ADAPTATION OF THE ISIS INDUCTION-CELL DRIVER TO A LOW-IMPEDANCE *X*-PINCH DRIVER

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Abstract

In this paper we summarize the work done to design a system to non-destructively convert the Idaho State Induction System (ISIS) induction cell driver (ICD) to a low impedance pulse power driver for *x*-pinch applications. The simulation results show that such a driver can supply about 300-kA peak current with about 70-ns rise time (10-90%). However, simulations also show that the negative reflective wave is formed, which can cause the destruction of the ISIS ICD's pulse forming line (PFL). Particular attention was taken to simulate the effect of misfire of one of the PFLs. To reduce the amplitude of this destructive wave, high power damping resistors should be placed after the output of each PFL. This would result in the maximum current achievable by this driver to be limited to about 200-kA peak value.

OVERVIEW

ISIS is a high-intensity, pulsed-power electron accelerator able to supply about 80 GW of power in a 35-nanosecond pulse [1]. It was donated to the Idaho State University by Titan Pulse Sciences, Inc. in 2002, and its primary purpose has been to serve as a radiation source for radiation effect testing in biological and semiconductor systems [2]. The power supply of ISIS [3] is composed from a Marx generator and five separate PFLs. Forty oil-filled, 77-ns-long cables connect the power supply to each acceleration unit (AU) of ISIS. The power supply of the ISIS is shown in Fig. 1. Each PFL produces a perfect 84-ns long, flat-topped 300-kV pulse which is directly used to accelerate electrons inside each AU.

In order to convert the ISIS power supply to a low-impedance *x*-pinch driver, an impedance transformer was designed [4]. The impedance transformer is the most important part of the *x*-pinch driver and serves to combine five, 300-kV outputs of the ISIS' induction cell driver (5 Ω each) into one, low-impedance (<1 Ω), 40-80 kV output to be fed to the *x*-pinch chamber. Analysis of the ISIS induction-cell driver showed that the most suitable spot for tapping its output pulse is at the end of the water-filled PFLs before the oil-filled connectors to the high-voltage cables [4].

We present the electrical circuit simulation results of proposed ISIS' based *x*-pinch driver. LTspice [5] simulations show that after directly connecting the output of each PFL to the impedance transformer and feeding the output pulse to *x*-pinch load, such a *x*-pinch driver can supply about 300-kA peak current with about 150-ns rise time (Fig. 3a). However, simulations also show, that the negative reflective wave is formed, which can cause the destruction of the ISIS PFL. Particular attention was taken to simulate the effect of misfire of one of the PFLs (Fig. 3b). To reduce the amplitude of this destructive wave, a high-power damping resistor should be placed after the output of each PFL. This would result in the maximum current achievable by this driver to be limited to about 200-kA peak value (Fig. 4a).

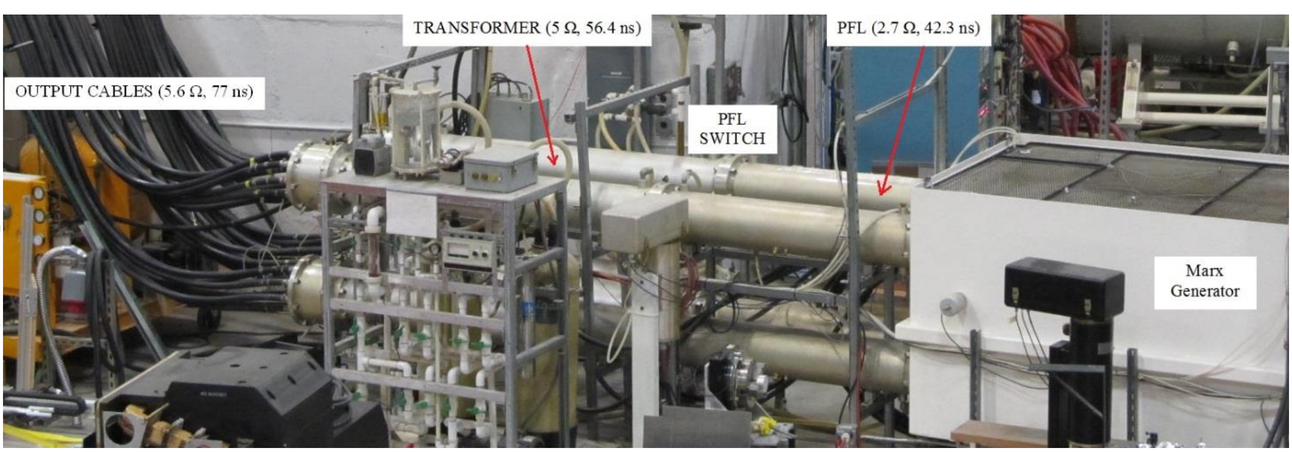

Figure 1: ISIS power supply.

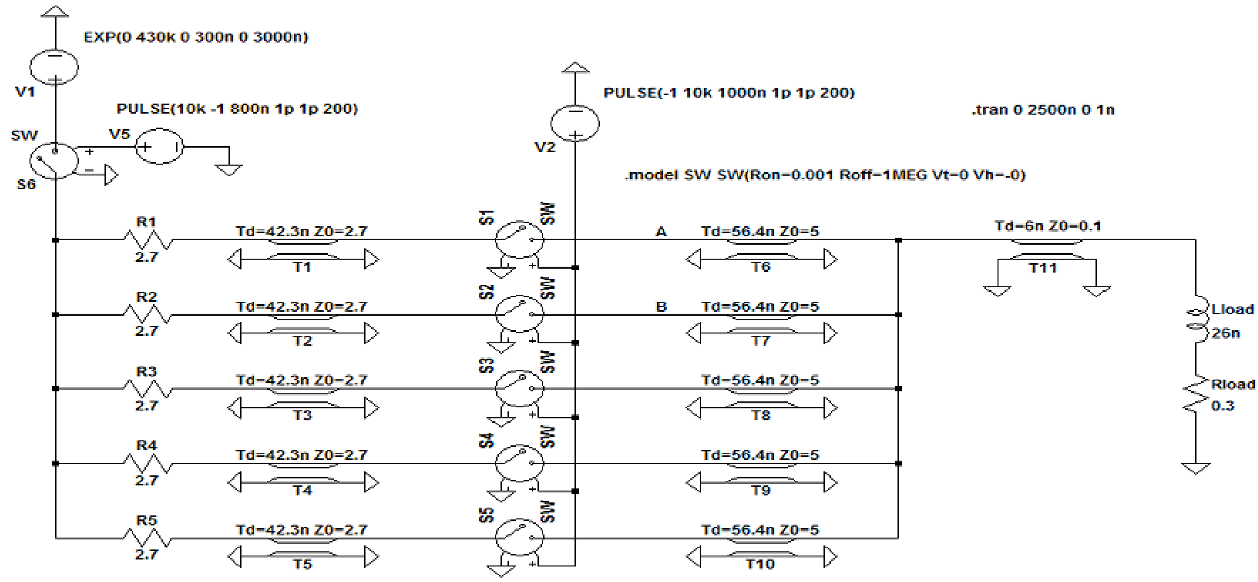

Figure 2: Electrical circuit of an ISIS-based *x*-pinch driver.

LTSPICE SIMULATIONS: 300-KA *X*-PINCH DRIVER

Figure 2 shows the electrical circuit of the ISIS' based *x*-pinch driver. The impedance transformer (represented by the transmission line element T11) is directly attached to the output of each PFL and the output of the impedance transformer is fed to the *x*-pinch load located in the middle of the vacuum chamber. The total inductance of the *x* pinch and all connection lines (header, lower feed, upper feed, etc.) can be roughly approximated to be equal to about 26 nH [6].

Simulation of current pulse as it propagates through the *x*-pinch load is shown in the Fig. 3a. After optimization of the impedance transformer parameters (6-ns long, 0.1 Ω), it was found that such a driver can supply about 320-kA peak current with 70-ns rise time (10-90 %).

Because the impedance transformer is necessary to transform down the impedance of PFLs by a factor of about 10, a reflective negative wave is formed traveling back to the PFL switch. This reflective wave will become even worse, if one or more PFL switches are not fired. Fig. 3b shows simulations of the voltage behaviour at the exit of PFL switch for two cases: the black line represents the scenario when all PFL switches are fired simultaneously (fire), and the red line represents the scenario when one PFL switch is not fired (misfire). As can be seen, the negative reflective wave with the maximum amplitude of about 150 kV is formed at the switch location for the normal regime of operation (fire). In the case of misfire of one of the switches, this reflective negative wave reaches the maximum amplitude of about 250 kV.

It is known [7], that such a high-voltage negative reflective pulse will probably destroy the PFL switch. Although the maximum current of about 320-kA peak value is achievable by this design, such a driver will probably not survive for a large number of shots due to possible damage to the PFL switches. As a result, a costly repairs would be necessary in the future.

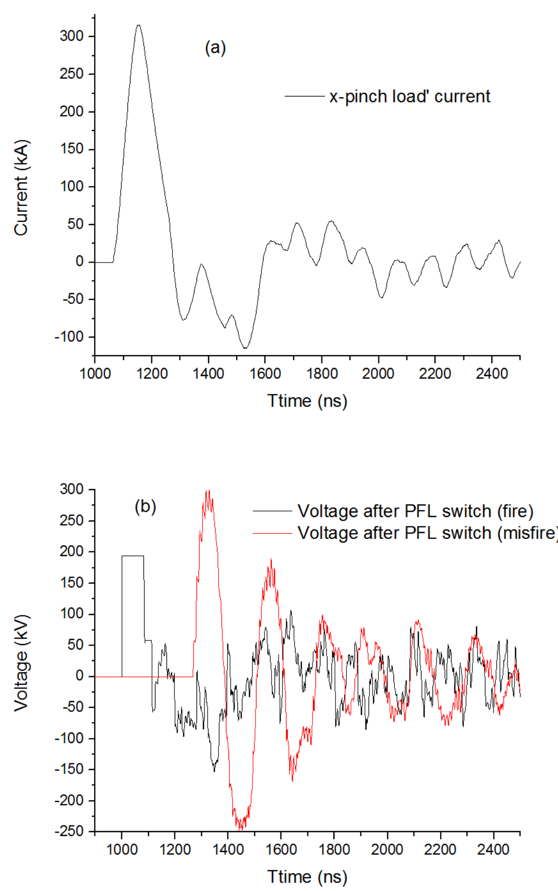

Figure 3: LTspice simulations of an ISIS-based *x*-pinch driver: (a) current measured at the *x*-pinch load (b) voltage measured after PFL switch.

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LTSPICE SIMULATIONS: 200-KA *X*-PINCH DRIVER WITH DAMPING RESISTORS

To reduce the amplitude of this destructive negative wave, high-power damping resistors (4.7 Ω) are placed after each PFL before the impedance transformer. This will reduce the amplitude of the reflective negative wave at the PFL switch location to the appropriate value, so the *x*-pinch driver can be safely operated.

As shown in Fig. 4a, such a modified *x*-pinch driver can supply about 200-kA peak current with 60-ns rise time (10-90%). The simulation results of the voltage behavior at the exit of the PFL switch for two cases, fire and misfire, as described above, are shown in Fig. 4b. In the normal regime of operation (fire), the amplitude of the negative reflective wave is almost reduced to the zero value. In the case of misfire of one of the switches, a negative reflective wave is still formed of maximum amplitude of about 25 kV, but the total duration of this wave is only about of 100 ns. This small negative reflective wave will probably not damage the PFL switches.

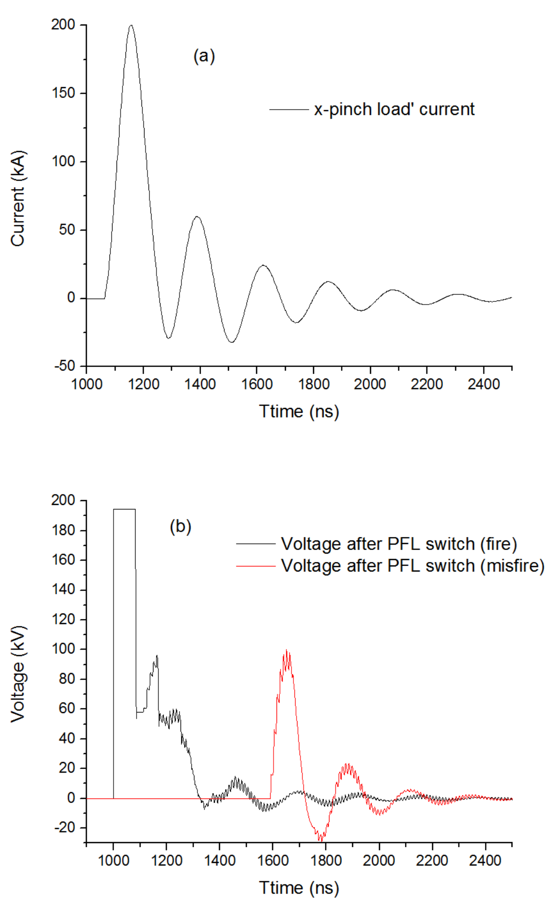

Figure 4: LTspice simulations of the ISIS-based *x*-pinch driver with a damping resistor placed after each PFL: (a) current measured on the *x*-pinch load (b) voltage measured after PFL switch.

CONCLUSION

In this report, we presented electrical circuit simulation results of a proposed ISIS-based *x*-pinch driver. LTspice simulations show, that after directly connecting the output of each PFL to the impedance transformer and feeding the output pulse to *x*-pinch load, such a *x*-pinch driver can supply about 300-kA peak current with about 70-ns rise time (10-90%). However, simulations also show, that the negative reflective wave is formed which can cause damage to the ISIS PFLs. Particular attention was taken to simulate the effect of misfire of one of the PFL switches, which causes the negative reflective wave to become even worse.

To reduce the amplitude of this destructive wave, a high-power damping resistor must be placed after the output of each PFL before the impedance transformer. This will to reduce the amplitude of the reflective negative wave at the PFL switch location to the appropriate value, so the *x*-pinch driver can be safely operated. But as a penalty, the maximum current achievable by this driver will be limited to about 200-kA peak value.

Taking into account these results and other considerations (time, effort and cost-needed to switch between the *x*-pinch operation mode and the normal operation mode of ISIS), the decision was made to design a new stand-alone, compact and portable pulse-power *x*-pinch generator [6].

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