100 GW Fast LTD Stage[1]

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Abstract – A fast LTD stage (called LTDZ) is developed providing ~1 MA current rising in ~100 ns into the matched 0.1 Ohm load. The stage consists of 80 GA 31165 storage capacitors (100 kV, 40 nF) and 40 multi gap HCEI switches type fast LTD. The outer diameter of the stage is ~3 m, at a length of ~22 cm. The stage is developed to demonstrate the possibility of the fast LTD technology to create high power pulsed generators.

1. Introduction

The LTD technology of primary energy storage is being developed at HCEI during the last ~10 years. Unlike Marx generators, the body of the LTD stage keeps ground potential during the shot. This allows reduction of the inductance of the discharge circuit and increase in the output power, because all parts inside the stage should be isolated for the charge voltage only. To the moment several modifications of LTD stages are produced that are used in different pulsed power installations [1–3].

The fast LTD technology is based on the features of the single circuit called "brick" that consists of two storage capacitors charged in opposite polarity, the switch and the buses connecting the capacitors with the load. The parameters of the brick are chosen in such a way that the output pulse in the matched mode has a rise time of ~100 ns. The fast LTD stage consists of some number of such bricks connected in parallel and triggered simultaneously. So, the output pulse of the fast LTD stage has a rise time of ~100 ns independent on how much bricks it includes, whereas the stored energy, the current amplitude and the output power of the fast LTD stage are directly proportional to the number of bricks.

The 100 GW LTDZ stage presented in this report was developed to investigate the possibility to build the system with ~1 MA output current rising in ~100 ns.

2. Design of the 100 GW LTD Stage

The design of the stage is shown in Fig. 1. It is similar to the design of other fast LTD stages presented elsewhere [4, 5], the main difference is the number of bricks which is 40 in the current design. The increased number of the bricks results in larger outer diameter of the cavity (~3 m) and the diameter of the output line (~1.6 m).

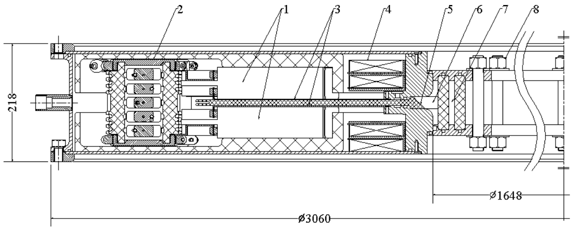

Fig. 1. Design of LTDZ stage: *1* – GA 31165 capacitors, *2* – multi gap HCEI switch, *3* – output buses, *4* – magnetic core, *5* – midplane insulator, *6* – vacuum or oil filled cavity, *7* – load cavity, *8* – caprolon rods

The 80 storage capacitors of the stage are charged in opposite polarity to ± 100 kV, the 40 switches are triggered by 4 trigger cables. They operate in dry air at absolute pressure of ~ 4 atm at full charge. The inner volume of the stage is filled with transformer oil.

The ~ 2 m diameter magnetic core is made of transformer iron ET3425 (Fig. 2). The iron tape is 18 mm wide and 80 um thick. Each of 4 core rings includes 995 turns resulting in total cross section of $57.3 \cdot 10^{-4}$ m^2 and the voltsecond integral of 22.3 mV·s for $\Delta B = 3.9$ T. In tests, the premagnetizing current pulse (1.5 kA, 40 ns rise time, single polarity) was applied ~3 min before the shot reducing ΔB to 3.2 T and the voltsecond integral to 18.2 mV·s. The core

Fig. 2. Magnetic cores produced at HCEI. The largest in the photograph is one of 4 core rings for LTDZ

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rings are made without of metal support, the turns are fixed by epoxy only using the technology developed at HCEI [6].

Fig. 3 shows the photograph of the LTDZ stage.

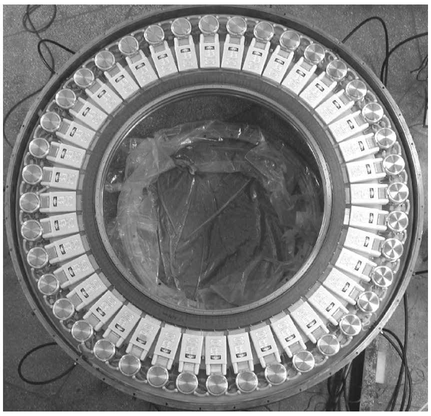

Fig. 3. The LTDZ stage with 80 GA 31165 capacitors and 40 HCEI multi gap switches

3. Test Results and Simulation

In tests, the resistance of the load, Rload, was varied from 60 to 190 mOhm by changing the concentration of the NaCl solution in the load cavity 7, Fig. 1. The resistive component of the load voltage, UL, and the trigger pulse, Utr, were measured by resistive dividers, the current in the load, IL, and the current in the primary turn, I1, were recorded by B-dots.

The results presented below are obtained at ± 100 kV charge voltage, with dry air in the switches at a pressure of 4 atm. The core was premagnetized ~ 3 min before the shot, the 40 switches were triggered by 4 cables delivering 100 kV, 25 ns rise time trigger pulses.

Test results are compared with simulation performed in PSPICE. In simulation, the stage was represented as a 40 parallel bricks connected to the 1.05 nH load inductance in series with Rload, that was varied according to the experiment. The value of the load inductance is defined from dimensions of the cavities 6, 7 in Fig. 1. All the bricks are identical except that half of them are delayed for 10 ns to simulate possible jitter. The resistance of the switches in the bricks is assumed to be 60 mOhm, the resistance of the capacitors is 270 mOhm, total inductance of the brick is set to 232 nH.

The electric scheme of the brick used in simulations is shown in Fig. 4. Here the resistance R1 connected in parallel to the output line, T1, represents the losses in the primary turn due to vortical currents in the core. It is set to 23 Ohms that is equivalent to 23/40 = 0.575 Ohms for the whole stage. This value is defined from the experiment and will be discussed below.

Figure 5 gives the load power, P = UL·IL, depending on the load resistance. It peaks at ~ 96 GW in vicinity of Rload ~0.1 Ohm indicating the matched mode for the LTDZ stage. At this Rload the load voltage is ~ 99 kV (see Fig. 6), the load current is ~ 970 kA.

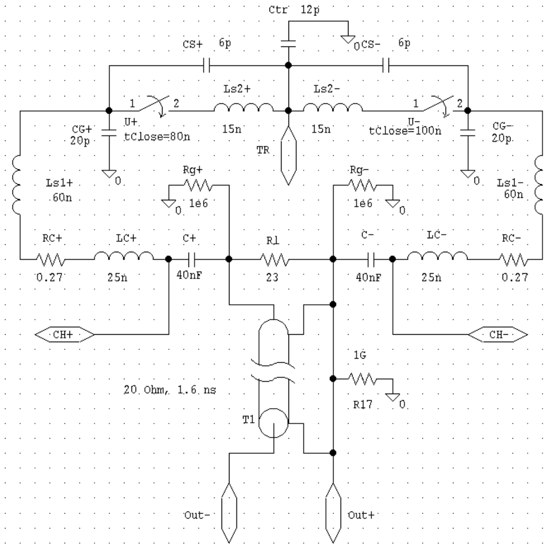

Fig. 4. Electric scheme of the LTDZ brick used in PSPICE simulation

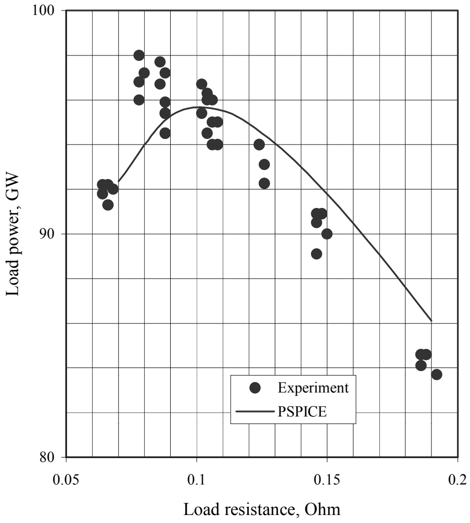

Fig. 5. Load power

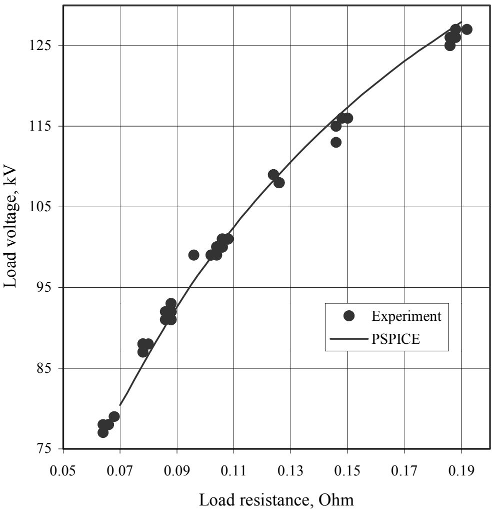

Fig. 6. Load voltage

Figure 7 shows the load power rise time from zero to peak which is below of 100 ns at all loads tested.

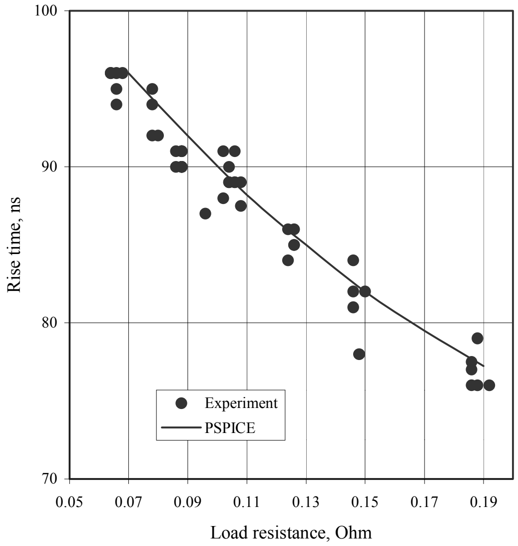

Fig. 7. Load power rise time

Figure 8 gives the energy delivered to the load. In matched mode it reaches ~11.5 kJ or ~72% of the stored energy.

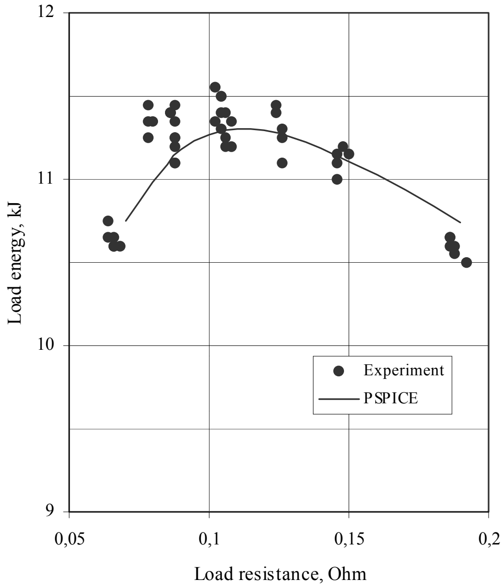

Fig. 8. Energy delivered to the load before the load voltage crosses zero

Figure 9 shows the recorded load voltage, U_L, and the current in the primary turn, I_1, at $R_{load} = 0.107$ Ohm. The voltsecond integral calculated as $VS = \int U_L dt$, is also shown to demonstrate that at such load resistance it does not reach the limit of 18 mV·s and the core does not saturate. At $U_L = 100$ kV the current in the primary turn peaks at $I_1 = 174$ kA giving the estimate for the resistance of vortical current, $R_{vc} \sim U_L/I_1 \sim 0.575$ Ohm. That is the reason why the resistance $R1$ in Fig. 4 was set to 23 Ohms.

In Fig. 10 same traces are given for $R_{load} = 0.188$ Ohm. Here the voltsecond integral reaches the limit of 18 mV·s in ~200 ns, the current I_1 peaks second time indicating saturation of the core. This saturation is supported also by increased reversal voltage across the load in spite of higher R_{load} compared to Fig. 9.

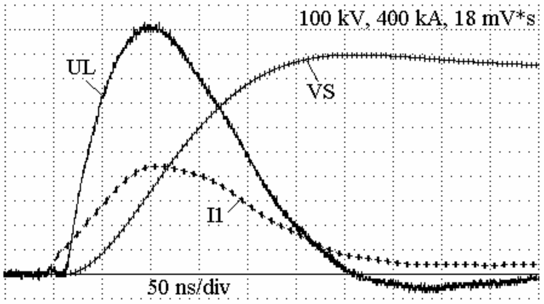

Fig. 9. Load voltage, U_L, current in the primary turn, I_1, and the voltsecond integral, VS, at $R_{load} = 0.107$ Ohm

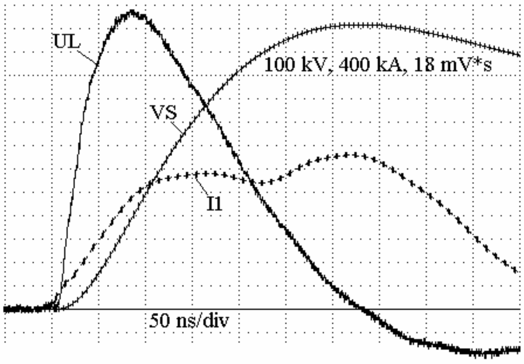

Fig. 10. Same traces as in Fig. 9 indicating saturation of the core at $R_{load} = 0.188$ Ohm

4. Conclusion

The fast LTDZ stage is developed and tested providing ~100 GW power, ~1 MA current pulse into the matched load of ~0.1 Ohm. The rise time of the pulse is ~100 ns.

The stage consists of 80 GA 31165 capacitors and 40 multi gap HCEI switches. The outer diameter of the stage is ~3 m, axial length is ~22 cm, and the weight is ~2 t.

The observed energy loss in the primary turn is ~17% of the energy delivered to the load in matched mode. The resistance of the vortical current, R_{vc}, can be estimated as [6]

$$R_{vc} \sim 12\,\frac{\rho S}{l\delta 2},$$

where ρ is specific resistance of the core iron, S is total cross section of the core, l is length of the core, and δ is thickness of the iron tape. For ET3425 $\rho = 0.5 \cdot 10^{-6}$ Ohm·m resulting in $R_{vc} \sim 0.6$ Ohm for our core made of 80 um thick tape. This estimate close to ~0.575 Ohm defined from experiment. If the scaling $R_{vc} \sim \delta^{-2}$ will be proved in experiment, the loss in the primary turn can be reduced by using 50 um tape also available at the manufacturer. According to simulation, this would increase for 10% the output power and energy delivered to the load.

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