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Simulation and experimental study of the solid pulse forming lines for dielectric wall accelerator *

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Abstract: Two types of pulse forming lines for dielectric wall accelerator (DWA) were investigated preliminarily. By simulation with CST Microwave Studio, the results indicate the pulse forming process, which can help to understand the voltage wave transmission process and optimize the line parameters. Furthermore, the principle of the pulse forming process was proved by experiments and some excellent pulse waveforms were obtained. During the experiments, the Blumlein line and zero integral pulse (ZIP) forming line, constructed with aluminum foil, poly plate and air gap self-closing switch, were tested. The full width at half maximum (FWHM) of the waveform is 16 nanoseconds (BL) and 17 nanoseconds (ZIP line)，and the formed pulse voltage amplitude is 5 kV (BL) and +2.2 kV/−1.6 kV (ZIP line). The experiments result coincides well with the simulation.

Key words: DWA, blumlein line, ZIP line, simulations, experiments

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1 Introduction

The dielectric wall accelerator (DWA)[1,2] is a new type of compact induction accelerator, where the pulse forming lines, switches and vacuum insulated wall are integrated into a single compact geometry. This type of accelerator is capable of accelerating any charged particle. It pursues a high accelerating gradient (30–100 MeV/m for proton) and a high beam intensity (kA), so the breakdown strength of the materials used must be very high. The key technologies for the DWA are switching (gas, oil, laser induced surface flashover and photoconductive), dielectrics (ceramics and nanoparticle composites) and multilayered vacuum insulator technology. With both domestic and overseas efforts, these technologies have developed greatly, so it is now possible to construct DWA. DWA can be used in many fields, such as flash X-ray radiography, cancer proton therapy (2.5 m long/ 70–250 MeV) and heavy ion inertial fusion. The ultimate goal is to assemble these technologies and design DWA structures. It is important to test and verify the principle first. We start with a pulse forming line (PFL), an architecture-parallel plate Blumlein line (BL) and a zero integral pulse (ZIP) line with air gap self-closing switches. By simulation and analysis, the experiments were fulfilled and results were obtained that are well coincident with the theoretical predictions, and the pulse waveforms are very suitable for use in accelerators.

2 Analysis and simulation of solid pulse forming lines

2.1 Parallel plate BL

A BL consists of two transmission lines and a load between them, which is shown in Fig. 1(a). Typically, the up and down transmission lines are made with identical lengths and characteristic impedances.

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The basic parameters are as follows:

$$Z_0 = 377(d/w)\sqrt{\mu_r/\varepsilon_r}, \tag{1}$$

$$T_0 = l\sqrt{\varepsilon_r}/c, \tag{2}$$

here, l is the lines plate electrode length, w is the width of the plate electrode, d is the height of the delectric material, ε_r is the permittivity of the dielectric, T_0 is the single line electrical length and Z_0 is the single line characteristic impedance.

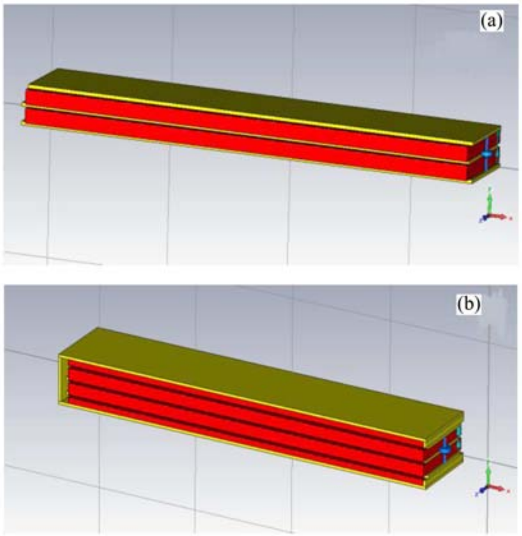

Fig. 1. (color online) The CST simulation model of BL(a) and ZIP(b).

The matched load is designed to be twice the value of the characteristic impedance. The middle electrode is permanently connected to a high-voltage source. The bottom electrode is grounded and the up electrode is “floating”. A switch triggering the pulse forming process, next to the high voltage source, is placed between the charged plate and the ground plate. The advantage of this configuration is that it produces a pulse of equal voltage amplitude to the charged voltage, which is more efficient than the single transmission line.

The pulse forming process is simulated with CST (CST Microwave Studio). Unfortunately, there is not a switch model in the CST code, which is one of the key parts of DWA. From Miroslav Joler [3], an efficient approach was mentioned to solve this problem, by a step pulse (Fig. 2). The high voltage part simulates the charging process and the falling edge represents the switching action. For most fast switches, the fall time is merely 100–500 ps. The impedance of the load consists of lumped element resistors. We built the BL with l=74 cm, w=12 cm, d=2 cm, t=0.5 cm and $\varepsilon_r = 10.0$, so $\tau = 2T_0$=7.3 ns, Z_0=42.4 Ω. t is the copper plate thickness.

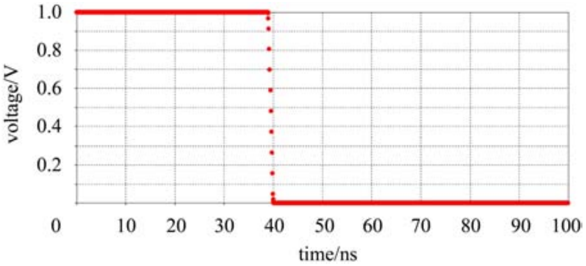

Fig. 2. (color online) The exciting signal waveform.

The simulated result of the BL is shown in Fig. 3. The lines are charged from the time of 0 ns and the switch switches on at 40 ns (high voltage). So in Fig. 3, the first part of the pulse (voltage (3),red line) is not the real process and after 40 ns (low voltage) the pulse forming process is consistent with the theory. Voltage (1) is the shorted end lines' voltage and voltage (2) is that of the open end lines.

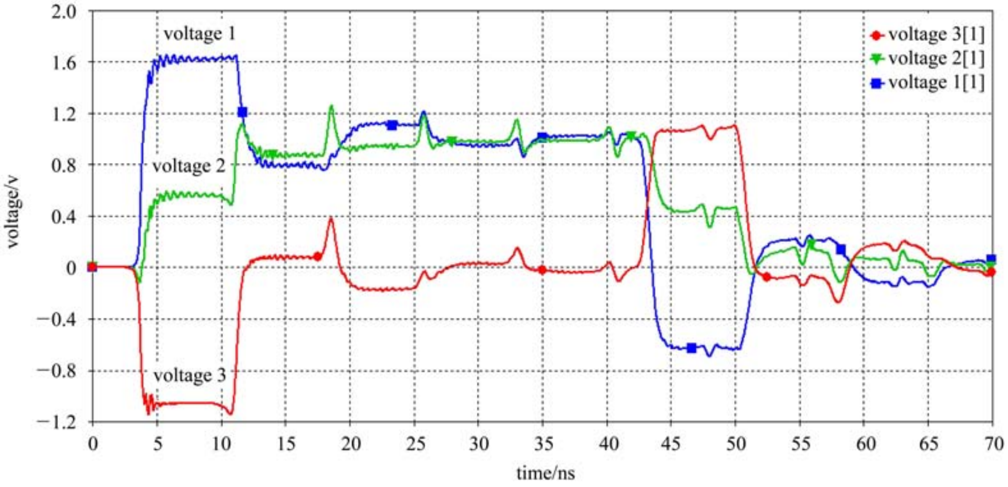

Fig. 3. (color online) The simulation results waveform of the BL.

The simulation demonstrates that whenever the lines are excited from discharged to charged (low voltage to high) or charged to discharged (high voltage to low), the output pulse waveform of the load is well created but only inverse polarized. If it just needs to obtain the formed pulse, the first part is enough, and if it needs to see the real pulse forming process, the simulation must take more time to first accomplish the charging process (low to high) and then the discharging process (high to low). The pulse forming process of the load can be clearly indicated by the voltage waveforms of the open and shorted end lines.

2.2 Zero integral pulse forming line

A novel, bi-polar pulse forming line, first put forward by I. Smith [4], is adopted by LLNL. They split the shorted line into two sections and wrapped these shorted sections above and below the active, charged line sections [5]. This structure is showed in Fig. 1(b). It produces a bi-polar pulse of $\pm V_0$ when charged to V_0 into a matched load of $2Z_0$ appearing at the second half cycle. They are known as bi-polar or zero-integral configurations because they produce a positive and negative voltage pulse with a net time integral of zero. The advantage of this structure is that it can deliver 100% energy to the load. This "switched load" can occur naturally in an accelerator application if the beam appears right at the zero-crossing to load the line. The simulation parameters are the same as BL.

The simulation is also created by CST, the same as used for the BL. However, it is found that, the ZIP needs long time when it is charged to be electrostatic, if not, the second part of the pulse will become confusing. So it needs a longer exciting signal, 100 ns duration of high voltage. We use a constantly matched load $R_{\mathrm{L}}=2Z_0$, and the result is voltage (3) in Fig. 4. From 0 ns to 100 ns, the ZIP is charged and at 100 ns the switch acts, so after 100 ns the real pulse is created. The wave transimission process from the simulation is well consistent with the theoretical analysis. In Fig. 4, voltage (1) is the waveform at the shorted end lines and voltage (2) is at the open-end lines. The pulse is formed by the voltage wave excited by the switch action, reflection and incidence occuring at the load junction. After two pulses, the pulse width becomes twice the width of the first and second pulses, and gradually attenuates to zero.

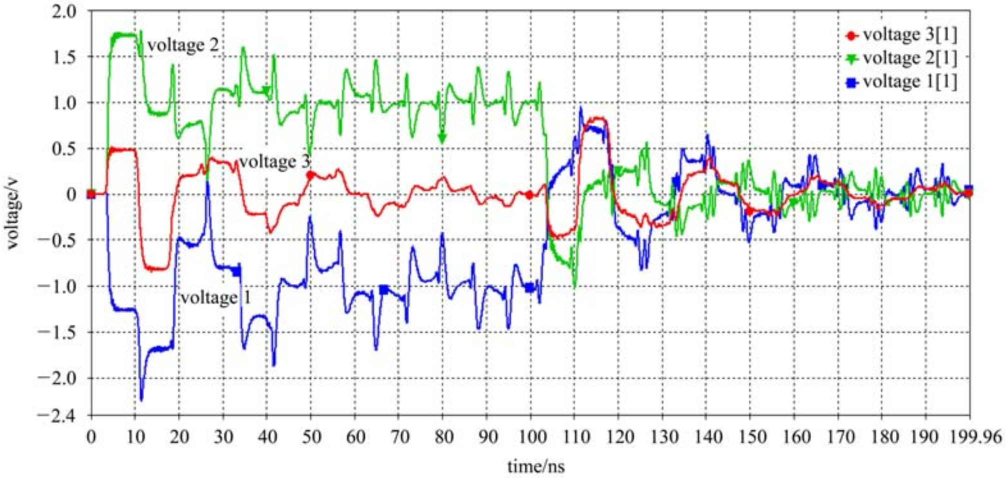

Fig. 4. (color online) The simulated full waveform of ZIP lines with a constant load.

The switched load consists of a diode and a resistor [6] in the simulation, and its result is compared with the constant load result in Fig. 5. It demonstrates that the pulses are different at the amplitude, the rise time and the fall time. The waveform of the switched load is better. The difference is attribute to the kind of load used.

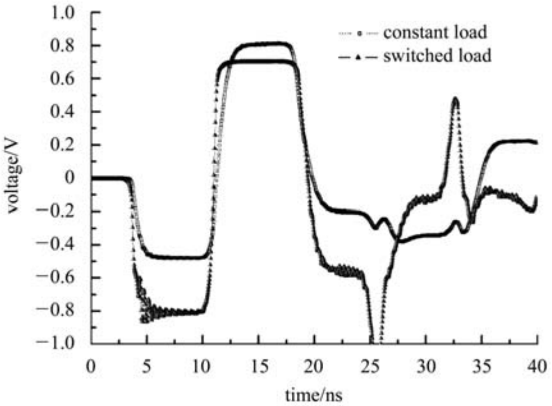

Fig. 5. Comparison between the switched load and the constant load of the ZIP line.

3 Experiment design and results

The experiments were implemented to test two types of PFL, constructed with poly plate, aluminum foil and self-closing spark-gap switches firstly. For the practical scheme, the high performance SiC photoconductive switch (PCSS) would be the best candidate because of its high breakdown strength voltage, low jitter and commutation time, but here self-closing spark-gap switches are adopted instead due to their ease of operation.

3.1 The BL experiment

The thickness, width and length of the poly plate are 5 mm, 20 cm and 168 cm, respectively. The width of the aluminum foil is 5 cm. A high DC voltage source of 5 kV is used to charge the BL. With such parameters, the calculated FWHM of the forming pulse will be 16.1nanosecond, the impedance is 25.4 Ω and the matched load resistor is 50 Ω. The pulse is measured by using a high voltage probe TeKP6015A, whose attenuation is 1000X. The result is shown in Fig. 6(a), which is very well coincident with the calculated one.

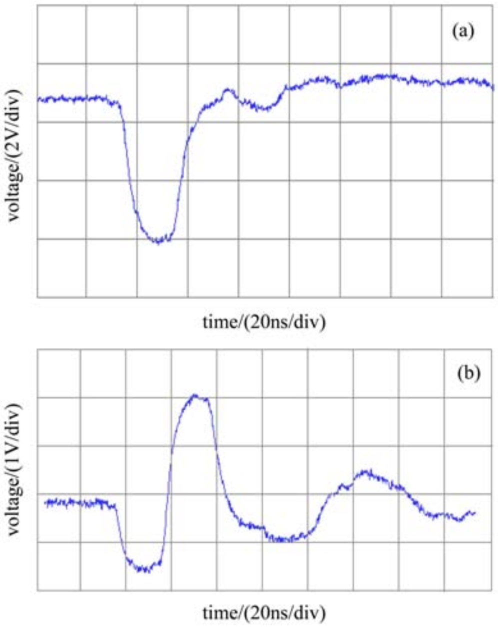

Fig. 6. (color online) The waveforms of the experimental result for the BL (a) and the ZIP (b).

3.2 The ZIP line experiment

The ZIP line is based on a parallel-plate, stacked Blumlein-like structure, with a symmetric bi-polar, zero-integral output pulse and an outer metal enclosure. The parameters of the ZIP line for the preliminary experiment are as follows.

The thickness, width and length of the poly plate are 2.4 mm or 4.8 mm, 20 cm and 179 cm, repectively. The width of aluminum foil is 5 cm. A high DC voltage source of 3 kV is used to charge the ZIP line. By the calculation of the above parameters, the FWHM will be 17.6 nanoseconds, the impedance will be 24.2 Ω and the matched load resistor will be 48.4 Ω.

During the experiments, confined by the devices, the experiments were only carried out with a constant approximately matched load of 50 Ω. The waveform of the ZIP lines is shown in Fig. 6(b), which accords with the simulation and theory very well. The pulse is oscillated because of imperfect matching.

4 Conclusion

By the simulation and analysis, the principle process of the pulse forming lines and the effect of the lines' parameters are well understood. This can help to make the DWA structure design more available. The experiments were well carried out and the waveforms are approved to be suitable for DWA. They are well consistent with the simulation results. The defect is that the voltage is not high enough to achieve a high accelerating gradient. It is only a principle experiment, because the material's breakdown strength is low and the permittivity is small. The volume is not compact enough. Secondly, the PCSS is not used and the rise and fall times of the pulse are not short enough. The next step is to find the appropriate material for the lines and to combine it with the PCSS to achieve a high gradient and compact volume to achieve the DWA structure ultimately.

References

1 Caporaso George J, Sampayan S, CHEN Y J et al. IEEE, PAC. 2007, 857–861

2 Sampayan S, Caporaso G, CHEN Y J et al. Plasma Science, 2007. ICOPS 2007. IEEE 34th International Conference on, 2007, 683

3 Joler, Miroslav. Ph.D., The University of New Mexico, AAT 3220947, 2006, 264

4 Smith I. Rev. Sci. Instr., 1979, **50**(6): 714–718

5 Rhodes M A, Watson J, Sanders D et al. Pulsed Power Conference, 2007 16th IEEE International, 2007, 538–541

6 Ozawa M, Watanabe M, Hotta E et al. 12th IEEE International Pulsed Power Conference, 1999, **2**: 951–954