Comparison of Different Test Methods in Seismic Qualification of Large Components

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INTRODUCTION

Seismic qualification of ground mounted electrical equipment will be usually performed on the basis of codes like IEEE, IEC, ENDESA, KTA and others. These standards give different possibilities of the excitation mode in qualification tests: sinusoidal excitation in every natural frequency (continuous, sine beat) or time history excitation with a test response spectrum which covers a prescribed Required Response Spectrum (RSS) in the frequency range 0.5 - 25 ... 35 Hz. Tests which were recently performed on the 6-axes Vibration Test Facility at HRB/Jülich are compared regarding the usefullness and severety of different excitation modes in seismic qualification.

TEST SPECIMEN AND PROCEDURE

The test specimen was a SF_6-gas insulated switchgear of ABB-Company (Fig. 1). The total weight including the two control electronic cabinets and a separate current transformer was about 11 000 kg. The tests were performed on the HRB Vibration Test Facility Jülich (Fig. 2). Table 1 gives the main technical data:

Table 1: Main technical data of the HRB Vibration Test Facility

Shaking table size:	5 m x 5 m
Maximum sample load:	25 t
Frequency range:	0.1 - 100 Hz
Max. acceleration:	3.5 g
Max. velocity	$1.0\ m \cdot s^{-2}$
Max. amplitude	± 200 mm
Degrees of freedom	6

The acceleration response in the three axes X, Y, Z was measured at 28 points of the switch gear, some of them as indicated in Fig. 1.

As objective the test specimen had to withstand the level AF 5 (zero period acceleration 0.5 g) which is the highest level for ground mounted equipment allowed by IEC.

The test procedure was as follows:

- vibration response investigation: single axis sine sweep excitation in the axes X, Y, Z with a logarithmic sweep rate of 1 Octave $\cdot\ min^{-1}$ up and down between 1 and 35 Hz with an acceleration level of 0.1 g.

- time history qualification test: The required response spectrum (RRS) is due to IEC17A (Helsinki/Secr.), Oct. 4, 1987. To fulfill the RRS-requirements, the time history of the El Centro Earthquake (May 18, 1945) was modified. After the triaxial test the test response spectra (TRS) were calculated. Fig. 3 shows the X-axis RRS and TRS for a damping ratio of 2 %.

  As an example the modified El Centro excitation in X-direction is shown in Fig. 4. The acceleration levels measured at the platform were:

Peak acceleration:	X/Y/Z	1 g
Mean acceleration during strong motion:	X/Y/Z	0.5 g

- sine-beat qualification test:

  The sine-beat tests consisted in a train of 5 sine beats with the following conditions:

cycles per beat:	10
couplings:	X + Z Y + Z Z
max. amplitude:	5 m · s^{-2} horizontal 4 m · s^{-2} vertical
Test frequencies:	All characteristic natural frequencies found in the vibration response investigations.

- Repeat of the primary vibration response investigations.

RESULTS

Some selected measuring points were listed in Table 2 to compare the dynamic amplification Q (Response/table-excitation) of acceleration. The Q-factors of sine sweep and sine beat excitation were calculated from the transfer functions of the measuring points; the amplification factors of the modified El Centro time history were estimated from the peak acceleration and mean value of strong motion of response time history.

These data show generally the differences between the three excitation types: Sine sweep, nearly a continuous excitation in the natural frequency, has the highest severity level; sine beat is a moderate and time history comparable smooth excitation, but the most realistic approach. The magnitude, especially in natural frequencies, with low damping ratio (≤ 2 % of critical damping) differed by a factor of up to 5 depending on the type of excitation.

The sine beat test in combination with the sine sweep frequency search has a great advantage in characterizing the test specimen regarding natural frequencies, damping ratios and vibration modes.

This can be shown by the sine beat test results of the measuring points 3 (circuit breaker drive) in X and 9 (pipe disconnector flange) in Z direction. As shown in Fig. 5 the response follows the excitation with a large time delay; the maximum response amplitude occurs only at the end of the excitation beat. Although the Q-factor 3.1 in sweep indicates a high damping ratio of 16 %, the damping of this mode is really very low: ~ 1.1 %, as can be calculated from the logarithmic decrement of the vibration amplitude decay. This behavior was found at several points, where a specific low-damped mode is not excited directly, but through other "weak" elements of the structure with lower natural frequency.

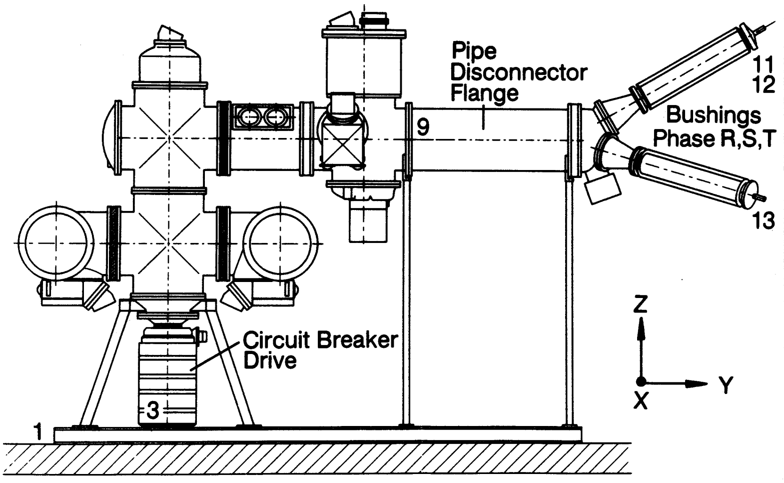
Table 2: Dynamic amplification factors Q
of some measuring points in X- and Y-direction

Measuring point/direction	frequency (Hz)	Q sine sweep	Q sine beat	Q El Centro strong motion max.	Q El Centro strong motion mean
3	12.8	3.1	1.9	-	-
11 X	5.8	9.4	8.9	3.5	4.0
11 X	19.8	7.4	6.1		
12 X	5.8	7.0	9.5	3.0	4.0
12 X	12.8	3.6	1.0		
12 X	28.2	2.6	3.4		
13 X	5.8	8.3	7.5	1.5	1.0
13 X	28.2	3.9	4.7		
9 Z	32.5	7.7	2.3	-	-
11 Z	16.8	21.8	9.6	7.0	10.0
11 Z	24.8	20.0	6.2		
13 Z	19.3	18.5	7.0	2.5	4.0

In comparison the sine beat diagram of measuring point 9 Z (Fig. 6) shows the typical vibration behavior of a mode with medium damping ratio of 6.5 %.

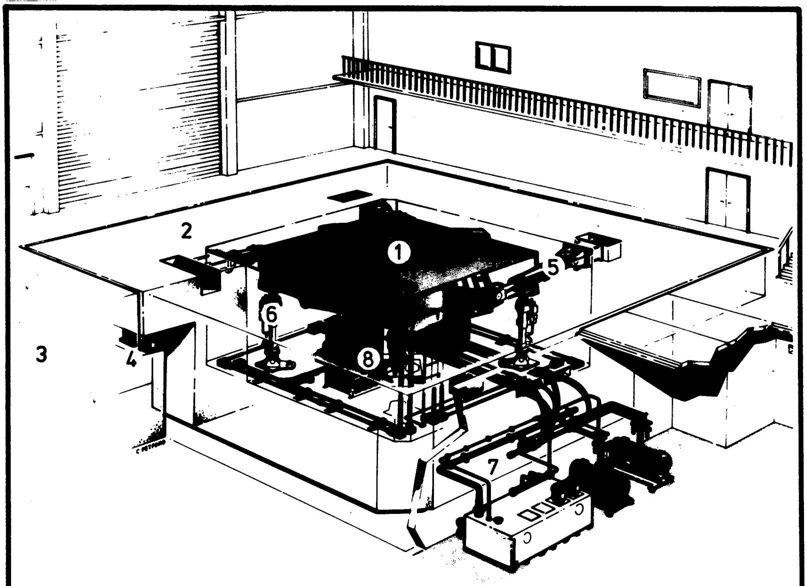
CONCLUSIONS

Modern test facilities offer the advantage to introduce sophisticated test methods for seismic and dynamic qualification. This fact is considered by the IEC-Technical Committees in recent efforts to select an IEC Standard of RSS to specify for the qualification procedure. This point is especially important in qualification of sensitive components with low-damping ratio. However, the sine beat test method will be a very feasible method to demonstrate the dynamic capability of components in proof tests.



HRB | SF$_6$-Gas Insulated Switchgear ABB | PNP 89.4-24

Fig. 1



1 Shaking table
2 Seismic block
3 Foundation
4 Springs and dampers
5 Horizontal actuator
6 Vertical actuator
7 Hydraulic supply
8 Gas-pressure tank

HRB | Vibration Test Facility Jülich | 89.4-19

Fig. 2

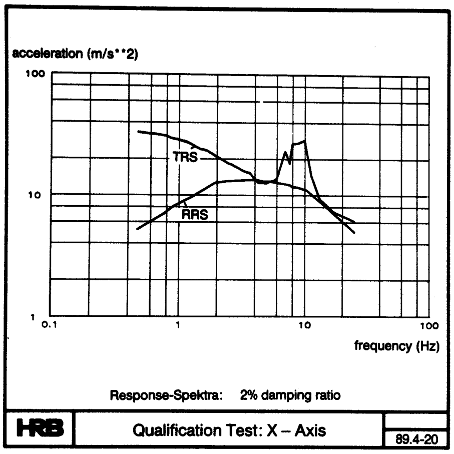


Fig. 3

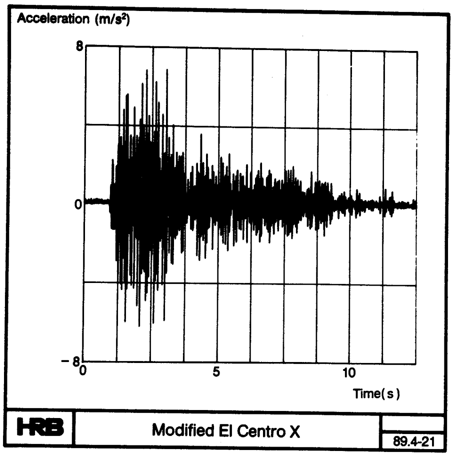


Fig. 4

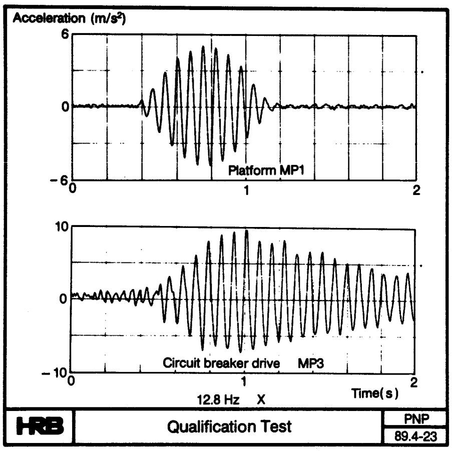


Fig. 5

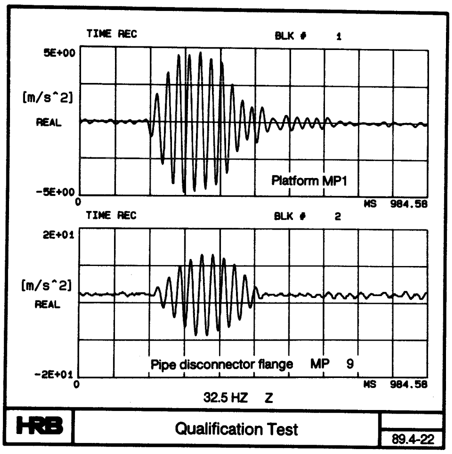


Fig. 6