COLD CATHODE THYRATRON BASED HIGH-VOLTAGE KICKER GENERATORS AT THE DUKE ACCELERATORS: SIX YEAR EXPERIENCE*

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Abstract

The performance of the Duke storage ring based light sources, the Duke storage ring FEL and High Intensity Gamma-ray Source (HIGS), has been greatly improved since 2007 as the result of operating a new full-energy, top-off booster injector (0.18 - 1.2 GeV) [1], allowing fixed energy operation of the storage ring (0.25 - 1.2 GeV). The injection/extraction kicker system is one of the key components of the accelerator facility which determines efficiency and reliability of the light source operation. Pseudo-Spark Switches (PSS), also known as cold cathode thyratrons, are the critical components of the high voltage pulse generators for kickers. More than six years of operation has allowed us to study the lifetime issue for the 10 kA class devices.

Recently, we have tested the next generation cold cathode thyratron, with one installed in our storage ring kicker high voltage generators. In the paper we present preliminary test results for this new thyratron, and the required modifications of its triggering driver, to improve its performance.

INTRODUCTION

At the present time Pseudo-Spark Switches (PSS) are still relatively uncommon devices. We have more than six year experience of operation of these switches, and have gained knowledge which may be useful for development of low jitter, efficient switches with a reasonable range of high voltage operation.

Table 1: Main Specifications of the TPI Type Thyratrons

	TPI1-1k/20	TPI1-10k/20 TPI3-10k/25
Peak forward anode voltage (max), kV	22	28
Peak forward anode current (max), kA	3	10
Average anode current, A	0.15	0.3
Maximum anode current rise rate, A/sec	$5*10^{11}$	$1*10^{12}$
Anode current pulse duration, µs	0.01-5	0.01-5/10
Time jitter, ns	<1	<1
Operating resource (switched charge), C	10^6	$5*10^5$

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Table 1 shows main specifications of the three types of PPS currently in use in the Duke accelerator kicker systems. More details are available in [2] and [3].

PRE-IONIZATION GLOW DISCHARGE AND STABILITY OF OPERATION

As distinct from a conventional thyratron, the PSS has more complex firing process. The glow discharge sustained inside the tube plays an important role in the triggering of the PSS. For more information see [4] and [5].

The presence of superdense glow discharge which is created and sustained by a keep-alive current between the auxiliary electrode ("second anode" or "pre-ionization electrode") and cathode provides PSS with unique performance parameters. At the same time, any instabilities of the discharge process may cause significant issues for reliable operation of the high voltage generator.

Mismatch between voltage-current characteristics of the power supply and the substantially nonlinear characteristics of the gas discharge provokes instability and even self-oscillation of discharge.

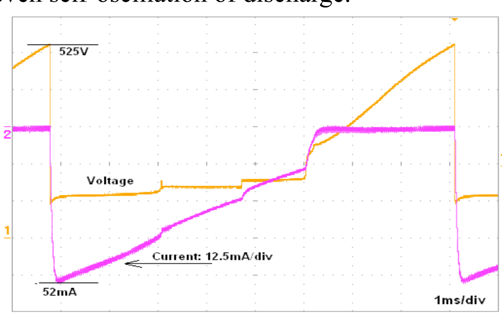

Figure 1: Self oscillating discharge observed for a TPI1-10k/20. The pre-ionization power supply uses current control feedback and a 5 k□ limiting resistor.

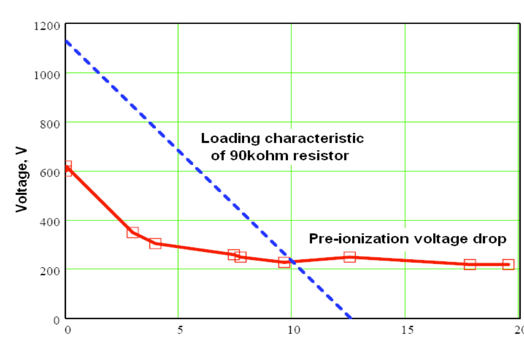

Figure 2: Static voltage-current characteristic of the new TPI1-10k/20 thyratron.

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Figure 2 shows the static voltage-current characteristic of the new TPI1-10k/20 thyratron. The intersection of the thyratron curve and the loading characteristic of the current limiting resistor determines the operating point. In our case it is 10 mA current and 240V of voltage drop.

The dynamic characteristics of the discharge during the thyratron firing and during the subsequent recovery process makes the interaction between the power supply and the gas discharge more complicated.

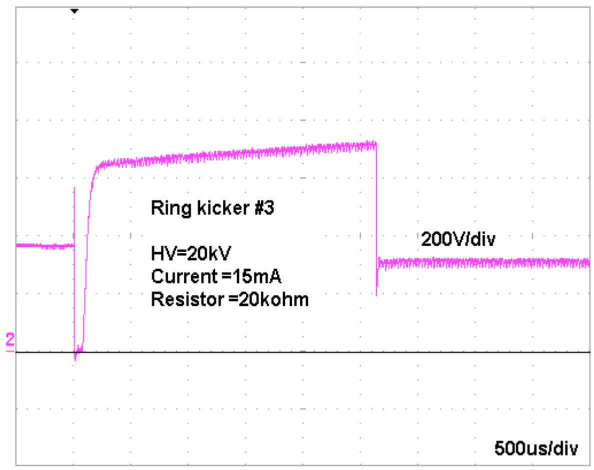

Figure 3: Voltage on the pre-ionization electrode of the TPI3-10k/20 thyratron. Mismatch between the power supply and glow discharge characteristics causes a long recovery time. This may limit the maximum repetition rate of the kicker system. The voltage drop shown has become stable, but differs from the initial level, which means that next triggering of the thyratron will have different initial conditions as compared to the last one.

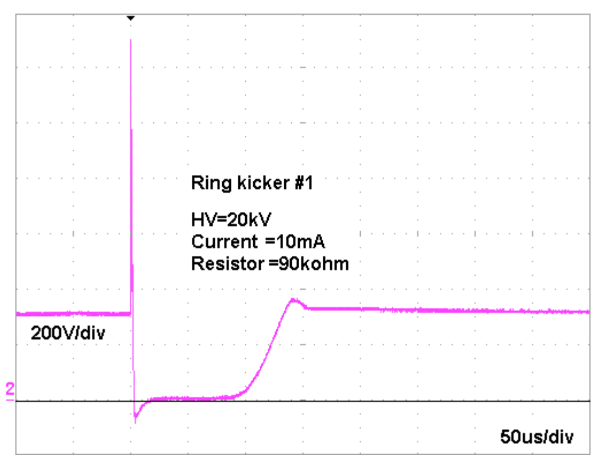

Figure 4: This scope snapshot demonstrates the well optimized recovery process for the new generation thyratron TPI1-10k/20.

Even a high output impedance of the power supply does not guarantee fast and repeatable recovery of the glow discharge after the thyraton has been fired.

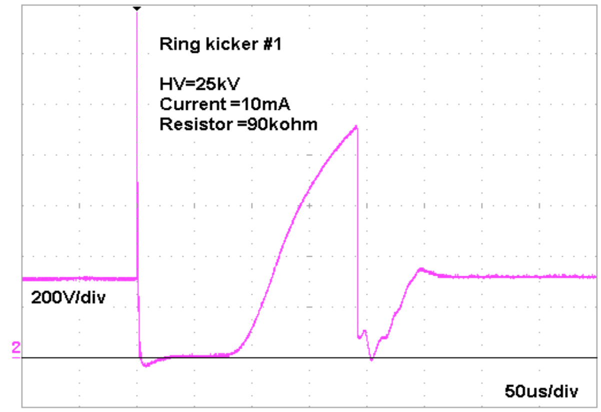

Figure 5: Recovery of the pre-ionization discharge with a 1300 V power supply and 90 k□ resistor after the thyratron has been fired.

NEGATIVE BIAS AND GLOW DISCHARGE

Another important factor determining parameters of the glow discharge is a pressure of hydrogen. Lowing pressure increases the voltage drop on the pre-ionization electrode and at some level makes it impossible to initiate discharge at all. Too low hydrogen pressure also reduces the life time of the thyratron. It is well known fact [6] that a negative bias voltage at the control grid helps to prevent self-firing of the thyratron and increase the operational hydrogen pressure. We found that originally installed power supply for the negative bias did not provide enough current to compensate the electrons coming to the anode-grid region. The elimination of this issue has allowed a reduction of the voltage drop at the pre-ionization electrode by 20-60 V.

The most uncontrollable factor is the aging of the thyratrons. The exhaustion of the cathode emitting element is accompanied by a growth of the voltage drop. The next generation TPI1-10k/20 thyratrons feature an embedded getter, and according to manufacturer's declaration, this new device has better cathode performance and, therefore, improved life time. We have one already installed and tested at ring kicker generator #1. While it is too early to judge any changes in life time, we have found that this thyratron is more sensitive to the negative bias voltage at the control grid, and requires better matching with the pre-ionization power supply.

EVOLUTION OF THE EXTRACTION KICKER PULSE

We have observed evident widening of the booster extraction pulses. The process of the pulse voltage growing consists of two distinguishable parts: an initial slow rise and a successive fast growth. Figures 6 and 7 show the evolution of this pulse distortion for the two extraction generators. It may be noticed that the half-height width of the pulse is still not changed. Also, when operating at a higher voltage setting, this pulse deformation is less noticeable.

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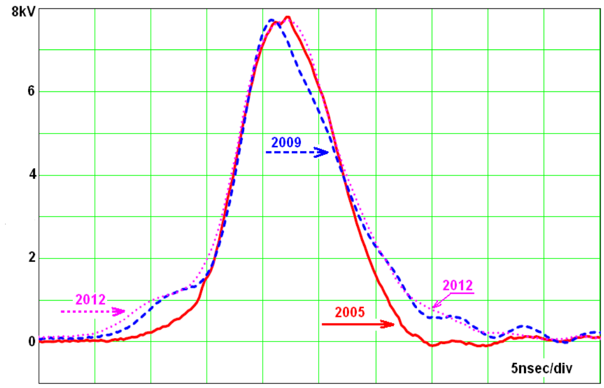

Figure 6: Evolution of the Booster extraction negative pulse at HV=15kV from 2005 to the present day.

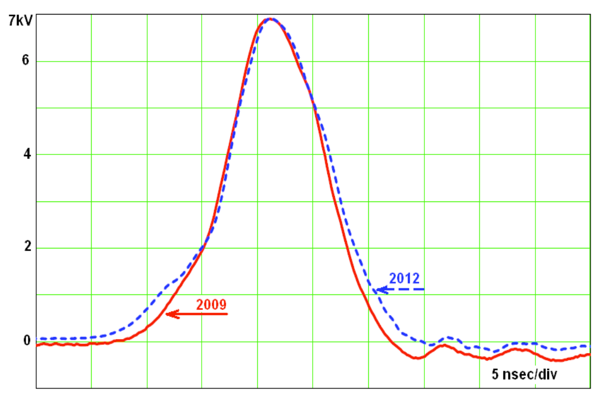

Figure 7: Evolution of the Booster extraction positive pulse at HV=15kV from 2009 to the present day.

TRIGGER PULSE AND HV GRID SPIKES

Another issue arising with the thyratron aging is the well known problem of grid spikes, for which we do not have an ultimate solution. We employ spark gap arresters to suppress spikes. The advantage of the spark gap is that the shape of the trigger pulse remains undistorted. Failed arresters need replacing approximately once every few months.

CONCLUSIONS

Detailed studies of some aspects of the PSS operation have made it possible to improve stability and repeatability of the entire kicker system, and to increase the thyratrons life time.

Better understanding of the recovery processes inside PSS will help to avoid potential limitations of the planned increase of kicker repetition rate.

The control electronics of the kicker drivers, developed in 2007 and installed in 2007-2008, have been improved to increase kicker reliability and maintainability.

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