Modern Thyratron Crowbar Protection Systems

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Abstract

In this paper two thyratron crowbar systems are described. The first, contained in an oil filled tank, is a complete system to protect a klystron powered from a 100KV, 20A d.c. supply. In the second system a CX1722 glass thyratron, operating in air, has been retro-fitted to a test equipment, in place of a spark gap, to protect an Inductive Output Tube (IOT). The supply here is 32KV, 4A d.c. The thyratron will operate on fault down to 5KV H.T. whereas the spark-gap would not trigger below 25KV.

An important parameter in the choice of the crowbar thyratron is the total coulombs to be switched. It is often not appreciated that most of the coulombs conducted by the thyratron come from the power-supply follow-on current rather than the initial storage capacitor discharge. Measurements of these follow-on currents are presented.

1 Introduction

Traditional television and other similar low power d.c. and pulse klystrons used in Linear Accelerators do not usually need crowbars. The stored energy is small and the power supply circuit breakers are usually fast enough to protect the klystron in the event of an arc. This is not the case, however, with high and super power klystrons[1], nor with the Klystrode[2] or the recently developed IOT[3].

The electrical circuit involving a crowbar is well known[1] and is shown in fig.1.

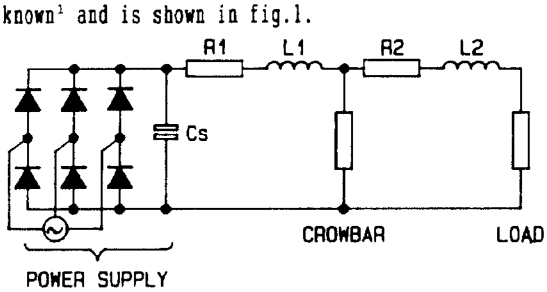

FIG.1. CROWBAR IN A PRACTICAL CIRCUIT

2 100KV Crowbar System

The crowbar system has been designed so that the only essential connections required are high voltage in, high voltage out, pulse ground and mains input(1.2KVA). Direct triggering from the fault current, via a Rogowski coil, is incorporated and provision is also made to trigger the crowbar via an optical link for test purposes. Fig.2 shows a photograph of a crowbar tank with the thyratron sub-assembly.

FIG. 2. 100KV CROWBAR

The heart of the system is the crowbar thyratron, which is a five gap double cathode tube, type number CX1194B. For very long term, reliable, voltage hold-off in a crowbar application, a rating of only 20KV per high voltage gap is appropriate. This thyratron has two auxiliary grids, grid 1 and grid 2, at each end. Grid 1 is driven with a d.c. current of 100mA, and the monitoring of this current together with the voltage drop across the grid 1 allows a thyratron 'ready to fire' interlock to be incorporated. Like the external trigger signal, this interlock signal is transmitted optically between the floating negative high voltage deck and the low level electronics. This is the essential, necessary feature for long term reliable operation of the crowbar system.

The system was tested using the well known shorting wire technique with 4uF of storage capacitance and two x 10Ω series resistors. The stray inductances L_1 and L_2 are estimated to be approximately equal and each about 4μH. These tests show that a short circuiting wire down to $0.0156mm^2$ cross-sectional area (38 SWG) is protected. Oscillograms in fig 10 show the fault and the crowbar currents and show that the delay between application of the short circuit and the instant of crowbar conduction is 0.36μs. When the crowbar is fired externally via the fibre optic the delay between the low level electronics signal and crowbar conduction was 1.2μs. The minimum H.T. at which the crowbar will fire reliably on an applied short circuit is 15KV, and the minimum H.T. at which the crowbar will fire reliably with an external trigger signal is 10KV.

The system has been shown to hold off 100KV reliably for long periods. The system operated for three weeks continuously, without a thyratron prefire.

The crowbar has been operating satisfactorily since August 1991, and up to March 1992 has clocked up 1010 crowbars so far. The surge current from the storage capacitor when the crowbar fires is shown in fig.3. Fig.4 shows only the follow-on current from the power supply on-load (i.e. without the capacitor surge). The total coulombs the crowbar switches is 0.7C max, made up of 0.4C from the storage capacitor and 0.3C from the power supply follow-on. Fig.5 shows that the "let-through" to the fault is 8mC.

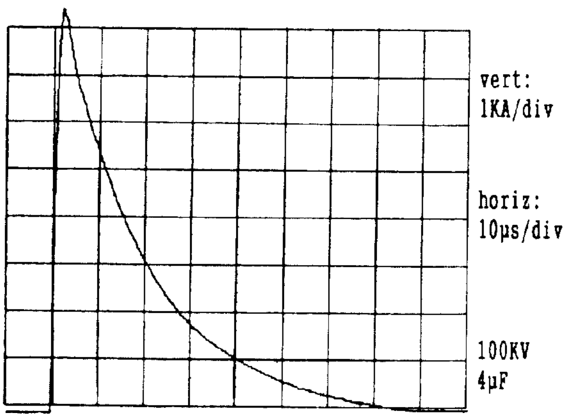

FIG.3. CURRENT SURGE ON FAULT.

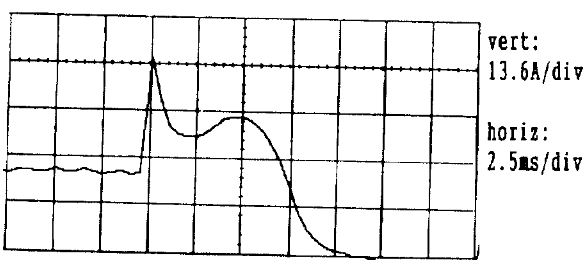

FIG.4. POWER SUPPLY FOLLOW-ON.

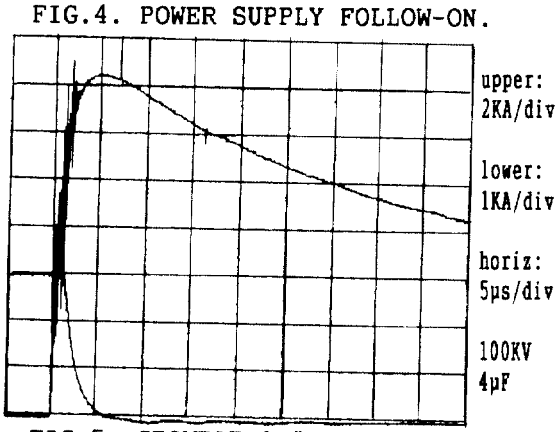

FIG.5. CROWBAR & "LET-THROUGH"

The follow-on current from this particular thyristor controlled power supply[4] is exceptionally low, especially compared to the results from the IOT power supply (see below), and illustrates the excellent control that can be achieved by a thyristor regulated supply.

3 I.O.T Crowbar System

Fig.6 is a circuit diagram of the IOT power supply, and fig.7 is a photograph of the crowbar system, which is built around a single gap CX1722 glass thyratron.

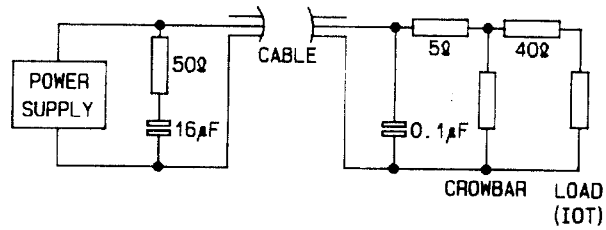

FIG.6. IOT POWER SUPPLY.

Since the H.T. is 32KV max a single gap thyratron is used. Other essential features from the 100KV system, such as automatic triggering from the fault current and grid 1 current interlock, are also incorporated. A reliable, air spaced isolation transformer is used to provide power for the thyratron heaters and trigger electronics. The system could be made more compact by using a potted isolation transformer.

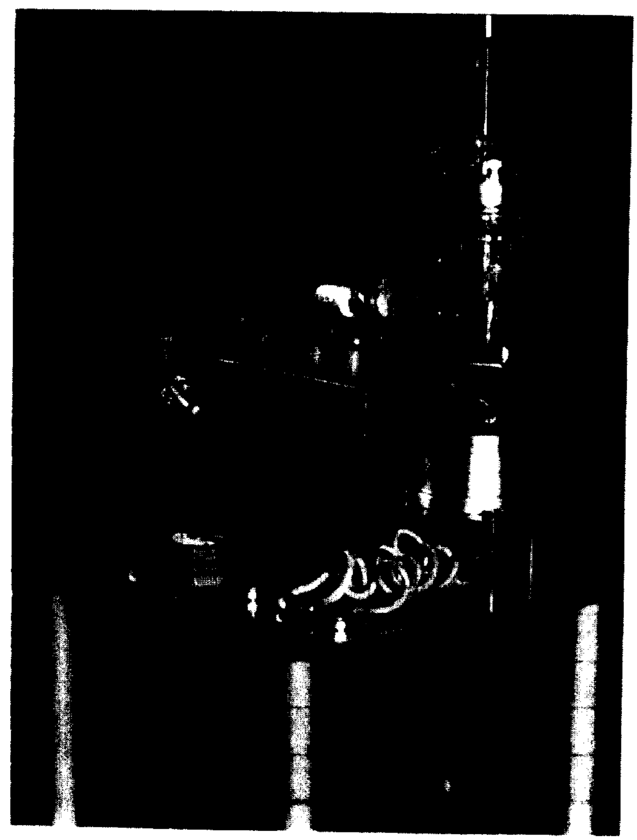

FIG. 7. THE IOT CROWBAR.

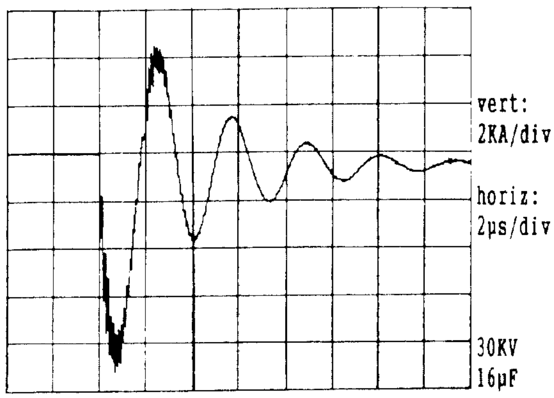

FIG. 8. CURRENT SURGE ON FAULT.

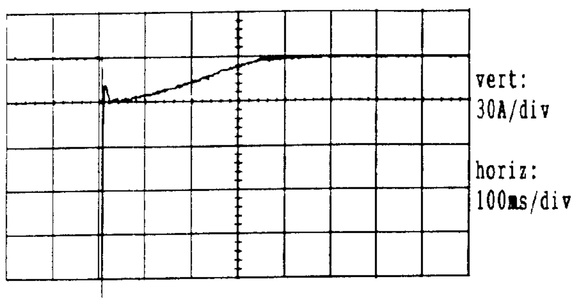

FIG. 9. POWER SUPPLY FOLLOW-ON.

The automatic triggering incorporated into the thyratron system gives a delay between fault and start of thyratron conduction of 0.3µs. When the thyratron is triggered via the fibre optic, the delay between the initiation of the low level signal and thyratron conduction is 1.2µs. The thyratron will operate on a fault down to 1KV and with external triggering down to 500V d.c.

Figs.8 and 9 show the fault current through the crowbar thyratron in the equipment. The total charge switched is 6.2C, with 0.5C from the storage capacitor and the remaining 5.7C from the power supply follow-on current. Fig.10 shows the the 'let-through' to the fault in the test circuit to be 1.2mC.

The crowbar has been operating satisfactorily since installation in November 1991, and up to 1'st March 1992 it had clocked up 750 firings.

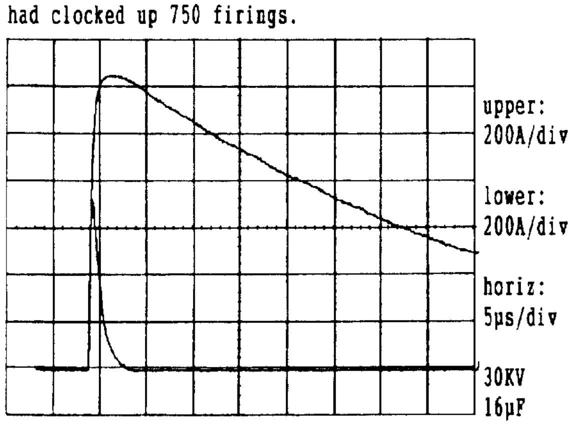

FIG.10. CROWBAR & "LET-THROUGH" CURRENTS

The results above illustrate the severe conditions which a crowbar switch must often handle. Fig. 8 shows a high forward peak current and subsequent current reversal through the crowbar caused by the underdamped 0.1µF capacitor. The high frequency oscillations superimposed on the current pulse are due to the cable between the power supply and the test equipment.

The power supply follow-on current is shown in fig. 9. Measurements of the follow-on coulombs in thyratron test modulators at EEV indicate that 2C to 3C is common, so the level of 5.7C found in this IOT test equipment is not exceptionally high.

Under capacitor discharge conditions, with discharge currents of several kilo-amps, the CX1722 is rated at only 0.6C. Under crowbar conditions, however, where most of the conducted charge comes from the follow-on current, which is of the order of tens of amps, then the results presented here indicate that the coulomb rating can be increased by a factor of at least 10 for such crowbar service.

4 Conclusions

Two thyratron crowbar systems, operating under very different conditions, have been designed and installed in production test equipment. Both operate over a wide dynamic range, and their ability to provide a 'ready to fire' interlock gives a reliability that other devices cannot provide.

In one of these applications the CX1722 glass thyratron has been shown to satisfactorily handle a high peak forward current, subsequent current reversal, and a high power supply follow-on current. The total conducted charge of 6.2C is over ten times the coulomb rating of this thyratron for capacitor discharge conditions. From this result it is concluded that a realistic coulomb rating for the larger CX1194B, under crowbar conditions, will be in excess of 20C.

5 References

[1] N.S.Nicholls, H.Menown and R.J.Wheldon. 'Double Ended Hydrogen Thyratrons for Crowbar Protection of High Power TWT Systems'. 13'th Power Modulator Symposium, Buffalo, N.Y., June 1978.

[2] D.H.Preist and M.B.Schrader. 'The Klystrode - An Unusual Transmitting Tube with Potential for UHF-TV'. Proc. IEEE, Vol.70, No.11, Nov 1982.

[3] G.T.Clayworth, H.P.Bohlen and R.Heppinstall. 'Some Exciting Adventures in The IOT Business'. International Broadcast Engineer, May 1992.

[4] N.S.Nicholls et al. To be published.