Table-top pulse power generator for soft X-ray radiography

N.A.Ratakhin, V.F.Feduschak, A.A.Erfort, A.A.Saushkin,
N.V.Zharova, S.A.Chaikovsky, V.I.Oreshkin

2/3 Akademichesky Ave., Tomsk, 634055, Russia, Phone (3822) 492-988, Fax (3822) 491-677, ratakhin@ovpe.hcei.tsc.ru

Abstract – X-ray radiography of short-lived objects using X-pinches is a new promising trend in diagnostics. The high spatial and temporal resolution achievable with X-pinches make them exceptionally interesting for studies of fast processes and behavior of matter in extreme states. This paper describes a compact high-current pulse generator (current amplitude ~350 kA at a 200-ns current pulse risetime) which will produce soft X-rays from high-temperature X-pinch plasmas.

The method of producing dense high-temperature plasma in electrically exploded crossed wires was proposed at the Lebedev Physical Institute (Russia) in the 80's [1]. Experiments showed that a bright soft X-ray source with a size of a few micron and with an X-ray pulse duration of 0.1-10 ns is formed at the cross point of the wires. At present such sources find application in X-ray radiography of small-scale objects, including short-lived plasma objects, in the soft (3-5 keV) and harder (10-20 keV) X-ray spectra [2]. The methods of registration of the radiation produced by an X-pinch and X-ray of the analyzed object are now highly developed. A great deal of data has been gained on the moment of an X-ray burst against the diameter, material, and mass of conductors [3]. This allows accurate prediction of the instant at which the object is probed in pulsed experiments. X-pinch radiation backlighting of plasma arrays has given a deeper insight into the processes such as stratoformation in electrically exploded microconductors, "cold start" and "plasma rainstorm" in magnetically imploded multiwire arrays on ANGARA (Russia) and MAGPIE (Great Britain) generators [4].

An X-pinch is two or more wires which are crossed in the shape of "X" and exploded under the action of the current they draw. The high-temperature plasma, which serves as an X-ray source, is generated at the cross point of the wires.

At present there are two methods for X-pinch imaging of plasma objects. In the first method, which is typical for experiments with plasma implosion on megaampere high-current generators, an X-pinch is powered by part of the main generator current; more specifically it is placed instead of one of the rods of the return conductor. Despite the advantages (the proximity of the X-ray source to the plasma, the absence of a separate generator), this arrangement has a number of shortcomings. One of them resides in the fact that the moment of an X-ray burst is difficult to vary; namely, one should either change the diameter or the number of the wires, which strongly affects the spectral distribution and the size of the radiation source. Moreover, this method is applicable only for studies on a given generator. In the second method, a separate generator is used. The main requirements imposed on the generator are the current amplitude 150-300 kA and the rate of the current rise 1-2 kA/ns.

At the moment, these parameters of the current pulse can be provided only by enough large fixed-site generators weighing from 300 kg to several tons.

These shortcomings limit to a great extent the feasibility of this diagnostic technique in studies of extreme states. Therefore, the design of a portable pulse generator which provides the required parameters makes it possible to proceed to a new level of diagnostics of fast processes.

The arrangement of the high-current pulse generator is shown in Figure 1. The main components of the generator are a high-voltage power supply, a system of high-voltage synchronization, a low-inductance capacitor bank, multichannel switches, and a transmission line. The principle of the generator operation is the following. The high-voltage power supply charges the capacitor bank to a voltage of 50 kV. On the operation of the multichannel switches, which are triggered by the synchronization system, a current pulse is transmitted to a load through the forming line.

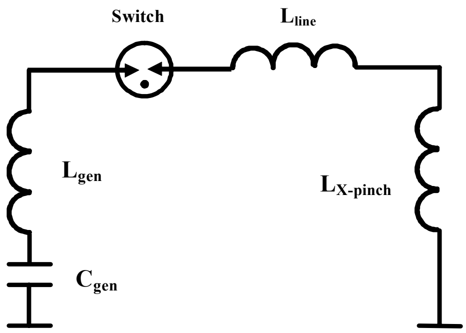

Fig. 1. The electric scheme of the high-current pulse generator

The generator consists of four capacitor-switch modules. Figure 2 shows schematically the view of one of these modules. A module is composed of a

0.25-μF capacitor and a 50-kV switch. In designing the capacitors, prominence will be given to minimize the resistance and to decrease the high current impact on the contacts. To decrease the inductance, the capacitor is placed in a coaxial position directly on the switch case.

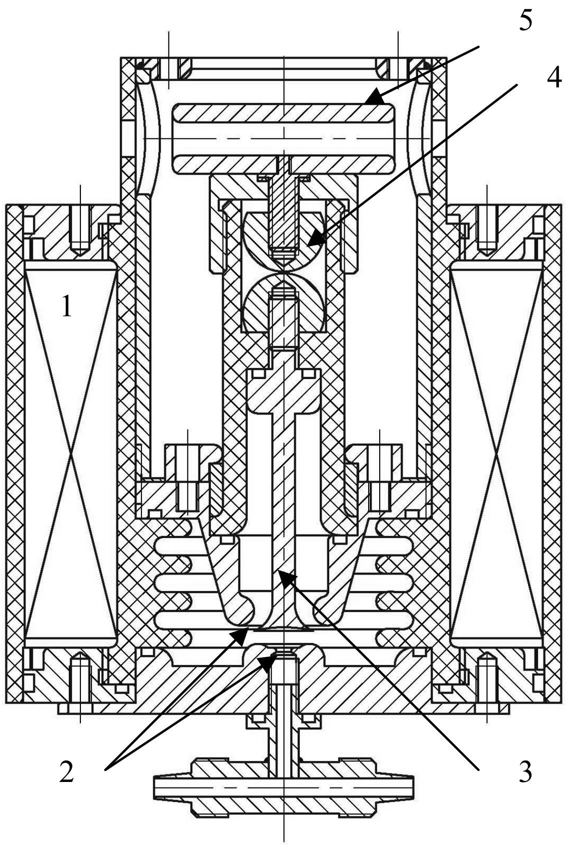

Fig. 2. Module design. 1 – capacitor, 2 – main electrodes, 3 – trigger electrode, 4 – trigger peaking gap, 5 – sleeve.

The pulse switch in the output stage of the energy store is an element which determines the parameters of an electromagnetic pulse through the load. The switch serves as a device of energy extraction from the capacitor. The switch is connected in series with the capacitor and must provide the required rate of energy extraction, i.e., have minimum inductance, and also transfer as much energy to the load as possible, i.e., have minimum resistance. To meet these requirements, the mode of multichannel switching is used which ensures both a low inductance and a high value of the charge transferred through the switch. The switch operates on the principle of field distortion at an increased air pressure (1-2 atm). The total inductance of each module (capacitor + switch) is 20 nH. The inductance of the generator consisting of four modules is 5 nH.

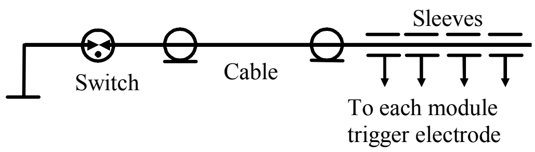

Fig. 3. Trigger generator scheme

The trigger generator provides synchronous operation of the four switches. The trigger generator scheme is shown in Figure 3. The generator consists of a cable section charged to 50 kV and connected to “ground” by a trigatron switch. The pulse switch is controlled via a sleeve which forms capacitive coupling with the trigger electrode of the each module. Between the sleeve and the trigger electrode there is a peaking gap. This arrangement makes it possible to obtain a trigger pulse with a risetime of 10 ns and with amplitude of 50 kV.

The transmission line serves for coupling between

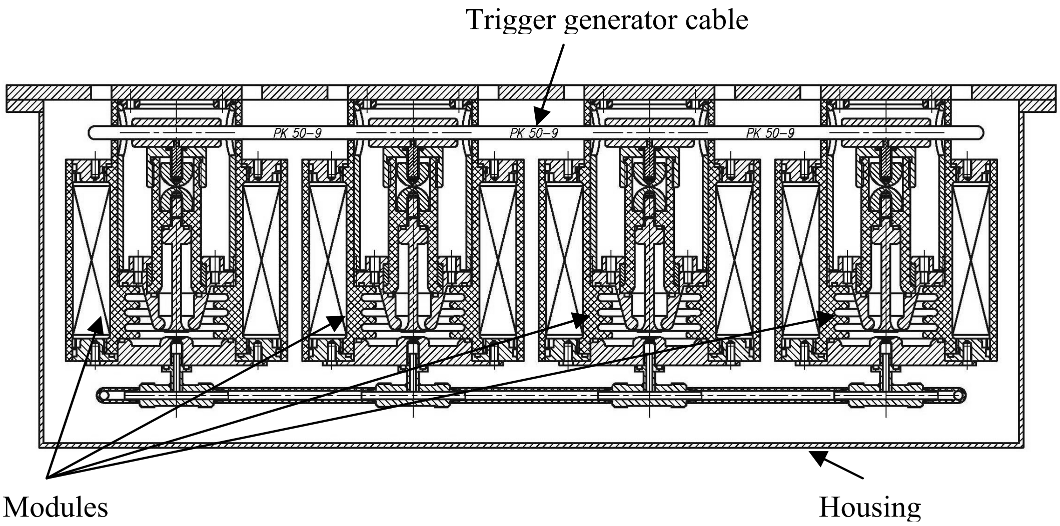

Fig. 4. The generator design

the pulse capacitor and the load. It is planned to place the load (the X-pinch) inside the vacuum chamber of the MIG generator (maximum current up to 3.5 MA, current rise time of 60-100 ns) [5], where the extreme states of matter will be investigated. Therefore, each capacitor-switch assembly is connected to the X-pinch (load) through eight KVIM cables. The cables form a transmission line which is rated at a voltage of 50 kV and has a total inductance of 4 nH for 32 cable sections 1 m in length each. X-pinch itself seems to be an inductance load with a low active resistance. The generator will be synchronized with the MIG installation with accuracy of 10 ns.

The use of the pulse capacitors and multichannel switches has made possible the design of a compact portable (weight ~30 kg, dimensions ~ 30 cm×30 cm× 85 cm) high-current pulse generator with a pulsed power of 10 GW. The parameters of the generator are the following:

- Energy stored in the capacitor bank: 1 kJ.
- Maximum charge voltage: 50 kV.
- Generator inductance: 5 nH.
- Transmission line inductance: 3-10 nH.
- X-pinch inductance: 10 nH.
- Maximum circuit current: 350 kA.
- Current risetime: 200 ns.

Small size of the generator allows using a set of the such generators in multi-frame X-ray backlighting systems.

The work was supported by RFBR grants #05-08-33331, #06-08-00001. The authors express their gratitude to the Russian Science Support Foundation for support of the work performed by V.I. Oreshkin.

References

1. S.M.Zakharov et.al, Sov. Tech. Phys. Lett. 8,456,(1982).
2. S.A. Pikuz et al, Nukleonika, 46, 115 (2001).
3. T.A.Shelkovenko et al, IEEE Trans.on Plasma Sci., 30,2,(2002).
4. V.V.Alexandrov et al, IEEE Trans.on Plasma Sci., 30,2,(2002).
5. A.V. Luchinsky, N.A. Ratakhin, V.F. Feduschak, N.A. Shepelev, Izv. Vyssh. Ucheb. Zaved, V. 40, No. 12, pp. 67-75 (1997).