New low-inductance capacitor-switch assembly

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Abstract. We have developed a new type of capacitor - switch assembly that are designed to be used with linear transformer drivers. This assembly can be DC charged to 160 kV and has a capacity of 110 nF. Due to the low inductance of 62 nH, this assembly is able to develop an output power of 10.2 GW. Also, we have designed and tested a three-electrode gas switch which is able to operate at the rated voltage and triggered with a jitter of 2 ns or less. This design of the capacitor-switch assembly allows creating new more compact and more powerful linear transformer driver.

1. Introduction
Currently, the idea of using the linear transformer driver (LTD) technology is widely used in pulse technology. This generator type does not require additional stages of pulse forming. As a result, it is possible to construct high-voltage, high-current pulsed-power accelerators with high specific parameters (such as a short rise pulse time, a high level of stored energy). Therefore, LTD technology finds its purpose in various in physical applications, such as very high current Z-pinch drivers, X-ray radiography, isentropic compression drivers, etc. In addition, the ability to relatively simply increase output power by combining cavity into large LTD modules gives us the opportunity to create a generator for Z-pinch inertial fusion energy (IFE) [1].

The main component LTD, which determines the efficiency of accelerator is capacitor - switch assembly (CSA). The CSA electrical schematic diagram is given in figure 1.

Figure 1. CSA electrical schematic diagram.

It was shown [2] that high circuit inductance bad influence on the output power of the generator. Therefore, the improvement of new designs of low-inductance capacitor-switch assembly is very important for the development of LTD technology.

2. Test-bench
We tested a new type of CSA on a laboratory bench schematically shown in figure 2.
Figure 2. Electrical schematic diagram of laboratory bench.

The CSA includes two capacitors and one gas switch placed in a cavity with transformer oil (figure 3).

Figure 3. Picture of CSA in a test cavity: 1 – capacitors, 2 – gas switch, 3 – magnetic probe 1.

Compressed dry air was supplied inside the switch (the water vapor dew point was about -50°C), and was replaced after each shot. The outer ends of the capacitors were connected to the charging sources through a protective resistor. The middle plate of the switch was connected to a triggering generator. After the pressure was released in the spark gap of the triggering generator, the surge came to the middle terminal with a delay of 40 ns. This impulse distorted the field inside the switch and provoked the interelectrode gap breakdown. The charging voltage was recorded by two independent kilovoltmeters. To record the time of the pulse beginning, a magnetic probe was placed in the discharge circuit. The second magnetic probe recorded the start time of the trigger signal. The signal from the magnetic probe was registered by an oscilloscope.

3. CSA inductance
To measure the inductance of CSA, one capacitor was charged up to +50 kV, the second to -50 kV. The shape of the output pulse is shown in figure 4.
Figure 4. Integrated short-circuit current waveform of CSA.

CSA inductance was calculated by equation (1):

\[ L \approx \frac{T_0^2}{C_c (4\pi^2)} \]  

(1)

Here, \( C_0 = C_c/2 \), \( C_c = 220 \text{nF} \), capacitance of capacitors, the natural frequency of the discharge circuit \( T_0 = 519 \text{ ns} \). The total inductance of the discharge circuit is 62 nH.

4. Self-breakdown curves

To determine the switch self-breakdown voltage, we supplied the necessary air pressure to the gas switch. After that, the voltage on one of the electrodes slowly rose to breakdown of the interelectrode gap. The opposite and control electrodes were connected to ground potential. The tests were carried out after 500 shots. The self-breakdown voltage curve is shown in figure 5.

![Self-breakdown curve](image)

Figure 5. Self-breakdown voltages of CSA as a function of dry air pressure.

The dispersion of the breakdown voltage was insignificant and amounted to a few percent of the mean value. Unfortunately, the available energy sources are not designed for voltages above 80 kV, so we extrapolated the obtained values. To reliably operate the switches at 160 kV total charge (80 kV each electrode), at 70% of the self-break voltage, we calculated the operating point. The calculated switch operating pressure is about 7.5 atm.

5. Switch delay and jitter

To increase the switch lifetime, we reduced the discharge energy. To do this, we replaced the capacitors. In these experiments we used solid-state capacitors with a total capacity of 250 pF. To preserve the shape of the field in the switch, the capacitors were arranged radially in steps of 120 degrees (figure 6).
Figure 6. Picture of a switch assembly with small capacitors for studying jitter.

Figure 7 shows the experiment results to determine the standard deviation of the switch. At a pressure corresponding to approximately 75% of the self-break voltage, the jitter of the spark gap was 2 ns or less. With further pressure increase, jitter increases. Also, the dependence of the delay time on pressure was observed, which agrees with [3].

Figure 7. Delay and jitter of the switch as a function of dry air pressure.

6. Discussions
Developed earlier CSA for LTD technology can be divided into 2 types. The first type of CSA involves two capacitors separated by an insulating body (figure 8). The switch is located near the charged terminals of the capacitors. It also has a control electrode and is filled with compressed dry air. This type of CSA for LTD was implemented in the 21-cavity Ursa Minor accelerator [4]. Unfortunately, such an arrangement of circuit components increases the inductance of the discharge circuit and reduces power output.
The second CSA type was developed in the HCEI SB RAS [5], which consists of one capacitor and one spark gap (figure 9). In this design, the switch is placed inside the cylindrical capacitor, which significantly reduces the inductance of the circuit. This makes it possible to increase the capacity of the capacitor, without decreasing pulse rise time. However, the construction of powerful LTD generators based on these CSA is unprofitable because of the small specific capacitance.

The new type CSA described in this article is a compromise between the first and second type. "HCEIcsa160-0.1" consists of two cylindrical capacitors, and the switch is in the center (figure 10). This design allows us to reduce the inductance of CSA as much as possible while increasing its specific capacity. Table 1 compares the characteristics of the first, second and third type CSA.

| Characteristic            | CSA type 1 | CSA type 2 | CSA type 3 «HCEI csa160-0.1» |
|---------------------------|------------|------------|-------------------------------|
| Design voltage, \( U_0 \), kV | 200        | 80         | 160                           |
| Inductance of CSA \( L_0 \), nH | 139        | 30         | 62                            |
| Electric power \( P_{\text{max}} \), GW | 4.55       | 5.5        | 10.2                          |
| Specific power \( p_{\text{max}} \), kW/cm³ | 1100       | 850        | 910                           |

The CSA type 3 power is twice as high as other types of assemblies. According to the measurements described above, the switch, which was designed specifically for this assembly, is suitable for reliable operation at a voltage of 160 kV. Jitter value and the delay of the switch CSA type 3 time are equivalent to the switches "L3" and "Kintech 2" [6], which were developed in the USA for use in the 21-cavity Ursa Minor accelerator.
7. Conclusions
We developed a new CSA type for LTD technology. Laboratory tests have shown that the inductance of this assembly is 62 nH, thereby providing output power level $P_{\text{max}} = 10.2$ GW and is significantly higher than the output power of other CSA type. For stable gas switch operation, without self-breakdown, a pressure of 7.5 atm. is sufficient for the rated voltage. The jitter and the delay switch time are small and allow the coordination of a large number of CSAs. All these facts enable us to create a new small-size generation accelerators based on CSA type 3.

In further works, we will investigate the operational life of capacitors and the gas switch, the jitter and delay times at the nominal voltage will be specified. In addition, a number of technical issues will be resolved to create a LTD generator project based on CSA type 3.

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