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Relay Test Program

Series II Tests
Integral Testing of Relays and Circuit Breakers

Prepared by
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Brookhaven National Laboratory

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

This report presents the results of a relay test program conducted by Brookhaven National Laboratory (BNL) under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC). The program is a continuation of an earlier test program the results of which were published in NUREG/CR-4867. The current program was carried out in two phases: electrical testing and vibration testing. The objective was primarily to focus on the electrical discontinuity or continuity of relays and circuit breaker tripping mechanisms subjected to electrical pulses and vibration loads. The electrical testing was conducted by KEMA-Powertest Company and the vibration testing was performed at Wyle Laboratories, Huntsville, Alabama. This report discusses the test procedures, presents the test data, includes an analysis of the data and provides recommendations regarding reliable relay testing.

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EXECUTIVE SUMMARY

This report presents the results of an experimental program on functionality of relays and circuit breakers connected in integral electrical circuits. This program was an extension of an earlier vibration test program on relays, conducted at BNL and reported in NUREG/CR-4867. The current program was initiated to achieve the following objectives:

1. To characterize the effects of chatter in the context of relay chatter acceptance criteria.

2. To explore the variation of relay capacities between specimens of the same model subjected to vibration.

3. To correlate the capacities of relays subjected to multifrequency vibration with those with single frequency excitation.

The experimental program was carried out in two phases. First, a group of lockout relays, and medium and low voltage circuit breakers was subjected to electrical pulses to determine the durations required for a change of state of these devices. In the second phase of the program, a subset of these test specimens was tested with a group of control relays connected in separate electrical circuits. Both single frequency and multifrequency excitations were applied to the control relays mounted on a shake table to determine the vibration levels and chatter durations required to trip a circuit breaker and lockout relays (i.e., load devices) located on a stationary stand. Subsequently, both the control relays and the load devices were mounted in a switchgear cabinet and excited on the shake table.

Electrical experiments showed that the pulse duration required to trip a lockout relay or circuit breaker is about half of the trip time of the device. The difference between the two corresponds to the duration of the inertial motion of the tripping latch after its disengagement caused by the electromagnetic force built up in the solenoid as a result of the control relay chatter.

The vibration experiments indicate the need for testing relays in integral electrical circuits. In general, lockout relays can be used in lieu of medium or low voltage circuit breakers for this purpose. The vibration withstanding capability of a relay can be highly influenced by the electrical conditions in the relay circuit and chatter monitoring instruments. The vibration capacity of a relay in an integral circuit in terms of its function to control a lockout relay or circuit breaker can be less than its capacity measured in a conventional way by separately testing with a chatter criterion of 2 ms.

The vibration testing also confirmed that for most relays the variation of capacities of specimens of the same model is within 100%. For some other relays, the variation could be as large as six- or seven-fold measured in terms of input sine dwell motion at certain frequencies. As observed in the earlier experimental program (NUREG/CR-4867), the current program confirmed for an additional relay model that the multiplication factor needed to convert the single frequency capacity sine dwell input motion amplitudes to the corresponding multifrequency test response spectrum at a damping value of 5% is in the range of 2.5 -3.0.

In summary, it is recommended that relays be tested in integral circuits representing field operating conditions and with multiple specimens (e.g., at least three). The capability of a relay at any particular vibration level should be demonstrated by testing at this and reasonably separated lower levels.

ACKNOWLEDGEMENTS

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CHAPTER 1

BACKGROUND

1.1 INTRODUCTION

This report presents the results of a test program conducted by Brookhaven National Laboratory (BNL) on relays, and low and medium voltage circuit breakers, under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC). The test program consists of two parts: electrical testing and vibration testing. The electrical testing was performed at locations of circuit breakers and at KEMA Powertest facilities in Chalfont, PA, and the vibration tests were performed at Wyle Laboratories, Huntsville, AL.

The background and objectives of the test program are discussed in this chapter. The test procedures are described in Chapter 2, and the results are presented in Chapters 3 and 4. The observations are summarized in Chapter 5.

1.2 BACKGROUND

An evaluation of the existing test data at BNL indicated that the seismic capacity of a relay can vary widely depending on many parameters including its specific design and the earthquake motion characteristics [1,2]. In order to assess the influence of these parameters and demonstrate generation of frequency-dependent fragility test response spectra (TRS), BNL conducted a test program (Series I) in 1989 on 46 relay specimens, and the results were published in NUREG/CR-4867 [3]. Most of the objectives were completely fulfilled and the issues were conclusively addressed by the test program (e.g., frequency sensitivity, input direction, electrical condition, contact state, etc.). For the remaining issues, BNL's Advisory Panel considered the test data to be inadequate to draw general conclusions, and recommended additional tests (e.g., conversion factor relating multifrequency fragility TRS with single frequency fragility input motion). In addition, the test program revealed information that raised some fundamental questions regarding qualification and definition of the fragility level of a relay model (e.g., 2-millisecond chatter criterion, variation of capacity levels among specimens of the same relay model, damaging effect of successive short duration [e.g., 1 ms] chatter compared to a single longer duration chatter). Furthermore, a need has been identified for determination of the effect of relay chatter on breaker operation.

The Series II test program discussed in this report addresses the above issues.

1.3 ISSUES

Unlike the Series I tests, the issues being addressed in the Series II tests are much more complex. Therefore, a detailed discussion of the issues is provided in the following sections so that the testing approach that was employed for each issue can be understood.

1.3.1 Relay Chatter and Acceptance Criteria

1.3.1.1 Discussion

The evaluation of the performance of relays during vibration testing requires documentation of the output effects against a pass-fail criterion. The commonly used criterion for output discontinuities which has been the basis for judging the fragility level is a 2-ms chatter duration. This criterion was developed by the industry in a consensus standard-making environment and is published in an IEEE Standard [4]. In addition, the contact monitoring circuits employed during various test programs have not been consistent. For example, frequently low voltage and current have been used because it facilitates ease of connection, improves safety, is less destructive to test specimens and provides equal or greater monitoring sensitivity.

Results of relay fragility testing to date are thought to effectively screen the relays which are likely to cause undesired outputs under seismic environments from those which will not. There are questions, however, as to whether this is the case for all circuits, or whether there are a few or many exceptions. Each question about applicability of the criteria typically involves details of a specific application, such as: a protective device tripping a large current load which will interrupt the current after it has tripped; a seal-in contact which closes when current to a load is sensed through the protective contact; any interlocking or permissive circuit scheme; a contact providing an important input signal to a computer or other solid state controller; a contact picking up a relay with very long interconnection wires with significant resistance and capacitance; etc.

These concerns are not always explicitly addressed by the generic 2-ms criterion. The use of a general criterion could result in disqualifying relays which may be adequate as well as qualifying those which are not. The fact is that the sensitivity of each specific circuit to contact chatter is different and the use of any single criterion (that can, of course, be realistically implemented) for a pass-fail determination could err in either direction on many actual circuit configurations.

Another aspect of the 2-ms criterion that has been considered very little during the criteria development, is the repetition rate of discontinuities. The occurrence of this type of behavior may be rare in qualification or proof testing but it is observed in fragility testing since the latter explores each device on the "edge" of its capacity level. In fact, a similar occurrence has been observed during the first test series [3].

1.3.1.2 An Approach to Define Acceptance Criteria

As implied above, the use of the 2-ms chatter criterion for all situations is a compromise and may not be realistic. The use of relay contacts can fall into two broad categories. As an example, for the first category, the main purpose of protective relay contacts is to complete the trip circuit of a circuit breaker. This results in a current flow of 2 to 10 amperes in modern circuit breakers. Due to the inductance of the circuit breaker trip coil, its energization for a period of 2 ms may not allow the current to increase to a value that is required to initiate a change of state; thus the circuit breaker will not trip. Therefore, a more realistic approach to determine contact failure would be to use the operation of a circuit breaker or a device such as a lockout relay. Such a device will have similar characteristics such as a spring loaded latching mechanism as well as an E/R (voltage/resistance) current value of approximately 5 amperes at 125 volts DC, to more truly simulate actual operating conditions.

The second major use of relay contacts is to activate a relatively low energy device, as compared to a circuit breaker, through either the closing or opening of a relay contact. These secondary devices can have characteristics that will cause operation on input pulses that range from less than 1 ms for electronic circuits to more than 40 ms for slowly acting electro-mechanical devices. The simulation of various low-energy devices would require another series of devices with known, specific input pulse requirements such as 2 ms, 5 ms, 10 ms, 20 ms and 40 ms, in order to obtain a final operation. These specific devices could then be used to classify the relay under test.[1]

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[1] Even though this approach is much more realistic than the single 2-ms criterion, it cannot be used as the only criterion in determining the fragility level of any circuit. The sensitivity of a device to the repetition rate as well as the wiring configurations in which distributed capacitance can affect overall circuit operation must also be taken

1.3.2 Relay Chatter and Circuit Breaker Malfunction

In the switchgear circuit of a nuclear power plant, the operation of a circuit breaker can be directly or indirectly controlled by a number of protective and auxiliary relays. It has been postulated that a 2-ms chatter of a relay will not cause a breaker trip. However, the amount of relay chatter that a breaker will tolerate before initiating an unintended operation is not usually known. The size of the breaker (e.g., low and medium voltage), the exact controlling circuit and the existence of seal-in or lockout devices, among other parameters, affect the breaker performance. The effect of relay chatter on the breaker operation was not adequately addressed in past studies (e.g., Reference 2).

1.3.3 Specimen Variation

The first test series indicated a large variation of seismic capacities even with specimens of the exactly, same relay model number and factory adjustments. This raises a fundamental question as to how many specimens of a relay model should be tested in order to gain adequate confidence in the median and the variance of the test results. The IEEE Standard [4] recommends testing a minimum of three relays. A resolution of this issue requires additional test data with consistent electrical adjustments.

1.3.4 Single Frequency to Multifrequency Conversion Factor

In Test Series I, several relays were tested with both single frequency and multifrequency vibration inputs where the shapes of the required response spectra for the multifrequency tests were matched with the shapes of the input motion curves obtained from the single frequency tests. For one relay model, the tests were successfully completed and the conversion factor relating the multifrequency test response spectra (TRS) with the single frequency input motion was computed for all frequencies. For other relays, the test results were inadequate for computing the conversion factors. In order to draw a general conclusion on the conversion factor, additional test data are needed.

1.4 SUMMARY

The Series II test program addresses the following basic issues:

1. Relay chatter acceptance criteria
2. Relay chatter associated with breaker trip
3. Capacity variation among specimens of the same relay model
4. Additional data for single frequency to multifrequency conversion factor.

Since the first two issues deal with the chatter criteria, these were addressed in one task in the vibration test series; whereas, separate tasks were performed for the other two issues. These are further elaborated in Chapter 2.

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into consideration. Each circuit in the nuclear safety systems needs to be evaluated on the basis of the devices in the circuit and the actual overall circuit. For example, the use of a circuit with two or more contacts in series should be evaluated relative to the seismic capability of each of the devices. The use of a low capability unit and a high capability unit relative to normally open contacts would have the capability of the highest device. Conversely, if the overall circuit depends on normally closed contacts for its operation, the fragility level of the overall circuit would be governed by the lowest capability device.

CHAPTER 2

TEST PLAN

2.1 INTRODUCTION

In order to determine the chatter-tolerant characteristics of the breaker tripping mechanisms and relay contacts, an electrical test program was carried out prior to the vibration tests. The results from the electrical tests were evaluated to plan the vibration tests. The test procedures followed for both the electrical and vibration tests are discussed in this chapter.

2.2 ELECTRICAL TEST PROCEDURES

The electrical testing was performed in two phases. In the first phase, eleven circuit breakers and two lockout relays were tested to determine the time required for these devices to trip at 100% and 80% of their rated voltage. Circuit breakers were for either medium voltage or low voltage applications and manufactured by Westinghouse, General Electric and ITE. These were functional, used devices, some of which were tested at locations (such as the High Flux Beam Reactor at BNL) with portable instruments. The trip current vs. time plots were obtained by use of an oscilloscope.

In the second phase, three lockout relays, three circuit breakers and eight auxiliary self-reset relays (of four models) were tested at an electrical power testing laboratory (KEMA Powertest). The trip current traces were obtained for the breakers and lockout relays. In addition, the electrical pulses of minimum durations required to trip all these devices were determined. Repeated alternating (i.e., on/off) pulses were also used to determine various combinations of "on" and "off" pulses that are required to trip the devices.

A listing of the breakers and relays used for the above two electrical test programs is provided in Table 2.1.

In addition to the electrical pulse characteristics testing described above, three specimens of each of HMA124, SC and SVF relay models (i.e., a total of nine relays) were tested for electrical pickup and dropout conditions. These relays had been shake-table tested as part of the Series I program [3] and exhibited large differences in their seismic capacities even within the same relay family. In the Series II electrical testing, each relay was visually inspected to search for observable design differences, and then was set to achieve comparable electrical pickup and dropout characteristics.

2.3 VIBRATION TEST PROCEDURES

The vibration testing was grouped into three tasks each of which is discussed below.

2.3.1 Task 1

The objective of this task was to explore alternatives to the 2-ms chatter limit as potential acceptance criteria for a relay in specific common circuit configurations. Five protective and auxiliary relays were used as the source relays to produce signals for possible tripping or chattering of a medium voltage circuit breaker, two lockout relays and another auxiliary relay (see Table 2.2 for listing of devices). Initially, the source relays were mounted on the shake table and the load devices on a stationary stand. Subsequently, they were all mounted on a switchgear cabinet and shake-table tested. The following are the test sequences:

- Five source relays were mounted on a rigid fixture which, in turn, was welded on the shake table. Four load devices were installed at a stationary location. The electrical output from each of four of the five source relays was connected to each of the load devices. The contact signal from the fifth source relay was monitored for chatter in a 25-milliamp circuit. The load devices were subjected to 125 VDC.

- The assembly was shake-table tested with single frequency, sine dwell motion applied separately in the front-to-back and vertical directions at the following frequencies: 1, 2.5, 5, 7.5, 10, 12.5, 15, 20, 25, 30, 40 and 50 Hz. The sine dwell amplitude was gradually increased to the machine limit or decreased from it until a narrow range is established between the success and malfunction (i.e., trip or chatter) levels. For the same electrical test setup, the contact chatter (for the fifth source relay) was also monitored separately with 1-amp and 150-milliamp currents. The voltage on the load devices for these last two sets of test runs was reduced to 100 VDC to determine the effect of a voltage change. Vibration testing for these runs was performed only at 5, 10 and 15 Hz.

- In the above tests, provisions were also made to monitor the chatter of the source relays connected to the load devices through parallel circuits. In order to minimize disturbance on the tripping function, the current used in these chatter monitoring circuits was 25 milliamps. This arrangement provided the opportunity to determine the contact chatter in the source relays that caused tripping of the load devices. The contact chatters were monitored by repeating the test runs that resulted in tripping or chattering of a load device.

- After successful completion of one electrical test setup described above, the connections were interchanged and the tests were repeated four more times so that each source relay was once connected to a load device and the chatter monitor circuit. The five test setups or conditions are listed and schematically presented in Table 2.3 and Figure 2.1. For example, in electrical setup 1, CO9 was monitored for chatter with a 25-mamp circuit, and IAC, IAV, SVF and HFA were respectively connected to HEA, LOR, 5HK and HMA11 using 125 VDC. In electrical setups 1a and 1b, CO9 was monitored drawing respectively 1amp and 150 mamps, and other relays were connected as before but using 100 VDC. The schematics of the source and load devices are shown in Figures 2.2 through 2.10.

- For the same electrical setups described above, the source relays were shake-table tested with both single-axis (separately in the front-to-back and vertical directions) and biaxial (simultaneously in the front-to-back and vertical directions) multifrequency motions. Vibration levels were increased up to the machine limit or until tripping or chattering was observed.

- Subsequently, both the source relays and the load devices were installed in a switchgear cabinet which, in turn, was attached to the shake table. Single-axis (separately in the front-to-back and vertical directions), biaxial (simultaneously in the front-to-back and vertical directions) and triaxial (simultaneously in the front-to-back, side-to-side and vertical directions) multifrequency motions were applied. The vibration levels were increased until tripping or chatter was observed or the machine limit was reached. The corresponding TRS were obtained.

2.3.2 Task 2

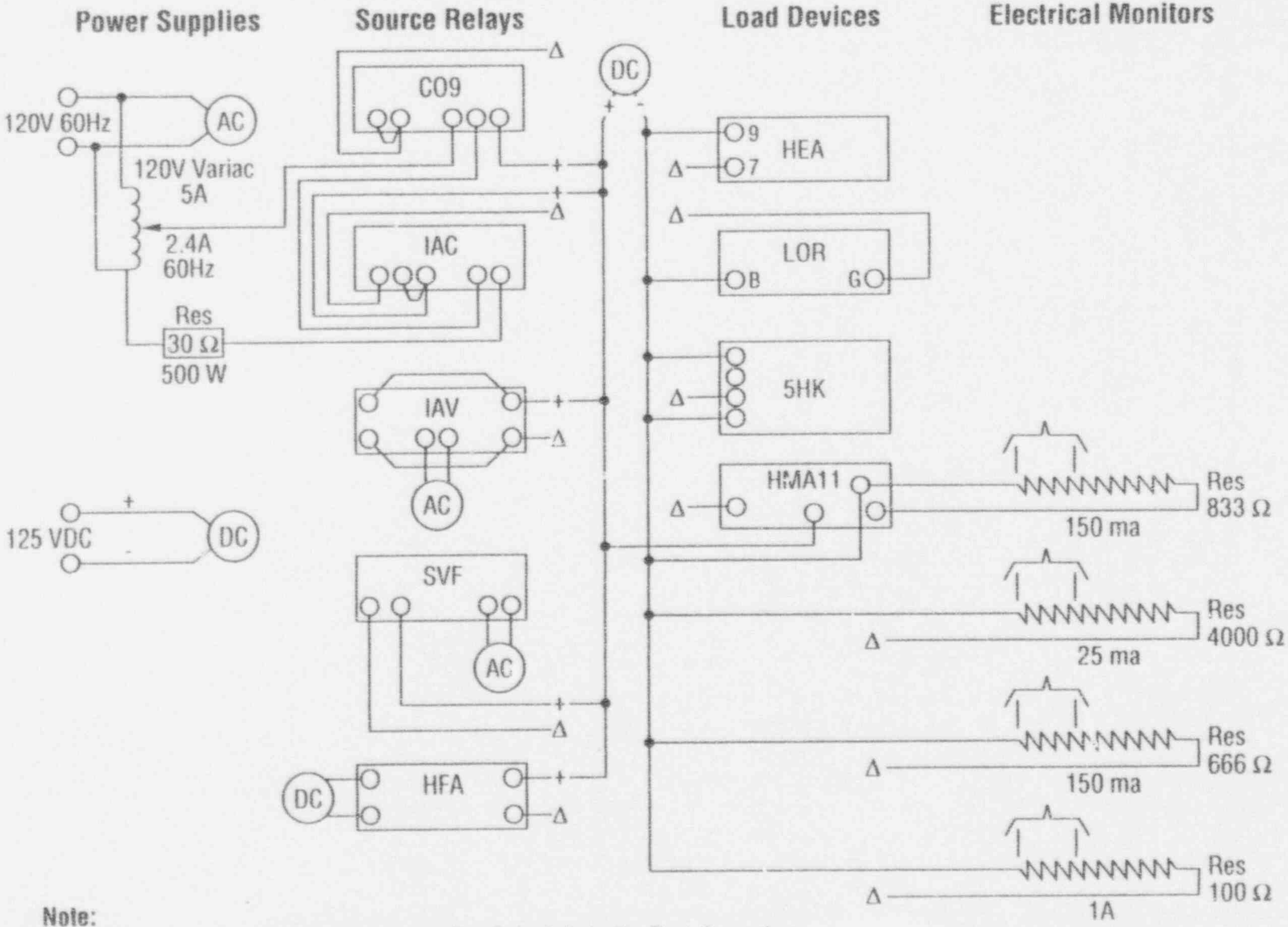
The objective of this task was to explore the variation of seismic capacities among specimens of the same relay model. Three specimens of HMA124, SC and SVF (i.e., a total of nine relays) were selected for this test (see Table 2.2 for relay descriptions and Figures 2.11 through 2.13 for electrical schematics). As discussed in Section 2.2, during electrical testing, these relays were set such that they have comparable pickup and dropout characteristics. During vibration testing, these relays were shake-table tested with single frequency sine dwell motion at the 12 frequencies listed above for Task 1. The vibration level was increased until a chatter duration of 2 ms or greater was detected for the weakest contacts, electrical conditions and vibration directions established from earlier Series I vibration tests [3]. The corresponding vibration levels were recorded.

2.3.3 Task 3

The objective of this task was to obtain additional data to correlate the single frequency capacity sine dwell input motion with the corresponding multifrequency response motion. Two specimens of HFA51 relay model were selected for this purpose as shown in Table 2.2 and Figure 2.14 (SG relays were tested in the earlier test series). The capacity limits were first established with the single frequency input motion. The multifrequency motion was then applied and the TRS shape was adjusted to make it comparable with the single frequency input motion curve (i.e., sine dwell input vs. frequency plot). The vibration level was increased until the capacity level was established. The weakest electrical mode and the vibration direction established in the Series I test program were used. The acceleration input and TRS data were recorded.

2.4 SUMMARY

A large number of test runs were conducted to explore the electrical pulse and the vibration levels required to cause a trip or chatter. The corresponding pulse and vibration levels were recorded along with selected tripping occurrence times and chatter durations. The results are discussed in Chapter 3.



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

Figure 2.1 Electrical Connections for Task 1

FT-11 Case

Relay Settings:
4A Tap
#4 Time Dial
40A Inst

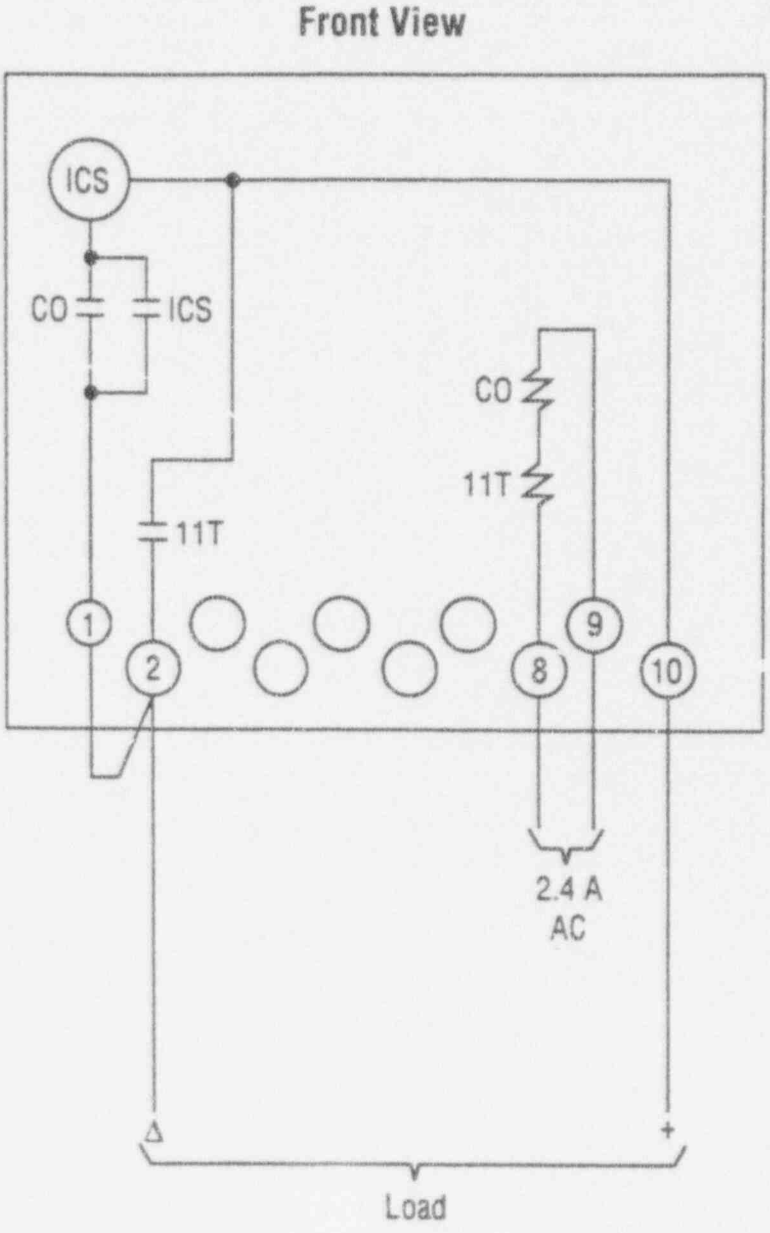


Figure 2.2 Source Relay CO9, 1875288A

SI Case

Relay Settings:
4A Tap
#5 Time Dial
40A Inst.

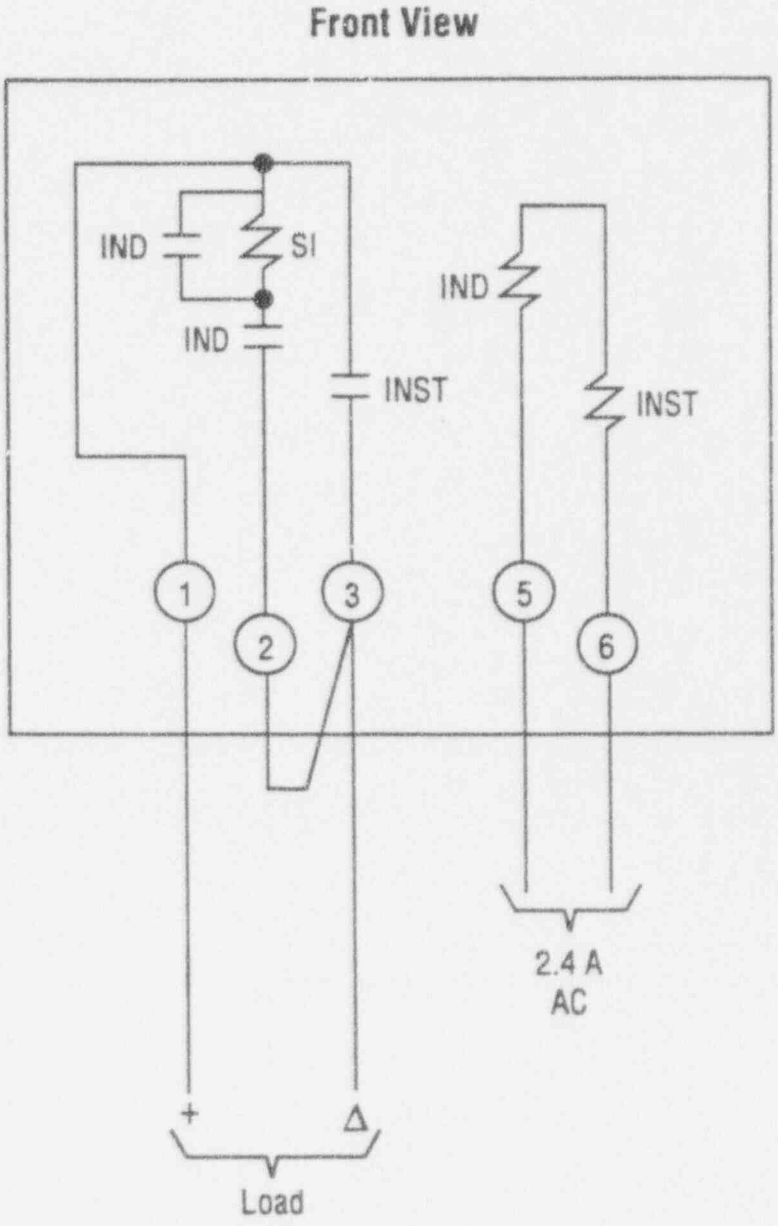


Figure 2.3 Task 1, Source Relay 12IAC51B1A

S2 Case

Relay Settings:
UV: 75% (105V)
#1 Time Dial
OV: 140V

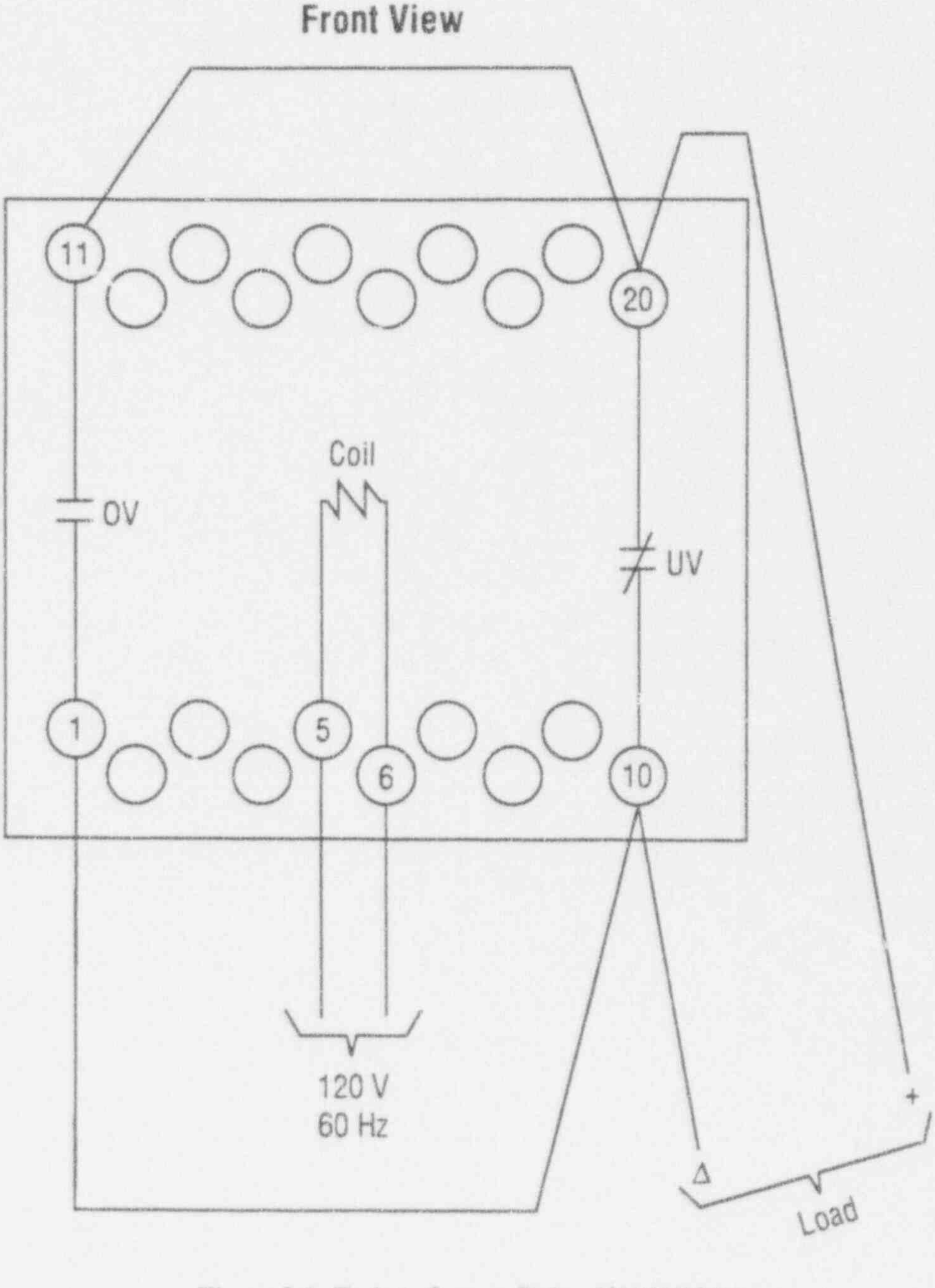


Figure 2.4 Task 1, Source Relay 12IAV53L1A

FT-21 Case

Relay Settings:
30V Dropout

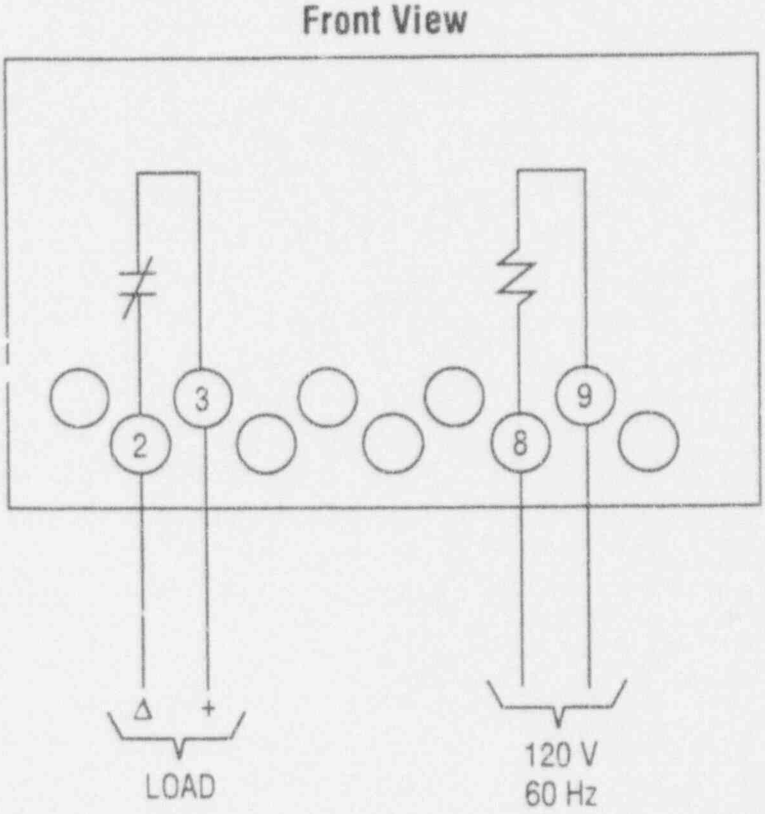


Figure 2.5 Task 1, Source Relay SVF, 1961843

Surface Case

Relay Settings:
8.3 oz. Spring Tension

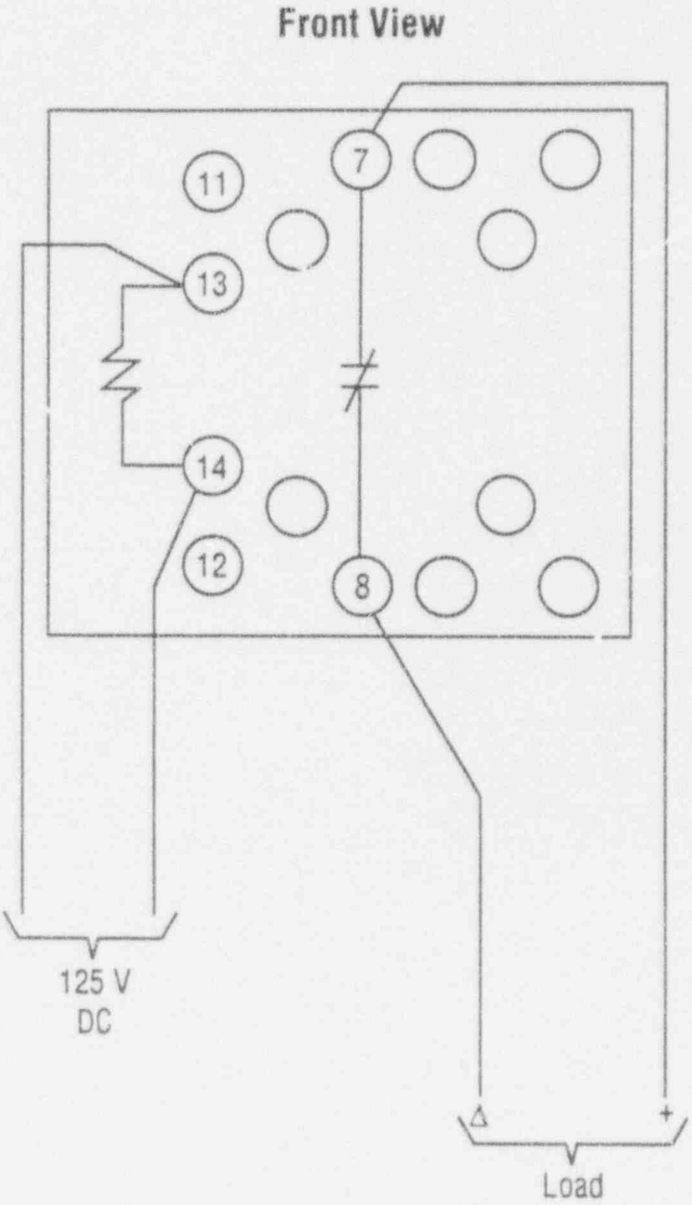


Figure 2.6 Task 1, Source Relay 12HFA51A42H

Panel Mounted
Lockout Relay

Electric Trip 125 VDC
Manual Reset

Relay in Reset
Position for all Tests

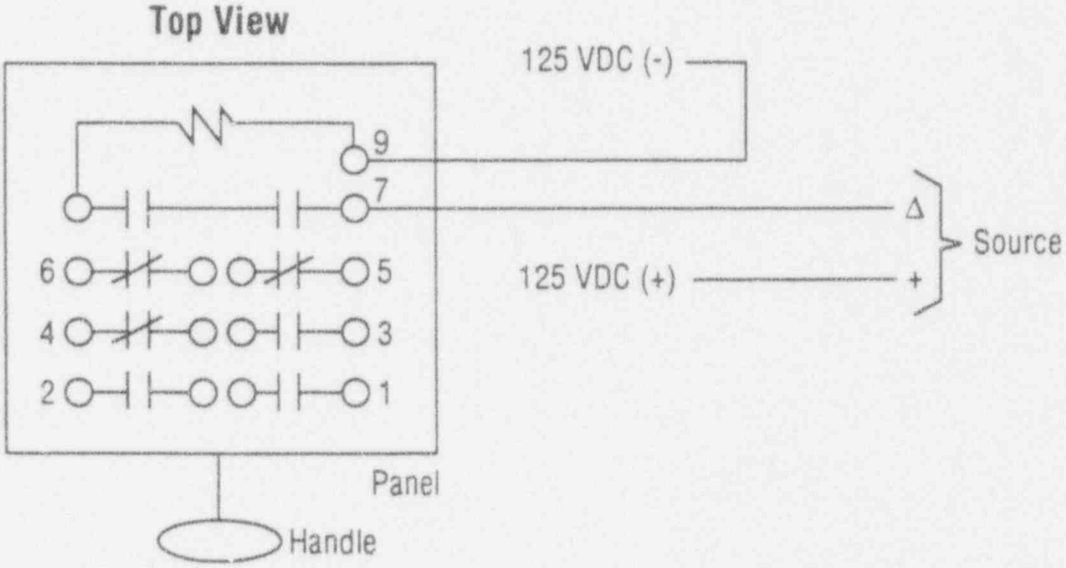


Figure 2.7 Task ., Load Relay 12HEA61A223

Panel Mounted
Lockout Relay

Electric Trip 125 VDC
Manual Reset

Relay in Reset
Position for all Tests

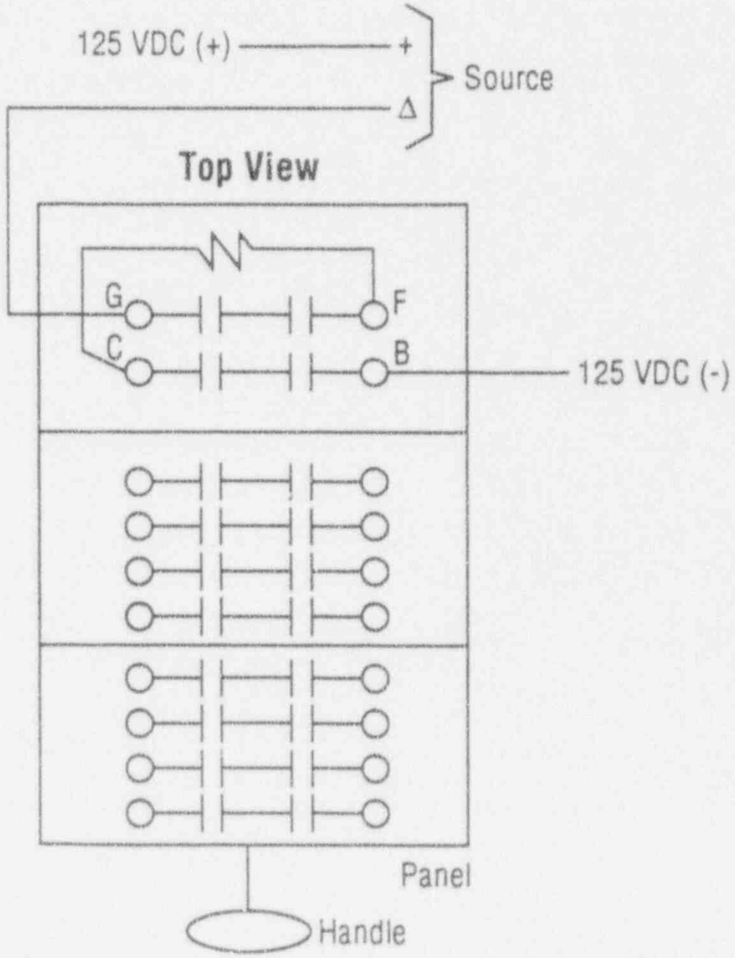


Figure 2.8 Task 1, Load Relay LOR, 7803D

Circuit Breaker in
Drawout Enclosure

Electric Trip 125VDC
Electric Close 125VDC
Electric Charge 125 VDC

Breaker in Closed
Position For All Tests

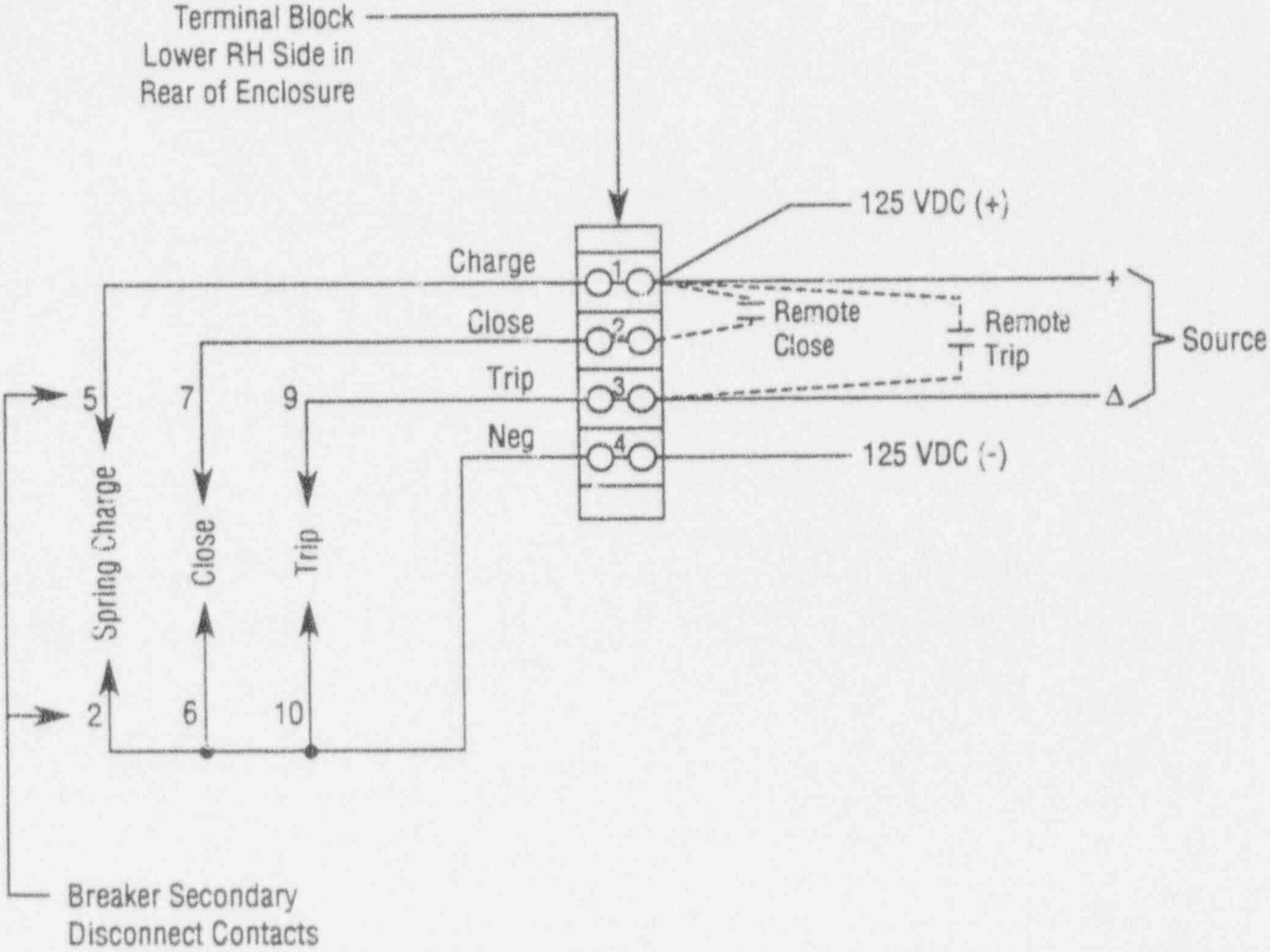


Figure 2.9 Task 1, Load Circuit Breaker 5HK

Surface Mount Relay

125 VDC Pickup
Self-Reset

Contact Monitored
(Relay Does Not Latch)

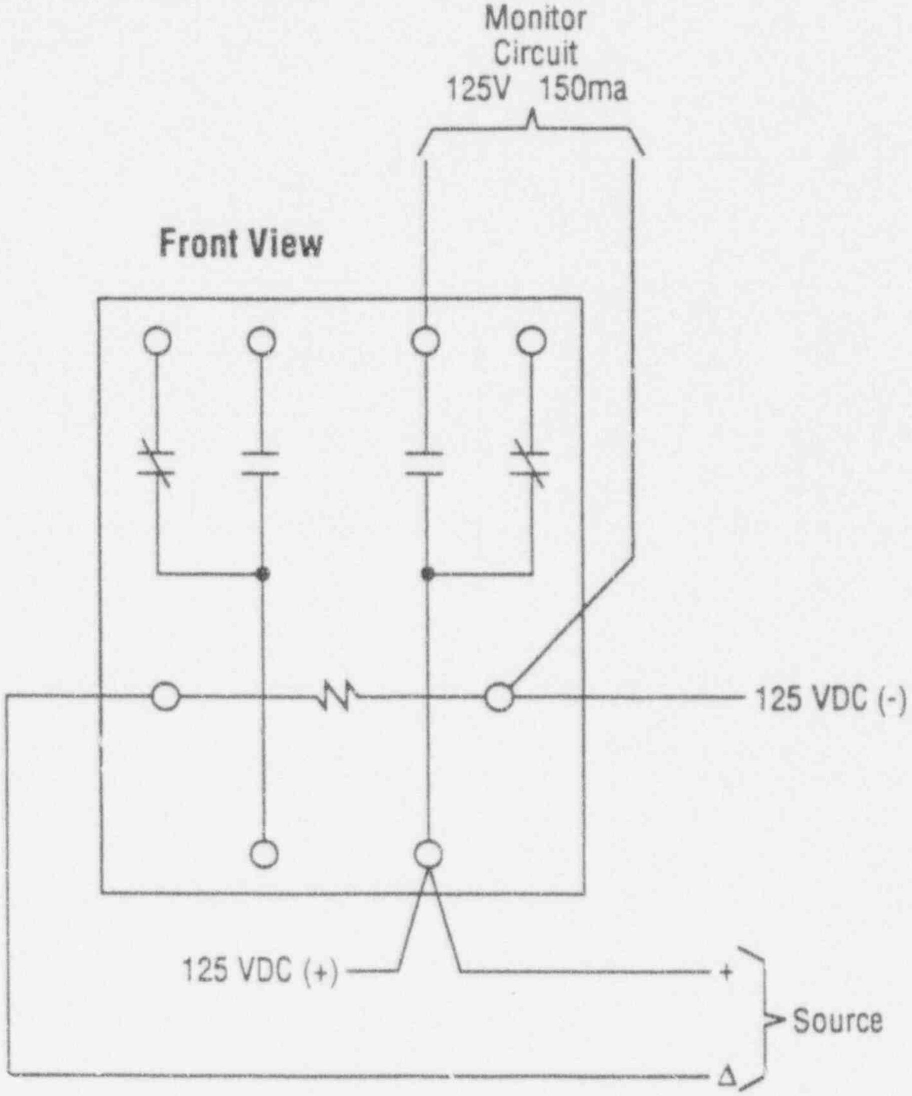


Figure 2.10 Task 1, Load Relay 12HMA11B6

Non-Operate Mode
Deenergized

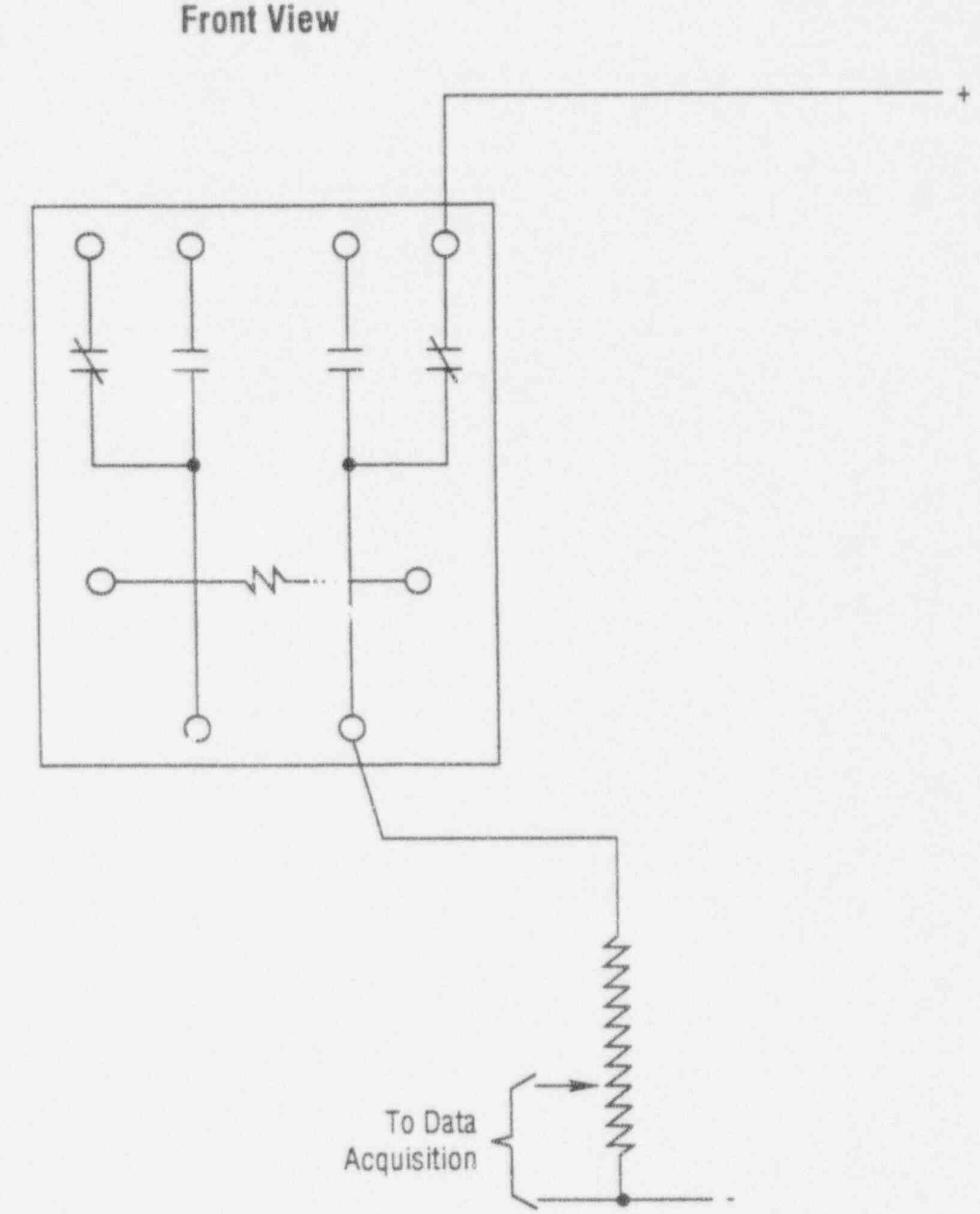


Figure 2.11 Task 2, Relay 12HMA124A2

30V Setting
Non-Operate Mode
120V 60Hz on Coil

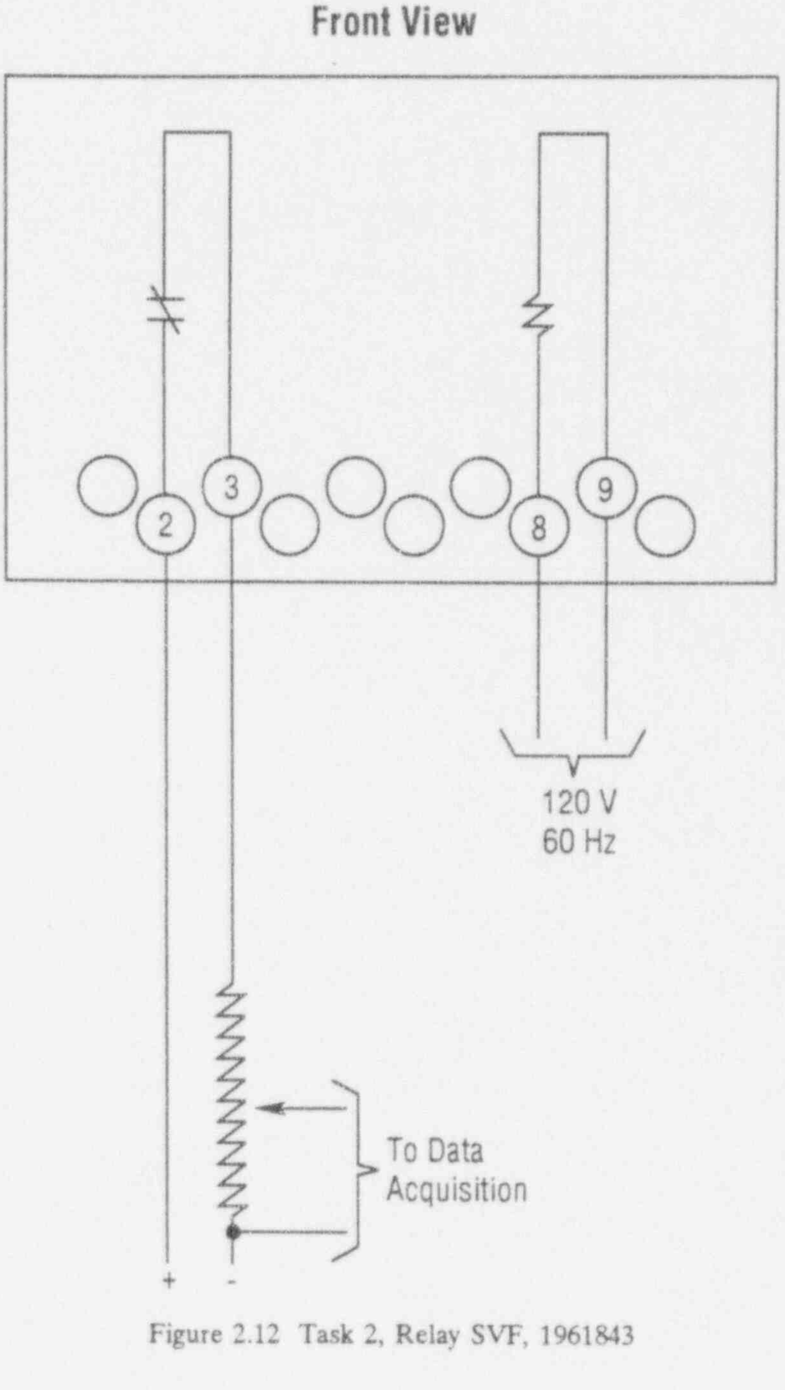


Figure 2.12 Task 2, Relay SVF, 1961843

2A Setting
Non-Operate Mode
0.5A 60Hz Thru Coil

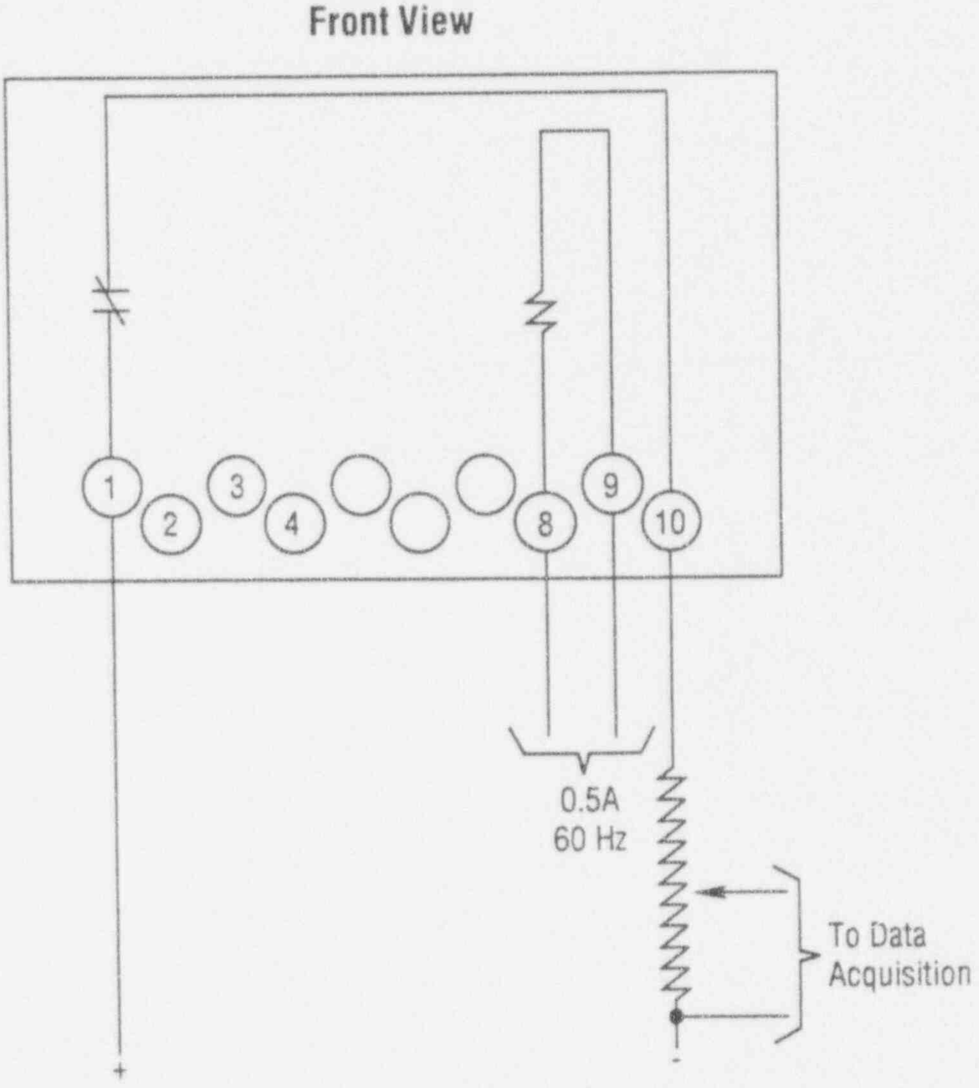


Figure 2.13 Task 2, Relay SC, 1876048

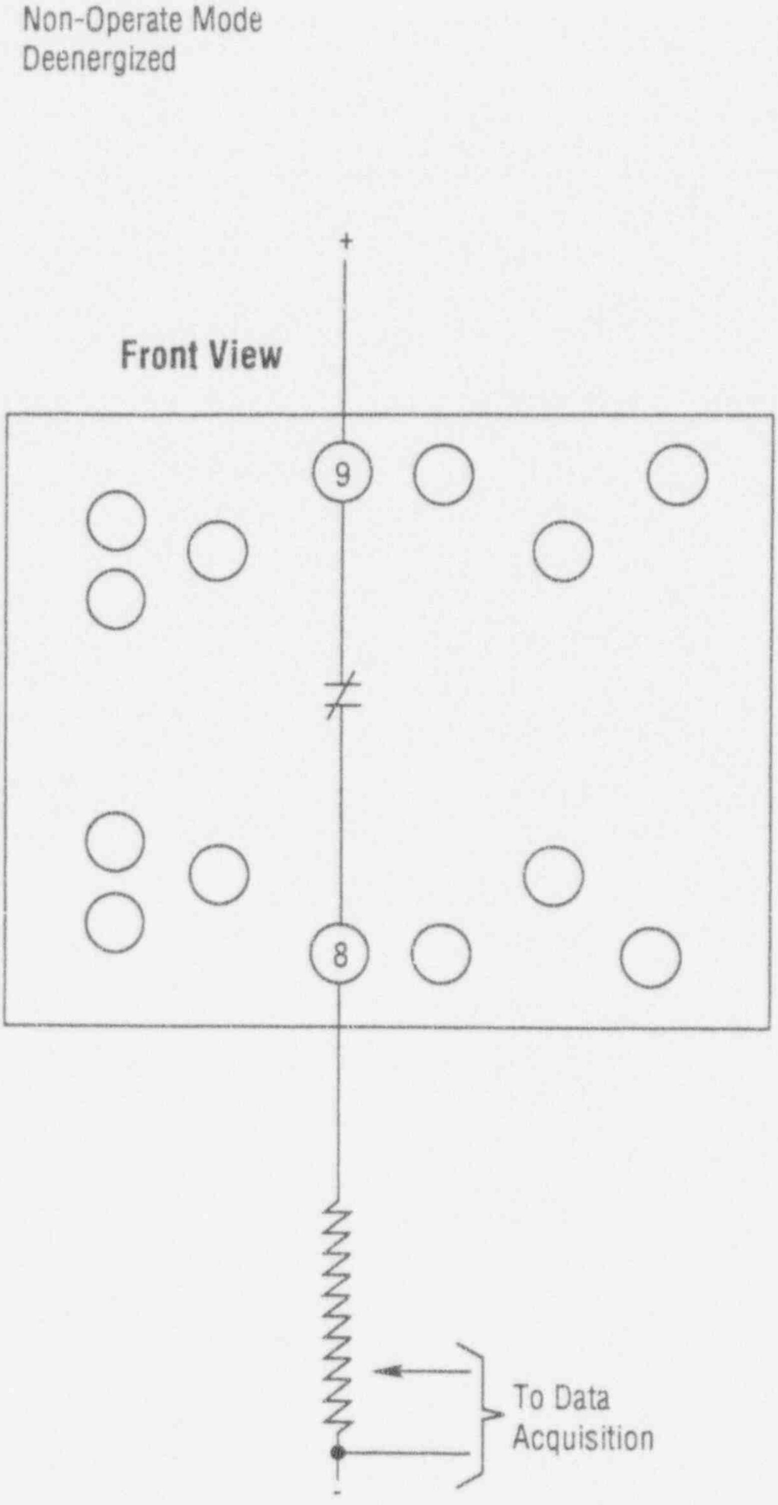


Figure 2.14 Task 3, Relay 12HFA51A42H

Table 2.1 Specimens for Electrical Tests

Field Test Program

Model No.	Manufacturer	Quantity	Description
LOR	Electro-Switch	1	Lockout relay
WL	Westinghouse	1	Lockout relay
DH3	Westinghouse	5	Medium voltage circuit breaker
AM 13.8-500	General Electric	1	Medium voltage circuit breaker
AKR 3200	General Electric	1	Low voltage circuit breaker
5HK	ITE	1	Medium voltage circuit breaker
DB25, 600	Westinghouse	1	Low voltage circuit breaker
AK-25, 600	General Electric	1	Low voltge circuit breaker
150DHP500	Westinghouse	1	Medium voltage circuit breaker

Laboratory Test Program

Model No.	Manufacturer	Quantity	Description
LOR	Electro-Switch	1	Lockout relay
WL	Westinghouse	1	Lockout relay
HEA	General Electric	1	Lockout relay
K1600	ITE	1	Low voltage circuit breaker
15HK	ITE	1	Medium voltage circuit breaker
5HK	ITE	1	Medium voltage circuit breaker
SG	Westinghouse	2	Auxiliary relay
HFA51	General Electric	2	Auxiliary relay
HMA11	General Electric	2	Auxiliary relay
A314X	Square D	2	Auxiliary relay

Table 2.2 Specimens for Vibration Tests[a]

Task	Model No.	Manufacturer	Quantity	Description
1	CO9	Westinghouse	1	Overcurrent relay (source)
	IAC-51	General Electric	1	Overcurrent relay (source)
	IAV-53	General Electric	1	Over/under voltage relay (source)
	SVF	Westinghouse	1	Under voltage relay (source)
	HFA51	General Electric	1	Auxiliary relay (source)
	HEA	General Electric	1	Lockout relay (load)
	LOR	Electro-Switch	1	Lockout relay (load)
	5HK	ITE	1	Medium voltage circuit breaker (load)
	HMA11	General Electric	1	Auxiliary relay (load)
2	HMA124	General Electric	3	Auxiliary relay
	SC	Westinghouse	3	Overcurrent relay
	SVF	Westinghouse	3	Under voltage relay
3	HFA51	General Electric	2	Auxiliary relay

[a] A detailed description of the relay models is provided in NUREG/CR-4867 [3] and in Figures 2.2 through 2.14. In this report, the relay model numbers except the HMA relays, are frequently abbreviated to the first three characters for convenience.

Table 2.3 Electrical Setups for Task 1

Electrical Setup 1	Electrical Setup 1a	Electrical Setup 1b
CO9 → 25 mamps	→ 1 amp	→ 150 mamps
IAC → HEA (125 VDC)	→ HEA (100 VDC)	→ HEA (100 VDC)
IAV → LOR (125 VDC)	→ LOR (100 VDC)	→ LOR (100 VDC)
SVF → 5HK (125 VDC)	→ 5HK (100 VDC)	→ 5HK (100 VDC)
HFA → HMA11 (125 VDC)	→ HMA11 (100 VDC)	→ HMA11 (100 VDC)

Electrical Setup 2	Electrical Setup 2a	Electrical Setup 2b
CO9 → HEA (125 VDC)	→ HEA (100 VDC)	→ HEA (100 VDC)
IAC → LOR (125 VDC)	→ LOR (100 VDC)	→ LOR (100 VDC)
IAV → 5HK (125 VDC)	→ 5HK (100 VDC)	→ 5HK (100 VDC)
SVF → HMA11 (125 VDC)	→ HMA11 (100 VDC)	→ HMA11 (100 VDC)
HFA → 25 mamps	→ 1 amp	→ 150 mamps

Electrical Setup 3	Electrical Setup 3a	Electrical Setup 3b
CO9 → LOR (125 VDC)	→ LOR (100 VDC)	→ LOR (100 VDC)
IAC → 5HK (125 VDC)	→ 5HK (100 VDC)	→ 5HK (100 VDC)
IAV → HMA11 (125 VDC)	→ HMA11 (100 VDC)	→ HMA11 (100 VDC)
SVF → 25 mamps	→ 1 amp	→ 150 mamps
HFA → HEA (125 VDC)	→ HEA (100 VDC)	→ HEA (100 VDC)

Table 2.3 Electrical Setups for Task 1 (Cont'd.)

Electrical Setup 4	**Electrical Setup 4a**	**Electrical Setup 4b**
CO9 → 5HK (125 VDC)	→ 5HK (100 VDC)	→ 5HK (100 VDC)
IAC → HMA11 (125 VDC)	→ HMA11 (100 VDC)	→ HMA11 (100 VDC)
IAV → 25 mamps	→ 1 amp	→ 150 mamps
SVF → HEA (125 VDC)	→ HEA (100 VDC)	→ HEA (100 VDC)
HFA → LOR (125 VDC)	→ LOR (100 VDC)	→ LOR (100 VDC)

Electrical Setup 5	**Electrical Setup 5a**	**Electrical Setup 5b**
CO9 → HMA11 (125 VDC)	→ HMA11 (100 VDC)	→ HMA11 (100 VDC)
IAC → 25 mamps	→ 1 amp	→ 150 mamps
IAV → HEA (125 VDC)	→ HEA (100 VDC)	→ HEA (100 VDC)
SVF → LOR (125 VDC)	→ LOR (100 VDC)	→ LOR (100 VDC)
HFA → 5HK (125 VDC)	→ 5HK (100 VDC)	→ 5HK (100 VDC)

CHAPTER 3

ELECTRICAL TEST RESULTS

3.1 INTRODUCTION

The electrical tests were conducted following the procedures described in Chapter 2. The test results consisting of trip and chatter responses of breakers and relays subjected to electrical pulses are presented in this chapter. An analysis of the test data including its use in planning the vibration tests is also provided in this chapter.

3.2 FIELD TEST RESULTS

A total of eleven (11) low and medium voltage circuit breakers and two (2) lockout relays were tested in the field. A DC power was applied to the trip solenoids and the resulting current-time oscilloscope traces were recorded. The results are presented in Table 3.1. The trip voltage (DC), current and total trip time are provided for each device. The time from application of the power to the solenoid to the occurrence of the trip is called the "total trip time." Sample pictures of oscilloscope traces are shown in Figure 3.1. The abscisa in the figure shows the total trip time (e.g., 55.8 ms for DH3) and the ordinate indicates the voltage or current (e.g., 4.14 VDC or 4.14 amps for DH3).

The total trip time varied between about 20 and 60 ms for the breakers and lockout relays except for the fast lockout relay LOR for which the trip time was 7.5 ms. This supports the earlier hypothesis that the lockout relays (except fast ones) can be used as surrogates for circuit breakers so far as the trip characteristics are concerned (Ref. Section 1.3.1.2). As expected, the solenoid requires a larger duration for tripping at a lower voltage. For example, the total trip time for the AKR circuit breaker is 47.5 ms at 125 VDC and is 55.4 ms at 100 VDC. For the tested specimens, the increase in trip time is between about 5% and 40% for a voltage drop from 125 VDC to 100 VDC.

3.3 LABORATORY TEST RESULTS

Three (3) lockout relays, three (3) circuit breakers and eight (8) auxiliary self-reset relay specimens were tested with electrical pulses to determine the minimum pulse durations required for trips. The results are presented in Tables 3.2 and 3.3. In addition to single pulses, repeated alternating (i.e., on and off) pulses were applied to verify a possible reduction of the required pulse duration. Single pulse durations were obtained at both 100% and 80% of the rated voltage.

The results indicate that for the tested breakers and lockout relays, the required single pulse duration varies between 8 ms and 18 ms except for the fast lockout relay LOR for which the required pulse duration is about 2 ms. An appreciable amount of reduction (15-30%) was observed when the pulses were repeated with 1-ms pauses. The reduction quickly disappeared when the pause duration is increased to 3 ms.

The self-reset auxiliary relays required single "on" pulse durations of 15-40 ms for a change of state. The corresponding "off" pulses are of much shorter durations (i.e., about 25-33% of the "on" pulse durations). The repeated alternating pulses have a much stronger influence on auxiliary relays than on the lockout relays and circuit breakers.

In addition, the solenoids of the lockout relays and circuit breakers were energized to determine the corresponding trip times similar to what was obtained from field testing discussed in Section 3.2. The device models (not the same specimens) that were tested both in the field and in the laboratory showed comparable results. The results of the additional lockout relay (HEA) and circuit breakers (15 HK and AK 1600) are included in Table 3.4 and discussed further in the following section.

3.4 DATA ANALYSIS

For any breaker or lockout relay, the trip time data shown in Table 3.1 are greater than the required pulse duration presented in Table 3.2. This can be explained as follows: The total trip time consists of 1) the time required for the current to build up sufficiently so that the energy in the solenoid is adequate to unlatch the tripping mechanism, and 2) the time required for the latch to complete the change of state. For convenience, the first one can be termed as "energization time" and the second one "mechanical time" and they can be equated to the total time as follows:

Total trip time = energization time + mechanical time

The total trip times shown in Table 3.1, thus, represent the summation of the energization and mechanical times. This phenomenon is further explained with the help of Figure 3.2.

On the other hand, the minimum time required by an electrical pulse to cause a trip represents only the energization time. Once the latch is set in motion, it completes the change of state due to its inertia alone imparted by the electromagnetic force built up in the solenoid during energization. Thus, the pulse durations shown in Table 3.3 correspond to the energization time and do not include the mechanical time. A comparison of the data in Tables 3.2 and 3.3 demonstrates that the energization time for a given lockout relay or breaker is about a half of the total trip time.

The chatter duration required in a relay to cause a trip in a downstream lockout relay or breaker is expected to be comparable to the energization time rather than the total trip time. Thus, for the purposes of vibration testing, the data of primary interest are the pulse duration data which should be comparable to the required chatter. Due to practical reasons, devices in the field could not be tested with pulses. The required pulse time for these devices can still be calculated from the field test data provided they were tested at two different voltage levels. The basic hypotheses in this calculation are as follows:

1. The time required to build up current until the latch is disengaged depends on the voltage (DC) level but the time required to complete the change of state does not depend on voltage.
2. The energy required to disengage the latch is the same regardless of the voltage level.

These two hypotheses provide adequate equations to calculate the two unknown variables, i.e., energization time (or pulse duration) and mechanical time.

In order to verify the above hypotheses and the resulting formulas, four devices were tested to obtain both the total trip time and minimum pulse duration. The calculated results match well with the test data as shown in Table 3.4. The energization time or required pulse durations calculated for other devices are also shown in Table 3.4.

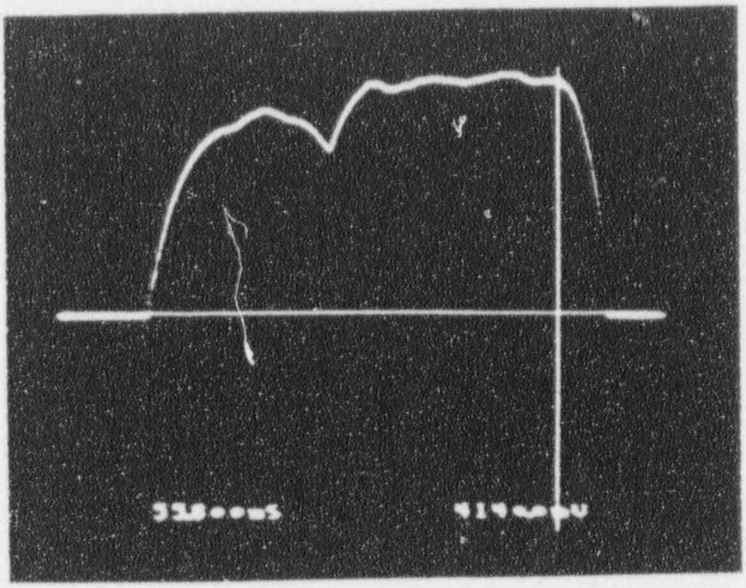
3.5 SUMMARY

The following conclusions can be derived from the electrical test data:

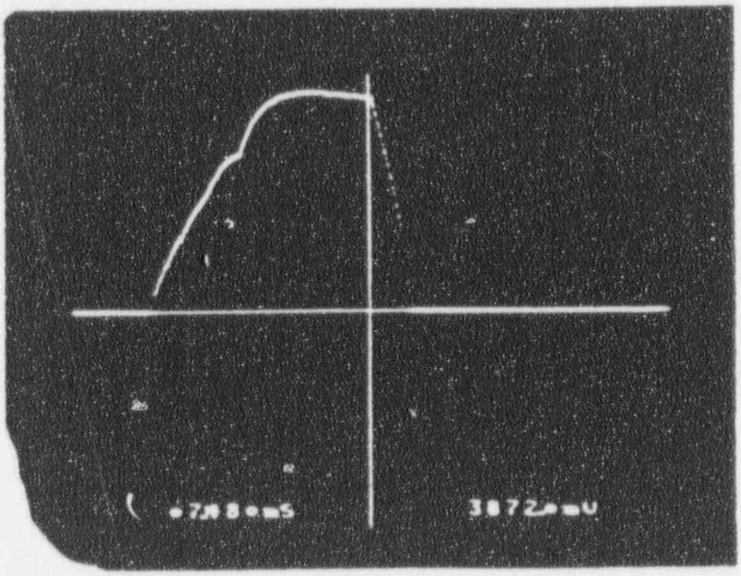
1. The minimum pulse duration required to trip a device is much less than the total time required to change state. For many devices, the energization pulse time is about a half of the total time, and for others the pulse time is even less than a half of the total time.

2. The minimum pulse durations for most breakers (10-20 ms) are comparable to those for most lockout relays. However, there are some fast lockout relays (less than 2 ms). Therefore, to determine the effect of relav chatter (during vibration testing) most often lockout relays (except the fast ones) can be used in place of breakers.

Further use and interpretation of the electrical test data are made after reviewing the vibration test data in the next chapter.



Westinghouse Breaker DH3, Specimen 1



Electro-Switch Lockout Relay LOR

Figure 3.1 Oscilloscope Voltage (Current)-Time Traces

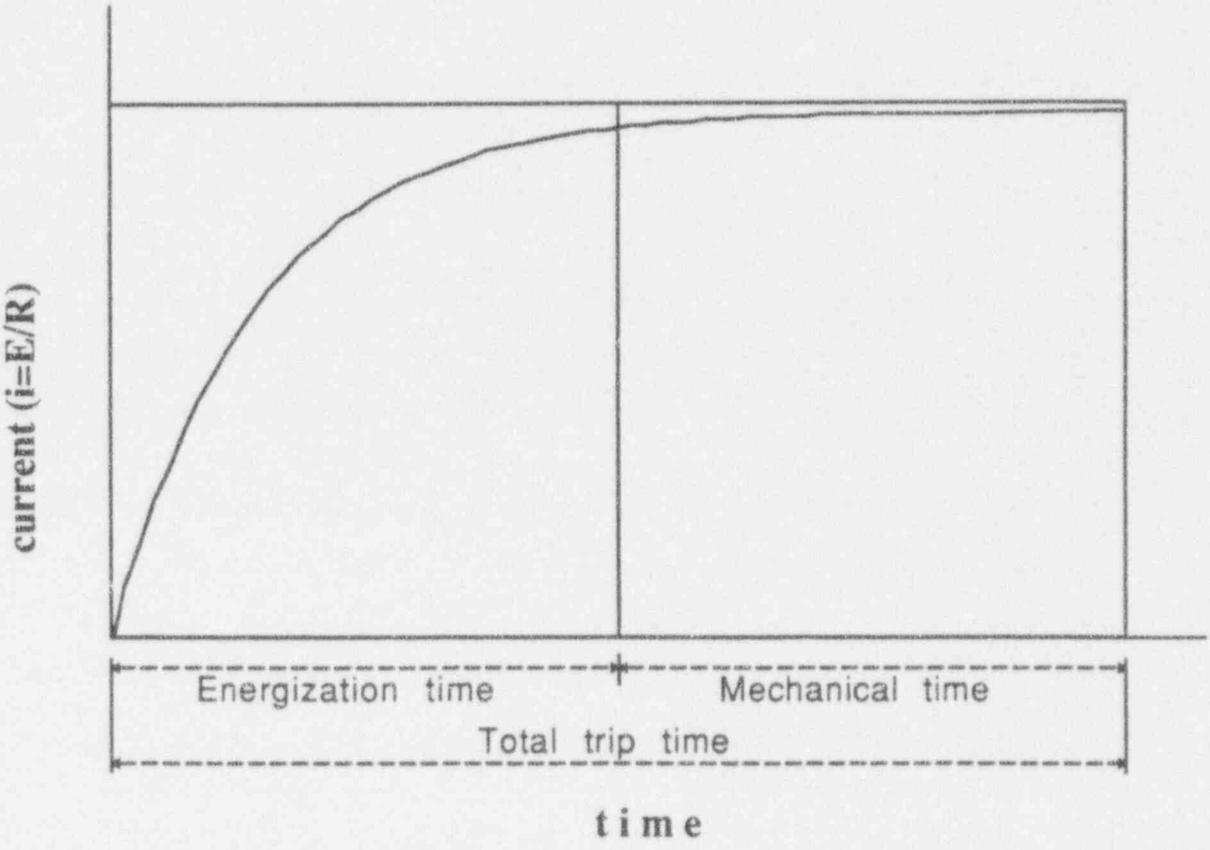


Figure 3.2 Current Build-Up vs. Trip Time

Table 3.1 Field Tests of Breakers and Lockout Relays - Current and Trip Time Data

Breaker/Lockout Relay	Rated Voltage (DC)	Trip Voltage (DC)	Current (amp)	Total Trip Time (ms)
E-S LOR	125	125	3.87	7.5
W DH3, Specimen 1	250	260	4.14	55.8
W DH3, Specimen 2	250	260	3.7	55.1
W DH3, Specimen 3	250	261	4.27	45.2
W DH3, Specimen 4	250	261	4.33	59.2
W DH3, Specimen 5	250	261	3.47	54.5
GE AM 13.8-500	125	125	3.68	55.3[a]
GE AM 13.8-500	125	115	3.28	54.5[a]
GE AKR, 3200	125	125	1.52	47.5
GE AKR, 3200	125	100	0.96	55.4
W DB25, 600	125	125	7.04	19.9
W DB25, 600	125	100	5.04	21.2
GE AK-25, 600	125	125	1.84	25.2
GE AK-25, 600	125	100	1.12	28.3
W 150 DHP 500	125	125	2.88	48.6
W 150 DHP 500	125	100	2.32	53.3
W WL	125	125	2.96	18.4
W WL	125	100	1.84	23.7
ITE 5HK	125	125	3.55	29.7
ITE 5HK	125	100	2.62	36.6

[a] Test anomaly. Since an increase of trip time should have occurred for the lower voltage condition, one of the two trip time recordings is in error.

Table 3.2 Electrical Pulse Time Characteristics of Breakers and Lockout Relays

Breaker/Lockout Relay	Single "on" Pulse Duration (ms)		Repeated "on/off" Pulse Durations (ms/ms)	
	100 VDC	125 VDC	100 VDC	125 VDC
E-S LOR	2	2	1.5/2	1.5/2
		1.5		
W WL	16	12	13/2	11/2
GE HEA	10	8	8/1	6/1
			9/2	7/2
			10/3	7/3
ITE K 1600	14	10	11/2	9/2
ITE 15HK	18	14	19/2[a]	14/2
ITE 5HK	17	13	16/1	9/1
			16/2	13/2
			17/3	13/3
			17/4	13/4

[a] Test anomaly.

Table 3.3 Electrical Pulse Time Characteristics of Self Reset Auxiliary Relays

Auxiliary Relay	Single "on" Pulse Duration (ms)		Single "off" Pulse Duration (ms)		Repeated "on/off" Pulse Durations for Pick-up (ms/ms)		Repeated "on/off" Pulse Durations for Drop-out (ms/ms)	
	100 VDC	125 VDC	100 VDC	125 VDC	100 VDC	125 VDC	100 VDC	125 VDC
SG, W2-2[a]	24	19	5	6		5/1		3/1
						9/2		4/2
						12/3		5/3
						13/4		7/4
						14/5		8/5
						14/6		9/6
						15/7		
						15/8		
SG, W2-3[a]	23	18	5	6		6/1		3/1
						10/2		4/2
						12/3		5/3
						13/4		6/4
						14/5		6/5

[a] See NUREG/CR-4867 [3] for specimen identification numbers.

Table 3.3 Electrical Pulse Time Characteristics of Self Reset Auxiliary Relays (Cont'd.)

Auxiliary Relay	Single "on" Pulse Duration (ms)		Single "off" Pulse Duration (ms)		Repeated "on/off" Pulse Durations for Pick-up (ms/ms)		Repeated "on/off" Pulse Durations for Drop-out (ms/ms)	
	100 VDC	125 VDC	100 VDC	125 VDC	100 VDC	125 VDC	100 VDC	125 VDC
HFA51,GE5-3[a]	21(NC)	17(NC)	14	16	3/2(NC)	9/2(NC)		2/1
	37	30			9/1	7/1		5/2
					17/2	11/2		8/3
					23/3	12/3		11/4
					29/4	16/3		15/5
								18/6
								22/7
								28/8
HFA51,GE5-2[a]	40	32	14	16				
HMA11, GE7-2[a]	20	15	4	5				
		17[b]		5[b]				
		16[c]		5[c]				

[a] See NUREG/CR-4867 [3] for specimen identification numbers.

[b] Mounted vertically

[c] Using 400-foot long leads.

Table 3.3 Electrical Pulse Time Characteristics of Self Reset Auxiliary Relays (Cont'd.)

Auxiliary Relay	Single "on" Pulse Duration (ms)		Single "off" Pulse Duration (ms)		Repeated "on/off" Pulse Durations for Pick-up (ms/ms)		Repeated "on/off" Pulse Durations for Drop-out (ms/ms)	
	100 VDC	125 VDC	100 VDC	125 VDC	100 VDC	125 VDC	100 VDC	125 VDC
HMA11,GE7-3[a]	10(NC)	8(NC)				7/1		3/1
	21	15	4	5		11/2		6/2
						13/3		12/3
A314X Sample 1	10(NC) 14	7(NC) 9	2[d]	3		6/1		4/1
A314X Sample 2	14	13	2	3				

[a] See NUREG (CR-4867[3] for specimen identification numbers

[d] Bouncing observed.

Table 3.4 Electrical Pulse Trip Time Characteristics of Breakers and Lockout Relays

Breaker/Lockout Relay	DC Voltage	Trip Time (ms)		
		Total	Pulse	
			Tested	Calculated
W WL	125 100	18.4 23.7	12.0 16.0	12.0 16.0
ITE 5HK	125 100	29.7 36.6	13.0 17.0	12.8 17.4
ITE 15HK	125 100	32.0 38.0	14.0 18.0	13.0 17.6
ITE K 1600	125 100	19.4 22.5	10.0 14.0	10.0 14.0
GE AKR, 3200	125 100	47.5 55.4	- -	21.6 29.5
GE HEA	125 100	14.0 16.8	8.0 10.0	7.8 10.5
W DB-25, 600	125 100	19.9 21.2	- -	5.0 6.4
W 150 DHP 500	125 100	48.6 53.3	- -	13.6 18.3
GE AK-25, 600	125 100	25.2 28.3	- -	5.3 8.5

CHAPTER 4

VIBRATION TEST RESULTS

4.1 INTRODUCTION

The vibration tests were conducted following the procedures described in Chapter 2. Electrical chatter or change-of-state time history data were recorded in addition to the vibration level data. The results are presented in this chapter for the three tasks described in Chapter 2.

4.2 TASK 1 TEST DATA

The chatter of the source relays and trip or chatter of the load devices were observed at various vibration levels, frequencies and directions. The chatter detection data and the vibration data are separately presented in the following sections. Some general observations such as the effects of contact current on source relay chatter and voltage drop on load devices are also presented.

4.2.1 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 4.1A. 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 reported in Chapter 3, "a" is similar to the "total trip time" of the breakers and lockout relays.

On the other hand, sometimes the trip of the load device occurred at t_2 after chatter in the source relay stopped at t_3 as shown in Figure 4.1B. In this case, the duration required to cause trip after initiation of chatter (i.e., a) is longer than the chatter duration (i.e., b). Thus, in this case "a" represents the total trip time and "b" represents a duration similar to or longer than the energization time or pulse duration as described in Chapter 3.

Examples of the above two types of chatter-trip relationships along with a few other more complex situations are shown in Figures 4.2 through 4.71. The effects of the source relays on LOR, HEA, and 5HK are respectively shown in Figures 4.2 through 4.62. For example, as shown in Figure 4.2, in an integral circuit with the output of the source relay CO9 controlling the 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. At occasions, several small-duration chatters preceded the long duration chatter that caused the trip (e.g., Figure 4.27).

For HMA11, which is an auxiliary relay and does not have a trip mechanism, the source relay induced chatter in it (instead of a trip). Effects of the source relays on HMA11 are shown in Figures 4.63 through 4.71. For example, as shown in Figure 4.63, in a circuit where the output of the source relay IAV controls the operation of the load relay HMA11, the load relay initiates chatter 25.75 ms after initiation of the source relay chatter.

Vibration Test Results

Some of the chatter history data are presented in Table 4.1. The durations required to cause tripping of the LOR and HEA lockout relays and 5HK breaker since initiation of chatter of the respective source relays (i.e., "a" in Figure 4.1) are extracted from various test runs. The mean values of the required durations for each load device are also shown. For comparison purposes, the results from the electrical tests are also presented. The following major observations are made from these data:

- The required trip time (i.e., "a" in Figure 4.1) for a given lockout relay or breaker is independent of the source relay.
- The chatter data from the vibration tests compare well with those from the electric tests. For example, for the breaker, the mean trip time from the vibration tests was about 34 ms and that from the electrical tests was about 30 ms.
- The electromagnetic (or pulse) time data also match well between the two tests. For example, with the HEA lockout relay, the required chatter duration of the IAC was about 7 ms compared to the 8-ms pulse duration data from the electrical tests (Figure 4.25). The total trip times in this example are 11 ms and 14 ms.

All the data presented above were obtained from electrical performance results at various frequencies for single frequency tests and from multifrequency vibration tests.

4.2.2 Vibration Data

The vibration level data corresponding to the chatter, trip or highest capacity were recorded. The results are discussed for the single frequency and multifrequency tests in the following sections.

4.2.2.1 Single Frequency Vibration Data

The source relays were vibrated on the shake table to obtain trips on the load devices which were initially located on a stationary stand. The vibration level was adjusted until a trip occurred in the target load device. The highest vibration level achieved without a trip in the load device is considered the capacity of the source relay as long as its function is limited to provide electrical signal only to the particular load device. Thus, the capacity of a source relay was determined in terms of each of the load devices. In addition, its capacity was measured based on the conventional 2-ms criterion. The capacity levels of the source relays obtained from the single frequency tests are presented in Figures 4.72 through 4.81. For each source relay, the capacity levels are shown in terms of its ability to chatter for a duration of 2 ms or greater, to cause a chatter in the auxiliary load relay HMA11 for a duration of 2 ms or greater, and to trip the breaker 5HK or lockout relays LOR and HEA. The capacity level was obtained at each of the following frequencies:

1, 2.5, 5, 7.5, 10, 12.5, 15, 20, 25, 30, 40, and 50 Hz.

The highest amplitude of the sine dwell input motion at each frequency corresponding to each acceptance criterion is plotted in the above figures and, for presentation purposes, a curve is drawn connecting these discrete points at the tested frequencies. At some frequencies, a chatter of the source relay, or a chatter or trip of the load device was not observed even when the source relay was vibrated up to the limit of the shake table. For these cases, the source relay capacity levels are shown as the nominal machine vibration limits. For presentation purposes, a slight separation is maintained between the capacity curve and the nominal machine limit curve so that they can be distinguished.

The single frequency capacity levels were established in both the front-to-back and vertical directions. The source relays were in their operating modes and load devices were at their rated voltage of 125 VDC.

All the capacity data presented in these figures are the relative capacity levels in that they represent the capacity levels of particular source relay specimens relative to the five acceptance criteria shown on each figure. None of these capacity curves should be construed as the real capacity of any of these relay models.

The capacity data presented in Figures 4.72 through 4.81 indicate that the capacity of a source relay based on a load device trip could be lower than the conventional 2-ms-based capacity levels. For example, in Figure 4.81, the IAV relay successfully withstood the vertical motion without a 2-ms chatter up to 1.8g to 1.3g at frequencies between 5 Hz and 10 Hz. However, the corresponding capacity level when measured in terms of tripping of the 5HK breaker was only 0.5 g. This is particularly a paradox for the breaker since it requires a total trip time of above 30 ms.

A probable explanation of this apparent anomalous chatter duration and capacity comparison is that another variable, namely the ability of contact to interrupt current, is involved. The tripping devices are operated by 125 VDC coils which are inductive devices. The current from a DC source flows continuously in one direction and is very difficult to interrupt, as compared to the current from a 60 Hz AC source. The source relay contacts have low mass, move slowly, and have relatively small gaps with low forces holding them open. If vibration causes contact closure for a sufficient duration to initiate excitation of the trip device coil, inductive current will persist. As source contacts begin to part, an arc develops ionizing the gap. The gap increases in size, but ionization continues, current continues and the trip device continues the tripping until it interrupts its own current, removing the voltage from the source contact gap and extinguishing the arc. The source relay contacts which caused tripping of the trip devices were unable to interrupt the current in many cases and had to rely on the load device itself to open the circuit. This condition is the same in the field and is considered to be normal behavior under vibration for this type of circuit with a DC control voltage.

It is also possible that there are electromagnetic forces involved but evaluation of their direction and magnitude will require additional research.

4.2.2.2 Multifrequency Vibration Data

The multifrequency capacity TRS plots at a damping value of 5% are shown in Figures 4.82, 4.83, and 4.84. Similar to the single frequency capacity results discussed in Section 4.2.2.1 above, the TRS data represent the relative capacities of the source relays corresponding to a 2-ms chatter criterion or a load device trip. The capacity TRS of CO9 for the 2-ms chatter criterion is comparable to those for a load device trip (Figure 4.82). But, for IAC and IAV relays, the capacity TRS based on the chatter data are substantially higher than those based on the load device trip data. The above results were obtained from shaking of the source relays while the load devices were located on a stationary stand.

Subsequently, both the source relays and the load devices were installed in a switchgear cabinet, and the entire assembly was shake-table tested with multifrequency input motion (Figure 4.85). The electrical setups were the same as before (i.e., five setups as shown in Table 2.3 in Chapter 2). The purpose of using the cabinet was to amplify the input motion through a switchgear cabinet structure but this does not necessarily represent any realistic switchgear configuration since the cabinet was reinforced with thick angle irons at four corners and other locations. Moreover, the breaker barrier box cover was removed to reduce amplification and torsion in the structure. Thus, the mass was not necessarily representative of any switchgear cabinet in the field. In spite of stiffening of the cabinet structure and reduction of mass, the cabinet was damaged at several locations including anchorage weld and required repair several times.

The control TRS data representing the shake table motion, i e., the TRS of the input motion applied at the base of the cabinet, are shown in Figures 4.86 through 4.100. These data represent the highest vibration levels at the cabinet base at which the particular source relays did not chatter for a duration of 2 ms or greater, did not trip a load device or did not cause a load device to chatter for a duration of 2 ms or greater. For example, as shown in Figure 4.86, when installed in the switchgear cabinet, the overcurrent relay CO9 chattered for a duration of 2 ms or greater at an input motion much stronger than the motion required for CO9 to trip a load device located at a suitable place on the same cabinet. Unlike all other information presented earlier, these TRS plots were obtained for each of the three orthogonal directions in incoherent triaxial tests (i.e., three axes were excited simultaneously).

4.2.3 Influence of Monitoring Current on Relay Chatter

The electrical discontinuity (or continuity) in a relay is measured by drawing current from the relay contact in a monitoring circuit. In an effort to determine the influence of this monitoring current on the chatter characteristics of the relay during a vibration test, the electrical discontinuity was monitored during the test with three different current levels (1 amp, 150 milliamps and 25 milliamps) by varying the resistance of the monitoring circuit. For the tested operating modes of the relays, although there seems to be a tendency for longer chatter at a higher current level, no definite rule can be established from the test data. For example, Table 4.2 shows data for CO9, IAV and IAC relays obtained during single frequency sine dwell tests. For CO9 relay, the data suggest that a larger monitoring current level indicates chatter of longer durations and greater number of events. However, this trend is not necessarily supported by the data for the IAV and IAC relays. In fact, the chatter data for IAV at 25 mamps and 150 mamps support contrary arguments. However, an observation can be clearly made from these and other chatter data that the chatter characteristics can be influenced by varying the monitoring current.

4.2.4 Influence of Drawing Monitoring Current on Trip

The outputs of the source relays were connected to the load devices to determine the trip. At the vibration level when the load devices tripped, the test was repeated by drawing current from the source relay contact in a high-resistance parallel circuit (i.e., low current) to determine the chatter duration required for the trip. Most often the load device tripped at the repeat test (at the same vibration level) when contact chatter was monitored, but at other times it did not trip and required a higher input motion for trip. Therefore, there seems to be a tendency for requiring a slightly higher input motion to trip a load device when monitoring current is drawn from the source relay contact in a parallel circuit.

4.2.5 Influence of Voltage Drop in Load Devices

Certain vibration tests were repeated by dropping voltage from the rated value of 125 VDC to 100 VDC. The highest vibration level at which the load device did not trip or the lowest level at which it tripped seems not to be appreciably influenced by the voltage drop. On many occasions, there were slight increases in the required motion at the lower voltage. Similarly, at many other tests, either there were no changes or slight reductions at the lower voltage.

On the other hand, the electrical tests consistently demonstrated that the total trip time or the pulse duration is appreciably greater with a voltage drop to 100 VDC (e.g., Table 3.1). This means that a higher vibration level would have been required to cause a trip at 100 VDC. But the vibration data do not consistently support this hypothesis. One possible explanation is that once a chatter level is reached the characteristics are very nonlinear and the exact chatter duration is unpredictable.

4.3 TASK 2 TEST DATA

Three specimens of each of HMA124, SC and SVF were tested with single frequency sine dwell input motion in their respective weakest modes. The results are presented in Figures 4.101 through 4.106. As mentioned earlier, these relays had been tested in the first series of testing and the results were reported in NUREG/CR-4867 [3]. However, at that time, the relays were tested as they were received from the manufacturers. In the current test program, the specimens of the same relay model were adjusted following the manufacturer's specifications to achieve the same electrical characteristics, i.e., pick-up and drop-out voltage.

The data for HMA124 show reasonable comparison in the front-to-back direction (Figure 4.101). In the vertical direction, the data for specimens 1 and 3 are comparable but both are substantially lower than the capacity data for specimen 2 at most frequencies (Figure 4.102). In spite of this difference, these results show a much better consistency than what had been observed in the earlier test program [3].

On the other hand, the test data for SC presented in Figure 4.103 and 4.104 show wide differences among the specimens. During the earlier physical inspection in the electrical testing laboratory, specimen 1 was suspected to be different. Even if the data for specimen 1 are ignored, the difference between specimens 2 and 3 is enormous especially in the vertical direction[2]. For example, specimen 2 has a capacity of around 0.5 g at frequencies up to 30 Hz whereas specimen 3 was successfully tested to the machine limit (i.e., 2.5 g between 5 Hz to 20 Hz) without any chatter.

For the SVF relays, the front-to-back data cannot be used to compare the differences since all three specimens reached the machine limit. In the vertical direction, they all indicated chatter even at the lowest acceleration level up to 30 Hz. Beyond 30 Hz, specimens 2 and 3 indicated slightly larger capacities. Thus, the SVF relays seem to have demonstrated reasonably consistent performance.

In summary, although many relay models are expected to show reasonably consistent capacity levels (e.g., variation by a factor of two) among specimens, some other relays can produce remarkable variations (e.g., variation by a factor of seven) in their capacity levels among specimens. Thus, testing of a single specimen can be very misleading. A focussed and careful inspection of relays in the energized state indicated physical differences in armature engagement conditions and air gap in the magnetic circuit. However, all these relays procured by BNL are commercially available relays and not Class 1E devices.

4.4 TASK 3 TEST DATA

In order to correlate the single frequency input motion data with the multifrequency TRS at the capacity levels, two specimens of HFA were tested with both single frequency sine dwell and multifrequency motions. The multifrequency motion was adjusted such that the TRS plots matched with the respective single frequency input shape with an aim to achieving a constant multiplier. The relay specimens were tested for the controlling electrical mode and vibration direction. The results are presented in Figures 4.107 and 4.108. For the sine dwell input curve, the major capacity values (between 5 Hz and 30 Hz) were within the machine

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[2] The comparison in the horizontal direction could not be made for specimens 2 and 3 due to limitations of the shake table.

limit and thus were useful. Multifrequency capacity tests were repeated with several time histories and thus more than one capacity TRS were obtained.

The ratios of the multifrequency TRS at a damping value of 5% to the sine dwell input motion amplitude was computed at discrete frequencies and the resulting curves over the frequency of interest are shown in Figure 4.109. Multiple plots for the same specimen correspond to the respective capacity TRS data. For most frequencies, the ratio is between 2 and 3 and the mean value is about 2.7 in the frequency range of 5-30 Hz. This ratio is similar to what had been obtained from the earlier test series for another relay model, i.e., SG relay [3].

In summary, a multiplication factor between 2.5 and 3.0 seems to be reasonable to convert the single frequency sine dwell capacity input data to the corresponding multifrequency capacity TRS at a damping value of 5%.

4.5 CONCLUSIONS

A large number of vibration test runs were conducted with various electrical and vibration parameters in independent and integral circuit configurations. The data show a wide variation of results. However, for many electrical parameters, it is difficult to establish any definite trend. A summary of the general observations is presented in the next chapter.

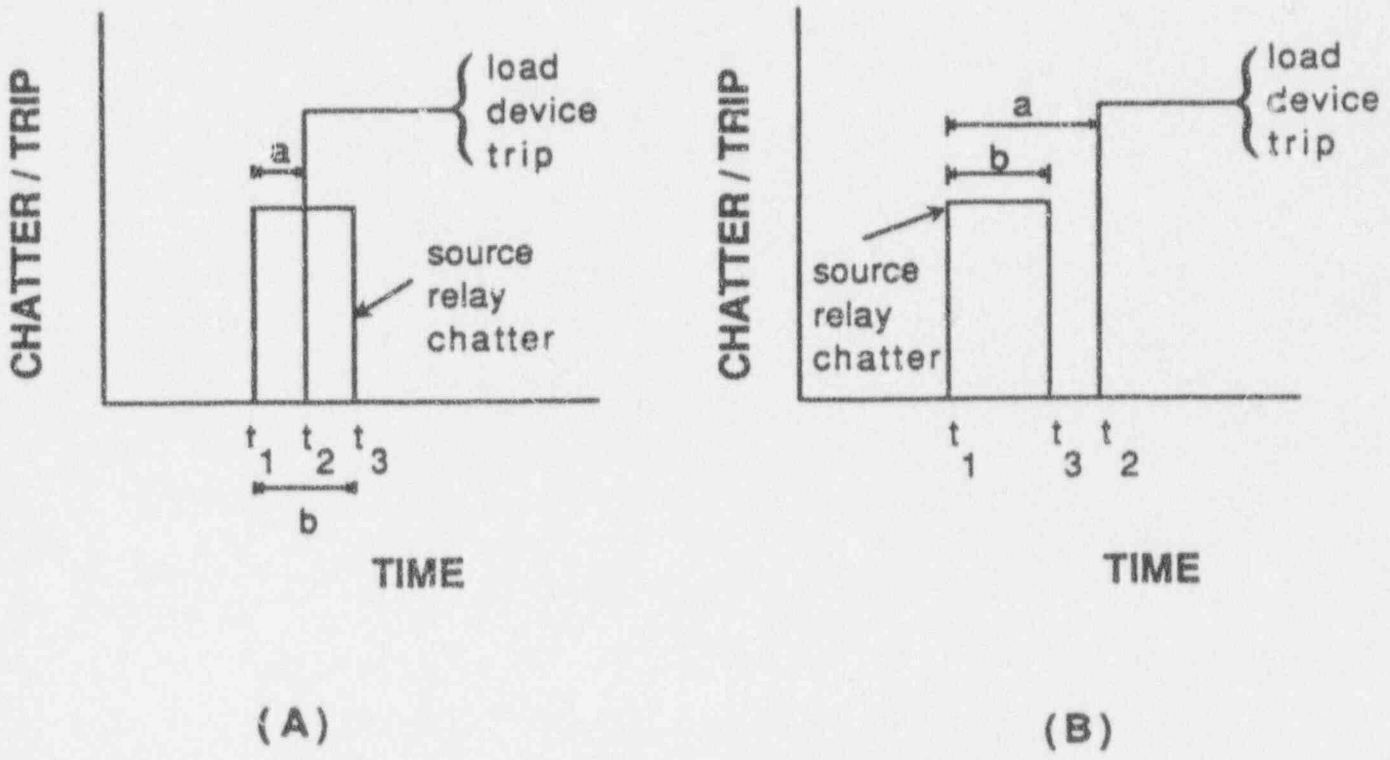

Figure 4.1 Effect of Source Relay Chatter on Load Device

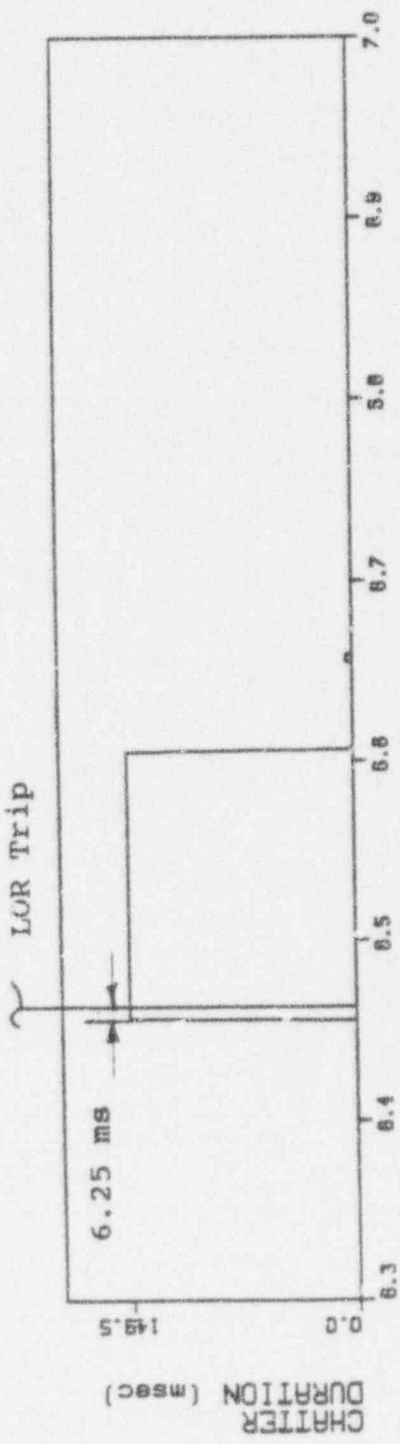

Figure 4.2 Effect of CO9 Chatter on LOR, Plot 1

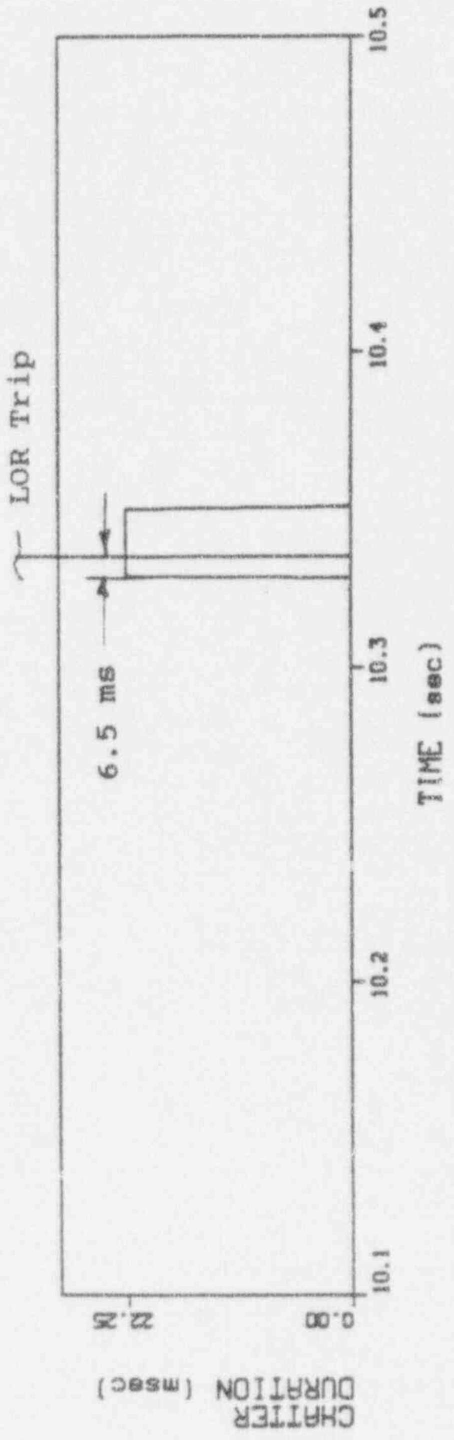

Figure 4.3 Effect of CO9 Chatter on LOR, Plot 2

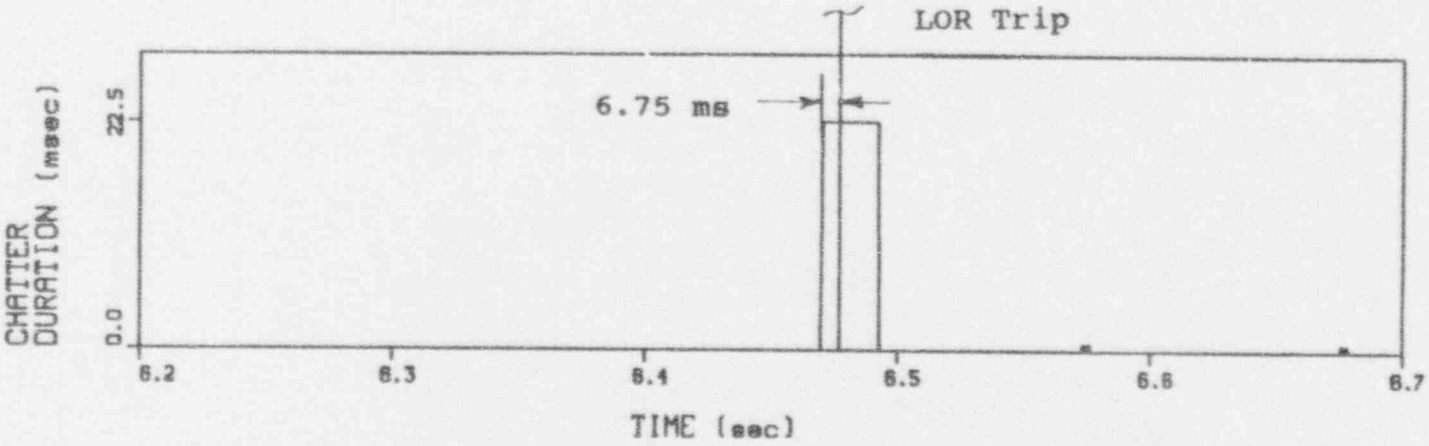

Figure 4.4 Effect of CO9 Chatter on LOR, Plot 3

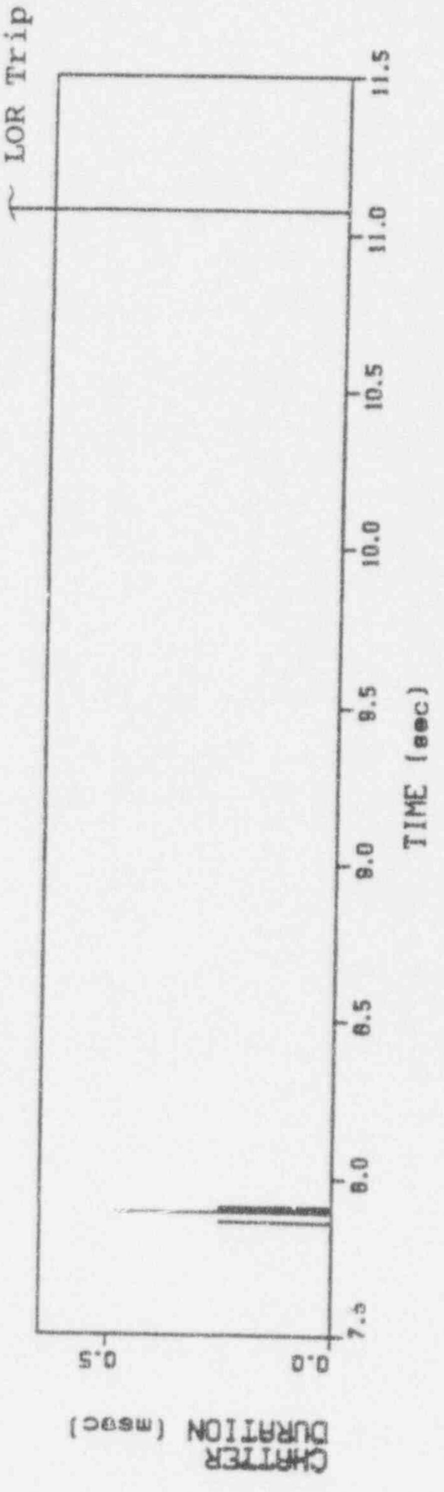

Figure 4.5 Effect of IAC Chatter on LOR, Plot 1

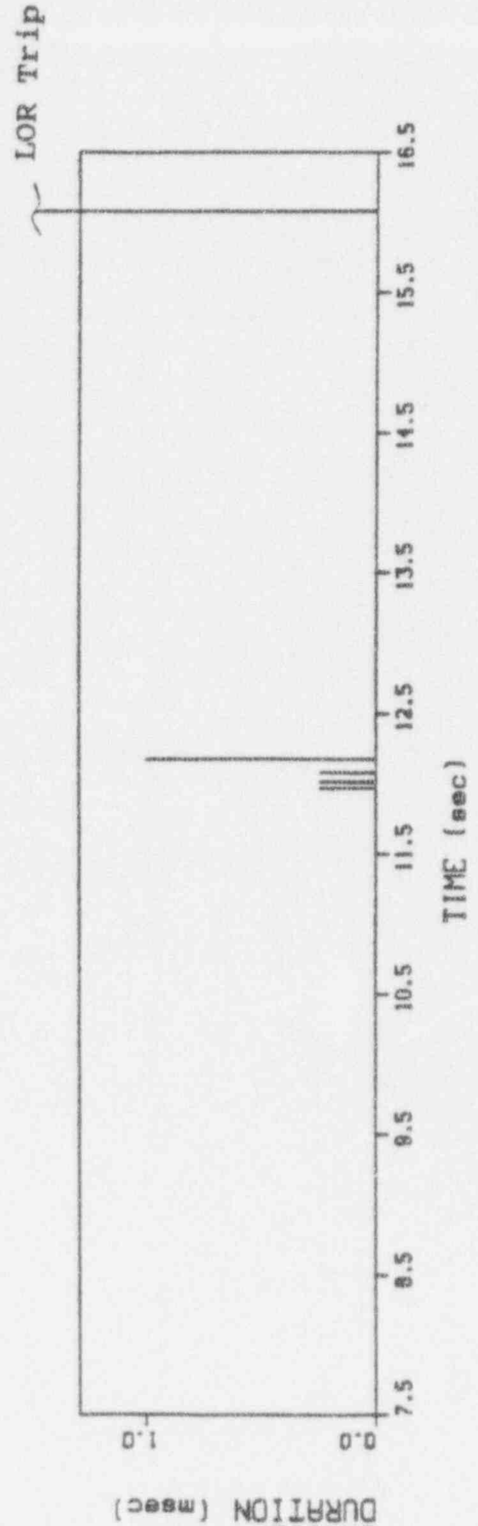

Figure 4.6 Effect of IAC Chatter on LOR, Plot 2

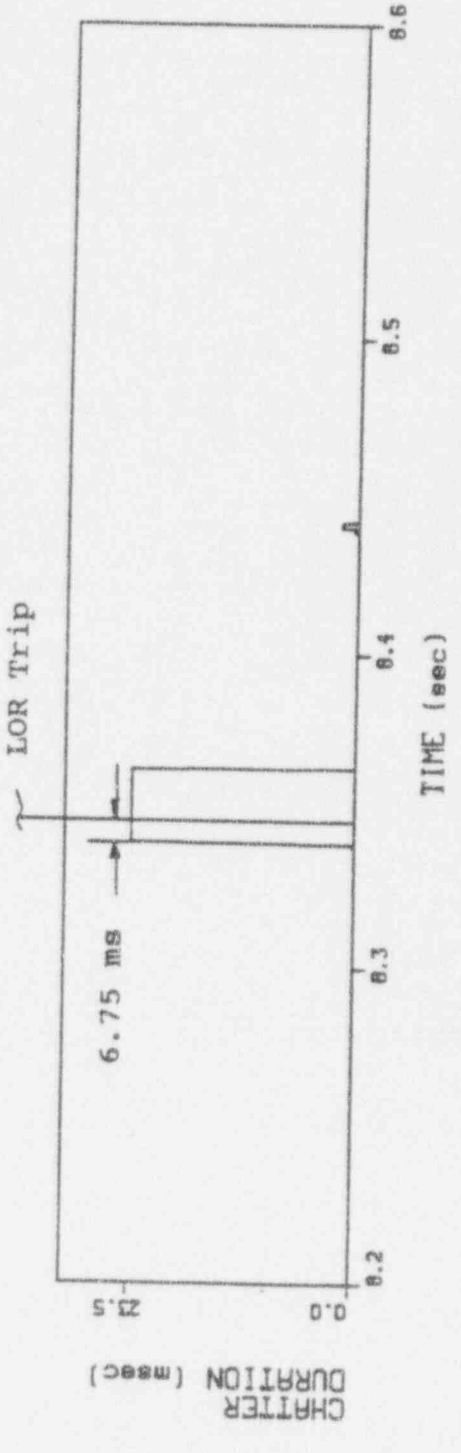

Figure 4.7 Effect of IAC Chatter on LOP., Plot 3

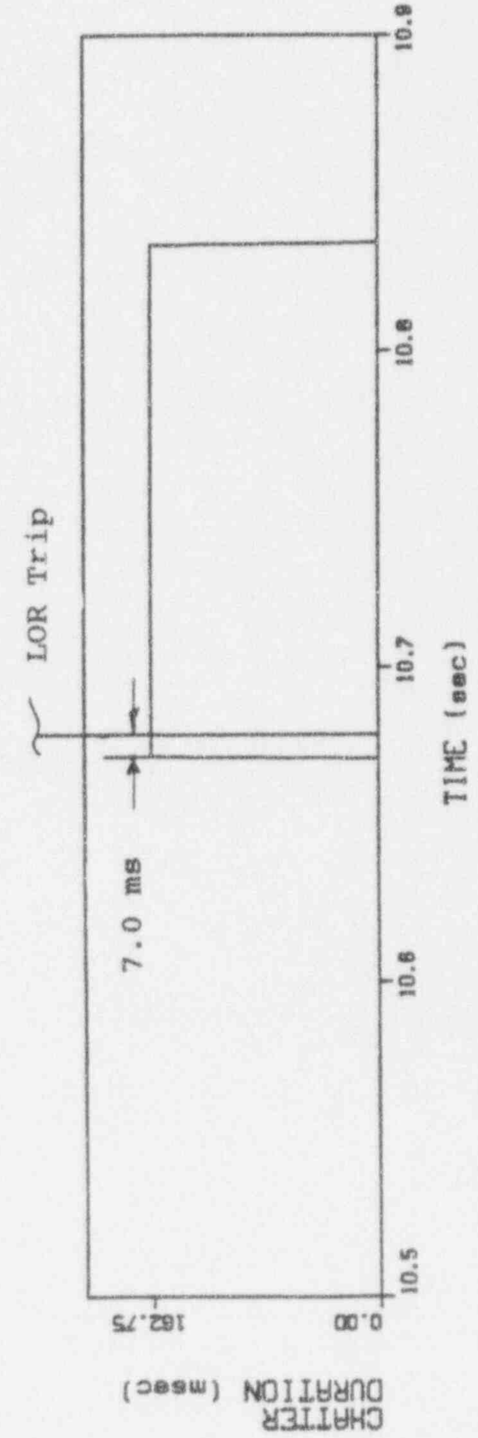

Figure 4.8 Effect of IAC Chatter on LOR, Plot 4

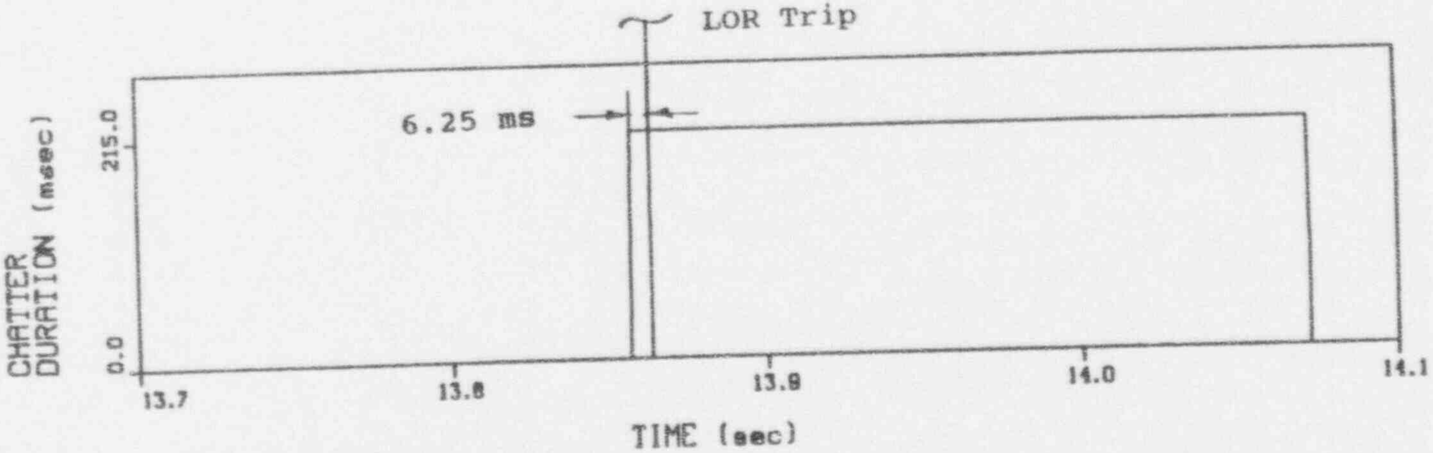

Figure 4.9 Effect of IAC Chatter on LOR, Plot 5

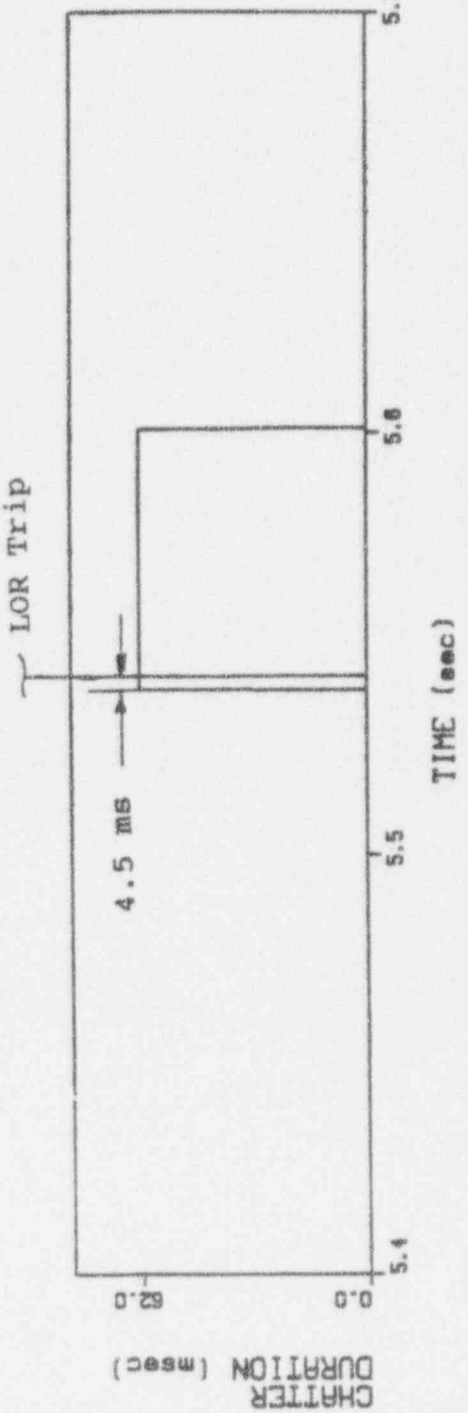

Figure 4.10 Effect of IAC Chatter on LOR, Plot 6

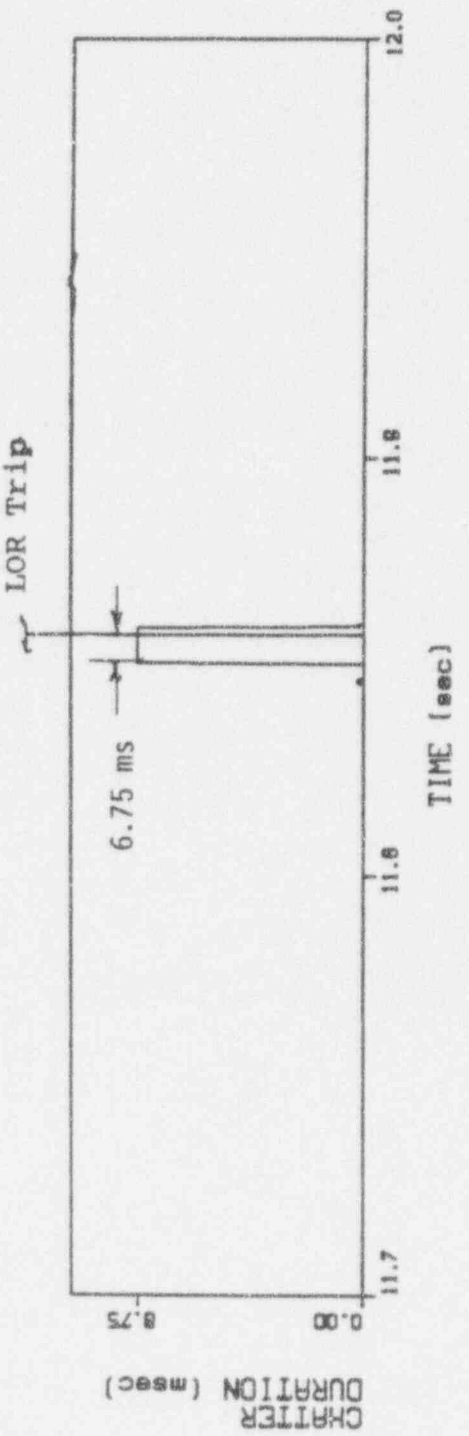

Figure 4.11 Effect of IAC Chatter on LOR, Plot 7

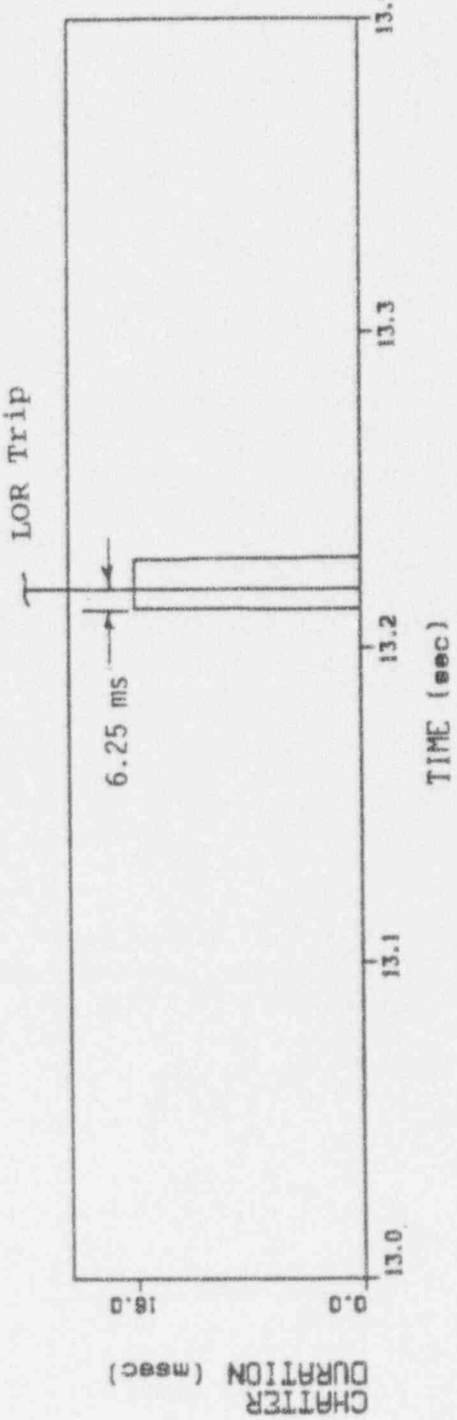

Figure 4.12 Effect of IAV Chatter on LOR, Plot 1

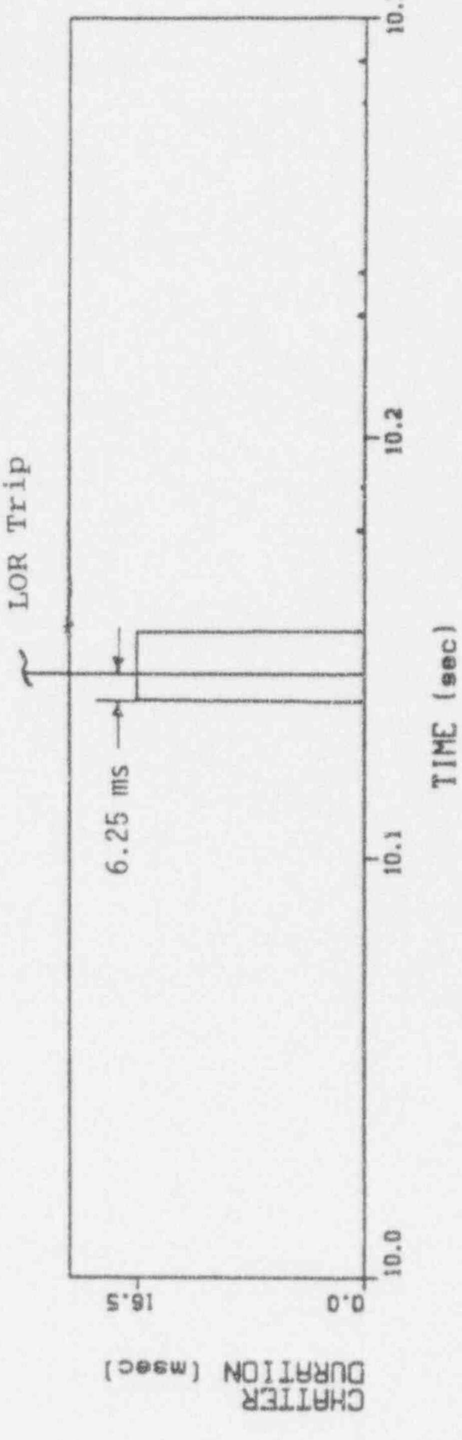

Figure 4.13 Effect of IAV Chatter on LOR, Plot 2

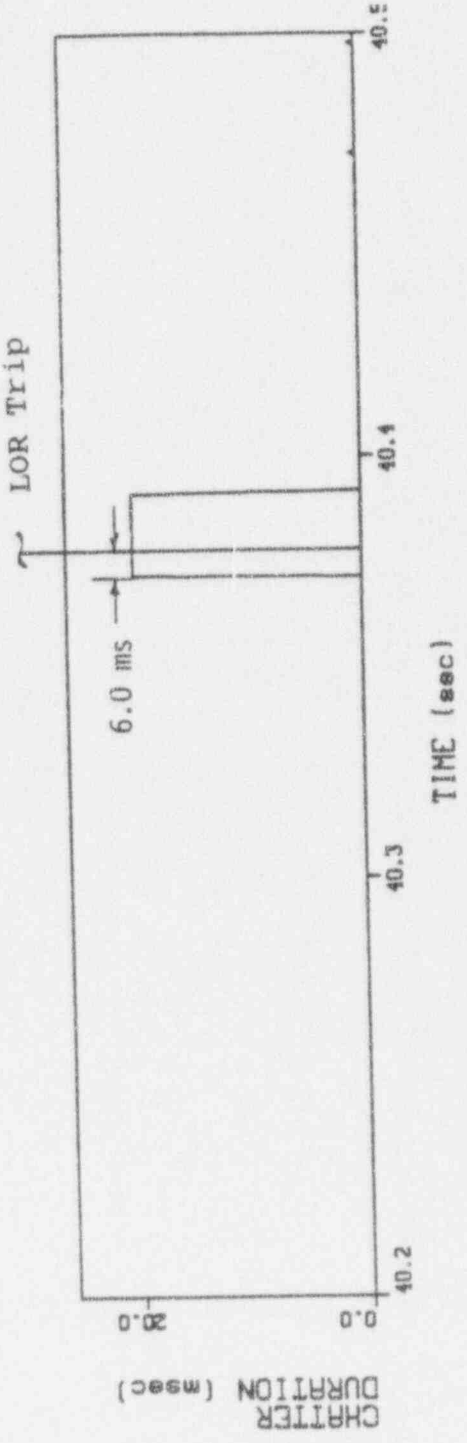

Figure 4.14 Effect of IAV Chatter on LOR, Plot 3

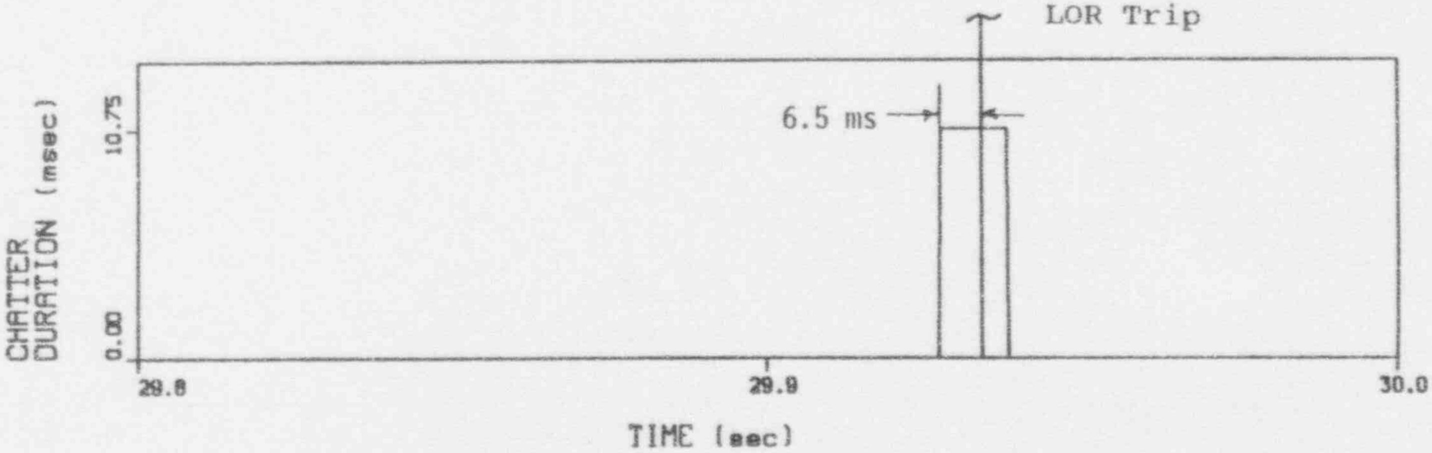

Figure 4.15 Effect of IAV Chatter on LOR, Plot 4

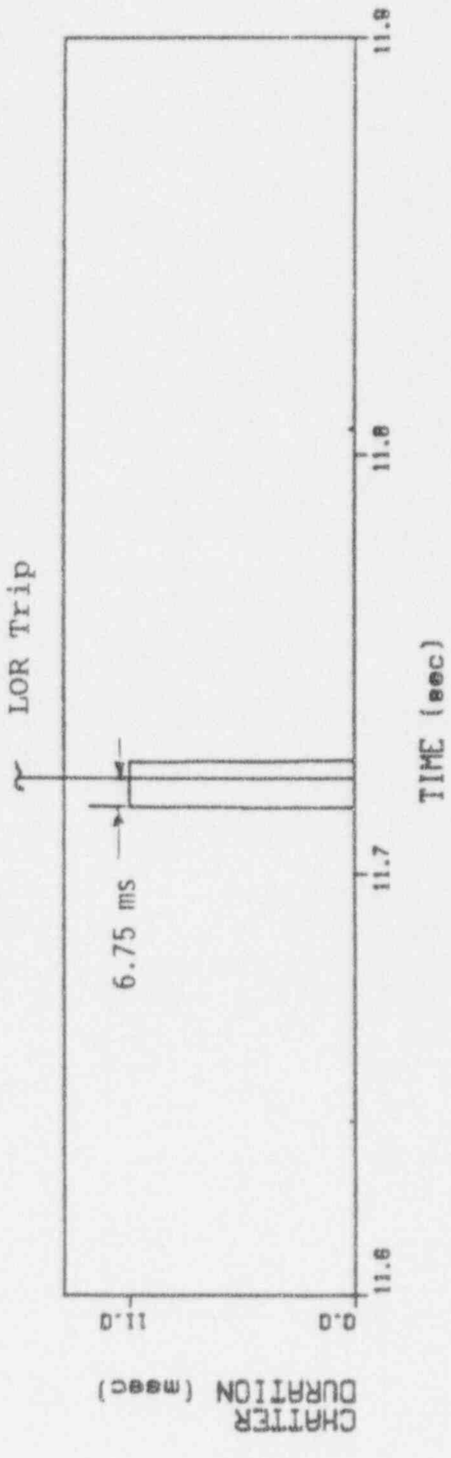

Figure 4.16 Effect of IAV Chatter on LOR, Plot 5

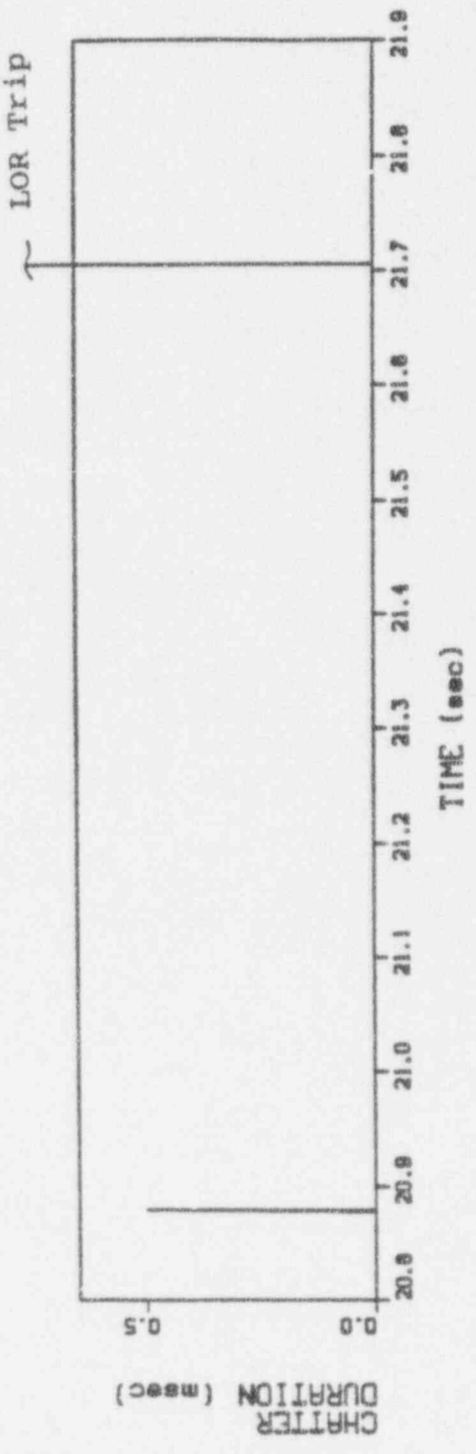

Figure 4.17 Effect of IAV Chatter on LOR, Plot 6

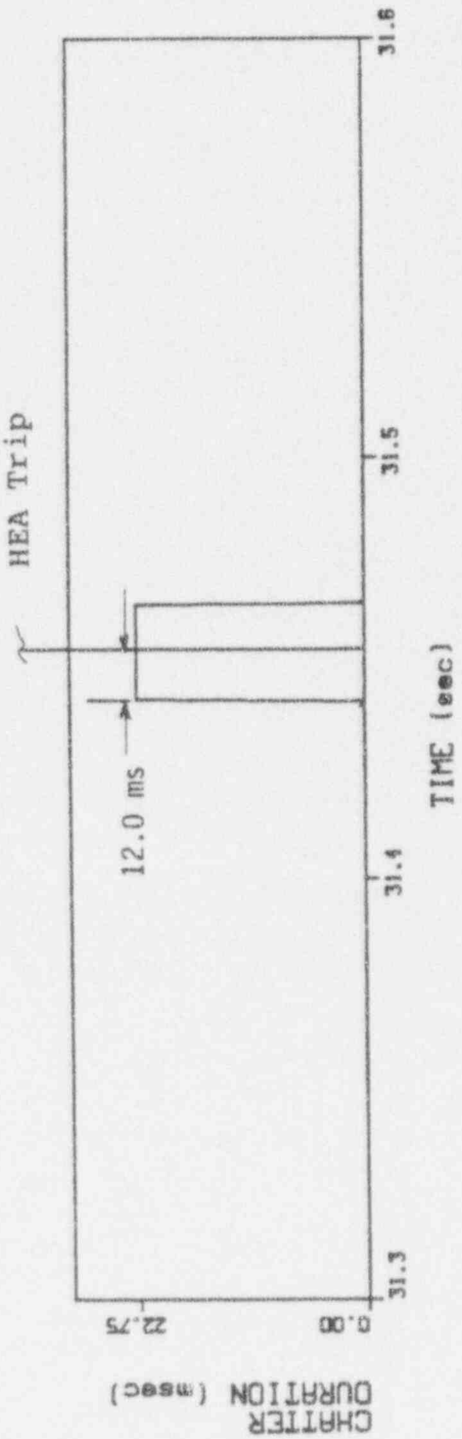

Figure 4.18 Effect of CO9 Chatter on HEA, Plot 1

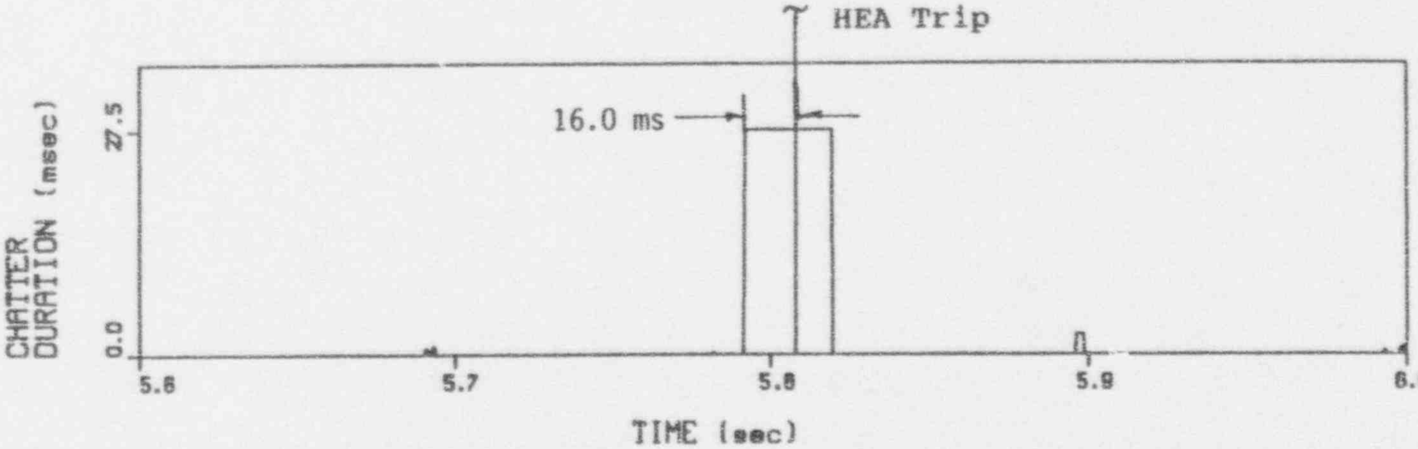

Figure 4.19 Effect of CO9 Chatter on HEA, Plot 2

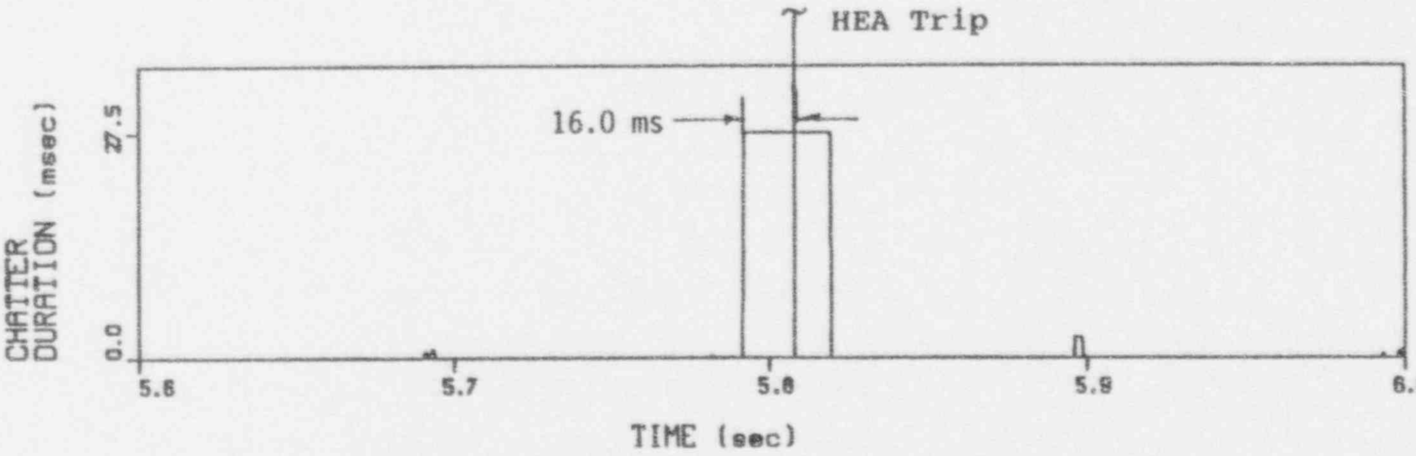

Figure 4.19 Effect of CO9 Chatter on HEA, Plot 2

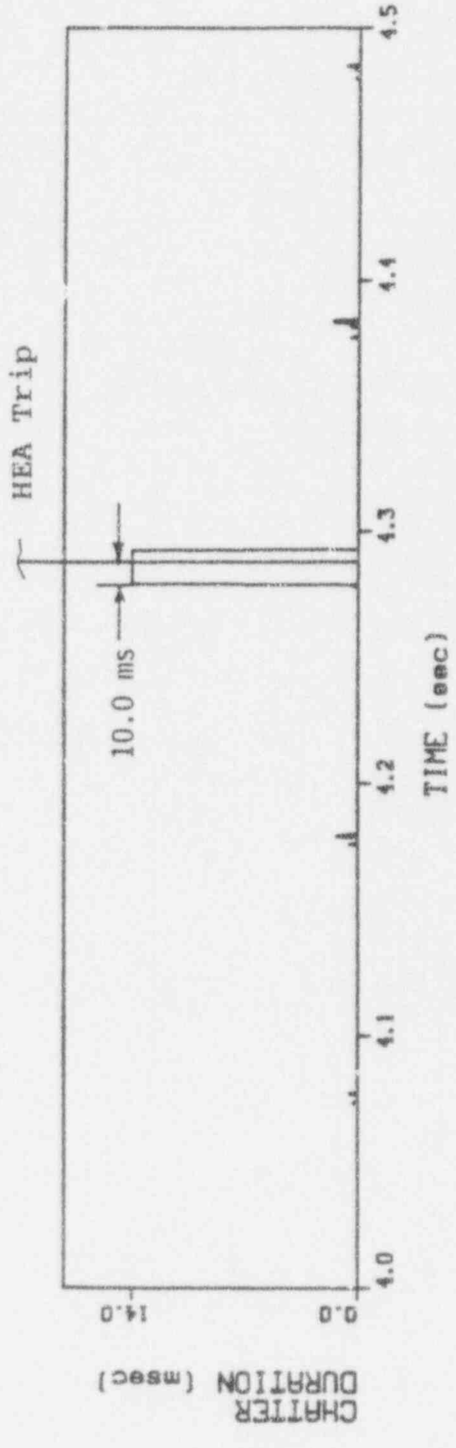

Figure 4.20 Effect of CO9 Chatter on HEA, Plot 3

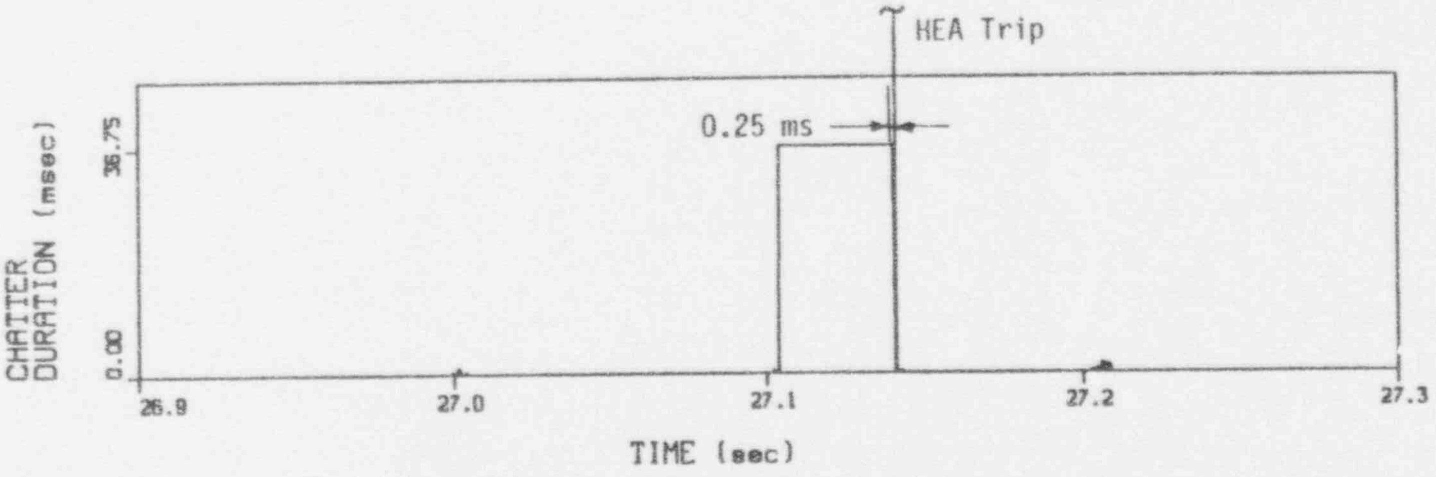

Figure 4.21 Effect of CO9 Chatter on HEA, Plot 4

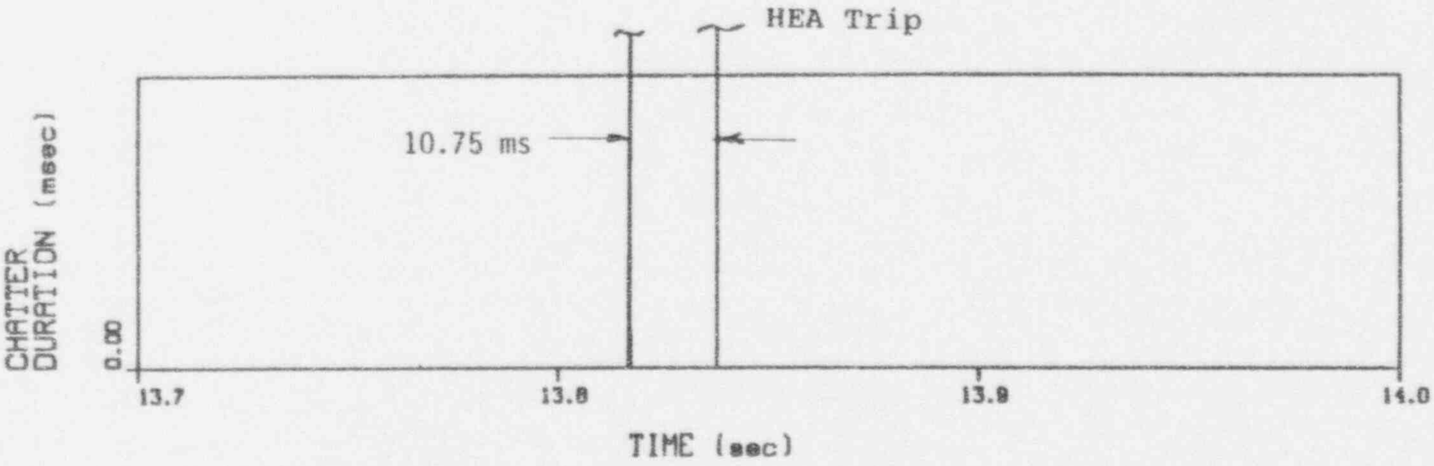

Figure 4.22 Effect of CO9 Chatter/Trip on HEA, Plot 5

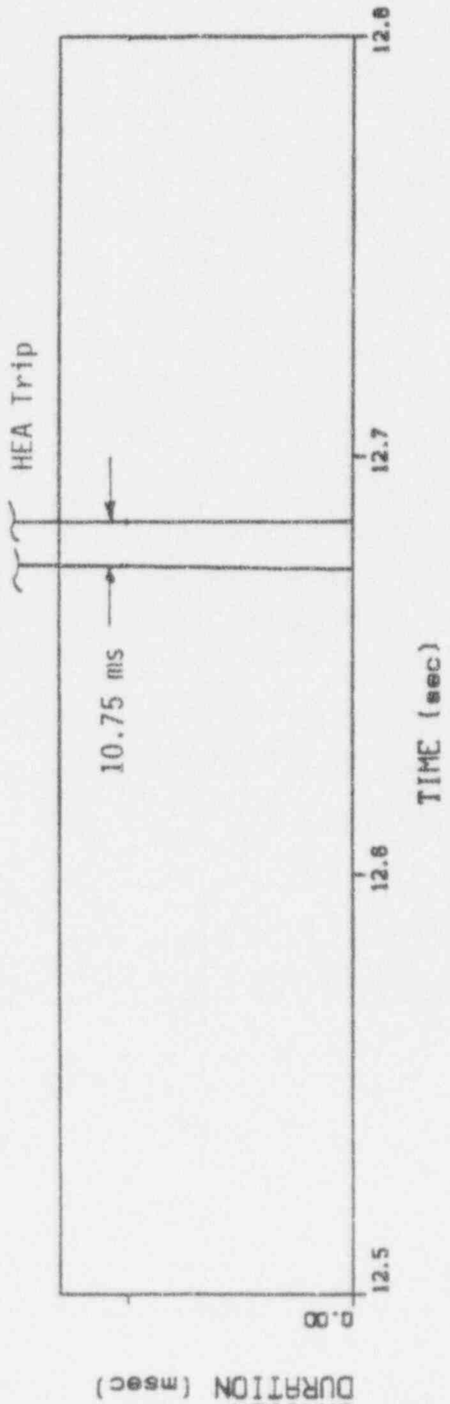

Figure 4.23 Effect of CO9 Chatter/Trip on HEA, Plot 6

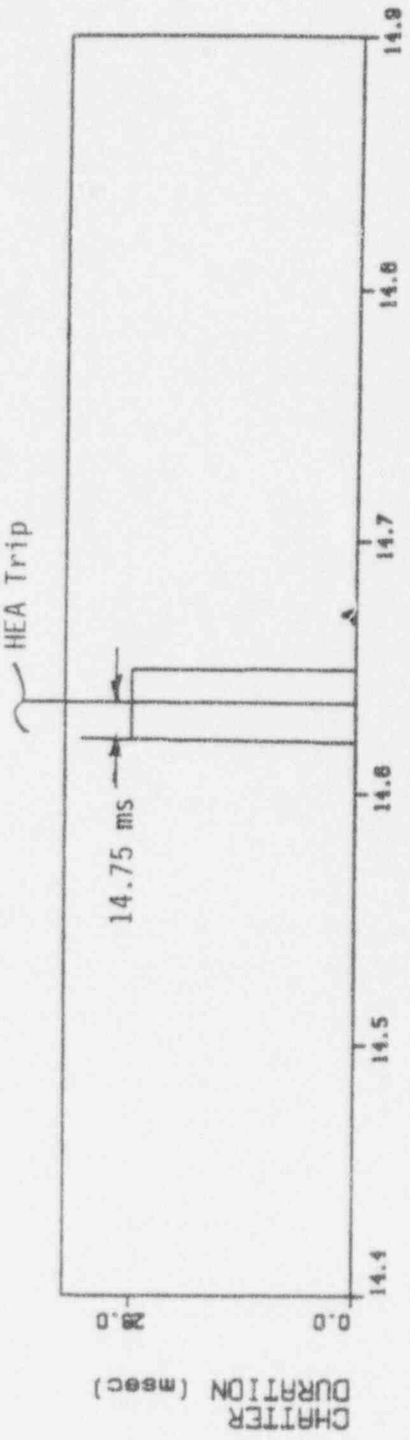

Figure 4.24 Effect of CO9 Chatter on HEA, Plot 7

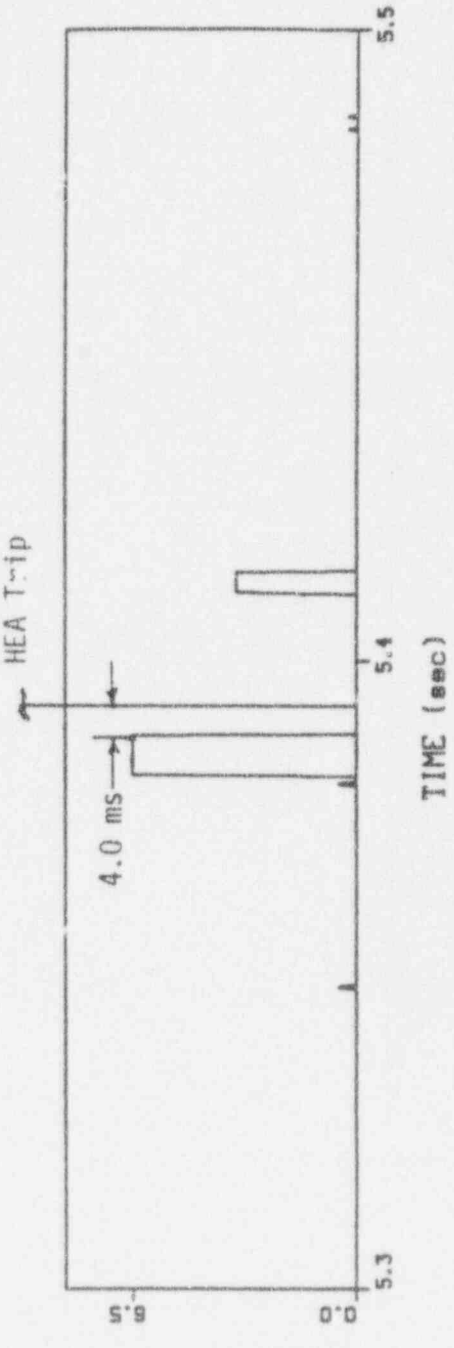

Figure 4.25 Effect of IAC Chatter on HEA, Plot 1

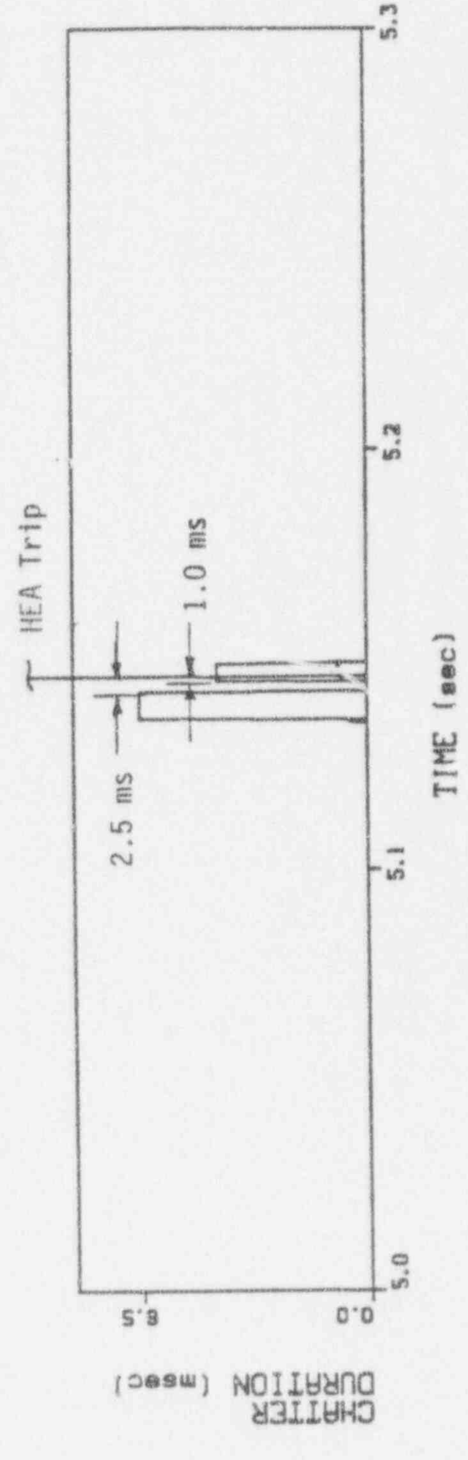

Figure 4.26 Effect of IAC Chatter on HEA, Plot 2

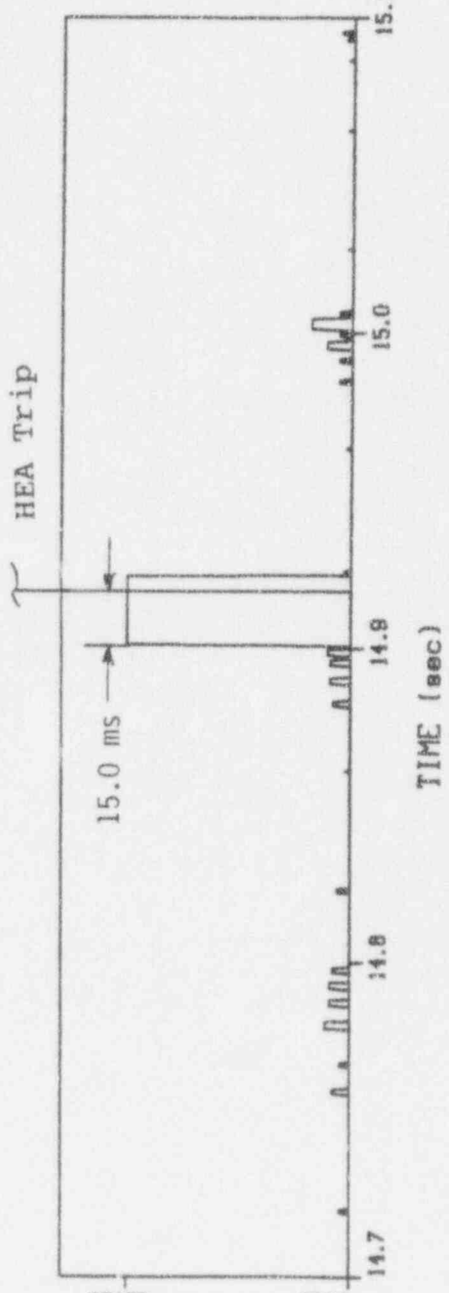

Figure 4.27 Effect of IAV Chatter on HEA, Plot 1

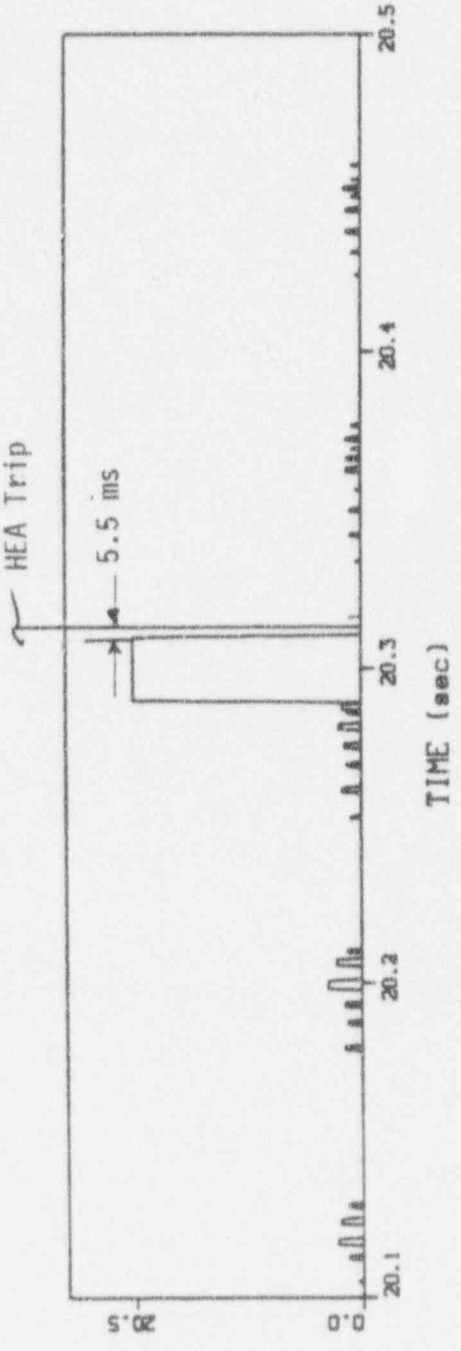

Figure 4.28 Effect of IAV Chatter on HEA, Plot 2

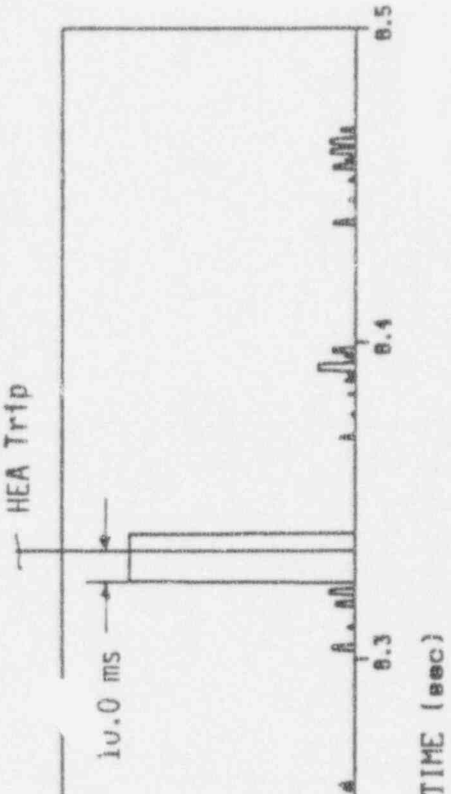

Figure 4.29 Effect of IAV Chatter on HEA, Plot 3

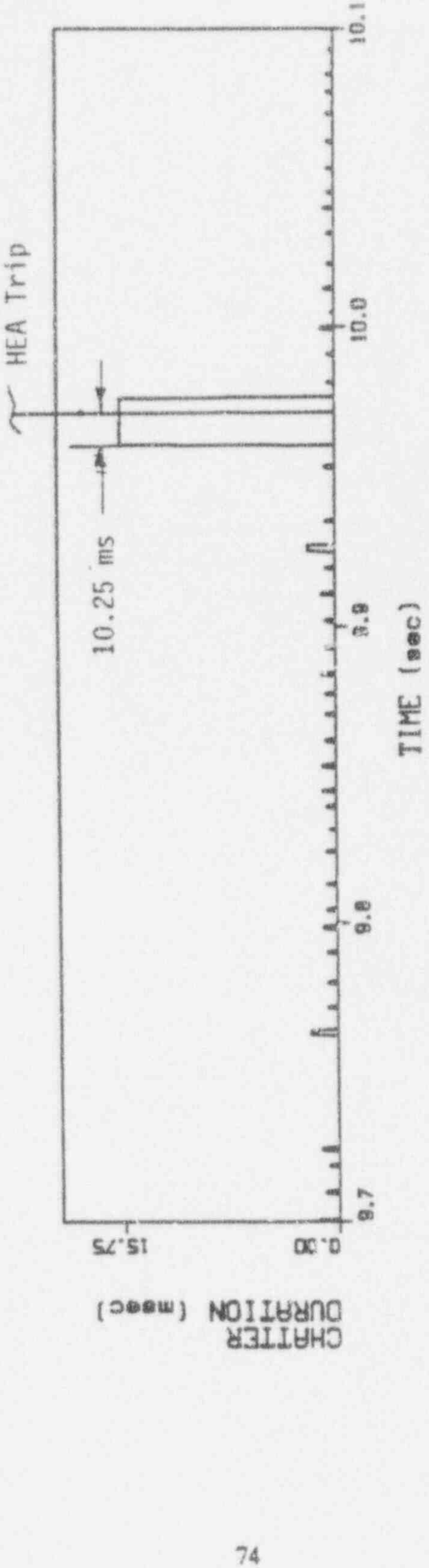

Figure 4.30 Effect of IAV Chatter on HEA, Plot 4

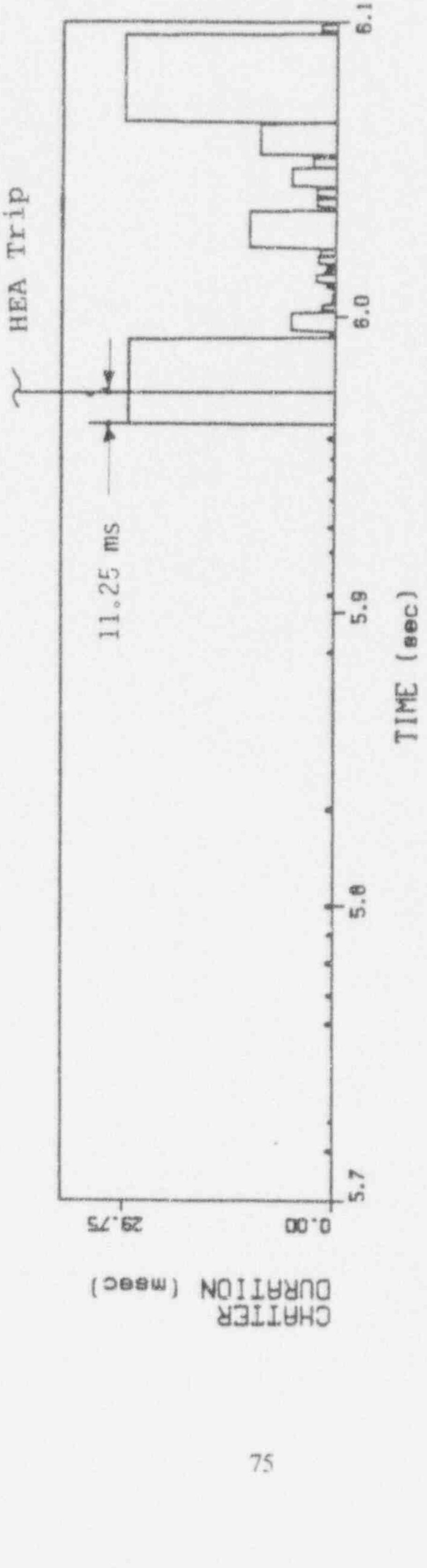

Figure 4.31 Effect of IAV Chatter on HEA, Plot 5

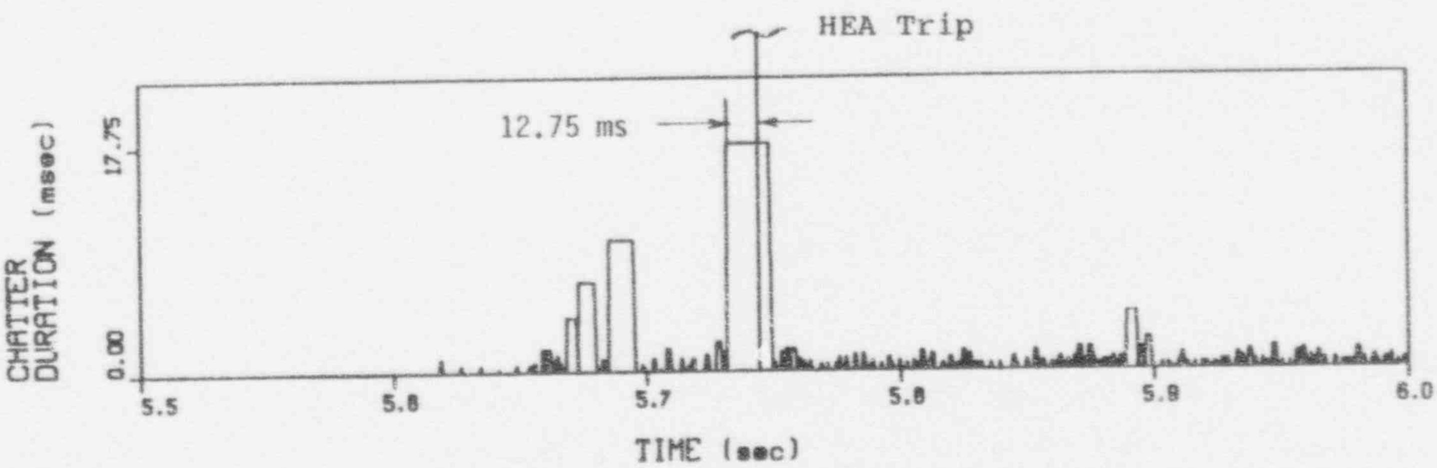

Figure 4.32 Effect of IAV Chatter on HEA, Plot 6

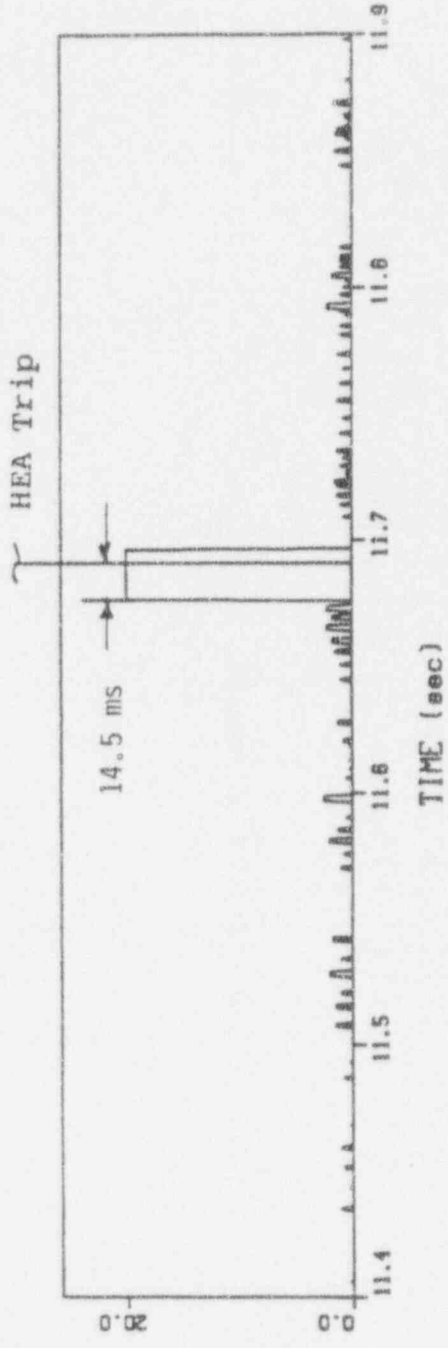

Figure 4.33 Effect of IAV Chatter on HEA, Plot 7

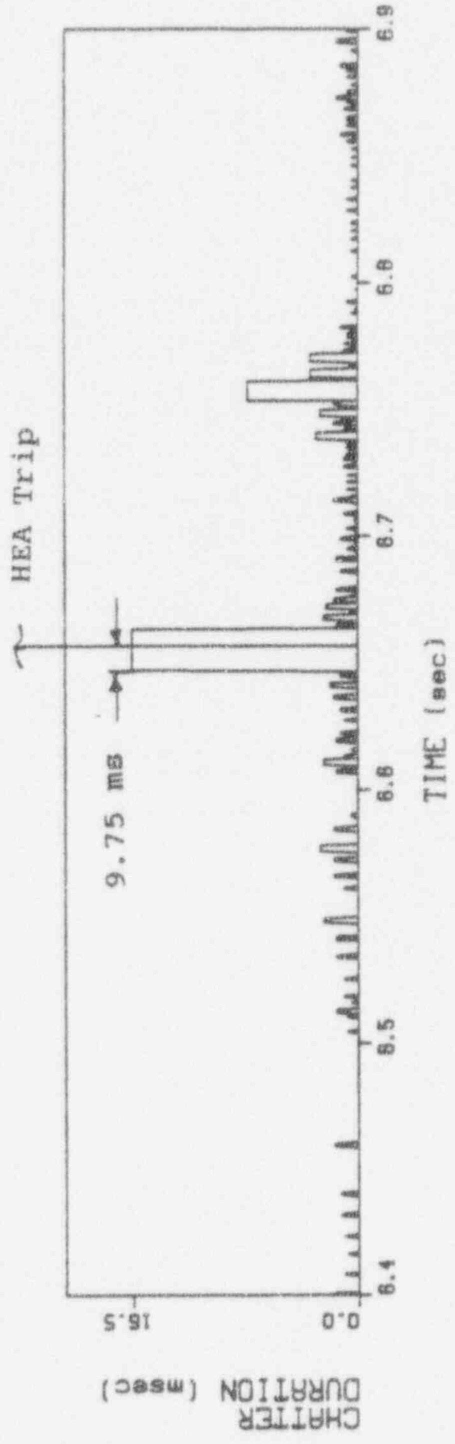

Figure 4.34 Effect of IAV Chatter on HEA, Plot 8

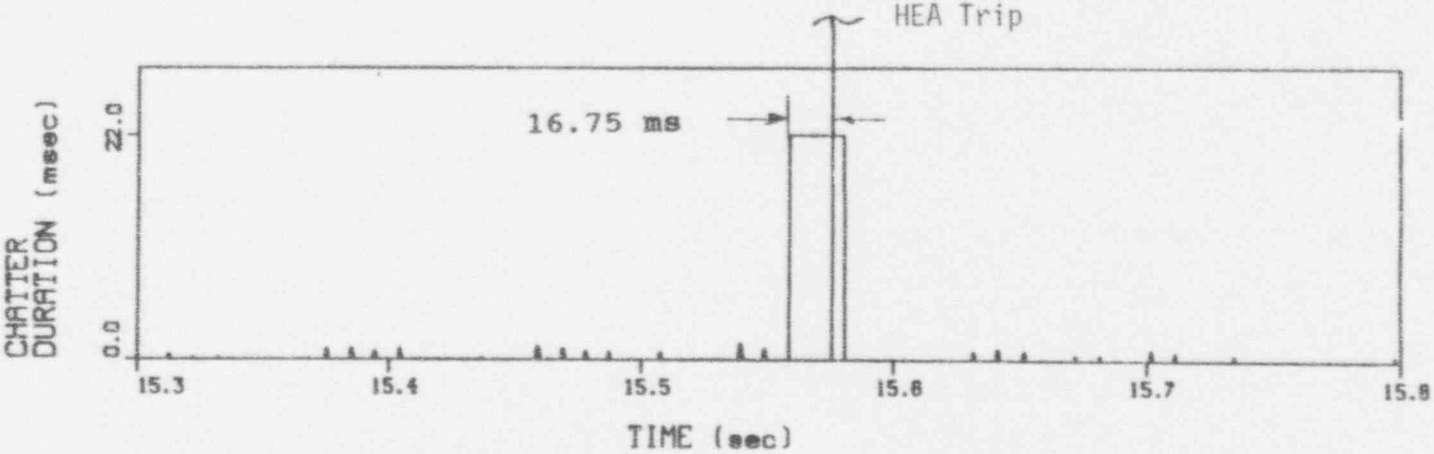

Figure 4.35 Effect of IAV Chatter on HEA, Plot 9

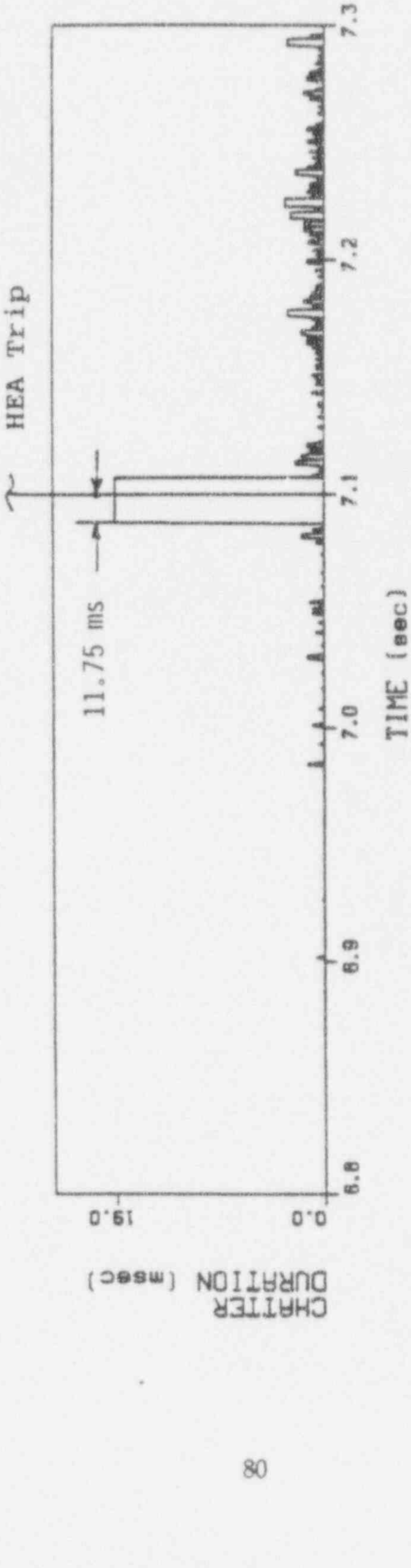

Figure 4.36 Effect of IAV Chatter on HEA, Plot 10

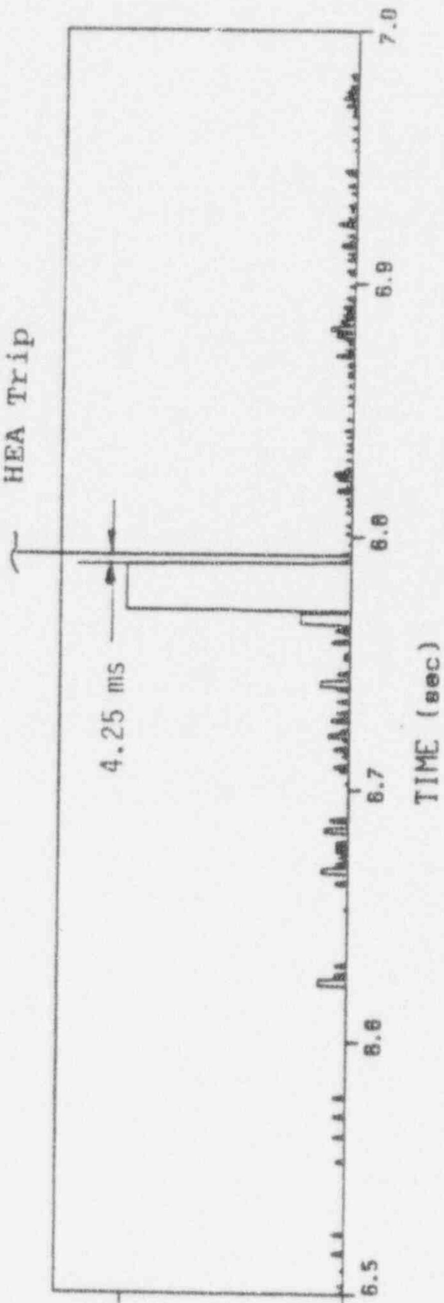

Figure 4.37 Effect of IAV Chatter on HEA, Plot 11

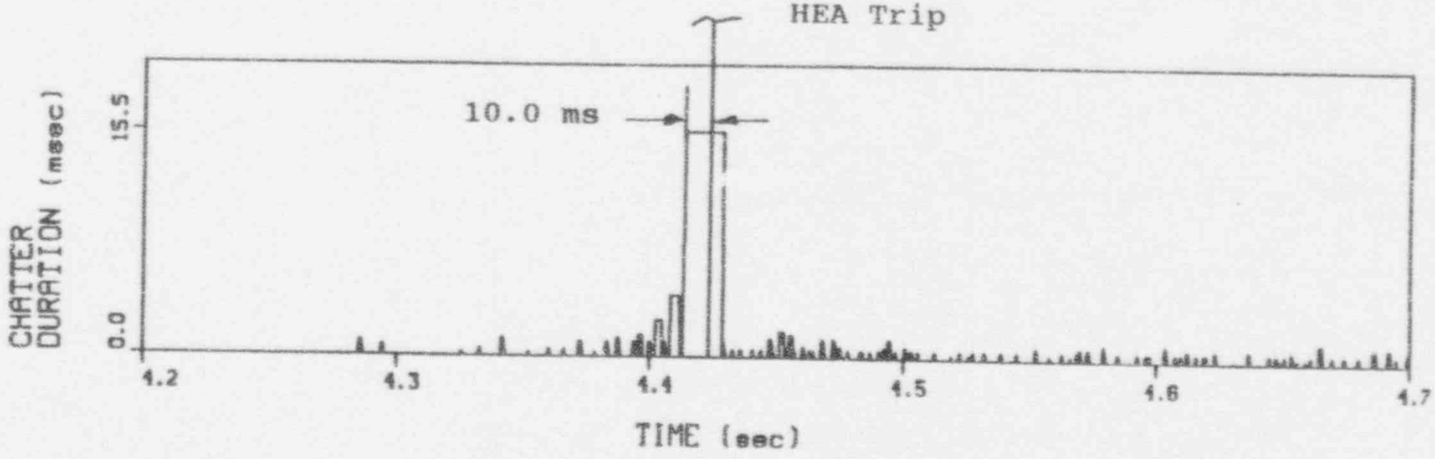

Figure 4.38 Effect of IAV Chatter on HEA, Plot 12

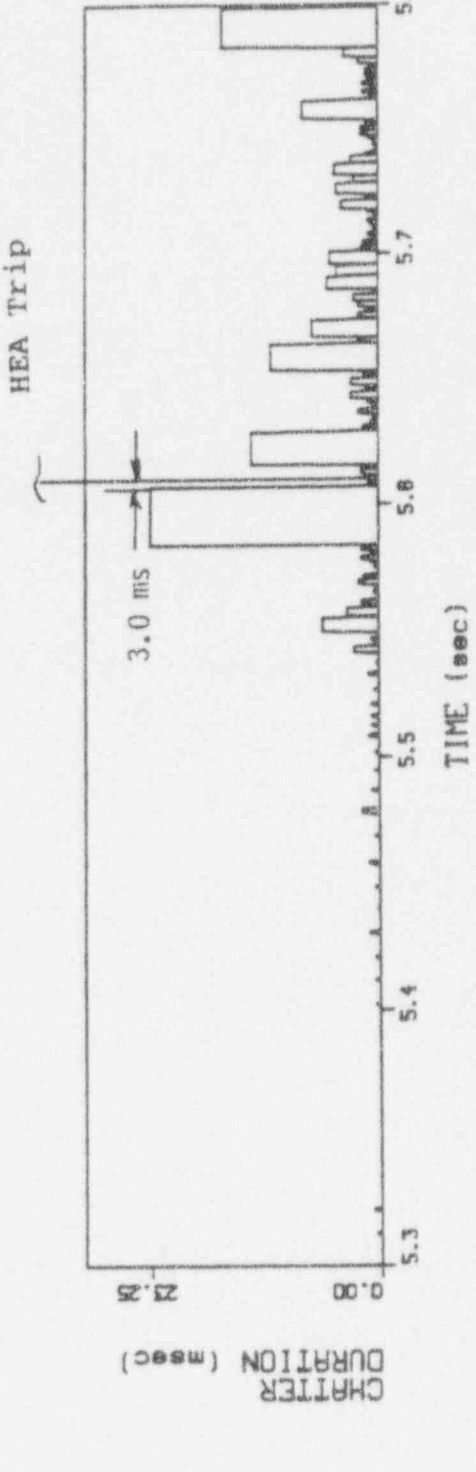

Figure 4.39 Effect of IAV Chatter on HEA, Plot 13

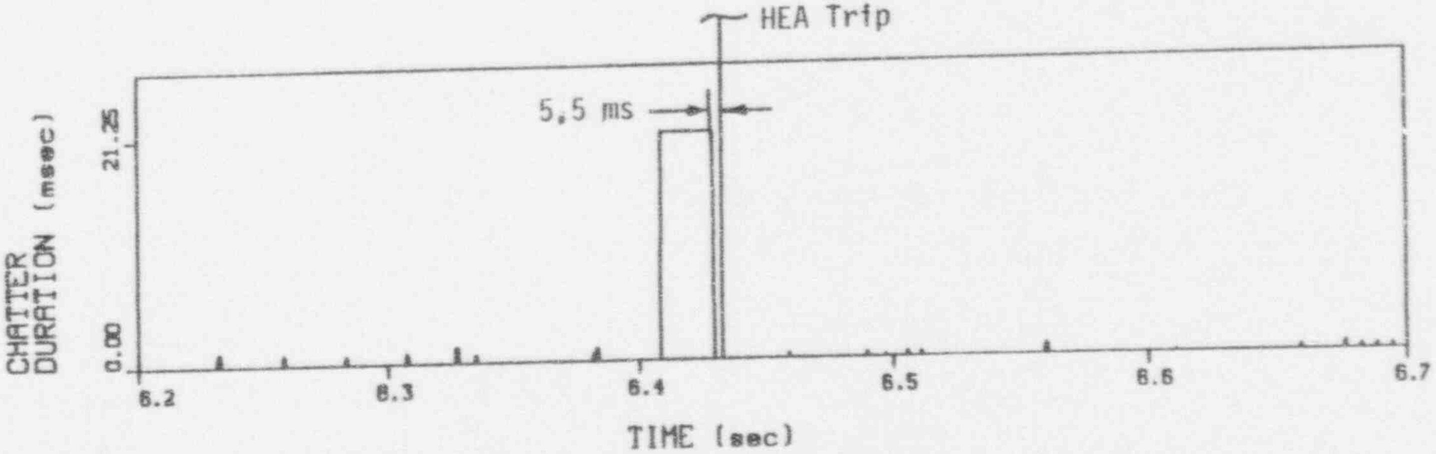

Figure 4.40 Effect of IAV Chatter on HEA, Plot 14

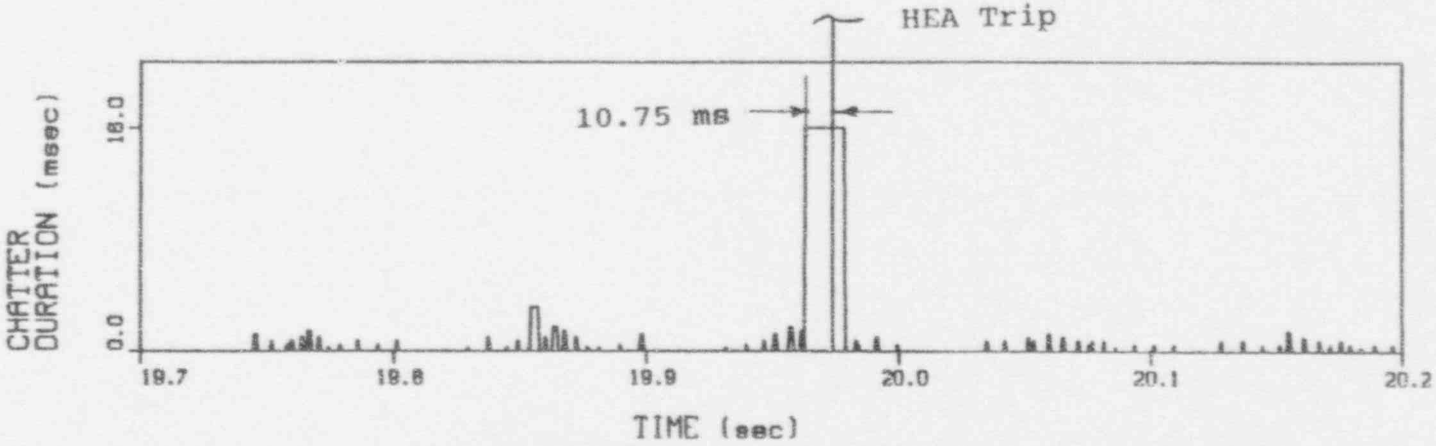

Figure 4.41 Effect of IAV Chatter on HEA, Plot 15

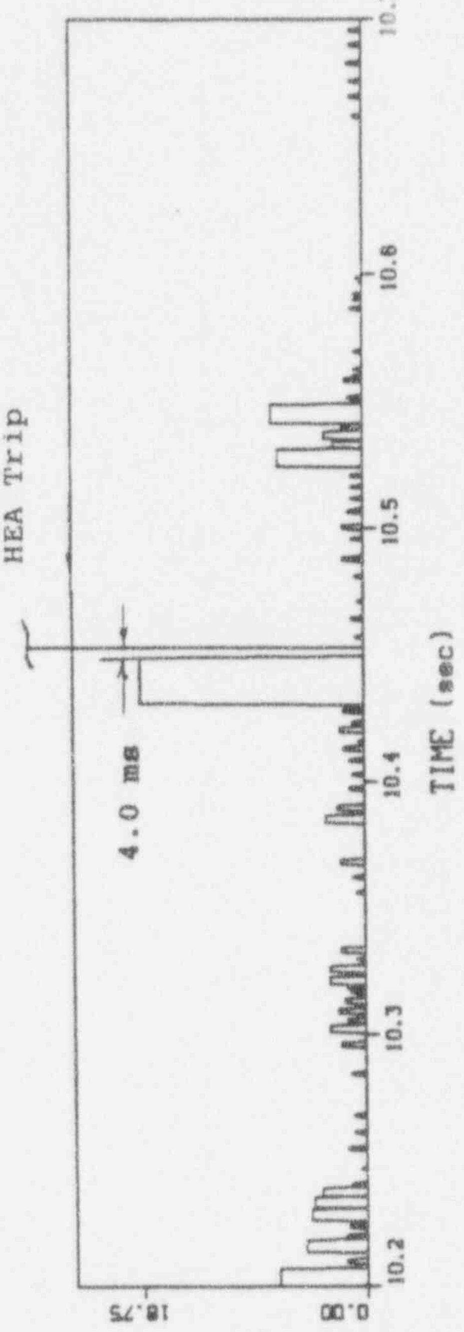

Figure 4.42 Effect of IAV Chatter on HEA, Plot 16

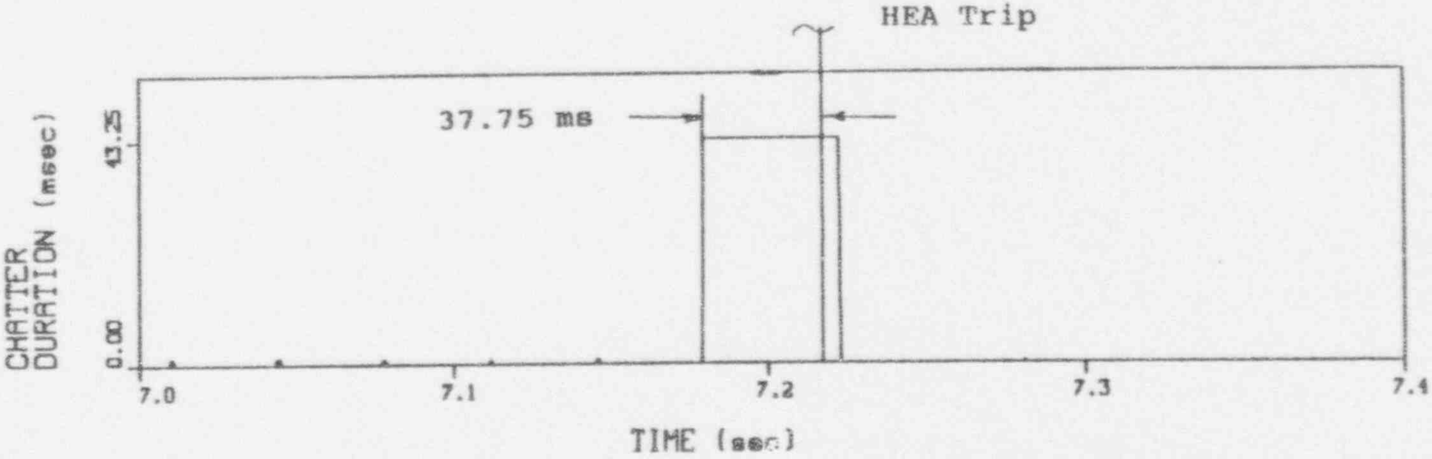

Figure 4.43 Effect of SVF Chatter on HEA, Plot 1

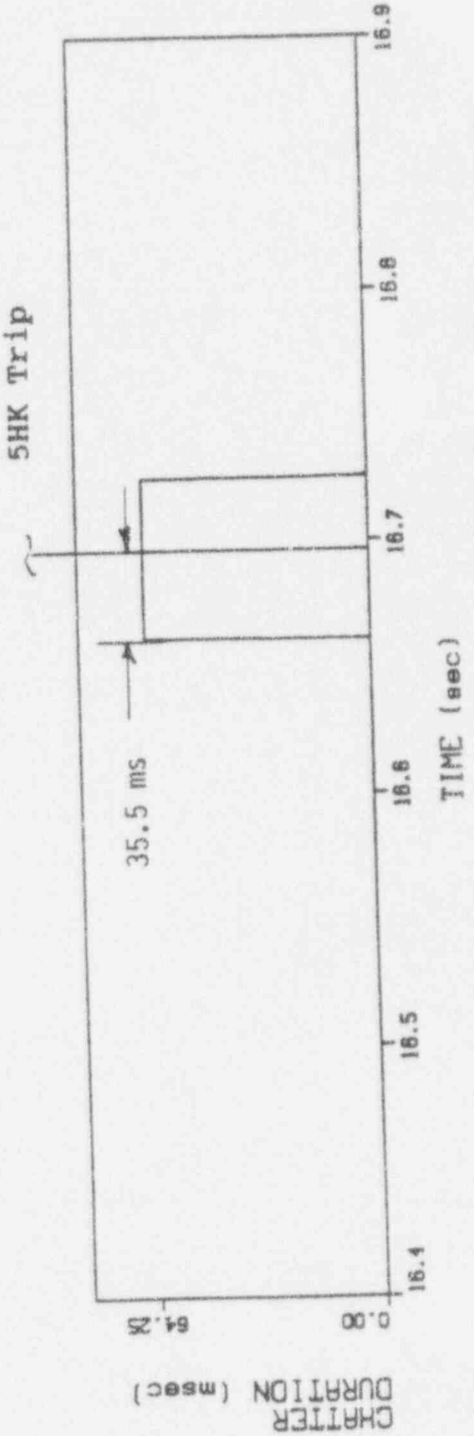

Figure 4.44 Effect of CO9 Chatter on 5HK, Plot 1

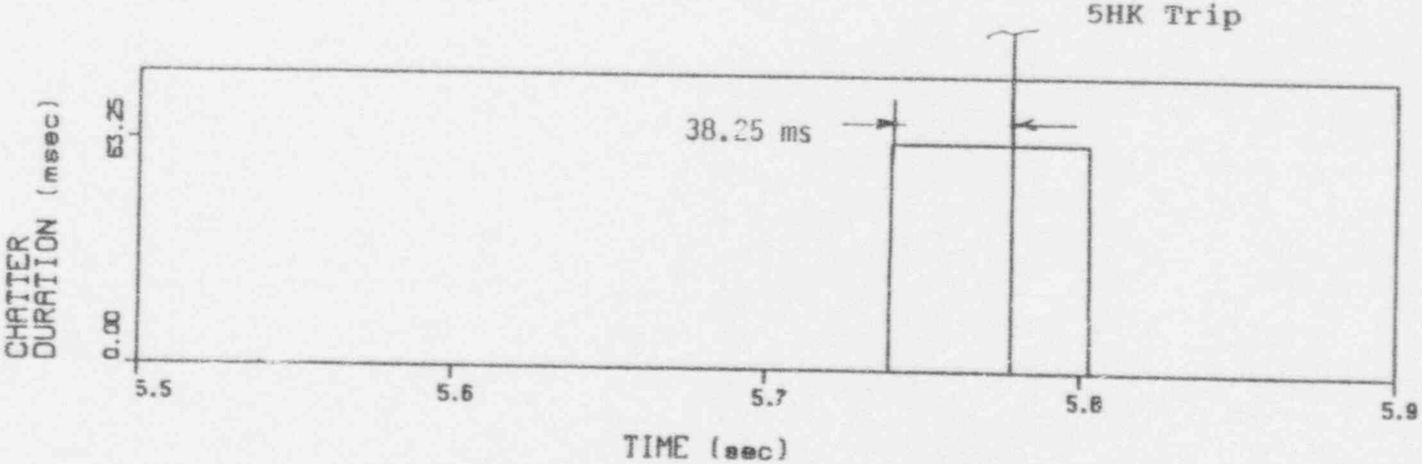

Figure 4.45 Effect of CO9 Chatter on 5HK, Plot 2

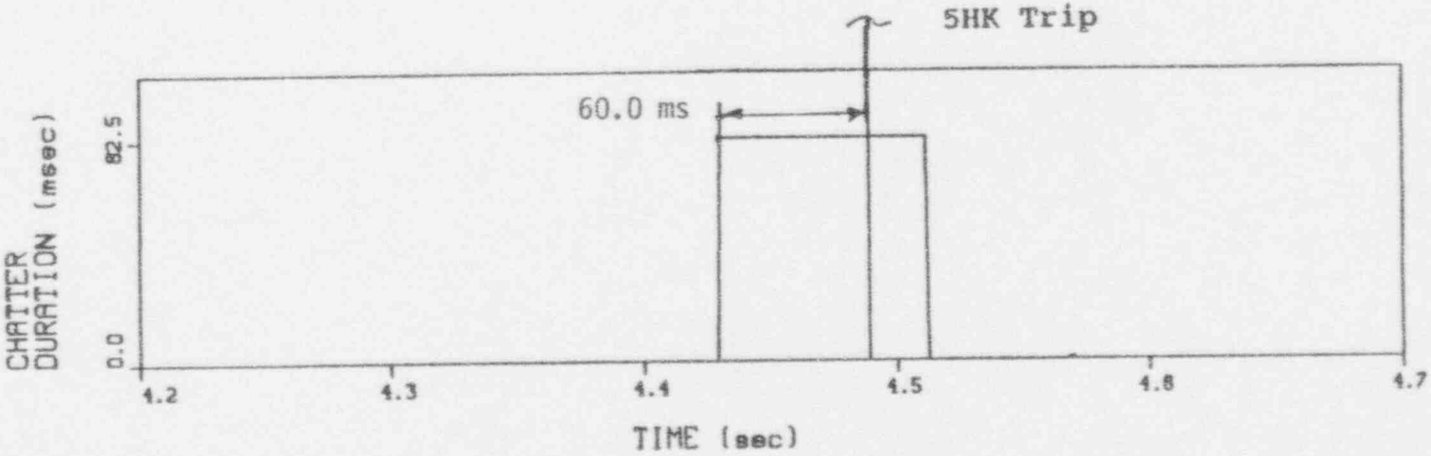

Figure 4.46 Effect of IAC Chatter on 5HK, Plot 1

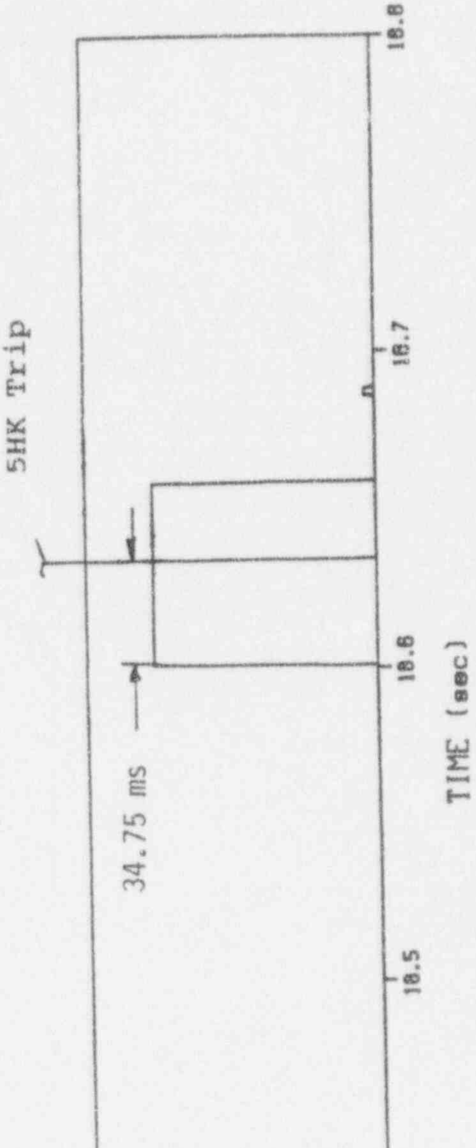

Figure 4.47 Effect of IAC Chatter on 5HK, Plot 2

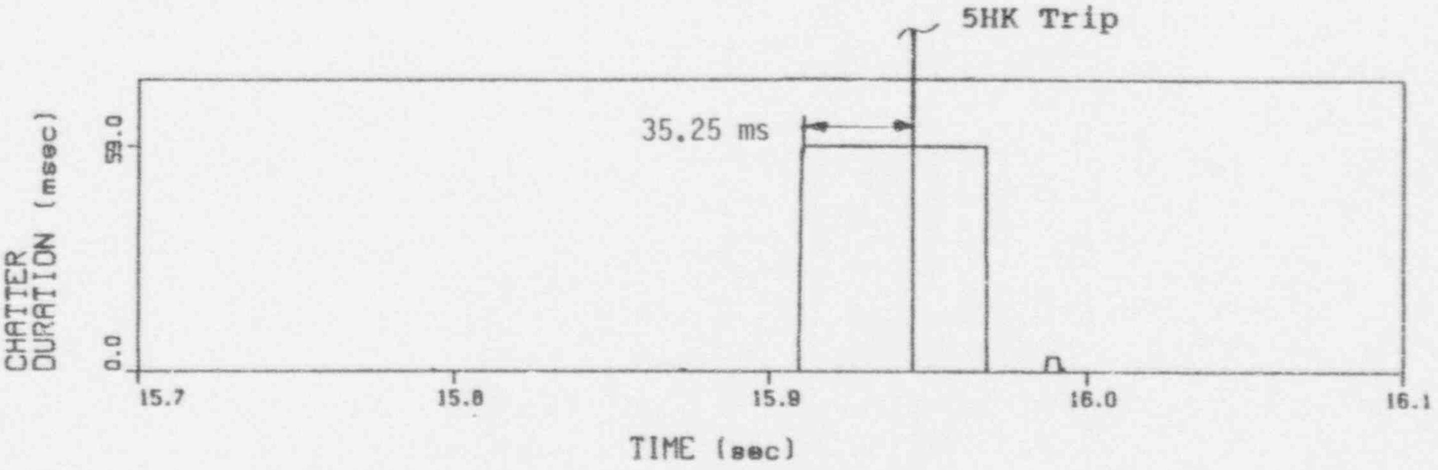

Figure 4.48 Effect of IAC Chatter on 5HK, Plot 3

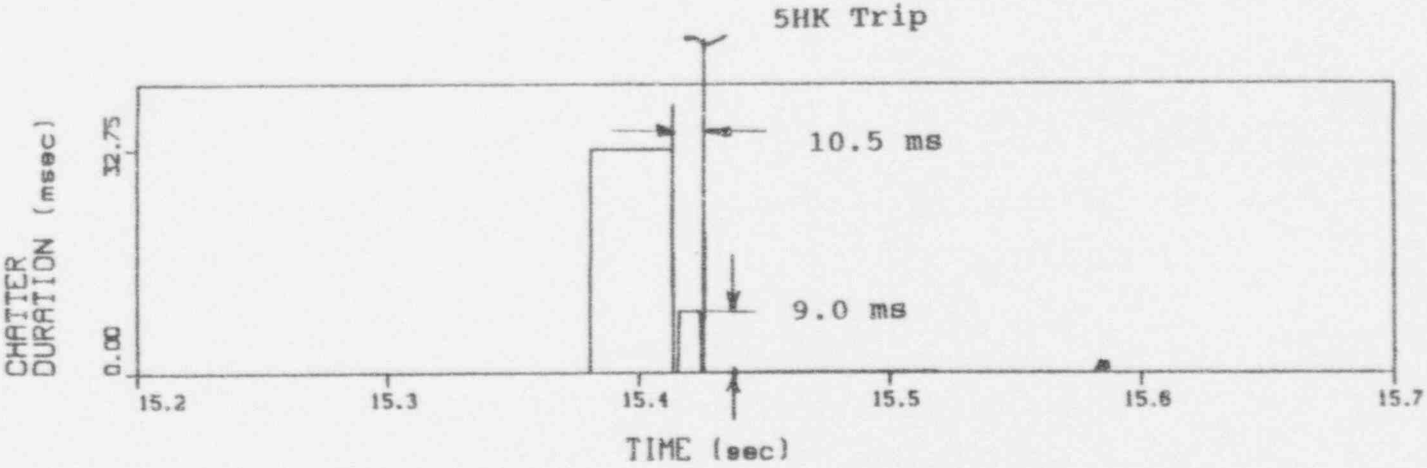

Figure 4.49 Effect of IAC Chatter on 5HK, Plot 4

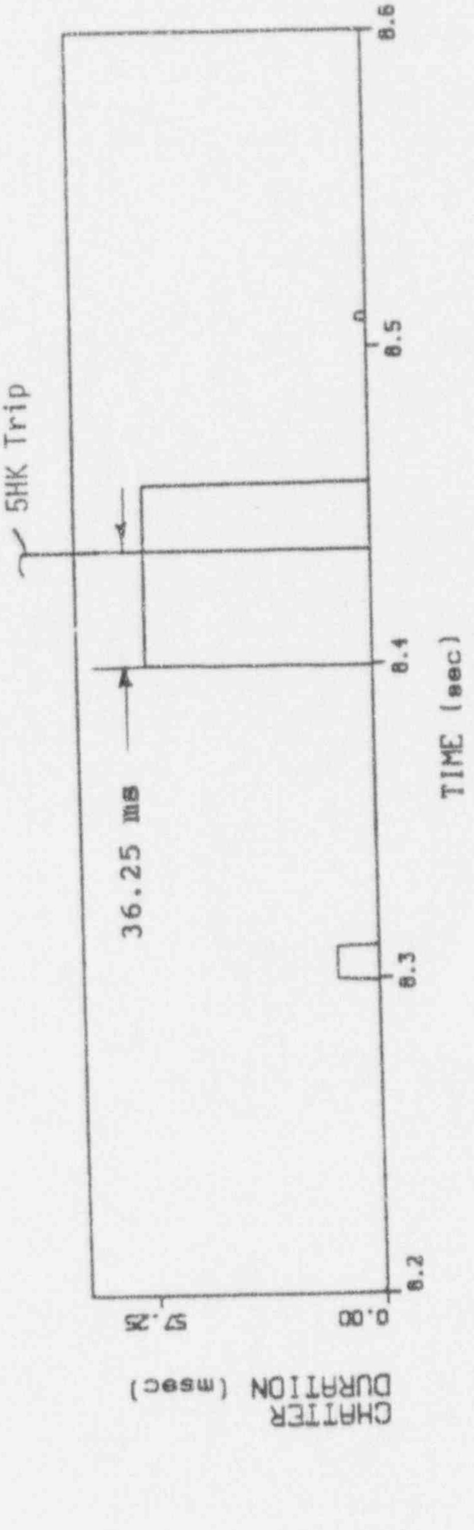

Figure 4.50 Effect of IAC Chatter on 5HK, Plot 5

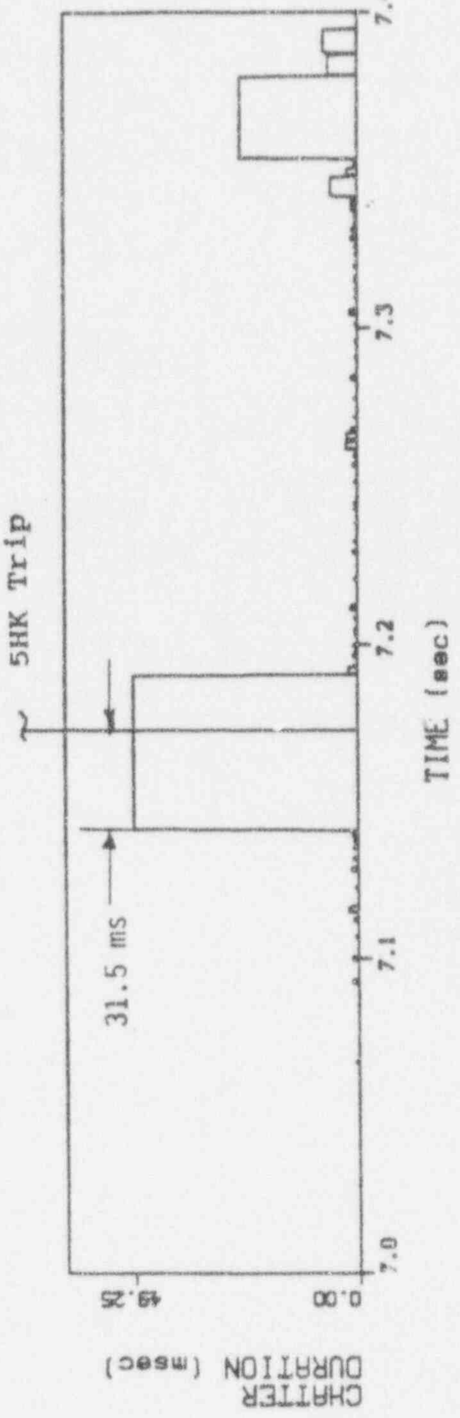

Figure 4.51 Effect of IAV Chatter on 5HK, Plot 1

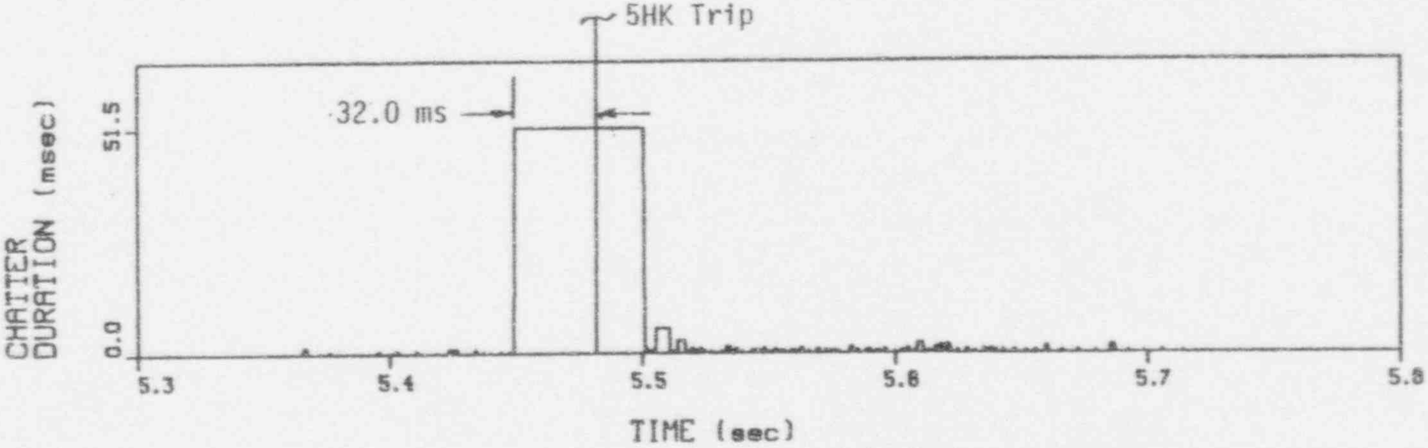

Figure 4.52 Effect of IAV Chatter on 5HK, Plot 2

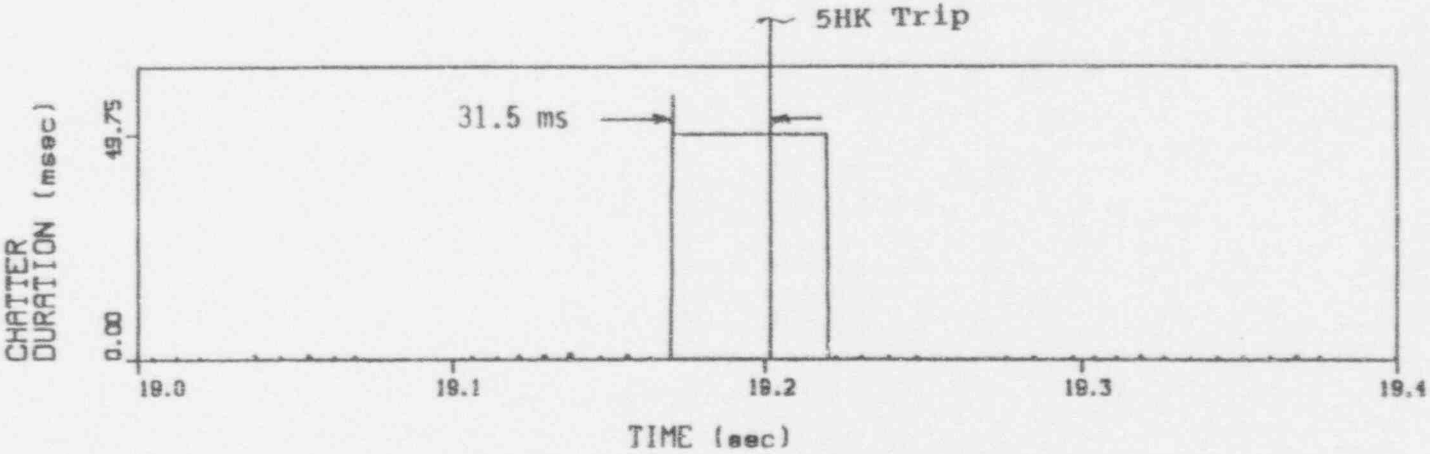

Figure 4.53 Effect of IAV Chatter on 5HK, Plot 3

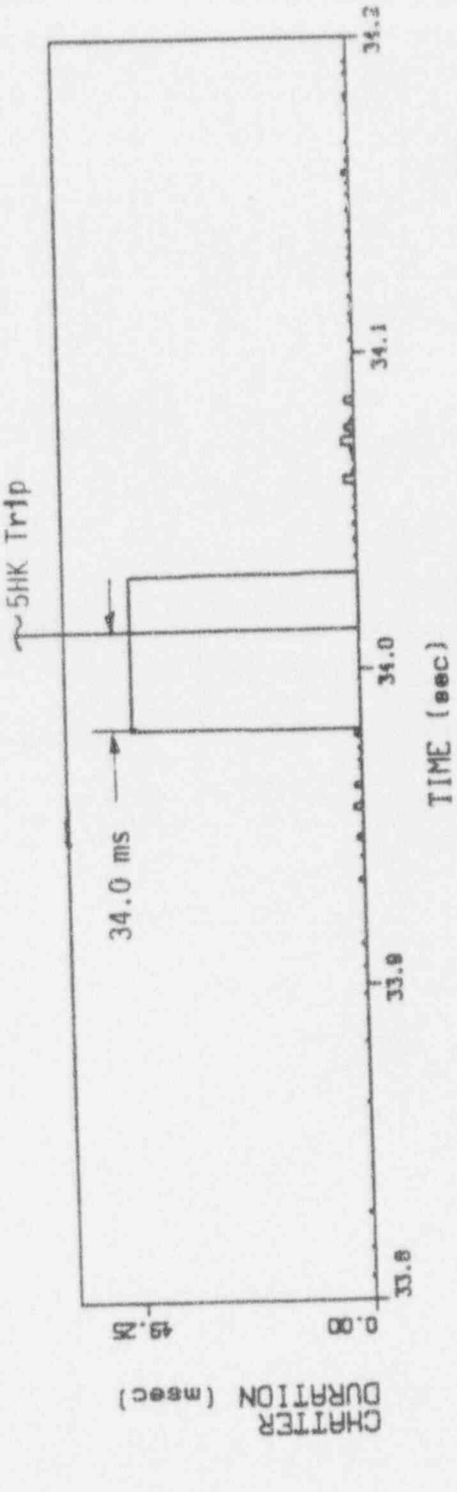

Figure 4.54 Effect of IAV Chatter on 5HK, Plot 4

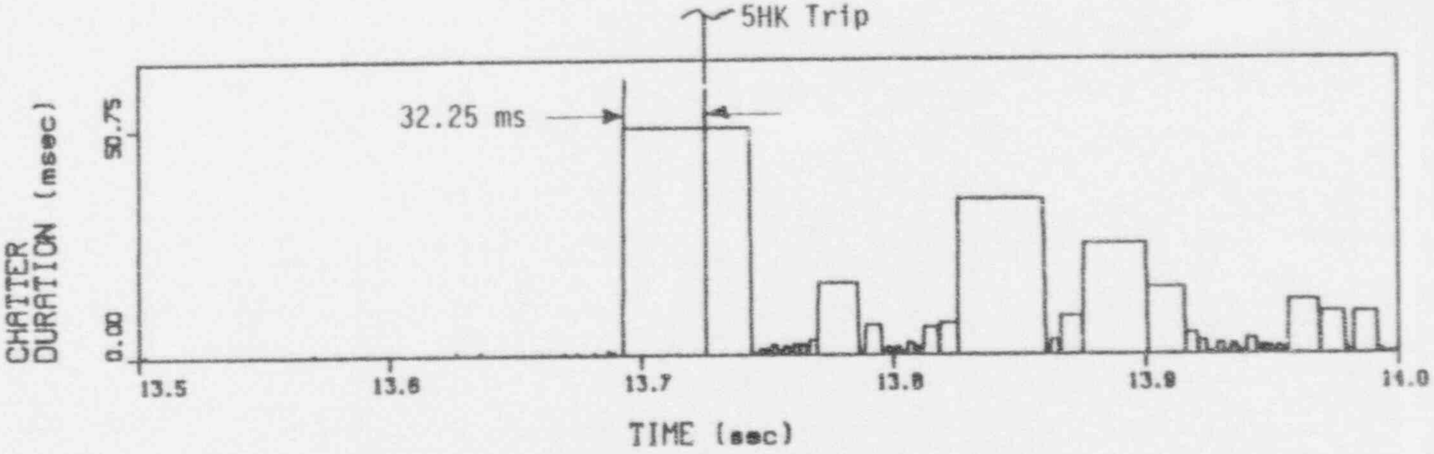

Figure 4.55 Effect of IAV Chatter on 5HK, Plot 5

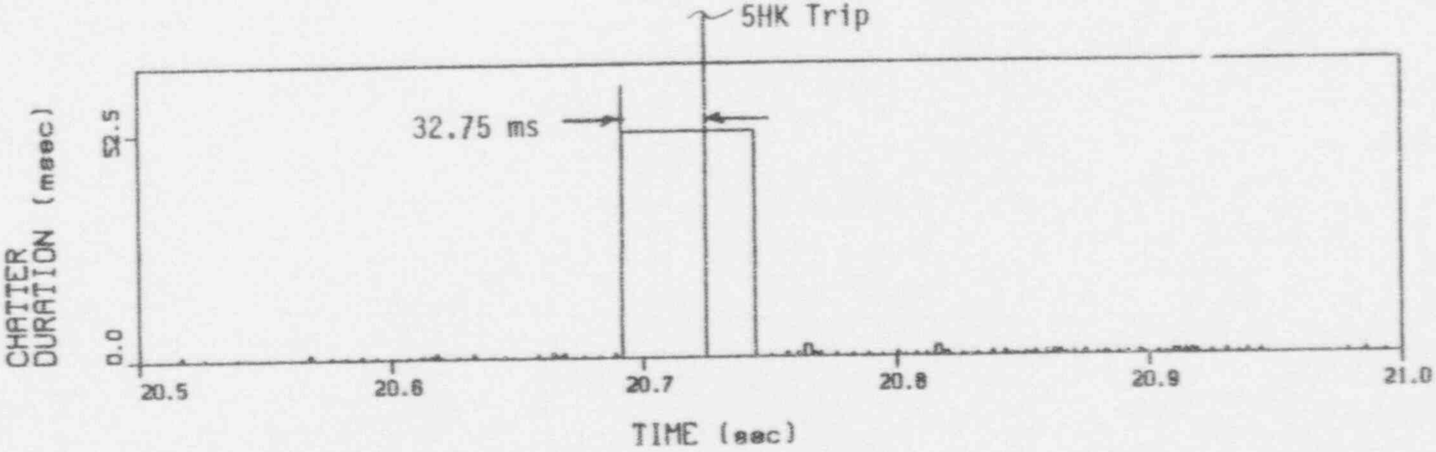

Figure 4.56 Effect of IAV Chatter on 5HK, Plot 6

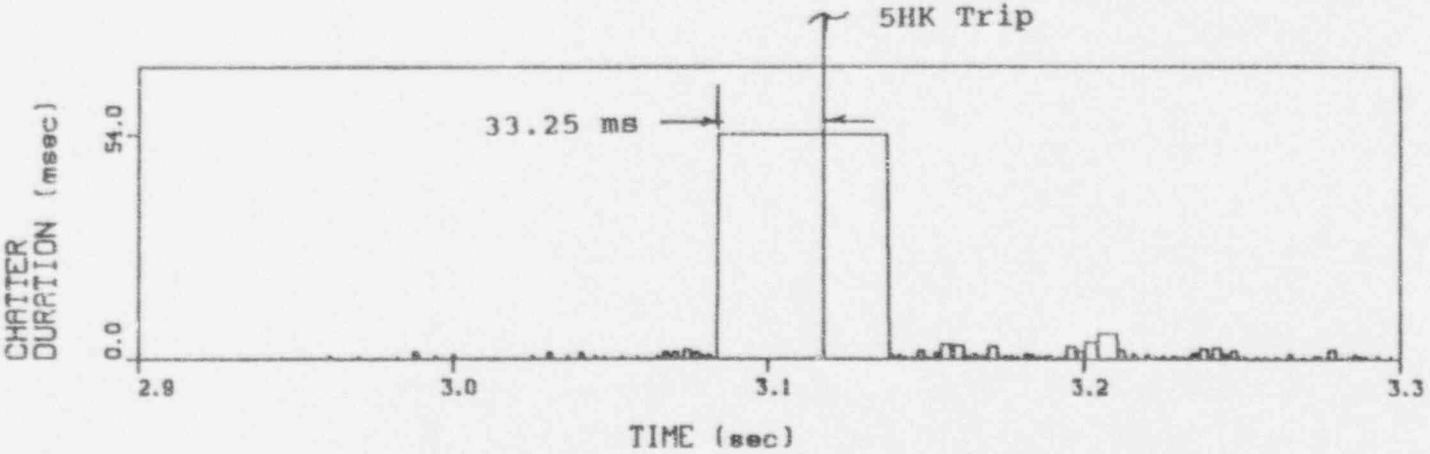

Figure 4.37 Effect of IAV Chatter on 5HK, Plot 7

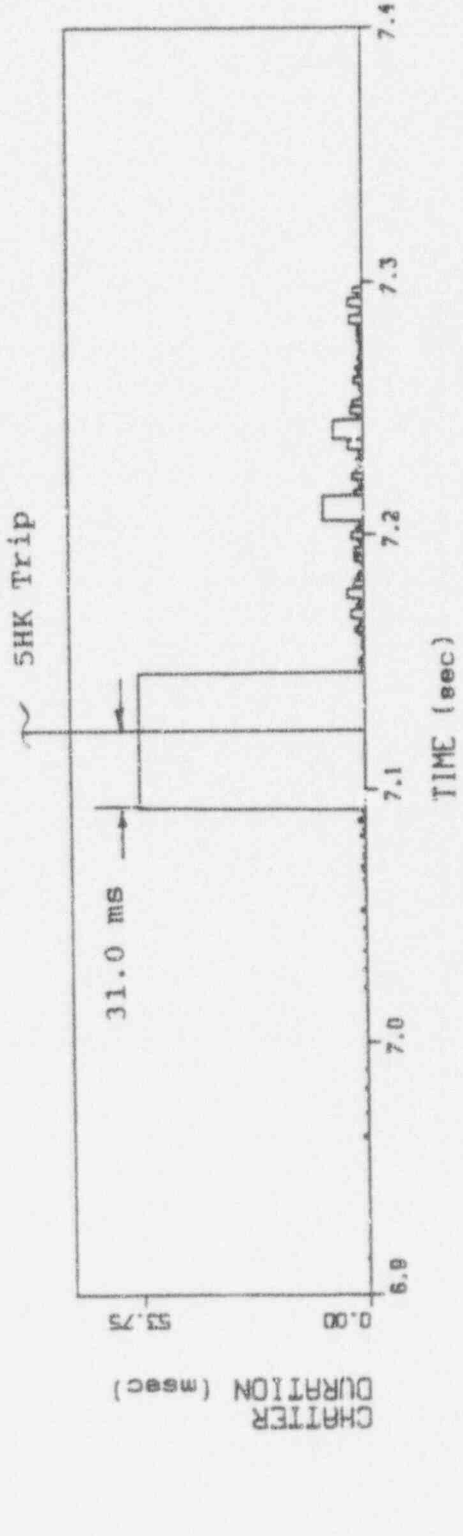

Figure 4.58 Effect of IAV Chatter on 5HK, Plot 8

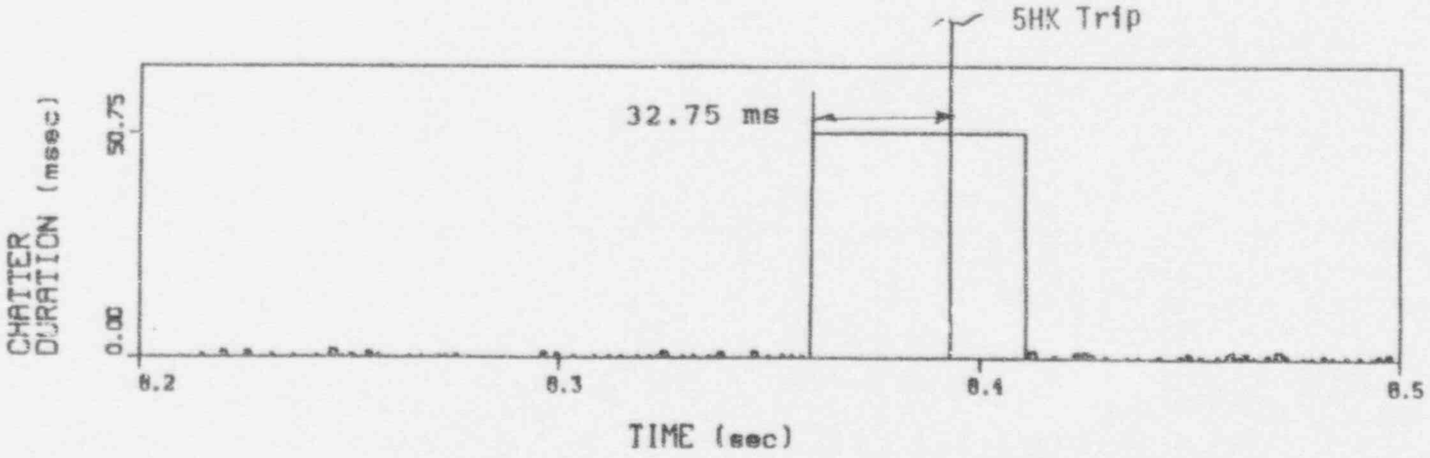

Figure 4.59 Effect of IAV Chatter on 5HK, Plot 9

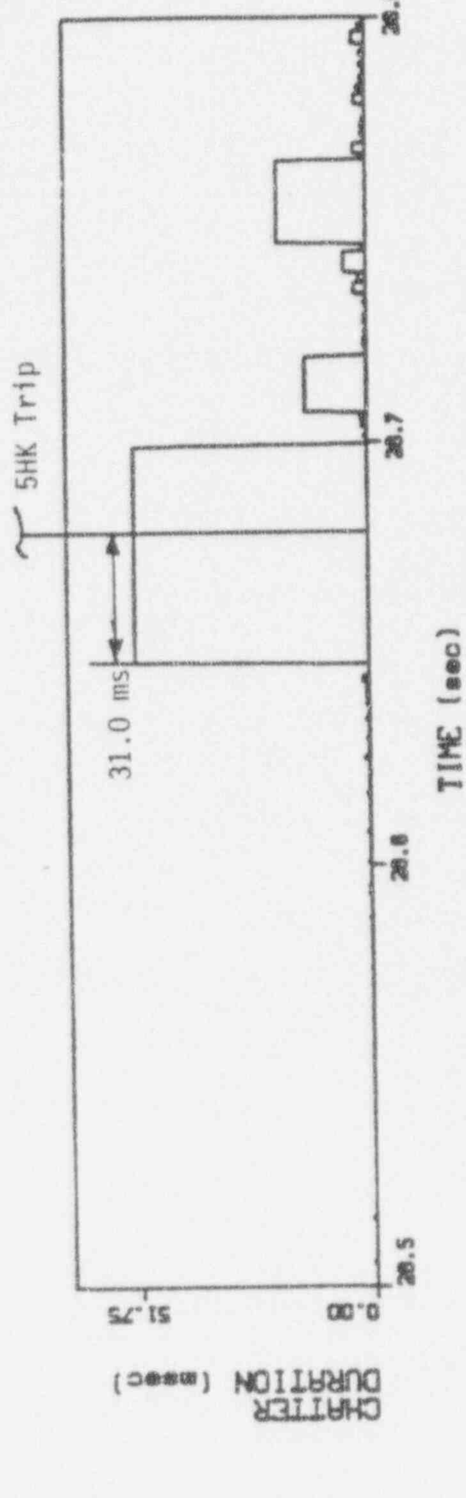

Figure 4.60 Effect of IAV Chatter on 5HK, Plot 10

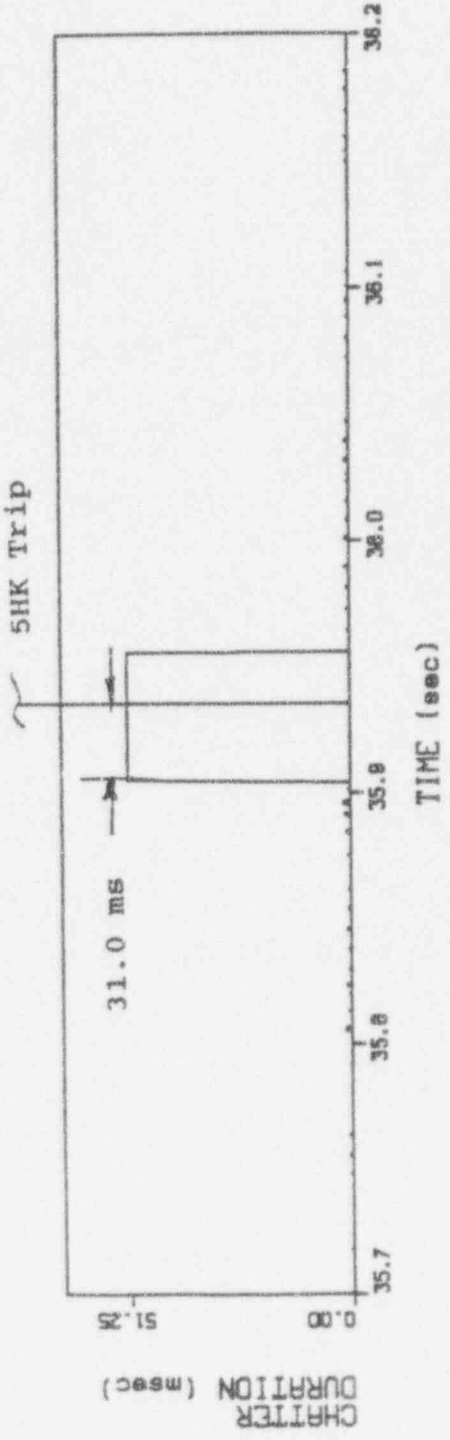

Figure 4.61 Effect of IAV Chatter on 5HK, Plot 11

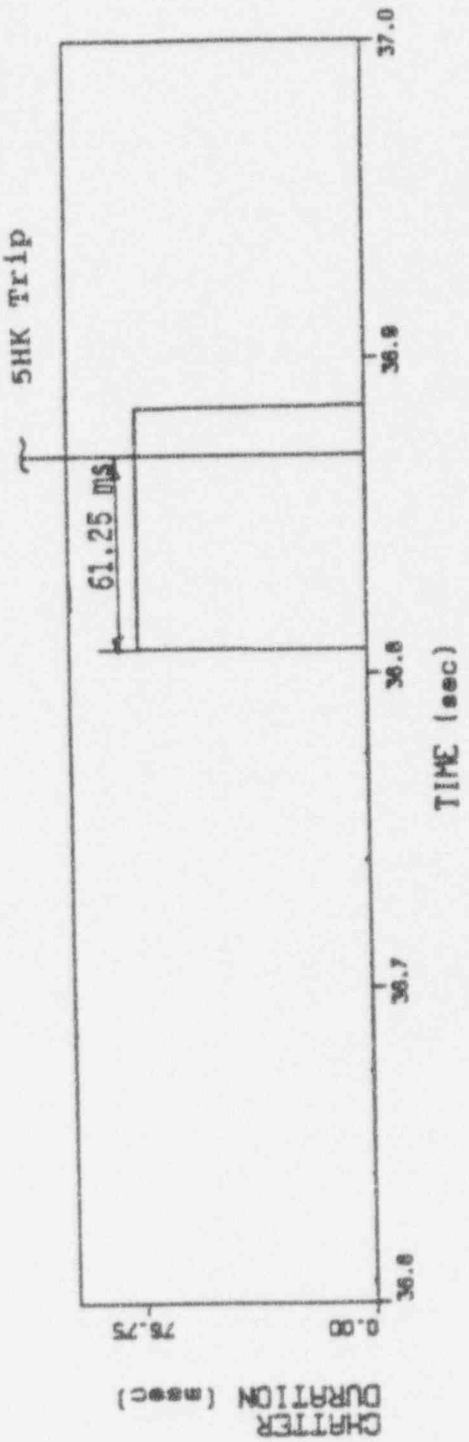

Figure 4.62 Effect of SVF Chatter on 5HK, Plot 1

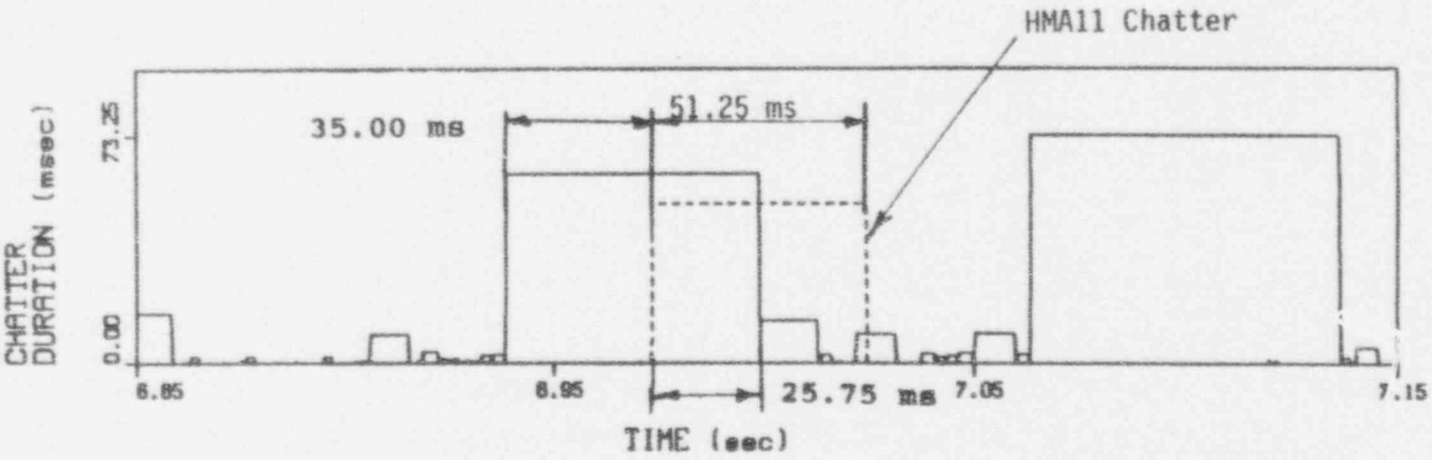

Figure 4.63 Effect of IAV Chatter on HMA11, Plot 1

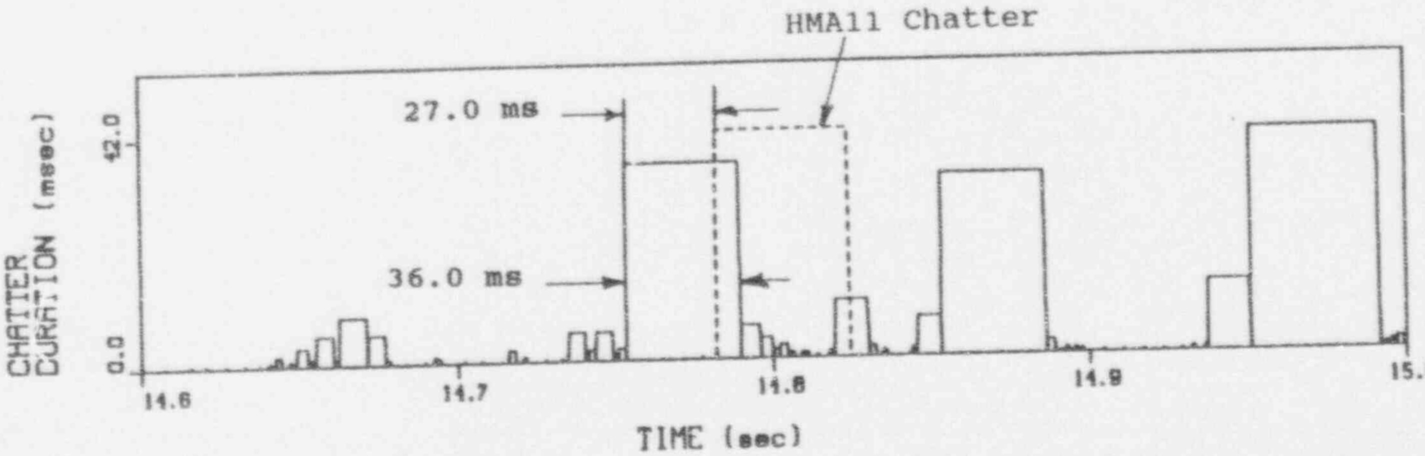

Figure 4.64 Effect of IAV Chatter on HMA11, Plot 2

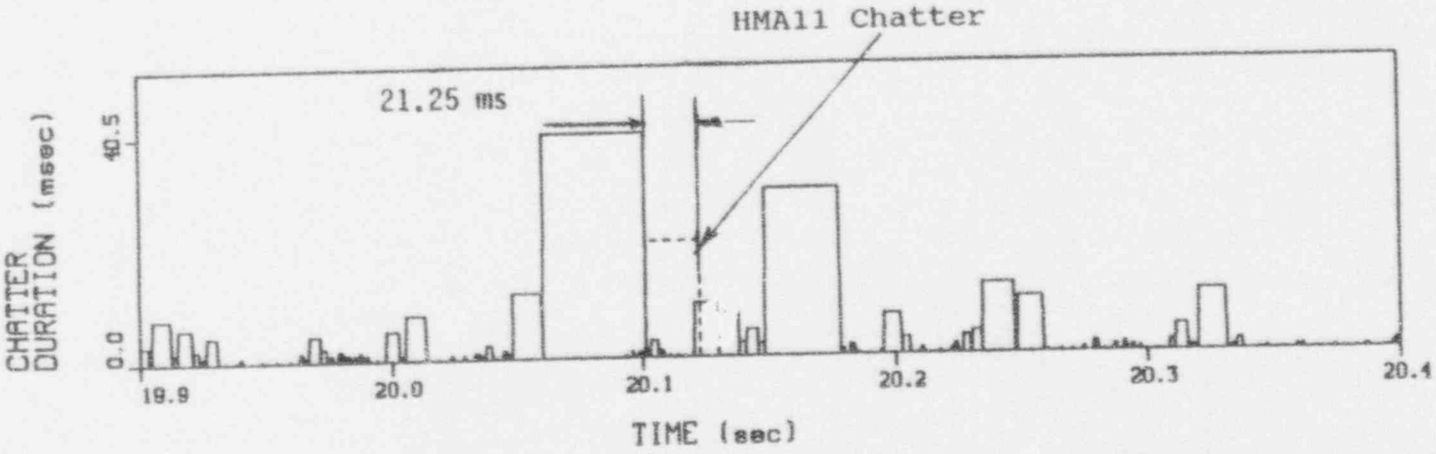

Figure 4.65 Effect of IAV Chatter on HMA11, Plot 3

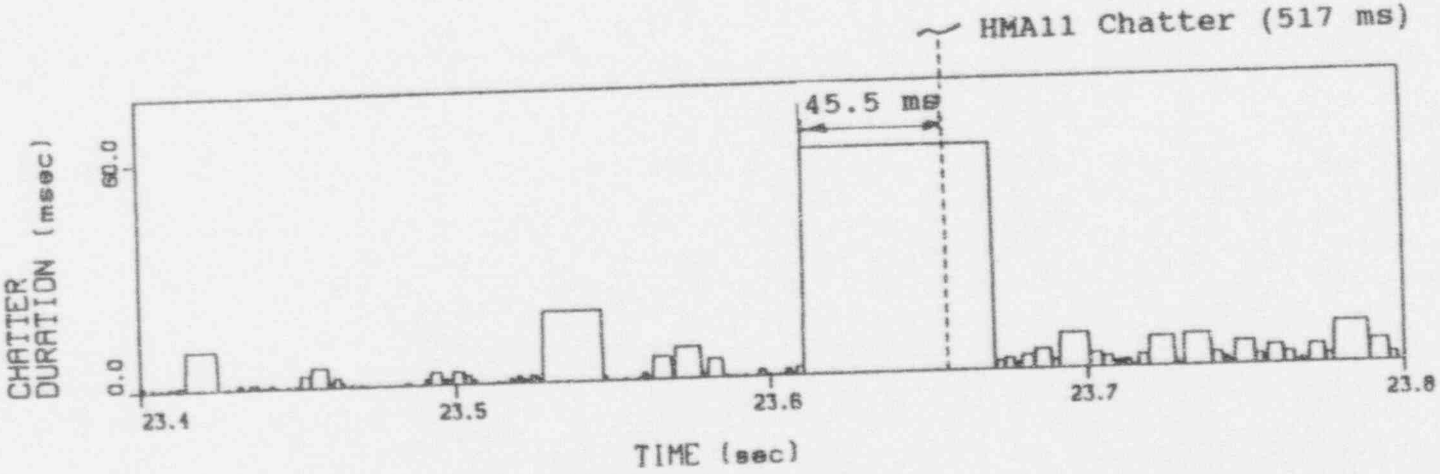

Figure 4.66 Effect of IAV Chatter on HMA11, Plot 4

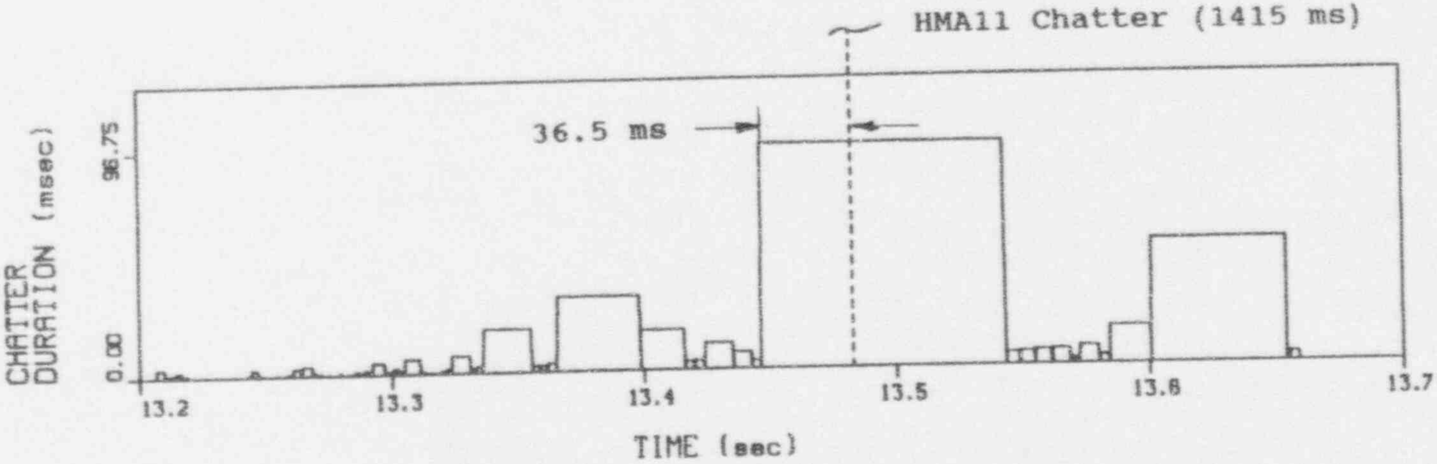

Figure 4.67 Effect of IAV Chatter on HMA11, Plot 5

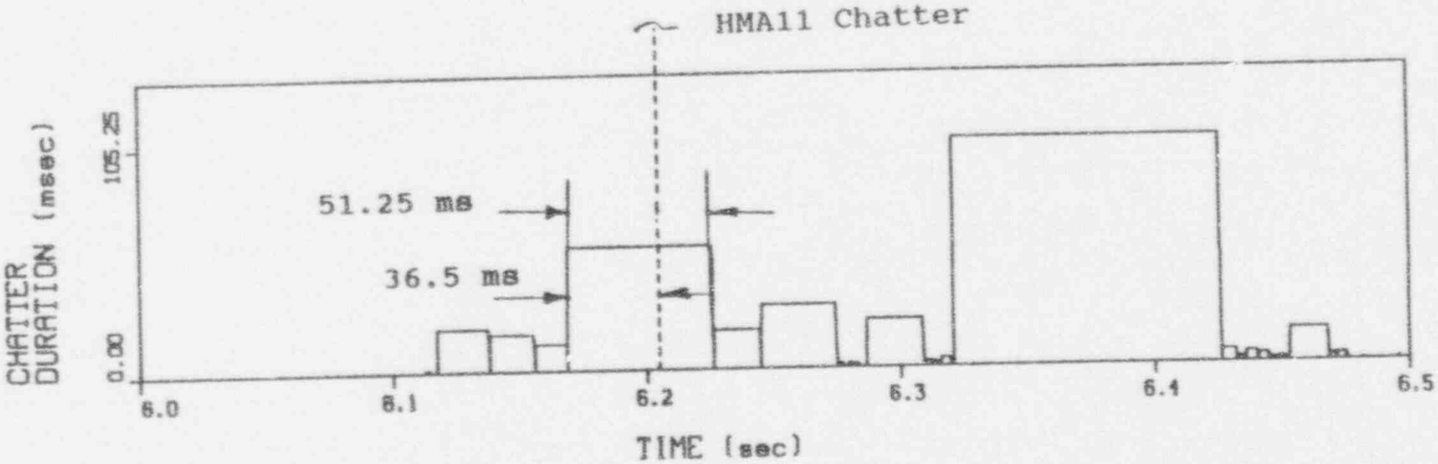

Figure 4.68 Effect of IAV Chatter on HMA11, Plot 6, (6.0 sec to 6.5 sec)

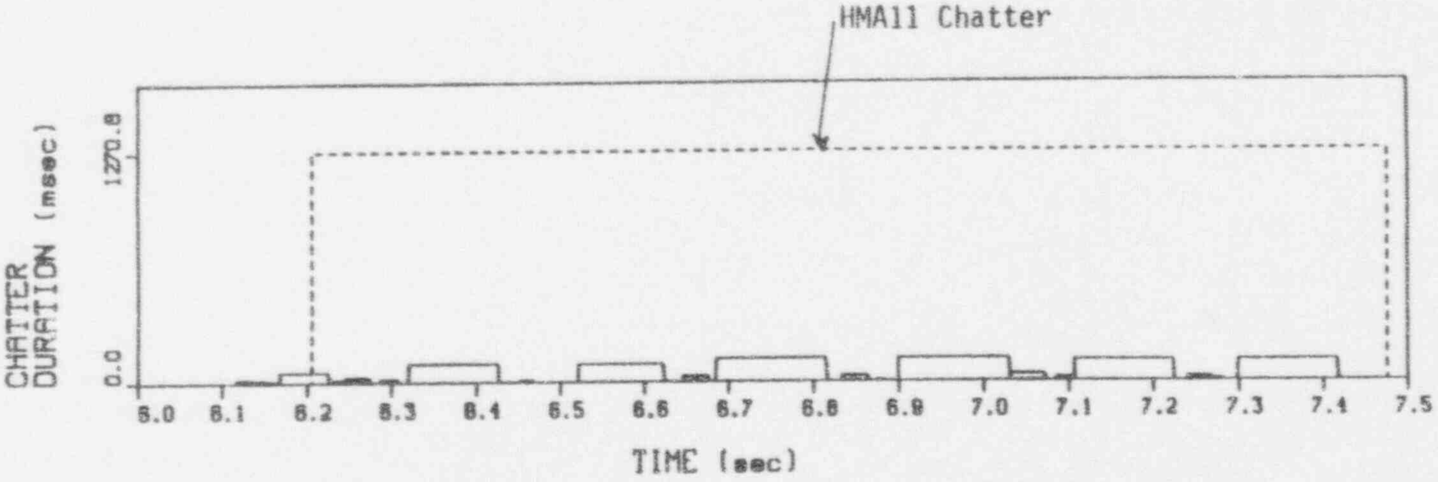

Figure 4.69 Effect of IAV Chatter on HMA11, Plot 6, (6.0 sec to 7.5 sec)

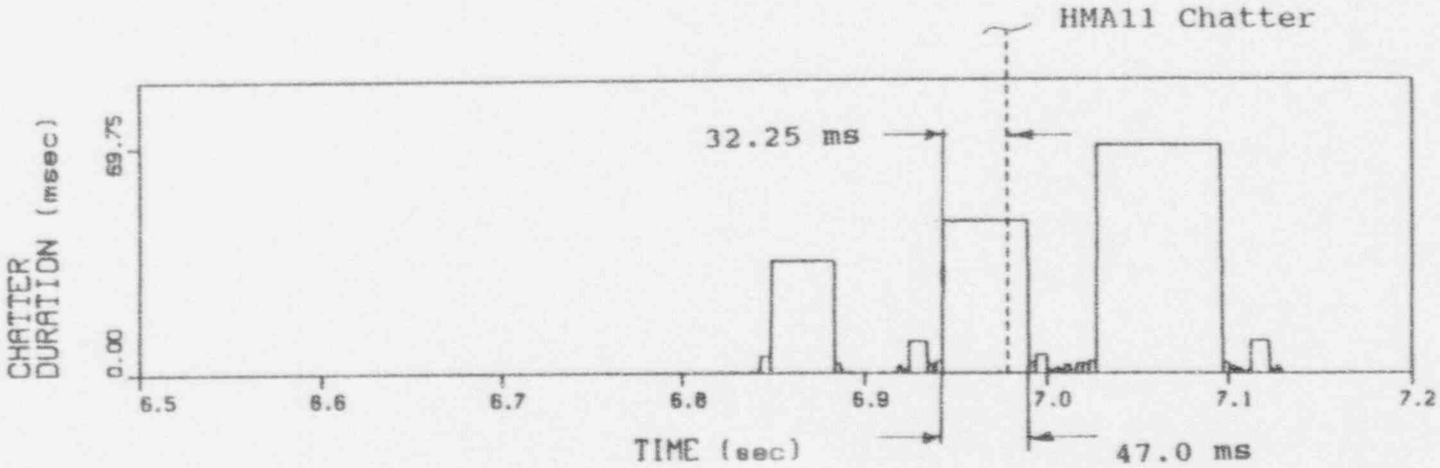

Figure 4.70 Effect of IAV Chatter on HMA11, Plot 7, (6.5 sec to 7.2 sec)

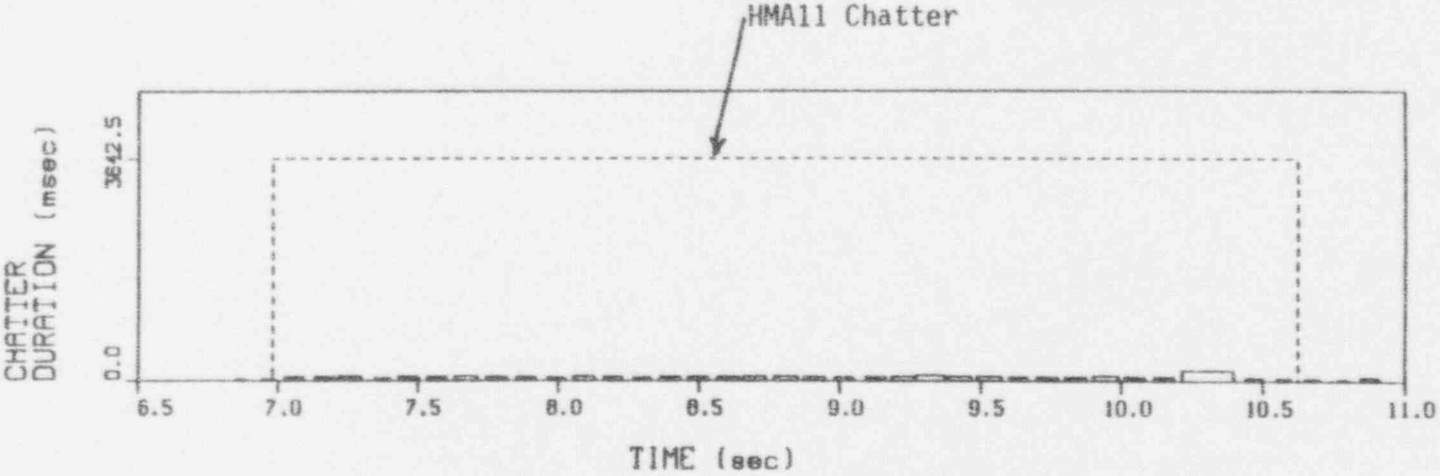

Figure 4.71 Effect of IAV Chatter on HMA11, Plot 7, (6.5 sec to 11.0 sec)

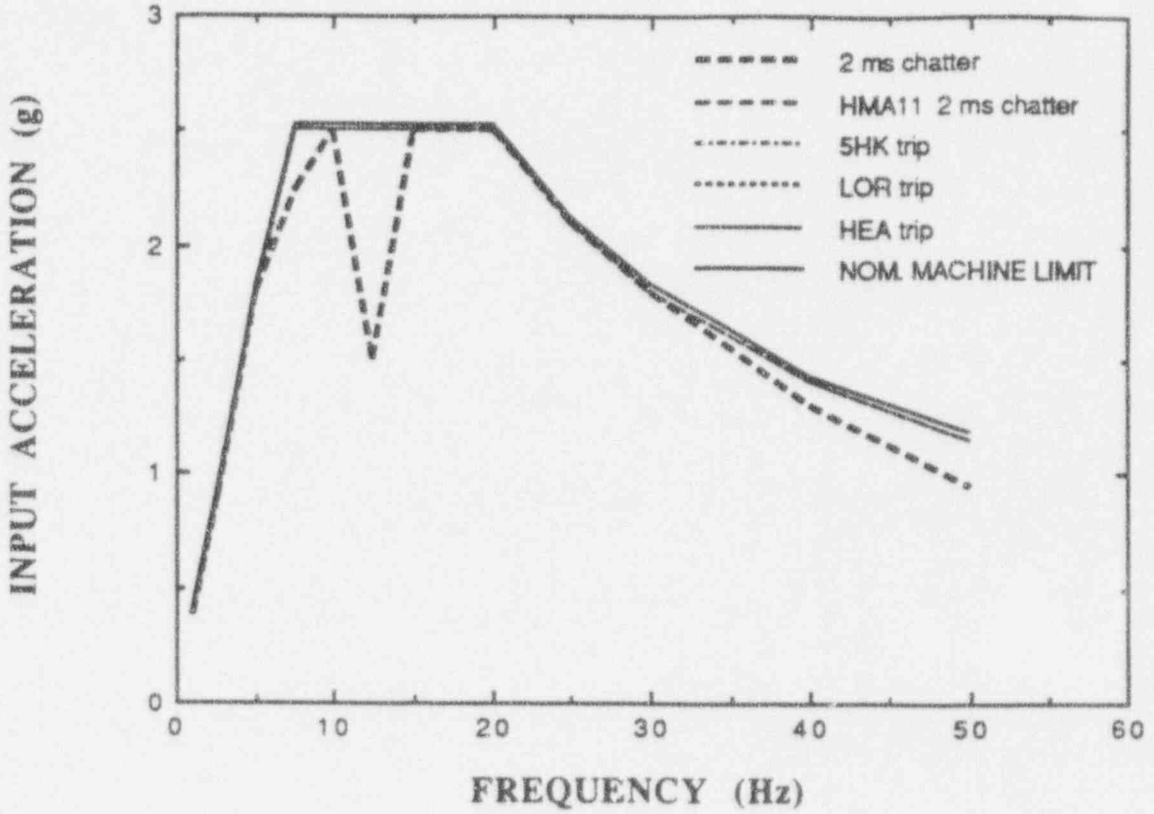

Figure 4.72 Sine Dwell Capacity Level, C09, Front-to-Back Direction

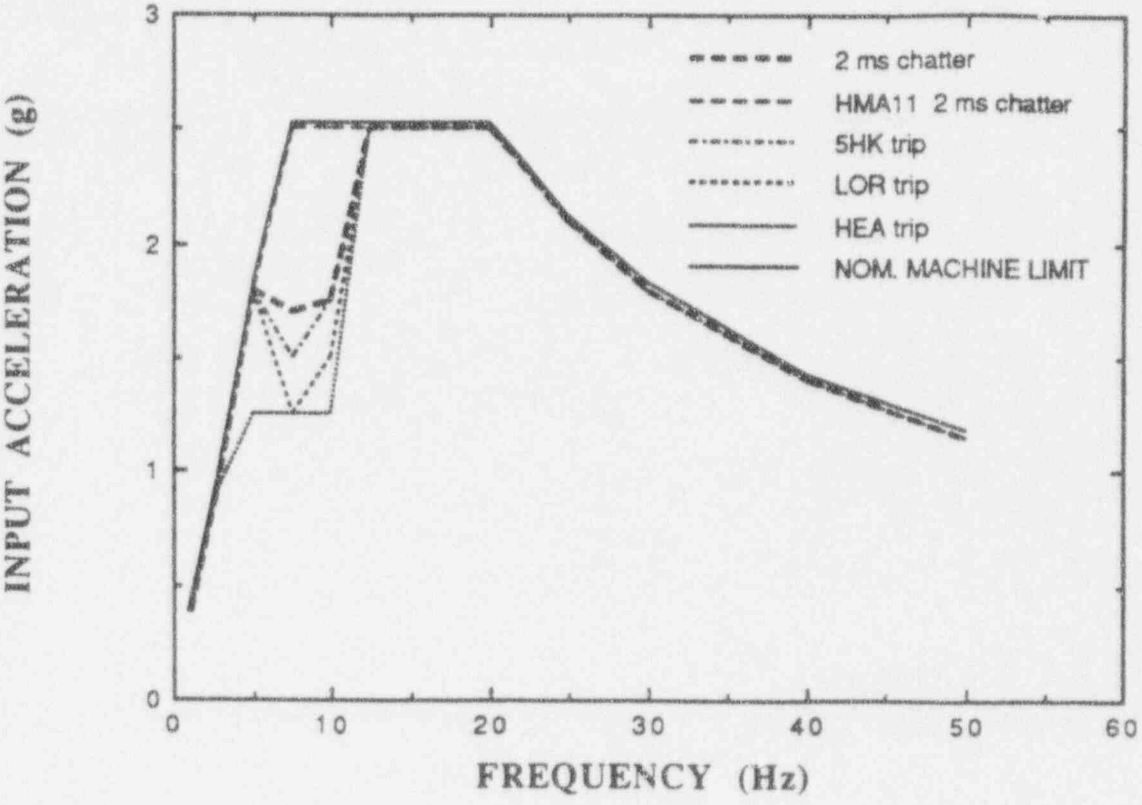

Figure 4.73 Sine Dwell Capacity Level, C09, Vertical Direction

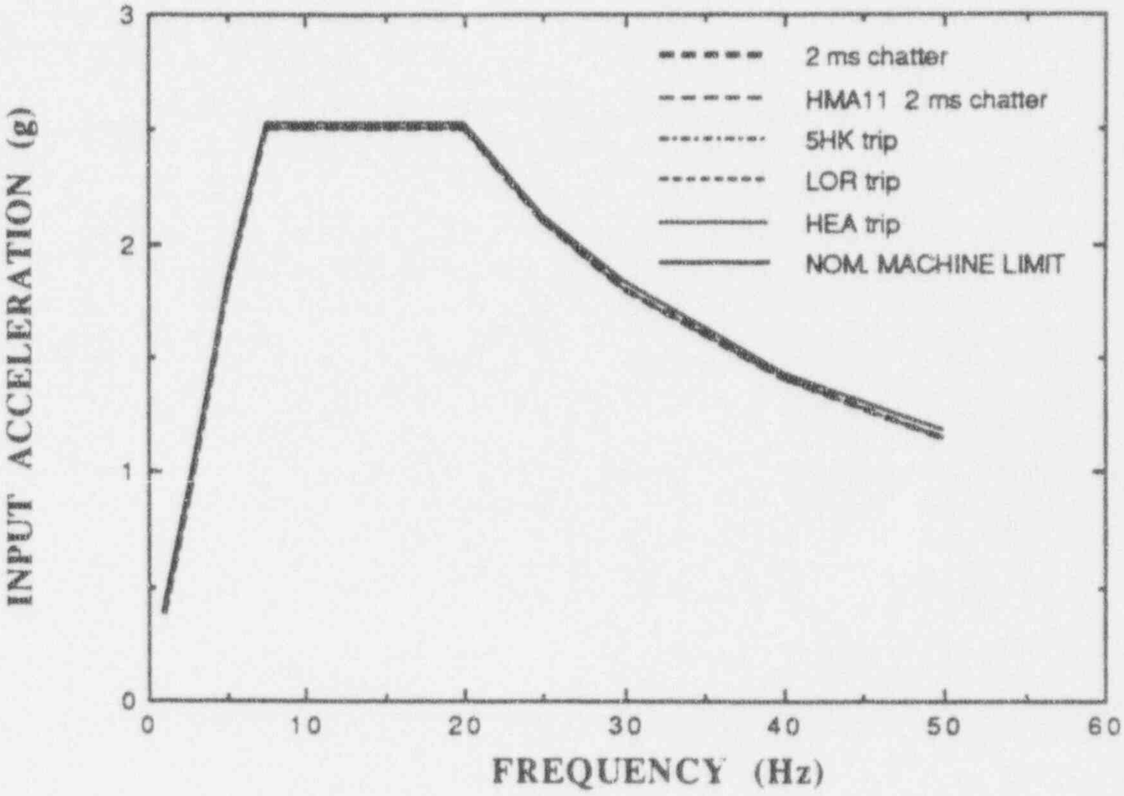

Figure 4.74 Sine Dwell Capacity Level, SVF, Front-to-Back Direction

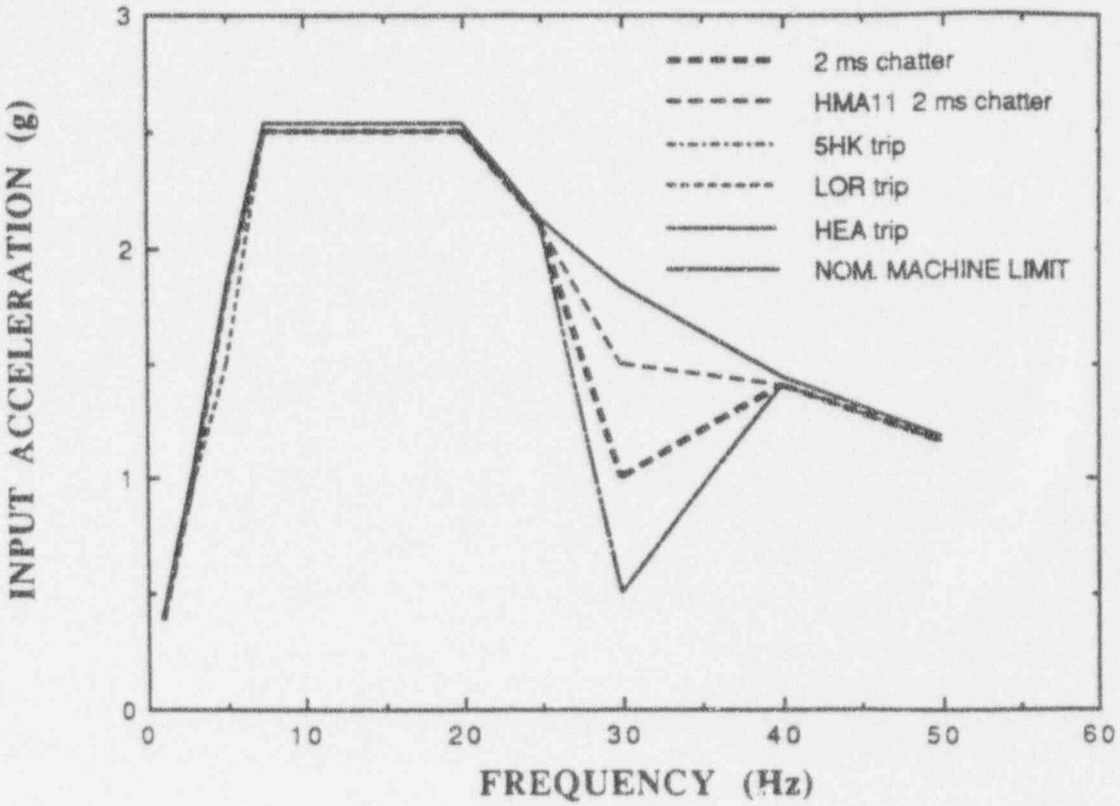

Figure 4.75 Sine Dwell Capacity Level, SVF, Vertical Direction

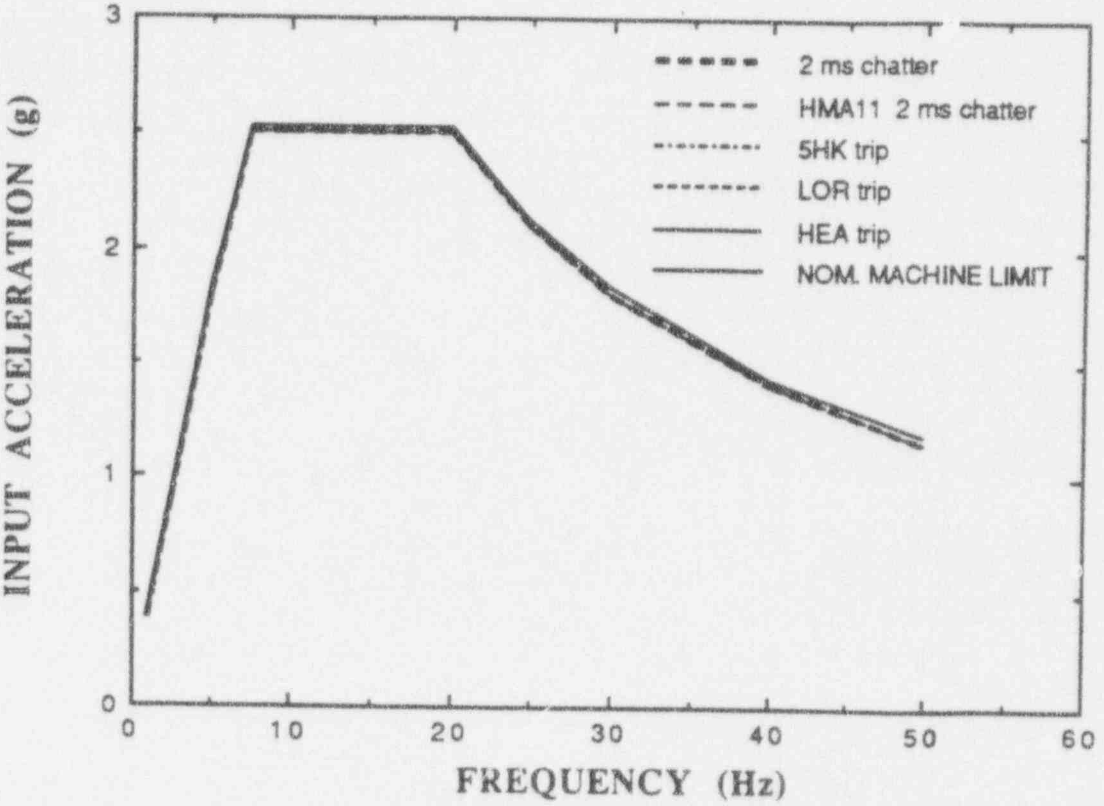

Figure 4.76 Sine Dwell Capacity Level, HFA, Front-to-Back Direction

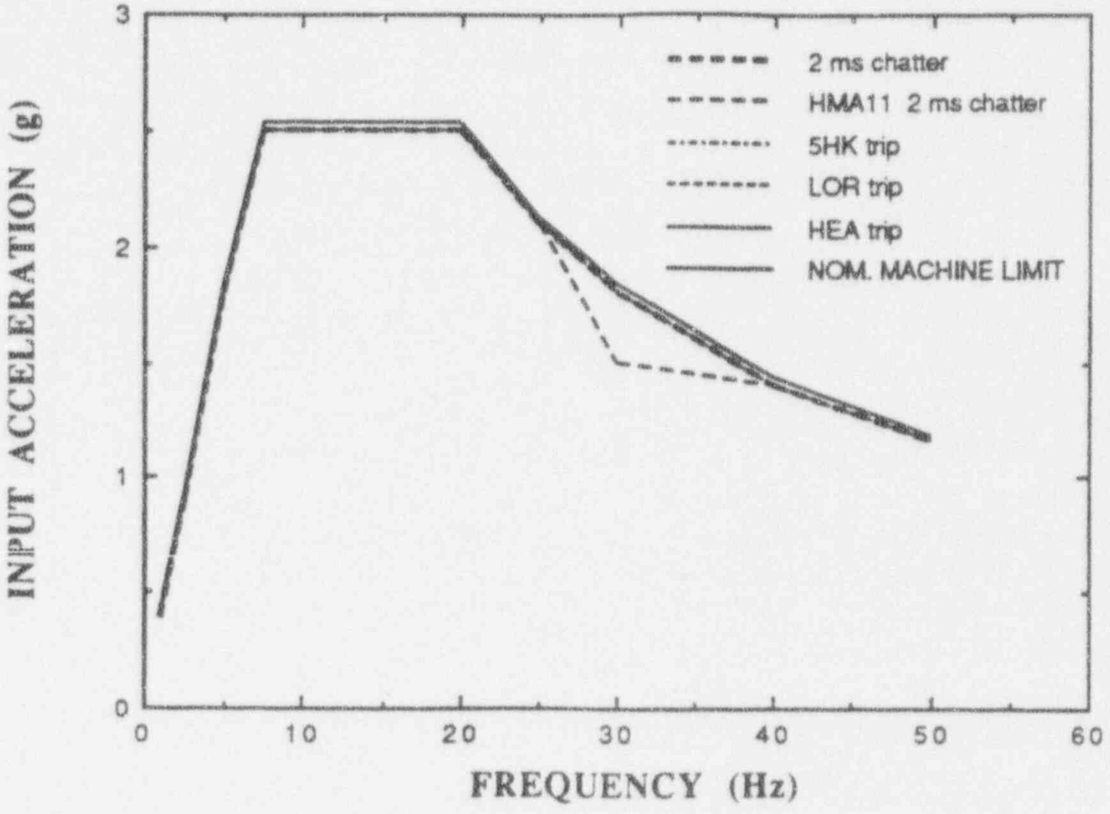

Figure 4.77 Sine Dwell Capacity Level, HFA, Vertical Direction

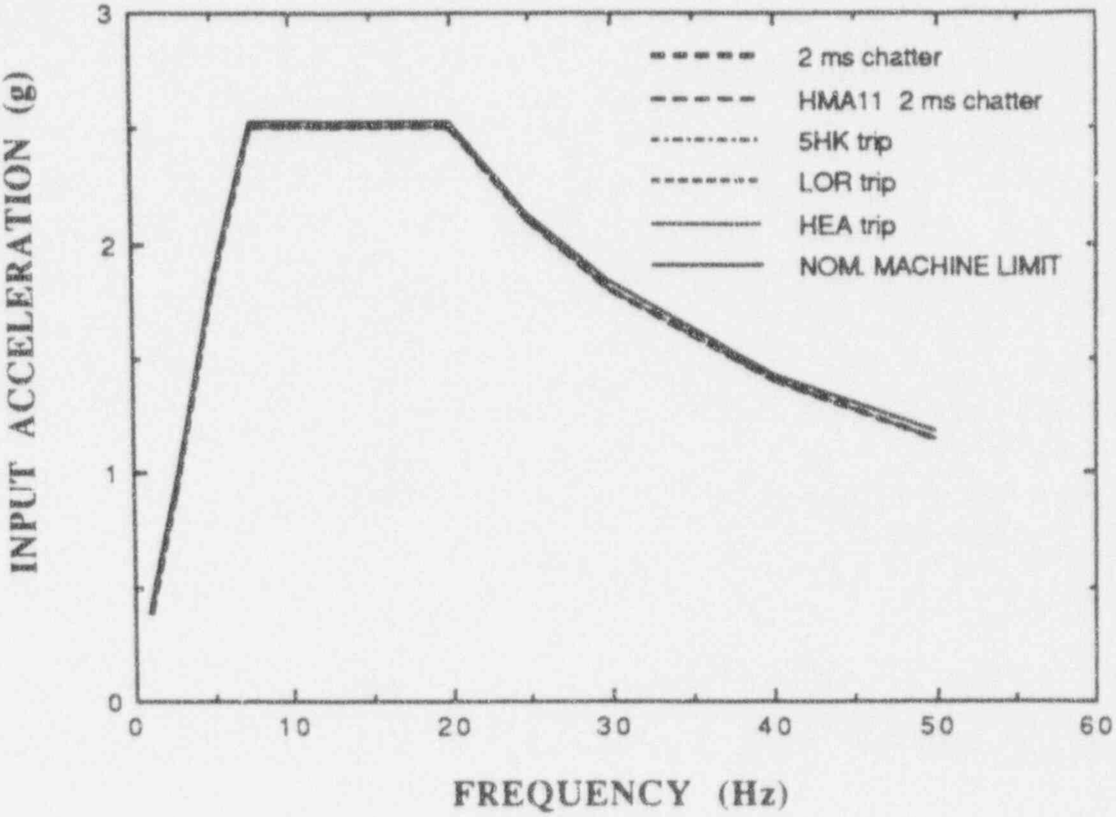

Figure 4.78 Sine Dwell Capacity Level, IAC, Front-to-Back Direction

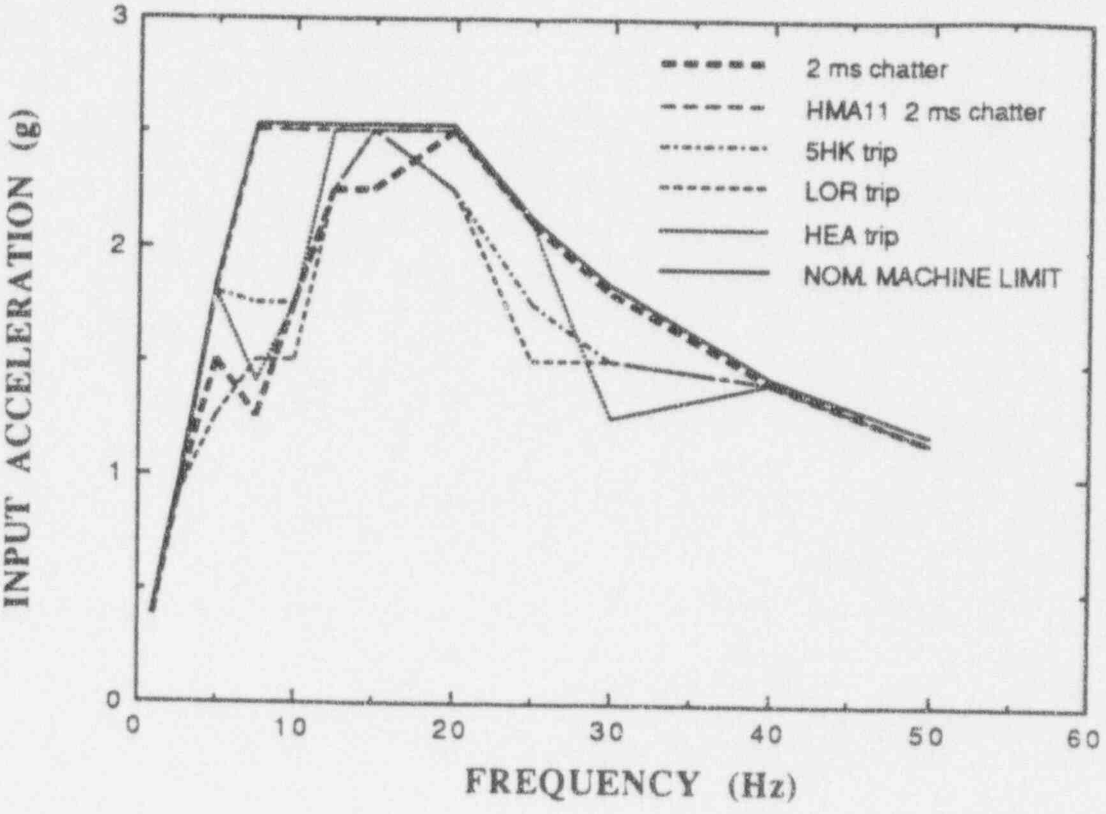

Figure 4.79 Sine Dwell Capacity Level, IAC, Vertical Direction

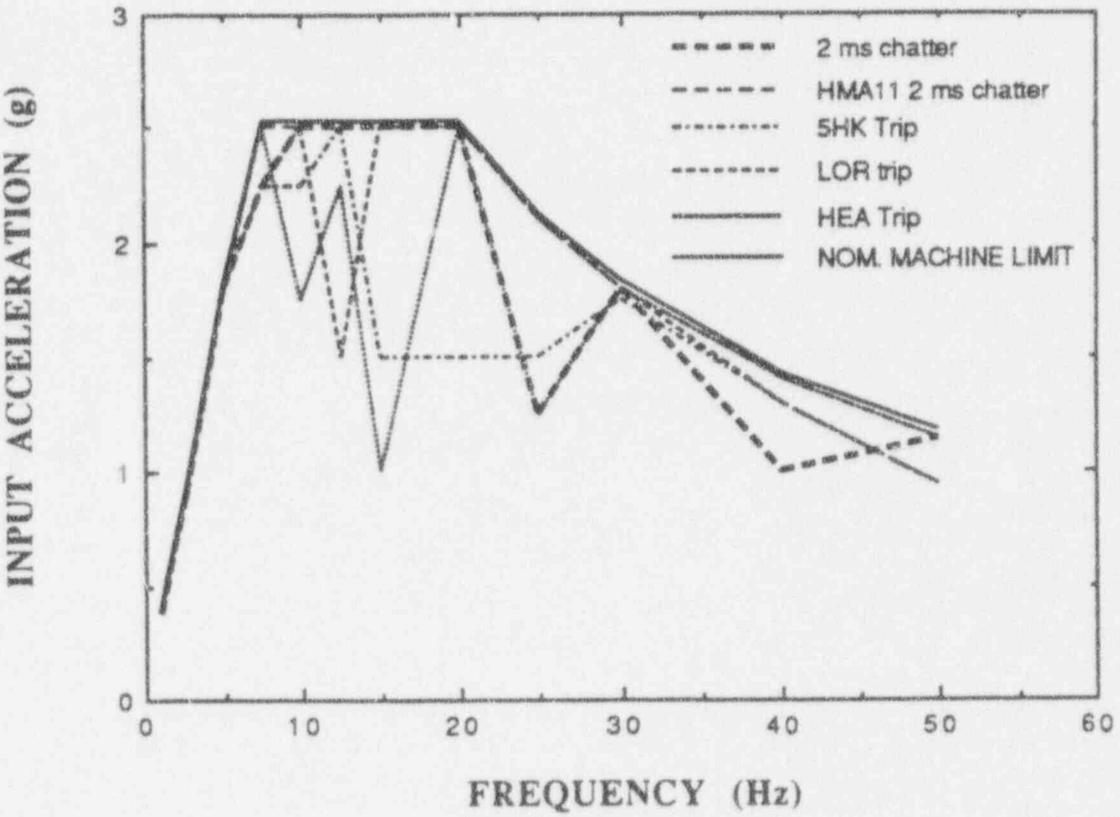

Figure 4.80 Sine Dwell Capacity Level, IAV, Front-to-Back Direction

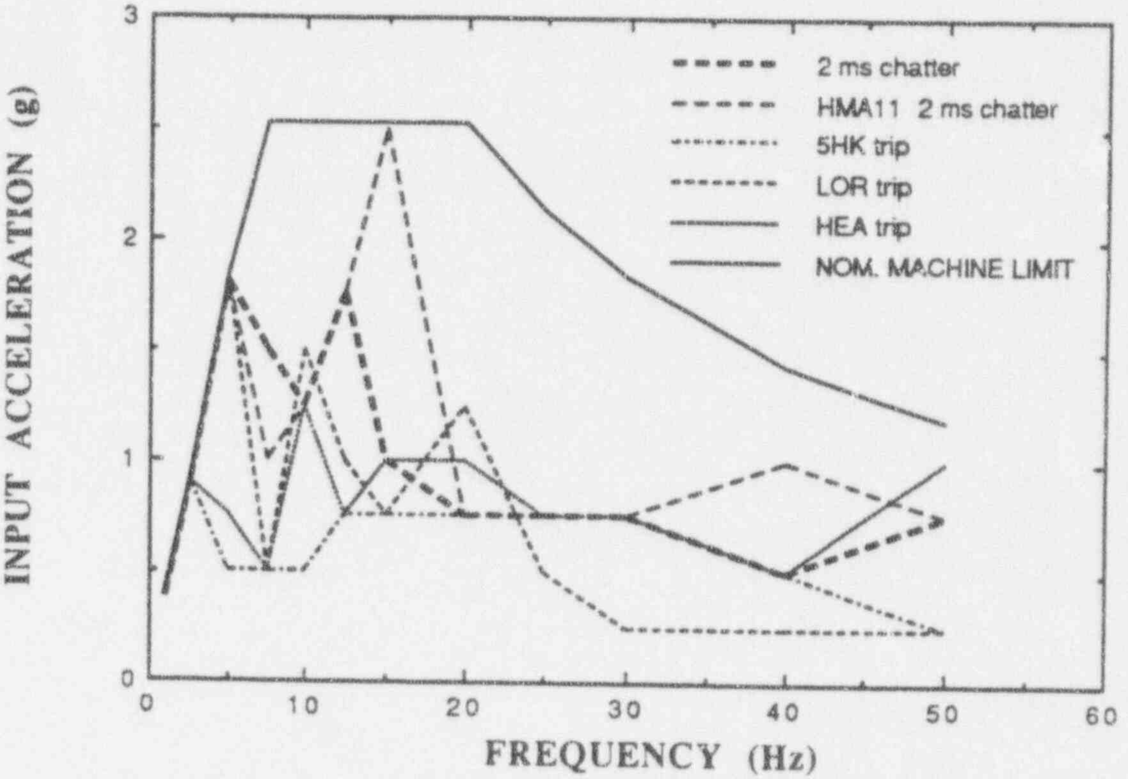

Figure 4.81 Sine Dwell Capacity Level, IAV, Vertical Direction

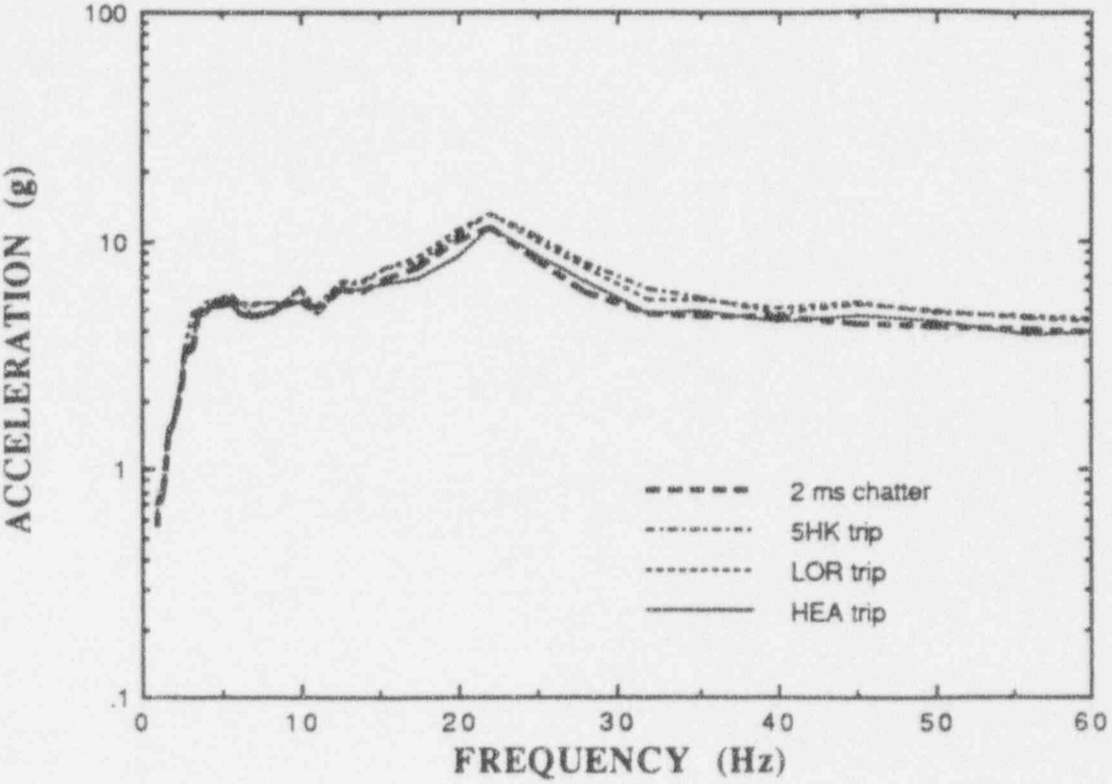

Figure 4.82 Multifrequency Capacity TRS @ 5% Damping, CO9, Vertical Direction

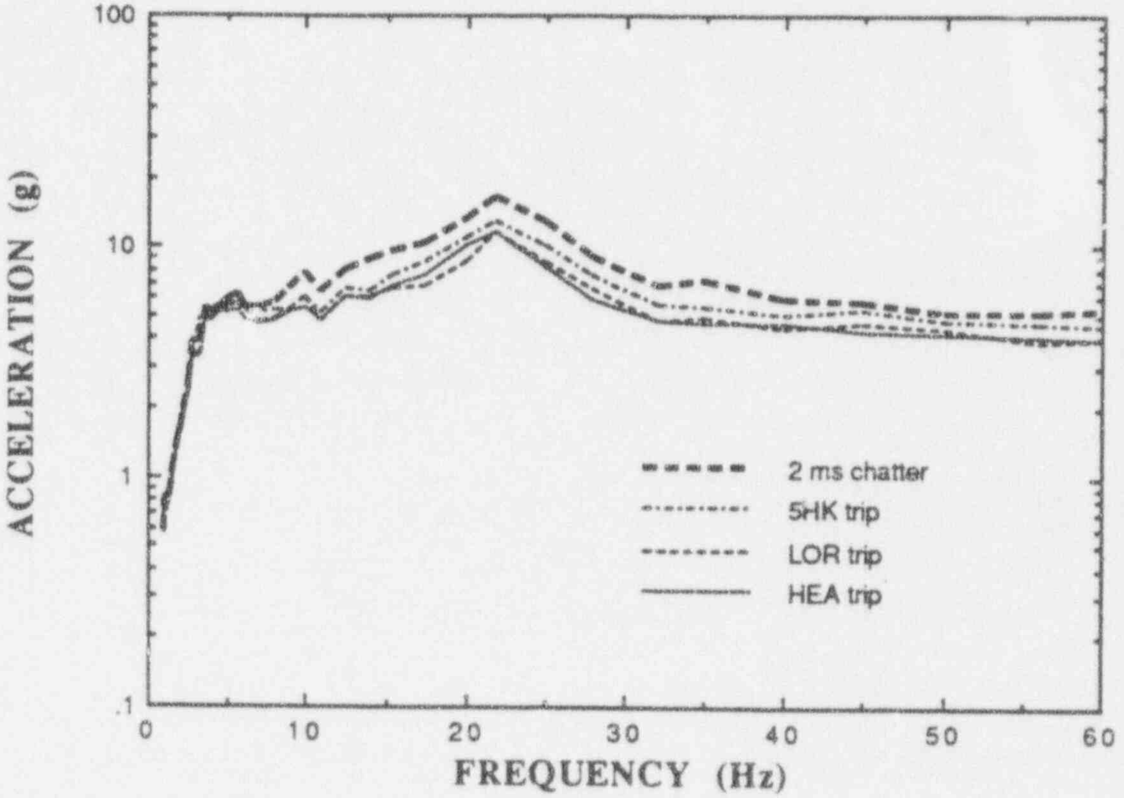

Figure 4.83 Multifrequency Capacity TRS @ 5% Damping, IAC, Vertical Direction

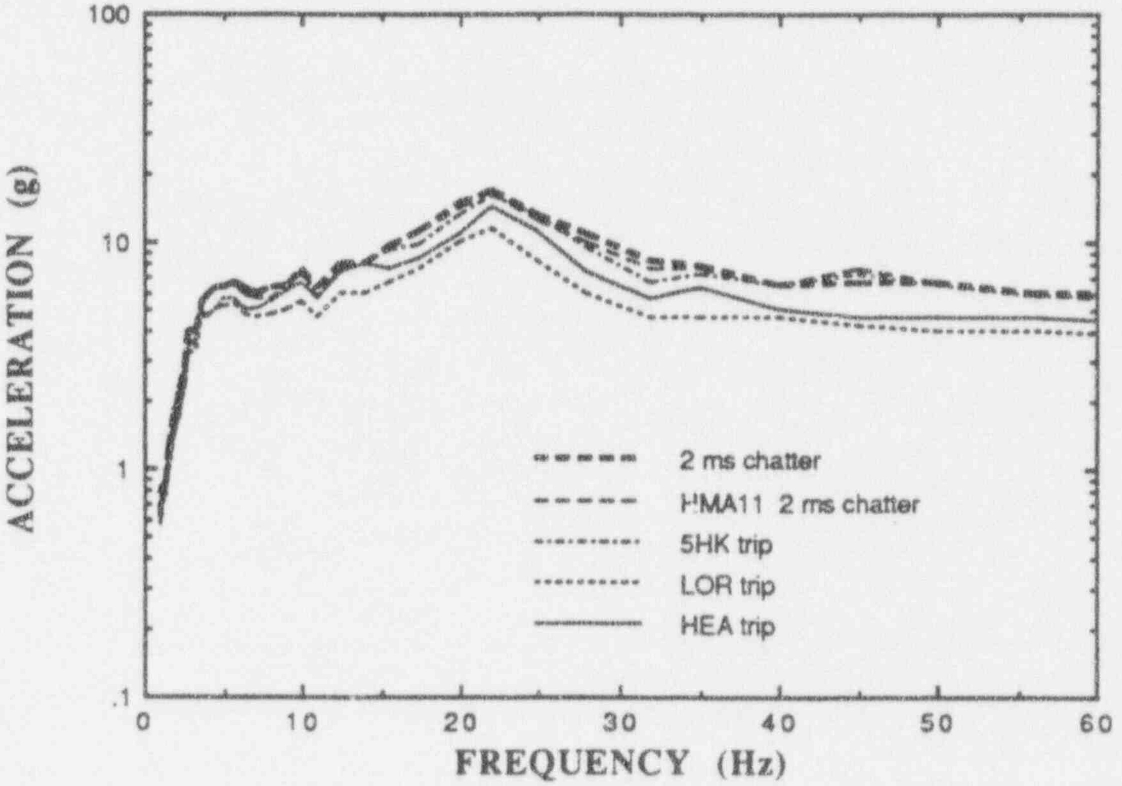

Figure 4.84 Multifrequency Capacity TRS @ 5% Damping, IAV, Vertical Direction

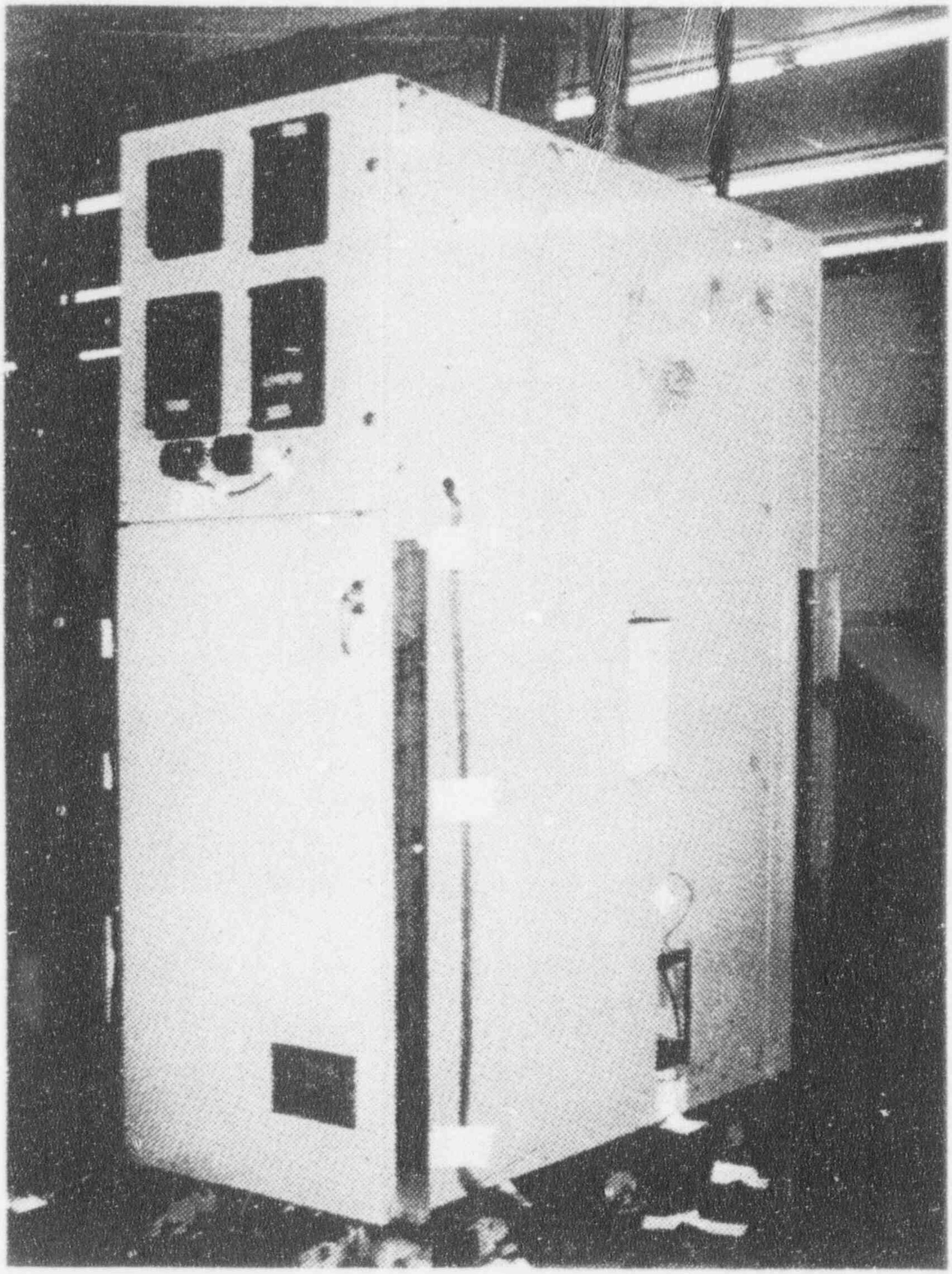

Figure 4.85 Switchgear Cabinet Test Specimen on Shake Table

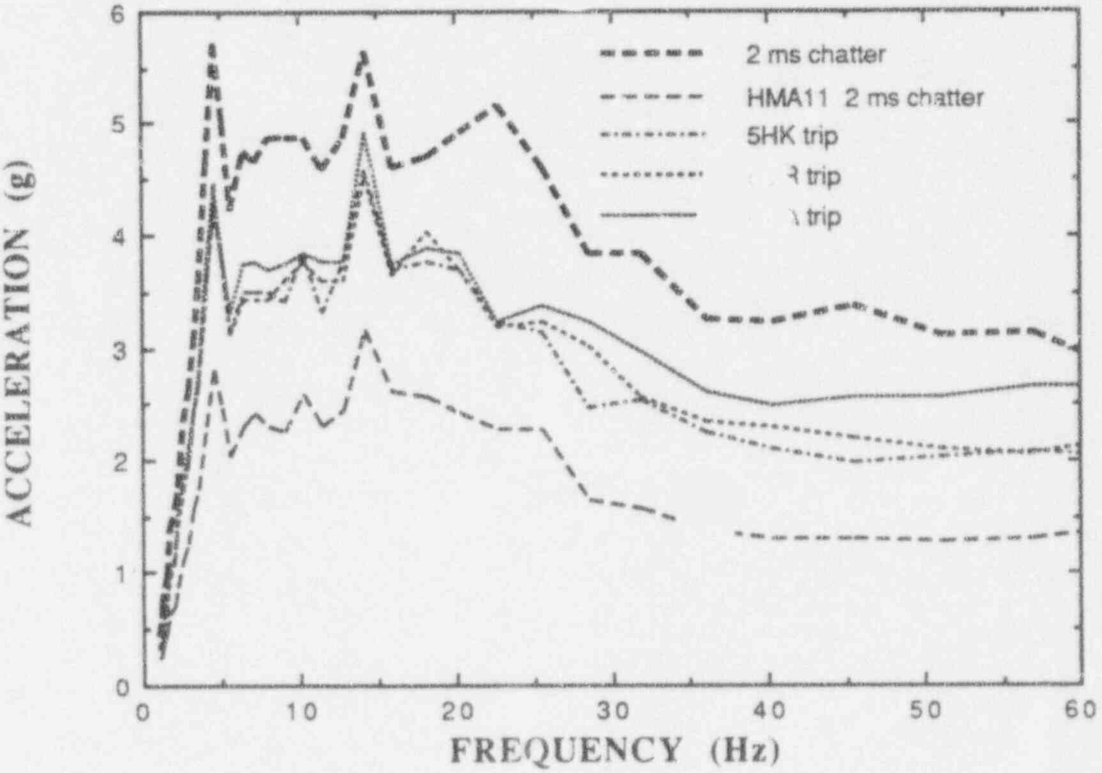

Figure 4.86 Multifrequency Capacity Control TRS @ 5% Damping, CO° in Switchgear Cabinet, Front-to-Back Direction

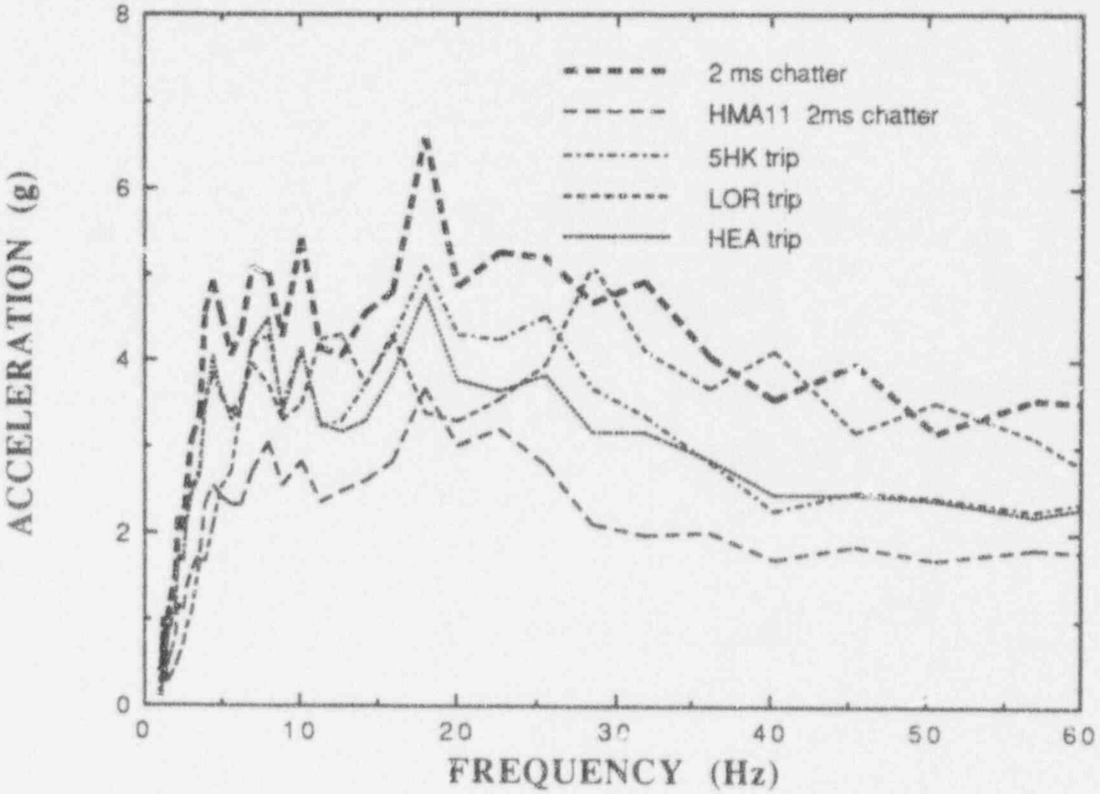

Figure 4.87 Multifrequency Capacity Control TRS @ 5% Damping, CO9 in Switchgear Cabinet, Side-to-Side Direction

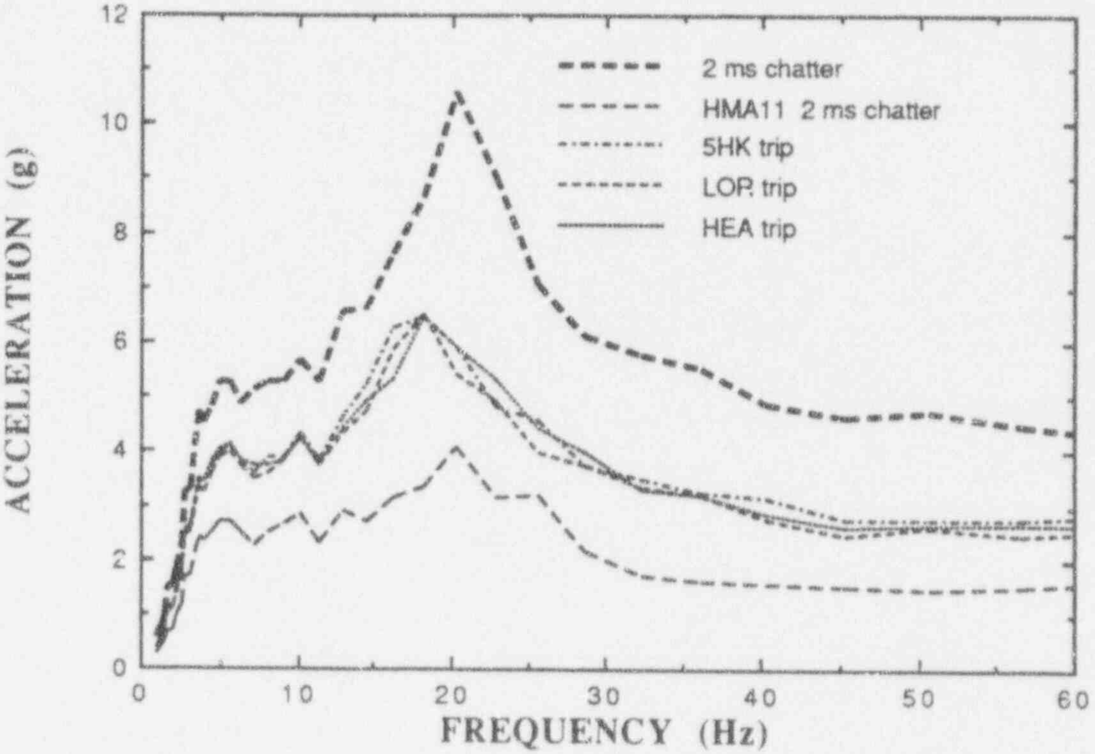

Figure 4.88 Multifrequency Capacity Control TRS @ 5% Damping, CO9 in Switchgear Cabinet, Vertical Direction

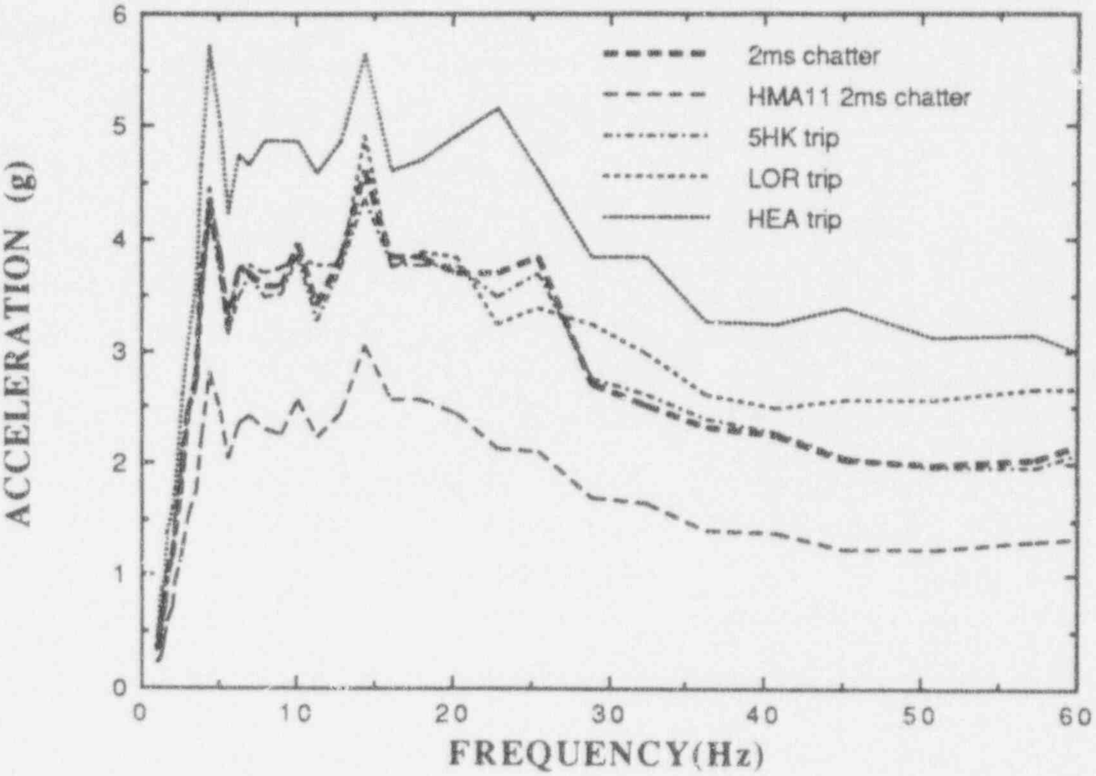

Figure 4.89 Multifrequency Capacity Control TRS @ 5% Damping, IAC in Switchgear Cabinet, Front-to-Back Direction

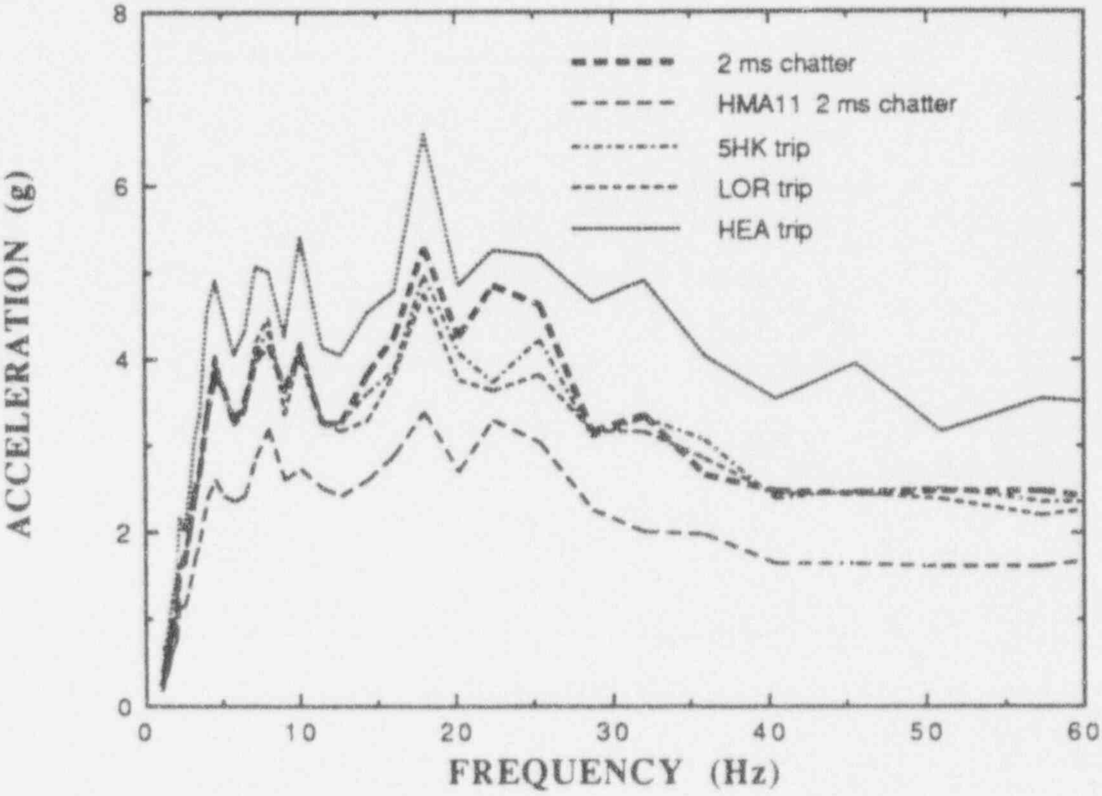

Figure 4.90 Multifrequency Capacity Control TRS @ 5% Damping, IAC in Switchgear Cabinet, Side-to-Side Direction

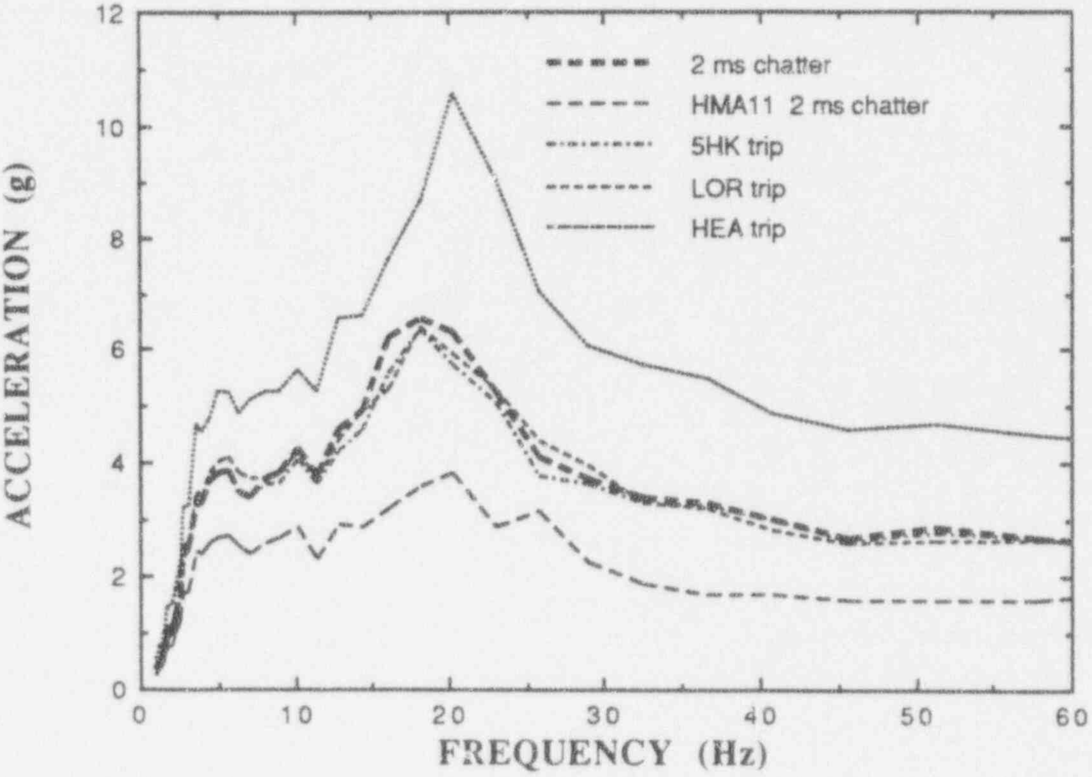

Figure 4.91 Multifrequency Capacity Control TRS @ 5% Damping, IAC in Switchgear Cabinet, Vertical Direction

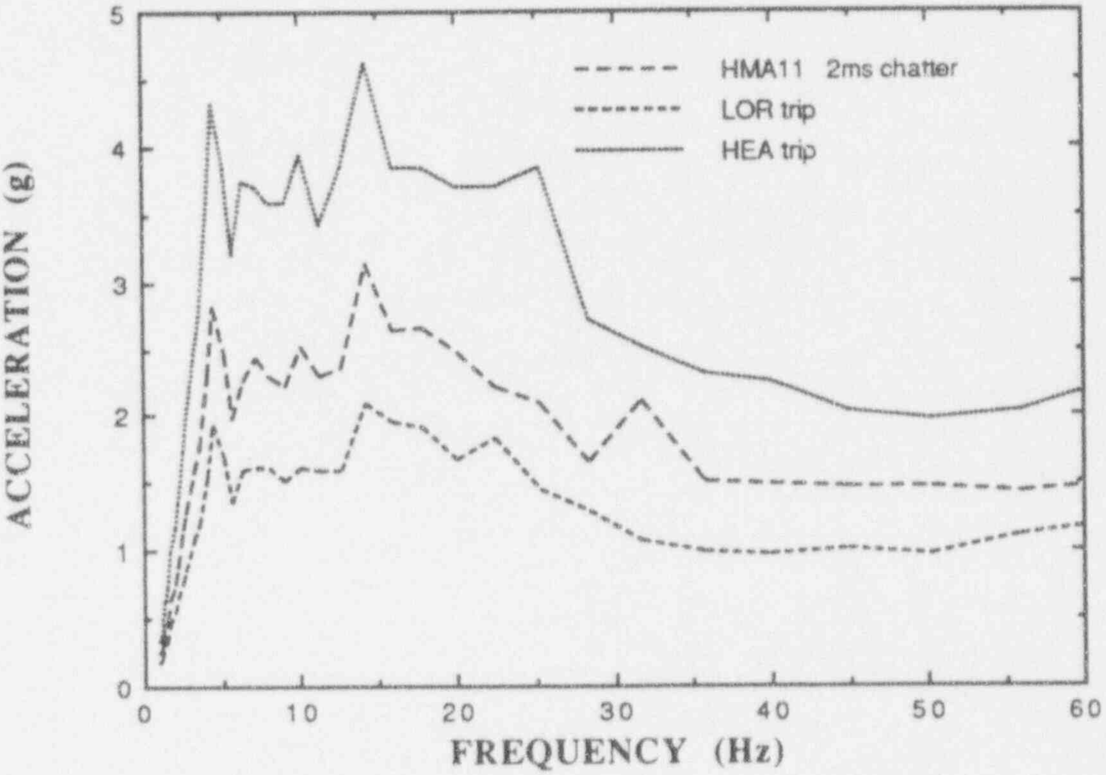

Figure 4.92 Multifrequency Capacity Control TRS @ 5% Damping, IAV in Switchgear Cabinet, Front-to-Back Direction

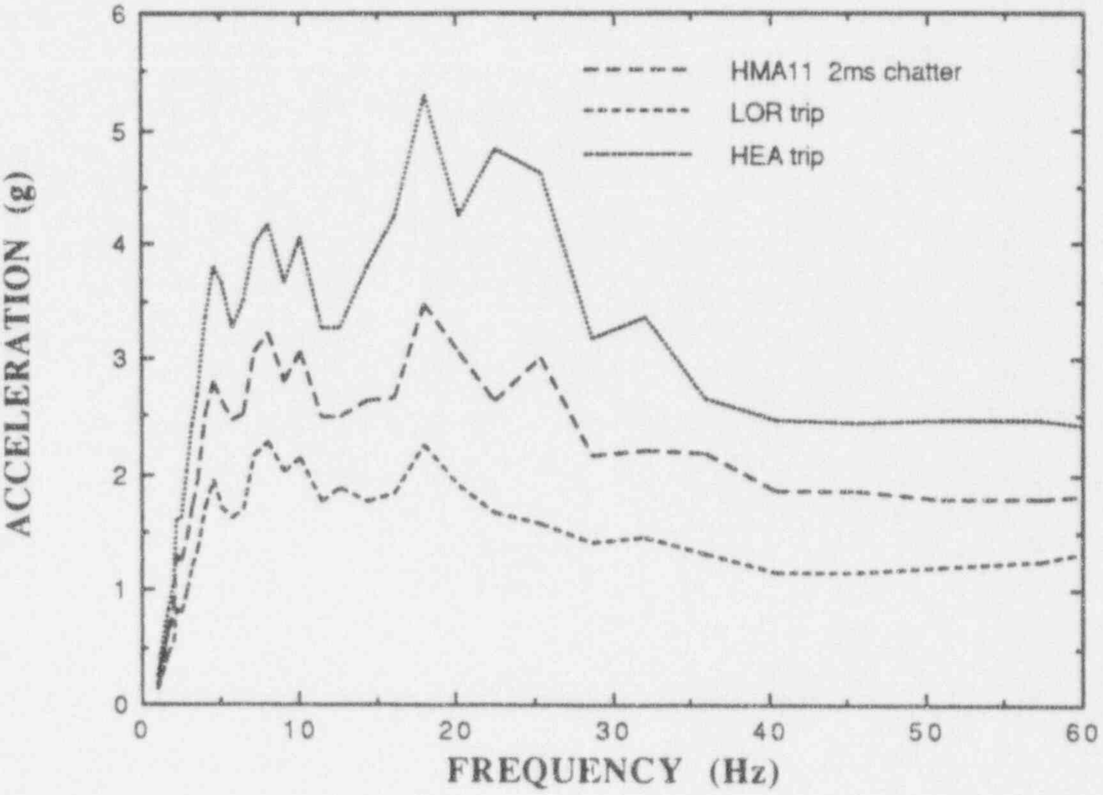

Figure 4.93 Multifrequency Capacity Control TRS @ 5% Damping, IAV in Switchgear Cabinet, Side-to-Side Direction

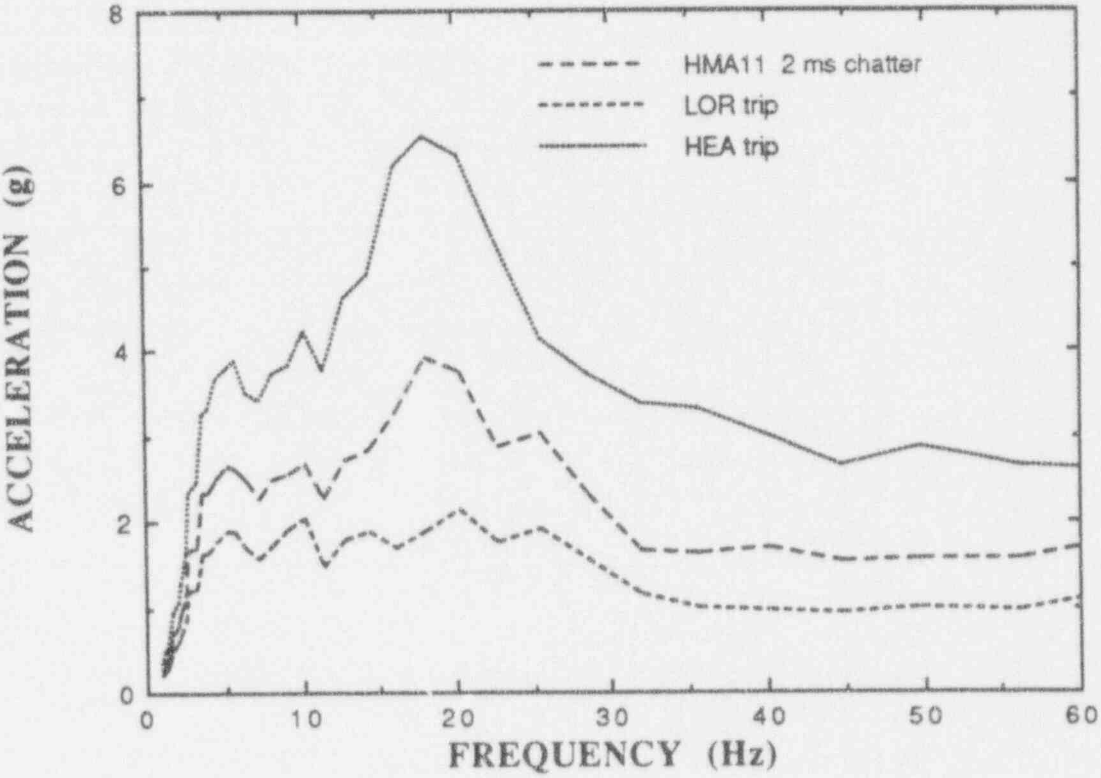

Figure 4.94 Multifrequency Capacity Control TRS @ 5% Damping, IAV in Switchgear Cabinet, Vertical Direction

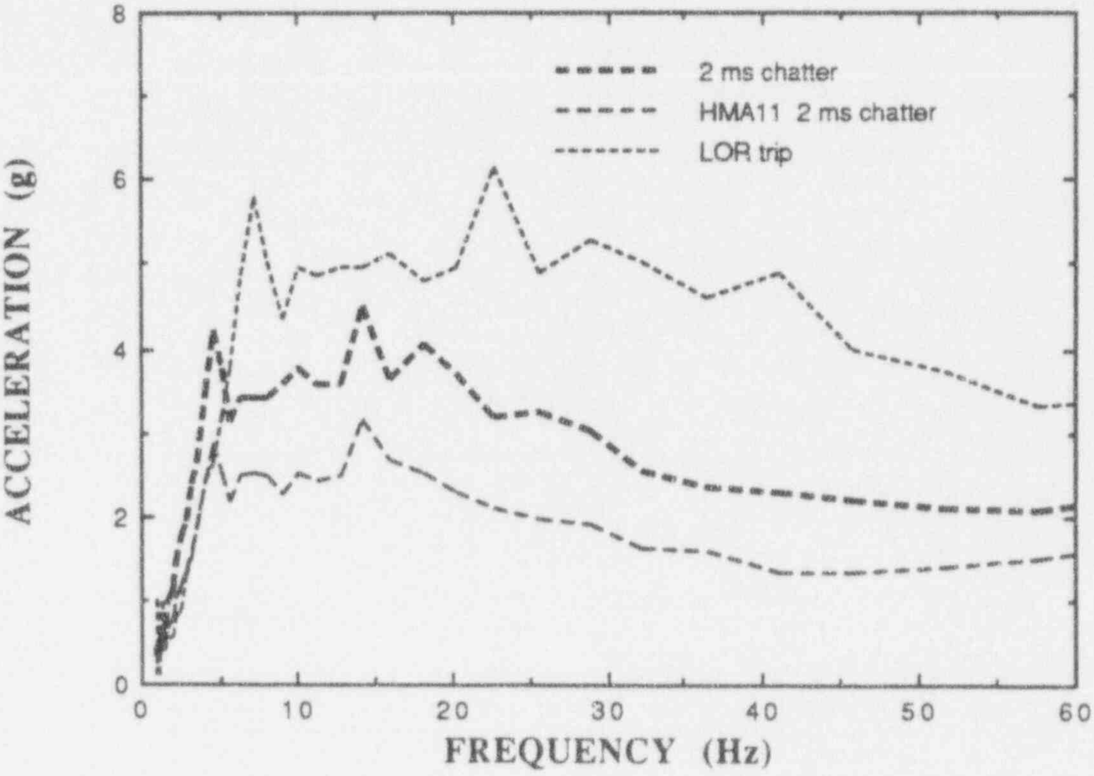

Figure 4.95 Multifrequency Capacity Control TRS @ 5% Damping, SVF in Switchgear Cabinet, Front-to-Back Direction

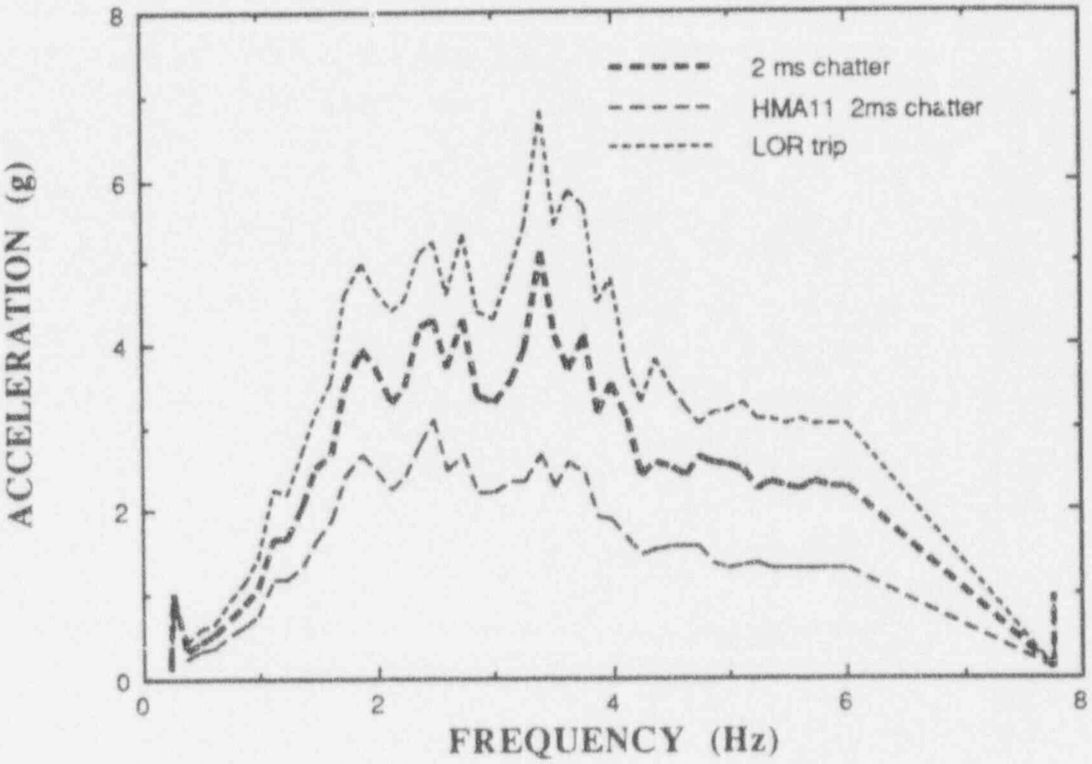

Figure 4.96 Multifrequency Capacity Control TRS @ 5% Damping, SVF in Switchgear Cabinet, Side-to-Side Direction

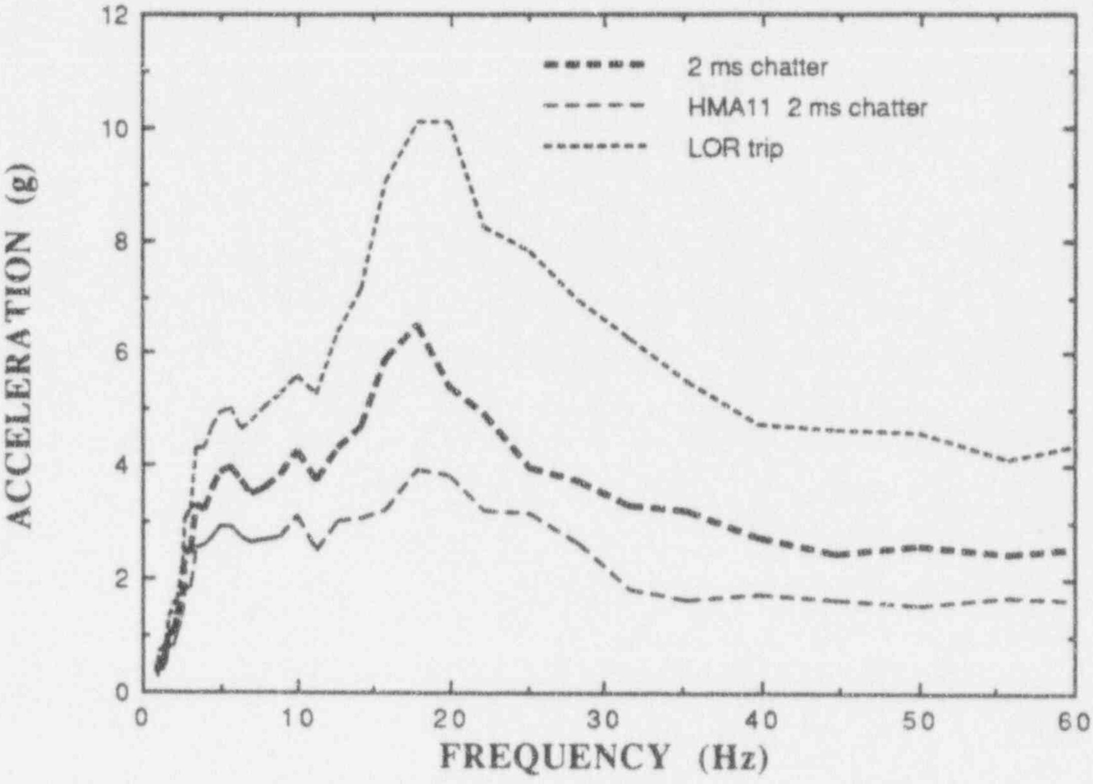

Figure 4.97 Multifrequency Capacity Control TRS @ 5% Damping, SVF in Switchgear Cabinet, Vertical Direction

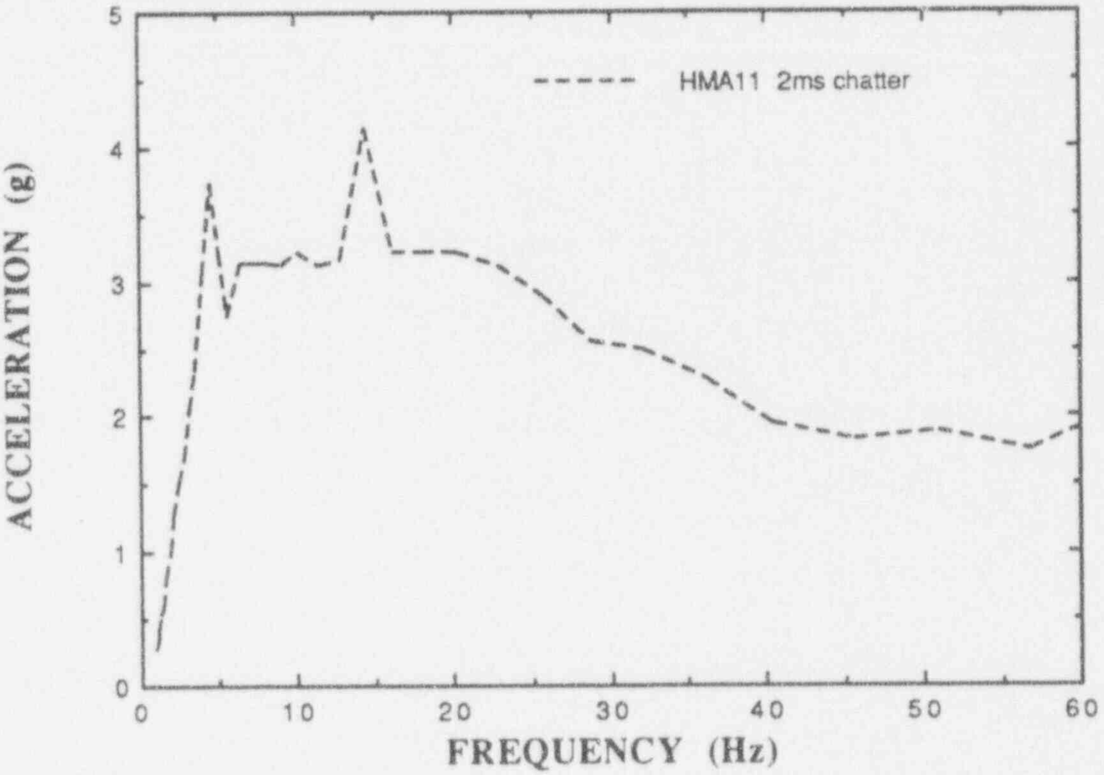

Figure 4.98 Multifrequency Capacity Control TRS @ 5% Damping, HFA in Switchgear Cabinet, Front-to-Back Direction

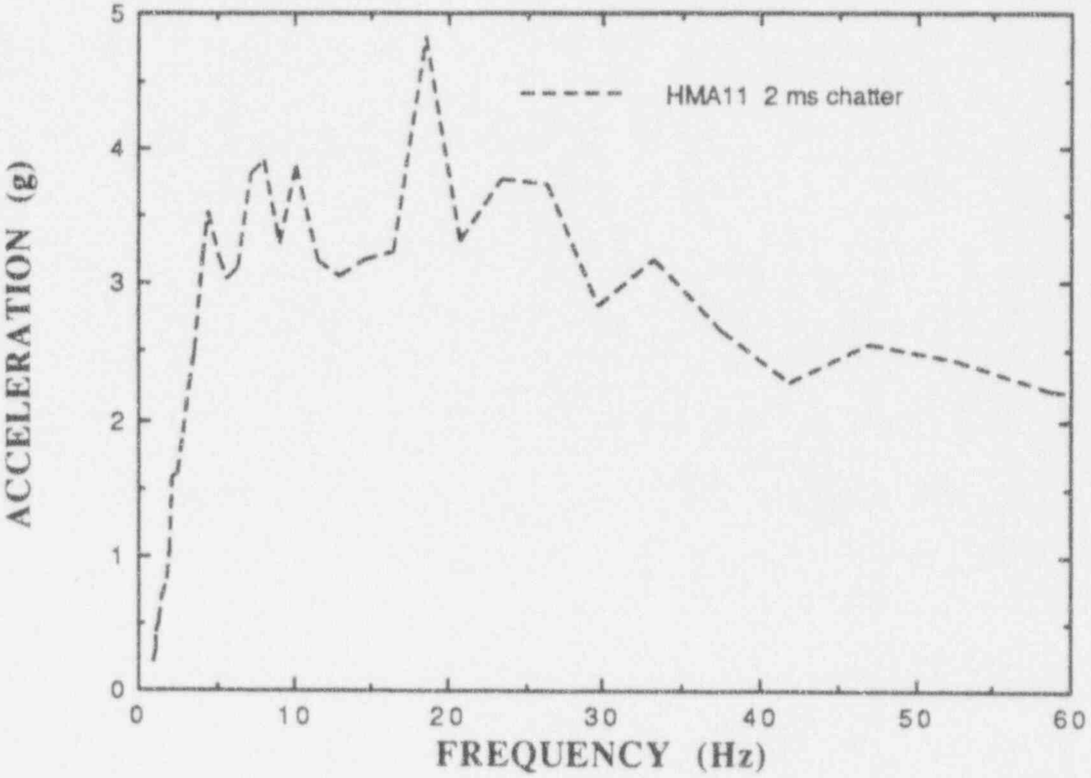

Figure 4.99 Multifrequency Capacity Control TRS @ 5% Damping, HFA in Switchgear Cabinet, Side-to-Side Direction

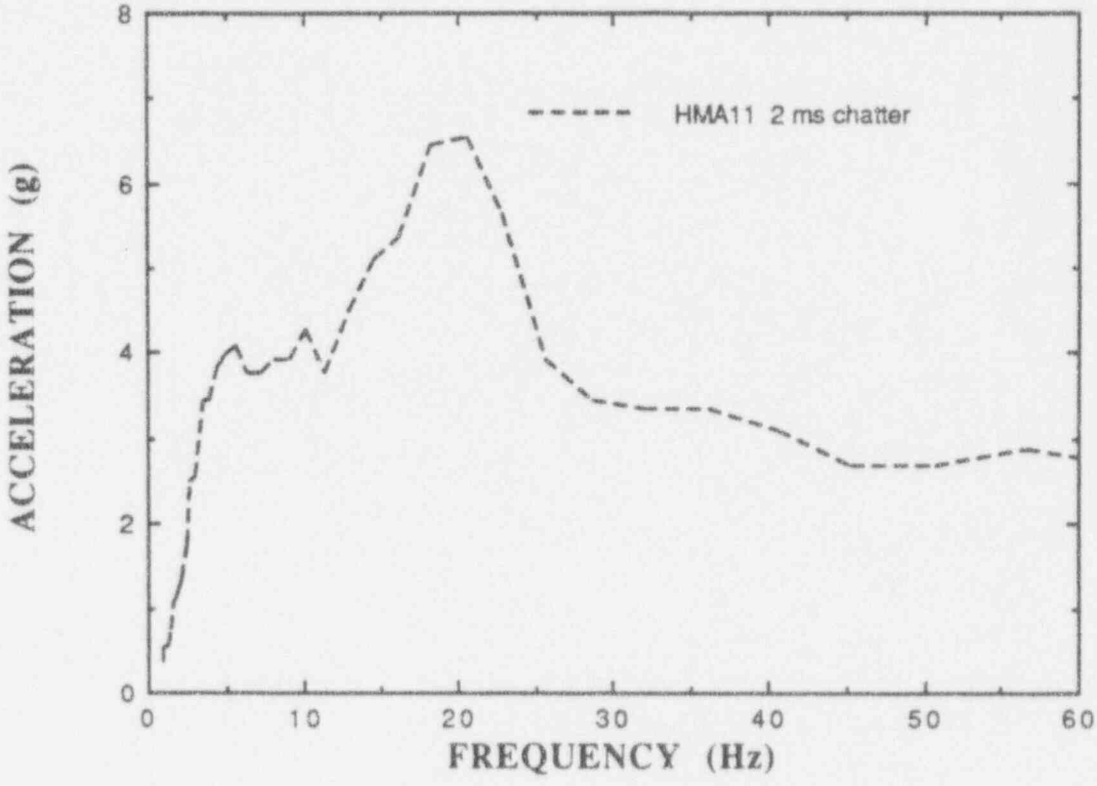

Figure 4.100 Multifrequency Capacity Control TRS @ 5% Damping HFA in Switchgear Cabinet, Vertical Direction

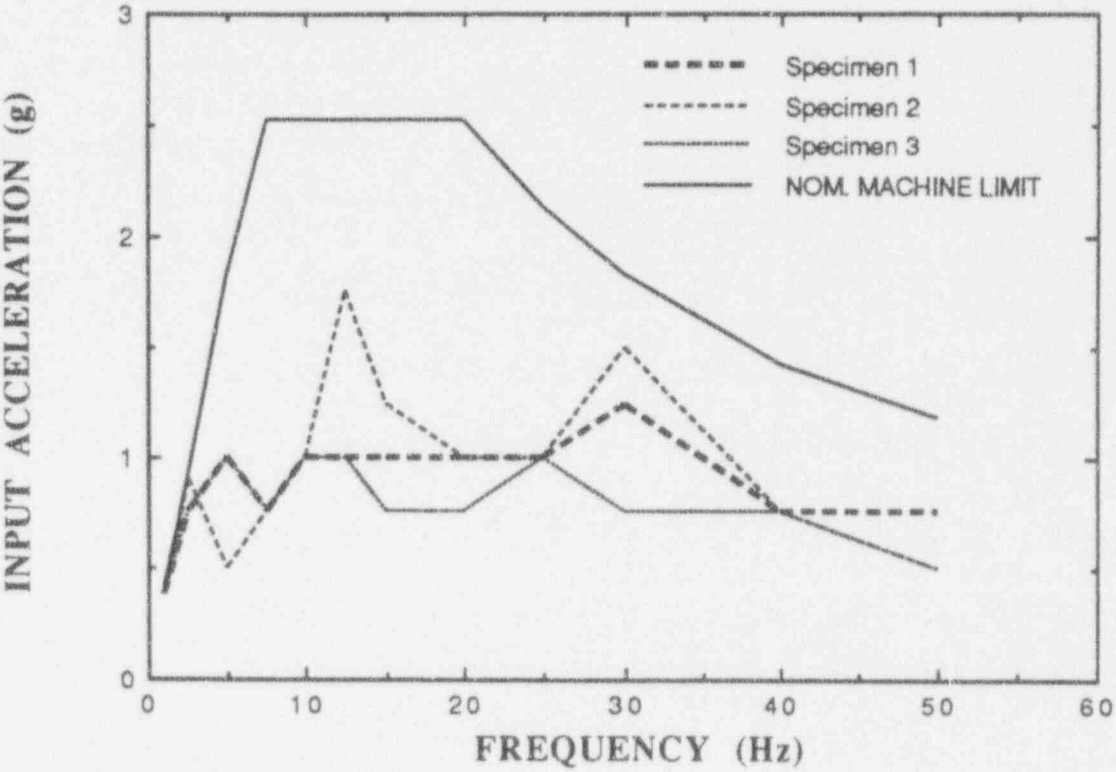

Figure 4.101 Comparison of Specimen Capacities - HMA124, Sine Dwell Amplitude, Front-to-Back Direction, Non-Operating Mode, NC Contact

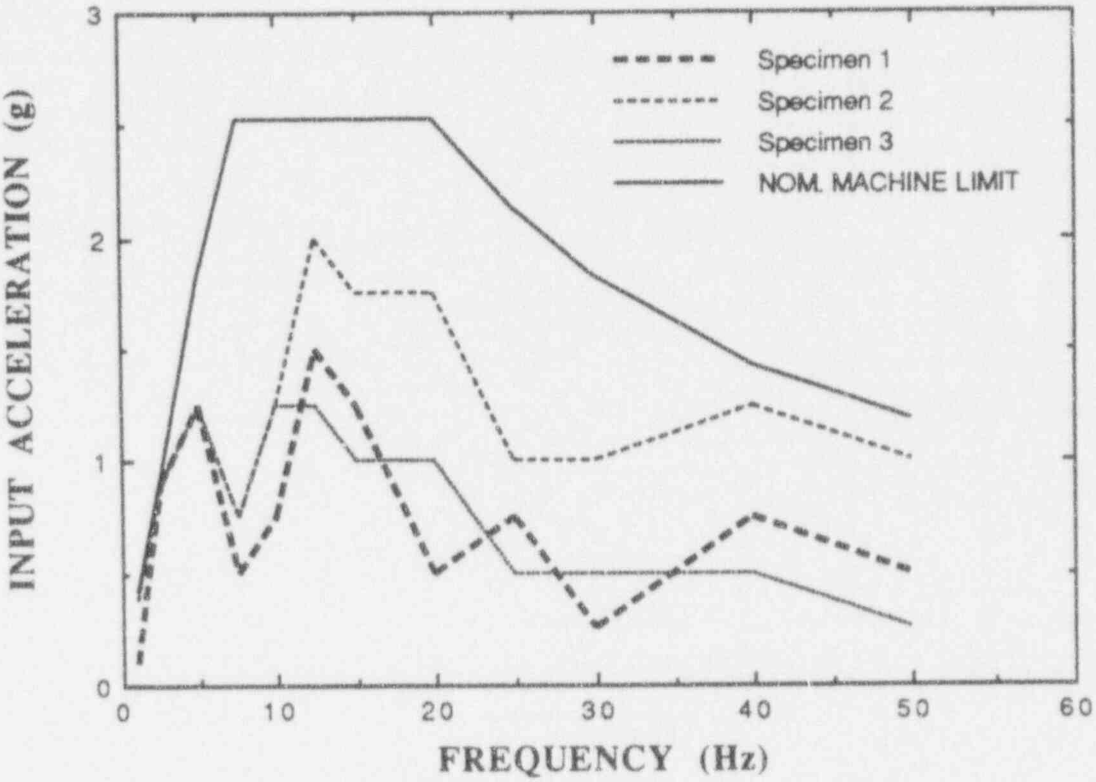

Figure 4.102 Comparison of Specimen Capacities - HMA124, Sine Dwell Amplitude, Vertical Direction, Non-Operating Mode, NC Contact

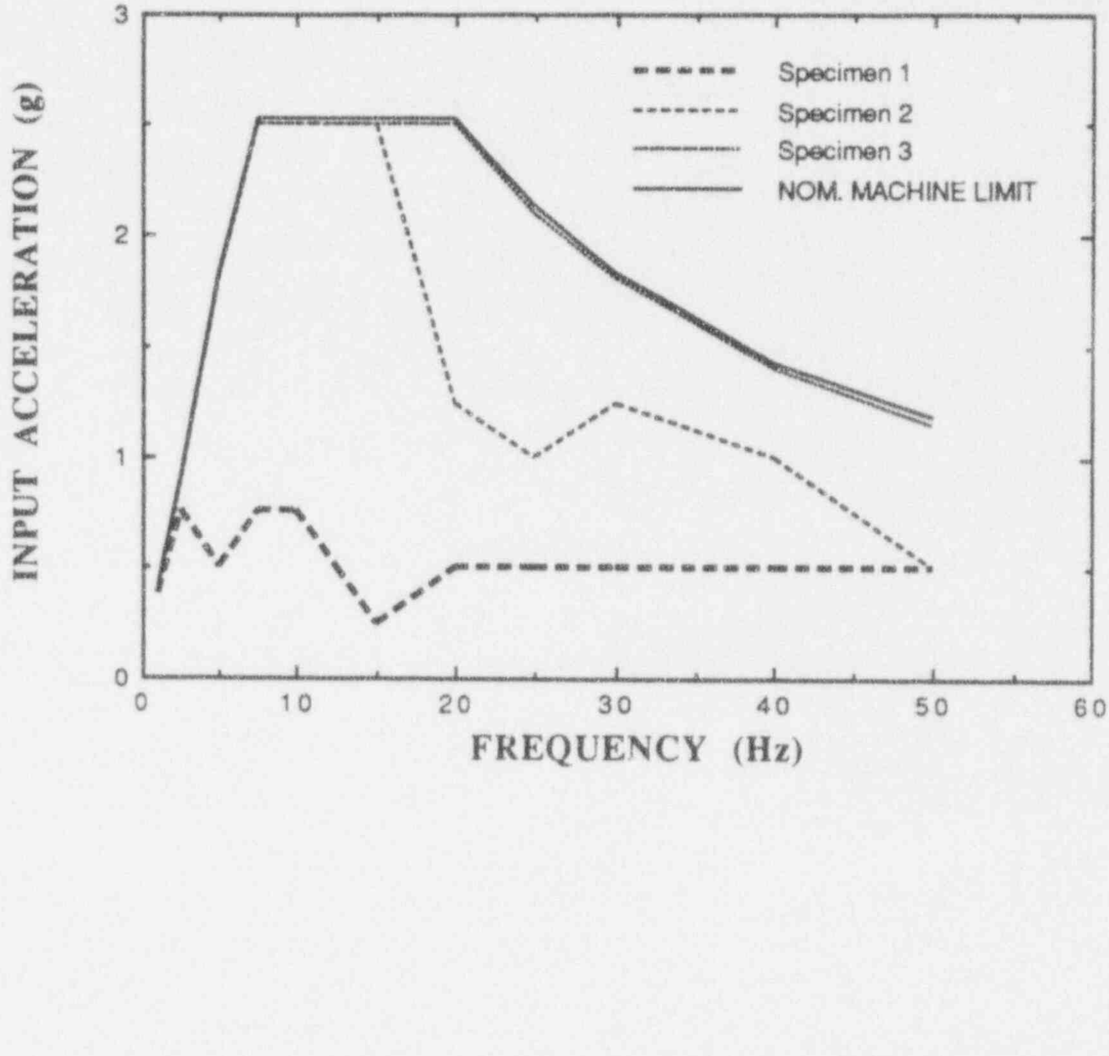

Figure 4.103 Comparison of Specimen Capacities - SC, Sine Dwell Amplitude, Front-to-Back Direction, Non-Operating Mode, NC Contact

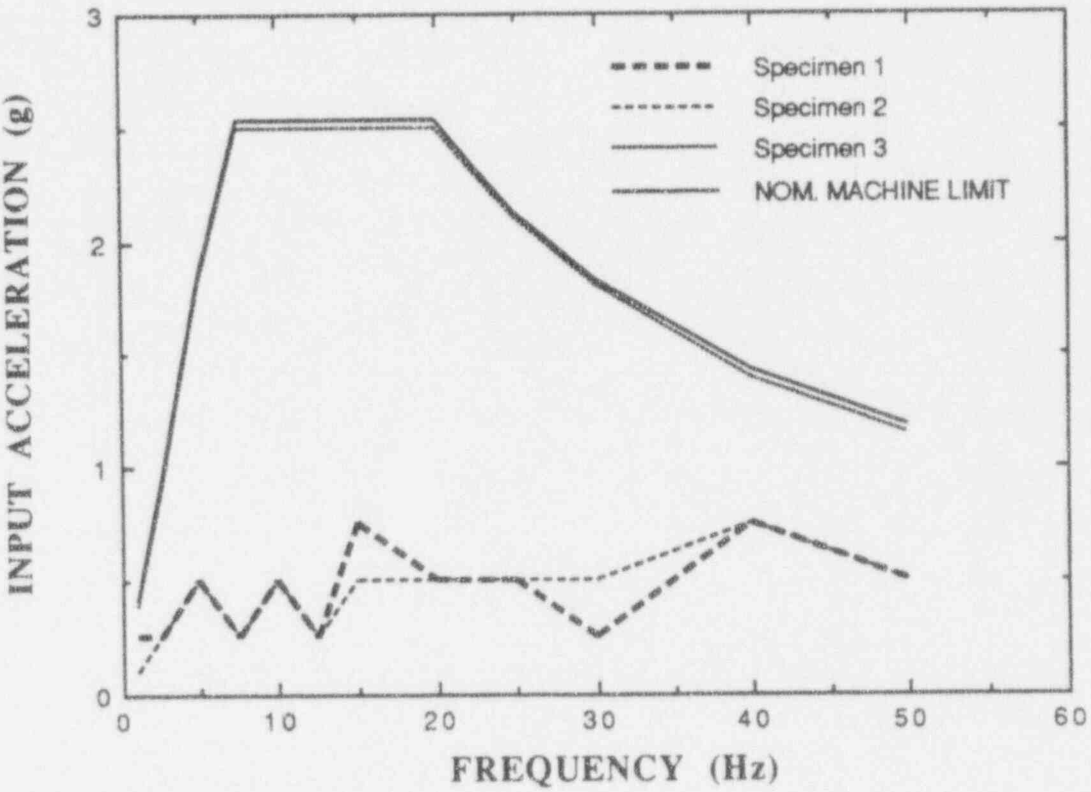

Figure 4.104 Comparison of Specimen Capacities - SC, Sine Dwell Amplitude, Vertical Direction, Non-Operating Mode, NC Contact

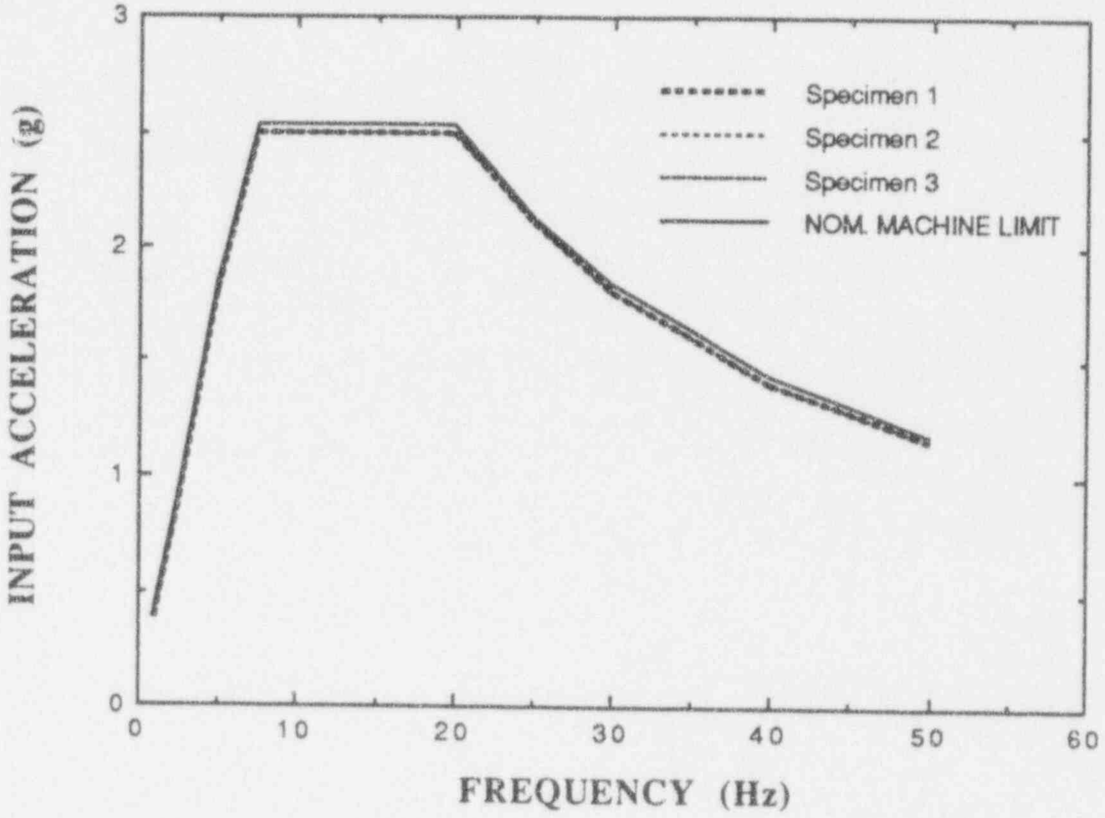

Figure 4.105 Comparison of Specimen Capacities - SVF, Sine Dwell Amplitude, Front-to-Back Direction, Operating Mode, NC Contact

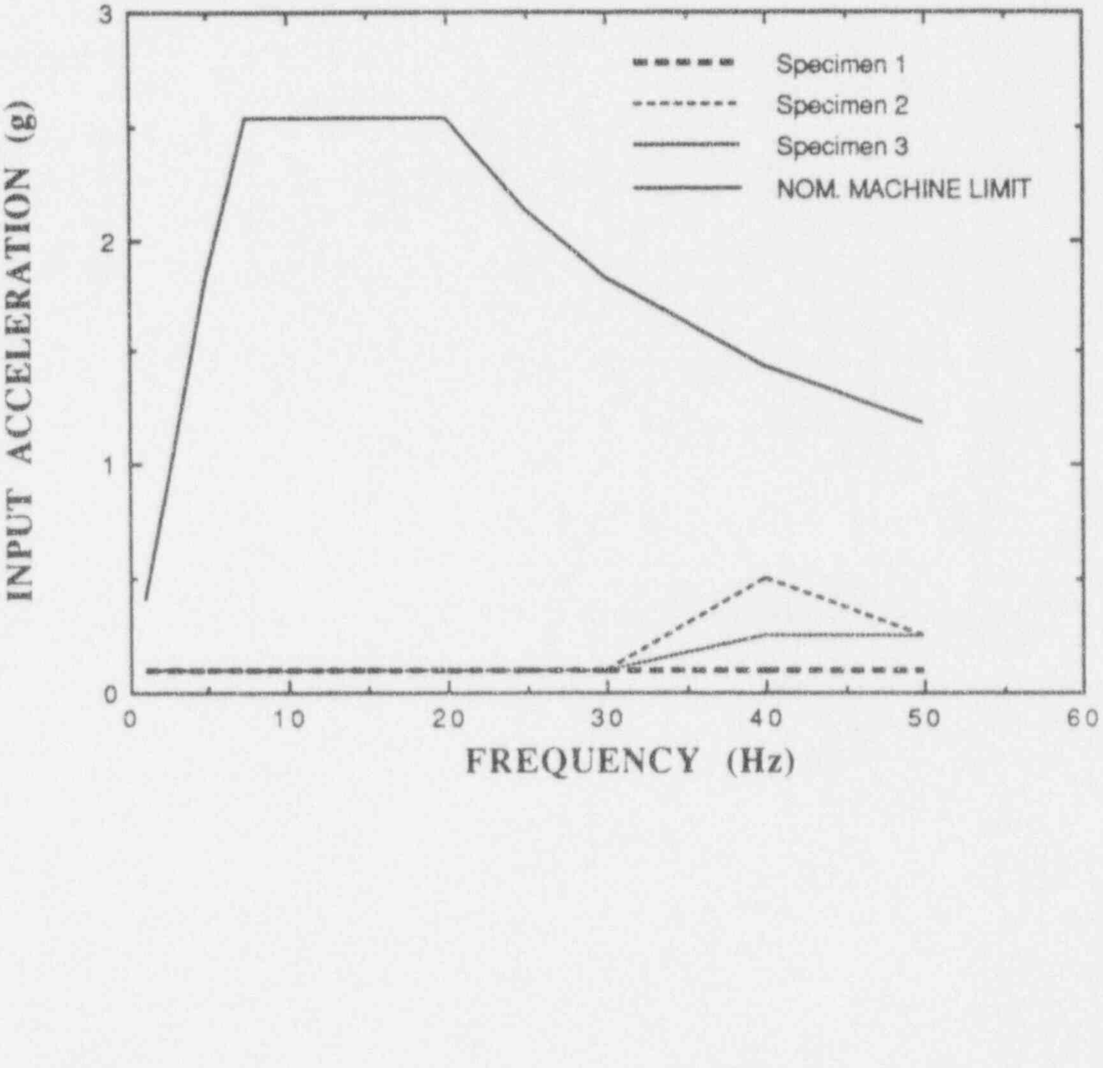

Figure 4.106 Comparison of Specimen Capacities - SVF, Sine Dwell Amplitude, Vertical Direction, Operating Mode, NC Contact

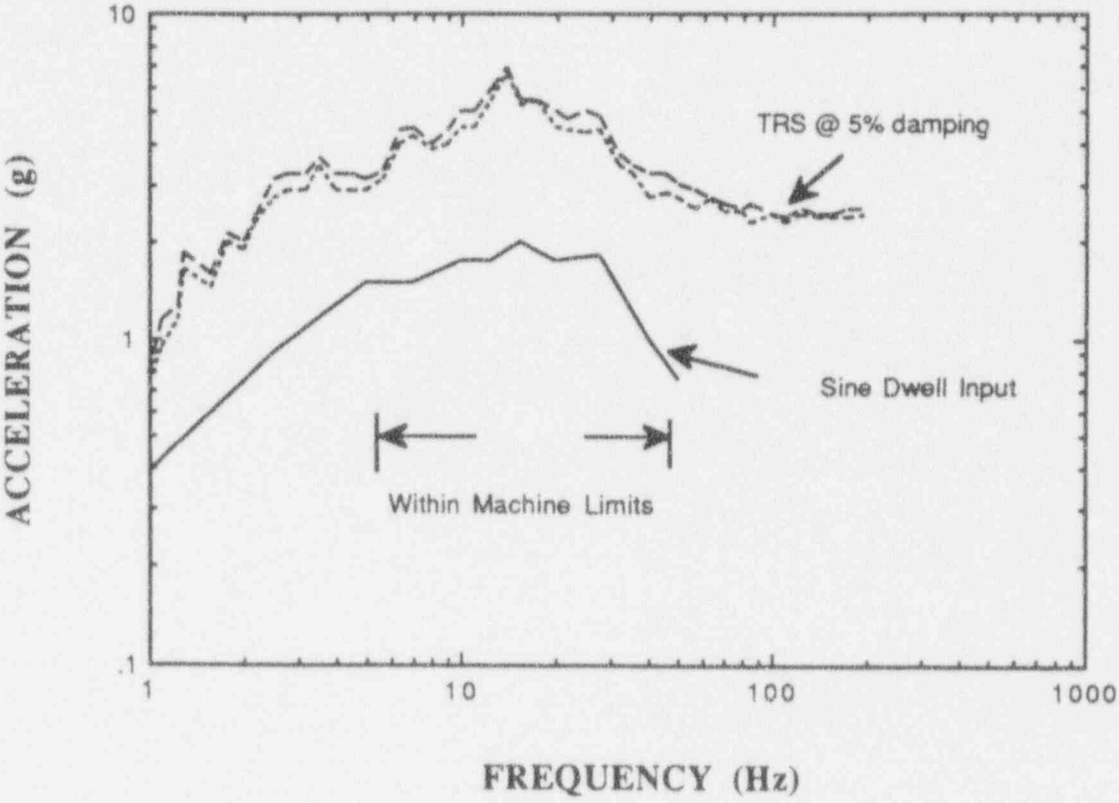

Figure 4.107 Capacity Levels - Multifrequency TRS and Sine Swell Input, HFA, Specimen 1, Front-to-Back Direction, Non-Operating Mode, NC Contact

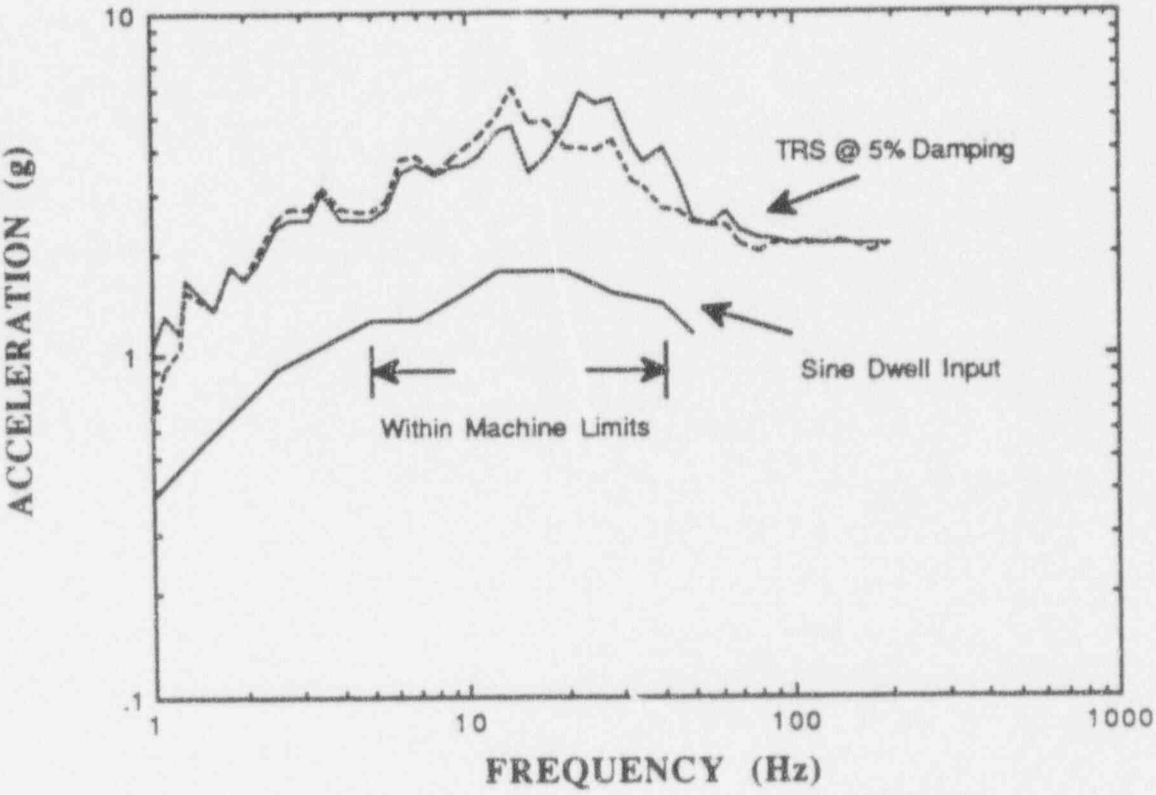

Figure 4.108 Capacity Levels - Multifrequency TRS and Sine Dwell Input, HFA, Specimen 2, Front-to-Back Direction, Non-Operating Mode, NC Contact

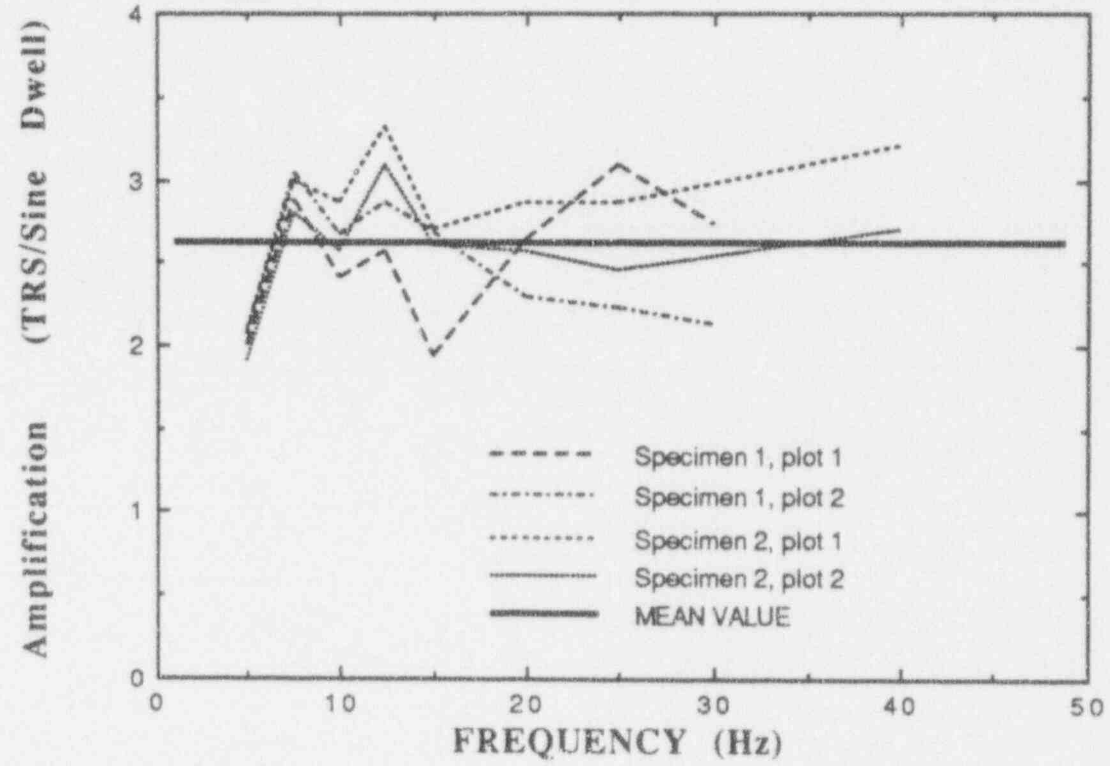

Figure 4.109 Ratio of Multifrequency TRS @ 5% Damping to Sine Dwell Input, HFA, Front-to-Back Direction, Non-Operating Mode, NC Contact

Table 4.1 Source Relay Chatter Required for Load Device Trip

LOR Trip History

Source Relay	Duration Required for LOR Trip Since Initiation of Source Relay Chatter (ms)	Mean Value	Electrical Test Data
CO9 Chatter	6,7,7	6.5 ms	7.5 ms (2 ms pulse)
IAC Chatter	7,7,6,5,7		
IAV Chatter	6,6,6,7,7,		

HEA Trip History

Source Relay	Duration Required for HEA Trip Since Initiation of Source Relay Chatter (ms)	Mean Value	Electrical Test Data
CO9 Chatter	12,16,10,37[+],11,11,15	15.2 ms	14 ms (8 ms pulse)
IAC Chatter	11,9		
IAV Chatter	15,26,10,10,11,13,15,10,17, 12,21,10,26,27,11,21,30		
SVF Chatter	38[+]		

[+] Not included in calculating the mean value

5HK Trip History

Source Relay	Duration Required for 5HK Trip Since Initiation of Source Relay Chatter (ms)	Mean Value	Electrical Test Data
CO9 Chatter	36, 38	33.8 ms	29.7 ms (12 ms pulse)
IAC Chatter	60[+],32,35,35,43,36		
IAV Chatter	32,32,32,34,32,33,33,31,33,31,31		
SVF Chatter	61[+]		

[+] Not included in calculating the mean value

Table 4.2 Influence of Monitoring Current

CO9, Single Frequency Sine Dwell Test

Monitoring Current	**1 amp**	**150 mamps**	**25m amps**
Input Motion	1.81 g	2.08 g	2.04 g
Maximum Chatter Duration	20 ms	5 ms	4 ms
Total Number of Chatter ≥ 2 ms	249	55	29
Occurence of First Chatter Event	5.724 sec	4.159 sec	6.503 sec

IAV, Single Frequency Sine Dwell Test

Monitoring Current	**1 amp**	**150 mamps**	**25 mamps**
Input Motion Level	1.42 g	1.63 g	1.63 g
Maximum Chatter Duration	467 ms	3 ms	78 ms
Total number of Chatter ≥ 2 ms	335	1	295
Occurrence of First Chatter Event	11.240 sec	35.708 sec	9.052 sec

IAC, Single Frequency Sine Dwell Test

Monitoring Current	**1 amp**	**25 mamps**
Input Motion	2.39 g	2.09 g
Maximum Chatter Duration	6 ms	5 ms
Total number of Chatter ≥ 2 ms	48	201
Occurrence of First Chatter Event	16.913 sec	7.191 sec

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 INTRODUCTION

A large number of electrical and vibration tests were performed to address the four basic issues listed in Sections 1.3 and 1.4 of Chapter 1. The test procedures and the data are presented in Chapters 2, 3 and 4. Some specific observations are also made in presenting the data. A summary of the general observations is presented in this section. The extent to which the data address the objectives is also discussed in this chapter.

5.2 SUMMARY

The major observations from the electrical and vibration test data are as follows:

1. The duration of an electrical signal (i.e., pulse) required to cause a trip in a circuit breaker or lockout relay is much less than the actual trip time of these devices. The required signal duration can be estimated from trip times obtained at least at two different voltage levels. The larger the difference in the voltage level is, the better is the estimate.

2. The minimum pulse durations required to trip low and medium voltage circuit breakers are comparable to those for most lockout relays, except the fast lockout relays.

3. The effect of alternating signals (i.e., "on" and "off" pulses) is more pronounced on self reset auxiliary relays than circuit breakers or lockout relays.

4. In an integral circuit with a source relay, where the electrical signal is generated through the relay contact, a lockout relay, or a low or medium voltage circuit breaker consistently requires the same current duration for a change of state regardless of the source relay model.

5. The vibration capacity of a source relay in terms of an undesirable trip of a circuit breaker or lockout relay could be less than that based on a 2-ms chatter criterion. A possible explanation is the inability of the source relay contact to interrupt the current in a DC circuit and reliance on the trip device itself to open the circuit.

6. A significant influence of electrical parameters, such as voltage in the trip coil or monitoring current in the chatter detection circuit, on the vibration capacities of the source relays has been observed. However, a definite trend could not be established. In other words, a combination of such parameters can produce one result (e.g., high or low seismic capacity) for a particular relay whereas another combination can produce a substantially different result for the same relay.

7. In a vibration test with increasing motion at each test, once some amount of chatter (e.g., 2 ms or less) is observed it is unpredictable what chatter duration will be observed at a slightly higher level. This could be very large (e.g., 100 times) or just the same.

8. Relay chatter (and consequently tripping of a breaker or a lockout relay receiving signal from this relay) occurring at a particular vibration level can absolutely disappear at a higher level and may not recur even up to the shake table vibration limit.

9. The vibration capacity of a relay model can vary from specimen to specimen. For most relays the variation is less than two-fold. However, for some other relays, the variation could be very large (e.g., 5 to 7 times). The deviation seems to stem from physical differences such as armature engagement conditions and air gap in the magnetic circuit[3].

10. The multiplying factor required to convert single frequency sine dwell capacity input motion to the respective TRS at a damping value of 5% is in the range of 2.5 to 3.0 for two auxiliary relay models tested in the current and the previous test programs.

5.3 COMPARISON WITH OBJECTIVES

The extent to which the data presented in this report and the observations made above address the issues listed in Chapter 1 can be summarized as follows:

1. Relay chatter acceptance criteria

   The test data adequately address the issue and indicate that a relay vibration capacity should best be obtained by representing the appropriate circuit during testing. In the absence of that, the capacity based on the conventional 2-ms chatter criterion is generally acceptable but could be substantially higher than what would have been obtained in an integral circuit.

2. Relay chatter associated with breaker

   The test program adequately addresses this issue. The trip time for a low or medium voltage circuit breaker is much greater than 2 ms. However, this does not increase the vibration capacity of the source relay providing DC signal to the breaker possibly due to inability of the source relay contacts to interrupt the current. Most lockout relays can be used for vibration testing in an integrated circuit test in lieu of the heavy low or medium voltage breakers since these lockout relays exhibit similar tripping characteristics.

3. Capacity variation among specimens of the same model

   This issue has been sufficiently addressed. The test data show variation up to 100% for most relays and 700% for some others. Physical differences in relays (non-class 1E) seem to be the explanation.

4. Additional data for single frequency to multifrequency conversion factor

   This issue has also been addressed to the desired extent, i.e., data for an additional relay. So far the data support a multiplication factor of 2.5 - 3.0 for two relay models.

5.4 CONCLUSIONS

The major conclusion is that the relay vibration capacity can be significantly influenced by any of the large number of electrical and vibration parameters that are used for testing. It is extremely difficult in an integral circuit to distinguish and quantify the effect of each parameter especially since most phenomena are influenced by more than one parameter and since the monitoring circuits are also affected by some of these parameters. Any further focusing on these parameters will probably not provide any more reliable insights.

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[3] All test specimens were non-class 1E relays. Such physical differences may not exist in class 1E relays.

Therefore, from a practical standpoint, it is believed that a reasonable confidence can be achieved if the following recommendations are implemented in a relay test program:

- Test multiple specimens. Three may be a reasonable balance as suggested by the IEEE Std. [4].
- Test electrical conditions representing field applications.
- Test in an integral circuit. Most lockout relays can be used instead of low or medium voltage breakers for this purpose. In an independent test, do not take advantage of the fact that devices such as low or medium voltage circuit breakers require a chatter duration much greater than 2 ms. A capacity level based on the 2-ms chatter criterion can be unconservative even for a medium voltage breaker.
- Test with progressively higher vibratory motion, i.e., all vibration levels (with a reasonable separation between consecutive levels) below the capacity level should be covered since the performance of a relay is not linear and it may chatter at a lower level. A successful test at only one level does not necessarily demonstrate the vibration-withstanding capability of the relay at all lower levels.

CHAPTER 6

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

This report presents the results of a relay test program conducted by Brookhaven National Laboratory (BNL) under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC). The program is a continuation of an earlier test program the results of which were published in NUREG/CR-4867. The current program was carried out in two phases: electrical testing and vibration testing. The objective was primarily to focus on the electrical discontinuity or continuity of relays subject to electrical pulses and vibration loads. The electrical testing was conducted by KEMA-Powertest Company and the vibration testing was performed at Wyle Laboratories, Huntsville, Alabama. This report discusses the test procedures, presents the test data, includes an analysis of the data and provides recommendations regarding reliable relay testing.

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