PLASMA-PULSE-ACCELERATION EXPERIMENTS

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ABSTRACT

This paper gives recent results of experiments with a coaxial Plasma-Pulse-Accelerator (PPA). Discharging a capacitor bank into the PPA more than 80 % of the stored energy could be transferred from the electrical circuit into the plasma. Accelerating masses of 10 g to velocities of 1020 m/s overall efficiencies of 22 % were achieved. A 3 g mass could be accelerated in the same PPA to 2000 m/s; the efficiency decreases in this case to 13 %. Some design aspects and main parameters influencing the energy conversion into the arcdischarge and questions of matching the power supply system to the acceleration process are discussed.

Introduction

The Plasma-Pulse-Accelerator (PPA) /1/ represents an electrothermal accelerator /2, 3/. It uses an arcdischarge ignited in a tube to absorb energy from an electric circuit (fig. 1).

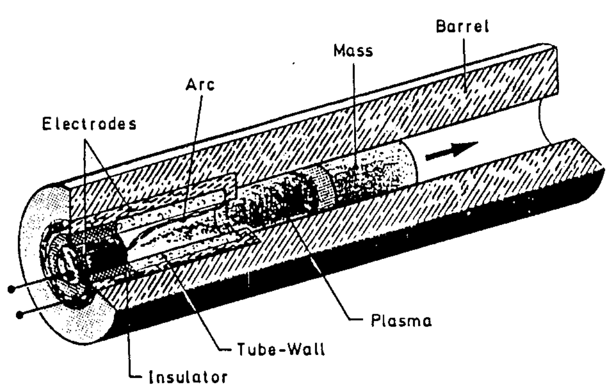

Fig. 1: Plasma-Pulse-Accelerator

The absorption process is controlled by forced interaction with the tube walls itself or an additional medium, which can be gaseous, liquid or solid. It results in a dense, pressurized plasma of high temperature, which acts as a propellant for the mass to be accelerated.

To absorb energy from an electric circuit via an arcdischarge is a well known method proved in several devices, i.e. circuit breakers /4, 5/, exploding wires /6/, plasma jet tubes /7/, and high pressure radiation sources /8/. In particular current limiting circuit breakers /9, 10/ and exploding wires /11, 12/, where an arc is drawn in a liquid, have some design criteria transferable to PPA's in principle.

Bloxsom /13/ was one of the first using an arc to heat helium electrically in order to accelerate small masses to high velocities. Another remarkable and successful demonstration of the efficiency of this acceleration method was performed by S. Goldstein et. al. /2/: Velocities of a few thousand m/s were achieved.

An important point for each electrothermal accelerator is to convert a high amount of energy absorbed from the power source into kinetic energy of the mass. In order to get high system efficiencies and high mass velocities it is necessary to match the power of the supplying circuit to the power the accelerator is able to absorb energy. The major aim of our experiments is to get more information on these questions.

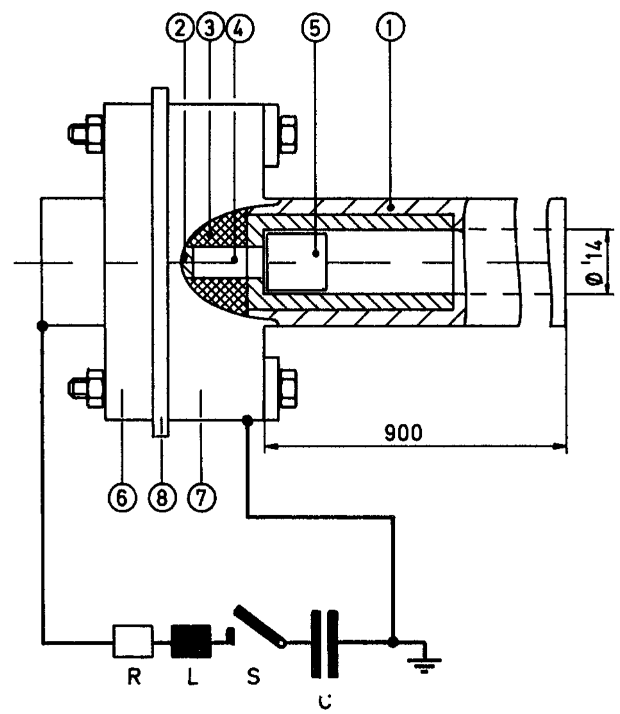

Fig. 2: Plasma-Pulse-Accelerator with power supply circuit (schematically)

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14. ABSTRACT
This paper gives recent results of experiments with a coaxial Plasma-Pulse-Accelerator (PPA). Discharging a capacitor bank into the PPA more than 80 % of the stored energy could be transferred from the electrical circuit into the plasma. Accelerating masses of 10 g to velocities of 1020 m/s overall efficiencies of 22 % were achieved. A 3 g mass could be accelerated in the same PPA to 2000 m/s; the efficiency decreases in this case to 13 %. Some design aspects and main parameters influencing the energy conversion into the arcdischarge and questions of matching the power supply system to the acceleration process are discussed.

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1. Experimental Setup

Figure 2 shows the design of the PPA with the power supply circuit schematically. The PPA consists of a metallic barrel (1) with an inner concentric pin (2), which is mechanically fixed in the barrel by a tube (3) made of insulating material.

The design of the tube forms a cylindrical discharge volume (4) behind the mass (5). The top of the pin, the end of the tube, and the first part of the inner wall of the barrel are made of material with low erosion rate. The barrel and the discharge tube with the electrodes are fixed by two steel blocks (6, 7) which are insulated by a plate (8) from each other. Both steel blocks are connected to the power supply circuit. The investigated PPA has an accelerating length of 900 mm and a bore of 14 mm diameter.

The power supply circuit consists of a capacitor bank C and an inductor L. R represents the unavoidable resistance of the circuit components. For discharging the bank into the accelerator a metal-to-metal switch S with low resistance is used /14/.

The discharge current is measured with a Rogowski-coil. The arc voltage is measured with a high voltage divider which is connected to the two steel blocks near the discharge volume. The final velocity of the accelerated mass is calculated from a signal given by four gates which are located in front of the accelerator. Power and absorbed energy are computed.

Another power supply circuit, which uses an inductive energy store is shown in fig. 3. The inductor L is charged from the mains via a transformer-rectifier-unit (T, R). When the current reaches the desired value (maximum value 20 kA) the switch S is opened and the current is transferred into the PPA. The maximum energy content of the inductor is around 500 kJ.

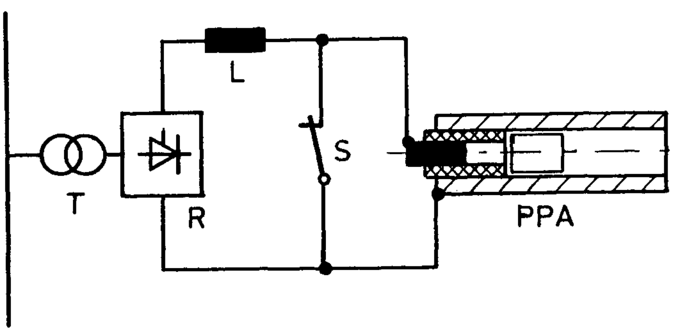

Fig. 3: Power supply circuit with inductive energy store

2. Results

Fig. 4 gives typical waveforms of a characteristic PPA-experiment: Current through and voltage across the discharge, power and energy absorbed by the discharge are plotted versus time. The initial discharge volume of 9 cm^3 was filled with Polyethylene-powder (PE-powder). The energy absorption process began with the explosion of a thin wire embedded in the PE-powder after the switch was closed. The ignited gasdischarge was forced to interact powerfully with the PE-powder, the tube walls, and the electrodes. This led to a strong damping of the current waveform. 80 µs after ignition the first current peak reached a value of 140 kA, after 160 µs the current passes zero, and its second peak had an amplitude of only 30 kA.

During each current halfcycle the voltage remained at a nearly constant value of about 1.5 kV. This makes evident the strong interaction between the gasdischarge and the tube volume and indicates that large parts of the gasdischarge volume must have been involved in this energy absorption process.

The power with which energy was absorbed by the discharge is nearly proportional to the current and reached a peak value of 210 MW during the first current maximum. 300 µs after ignition the energy transfer from the circuit into the accelerator was finished. From the total energy of 24 kJ stored in the 1.9 mF capacitor bank 16 kJ - i.e. 66.7 % - were absorbed by the discharge and available for the acceleration process.

In this experiment a 10 g aluminum mass had been accelerated. 1.4 ms after ignition the mass had left the accelerator with its final velocity of 1020 m/s. From the energy of 24 kJ stored in the capacitor bank 5.3 kJ - i.e. 22 % overall efficiency - were converted into kinetic energy of the mass. Compared with the energy of 16 kJ available in the accelerator it results an internal efficiency of 33 %.

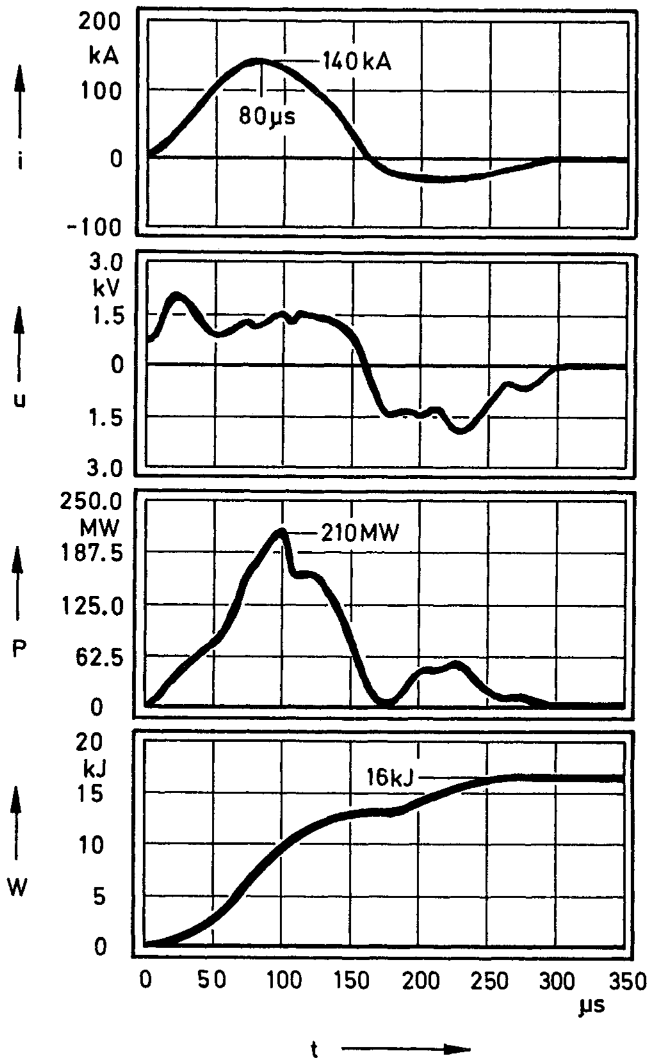

Fig. 4: Current, voltage, power, and absorbed energy waveforms of a characteristic PPA acceleration experiment. W = 24 kJ, m = 10 g

In figure 5 the results of another experiment conducted with the same accelerator are plotted. In order to achieve higher velocities the mass was decreased from 10 g to 3 g by using insulating material instead of aluminum. In addition the stored energy was increased to 46 kJ. The characteristic waveforms of current, voltage, power and absorbed energy are qualitatively similar to the first experiment. A peak current of 188 kA was reached, the voltage amplitude was about 1.8 kV, and the peak power was in the range of 360 MW. 38 kJ - i.e. 82 % - of the total energy stored in the capacitor bank were transferred within 500 µs into the accelerator. The 3 g mass left the accelerator 0.7 ms after ignition with a final velocity of 2000 m/s. In this case only 6 kJ - i.e. 13 % overall efficiency resp. 15 % internal efficiency - could be converted into kinetic energy of the mass.

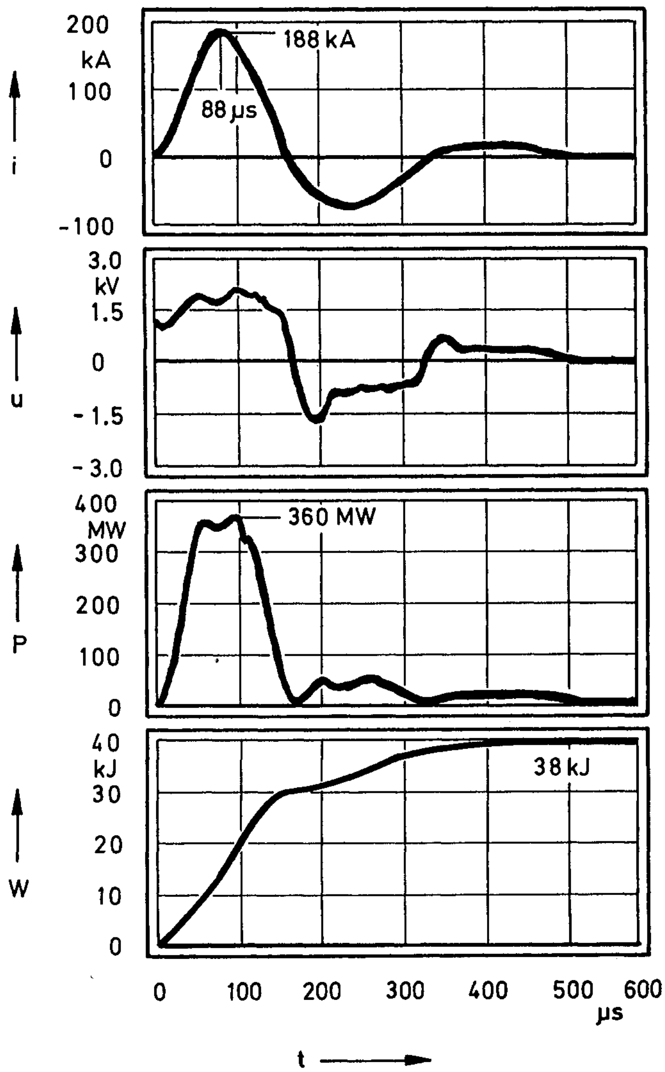

Fig. 5: Current, voltage, power, and absorbed energy waveforms of a characteristic PPA acceleration experiment. W = 46 kJ, m = 3 g

3. Discussion

Comparing these two experiments it turned out that in spite of an improved energy transfer into the accelerator the amount of energy converted into kinetic energy of the mass drops drastically with increasing mass velocity. This behavior is closely correlated to the acceleration process and has predominantly the following reason: During the energy absorption a different movement of both masses was obtained. The 3 g mass moved faster from its start position into the barrel. This resulted in a larger expansion volume for the gasdischarge with the consequence of locally lower gas temperatures, smaller gas pressures, and reduced propelling forces. These results are in agreement with Cranz /15/, who demonstrated in order to achieve high efficiencies that a barrel volume behind the mass should be kept as small as possible and should remain nearly constant during the pressure formation. From this point of view the energy input into the accelerator has to take place in a short time i.e. on the highest power level the accelerator tolerates.

In both experiments further improvements could be achieved by the use of materials generating a high amount of light gas components when penetrated by the arcdischarge in the tube volume. Due to their smaller mass light gases are more qualified to meet the requirements for high mass velocities and improved efficiencies which is well known from light-gas-accelerators.

To find out the maximum power PPA's can withstand is one of the major tasks of our experiments. The power and pressure values obtained from the above mentioned experiments are far away from the safety margin. In close correlation is the important task to adjust the power of the supplying circuit to the power the accelerator can withstand. This can be done either by current-limiting elements, in particular by inductances, or by a proper design of the discharge volume of the accelerator (length, radius, shaping, material to be evaporated etc.). Here it is possible to transfer design criteria from current-limiting circuit breakers and fuses. In this context we also investigate the possibility to achieve the required power ratings with reduced current and how the results can be extrapolated to larger masses and larger barrel diameters.

In order to utilize the entire PPA-length to full advantage the accelerating forces have to be maintained during the movement of the mass through the barrel, which in return affects the efficiency. Up to now we have excluded questions of barrel erosion and PPA-lifetime.

4. Summary

The PPA-experiments have demonstrated clearly the parameters which influence the efficiency and the final velocity of the accelerated masses as well as their interdependencies. These are

- maximum pressure and temperatures the accelerator tolerates
- size of the discharge volume and physical properties of the propelling gas and the erosion products
- cross-section and length of the barrel
- weight of the accelerated mass
- initial conditions for mass movement
- power-capability of the supply network.

To achieve the optimum efficiency the entire accelerating system including the elements of the power supply circuit has to be regarded. In order to find the technical limits of this accelerating method further experiments will be conducted to optimize the discharge chamber and to match the supply circuit to this load.

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