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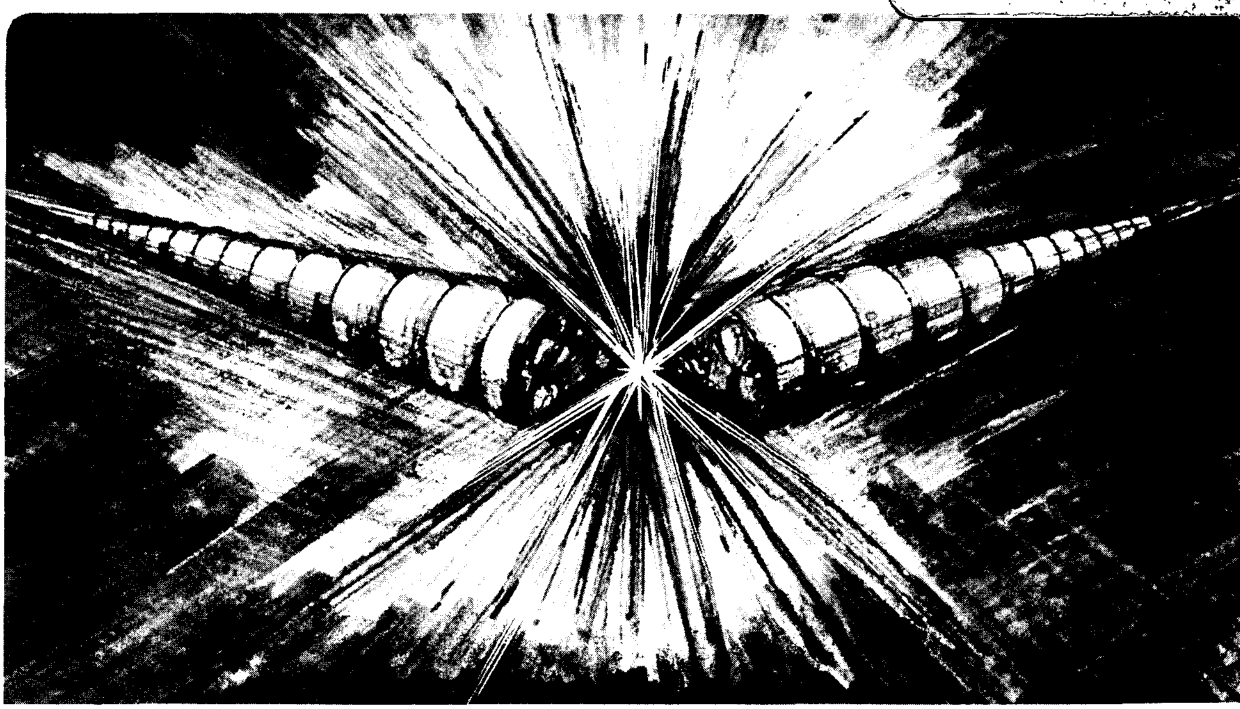

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DISCLAIMER

FAULT DETECTION AND PROTECTION SYSTEM FOR NEUTRAL BEAM GENERATORS ON THE NEUTRAL BEAM ENGINEERING TEST FACILITY (NBETF)

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Summary

Neutral beam sources, their power supplies and instrumentation can be damaged from high voltage sparkdown or from overheating due to excessive currents. The Neutral Beam Engineering Test Facility (NBETF) in Berkeley has protective electronic hardware that senses a condition outside a safe operating range and generates a response to terminate such a fault condition. A description of this system is presented in this paper.

Introduction

High voltage sparkdown can cause deterioration or damage in a neutral beam injector. Deterioration in performance of the neutral beam source is influenced by the amount of energy that is stored in the capacitances associated with the accelerator.[1] Damaging effects can be diminished by slowing the discharge with a core snubber.[2]

Overheating the accelerator grids (due to excessive currents) can also cause damage to the neutral beam source. To prevent damage, it is required that certain voltages and currents are monitored closely and if their value exceeds their safe operating value (fault condition), the high voltage is quickly interrupted. The fault detection electronic hardware is designed to respond to a fault condition in microseconds. Three types of responses are possible and the type of response generated depends on the fault identified. The fault detector is an upgraded version of an earlier design, tested on the Neutral Beam System Test Facility (NBSTF).[4]

Fault Detector Input Signals

Various voltages and currents are monitored closely and compared to a preset safe operating threshold value during beam operation. If these signals exceed the preset operating thresholds, a response is generated by the fault detector.

The monitored signals, used in the NBETF, are listed in Table 1. The "inhibit time", listed in this table for each signal, is the time that the fault detector is disabled during the accel voltage turn-on. The "persistence time" is the time that the fault signal is allowed to continue before an action is taken. The fault detection input signals used in the NBETF are:

1. -dV/dt

"-dV/dt" senses a rapid decrease in accel voltage. The signal is generated by differentiating the accel sense voltage (τ = 20 μsec) and provides the earliest information that a spark has occurred.

2. V_{1-2}/V_{Accel}

"V_{1-2}" senses the voltage difference between the first grid, which is at accel potential, and the second grid (gradient grid). This voltage is monitored on the neutral beam sources since its collapse can cause severe overheating in the accelerator grids. V_{1-2} is usually about 20% of V_{Accel}. The ratio V_{1-2}/V_{Accel} permits an operating threshold setting that is independent of the accel voltage.

3. V_{gg}/V_{Accel}

V_{gg} is the gradient grid (second grid) voltage measured to ground. The V_{gg}/V_{Accel} monitor can be used in addition to or as a substitute for the V_{1-2}/V_{Accel} monitor. V_{gg} is in the order of 80% of V_{Accel} and since it is measured to ground potential, no telemetry channel is required.

4. I_{gg} and I_{Supp}

The gradient grid current and the suppressor current are monitored by the fault detector because excessive currents in the grids can bend the grids and thus degrade or damage the source. The inhibit time (600 μsec) permits excessive currents to flow during the accel transient turn-on.

5. I_{Accel}

The beam related accel current is monitored at two places with shunts: near the source and near the accel power supply rectifiers. Both signals are used as fault detector inputs and their thresholds can be adjusted for operating conditions.

6. V_{Accel}-Strobe

The accel voltage is switched to the neutral beam source with a SCR switch,[5] after the accel power supply has been turned on. The command comes from the computer. A logic gate pulse (beam request time or "strobe") controls the duration of the "neutral beam pulse request." The V_{Accel}-strobe fault detector compares the presence (or absence) of the high voltage with the beam request duration. A fault condition exists if no accel voltage is measured during this request time or if accel voltage is present without the computer logic strobe pulse.

7. Metal Arc (Spot) Detector[6]

A persistent metal arc can cause severe damage to the plasma chamber and should be terminated within a few milliseconds. A metal arc usually decreases the efficiency of the plasma production. The ion output, measured with a Langmuir plasma probe, is compared to the arc current. The ratio of the plasma probe current and the arc current is a measurement of the source efficiency. If the ratio falls below a preset value (operator adjustable), the neutral beam is terminated (or interrupted depending on operating conditions). The spot detector also measures a "noise" component of the probe current since a metal arc also produces high frequency plasma fluctuations.

8. Gradient Grid Voltage

The gradient grid voltage also has a -dV/dt sparkdown sensor. It provides independent spark protection. Its status is displayed with a LED indicator.

Table 1 Type of Responses Versus Detected Faults

Fault Detector Monitor Signal	Calibration	Inhibit Time	Persistance Time	Type of Response 1	2	3
V_{Accel} dV/dt	20 kV/V	4 μs	4 μs	X		
V_{1-2}/V_{Accel}	Ratio FS = 20%	6 μs	100 μs	X		
$V_{Grad\ Grid}/V_{Accel}$	Ratio FS = 100%	200 μs	85 μs	X		
I_{Accel} Source	10 A/V	50 μs	10 μs	X		
I_{Accel} P.S.	10 A/V	-	500 μs		X	X
$\pm I_{Grad\ Grid}$	0.1 A/V	600 μs	100 μs	X		
I_{Supp} P.S.	1 A/V	50 μs	10 μs	X		
Spot Detector	Plasma Probe 0.5 V/V	-	~5 ms		X	
Grad Grid dV/dt	20 kV/V	-	<10 μs	X		
V_{Accel}-$\overline{Strobe}$	20 kV/V	20 μs	570 μs		X	X
$\overline{V_{Accel}}$-Strobe	20 kV/V	40 μs	7 μs	X		
V_{Arc} Overvoltage	20 V/V	-	-		X	
Arc Modulator Overload	Logic Signal	-	-		X	
Interlock Chain	Logic Signal	-	-		X	X
Maximum Number Interrupt	Logic Signal	-	-		X	

9. Interlock Chain

Safety requirements demand that high voltage areas and other potential health hazard areas are closed and interlocked during neutral beam operation. Any intervention of the interlock chain terminates the neutral beam operation. A few key elements of this chain, such as high pressure water flow, are displayed with LED indicators.

Fault Detector Output Signals

Three levels of responses have been designed as output commands of the fault detector. (Table 2). A level 1 response produces a temporary interruption in neutral beam operation. An interruption may occur frequently when an unconditioned neutral beam source has been installed. Contamination in the source requires a conditioning period under reduced operating power. During this period, the power to the source is interrupted for a short time (3-40 ms) when a fault has been detected. The high voltage is interrupted with a SCR switch. The plasma arc current is diverted by means of an arc modulator.[7]

A level 2 terminates the beam pulse by removing the power to the neutral beam. The level 2 responds to a more severe malfunction, such as overloading or overheating. A level 3 response terminates the beam in the same manner as a level 2 response and also turns off the power to the power supplies. This response will occur when a power supply current limit is exceeded or if the high voltage persists after a

Table 2 Type of Response Causing Protective Actions

	Type of Response 1	2	3
Accel Voltage Off	X	X	X
Suppressor Voltage Off	X	X	X
Computer Timing Strobe Off	X	X	X
Accel P.S. SCR Control Off		X	X
Accel P.S. 12 kv Supply Off			X
Auxiliary P.S. 480 V Supply Off			X

level 1 or a level 2 has been generated. From Table 1, it can be noted that whenever a level 3 response is generated, a level 2 response is also generated.

Block Diagram (Fig. 1)

The inputs to the fault detector electronics are analog or digital fault monitor signals. The monitor signals, measured at high voltage levels, are transmitted via high frequency response telemetry fiber optic links[8]. The outputs of the fault detector are the commands to react to the specific fault(s).

The input signals are grouped with OR-gates to cause the desired output effect. The threshold detectors allow the neutral beam source operators to choose fault trip levels for the analog signals. The digital signals are obtained from on-off type inputs (such as high pressure water flow detector and maximum number of interrupts/beam pulse). Time of fault, measured from beam start, is indicated on a LED display and aids the neutral beam source operators to troubleshoot the cause of the fault. A computer interface has been designed for future fault display and analysis. The type of fault and the type of output response (level 1, 2 or 3) are also marked by a LED display. (Fig. 2) The output pulses (50 V, 10 μsec) are used to turn off the high voltage and suppressor supply; the logic level pulses (10 V) are used as input signals to the computer timing circuits.

Circuit Design Notes

Threshold Detector

The input voltages to the threshold detectors are in the range of 0 to +10 V. They can be filtered with a two pole bessel filter if noise rejection is required. The input signals are compared to reference voltages using signal comparators (LM311); their outputs are enabled with an external logic pulse. The enable pulse is usually synchronous with the beam request gate pulse (strobe) and can be delayed by means of an internal adjustable delay, thus disabling the fault detector output during accel turn-on transient time. The adjustability of the persistence time and inhibit delays is accomplished with an analog timer (LM555).

The time at which a threshold detector generates an output signal (level 1, 2 or 3) is referenced to the start of the "beam request" pulse. The elapsed time is registered with a seven segment display; its accuracy is a few microseconds (a 1 MHz crystal oscillator is used as the clock frequency). The display is driven with a digital counter (ICM7217A).

A "test" button located on the front panel of the threshold detector, when activated, causes the seven segment display to indicate the internal enable delay or the fault persistence duration of each detector. It also generates output signals for system test purposes.

OR-Gate Logic

The desired level of response (level 1, 2 or 3) to a fault signal is determined by diode connections between the input (fault) and output (level). The logic circuit is designed to accommodate any user defined choice of response to fault input signals.

Pulse Generator

The pulse generators are blocking oscillators. The output pulses are 50 V and about 10 μsec wide; their driving capability is 50 V into 50 Ohms. The output pulses are transformer coupled to eliminate ground loops. The 50 V level is chosen to obtain a high signal to noise ratio.

Packaging

Two fault detector discriminators are packaged in a NIM plug-in module (Fig. 2). The fault detector OR-gate logic, the 50 V pulse generators and the LED fault indication display are also constructed with plug-in modules, thus providing quick access to the electronic hardware if service is needed.

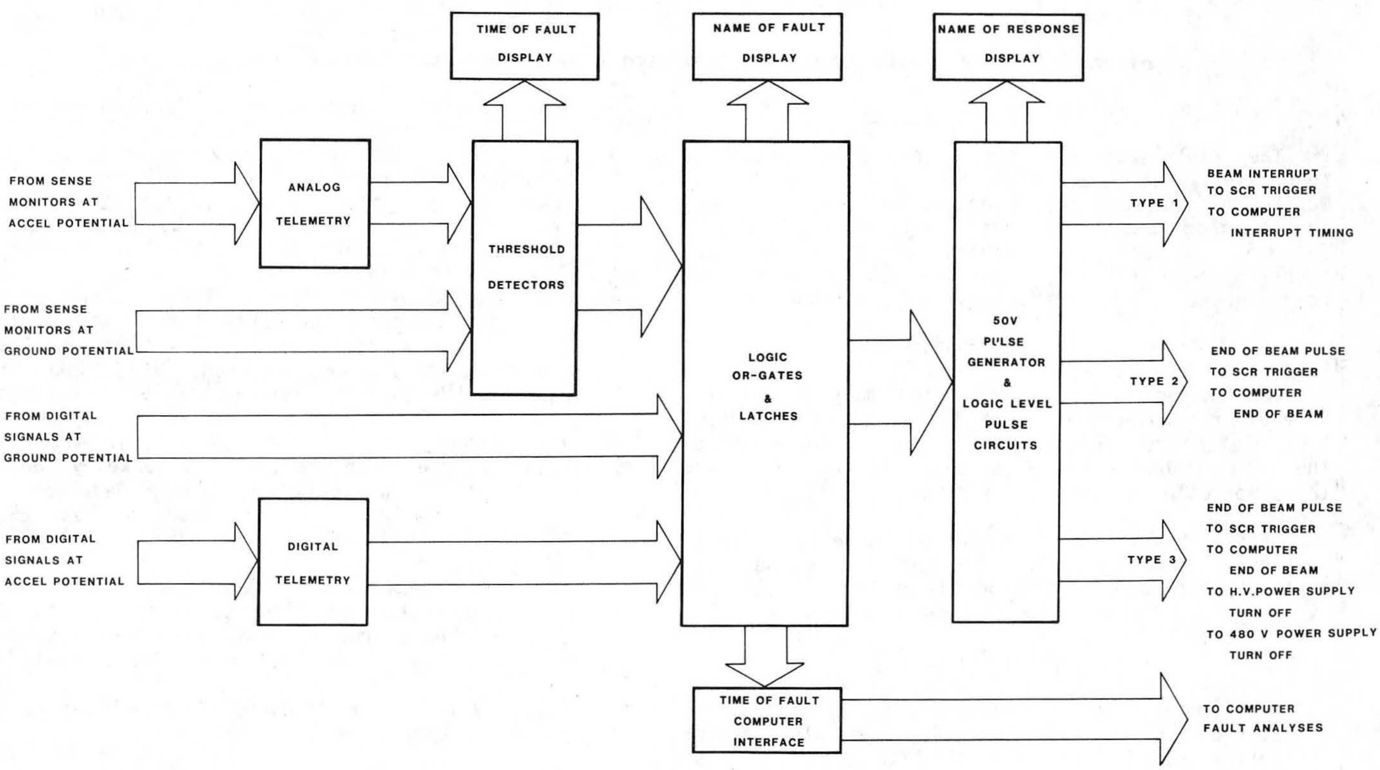

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Figure 1 Block Diagram of Fault Detection and Protection System

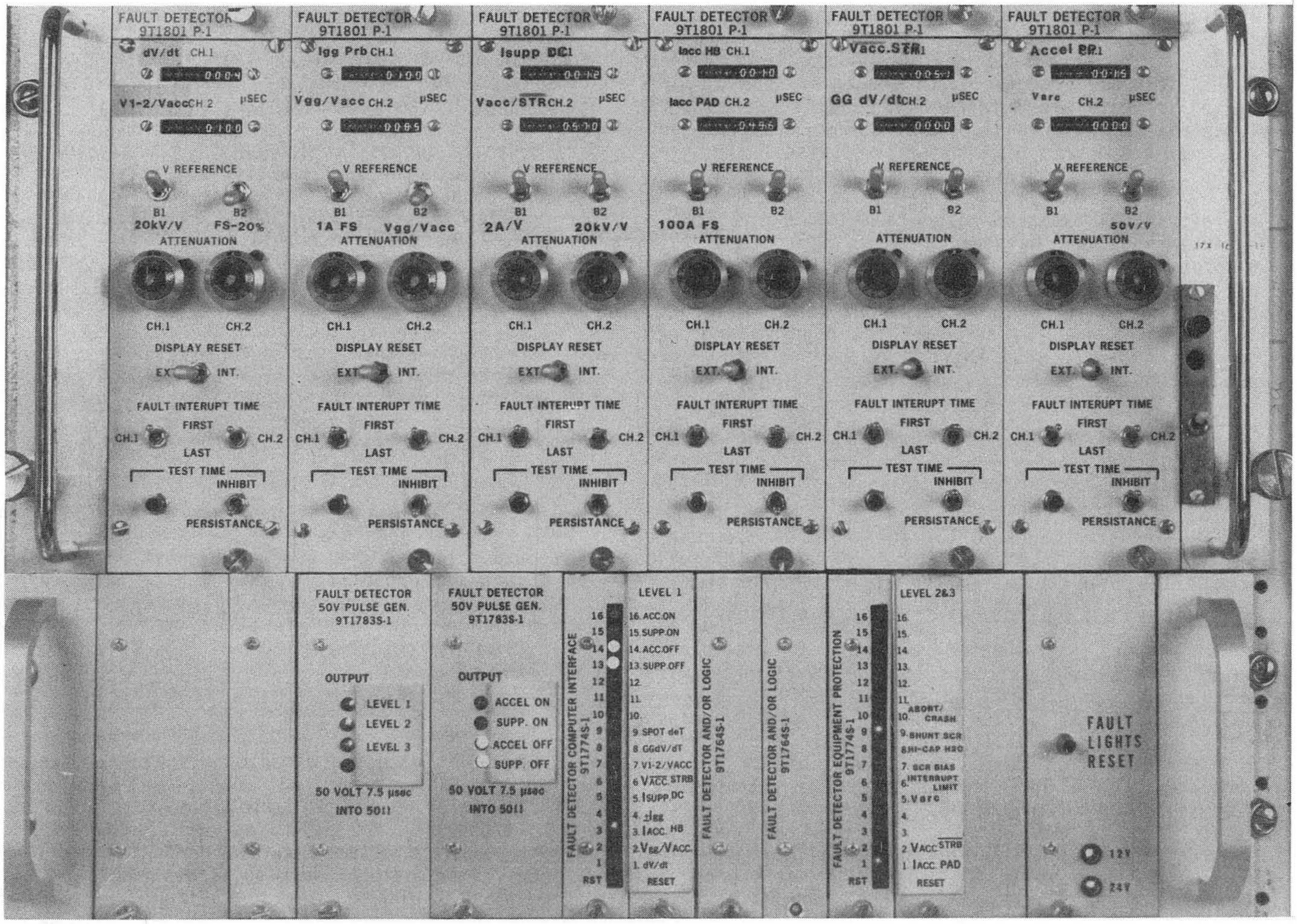

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Figure 2 Modular Fault Detector System With Time of Fault and Type of Fault Display

Performance Description

The fault detector system has been operating successfully at NBETF for the last 1-1/2 years. During this period, test sources, built in Berkeley, have been operated at a power range of 40 to 120 kV for 0.5 to 30 sec pulse lengths; the system has been operating well recently with the Oak Ridge neutral beam source. Its adaptability has been noteworthy.

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