COMPACT 400 KV MARX GENERATOR WITH COMMON SWITCH HOUSING

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Abstract

A compact four stage Marx with six parallel Marx generators per stage and a common switch housing, developed for various Air Force applications, is described. Unique features of the Compact Marx include a single cast epoxy switch housing common to each stage that can use six independent spark gaps or one continuous ring gap packaged in a housing measuring 76 cm in diameter, 56 cm in height, and 295 kg. Initial test results of the Marx into a 5 Ω resistive load, and rep-rate performance of the Marx's four stage 160 kV open air trigger Marx, are discussed. Individual Marx stages were designed to operate with a maximum bipolar +/- 50 kV charge and erected capacitance of 60 nF providing a per pulse energy of 4.8 kJ. Design goals were to provide a 500 ns wide pulse with a 100 ns rise time into the 5 Ω load. The spark gaps and capacitors are arranged radially at sixty degree intervals, and the latter are connected with simple banana plugs to provide easy removal. The switches are designed to operate with dry air pressurized to 80 psig, and the Marx was designed to be submerged in dielectric oil. The first stage of the Marx is triggered by the four stage 160 kV trigger Marx. Pulsed operation at several hertz was investigated for burst mode operation with and without gas flow. Possible investigation of an eight stage 800 kV Marx is contemplated.

Compact Marx Generator Description

The Compact Marx was tested in a 950 liter polyethylene tank filled with Shell Diala-AX dielectric oil. A second 1,140 liter oil tank was used as a containment vessel. The electrical components of the Marx have a total mass of 295 kg. The relevant demonstrated performance specifications for the Compact Marx are listed in Table I.

Table I
Compact Marx Specifications

Output voltage range	100 kV to 400 kV
Load Impedance	5 Ω
Pulse width	~300ns
Rise Time (10 to 90%)	< 100ns
Rep rate capability	Trigger Marx demonstrated 10Hz
Pulse feedback to first stage	Negligible with 5 Ω load

Marx Generator System

Figure 1 shows a photograph of the assembled Compact Marx with four series stages, trigger Marx on top, four 20 Ω load resistors in parallel, and diagnostics. Eighteen Maxwell Technologies, Inc. 0.04 μF capacitors are used in the middle stages and twelve Maxwell 0.08 μF capacitors make up the top and bottom half stages. Bipolar

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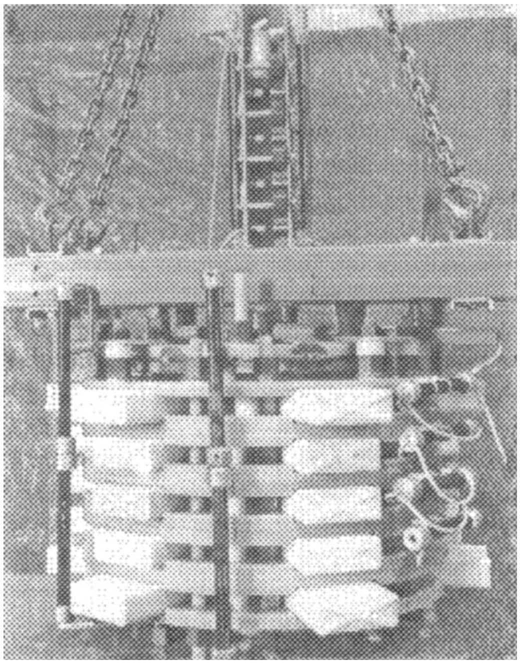

Figure 1. Assembled Four Stage Compact Marx

charging required that the end capacitors be double the value of the middle capacitors so that the series capacitances were equivalent. Figure 2a shows the radial parallel six stage arrangement of the capacitors and switch electrodes in one of the Marx's four stages, and Figure 2b shows a vertical cross section of the Compact Marx's four switch housings with threaded fiberglass compression rods. A Maxwell +/- 50 kV bipolar 150 mA power supply charges the capacitors and provides the system dump. Considerable design planning was placed upon arranging the individual components of the Compact Marx in order to minimize its overall size. As the component layouts indicate in Figures 2a and 2b, parallel capacitors are touching and cannot be placed at a smaller radius, and series spacing is predetermined by switch electrode gap spacing of 0.84cm. Although the vertical dimension could be improved slightly by minimizing the thickness of switch electrode buses and structural support hardware, it was not deemed a critical design requirement for this version of the Compact Marx. The circuit diagram for the Compact Marx is shown in Figure 3.

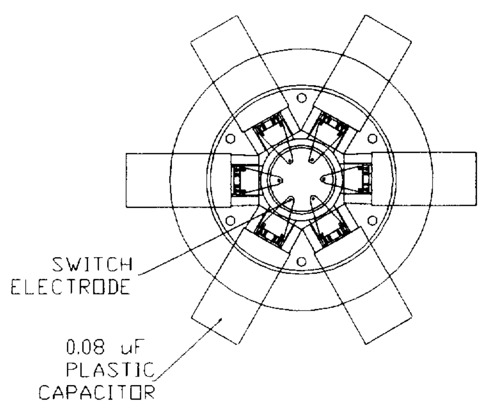

Figure 2a. Axial View of Single Marx Stage

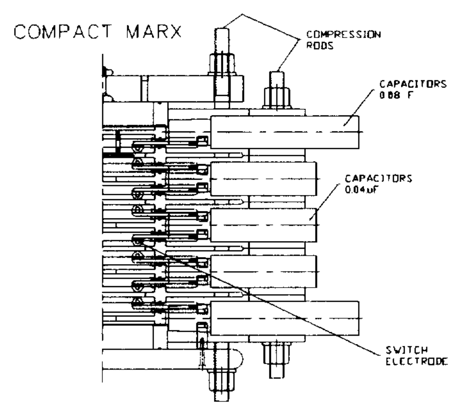

Figure 2b. Radial Cross Section View of Four Stage Marx

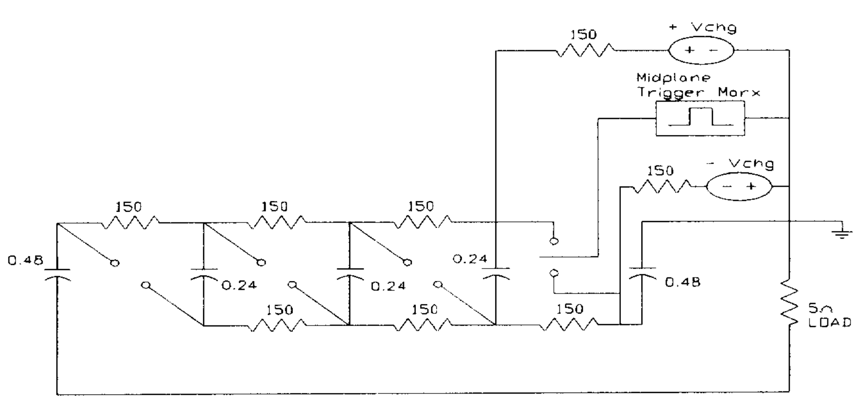

Figure 3 Circuit Diagram of Bipolar Four Stage Marx

Common Switch Housing

The annular shape and size constraints of the Compact Marx prohibited the use of off-the-shelf commercially available spark gap switches. Possible options then included fabricating switch housings from polycarbonate or other plastic materials or casting the switches using an epoxy type of material. Successful in-house experience epoxy casting other complex switch assemblies resulted in the decision to machine void-free aluminum mold components and cast the switch assemblies in-house. Figure 4 shows a completed switch element with embedded brass electrodes and machined o-ring grooves. Alternating o-ring grooves in the top and bottom of the switches provide series stage-to-stage pressure integrity by means of threaded fiberglass rods that run through the entire assembly and are tightened to a torque specification of 8 ft-lbs.

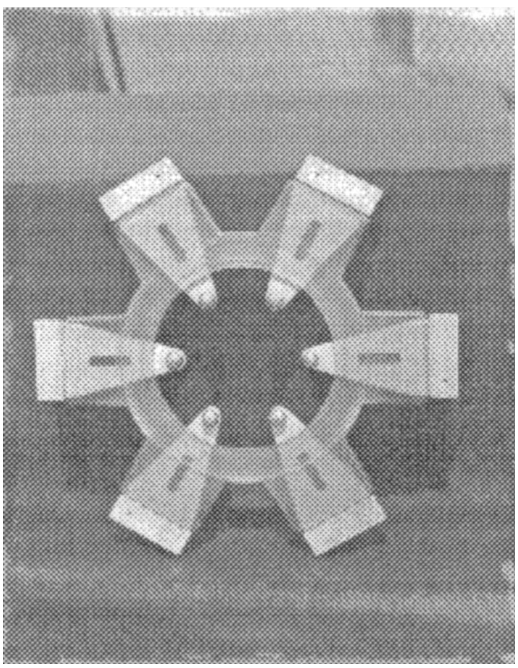

Figure 4.Completed Cast Switch Element

A four stage switch assembly was successfully hydrostatic tested to 350 psig, providing for a safe operating pressure of 80 psig. The first hydrostatic test failed when over torquing of the nylon rods stretched them enough to allow gaps to open between the stages. The displacement was enough to cause an o-ring to be extruded under the hydrostatic load. The nylon rods were replaced with G-10 fiberglass rods with a pre load torque specification sufficient to maintain o-ring compression at the full hydrostatic test pressure. However, this torque caused the individual switch assemblies to deform. As a result, all of the switch housings had to be recast. The embedded surfaces of the brass electrodes were conditioned to improve the bond to the epoxy, and torque specifications were relaxed to minimize deformation.

Switch Trigger Evolution

Achieving reliable triggering with acceptable jitter between the six parallel Marx stages in each stage of the Compact Marx was a primary consideration as well as problem. Shot-to-shot jitter proved to be equally difficult to resolve. Since obtaining diagnostic access to individual switch elements in the common switch housing was unfeasible, diagnosing jitter was largely limited to observing switch breakdown evidence in the output voltage waveforms. The initial triggering scheme used a Maxwell 40168 trigger generator to pulse electrodes configured as triggatrons. Each electrode was bored out to a 4 mm inner diameter and an insulated #14 AWG conductor was inserted as the center electrode pin. The output of the 40168 was connected to each pin through a common 0.1 μF blocking capacitor and individual 2 kΩ resistors made of 8 mm spark plug wire. Jitter between parallel switch elements was about 40 to 50 ns with total end-to-end jitter for the six parallel elements of approximately 200 ns. Shot-to-shot jitter, with the switches pressurized to 5 psig of SF_6, was observed to be as high as 2 μs. Switching from SF_6 gas to dry air, closing switch gaps and increasing voltage had little affect on improving either type of jitter. As a result, the triggatron approach was abandoned in favor of a mid-plane triggering mechanism.

The mid-plane arrangement required positioning a radiused-edge metal disc half way between the two switch electrodes and biased midway between the electrodes with two 400 MΩ resistors connected to the charge lines. Since the 40168 trigger generator output was only 50 kV, an alternate main Compact Marx trigger source was deemed necessary with an output of at least 100 kV. Also, since achieving rep-rate capabilities of several hertz was a design goal, the decision was made to design, fabricate, and assemble in-house a mini-Marx that would provide an output > 100 kV, be easy to operate, and that could be rep-rated. The final design for the trigger Marx consisted of a very simple open air assembly using 2 nF door knob type capacitors each inductively charged and that interfaces directly to the top of the Compact Marx above the oil level. The 40168 trigger generator was modified to provide both the charge voltage to the four stages of the trigger Marx and a 50 kV repetitive trigger pulse to the first stage. Past experience has demonstrated this modification of the 40168 provides a very compact charge and rep-rate trigger source.

The trigger Marx was successfully integrated into the Compact Marx system and has proven very reliable in eliminating both parallel switch element jitter and shot-to-shot jitter. Its simple design, ease of fabrication, and reliability has resulted in fabrication of additional units that have been successfully used in other Marx generators as a trigger source.

Diagnostics

Output voltage across one of the four 20 Ω load resistors, current through one of the resistors, and reflected voltages at the first Compact Marx stage are the primary diagnostics. The voltage probe consists of a 1.7 kΩ liquid resistor with integral 17.5 Ω liquid resistor at one end that provides an output of 11.8 kV/volt. The current diagnostic is a Model 410 Pearson Current Monitor with an output resistor lead running through it that provides 0.1 V/amp. For simplicity, a Northstar PVM-5 voltage monitor is attached to a positive charge lead on a capacitor in the first stage of the Compact Marx to monitor reflected voltages. It provided useful information up to charges of +/- 35 due to data acquisition limitations.

Compact Marx Performance

Initial tests were done on only two stages of the Marx in air at voltages up to 40 kV. Charge resistors of 5.1 kΩ were installed between parallel Marx stages in the typical Marx configuration. However, tests revealed that unacceptable ringing occurred between parallel stages which was eliminated by removing the charge resistors between each parallel stage. The resulting waveform for the two stage Marx is depicted in Figure 5. The positive connection from the power supply connects through a 150 Ω resistor between each series stage to the top of each capacitor. The negative connection similarly connects through 150 Ω resistors to the bottom of each series stage capacitor. A low inductance connection is made using a singe wire to connect each plane of the individual Marx assemblies.

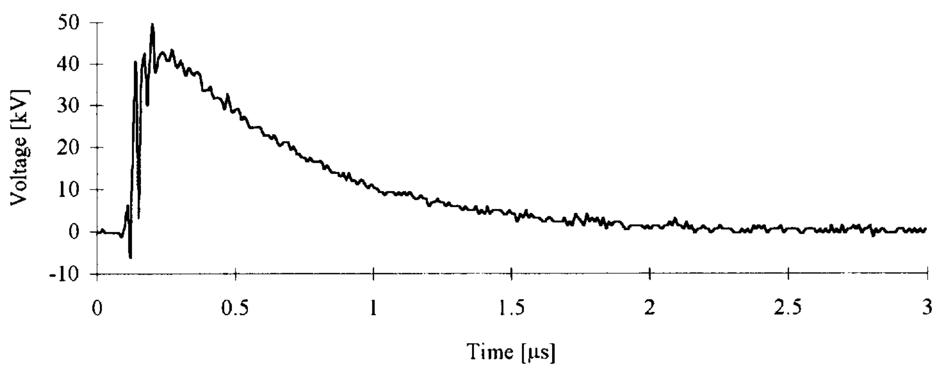

Figure 5. Output Voltage into 5 Ω from +/- 20 kV Charge of Two Stage Marx

A total of fifteen shots were conducted on the completed four stage Compact Marx with charge voltages ranging from +/- 15 kV to +/- 50 kV. Erection of the Marx is particularly sensitive to the switch pressure. A plot of the breakdown voltage versus the switch pressure is shown in Figure 6. Data from the self break curve has been used to determine the operating pressures for charge voltages of m=1.2, 1.3, and 1.4 times the static breakdown voltage. When operated at m-factors of 1.4 or higher, there was a noticeable delay in the erection of the Marx voltage. The Marx switches worked best when pressurized for m=1.3. The waveform shown in Figure 7 is output voltage measured for a +/-50 kV charge with the switches pressurized to 70 psig. The erection of the Marx could be further improved by triggering the bottom three stages instead of only one.

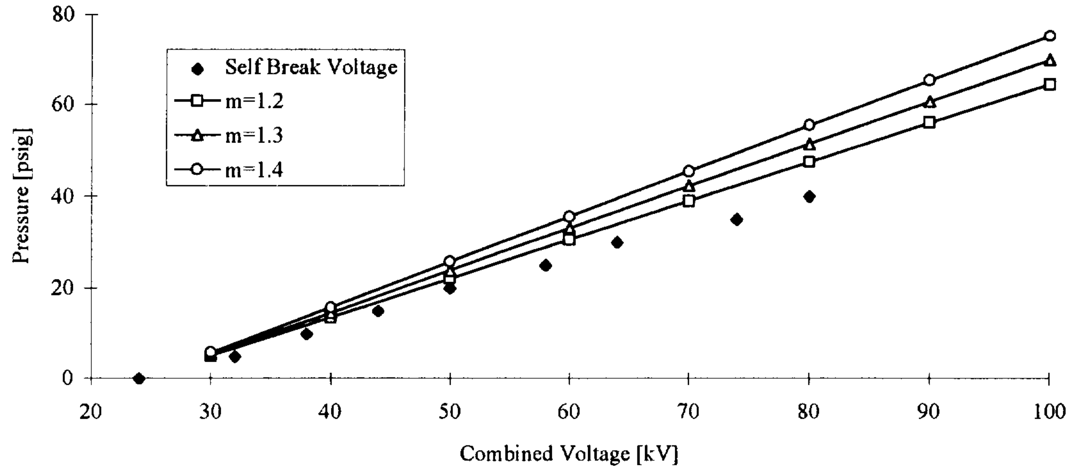

Figure 6. Static breakdown and operating pressures for the Compact Marx.

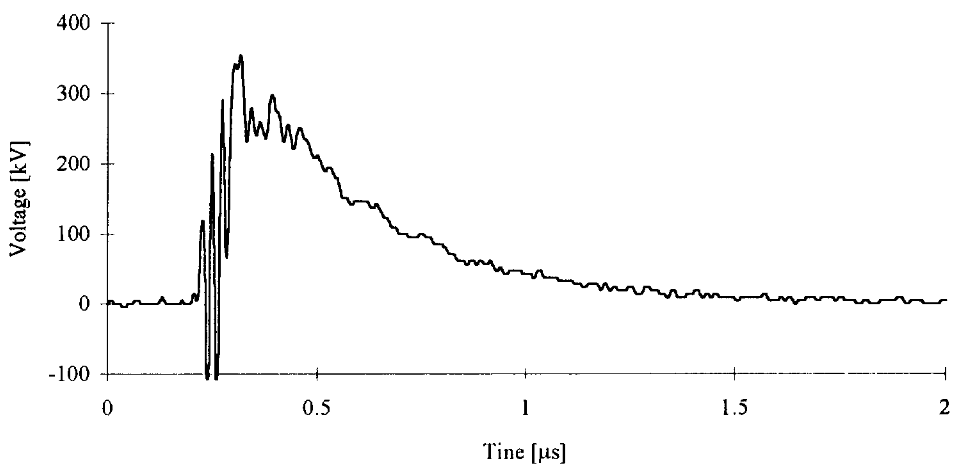

Figure 7. Output Voltage into 5 Ω from +/- 50 kV Charge of Four Stage Marx

Conclusions

Initial tests of the completed four stage Compact Marx indicate the extremely compact design produces a ~260 kV, 300 ns wide pulse with ~100 ns rise time into a 5 Ω load . After trigger problems were solved using a mid-plane common to the six parallel spark gaps in each stage, performance of the parallel Marx has been reliable with minimal jitter. Series jitter was undetectable using existing diagnostics. Trigger Marx rep-rate performance was demonstrated up to 10 Hz, and with proper power distribution rep-rate performance of the four stage Compact Marx should be comparable, however, those rep-rate tests have not been conducted.

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