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RELAY TESTING*
PARAMETRIC INVESTIGATION OF SEISMIC FRAGILITY

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INTRODUCTION

The seismic capacity of most electrical equipment is governed by malfunction of relays. An evaluation of the existing relay test data base at Brookhaven National Laboratory (BNL) has indicated that the seismic fragility of a relay may depend on various parameters related to the design or the input motion. In particular, the electrical mode, contact state, adjustment, chatter duration acceptance limit, and the frequency and the direction of the vibration input have been considered to influence the relay fragility level. For a particular relay type, the dynamics of its moving parts depends on the exact model number and vintage and hence, these parameters may also influence the fragiltiy level. In order to investigate the effect of most of these parameters on the seismic fragility level, BNL has conducted a relay test program. The testing has been performed at Wyle Laboratories. Establishing the correlation between the single frequency fragility test input and the corresponding multifrequency response spectrum (TRS) is also an objective of this test program. This paper discusses the methodology used for testing and presents a brief summary of important test results.

TESTING METHOD

Single axis, single frequency sine dwell tests have been performed at 2.5Hz intervals in the frequency range of 1-50Hz to study the effect of vibration frequency on the fragility levels. A total of forty six specimens of nineteen popular relay models from three manufacturers (Westinghouse Electric Corp., General Electric Co., and Square D Co.) have been tested. For ten models, more than one specimen has been used to study the consistency of results. The input level was increased or decreased until the failure threshold was established.

Random multifrequency tests have been performed on twelve relay models. Spectral shapes have been matched, as much as possible within the shake table limitation, with the respective single frequency fragility inputs so that the conversion factors relating the single frequency test inputs to the multi-frequency test response spectra can be computed.

All the above tests have been performed on new (i.e., current vintage) relay models. The effect of spring tension and contact gap adjustments have been studied by varying the respective parameters of two hinged armature relay models. The effect of end play adjustments have been tested on two rotary disk relays. All adjustment tests have been performed with single axis, single frequency inputs.

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The initial single frequency tests have been conducted in all three orthogonal directions, for all three electrical modes (i.e. operating, nonoperating and transition), and two contact conditions (i.e. normally closed and normally open). All subsequent tests have been performed only in the weakest direction for the weakest electrical mode and contact condition. A chatter duration of 2ms or greater has been used as the failure criterion to establish the fragility levels.

TEST RESULTS

The capacity levels are obtained in terms of the sine dwell input acceleration values for the single frequency tests and in terms of the test response spectra at a 5% damping value for the random multifrequency tests. Unless otherwise mentioned, the capacity levels are defined in this paper as the maximum acceleration levels the specimen withstood without exhibiting a chatter duration of 2ms or greater. At a level slightly above the capacity level the specimen has indicated a chatter exceeding this limit. The results revealing the influence of each parameter are discussed in the following paragraphs. The test data presented in this paper are to illustrate the influence of the parameters and are not necessarily typical for all relays.

Frequency of Vibration Input

Single frequency tests indicated that the specimens 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 front-to-back (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 governed by the shake table limit at other frequencies (e.g. 2.5g at 7.5-20Hz) in the same direction, as shown in Figure 1[1]. On the other hand, the SC specimen, a plunger relay, is sensitive at 40Hz in the side-to-side (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 exhibited a high capacity level in the vertical (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 1.

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 2. 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 shown in Figure 3 for an SC relay which is much weaker in the vertical direction.

Electrical Condition

Relays were tested in the operating, nonoperating and transition modes as defined by ANSI/IEEE 37.98(ANSI, 1978). Most relay specimens are weaker in the nonoperating mode as illustrated in Figure 4. The HMA (hinged armature) specimen withstood vibration inputs at all frequencies up to the machine limit (e.g. 2.5g at 5-20Hz) in the operating mode; whereas, the capacity level in the

1 In all Figures, the single frequency test data are plotted at an interval of 2.5Hz and are presented as curves connecting the data points.

nonoperating mode is less than 0.5g sine dwell input. However, some relays are weaker in the operating mode. The SVF relay is one such example as shown in Figure 5. 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. There are some relay models for which the capacity levels 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 6. An IAV relay was tested at two alternate operating modes (Figure 7). The results indicated 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.

Adjustment

Limited single frequency testing was performed to determine the effect of adjustment of spring tension, contact gap and end play. The spring tension and the contact gap were adjusted for two hinged armature relay models. The end play of two rotary disk relay models was adjusted by lowering or raising the disk. In all cases, the adjustment was made to values higher and lower than the respective standard adjustments with which the manufacturers supplied the specimens. The adjustments significantly changed the capacity of the specimens, but no conclusive general trend could be established from the limited tests. Figure 8 illustrates the performance of an HFA relay with three different spring tension adjustments. At 15Hz, for example, the capacity levels are 1.3g, 1.6g and 1.9g for the respective low, standard and high tension values. This follows the expected trend that the capacity level should be higher with a greater tension value. But the same argument does not apply at 20Hz for which the respective capacity levels are 0.7g, 1.6g and 0.4g. In the lowered position of an end play adjustment test, the rotary disk relay contact did not immediately return to the closed condition at the completion of the sine dwell tests at 40 and 50Hz.

Same Model, Different Specimens

For most relays, multiple specimens of the same model were tested. A wide variation of the capacity levels in a particular direction was observed for the tested specimens as illustrated in Figure 9. Both specimens were in the nonoperating mode and tested in the SS direction. One specimen was successful in withstanding sine dwell input to the machine limit almost at all frequencies (e.g. 2.5g at 7.5-20Hz, 1.7g at 25Hz); whereas, the other one showed a much lower capacity level (e.g. 1.0g at 7.5Hz, 0.25g at 25Hz). However, both specimens indicated frequency sensitivity at 25Hz.

Multifrequency vs Single Frequency

Selected specimens were tested with random multifrequency inputs such that the TRS curve matched with the shape of the input curve already obtained from the single frequency tests. The specimens were tested in the weakest direction and for the weakest electrical condition. Since the TRS value at each frequency was approximately matched[1] with the respective single frequency capacity level, the ratio of the TRS data to the single frequency input data provides a measure of the response amplification of the single frequency sine dwell amplitude

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1 Due to resonance of the shake table, the shapes of the two curves could not be exactly matched.

required to cause the same malfunction. The results for an SG relay are shown in Figure 10. The response amplification at 5% damping varies from 2.1 to 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.

CONCLUSIONS

The single frequency test results confirm that the performance of a particular relay specimen is significantly influenced by various parameters, including the frequency and direction of the test input, and the electrical condition and adjustment of the relay. Since there was a wide variation of the single frequency capacity levels of different specimens of the same model, testing of multiple specimens appears to be necessary for establishing a fragility level with reasonable confidence. Over 2900 tests were performed during this test program and a vast amount of data was obtained. Efforts are continuing to further analyze the data to enhance the understanding of the seismic capacity levels of relays. The results will be presented in a future publication.

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REFERENCES

ANSI/IEEE C37.98-1978, IEEE Standard Seismic Testing of Relays.

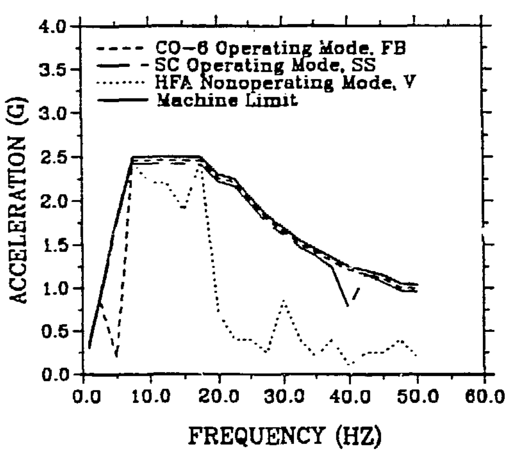

Figure 1: Sine Dwell Amplitude Influence of Input Frequency

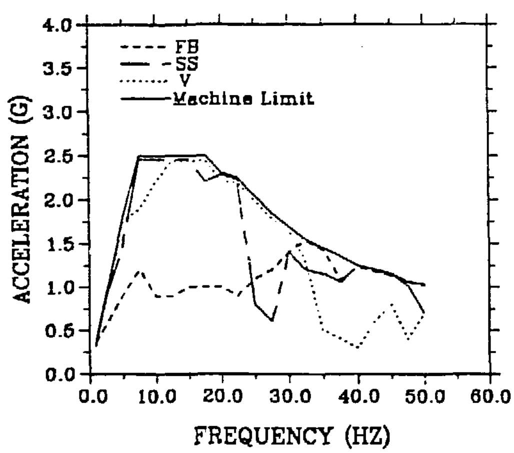

Figure 2: Sine Dwell Amplitude Influence of Input Direction SG Relay, Nonoperating Mode

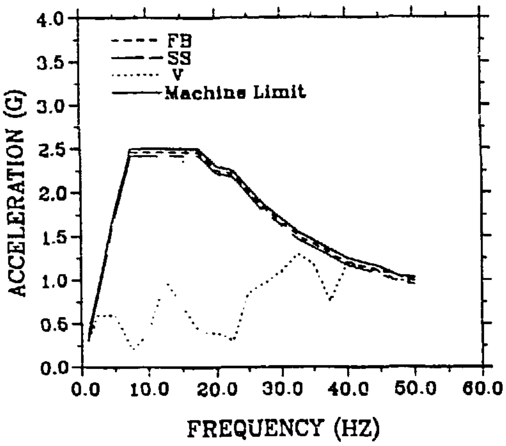

Figure 3: Sine Dwell Amplitude
Influence of Input Direction
SC Relay, Nonoperating Mode

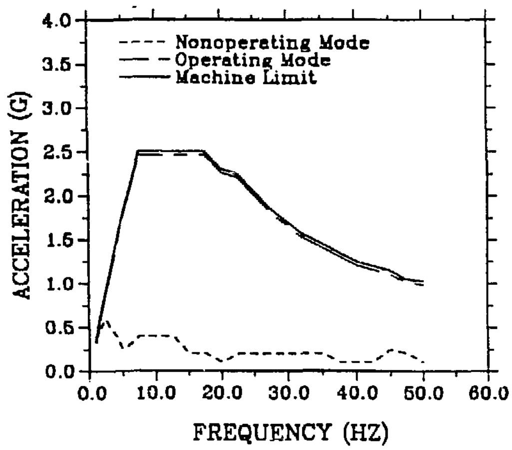

Figure 4: Sine Dwell Input
Influence of Electrical Conditions
HMA Relay, Vertical Direction

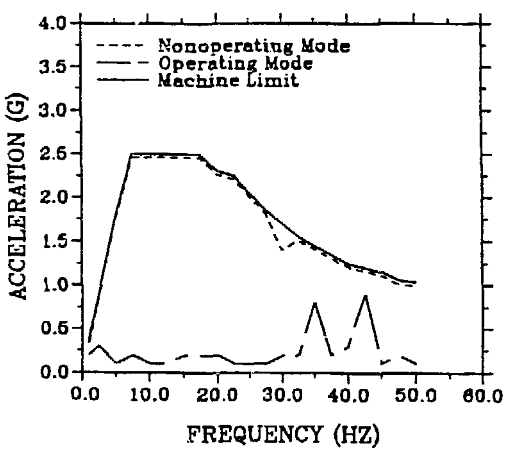

Figure 5: Sine Dwell Amplitude
Influence of Electrical Condition
SVF Relay, Vertical Direction

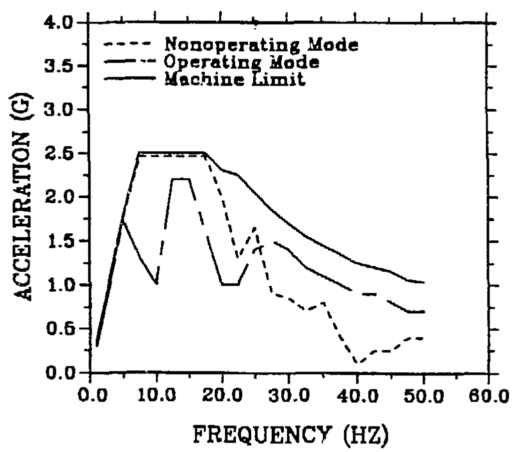

Figure 6: Sine Dwell Amplitude
Influence of Electrical Condition
HFA Relay, Vertical Direction

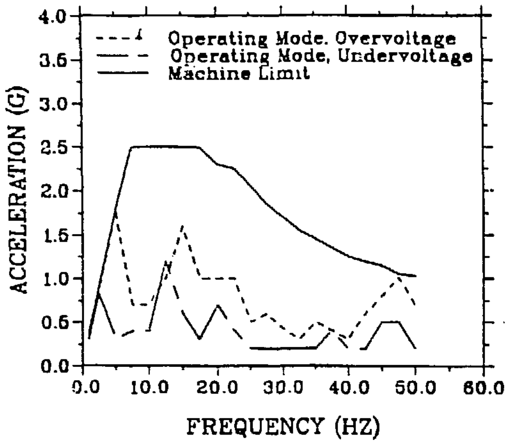

Figure 7: Sine Dwell Amplitude
Influence of Electrical Condition
IAV Relay, Vertical Direction

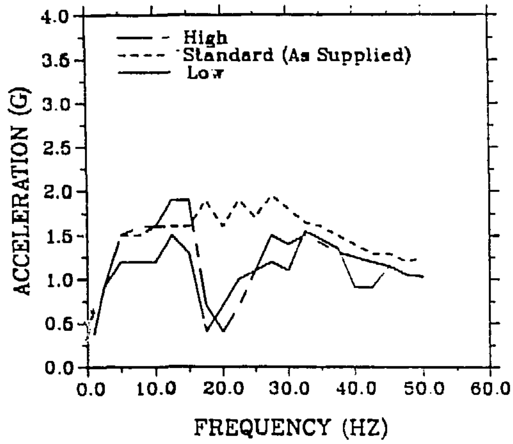

Figure 8: Sine Dwell Amplitude
Influence of Spring Tension Adjustment
HFA Relay, Nonoperating Mode, FB Direction

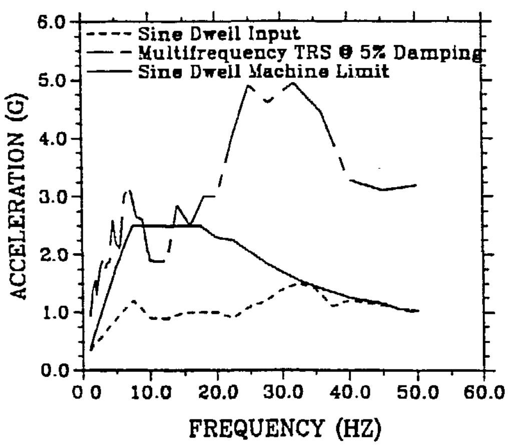

Figure 10: Correlation of Sine Dwell Amplitude
and Random Multifrequency TRS
SG Relay, Nonoperating Mode, FB Direction

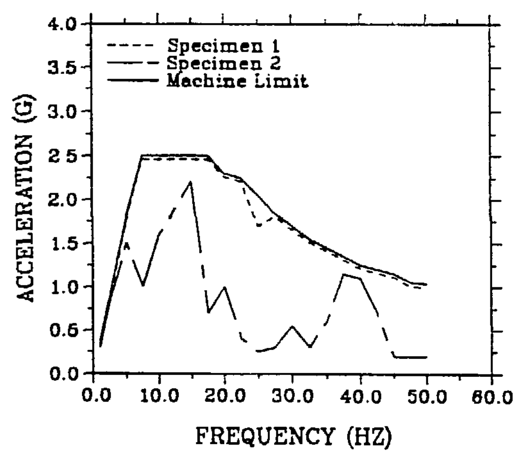

Figure 9: Sine Dwell Amplitude
Influence of Specimen Variation
HMA Relay, Nonoperating Mode
SS Direction