A New Crowbar System for the Protection of High Power Gridded Tubes and Microwave Devices

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As part of the Electron Cyclotron Heating (ECH) Facility upgrade at the DIII–D National Fusion Facility, an 8.4 MW Modulator/Regulator Power System was designed and constructed [1]. The power system uses a high power tetrode to modulate and regulate the cathode voltage for two 1 MW-class 110 GHz gyrotrons [2]. A critical element in the power system is the energy diverter, or crowbar switch, that protects the tetrode and the gyrotrons in the event of an arc fault. Traditionally, mercury filled ignitron switches are used for this application, but it was desired to eliminate hazardous materials and improve the overall switching performance. The new crowbar switch system would meet the following requirements:

Operating voltage:	–105 kVdc
Peak current (750 μs e-fold):	1.2 kA
Follow-on current:	<1 kA (25 ms)
Charge transfer per shot:	<20 Cb
Turn-on time:	<1 μs

The switch that was chosen for the new design is a low pressure deuterium filled device manufactured by Marconi Applied Technologies [3]. Designated the HX-2500, it has combined characteristics similar to a hydrogen thyratron and a triggered vacuum gap and is referred to as a metal arc thyratron. The thyratron-like triggerability and high-speed response combined with high charge transfer capability and a wide operating voltage range make the HX-2500 an appropriate choice for crowbar service. Four HX-2500 switches are connected in series to meet the operating voltage requirement. A photograph of a single stage is shown in Fig. 1. In addition to the improved crowbar switch assembly, improved fault signal processing circuitry was developed. This new circuitry uses fiber-optics for signal and trigger transmission and a complex programmable logic device for high speed signal processing.

Initially, the crowbar system performed extremely well, meeting all of the operating requirements and demonstrating its ability to protect a 36 gauge copper wire from fusing (energy let-through <10 J). At low anode voltage (<100 V), the turn-on time of all four switches is <800 ns with a spread between the four of <50 ns. The total delay time from start

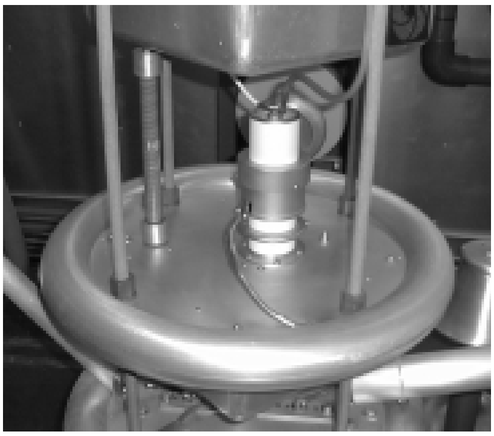

Fig. 1. A single stage of the crowbar switch assembly.

of the sensed fault current to the peak of the fully diverted crowbar current is <1.5 μs. An oscilloscope photograph of the wire test is shown in Fig. 2.

After approximately 400 hours of system operation, that included >500 crowbar events, the voltage hold-off capability of the tubes had degraded. High voltage, low energy conditioning would restore hold-off, but it would degrade after a few crowbar events. It was determined by Marconi that copper material had unexpectedly deposited on the main insulator in a region where the highest electric fields existed. The copper most likely migrated to that region due to the relatively high follow-through current that persists for long time scales. To achieve longer life and reliability when operating in this current-time regime, Marconi designed new electrodes with greatly improved electric field stress control and a much longer path through which the metal vapor would have to travel. The newly designed tubes were tested to satisfaction at Marconi.

At DIII–D, the new design tubes were installed, but have not yet been tested at the time of this writing. The design of the crowbar switch and the fault signal processing system and their performance will be presented in this paper.

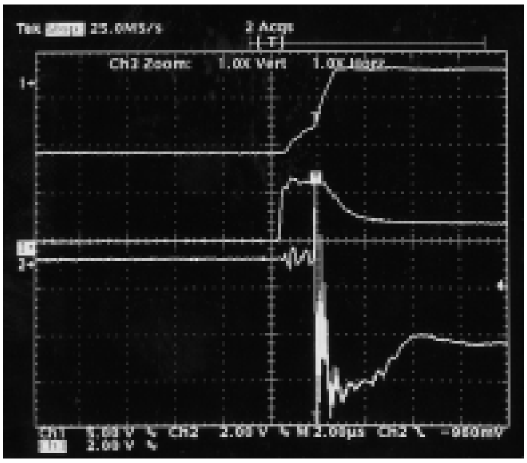

Fig. 2. Results of the crowbar wire test in which a 36 gauge wire survived repeated trials. The middle trace is the wire current (400 A/div), the bottom trace is the crowbar current (400 A/div), and the top trace is the output voltage.

Acknowledgement

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References

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