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CONSEQUENCES OF ELECTRICAL CONTACT CHATTER CAUSED BY A SEISMIC EVENT

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1 INTRODUCTION

Electric contacts of electromechanical devices such as relays, motor starters, and controllers are the primary functional component of power plant control circuits. Seismic shaking of the device mounting point can cause inadvertent contact closure or opening, denoted as "chatter", which provides a momentary circuit closure or disconnection. In the absence of contrary data, it is assumed that such chatter can prevent certain equipment components from performing a necessary power plant safety function both during and after a seismic event. The focus of seismic equipment qualification to date has been to demonstrate, by a shake table test, that the time duration of a single contact chatter does not exceed a preset criterion (usually 2 ms). The occurrence of a single chatter with duration greater than the criterion value is failure.

However, contact chatter duration greater than a specified value may or may not be a limiting condition depending on how a particular item of equipment and corresponding control devices are used (wired) in the plant control system. The evaluation of a given device, for a longer duration chatter criterion, depends upon what type of device is downstream of (being controlled by) the device in question. When system effects are considered, the entire chatter issue may, in certain cases, be unimportant. This occurs if contacts chatter but do not initiate a change of state, or cause systems to change state by activation of circuit lockout or seal-in. However, the effect of the contact chatter on downstream control devices has not been quantified to date. This paper discusses experimental test results for common power plant terminal control circuits that demonstrate both the chatter tolerance of certain circuit configurations and the chatter susceptibility of other configurations. The test procedures discussed provided a means of rationally determining the seismic fragility level of a given control circuit.

2 RELAY BASED CONTROL CIRCUITS

Older power plants were designed to be controlled entirely by "relay logic". In recent years, digital controls coupled with solid-state relays have been utilized, however, for many applications electromechanical relays remain as the primary means of switching equipment function. For many seismic engineers, relay terminology is unfamiliar. An electromechanical relay, in its simplest configuration, is an solenoid or a hinged-armature pulled by an electromagnet. Electric contacts are directly attached to the solenoid core or hinged armature which open or close when the coil of the solenoid or electromagnet is energized. The reference or "normal" position of a contact is defined by the contact status when the electromagnet coil is de-energized (non-operate condition). A closed contact, with the coil de-energized is termed a "normally closed" (NC) contact, while an open contact with the coil de-energized is termed a "normally open" (NO) contact.

A schematic of a typical terminal control circuit is shown in Fig. 1. When the "upstream" or controlling relay coil (A) is energized, the NO contact (B) closes, which energizes the terminal control relay coil (C). Note that this can only occur if the "permissive" NC contact (D) is closed. (Contact D is located on another control relay; in this manner, the activation of the terminal control relay can be prevented, given another control relay is energized. When the coil (C) is energized, contact (E) closes which activates the terminal device (G). Contact (F) is referred to as a "seal-in" contact, since another source of power is provided to the coil (C) when the coil is energized. This action effectively prevents the terminal control relay from changing state if the upstream relay (A) changes state.

3 CIRCUIT SPECIFIC TESTING

The standard industry (IEEE) chatter duration threshold criterion of 2 ms is the basis for establishing the test fragility level for a relay. Standard tests utilize broad-band input motions of varying levels to establish the threshold fragility level. If a chatter criterion greater than 2 ms is justifiable in specific circuits, higher fragility levels should be obtained allowing, in turn, a higher level of seismic ruggedness of the controlling relay to be established. Testing has shown that, for longer chatter durations, many relays exhibit increased ruggedness (higher fragility levels). The 2 ms limit is a conservative criterion for the slow reaction (typically greater than 16 ms) of most electromechanical relays. Since many nuclear plants do not have instantaneous response control equipment, a longer chatter duration criterion might be acceptable in many situations. The evaluation of a given relay, for a longer chatter criterion, depends upon what type of device is downstream of (being controlled by) the relay in question. If relays chatter but do not change state, or do not cause systems to change state by activation of lockout or seal-in, the entire chatter issue may, in certain cases, be unimportant. If the "standard" chatter limit of 2 ms is to be relaxed, then it must be demonstrated by test that increased chatter limits do not cause unforseen consequences in specific relay control circuits. Chatter response testing is one type of circuit specific testing.

4 CHATTER RESPONSE TESTS

Experience data as well as test data have shown that most electromechanical devices will not respond to control relay contact chatter on the order of several milliseconds. Common auxiliary relays have a response time (e.g., pick-up time) on the order of 20 to 70 ms or more. For this type of device, a chatter to the signal to its coil of 10- to 15-ms duration would not be expected to cause the device to either pick up or drop out.

A common terminal control logic circuit configuration is a DC multi-contact auxiliary relay wired for seal-in, using one of the available normally open contacts. Such a relay would be controlled by relay contacts on other upstream relays. Upon activation of the upstream relays, causing the controlling contacts to close, the coil of the terminal control relay would be energized causing its contacts to change state. The seal-in contact provides an alternate source of power to the relay coil causing it to maintain the change of state until the power to the coil is turned off. Another common terminal control device is a DC multi-contact lockout relay which mechanically changes state (requiring manual reset) upon coil energization from the contact of an upstream controlling relay. Contactors which use an auxiliary contact for seal-in are another example of common control circuits with a seal-in feature.

To examine the effects of relay chatter in some common circuit situations, a number of DC relays were chosen for a sequence of chatter response tests to ascertain the susceptibility of the relays to contact chatter from an upstream controlling relay. Auxiliary relays, lockout relays and contactors were examined. The basic test diagram for an individual relay is shown in Fig. 2. An opto-isolated solid-state relay (SSR) was utilized as a simulated contact of the controlling upstream relay. Voltage pulses of varying duration were computer-generated (PC) and D/A output to the SSR which then gated the power supply with a full-voltage pulse of the same duration. The responses of the normally closed and open contacts (excluding the seal-in contact or lockout contact) were monitored with a PC-based chatter monitoring system. Since both the controlling relays and terminal control devices are shaken simultaneously during an actual seismic event, the test setup was mounted on a shake table and subjected to a series of seismic inputs during the individual pulse tests.

5 CASE SPECIFIC CIRCUIT TESTING

More extensive control circuits may also be tested for chatter response. A reversing motor starter (contactor) and control relay (typical of a valve control circuit) are shown in Fig. 3. Given that the valve is closed, the issue of concern is whether the contactor can spuriously seal-in due to seismic shaking, allowing the valve to stroke fully open. Seal-in can occur due to either relay contact chatter or contactor auxiliary contact chatter caused by the contactor armature motion. Testing demonstrated that spectral levels of 12 g were required to initiate seal-in for this circuit.

6 CONCLUSIONS

The test relays were subjected to a variety of simulated multiple pulse signals, recorded relay contact chatter, and in some tests actual relay contact chatter. Triaxial seismic inputs were utilized with input levels up to 10 g average spectral acceleration (5% damping) over the frequency range of 4-16 Hz. The chatter response test results indicated that typical DC auxiliary relays, wired for seal-in, will not change state due to a seismic event causing controlling relay chatter which is less than 70-80% of the controlled auxiliary relay operation time but common DC lockout relays will change state in a seismic event if the controlling relay has 3-4 ms contact chatter. Thus, circuits with terminal control devices which are DC auxiliary relays with seal-in are chatter tolerant while circuits with terminal control devices which are DC lockout relays are susceptible to chatter greater than 2 ms. The contactor/ relay circuit did not seal-in until the spectral level exceeded 12 g. These results provide guidance in determining whether circuit specific testing would be a likely method of demonstrating seismic adequacy for a circuit for which more generic evaluation are unsuccessful.

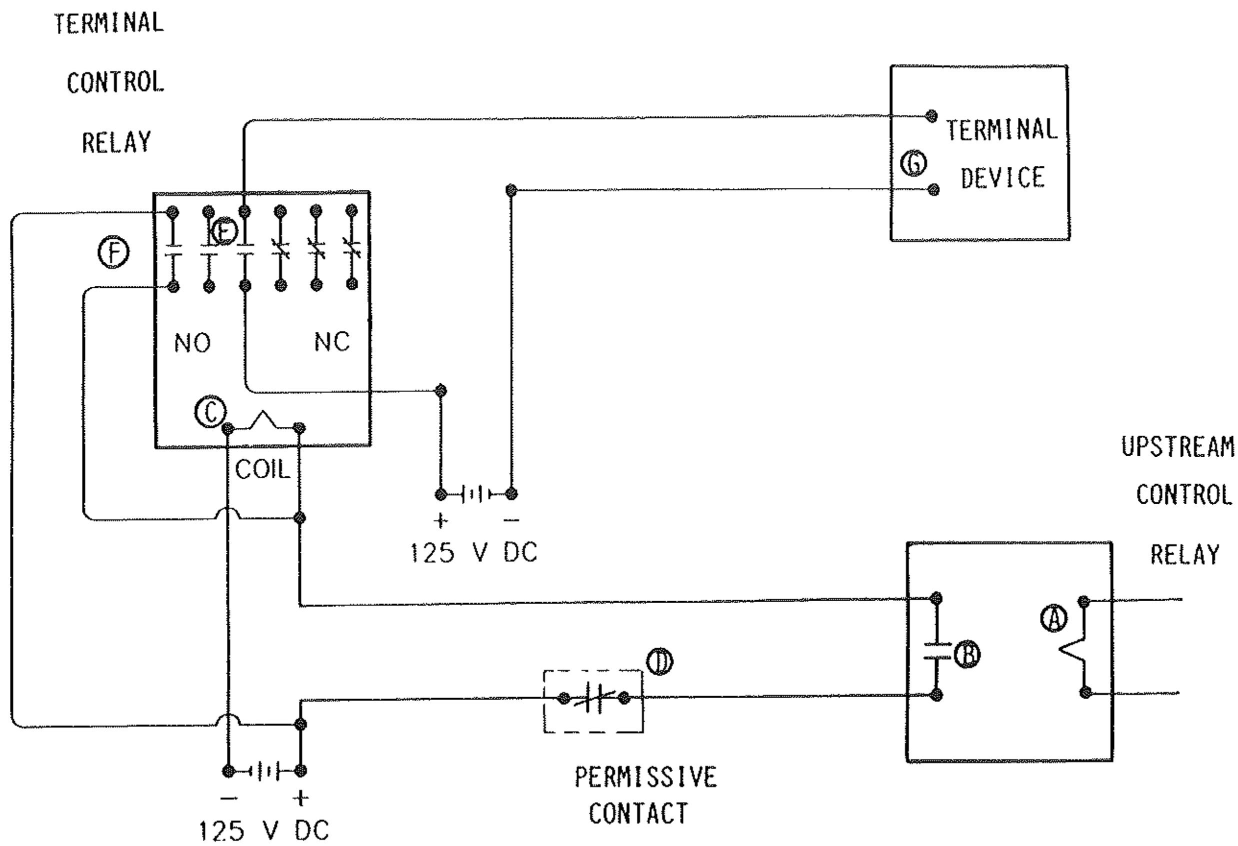
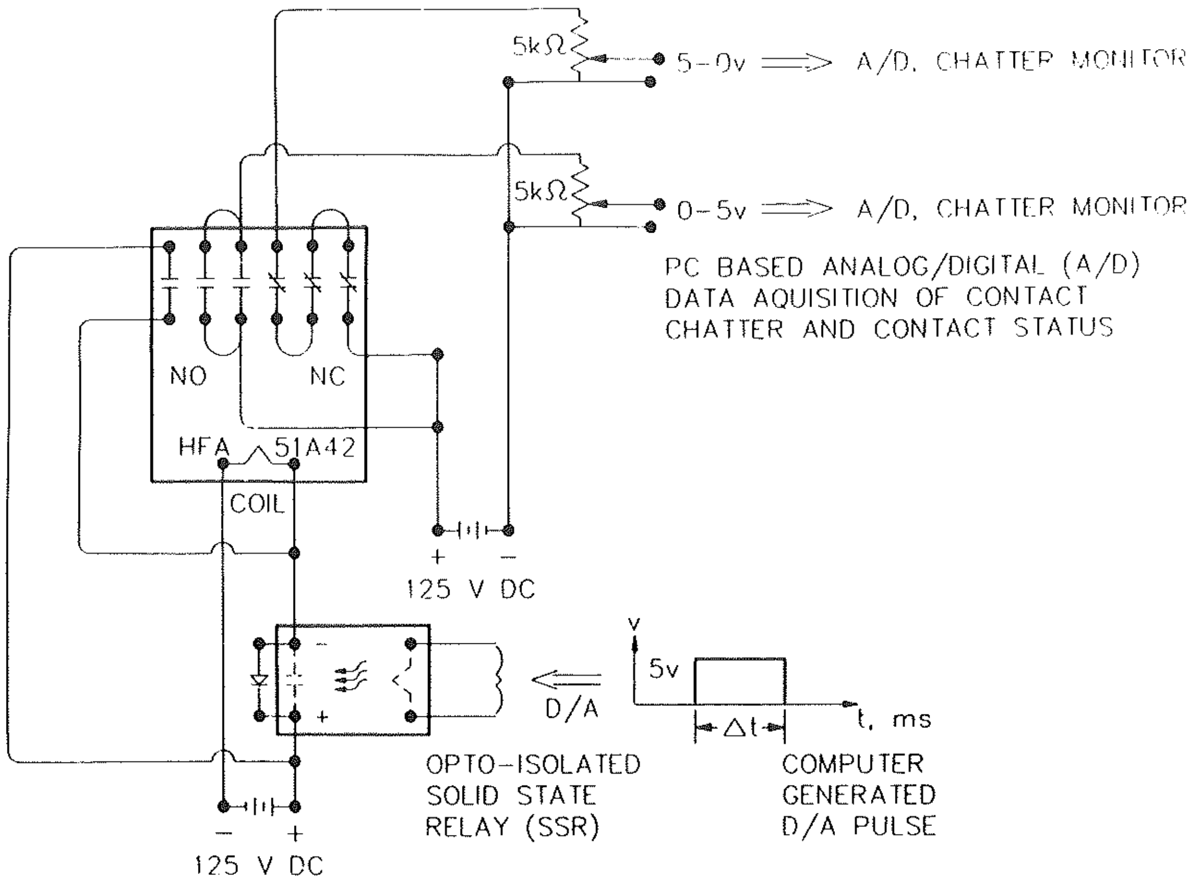
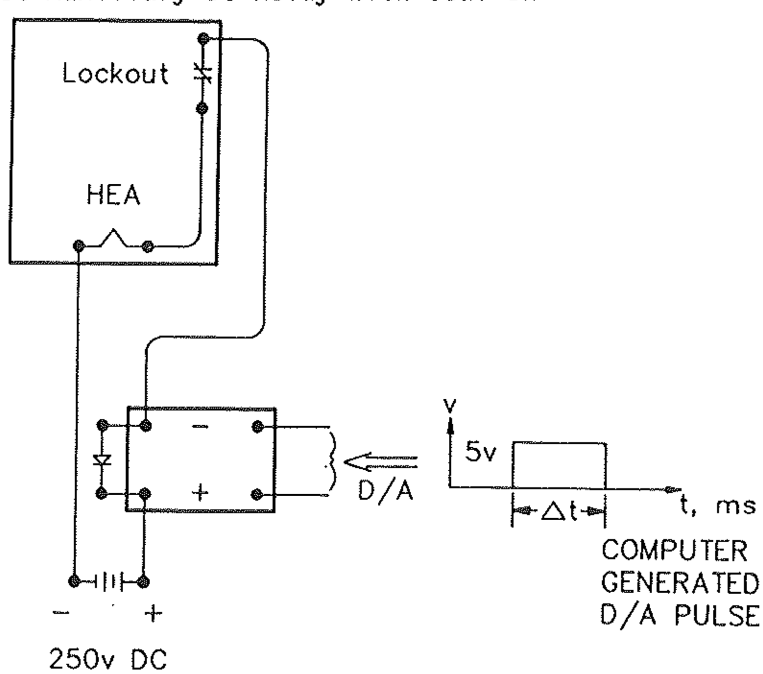


Fig. 1: Terminal Control Relay Configuration

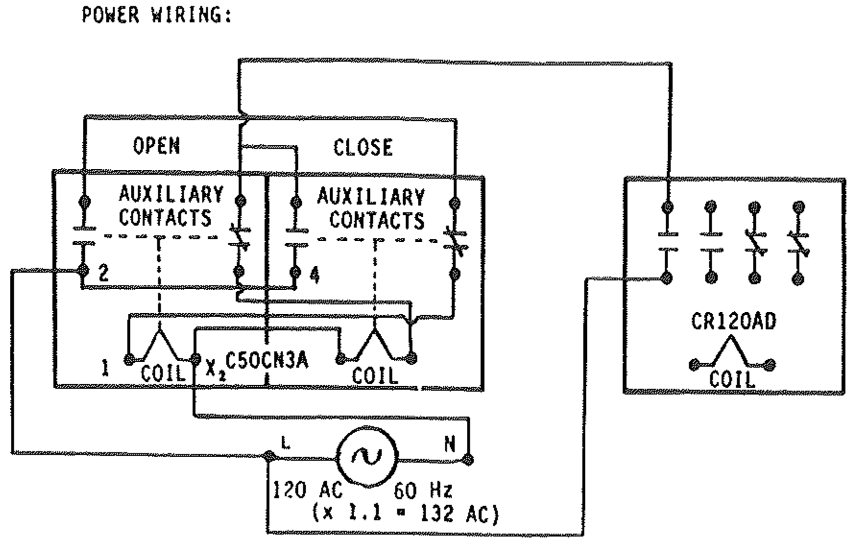


a) Multi-Contact Auxiliary DC Relay with Seal-In



b) DC Lockout Relay

Fig. 2: Chatter Response Test Circuit Diagrams



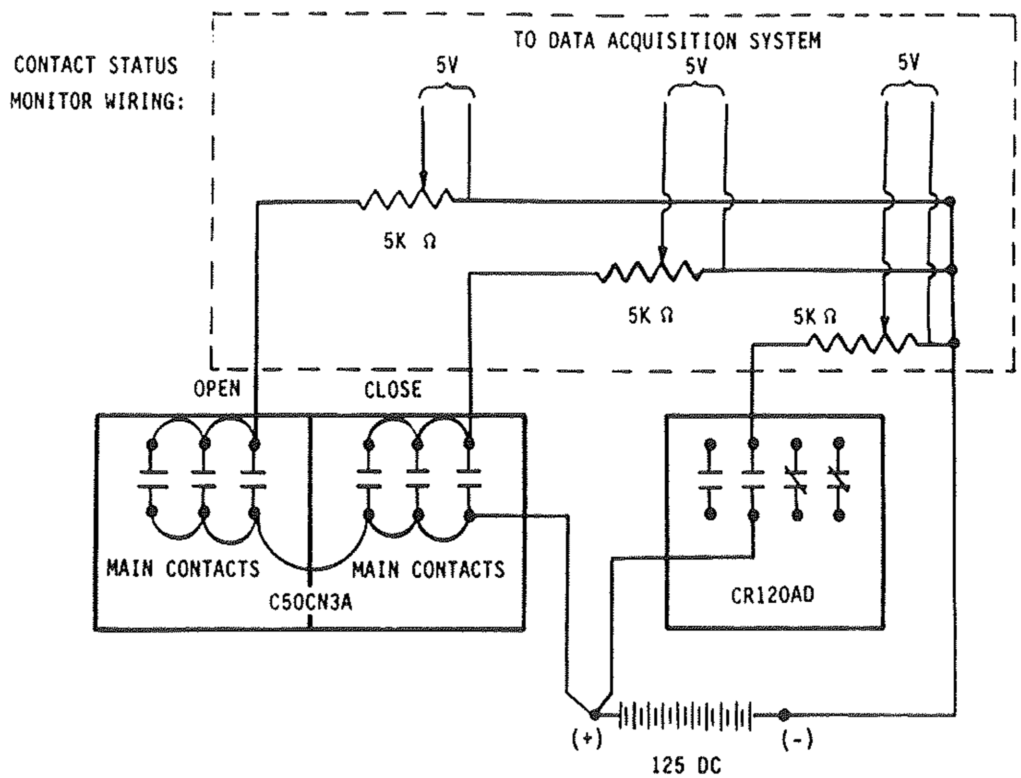


Fig. 3: Case Specific Test Circuit