FAULT PROTECTION

INTRODUCTION

An arc is a self-sustained discharge of electricity between electrodes in a vacuum environment which has a voltage drop at the cathode of the order of the minimum ionizing potential of the environment. The arc supports large currents by providing its own mechanism of electron emission from the negative terminal plus space-charge neutralization.

All power grid tubes operate at voltages that can cause severe damage in the event of an internal arc unless the tube is properly protected. This damage may be relatively minor in tubes operating from low energy power supplies but will become catastrophic in cases where a large amount of stored energy or follow-on current is involved. Since any high voltage vacuum device may arc at one time or another, some means of protection is advised in all cases but is mandatory in those instances where destructive quantities of energy are involved. In addition to protecting the tube in the event of a tube or circuit malfunction, these protective measures also protect the external circuitry.

Eimac has developed guidelines for protection of the various tubes in its product line. Adherence to these guidelines will insure longer tube life and will insure that the tubes are not destroyed during a fault – a condition not covered by the Eimac standard warranty.

LOW ENERGY OPERATION

In cases where operation involves oxide cathode tube types up to about 1500 watts plate dissipation, the addition of a series resistor in the anode and/or screen grid high voltage lead will limit peak currents and provide a means of dissipating energy in the event of a tube or circuit arc.

This resistance should be as high as is practical without dissipating an excessive amount of power. Typically, a resistance of 20-50 ohms is sufficient to protect the internal tube structure in the event of an arc. It also serves as protection to the other circuit components such as bypass capacitors, RF chokes, meters and diodes. For oxide cathode tubes a maximum of four Joules total energy is permitted to be dissipated in an internal arc. An amount in excess of four Joules will permanently damage either the cathode or the fine wire grid structure during repetitive arcing. In a typical case involving a 2000 volt power supply with a 2 MFD filter capacitor a total of four Joules is stored in the capacitor alone not including the energy resulting from follow-on current from the power supply.

Most power supplies employ much larger filter capacitors than 2 MFD, resulting in even more stored energy. With no series resistor all this energy is dissipated in the tube structure in the event of a tube arc. Typically, there is about 50 volts across a tube arc and the addition of a series resistor of 50 ohms will limit the peak fault current to 40 amperes. With 1950 volts across the resistor and 50 volts across the tube arc, less than 5% of the total energy is dissipated in the tube with 95% being absorbed in the series resistor. Note that a major portion of the fault energy may come from the follow-through current if the overload relay(s) take excessive time to open the primary contactor. Without protection, several low energy arcs may occur before serious degradation in tube performance is noted. However, in extreme cases where sufficient energy is involved, a single arc may completely destroy the tube.

In extreme cases such as an application using many tubes in parallel or in a distributed amplifier where stored energy is high, it is necessary to employ a "crowbar" or other type of energy diverting circuit to protect the tubes. Such a circuit may employ a thyratron, ignitron or SCR as the energy-diverting element (see Fig. 1). The fault-sensing element must

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sense a fault condition and trigger the crowbar to divert the energy so that no more than four Joules is dissipated in the tube structure.

As a test for the amount of energy delivered in an arc, Eimac suggests that the power supply used be short-circuit tested by causing an arc (in air) from a short lead connected to the tube terminal to the surface of a grounded sheet of 0.025mm (0.001 in.) thick aluminum foil. If total energy delivered is less than four Joules, the hole burned in the foil will be no greater than 3mm (0.120 in.) diameter.

An alternative test which will verify tube protection is to short-circuit test the power supply through a 6-inch length of 0.079 mm diameter (#40 AWG) soft copper wire. If total energy delivered is less than four Joules the wire will remain intact. This test must be run at full operating voltage and may be performed by using a vacuum switch or other suitable high voltage relay to apply a short to the supply through the aluminum foil or the copper wire.

HIGH ENERGY OPERATION

Most tubes employing thoriated tungsten filaments are capable of withstanding higher energy arcs than are the oxide cathode types. However, some of the smaller types (such as the 4CX1500A and 5CX1500A) as well as some larger high-mu triodes (such as 3CX3000A7, 3CX10,000A7 or 3CX20,000A7) while employing thoriated tungsten emitters, have very fine wire grid and cathode structures and should be protected in much the same way as the smaller oxide cathode tubes. However, larger tubes should be capable of withstanding arcs containing up to 50 Joules total energy.

In large tube applications it is often found that the screen grid or bias supply, in addition to the anode supply, is capable of delivering destructive energy to the tube structure in the event of an arc. Consequently, protection must be provided in all cases where potentially destructive energy is involved.

As in the lower energy case, Eimac has devised a test to insure that the energy dissipated in a tube arc is less than 50 Joules. Each power supply, whether anode or grid, should be short-circuit test-ed through a 6-inch length of 0.255mm diameter (#30 AWG) soft copper wire. A similar test must be made from plate to screen grid to insure that the tube is protected in the event of a plate-to-screen arc. A protective spark gap between screen grid and cathode is recommended so that in the event of an arc the resultant spark from screen to cath-ode is external to the tube structure. The wire will remain intact if the energy dissipated is less than 50 Joules. The 50 Joules includes total energy de-livered whether from the energy storage device or from the follow-on current from the power supply prior to the primary circuit opening.

Each power supply in the circuit must pass this test or some form of energy diverting or energy limiting circuit must be employed (Fig. 1). Energy divert-ers at this power level become much more com-plex than those employed in the lower energy case. They employ large high speed diverting elements such as thyratrons, ignitrons, triggered spark gaps, or in some cases, a high-speed vacuum switch which may be required to handle thousands of am-peres peak current.

The resistor R1 is used to limit the peak current into the energy diverting switch V1 as well as limit peak current demand on the transformer and rectifiers in the power supply. Resistor R2 must be large enough to keep the voltage across V1 from dropping so low under load arc conditions as to inhibit the proper firing of the fault diverting elements. R1 and R2 also must damp the circuit "ringing" sufficiently to prevent current reversal in V1 which could cause V1 to open before fault conditions are cleared.
R1 and R2 must be sized to minimize average power losses and handle the required voltage and power transients while still properly performing their func-tions. The sensing element CT-1 senses any abnor-mal peak current levels in the system. Signals from the current transformer are used to trigger V1 in the event of an over-current condition. A crowbar

test switch, S-1, should be used to perform the test outlined above to insure that the total energy dissipated in an arc is less than 50 Joules (or 4 Joules). Typically, S-1 is a high voltage of either air or vacuum construction. It applies a short circuit through a 6-inch length of soft copper test wire. If the wire does not remain intact during the test, the protective circuitry is not adequate and corrective measures must be taken. In a typical test, when S-1 is closed, the current transformer CT-1 senses the fast rising current and fires the energy diverting element V1, while simultaneously sending a fast trip signal to the main circuit breaker. Typical energy diverters fire within a few microseconds of the time the fault is detected and remove all voltages and currents from the protected device(s) in tens of microseconds.

Using the above techniques, it is possible to limit the energy delivered during an arc to much less than the recommended maximum. In a properly operating system essentially no damage will occur within the tube even under severe arcing conditions. The test wire or aluminum foil must be connected at the tube in order to include all stored energy (L & C) in the test. For more complete information on protection criteria or design of protective circuitry references are listed below. (These publications may be out of print and available only at a technical library).

1. Capacitor Discharge and Crowbar Service Application. Notes M-1256, General Electric Company, Tube Products Division, Schenectady, NY 12345.

2. Ignitrons, Capacitor Discharge and Crowbar Service PT-57A, General Electric Company, Tube Products Division, Schenectady, NY 12345.

3. The Fault Diverter – A Protective Device for High Powered Electron Tubes by R.H. Smith, August 1957, Lawrence Radiation Laboratory Report UCRL-3701, Univ. of Calif. Lawrence Livermore Laboratory, PO Box 808, Livemore, CA 94550.

4. Vacuum Arcs – Theory and Application, by J.M. Lafferty, John Wiley and Sons, New York. ISBN-0-470-06506-4.