with successive turns spaced 0.8 mm apart. The nominal A-K spacing is 3.75 cm. The diode design assumes Child-Langmuir behavior, once the cold cathode has been turned on through field emission followed by the explosive burning of microprotrusions at the foil tips. The total emitted current is nominally 15-20 kA at 1.5 MV, giving a diode impedance near 100 ohms. This impedance constitutes a mismatch to the tandem source modules which have an effective surge impedance of 6-8 ohms each. However, the taper of the cathode and anode stems is such that energy reflected from the diode back towards the sources should be absorbed completely.

Earlier experiments on a similar, 2-3 kA, 1 MV diode (Ref. 2) had shown that it was useful to collimate the emitted beam through a beam scraper, as this would improve the beam quality by eliminating the relatively high-emittance outer layers of the beam envelope. Using the same approach on the FXR injector, the emitted beam is collimated to a 40 mm dia. immediately behind the anode mesh, leaving roughly 4 kA to travel down the hollow anode stem, guided by the magnetic field of the focusing solenoids. The aluminum collimator is water-cooled.

An important constraint on the design of the anode and cathode stems was the field stress, especially near the gaps, which was kept below 200 kV/cm in order to avoid stray field emission from negative surfaces other than the cathode itself. This forced a choice, first, of 250 kV maximum voltage per module, rather than the 400 kV per module that is used elsewhere in the machine. Second, the inner diameter of the four modules housing the cathode stem was increased from 147 mm to 241 mm by eliminating the (unneeded) space for the focusing solenoids, as this reduced the field stress on the cathode stem significantly.

The cathode current, the total emitted current, and the collimated current are measured, respectively, by current viewing resistors (CVR's) at the cathode end and at the anode end of the injector assembly. Two cryopumps maintain a vacuum in the 10^{-6} range. All solenoids are wound with water-cooled, 6.5 mm square, hollow copper conductor.

Pulsed-Power Conditioning

A schematic representation of the FXR accelerator module is shown in Fig. 4. This module is basically a reentrant coaxial cavity with the center post driven negative from two symmetrically placed, coaxial feed lines, and loaded in quadrature to the feed lines by two ballast loads. The latter are 50 mm dia. copper sulfate columns, with the electrolyte recirculated externally for monitoring and cooling. The center post is filled with 14 ferrite toroids, 25 mm thick, that provide a sufficiently large volt-second product to support a 400 kV, 90 ns FWHM applied pulse. At the end of this pulse, the ferrite saturates and the driving voltage is shorted out through the ferrite housing. The accelerating potential appears across the 45 mm wide gap on the vacuum side of the cavity. An epoxy insulator separates the vacuum from the oil side; the latter contains the ferrite and the connections to the feedlines and ballast load housings which are also filled with oil. The oil

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract number W-7405-ENG-48.

volume routinely is evacuated before being filled with the vacuum degassed oil, in order to forestall bubble formation which could lead to voltage breakdown. The cavity also contains an integral solenoid that is capable of producing up to 2000 Gauss, central field on axis. In the injector assembly, only the anode cavities contain such solenoids. Nominal peak field stresses at 250 kV gap voltage are 60 kV/cm on the inner lip of the gap; 40 kV/cm along the upper corner of the epoxy insulator; and 90 kV/cm along the inner diameter of the ferrite toroids, under oil.

Figure 5 illustrates the Blumlein-feed line assembly, one of which drives each accelerator cavity. The water-filled, ten ohm Blumlein is charged to 260 kV and then discharges into the symmetrical 20-ohm feedlines and, hence, into the cavity. As the gap loading due to the emitted current in the injector typically is on the order of 13-17 ohms, some of the Blumlein energy must be absorbed by the ballast loads. The six injector Blumleins are charged from a common, five-stage Marx bank, with a charging period of 1.8 μs. The charging current is in the right direction to reset the ferrite in the cavity; however, the resetting ferrite also causes an opposite-polarity prepulse to appear across the diode which is undesirable and, hence, must be minimized by limiting the charging current amplitude. Both the Blumlein and part of the feedline assembly use water as a dielectric; this water is filtered, deionized and degassed continuously, maintaining a resistivity on the order of 10 megohm-cm. Again, great care is taken to prevent the trapping of bubbles anywhere, especially while the oil and the water are being transferred into their respective housings.

We use a commercial spark gap to switch the middle Blumlein conductor to the outer. This is a coaxial midplane gap, that has been well-proven at 300 kV charging voltage levels, using SF_6 pressurization at 40-60 psi. The SF_6 is recirculated continuously. The gap is triggered through shorting a charged cable length, with the latter being charged from a tapoff near the electrical center of the Marx bank. By using appropriate cable lengths, the firing times of the six injector Blumleins are set to provide simultaneous arrival at the diode gap of the six voltage contributions. The heavy currents carried through the banana-type connectors to the spark gap electrodes have in the past caused erosion of the spring contacts; these contacts have since been gold-plated which seems to solve the problem.

The high voltage limit of a tandem arrangement of four modules was tested by energizing to 530 kV gap voltage for some tens of shots without breakdown. In addition, a life test of 10^5 shots was run at 400 kV that was used to derive statistical data on the switch gaps when operating under normal conditions.

Beam Tests on the Injector

Twenty shot overlays of typical pulse shapes measured on the injector assembly are shown in Fig. 6. With the ballast loads set at 60 ohms each, or 30 ohms total, the equivalent surge impedance of each source module is reduced to 7.5 ohms. The Blumleins then are charged to 260 kV in order to get a gap voltage of 250 kV with 15 kA emitted current. A single gap voltage pulse is represented in Fig. 6a; this trace actually shows the current pulse going into a ballast load, and hence is proportional to the cavity voltage. Figure 6b shows the emitted current pulse; the small pip at the beginning of the pulse is due to displacement current charging the anode stem-to-wall capacitance. The collimated current (Fig. 6c) does not show this pip.

Emittance measurements were made, using a perforated, 1 mm thick brass plate as the collimating target and measuring the expansion and the lateral divergence of the individual beamlets. From this measurement, the emittance is estimated to be 65 mr-cm, integrated over the entire pulse width for a 3.4 kA beam.

As the ferrite discs are being reset through the Blumlein charging current, a reverse polarity pulse appears across all the cavity gaps. These contributions may add up to a considerable prepulse voltage amplitude at the diode gap. We have measured up to 600 kV peak prepulse potential; however, simultaneous current measurements have disclosed no emitted current from the anode.

Conclusion

High voltage and beam tests on the FXR injector have reasonably demonstrated the predicted behavior on the emitted current, showing good repeatability and pulse shape. Emittance measurements have shown good beam quality, on the order of 65 mr-cm for a 3.4 kA beam.

Acknowledgments

The design and test phases of the FXR injector have benefitted from the capable efforts of many members of the FXR project team. The successful layout, wiring, and operation of the injector test stand were due largely to the work of R. Kihara, ably assisted by L. Booth and J. Claar.

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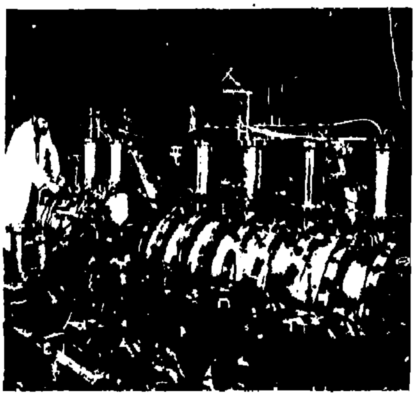


FIGURE 1. The FXR injector, seen from the cathode end.

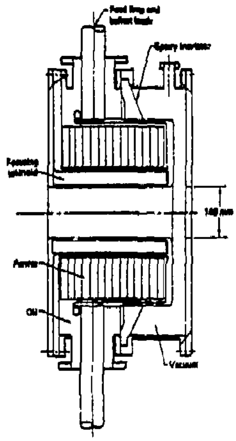


FIGURE 4. The FXR induction module.

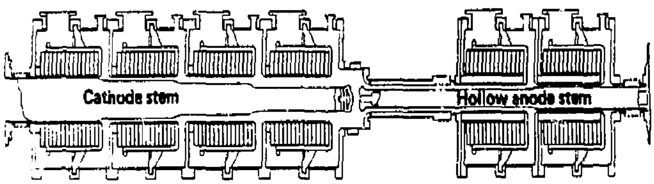


FIGURE 2. Schematic of FXR injector.

FIGURE 3. The cathode button, consisting of 0.03 mm tantalum foil wound into a 9 cm dia. spiral and brazed to a convex, spherical cap.

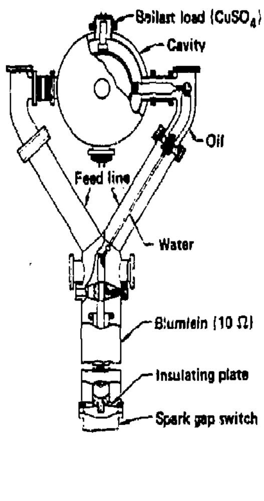
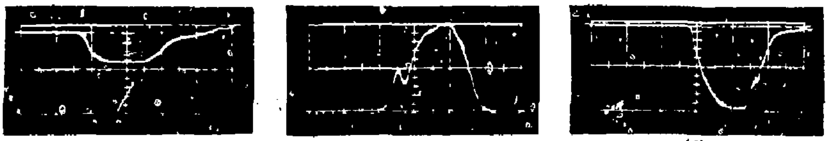


FIGURE 5. The FXR power module, including induction cavity, feedlines, and Blumlein pulse line. The Marx bank is not shown.



(A) (B) (C)

FIGURE 6. Injector pulse shapes, showing 250 kV voltage pulse per module (A); 15.1 kA emitted current pulse (B) and 3.1 kA collimated current pulse (C). These are twenty-shot overlays. The time scale is 50 ns/div.