Transformer Shipping Handbook

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Technical and purchase guide for impact recorders. Learn how to reduce transformer-shipping risks and manage insurance claims better.

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Why use this handbook?

1. Improve your undersanding of impact recorders.
2. Select and order the right product for your applications.
3. Improve your knowledge of transformer shipping care.
4. Includes a free copy of technical article presented at IEEE.
5. Learn how to interpret shock recorder data as per DIN EN 13011 and identify transformer damage.
6. Approximate fragility level for transformers based on their weight

Our Customers

- BHEL
- ABB
- Siemens
- Areva
- Schneider
- Voltamp
- Vijai Electricals
- TELK
- Aditya Vidyut
- Mahati Electricals
- PEL
- Skipper Electricals
- ECIL
- Technical Associates
- Tesla Transformers

Product Selection

MoniLog MicroShockDetector (MSD)

Low cost solution for projects that are cost sensitive.

Transformer Weight: < 50 Tons

MoniLog SDC

Predict transformer damage accurately with DIN EN13011 analysis.

Transformer Weight: 50+ Tons

MoniLog EnDal Smart

Predict transformer damage accurately with DIN EN13011 analysis. Track GPS location and transformer tipping.

Transformer Weight: 50+ Tons

Transformer Shipment Monitoring

During transportation if a transformer experiences a mechanical shock more than the suggested “g” level, then the following damages may occur:

- Windings/core may get displaced or distorted.
- Damage to insulation can occur due to movement of the active part. This can lead to a short circuit and damage to the windings later during operation.
- Mechanical vibrations may cause loss of windings clamping pressure. This can eventually lead to collapse of the windings during electrical faults.
- The safe clearance between the tank and the active part may get compromised.

We can categorize these issues as following:

- **Visible Damage:** Leading to on site or factory repairs
- **Concealed Damage:** Causing out of warranty failure

During Loading, Unloading and Rigging: Generally low occurrence but with the potential of high magnitude impact (like lifting gear failure, dropped transformer). Shock events from 2.5 to 10.0g in 2-20 Hz band experienced.

Onboard a Trailer: Impacts in longitudinal axis during braking operations and vertical and lateral shocks due to road conditions. Normally acceleration from 0.5 to 1.0g in 3-350 Hz band experienced.

Onboard a Ship: Rolling, Pitching and Yawing; low frequency vibrations repeating at regular periods. Normally acceleration from 0.3 to 0.8g in 2-30 Hz band experienced.

Onboard a Rail: Impacts in longitudinal axis during shunting operations and vertical shocks due to rail joints. Normally acceleration from 0.5 to 1.0g in 2-500 Hz band experienced. During shunting operations, the transformer can experience acceleration of up to 4.0g in 2-20 Hz band.

Mechanical Shock and Damages

A mechanical **shock** or **impact** is an event that damages the transformers due to excessive and sudden acceleration. A shock has an **amplitude** (the maximum value of the occurring acceleration or deceleration) and **duration**. *Figure 1* shows acceleration plotted over time t, the acceleration scale is in units of "g" where $g=9.8m/s^2$.

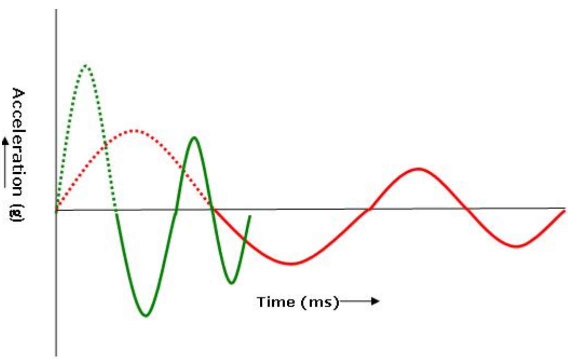

Figure 1: Mechanical Shock Pulse

Why is a transformer more fragile, in terms of 'g', than a laptop?

During an impact, acceleration increases, reaches a maximum value and then decreases. When an elastic body such as a transformer hits a hard surface, it does not come to a sudden standstill. Due to the elastic properties of the transformer, it continues to move for some milliseconds. As the transformer slows down over an extended time interval, shock pulse dampens. The cause of the damage is the half sine portion of the shock pulse that has the maximum amplitude (marked as a dotted line in *Figure 1*).

If, however, a small hard steel ball hits the same wall with the same initial impact velocity, the impact duration is considerably shorter, but

maximum acceleration is higher (green curve in *Figure 1*). This means that for the same impact energy, a smaller mass achieves higher amplitude acceleration and shorter duration or higher frequency (f=1/T).
This is why large power transformers (>100T) are damaged between 2.5 to 5.0 g (2-20 HZ) band. While small equipments, like laptops, are damaged between 37 to 50g (2-250Hz). As compared to a laptop, for the same impact energy, a transformer reaches lower peak accelerations.

Damage caused by mechanical shock:

- Mechanical damage concealed or visible
- Geometrical distortion of winding/core
- Loss of coil clamping pressure
- Loss of Nitrogen gas pressure due to leaks
- Damage to accessories like radiators, bushing etc

Mechanical Vibrations and Damages

Vibrations are periodic oscillatory movements initiated by the most diverse causes. The complex transportation environment always results in frequency composition (frequency spectrum) with individual frequencies having different amplitudes. In road transport, the vibrations occur between 3 and 350 Hz. On board a ship vibrations between 2 and 33 Hz occur.

Vibrations are capable of exciting resonance vibrations or co-vibrations in other potentially vibrating bodies like transformers. When the natural frequency of a body (e.g. a transformer) coincides with the frequency of the inducing vibration resonance occurs. The body's natural frequency depends on its material properties such as mass and modulus of elasticity. The resonance frequency can be excited to such an extent that the destruction of the system ensues (resonance catastrophe). This resonance vibration has sufficiently large amplitude.

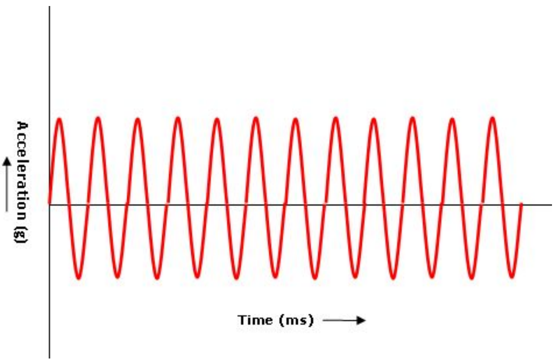

Figure 2: Vibration Pulse

Vibration can cause following damages:

- Loose Components
- Hardening of Metals
- Micro Cracks

Basics of Mechanical Shock Pulses

Mechanical shock pulses are sinusoidal waves. The damage potential of a shock pulse depends upon its:

- **Peak Amplitude**
- **Waveform**

The peak amplitude is measured in units of "g" where $g=9.8m/s^2$.The waveform is described in three ways and any one can be adopted for transformers:

- **Frequency**
- **Duration**
- **Velocity Change (ΔV)**

Frequency describes the time as compared to cycles per second and the unit of measurement is Hertz (Hz).

Duration describes the time as compared to seconds and the usual unit of measure is milliseconds (ms).

The mathematical expressions related to these two terms are:

Duration = (1 / Frequency) / 2
Frequency = (1 / Duration) / 2

Velocity change (ΔV) is the area under the acceleration time graph of the shock. It directly relates to the energy contained in the shock. The higher the velocity changes the higher the energy content.

Figure 3 shows a shock wave or an impact wave in time domain. The wave is a sine curve with acceleration in g ($g=9.8m/s^2$) along the y-axis and time in ms along the x-axis.

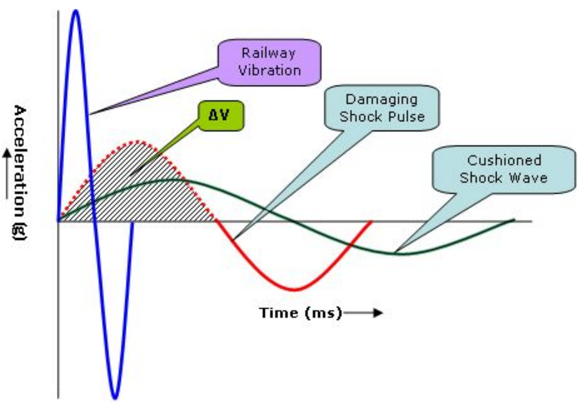

Figure 3: Shock pulse compared

There are two parts of a shock, which cause damage:

- **Peak amplitude (g)**
- **Velocity change (ΔV)**

Transformer damage occurs only when the velocity change is more than the ***critical velocity change***. Below the critical velocity change, no damage occurs regardless the input acceleration level. In essence, there is not enough energy in the shock to damage the transformer.

Exceeding the critical velocity change, however, does not necessarily imply that damage will occur. If the change in velocity occurs in a manner that it administers acceptable doses of acceleration to the product, the velocity change can be very large without causing any damage.

***"Damage occurs only if both, the velocity change (ΔV) and the peak acceleration amplitude (g) exceed their critical threshold*."**

In *Figure 3*, railway vibration (blue shock wave 2000g@0.1ms Amplitude=2000g & Duration=0.1ms Frequency: 500Hz) does not cause damage as the critical ΔV is not reached.

Whereas a drop from few inches (depending on the transformer weight, volume and nature of the impact surface) may produce a shock of 7g@50ms (red wave Amplitude=7g & Duration=50ms Frequency: 10Hz) and may damage the transformer.

Damage to a transformer occurs only when the **peak amplitude (g)** and the **duration** (or **frequency** or **velocity change (ΔV))** of the shock pulse simultaneously reach the damage threshold. These two together specify the damage criteria or **NOSS** (Non Operating Shock Specification) of a product. One can specify the fragility or NOSS of a transformer in the following ways:

1. In terms of critical **amplitude** and **duration** (E.g. 7g@50ms)

OR

2. In terms of critical **amplitude** and **frequency** (E.g. 7g@10Hz)

OR

3. In terms of critical **amplitude** and critical **velocity change** (ΔV) (E.g. 7g@2.18 m/s)

It is strongly recommended that the damage potential of a shock should be analyzed as per DIN EN 13011. Any one of the following frequency analysis may be used:

- FFT: Fast Fourier Transformation or Octave Analysis
- PSD: Power Spectral Density

Estimation of Transformer Fragility

The transformer fragility is dependent on its material properties, mass, volume and design. Due to transformer size and monetary value, it is impossible to establish its fragility using standard drop or shock table tests. Theoretically, one can calculate fragility by Shock Response Spectrum (SRS) analysis or in more detail using FEA analysis.

The best practical way of estimating transformer fragility is to analyze the historical records of impact record data in co relation with the damage that might have occurred during earlier shipments. Maintain a historical co relation table between shock and actual damage for different transformer design (MVA) or weight.

A general guideline based on empirical results, for transformer fragility (amplitude and ΔV) as a function of its weight is:

Weight of transformer (T)	**Fragility level (g@20Hz)**	**ΔV (Velocity change) (m/s)**
Up to 10 T	9	1.40
10-50 T	6	0.94
50-100 T	5	0.78
100-200 T	3	0.47
200-300 T	2.5	0.39
>300 T	2	0.31

Impact recorders should measure accelerations in three axes, with a recommended range of 0g to 10g. Impacts that exceed design criteria in any of the three axes may cause damage. Depending upon the design criteria, consider longitudinal impacts above 5g and between 2-20 Hz as rough handling.

Impact or Shock Recorders

Impact recorders are equipments that log shock value and the time of its occurrence. Use impact recorders to monitor shipments, like transformers, where concealed transit damage is a key concern. **The benefits of using Impact Recorders for monitoring transformers are**:

1. Determine if any mishandling (impact) during transit has caused a concealed damage.

2. Use the data to substantiate any insurance claims, as these recorders log the time of impact that might have caused the damage. The most modern loggers also record geographical location of impact via GPS.

3. Reduce warranty claims that may occur later during operations. Some of these claims occur due to concealed transit damage going unnoticed. These damages should have been identified before commissioning and damages covered under transit insurance – but the cost is borne by the transformer manufacturer under warranty due to transit damage going unnoticed.

4. Empirically calculate transformer fragility using the shock data collected over time and improve transformer designs.

5. Helps one decide if potential of transformer damage exists and whether to do more expensive tests, like FRA.

There are two types of Impact Recorders:

- Electromechanical Impact Recorders
- Electronic Impact Recorders, which are further categorized as:
  - Peak Acceleration Impact Recorders
  - Waveform Impact Recorders

Electromechanical Impact Recorders

These are the earliest form of impact recorders. They have been in use since a long time. They consist of a sensor attached to a mechanical recording arm, which registers the shock event on a moving paper chart.

Pros

- Been in use since a long time
- Widely understood

Cons

- Jamming or running out of paper
- Long length of paper to inspect and possible human error while interpreting data
- The data can be easily tampered
- Difficulty in determining the date and time when the impact occurred
- Cannot perform detailed frequency analysis to determine if damage has occurred or not
- Cannot maintain records in electronic form

Electronic Impact Recorders

The electronic impact recorders are of two types:

- Peak Acceleration Recorders
- Waveform Recorders

The **peak acceleration recorders** record only the amplitude of the shock and not the waveform. Though they are less expensive as compared to waveform recorders, they only provide half the information (amplitude) about the damage potential of the impact.

The **waveform recorders** record impacts that are above the threshold defined by the user (usually the transformer critical acceleration) in form of digital graphs. They provide complete information (amplitude and frequency) about the damage potential of the impact.

Take care of the following points when choosing an impact recorder for monitoring transformers. A wrongly, selected recorder will not provide sufficient data to estimate the transformer damage:

1. For large transformers use a waveform recorder that provides both amplitude and frequency data of the shock.

2. The recorder software should analyze the shock data in frequency domain as per DIN EN 13011.

3. Has minimum three months battery life to enable recording during the entire voyage.

4. It should have an option to attach an external GPS/GPRS device. This enables remote monitoring and tracking of transformers. This also acts like a physiological deterrent against mishandling.

Pros

- Impact data stored electronically in memory
- No moving parts to break or fail
- Date and time stamps for each major shock event
- Improved accuracy, usually within +/- 2%
- Instant verification if recorder is working and if it has exceeded preset thresholds
- Records multiple distinct events that occur consecutively and their exact time of occurrence
- Detailed event data which is very easy to understand and can be further analyzed for damage potential
- Long life and a good ROI
- Additional devices like GPS can be integrate for tracking

Cons

- Require training to properly set-up devices and analyze data
- Potential loss of complete data on electronic failure

Impact Recorder Data Analysis

Use the following two methods for analyzing shock data:

- Time Domain Analysis
- Frequency Domain Analysis

Time Domain Analysis

1. Analyzing shock amplitude and duration/frequency:

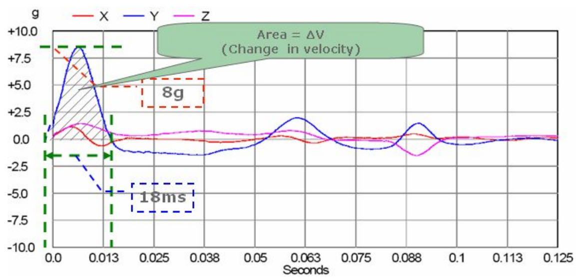

Figure 4: Impact recorded by an electronic impact recorder

Amplitude (a) = 8g
Duration (t) = 18ms or .018s
Frequency (1/2t) = 1/ (2 * 0.018) = 28 Hz
Shock of 8g@18ms or 8g@28Hz

The following conditions when simultaneously reached damage a transformer:

- The peak acceleration **exceeds** the critical acceleration
- The duration of the peak half sine curve **exceeds** the critical shock duration **OR** the frequency is **lower** than the critical frequency

Example: Take a hypothetical case of a transformer for which the fragility or NOSS is 7g@50ms or 7g@10Hz. The impact recorder attached to this transformer recorded a shock as shown in *figure* 4. As per the analysis explained earlier, the shock has a peak acceleration of 8g and a corresponding duration of 18ms or frequency 28Hz. The peak acceleration 8g is higher than the transformer critical acceleration of 7g. The duration of the peak acceleration is less than critical duration of 50ms. Analyzing in terms of frequency, the shock frequency of 28HZ is more than the critical frequency of 10HZ. Simultaneously not violating both the conditions (of critical acceleration and duration/frequency), the shock will not damage the transformer even though the peak acceleration is more than the critical acceleration.

2. Analyzing shock amplitude and velocity change:

The data can also be analyzed in terms of peak acceleration and critical velocity change. The method is the more accurate but is a little difficult to use as compared to the earlier method. It requires software tools to analyze raw data accurately. When the following two conditions occur together, they damage the transformer:

- The peak acceleration **exceeds** the critical acceleration.
- The velocity change corresponding to the peak acceleration **exceeds** critical velocity change for the transformer

Figure 4 represents the progression of a mechanical shock wave in time domain. Calculate the energy transferred to the transformer during the impact using the formulae:

$$E = \frac{1}{2} m \Delta v^2$$

Where:
m: Mass of the transformer
Δ***v***: Velocity change (area under the peak acceleration half sine curve)

The energy in the impact is converted into ductility and heat. In practice, mixed forms consisting of elastic and inelastic impacts arise. The progression of the acceleration in time can often be described approximately by the first half cycle of a sinusoidal oscillation. Consequently

$$\Delta V = \frac{2}{\pi} ta$$

Where:
t: Duration of shock wave

a: Peak acceleration

This applies that the decisive energy for the destruction by the impact is directly proportional to the square of the velocity change (ΔV) **or** the product of the maximum acceleration “**a**” and shock time “**t**”. This product “***ta***” with the dimension of "velocity" is known as the shock force. The maximum acting force, on the other hand, is in accordance with Newton's law, equal to the product of the maximum acceleration and mass.

$$F_{\max} = ma$$

Where:

m: Transformer mass
a: Peak acceleration

This force can be used to calculate dynamic loading on different components during design phase.

Limitations of Time Domain Analysis

- It cannot distinguish noise data from actual data.
- It cannot distinguish between aliased shock waves. Aliasing refers to an effect that causes different continuous shock waves to become indistinguishable when sampled. In this case, the distorted data recorded by the recorder may lead to false estimation of the potential damage.

Frequency Domain Analysis

The data recorded by the impact recorder may also be analyzed, for damage potential, in the frequency domain. The two methods used are:

- Octave Analysis or Fast Fourier Transformation (FFT)
- Power Spectral Density (PSD)

Octave Analysis or Fast Fourier Transformation (FFT) Analysis

This mathematical method analyzes the raw shock for its frequency composition (or octaves). The transformation breaks the shock data into amplitude and frequencies. It converts the raw time domain (amplitude and duration) data into frequency (amplitude and frequency) domain data. This enables identifying the frequency with maximum amplitude (or energy). The acceleration ‘g’ levels in the relevant frequency space can be compared with transformer NOSS.

E.g. if the transformer NOSS is 5g@20HZ, it should be compared with the amplitude of shock in frequency band of 0-20 Hz in the FFT curve (Amplitude Vs Frequency curve).

The FFT transformation of amplitude versus time shock curve (Figure 5) is amplitude versus frequency curve (Figure 6). It is best to perform octave analysis, as per DIN EN13011, with the shock recorder software (Figure 6.2).

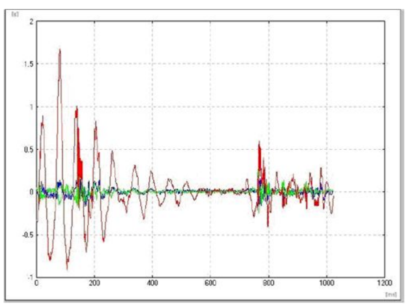

Figure 5: Raw time domain data

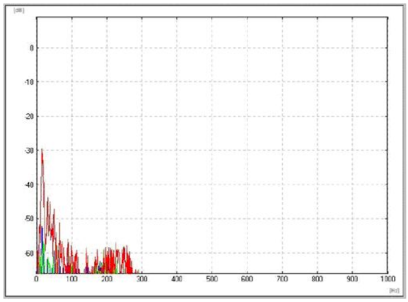

Figure 6: FFT- Fast Fourier Transformation

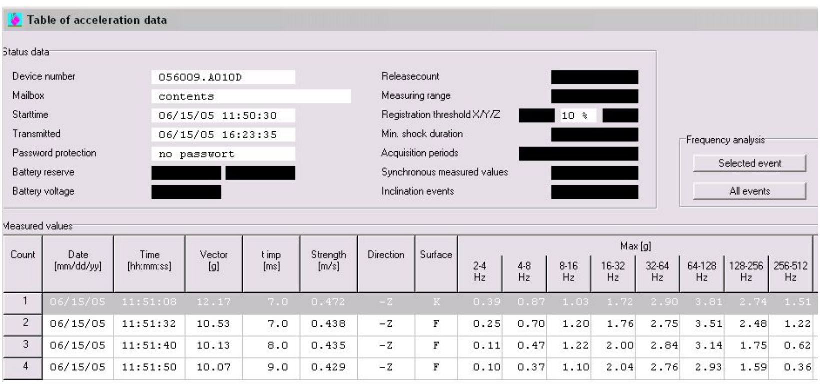

Table of acceleration data

Status data

Device number	056009.A010D	Releasecount	[redacted]
Mailbox	contents	Measuring range	[redacted]
Starttime	06/15/05 11:50:30	Registration threshold X/Y/Z	[redacted] 10 % [redacted]
Transmitted	06/15/05 16:23:35	Min. shock duration	[redacted]
Password protection	no passwort	Acquisition periods	[redacted]
Battery reserve	[redacted] [redacted]	Synchronous measured values	[redacted]
Battery voltage	[redacted]	Inclination events	[redacted]

Frequency analysis: Selected event / All events

Measured values

Count	Date [mm/dd/yy]	Time [hh:mm:ss]	Vector [g]	t imp [ms]	Strength [m/s]	Direction	Surface	Max [g] 2-4 Hz	4-8 Hz	8-16 Hz	16-32 Hz	32-64 Hz	64-128 Hz	128-256 Hz	256-512 Hz
1	06/15/05	11:51:08	12.17	7.0	0.472	-Z	K	0.39	0.87	1.03	1.72	2.90	3.81	2.74	1.51
2	06/15/05	11:51:32	10.53	7.0	0.438	-Z	F	0.25	0.70	1.20	1.76	2.75	3.51	2.48	1.22
3	06/15/05	11:51:40	10.13	8.0	0.435	-Z	F	0.11	0.47	1.22	2.00	2.84	3.14	1.75	0.62
4	06/15/05	11:51:50	10.07	9.0	0.429	-Z	F	0.10	0.37	1.10	2.04	2.76	2.93	1.59	0.36

Figure 6.2: DIN EN13011 Octave Analysis

The **power spectral density (PSD)**, describes how the power of the shock wave is distributed in frequency domain. Mathematically, it is the squared modulus of the FFT, scaled by a constant term.

Being power per unit of frequency, the dimensions are those of power divided by Hertz. The PSD data can be used to estimate damage potential of the impact. As shown in *Figure 7* the analyzed vibration has a high power density in the 10 - 20 Hz band and therefore a great potential for damage.

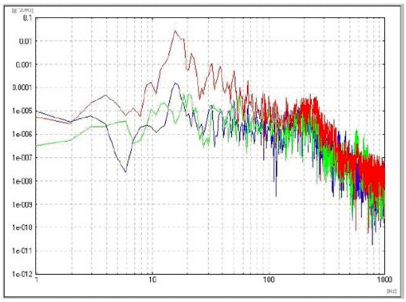

Figure 7: PSD- Power Spectral Density

Shipping Care

1. Design transformers that are able to withstand reasonable shipping forces expected during transit.

2. FOB site or foundation should be clear in supply contract. Most accidents occur during shifting of transformer to its foundation.

3. Find suitable impact recorders that record waveform data and have frequency analysis as per DIN EN 13011. Set them appropriately as per transformer NOSS; and mount them as low as possible on a rigid location. IEEE guidelines PC57.150 recommend using two recorders per transformer to eliminate chances of loss of data due to impact recorder failure. Mount these recorders on diagonally opposite positions for best results.

4. Perform the following tests:

    a. Capacitance measurements, FRA on HV side

    b. Earth to Winding Capacitance tests

c. Loss measurements on each tap to ensure the tap connections are properly made up

5. Increase internal bracing between the tank and the active part frame.

6. Provide additional support for the core from the frame.

7. Place desiccant inside the tank to maintain state of dryness.

8. Use of damping dunnage between transformer and bracing (*Figure 8*)

9. Use of proper lashing, refer to the IMO lashing code or AAR lashing guidelines. *Figure 9* shows a good cross lashing arrangement:

10. At least one dry air bottle must be there with the shipment

Figure 8: Dunnage to cushion shocks

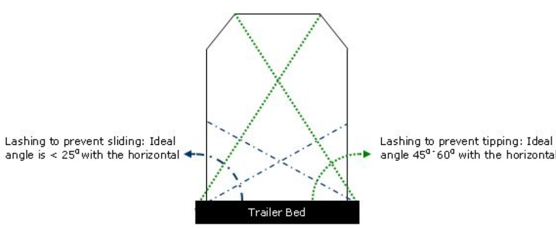

Figure 9: Proper lashing for tipping and sliding

11. Ask the logistics company or rigger to take care of the following:

    a. Proper consideration of SRT (Static Roll Threshold) reduces the risk of overturning. Refer to local guidelines on SRT.
    b. Maintain proper axle load distribution.
    c. Brake force distribution between tractor and trailer should be as per trailer manufacturer guidelines.
    d. Maintain proper trailer and tractor mass ratio.
    e. The vehicle must adhere to the designated route and not travel on a road if fog, heavy rain, hail or any other such factor restricts ambient visibility to less than 500 m.
    f. Use hydraulic trailers for large power transformers.
    g. Carry out an actual survey of the planned route.
    h. Permission to travel on particular roads, bridges or highways.

Shock Recorder Installation Checklist

1. Impact recorders have sufficient paper, battery life, and memory capacity for the expected duration of transport.

2. Mount the impact recorders on a sufficiently rigid surface to prevent recording of false shock responses.

3. The data port of the impact recorders should be accessible without removing the mounting hardware.

4. Mount the shock recorder as low as possible near the transformer centreline. Always keep the impact recorder axis aligned with the transformer major axis. This orientation and proximity to the base of the framework provides the best possible recorded data.

5. Impact recorder should be in a stop or standby state when it is being mounted or removed from the transformer. Else, it will record shock events encountered during these operations.

Dispatch Checklist

1. Check nitrogen pressure and verify bottle content.

2. Check "**Dry Nitrogen Filled Equipment**" labeling on transformer to alert personnel who will be working with the equipment.

3. Ensure proper setting and operation of main pressure relief vent and backup pressure relief device.

4. Dismantle and pack all accessories and large parts separately with proper markings.

5. The nitrogen pressure is high enough to ensure that it will remain positive during any expected low temperatures during transit, especially during mountain crossings.

6. Check external gas bottles and regulator controls to ensure positive pressure maintained throughout the voyage.

7. Carefully carry out a final internal inspection, especially for loose objects inside the tank.

8. All openings in the tank are sealed.

9. Check that the gas cylinders, valves, regulators, and gauge assembly are protected from tampering and transportation damage. They should also be accessible for checking during transit.

10. Pack bushing hardware separately. Coil and securely attach draw-lead type bushing leads to the underside of the bushing cover plate or to the test-bushing terminal.

11. Bushings left installed for transport should have static grounds installed by means of a temporary jumper from the bushing terminal to an appropriate grounded location on the tank.

12. Center-of-gravity marked on the tank.

13. Short and ground current transformers by means of temporary jumpers on a terminal block in the equipment control cabinet.

14. Check proper stamping of transformer serial number and measured impedance on transformer nameplates.

On-site Inspection Checklist

1. **Visual checks:** Thoroughly inspect transformer for any visible signs of damage before unloading or removing it from the truck or rail car.

2. **Check impact recorders:** Inspect the impact recorder data for any evidence of rough handling during transit. On suspecting damage, notify the supplier and carrier immediately.

3. **Check shipping documents:** Check transportation documents, packing list, route information, destination and conditions of carrier's agreement and bill of lading

4. **Inspection of the separately shipped parts:** Inspect separately shipped parts and components as per the detailed packing list and outline drawing. Outline drawings usually indicate which components had been removed for shipment.

5. **Internal inspection:** Carry out internal inspection as per the carrier norms - either on the rail car / trailer or on the installation site, but always in the presence of representative of all the parties includes supplier, transporter, end customer etc.

    a. Allow only skilled workers to carry out internal inspection of the transformer.
    b. Check that the internal transformer environment is safe for man entry. Follow local rules and regulations.
    c. All loose articles should be removed from the pockets of anyone working above the open equipment tank and all tools should be tied with clean cotton tape or seine cord securely fastened

either to the outside of the equipment tank or to a point inside the tank.

d. Avoid tools with parts that may become detached.

6. Internal inspection should include:

a. Removal of any transportation blocking
b. Examination of indication of core shifting
c. Test for unintentional core grounds
d. Visual inspection of windings, leads, and connections including clamping, bracing, and blocking
e. Inspection of tap switches, including contact wipe, alignments, and contact pressure
f. Inspection of current transformers, including supports, condition, and clearance of leads
g. Examination of bushing draw leads
h. Check for dirt, metal particles, moisture, etc
i. All tools should be accounted for before and after the internal inspection.

7. **Report damage:**

a. Photograph and document any damage or foreign materials found inside the tank.
b. Inform carrier and the supplier of any internal damage found during inspection.
c. On discovering, any foreign materials inside the tank notify the supplier.

Tests Suggested to Check Against Damages

Perform the following tests on the transformer both prior to transport and after receipt. Compare both test results to determine transformer damage during transit.

Standard Tests Performed Upon Arrival

1. Positive nitrogen pressure and dew point check
2. Shock recorder data analysis to ascertain concealed damage:
    a. Amplitude of shock
    b. Frequency analysis of shock as per DIN EN 13011 to estimate the damage potential of shock
3. Magnetic Balance Test
4. Earth to Winding Capacitance Test
5. Core Ground (Meggar)
6. Winding Insulation Resistance and Turn Ratio Test
7. Insulation Power Factor and Leakage Reactance
8. Bushing Capacitance and Power Factor
9. SFRA (Sweep Frequency Response Analysis)

Tests listed from 3 to 9 are useful only when compared with factory tests carried out before dispatch of transformers.

Standard Tests Prior Energizing the Transformer

Perform the following tests prior to energizing:

1. Test fiber optic temperature probe before oil filling

2. Tests after filling oil:
    a. Power Factor & Capacitance
    b. Meggar (including core ground)
    c. FRA
    d. TTR
    e. Fiber Optic Temperature Probes
    f. 10kV Excitation Test

3. Final Checks:
    a. Full oil screen meets C57.106
    b. Total dissolved gas < 0.50%
    c. System protection verifications
    d. De-energized tap changer tap position
    e. Load tap changer tap position
    f. Bushings and placement

Note: Sweep Frequency Response Analysis (SFRA) test should be the last test prior to transportation and the first test after arrival. Other tests in between, especially DC tests (e.g. winding resistance test) may change the core magnetization status and hinder a reliable evaluation of the core integrity. Performing the test under the same conditions is important for comparison purposes. It is important to identify and exactly duplicate the configuration of the equipment for pre and post shipping tests.

Acknowledgement

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