IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

RECENT PERFORMANCE IMPROVEMENTS ON FXR*

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Abstract

The FXR machine is a nominal 4 kA, 20 MeV, linear induction, electron accelerator for flash radiography at LLNL. The machine met its baseline requirements in March 1982. Since then, the performance has been greatly improved. We have achieved stable and repeatable beam acceleration and transport, with over 80% transmission to the tungsten bremsstrahlung target located some 35 m downstream. For best stability, external beam steering has been eliminated almost entirely. We regularly produce over 500 Roentgen at 1 m from the target (TLD measurement), with a radiographic spot size of 3-5 mm. Present efforts are directed towards the development of a 4 kA tune, working interactively with particle-field and beam transport code models. A remaining uncertainty is the possible onset of RF instabilities at the higher current levels.

Introduction

Since its commissioning in early 1982, the FXR induction linac[1,2] has undergone important changes. Many of these addressed weaknesses that became apparent during the first few months of running the machine. The goal was primarily to achieve reliable and repeatable operation of the basic pulsed-power system, and consequently, to facilitate accurate tuning of the beam transport. These changes will be discussed in this paper.

Modifications to the Pulsed Power System

The FXR pulsed power system converts the line power from the AC mains into high-voltage pulses that ultimately result in the nominal 20 MeV, 4 kA, 5 kJ beam pulse. The basic pulse power train (Fig. 1) is capable of a 1/3 Hz repetition rate to facilitate tuning. A 100 nF Marx bank is bipolar-charged to ± 35 kV and discharged into four (or for the injector, six) Blumlein pulse-forming lines in parallel, over a 1.8 μs interval. The 10 ohm, 18 nF, water-filled Blumleins in turn are command-triggered to produce a 90 ns FWHM output pulse that energizes the accelerator cavities. A large fraction of the stored energy is dumped into 30-40 ohm ballast loads that help to improve the impedance match and to stabilize the accelerator potential. Fourteen toroidal ferrite cores that form part of the coaxial cavity geometry prevent the applied Blumlein pulse from being shorted out prematurely through the metal cavity walls. The basic Marx-Blumlein pulse compression scheme was pioneered by J. C. Martin at AWRE in the 1950's and has been used many times since then. However, a synchronized array of 54 water-filled Blumleins, charged in sets of four or six from single Marx banks, and discharged at the 300-400 kV level, had not heretofore been built, and the successful, low-jitter operation of this system did require some development effort.

Marx Spark Gap Switches. The Marx spark gap switches (six switches for each of 14 Marx banks)

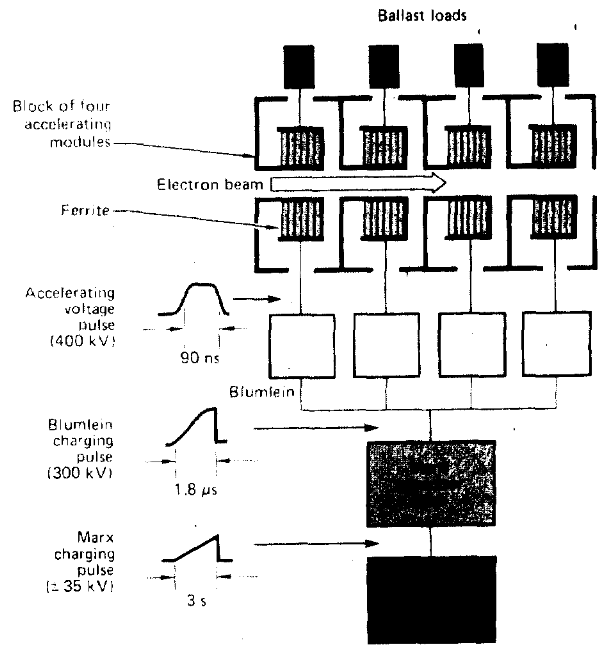


Figure 1. Basic pulsed-power train for FXR.

are planar midplane gaps, with the three electrodes spaced by short segments of 5-inch O.D. polycarbonate tubing. The assembly is held together by 1/2-inch, threaded rods, and pressurized to 30-60 psi (air). When it became apparent that the original design, polycarbonate rods would crack and eventually break from the stress of a few thousand shots, we replaced them with stronger, epoxy-fiberglass material. The midplane electrodes carry illuminator pins which produce a small spark along the inner diameter prior to application of the main trigger pulse. These electrodes are held on the end of thin, insulated brass rods that traverse the midplane electrode body radially. The original, split rods were connected by a spring contact which would periodically open and so prevent the gap from firing. These illuminator electrodes were redesigned to eliminate the spring. We also found that a modest amount of air pressure must be maintained continuously in the Marx switch gaps in order to prevent insulating oil from leaking into the gaps, thus, when the air compressor is lost due to a power outage, an automatic crossover valve now connects the system to a compressed-air bottle farm. Other changes included the installation of special safing terminals on the capacitors, and of an oil supply and return manifold to which all Marx tanks are permanently connected.

Marx Charging Resistors. As delivered, all Marx charging resistors (50-500 ohm range, 1 inch diameter) were of the uncoated carborundum variety. These resistors caused much difficulty as they would

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

0018-9499/83/0800-3030$01.00© 1983 IEEE

disintegrate, sometimes dramatically and after only a few pulses, contaminating the oil volume in the Marx tank and necessitating tedious pumping, filtering, and cleaning operations. A possible explanation is that oil penetration into the uncoated resistors is not always uniform, leaving voids that arc over and cause local overpressure. We also found that arcing in partially failed resistors could cause false triggering of nearby spark gap switches, leading to early erection of the Marx bank or to prefires in the Blumlein or Stage II (intermediate triggering) gaps. These resistors were replaced with a more trouble-free, epoxy-sealed variety where oil is excluded from the conducting volume. Pairs of 30 ohm, carborundum resistors were originally used for damping two Marx banks after charging and firing the two sets of 13 high-voltage cables that trigger and synchronize the charging Marxes and the Blumlein switches. Here it was found that even the epoxy-coated variety of resistors did not stand up under the stress, and new, wirewound resistors were designed and built as a substitute. Earlier experience also had indicated a poor survival rate for a set of six-inch long, 15 ohm, carborundum resistors that were mounted in series with each trigger cable in order to damp out cable-to-cable ringing. These resistors were replaced with short segments of Schedule 80 plastic pipe, filled with NH_4Cl solution, sealed, and capped with specially designed, high-voltage connectors.

High-Voltage Hold-off in Blumleins, Feed Lines, and Cavities. Early on it had been discovered that in order to prevent air pockets and subsequent voltage breakdown at the upper feed line insulators (water-oil interface), it helped to throttle down the flow of high-purity water through the lower part of each Blumlein. However, the resultant stagnation of water allowed debris to collect over the lower Blumlein insulators, causing eventual breakdown and tracking. All these insulators were removed and resurfaced as necessary to remove the tracks. In addition, the water flow pattern was improved by installing a different, more efficient manifolding system.

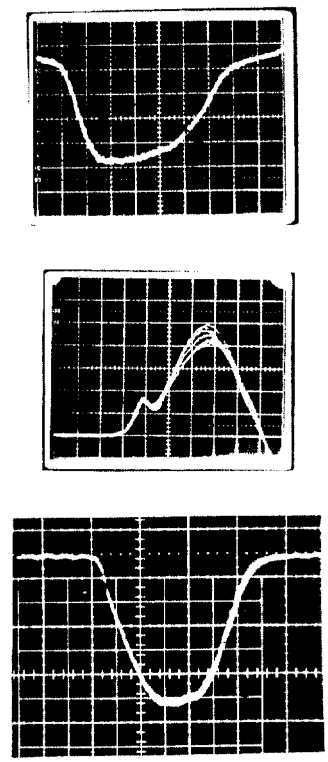
Switching System and Synchronization. The FXR switching system includes thyratrons, small Marx generators, and pressurized spark gaps. The basic synchronization is built into the machine through calibrated, charged lengths of high-voltage cable that trigger the switch gaps either singly or in groups, depending on the stage of the fanout. Through the use of our automated diagnostics, we initially discovered significant timing errors such as offsets up to 10 ns in one group of spark gaps. By centering certain midplane electrodes to within 5% of the interelectrode spacing, by adjusting the electrical bias, and by optimizing the gas pressures, we corrected the timing offsets and reduced the jitter to $\sigma \leq 1$ ns for all gaps. Table I gives some typical pressure-voltage combinations for the FXR switching system.

TABLE I. Typical Voltage/Pressure Combinations for FXR Switch Gaps

Element or Gap	Applied Voltage	Gas Pressure
Thyratron	15 kV	N/A
Minimarx	25 kV	32 psi (air)
Charging Marx	32-38 kV	45-55 psi (air)
Stage I	120 kV	65 psi (air)
Stage II	150 kV	30 psi (SF_6)
Blumlein	300 kV	45 psi (SF_6)

Beam Transport and Radiographic Performance

The FXR injector contains six induction modules in tandem to generate the 1.5-1.7 MV potential across a nearly planar, cold cathode diode. The 10-20 kA emitted beam is collimated immediately following the anode mesh, leaving 2-4 kA to travel down the hollow anode stem. Figure 2 shows ten-shot overlays of the diode voltage and current and of the collimated current pulses. While the peak current variation on the emitted current may range up to 30%, this variation fortunately seems to stem mostly from the outer edges of the cathode and, hence, does not appear to affect the collimated current amplitude.



(a) Diode potential, 360 kV/div. (1.55 MV peak, inverted).

(b) Emitted current, 3.76 kA/div. (15.8-18.4 kA peak).

(c) Collimated current, 453 A/div. (2.8 kA peak, inverted)

Figure 2. Diode potential, emitted current, and collimated current overlays for a series of 10 pulses at 15 sec intervals (Shots No. 12917-12926), 20 ns/div.

Although guided somewhat by code modeling and analysis, the actual tuning of the FXR beamline has remained a largely empirical exercise. We observe the beam current and the position of the beam centroid on successive, axisymmetric current viewing resistors that are placed after every block of four accelerator modules. The beam transmission and centering are then optimized by varying the solenoid excitations and by energizing selected transverse steering magnets. The measured beam transmission from injector to target now is better than 90% at the 2.6 kA level. Transverse beam steering for this tune is applied in only two places, i.e., following the 20th and the 44th accelerator modules. A typical two-quadrant sum signal from the beam current monitor immediately preceding the target is shown in Fig. 3. On this particular pulse, we measured a radiation dose of 550 Roentgen at one meter from the bremsstrahlung target. The dose on axis depends on the excitation of the final focusing magnet which controls the beam diameter at the

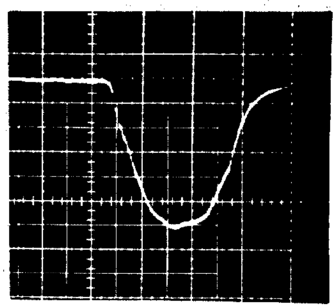


Figure 3. Typical sum signal from the beam current monitor immediately preceding the target. Shot No. 13069, 20 ns/div., 453 A/div. (2.7 kA peak, inverted). Beam energy is 17.6 MeV.

target; the largest dose measured to date is 680 Roentgen at one meter. Direct measurements of the radiographic spot size were made by observing the fuzzy edge of the X-ray shadow cast by an opaque (uranium) bar.[3]

In an attempt to tune for higher currents on target, we extracted current pulses of 4.1 kA at 1.6 MeV from the injector. This beam proved difficult to transport much beyond the first half of the machine. Project deadlines discouraged further pursuit of this tune, and we concentrated instead on tuning at the 2.5-3 kA level. Through careful measurements with B dot probes which are placed after every 16 modules, we satisfied ourselves that no RF beam breakup instabilities are excited at the lower current level, but it is not clear whether beam transport at the higher current was in fact prevented by such instabilities. Table II lists the present best operating parameters for the FXR machine. For most shots, the focused beam will damage the target. Figure 4 shows a display of used 0.75 mm thick tungsten platelets which were taken from our 18 target, rotatable array.

TABLE II. FXR Operating Parameters, March 1983

Injected current, energy, pulse width	2.8 kA, 1.6 MeV, 75 ns FWHM
On target current, energy, pulse width	2.6 kA, 18 MeV, 70 ns FWHM
Radiation dose per pulse, at one meter	550 Roentgen
Radiographic spot size	3-5 mm

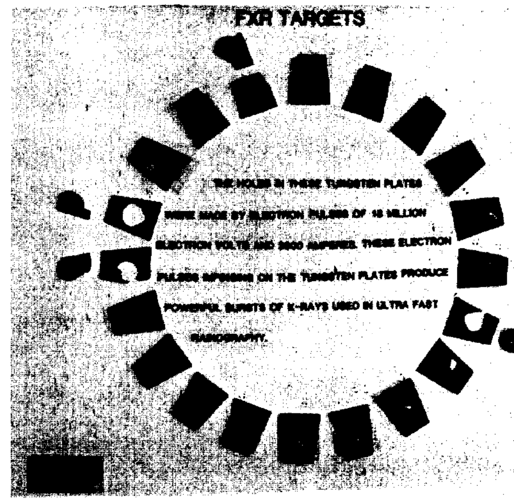


Figure 4. Tungsten target platelets, each damaged by a single pulse, arranged approximately as in the FXR rotatable target array.

Conclusion

Improvements to the pulsed power system of FXR that were made over the past year have resulted in much better reliability and repeatability. At a current level of 2.6 kA on target, the machine produces a radiation dose of 550 Roentgen at one meter, with a spot size of 3-5 mm.

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