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REPETITIVE SHORT-PULSED GENERATOR USING MPC AND BLUMLEIN LINE

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Abstract

Recently, repetitive pulsed power generators using magnetic pulse compression (MPC) and semiconductor switches have been developed. A repetitive short-pulsed generator for an ozonizer was studied and developed.

In this work, the short-pulsed generator consists of a controller, a command charger, a high-speed thyristor, a MPC and a Blumlein line. The controller and the command charger are able to control the charging voltage to the MPC and the pulse repetition rate. The high-speed thyristor, which was improved in switching speed for the pulsed power applications, generated the primary pulse. The MPC has single stage pulse compression circuit using a pulse transformer and a saturable transformer. The saturable transformer has two functions, a step-up transformer and a magnetic switch. The Blumlein line is the final stage of the short-pulsed generator. The Blumlein line is three-coaxial geometry, which has an external electrode diameter of 110 mm, a middle electrode diameter of 20 mm, an internal electrode diameter of 4 mm, and a length of 500 mm. The short-pulsed generator which has an output voltage of about 65 kV, pulse repetition rate of 150 pulses per second (pps) and a pulse duration of less than 10 ns was used to generate ozone.

The results of ozone production using the short-pulsed generator and a simple coaxial electrodes are reported. The attained concentration of ozone was 18 g/m³.

I. INTRODUCTION

In recent years, researches on practical industrial applications of repetitive pulsed power generated by a MPC have been increased. These researches have focused on lasers for a long time. In particular, the excimer laser, which is used as a microlithographic light source in semiconductor fabrication, requires a high repetition rate, a high stability, and a long lifetime. Therefore, most of the excimer lasers for microlithography use a semiconductor switch and a MPC for their exciter [1, 2]. Moreover, the applications to environmental fields involving the decompositions of harmful gases and the generation of ozone utilizing pulsed power discharges have been studied [3, 4]. In these applications, the repetitive operation and the long lifetime are also necessary for the pulsed power generators.

Heretofore, the ozone generations by a pulsed power supply, which used a semiconductor switch and a MPC, have reported [4, 5]. In these papers, the pulse width of the output voltage from the pulsed power generator was about 90 ns. However, the duration of high voltage pulse needs to be short enough to prevent corona-to-arc transition. Furthermore, the pulsed power generator with short-pulse width is necessary. Nevertheless, it is difficult to generate the short-pulsed voltage less than 10 ns using the MPC.

In order to generate the short-pulsed voltage which is shorter than the output voltage from the MPC, a Blumlein line was added on the output side of the MPC. This was called as the short-pulsed generator. In the present work, the characteristics of the output voltage from and the ozone generation by the short-pulsed generator are reported.

II. EXPERIMENTAL APPARATUS AND PROCEDURES

A. MPC and Semiconductor Switch

A schematic diagram of the MPC is shown in Fig. 1. The MPC consists of a semiconductor switch, a pulse transformer (PT), a saturable transformer (ST), saturable inductors (SI₀, SI₁), and low inductance capacitors (C₀, C₁). The high-speed gate turn off thyristor (GTO, H10D33YFH, Meidensha Corp., Japan) was used as a switch of the primary circuit. The GTO thyristor was improved to decrease switching energy loss for pulsed power applications [6]. Table 1 shows the specifications of the GTO thyristor. A Fe-based nanocrystalline magnetic core (FT-1H, Hitachi metals Ltd, Japan) was used as the coupling core of the ST. The ST has two functions, step-up transformer and magnetic switch [6, 7]. The nanocrystalline soft magnetic alloys were used as the magnetic switches (ST, SI₀) and the PT. The magnetic and the physical characteristics of the magnetic alloys are shown in Table 2. The voltage gain of the ST is 8 (winding ratio, primary : secondary = 1 : 8), and the overall step-up ratio which is including both of PT and ST is 24. The capacitances of C₀ and C₁ are 800 nF and 1nF, respectively. A command charger that can provide a charge whenever the capacitor C₀ requires was employed. The GTO thyristor turned on with the current I₀, and then

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SI₀ saturated (turned on) immediately after the assist time. The current I₀ with duration of 1.2 μs flowed in the primary circuit. As a result, C₁ is charged to a high-voltage through the step-up transformers (PT and ST). In this time, SI₁ performed as a diode, which acts as an inductor to charge C₁, also acts as an inductor to block the discharge of C₁. Finally, the pulse current with the duration of about 90 ns was generated after saturating the ST. On the other hand, the Blumlein line was charged rapidly by the output current from the MPC.

Fig. 2 shows the dependence of the peak voltages from the MPC on the charging voltage to C₀. In Fig. 2, a 100 Ω resistor was used instead of the Blumlein line in Fig. 1. Fig. 2 shows that the peak voltages are in proportion to the charging voltages.

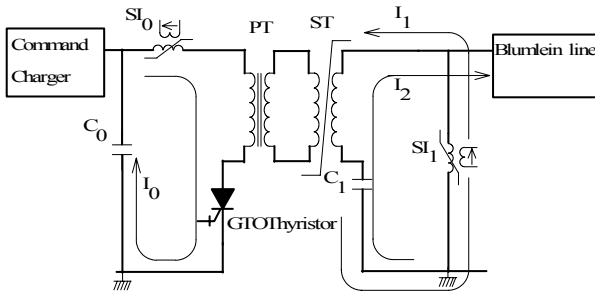


Figure 1. Schematic diagram of MPC.

Table 1. Specifications of high-speed GTO thyristor.

Repetitive peak off-state voltage	: 3300 V
Surge on-state current	: 5000 A
Critical rate of on-state current	: 8000 A/μs
Gate current	: 50 A _{peak}
External dimension	: 79 × 26.5 mm
Weight	: 600 g

Table 2. Magnetic and physical characteristics of nanocrystalline magnetic core.

Saturation induction B _s	: 1.35 T
Remanent flux density B _r	: 1.22 T
Coercive force H _c	: 0.8 A/m
Saturation magnetostriction s	: +2.3 × 10 ⁻⁶
Curie temperature T _c	: 570
Resistivity	: 1.1 μΩ·m

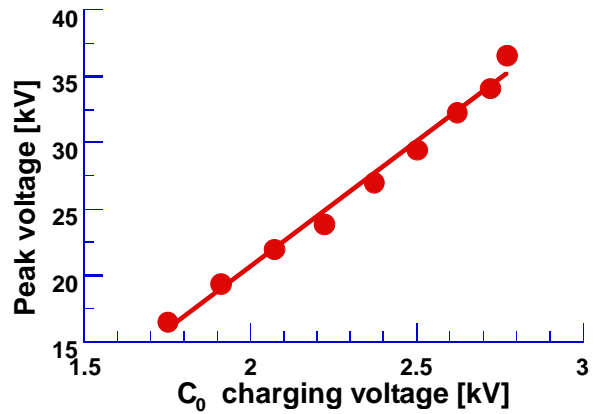


Figure 2. Peak voltage of MPC as a function of the charging voltage to C₀.

B. Short-pulse generator

Fig. 3 shows the schematic diagram of the short-pulsed generator. The MPC is used as a charging generator for the Blumlein line. The Blumlein line consisted of coaxial cylindrical tubes, filled up insulated oil, and a spark gap switch (GS). An inductor L is used as a charging inductor for Blumlein line. The inductance of L was 2 μH.

Fig. 4 shows the structure of the Blumlein line. The GS was filled up with SF₆ gas in the range of 0.1 to 0.35 MPa. The Blumlein line had three-coaxial geometry, which had an external electrode diameter of 110 mm, a middle electrode diameter of 20 mm, an internal electrode diameter of 4 mm, and a length of 500 mm. The calculated impedance, capacitance and inductance of the Blumlein line were 130 Ω, 38 pF and 640 nH, respectively. The output voltage from the short-pulsed generator was successfully as same as the charging voltage to it. The peak of the charging voltage was controlled by the pressure of SF₆ gas.

Fig. 5 shows the typical waveforms of the charging voltage to and the output voltage from the short-pulsed generator for different gap pressures. In Fig. 5, a 100 Ω resistor was used as a load of the short-pulsed generator. It will be observed from Fig. 5 that the peak voltage from the short-pulsed generator increased with increasing the pressure of SF₆ gas. The highest peak voltage was approximately 65 kV with 7 ns width at 0.35 MPa of SF₆ pressure.

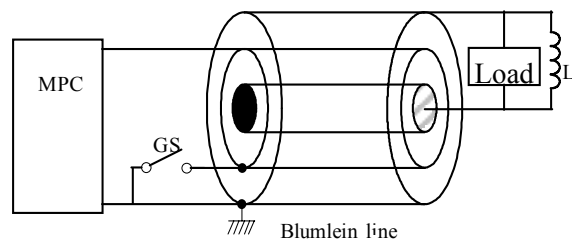


Figure 3. Schematic diagram of the short-pulsed generator.

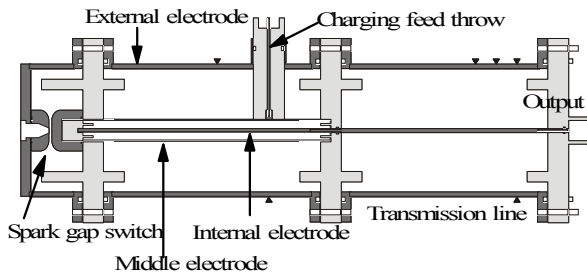


Figure 4. Structure of the Blumlein line.

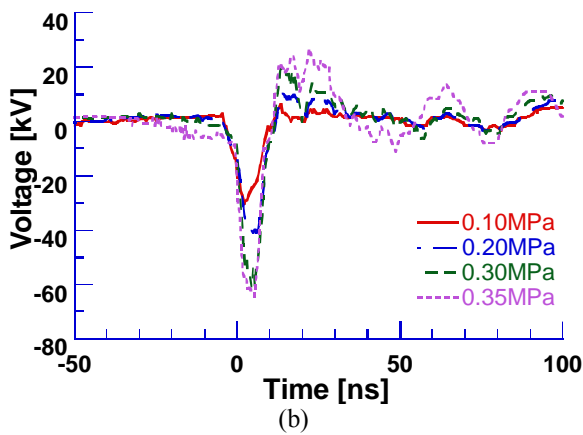
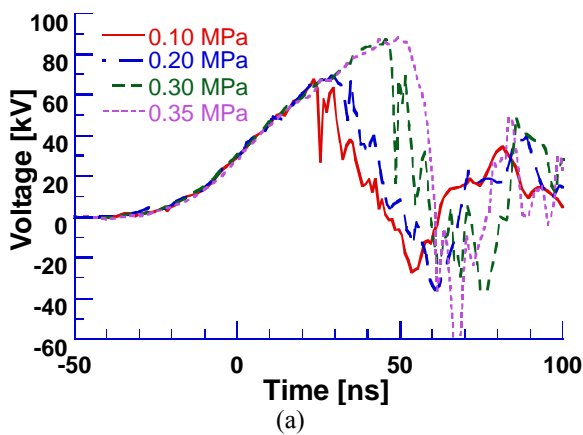


Figure 5. Typical waveforms of the charging voltage to (a) and the output voltage from (b) the short-pulsed generator for different SF_6 gas pressures.

C. Ozone production using the short-pulsed generator

The experimental set-up is shown in Fig. 6. The production of ozone using the short-pulse generator was examined. The set-up consisted of a cylinder of oxygen, the discharge reactor, an ozone monitor and the short-pulsed generator. A coaxial simple electrodes was used

as the discharge reactor. A tungsten wire having 1 mm of diameter was placed concentrically in a brass cylinder having 50 mm of inner diameter and 200 mm of length (in Fig. 7). The short-pulsed voltage was applied to the inner wire. The outer cylinder was grounded. The purity of the oxygen cylinder was 99.5 %. The gas flow rate and the ozone concentration were monitored by a flow-stat meter and an ozone monitor based on the ultraviolet ray absorption, respectively. The gas flow rate was fixed at 1.0 l/min.

The applied voltage to and the discharge current through the reactor were measured using a resistive voltage divider ($1\Omega/20k\Omega$), which was connected between the center wire and the ground, and a current monitor (Model 2878, Pearson Electronics, USA), respectively.

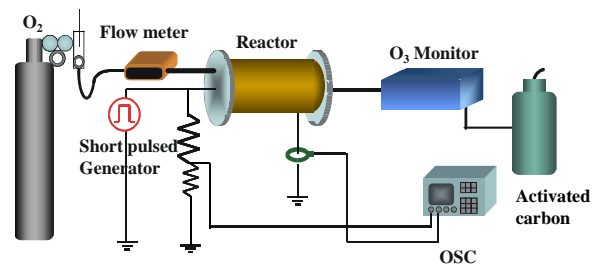


Figure 6. Experimental set-up for production of ozone

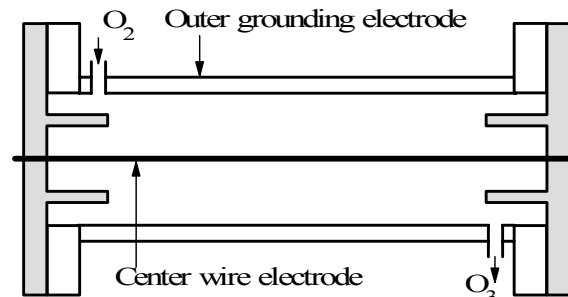


Figure 7. Discharge reactor configuration.

III. RESULTS OF OZONE PRODUCTION EXPERIMENT

Fig. 8 shows typical waveforms of the applied voltage to and the discharge current through the reactor. It will be observed that the FWHM of the applied voltage was about 6 ns, while that of the discharge current was about 8 ns.

The results of the ozone production using the short-pulsed generator are shown in Fig. 9. It will be observed that the concentration of ozone depended on the charging energy to C_0 .

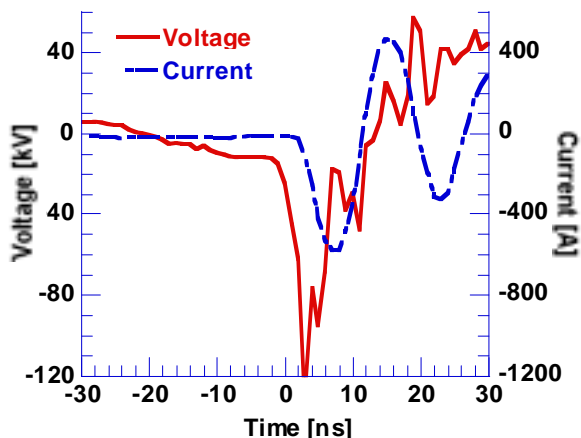


Figure 8. Typical waveforms of the applied voltage to and the discharge current through the reactor.

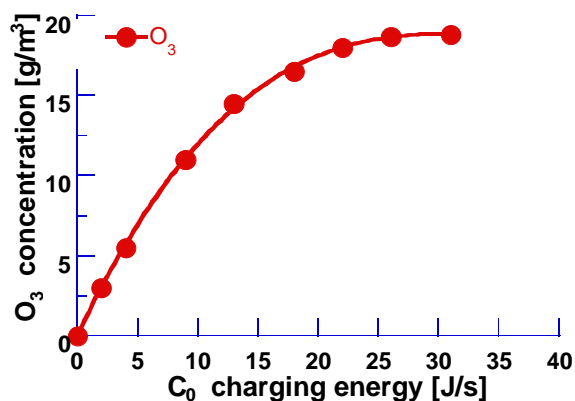


Figure 9. Dependence of ozone concentration on input energy to C_0 of the Short-pulsed generator.

IV. SUMMARY AND FUTURE DEVELOPMENT PLANS

Stable operation of the short-pulsed generator at several hundreds pps was succeed. The output voltage had the peak value of 65 kV with less than 10 ns width. The ozone production using the short-pulsed generator and a coaxial electrodes was done. The attained concentration of ozone was 18 g/m³. This means that the short-pulsed generator is able to be a power supply to generate ozone. Although the obtained concentration of ozone was not superior to that of using a silent discharge ozonizer, the short-pulsed voltage has a great potential for an improved short-pulsed generator by choosing the certain circuit and the characteristics of the reactor.

The future plans should be to increase the pulse repetition rate and maximum output voltage, and to employ the magnetic switch instead of the gap switch of the Blumlein line. In addition, it is eager to replace the Blumlein line to a pulse forming network.

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