Extract Kicker Thyratron Replacement

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Introduction

A thyratron is a type of triggered electrical switch. The first commercially available thyratrons appeared in the late 1920s, finding applications in radar pulse modulators, lasers, high voltage medical equipment, and particle accelerators. By the 1960s, the latest developments in silicon thyristor technology were demonstrating advantages over the thyratron for most low and medium power applications. For high power applications, however, few alternatives are available.

Due to increasing costs, limited supply, and low mean time to failures of high-power thyratron used at ISIS, as well as recent advances in wide bandgap semiconductors devices, research in a novel replacement can begin. The semiconductor devices will be assembled into a switch array to handle the high voltages and current requirements.

Picture of CX1952 Thyratron Assembly [1]

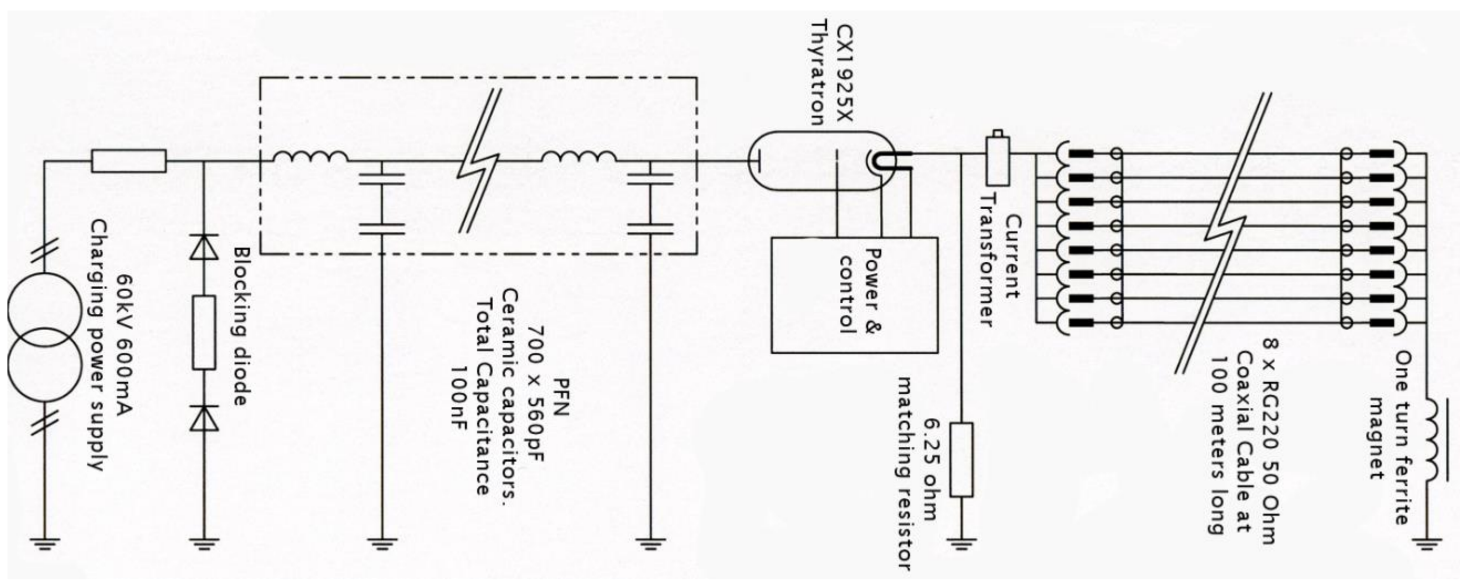
Application – TS1 Extract Kickers

The TS-1 Extract Kickers remove the proton beam from the synchrotron into the extracted proton beamline towards the target stations. The kicker is made up of 3 magnets of differing lengths. Each provides a magnetic kick of approximately 5.23 mrad, driven at 5260 A, at 35.5 kV.

Operating Voltage	50kV
Output Current	6kA
Maximum Rise time (5%-95%)	80ns
Pulse Width (set by PFN, FWHM)	1µs
Maximum Jitter	5ns
Maximum turn on delay	100ns
Operating frequency	50Hz
Mean Time Before Failure	5 years

Specifications for New Switch Assembly

Picture of Extract Kicker Power Supply



Circuit Diagram of Extract Kicker Power Supply

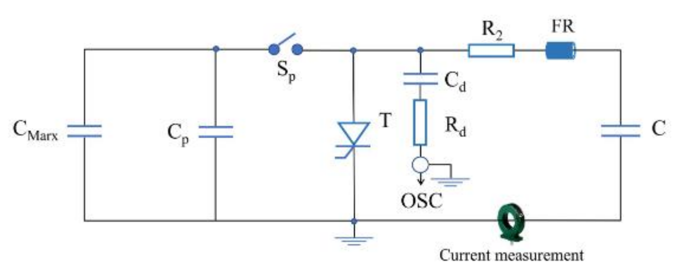
Circuit Operation:

1. A charging power supply charges the PFN to approximately 37.5kV
2. The thyratron is triggered, connecting the charged PFN to the output.
3. A voltage wave travels down the coax lines reaching the magnet in 500ns.
4. The low impedance of the magnet presents itself as a short circuit to the traveling wave. This forces the traveling wave to be fully reflected and travel back down the coax lines.
5. This reflected wave is then terminated by the dumping resistor, which has the same impedance as the coax line.

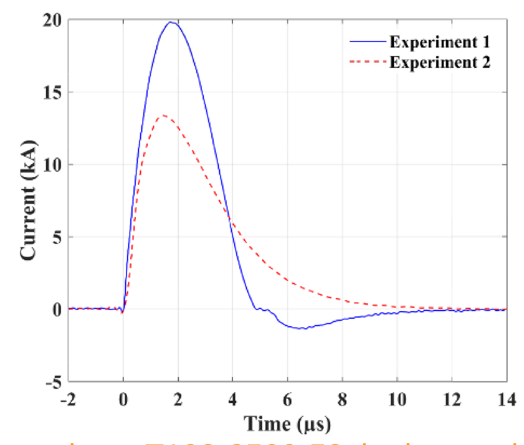
Avenues of Research

Thyristor stacks have been shown to be functional replacements for thyratron systems. However, the high current and di/dt requirements mean that the devices or triggering methods will need to be developed further.

One potential solution is using impact ionisation triggering on existing thyristors in the market. This driving method applies a very high dv/dt voltage pulse of reverse polarity across the thyristors anode and cathode [2]. Driver circuits will have to be developed to trigger a stack of larger current carrying thyristors. The triggering of a thyristor stack using this method will also cause a larger voltage overshoot across the PFN. The effect of this will need to be studied further

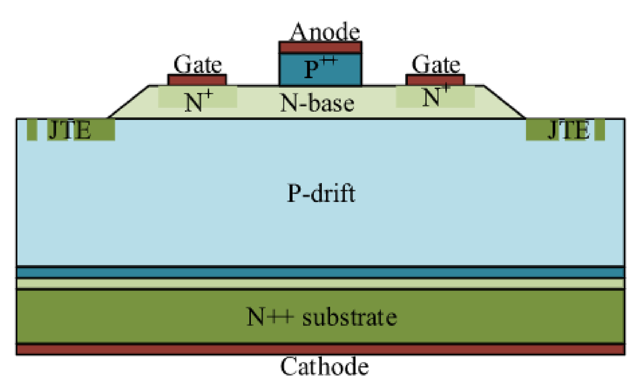


Simplified Schematic of Triggering Circuit [2]

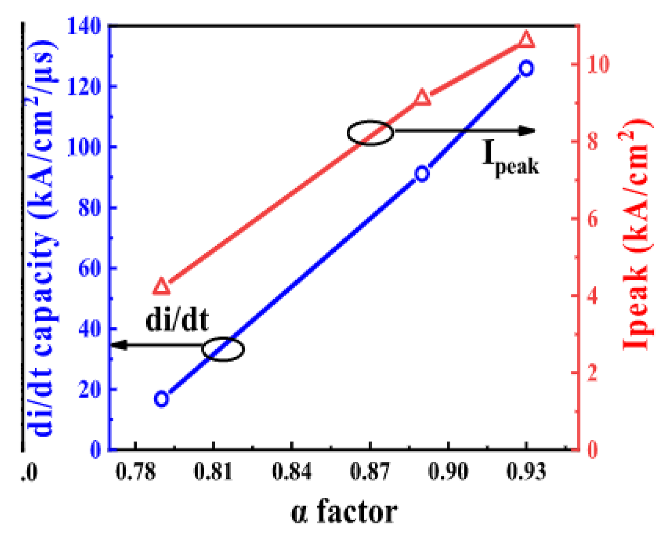


Current pulse using a T193-2500-52 thyristors with R2 at 0.2Ω and 0.25Ω respectively [2]

Another option is to manufacture SiC thyristors; which have greater current density, thermal and switching performance when compared to standard Si thyristors [3]. Devices could be manufactured that are bespoke to our application, allow the optimisation of turn on time and current density capability, while sacrificing leakage current, reverse blocking capability and turn off time. Manufacturing limitations with SiC, due to wafer defects will be a limiting factor, as well as packaging for high current applications.

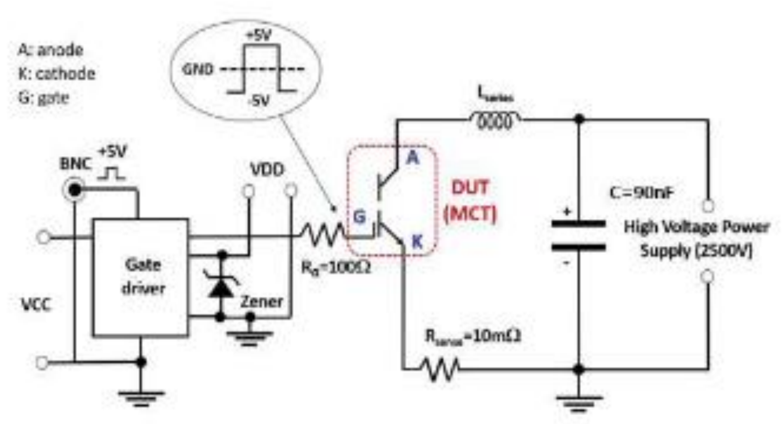


Cross section of SiC GTO device [3]

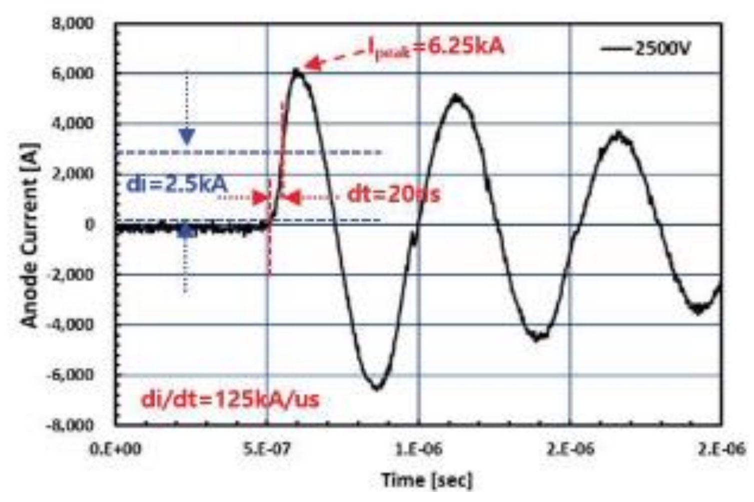


Dependence of measured di/dt and peak capacity with varying α factor (sum of internal NPN and PNP α factors) [3]

Existing novel thyristor topologies such as MOSFET Controlled Thyristors (MCTs) are another avenue for research. Current research has shown the potential in manufactured MCTs that can handle the high current and di/dt requirements for our application [4]. These could initial be manufactured in silicon, allowing for more mature techniques increasing reliability.



Test circuit for 2.5kV MCT [4]



Measures switching performance of MCT [4]

References

[1] Teledyne e2v, "CX1925, CX19252X: Liquid Cooled, Hollow Anode, Three-Gap Metal/Ceramic Thyratron, Sep. 2018
[2] E. Shahriari, T. Maysonnave, A. I. Gusev, A. S. de Ferron and L. Pécastaing, "A Study of a 5.2-kV/100-mm Thyristor Triggered in Impact-Ionization Mode Toward Fast High-Current Applications," in IEEE Transactions on Plasma Science, vol. 50, no. 10, pp. 3452-3458, Oct. 2022, doi: 10.1109/TPS.2022.3192561.
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[4] Cho D, Park K, Won J et al. 2022. Analysis of Electrical Characteristics of 2500V Class MOS Controlled Thyristor (MCT) Device for Pulse Power Applications, EAPACC & BEAMS 2022 Proceedings

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