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ELECTRICAL CHARACTERISTICS OF A SMALL PLASMA FOCUS DEVICE

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ABSTRACT

Efficient plasma focus operation relies on uniform initial breakdown across the insulator surface. In this paper, we discuss basic plasma focus electric circuit, in order to highlight circuit modifications that produce high voltage oscillation at initial breakdown time. Superimposed on the main discharge voltage such oscillating voltage has been found in real systems to enhance the initial gas breakdown by localizing the initial current path across the insulator surface. PSpice circuit simulations are compared with electric signals from different operational plasma focus devices.

INTRODUCTION

Plasma focus device is one of the experimental apparatus which is capable of producing transient dense magnetized plasmas of interesting parameters. Very high temperature and density plasmas can be produced in modest size machines at the kJ level. Apart from basic scientific interests, such plasmas are of fundamental importance in the production of X-rays and particle beams for a wide range of technological applications. A number of previous studies have outlined the design principles and the operating characteristics of the plasma focus [1,2]. However, the scaling of the plasma parameters do no fall into the general trend when the bank energy of the system is above a few hundred kJ or below a few kJ [3,4]. The importance of the initial breakdown formation processes and the power limit in very high energy system has been pointed out [5]. The operation at the lower energy regime is less well characterized. In general, the initial breakdown and the formation of the current carrying plasma sheath determine the formation of a snow-ploughing structure during the axial run down phase. The structure of this propagating sheath directly influences the behavior of the plasma in the final collapse phase. The initial breakdown occurs along the insulator under the effect of an applied voltage and subsequently develops into a current carrying sheath which lifts off from the insulator surface. An important point in the optimization of the sheath formation process would be by the control of the shape and amplitude of the initial applied voltage. The circuit for a typical plasma focus consists of a capacitive discharge system with the rate of application of voltage and current determined by circuit inductance and capacitance. The maximum voltage is limited to that of the charging voltage on the capacitor bank and could not be adjusted independent of the energy storage system. In this paper, we discuss basic plasma focus circuits and circuit modifications, which enable the creation of a high frequency, high voltage oscillating waveform superimposed on the main capacitive discharge waveform. Such oscillating voltage is found in real operating systems [6] to enhance the initial gas breakdown and localizes the development of the current path.

CIRCUIT SIMULATION AND EXPERIMENTAL RESULTS

Circuit simulation using PSpice is used to model the voltage across the base plate of a typical small plasma focus device, at the time of initial breakdown. Figure 1 shows two different circuits used in the simulation. Fig. 1-a corresponds to a simple plasma focus, with an LC configuration. In Fig. 1-b, a coupling transmission line has been added after the spark-gap that switches the bank energy into the focus. C_B is the capacitor bank, L_B corresponds to the capacitor bank inductance, SG is the transfer spark-gap, R is a typical high impedance damping resistor, C_F represents either the base plate stray capacitance or any additional capacitance added in parallel, S_F represents the breakdown across the insulator, and L_L is the initial focus inductance, at breakdown time. T is a transmission line, of realistic impedance and transit time.

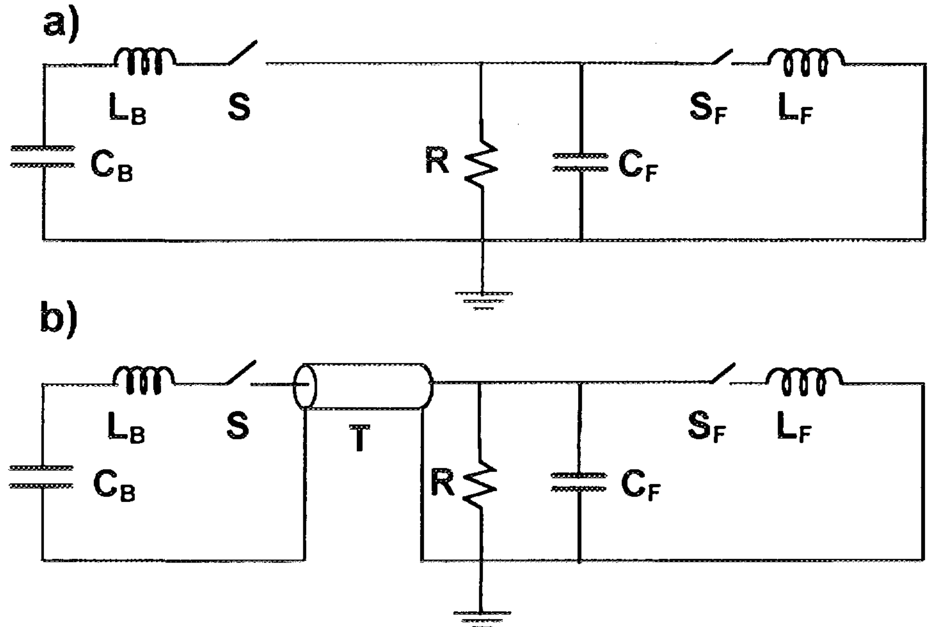

Figure 1: a) basic plasma focus LC circuit. b) basic plasma focus circuit with additional transmission line after the main spark-gap.

PSpice simulations of the above circuits are shown in figure 2. Realistic circuit component values have been used, similar to those corresponding to a small low energy plasma focus device. Fix values in the simulation are: C_B = 9 μF, L_B = 50 nH, R = 3.4 kΩ, L_F = 20 nH. SG closes at t = 100 ns, with a closing time of 50 ns. S_F closes at t = 150 ns, with a transition time of 40 ns. Charging voltage of the capacitor bank is 20 kV. Figs. 2-a and 2-b correspond to the basic circuit in Fig. 1-a. In Fig. 2-a, a small realistic value of the base plate capacity, C_F = 20 pF, is used. In Fig. 2-b, additional capacitance in parallel is added, and C_F = 5 nF is used. Figs 2-c and 2-d correspond to the circuit with additional transmission line shown in Fig. 1-b. A transmission line of 4.2 Ω impedance, 8 ns single transit time is used. Values of C_F in Figs. 2-c and 2-d are the same than in Figs. 2-a and 2-b, respectively.

One immediately obvious feature obtained, when an additional capacitance is introduced next to the load is the almost doubling of the voltage delivered to the load chamber in the beginning. This voltage enhancement is the result of transferring charge from the relatively large bank capacitance to a much lower capacitor across the load chamber. When a suitable transmission line is added, similar voltage doubling is obtained. In the case of the transmission line the doubling is due to the reflection off the practically open circuit at the load side, before breakdown occurs. Another feature is the enhanced high frequency ringing after breakdown is initiated. Here, a very simple model has been used to describe the sheath and no resistivity history of the plasma is included. the circuit simulation is simply providing a guide line to the oscillating component in the circuit. In reality, significant damping of the ringing would be expected as a result of the finite resistivity sheath plasma at the early time.

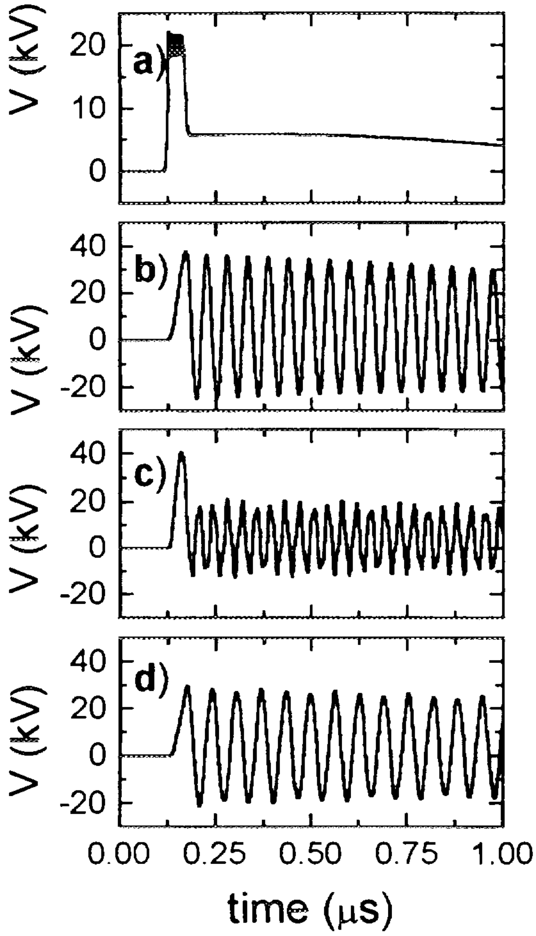

Figure 2: Pspice simulations of basic plasma focus electric circuits.

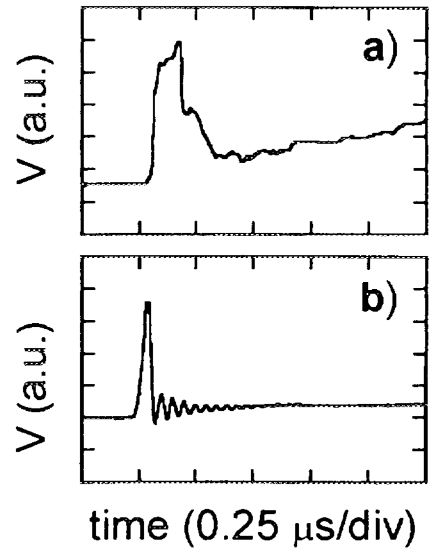

Figure 3: voltage trazes at initial breakdown in operational devices.

Characteristic voltage signals at initial breakdown from two different operational small plasma focus devices are shown in figure 3. Fig. 3-a corresponds to the UNU/ICTP PFF device [7] operating at 14 kV applied voltage, in air at 15 mTorr. Due to the low operational pressure, initial breakdown is assisted by plasma injection 80 ns after the bank switch closes, using a set of cable guns. The discharge is highly resistive at the initial stages, with similar features to the simulation shown in Fig. 2-a. Fig 3-b corresponds to the PFP-I device [6], operating at 20 kV, in hydrogen/argon mixture, at 270 mTorr, in self breakdown mode. In this case, a 4.2 Ω, 8.75 ns transmission line, is used after the bank spark-gap. In this particular device, efficient initial breakdown has been found to be improved as a result of the high voltage oscillation, thus extending the operating voltage and pressure range of the plasma focus.

CONCLUSIONS

The circuit simulations in Fig. 1 show clearly that a small circuit modification can result in a major change in voltage waveform at breakdown time. In particular, it is shown that the addition of a parallel capacity, a transmission line or a combination of both, produces a high frequency oscillating waveform superimposed on the applied voltage, with peak voltage exceeding the initial capacitor bank voltage. This combination of enhanced voltage and high frequency oscillation favors initial breakdown across the insulator surface, providing a favorable condition for sheath formation at low pressure, as it is shown in Fig. 3-b. After breakdown, a high rate of rise of current will facilitate the detachment of the sheath from the insulator. A local capacitor, close to the load will minimize the inductance in the current circuit at this stage. For practical applications, the geometrical layout will dictate the physical separation between the energy storage section of the load and thus the minimum length of coaxial cable that could be used. A suitable selection, based on realistic circuit simulation, of transmission line length and/or additional capacity, can easily be implemented to enhance the amplitude of the voltage delivered to the plasma focus chamber at early time. in order to improve breakdown and sheath formation, thus extending the operating pressure range of existing devices.

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