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MAGNET PROTECTION USING ZNR SURGE SUPPRESSORS

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SUMMARY

In the Fermilab Main Ring power supply system, we have added ZNR type (zinc oxide nonlinear resistor) suppressors to each power supply terminal to limit the magnet voltage-to-ground to 2.1 kV. The ZNR's conduct 50 A at the 2.1 kV clipping voltage, and leak less than 1 mA at the 1.5 kV maximum operating voltage. Their repetitive surge rating is 1.4 kJ. Their main advantage, in comparison to spark gaps, is that the ZNR's do not break down and cause transients and high voltages at neighboring points on the magnet bus.

ZNR FUNCTION

The ZNR's act like large zener diodes, clipping magnet bus voltages at between 1.7 kV and 2.1 kV. Detection of more than 20 mA through a ZNR, indicating that the device is actively clipping, triggers a protective loop ("Fast Trip Loop") which turns off all of the power supplies by phasing them back into the bypass state. The ZNR absorbs the transient energy until the power supply turn-off is complete. Voltage monitors at the power supply terminals also trigger the Fast Trip Loop when voltages exceed 1.75 kV. This protection system for the bending magnet bus is diagrammed in Fig. 1.

ENERGY ABSORPTION

The amount of energy absorbed by a ZNR depends upon the nature of the problem that caused the excess bus voltage. Two cases are described below.

1) High Impedance-To-Ground Type Fault

In this case, one ZNR is the only element that conducts to ground (other than the 50 kΩ distributed ground resistors). Since the return path for ZNR current is limited to the ground resistors (parallel R = 520 Ω), the current remains quite small. Figure 2A shows the normal voltage to ground distribution at 400 GeV. Fig. 2B shows what happens if power supply LA3 is accidentally substituted for UC1, with and without protection. The ZNR clips the bus voltage at 1850 V; its 20 mA detector triggers the fast trip loop, which turns the power supplies off within 7 ms. The energy absorbed by the ZNR is 5.2 Joules (1850 x 400 mA x 7 ms).

2) Low Impedance-To-Ground Type Fault

In this case, a second low impedance path is involved in the fault, causing higher ZNR currents. Fig. 3 shows the voltage distribution that occurs if an insulator in the UC3 supply shorts to ground, with and without protection. The clamping ZNR is power supply LA4 increases the voltage across magnet string "A" by 1 kV, while decreasing the voltage across string "B" correspondingly. The current in string "A" increases at the rate: $dI/dt = 1.1$ kA/S (1 kV/6 mH x 144 magnets). Current in string "B" decreases at a slower rate. The ZNR current is the difference between the two currents, and increases at 1.3 kA/S, reaching a maximum of 9 Amps before the fast trip loop completes the power supply turn-off. Allowing an extra 5 ms for the ZNR current to decay, one calculates that the energy abosrbed is 108 Joules (½ · 9 A · 2 kV · 12 ms). A worst case calculation of this type, using an extremely unbalanced voltage distribution and strategically located short circuit, yields 840 Joules with a maximum current of 70 Amps.

COMPARISON WITH SPARK GAPS

Figures 2 and 3 suggest the potential problems of using spark gaps rather than surge suppressors. Had a 2 kV spark gap been located at power supply UC3 in Fig. 2B, it would have shorted to ground and lifted the voltage at LF4 towards +3.3 kV. Other spark gaps would have fired to prevent that voltage from occurring, but such a protection sequence would be less gentle and more trouble-prone than the ZNR action.

ZNR CHARACTERISTICS

1) V-I Curve

We chose ZNR's over other suppressors primarily because of the sharp nonlinearity of their V-I curve, which allows us to clamp very close to operating levels. The curve is shown in Fig. 4. We specified a closer tolerance than standard for the low current end (1600 ± 50 V at 1 mA D.C.), and also noted that the devices performed consistently better than their maximum ratings at higher currents (2100 ± 50 V @ 50 A vs. a 2450 V max. rating). We had anticipated this following studies of lower voltage samples.

2) Surge Ratings

The ZNR's can absorb the following surges without changing their characteristics by more than 10%:

14 kJoules - one time

or

1.4 kJoules - 500 times

or

300 Joules - 10^6 times

3) Lifetime

ZNR's become leaky under prolonged high voltage--high temperature usage. Their lifetime curves are shown in Fig. 5. Our devices are rated at 1080 volts D.C., which gives them a 200 year lifetime at 40°C. Though our maximum operating voltage is 1.5 kV, voltages this high are generated for only short times in the ramp cycle. The maximum RMS voltage is less than 800 V. During Storage Ring mode operation, when 15 power supplies are ON continuously, we will take care to establish a voltage distribution under 1200 V, to avoid shortening device lifetimes significantly.

OPERATION

Installation of the ZNR's was just completed during March 1979, so we have no prolonged operational experience yet. We can only report that the devices have caused no problems, and that two samples installed six months earlier have worked successfully: no transients greater than 1800 V have been recorded on our peak detectors at their locations.

CONCLUSION

We think the ZNR's constitute a viable alternative to spark gaps for magnet protection systems. They have sufficient surge capability to handle fairly large transients; their leakage currents are small enough to be non-interfering; their clamping action is inherently gentler than the breakdown response of spark gaps.

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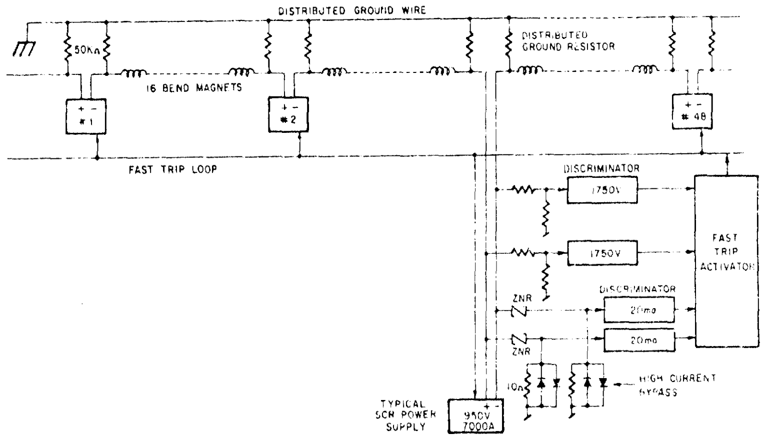

Figure 1. Bend Bus Safety System.

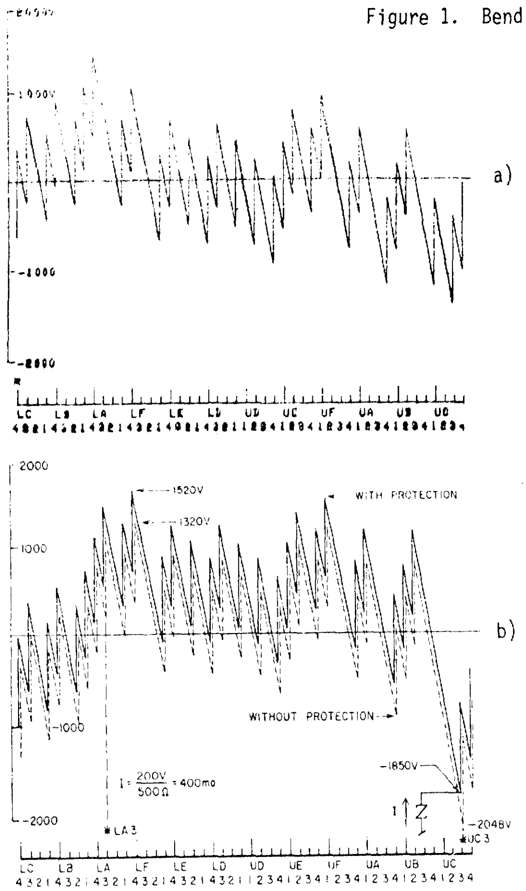

Figure 2. a) Normal Voltage Distribution.
b) High Impedance Fault.

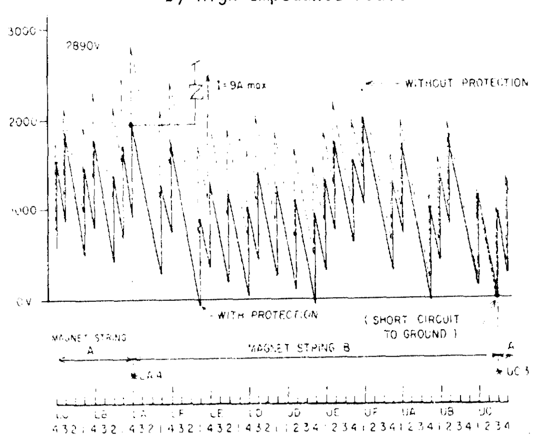

Figure 3. Low Impedance Fault.

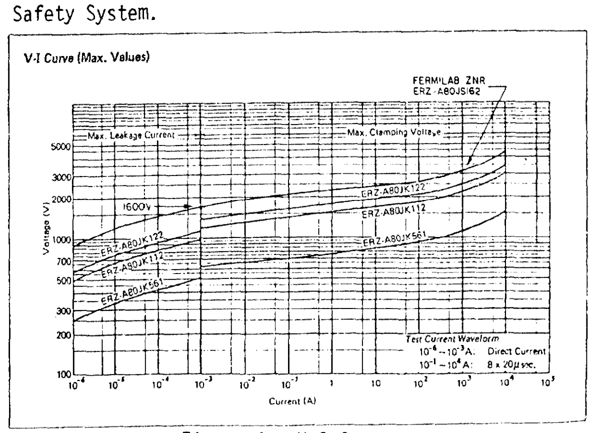

Figure 4. V-I Curve.

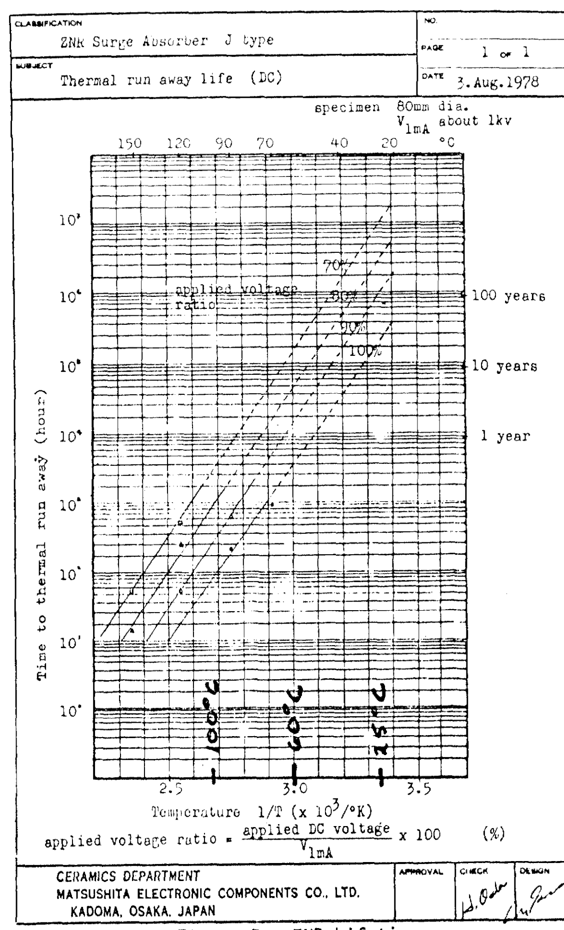

Figure 5. ZNR Lifetime.