A 150kV/300A/1μs COAXIAL BLUMLEIN PULSER [*]

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Abstract

Blumlein pulsers are well-suited devices for high voltage pulse generation in the range of μs. They consist of pieces of transmission lines charged in parallel , which discharge synchronously in series into the matched load by using a single switch. The main problems with this type of circuit are the presence of the shield cable impedance that contributes to the power loss of the device and the requirement of long lengths of lines for operation in the microsecond range. In view of that, this paper presents a construction method that minimizes these losses and reduces the generator size by using coaxial lines coiled up on insulating tubes. In particular we report the construction of a 150kV/300A/1us Blumlein pulser that has been carried out in our laboratory. Also the output voltage pulse measured up to 45kV for the initial tests is given and compared with numerical simulation.

I.INTRODUCTION

Blumlein pulsers are high voltage generators made of pieces of transmission lines and normally used in a great variety of applications such as in x-ray generation, breakdown tests, etc [1-2-3]. Also as described elsewhere [4] these devices have the potential to be used in surface treatment of plastics by plasma immersion ion implantation. Basically they consist of coaxial lines that are charged in parallel and discharged synchronously in series into the load by a single switch at the device input. For example, Fig. 1 shows a configuration circuit using 10 coaxial lines in which a negative pulse voltage is generated from a charging positive voltage +V. The principle of operation of the device can be summarized as follows: in the initial state the lines are positively charged, but the net output voltage is zero because of the initial voltage vector opposition as indicated in Fig. 1. As soon as the switch is closed, pulse voltages propagate (to the left) down the active lines. After one propagation delay time they arrive at the output where reflections occur converting the initial vector opposition to a series addition, which persists for twice the line propagation time. This leads to an output voltage of nV for an open end or else nV/2 for the case of a load nZ_0 matched to the generator output, where n is the number of lines and Z_0 is the line characteristic impedance. Regarding the pulser configuration circuit, there are two important impedances in a cable, the inner cable characteristic impedance Z_0 and the impedance Z of the outer part of the shield (see Fig.1). If $Z<<Z_0$ a fraction of the output current can reach ground via cable shielding without going through the load. If the outer impedance Z can be made large, for example by winding the cable on a former so that the inductance of the outer part of the jacket is high, then it reduces the drained current and, consequently, the overall power loss of the device. In this paper we present a construction method to make $Z>>Z_0$ of a high voltage Blumlein pulser (150kV/300A/1μs) under construction in our laboratory [5]. To determine the device efficiency we have also reported the first results up to an output voltage of 45kV and compared with the PSPICE circuit simulation considering the shield cable impedance.

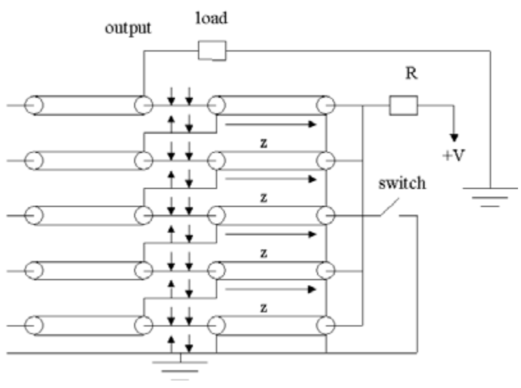

Figure 1. A coaxial Blumlein pulser made of 10 lines.

II.PULSER ASSEMBLING

The requirements of our pulser design are: 150kV/300A with pulse duration of 1μs. Thus the pulser load of 500Ω requires a design with 10 pieces of a 50-Ω coaxial cable (or 5-stages). To ensure a high breakdown voltage, we chose the coaxial cable URM67/50Ω with the maximum rating of 40kV. Considering a pulser with 10 lines (i.e., with an ideal gain of n/2= 5) and its output

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nominal voltage of 150kV gives a maximum charging voltage of 30kV, below the cable breakdown voltage. The length of each transmission line is 100m as the selected cable URM67 has a double transit time of 10ns/m, which implies in the pulse duration of 1μs. To increase the device gain efficiency, the coaxial lines were wound around cylindrical tubes, made from PVC and supported by an aluminum structure as shown in Fig. 2. In practice, we have estimated the shield cable impedance by measuring the inductance L and capacitance C (with respect to ground) of one coaxial winding in the pulser structure. By using a L-C bridge meter we obtained an inductance of about 1.0mH for each coaxial coil. In relation to C, we verified that the meter provided approximately the same capacitance (on the order of 250pF) for each coaxial coil with respect to ground. Calculating through the well-known formula for the line characteristic impedance $\sqrt{L/C}$ gives a value of 2kΩ for the cable shield impedance Z.

To charge the coaxial cables we used a conventional charging power supply with positive polarity of 10kV/20mA. For the switching system a thyratron tube with voltage/current ratings of 35kV/5kA was used. This switch incorporates a glass envelope single gap tube that conducts in the reverse direction (hollow anode version), which is an important characteristic for the pulser design as the impedance mismatch into the system caused by the shield cable impedance produces negative reflected voltages at the generator input side. Fig. 3 shows a picture of the Blumlein pulser structure (back), conventional charging power supply (to the left in the corner) and racks (front to the right) containing the auxiliary systems such as thyratron switch metallic box and tube trigger/heater circuits.

To make the pulser input connections, coaxial cable shieldings are stripped back by 300mm and the inner conductors are connected to a small cooper plate as seen in Fig. 4. Then the shieldings are joined through special connectors to a second cooper plate separated from the first one by the stripped shielding distance of 300mm. To reduce the inductance of the tube input connection, we used the inner conductors of both URM67 coaxial cable short lengths (≈ 0.7m) connected in parallel to link the thyratron anode to the first plate and the cable shieldings to link the tube cathode to the second plate (see Fig. 4). The same technique is applied to make the output connections where the shieldings (or the inner conductors) of adjacent cables are joined and the shieldings of the most upper and lower cables are connected to the load.

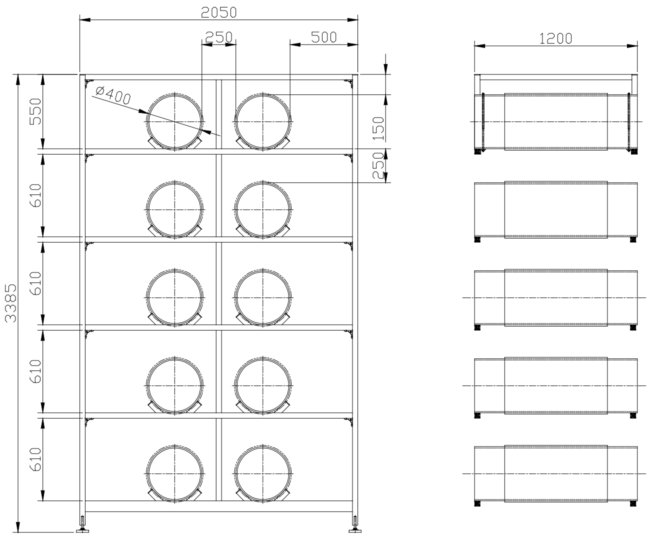

Figure 2. Pulser sectional cross view in mm.

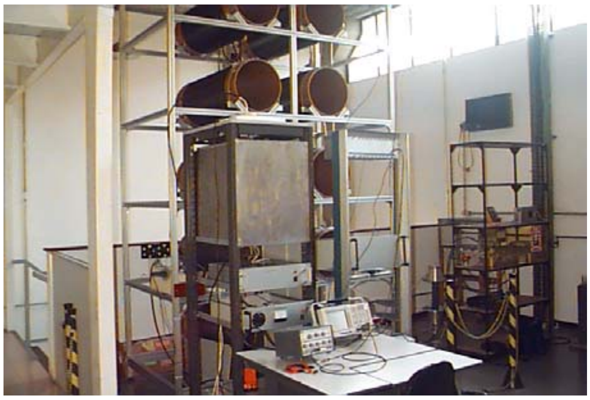

Figure 3. The pulser structure and auxiliary systems.

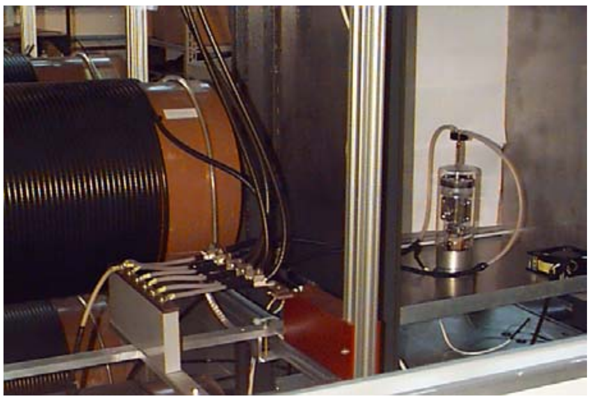

Figure 4. Picture showing the coaxial input connection.

III.PULSER ASSESSMENT

In this section, a PSPICE model circuit shown in Fig. 5 assesses the performance of the device. In the simulation, the pulse generator is modeled by ideal coaxial lines (with characteristic impedance Z_0=50Ω and transit time δ=500ns) connected to a resistive matched load of 500Ω. The open ends of the passive lines are simulated through high value resistors (1GΩ) to avoid node list problems in the PSPICE simulation. The cable shield impedances are also represented in the model circuit by ideal transmission lines laid between the adjacent pulser lines (see lines T11-T14 in Fig. 5). This is so because the cable shielding impedance Z represents the characteristic impedance of a parasitic transmission line formed by the shielding itself and the ground plane. As each cable shielding at the switch side is grounded the parasitic lines are short-circuited at their input in the model by grounding the line inner conductors.

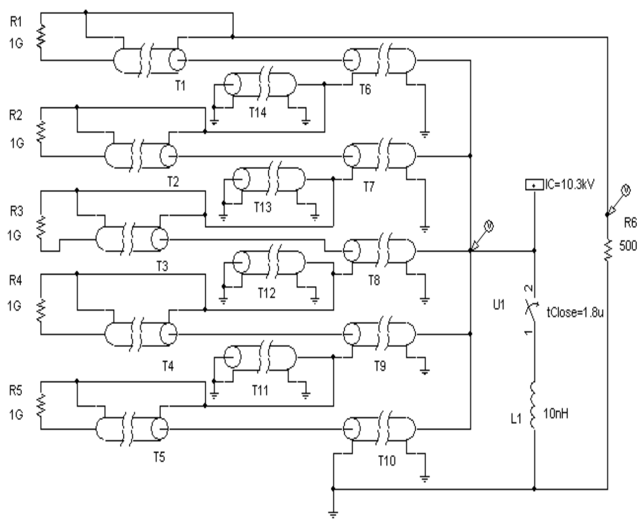

Figure 5. PSPICE circuit model.

In the simulation, the parasitic line characteristic impedance is equal to the shield cable impedance given by $\sqrt{L/C}$, where L and C are respectively the coil inductance and capacitance described in section II. Moreover, it is assumed that all the parasitic lines have the same transit time T calculated such as $\sqrt{LC}$. By using the same measured values for L and C we tested the model with Z=2kΩ and T=0.5μs. Fig. 6 shows the simulation of the output and input pulse voltages in a short time scale (1.6 to 4μs) for an initial charge voltage of about 10 kV. First observe in this figure that the charging input voltage (thin line) decreases rapidly to zero (in less than 100ns) as soon as the switch is closed at a set time on the order of 1.8μs. As is supposed a very low inductance at the switch connections of about 10nH, we verify in the simulation that the rise time of the output pulse voltage is also less than 100ns, being defined basically by closure time characteristic of the switch. Also observe that the output voltage is generated after a line delay time of 500ns with pulse duration equal to the double propagation time as expected. Moreover due to the shielding cable impedance effect we verify some power loss in the device, as the output pulse amplitude on the order of 45kV is lower than the expected value of 50kV. From this, we can infer that pulse generator efficiency is on the order of 90 %. On the other hand, the experimental data obtained for an initial charging voltage of 10 kV confirms this result providing approximately the same pulser efficiency as expected, but with an increased pulse rise time on the order of 300ns as shown by the thick line in Fig. 7. This rise time increase is explained by taking into account the higher inductance at the switch connections measured on the order of 700nH, which prevents the input voltage from dropping in a very short time (<100ns) as soon as the switch is triggered (see thin line in Fig. 7). To compare with the low inductance case, see again thin line in Fig. 6 in which the input voltage is grounded very rapidly in less than 100ns. If this condition is met the pulse rise time is short and the output pulse shape is approximately flat with pulse duration given by the double delay line of 1μs (see thick line in Fig. 6).

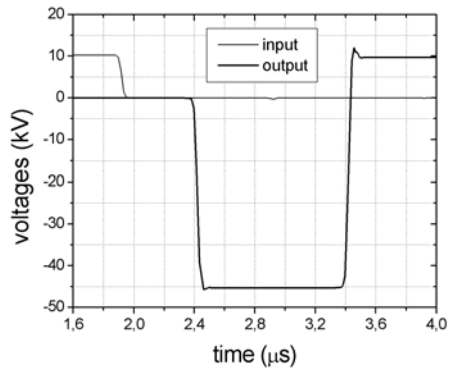

Figure 6. Simulations of the input/output voltages.

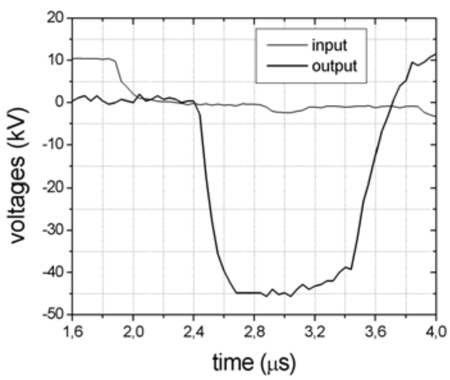

Figure 7. Experimental input/output voltages.

To illustrate the model performance Figs. 8 and 9 compare respectively the simulated input/output voltages with the experimental results in an expanded time scale, considering the measured connection inductance of 700nH. The analyses of these figures show that our PSPICE model fits well the experimental results, despite some small discrepancies in the long tails of the input/output pulses. As expected these long pulse tails are caused by the impedance mismatch at the pulser output due to the presence of the shielding cable impedances. Finally, further improvements in the model may be possible by taking into account the small inductances existing at pulser output connections or considering the coaxial cables as lossy transmission lines.

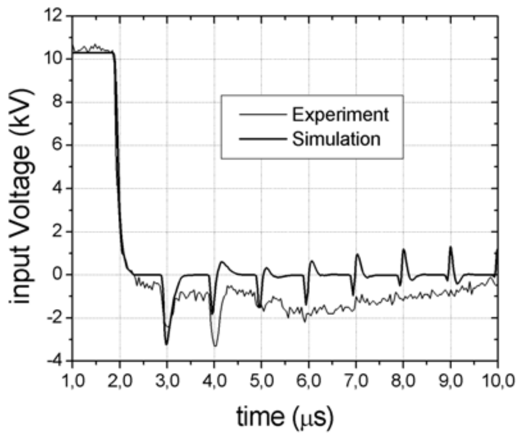

Figure 8. Experimental and simulated input voltages shown in an expanded time scale.

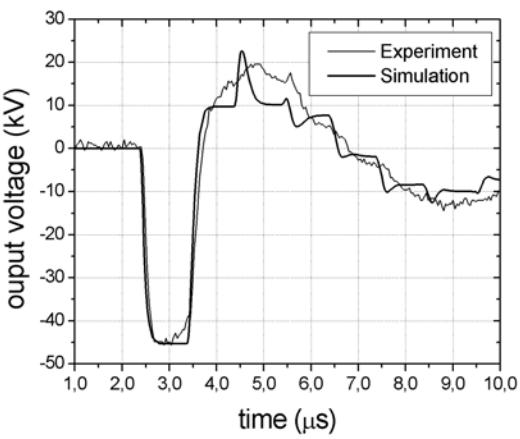

Figure 9. Experimental and simulated output voltages shown in an expanded time scale.

IV.CONCLUSIONS

In this work we have presented the design and construction of a 150kV/300A high voltage Blumlein pulse generator for long pulse operation in the 1μs range. Basically the pulser has been built by connecting long lengths of transmission lines coiled up on insulating tube formers to minimize the adverse effect of the shield cable impedance on the voltage gain of the device. In contrast with a coaxial line pulser described elsewhere [3] we have opted for insulating PVC tubes of great dimensions (diameter of 400mm and 1.2m in length) to increase the coaxial cable inductance and avoid the use of expensive ferrite cores into the former coils at the cost of some loss of the device gain. At present the pulser is operating at peak voltages of about 45kV and pulse rise time on the order of 300ns for an initial charging voltage of about 10kV. As expected this result confirms some power loss in the device (on the order of 10%). Also we have simulated the pulser operation by using the PSPICE circuit simulator program, where ideal transmission lines represent the coaxial cables as well as the parasitic shielding lines. The good agreement obtained between the simulated and experimental results gives confidence in our model and suggests a useful simulation tool for the design of coaxial line pulse generators. Because of the pulser efficiency loss (10%) we intend to charge the coaxial cables up to 33kV (instead of 30kV) in order to reach the specified value of 150kV. For this final test, we will employ a high voltage switched-mode power supply with a maximum voltage capability of 35kV and charge rate of 8kJ/s.

V.REFERENCES

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