RECENT ADVANCES IN KICKER PULSER TECHNOLOGY FOR LINEAR INDUCTION ACCELERATORS

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Abstract

Recent progress in the development and understanding of linear induction accelerator have produced machines with 10's of MeV of beam energy and multi-kiloampere currents. Near-term machines, such as DARHT-2, are envisioned with microsecond pulselengths. Fast beam kickers, based on cylindrical electromagnetic stripline structures, will permit effective use of these extremely high-energy beams in an increasing number of applications. In one application, radiography, kickers are an essential element in resolving temporal evolution of hydrodynamic events by cleaving out individual pulses from long, microsecond beams. Advanced schemes are envisioned where these individual pulses are redirected through varying length beam lines and suitably recombined for stereographic imaging or tomographic reconstruction.

Recent advances in fast kickers and their pulsed power technology are described. Kicker pulsers based on both planar triode and all solid-state componentry are discussed and future development plans are presented.

I. INTRODUCTION

Although direct application of Faraday's Induction Law as a means to accelerate particles in a circular orbit in a changing magnetic field [1] was utilized early in the history of accelerators, the technique was not successfully applied to linear acceleration until the mid 1960's [2]. Advances in pulsed power technology have enabled this technology to steadily develop. Modern induction linacs find application [3] in fields such as heavy ion fusion, advanced radiography, and advanced rf sources for next-generation linear colliders.

Stanley Livingston [4] began the practice in the late 1950's of plotting peak particle accelerated energy as a function of time as accelerator technology matured. Such Livingston Charts have been extended [5] by modern researchers. Using more appropriate figures of merit for induction linacs, an analogous graph of either beam power or beam energy per pulse can be generated. As a function of the year in which the machine came on line, Fig. 1 plots points for Astron [2], ERA [6], FXR [7], ATA [8], ETA-II [9], FXR-Upgrade [10], DARHT single axis [11], and DARHT-II [12]. Although a significant degree of spread exists among these special-purpose machines, a general trend of doubling every 6-7 years seems apparent.

Fast beam kickers and the pulsed power technology to drive them are an enabling technology in the full utilization of induction linac power, particularly for advanced radiography applications.

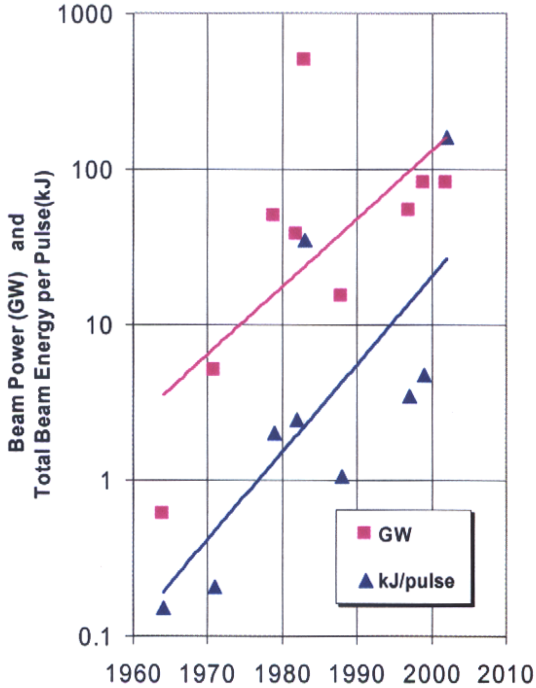

Figure 1. Beam power in GW and beam energy per pulse in kJ plotted vs. time for induction linacs.

II. KICKER REQUIREMENTS

Kicker technology has evolved [13-16] to a topology analogous to stripline-based beam position monitors. LLNL kickers (Fig. 2) have demonstrated the ability [17] to control beam direction on nano-second time scales.

Kickers for radiography applications are being developed (Fig. 3) in the 10-15 kV, 200-300 A range that present a 50-ohm load to the pulser. Pulse widths from 20-200 ns are nominal. Although the overall e-beam rise and fall time is also a function of the kicker's "fill time", fast rise and fall times from the kicker pulsers is critical to ensure a minimum of beam interception within the accelerator structure. A 10-90% specification for pulser rise and fall time that is currently in use is 10 ns.

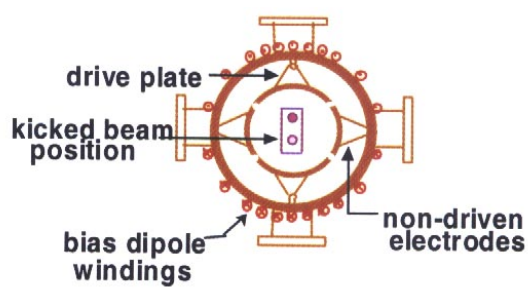

Figure 2. Schematic of stripline kicker with coaxial feeds and dc bias windings.

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14. ABSTRACT

Recent progress in the development and understanding of linear induction accelerator have produced machines with 10s of MeV of beam energy and multi-kiloampere currents. Near-term machines, such as DARHT-2, are envisioned with microsecond pulselengths. Fast beam kickers, based on cylindrical electromagnetic stripline structures, will permit effective use of these extremely high-energy beams in an increasing number of applications. In one application, radiography, kickers are an essential element in resolving temporal evolution of hydrodynamic events by cleaving out individual pulses from long, microsecond beams. Advanced schemes are envisioned where these individual pulses are redirected through varying length beam lines and suitably recombined for stereographic imaging or tomographic reconstruction. Recent advances in fast kickers and their pulsed power technology are described. Kicker pulsers based on both planar triode and all solid-state componentry are discussed and future development plans are presented.

15. SUBJECT TERMS

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Figure 3. ETA-II kicker viewed with ends and coaxial connections removed.

III. KICKER PULSER DEVELOPMENT

Fast pulsers have previously been developed [18-20] in conjunction with the ATA program to support both an Injection Current Modulation scheme and a Fast Correction Coil scheme to correct for time-dependent beam transverse motion effects such as corkscrew motion. Both approaches were based on Eimac YU-114 planar triode pairs in cascode with a fast DEI FET. The FET was driven by a wideband op-amp followed by an rf transistor in an emitter follower configuration. This basic circuit (Fig. 4) was packaged on a 45-degree wedge-shaped sector. The outputs from 8 such sectors were paralleled and output to a 50-ohm coax. These compact units (Fig. 5) have been adapted to ETA-II kicker experiments and have proven a reliable kicker pulser.

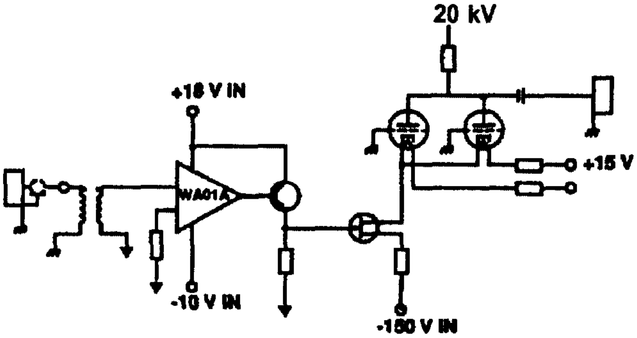

Figure 4. Simplified schematic of a single sector of the FET and planar-triode based fast pulser design.

In an effort to extend the linearity of these pulsers for finer beam control, a new design [21] based on two stages of planar triodes was implemented. The output stage is a parallel array of 18 Eimac Y-820's, a production version of the YU-114. The intermediate stage is based on developmental YU-176 tubes. A diagram of 1/3 of the final circuit is shown in Figure 6. The tubes of both stages are operated in grounded cathode configuration and a semi-rigid coax-based transmission line transformer is utilized for impedance matching between stages. The design also takes advantage of fast linear hybrid micro-circuit technology developed for high-resolution CRT

Figure 5. Photograph of the compact FET and planar-triode based fast pulser design.

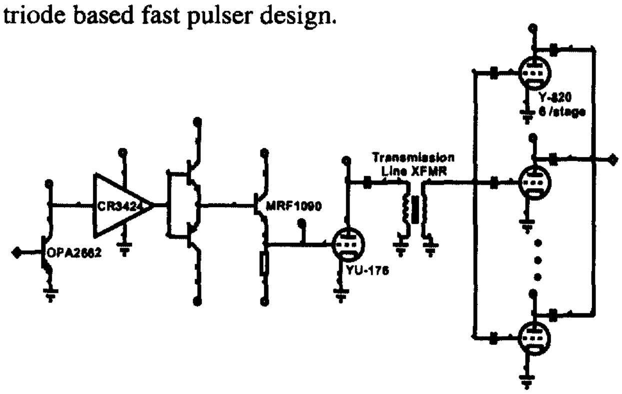

Figure 6. Simplified schematic of new planar triode-based kicker pulser with improved linearity.

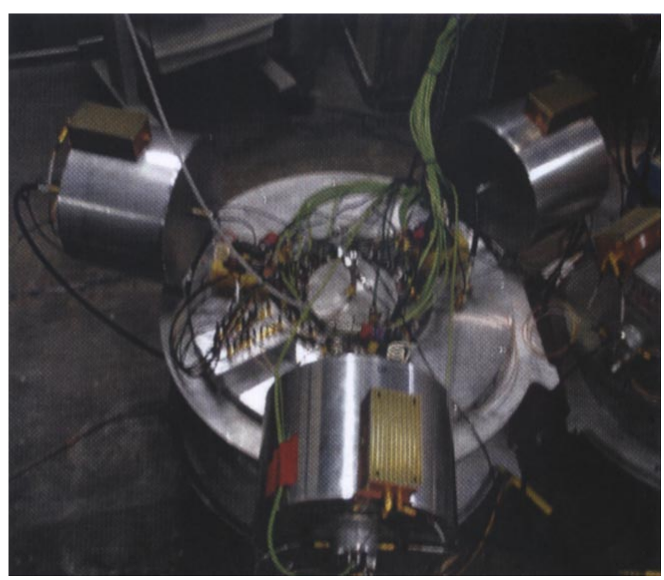

Figure 7. Photograph of improved-linearity kicker pulser.

displays. This linear hybrid is driven by an operational transconductance amplifier to form the bulk of the input stage. The completed design (Fig. 7) has recently proven to be stable over a wide dynamic range (Fig. 8) and capable of high bandwidth amplitude modulation (Fig. 9).

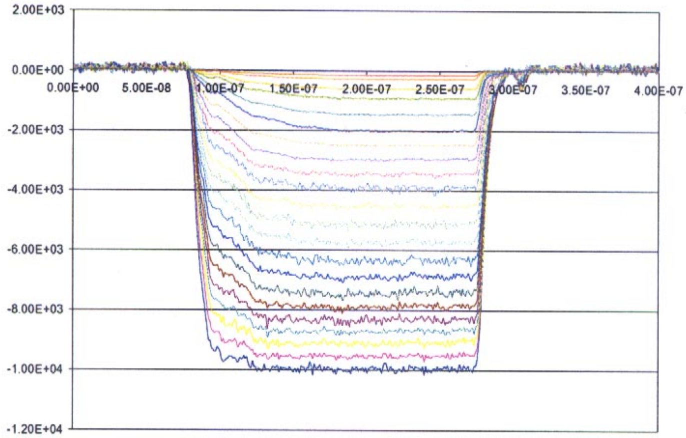

Figure 8. Overlaid 200-ns output pulses for varying drive levels to the improved linearity kicker pulser.

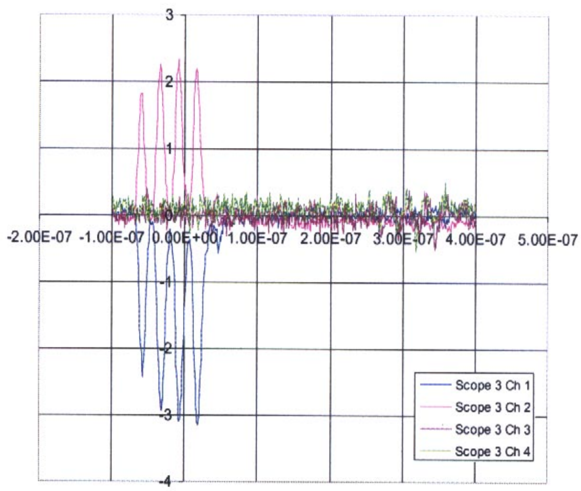

Figure 9. 100-ns pulse demonstrating 100% modulation at 40 MHz from the improved linearity kicker pulser.

IV. ONGOING WORK

In recent years, our supply of high-frequency planar triodes has become increasingly uncertain. Particularly when designing for accelerators with an anticipated lifetime measured in decades, it seemed necessary to develop an all solid-state kicker pulser design to ensure long-term system maintainability. Based on the ARM-II [22] modulator technology (Fig. 10) the new kicker pulser will be comprised of multiple, stacked modulators based on Metglas cores whose output is inductively added on a voltage-summing center stalk (Fig. 11). A capacitive energy store is switched through a modern enhancement-mode MOSFET. Each stacked cell must be capable of full-current operation and so is comprised of multiple FETs. This manifold parallelling of FETs has been successfully demonstrated on ARM-II [22].

Initial tests with the STMicroelectronics STW5NB100 from have been encouraging (Fig. 12). The FET gates are driven by a Siliconix totem-pole driver following an Elantec level shifter. Newer FET devices from IXYS and APT promise enhanced performance. Analog control to the ±10% level felt necessary for electron beam control will be provided by 2-4 stacks of analog modules, presently envisioned as "voltage subtractors" and utilizing FETs biased in their linear region.

Figure 10. ARM-II inductive adder implementation.

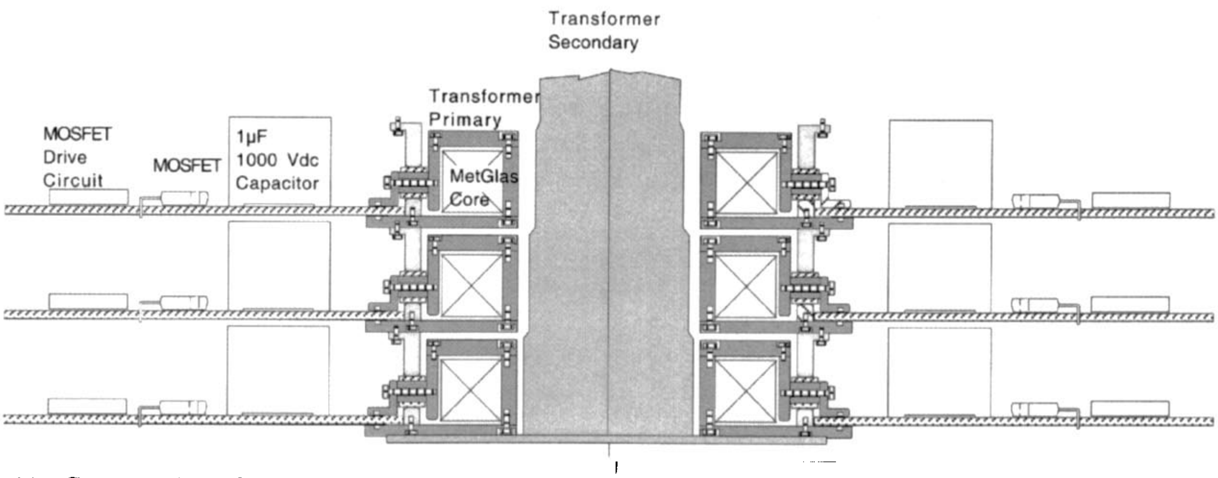

Figure 11. Cross-section of stacked modules making up an all solid state kicker pulser based on ARM-II technology.

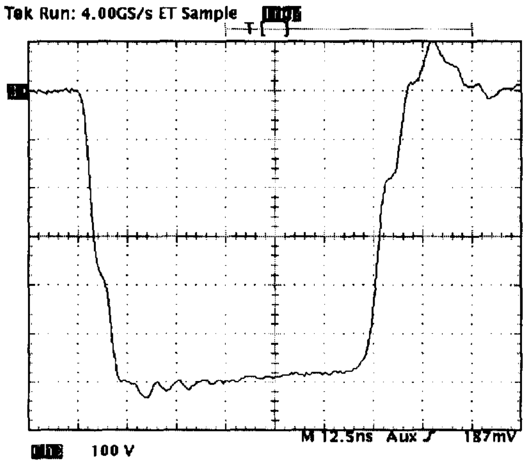

Figure12. 60-ns pulsed response of partial FET assembly and core envisioned for an all solid-state kicker pulser.

The beam control algorithm (Fig. 13) currently being implemented will also correct for non-linearities in the pulsers and for cable dispersion effects.

V. ACKNOWLEDGEMENT

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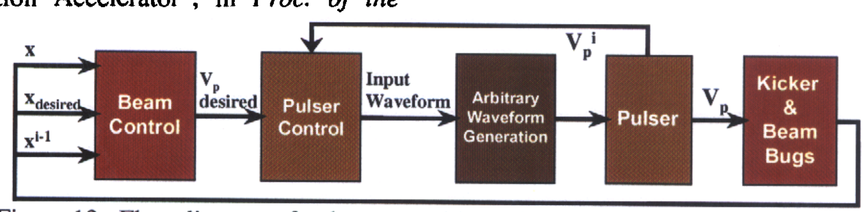

Figure 13. Flow diagram of pulser control logic for integrated beam/pulser control.