TEST OF THE PROTOTYPE MODULE OF PTS

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Abstract

The prototype module of PTS, a 24 modules 10MA /6MV z-pinch primary test stand, adopted capacitive storage scheme has been built and tested. The measured output current of the prototype is approximate 520kA, and output voltage is approximate 2.1MV. The unique multi-stage LTS based on uniform field distribution design and multi-pin unsymmetrical WS make the prototype modules have low systemic delay jitter which is necessary for synchronization of multi-module facility. 1-δ jitter of delay of the system is less than 4ns.

INTRODUCTION

Z-pinches have wide application because they are very efficient ways to heat and/or confine high-temperature plasma that can be used to efficiently generate X rays and to possibly produce conditions required for thermonuclear fusion. The advances of z-pinches physics depend on the evolution of pulsed power technology.

Although some new designs based on LTD, FMG, IVA was proposed for future super high power Z-pinch diver, a lot of key techniques are waiting for break through. Up to now, most of the available devices such as ZR (36modules, 26MA) at Sandia National Laboratories, USA; Angara-5 (8 modules, 4.5 MA and 6 TW) at the Kurchatov Institute of Atomic Energy, Russia are based on capacitive pulse generation, multi-modules synchronization and closing switch techniques[1-2]. Therefore, PTS, a 10MA/6MV Z-pinch primary test stand, adopts the capacitive engergy storage scheme which was adopted abroadly by Z, Saturn and other high power pulsed devices. It will comprise 24 identical modules. As shown in Fig. 1, Each module consists of Marx generator (MG), intermediate storage capacitor (IC), laser-triggered switch (LTS), pulse forming line (PFL), water self-breakdown switch (WS) and tri-plate pulse transmission line (PTL). 24 PTLs assembled to insulator stack congregate into magnet insulator transmission line (MITL). The low inductance load will be fixed at the end of MITL. In order to make the power feeding into the load high enough, the synchronization of the 24 modules and the transmission efficiency of energy are key techniques. As the key components such as MG, LTS, WS adopting some unique designs which had never been studied, a prototype module has been design and examined.

MARX GENERATOR

The key requirements to the 6MV/300kJ MG are low delay jitter and high erection efficiency. Therefore the Marx generator consisted of sixty 100kV/1μF capacitors and thirty 200kV switches was designed as a bipolarity hybrid-triggered S type MG. The low jitter field distortion switch is a SF_6/N_2 filled multi-channel annular rail gap. As the working voltage of the switch is more than 20%U_{SB} (selfbreakdown voltage), the standard deviation of the delay (jitter) is less than 1.5ns. The capacitors and switches are arranged into five rows. The six switches in first row are triggered by the external trigger pulse generator which outputs maximum 300kV/700ns pulse with 50ns frontal risetime (10-90%). The rest are triggered by the coupling voltage from the frontal row by $CuSO_4$ solution resistors. As shown in Figs. 2 and 3, the delay and its jitter of MG decrease exponentially as the working ratio (ratio of charging voltage to selfbreakdown voltage) and the peak voltage of the trigger pulse increase. The erection time decrease slightly as the working ratio increase. As the working ratio kept constant, the delay and its jitter decrease slightly as the pressure of the gas filled increase from 0.2Mpa to 0.4Mpa. The erection time is almost unchanged under this condition. As the voltage of the trigger pulse is 220kV, the jitter of delay is less than 5ns as the working ratio changed between 60%-82% and

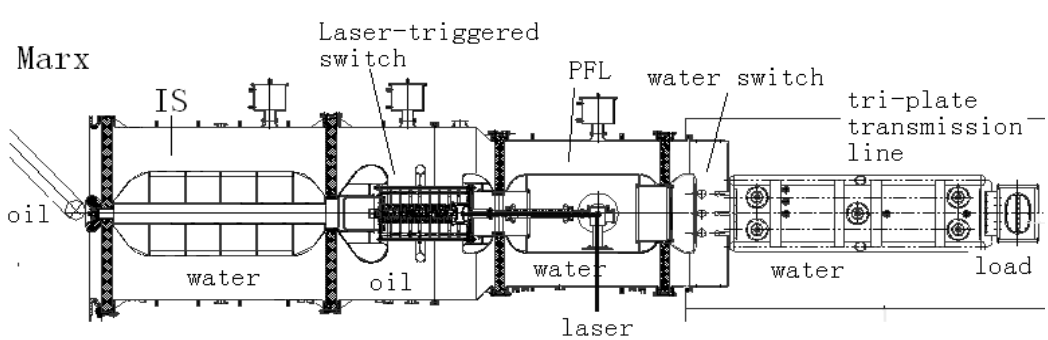

Figure 1: Scheme of the PTS Prototype.

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the pressure of the gas changed from 0.2Mpa to 0.55Mpa. Working under optimal condition, the jitter is less than 3.5ns as the charging voltage is more than 65kV. Experimental results shows that the inductance and serial resistance of MG is 14μH and 5ohm respectively. The output voltage of MG increases linearly with charging voltage. As capacitors are charged to 80kV, IC is charged to approximately 4.2MV in 800ns. Experimental results indicate that the intermediate store capacitor is 15.2nF which is a little more than the supposed value.

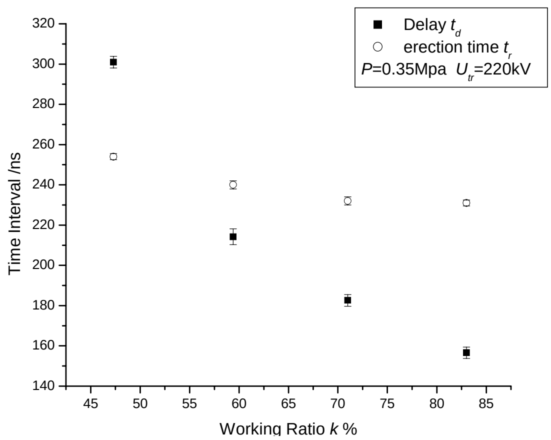

Figure 2: Delay and erection time vs. Working ratio.

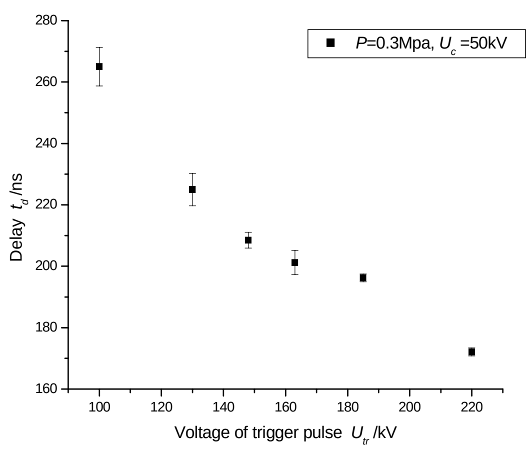

Figure 3: Dealy vs. Voltage of trigger pulse.

LASER TRIGGERED SWITCH

As shown in Fig. 4, the laser-triggered multi-stage multichannel switch is composed of one laser-triggered gap and 21 serial selffired gaps. The laser-triggered gap of the 4MV switch is formed with Bruce contoured electrodes. The selffired gaps are formed with disk-shaped electrodes separated by 8mm gap. The electrodes are supported by PMMA insulators at the axis of the switch. A special field regulator, the big metal ring shown in Fig 4, is designed to regulate the field distribution in the gaps. The electrodes of the switch are isolated from the external oil environment to reduce the interstage capacitance and minimize the possibility of the flashover on the oil-PMMA interface that may occur during switch operation.

The selfbreakdown voltage increases linearly with gas pressure. The relative deviation of the experimental results to the linear fit and the prediction based on the static electrical field calculation is less than 5% and 10% respectively. The position of the field regulator greatly affects the property of the switch. However, it is also found that the utilization of field regulator make the gradient ring is not necessary for the regulation of the field distribution of the switch. A 100mJ 266nm YAG laser is utilized as trigger. The jitter and the duration of the laser pulse are about 1.5ns and 3ns respectively. As shown in Fig. 5, the delay (t_d) and its jitter decrease exponentially as the working ratio k (the ratio of the working voltage to the selfbreakdown voltage) increase. The delay and its jitter decrease as the pressure of the gas filled and the working voltage increase when k is kept as constant.

Figure 4: Laser triggered switch.

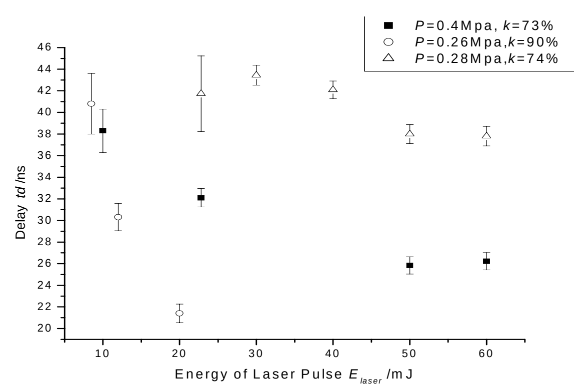

Figure 5: Delay vs Energy of laser pulse.

The delay and its jitter decrease exponentially as the energy of the laser pulse (E_{laser}) increase (Fig. 5). The slope of the t_d - E_{laser} increases with k. The jitter of the switch is less than 1.5ns as the operation condition is kept as the pressure is more than 0.3Mpa, voltage is more than 2.0MV, E_{laser} is more than 20mJ and k is 85 ± 3%. Operating under this condition, the delay is approximately

20-25ns. No prefire is found during approximately 100 shots as *k* is set as 95%.

WATER SELFFIRED SWITCH

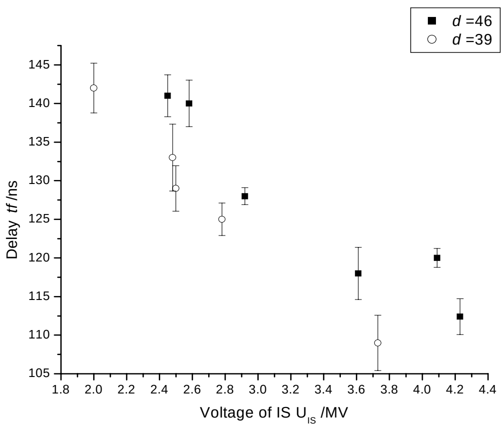

Figure 6: Delay of WS vs. UIS.

A water selffired switch (WS) is utilized as the pulse forming switch which transfer the energy from PFL into PTL. The switch contains three linear arrayed selffired sphere-ring gaps. As shown in Fig. 6, The charge time (delay) decrease as the voltage of IS increase. However, the jitter does not show apparently decrease when the ratio (k_2) of the voltage of PFL (U_{PFL}) to the voltage of IS (U_{IS}) is more than 0.8. As U_{IS} is kept as constant, delay increases with gap distance. The pre-pulse shielding board (PPS) does not show apparent effect on the decrease of prepulse, but it makes the jitter increase greatly. The jitter of the switch with PPS is 6 ns while 3 ns for without PPS. However, the experiments without PPS show that the amplitude of the prepulse is less than 6% of U_{IS}. As the gap distance kept as constant, the voltage of PFL and PTL increase as the U_{IS} increase although the difference between the U_{IS} and U_{PFL} increase slightly. The inductance of the switch without PPS is about 100 nH.

JITTER OF THE PROTOTYPE

As LTS is the command switch of the system, the jitter of the prototype module is the jitter of the delay between the time when the laser pulse is emitted and the time when the voltage pulse of PTL is made. In the experiments, the delay is defined as the interval between the time of 10% frontal of the laser pulse which is detected near output windows of the laser set and the time of 10% of rise front of the electrical pulse transferring in the PTL. It is known that the systemic jitter of the prototype is mainly composed of the jitter of LTS and WS. As shown in Fig. 7, as the gap distance of WS is kept as constant, the delay and its jitter of system decrease as the voltage of the IS increase. As the voltage of IS be kept as constant, the jitter increase with the gap distance of WS. The systematical jitter mainly cause by the jitter of WS. The jitter is less than 3.5ns as the voltage of the IC is more than 2.6MV and the working ratio of WS is 85%. If the jitter of the laser set is included, the systematical jitter is about 3.8ns.

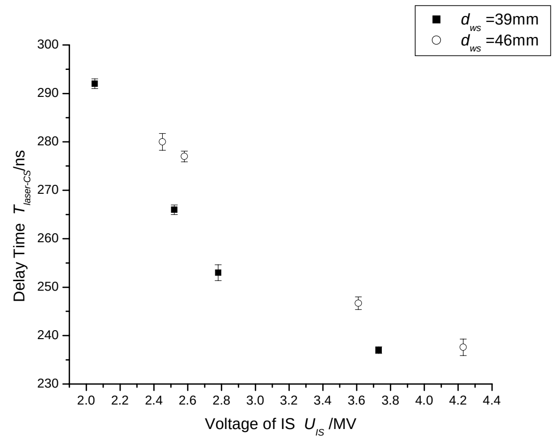

Figure 7: Delay vs.voltage of IS.

CONCLUSION

The prototype module of the 6MV/ 10MA Z-pinch primary test stand had been built and tested. The experimental results indicate that the performance of the prototype approximate that of the module of Z and ZR accelerators. The main performance parameters of the prototype are: Charging voltage of IS: 4.2MV; Current of the load: 520kA; Jitter of the systematical delay: 3.8ns; Jitter of the delay of the laser-triggered multistage switch: 1.5ns; Jitter of the delay of the Marx generator: 3.5ns.

The main progress obtained on the prototype is the successful development of 4MV low jitter command/ synchronization switch (LTS) and pulse-forming switch (WS). The uniform field distribution design based on field regulator make LTS have good performance such as low jitter and high reliability. The unique sphere-ring electrode system makes the low jitter of WS. The module is one of the smallest devices of same power scale. The oil required by MG is no more than 60 tons. Moreover, the fairly low jitter of MG which is based on the annular field distortion switch promise its wide application in future.

However, it is also found that the jitter of the water selffired switch is the obstacle for more improvement of the device performance.

REFERENCES

[1] Spielman.R.B and Groot.J.S. 2001. Z pinches—A historical view. Laser and Particle Beams (19): 509–525.

[2] Spielman. R. B, Long. F, Martin. T. H, Poukey. J. W. 1995. PBFA II-Z: a 20-MA driver for Z-pinch experiments. Digest of 10th IEEE International Pulsed Power Conference. Albuquerque, New Mexico, USA. p396-404.