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INTEGRAL TESTING OF RELAYS AND CIRCUIT BREAKERS

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ABSTRACT

Among all equipment types considered for seismic qualification, relays have been most extensively studied through testing due to a wide variation of their designs and seismic capacities. A temporary electrical discontinuity or "chatter" is the common concern for relays. A chatter duration of 2 milliseconds is typically used as an acceptance criterion to determine the seismic capability of a relay. Many electrical devices, on the other hand, receiving input signals from relays can safely tolerate a chatter level much greater than 2 ms.

In Phase I of a test program, Brookhaven National Laboratory performed testing of many relay models using the 2-ms chatter criterion. In Phase II of the program, the factors influencing the relay chatter criterion, and impacts of relay chatter on medium and low voltage circuit breakers and lockout relays were investigated. This paper briefly describes the Phase II tests and presents the important observations.

1.0 INTRODUCTION

A large number of relays are used in a nuclear power plant. They perform various logic functions in integral electrical and electronic circuits. If the structure housing the relays is subjected to ground shaking due to an earthquake, the relay contacts vibrate causing the potential for opening or closing of the contacts. Most contacts experience repeated opening and closing in a vibrating environment, and this is commonly known as contact chatter. A single chatter may be as short as a fraction of a millisecond. Therefore, most circuits do not respond to many of the contact chatters in the event of an earthquake. The maximum duration of chatter that can be tolerated in a circuit varies depending on, for example, capacitance and inductance of the circuit. The current industry practice is to use 2 ms as the maximum acceptable chatter duration for seismic qualification of relays. In an effort to explore the chatter-tolerant capability of power circuits, BNL conducted an experimental program with relays and circuit breakers. The program was carried out in two parts: electrical and vibration. Both electrical and vibration experiments including a data analysis are discussed in this paper.

2.0 ELECTRICAL EXPERIMENTS

2.1 Test Procedures

Electrical experiments were performed in two phases. In the first phase, eleven low and medium voltage circuit breakers, and two lockout relays were tested at locations for determination of the time required for these devices to trip. The trip current vs. time plots were recorded with a portable oscilloscope.

In the second phase, three lockout relays, three circuit breakers and eight auxiliary self-reset relays were tested at a power testing laboratory. The trip current traces were recorded. In addition, electrical pulses of minimum durations required for tripping were determined.

2.2 Test Results

A sample oscilloscope trace is shown in Figure 1. The abscissa represents the time and the ordinate indicates the voltage or current as it builds up as a DC power source is applied to the trip solenoid. The total trip time for breakers and lockout relays varied between 20 and 60 ms except for the fast lockout relay. The total trip time consists of the time required for energization of the trip solenoid and the time required for the latching mechanism to complete its motion until trip occurs as pictorially presented in Figure 2. As expected, the trip time increased as the voltage was dropped. Laboratory tests with single and multiple pulses provided further understanding of the field test data. The required duration of a single pulse corresponds to the energization time (Figure 2). In summary, the minimum pulse duration required to trip a device is about a half of the total trip time. The minimum pulse durations for most breakers are comparable to those for lockout relays. The latter justifies the use of lockout relays as surrogates in integral testing.

3.0 VIBRATION EXPERIMENTS

3.1 Test Procedures

The vibration tests were performed with a group of source relays producing the chatter and a group of load devices responding to the chatter, all connected in integral circuits. Five protective and auxiliary relays were used as the source relays, and a medium voltage circuit breaker, two lockout relays and another auxiliary relay were used as the load devices. Initially, the source relays were placed on the shake table and the load devices were seated on a stationary stand. Testing was conducted with both single frequency and multifrequency input motions. Subsequently, both the source relays and load devices were mounted in a switchgear cabinet and vibrated on the shake table with multifrequency input motion. Electrical outputs were monitored for both sets of experiments to determine the chatter durations required for tripping of the load devices. The circuit configuration is shown in Figure 3. The connections between the source relays and load devices were interchanged and the tests were repeated four times so that each source relay was once connected to a device. Monitoring current and load device voltage were varied for determination of their effect on chatter and tripping characteristics.

3.2 Test Results

3.2.1 Chatter/Trip Data

The chatter of source relays caused tripping of lockout relays and the breaker. The most common type of time relationship between the source relay chatter and load device (i.e., breaker or lockout relay) trip is shown in Figure 4A. The source relay initiates chatter at t_1 (i.e., temporary change-of-state) as the vibration continues and the load device trips a few milliseconds later at t_2. But the source relay remains in the alternate state for a few more milliseconds before it returns to its original electrical state at t_3, and the load device remains tripped. Therefore, the duration required to cause the trip after initiation of the chatter (i.e., a) is less than the chatter duration (i.e., b). Thus, in comparison with the electrical test data discussed in Section 2.2, "a" is similar to the "total trip time" of the breakers and lockout relays. A sample chatter/trip test result is shown in Figure 5. In an integral circuit with the output of the source relay CO9 controlling operation of the lockout relay LOR, the lockout relay trips 6.25 ms after initiation of the source relay chatter. The source relay returned to its original state after 149.5 ms.

3.2.2 Single Frequency Vibration Data

The source relays were vibrated at selected frequencies and the vibration levels were adjusted until a trip occurred in the target load device. The highest vibration level achieved without a trip in the target load device is considered the capacity of the source relay in terms of its function in that particular circuit. For example, the capacity levels of IAV measured in terms of sine dwell amplitudes are shown in Figure 6. As evident from the data, the capacity of this relay to trip a 5 HK breaker is lower than that based on the conventional 2-ms criterion.

3.2.3 Multifrequency Vibration Data

The capacity data for the same IAV relay when subjected to multifrequency excitation are presented in Figure 7. These results were obtained from shaking of the source relay while the load device was located on a stationary stand. Figure 8 shows capacity levels of a CO9 relay in terms of the shake table motion (i.e., the control accelerometer reading) when the devices were mounted in a switchgear cabinet.

4.0 SUMMARY AND CONCLUSIONS

The duration of an electrical signal required to cause a trip in a circuit breaker or lockout relay is much less than the actual trip time of these devices. The minimum pulse durations required to trip circuit breakers and most lockout relays are comparable. Testing in integral circuits with electrical conditions representing field applications is recommended since the 2-ms chatter criterion can be unconservative.

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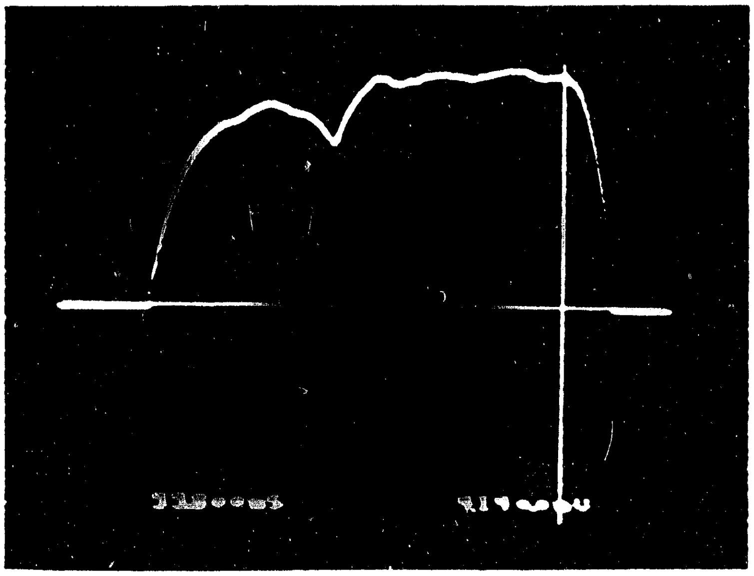


Figure 1 Oscilloscope Voltage (Current) Time Trace for Westinghouse Breaker DH3

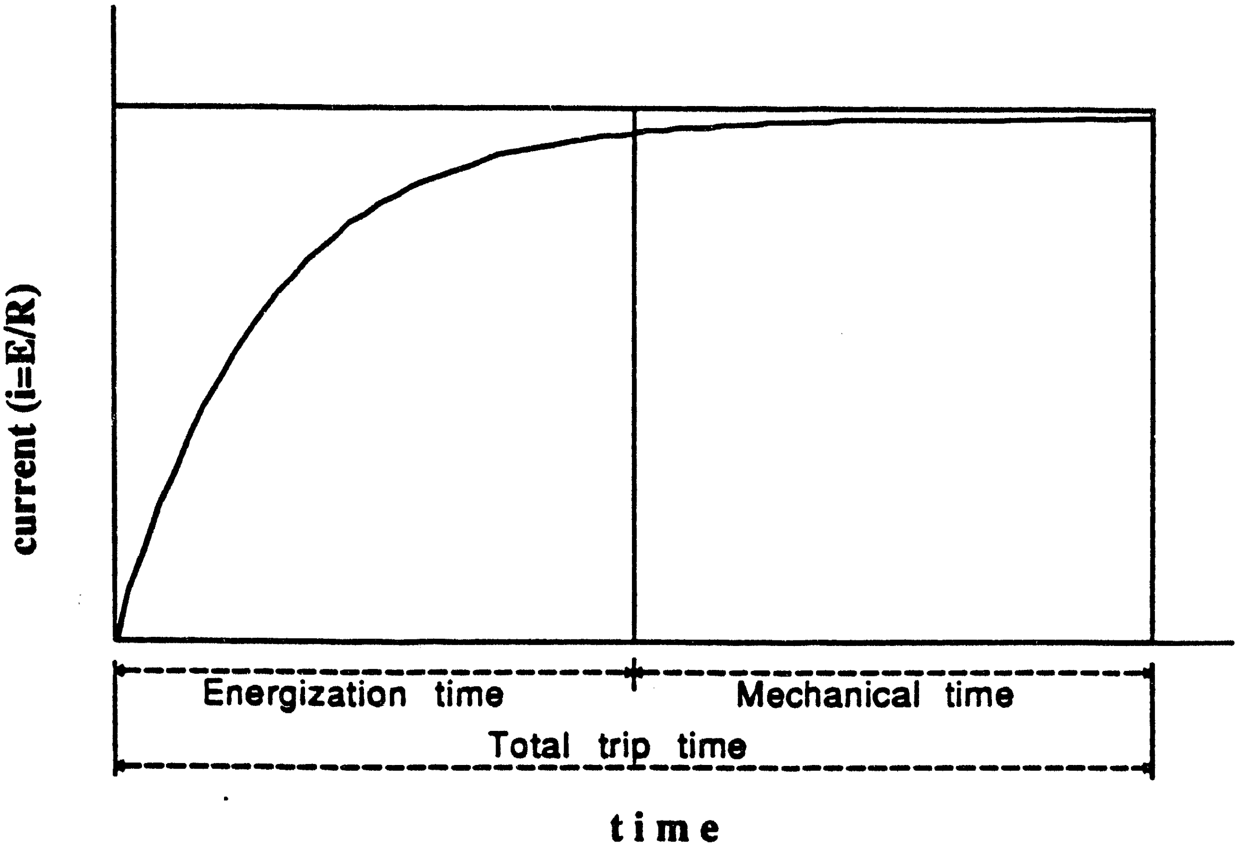
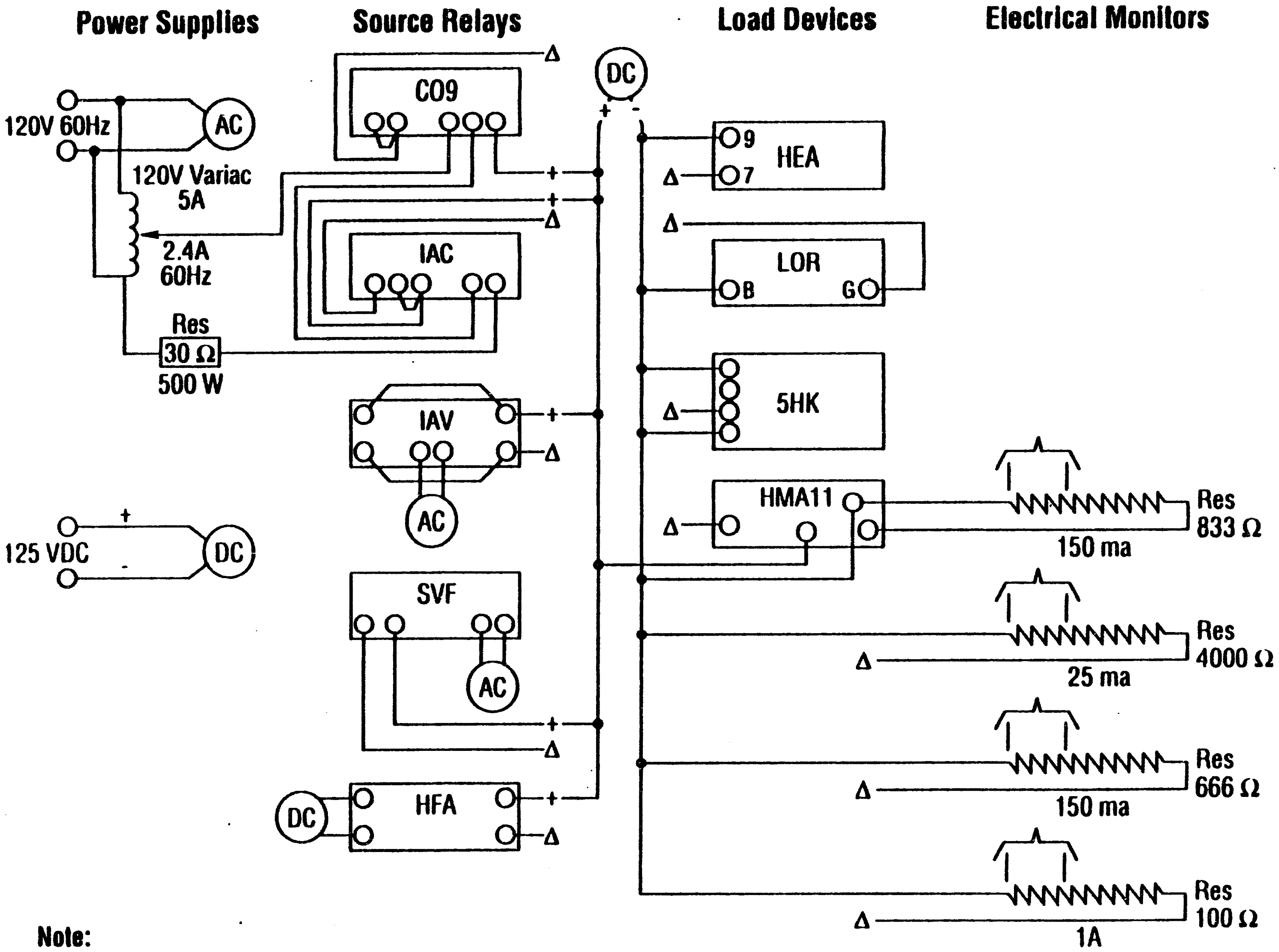


Figure 2 Current Build-Up vs. Trip Time



Note:
Source Δ's Were Connected to Load Δ's Per Schedule in the Test Procedure.

Figure 3 Electrical Connections for Vibration Tests

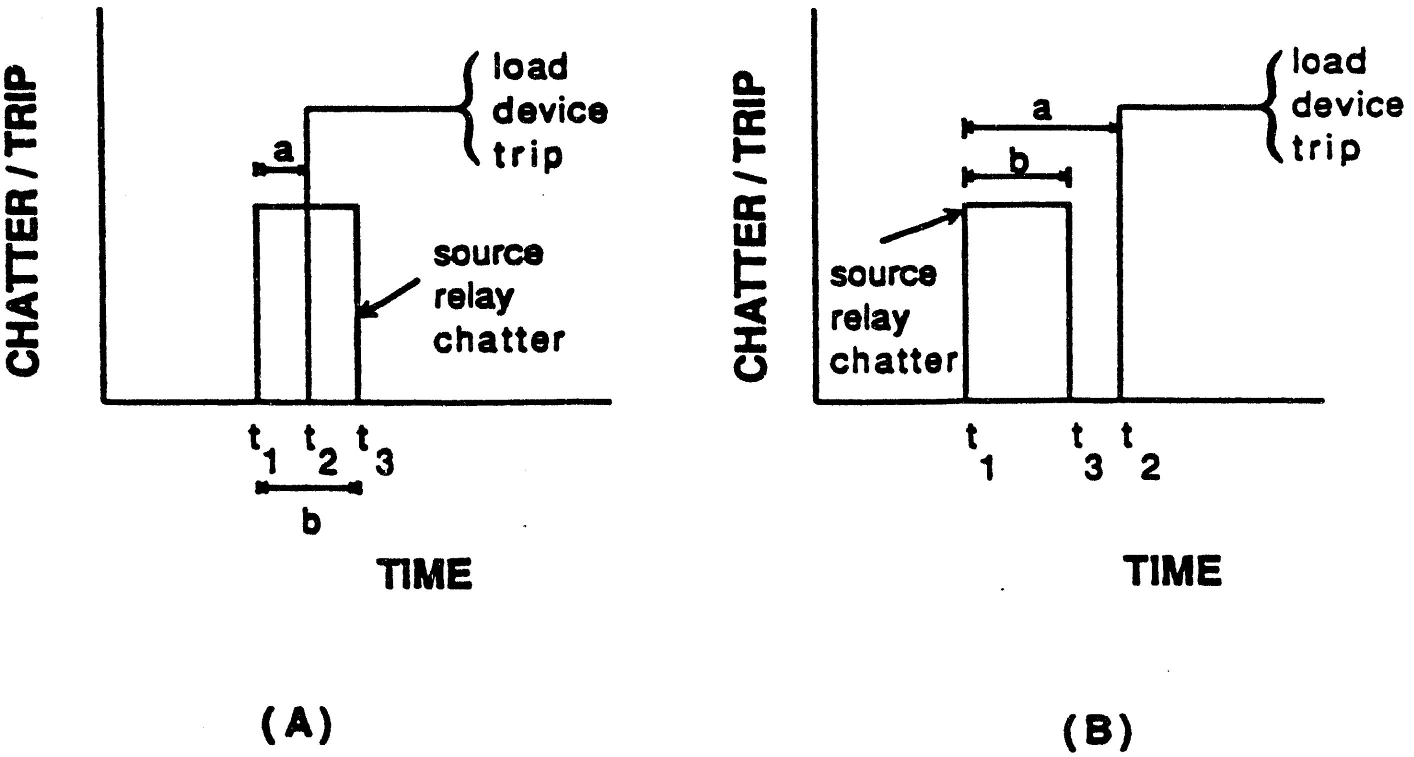


Figure 4 Effect of Source Relay Chatter on Load Device

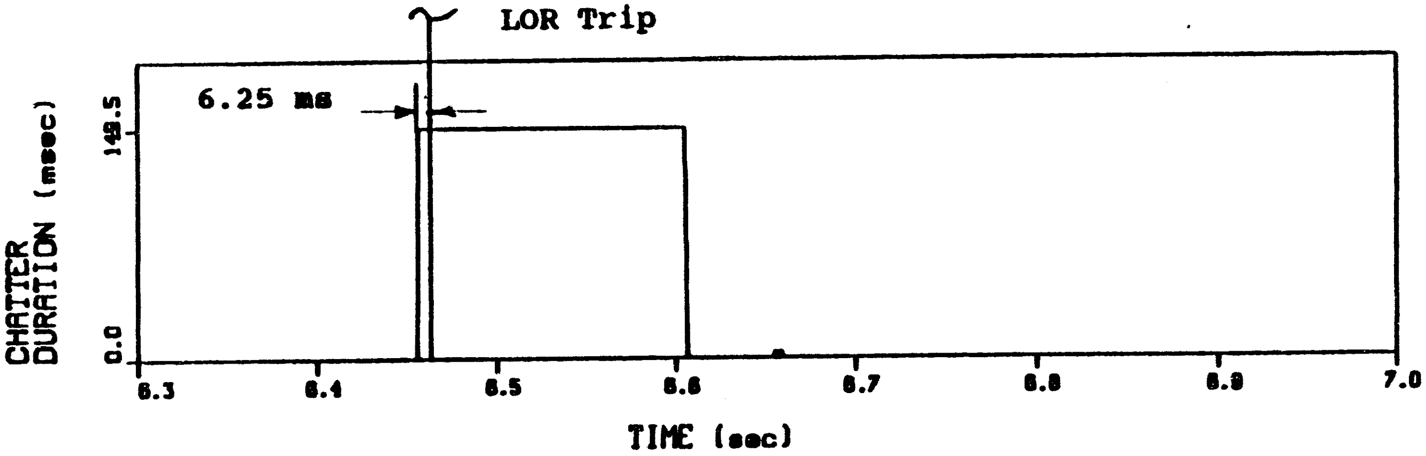


Figure 5 Effect of CO9 Chatter on LOR

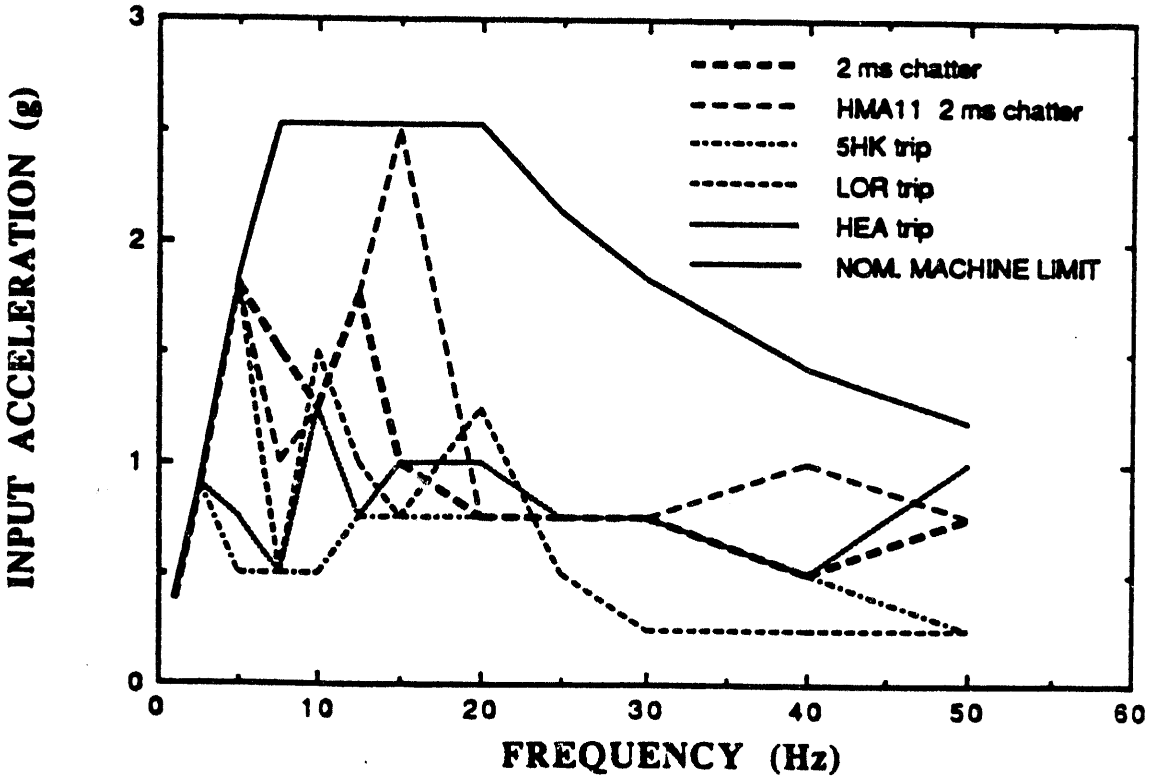


Figure 6 Sine Dwell Capacity Level, IAV, Vertical Direction

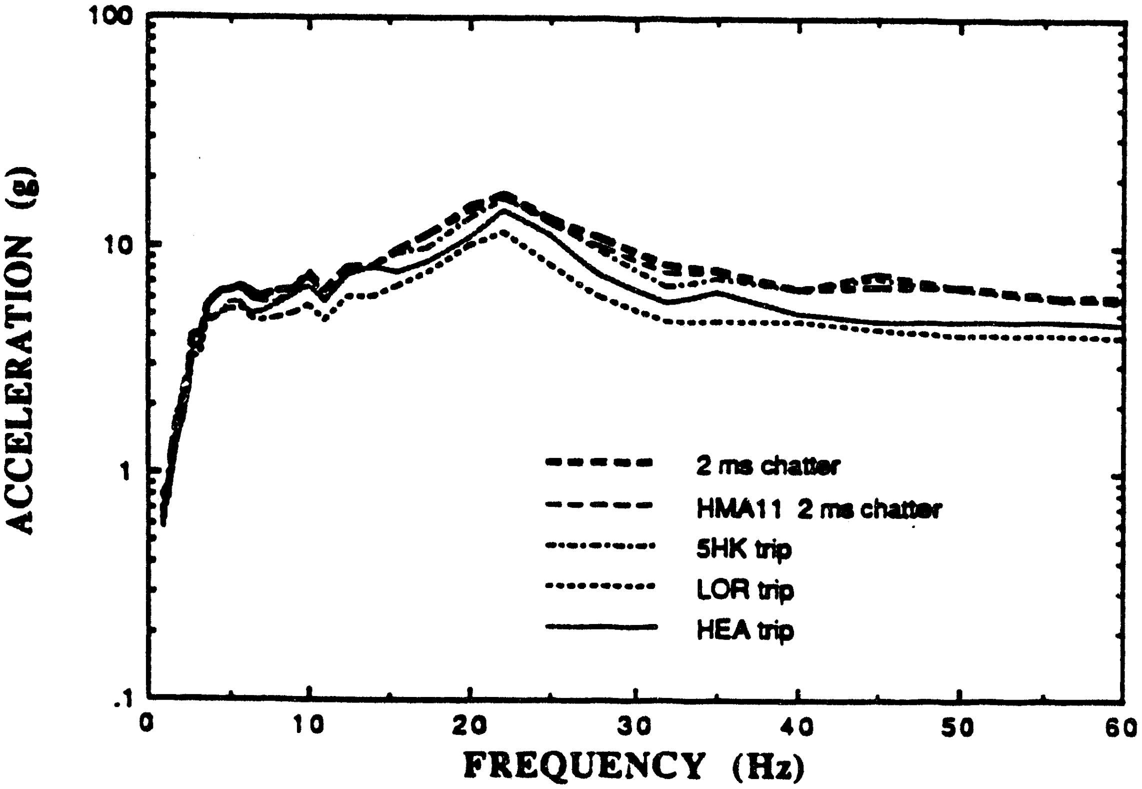


Figure 7 Multifrequency Capacity TRS @ 5% Damping, IAV, Vertical Direction

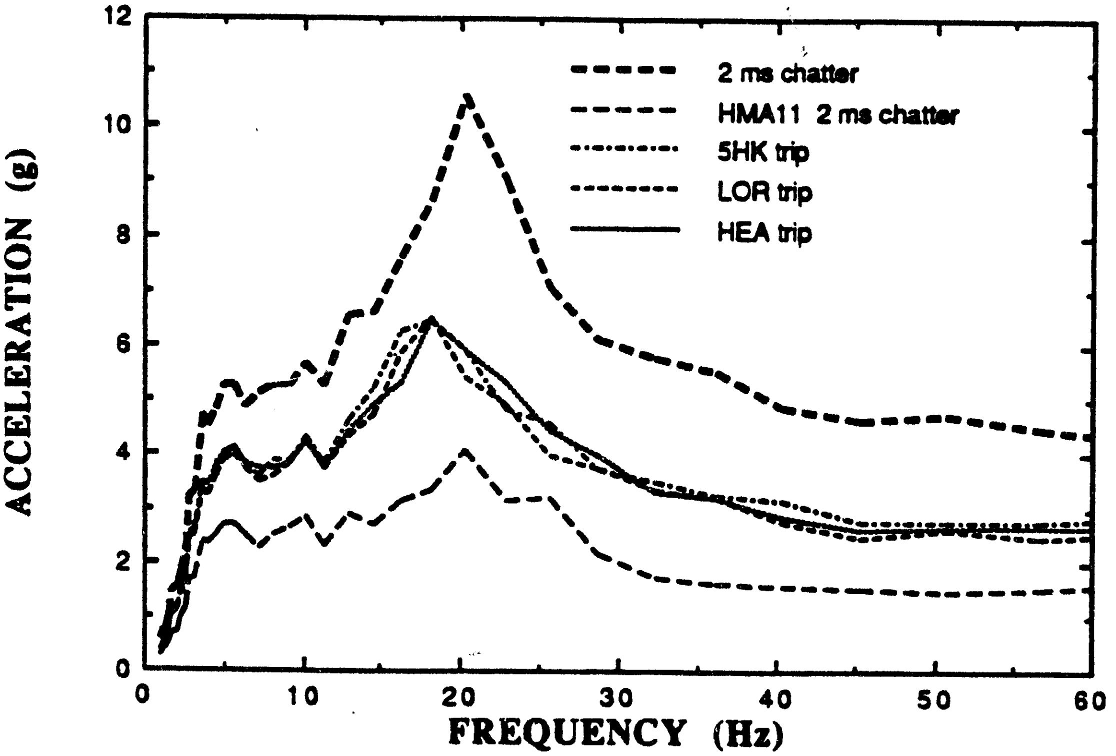


Figure 8 Multifrequency Capacity TRS @ 5% Damping, CO9 in Switchgear Cabinet, Vertical Direction (Shake Table Motion i.e., Control Accelerometer Reading)

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