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Vibration and Seismic Qualification of Products and Equipment

Vibration analysis and testing helps to accelerate progress in many industries, including aerospace, automobile, Electrical equipment manufacturing, power generation, defence, consumer electronics and telecommunication. Vibration tests are carried out to identify and eliminate unwanted vibration to improve product quality and durability. Many standards have been evolved over the years to prescribe suitable test procedures for qualifying the finished products and equipment. Earthquake Engineering and Vibration Research centre (EVRC) is equipped with state-of-the-Art facilities to carry out vibration and seismic tests according to the National and International Standards.

1.0 INTRODUCTION

Vibration is mechanical oscillation about a reference position, resulting from the application of oscillatory or varying forces to a structure or an equipment. The oscillation may be continuous during some time period of interest or it may be intermittent. It may be periodic or non-periodic, i.e., it may or may not exhibit a regular period of repetition. Vibration is an everyday phenomenon; experienced in homes, during transport and at work. Vibration is often a destructive and annoying side effect of a useful process, but is sometimes generated intentionally to perform a task.

One of the best tests for quality when dealing with important equipment is the use of vibration, which includes shaking, shocking, or dropping certain components to ascertain how well they stand up during distressing conditions. Vibration test labs provide proof of component quality, according to national and international standards, in a variety of applications. In the laboratory test engineer simulate different types of vibration: for example, Test engineer simulates rough road conditions that are similar to what the equipment may experience during shipment. Other considerations include acceleration, velocity, and the product's characteristics and structure. Simulation of vibration in the laboratory requires a suitable shaker system, which employs many technical devices and sensors for measurement. Electro-dynamic shakers are used widely for vibration testing.

Seismic testing commonly known as Earthquake testing is similar to vibration testing with a frequency range between 0.1 Hz and 50 Hz. When equipment or Instruments are expected to withstand seismic events, then design engineers consider the forces induced during seismic events in addition to other design forces. Finally the designed equipment or instrument is subjected to earthquake testing as per the relevant standards for qualification. Earthquake testing is commonly specified by Required Response Spectra (RRS) as the tests are typically simulating events that are over in 30 seconds but involve large displacements at low frequency. Since earthquake testing involves excitation with a much bigger displacement (up to 300 mm peak to peak), servo-hydraulic systems are used.

2.0 EARTHQUAKE ENGINEERING AND VIBRATION RESEARCH CENTRE (EVRC)

Earthquakes are the result of a sudden liberation of energy accumulated at the geological faults. The consequences of earthquake events are well known to the public – thousands of peoples are killed or injured each year, thousands are homeless, heavy damage to the building stock, complete disruption of the infrastructure, irreversible

damage to the cultural heritage, very large indirect costs resulting from business interruption, loss of revenues, interruption of industrial production. Post earthquake reconnaissance has identified equipment of substations being particularly vulnerable to severe earthquake shaking. The major causes of outages during past earthquakes were the catastrophic failures of circuit breakers, transformer bushings and disconnect switches at the substations.

A need for reliability of electrical equipment and their supporting structures against vibrational hazards due to earthquakes has become prime importance. In order to meet the basic requirements regarding seismic qualification of equipment and thereby to ensure reliable power transmission, Earthquake engineering laboratory capable of performing a diverse range of seismic qualification requirements on equipment, sub-assemblies and components as per National and International standards has been established at CPRI, Bangalore.

EVRC tests finished products or components using shock, sine and random vibration, or other dynamic test conditions. Typically, it performs a battery of tests in accordance with National and International Standards (BIS, IEC, IEEE, IBC), published standards from organizations such as Underwriters Laboratories (UL) and the International Standards Organization (ISO). EVRC tests many types of parts, products, systems and facilities. Examples include aerospace and avionics equipment, automotive parts, building products, consumer appliances, electronics and microelectronics, electrical distribution devices, industrial equipment and machinery, and instrument sensors. It also tests valves and pumps, plumbing and lighting, pneumatic and hydraulic systems, health care and medical devices, battery and energy products, and laboratory equipment. Guidelines of Standards for vibration and Seismic qualification of products and equipment are briefly presented in this paper.

3.0 VIBRATION TESTING

Vibration is a major cause of machine and plant downtime, as well as a safety concern. Three main reasons for carrying out Shock and vibration tests are to ensure:

1. Reliability
2. Functionality and
3. Structural integrity.

The equipment, Instrument or any product is expected to be reliable, to continue to function correctly and not to fall apart. Even equipment that is permanently fixed in one place needs to withstand vibration during its lifecycle. The four stages in the lifecycle of an equipment or product when it has to withstand vibration are:

- *Manufacture/Assembly*: whilst the equipment is being manufactured, circuit components are often subject to shock and vibration. Sometimes they may be dropped on the assembly bench.
- *Transportation*: when the equipment is being transported, must withstand vibration, shocks and drops. The equipment is subjected to the greatest mechanical stresses.
- *Installation*: equipment that must be installed needs to withstand manual handling
- *Service environment*: the environment in which the equipment must operate. The Equipment may be expected to with stand track vibrations, shock, gearbox induced vibration, handling and drops depending on the environment.

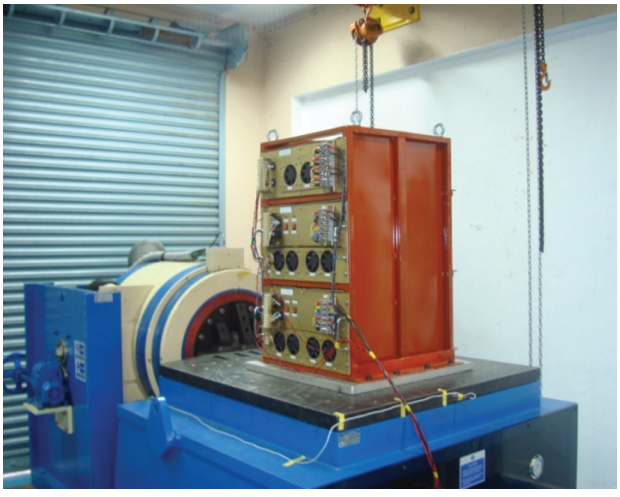
4.0 VIBRATION TESTING EQUIPMENT

Electro-dynamic shakers are typically used for higher frequency vibration testing. The frequency of vibration is normally between 5 Hz and 5000 Hz. Vibration testing is the shaking or shocking of a component or assembly to see how it will stand up to real world conditions. If one is designing, developing or producing a component or product, for example, an energy meter, a relay, a circuit board for a mobile phone, a car or a plane, it probably has to fulfil specific national and international standards, such as DIN, ISO, BS, MIL, IEC, IEEE and ASTM. One can establish proof of quality according to these

standards by performing vibration testing with use of a vibration exciter. This can be done by simulating the components' natural environment with help from a controller, a climatic chamber and different accessories for the exciter. A lot of different vibration tests can be performed on products, including Quality Assurance tests, Durability test, Stress and strain, Reliability test and Modal analysis. Dynamics laboratory of EVRC is equipped with two Electro-dynamic shaker systems. These vibration systems are capable of simulating the following types of vibrations recommended in various National and International Standards.

1. Sinusoidal Vibration
2. Random Vibration
3. Sine Sweep Test
4. Sine on Sine
5. Sine on Random

In addition a servo-hydraulic vibration test system is installed in this centre to carry out low frequency endurance and seismic tests on products and equipment in one axis at a time. This facility is extensively used to qualify equipment for Railways, Automobile and Electronic Industries.



VIBRATION TEST USING ELECTRO DYNAMIC SHAKER

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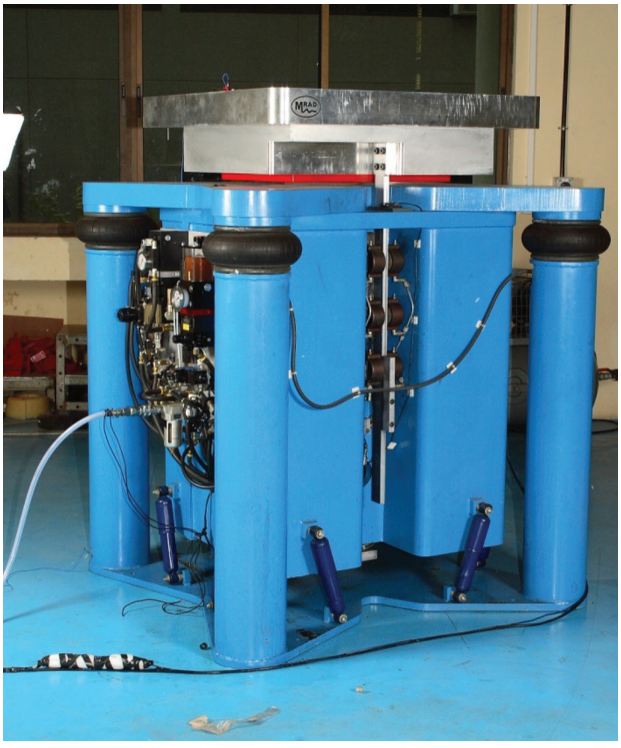
SERVO-HYDRAULIC TEST SYSTEM

5.0 MECHANICAL SHOCK TEST SYSTEMS

Shock tests are used to accurately measure the fragility of products and to evaluate how they respond when subjected to a particular shock input. Shock test data is key information necessary to ensure any product is capable of withstanding its intended "real world" use. The Mechanical Shock Test is a test performed to determine the ability of devices or products to withstand moderately severe shocks resulting from suddenly applied forces or abrupt changes in motion encountered during mishandling, improper transportation, or field operation. Shocks of this type can cause devices to degrade in performance, or to even get damaged permanently. Shock pulses that are repetitive can also cause damage that is similar to those caused by extreme vibration. A shock testing machine is installed in this centre is capable of performing half sine, trapezoidal and saw tooth waveforms Table size is 100 cm × 100 cm.This is a PC controlled equipment with built-in calibration facility withmaximum Pay load of 300 kg and shock level up to 300 g. The mechanical shock testing machine is mounted on a sturdy and levelled surface. During testing, the

test specimen is rigidly mounted or restrained by its case or body, with ample protection for the leads. The specimen is subjected to stipulated number of shock pulses, with the peak intensity and duration of the pulses complying with those defined by the specified test condition, in each of the following orientations:

X1, X2, Y2, Y1, Z1 and Z2.



SHOCK TESTING MACHINE

6.0 DROP TESTING

Drop testing is performed to determine the ability of equipment or products to withstand abrupt changes in motion and suddenly applied forces. It has direct applications for any materials that will potentially be dropped or mishandled in transportation or by end consumers. Common products that are tested include printed circuit boards for cellular telephones, personal digital assistants, and handheld GPS units. However, this testing is not limited to these handheld devices. Any circuit board, product, device, or casing can be tested for reliability and durability. There are several standards for drop testing. JEDEC Standard JESD22-B111, "Board Level Drop Test Method of Components for Handheld Electronic Products," is one of the widely used standards.

DROP TESTING MACHINE

7.0 ENVIRONMENTAL TEST

Environmental chambers are used to test the effects of specified environmental conditions on industrial products, materials, and electronic devices and components. Environmental chambers help evaluate product quality and reliability, and identify manufacturing flaws and weaknesses. By simulating environmental conditions within a contained space, the chamber offers test results that can show the process of product decay and degradation and help predict the potential lifespan of a product or material.

This chamber is used as a stand-alone test for environmental effects on test specimens. An environmental test chamber artificially replicates the conditions under which machinery, materials, devices or components might be exposed. It is also used to accelerate the effects of exposure to the environment, sometimes at conditions not actually expected. These conditions include extreme temperatures, extreme temperature variations, moisture or relative humidity and electrodynamic vibrations.

Manufactured samples, specimens, or components are placed inside the chamber and subjected to

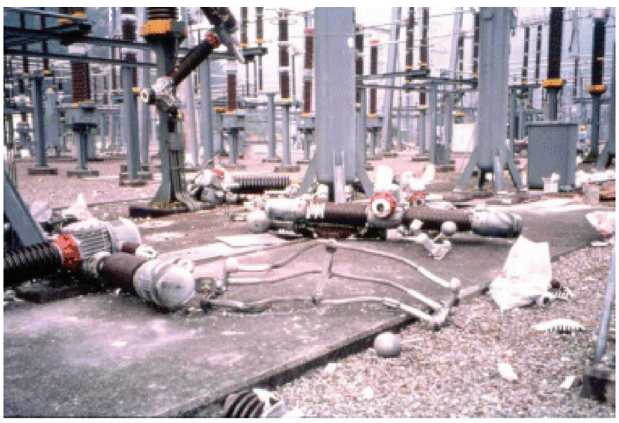
one or more of these environmental parameters to determine reliability or measure after-effects. In this chamber temperature can be varied from –70°C to 180°C with a maximum at the rate of 10°C/min. The humidity can be varied from 10–98 %.

ENVIRONMENTAL CHAMBER

8.0 NEED FOR EARTHQUAKE TESTING

Although earthquakes are not very frequent, they generally have significant energy content at the lower frequencies (0.1–33 Hz) in critical applications where failure can be disastrous (e.g. nuclear power plant) or expensive (e.g. Telecommunications equipment). The equipment or products designed for installation in seismic prone zones need to be tested for earthquake loading using shake Table. Safety considerations and demands for higher reliability are not the only factors that are increasing the need for testing. Engineers are also realizing that modelling seismic response is often not sufficient for electronic/ electrical systems. Modelling will predict if a structure can withstand an earthquake, but will give no guarantee of continued operation during or after a seismic event. Many products which have traditionally undergone standard vibration testing are now also being specified against earthquake tests, as the characteristics of the two tests are significantly different.

The IEEE Standard 693, "recommended Practice for Seismic Design of Substations" clearly defines seismic qualification levels, qualification procedures, and acceptance criteria. Earthquakes with zero period acceleration of 0.1 g can cause severe damage to the substation equipments. The IEEE Standard 693 recommends that sites with projected ground motions above 0.1 g should have their equipment seismically qualified. Thus power utilities with service areas in seismic Zone-III, IV and V (according to the IS 1893:2000) should have their substation equipment seismically qualified. One of the most effective ways of reducing earthquake damage for new installations is to use equipment that has been seismically qualified.



Damage like this has been observed from ground motions less than 0.1 g.

DAMAGE OF SUBSTATION EQUIPMENT

8.1 SHAKE TABLE TEST

The seismic qualification of equipment should demonstrate equipment's ability to perform its safety function during and after the time it is subjected to the forces resulting from earthquakes. The most commonly used methods for seismic qualification are grouped into four general categories that

- Predict the equipment's performance by analysis
- Test the equipment under simulated seismic conditions
- Qualify the equipment by a combination of test and analysis

- Qualify the equipment through the use of experience data

The most natural testing concept is the use of a shaking table. The equipment to be tested is fixed to a moving platform called shaking table to which a motion history representative of past seismic events or artificial time history is applied. The test on a shaking table has the advantage of being dynamically similar to a real earthquake event. Seismic ground motion occurs simultaneously in all directions in a random fashion. However, for test purposes, single-axis, biaxial and tri-axial tests are allowed. If single-axis or biaxial tests are used to simulate the three-dimensional environment, they should be applied in a conservative manner to account for the absence of input motion in the other orthogonal direction(s). The simulation if only in single or biaxial then the tests need to be done mounting the specimen along different axes and hence many a times the specimen fails due to fatigue. Among different methods recommended in the relevant codes, tri-axial test is the most suitable since earthquake produces random motions simultaneously in all three directions. Earthquake Engineering Laboratory of CPRI has a state-of-the-art tri-axial shaker system for earthquake simulation.

8.2 TRI-AXIAL SHAKER SYSTEM AT CPRI

Earthquake engineering laboratory housing the tri-axial shaker system with six degrees of freedom, capable of performing a diverse range of seismic qualification test requirements on equipment, sub-assemblies and components according to the National/International standards had been established at Central Power Research Institute, CPRI, Bangalore in the year 2003. The tri-axial shaker system consisting of a shaking-table is a unique facility only one of its kind in India that can strictly simulate the earthquake ground motion without any distortion.

The shaking table can vibrate in one axis to three axes with six degrees of freedom. The advanced control system allows the reproduction of earthquake ground motions with high fidelity and little distortion. The seismic qualification tests on various electrical equipments are being conducted using the tri-axial earthquake simulation system, which features a 10-ton pay load capacity shake table of size 3 m × 3 m. An advanced control system allows the reproduction of earthquake ground motions with high fidelity.

SHAKE TABLE TEST ON A CIRCUIT BREAKER

9.0 OTHER FACILITIES

This centre is equipped with the following facilities:

Uni-axial Actuator with Digital Controller: This system is effectively used to test lighter and smaller electronic components/equipment for seismic loading in one axis at a time. This system is also used to carryout fatigue and dynamic characteristics tests on electrical/mechanical equipment and transmission line components weighing up to 100 kgs.

UNI-AXIAL ACTUATOR

1000 kN Universal Testing Machine: It is used to carry out tensile, compression, bending, hardness and shear tests on specimen of ferrous and non-ferrous materials, stranded conductors, cables, insulators, etc. Specimen can be tested according to the IS, BS, ANSI, ASTM and DIN standards.

UNIVERSAL TESTING MACHINE

Experimental Modal Analysis: It is a well-known method to determine the resonance frequencies, mode shapes and damping. CPRI is equipped with advanced LMS CADA-X modal analysis software and test system for carrying out modal analysis on test specimen.

Non-contact type Laser Vibrometer: It is used to measure the two-dimensional distribution of vibration velocities on test equipments on the basis of laser interferometry, especially when the specimen needs to be tested under energized condition in which conventional transducers cannot be used. The measurement data is digitally recorded in the Workstation. The software controls the data acquisition and analyses the same.

LASER VIBROMETER

Field Vibration Measurement: Portable vibration analyzer, Impulse hammer kit, Transducers and portable vibration data acquisition system are available to carry out vibration measurement in the field.

Workshop facility: minimum workshop facilities like welding generator, drilling and grinding machines for fabrication/modification of fixture are available.

Material handling facilities: The laboratory is equipped with 15 Ton EOT crane, fork lifts (5T and 1T capacity) and adjustable height hydraulic mobile platform for mounting transducers and inspection of test specimen.

INSULATOR TESTING AT EVRC

10.0 CONCLUSIONS

To carryout stipulated vibration and shock tests and properly analyze the results of these tests, *always* a great deal of engineering judgement and expertise are required. EVRC is equipped with the–state-of-the–art test systems to carry out shock, vibration and Environmental tests according to the National and International Standards.

Earthquake Engineering laboratory, a unique facility with Tri-axial Seismic Shaker system established at CPRI acts as a national centre for research, testing and certification in the field of earthquake engineering. Shake table tests are carried out on industrial components and structures for nuclear applications, railways, electronic, telecommunication and automobile industries etc. EVRC offers the customers, access to Research and Development facilities in the above areas and multi-disciplinary expertise

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