COLD CATHODE THYRATRON BASED HIGH-VOLTAGE KICKER SYSTEM FOR THE DUKE ACCELERATORS: PERFORMANCE AND IMPROVEMENTS*

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Abstract

The Duke FEL/HIGS (Free Electron Laser/High Intensity Gamma-ray Source) facility has recently undergone through a series of major upgrades. As a part of this upgrade, a kicker system was designed to provide reliable injection from the booster into the storage ring at any energy chosen from the range of 240 MeV to 1.2 GeV. Relatively new and not sufficiently studied switching devices were selected as a basic component to build a set of nanosecond resolution high-voltage generators. So called Pseudo-Spark Switch (PSS), also known as a cold cathode thyratron, has the same or slightly better jitter, reasonable range of switched high voltages and significantly lower heater power as compared to the traditional “hot” thyratrons. Despite the fact that it requires more complicated triggering system, this device still seems very attractive as a driver for short pulse kickers. Three years of operation of the Duke FEL facility have revealed a number of advantages and challenges related to the thyratrons of this type. In this paper we review design features of the kicker system, discuss some completed improvements, and summarize our three year experience.

INTRODUCTION

The DUKE FEL/HIGS complex includes three major accelerators: a 280 MeV linac, a 1.2 GeV booster synchrotron and FEL dedicated storage ring. Five sets of kickers, based on a stripline pair design, are driven from high-voltage pulse generators. More details about the Duke accelerators related to the kicker system can be found in [1] and [2].

A single coaxial cable line with 30 ohm impedance pre-charged from a DC power supply is applied as a PFN (Pulse Forming Network) for the injection to the booster pulse generator. The pseudo-spark switch (PSS) also known as a “cold” cathode thyratron of the TPI1-1k/20 type is employed as a fast switch. The required range of high voltage tuning is from 4 kV to 10 kV. Our original intention was to inject 106 nsec train of electron bunches from the linac to the booster to fill all 19 RF buckets. Recently we have only one short bunch of electrons from the linac every shot and so the injection scheme has been changed.

A requirement to extract any bunch from the booster to any RF bucket into the main ring results in the need to generate high voltage pulses with amplitudes up to 22 kV and pulse widths of 10 nsec. The two coaxial Blumleins as a PFN and the two TPI1-1k/20 PSS as a fast switch were used to obtain required pulse individually for each plate of the stripline kicker. One of the plates is connected through an inverting transformer. According to the manufacturer specifications, maximum peak forward anode voltage of the TPI is rated at 22 kV. In order to reduce exposure of the thyratrons to high voltages, a scheme of pulse charging for the PFNs is employed. Both Blumleins are charged from the same HV power supply. Low jitter of the booster extraction kicker pulses is extremely important for the reliable performance of the DUKE FEL/HIGS facility.

Table 1. Main parameters of the Duke kicker generators.

Kicker	Switch type	#	Voltage range	Pulse width	Charge/ pulse(max)
Booster Inject.	TPI1-1k/20	1	4-10kV	106 ns/ 17 ns	12 μC/ 2 μC
Booster Extract.	TPI1-1k/20	2	4-20kV	10 ns	7 μC
Ring Inject.	TPI3-10k/25	3	4-25kV	50 ns	100 μC

The scheme for injection to the main ring requires three independently controlled kickers. Three identical high voltage generators are used. At least two of them must provide pulses with voltages of up to 25 kV on the kicker plates. One of each pair of plates is connected to a generator through an inverting transformer. Thus, the output high voltage pulse of 25 kV is applied to the 12.5 ohm impedance of a kicker. As much as 4 kA current is running through a switch. This is a real challenge for the TPI3-10k/25 employed as a fast switch in the ring pulse generators. This device is rated for a 10 kA peak forward anode current and for a 25 kV peak anode voltage. About 100 μC charge per pulse is coming through the switch during the 50 nsec pulse. The detailed information about high voltage generators design can be found in [3] and [4]. Table 1 summarizes some parameters of the kicker generators.

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MODIFICATIONS

A number of the improvements for the kicker system were carried out since the booster has been commissioned in 2006.

The original design of the high voltage generators was to use a DC charging scheme for all five kickers. The necessity for pulse charging of extraction from the booster and injection to the main ring was realized even before the commissioning of the booster. Soon after the commissioning all necessary equipment for pulse charging was installed and tested. The timing system was significantly modified to provide pre-triggers for the charging circuits prior to the triggers for the kicker generators.

Initially the kicker system had a minimal set of control and monitoring abilities. Soon after commissioning of the booster systems, the kicker generators were modified to be more integrated with the EPICS control system.

The major number of the kicker system failures during regular operation has been occurred in the thyratron drivers. The most critical components of the control electronics have been upgraded with more immunity to the high level of electromagnetic interference (EMI) inside the generator racks. A hydrogen source heater power supply was replaced with an industrial model with adjustable voltage and limited output current.

To maximize the efficiency of injection, we developed a multi-bunch injection scheme by shortening the length of the injection pulse. Since the beginning of 2009, we were able to inject into 7 of 19 booster RF buckets for multi-bunch ramping.

PERFORMANCE

The operational statistics of the Duke accelerators for the last three years shows a total operating time of about 10000 hours. Overall the number of shots for injection to the booster is about $6{\cdot}10^6$, while for extraction from the booster and injection to the main ring is about $3{\cdot}10^6$. During this time, the major loss of operational time was related to the thyratron driver faults. Since the drivers have been modified our attention has switched to the thyratron issues. Three years experience demonstrates adequate stability of amplitude of the kicker pulses, low pulse rise time and less than 1 nsec jitter. Another very important parameter for any switching device is life time. Up to now we did not have any reliable information about the durability of the TPI type thyratrons. The manufacturer markets this device as a competitor for conventional "hot" cathode thyratron in durability and proclaims that "the thyratron operating resource in terms of total switched charge" is $1{\cdot}10^6$ C. Our estimations for the switched charge show value of about 70 C for the injection generator and not more than 300 C for each of the main ring generators. These are negligible charges as compare to the TPI specs. Nevertheless we have observed evidence of thyratron degradation.

One of the key features of the "cold" cathode thyratron is a presence of superdense glow which is created and sustained by a keep-alive current between the auxiliary electrode (second anode) and cathode. This DC current must be in the range of 5 to 50 mA. The drop voltage between these two electrodes depends on the DC current value, the material of cathode emitting element, gas pressure and so on. A new thyratron has the drop voltage of about 200 V. During regular operation this voltage irreversibly grows. We observed increase from 200 V to 330 -340 V for the TPI1-1k/20 and up to 420 V for the TPI3-10k/25 respectively. According to manufacturer's explanation, instability of the cathode emitting element causes this growth. More detailed information about the TPI type thyratrons can be found in [5] and [6]. Fig. 1 depicts an evolution of this growth for the one of the extraction generators.

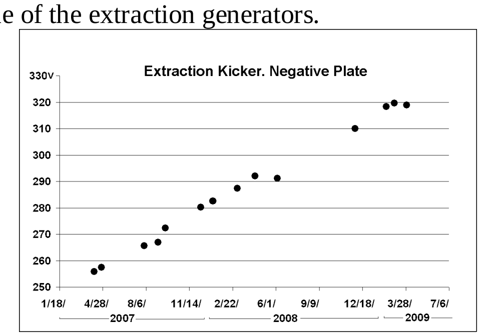

Figure 1. DC voltage on the pre-ionization electrode.

As comparing to a conventional thyratron, the pseudo-spark switch has more complex switching-on process. The glow discharge sustained inside the tube plays a role of the triggering device. Since the switching capability of the PSS essentially depends on stability of the triggering mechanism, the above mentioned increase of the drop voltage of glow discharge may indicate some degradation of the switches.

We also detected evident widening of the booster extraction pulses. The process of the pulse voltage growing consists of two distinguishable parts: initial slow raise and successive fast growth. Fig. 2 shows the evolution of this pulse distortion for the one of the extraction generators. It may be noticed that a half-height

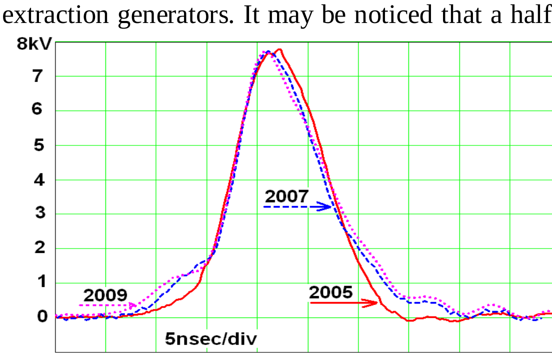

Figure 2. Evolution of the extraction kicker pulse.

width of the pulse is still not changed. Moreover, as soon as operation deals with higher voltage setup this pulse deformation becomes less noticeable.

The booster injection kicker has considerably lower operational voltage but its thyratron was exploited

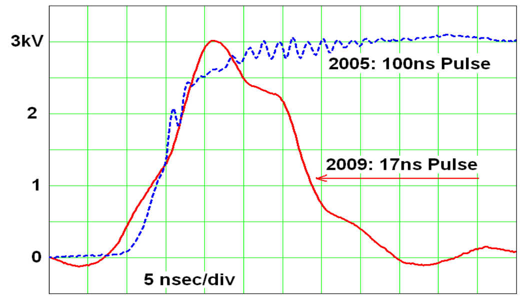

Figure 3.Evolution of the injection pulse front edge.

more intensively in terms of switched charge. Fig. 3 demonstrates a dramatic deformation of the front edge of the booster injection pulse. We believe that above mentioned degradation of the pseudo-spark switches might be responsible for the observed shape of the injection pulse after its shortening.

Another indication of the destructive changes of thyratron performance is well known for the “hot” cathode siblings, which is the problem of grid spikes. Large transient voltages take place on the control grid in the instant of the thyratron firing [7]. Recently this issue becomes critical for the main ring kickers. Fig. 4 and 5 show the magnitudes of the spikes for two thyratrons which have different overall operating time. We have already changed some elements of the original design in order to improve an electrical strength of circuits around the grids. A reliable protection against grid spikes without distortion of the triggering pulse continues to be a real challenge.

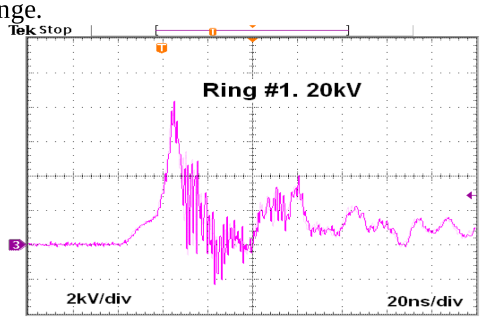

Figure 4. Trigger pulse and HV spikes.
Thyratron is in operation since October 2007.

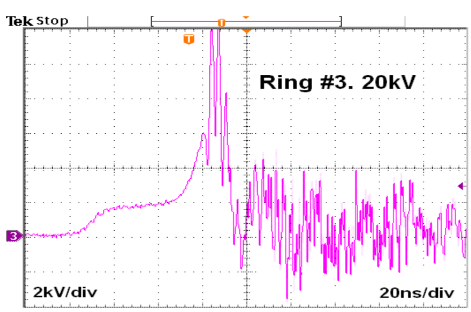

Figure 5. Trigger pulse and HV spikes.
Thyratron is in operation since September 2006.

CONCLUSIONS

Essential modification of the thyratron drivers has enhanced reliability and maintainability of the kicker system.

Despite an evidence for some thyratrons degradation, the overall performance of the kicker system still meets strict requirements for efficient and reliable operation of the Duke FEL/HIGS facility.

More efficient injection to the booster synchrotron could be achieved after replacement of a worn TPI1-1k/10 thyratron with a “fresh” one.

Three years operation of high voltage generators based on cold cathode thyratrons as fast switches proves excellent switching capabilities of such devices. However, the durability of cold cathode thyratrons is still the subject of further investigation.

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