PULSE GENERATORS WITH NANOSECOND LEADING EDGE DURATION BASED ON TPI-TYPE PSEUDOSPARK SWITCHES FOR FEL COMPLEX

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Abstract

For FEL (Free Electron Laser) complex used at the Duke University, pulse generators (kickers) of Injection, Extraction and Generator of injection into a big ring have been developed and built. As fast switches TPI-type thyatrons (PSS - pseudospark switches) have been employed. In contrast to other pseudospark switches the TPI-thyratrons are capable of operating in circuits with grounded cathode, which offers lifetimes up to 20 000 hours.

The thyatrons can be considered as alternative to well-known switches, including hot cathode hydrogen thyatrons and up-to-date power solid state switches, whereas being more compact and cost-effective. The absence of hot cathode provides for turn-on time of the TPIs about 3÷5 ns in the modes with thousands-amperes peak currents and sub-nanosecond jitter. The results of over 1.5 years of the pulse generators service are presented.

I. INTRODUCTION

The deflector "kickers" plates with high-voltage nanosecond-width pulses applied to them are used to pass-by charged particles from one accelerator element to another [1]. Short pulse duration is necessary to kick out or in contrary to put onto the equilibrium orbit of the accelerator a single beam without touching neighboring ones.

The principal objectives for designing FEL complex generators were:

1) providing the minimum time jitter to avoid contacting adjacent beams;
2) providing the minimum rise and decay time;
3) achieving “flattop” instability not more than ±5% for long pulses (100 ns);
4) providing capability of fivefold output voltage tuning with pulse shape conservation.

The objective of development, research and operation of the generators is closely connected with application of switches. The first switches used in kickers were thyatrons with hot cathode. For high currents to achieve ultra-fast switching tetrode thyatrons are normally used. At that, grid 1 is pulsed with up to 100 A and delayed trigger pulse is applied to grid 2. This results in a current rise-time of less than 3 ns with the CX1599 thyatrons (10 kV, 50 Ω). CX1171 thyatrons are employed in a variation of kickers circuit which offers a rise time of 25 ns to 6 kA [2].

Figure 1. Schematic drawing of the TPII-1k/20 PSS triggered with a glow discharge inside a hollow cathode. A - anode, G - grid, C- cathode, AA - auxiliary anode, AE - low-work-function element. Position 1 - erosion damages of cathode surface in micosecond mode; position 2 - in submicosecond mode.

The shortcomings of conventional thyatrons - uncontrolled prefires, substantial power losses in heating circuits – had led to their replacement by solid state switches (SSS) [3, 4]. However, due to high cost of the SSS-based kickers, substantial overall dimensions and

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complexity of the devices, the designers of the kickers
are compelled to look for alternative switches of the type.
In the report the collected results of research and em-
ployment of kickers with pseudospark switches TPI-type
[5] are presented.

II. SETUP AND RESULTS

TPI - thyratrons (Fig.1) with superdense glow and par-
tially arc discharge form are intended for switching of up
to $10^7$ Coulombs in pulse mode at high frequency rate.
In circuits with grounded cathode they offer the longest
lifetime at lower cost than classical thyratrons with
heated cathode.

The computer simulation of electrical fields inside the
trigger region is carried out by solving the Laplas equa-
tion in absence of space charge. The pictures of fields
and distribution of potential on axis of the electrode sys-
tem allows to make a preliminary conclusion that there is
an electrostatic trap in a cavity of the cathode of the
given design (Fig.2).

![Equiplotential contours in the cathode-trigger unit of PSS. AA - auxiliary anode, Uax - potential on the axis.](image)

Such a trap at the initial stage of temporal development
of the discharge can promote effective triggering of the
discharge.

![Principal circuit of TPI-thyratron triggering, operating in the mode with direct and pulsed auxiliary preionization current.](image)

TPI-thyratrons were commercialized in the beginning
of 2000. With the purpose to define prospective of appli-
cations of TPIs in modes with low discharge develop-
ment time BINP together with Pulsed Technologies ltd,
Ryazan, since 2001-2006 have been conducting profound
investigations of the switches and modes of triggering of
the devices. We designed a driver for pulse triggering via
2 grids with constant preparatory discharge on the first
grid (Fig.3). The design deficiencies are discovered,
prospects of application are shown.

Employing TPI-thyratrons for FEL-complex of the
Duke University five generators are designed and fabri-
cated: two of them are based on TPI1-1k/20 thyratrons
and three of them on TPI1-10k/20.

In the generators pulse command charging via pulse
forming network (PFN) with charging time 180 and 720
µs is employed.

*Injection Generator #1* (Fig. 4, 5) is built employing
compact 150 grams TPI1-1k/20 thyratron, shaping in a
load with impedance of 50 $\Omega$ square bi-polar pulses with
duration of 100 ns, pulse leading edge of $5\div10$ ns and
“flattop” instability not greater than $\pm 5\%$ at the peak
overall voltage on deflecting plates from 5 to 10 kV.

![Injection Generator #1 schematic drawing.](image)

Figure 4. Injection Generator #1 schematic drawing.

![Injection Generator #1 Outline. 1 – thyratron in screen; 2 - PFN; 3 - driver; 4 - inverter; 5 – high-voltage DC generator.](image)

Figure 5. Injection Generator #1 Outline.
1 – thyratron in screen; 2 - PFN; 3 - driver; 4 - inverter; 5 – high-voltage DC generator.

Considering relatively low voltage of the system a cir-
cuit with single PFN is accepted. The circuit offers a
minimum pulse edge limited by the response speed of
thyratron only. The second deflector plate is connected
via inverter to avoid two generators connection for upper
and lower plates simultaneously. The inverter is performed of ferrite ring with coaxial cable PK coiled on it.

Two PK cables constitute the PFN. It is discovered by experiment that the matching is optimum if impedance (ρ) of one cable is 75 Ω. At that, impedance of PFN is 30 Ω, and internal impedance of thyratron in the given configuration is 5 Ω (Fig.6).

Figure 6. On the oscillogram the change of flattop after pulse in PFN from ρ=25 Ω to 30 Ω.

It is worth specifying that the pulses presented on the oscillograms were taken not from generators output, but from kickers matching terminators, when the pulses are distorted by transport cables, plates and unmatched loads. In the first injection generator the output pulse had a leading edge of 5 ns.

Extraction Generator is built also on TPI1-1k/20 thyratron as well. It provides in a load with impedance of 50 Ω, high-voltage pulses with duration at level 0.1 not greater than 15 ns at the peak overall voltage on plates from 8 to 40 kV.

For the project realization we chose a circuit with separated supply of each plate from a separate generator.

Figure 7. Extraction Generator schematic drawing.

Both generators are based on double coaxial PFN (Blumlein line), since providing output voltage of a single generator up to 20 kV on one PFN, employing TPI1-1k/20 thyratrons as the fastest switches ever used, is not possible due to the fact, that in this case the PFN charging voltage and, hence, anode voltage of the thyratron, will be increased up to over 45 kV. Both generators are identical except for one of the plates is connected to inverter, offering positive supply polarity (Fig.7, 8).

Figure 8. Extraction Generator. General view.
1 - driver, 2 – thyratron unit, 3 - pulse forming network, 4 - inverter.

It is worth mentioning, that in the extraction generator pulse rise time did not change within a range of 4-20 kV (i.e. at current change via the switch from 240 up to 1200 A), whereas in big ring injection generator - from 5 to 25 kV (800÷4000 A).

Figure 9. Pulse from the matching loads.

The generator built by the scheme (see Fig. 7) has the advantage by offering output voltage close to charging one, however we have a problem connected with a feature of Blumlein line to increase output pulse leading edge approximately as much as twice in respect to response time of the switch. However, increasing PFN charging voltage up to 30 kV we obtained acceptable parameters of the output pulses for the given thyratrons.

Pulses from the matching loads are identical; one of them is presented in Fig.9. Time jitter was less than 0.8 ns. Unlike previous generator in the presented one we used pulse command charging of PFN via high-voltage
step-up transformer with capacitor discharged onto a primary winding. PFN charging time was 180 µs.

**Generator of Injection into a Big Ring** is built on TPI1-10k/20 thyatrons. With plate impedance of 25 Ω it provides pulse duration at level 0.1 not greater than 100 ns at the peak overall voltage on plates from 10 to 50 kV. In this case it was decided to employ Blumlein line, since the requirements to the pulse shapes are less tough and voltage is sufficiently higher.

Both plates are supplied from a single generator but since their impedance is 25 Ω they must be connected via two parallel cables PK50. That is why PFN impedance was to be 6 Ω. The choice of the switch was conditioned by that reason and it was a high-current thyratron TPI1-10k/20. In the given circuit at charging voltage of 25 kV switching current is about 4 kA.

The pulse forming network consists of discrete elements - two parallel lines of 11 cells with 3 series ceramic capacitors 470pF × 16 kV, 470 pF (Fig. 10, 11).

![Figure 10. Scheme of the generator of injection into a big ring.](image1)

**III. CONCLUSION**

TPI-thyratrons offer parameters fitting the principle requirements to the generators: time jitter not greater than 0.8 ns, rise and decay time of 4-5 ns, flattop instability for long-width pulse (100 ns) not greater than 5%, capability of fivefold output voltage tuning with pulse shape conservation.

Also:

- design of the generator is significantly simplified at the expense of employment of one switch for supply of both kicker plates and higher switching current (up to 10 kA);
- reliability of the generators is sufficiently higher as well as manufacturability of fabrication and assembling, in the accelerator system there is no evidence of self-breakdowns.

It is worth mentioning that since in this configuration fabricated cabinets were used, there was a lot of free space in them. As a matter of fact the design could be made much more compact.

The generators have been employed at FEL Laboratory Duke University since 2005. From the beginning of periodic operation the system has been working over 2000 hours. During this time the major problems were connected with reliable operation of high-voltage drivers, by this time the problems are almost eliminated. After 2000 hours increase of voltage drop through the thyratron on preionization electrode due to occurrence of direct current was observed. In order to reduce the tendency, a “quaziconstant” preionization must be introduced with applying of low-current trigger pulse with delay to the moment of thyratron firing not greater than 1 ms.

**IV. REFERENCES**