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Relay Test Program

Series I Vibration Tests

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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

PNL has conducted a test program on relays to determine the influence of parameters related to design, electrical conditions and vibratory motion on their respective seismic capacity levels. Single frequency excitation was used for most of the test runs; multifrequency random motion was also used for some test runs. The test data have been evaluated and the results are presented in this report.

EXECUTIVE SUMMARY

As part of the Component Fragility Research Program, BNL has conducted a test program to explore the influence of various vibration and electrical parameters on the seismic capacity of relays. A total of forty six commercial grade relays were tested. Most of the tests were performed with single axis sine dwell excitation in the frequency range of 1-50Hz. Relays were tested both with the electrically operating and nonoperating conditions. Both the normally open and normally closed contacts were monitored. Limited multifrequency tests were also performed to determine the correlation between the single frequency and multifrequency fragility levels. Electrical chatter for a duration of 2 milliseconds or greater was used as the failure criterion.

The enormous amount of data generated from approximately three thousand test runs have been evaluated and the results are contained in this report. The capacities of the tested relays are provided at each frequency in terms of the acceleration of the input sine dwell motion. Multifrequency test results are presented in terms of test response spectra. Substantial variations of the capacity results are observed due to influence of the frequency and direction of the input motion, electrical modes and contact states. The capacities of multiple specimens of the same relay model typically vary up to 50-100%. Repeated short duration chatter is observed in some cases to be more harmful than a single long duration chatter output.

At low frequencies, the capacity levels of the tested relays were controlled by input motion either in the front-to-back or in the vertical direction; whereas, at high frequencies typically the vertical motion was more damaging. The side-to-side motion seldom controlled the capacity level. For most relays, the normally closed contacts in the nonoperating electrical condition were first to indicate chatter. It was difficult to control the shake table motion in determination of the frequency dependent fragility test response spectra. This was successful for one relay model. The mean ratio between the spectral acceleration at 5% damping and the respective sine dwell amplitude was approximately three (3). A few relays were tested with alternate adjustments and settings. It appears that at each frequency there is an optimum adjustment for each specimen at which it performs best.

The current test program is also described in this report. The impact of the 2 millisecond chatter on the relay capacity levels will be investigated by further testing. The variation of the capacity levels among specimens of an identical relay model will be further explored. The conversion factor relating the multifrequency test response spectra with the corresponding single frequency input motion will be established for additional relay models.

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CHAPTER 1
BACKGROUND

1.1 INTRODUCTION

This report discusses a relay seismic test program which was conducted as part of the Component Fragility Program at BNL sponsored by the NRC. The testing was performed at Wyle Laboratories' Huntsville facility during the period November 1988 through January 1989[1]. The background and objectives of the test program are discussed in this chapter. The test procedure is described in Chapter 2 and the test results are presented in Chapter 3. A summary of results is provided in Chapter 4.

1.2 BACKGROUND

As part of the Component Fragility Research Program, BNL has collected and studied seismic test data of relays[2]. These fragility tests were performed in the period 1973-85. Depending on the standards and requirements of the time, relays were tested by use of different testing techniques that can be broadly categorized as follows:

1. Single axis, single frequency fragility tests, e.g., sine dwell, sine beat
2. Multiaxis, multifrequency tests to specific requirements
3. Multiaxis, multifrequency tests per ANSI/IEEE C37.98[3].

In these tests, the contact chatter was considered as the failure mode. The single frequency tests were performed in the early 1970's and the corresponding vibration levels were presented in terms of the input acceleration level vs. frequency. Since the mid-1970's, relays were tested with multiaxis, multifrequency excitation and the results were presented in terms of the test response spectrum (TRS). In some test programs, the specimens were tested to a preselected required response spectrum (RRS) shape. Since 1977 relays were typically tested to the IEEE response spectrum shape which shows a peak spectrum acceleration of 250% ZPA at a damping value of 5% in the frequency range 4-16Hz[3]. Due to the limitation of the capacity of the shake table, the relays were tested to a maximum of 6g ZPA although there were some tests at 4g ZPA. If the relay indicated chatter below the shake table limit, the corresponding IEEE spectrum was used as the capacity of the relay. Although such multi-requency test data are very useful in comparing with the RRS, the real fragility level is not depicted by the corresponding TRS for the obvious reason that at some frequencies the relay could have withstood a higher acceleration level than the value represented by the IEEE curve. In other words, the frequency dependent true fragility TRS curve[1] usually cannot be obtained from such test data.

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[1] The "frequency dependent true fragility TRS" curve is defined in this report as an ideal fragility curve such that the acceleration level at each frequency represents the fragility level of the component at that particular frequency and exceedance of the acceleration level will cause failure of the component.

In addition to the individual relay tests described above, wherein the specimens were mounted on rigid fixtures, a large number of tests were conducted with relays mounted on flexible panels. These panels were tested with either single frequency or multifrequency inputs, and in some cases relays exhibited chatter. Accelerometers mounted at the relay locations provided the corresponding vibration levels at which the relays malfunctioned. Thus, the relay fragility information can also be derived from the panel test data. Since relays are mounted on flexible panels in the field, data obtained from panel testing, where the vibration has been filtered through the panel structure, are expected to reflect the plant conditions more realistically.

It has been observed that the fragility levels of a particular relay obtained from the various tests described above are not necessarily consistent. The following causes, individually or in any combination, can be postulated to be responsible for such inconsistencies:

1. True frequency-sensitive fragility TRS data were not obtained in the multifrequency tests
2. There were differences in testing techniques, time histories, testing conditions and acceptance criteria
3. The test specimens were really not identical although the basic model numbers were the same. The difference in test specimens could have been due to either a design change without a change of the model number or an adjustment of the relay or both
4. The vibration level that causes a specific amount of relay chatter varies over a wide range. In other words, the threshold of the chatter limit can be attributed to different vibration levels.

1.3 OBJECTIVES OF BNL TESTS

The essential objectives of the BNL test program are to address the inconsistencies of the fragility data as discussed above and to demonstrate how to construct frequency dependant fragility TRS by taking a few popular relay models as examples. This will lead to a better understanding and a better use of the existing test data. The objectives can be enumerated and further detailed as follows:

1. To determine frequency sensitivity of relays by single frequency testing
2. To construct frequency dependent fragility TRS by use of multifrequency vibration input
3. To determine a conversion factor that can be used to obtain a multifrequency TRS from single frequency test amplitudes
4. To verify similarity of relays of the same type but different specific model numbers for which the manufacturers have recommended the same capacity rating by use of similarity arguments

5. To determine the effect of different variables (e.g., adjustment of contact gap, spring tension for hinged armature relays and end play of disk for rotary relays) on the seismic fragility.

The tests were performed to satisfy the above goals and the extent to which the test results were successful in fulfilling the objectives is discussed in Chapter 4.

CHAPTER 2
TEST PLAN

2.1 INTRODUCTION

The seismic tests were performed on a 10ft x 10ft triaxial shake table following the procedures described in this chapter. Popular relay models were selected for testing and a description of the specimens is provided in the following section. The test specimens were mounted on rigid fixtures a description of which is also included in this chapter.

2.2 TEST SPECIMENS

The relay test specimens were selected to represent various types (e.g., auxiliary, protective, general purpose), operating mechanisms (e.g., hinged armature, rotary induction disk, plunger, solenoid), mounting configurations (e.g., flush, semi-flush, surface) and electrical conditions (e.g., AC, DC). A total of forty six (46) relays of nineteen different models manufactured by General Electric, Westinghouse and Square D Co. were tested. Of these, forty two relays were purchased from General Electric and Westinghouse in 1988 as current-vintage commercial grade items (i.e., non-class IE). The remaining four relays (one GE, one Westinghouse and two Square D relays) had been procured by Lawrence Livermore National Laboratory in 1985 and previously been shake table tested as part of their motor control center test program[4]. For thirteen models, three specimens of each model were tested in order to verify consistency of the results. The relay specimens and their functions, operating mechanisms and mounting configurations are listed in Table 2-1.

The relays were tested at the factory setting and adjustment and no alteration was made. In addition, eleven relay specimens were tested with two alternate adjustments for determination of the effect of adjustment on relay chatter as discussed in the following sections. Relays obtained from LLNL were tested in the as-received conditions. Normal electrical function was confirmed for all relays prior to vibration tests.

2.3 MOUNTING FIXTURES

The relays were installed on four test fixtures following the mounting patterns and cutouts as required for each specimen. The screws furnished by the respective manufacturers were used to attach the relays on the fixtures. The 1/4-inch thick fixture steel plates were supported on and braced by steel angle members as shown by photographs in Figure 2-1. Each fixture assembly was welded to the shake table in a manner such that the horizontal axes of the vertical fixture plates were colinear with one of the two principal horizontal axes of excitation of the test machine. By construction, the fundamental mode of vibration of the fixtures was in the front-to-back (FB, normal to the plate surface) direction and the fundamental frequency was around 90-100Hz.

TABLE 2-1
Relay Test Specimens

Manufacturer Model Number[2]	Number of Specimens	Relay Description
General Electric 12HFA151A9F Code 33	3	Instantaneous, hinged armature, standard speed, self reset, 120VAC, semi-flush mounted, back connected, 3 NO and 3 NC contacts auxiliary relay
General Electric 12HFA151B2H Code 33	3	Instantaneous, hinged armature, standard speed, hand reset, 125VDC, surface mounted, front connected, 3 NO and 3 NC contacts auxiliary relay
General Electric 12HFA154E49H Code 33	3	Instantaneous, hinged armature, standard speed, electric reset, 120VAC 60Hz, surface mounted, front connected, 3 NO and 3 NC contacts auxiliary relay
General Electric 12HFA154B22F Code 33	3	Instantaneous, hinged armature, standard speed, self reset, 125VDC, surface mounted, front connected, 3 NO and 3 NC contacts auxiliary relay
General Electric 12HFA51A42H Code 33	3	Instantaneous, hinged armature, standard speed, self reset, 125VDC, surface mounted, front connected, 3 NO and 3 NC contacts auxiliary relay

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[2] For subsequent discussions in this report, the model numbers are abbreviated to the extent that each model is uniquely identified and the relevant test data are applicable ONLY to the complete model numbers listed in this table.

TABLE 2-1 (continued)
Relay Test Specimens

Manufacturer Model Number	Number of Specimens	Relay Description
General Electric 12HGA11J52	3	Instantaneous, hinged armature, standard speed, DP DT contacts, surface mounted, front connected, 125VDC auxiliary relay with solid cover
General Electric 12HMA11B6	3	Instantaneous, hinged armature, high speed, (35ms), DP DT contacts, surface mounted, front connected, 125VDC auxiliary relay without cover
General Electric 12HMA124A2	3	Instantaneous, hinged armature, high speed (35ms), semi-flush mounted, back connected, 125VDC auxiliary with glass cover
General Electric 12IAV53L1A	2	2 separate contacts, UV adjustable 50 to 95% of OV tap setting, time delay on bottom contact, S2 drawout case, semi-flush mounted, 115VAC 60Hz, 55 to 140 V tap range over and under voltage relay
General Electric 12PVD21D1A	1	Single phase high speed differential relay with 87L and target seal-in and separate 87H, adjustment range 87L: 75-500 V 87H: 2-50A, M1 drawout case, semi-flush mounting
General Electric CR120B	1	Self reset, solenoid, 120VAC 60Hz, surface mounted, front connected auxiliary relay

TABLE 2-1 (continued)
Relay Test Specimens

Manufacturer Model Number	Number of Specimens	Relay Description
Westinghouse CO-6 288B715A12	3	Definite time overcurrent relay with 1 NO contact with target seal-in adjustment time unit: 2-6A instanta-neous unit: 2-8A, FT-11 drawout case, semi-flush mounting
Westinghouse SG 293B254A20	3	Instantaneous, hinged armature, 125VDC, standard speed, DP DT contacts, front connected, surface mounted auxiliary relay with solid cover
Westinghouse MG-6 288B977A19	3	Instantaneous, hinged armature, 125VDC, standard speed, 6 contacts, flexi-test FT-22 drawout case, semi-flush mounted auxiliary relay
Westinghouse SC 1876048	3	Instantaneous, current operated, 2-8A adjustment, 2 NO contacts, mechanical target, FT-21 drawout case, semi-flush mounted current relay
Westinghouse SVF 1961843	3	Self reset, rated 120VAC, maximum pickup 95VAC, dropout 30 to 45VAC adjustment, 2 NC contacts, FT-21 drawout case, semi-flush mounting, general purpose single phase undervoltage relay

TABLE 2-1 (continued)
Relay Test Specimens

Manufacturer Model Number	Number of Specimens	Relay Description
Westinghouse AR660AR	1	Self reset, solenoid 120VAC 60Hz, surface mounted, front connected 5 NO and 1 NC contacts auxiliary relay
Square D 8501X0-60	1	Self reset, solenoid 120VAC 60Hz, surface mounted, front connected, 5 NO and 1 NC contacts auxiliary relay
Square D 12, P14	1	Self reset, hinged 8501KP- armature, 120VAC 60Hz, socket mounted, 2 NO and 2 NC contacts auxiliary relay

Figure 2-1 Typical Test Fixtures

2.4 TEST PROCEDURES

A total of 2836 vibration tests were performed for determination of the relay characteristics and achieving the goals described in Chapter 1. For most of the tests, single axis single frequency excitation was used on all the specimens. The remaining tests were performed on a selected group of relays with multifrequency excitation in one, two and three directions. All relays were powered during the tests and electrical continuity was ascertained by means of monitoring channels which were connected to the relay contacts. The electrical monitoring channels were recorded on oscillograph recorders containing galvanometers that detect a change of state of the relay contact. A temporary change of state, which is popularly known as contact chatter, for a duration of 2 milliseconds or greater was used as the failure criterion. The test vibration level was increased (or decreased) in small steps until a chatter failure or a sustained change of state was observed. The procedures adopted for the specific vibration tests and the corresponding electrical powering and monitoring are discussed in more detail in the following sections.

2.4.1 Sine Dwell Tests

All forty six relays were subjected to single axis sine dwell vibration inputs for a duration of approximately 30 seconds at 1Hz, 2.5Hz and thereafter at every 2.5Hz up to 50Hz. The relays were tested at all these frequencies for both the nonoperating and the operating modes that are described in Table 2-2. These electrical modes were defined following the recommendations of the IEEE Std[3]. Both the normally open (NO, i.e., open when operating coil of the relay is deenergized) and the normally closed (NC, i.e., closed when operating coil of the relay is deenergized) contacts of the specimens were monitored before, during and after the shaking for detection of a temporary or a sustained change of state. The specimens were also tested in the transition mode (i.e., change of mode during shaking) at 10Hz interval up to 50Hz to confirm that the capacity level in the transition mode is not lower than that already established in the nonoperating and operating modes.[3]

All the above tests were separately performed in the front-to-back (FB, i.e., normal to the fixture plate containing the relays), side-to-side (SS) and vertical (V) directions. The shake table capacity in terms of the amplitude of the input sine wave was approximately 2.5g in the frequency range 7-20Hz and less at other frequencies as shown in Figure 2-2.

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[3] The hand reset HFA relays were not tested in the transition mode since these relays could not be remotely operated.

TABLE 2-2
Conditions at Test Electrical Modes

Relay Model	Nonoperating Mode	Operating Mode
HFA151A	0V (i.e., zero volt)	96V-60Hz
HFA151B	0V	125VDC
HAF154E	0V[a]	96V-60Hz[b]
HFA154B	0V[c]	125VDC
HFA51A	0V	125VDC
HGA	0V	125VDC
HMA11	0V	125VDC
HMA124	0V	125VDC
IAV	120V-60Hz	155V-60Hz[d]
		95V-60Hz[e]
PVD	0V	150V-60Hz
CR120	0V	96V-60Hz
CO-6	1.2A-60Hz	4A-60Hz
SG	0V	125VDC
MG-6	0V	125VDC
SC	0.5A-60Hz	4A-60Hz
SVF	120V-60Hz	36V-60Hz
AR	0V	96V-60Hz
8501XO	0V	96V-60Hz
850KP	0V	96V-60Hz

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[a] 96V-60Hz on reset coil
[b] Latched condition, i.e. momentary application of power on operate coil
[c] 125VDC on reset coil
[d] Overvoltage condition
[e] Undervoltage condition

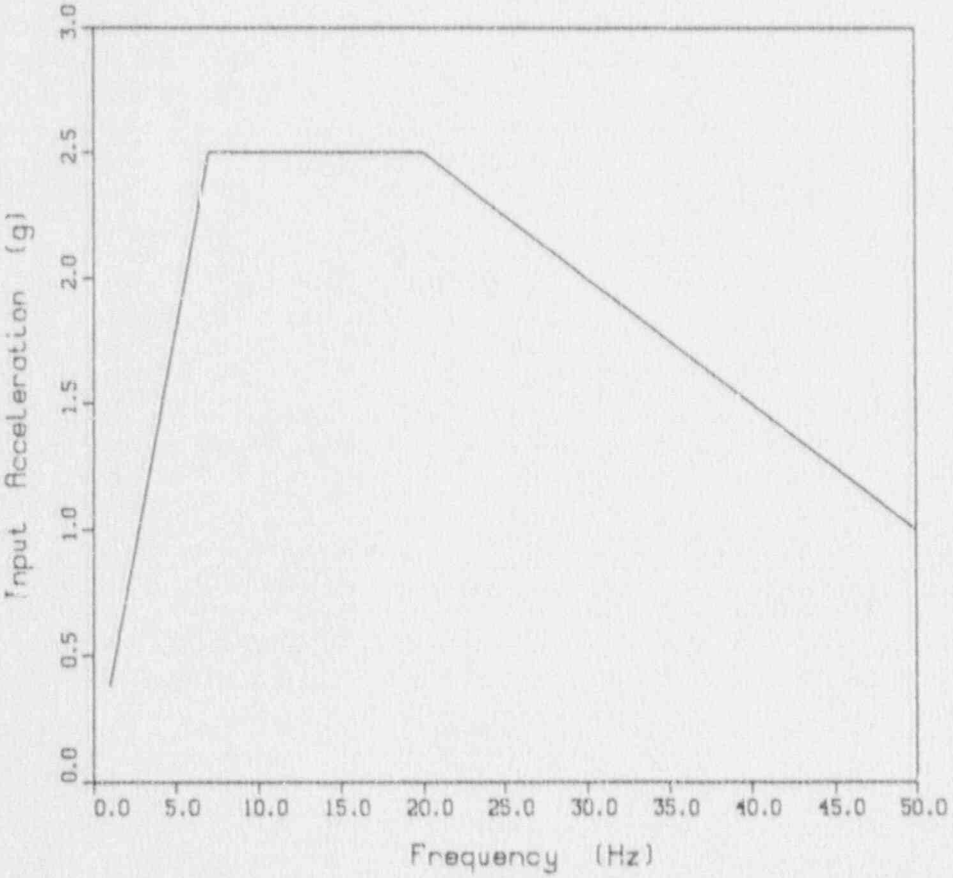

Figure 2-2 Approximate Capacity of Shake Table for Sine Dwell Test (Machine Limit)

Since the relays were tested in all electrical modes with normally open and closed contacts for excitation separately in all three directions, the sine dwell tests identified the respective electrical mode, contact state and input direction for which a particular relay exhibited its weakness. For subsequent tests, the relays were tested only for the respective weakest electrical mode, contact state and input direction.

2.4.1.1 Adjustment Tests

The sine dwell tests discussed above were performed on the relays with their factory settings without any alteration. In order to determine the effect of alternate settings, certain parameters, namely, spring tension, contact gap and rotary disk end play, were adjusted to a higher and a lower value than the respective original settings and the relays were tested again with sine dwell inputs as described in the following subsections.

2.4.1.1.1 Spring Adjustment

The tension of the springs controlling the armature movement of two hinged armature relay models HFA51A and MG-6 (three specimens for each model) was adjusted. The specimens were tested to the fragility limit for both the increased and the decreased tension settings. Only the normally closed contacts of the relays were monitored for the nonoperating electrical mode since these conditions governed the fragility level in the earlier sine dwell tests. All six specimens were tested in the FB direction and, in addition, the HFA relays were tested in the vertical direction.

2.4.1.1.2 Contact Gap Adjustment

The contact gaps for HFA51A and MG-6 (three specimens of each model) were adjusted larger and smaller than the factory setting and the specimens were tested at both settings exactly in a similar manner as described in Section 2.4.1.1.1 above.

2.4.1.1.3 End Play Adjustment

The end play of two rotary disk relay models (two specimens of IAV53 and three specimens of CO-6) was adjusted by raising and lowering the disks from the position set at the factory. The IAV relays were tested in the under-voltage operating mode and their normally closed contacts were monitored for electrical continuity. The CO-6 relays were also tested in the operating mode and the CO contacts were monitored for detection of contact chatter. All five relays were subjected to vertical motion for both the higher and the lower positions of the disks.

2.4.2 Sine Sweep Tests

Two relays (HMA124 Specimen 1, SG Specimen 1) were subjected to a single-axis sine sweep over the frequency range of 1 to 50Hz at a sweep rate of one octave per minute. The testing was performed in the nonoperating electrical mode with vertical excitation for the HMA relays and FB excitation for the SG relay. Normally closed contacts were monitored for both relays.

2.4.3 Random Multifrequency Tests

Selected relays were subjected to 30-second duration multifrequency random motion which was amplitude-controlled in one-third octave bandwidths spaced one-third octave apart over the frequency range of 1 to 100Hz. Electrical powering and monitoring were used only for the worst conditions determined during the sine dwell tests discussed above. The objectives of the multifrequency tests were two-fold: first, to develop multifrequency fragility TRS matching the shape of the respective sine dwell amplitude vs. frequency curves; second, to confirm the dynamic similarity of relays by testing them in accordance with the IEEE recommendations[3]. Tasks related to these two objectives are discussed separately in the following two subsections.

2.4.3.1 Fragility TRS

Since the single frequency sine dwell capacity results are typically different for different relays, each relay would require different multifrequency inputs for matching the TRS with the shape of the respective sine dwell amplitude curves. To this end, the tests were performed in two different set-ups. In one set-up, the target was to match the sine dwell results for a nonoperating SG relay in the horizontal directions and for an operating SVF relay in the vertical direction. In the second test set-up, a nonoperating HMA124 relay was considered in all three directions.[4]

In both set-ups, the relays were first tested with uniaxial inputs (FB and vertical separately), then with biaxial inputs (FB and vertical simultaneously, but phase incoherent) and finally with triaxial inputs (FB, SS and vertical simultaneously, but phase incoherent).

2.4.3.2 Dynamic Similarity

Because of specific functions and use in an electrical panel, relays even of the same type differ within themselves in their designs. Most often, these differences are minor and considered to have insignificant effects on their dynamic characteristics. In practice, the manufacturer typically tests

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[4] There were other relays mounted on the same test fixtures. However, since the shapes of the single frequency input curves for these relays were very different from the respective target RRS shapes, construction of frequency dependent fragility TRS for these relays was not part of this task.

only one relay of such a group and judges the other relays of the group to have the same seismic capability. A concern was raised on this practice of seismic qualification of relays of the same group by judging dynamic similarity.

In order to address the concern, BNL selected a relay type for many models of which the manufacturer recommends the use of the same seismic capacity rating. The relay type is HFA which is a multicontact hinged armature auxiliary relay. The model numbers starting with HFA151 and HFA154 (both belong to the so-called century series, i.e., recent products with a new design of the electric insulation system) have been rated to have an IEEE seismic capacity of 2.5g ZPA for the nonoperating mode and NC contacts based upon test results for HFA154BF (DC). The differences in their design accommodate the following functions and use:

a) Reset function - self reset (HFA151A), hand reset (HFA151B), electric reset (HFA154E) and both electric and hand reset (HFA154B).

b) Electric potential - AC and DC.

c) Mounting - semi-flush mounting (i.e., back connected denoted by "F") and surface mounting (i.e., front connected denoted by "H").

After review of all the models, the following ones were considered to represent all the above characteristics and selected for testing:

HFA151AF (AC)
HFA151BH (DC)
HFA154EH (AC)
HFA154BF (DC)

Only the last model had been tested by the manufacturer for qualification of the others.

In the BNL test program, three specimens of each of the above four models were tested with random biaxial incoherent vibration inputs. The target response spectrum shape was that recommended by IEEE[3] i.e., spectral accelerations between 4 and 16Hz are 2.5 times the ZPA. The specimens were tested for the nonoperating electrical mode and the NC contacts were monitored. In addition, HFA154 relays (i.e., six specimens) were also tested for the operating mode during which the operating coil was temporarily energized for picking up of the latching mechanism.

2.4.4 Pickup and Dropout Tests

In order to investigate any permanent effect of the vibration tests on the electrical characteristics, pickup and dropout tests were performed on the following relays before and after certain vibration tests:

HFA51 (3 specimens)
HMA124 (1 specimen)
CO-6 (1 specimen)
MG-6 (1 specimen)
SVF (1 specimen)

Depending on the relay type, either voltage or current was gradually increased or decreased until the relay picked up or dropped out by changing state. The pickup and dropout tests were performed three times on each specimen. In addition, the times required by the undervoltage and overvoltage contacts of the IAV relay to change state were also monitored. The test results are discussed in the next chapter.

CHAPTER 3
TEST RESULTS

3.1 INTRODUCTION

Tests were performed following the procedures described in Chapter 2. The seismic capacity of a relay has been defined as the highest vibration level at which the specimen did not exhibit a change of electrical state for a duration equal to or greater than 2ms. At a slightly higher vibration level, the relay experienced a minimum of 2ms chatter. For single frequency sinusoidal tests, the amplitude of the sine wave recorded by the accelerometer installed on the shake table is used as a measure of the seismic capacity at a specific frequency. The amplitude accelerations are presented for frequencies in the range 1-50Hz. For multifrequency tests, the test response spectrum analyzed from the time history motion recorded by the table accelerometer is used as a measure of the relay capacity level.

Results from both single frequency and multifrequency tests are presented in the following sections. The extent to which the test data respond to the objectives delineated in Chapter 1 has been critically evaluated and is discussed in the next chapter.

3.2 SINGLE FREQUENCY SINE DWELL TEST RESULTS

The results of the single frequency tests are graphically presented[5] in Figures 3.1 through 3.39 and also listed in Table 3-1. In these figures, the solid curves indicate the approximate capacity of the shake table. At some frequencies, testing was performed at slightly higher input levels. In all these figures wherever the relay capacity is shown at or above the approximate machine limit, the relay was qualified up to the machine limit and the true capacity level is greater than the input acceleration level shown at that frequency.

The capacity of each specimen in each of the three orthogonal directions (FB, SS and V) is shown in the figures for the controlling electrical mode and contact state. The test data for the controlling modes are also summarized in Table 3-1. The entire frequency range is divided into three bands: 5-15Hz, 16-30Hz and 31-50Hz. At each frequency band, the lowest capacity sine dwell input acceleration and the average of all capacity accelerations in the range are provided for each excitation direction and the controlling electrical modes. If the fragility level of the relay is beyond the capacity of the shake table, the highest qualification test level is reported with a note that the data correspond to the "machine limit." If a specimen chattered even at the lowest vibration level of 0.2g the capacity is designated as < 0.2g since no further attempt was made to determine the exact capacity level. The corresponding levels are shown as 0.1g in the graphical presentations.

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[5] The single frequency test data have been plotted at an interval of 2.5Hz and are presented as curves connecting the discrete data points.

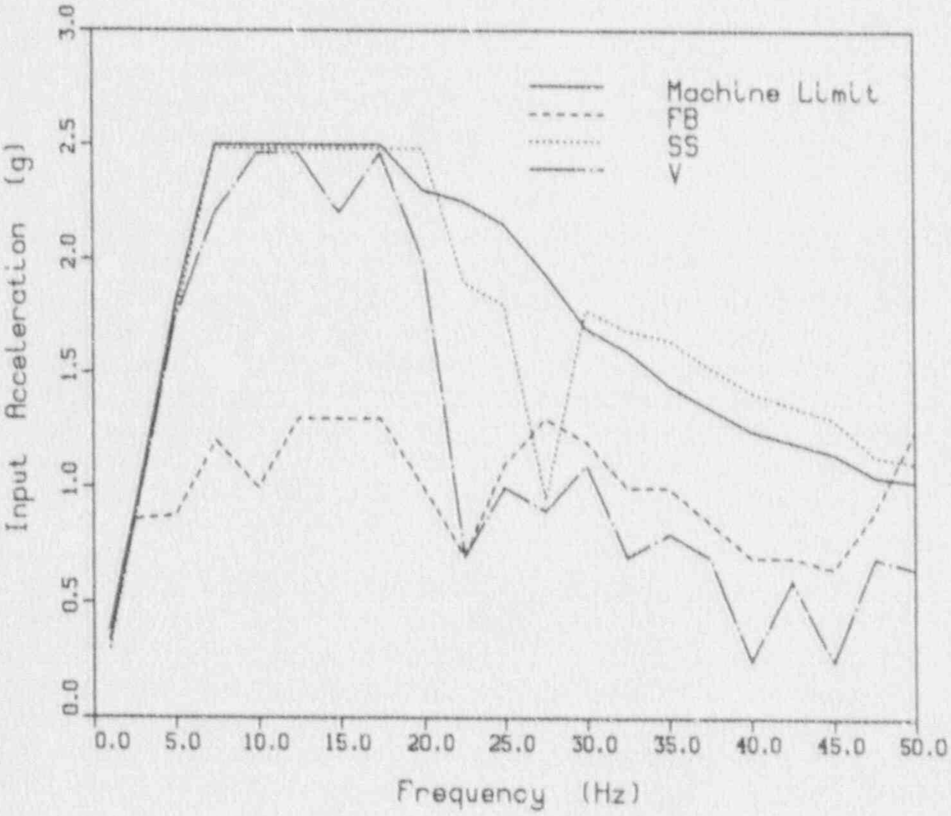

Figure 3.1 Sine Dwell Capacity Level
HFA151A, Nonoperating Mode, NC Contact

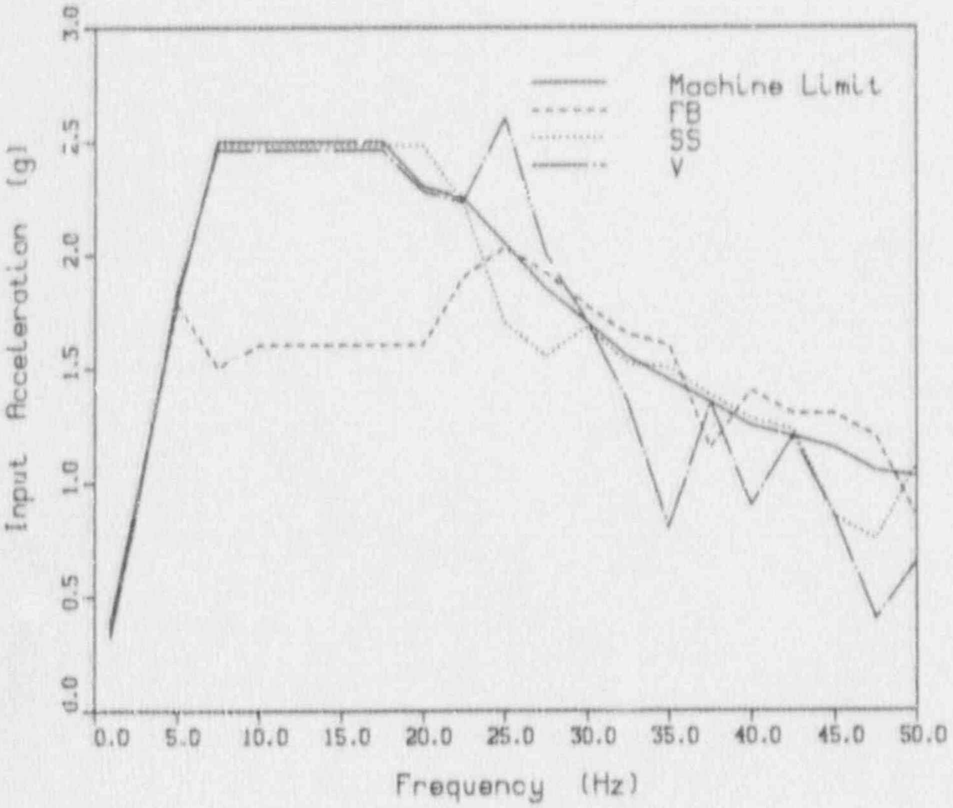

Figure 3.2 Sine Dwell Capacity Level
HFA151B, Nonoperating Mode, NC Contact

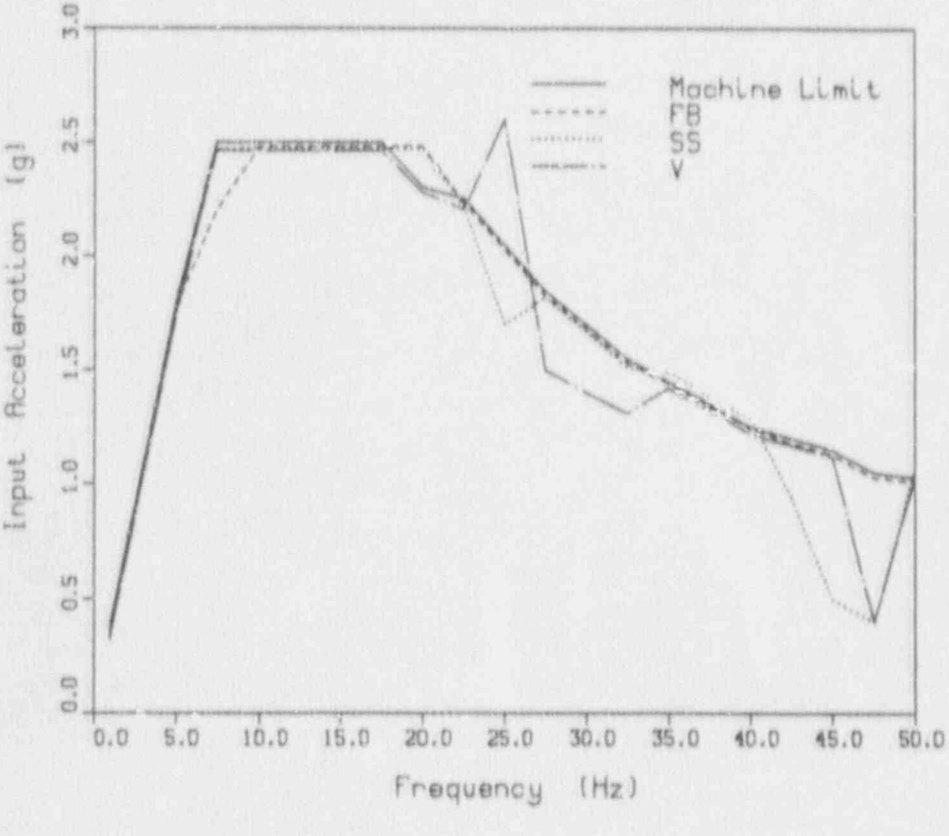

Figure 3.3 Sine Dwell Capacity Level
HFA154E, Nonoperating Mode, NC Contact

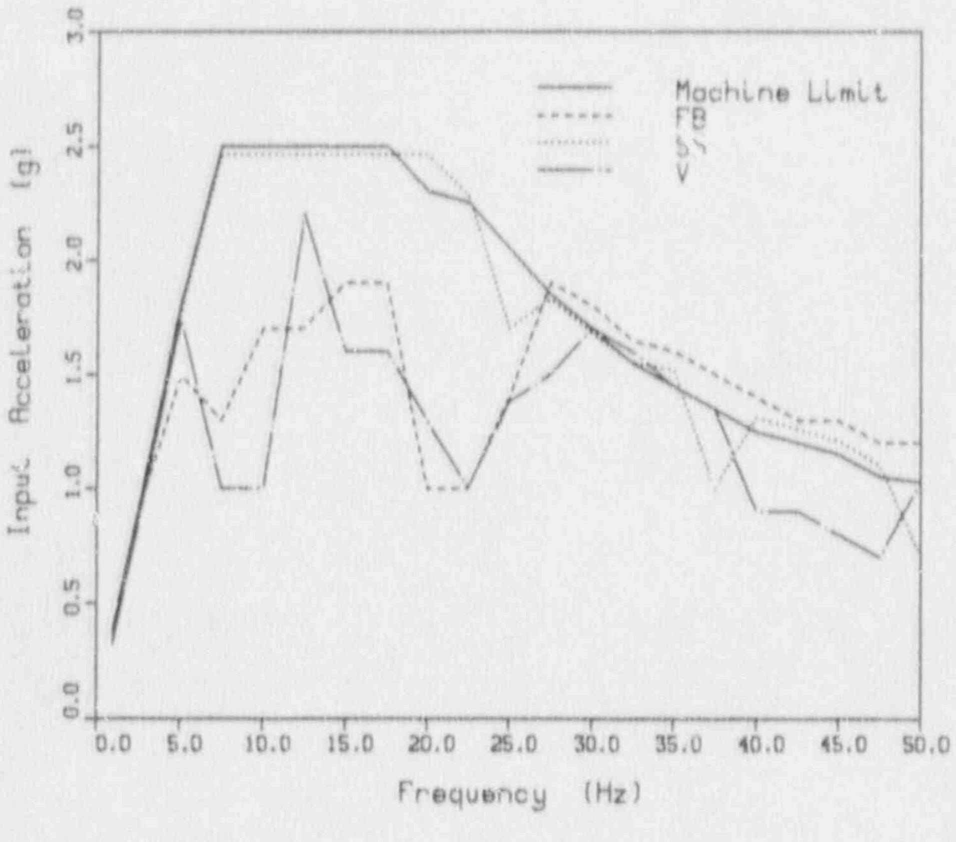

Figure 3.4 Sine Dwell Capacity Level
HFA154E, Operating Mode

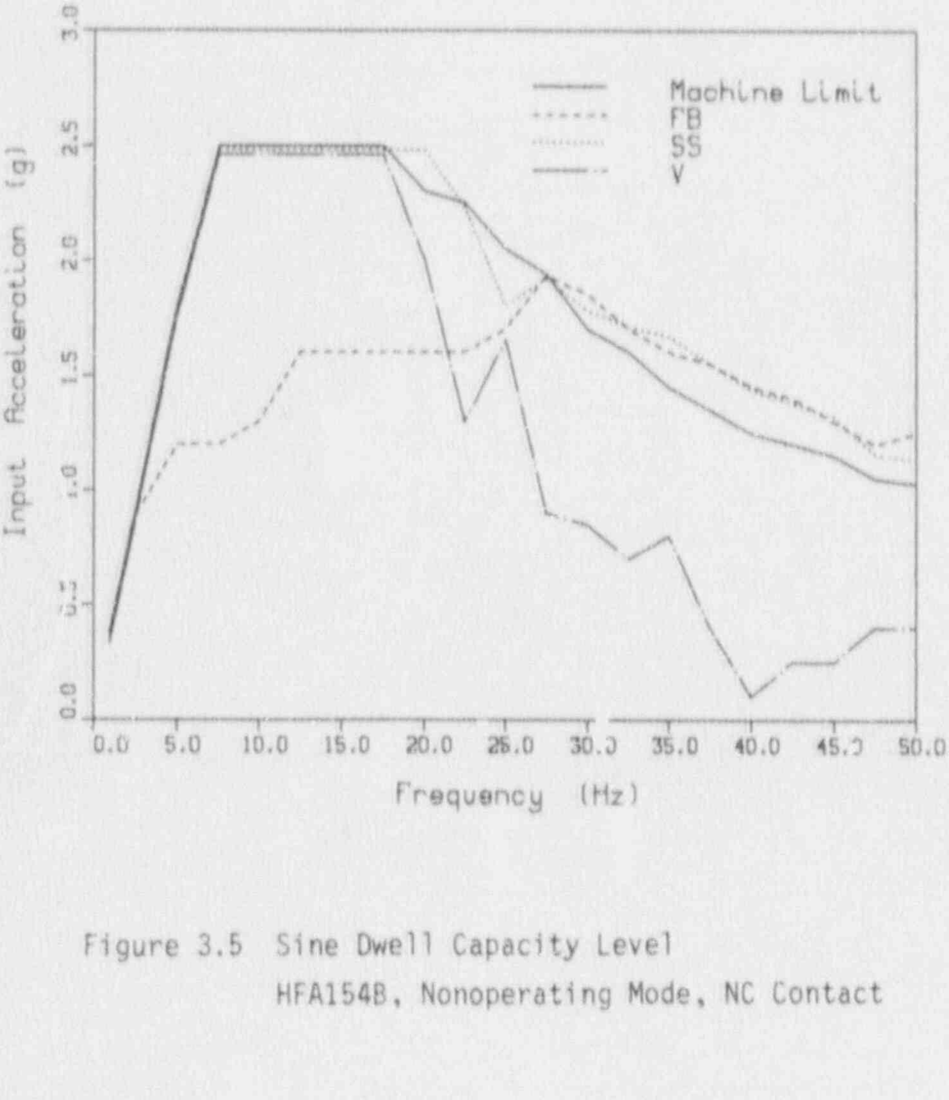

Figure 3.5 Sine Dwell Capacity Level
HFA154B, Nonoperating Mode, NC Contact

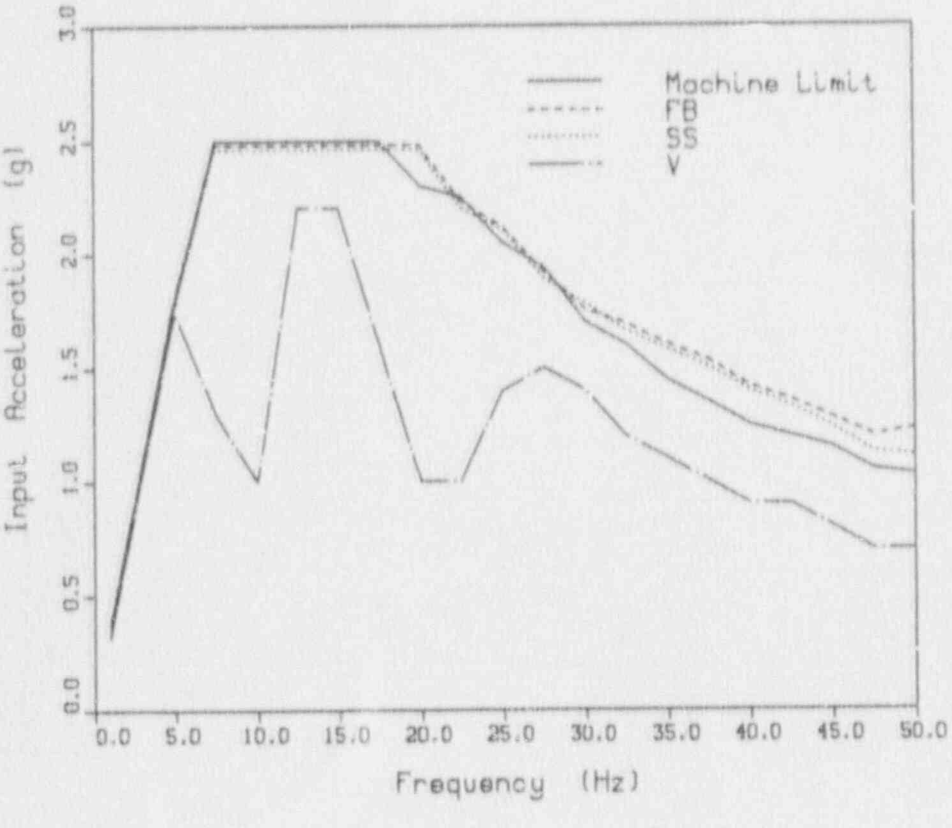

Figure 3.6 Sine Dwell Capacity Level
HFA154B, Operating Mode

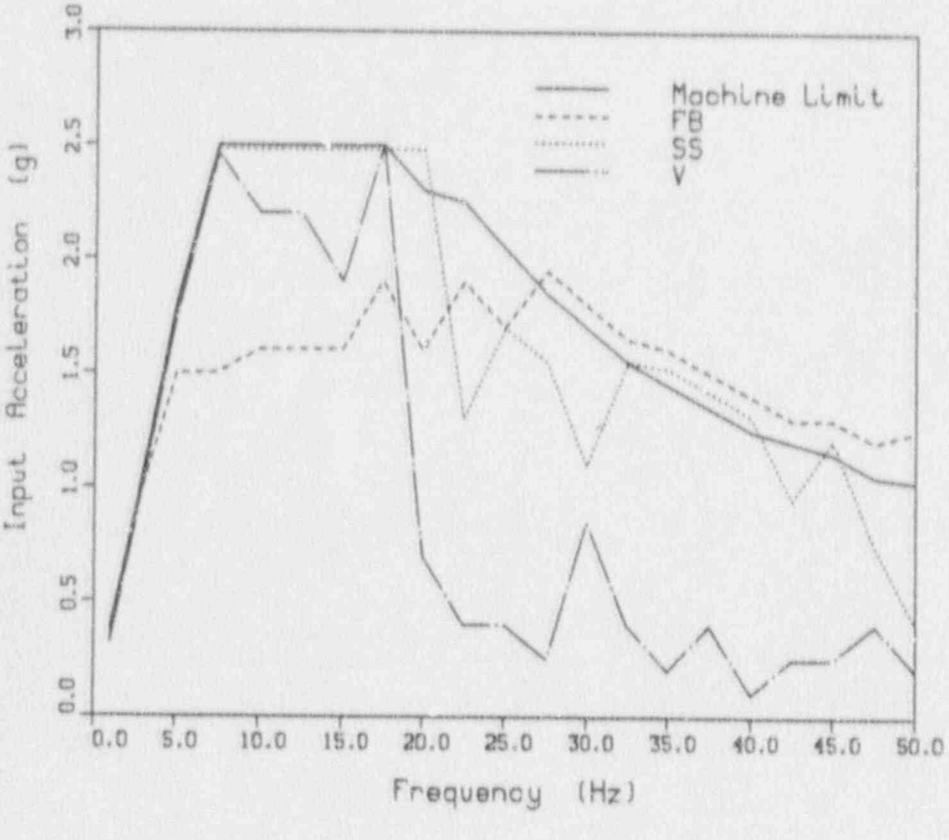

Figure 3.7 Sine Dwell Capacity Level
HFA51, Specimen 1
Nonoperating Mode, NC Contact

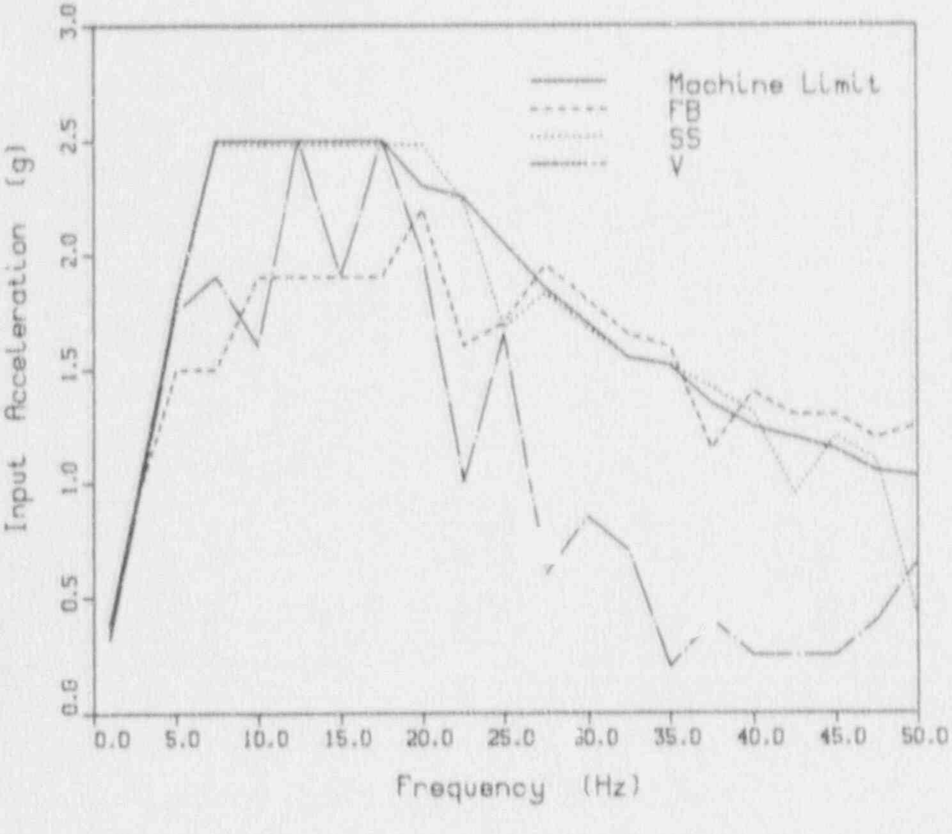

Figure 3.8 Sine Dwell Capacity Level
HFA51, Specimen 2
Nonoperating Mode, NC Contact

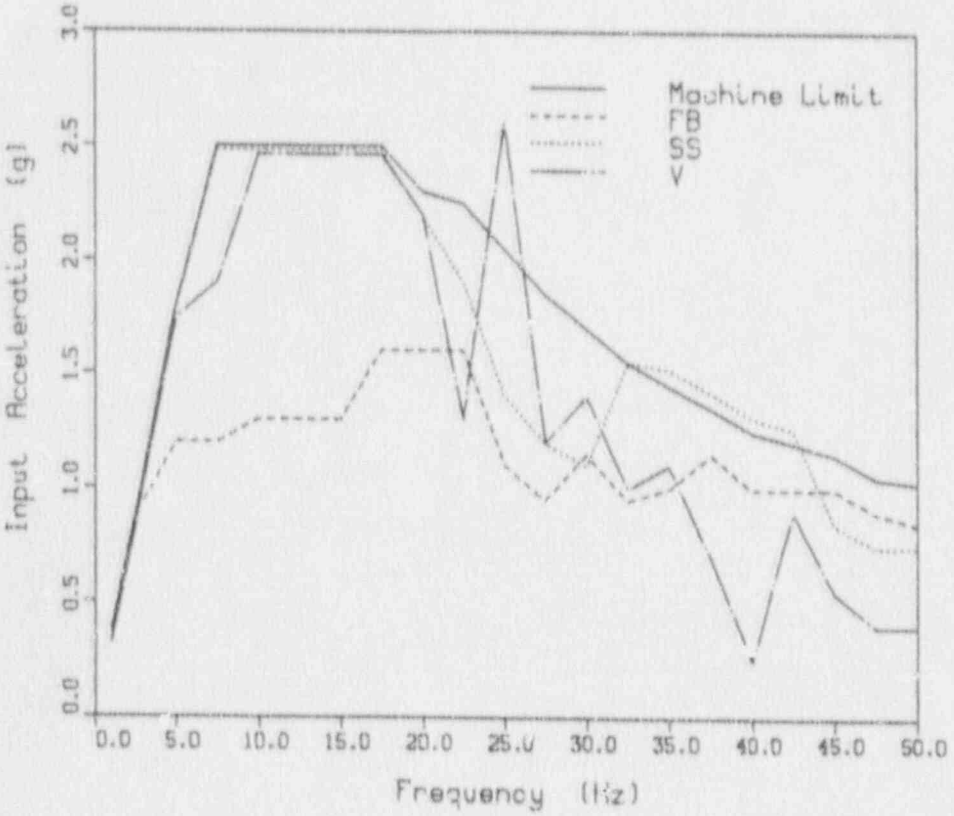

Figure 3.9 Sine Dwell Capacity Level
HFA51, Specimen 3
Nonoperating Mode, NC Contact

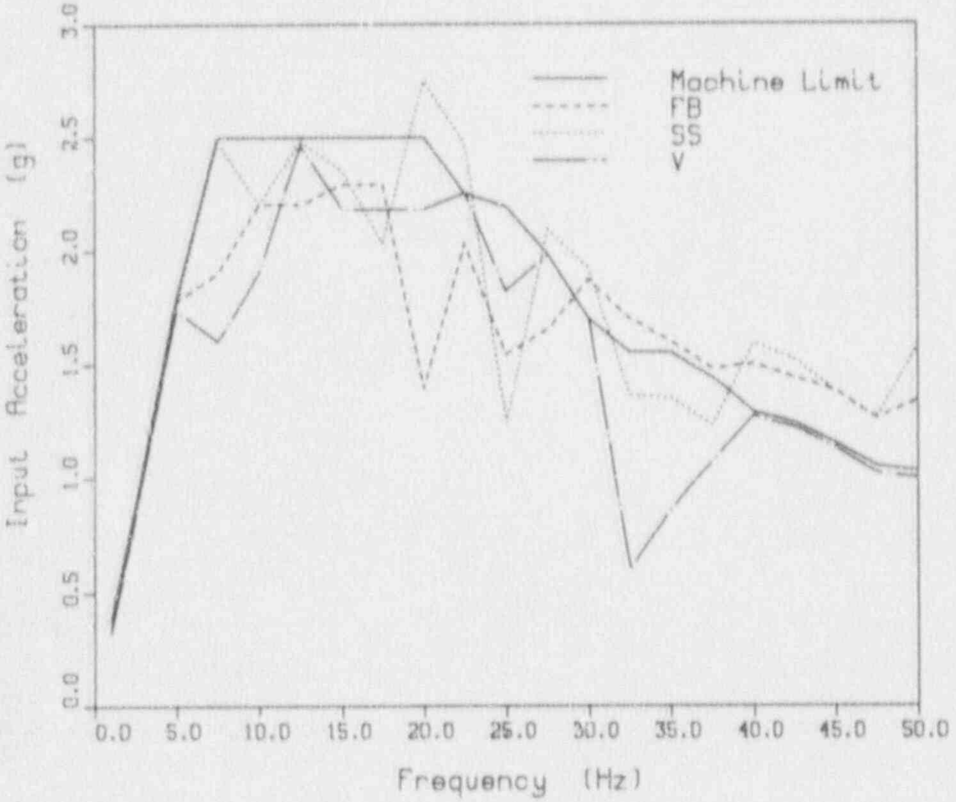

Figure 3.10 Sine Dwell Capacity Level
HGA, Specimen 1
Nonoperating Mode, NC Contact

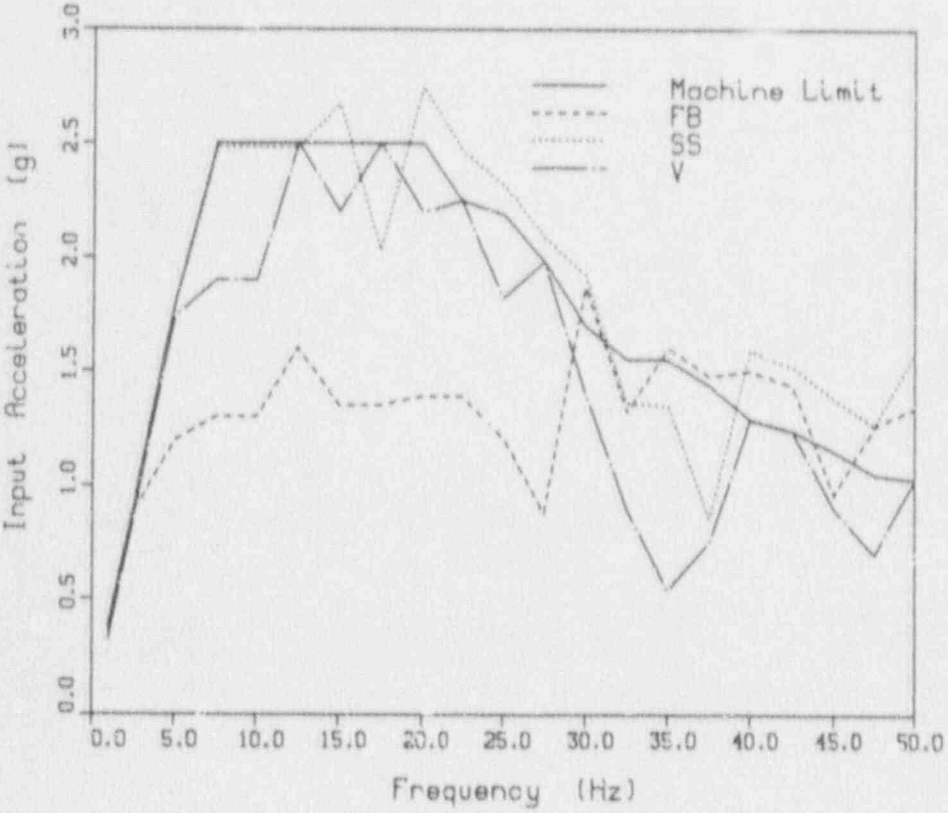

Figure 3.11 Sine Dwell Capacity Level
HGA, Specimen 2
Nonoperating Mode, NC Contact

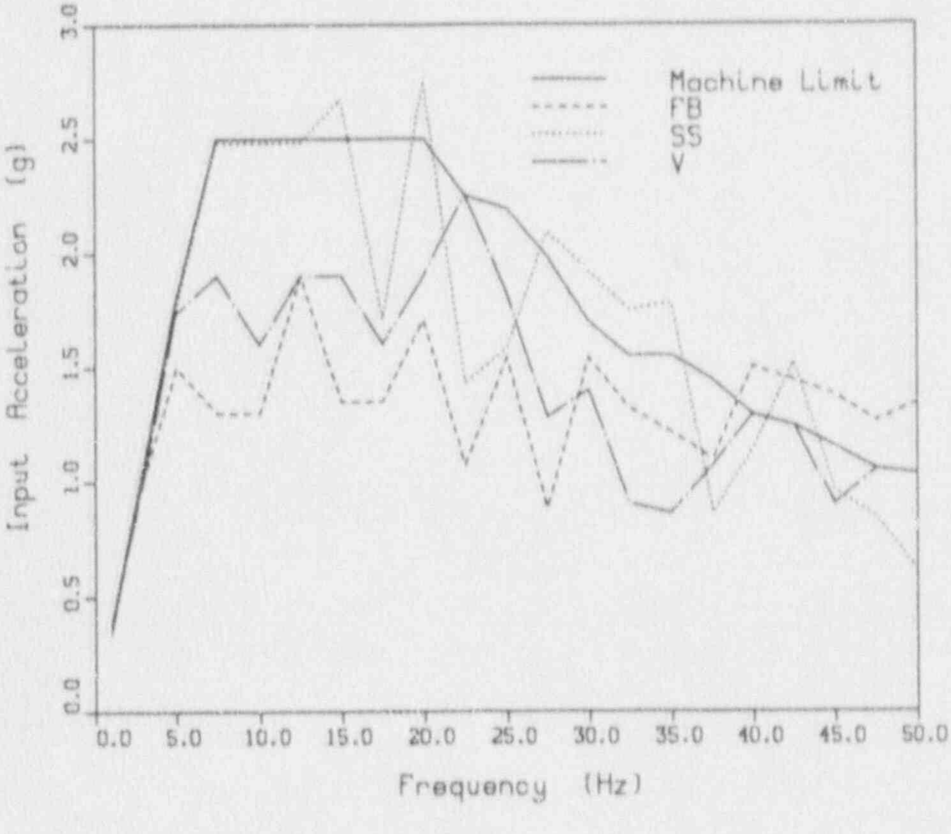

Figure 3.12 Sine Dwell Capacity Level
HGA, Specimen 3
Nonoperating Mode, NC Contact

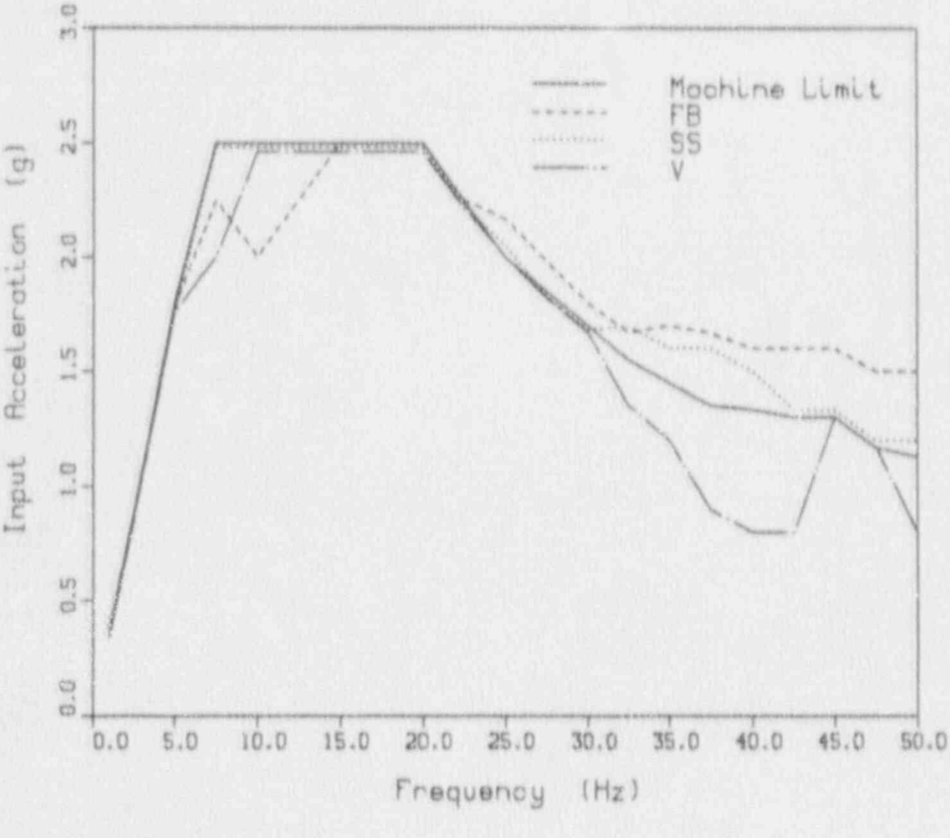

Figure 3.13 Sine Dwell Capacity Level
HMA 11, Specimen 1
Nonoperating Mode, NC Contact

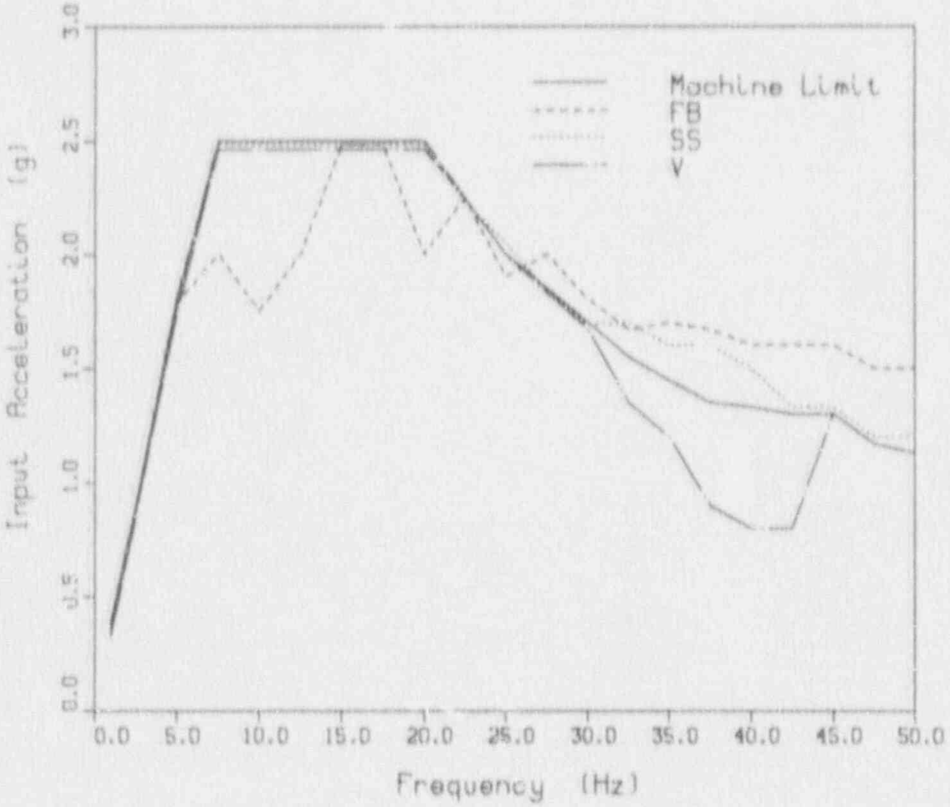

Figure 3.14 Sine Dwell Capacity Level
HMA11, Specimen 2
Nonoperating Mode, NC Contact

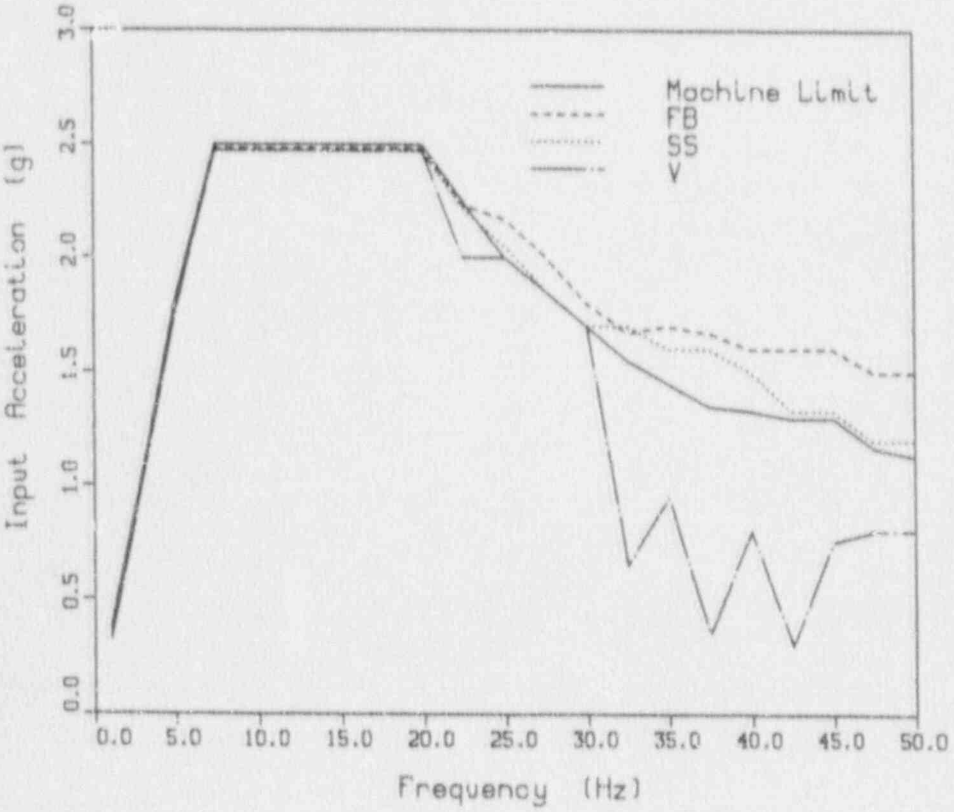

Figure 3.15 Sine Dwell Capacity Level
HMA11, Specimen 3
Nonoperating Mode, NC Contact

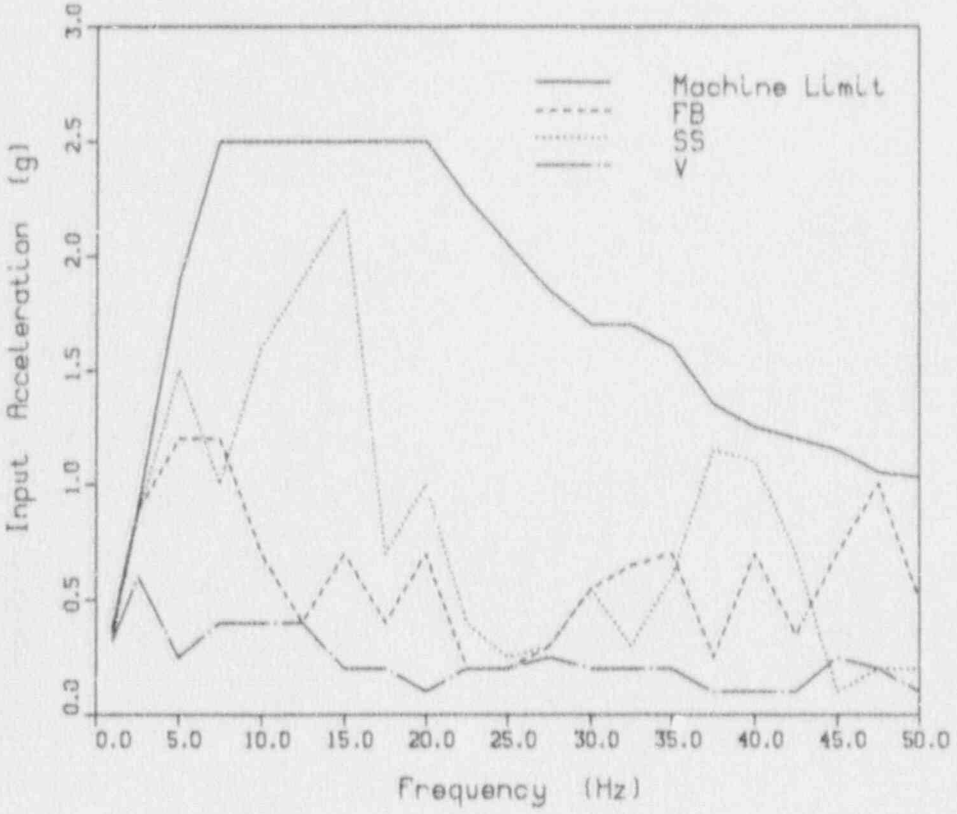

Figure 3.16 Sine Dwell Capacity Level
HMA124, Specimen 1
Nonoperating Mode, NC Contact

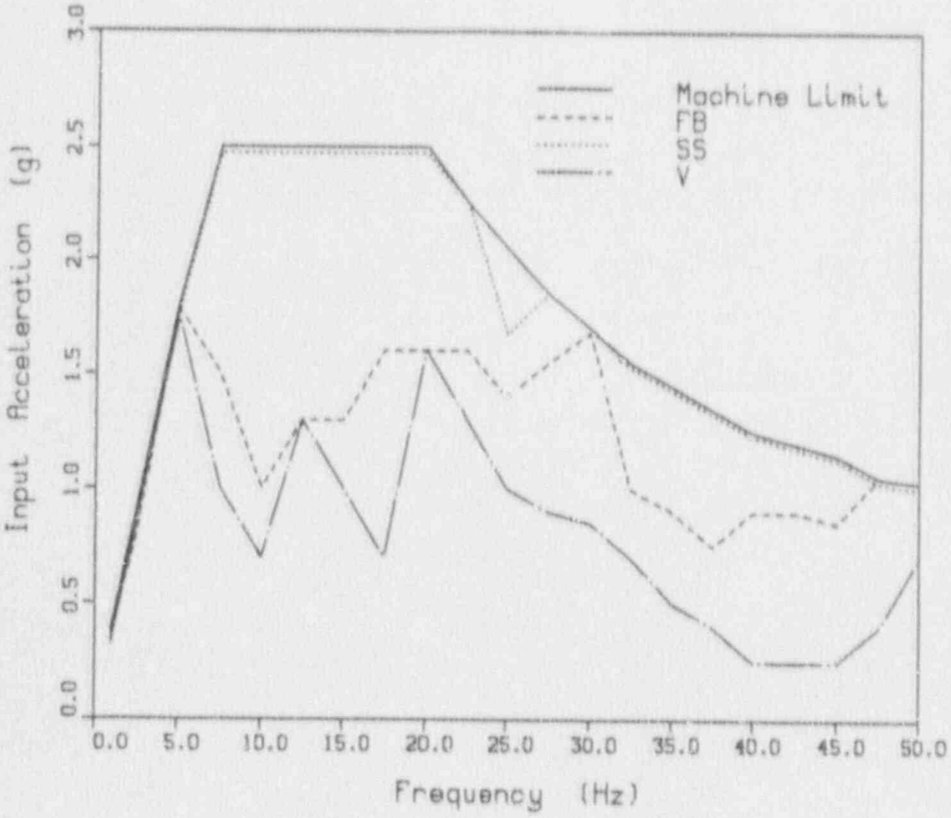

Figure 3.17 Sine Dwell Capacity Level
HMA124, Specimen 2
Nonoperating Mode, NC Contact

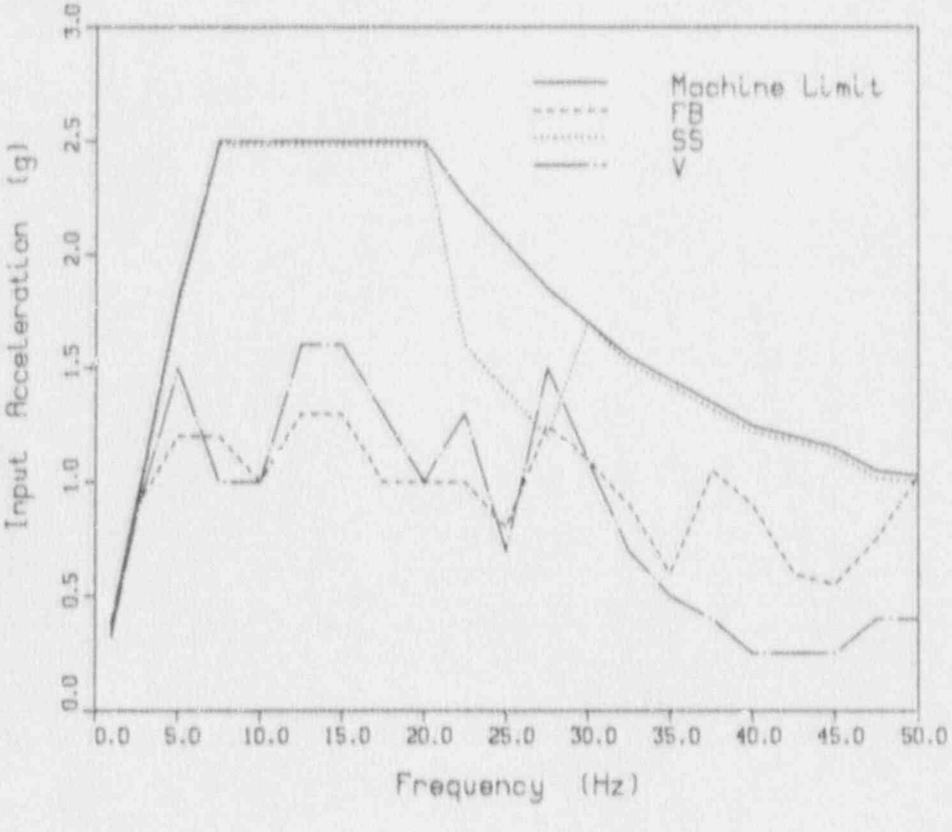

Figure 3.18 Sine Dwell Capacity Level
HMA124, Specimen 3
Nonoperating Mode, NC Contact

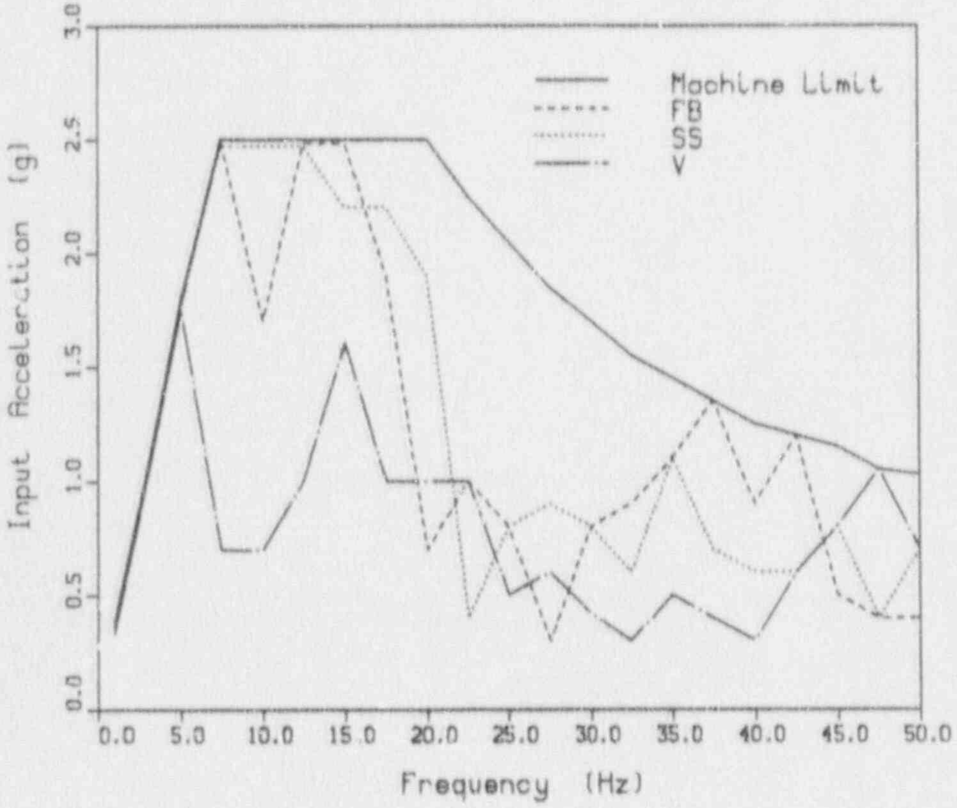

Figure 3.19 Sine Dwell Capacity Level
IAV, Specimen 1, Operating Mode
Overvoltage, NO Contact

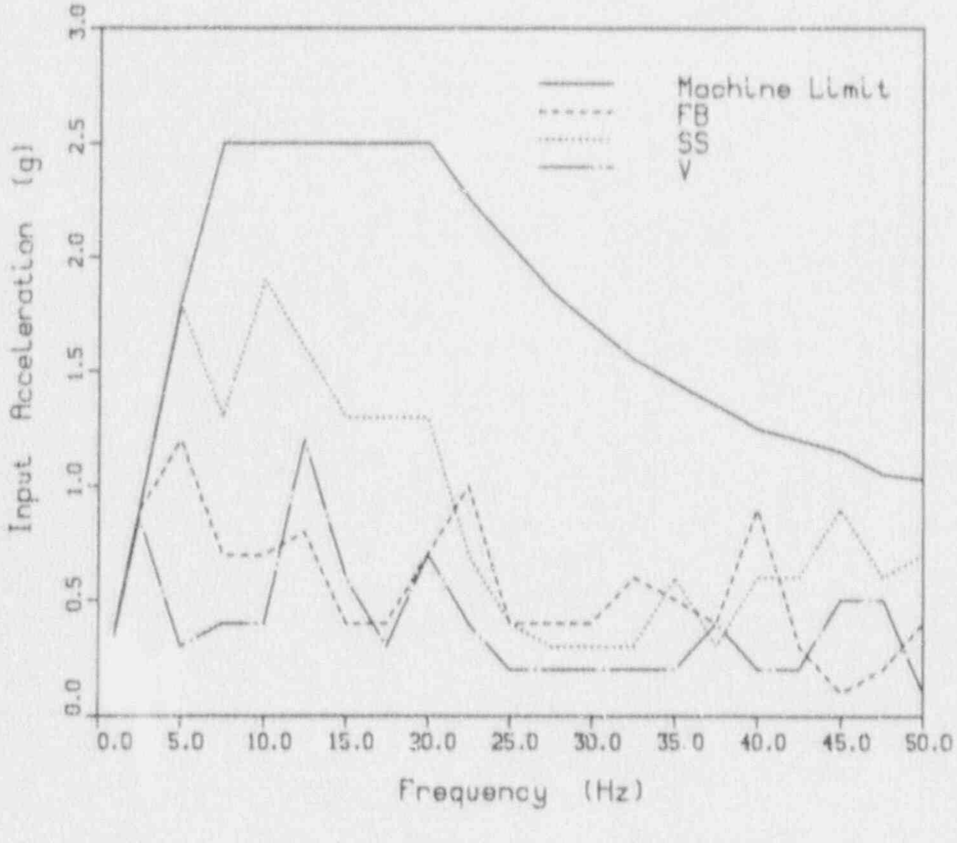

Figure 3.20 Sine Dwell Capacity Level
IAV, Specimen 1, Operating Mode
Undervoltage, NC Contact

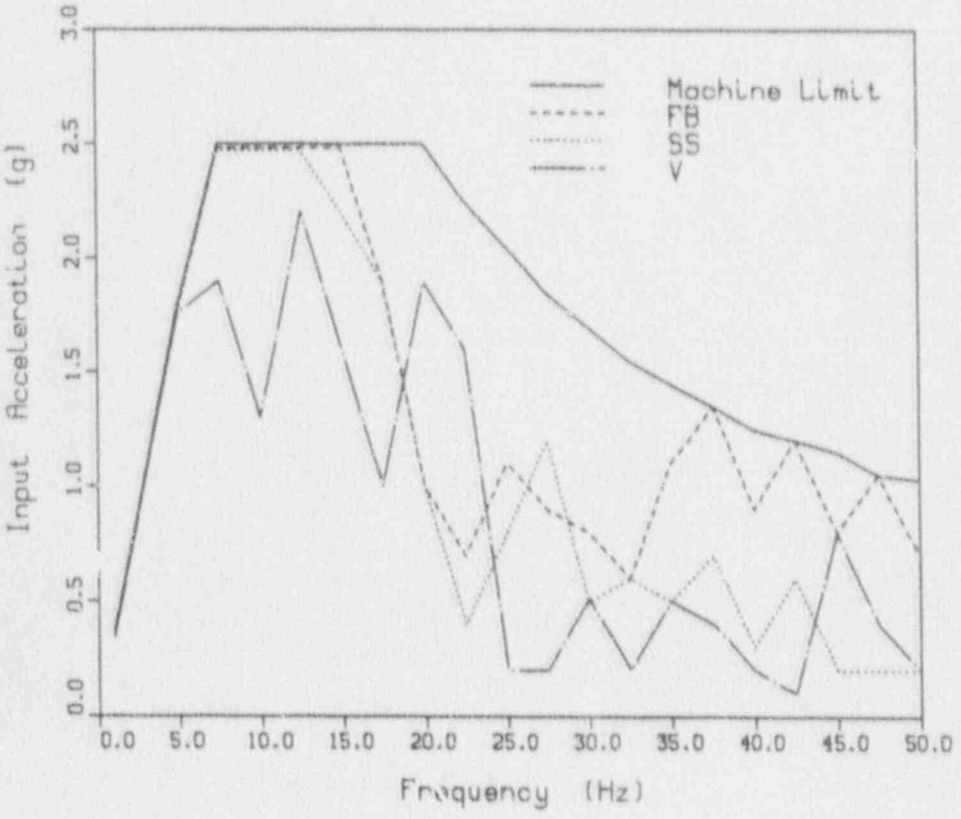

Figure 3.21 Sine Dwell Capacity Level
IAV, Specimen 2, Operating Mode
Overvoltage, NO Contact

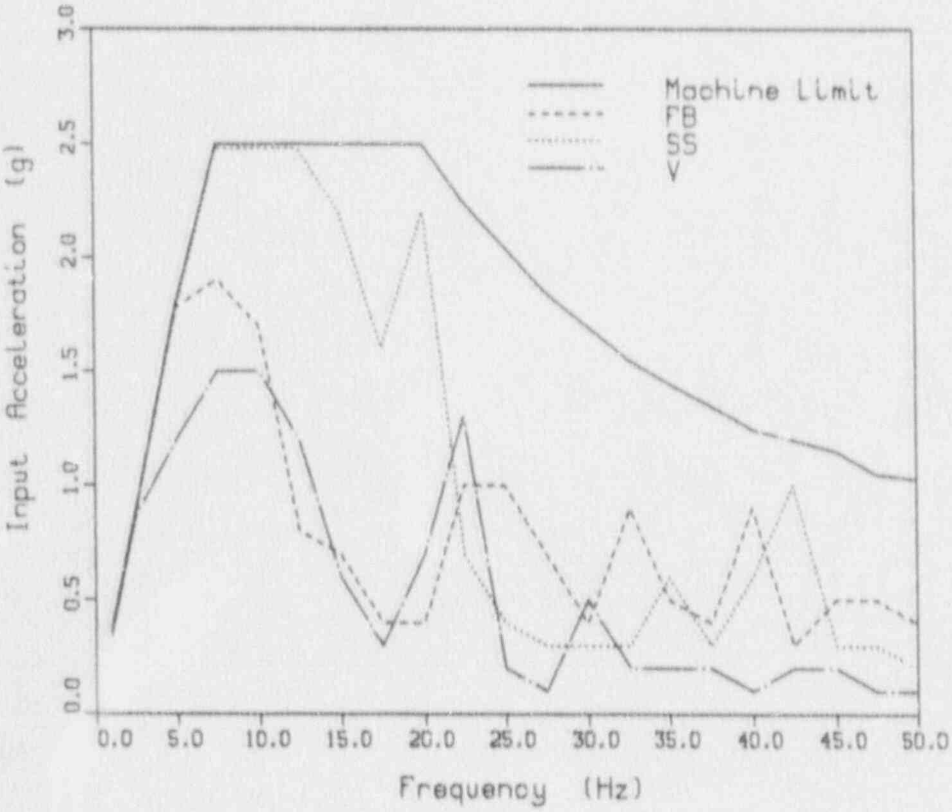

Figure 3.22 Sine Dwell Capacity Level
IAV, Specimen 2, Operating Mode,
Undervoltage, NC Contact

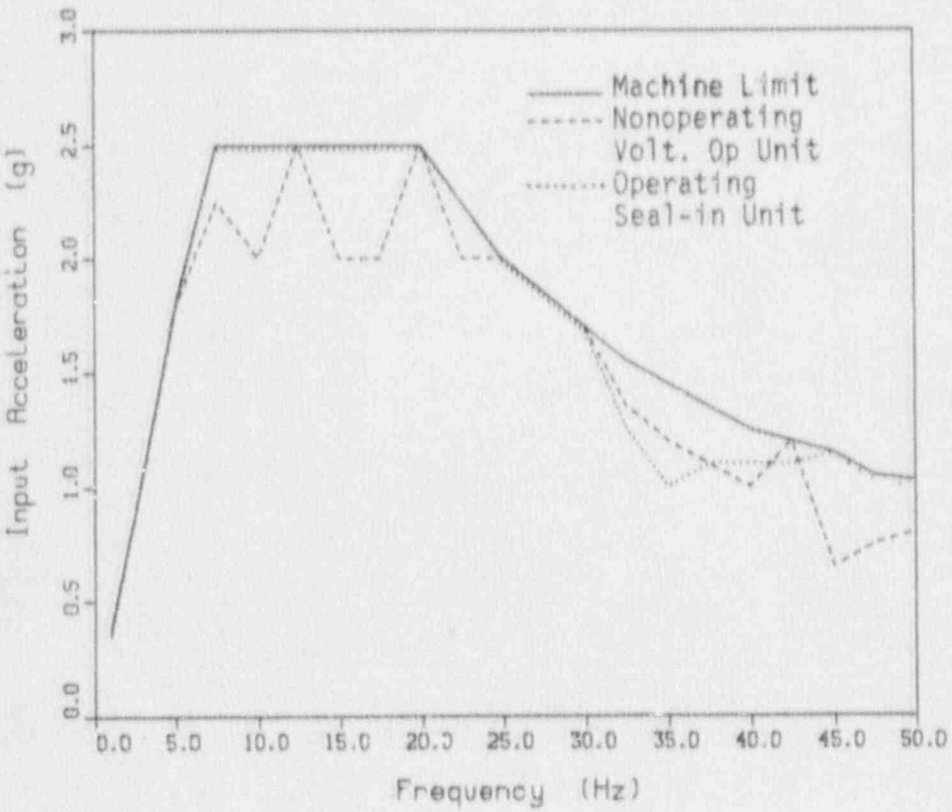

Figure 3.23 Sine Dwell Capacity Level
PVD, V Direction

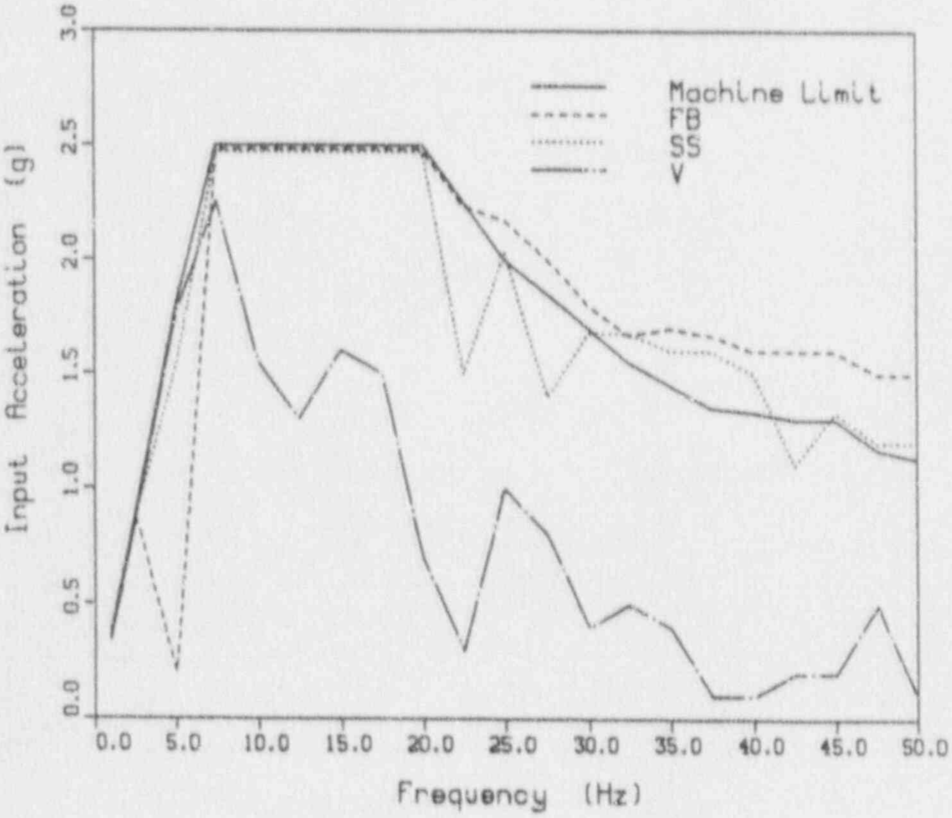

Figure 3.24 Sine Dwell Capacity Level
CO-6, Specimen 1
Operating Mode, CO Contact

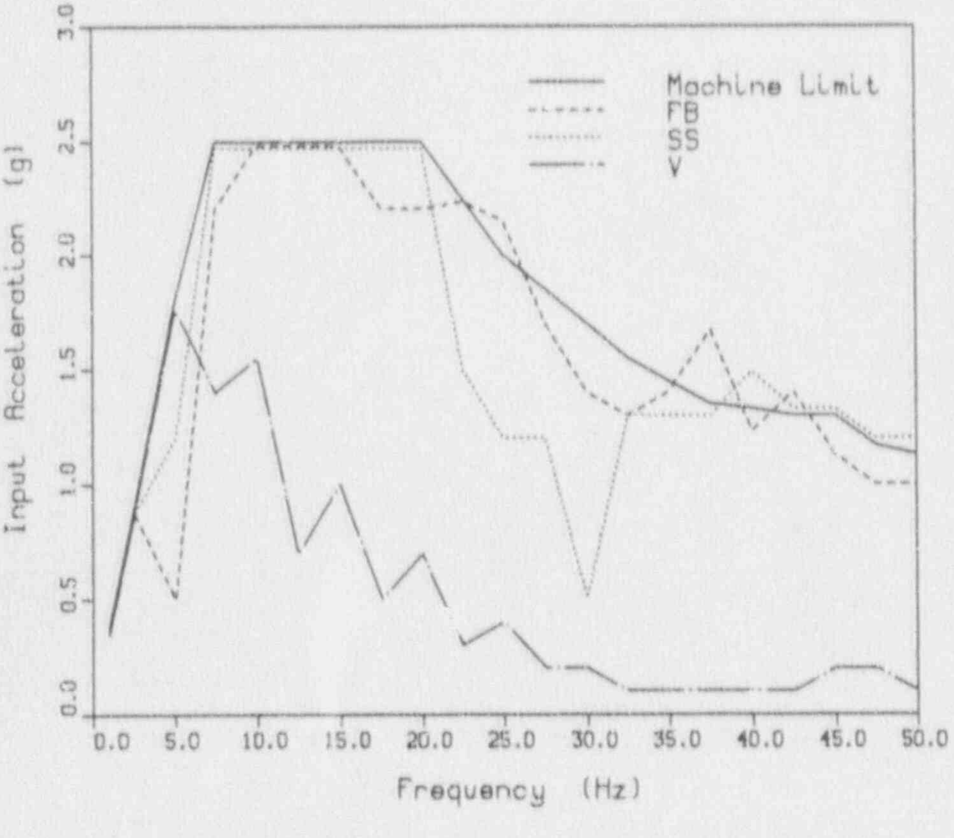

Figure 3.25 Sine Dwell Capacity Level
CO-6, Specimen 2
Operating Mode, CO Contact

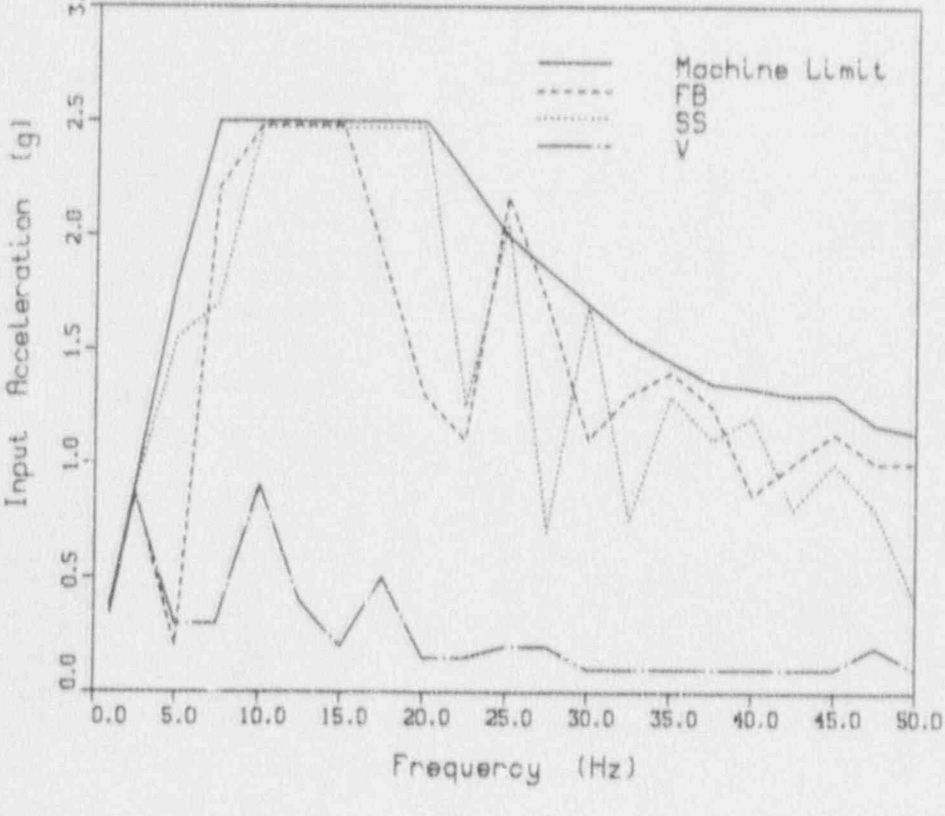

Figure 3-26 Sine Dwell Capacity Level
CO-6, Specimen 3
Operating Mode, CO Contact

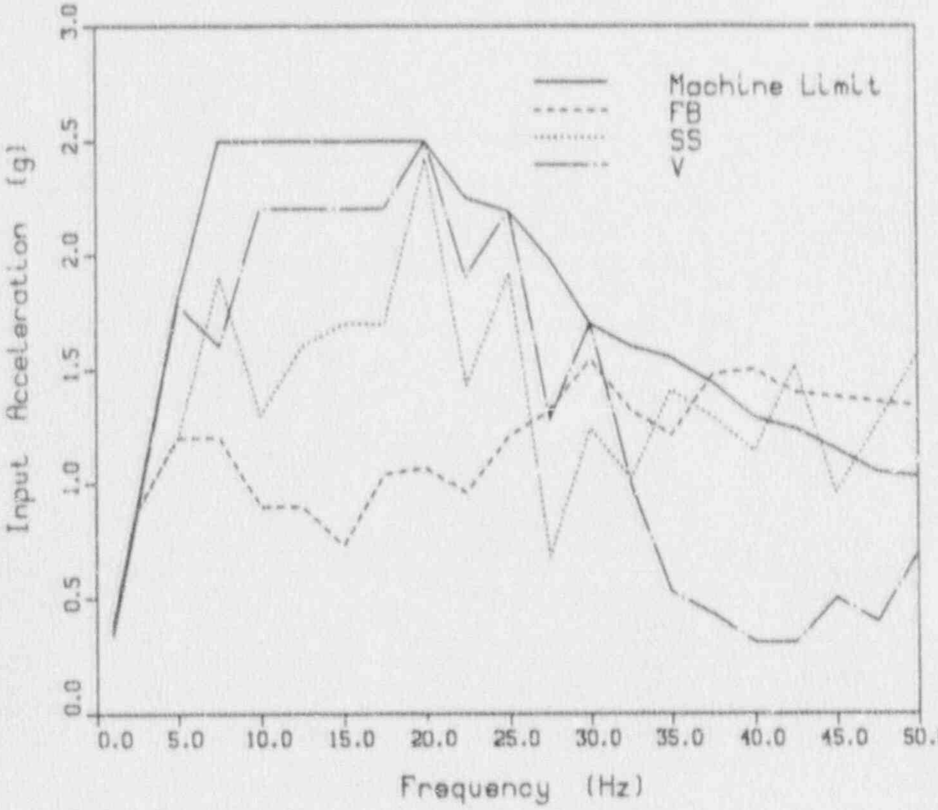

Figure 3.27 Sine Dwell Capacity Level
SG, Specimen 1
Nonoperating Mode, NC Contact

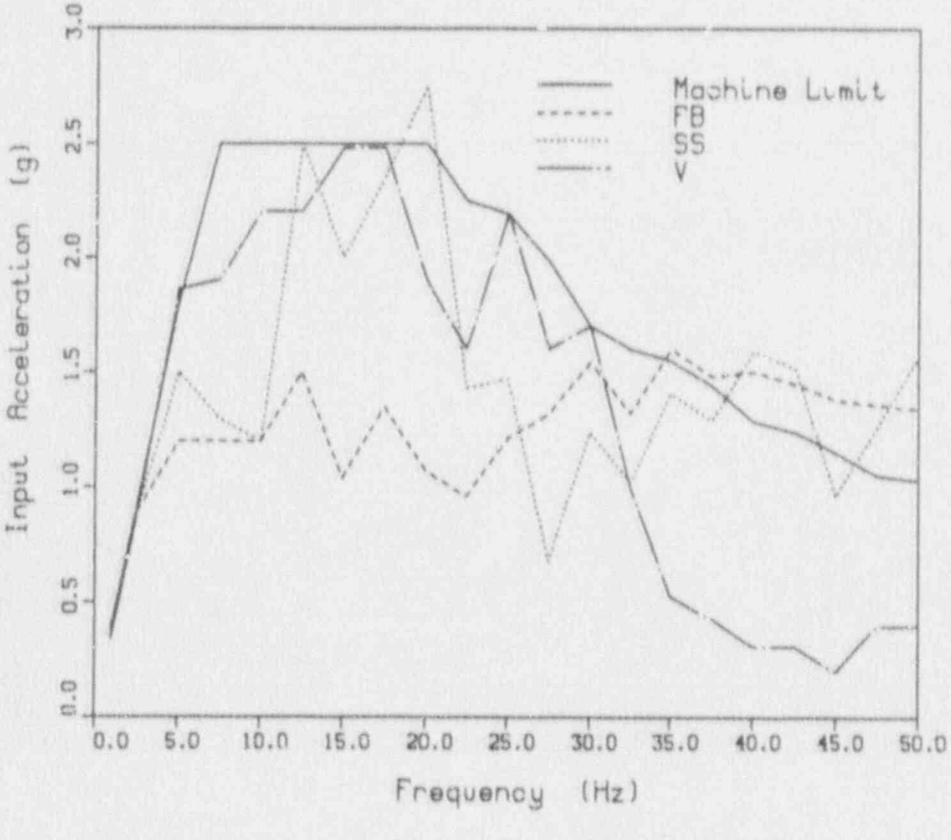

Figure 3.28 Sine Dwell Capacity Level
SG, Specimen 2
Nonoperating Mode, NC Contact

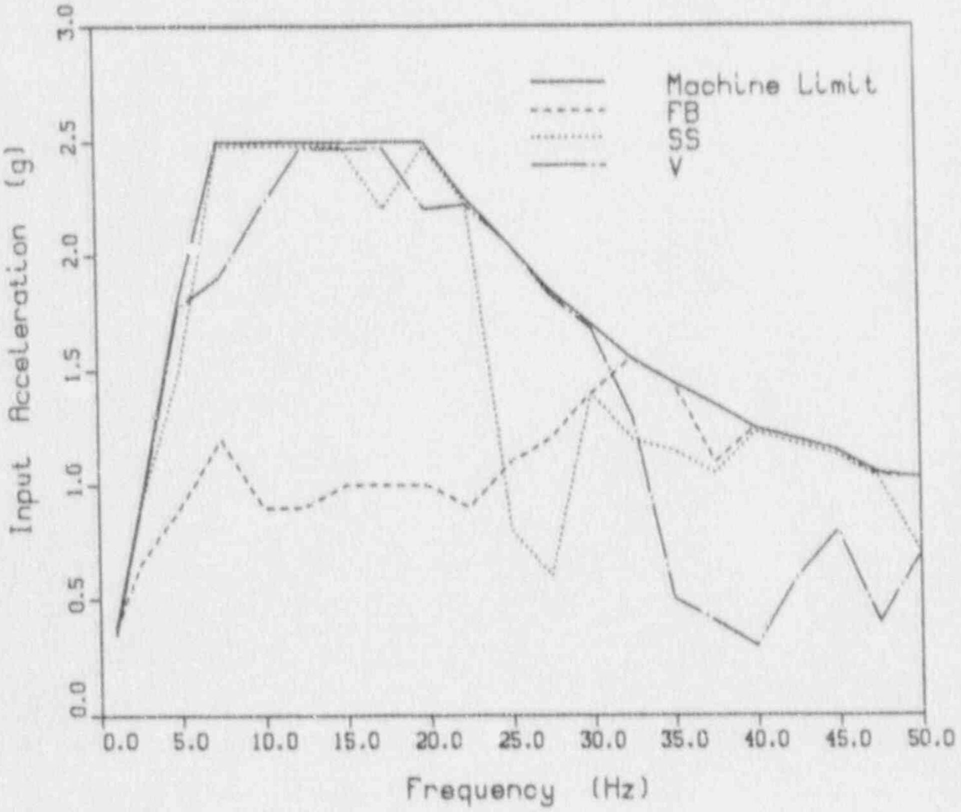

Figure 3.29 Sine Dwell Capacity Level
SG, Specimen 3
Nonoperating Mode, NC Contact

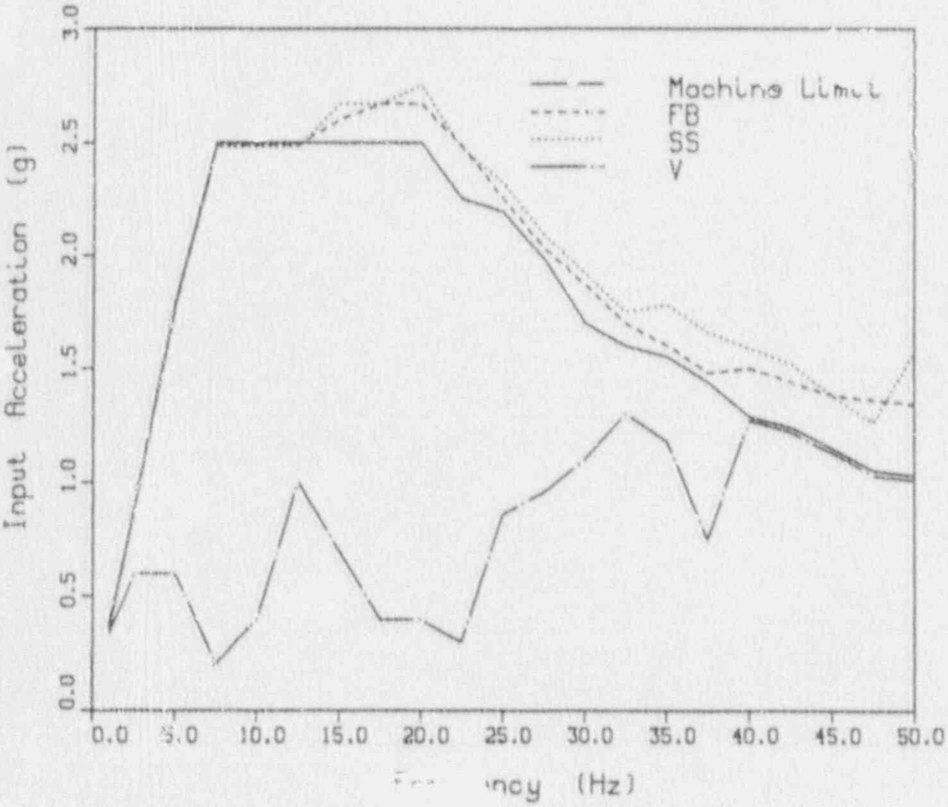

Figure 3.30 Sine Dwell Capacity Level
SC, Specimen 1
Nonoperating Mode, NC Contact

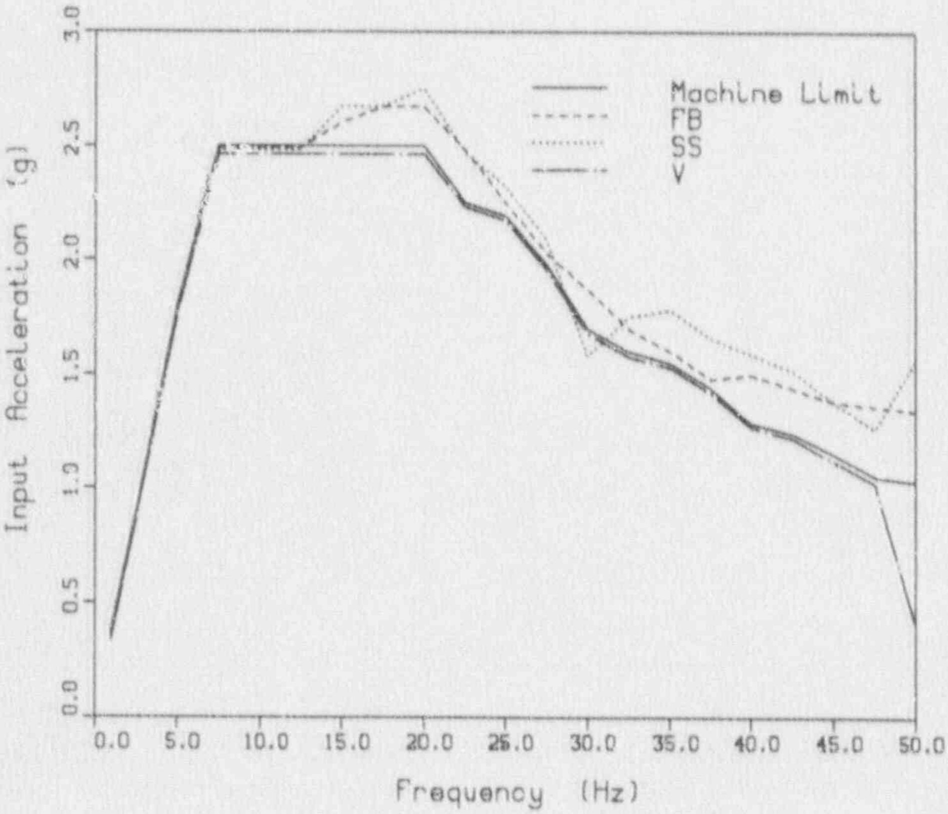

Figure 3.31 Sine Dwell Capacity Level
SC, Specimen 1
Operating Mode, NO Contact

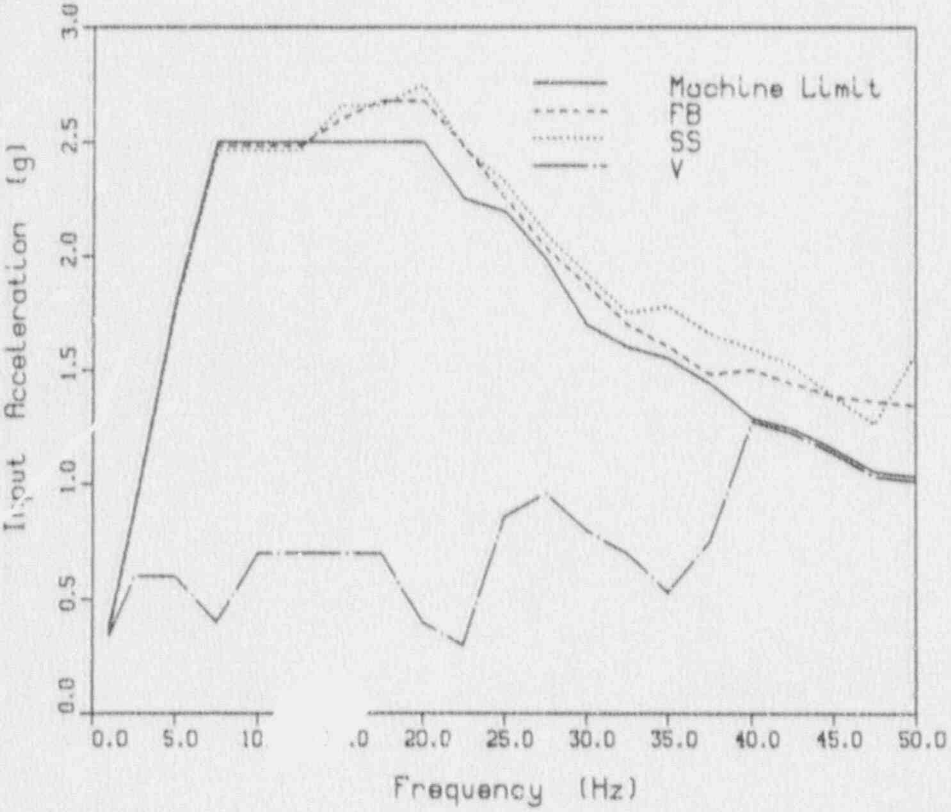

Figure 3.32 Sine Dwell Capacity Level
SC, Specimen 2
Nonoperating Mode, NC Contact

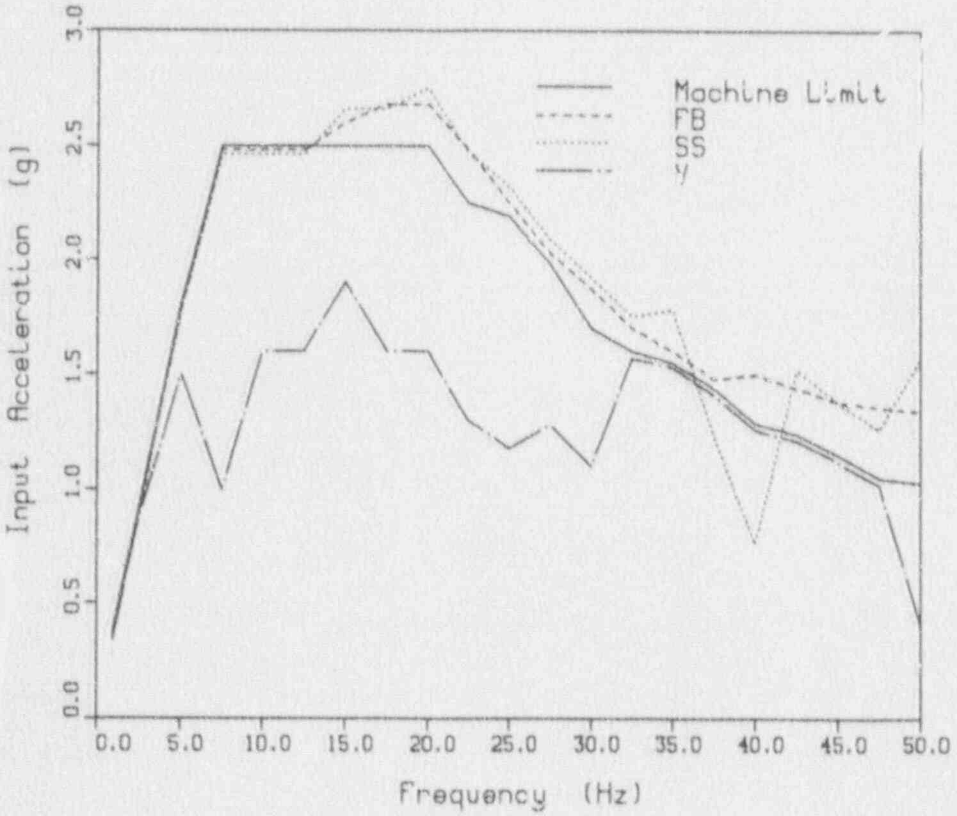

Figure 3.33 Sine Dwell Capacity Level
SC, Specimen 2
Operating Mode

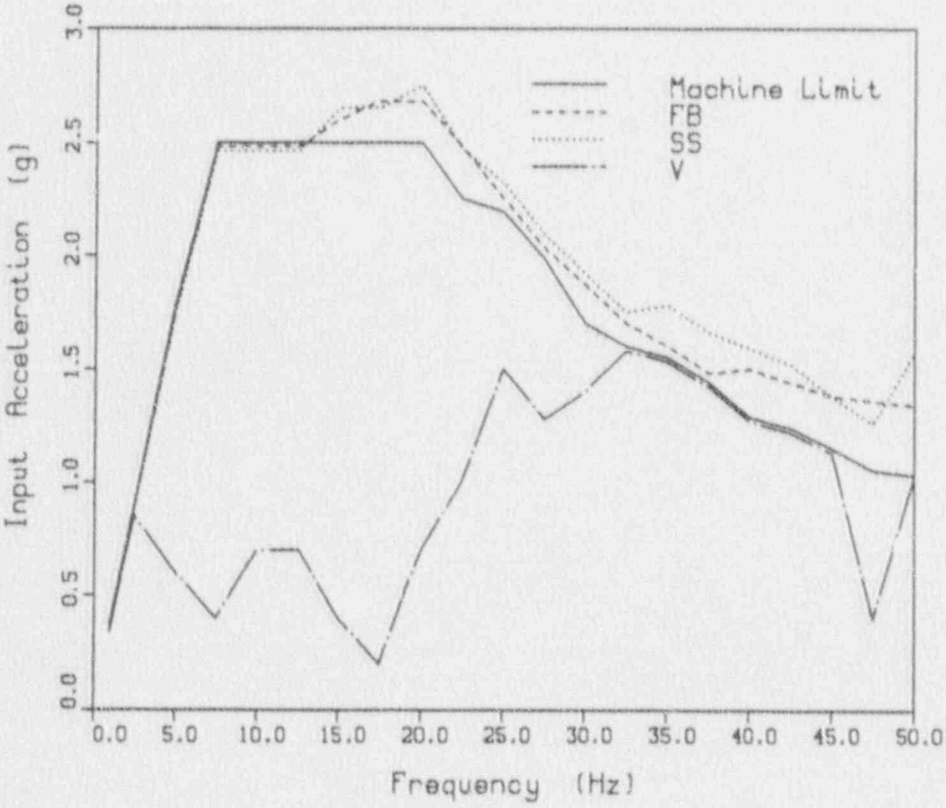

Figure 3.34 Sine Dwell Capacity Level
SC, Specimen 3
Nonoperating Mode, NC Contact

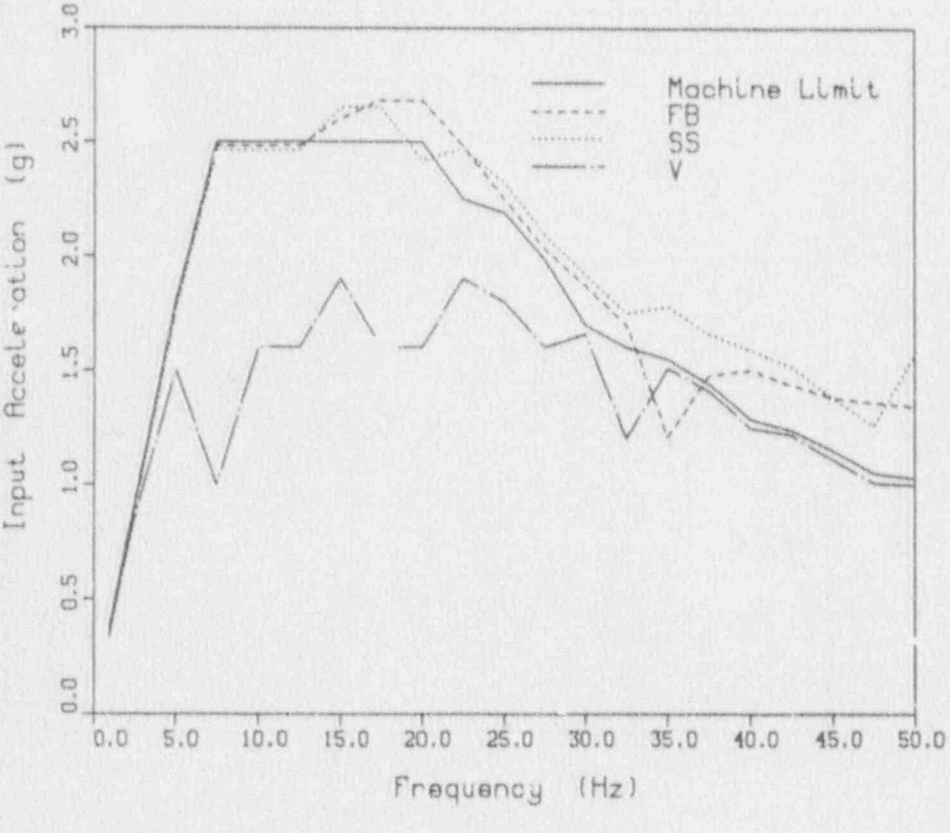

Figure 3.35 Sine Dwell Capacity Level
SC, Specimen 3
Operating Mode, NO Contact

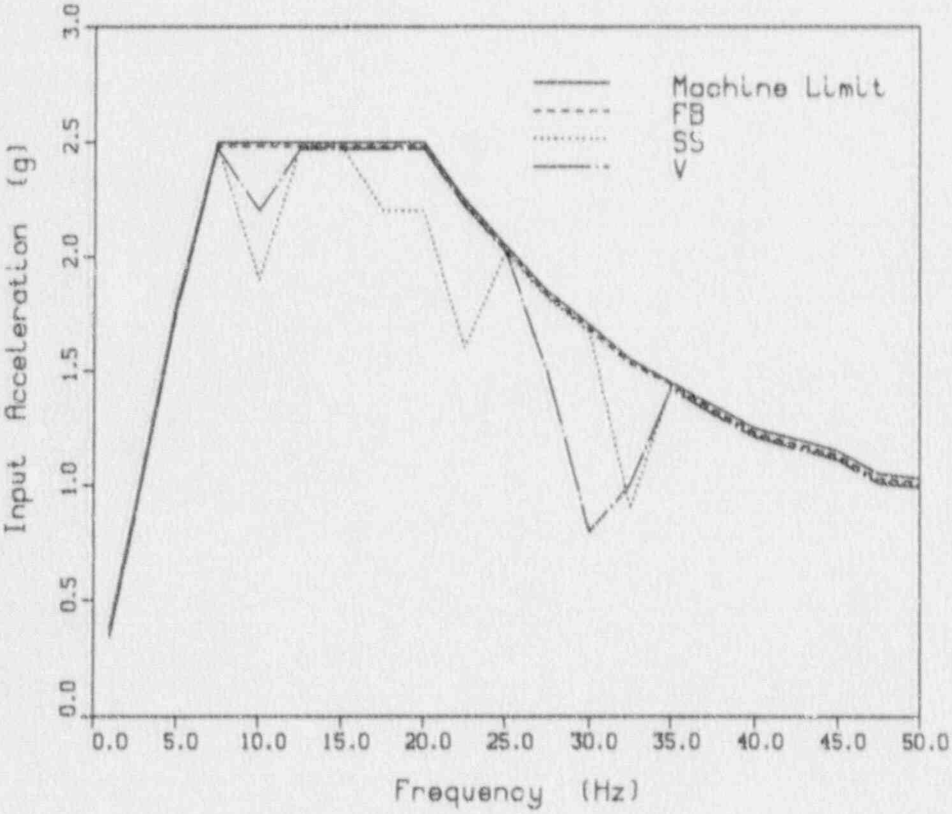

Figure 3.36 Sine Dwell Capacity Level
SVF, Specimen 1
Nonoperating Mode, NC Contact

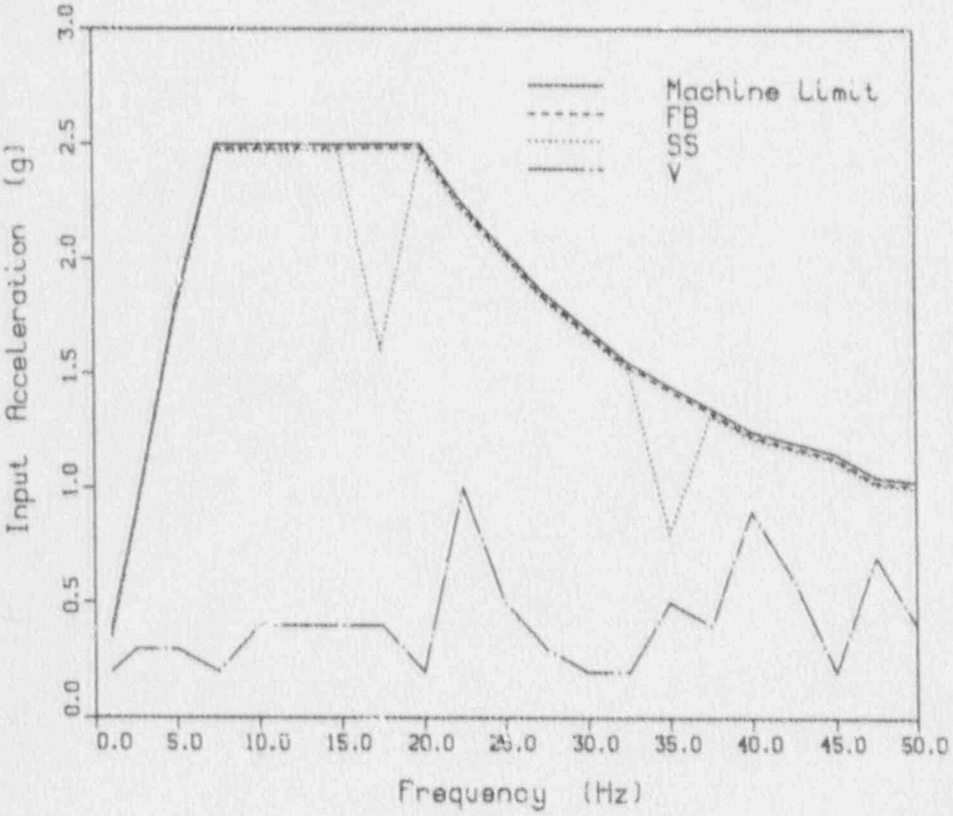

Figure 3.37 Sine Dwell Capacity Level
SVF, Specimen 1
Operating Mode, NC Contact

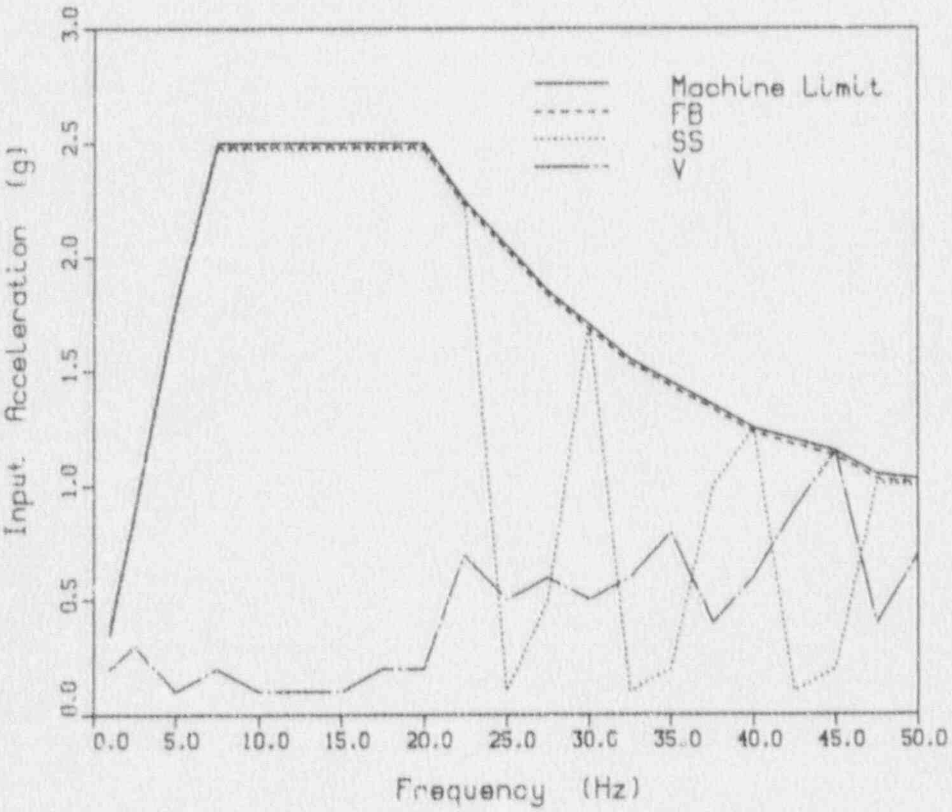

Figure 3.38 Sine Dwell Capacity Level
SVF, Specimen 2
Operating Mode, NC Contact

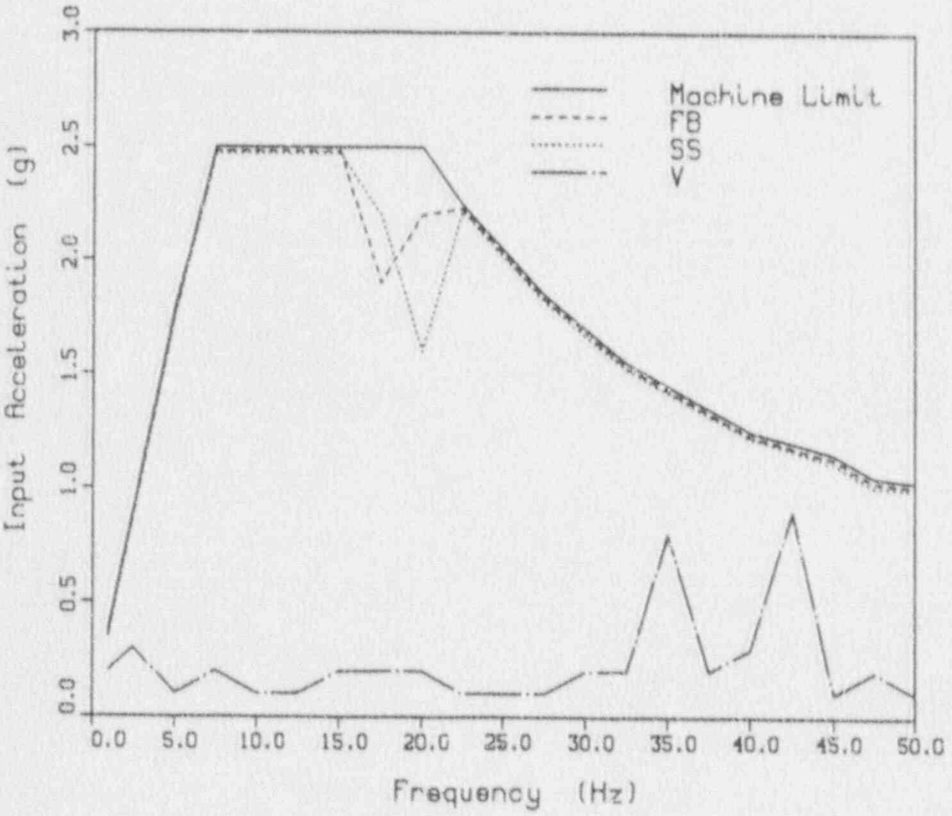

Figure 3.39 Sine Dwell Capacity Level
SVF, Specimen 3
Operating Mode, NC Contact

TABLE 3-1
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No.		
					1	2	3
HFA151A	FB	5-15	Nonop, NC	Lowest	0.90		
				Average	1.14		
		16-30	Nonop, NC	Lowest	0.70		
				Average	1.10		
		31-50	Nonop, NC	Lowest	0.65		
				Average	0.88[b]		
	SS	5-15	Nonop, NC	Lowest	1.80[b]		
				Average	2.36[b]		
		16-30	Nonop, NC	Lowest	0.95		
				Average	1.90[b]		
		31-50	Nonop, NC	Lowest	1.13[b]		
				Average	1.42[b]		
	V	5-15	Nonop, NC	Lowest	1.80[b]		
				Average	2.24[b]		
		16-30	Nonop, NC	Lowest	0.70		
				Average	1.37		
		31-50	Nonop, NC	Lowest	0.25		
				Average	0.58		
HFA151B	FB	5-15	Nonop, NC	Lowest	1.50[c]		
				Average	1.62		
		16-30	Nonop, NC	Lowest	1.60		
				Average	1.82[b]		
		31-50	Nonop, NC	Lowest	0.85		
				Average	1.30[b]		
	SS	5-15	Nonop, NC	Lowest	1.80[b]		
				Average	2.36[b]		
		16-30	Nonop, NC	Lowest	1.55		
				Average	2.00[b]		
		31-50	Nonop, NC	Lowest	0.75		
				Average	1.22[b]		

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No.		
					1	2	3
	V	5-15	Nonop, NC	Lowest	1.80[b]		
				Average	2.36[b]		
		16-30	Nonop, NC	Lowest	1.70[b]		
				Average	2.21[b]		
		31-50	Nonop, NC	Lowest	0.40		
				Average	0.94[b]		
HFA154E	FB	5-15	Nonop, NC	Lowest	1.80[b]		
				Average	2.30[b]		
			Op	Lowest	1.30		
				Average	1.62		
		16-30	Nonop, NC	Lowest	1.70		
				Average	2.14[b]		
			Op	Lowest	1.00		
				Average	1.50[b]		
		31-50	Nonop, NC	Lowest	1.03		
				Average	1.25		
			Op	Lowest	1.20[b]		
				Average	1.40[b]		
	SS	5-15	Nonop, NC	Lowest	1.80[b]		
				Average	2.36[b]		
			Op	Lowest	1.80[b]		
				Average	2.36[b]		
		16-30	Nonop, NC	Lowest	1.70[b]		
				Average	2.10[b]		
			Op	Lowest	1.70[b]		
				Average	2.10[b]		
		31-50	Nonop, NC	Lowest	0.40		
				Average	1.10[b]		
			Op	Lowest	0.70		
				Average	1.20[b]		

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No. 1	2	3
	V	5-15	Nonop, NC	Lowest	1.80[b]		
				Average	2.36[b]		
			Op	Lowest	1.00[c]		
				Average	1.50		
		16-30	Nonop, NC	Lowest	1.40		
				Average	2.08[b]		
			Op	Lowest	1.00		
				Average	1.41[b]		
		31-50	Nonop, NC	Lowest	0.40		
				Average	1.15[b]		
			Op	Lowest	0.70		
				Average	0.91[b]		
HFA154B	FB	5-15	Nonop, NC	Lowest	1.20		
				Average	1.38		
			Op	Lowest	1.80[b]		
				Average	2.36[b]		
		16-30	Nonop, NC	Lowest	1.60		
				Average	1.73[b]		
			Op	Lowest	1.85[b]		
				Average	2.20[b]		
		31-50	Nonop, NC	Lowest	1.20[b]		
				Average	1.43[b]		
			Op	Lowest	1.20[b]		
				Average	1.43[b]		
	SS	5-15	Nonop, NC	Lowest	1.80[b]		
				Average	2.36[b]		
			Op	Lowest	1.80[b]		
				Average	2.36[b]		
		16-30	Nonop, NC	Lowest	1.78[b]		
				Average	2.12[b]		

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No.		
					1	2	3
			Op	Lowest	1.78[b]		
				Average	2.18[b]		
		31-50	Nonop, NC	Lowest	1.13[b]		
				Average	1.42[b]		
			Op	Lowest	1.13[b]		
				Average	1.42[b]		
	V	5-15	Nonop, NC	Lowest	1.80[b]		
				Average	2.36[b]		
			Op	Lowest	1.00[c]		
				Average	1.70		
		16-30	Nonop, NC	Lowest	0.85		
				Average	1.55		
			Op	Lowest	1.00		
				Average	1.26		
		31-50	Nonop, NC	Lowest	<0.20		
				Average	0.45		
			Op	Lowest	0.70		
				Average	0.91		
HFA51	FB	5-15	Nonop, NC	Lowest	1.50	1.50	1.20
				Average	1.56	1.74	1.26
		16-30	Nonop, NC	Lowest	1.60	1.60	0.95
				Average	1.80	1.87[b]	1.33
		31-50	Nonop, NC	Lowest	1.20[b]	1.15	0.85
				Average	1.40[b]	1.40[b]	0.98
	SS	5-15	Nonop, NC	Lowest	1.80[b]	1.80[b]	1.80[b]
				Average	2.36[b]	2.36[b]	2.36[b]
		16-30	Nonop, NC	Lowest	1.10	1.70[b]	1.10
				Average	1.77[b]	2.08[b]	1.71
		31-50	Nonop, NC	Lowest	0.40	0.40	0.75
				Average	1.26[b]	1.26[b]	1.21[b]

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No. 1	2	3
	V	5-15	Nonop, NC	Lowest	1.80[b]	1.60	1.80[b]
				Average	2.12[b]	1.94[b]	2.18[b]
		16-30	Nonop, NC	Lowest	0.25	0.60	1.20
				Average	0.85	1.43	1.87[b]
		31-50	Nonop, NC	Lowest	<0.20	0.25	0.25
				Average	0.27	0.38	0.66
HGA	FB	5-15	Nonop, NC	Lowest	1.80[c]	1.20	1.30
				Average	2.15	1.35	1.47
		16-30	Nonop, NC	Lowest	1.39	0.88	0.88
				Average	1.80	1.35	1.35
		31-50	Nonop, NC	Lowest	1.26[b]	0.96	1.10
				Average	1.48	1.34	1.30[b]
	SS	5-15	Nonop, NC	Lowest	1.80[b]	1.80[b]	1.80[b]
				Average	2.28[b]	2.40[b]	2.40[b]
		16-30	Nonop, NC	Lowest	1.24	1.92[b]	1.43
				Average	2.08[b]	2.26[b]	1.91[b]
		31-50	nop, NC	Lowest	1.23	0.86	0.61
				Average	1.42[b]	1.37[b]	1.18[b]
	V	5-15	Nonop, NC	Lowest	1.60	1.80	1.60[c]
				Average	2.00[b]	2.06[b]	1.82
		16-30	Nonop, NC	Lowest	1.70	1.40	1.28
				Average	2.05[b]	1.86	1.71[e]
		31-50	Nonop, NC	Lowest	0.60	0.54	0.86
				Average	1.03[b]	0.92[b]	1.03[b]
HMA11	FB	5-15	Nonop, NC	Lowest	1.80[b]	1.75[b]	1.80[b]
				Average	2.16[b]	2.00[b]	2.36[b]
		16-30	Nonop, NC	Lowest	1.80[b]	1.90[b]	1.80[b]
				Average	2.20[b]	2.07[b]	2.20[b]
		31-50	Nonop, NC	Lowest	1.50[b]	1.50	1.50[b]
				Average	1.60[b]	1.60[b]	1.60[b]

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No. 1	Specimen No. 2	Specimen No. 3
	SS	5-15	Nonop, NC	Lowest	1.80[b]	1.80[b]	1.80[b]
				Average	2.36[b]	2.36[b]	2.36[b]
		16-30	Nonop, NC	Lowest	1.70[b]	1.70[b]	1.70[b]
				Average	2.14[b]	2.14[b]	2.14[b]
		31-50	Nonop, NC	Lowest	1.20[b]	1.20[b]	1.20[b]
				Average	1.43[b]	1.43[b]	1.43[b]
	V	5-15	Nonop, NC	Lowest	1.80[b]	1.80[b]	1.80[b]
				Average	2.26[b]	2.36[b]	2.36[b]
		16-30	Nonop, NC	Lowest	1.70[b]	1.70[b]	1.70
				Average	2.13[b]	2.13[b]	2.10[b]
		31-50	Nonop, NC	Lowest	0.80	0.80	0.30
				Average	1.03[b]	1.03[b]	0.65[b]
HMA124	FB	5-15	Nonop, NC	Lowest	0.40	1.00[c]	1.00
				Average	0.84	1.27	1.20
		16-30	Nonop, NC	Lowest	0.20	1.40	0.80
				Average	0.39	1.57[b]	1.02
		31-50	Nonop, NC	Lowest	0.25	0.75	0.55
				Average	0.60	0.94[b]	0.80[b]
	SS	5-15	Nonop, NC	Lowest	1.00	1.80[b]	1.80[b]
				Average	1.64	2.36[b]	2.36[b]
		16-30	Nonop, NC	Lowest	0.25	1.70[b]	1.20
				Average	0.53	2.08[b]	1.82[b]
		31-50	Nonop, NC	Lowest	<0.20	1.03[b]	1.03
				Average	0.55	1.26[b]	1.25[b]
	V	5-15	Nonop, NC	Lowest	0.20	0.70[c]	1.00
				Average	0.33	1.00	1.34
		16-30	Nonop, NC	Lowest	<0.20	0.70	0.70
				Average	<0.20	1.05	1.15
		31-50	Nonop, NC	Lowest	<0.20	0.25	0.25
				Average	<0.20	0.42	0.38

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No.		
					1	2	3
IAV	FB	5-15	Op, OV[f], NO	Lowest	1.70[b]	1.80[b]	
				Average	2.22[b]	2.36[b]	
			Op, UV[g], NC	Lowest	0.40	0.70[c]	
				Average	0.75	1.37	
		16-30	Op, OV, NO	Lowest	0.30	0.70	
				Average	0.91	1.05	
			Op, UV, NC	Lowest	0.40	0.40	
				Average	0.55	0.65	
		31-50	Op, OV, NO	Lowest	0.40	0.70	
				Average	0.85	0.98	
			Op, UV, NC	Lowest	<0.20	0.40	
				Average	0.40	0.55	
	SS	5-15	Op, OV, NO	Lowest	1.80[b]	1.80[b]	
				Average	2.30[b]	2.30[b]	
			Op, UV, NC	Lowest	1.30[c]	1.80[b]	
				Average	1.52	2.30	
		16-30	Op, OV, NO	Lowest	0.40	0.40	
				Average	1.17	0.96	
			Op, UV, NC	Lowest	0.30	0.40	
				Average	0.71	0.92	
		31-50	Op, OV, NO	Lowest	0.40	0.20	
				Average	0.69	0.41	
			Op, UV, NC	Lowest	0.30	0.20	
				Average	0.57	0.45	
	V	5-15	Op, OV, NO	Lowest	0.70[c]	1.30[c]	
				Average	1.00	1.78	
			Op, UV, NC	Lowest	0.30	0.60	
				Average	0.58	1.20	
		16-30	Op, OV, NO	Lowest	0.42	0.20	
				Average	0.75	0.90	

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No.		
					1	2	3
			Op, UV, NC	Lowest	0.20	<0.20	
				Average	0.33	0.50	
		31-50	Op, OV, NO	Lowest	0.30	<0.20	
				Average	0.59	0.35	
			Op, UV, NC	Lowest	<0.20	<0.20	
				Average	0.28	<0.20	
PVD	V	5-15	Nonop[d]	Lowest	1.80[b]		
				Average	2.11[b]		
			Op[e]	Lowest	1.80[b]		
				Average	2.36[b]		
		16-30	Nonop[d]	Lowest	1.70[b]		
				Average	2.01[b]		
			Op[e]	Lowest	1.70[b]		
				Average	2.12[b]		
		31-50	Nonop[d]	Lowest	0.65		
				Average	1.01		
			Op[e]	Lowest	1.00[b]		
				Average	1.21[b]		
CO-6	FB	5-15	Op, CO[h]	Lowest	0.20	0.50	0.20
				Average	2.04[b]	1.70[b]	1.98[b]
		16-30	Op, CO[h]	Lowest	1.80[b]	1.40	1.10
				Average	2.20[b]	1.98[b]	1.52[b]
		31-50	Op, CO[h]	Lowest	1.50[b]	1.00	0.86
				Average	1.61[b]	1.26[b]	1.12
	SS	5-15	Op, CO[h]	Lowest	1.55	1.20	1.55
				Average	2.32	2.24[b]	2.16[b]
		16-30	Op, CO[h]	Lowest	1.40	0.50	0.70
				Average	1.93[b]	1.57	1.78[b]
		31-50	Op, CO[h]	Lowest	1.10	1.20[b]	0.40
				Average	1.40[b]	1.30[b]	0.93

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Accele-ration	Specimen No.		
					1	2	3
	V	5-15	Op, CO[h]	Lowest	1.30	0.70[c]	0.20
				Average	1.72[b]	1.16	0.42
		16-30	Op, CO[h]	Lowest	0.40	0.20	<0.20
				Average	0.78	0.38	<0.20
		31-50	Op, CO[h]	Lowest	<0.20	< 0.20	<0.20
				Average	0.30	< 0.20	<0.20
SG	FB	5-15	Nonop, NC	Lowest	0.73	1.04	0.90
				Average	0.98	1.23	0.98
		16-30	Nonop, NC	Lowest	0.96	0.96	0.90
				Average	1.20	1.25	1.10
		31-50	Nonop, NC	Lowest	1.21	1.34	1.03[b]
				Average	1.34[b]	1.45[b]	1.25[b]
	SS	5-15	Nonop, NC	Lowest	1.20	1.30	1.50
				Average	1.54	1.90	2.30[b]
		16-30	Nonop, NC	Lowest	0.68	0.68	0.60
				Average	1.56	1.66	1.63[b]
		31-50	Nonop, NC	Lowest	0.96	0.96	0.70
				Average	1.28	1.33[b]	1.10[b]
	V	5-15	Nonop, NC	Lowest	1.60[c]	1.80[b]	1.80[b]
				Average	2.05	2.12[b]	2.20[b]
		16-30	Nonop, NC	Lowest	1.28	1.60	1.70
				Average	1.97[b]	1.91[b]	2.10[b]
		31-50	Nonop, NC	Lowest	0.31	0.20	0.30
				Average	0.52	0.45	0.62
SC	V	5-15	Nonop, NC	Lowest	0.20	0.40	0.40
				Average	0.58	0.62	0.58
			Op, NO	Lowest	1.80[b]	1.00	1.0
				Average	2.36[b]	1.52	1.52

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels^{a}
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No. 1	Specimen No. 2	Specimen No. 3
		16-30	Nonop, NC	Lowest	0.30	0.30	0.20
				Average	0.68	0.67	1.02
			Op, NO	Lowest	1.70^{b}	1.10	1.60
				Average	2.19^{b}	1.35	1.70^{b}
		31-50	Nonop, NC	Lowest	0.75	0.53	0.40
				Average	1.12^{b}	0.87^{b}	1.22^{b}
			Op, NO	Lowest	0.40^{b}	0.40	1.03
				Average	1.22^{b}	1.22^{b}	1.28
SVF	FB	5-15	Nonop, NC	Lowest	1.80^{b}	1.80^{b}	1.80^{b}
				Average	2.36^{b}	2.36^{b}	2.36^{b}
			Op, NC	Lowest	1.80^{b}	1.80^{b}	1.80^{b}
				Average	2.36^{b}	2.36^{b}	2.36^{b}
		16-30	Nonop, NC	Lowest	1.70^{b}	1.70^{b}	1.70^{b}
				Average	2.13^{b}	2.13^{b}	2.13^{b}
			Op, NC	Lowest	1.70^{b}	1.70^{c}	1.70^{b}
				Average	2.13^{b}	2.13^{b}	1.98^{b}
		31-50	Nonop, NC	Lowest	1.03^{b}	1.03^{b}	1.03^{b}
				Average	1.25^{b}	1.25^{b}	1.25^{b}
			Op, NC	Lowest	1.03^{b}	1.03^{b}	1.03^{b}
				Average	1.25^{b}	1.25^{b}	1.25^{b}
	SS	5-15	Nonop, NC	Lowest	1.80^{b}	1.80^{b}	1.80^{b}
				Average	2.23^{b}	2.36^{b}	2.36^{b}
			Op, NC	Lowest	1.80^{b}	1.80^{b}	1.80^{b}
				Average	2.36^{b}	2.36^{b}	2.36^{b}
		16-30	Nonop, NC	Lowest	1.60	1.70^{b}	1.70^{b}
				Average	1.93^{b}	2.14^{b}	2.14^{b}
			Op, NC	Lowest	1.60	<0.20	1.60^{b}
				Average	1.98^{b}	1.55^{b}	1.95^{b}
		31-50	Nonop, NC	Lowest	0.20	1.03^{b}	1.03^{b}
				Average	1.17^{b}	1.25^{e}	1.25
			Op, NC	Lowest	0.80	<0.20^{b}	1.03^{b}
				Average	1.15^{b}	0.59^{b}	1.25
	V	5-15	Nonop, NC	Lowest	1.80^{b}	1.80^{b}	1.80^{b}
				Average	2.30^{b}	2.36^{b}	2.36^{b}
			Op, NC	Lowest	0.20	<0.20	<0.20^{d}
				Average	0.34	<0.20	<0.20

TABLE 3-1 (continued)
Single Frequency Sine Dwell Capacity Levels[a]
Input Accelerations in "g"

Model No.	Direction	Frequency Range (Hz)	Electrical Condition	Acceleration	Specimen No. 1	Specimen No. 2	Specimen No. 3
		16-30	Nonop, NC	Lowest	0.80[b]	1.70[b]	1.40[b]
				Average	1.93[b]	2.14[b]	2.10[b]
			Op, NC	Lowest	0.20	0.20	<0.20[c]
				Average	0.43	0.49	<0.20
		31-50	Nonop, NC	Lowest	1.00	1.03[b]	1.03[b]
				Average	1.18[b]	1.25[b]	1.25[b]
			Op, NC	Lowest	0.20	0.40	<0.20
				Average	0.49	0.70	0.30

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[a] For CR120, MG-6, AR, 8501X0 and 8501-KP relays, the capacity levels could not be established due to limitation of the shake table.

[b] Due to the shake table limitation, the relay capacity at some frequencies could not be established. The average acceleration was computed based on the highest test level, and the true average capacity level is higher than the listed value.

[c] Due to the shake table limitation, the relay capacity at 5Hz could not be established and the reported value is applicable in the frequency range of 7.5-15Hz

[d] Voltage operated unit

[e] Seal-in unit

[f] Overvoltage

[g] Undervoltage

[h] CO contact

The effects of various parameters as observed from the single frequency test data are discussed in the following sections. This is followed by discussion on individual characteristics of each relay.

3.2.1 Frequency of Vibration Input

The single frequency test data demonstrate that relays are sensitive to the frequency of the vibration input, i.e., the capacity levels at certain frequencies are much lower than those at other frequencies. Depending on the design and the electrical state, some relays are sensitive at low frequencies (e.g., 5-15Hz), some at medium frequencies (15-30Hz) and some at higher frequencies. For example, in the FB direction a CO-6 specimen which is a rotary disk relay, is very weak at 5Hz with a capacity of only 0.2g compared to the capacity level exceeding the shake limit at other frequencies (e.g., 2.5g at 7.5-20Hz) in the same direction, as shown in Figure 3.40. On the other hand, an SC specimen, a plunger relay, is sensitive at 40Hz in the SS direction. Unlike these two examples, some relays are weak over a range of frequencies rather than at a particular frequency value. One such example is an HFA (hinged armature) relay which demonstrated a high capacity level in the V direction at low frequencies (e.g., greater than 1.8g at 5-17Hz), and a very low capacity level at high frequencies (e.g., 0.4g or less at most frequencies between 23 and 50Hz), as shown in Figure 3.40.

3.2.2 Direction of Vibration Input

The relay capacity level changes with the direction of the vibration input. For example, the capacity levels of an SG relay in the FB, SS and V directions are shown in Figure 3.29. At low frequencies, the capacity level is governed by input in the FB direction, whereas at high frequencies, the vertical direction controls the capacity level. The SS input governs at 27Hz. For some relays, one direction controls the entire frequency range. One such example is an SC relay which is much weaker in the vertical direction as shown in Figure 3.30. Usually, either the FB or the V direction controls the relay capacity levels in the low frequency range. For most relays, excitation in the V direction is more damaging than the FB direction at high frequencies. For example consider Figures 3.1, 3.8 and 3.39. Figure 3.1 shows that at low frequencies the capacity of an HFA relay in the FB direction is much less than that in the V direction; whereas at all frequencies above 22Hz the capacity in the vertical direction is lower. In Figure 3.8 at low frequencies (e.g., < 25Hz) the capacity of another HFA relay is controlled by either the FB or the V direction input and at higher frequencies the capacity in the V direction is much lower than that in the FB direction. Figure 3.39 exhibits the capacity of an SVF relay which is very weak against vertical excitation at all frequencies. The SS direction rarely controls the relay capacity and even if it does, it governs only at a short frequency range as illustrated in Figure 3.19 which shows that the SS direction governs the capacity of an IAV relay only in the frequency range 22-24Hz.

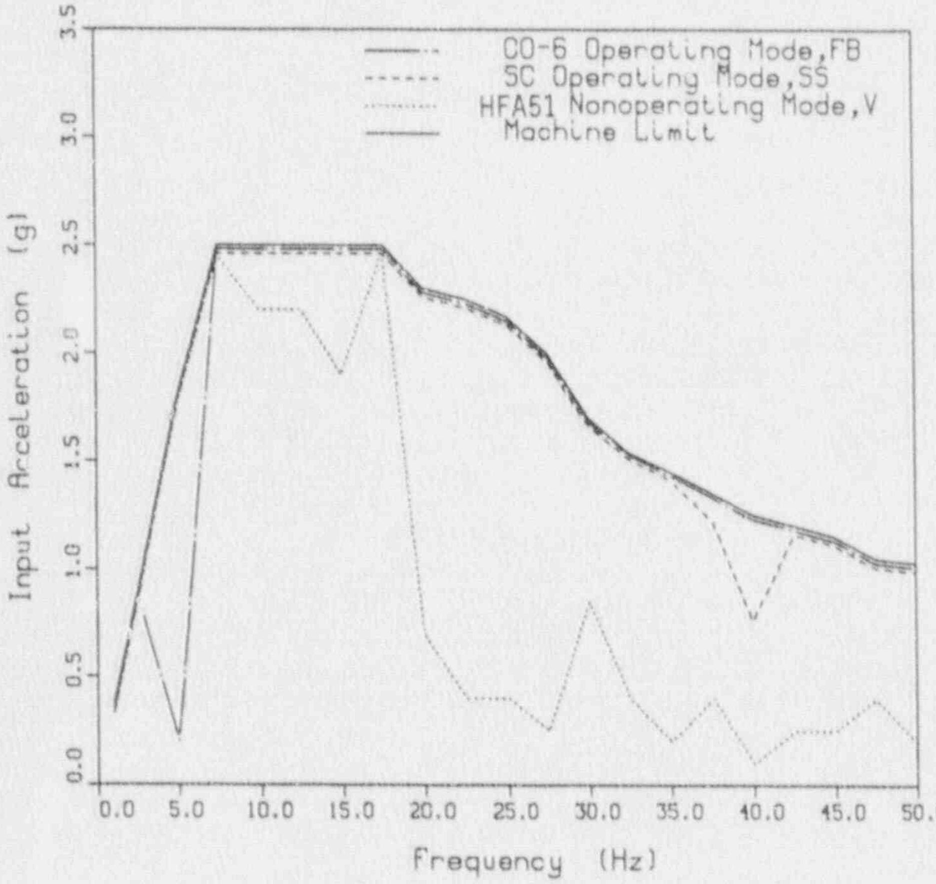

Figure 3.40 Influence of Vibration Frequency
Sine Dwell Capacity Level

3.2.3 Operating Mechanism and Dynamic Characteristics

Although the dynamic characteristics such as resonance frequency of a relay were not monitored during the vibration tests, the movement of the operating mechanism was captured through chatter detection. Hinged armature operating mechanisms were observed to vibrate causing chatter over a wide frequency range. For example, Figure 3.1 shows how the movement of a hinged armature mechanism in the FB direction causes chatter. The capacity in the FB direction did not change much over the entire frequency range (0.7-1.3g). More importantly, there are other elements in the relay design that can affect the capacity level. Figure 3.7 illustrates that although the armature of the HFA relay moves in the FB direction, other elements in the relay design greatly influences the capacity level at high frequencies since the capacity in the vertical direction is much lower. Moreover, the influence of these elements can be exhibited at several distinct frequencies analogous to multimode behavior in vibration mechanics. As illustrated in Figure 3.8, the HFA relay (which has an armature mechanism in the FB direction) was distinctly sensitive at 10, 15, 22 and 27 and 35-45Hz in the vertical direction exhibiting resonant-type characteristics.

3.2.4 Electrical Condition

Most relays are stronger in the operating mode. As illustrated in Figure 3.41 the HMA specimen withstood vibration inputs at all frequencies up to the machine limit (e.g. 2.5g at 7-20Hz) in the operating mode; whereas, the capacity level in the nonoperating mode is less than 0.5g sine dwell input. However, some relays are stronger in the nonoperating mode. The SVF relay is one such example as shown in Figure 3.42. In the nonoperating mode the relay was successfully tested almost at all frequencies to the machine limit, but in the operating mode its capacity at most frequencies is limited to less than 0.3g sine dwell input. Again, there are some relay models for which the capacity level at some frequencies are controlled by the nonoperating mode and at other frequencies by the operating mode. For example, an HFA relay performed better in the nonoperating mode at low frequencies (up to 25Hz), and in the operating mode at high frequencies, as shown in Figure 3.43. The IAV relay was tested at two alternate operating modes. The results as shown in Figure 3.44 indicate that the relay is weaker in the undervoltage condition than in the overvoltage mode.

In summary, the electrical mode strongly influences the relay performance and the precise electrical mode controlling the capacity level depends on the relay model and, in some instances, on the frequency of the vibration input.

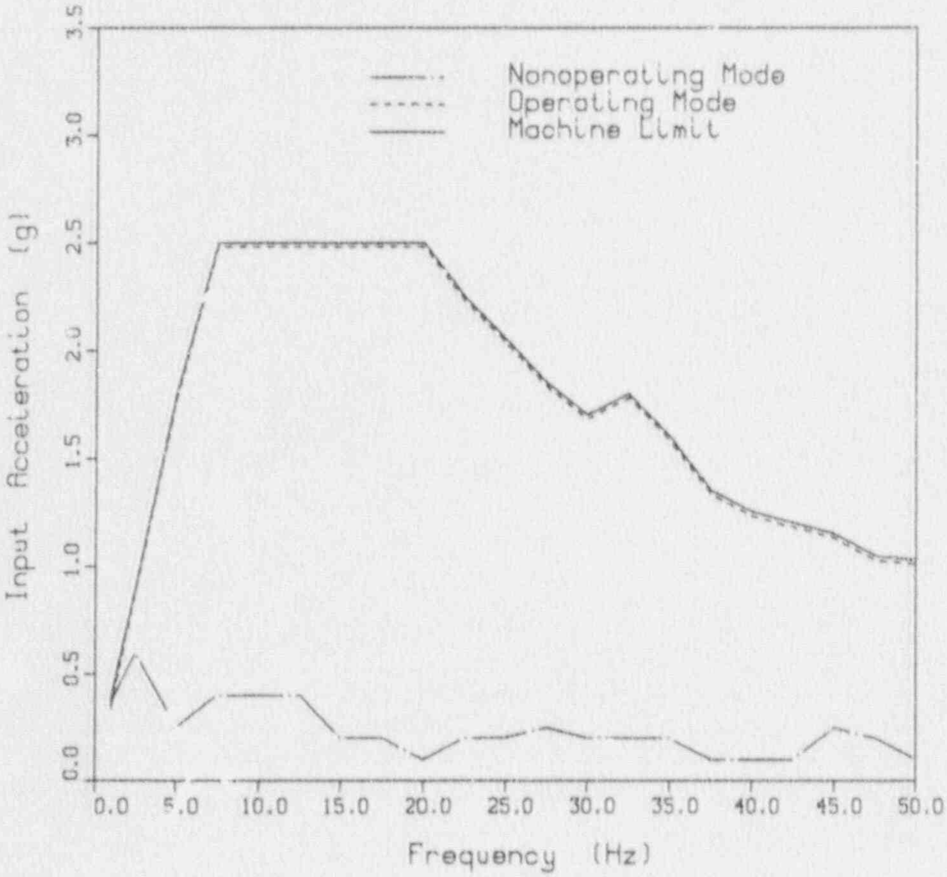

Figure 3.41 Influence of Electrical Conditions
Sine Dwell Capacity Level
HMA124, Specimen 1, V Direction

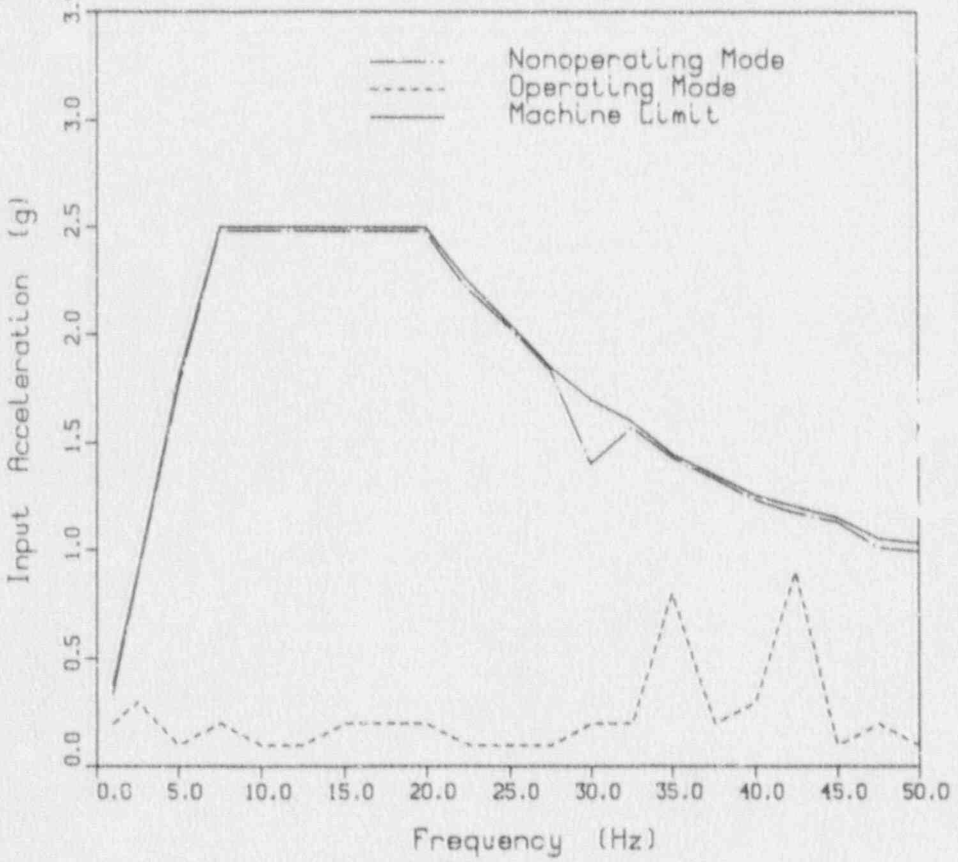

Figure 3.42 Influence of Electrical Conditions
Sine Dwell Capacity Level
SVF, Specimen 3, V Direction

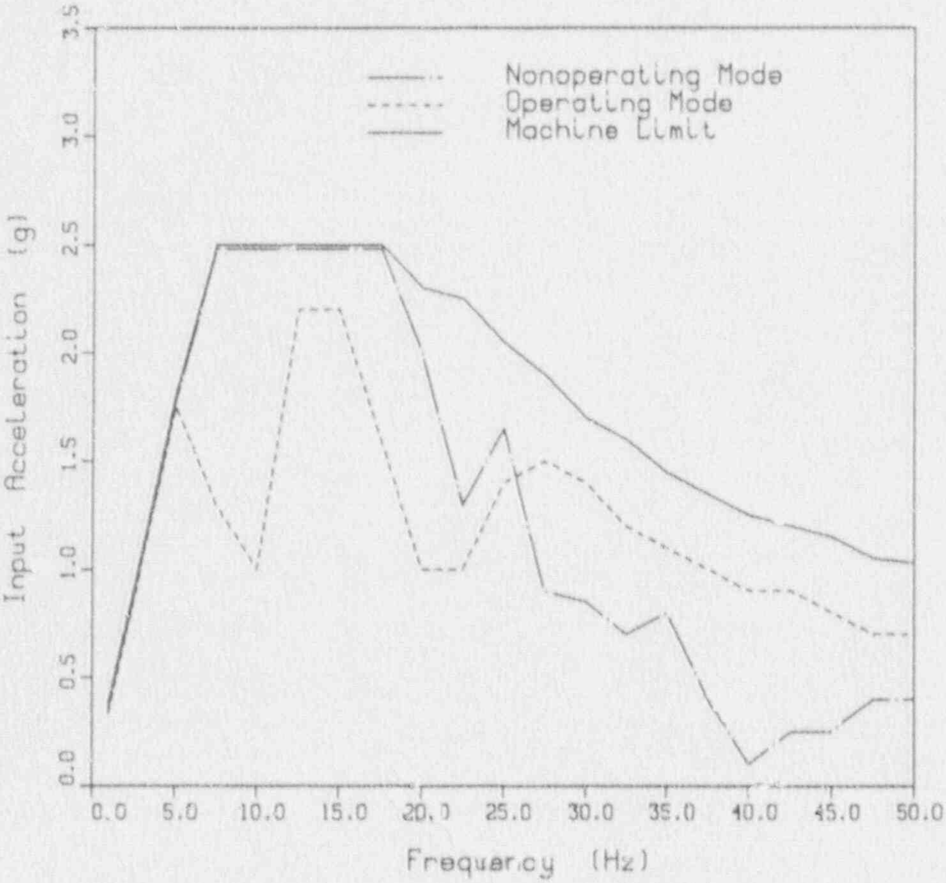

Figure 3.43 Influence of Electrical Conditions
Sine Dwell Capacity Level
HFA154B, V Direction

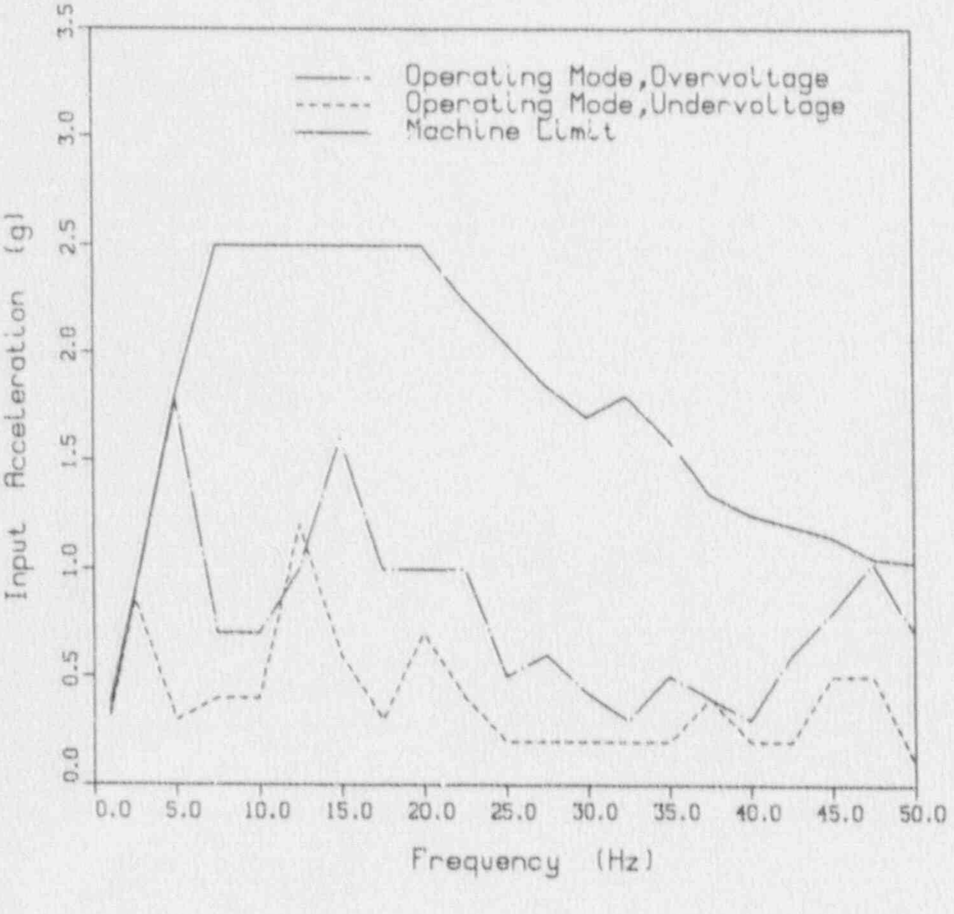

Figure 3.44 Influence of Electrical Conditions
Sine Dwell Capacity Level
IAV, Specimen 1, V Direction

3.2.5 Same Model, Different Specimens

For many relays, multiple specimens of the same model were tested. A comparison of the capacity levels of these specimens is pictorially presented in Figures 3.45 through 3.68 for each relay model.[6] Depending on the frequency and direction of vibration, electrical mode and contact state, a moderate to wide variation of the capacity levels is observed for specimens of the same model. For example, three HMA124 relays in the nonoperating mode exhibited a large variation of their capacities at most frequencies in all three directions as shown in Figures 3.49, 3.50 and 3.51 (e.g., at 2[illegible]Hz: 0.2g, [illegible].4g and 0.8g in FB direction; 0.25g, 1.70g and 1.4g in SS direction; 0.2g, 1.0g and 0.7g in V direction). Similar characteristics were also exhibited by three CO-6 relays in the operating mode for the vertical direction which is the weakest direction for these relays at most other frequencies as shown in Figure 3.60. In the FB direction, these relays show a consistent sharp reduction of capacity at 5Hz (Figure 3.58) but inconsistent capacities at most other frequencies (e.g., machine limit 2.5g, 2.2g and 1.3g at 20Hz). On the other hand, three SG relays in the nonoperating mode show comparable results at most frequencies in the FB and V directions (Figures 3.61 and 3.63) but inconsistent capacities at low frequencies in the SS direction (Figure 3.62, e.g., 1.3g, 2.2g and machine limit 2.5g at 10Hz). Repeated sudden drops of the capacity level of one specimen of the SVF relay in the SS direction (Figure 3.67) raises questions regarding similarity among the specimens.

In summary, the test data indicate that a variation of the capacity among specimens of the same relay model can easily be 50%-100% for many relays and can be much higher for a few others.

3.2.6 Settings and Adjustments

The relays were initially tested in the as-received condition (i.e., factory setting). However some relays were adjusted during the test program and tested at alternate settings as described earlier in Section 2.4.1.1. The respective results are discussed in the following sections.

3.2.6.1 Spring Tension Adjustment

The test data for the HFA51 specimen at three different tension settings are shown in Figures 3.69, 3.70 and 3.71, all for the nonoperating mode in the FB direction. The results indicate a noticeable variation of the capacity levels due to spring tension settings. However, a general trend of the data could not be established. For example, at low frequencies Specimen 1 followed the expected trend that the capacity increases with the spring tension (Figure 3.69); however, at high frequencies the data greatly defy the expected rule (e.g., at 20Hz the capacities for the high, medium and low tension values are respectively 0.4, 1.7

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[6] If the comparison is not possible since the shake table capacity was less than the actual relay capacity, the information is not presented for those relays.

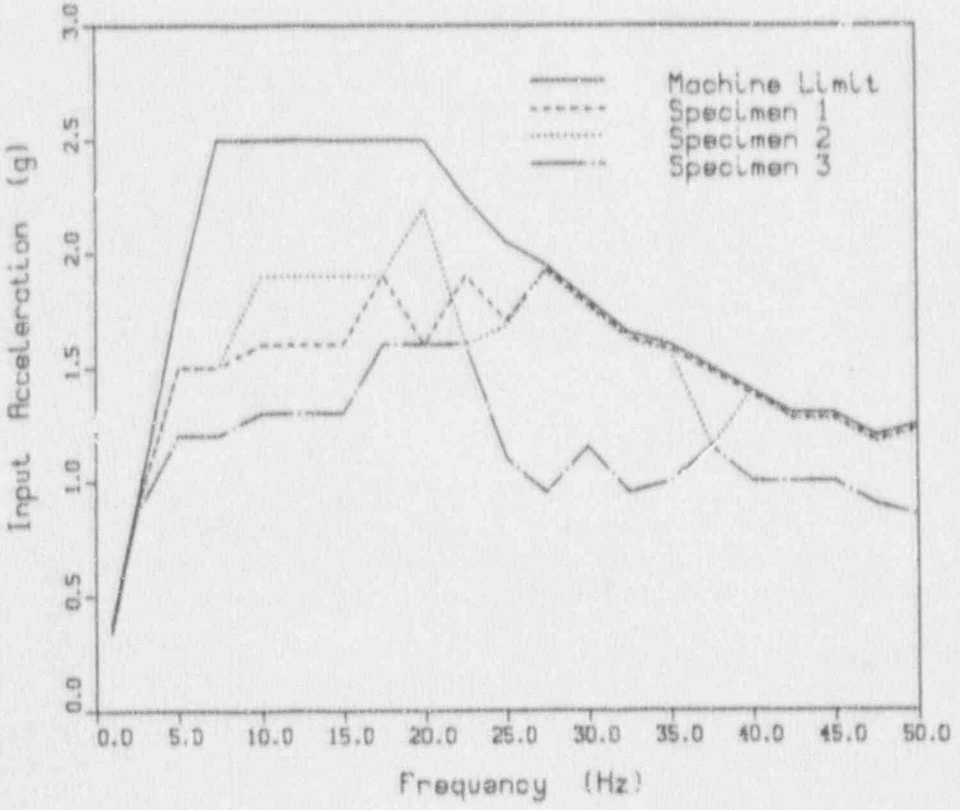

Figure 3.45 Comparison of Specimen Capacities - HFA51
Sine Dwell Amplitude, FB Direction
Nonoperating Mode, NC Contact

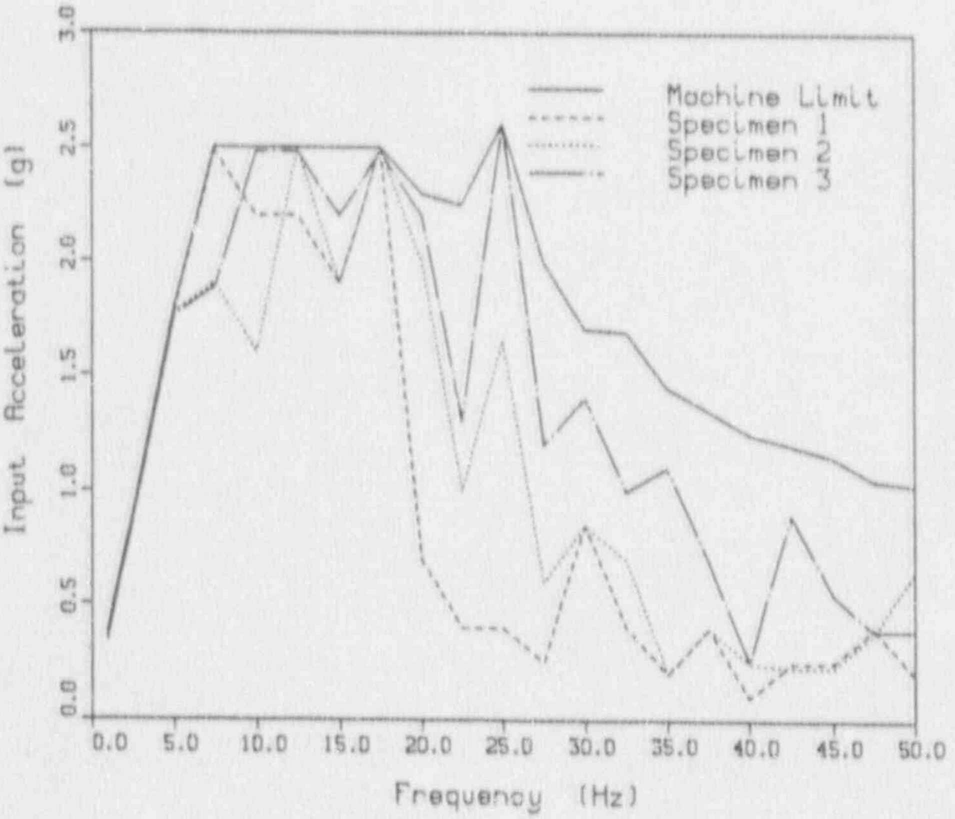

Figure 3.46 Comparison of Specimen Capacities - HFA51
Sine Dwell Amplitude, V Direction
Nonoperating Mode, NC Contact

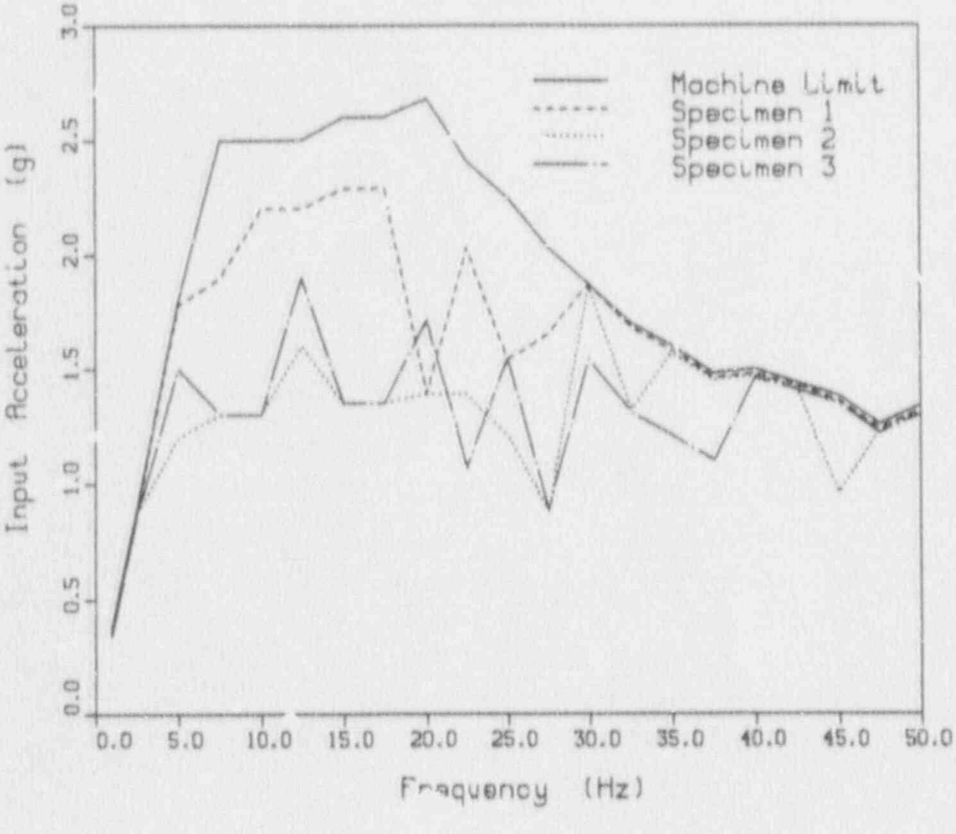

Figure 3.47 Comparison of Specimen Capacities - HGA
Sine Dwell Amplitude, FB Direction
Nonoperating Mode, NC Contact

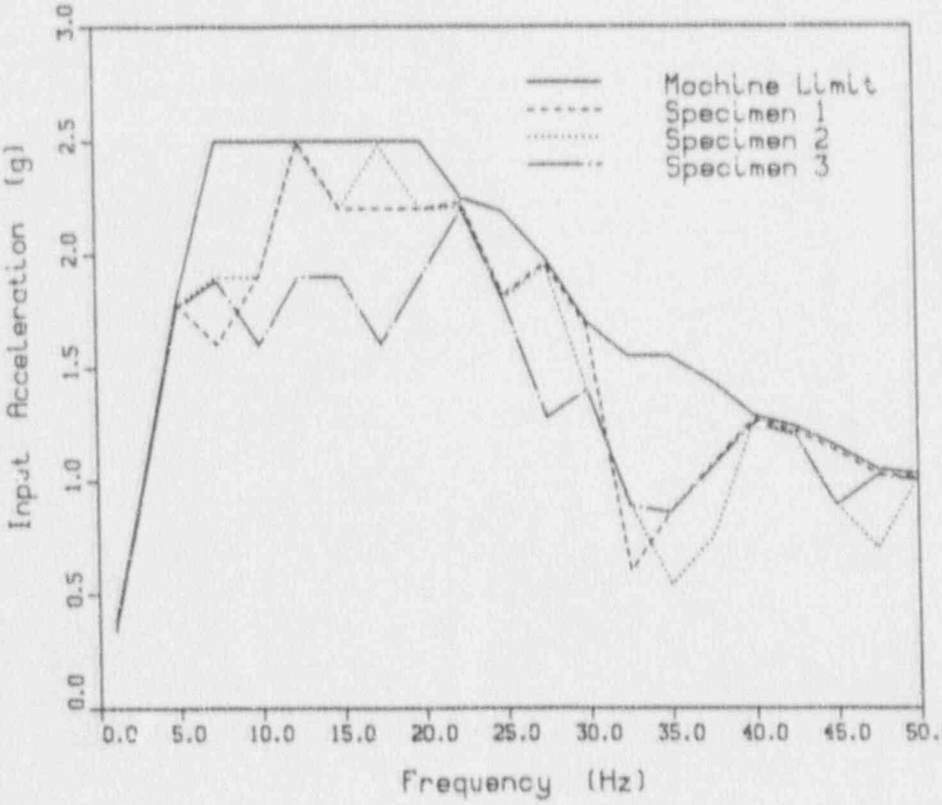

Figure 3.48 Comparison of Specimen Capacities - HGA
Sine Dwell Amplitude, V Direction
Nonoperating Mode, NC Contact

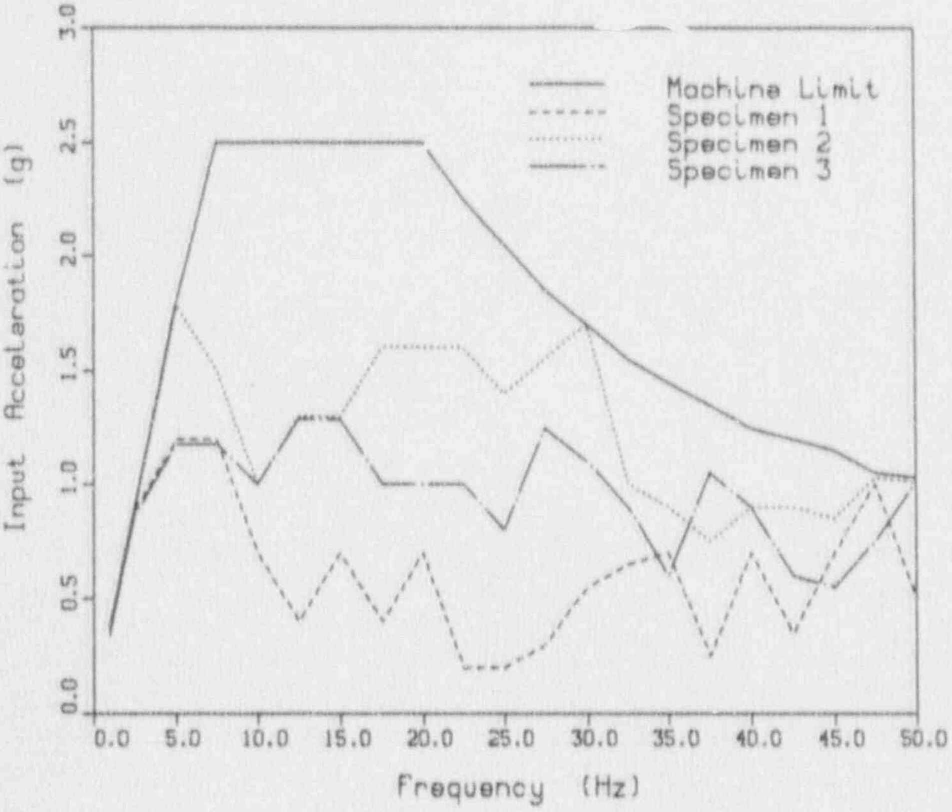

Figure 3.49 Comparison of Specimen Capacities - HMA124
Sine Dwell Amplitude, FB Direction
Nonoperating Mode, NC Contact

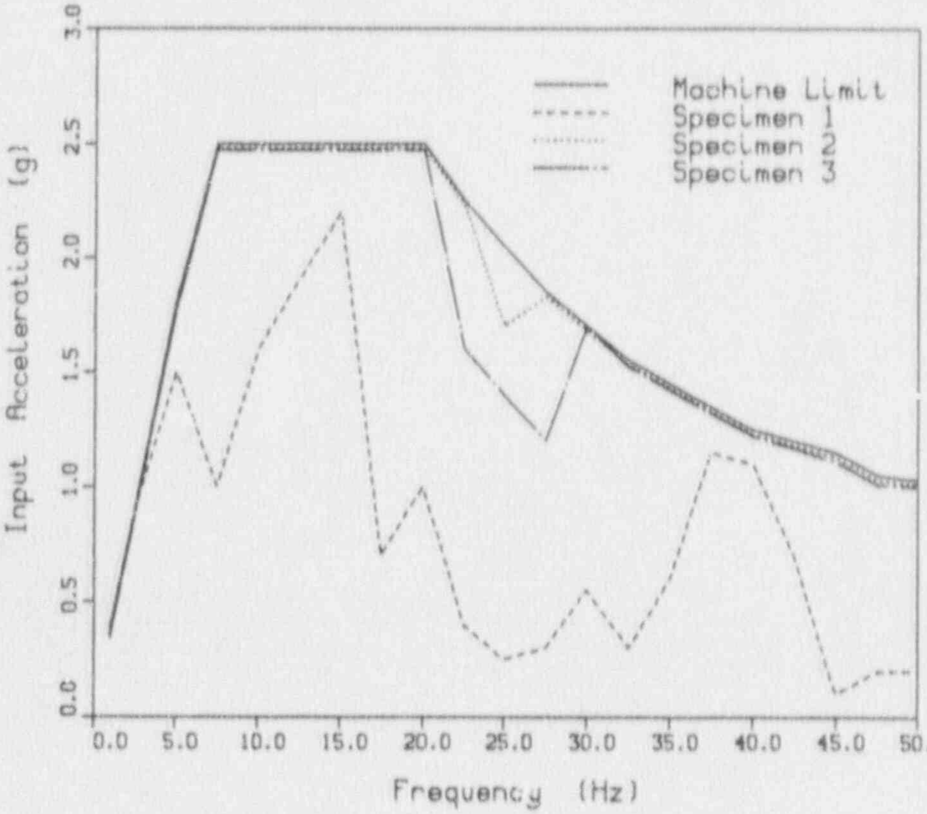

Figure 3.50 Comparison of Specimen Capacities - HMA124
Sine Dwell Amplitude, SS Direction
Nonoperating Mode, NC Contact

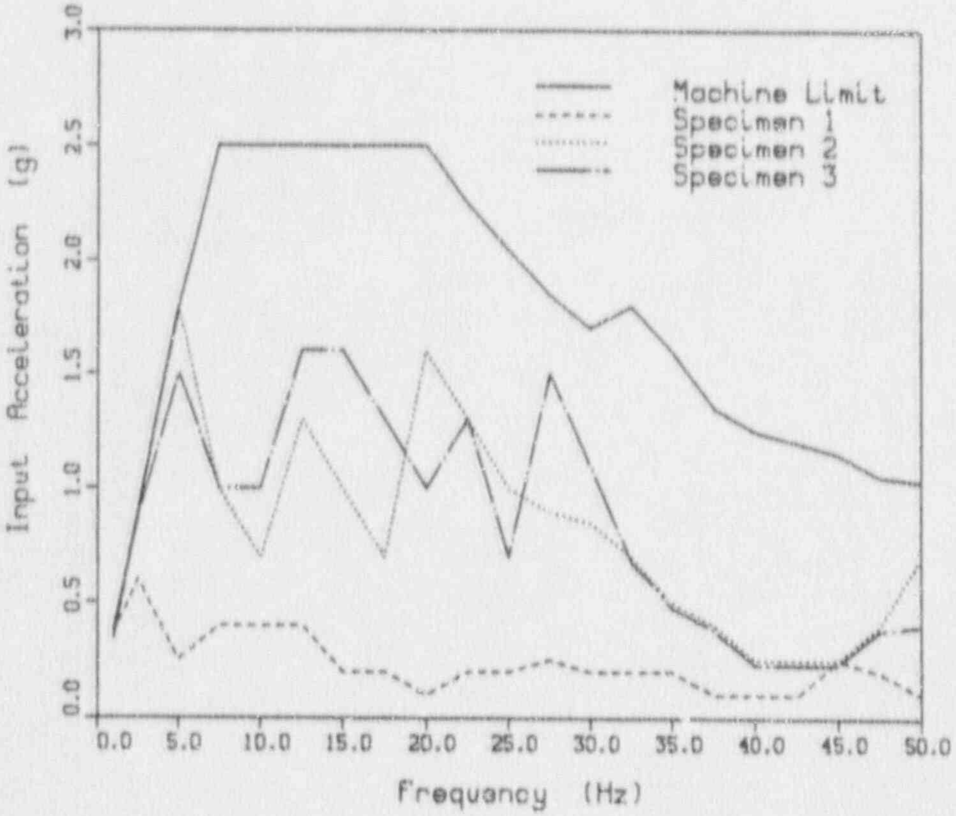

Figure 3.51 Comparison of Specimen Capacities - HMA124
Sine Dwell Amplitude, V Direction
Nonoperating Mode, NC Contact

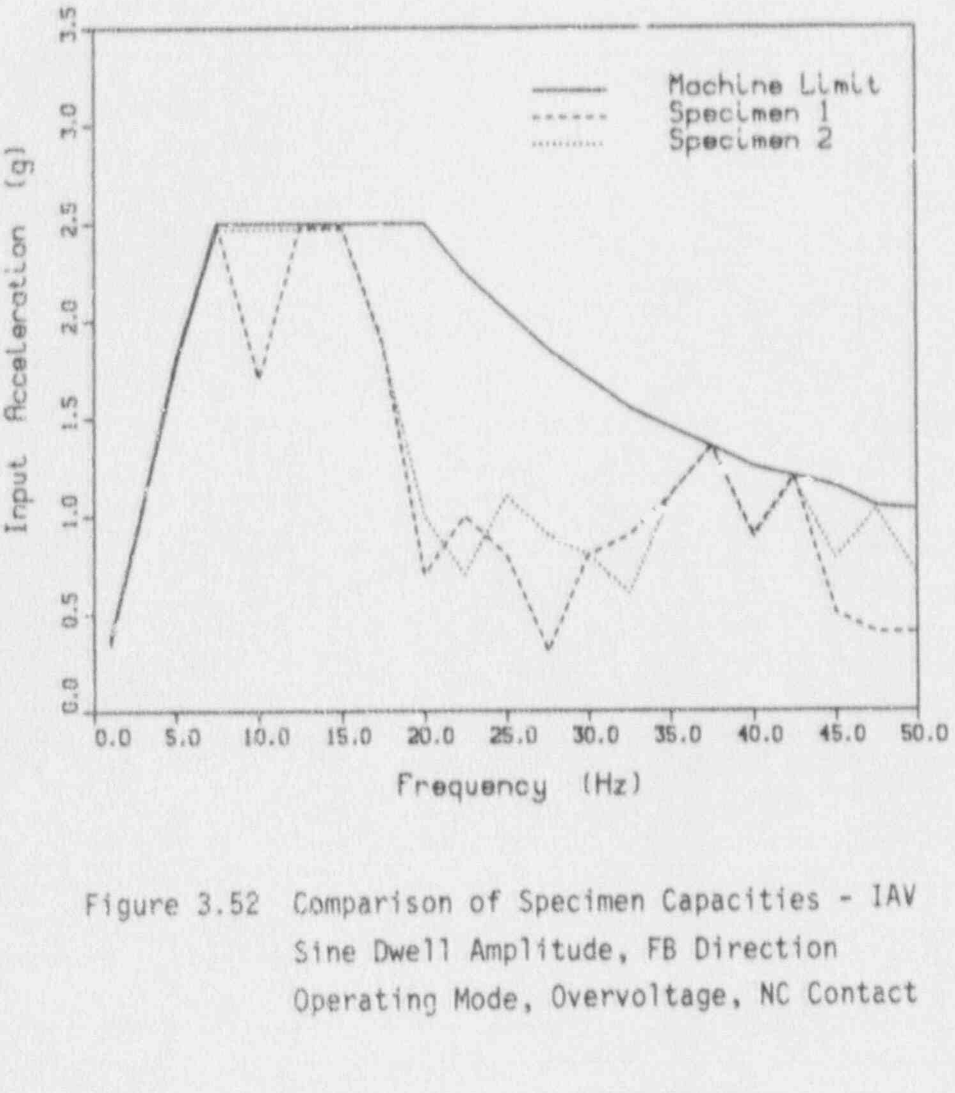

Figure 3.52 Comparison of Specimen Capacities - IAV
Sine Dwell Amplitude, FB Direction
Operating Mode, Overvoltage, NC Contact

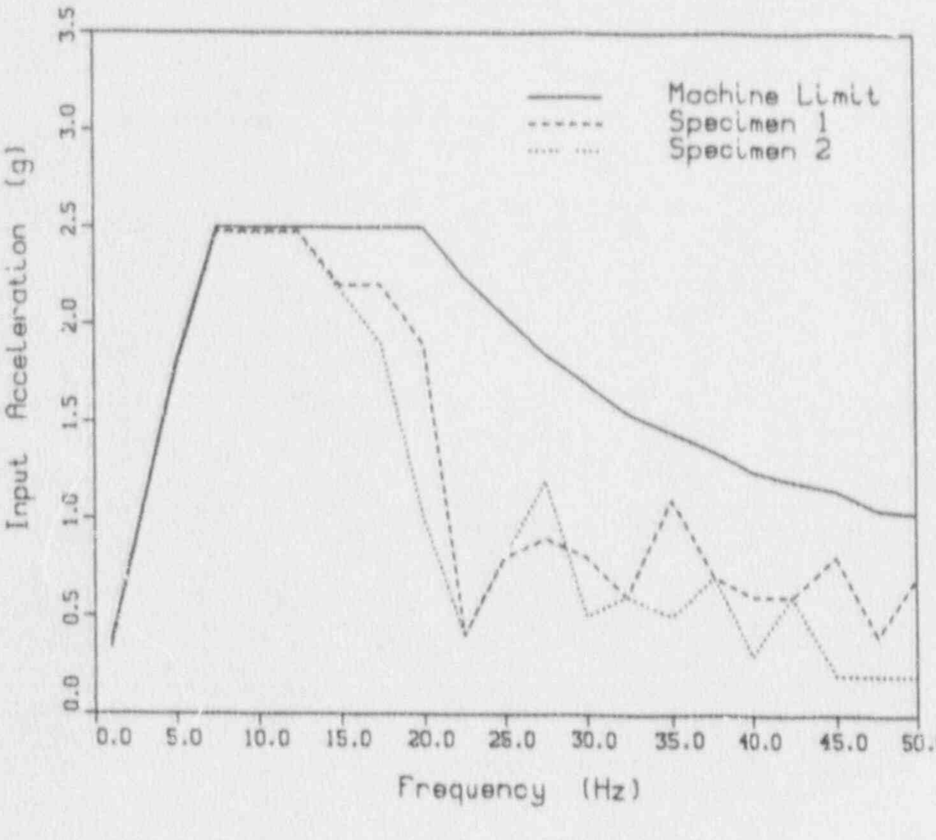

Figure 3.53 Comparison of Specimen Capacities - IAV Sine Dwell Amplitude, SS Direction Operating Mode, Overvoltage, NC Contact

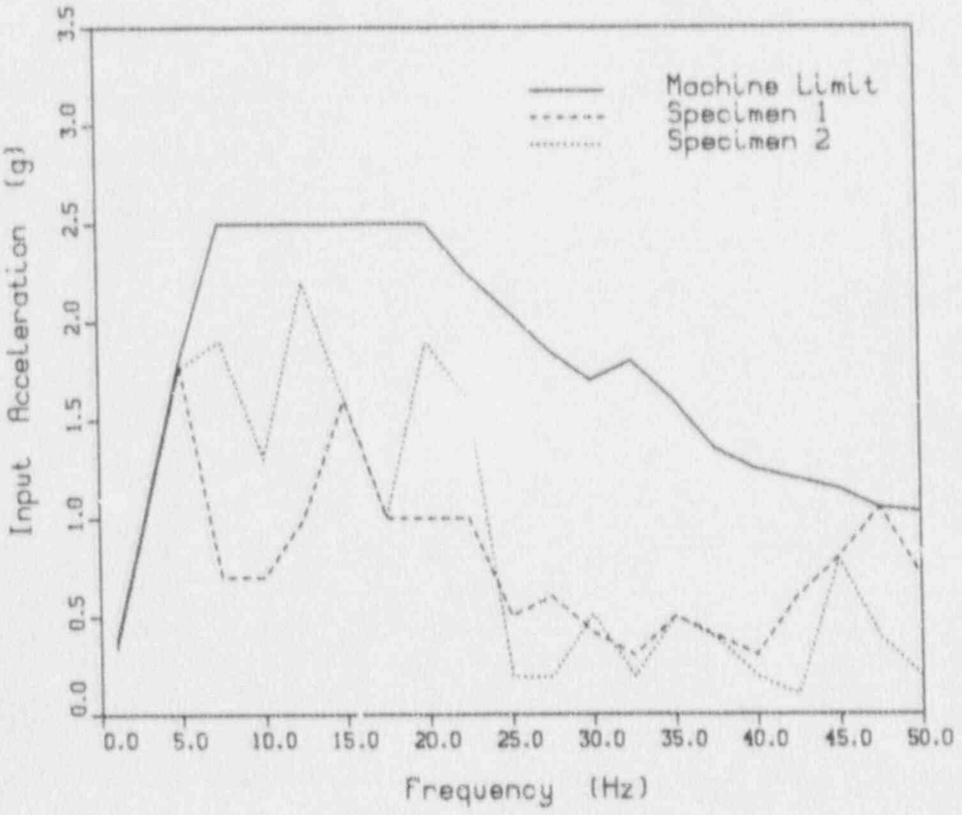

Figure 3.54 Comparison of Specimen Capacities - IAV Sine Dwell Amplitude, V Direction Operating Mode, Overvoltage, NC Contact

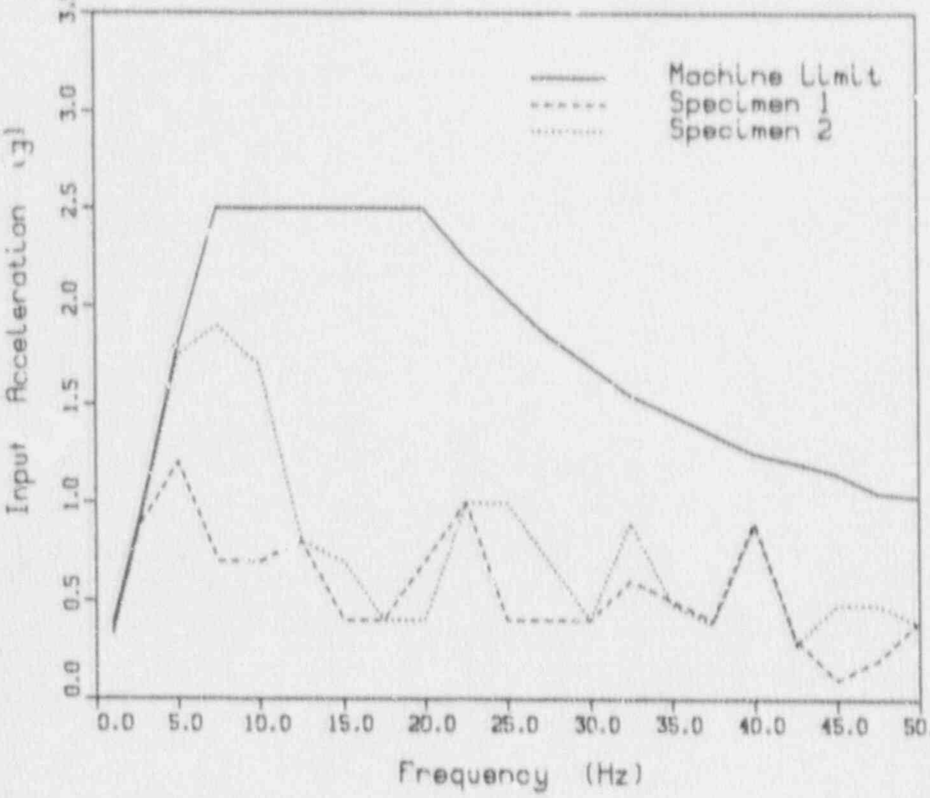

Figure 3.55 Comparison of Specimen Capacities - IAV
Sine Dwell Amplitude, FB Direction
Operating Mode, Undervoltage, NO Contact

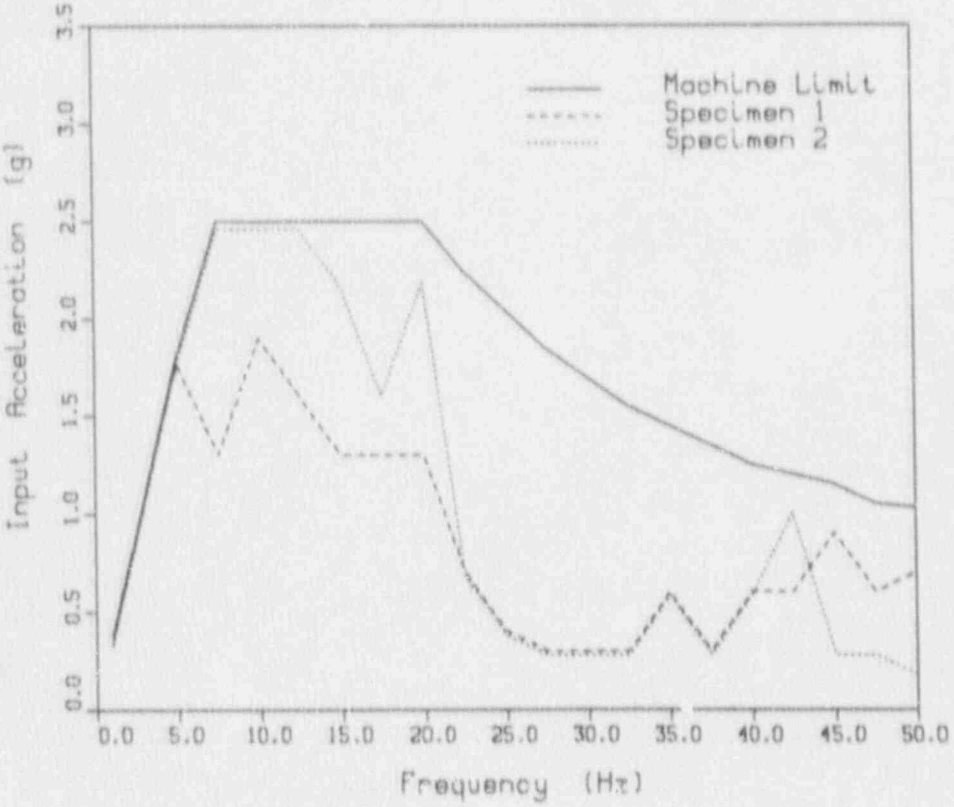

Figure 3.56 Comparison of Specimen Capacities - IAV Sine Dwell Amplitude, SS Direction Operating Mode, Undervoltage, NO Contact

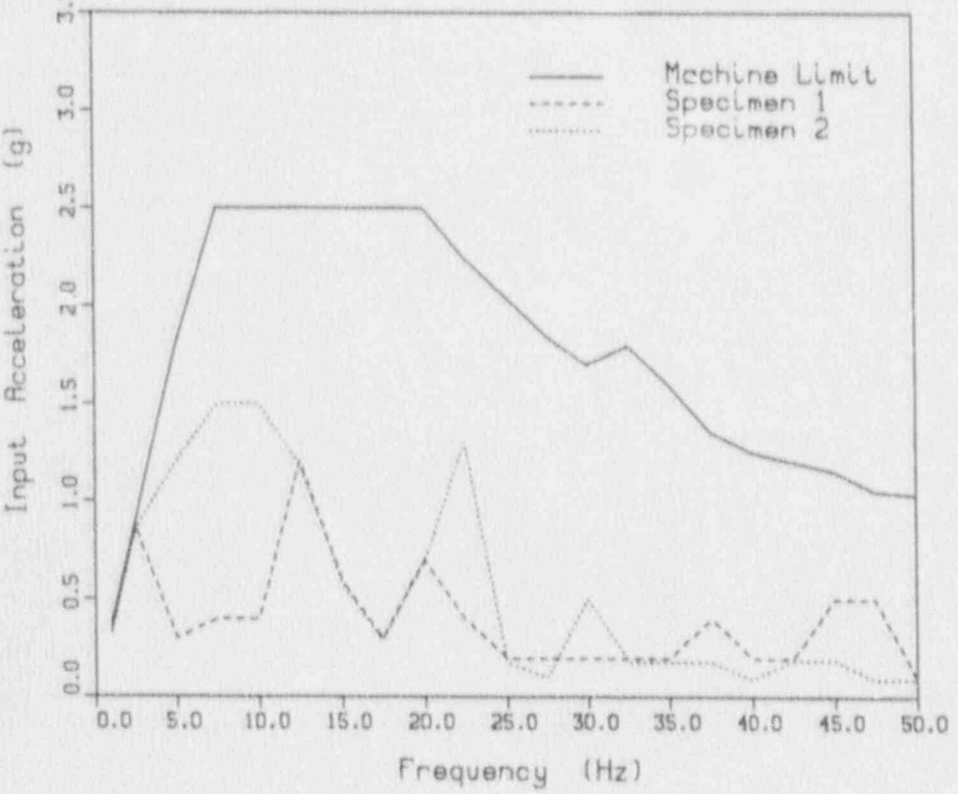

Figure 3.57 Comparison of Specimen Capacities - IAV
Sine Dwell Amplitude, V Direction
Operating Mode, Undervoltage, NO Contact

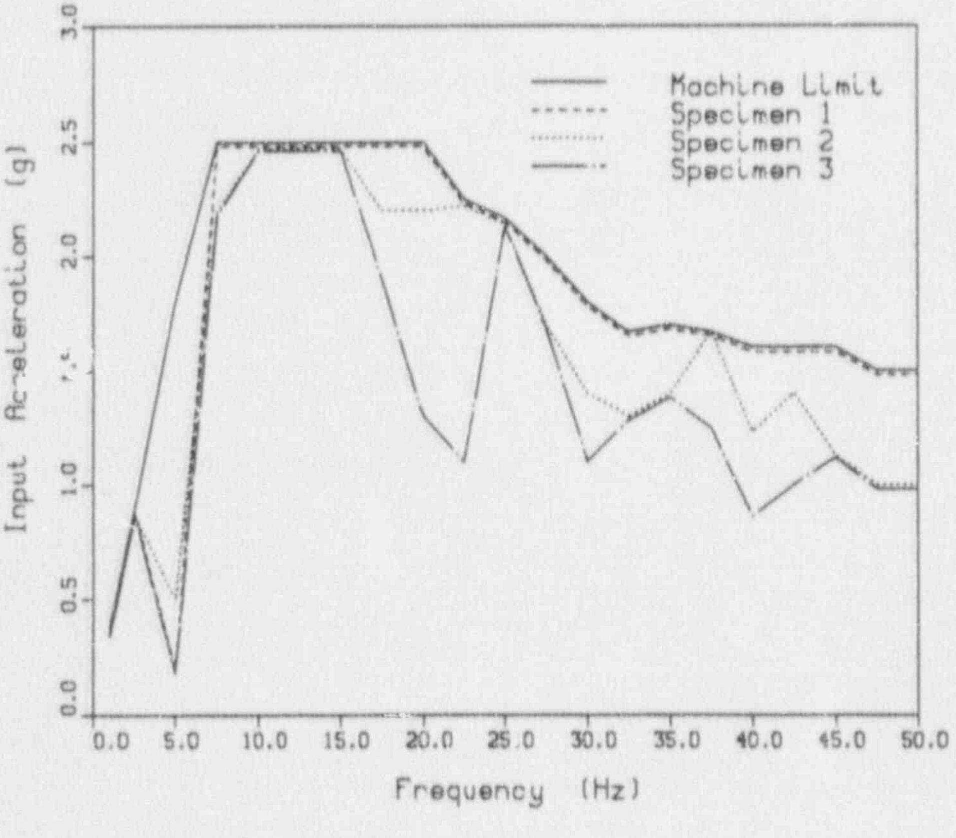

Figure 3.58 Comparison of Specimen Capacities - CO-6
Sine Dwell Amplitude, FB Direction
Operating Mode, CO Contact

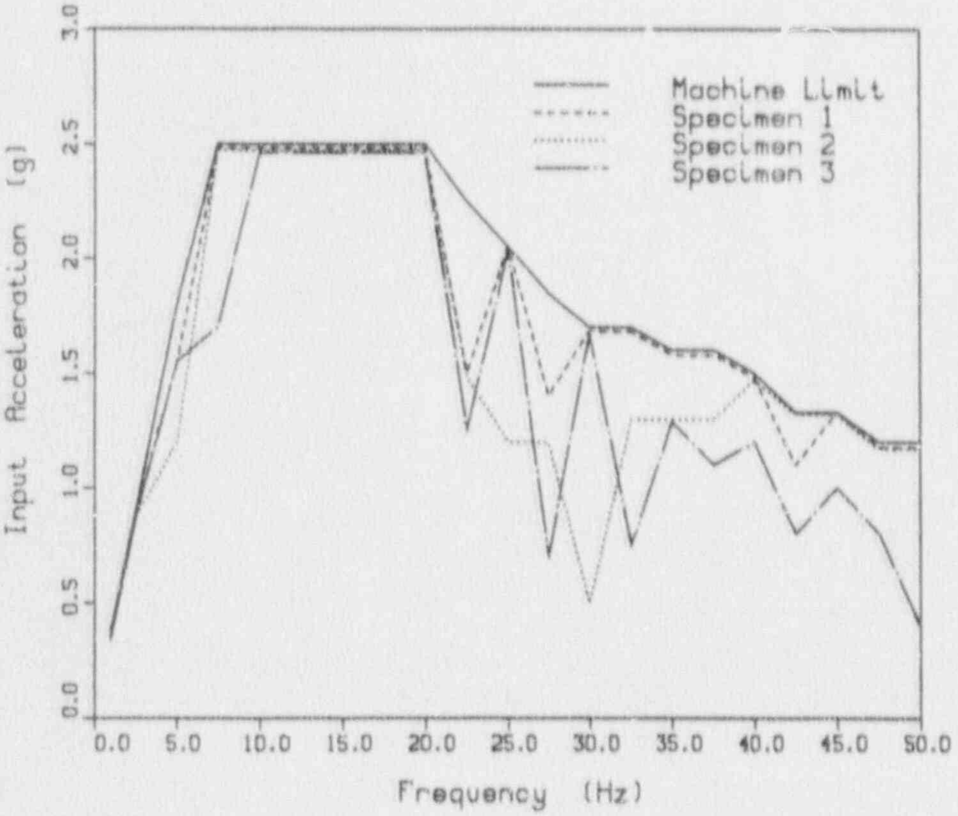

Figure 3.59 Comparison of Specimen Capacities - CO-6
Sine Dwell Amplitude, SS Direction
Operating Mode, CO Contact

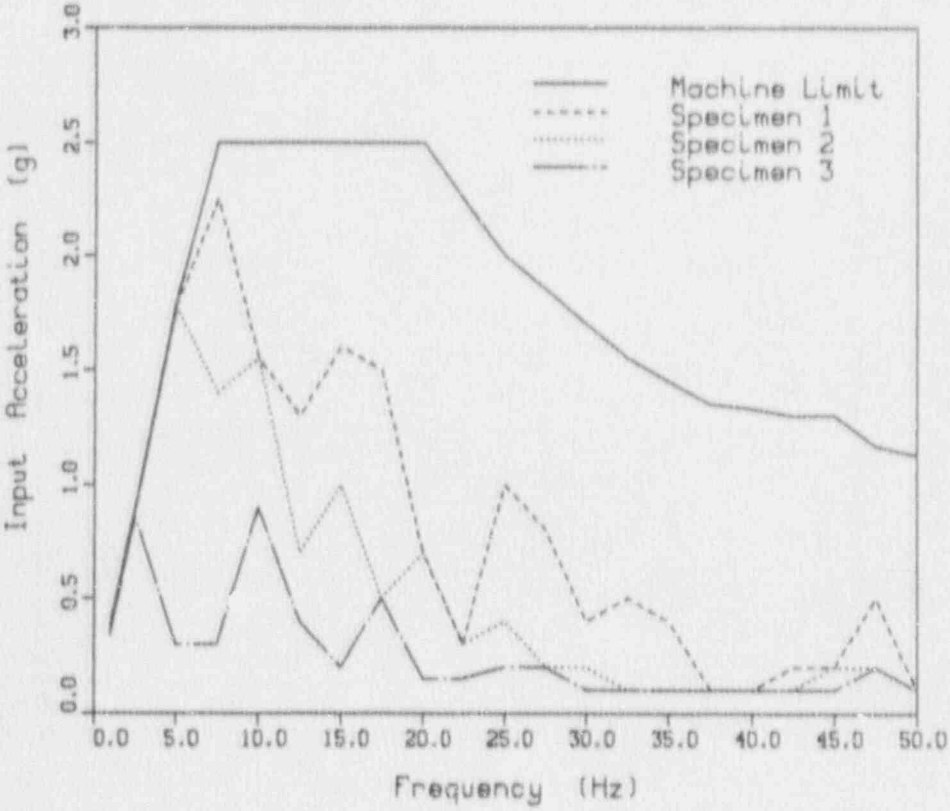

Figure 3.60 Comparison of Specimen Capacities - CO-6
Sine Dwell Amplitude, V Direction
Operating Mode, CO Contact

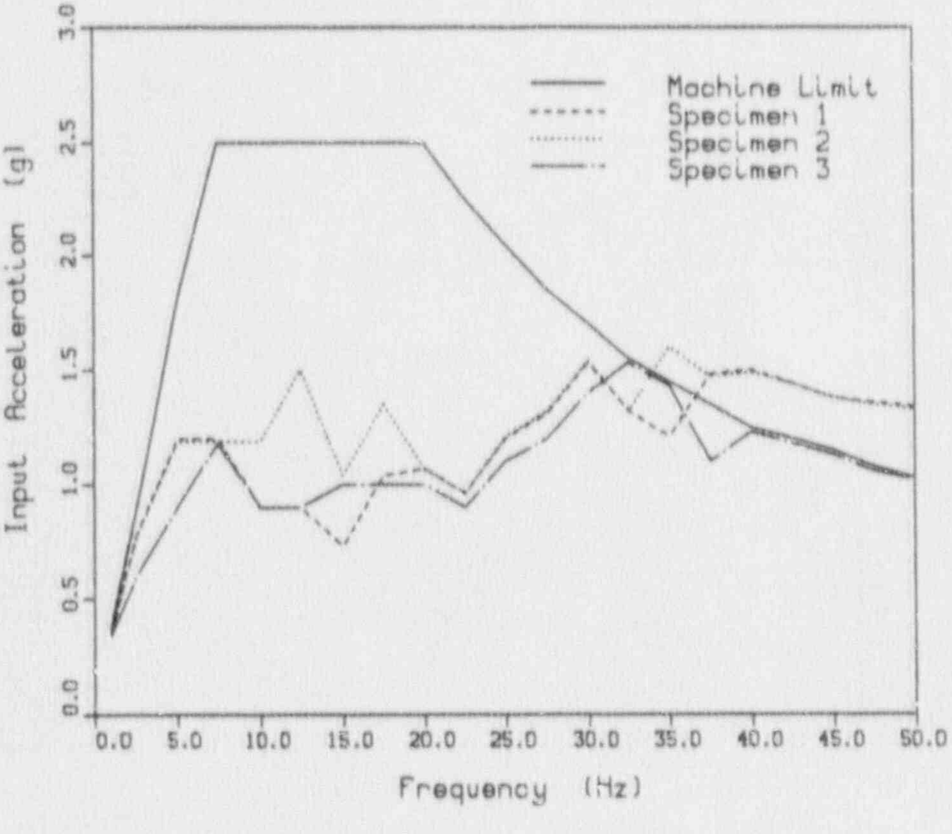

Figure 3.61 Comparison of Specimen Capacities - SG Sine Dwell Amplitude, FB Direction Nonoperating Mode, NC Contact

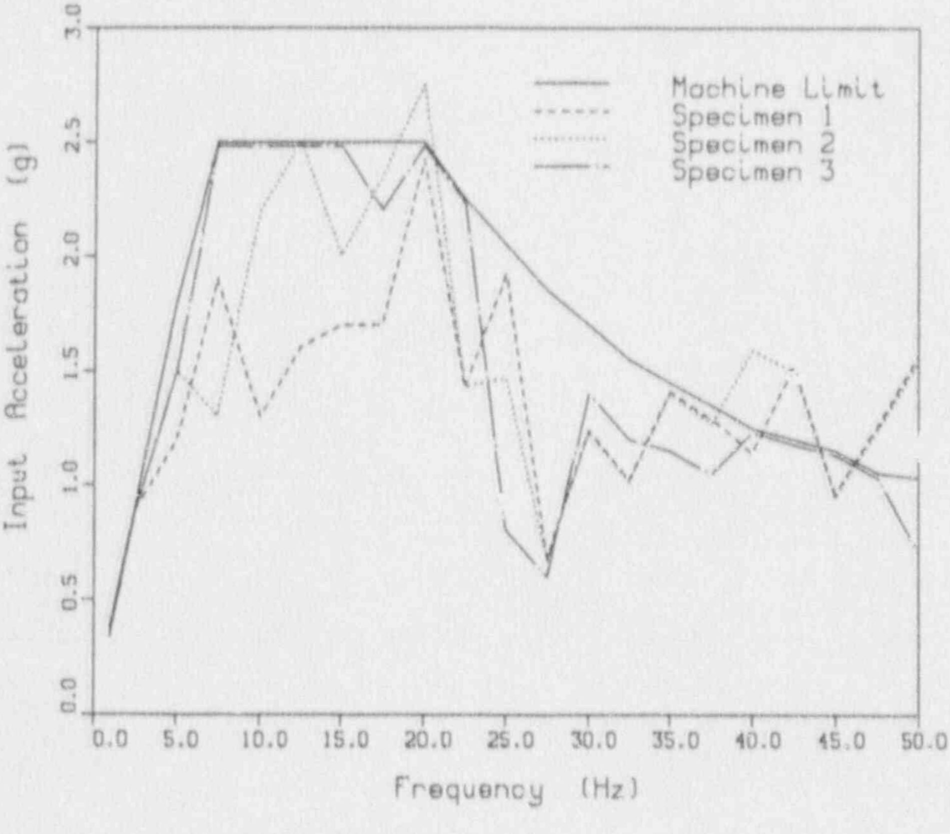

Figure 3.62 Comparison of Specimen Capacities - SG Sine Dwell Amplitude, SS Direction Nonoperating Mode, NC Contact

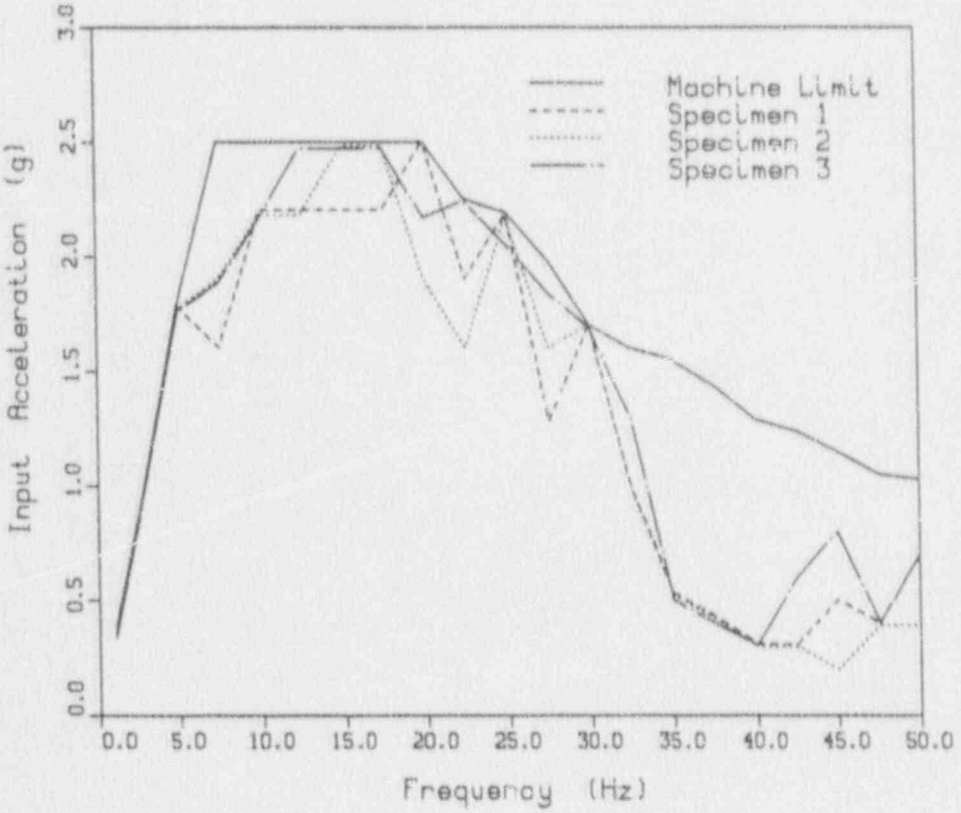

Figure 3.63 Comparison of Specimen Capacities - SG
Sine Dwell Amplitude, V Direction
Nonoperating Mode, NC Contact

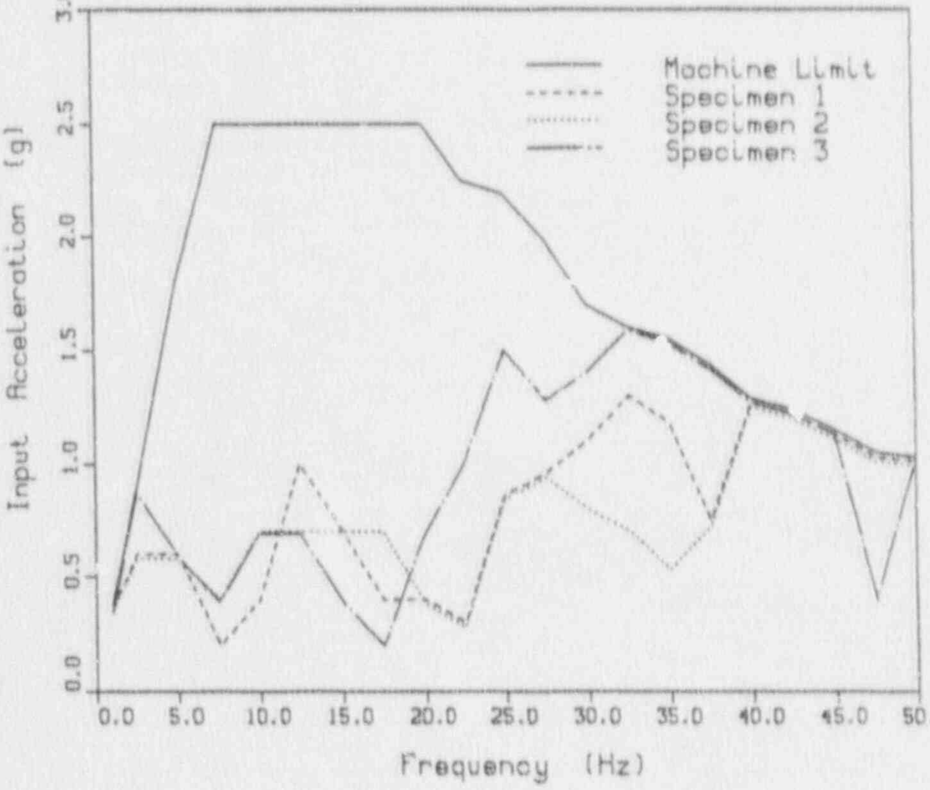

Figure 3.64 Comparison of Specimen Capacities - SC
Sine Dwell Amplitude, V Direction
Nonoperating Mode, NC Contact

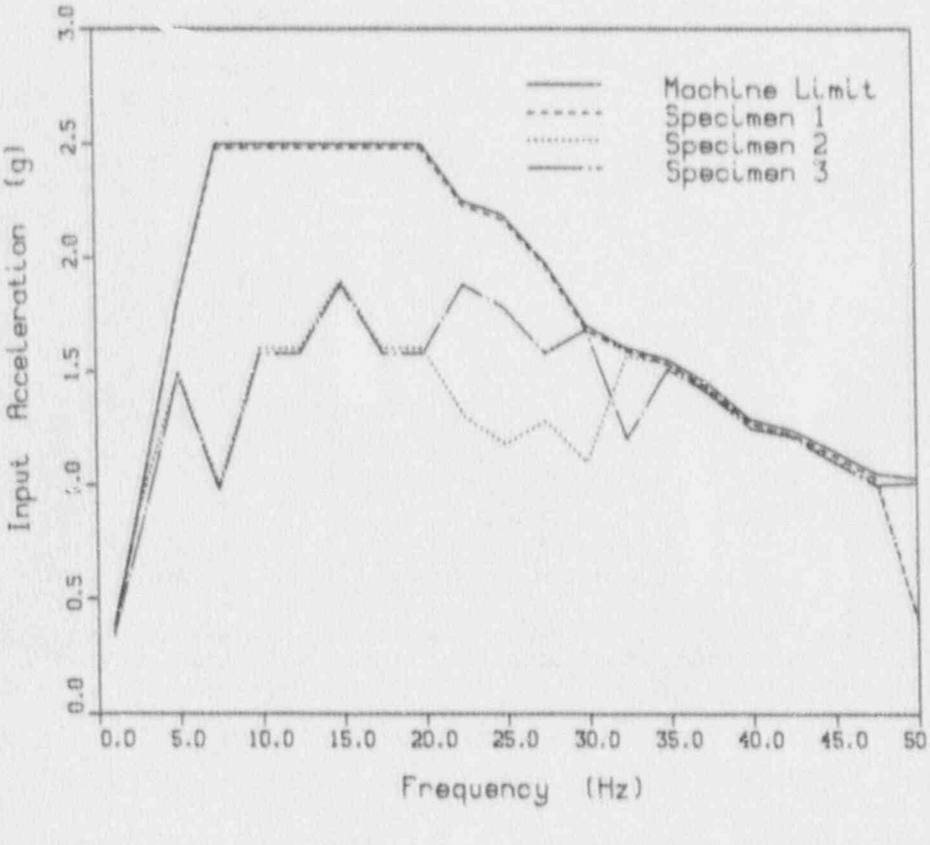

Figure 3.65 Comparison of Specimen Capacities - SC
Sine Dwell Amplitude, V Direction
Operating Mode, NO Contact

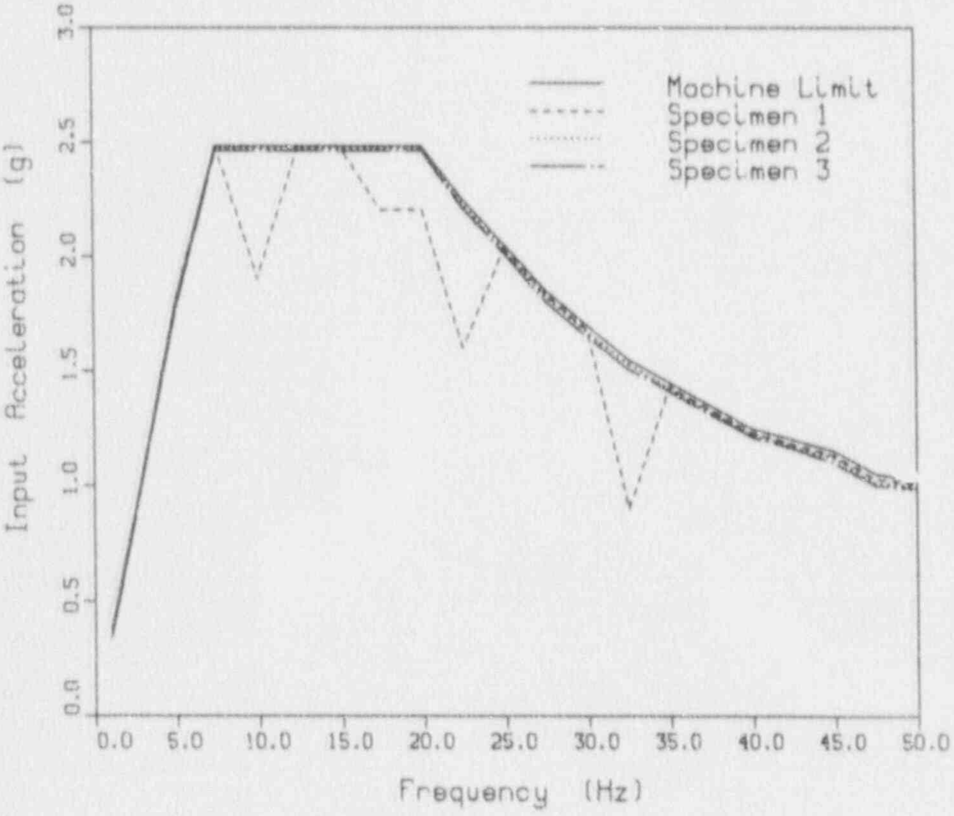

Figure 3.66 Comparison of Specimen Capacities - SVF Sine Dwell Amplitude, SS Direction Nonoperating Mode, NC Contact

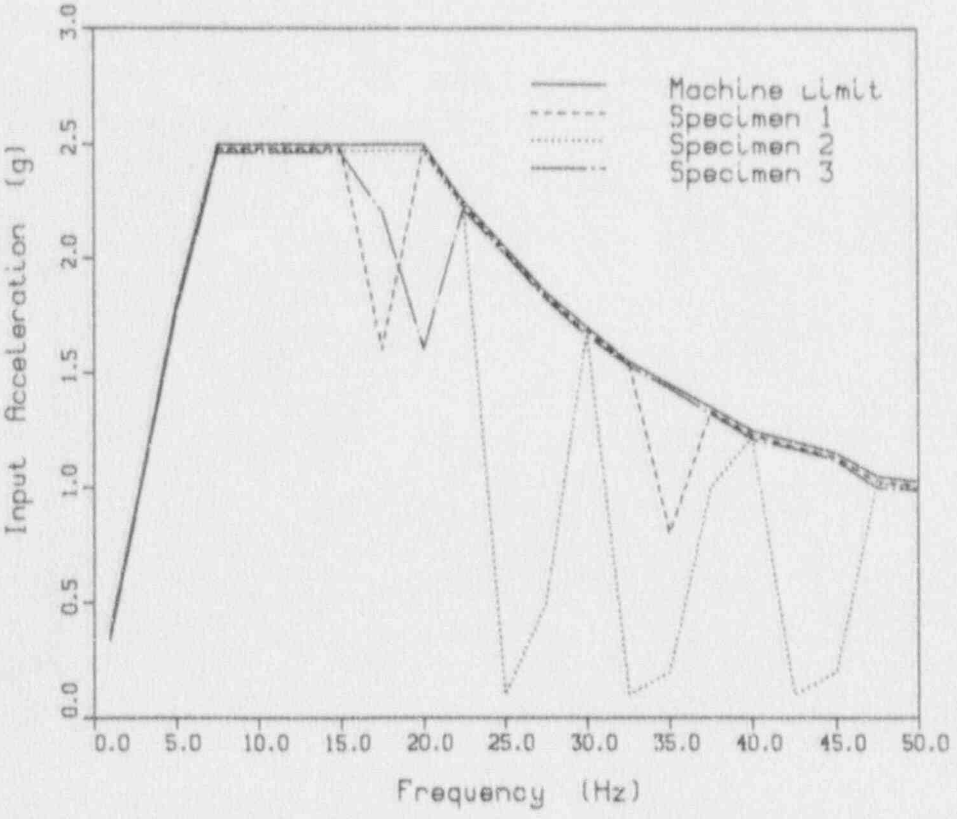

Figure 3.67 Comparison of Specimen Capacities - SVF
Sine Dwell Amplitude, SS Direction
Operating Mode, NC Control

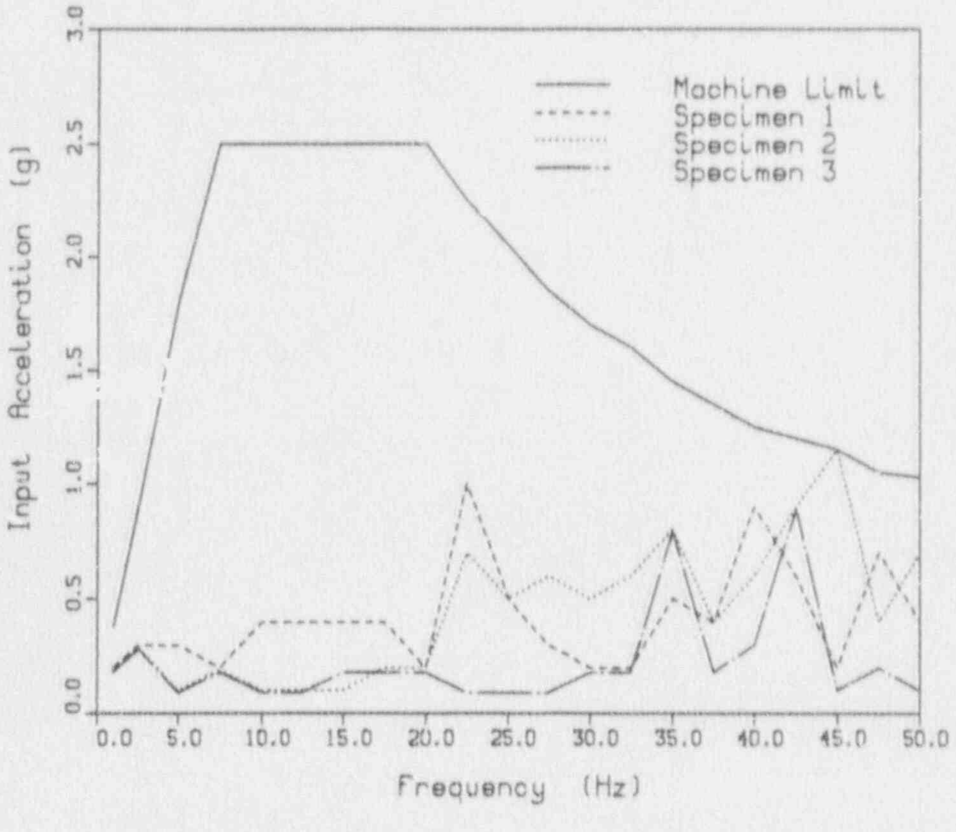

Figure 3.68 Comparison of Specimen Capacities - SVF Sine Dwell Amplitude, V Direction Operating Mode, NC Control

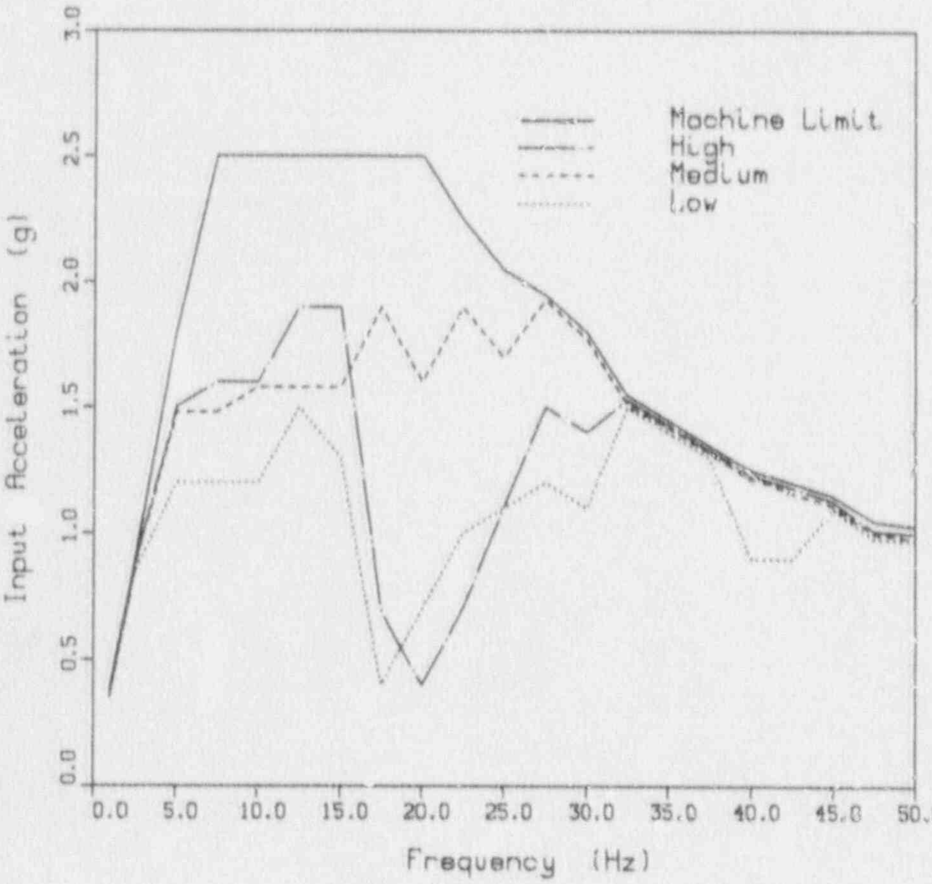

Figure 3.69 Influence of Spring Tension Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 1
FB Direction, Nonoperating Mode, NC Contact

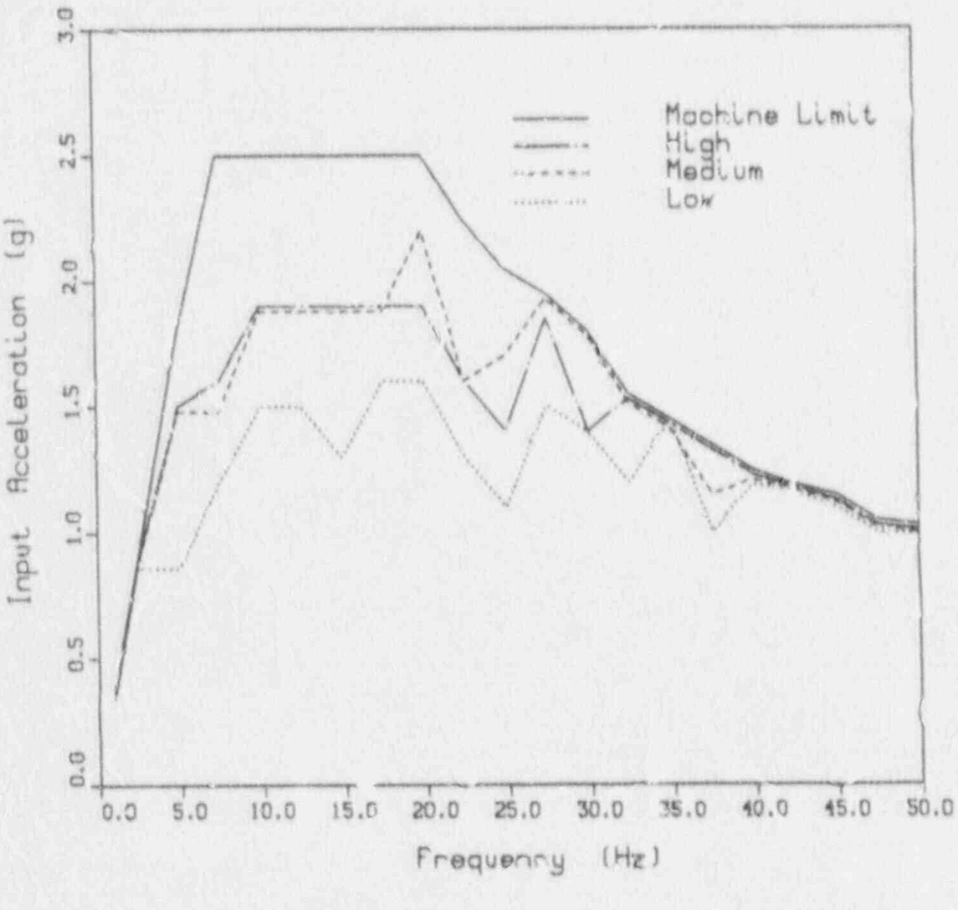

Figure 3.70 Influence of Spring Tension Adjustment
Sine Dwell Capacity Level, HFA51, Speciman 2
FB Direction, Nonoperating Mode, NC Contact

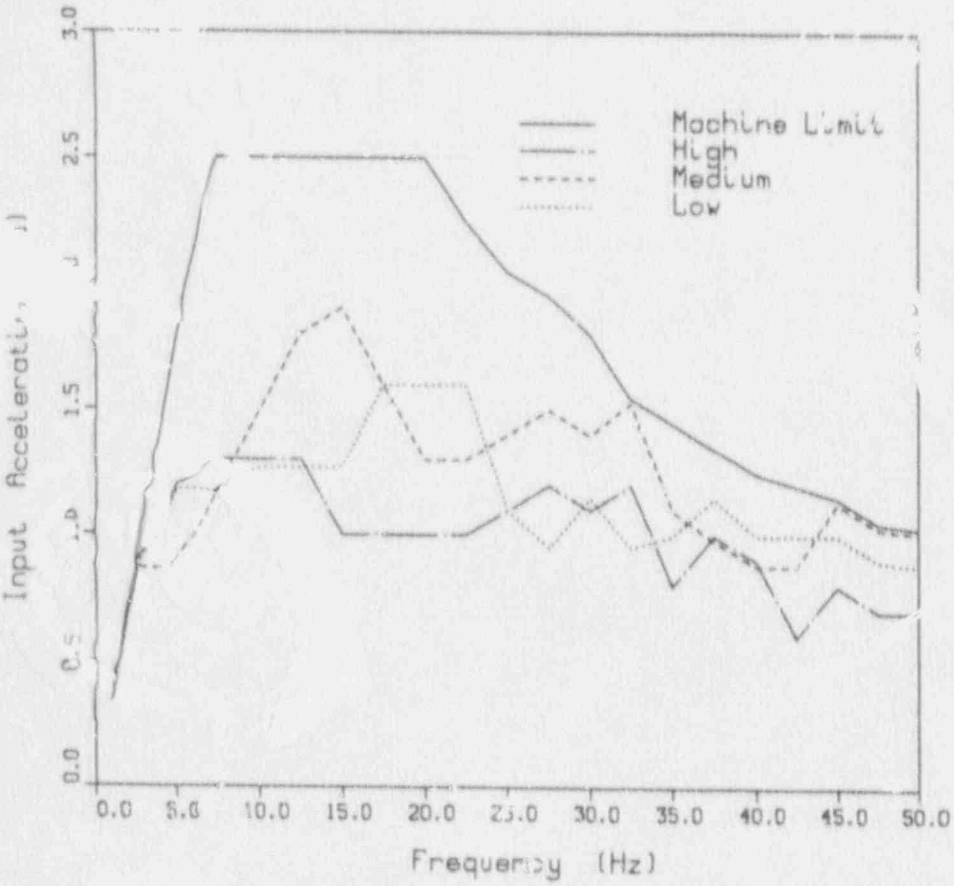

Figure 3.71 Influence of Spring Tension Adjustment
Sine [illegible] Capacity Level, HFA51, Specimen 3
FB Direction, Nonoperating Mode, NC Contact

and 0.7g). The results for Specimen 3 (Figure 3.71) is more surprising since the relay capacity at the medium tension setting is greater than that at the higher setting at most frequencies. Similar results are also observed in the vertical direction (Figures 3.72, 3.73 and 3.74).

The MG-6 relays were successfully tested to the machine limit at the factory setting. At alternate tension settings, two of the three specimens did not exhibit any anomaly up to the machine limit. Therefore, the effect of spring tension setting could not be established for these two specimens due to the limitation of the shake table capacity. However, the third specimen showed a sharp drop in its capacity level (from machine limit 1.0-2.5g to 0.2-0.3g) at all frequencies. The explanation for this behavior requires further investigation.

In summary, the effect of a change of spring tension setting on the capacity level can be from moderate to substantial. It appears that each relay specimen (and not just the model name) has an optimum tension setting at each frequency at which it performs best and outside this setting range, whether higher or lower, the capacity level drops. However, further investigation is required in order to exactly relate the change in the relay capacities with the spring tension settings and the vibration frequencies.

3.2.6.2 Contact Gap Adjustment

Similar to the spring tension adjustment results discussed above, the variation of the relay capacities due to contact gap settings was also not consistent as shown in Figures 3.75, 3.76 and 3.77. The capacity with the medium contact gap appears to be the highest at most frequencies in the FB direction. Two of the three HFA51 relays tend to indicate that capacity level increases with reduction of the contact gap (Figures 3.76 and 3.77). But the exceptions are so many that no general conclusion can be drawn from the test data (e.g., Figure 3.75, at 20Hz the capacities corresponding to the large, medium and small gap settings are respectively 1.0g, 1.6g and 0.7g) . The results in the vertical direction as shown in Figures 3.78, 3.79 and 3.80 also indicate similar frequency-dependent variation.

For the MG-6 relays, the effect of contact gap adjustment could not be verified from the results of the first two specimens since they were tested to the shake limit successfully at all three settings. The third specimen showed a reduction of more than 40% at a few frequencies (7.5, 10, 17.5 and 20Hz) when tested at the lower gap setting.

In summary, the effect of contact gap adjustment can be substantial. Each relay specimen appears to have an optimum contact gap for best performance at a given frequency. Further research is needed to determine the exact relation among the relay capacity, contact gap and the vibration frequency.

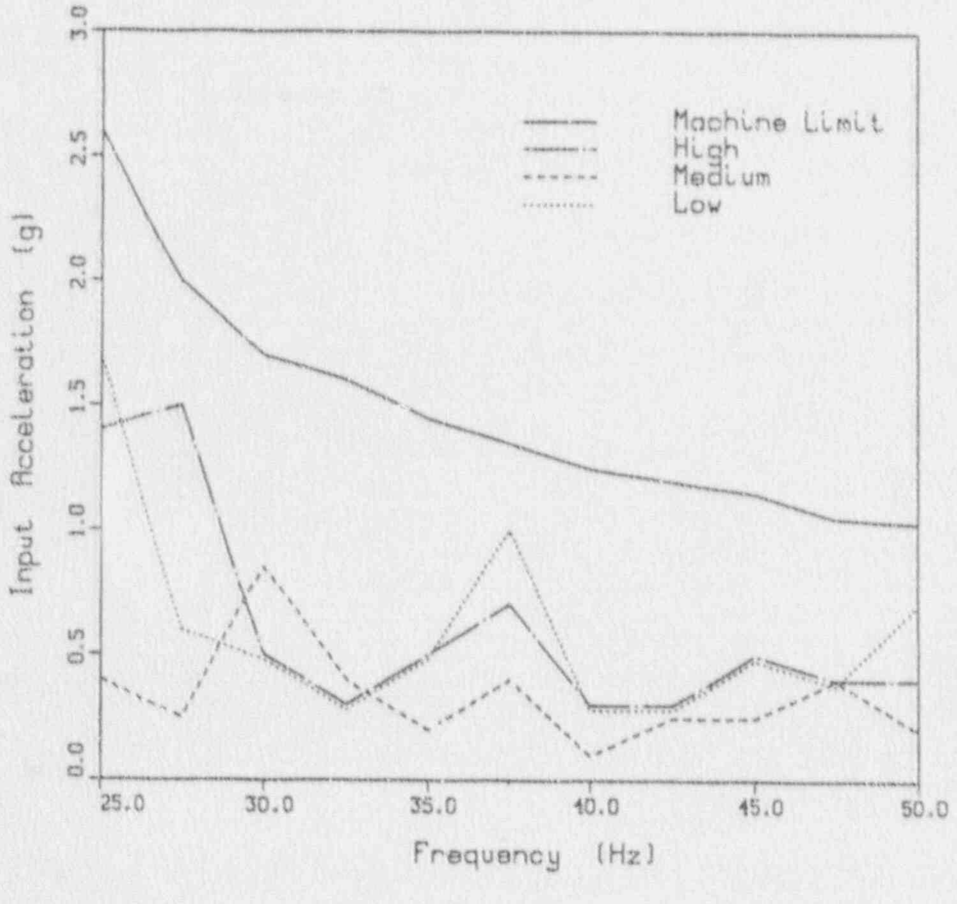

Figure 3.72 Influence of Spring Tension Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 1
V Direction, Nonoperating Mode, NC Contact

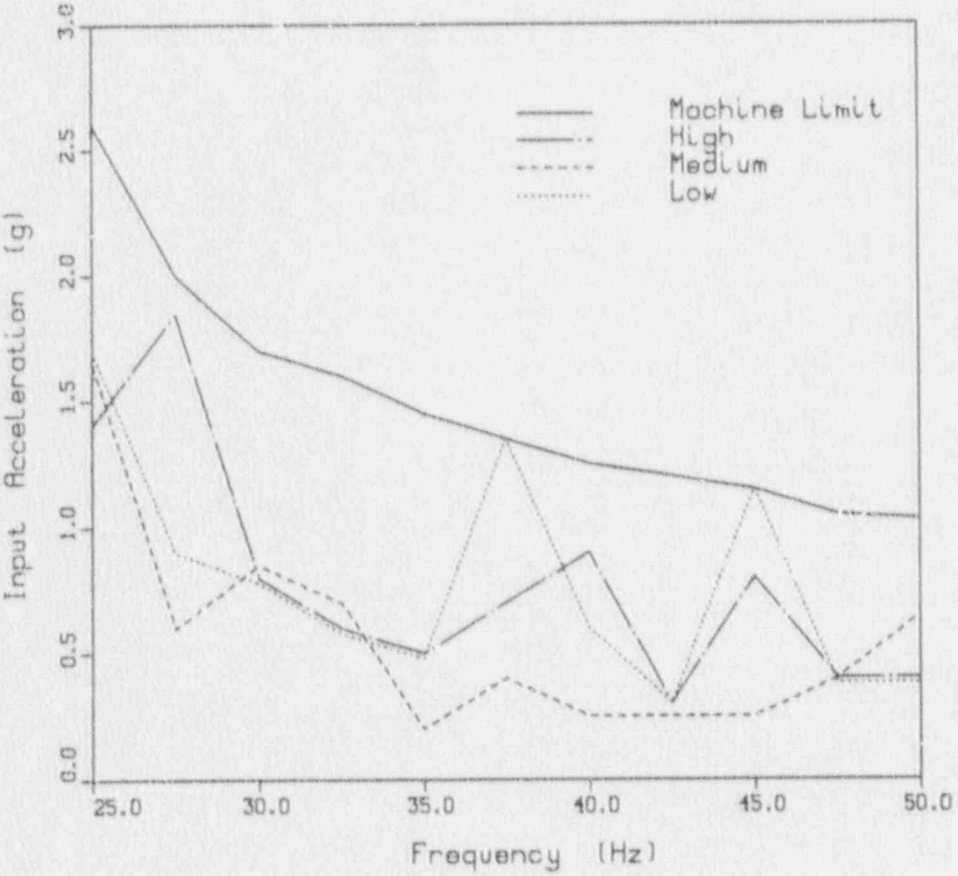

Figure 3.73 Influence of Spring Tension Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 2
V Direction, Nonoperating Mode, NC Contact

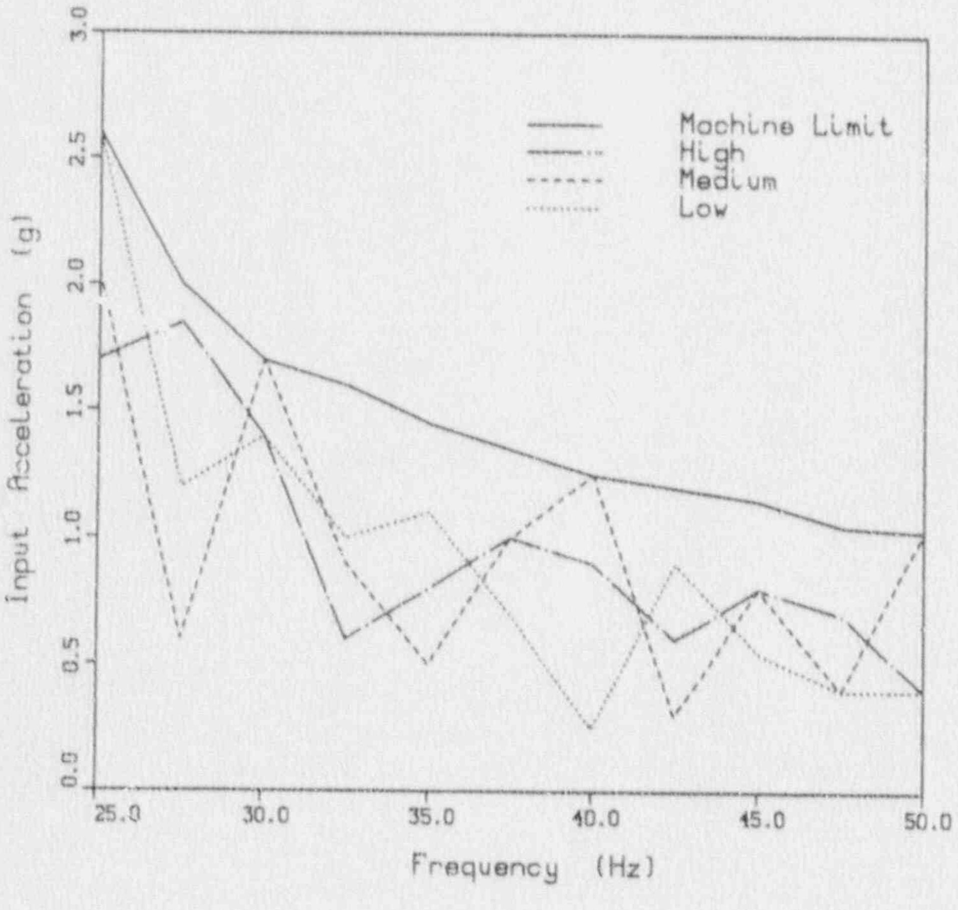

Figure 3.74 Influence of Spring Tension Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 3
V Direction, Nonoperating Mode, NC Contact

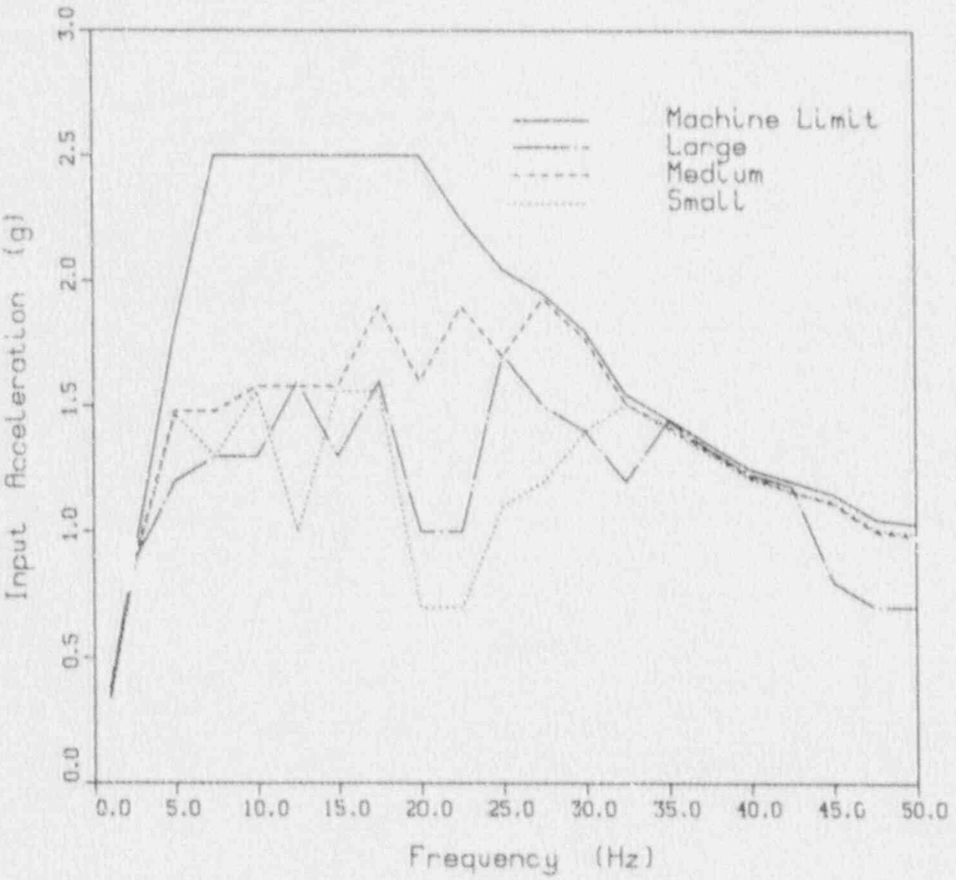

Figure 3.75 Influence of Contact Gap Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 1
FP [illegible]tion, Nonoperating Mode, NC Contact

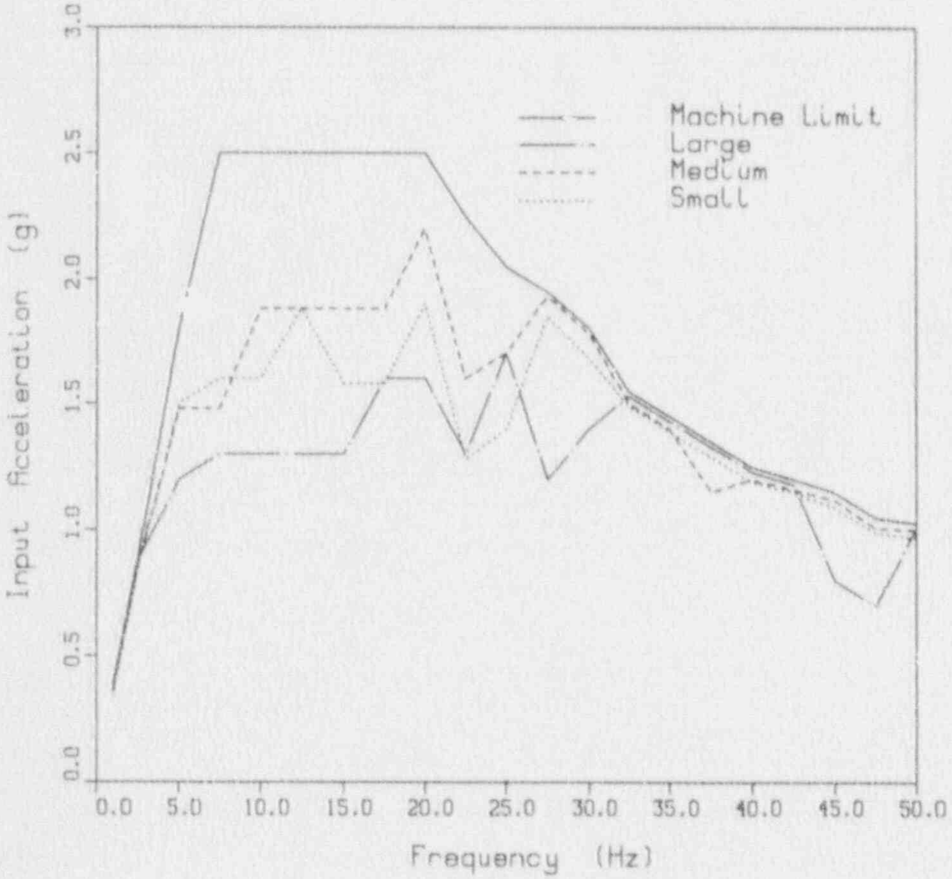

Figure 3.76 Influence of Contact Gap Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 2
FB Direction, Nonoperating Mode, NC Contact

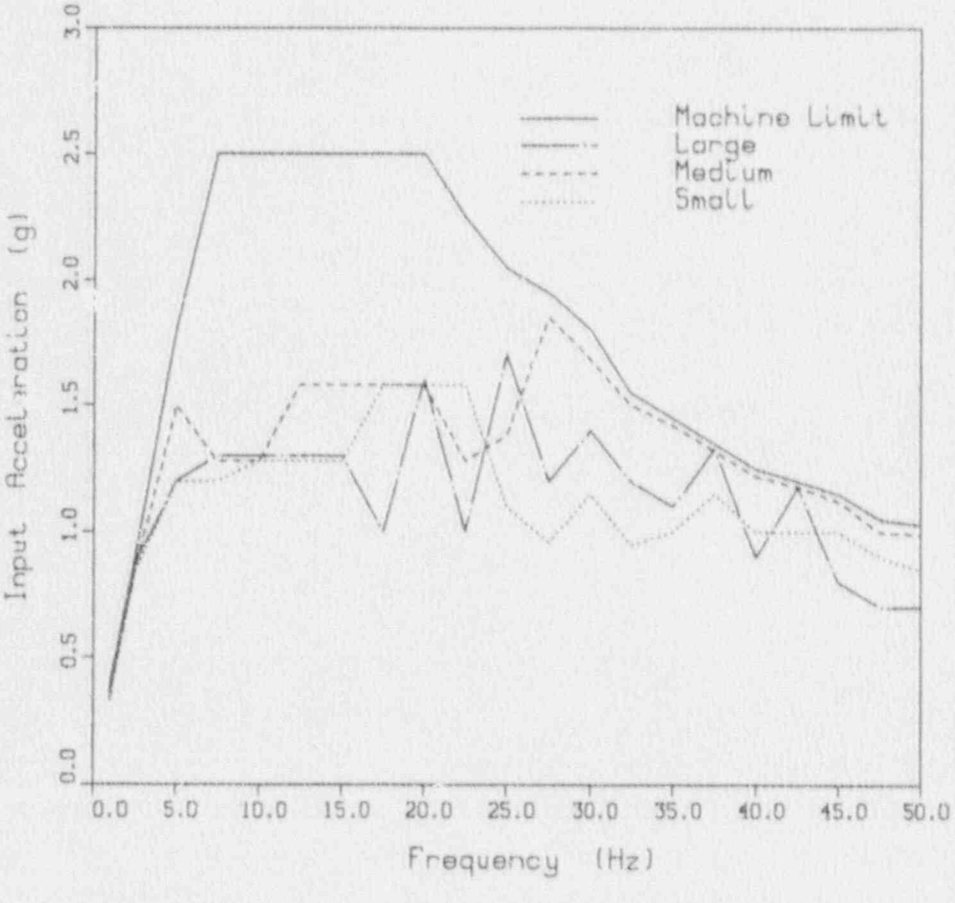

Figure 3.77 Influence of Contact Gap Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 3
FB Direction, Nonoperating Mode, NC Contact

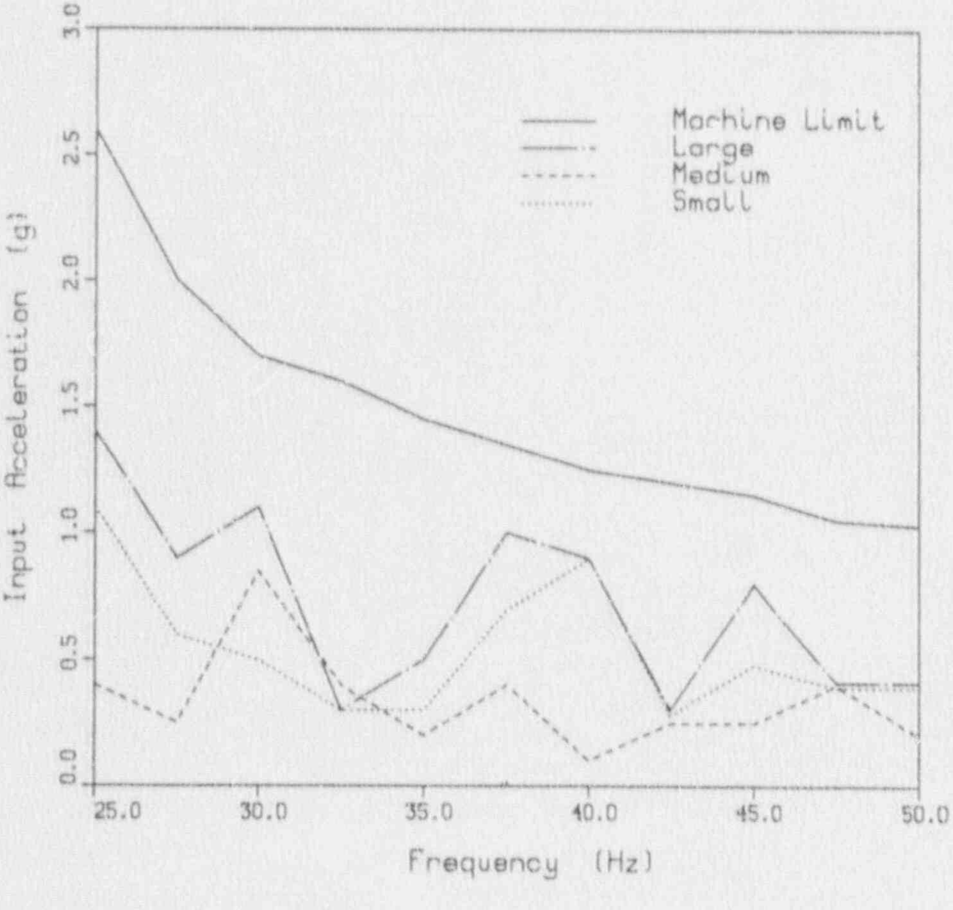

Figure 3.78 Influence of Contact Gap Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 1
V Direction, Nonoperating Mode, NC Contact

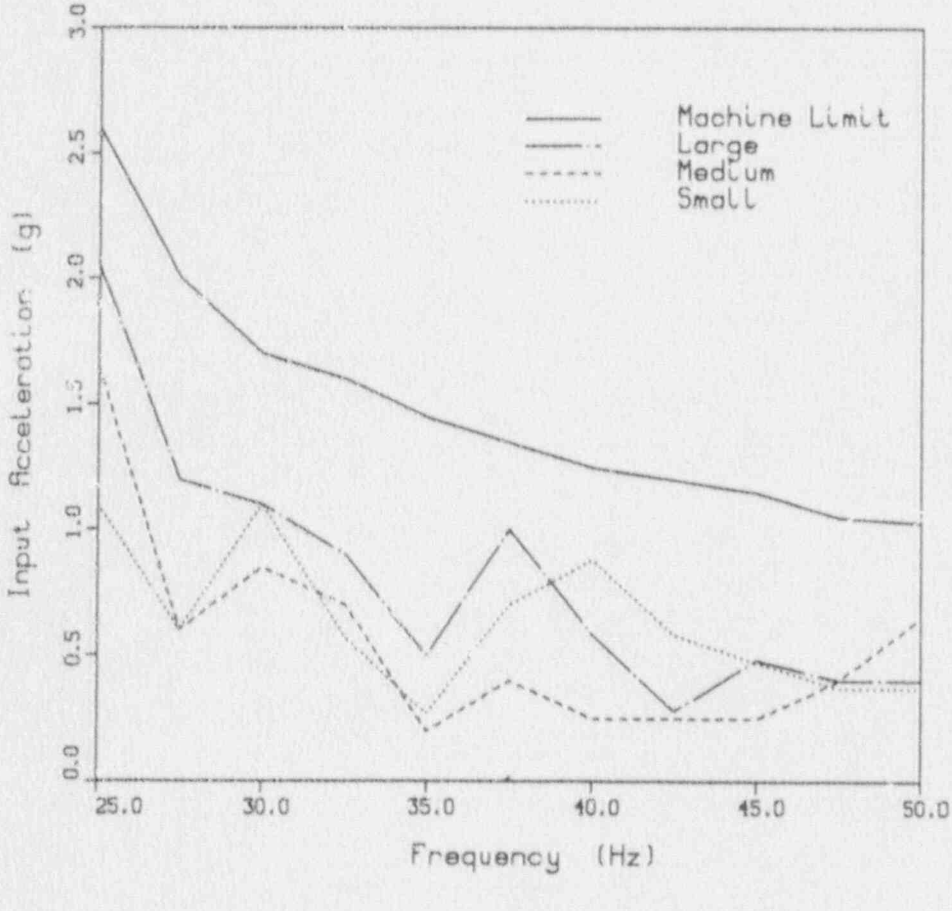

Figure 3.79 Influence of Contact Gap Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 2
V Direction, Nonoperating Mode, NC Contact

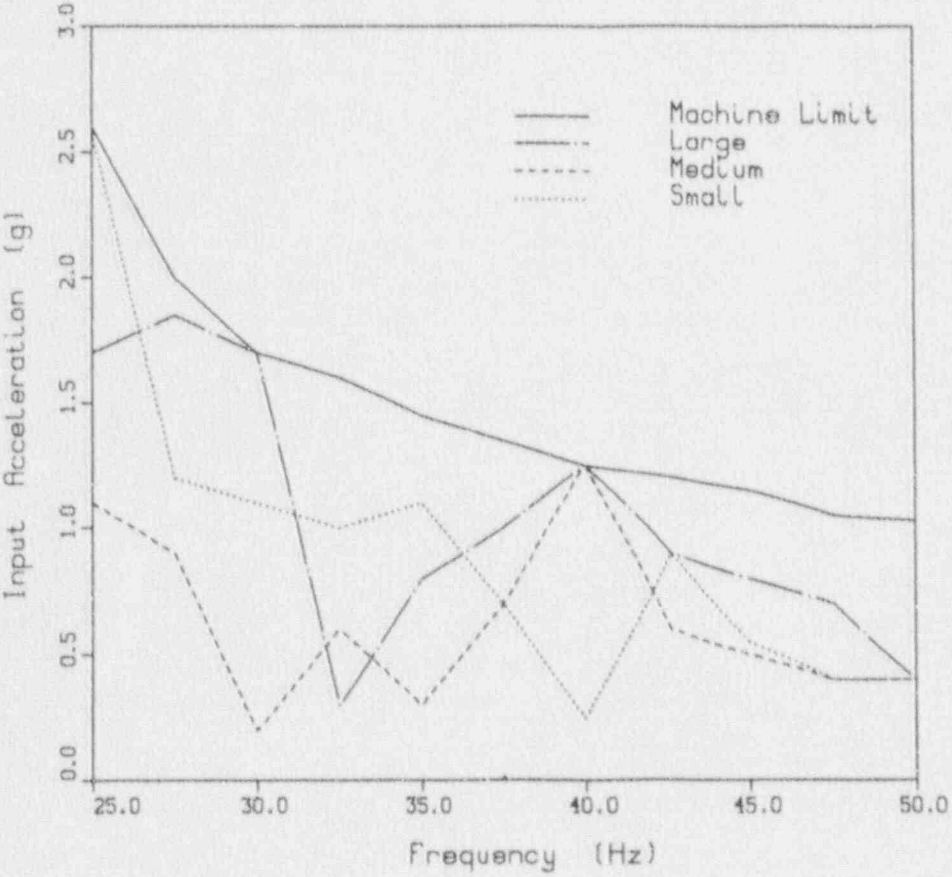

Figure 3.80 Influence of Contact Gap Adjustment
Sine Dwell Capacity Level, HFA51, Specimen 3
V Direction, Nonoperating Mode, NC Contact

3.2.6.3 End Play Adjustment

The test data of IAV and CO-6 relays at alternate positions of the rotary disks are shown in Figures 3.81 through 3.85. A strong effect of the end play adjustment was observed especially for one IAV relay (Figure 3.82, 0.7g, 1.5g and machine limit 2.5g at 10Hz). The amount of change of the capacity level varies with the frequency of vibration (e.g., in Figure 3.81 the capacity levels at positions 1 and 3 at 5Hz are respectively 0.3g and 1.5g whereas the levels are the same at 10Hz). The nature of the effect (i.e., increase or decrease of the capacity level) is usually consistent over the entire frequency range but it can also vary with frequency. For example, IAV Specimen 2 is much stronger at position 3 almost at all frequencies but CO-6 Specimen 1 at position 3 is stronger at 10Hz and weaker at 15Hz than at other positions. At high frequencies, one IAV relay exhibited a sustained change of state; however, it resumed normal function upon adjustment of the disk position back to the factory setting.

In summary, an adjustment of position of the disk of a rotary disk relay greatly influences the capacity level and the factory setting may not be the optimum setting at which the relay performs best. In addition, at some settings, a relay can suffer a sustained change of state.

3.2.7 Capacity Results by Model Number

The capacity of each relay model is discussed in this section. As mentioned earlier, the single frequency capacity level of each relay is presented in Figures 3.1 through 3.39. The same test data have been summarized and listed in Table 3-1. The individual characteristics of each relay model as observed from the single frequency test data are briefly highlighted as follows:

HFA151A (Figure 3.1)

The NC contacts in the nonoperating electrical mode governs the capacity level. The hinged armature operating mechanism can withstand about 1.0g sine dwell input across the frequency range (lowest 0.7g) in the FB direction. At higher frequencies, the relay is weaker in the vertical direction (average 0.6g, lowest 0.3g).

HFA151B (Figure 3.2)

The characteristics are very similar to the above HFA151A relay except that this one exhibited higher capacities (e.g., above 1.5g at low frequencies in the FB direction).

HFA154E (Figures 3.3 and 3.4)

Unlike the above two relays, in the nonoperating mode, this relay successfully withstood vibration up to the machine limit almost at all frequencies in all three directions. However, in the operating mode, the relay drops the latch and changes state at a much lower level (1.0-2.0g at low frequencies in FB and V directions; 0.7-0.9g at high frequencies in V direction).

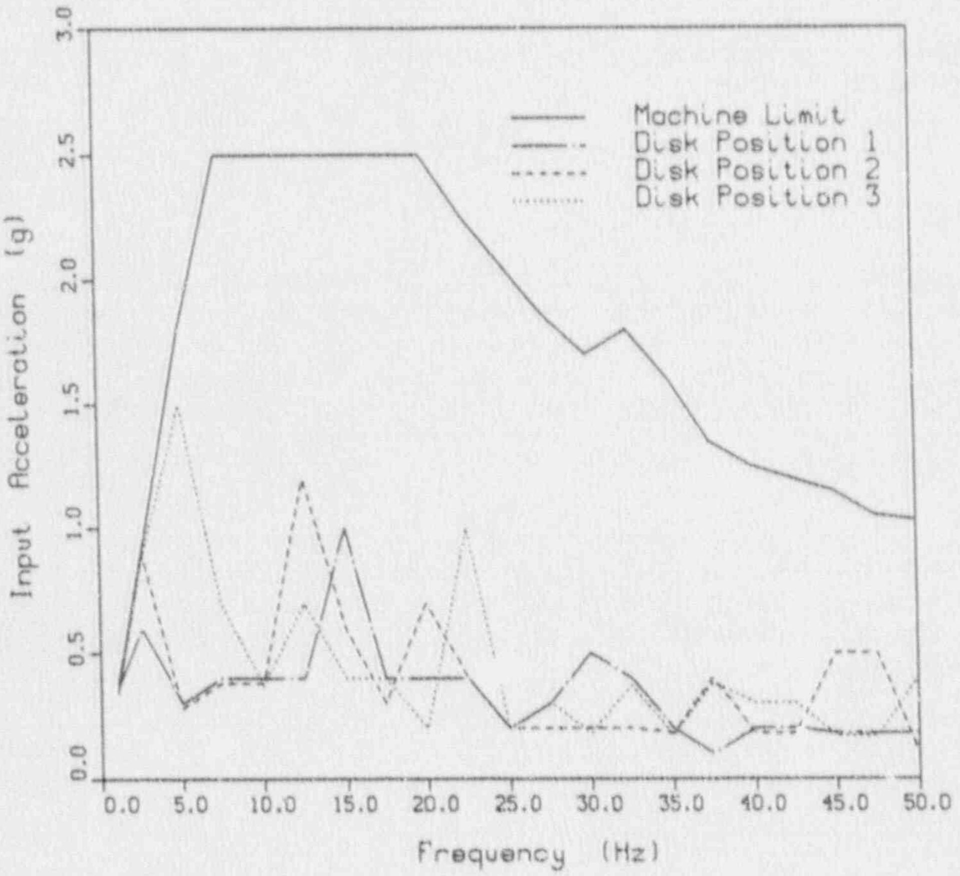

Figure 3.81 Influence of End Play Adjustment
Sine Dwell Capacity Level, IAV53, Specimen 1
V Direction, Operating Mode, UV, NC Contact

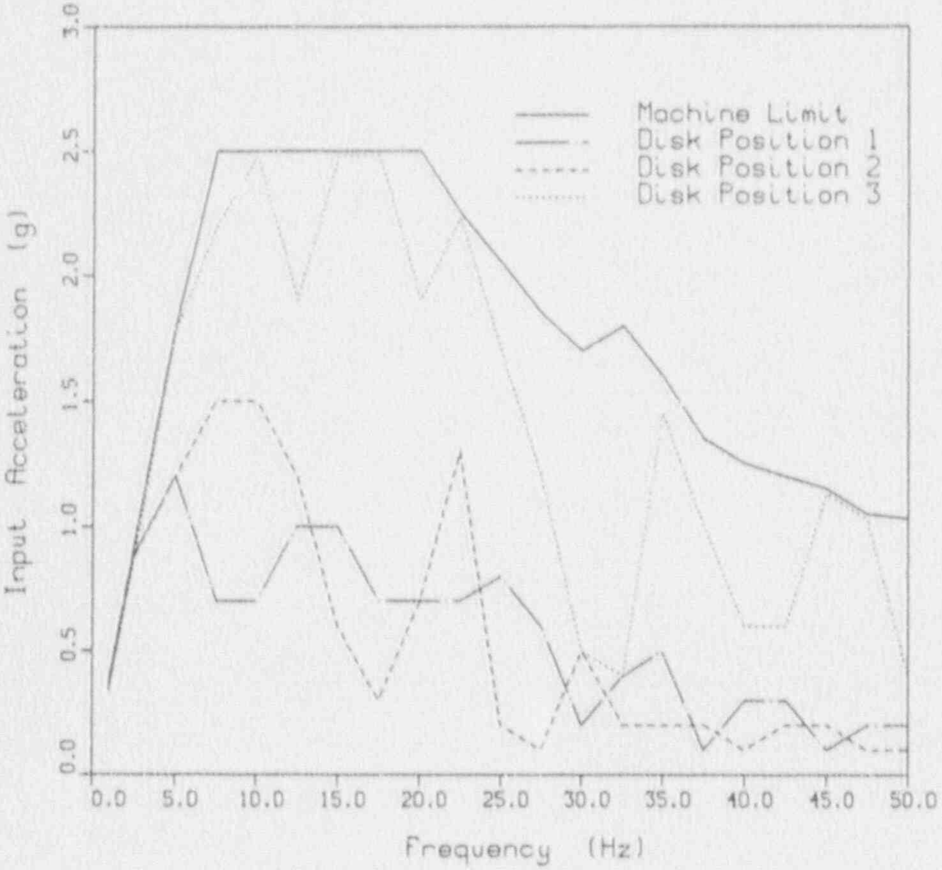

Figure 3.82 Influence of End Play Adjustment
Sine Dwell Capacity Level, IAV53, Specimen 2
V Direction, Operating Mode, UV, NC Contact

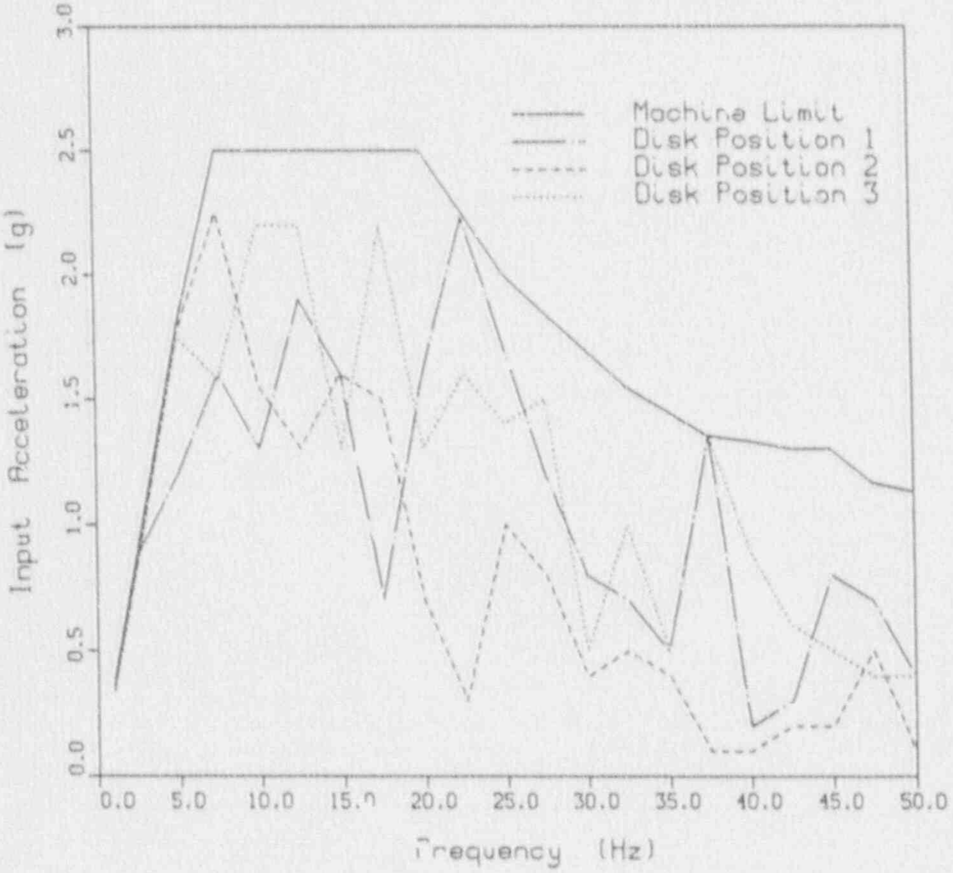

Figure 3.83 Influence of End Play Adjustment
Sine Dwell Capacity Level, CO-6, Specimen 1
V Direction, Operating Mode, CO Contact

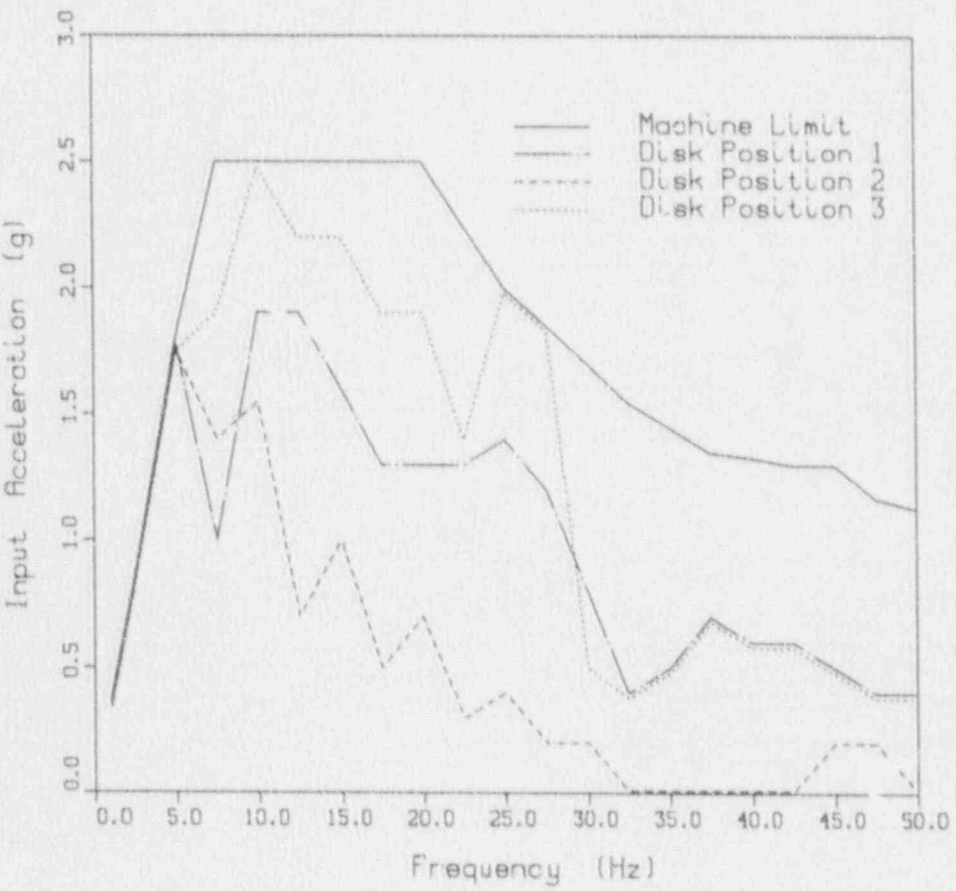

Figure 3.84 Influence of End Play Adjustment
Sine Dwell Capacity Level, CO-6, Specimen 2
V Direction, Operating Mode, CO Contact

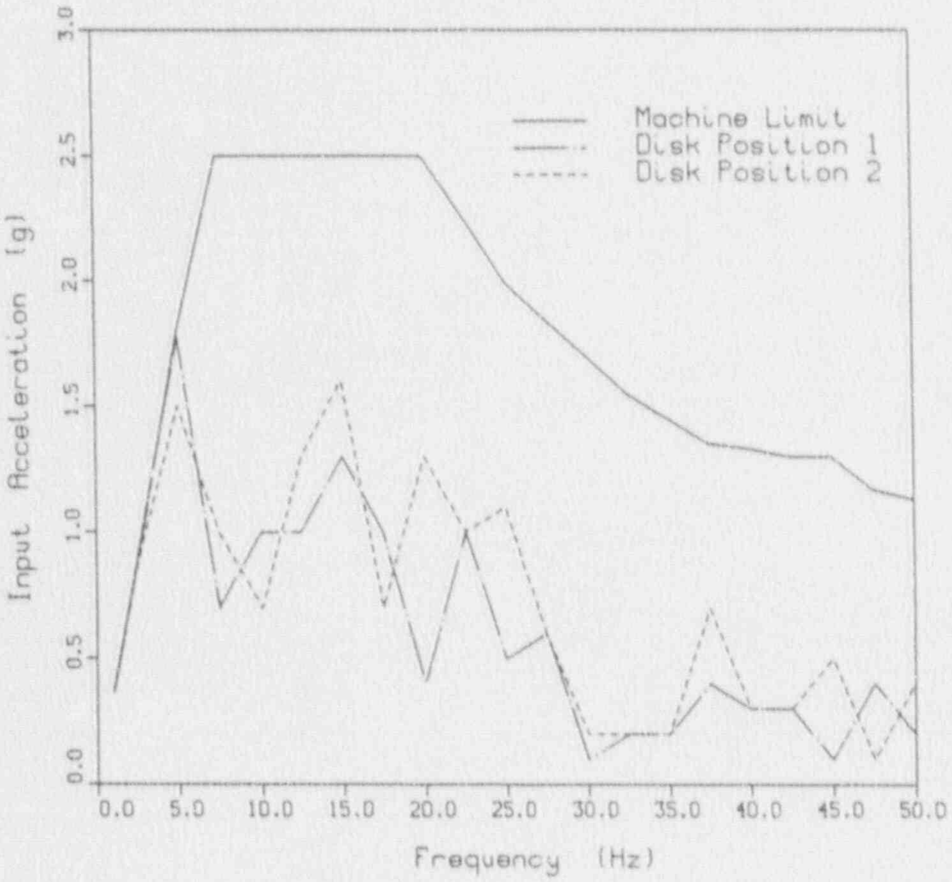

Figure 3.85 Influence of End Play Adjustment
Sine Dwell Capacity Level, CO-6, Specimen 3
V Direction, Operating Mode, CO Contact

HFA154B (Figures 3.5 and 3.6)

This is another latching relay. However, unlike HFA154E, in the nonoperating mode, this relay performs similar to HFA151A and HFA151B (1.2-1.6g at low frequencies in the FB direction and 0.2-1.0g at high frequencies in the V direction). In the operating mode, the relay was successfully tested to the machine limit in the FB direction but the capacity was limited to 0.7-1.6g at most frequencies in the vertical direction (the relay changed state due to dropping of its latch).

HFA51 (Figures 3.7-3.9)

The weakest mode of this hinged armature relay is nonoperating, NC contacts. At low frequencies, the FB direction governs the capacity (1.2-1.8g) and at high frequencies the vertical direction controls (0.2-0.7g)

HGA (Figures 3.10-3.12)

The nonoperating mode governs the capacity level in all directions. At low frequencies, the capacity levels are just about the same in both the horizontal and vertical directions (1.3-2.3g) and at high frequencies the capacity in the vertical direction is slightly lower (0.5-1.0g). In the operating mode, the capacity level is slightly higher than that for the nonoperating mode at high frequencies and was tested to the machine limit almost at all low frequencies.

HMA11 (Figures 3.13-3.15)

The nonoperating condition is the controlling electrical mode. In the low frequency range, the relay was tested to the machine limit at most frequencies, the FB direction being the weakest direction (1.7-2.5g machine limit). At high frequencies, the relay showed sensitivity in the vertical direction (0.3-1.0g).

HMA124 (Figures 3.16-3.18)

The NC contact in the nonoperating mode governs the relay capacity. The relay is weak in both the horizontal and the vertical directions (0.2-1.5g).

IAV53 (Figures 3.19-3.22)

In the operating condition, the relay is very weak in all directions, the undervoltage mode being slightly more sensitive than the overvoltage (0.2-1.0g)

PVD21 (Figure 3.23)

In the horizontal directions, the relay was tested to the machine limit (2.5g at 7.5-20Hz) without any problem. In the vertical direction, the capacity is about 2.0g in the nonoperating mode at low frequencies and 0.8-1.2g in both the nonoperating and operating modes at high frequencies.

CR120

The relay was successfully tested to the machine limit at all frequencies in all directions for both operating and nonoperating modes.

CO-6 (Figures 3.24-3.26)

The CO contact in the operating mode governs the relay capacity and the relay is very weak in the vertical direction (<0.2-0.5g).

SG (Figures 3.27-3.29)

The nonoperating mode controls the relay capacity. At low frequencies, the hinged armature operating mechanism is weaker in the FB direction (about 1.0g) and at high frequencies the vertical excitation causes more chatter (0.3-0.6g).

MG-6

The specimens were successfully tested to the machine limit in both electrical modes and in all three directions at all frequencies except that at 10Hz one specimen indicated unacceptable chatter at a level above 2.2g in the operating mode.

SC (Figures 3.30-3.35)

The relay is strong against horizontal excitation and successfully withstood vibration up to the machine limit in both electrical conditions almost for all frequencies. However, it is weak in the vertical direction especially in the nonoperating mode (operating mode 1.0-2.0g, nonoperating mode 0.2-1.0g).

SVF (Figure 3.36-3.39)

The operating mode controls the relay capacity which is very high in the FB direction and is weaker in the SS direction, especially at higher frequencies. In this direction (SS) the capacity of one specimen sharply dropped to a level less than 0.2g at 25, 32.5 and 42.5Hz. The relay is very weak in the vertical direction at all frequencies (<0.2-0.5g).

AR

The relay was successfully tested to the machine limit for both electrical conditions and in all directions at all frequencies.

8501XO, 8501KP

Both relays withstood vibration up to the table limit for both electrical modes and in all directions at all frequencies except that 8501XO was assigned a capacity of 2.25g at 7 and 10Hz in the FB direction for the nonoperating mode.

3.3 SINE SWEEP TEST RESULTS

Sine sweep tests were performed on two relays in accordance with the procedure described earlier in Section 2.4.2. The HMA124 relay chattered for less than 2ms at 0.1g and greater than 2ms at 0.2g. The SG relay withstood up to 0.7g with chatter less than 2ms and exhibited greater than 2ms chatter at 1.0g. Both results are consistent with the respective sine dwell test data (Figures 3.16 and 3.27).

3.4 RANDOM MULTIFREQUENCY TEST RESULTS

The multifrequency tests were performed in accordance with the procedures described in Section 2.4.3 in order to demonstrate generation of true frequency dependent fragility TRS data and to verify the dynamic similarity of relays with the IEEE standard response spectrum input. The results are separately presented in the following two sections.

3.4.1 Capacity TRS

Generation of a capacity TRS matching the shape of the capacity sine dwell input accelerations is demonstrated in Figure 3.86 for an SG relay. The multifrequency input in the FB direction was gradually raised from Level 1 to Level 4 with the target to match the single frequency input shape at each level. Up to Level 3, the relay did not exhibit chatter greater than 2ms duration and at Level 4 the relay chattered for 10ms. Therefore, the Level 3 TRS is considered to be the capacity TRS for this relay. Ideally, the target was to generate the TRS such that at every frequency the response acceleration can be obtained by multiplying the respective sine dwell input with a constant factor. However, due to limitation of controlling the TRS shape at the laboratory, Level 3 TRS has been considered to meet the target for practical purposes. Figure 3.87 shows the conversion (or amplification) factor relating the single frequency input with the multifrequency response at every frequency. The so-called amplification varies between 2.1 and 4.5 in the frequency range 5-30Hz. The average value is 2.3 in the frequency range 5-15Hz and 3.0 in the frequency range 5-30Hz. Similar capacity and amplification curves were also constructed for two other SG specimens and are shown in Figure 3.88 and 3.89. A comparison of the amplification values for all three SG relays is made in Figure 3.90. An average

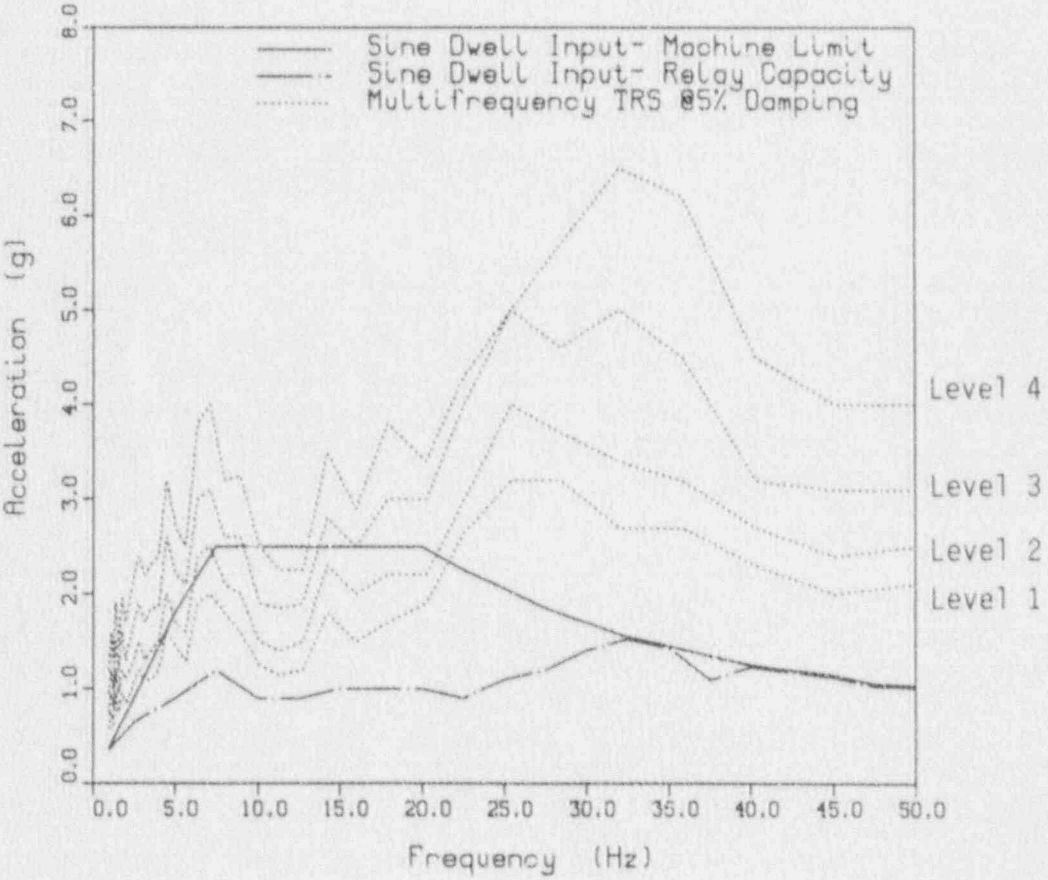

Figure 3.86 Generation of Capacity TRS for Sine Dwell Input, SG, Specimen 3 Nonoperating Mode, NC Contact

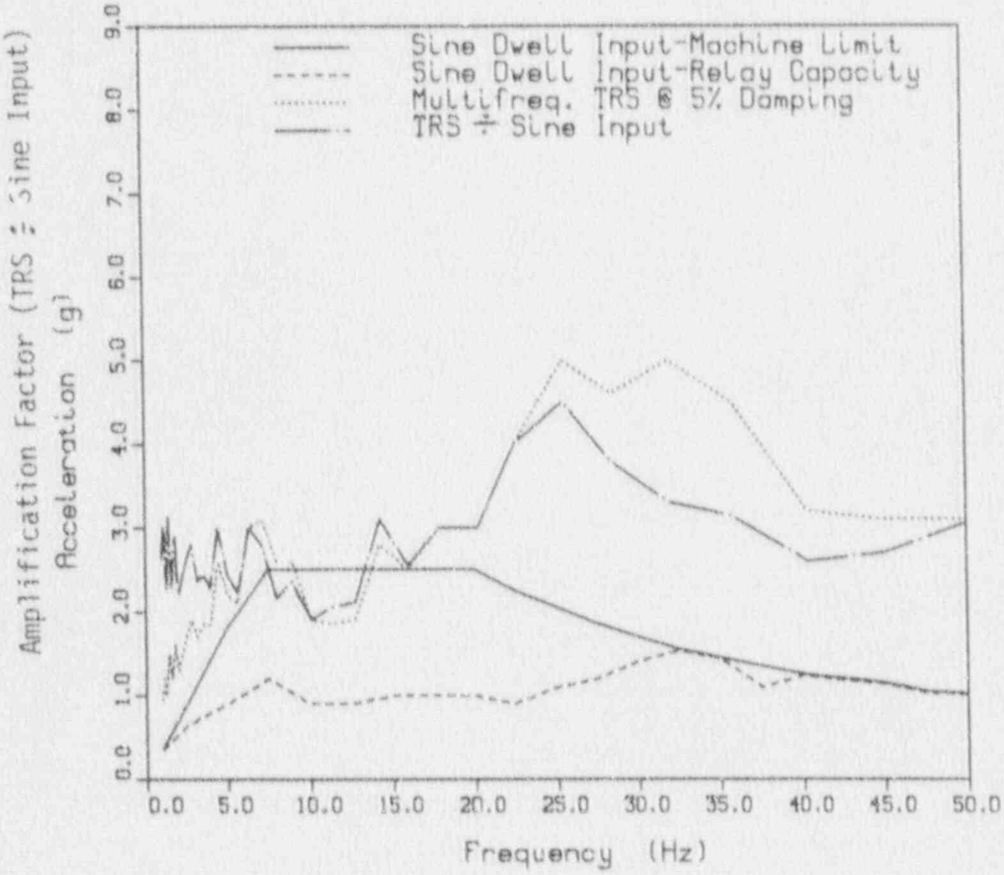

Figure 3.87 Correlation of Sine Dwell Input and Multifrequency TRS, SG, Specimen 3 FB Direction, Nonoperating Mode, NC Contact

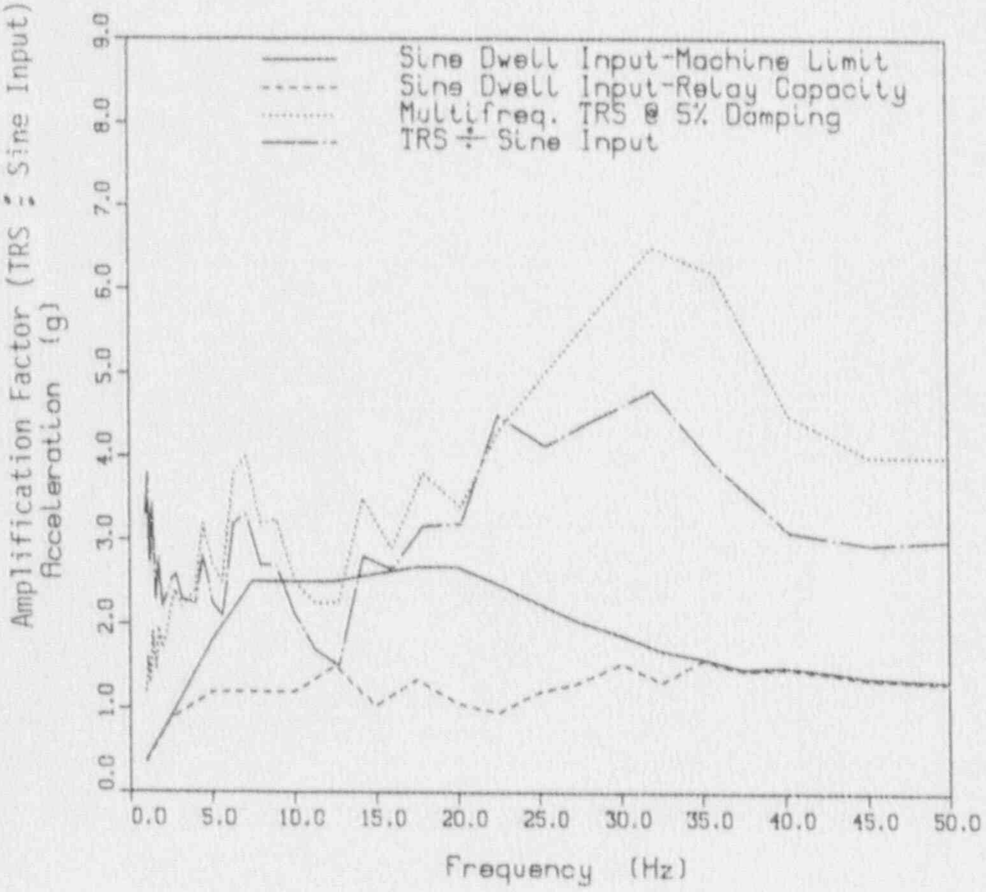

Figure 3.88 Correlation of Sine Dwell Input and Multifrequency TRS, SG, Specimen 1 FB Direction, Nonoperating Mode, NC Contact

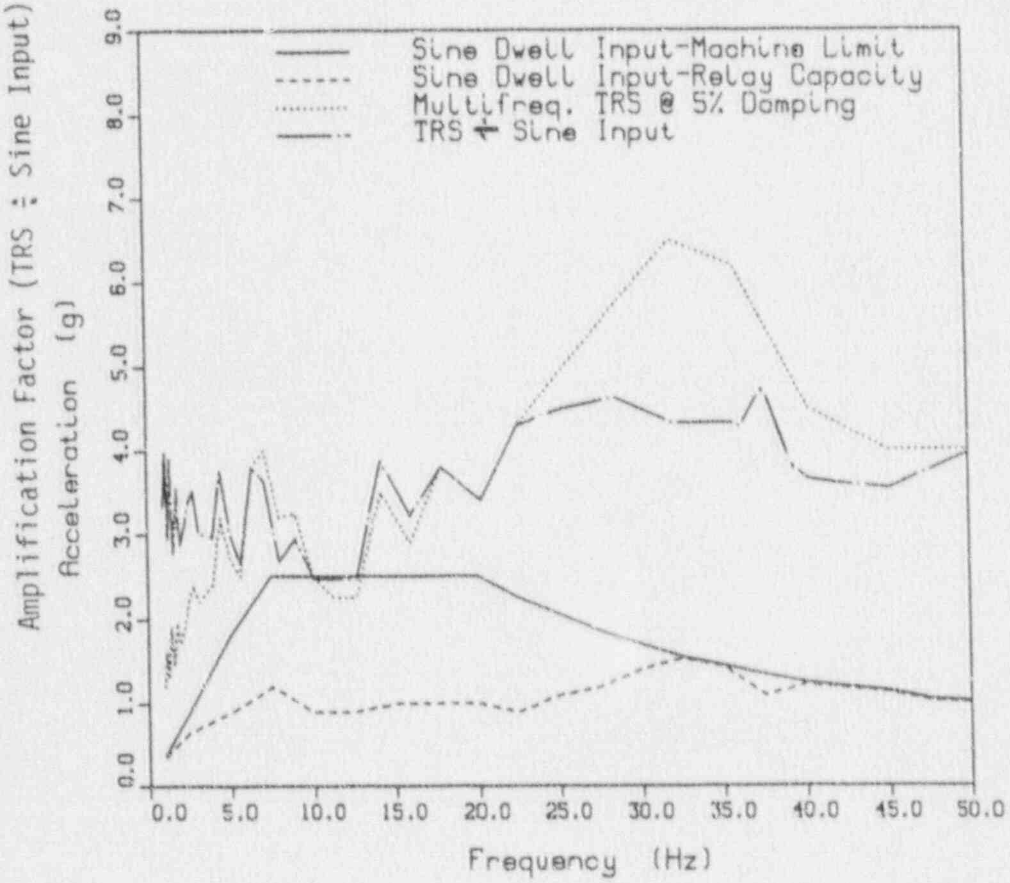

Figure 3.89 Correlation of Sine Dwell Input and Multifrequency TRS, SG, Specimen 2 FB Direction, Nonoperating Mode, NC Contact

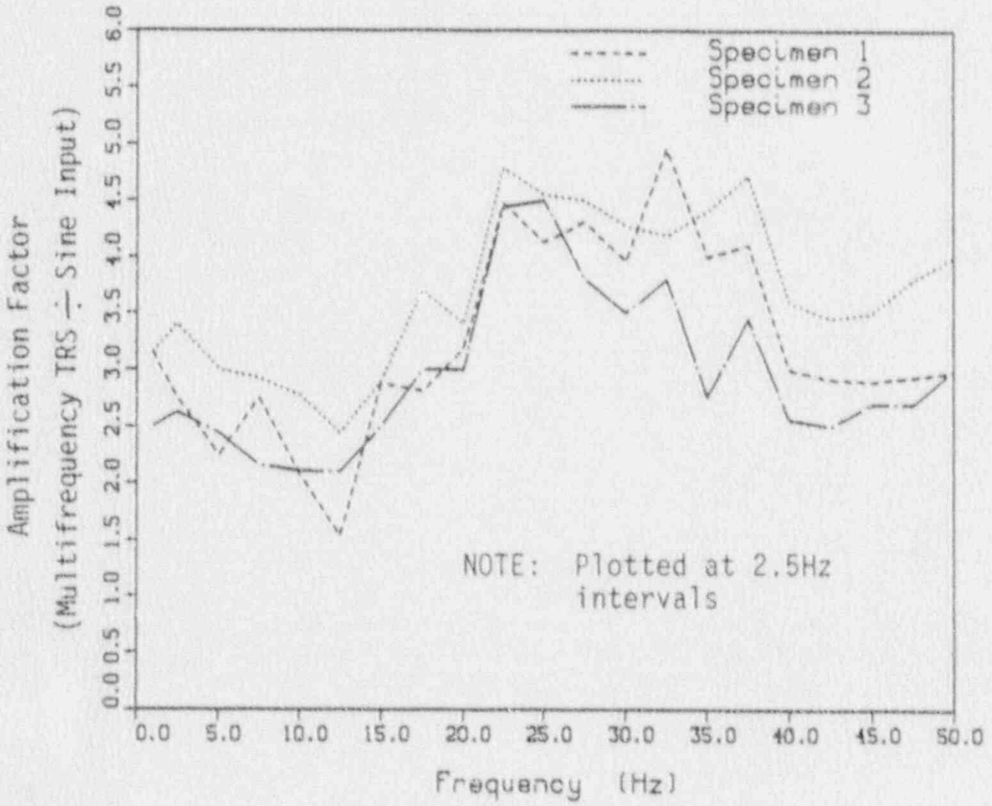

Figure 3.90 Comparison of Amplification Factors
TRS @ 5% Damping ÷ Sine Input
SG, FB Direction, Nonoperating Mode, NC Contact

amplification value of 3.0 appears reasonable for this relay model in order to convert the single frequency sine dwell input to the respective multifrequency TRS at 5% damping.

Similar attempts were made to generate true capacity and amplification curves for two other relays as mentioned in Section 2.4.3.1. However, the repeated peaks and valleys in the single frequency capacity curves could not be simulated to obtain reasonable TRS shapes. Due to the same reasons the multiaxial multifrequency test data did not shed additional light to modify the single axis results as presented above for inclusion of the multiaxis effect.

3.4.2 Dynamic Similarity

Four HFA relay models (three specimens of each model) of the Century Series were tested for exploration of dynamic similarity of relays of the same type as described in Section 2.4.3.2. First, all twelve relays were tested with biaxial excitation in the nonoperating mode and chattering of the normally closed contacts were monitored. Since the single frequency tests showed that the HFA154 relays are also almost equally sensitive in the operating condition due to dropping of the latch, these six relays were next tested with multifrequency inputs in the operating condition. The TRS data are presented in Figure 3.91.

None of the relays exhibited chatter of 2ms or greater up to the TRS of Level 1. All three 151AF relays exceeded the chatter limit at all higher levels. Specimens 1 and 3 of both 151BH and 154BF (both DC) chattered for more than 2ms at Level 3; but only Specimen 1 of 154BF chattered at level 4 and only Specimens 1 and 3 of 151BH chattered at Level 5. However, when the vibration was raised to Level 6, all three specimens of 151BH and 154BF exceeded the chatter limit. Up to this level none of the 154EH relays indicated chatter greater than 2ms. With a further increase of excitation to Level 7 all twelve relays chattered including the three 154EH relays. The corresponding vertical TRS plots of the biaxial excitations are shown in Figure 3.92.

The test data corresponding to the operating mode are shown in Figure 3.93. All six HFA154 relays were qualified up to Level 1. At Level 2, one 154EH specimen changed electrical state due to dropping of the latch. All three 154EH and two of the three 154BF relays changed state at Level 3. The corresponding vibration levels in the vertical direction are shown in Figure 3.94.

In summary, the four HFA models did not exhibit similar vibration characteristics at all. In the nonoperating electrical mode, the 151AF relays showed the lowest capacity (Figure 3.91, Level 1) and 154EH relays demonstrated to be the strongest (Figure 3.91, Level 6) while the 151BH and 154BF were in the middle (Figure 3.91, Levels 2-5). On the other hand, in the operating mode only the 154EH and 154BF relays malfunctioned and not the other two models. These results are consistent with the corresponding single frequency test data as shown in Figures 3.95 through 3.98.

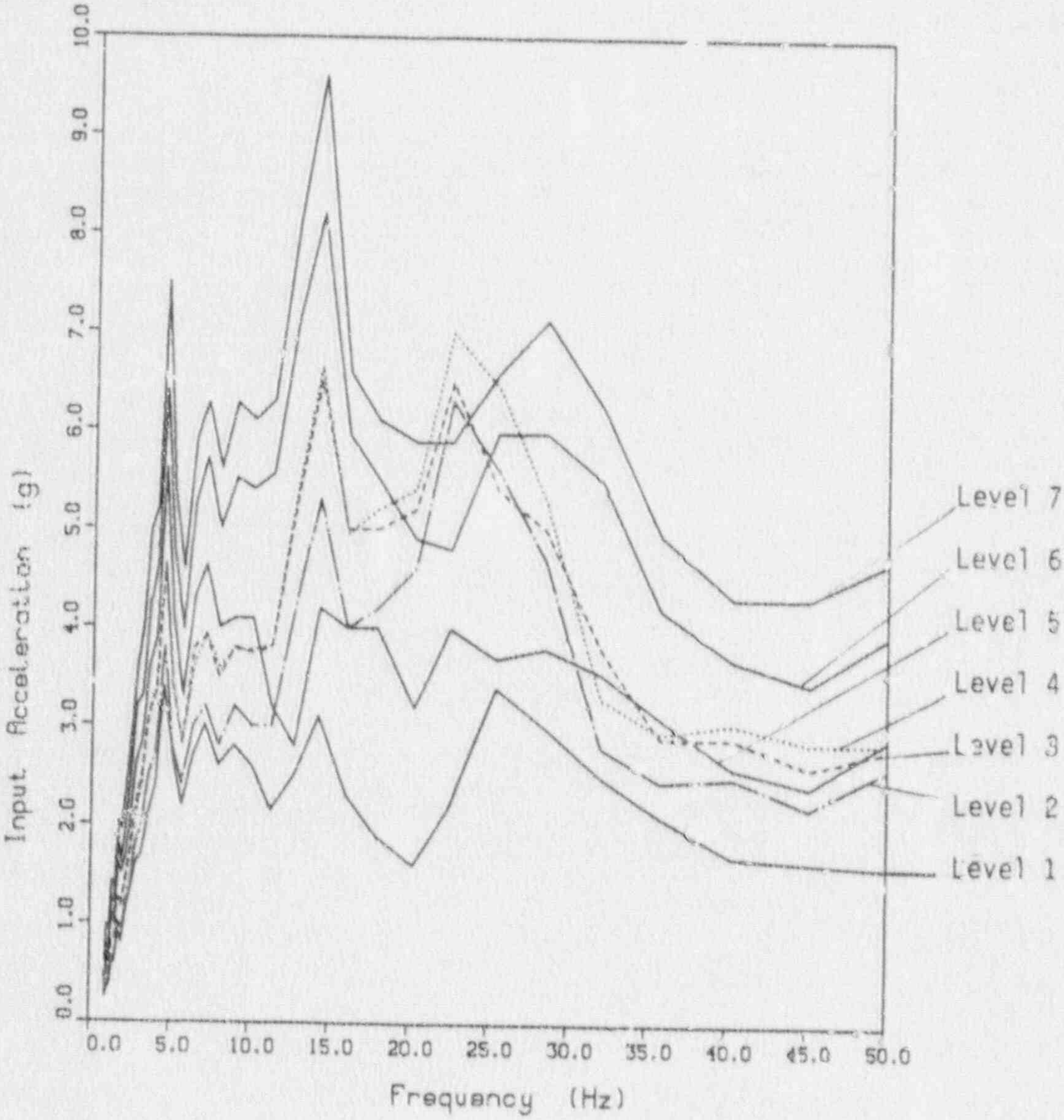

Figure 3.91 Multifrequency TRS @ 5% Damping
HFA151AF, 151BH, 154EH and 154BF
FB Direction, Nonoperating Mode, NC Contact

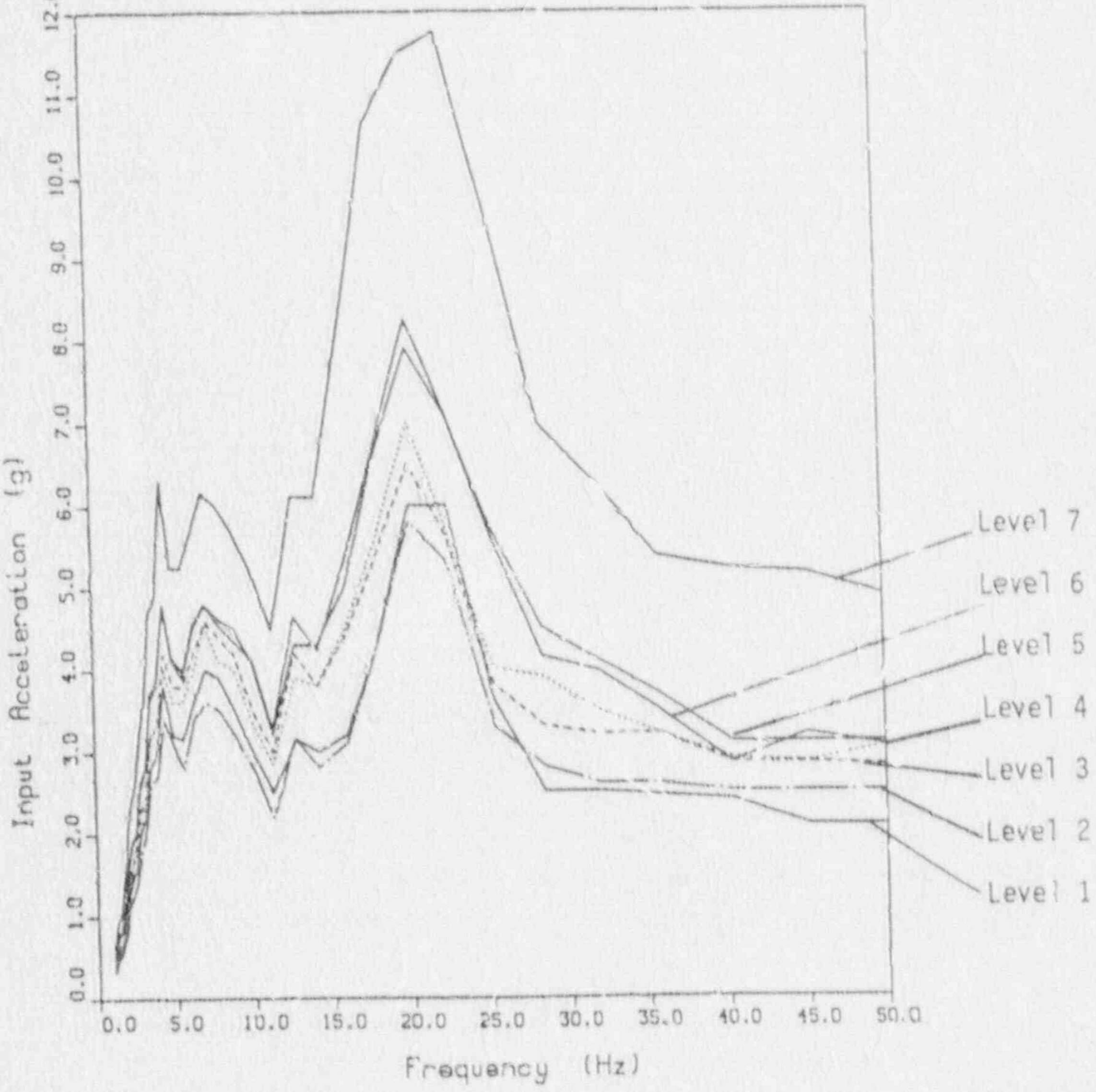

Figure 3.92 Multifrequency TRS @ 5% Damping
HFA151AF, 151BH, 154EH and 154BF
V Direction, Nonoperating Mode, NC Contact

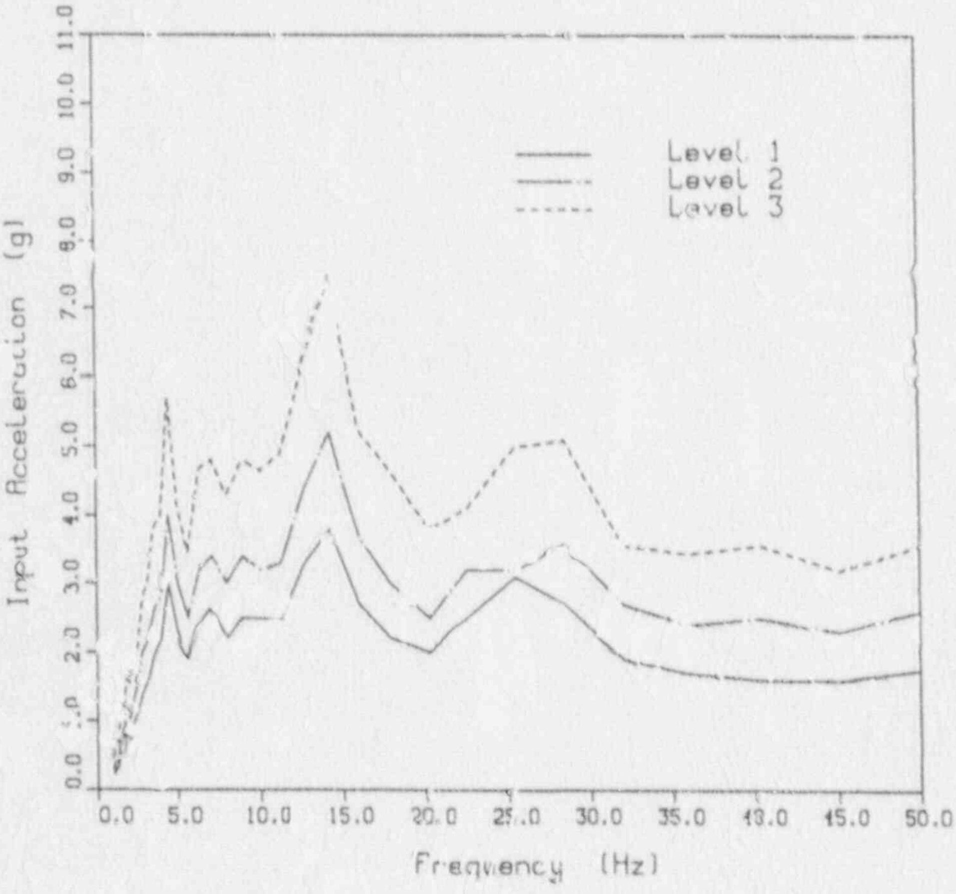

Figure 3.93 Multifrequency TRS @ 5% Damping
HFA154EH and 154BF
FB Direction, Operating Mode

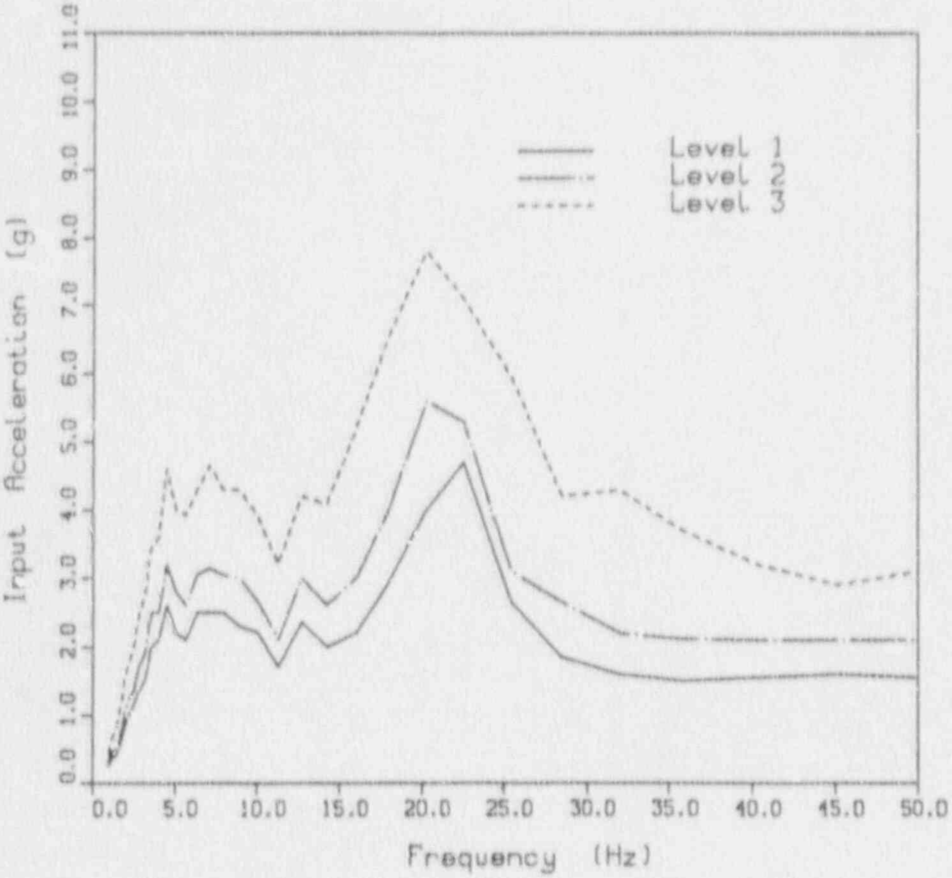

Figure 3.94 Multifrequency TRS @ 5% Damping
HFA154EH and 154BF
V Direction, Operating Mode

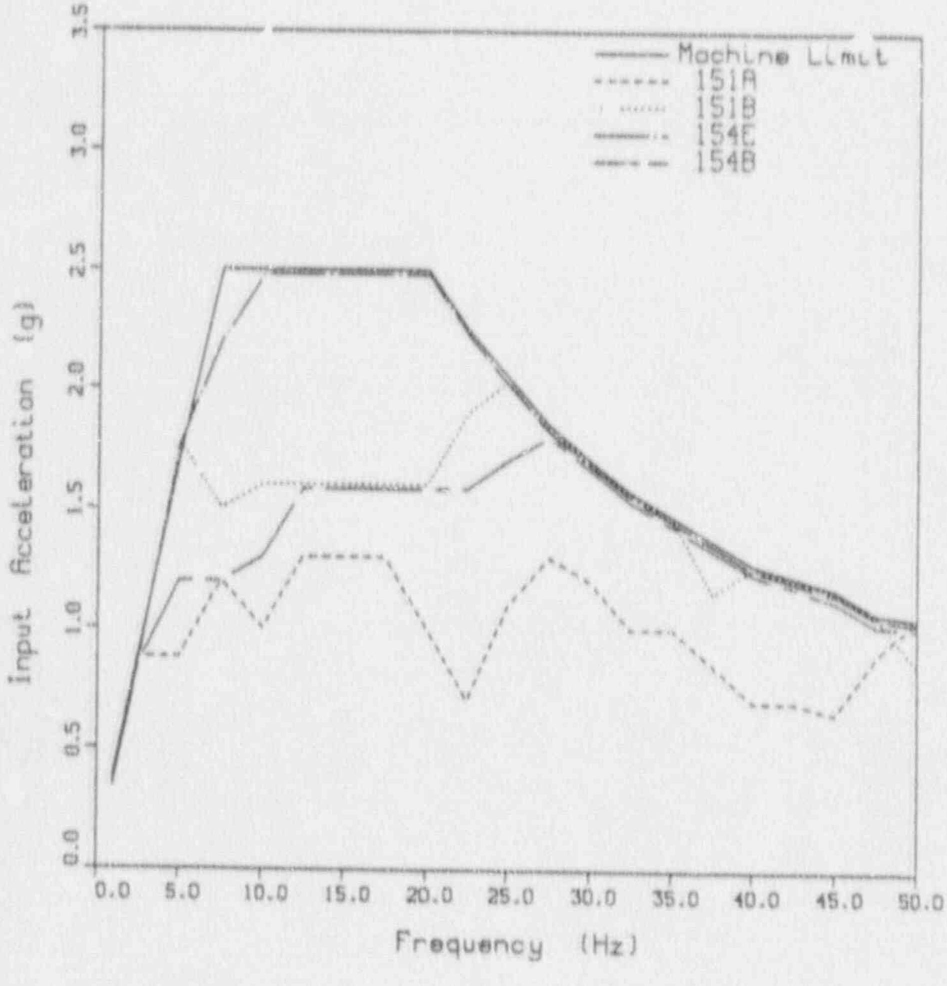

Figure 3.95 Dynamic Similarity of HFA Relays
Sine Dwell Capacity Level
FB Direction, Nonoperating Mode, NC Contact

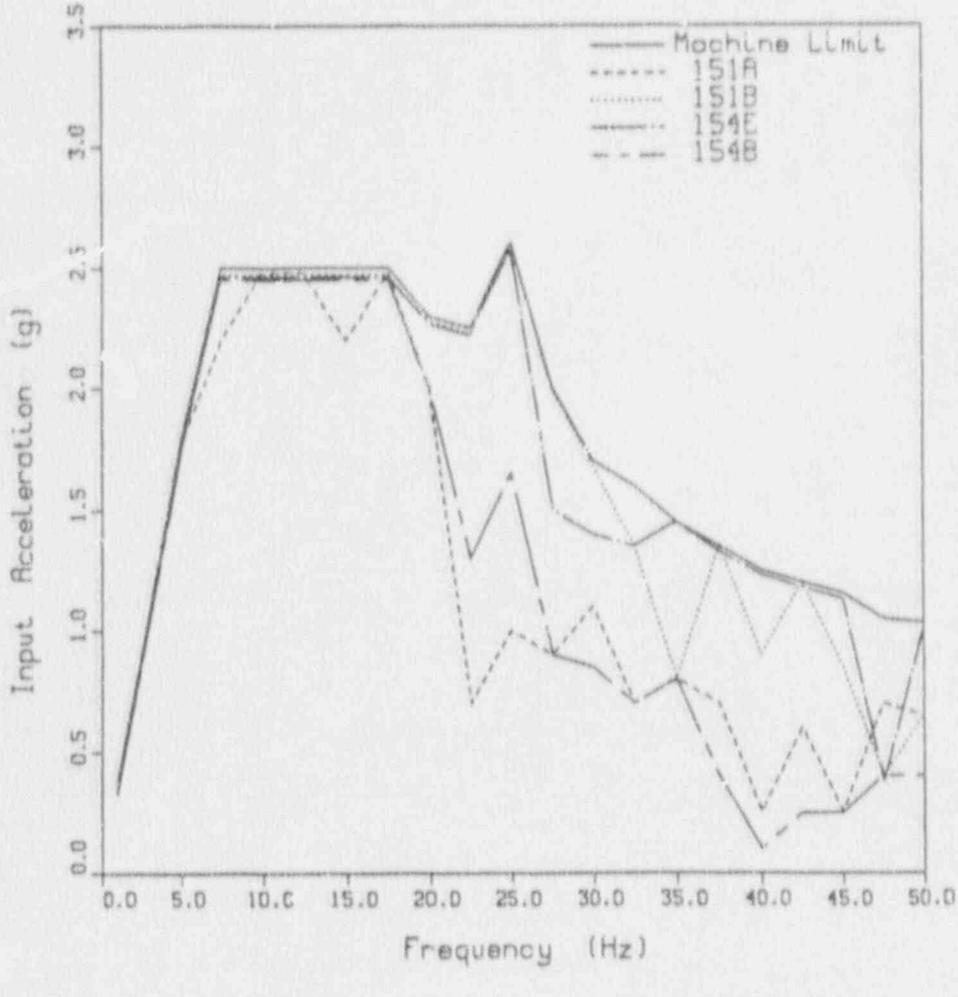

Figure 3.96 Dynamic Similarity of HFA Relays
Sine Dwell Capacity Level
V Direction, Nonoperating Mode, NC Contact

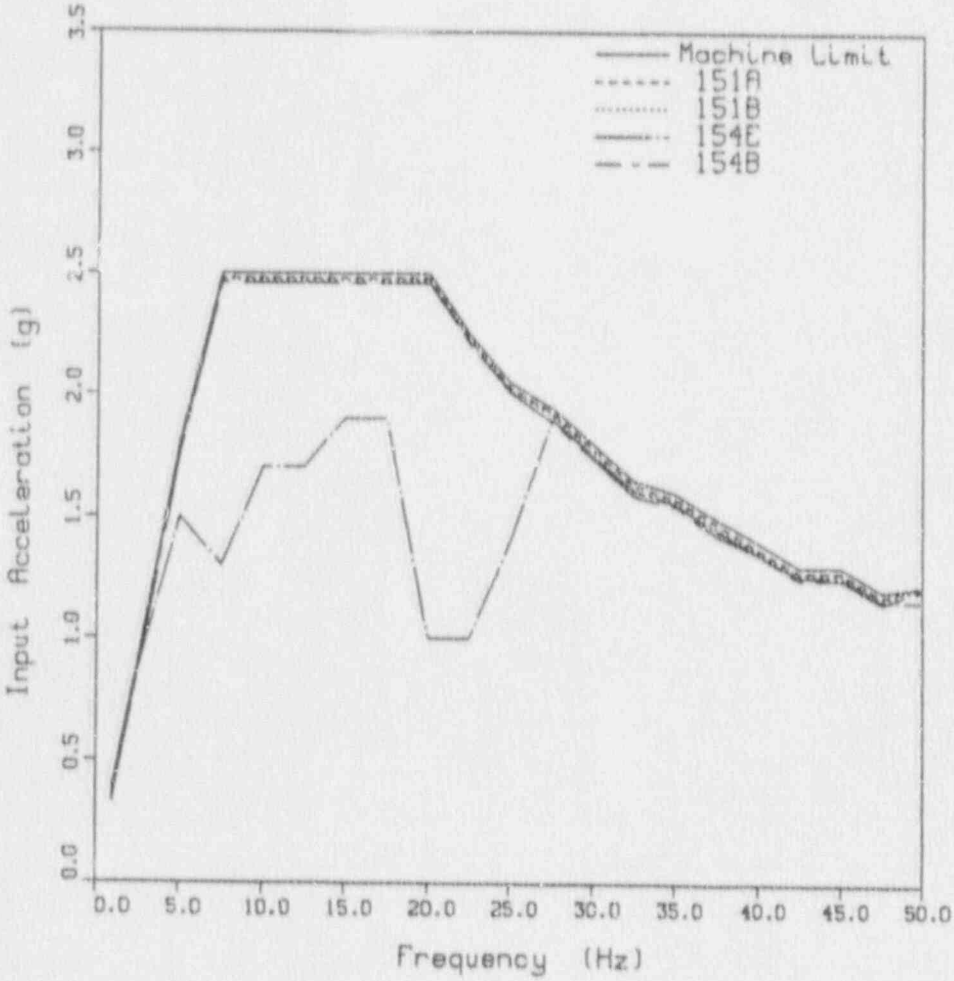

Figure 3.97 Dynamic Similarity of HFA Relays
Sine Dwell Capacity Level
FB Direction, Operating Mode

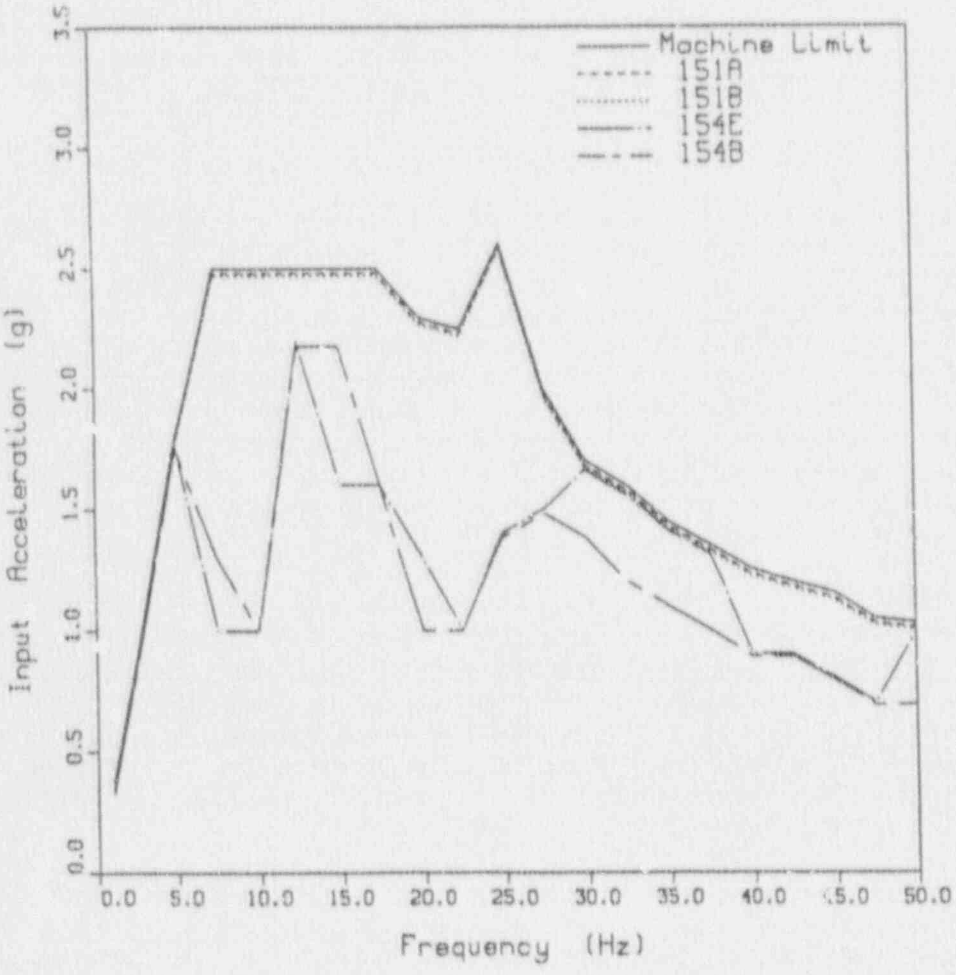

Figure 3.98 Dynamic Similarity of HFA Relays
Sine Dwell Capacity Level
V Direction, Operating Mode

3.5 PICKUP, DROPOUT AND TRIP TIME

The pickup and dropout tests were performed on five relay models and the trip time was recorded for another relay following the procedures described in Section 2.4.4. Three tests were performed for each operation and an average of three readings is provided in Table 3-2. For the HMA124 relay, the changes in the pickup and dropout values are significant; but they do not indicate any degradation of the relays. The results for other relays are within the tolerance limit. In summary, no permanent electrical malfunction was observed following the vibration tests given the fact that contact screws required tightening during the fragility test series.

3.6 MISCELLANEOUS OBSERVATIONS

In the course of testing and data evaluation two important phenomena have been observed: one regarding the effect of successive short duration chatter and the other related to the single axis vs multiaxis excitation. Both these observations are discussed in some detail in the following sections.

3.6.1 Repeated Short Duration Chatter

As mentioned earlier, the chatter acceptance criterion followed in this test program was 2ms, i.e., at the failure level the relay changed state for a duration of at least 2ms. Typically, at lower vibration levels, a large number of short duration chatter (i.e., each < 2ms) was observed and as long as the duration of any single chatter pulse did not equal or exceed 2ms the relay performance was judged satisfactory. In order to investigate the possible effect of repeated short duration chatter, limited tests were performed by powering the coils of relays placed off the shake table through the contacts of relays being vibrated on the shake table. It was observed that successive short duration chatter (none of which exceeds 2ms) can induce a change of state exceeding 2ms on a relay placed off the shake table

For example, in the nonoperating mode the normally closed contacts of an HMA11 relay withstood up to 0.75g sine dwell input at 40Hz when vibrated in the vertical direction without exhibiting a chatter pulse of duration greater than 2ms. However, in the same test set-up when these contacts were used to provide power to an AR relay placed off the shake table, the HMA11 relay caused loud and repeated chatter on the AR relay exceeding 2ms at the same vibration level. When the AR relay was replaced by an HFA151A relay, the contact chatter (> 2ms) was observed even at a lower level of 0.5g.

In another test setup, the same HFA151A relay was powered through the normally closed contacts of a PVD relay which previously had demonstrated a capacity level of 2.0g at 10Hz against vertical excitation. The HFA contacts chattered greater than 2ms at the same vibration level.

In summary, although typically a single chatter pulse of 2ms or greater duration is considered unacceptable, a number of pulses of shorter duration usually occur at a lower vibration level. Such short duration pulses, if the occur successively, can trigger a longer duration (e.g., > 2ms) change of state on a downstream relay.

TABLE 3-2
Pickup, Dropout and Trip Time Test Results[1]

Relay Model	Specimen Number	Test	Preseismic	Postseismic
HFA51	1	Pickup	67.07 VDC	65.90 VDC
		Dropout	6.61 VDC	7.65 VDC
	2	Pickup	72.36 VDC	65.66 VDC
		Dropout	9.30 VDC	8.55 VDC
	3	Pickup	61.76 VDC	63.10 VDC
		Dropout	7.61 VDC	7.45 VDC
HMA124	1	Pickup	66.32 VDC	54.50 VDC
		Dropout	45.77 VDC	19.60 VDC
IAV53	1	OV Trip Time	1.07 secs	2.40 secs
		UV Trip Time	4.63 secs	5.40 secs
CO-6	1	Pickup	1.97 amps	2.16 amps
		Dropout	1.59 amps	1.93 amps
MG-6	1	Pickup	64.30 VDC	70.30 VDC
		Dropout	34.70 VDC	37.50 VDC
SVF	1	Pickup	55.50 VAC	50.10 VAC
		Dropout	45.40 VAC	48.20 VAC

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[1] The average of three tests is reported.

3.6.2 Single Axis vs Multiaxis Excitation

As discussed in Section 3.2.2, some relays are much weaker when shaken in one direction compared to other directions. In order to explore whether in a multiaxis test, excitation in other directions have any effect on the overall capacity of the relay, three SVF relays were tested in a controlled way separately with single axis multifrequency and multiaxis multifrequency vibration inputs. As observed from the single frequency test results, these relays are very weak in the vertical direction compared to the horizontal directions (e.g., Figure 3.37). In a biaxial fragility test series both the FB and the vertical directions were simultaneously excited with gradually increasing levels until the relays chattered for longer than 2ms. The FB excitation was substantially stronger than the vertical input. At the next test run, the relays were tested with the same vertical input but no excitation at all in the FB direction. The chatter level remained unaltered. Therefore, the test results demonstrate that if a relay is very weak in one direction compared to the others, excitation in the other directions is irrelevant so far as the overall fragility of the relay is concerned. Note that in the above test a substantial reduction was made in the vibration input energy with no effect at all on the relay performance.

Consider one practical application of the test results. If the fragility of the same relay was achieved by means of the vertical multifrequency input alone and if it is desired to obtain an equivalent biaxial multifreqency TRS level compared to the requirements of the IEEE Std[3], no reduction of the vertical TRS should be made to accommodate the biaxial effect. On the other hand, if the fragility level was obtained with the FB input alone, an exceedingly large amount of reduction (e.g., 80-95%) would be required to account for the biaxial effect.

In summary, the concept of a reduction factor (computed based on the overall test input energy) to convert a single axis TRS to a multiaxis one must be very carefully considered in evaluating relays. The result can be from slightly (e.g., 30%) conservative to extremely unconservative. An attempt to estimate such a reduction factor can only be made if the characteristics of the relay are known from single frequency tests.

CHAPTER 4
SUMMARY AND RECOMMENDATIONS

4.1 INTRODUCTION

A summary of the test results is presented in this chapter. In addition, a critical evaluation of the test program is made in fulfilling the objectives enumerated in Chapter 2. The current research efforts at BNL in this area are also discussed in this chapter.

4.2 SUMMARY

Forty six relay specimens of nineteen different models from three major manufacturers were seismically tested to the fragility limit. In most of the tests a single frequency sine dwell wave form was used in the frequency range 1-50Hz. The motion was provided in different orthogonal directions and different electrical modes were simulated. Multifrequency vibration inputs were used on a selected group of relays to draw true fragility TRS curves matching the shape of the respective single frequency input curves. The results are briefly discussed in the following sections.

4.2.1 Single Frequency Tests

The governing capacity of each relay model is summarized in Table 4-1. The results are shown only for the controlling electrical mode, contact state and direction of excitation. If multiple specimens of a relay model were used, the highest vibration level at which none of the specimens exhibited chatter equal to or longer than 2ms is reported. The test data show that most relays are weaker in the nonoperating mode. Normally closed contacts are typically weaker than the normally open contacts. A latching mechanism, if present, can drop causing a change of electrical state. Excitation in the side-to-side direction seldom controls. At low frequencies either the front-to-back or the vertical input or both control the fragility whereas at high frequencies typically the vertical excitation governs the relay capacity. The variation of the capacity level among the specimens of the same relay model is high. Adjustments and settings can greatly influence the capacity results and the effect varies with frequency.

4.2.2 Multifrequency Tests

A true fragility TRS matching the shape of the single frequency input curve can be drawn. However, if the single frequency capacity varies greatly at subsequent frequencies, it is very difficult to achieve the matching TRS shape due to limitation of shake table controls. In the test program, a reasonable matching was achieved for three specimens of one relay model. The result shows that an average multiplication factor of three can be used to draw a mutli-frequency TRS capacity curve by use of the corresponding single frequency sine dwell input curve. This factor appears to be higher for relays with low single frequency capacities (e.g., < 0.5g input) and lower for relays with high capacities. Four relay models of the same type that were judged similar by the manufacturer were tested to explore the dynamic similarity. The relays exhibited very different characteristics.

TABLE 4-1
Governing Single Frequency Sine Dwell Capacity Level[a]
Input Acceleration in "g"

MODEL No.	FREQUENCY RANGE HZ	ACCELERATION LOWEST	ACCELERATION AVERAGE	CONTROLLING CONDITIONS
HFA151A	5-15	0.90	1.14	FB, Nonop, NC
	16-30	0.70	1.10	FB, Nonop, NC
	31-50	0.25	0.58	V, Nonop, NC
HFA151B	5-15	1.50[b]	1.62	FB, Nonop, NC
	16-30	1.60	1.82[c]	FB, Nonop, NC
	31-50	0.40	0.94[c]	V, Nonop, NC
HFA154E	5-15	1.00[b]	1.50	V, Op
	16-30	1.0	1.41[c]	V, Op
	31-50	0.40	1.10[c]	V, SS, Nonop, NC
		0.70	0.91[c]	V, Op
HFA154B	5-15	1.20	1.38	FB, Nonop, NC
	16-30	0.85	1.55	V, Nonop, NC
	31-50	<0.20	0.45	V, Nonop, NC
HFA51	5-15	1.20	1.26	FB, Nonop, NC
	16-30	0.25	0.85	V, Nonop, NC
	31-50	<0.20	0.27	V, Nonop, NC
HGA	5-15	1.20	1.35	FB, Nonop, NC
	16-30	0.88	1.35	FB, Nonop, NC
	31-50	0.54	0.92[c]	V, Nonop, NC
HMA11	5-15	1.75[c]	2.00[c]	FB, Nonop, NC
	16-30	1.70[c]	2.10[c]	V, Nonop, NC
	31-50	0.30	0.65[c]	V, Nonop, NC
HMA124	5-15	0.20	0.33	V, Nonop, NC
	16-30	<0.20	<0.20	V, Nonop, NC
	31-50	<0.20	<0.20	V, Nonop, NC
IAV	5-15	0.30	0.58	V, Op, UV[d], NC
	16-30	<0.20	0.33	V, Op, UV, NC
	31-50	<0.20	<0.20	V, Op, UV, NC
PVD	5-15	1.80[c]	2.10[c]	V, Nonop, Volt. Oper.
	16-30	1.70[c]	2.01[c]	V, Nonop, Volt. Oper.
	31-50	0.65	1.00[c]	V, Nonop, Volt. Oper.
CO-6	5-15	0.20	0.42	V, Op, CO
	16-30	<0.20	<0.20	V, Op, CO
	31-50	<0.20	<0.20	V, Op, CO

TABLE 4-1 (continued)
Governing Single Frequency Sine Dwell Capacity Level[a]
Input Acceleration in "g"

MODEL No.	FREQUENCY RANGE HZ	ACCELERATION		CONTROLLING CONDITIONS
		LOWEST	AVERAGE	
SG	5-15	0.73	0.98	FB, Nonop, NC
	16-30	0.60	1.56	SS, Nonop, NC
		0.90	1.10	FB, Nonop, NC
	31-50	0.20	0.45	V, Nonop, NC
SC	5-15	0.20	0.58	V, Nonop, NC
	16-30	0.20	0.68	V, Nonop, NC
	31-50	0.40	0.87[c]	V, Nonop, NC
SVF	5-15	<0.20	<0.20	V, Op, NC
	16-30	<0.20	<0.20	V, Op, NC
	31-50	<0.20	0.30	V, Op, NC

[a] For CR120, MG-6, AR, 8501X0 and 8501-KP relays, the capacity levels could not be established due to limitation of the shake table.

[b] Due to the shake table limitation, the relay capacity at 5Hz could not be established and the reported value is applicable in the frequency range of 7.5-15Hz

[c] Due to the shake table limitation, the relay capacity at some frequencies could not be established. The average acceleration was computed based on the highest test level and the true average capacity level is higher.

[d] Undervoltage

4.3 OBJECTIVES VS. TEST RESULTS

The objectives of the test program have been listed in Section 1.3. The extent to which the tests were successful and the results can be used to address these objectives are discussed as follows:

Frequency Sensitivity

A vast amount of single frequency test data have been generated to address this issue. The data clearly indicate that depending on the design, electrical mode and input motion, a relay can be sensitive at low (e.g., 5-15Hz), medium (e.g., 16-30 Hz) and high (31-50 Hz) frequencies. In addition, the test results show the effect of the direction of excitation, e.g., at high frequencies most relays are weak in the vertical direction. In summary, it is felt that the frequency sensitivity issue has been adequately addressed by the test program.

Frequent Dependent Fragility TRS

The objective was to demonstrate construction of a multifrequency TRS (at a damping value of 5%) such that the acceleration at each frequency would provide an approximate measure of the fragility level. To this end, the shape of the single frequency sine dwell input capacity curve was used as the required response spectrum (RRS) shape and the multifrequency input motion was adjusted to closely match the RRS shape. Since the shape of the single frequency capacity curve varies with the relay, attempts were made to generate frequency dependent TRS for only three relay models. It is felt that for three specimens of one relay model, the TRS reasonably matched the RRS shape. However, due to inadequate control of the multiaxis shake table, the RRS for other relay models could not be matched. In summary, generation of the frequency dependent fragility TRS was successful only for one relay model. It requires much more effort to generate a frequency dependent fragility TRS compared to the level of effort needed for obtaining IEEE Std[3] fragility TRS.

Conversion Factor - Multifrequency TRS vs. Single Frequency Input

The ratio of the amplitudes of the frequency dependent fragility TRS (at 5% damping) and the single frequency sine dwell input motion was computed at the test frequencies to obtain the conversion factors in the frequency range of 1-50 Hz. Since, as discussed above, the frequency dependent TRS data were generated for three specimens of one relay model, the conversion factors were computed for these specimens. If required, similar data can be generated for other relays provided the respective frequency dependent TRS are obtained first.

Dynamic Similarity

The issue of dynamic similarity of relays was addressed by testing four models (three specimens of each model) of the same general relay model. The results clearly show that the relays are very dissimilar. Even their failure modes are different. However, additional testing is required to verify the IEEE Std seismic rating recommended by the manufacturer.

Effect of Adjustments

Limited single frequency testing was performed to explore the effect of various adjustments and settings on the relay capacity levels. The results clearly show that the adjustment of spring tension, contact gap and end play greatly influences the seismic capacity. However, it appears that at each frequency there is an optimum adjustment for each specimen at which it performs best. Additional testing is required to characterize the optimum setting which may not necessarily be an extreme adjustment.

4.4 CURRENT TEST PROGRAM

As discussed above, most of the objectives were addressed by the relay test program. 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., tests on conversion factor relating multifrequency fragility TRS with single frequency fragility input motion). In addition, the test program revealed information that raises some fundamental questions regarding qualification and definition of the fragility level of a relay (e.g., repeated short duration chatter, variation of capacity levels between specimens). Furthermore, other recent studies[2] identified the need for resolution of certain other relay issues (e.g., effect of relay chatter on breaker operation). In order to address these concerns, BNL will perform a second series of testing as briefly discussed in the following sections.

4.4.1 Relay Chatter and Acceptance Criteria

The evaluation of performance of relays during vibration testing requires documentation of the output effects against a pass-fail criterion. The commonly used criterion for output discontinuities is a 2ms period. This has been recommended by the IEEE Std[3] and was used in the BNL relay test program. However, the sensitivity of each specific circuit to contact chatter is different and the use of any single criterion for a pass-fail determination could err in either direction on many actual circuit configurations.

Another aspect of the 2ms criterion that has been considered little in the past is the repetition rate of discontinuities. The use of the 2ms criterion for a single discontinuity is probably conservative for essentially all circuits (except solid state circuits); however, if a 1ms discontinuity repeats every 2ms, the effect may result in the picking up or dropping out of a device that would otherwise require a longer duration (e.g., 8ms) single discontinuity pulse. Occurence of this type of behavior may be rare in qualification or proof testing but it has been observed in fragility testing since the latter explores each device on the "edge" of its capacity level (see Section 3.6.1).

In the second series of testing, BNL will explore whether and how chatter acceptance criteria can be related to some circuit parameters in an attempt to refine the 2ms criterion.

4.4.2 Specimen Variation

As discussed earlier, the relay test program indicated a large variation of seismic capacities within specimens of the exact same model number. In the current program, BNL will investigate the causes of such variation and characterize it in an attempt to answer the question as to how many specimens of a relay model should be tested in order to gain adequate confidence in the test results. The IEEE Std[3] recommends testing of a minimum of three relays.

4.4.3 Relay Chatter and Circuit Breaker Malfunction

In the switchgear circuit, the operation of a circuit breaker is directly or indirectly affected by a large number of protective and auxiliary relays. There is evidence that a 2ms chatter of a relay may not cause a breaker tripping. However, the amount of relay chatter a breaker will tolerate before initiating an unintended operation is not usually known. In the current test program, relays will be tested on the shake table while being electrically connected to the circuit breaker placed off the table. A device that has impulse characteristics comparable to that of the breaker tripping mechanism may be used instead of the breaker itself during the shake table test.

4.4.4 Single Frequency to Multifrequency Conversion Factor

As discussed earlier, the relay test program provided data for one relay model that can be used to obtain multifrequency fragility TRS from single frequency sine dwell tests. In order to draw a general conclusion on the conversion factor additional test data are needed. In the current test program a minimum of two additional frequency dependent multifreuqency fragiltiy tests will be performed.

4.4.5 IEEE Std Seismic Rating

A group of relays will be tested following the spectral shape recommended by the IEEE Std[3]. The relay selection for testing will be from those whose stated capacity levels are at issue.

4.5 CONCLUDING REMARKS

The vast amount of single frequency test data for many relays generated as part of the test program reveals a comprehensive picture of relay performance under a vibratory environment. Dwelling on one frequency at a time provides a unique opportunity to characterize the relay under various electrical conditions and other parameters. A substantial amount of variation and, consequently, unpredictability was observed at the single frequency level. It is suspected that the single pass-fail criterion (i.e., 2ms) might have contributed to some extent towards such variation. The current test program will focus on this and several other issues and is expected to produce information that will, in turn, help make a better and a more appropriate use of the existing data.

CHAPTER 5
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Washington, DC 20555

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

BNL has conducted a test program on relays to determine the influence of parameters related to design, electrical conditions and vibratory motion on their respective seismic capacity levels. Single frequency excitation was used for most of the test runs; multifrequency random motion was also used for some number of test runs. The test data have been evaluated and the results are presented in this report.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

relays-seismic effects
relays-performance testing
electrical equipment-seismic effects
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performance
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