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Performance of Relays and Protection Equipment under Vibration Environment

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Abstract

Relays are the protection and switching devices in most of the control processes or equipment. Relays respond to one or more electrical quantities like voltage or current such that they open or close the contacts or circuits. Relays are subjected to vibration and mechanical shock due to operating environment, transportation, mishandling and earthquake. Operating environmental vibration and shock may result in spurious operation of relays. Understanding cause and effect of vibration on relay performance is paramount to ensure reliable functioning of relays. Relays should be designed for the anticipated operating environmental vibration and shock levels. Vibration and shock qualification is performed to determine if a product can withstand the rigors of its intended use environment, to insure the final design will not fall apart during shipping, for environmental stress screening and to weed out production defects. CPRI is equipped with state-of-the-art facilities to qualify equipment and components for vibration and shock conditions. Performance of relay under vibration environment is discussed in this paper.

Keywords: Resonance Frequency, Shock, Vibration

1. Introduction

Vibration is mechanical oscillation about a reference position. Vibration is described by three factors: amplitude, frequency and the phase or timing of the oscillations relative to some fixed time. Vibrating system can be represented by mass, rigidity and damper. Frequency at which a system oscillates after initial excitation is the natural frequency of the system and it is specific for each system. Greater the mass and lesser the rigidity, lower will be the natural frequency. Oscillation amplitude diminishes in time until the system stops oscillating due to damping effect. Every equipment has its own natural frequency, the frequency at which a body vibrates due to its own physical characteristics (mass and stiffness) when the body is distorted in a specific direction and then released. Resonance occurs when the external forcing frequency coincides with the natural frequency of the system. At resonance, the amplitude of oscillation tends to increase indefinitely, and the structure is subjected to increasing deformation, which may cause failure. Malfunctioning of relay (chattering) usually occurs at the resonance frequency. Electrical equipment experience vibration and shock under following conditions:

a) Transportation
b) Environmental condition
c) Mishandling
d) Earthquake

Vibration due to transportation is random in nature. Mode of transportation may be road, rail or air, vibration and shock are induced in all the mode of transportation. Proper design of packaging can avoid failure of equipment during transportation.

Environmental condition vibration may be due to the equipment itself or vibration transferred from the surrounding environment. Equipment with moving parts generally generates vibration, equipment is expected to function normally under vibration and shock due to environmental conditions. Understanding the source and

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level of vibration is the primary requirement for design of any equipment/components. Based on the level of environmental vibration and shock, measures should be taken to design and qualify the equipment. This will ensure quality of product. Careful designs usually minimize unwanted vibrations generated by equipment during its regular process. In addition to careful design, proper installation of rotating machines and maintenance can minimize the unwanted vibration.

Earthquake is a natural event causing vigorous ground shaking. Seismic waves results in a complex multi-frequency vibratory ground motion, having both horizontal and vertical components.

Vibration in mechanical systems is a destructive and annoying side effect of a process. Hence it is required to study the source of vibration and reduce or avoid vibration. In addition to level of vibration, information about frequency of vibration is also required for designing of product. Avoiding equipment natural frequencies falling in the frequency range of environmental vibration can protect the equipment. But it is not always possible to avoid resonance in most of cases. Amplification of vibration due to resonance and damping should be considered during design. In case required, option of providing additional external damper can be explored. Anti-vibration pad can be used to reduce the level of vibration being transferred to the product. Proper selection of anti-vibration pad based on frequency range of vibration and natural frequency of system should be made to avoid vibration being transferred to the equipment. Anti-vibration pad having natural frequency in the range of natural frequency of equipment will worsen the condition.

Vibration and shock test is carried out to determine any mechanical weakness and/or degradation in the specified performance of relays and protection equipment and to use this information, in conjunction with the relevant specification, to decide upon the acceptability of the specimens. In some cases, the test method may also be used to demonstrate the mechanical robustness of specimens and/or to study their dynamic behaviour. Vibration and shock testing of relays and protective equipment will ensure suitability for the required environment, hence reliable and safe power supply is ensured.

Earthquake Engineering and Vibration Research Centre of CPRI, Bengaluru is equipped with state of art test facility for vibration, shock and seismic qualification requirements on equipment, sub-assemblies and components as per National and International standards. Performance of relay under vibration and shock environment is covered in this paper.

2. Relay Performance

Mechanical integrity of relays under vibration and shock environment can be determined by finite element analysis. Finite element analysis is usually carried out at the initial design stage. Functional aspects of relay can be evaluated only by actual testing. Hence performance evaluation of relays by actual testing is recommended in National / International standards. By subjecting the relays to vibration and shock environment using vibration system, mechanical integrity and functional aspects can be assessed for various severity levels. Real time vibration and shock environment can also be simulated to check relays and protection equipment capability to perform its function without any spurious operation.

Electromechanical type relays with coil and moving contacts are more likely to malfunction in vibration and mechanical shock environment. Change in state of relay contacts due to vibration and shock will result in false alarm / tripping. Change in state of relay contacts and duration of change in state depends on acceleration level, frequency of vibration and also direction of vibration. In case of electromechanical type relays, vibration along the contact moving direction will have comparatively more harmful effect. Absence of moving contacts makes solid state relay comparatively less vulnerable to vibration and mechanical shock. In case of solid state relay every component should be capable of withstanding the required level of vibration. Methods of component mounting play a vital role in withstanding vibration dynamic load, hence it should be taken into consideration at the design stage. Mounting of printed circuit board and location of components in the printed circuit board should be decided by considering vibration and mechanical shock load. Usually heavier components in printed circuit board are located closed to printed circuit board fixing point.

3. Codal Recommendation

Relays and protective equipment are subjected vibration qualification as per IEC 60255-21-1, shock and bump as per IEC 60255-21-2 and seismic qualification as per IEC 60255-21-3.

Severity levels for vibration and shock qualification are to be selected based on applications. Three test severity classes are specified in the standard, class-0, class-1 and class-2. Class-0 refers to the environment were relays and protective equipment are not experiencing any vibration and shock, hence no vibration and shock testing is required. Class-1 severity is applicable to the measuring relays and protective equipment for normal use in power plants, substation and industrial plants and normal transportation conditions. Class-2 severity is applicable to the measuring relays and protective equipment for which a very high security margin is required or where the vibration and shock levels are very high and for severe transportation conditions. Sinusoidal vibration and half sine shock pulse are recommended in the standard.

4. Vibration Qualification

Most of the real world vibration is random in nature with broadband of frequency. IEC 60255-21-1 standard recommend sinusoidal vibration to assess relays and protection equipment suitability for the intended environmental condition. Vibration and shock conditions are simulated using electro dynamic shaker system.

4.1 Mounting

Relays and protection equipment should be fastened to the electro dynamic shaker system or fixture by its normal means of attachment in service, such that the gravitational force acts on it in the same relative direction as it would in normal use. Usually relays are mounted on suitable fixture to simulate actual mounting condition and the fixture is fastened to the vibration system. Rotating of test specimen for testing in three mutual perpendicular axes is not recommended. Fixtures used to simulate actual mounting condition should be rigid and should not have resonance in the frequency band of interest. Fixture resonance will amplify the input vibration excitation and may result in failure of test specimen. Hence fixture design is very important for any vibration testing, with basic requirement of rigidity and no resonance in the frequency band of interest. Typical relay mounting fixture mounted on electro dynamic vibration table is shown in Figure 1.

4.2 Resonance Search Test for Fixture

Fixture is subjected to resonance search test by base excitation method. Resonance search test is carried out by sinusoidal swept vibration with low vibration level. Acceleration level is maintained constant and frequency is swept over the frequency range of interest, usually at 1 octave/minute. Resonance search test is carried out with constant acceleration of 10 m/s^2, for frequency range of 10 to 150 Hz in all three mutually perpendicular axes. During this test response accelerometer were mounted on fixture as shown in Figure 1. Response acceleration and table excitation are used to compute resonance frequency. No resonance was found in the frequency range of 10 to 150 Hz in all three mutual perpendicular axes, hence fixture is rigid and can be used for vibration testing of relay.

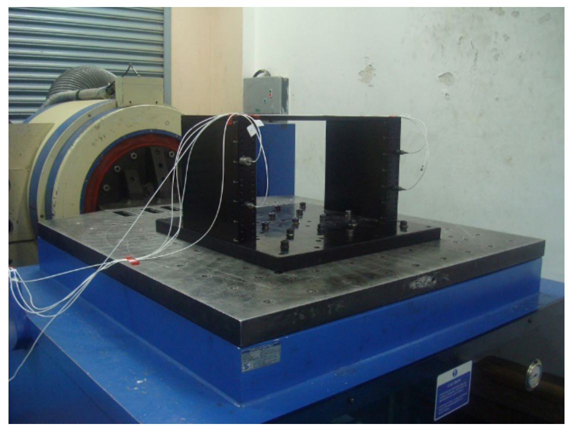

Figure 1. Typical fixture for relay mounting.

4.3 Vibration Response Test

4.3.1 Functional Check

Relays and protection equipment performance is checked by carrying out accuracy test and operating characteristics test before and after vibration response test.

4.3.2 Vibration Simulation

Vibration response test is carried out on a measuring relay or protective equipment, energized under specific conditions, to determine its response to normal service conditions. This test is performed by swept sinusoidal vibration in the three different axes of the specimen with constant displacement acceleration over the frequency range of 10 to 150 Hz.

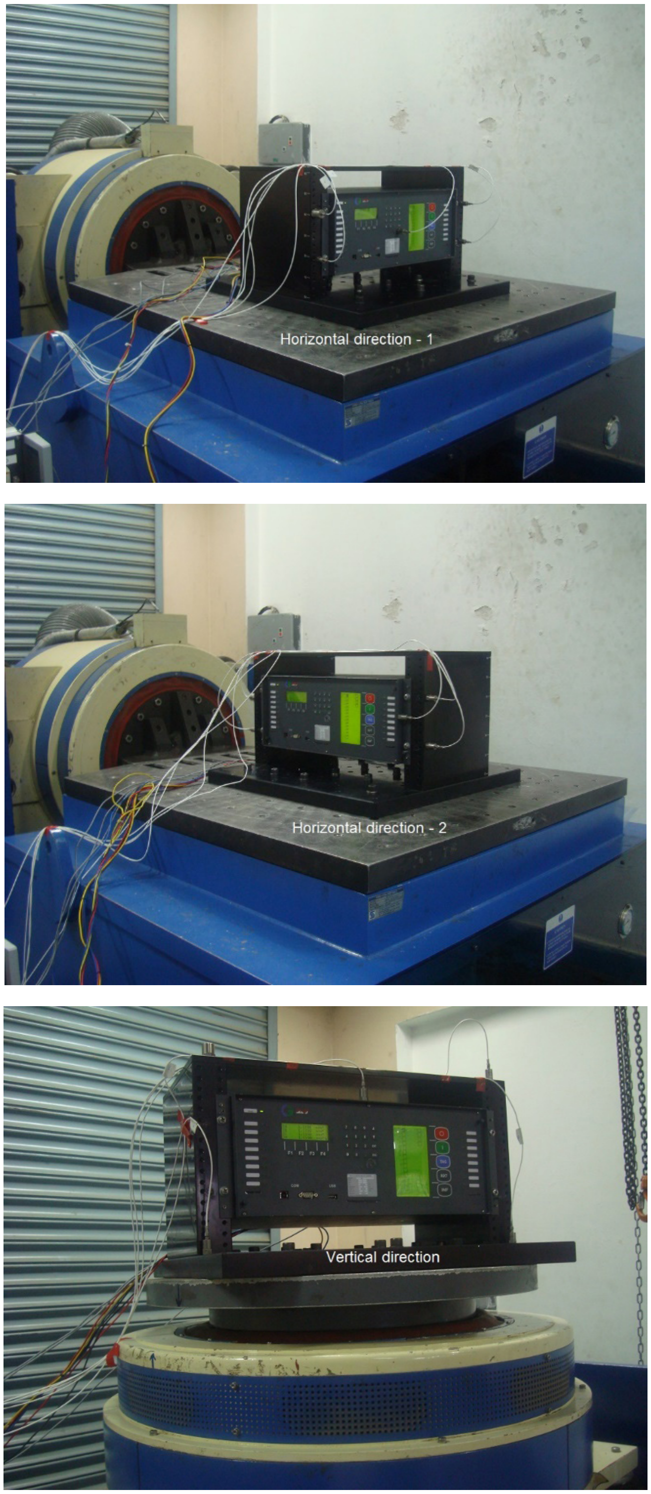

Figure 2. Relay test arrangement in three mutual perpendicular axes.

Vibration levels depends on severity class, for relays and protective equipment used in power plants, substation and industrial plants, constant peak displacement of 0.035 mm from 10 to 60 Hz and 5 m/s^2 acceleration from 60 to 150 Hz is recommended in the standard. Duration of test is one sweep cycle with 1 octave per minute sweep rate corresponds to a time of about 8 minute. Specimen requiring high security margin or mounted in high vibration environment peak displacement of 0.075 mm from 10 to 60 Hz and 10 m/s^2 from 60 to 150 Hz is recommended. During vibration response test, relays are kept in energized condition and operating value is set at highest sensitivity. Output circuit Normally Open (NO) and Normally Closed (NC) contacts are monitored for change in status using high speed data logger. Typical contact monitoring profile is shown in Figure 3. Typical vibration response test profile is shown in Figure 4.

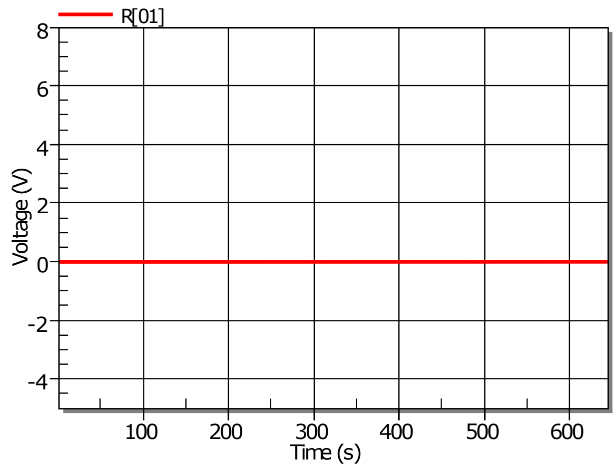

Figure 3. No contact monitoring profile.

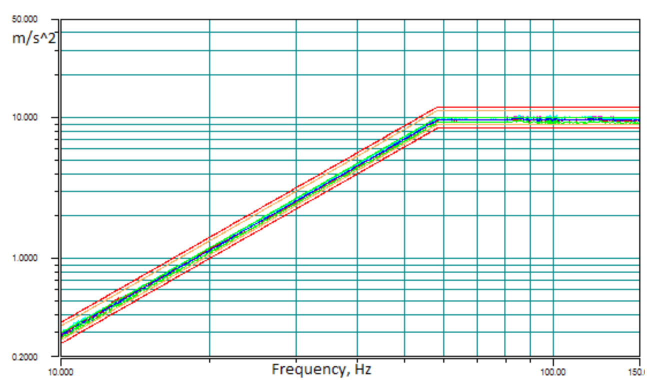

Figure 4. Vibration response test profile.

4.3.3 Acceptance criteria

During vibration test, the relay should not mal-operate. Change in status of output contacts for more than 2ms is considered as mal-operation. Acceptable limit for duration of change status of contact depends on system requirement. Specimen should perform its function as per relevant specification, before and after vibration test. Relay should not have any physical damage.

4.4 Vibration Endurance Test

4.4.1 Functional Check

Relays and protection equipment performance is checked by carrying out accuracy test and operating characteristics test before and after vibration endurance test.

4.4.2 Vibration Simulation

Vibration endurance test is carried out on a non-energized measuring relay or protective equipment, with higher vibration levels than in normal service conditions, as an accelerated life test to simulate long-term vibration. This test is performed by swept sinusoidal vibration in the three different axes with constant acceleration over the frequency range of 10 to 150 Hz. Vibration levels depends on severity class, for relays and protective equipment used in power plants, substation and industrial plants, constant acceleration 10 m/s^2 from 10 to 150 Hz is recommended in the standard. Duration of test is 20 sweep cycles with 1 octave per minute sweep rate corresponds to a time of about 160 minute. Typical vibration endurance test profile is shown in Fig.5.

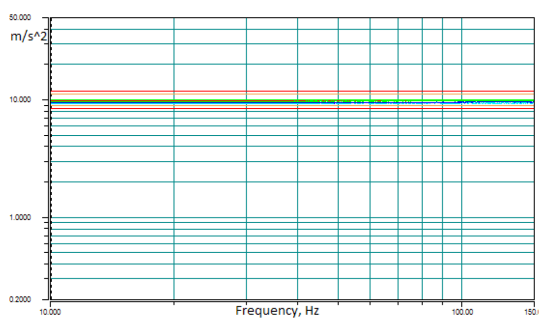

Figure 5. Vibration endurance test profile.

Specimen requiring high security margin or mounted in high vibration environment acceleration of 20 m/s^2 from 10 to 150 Hz is recommended.

4.4.3 Acceptance Criteria

Specimen should perform its function as per relevant specification, before and after vibration test and should not have any physical damage. Accuracy of setting (start) value for Phase instantaneous overcurrent unit before and after endurance test are shown in Table 1 and Table 2.

Endurance test is carried out with higher vibration level than in normal service conditions as an accelerated life test, change in accuracy of setting (start) value before and after vibration endurance test is marginal and is within claimed value, and hence relay is qualified.

Table 1. Accuracy of setting (start) value for phase instantaneous overcurrent unit before endurance test

IED setting (A AC)	Measured start value (A AC)	Claimed start value (A AC)
0.01	0.013	0.000 – 0.020
0.15	0.158	0.147 – 0.167
0.30	0.317	0.305 – 0.325
0.60	0.628	0.611 – 0.648
0.90	0.946	0.916 – 0.973
1.50	1.575	1.527 – 1.622
3.00	3.148	3.055 – 3.244
9.00	9.452	9.166 – 9.733
18.00	18.898	18.33 – 19.46
30.00	31.496	30.55 – 32.44

Table 2. Accuracy of setting (start) value for phase instantaneous overcurrent unit after endurance test

IED setting (A AC)	Measured start value (A AC)	Claimed start value (A AC)
0.01	0.014	0.000 – 0.020
0.15	0.158	0.147 – 0.167
0.30	0.317	0.305 – 0.325
0.60	0.628	0.611 – 0.648
0.90	0.945	0.916 – 0.973
1.50	1.574	1.527 – 1.622
3.00	3.148	3.055 – 3.244
9.00	9.452	9.166 – 9.733
18.00	18.950	18.33 – 19.46
30.00	31.500	– 32.44

5. Conclusions

Electrical equipment is exposed to vibration and shock in the operating environmental condition and during transportation. Understanding the environmental condition vibration level and frequency band is very important for design purpose. Designing equipment for operational environmental vibration and transportation vibration can ensure reliability of equipment during its life span. Vibration qualification can also be used as accelerated screen testing. Relays and protective equipment being important component in electrical power system, reliability and safety of electrical power system can be ensured by considering environmental vibration condition as one of the design parameter in addition to basic electrical performance parameters.

6. Acknowledgement

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