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SOLID-STATE PULSED POWER SUPPLY FOR A 100 keV ELECTRON SOURCE OF THE NEW SYNCHROTRON FACILITY IN THAILAND

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Abstract

The new synchrotron light source project in Thailand will utilize a thermionic DC electron gun. The maximum operation of the gun is 100 keV, which requires a pulsed power supply of 100 kV. The present synchrotron machine uses a conventional design of the gun power supply. To improve the high voltage pulsed quality, the solid-state design of the gun power supply is utilized. The output pulse width can be adjusted easily and the droop is less compared to the conventional design. The designed output of 100 kV amplitude with 5 µs pulsed width can be achieved with this design. It also produces a less droop of 1.8%. The design process and results will be presented.

INTRODUCTION

The Synchrotron Light Research Institute (SLRI) is developing a new synchrotron light source with electron beam energy of 3 GeV. Injector is a conventional linac and booster ring. The 150 MeV linac is utilized with the 3 GeV booster ring. A DC thermionic electron gun was considered as an electron source for the 150 MeV linac. Thus, SLRI need to develop knowledge and expertise of staff and techniques related to the injector. The 100 keV electron gun [1] is developed to serve this purpose. The pulsed high voltage power supply to the electron gun is also planned for the research and development. These activities will be a platform to train and practise staff of electron beam injector.

The DC thermionic electron gun with a maximum beam energy of 100 keV requires the high power DC pulsed power supply that can supply a 100 keV pulsed with adjustable pulsed width. Conventional pulse modulator is utilized normally for the second generation light source injector. These modulators use pulse transformers to obtain the required pulse energy. However, it requires a huge amount of subsystems and pulse-forming networks (PFN's) to drive the pulse transformer. This make the large physical size of modulator systems. The PFN of a conventional modulator normally operates at high voltage. It is driven by high voltage capacitors. Working with high voltage requires an experienced engineers and technicians.

A conventional pulse modulator has a PFN which comprised of several inductors (L) and capacitors (C) as in the simplified diagram in Figure 1. This PFN is charged rapidly to a range of 10 to 40 kV. Output of the PFN is connected to the primary winding of a pulse transformer by a high voltage switch. This switch is typically a hydrogen thyratron tube. It will deliver half the charging voltage to the pulse transformer. The transformer is typically a voltage step-up transformer with the turns ratio of the transformer, a primary winding to a secondary winding, is N:1.

The PFN discharges will extract energy from the capacitors (C) and feed this energy into the pulse transformer. The load will get energy from the pulse transformer as a rectangular voltage pulse, with a fast rise time to peak, a relatively flat pulse top, and a relatively fast fall time. A high-voltage capacitors and a high voltage switch are required in the PFN structure. So, this makes it a large physical size, and there are high electrical and thermal stress applied to its components, at high voltage. The PFN structure requires complex tuning. This makes the design and implementation of a reliable PFN a major challenge.

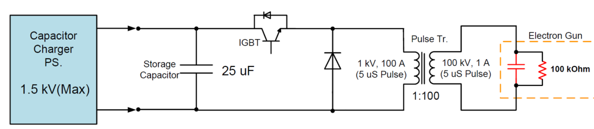

Figure 1: Simplified schematic diagram of a conventional modulator.

MODULATOR DESIGN

The modulator for electron gun is developed based on the new solid state type, CLW system [2, 3]. This is for the benefit of pulse energy, pulse width, rise time, fall time and pulse flatness, in which the solid state type is superior that the conventional type. The conceptual design diagram of the solid state type modulator is shown in Figure 2.

Major difference from the conventional modulator is the high voltage switch. The solid-state switches, such as IGBT-switches, are used in the solid state power modulator. The IGBT (Insulated-Gate Bipolar Transistor) switch is a solid-state switch. These switches can be turned on and turned off electronically. This is in contrast to thyristor switches, which can only be turned on electronically. The IGBT-switches eliminate the need for PFNs and high voltage capacitors in the modulator.

The modulator uses an energy storage capacitors connected to electronically on/off switches. Each capacitor is individually connected to the pulse transformer by a respective switch. Energy from the energy storage capacitors are transferred through the switches to the load through the pulse transformer for a specified time, and are then turned off electronically. The voltage droop-compensating circuit

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should be used to connects each solid-state switch to the pulse transformer. This help improving the output pulse properties which make it almost a perfect rectangular pulse. The solid sate type modulator has a compact construction size. The need for PFN is eliminated. It can produce a high efficiency and a good output pulse quality.

The conceptual design modulator has a charging capacitor power supply, which the output voltage is adjustable, of maximum 1.5 kV. This power supply charges the energy storage capacitors of 25 µF. IGBTs are used as a high voltage switch. The pulse transformer has a ratio of 1:100. This will step up voltage from 1 kV at primary winding to 100 kV at secondary winding.

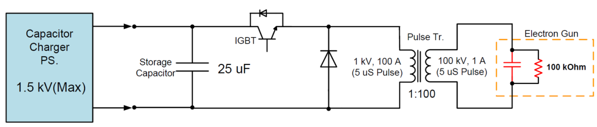

Figure 2: Conceptual design diagram of solid state power modulator.

MODULATOR SIMULATION

The modulator circuit has been studied in a simulation software to investigate an output pulse properties. PSIM version 7.1.2 [4] is used in simulation. Input circuit is shown in Figure 3. The circuit is driven by input voltage of 1 kV with 5 µs pulse width from a charging power supply. The energy storage capacitor has a capacitance of 25 µF. The electron gun is modelled in software by R-C circuit. The electron gun potential is 100 kV and it produces maximum 1 A. So, it can be modelled with a resistor of 100 kΩ. The capacitance of electron gun depends on the physical dimension of the gun. So, the 25 pF is obtained from a gun simulation code. This is connected in parallel with the 100 kΩ resistor acts as a load of the circuit.

Simulation was done with 5 µs pulse width at a pulse repetition rate of 500 Hz.

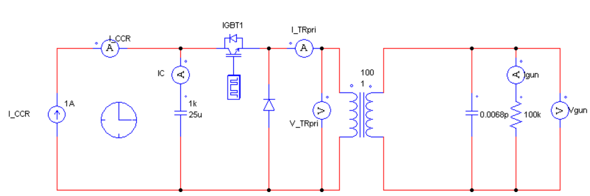

Figure 3: Conceptual design diagram of the solid sate modulator.

PROTOTYPE MODULATOR

The conceptual design diagram, as in Figure 3, is used in the early phase of the study and design. It produced the positive pulse with 100 kV approximately. It has a voltage droop 1.88% as shown in the simulation results of an electron gun voltage (Vgun) in Figure 4. The voltage droop is

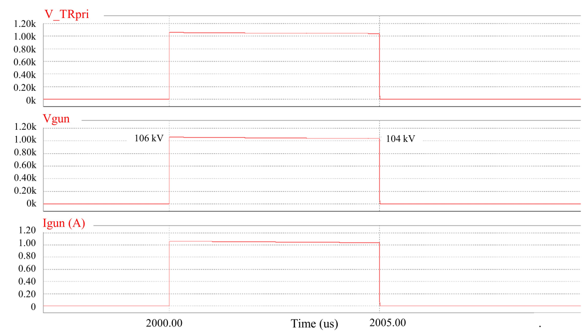

Figure 4: The simulation result of the conceptual modulator.

calculated from the voltage difference between rising edge and falling edge of a squared pulse shapes.

The prototype modulator must provide a negative pulse to the electron gun as a high voltage configuration diagram of the electron gun in Figure 5. Diagram showed another fast pulser, a bias power supply, and a heater power supply. These power supplies will be included as a sub-system of the modulator. So, a conceptual modulator has been modified.

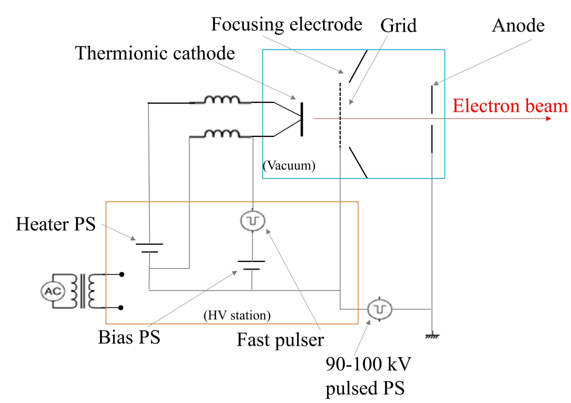

Figure 5: The high voltage configuration the electron gun.

The prototype modulator has a pulse generator stage and a step-up pulse transformer. A low voltage pulse is generated by a pulse generator stage. This pulse is connected to a step-up transformer to produce a output pulse of higher voltage. A pulse generating section comprises of an energy storage capacitor, an IGBT-pulse switch electronically controllable at turn-on and turn-off, and connected between an energy storage capacitor and a pulse transformer, and a passive voltage droop-compensating circuit which connects a IGBT -pulse switch to a pulse transformer for compensating for a voltage droop during a discharge of a capacitor, thus controlling the shape of the output pulse.

There are more detailed discussed regarding the droop compensations of a Marx modulator type in [5–8]. The output voltage droop is directly related with stored energy in capacitors. The higher stored energy the lower voltage droop. The stored energy of approximately 100 times of the pulse energy can result in a 0.5% droop, but the drawback is a higher stored energy and size. Hence, for reducing the

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stored energy and size of capacitors, other techniques are required to compensate the droop in output pulse.

A hybrid Marx module [6] has been developed for droop compensation. The droop compensation is done by series resonant L-C bouncer circuit using inductor and capacitor. This bouncer circuit is triggered on to start its cycle before the start of the main pulse of the modulator. A novel compensation design scheme for the Marx modulator using a low-cost circuitry designed to effectively compensate the voltage droop of the Marx main cell output is also discussed in [7]. A technique of addition a multi-cell interleaved and filtered pulse width modulation regulator on top of the main Marx cells in [8] has a promising results. The main Marx cells will run the modulator voltage up to flattop value and then back down while the filtered cells flatten and regulate the voltage during the flattop. This helps compensate the voltage droop.

A CLW type modulator [3] has a passive droop compensation by using a simple R-L circuit. This circuit compensates for the droop of capacitor voltage. This R-L circuit is connected to each of IGBT pulsed module just before connecting them to the pulse transformer primary. The inductor in the droop compensation network carries no current, and some voltage is dropped across the resistor when the IGBT is switched on. Then the capacitor voltage is increasing, as the pulse current is constant during the pulse. During this condition, the inductor current is increasing. This reduces the voltage dropped across the resistor, and the net result is a fairly constant pulse voltage at the pulse transformer primary. These all possibilities schemes will be studied in the prototype design modulator. Passive droop compensation schemes will be considered practically with the prototype.

The output results of a prototype modulator is illustrated in Figure 6. The output voltage that supplied to electron gun (Vgun) has been modified to a negative potential. A droop compensation has also been studied. This results a very low droop of 0.5%.

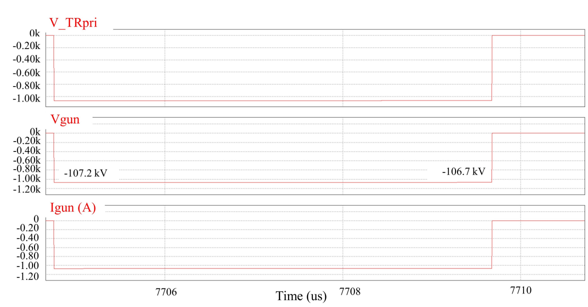

Figure 6: The simulation result of the prototype modulator.

CONCLUSION

A conventional pulse power supply with series of PFNs has been explored for advantages and disadvantages. A solid state modulator using IGBT to replace thyratron tube as a high voltage switch. This eliminates the need of PFN and a high-voltage capacitors. A conceptual design modulator has been studied. It provided a good quality square pulse with a voltage droop of 1.8%. This circuit was then modified to be able of producing a negative pulse. Information of a voltage droop compensation techniques were explored and studied. The suitable techniques will be implemented and simulated in PSIM software to see efficient compensation of each scheme. The voltage droop compensation circuits have been added in the design. This makes a prototype modulator with a low voltage droop of 0.5%. The fabrication phase of this solid state pulse power supply is planned. A solid state devices and semi-conducting devices were already procured. The charging power supply and the step-up transformer will be available onsite in the next fiscal year. The high voltage transformer's tank will be design to fit a step-up transformer and another high voltage parts. Fabrication of this prototype modulator is expected in the next fiscal year.

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