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Comparison of different methods in seismic qualification of electrical equipment

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ABSTRACT: After a brief introduction into the seismic requirements of ground-mounted electrical equipment of power stations, different qualification methods according national and international specifications performed with a gas insulated switchgear (GIS) are compared regarding the usefulness and severity of different excitation methods in testing. The natural frequencies found during the tests are compared with the results of a calculation model, in which the structure was idealized by an assembly of beam finite elements.

1 INTRODUCTION

For electrical equipment installed in earthquake regions the seismic withstand behaviour is very important, as the continuity of electrical power supply is essential in case of an earthquake.

High voltage switchgear as circuit breakers, current and voltage transformers etc. basically shall be designed considering seismic stresses when used in earthquake zones.

Seismic qualification of those components will be performed usually 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.

This report describes tests with a representative arrangement of Gas-Insulated Switchgear (GIS) for 145/170 kV.

According to IEEE Standard C37.122 (1989) seismic verification is permitted by calculation, too. This is very reasonable, because due to the generally large size of GIS installations full scale proof-testing is impractical or at least complicated and expensive, especially for GIS at higher voltage ratings. Due to size limitations of suitable test plants it even may be impossible to perform seismic tests on one complete feeder bay of e. g. a 550 kV GIS.

Purpose of the tests was to collect informations about the dynamic behaviour of the test object in order to adjust and improve a mathematical model for further calculations of seismic behaviour of extended GIS substations.

2 TEST PROCEDURES

2.1 Test plant

The tests were performed on the six DOF vibration test facility MAVIS 1 at DLR/Juelich (see Figure 1).

Table 1 gives the basic performance data:

Table 1. Main technical data of the DLR Vibration Test Facility MAVIS 1

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. volocity:	$1.0 \mathrm{m \cdot s^{-2}}$
Max. amplitude:	± 200 mm
Degrees of freedom:	6

The test facility is controlled by

an analog system and a computer-based digital system, either of which can be used independently to control the facility. Motion of each of the six axes can be excited individually and simultaneously by the following types of excitation: Time history (transients), sinusoidal tests (sine sweep; sine beat) and random tests.

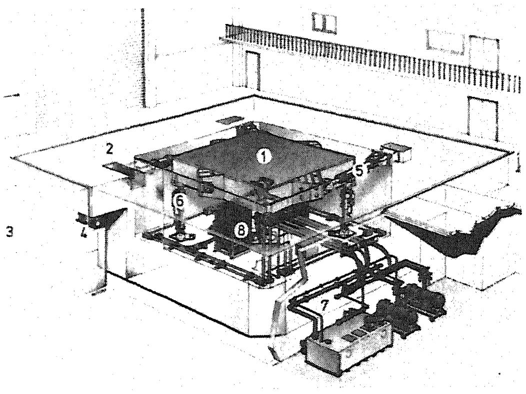

Figure 1. Vibration Test Facility MAVIS 1.

2.2 Test object

The tests were carried out on a combination of two representative bays, a typical double busbar feeder bay and a bus coupling bay.

The electrical control cubicles were included in the tests. The total weight was about 11000 kg.

To simulate the wall of the switchgear building the SF_6 outdoor bushings were connected to the base frame of the feeder by means of additional steel support structure.

All gas compartments of the switchgear were filled with SF_6 gas at rated pressure. During the tests the circuit breaker operating mechanism were energized and the control and auxiliary voltages were applied to the switchgear.

At 28 points the switchgear was equipped with accelerometers for measuring the acceleration responses in the three axes X, Y, Z. Additionally, strain gauge measurement was performed at 12 points.

Figure 2 shows a photo of the test arrangement, mounted onto the shaking table of the test plant.

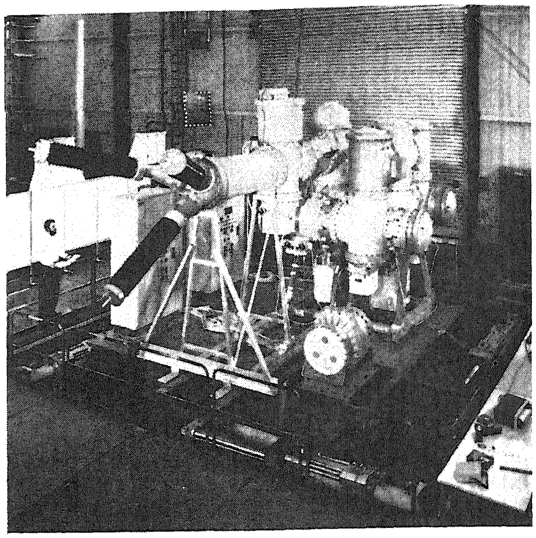

Figure 2. Test arrangement on the shaking table.

2.3 Test procedure

The test procedure was as follows:

1. vibration response investigation: single axis sine sweep excitation in the axes X, Y, Z with a logarithmic sweep rate of 1 Octave · min^{-1} up and down between 1 and 35 Hz with an acceleration level of 0.1 g.
2. 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. Figure 3 shows the X-axis RRS and TRS for a damping ratio of 2 %.

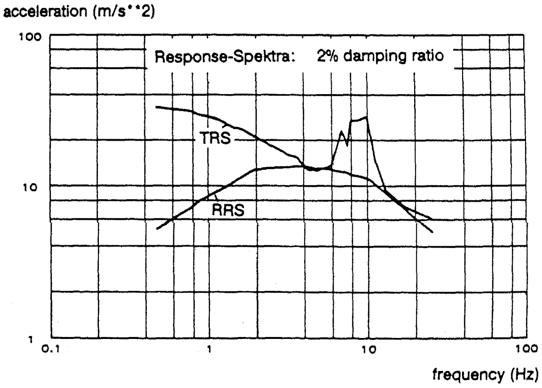

Figure 3. Response Spectra for the test in X-direction.

As an example the modified El Centro excitation in X-direction is shown in Figure 4.

Peak acceleration: X/Y/Z 1.0 g
Mean acceleration
during strong motion: X/Y/Z 0.5 g

3. 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: $5 m\cdot s^{-2}$ horizontal
$4 m\cdot s^{-2}$ vertical
Test frequencies: All characteristic natural frequencies found in the vibration response investigations.

4. Repeat of the primary vibration response investigations.

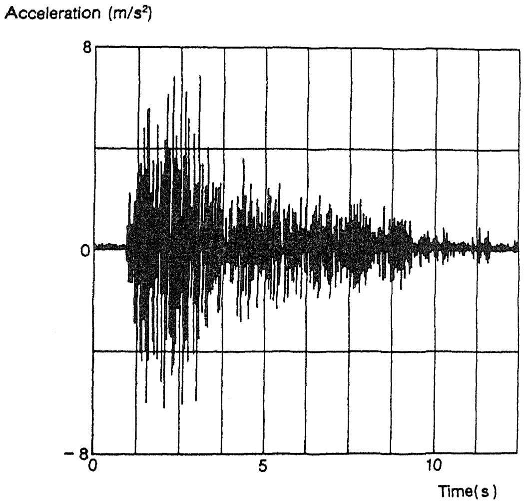

Figure 4. Modified El Centro, time history in X-direction.

3 RESULTS

Some selected measuring points (see Figure 5) were listed in Table 2 to compare the dynamic magnification 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 magnification factors of the modified El Centro time history were estimated from the peak acceleration and mean value of strong motion of response time history.

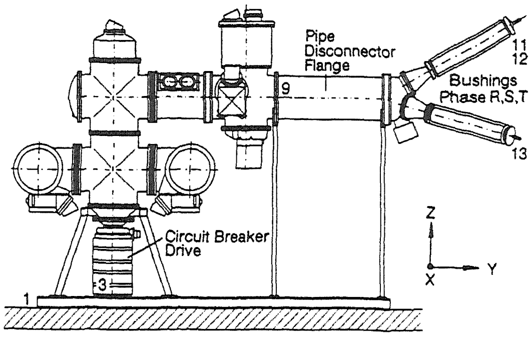

Figure 5. Sectional view of GIS.

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 ($\leq$ 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 Figure 6 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

Table 2. Dynamic magnification factors Q of some measuring points in X- and Y-direction

Measuring point/direction	frequency (Hz)	Q sine sweep	sine beat	El Centro max.	El Centro strong motion mean
3 X	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

structure with lower natural frequency.

In comparison the sine beat diagram of measuring point 9 Z (see Figure 7) shows the typical vibration behavior of a mode with medium damping ratio of 6,5 %.

Buck, Kleine-Tebbe and Rees (1991) reported about results of calculations with a finite element idealization (beam elements) of the GIS-arrangement, regarding the natural frequencies. In those cases, where it was possible to match the measured and calculated modes, the calculated resonance frequencies were definitely above their measured counterparts (15-90 % higher).

By introduction of stiffness correction factors in the finite ele-

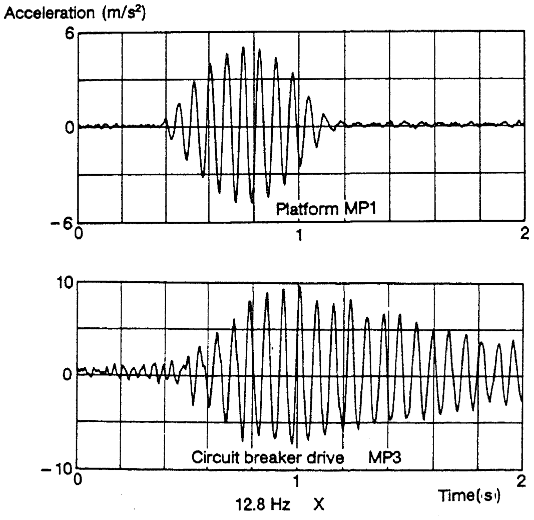

Figure 6. Qualification test 12,8 Hz, X.

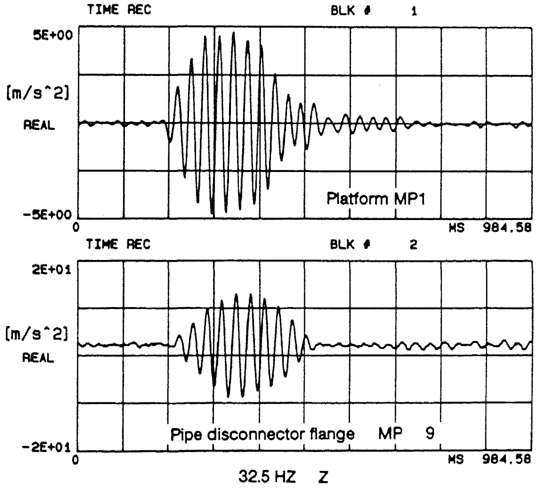

Figure 7. Qualification test 32,5 Hz, Z.

ment model the calculated values could be adapted rather close to the measured resonances. This calculational method basically follows IEEE Std. 344 and IEEE Std. C37.122.

4 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 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.

The application of analysis to seismic qualification is possible for similar structures, if at least one of the structural arrangements will be tested in order to determine the stiffness correction factors for the analysis.

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