A SOLID STATE MARX GENERATOR FOR TEL2*

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Abstract

The solid-state Marx generator modulates the anode of the electron gun to produce the electron beam pulses in the second Tevatron Electron Lens (TEL2). It is capable of driving the 60 pF terminal with 600 ns pulses of up to 6 kV with a p.r.r. of 50 kHz. The rise and fall times are 150 ns. Stangenes Industries developed the unit and is working on a second version which will go to higher voltage and have the ability to vary its output in 396 ns intervals over a 5 μs pulse.

INTRODUCTION

The 2nd Tevatron Electron Lens (TEL2) was installed and commissioned in 2006 in the framework of Beam-Beam Compensation project at Fermilab [1]. The project aims at reducing non-luminous proton/antiproton losses in collider operation by mitigating head-on and long range beam-beam effects [2]. This is done by means of an electron beam interacting with high energy proton/antiproton bunches. Since beam-beam effects vary bunch by bunch the TEL has to be able to generate pulsed electron beam. For linear beam-beam compensation in the Tevatron up to 3A of peak electron current are required. Therefore, considering the perveance of the SEFT electron gun of 4 μP [3] the pulse generator has to deliver over 8 kV to the gun anode. The Tevatron is filled with 3x12 proton and 3x12 antiproton bunches. The bunch separation is 396 ns and the abort gaps are about 2.24 μs long. For single bunch beam-beam compensation a pulse repetition rate equal to the revolution frequency of 47.7 kHz is required. Because of the 3-fold symmetry simultaneous compensation of three bunches (one in each train) is possible requiring a repetition rate of about 150 kHz. The ultimate goal is to be able to adjust peak electron current for every bunch in the machine meaning that the HV pulse driving the gun anode has to have twelve adjustable flattops.

The first-generation (TEL1) modulator uses a high-power switch tube to generate the anode pulses. This modulator has a rise time of .6us, which is slower than desirable. It also dissipates 50 kW of power to maintain its operation. We were looking for a different kind of modulator when we read about the solid-state Marx Generator [4].

THE MARX GENERATOR

Historically, Marx generators consisted of capacitor banks charged through inductors and erected using triggered spark gaps. Modern versions are both charged and erected using solid-state switches such as IGBT's

The Marx Generator we contracted for from Stangenes Industries has 12 stages which can each be charged to 1.2 kV and erected in series to produce a 14 kV pulse. The discharge IGBT switches erect the pulse with a rise time of 150 ns, and the charging IGBT switches terminate the pulse with a fall time of 150 ns, and then provide a path for charging the capacitors in parallel.

Specs

We specified the generator to produce pulses of up to 14 kV with a flat top of 100ns, a total width (zero to zero) of 600ns and a rep rate of 50 kpps. The load to be driven is the 60 pF capacitance of the anode terminal.

Challenges

Although the generator pulse output shape has met the specification, a major design issue in the system has been the excessive switching losses in the IGBT's while running at a 50 kHz rep rate. The devices are air-cooled, and the system has run into thermal problems that have limited it to operating at less than 6 kV at the nominal rep rate. This level, though less than desired, was similar to the level of the TEL1 modulator. It was sufficient to be useful for the TEL2 experiments that were carried out [1,5].

Performance and experience

The Marx Generator was designed to drive approximately 60 pF, so it must be mounted in close proximity to the gun anode terminal to avoid the extra capacitance of a long connecting cable (see Fig.1).

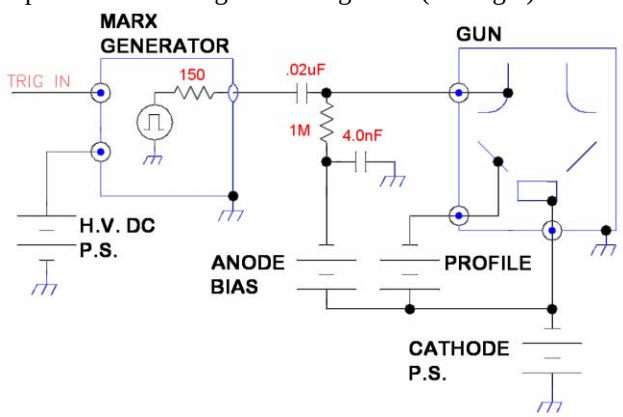

Figure 1: Electron gun driving scheme. Only the cathode, the control electrode (profiler) and the anode of the electron gun are shown.

TEL2 is located in the Tevatron tunnel, a few yards downstream from the beam dump. This is possibly the worst location in the tunnel for solid-state equipment that is not radiation-hardened (see Fig. 2).

* Work supported by the U.S. Department of Energy under contract No. DE-AC02-07CH11359
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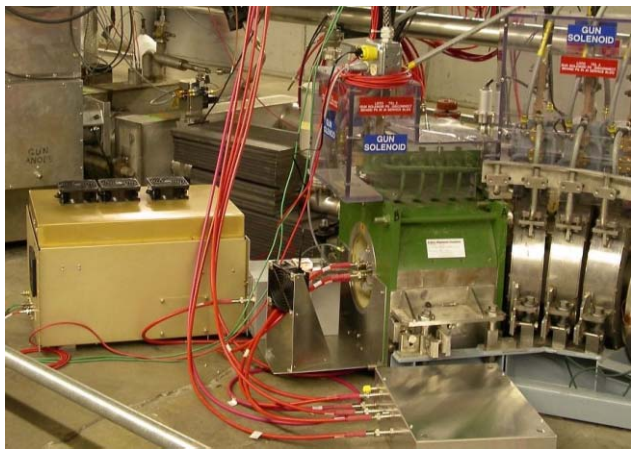

Figure 2: Marx generator connected to the TEL2 electron gun in the Tevatron tunnel.

The Marx generator stopped functioning in less than a week of Tevatron operation, and we found it to be Class I radioactive when we removed it from the tunnel. However, after cooling down for a few days, it started operating again. We reinstalled it behind two feet of steel shielding, and it functioned for several weeks before failing. We added four more feet of shielding (see Fig. 3), and the unit has been operating continuously for the last six months.

Fig. 4 shows the output voltage of the Marx generator when gated with a 520 ns pulse. At 4.2 kV of Marx output voltage and anode bias voltage of 200 V the peak electron current is 1 A which is consistent with the gun perveance.

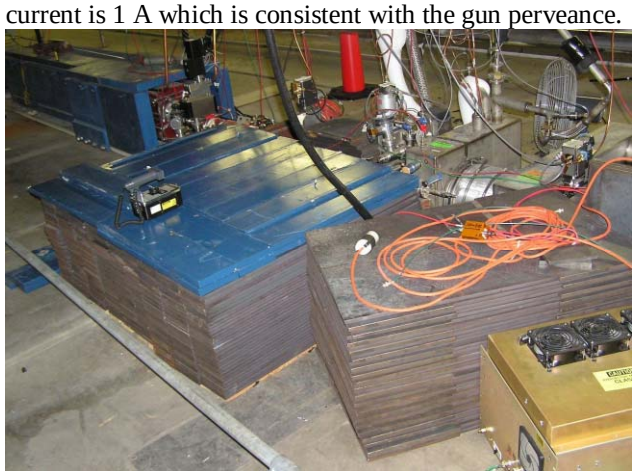

Figure 3: Radiation shielding protecting the Marx generator.

FUTURE PLANS

Stangenes Industries is developing a second-generation Marx Generator for us with a few improvements. The IGBT's will be water-cooled so as to be able to work at higher voltage at the 50 kHz rep rate. The unit will also have individual control of each of the stages so that we will be able to create 12 different voltage levels, spaced 396 ns apart during the 5 μs bunch train.

At Fermilab, we are also working on a solid-state modulator based on summed pulse transformer scheme [6] to generate similar waveforms, but at a rate of 150 kHz, which is what a full-scale system would require.

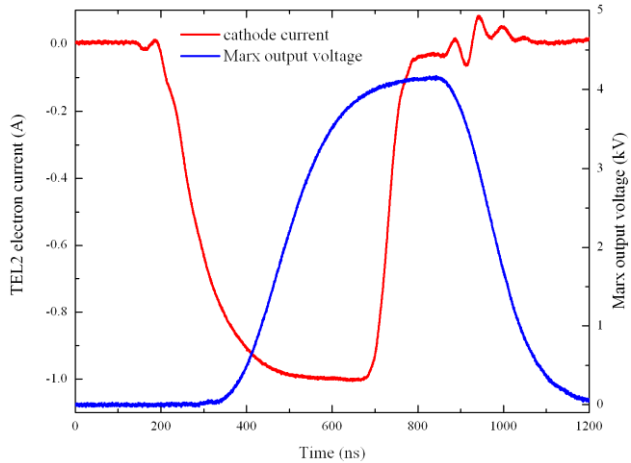

Figure 4: Marx output voltage and electron beam current.

SUMMARY

Successful beam-beam compensation experiments have been performed using the solid state Marx generator to drive the electron gun of the 2nd Tevatron Electron Lens. In order to ensure reliable operation of the generator installation of additional radiation shielding was necessary. An improved version of the solid state Marx generator and a modulator utilizing summed pulse transformer scheme are under development to make multi-bunch beam-beam compensation possible.

ACKNOWLEDGEMENTS

The authors would like to thank Stangenes Industries, specially Richard Cassel and Sherry Hitchcock, for their development of the Marx Generator circuits.

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