Issue 19 / June 2006

newsletter

supported by the DG Research of the European Commission

SAMCO NEWS

Structural Assessment Monitoring Control Issue 19 / June 2006

contents

Published by VCE.

SAMCO Association

Our plan to continue working on structural assessment monitoring and control has materialized. The SAMCO Association was founded in the course of the final SAMCO workshop in Switzerland at the end of March.

By now the Association has already more than 100 members. You can download the current list of members from the SAMCO website on www.samco.org

Foundation

- Start Date: April 1st 2006
- Proposed By-Laws to be accepted
- Possible revisions
- Proposed President: Livia Pardi
- Proposed Secretary: Helmut Wenzel
- Steering Committee of SAMCO
- Elections after 2 Years

Next SAMCO Objectives

- Preparation for FP7
- Organisation of joint proposals
- Keeping contact to technology platforms
- Gaining and providing information on facts and opportunities
- International Collaboration
- Creating opportunities

The main target is the representation towards the Commission and the 7th framework program. The current trend in Brussels favors and supports associations and contacts to representatives of interest groups rather than individuals.

It is therefore important that our group is strong. New members are welcome anytime. You can register by filling in the form which can be downloaded from the SAMCO website www.samco.org and by sending it via fax to the number given on the form.

The motivation to join could be:

- Becoming part of a strong European monitoring community (overseas partners are welcome)
- To receive consolidated information on monitoring and assessment
- To get access to the lobbying efforts towards the 7th framework program
- To receive priority in new research proposals
- To participate and benefit from the huge possibilities in international collaboration the network has worldwide
- To benefit from joint activities
- To become a European Centre of Competence

With best regards

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SAMCO Monitoring Glossary

Structural Dynamics for VBHM of Bridges

Abstract

Part I, glossary, is an empirical collection of technical terms that appear in literature in association with the vibration-based health monitoring (VBHM) of bridges. The definition of terms is mainly aimed at intuitive understanding of the matter and little attention is paid for mathematical rigour or linguistic precision.

Understanding of the terms, however, particularly for the practical application of them, is sometimes easier with mathematical expressions. In order to help this aspect, three chapters of Part II present the basic mathematical formulation in dynamics, statistics and random vibration of structures, which are essentially related to the topic. Also attached are some notes on various types of damping characteristics and vibration tolerance criteria for practical purposes.

Part III is a brief description particularly on the wind-induced vibration of bridges and cables. The contents are obviously related to the rest of the document and yet they require a significant extent of different preparation, and are not necessarily familiar topics to all readers. Hence, it was considered useful to have a separate section.

Contents

PART I GLOSSARY OF TERMS FREQUNTLY EMPLOYED

Acceleration: The rate of change of velocity with respect to time.

It is often the quantity most easily detected in vibration measurement. If the motion is ideally simple harmonic, the magnitude of acceleration is given by the amplitude of vibration multiplied by the circular frequency squared. Note that the mean of acceleration is supposed to be zero. The estimation of vibration amplitude from measured acceleration often involves significant errors.

Accelerometer: An instrument used for measuring the acceleration.

In particular, low frequency, low amplitude accelerometers are suitable for the application in bridge dynamics. The common types of accelerometers for this application are piezoresistive, capacitive, and force balance accelerometers.

The accelerometer, in principle, is usually a high frequency spring-mass system, for which the elastic spring is often made of a cantilevered beam of metal or ceramic material, which bends under given acceleration. The displacement is measured by strain-sensitive gauges placed on the beam, or detected by the change of electric capacitance. The gauges are usually connected in a Wheatstone bridge.

Accounted Truth: What is claimed to be true with some theoretical and/or experimental explanations that are objectively acceptable.

J.L. Austin, a British philosopher of language, says, "To assert that a proposition p is true is to maintain that p corresponds to the facts". In the field of natural science, though they can be still subjected to interpretations, these "facts" need to be scientific facts, which are expected to be explained by rigorous and robust theory or repeatable and replaceable experiments. Some other facts, for example from the religious point of view, may not be thus categorised.

ACM: Advanced Composite Materials.

Acoustic Emission (AE): The propagation of an elastic wave as the rapid release of energy associated with plastic deformation or development of defects within a stressed material.

AE analysis is a useful method for the investigation of local damage in materials. It has been successfully applied to detecting and locating faults in pressure vessels or leakage in storage tanks or pipeline systems, monitoring welding applications, corrosion processes, partial discharges from components subjected to high voltage and the removal of protective coatings. Research and development of AE applications are also in monitoring civil engineering structures, such as bridges, pipelines and offshore structures, and crack development in massive concrete structures and rocks.

Advanced Composite Materials (ACM): Materials which consist of a polymer matrix reinforced with high-strength fibres and, compared to other traditional materials, possess distinctly advantageous characteristics such as light weight and high strength.

Every composite has at least two components: reinforcements which are high-strength, high-stiffness fibres and are immersed in a matrix, which is usually a high-performance resin system and combine the reinforcement material together at a microscopic level. Three basic types of fibre reinforcement materials in use are carbon/graphite, glass fibres and aramid. Their major advantages in comparison to conventional materials include high strength and stiffness, light weight, fatigue strength, impact resistance and corrosion resistance.

Major users of ACM were traditionally the aerospace industry but the market has been gradually expending to sporting goods and civil engineering applications as well. Carbon fibre reinforced polymer (CFRP) is now extensively applied to bridges for strengthening, reinforcement and repairs.

AE: Acoustic Emission.

Aerodynamic Admittance Function: A transfer function to express how effectively the frequency characteristics of velocity fluctuation are picked up by the aerodynamic force components.

It is expected that the magnitude of this function is close to unity in low frequency range and quickly tapers off in higher frequencies. A classical example is the ***Sears function***, which reflects the frequency characteristics of aerodynamic lift force in relation to a sinusoidal fluctuation of vertical velocity component. In general, the aerodynamic admittance is not decided analytically and needs to be estimated experimentally.

Aerodynamic Instability: Dynamic instability of structures caused by aerodynamic forces.

A dynamic failure of aircraft wings caused by aeroelastic phenomena, called flutter, was a serious engineering concern from the early days of flight. Though the excitation mechanism was not exactly identical, the collapse of the old Tacoma Narrows Bridge in 1940 was often compared to the aerofoil flutter. Galloping instability of ice-covered power transmission lines is another example of aerodynamic instability. The term ***flutter*** is, strictly speaking, restricted to the classical flutter which is a coupled motion in bending and torsion of streamlined bodies but is also used rather loosely without a clear definition. It sometimes means the catastrophic structural vibration caused by fluid dynamic forces, which are coupled with the body motion.

AI: Artificial intelligence.

Allowable Stress Design: A method to design structures such that allowable stresses are not exceeded when the structure is subjected to specified working loads.

Basically, an elastically computed stress from the combined nominal loads must be less than the material yield stress or the buckling stress divided by the safety factor.

Ambient Vibration Survey (AVS): A method to determine the dynamic characteristics of a structure by measurement of small vibrations, mostly micro-tremors, caused by existing disturbances such as earthquakes, wind and traffic, while the structure is in service.

In terms of data reliability, the forced vibration tests using shakers is probably the best method for the evaluation of dynamic characteristics of bridges. However, it usually requires a large operation, which is naturally costly, and could also mean an interruption of services. The ambient vibration survey, without any control on the input, is consequently an attractive alternative. This method is based on a few basic assumptions as follows: a) The input excitation is a broadband stochastic process which is adequately modelled by white-noise; b) The system characteristics are therefore well represented by the power spectral density function of dynamic response; c) The technique for measuring the dynamic response is sufficiently reliable; and d) The data acquisition and analysis are also sufficiently reliable. Hence, the reliability of this method is largely decided by these factors.

ANPSD: Averaged Normal Power Spectral Density.

ARIMA Model: Auto-regressive integrated moving average model.

It is one of the statistical forecasting techniques systemized by Box and Jenkins in 1976. The ARIMA time series analysis uses lags and shifts in the historical data to uncover patterns and predict the future.

Artificial Intelligence (AI): AI is intelligence exhibited by any manufactured systems. The term is often applied to general purpose computers which are expected to work on intelligent tasks that resemble to human activities.

AI methods are often employed in cognitive science research, which explicitly tries to model subsystems of human cognition, whereas AI research seeks to build more useful machines. ***Expert systems*** and ***neural networks*** are two of the most common techniques used for applied artificial intelligence.

***Assessment: A set of activities performed to verify the reliability of an existing structure for future use.**

Averaged Normal Power Spectral Density (ANPSD): A method to identify all the possible natural frequencies participating in the vibration at a time by taking the average of all the normalized power spectral density functions obtained from the multi-point records.

The method was developed by Felber (1993) as a fast and effective way to identify many structural vibration modes participating in the vibration measured in ambient survey. It is a convenient way to display the most significant frequencies at a single spot in a series of motions in a certain direction. However, it should be noted that not all the peaks identified in this method necessarily correspond to the natural frequencies.

AVS: Ambient Vibration Survey.

Bayesian Statistics: A statistical method that handles all uncertainties by probability. It provides a different paradigm for both statistical inference and decision making from the conventional statistics.

The name is after Thomas Bayes (1702-61) but it may not be following particularly his idea. Bayes theorem states that the probability of A given B times the probability of B is equal to the joint probability of A and B, or $P(A \mid B) = P(A \cap B) / P(B)$.

The major difference between Bayesian statistics and other statistical methods is that the traditional statistics examine the probability of the data given a model or hypothesis, while Bayesian statistics examine the probability of a model given the data. This significantly enhances the power of statistical analysis. In particular, Bayesian methods make it possible to incorporate scientific hypothesis in the analysis by means of the prior distribution. It can be then applied to problems whose structure may be too complex for conventional methods to handle. The Bayesian paradigm is based on an interpretation of probability as a rational, conditional measure of uncertainty, which closely matches the sense of the word “probability” in ordinary language.

The full document (198 pages) can be downloaded from the SAMCO Website www.samco.org (Download Area) as well as from the SAMCO Database http://samco.jrc.it/ (SAMCO Results)

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News from Profession & Practice

Seismic Capability Assessment of a High Voltage Disconnecting Switchgear by Experimental Modal Analysis

Abstract

The paper presents a methodology for network seismic capability assessment of the high voltage electric equipment by experimental modal analysis. There are presented specialized equipment for testing in the high voltage electric network and a package programs for: data acquisition, modal identification and seismic capability assessment, according to IEC 61166/1993. At the end of the paper it is presented an application for seismic capability assessment of a 400 kV / 2500 A disconnecting switchgear.

1. Introduction

The safe functioning of the power system must be assured in both normal and limit conditions of working, like seism, storms or short-circuit. From this point of view special problem arise to the high voltage electric equipment with column type construction, such as circuit breakers and disconnecting switchgear. For this type of equipment the international standards like IEC 61166:1993 recommend verification of the seismic capability by one of the following methods: tests, theoretical analysis and combined analysis.

The test is realised on seismic platforms and is necessary for complex equipments assessment which cannot be correctly modelled by theoretical methods, or when we intend to verify the functional capability during seismic loads.

The theoretical analysis uses well-known programs of finite elements analysis and generally is adopted when the equipment can be correct modelled by a mathematical model whose dynamic response can approximate with a good precision the response of the real system. A good mathematical model permits the theoretical simulation of all the test and functioning conditions of the real equipment. Used by her self it cannot determine precise values for the equipment dynamic response even if the theoretical model is well-known, because of the geometrical and material data are approximately known and they are not corresponding with the real equipment data. A good theoretical analysis demand validation of theoretical model by experimental tests.

The combined analysis consists in determination of the equipment mathematical model based on experimental data obtained by measurements of the variables which characterize the system evolution in known conditions. The system is excited in well-defined conditions and by determining the evolution laws of the excitation and response it can be identified a minimal set of parameters which are the intrinsic characteristics of equipment, independent of external conditions. A correct mathematical model permits the assessment of the equipment response to several base applied excitations (seism), concentrated in distinct points (electro-dynamic forces), distributed on surface (wind).

The technical base necessary for assessment by combined analysis is more accessible than test, having the advantage of portability, being useful for the equipments in network area.

The paper presents the theoretical and experimental basis for applying the experimental modal analysis for network high voltage electric equipment and an application for seismic assessment of high voltage disconnecting switchgear of 400 kV / 2500A.

2. Theoretical background of modal analysis

Any mechanical system can be modelled by 'n' concentrated mass points 'm_k', joint by elastic elements with 'k_k' stiffness and elements with 'c_k' damping. For this damped system with 'n' degrees of freedom, loaded by exterior excitation system $\{Q(t)\}$, the motion equations are given by the following relation:

$$[M]\{\ddot{x}(t)\}+[C]\{\dot{x}(t)\}+[K]\{x(t)\}=\{Q(t)\} \quad [1]$$

where

-[M], [C], [K], the mass, damping and stiffness matrices,

- $\{\ddot{x}(t)\},\{\dot{x}(t)\},\{x(t)\}$, the acceleration, velocity and displacement vectors,

- $\{Q(t)\}$ generalised forces vector.

The system response at external excitation is presented as a sum of 'n' modal contributions due to each separate degree of freedom:

$$\{X(\omega)\}=\sum_{k=1}^{N}\left[\frac{\{\psi^k\}\cdot\{\psi^k\}^T\cdot\{Q(\omega)\}}{a_k(-\mu_k+i(\omega-\nu_k))}+\frac{\{\overline{\psi}^k\}\cdot\{\overline{\psi}^k\}^T\cdot\{Q(\omega)\}}{\overline{a}_k(-\mu_k+i(\omega+\nu_k))}\right] \quad [2]$$

where

- $\{X(\omega)\}$ - Fourier Transform of displacement,
- $\{\psi^k\}$ and $\{\overline{\psi}^k\}$ -the "k" order eigenvector and his complex conjugate,
- μ_k - the "k" order damping ratio,
- ν_k - the "k" order damped natural frequency,
- a_k and $\overline{a}_k$ - norm constants of eigenvector
- ω - external excitation frequency.

In practical applications the modal vectors are replaced by two modal constants U_{ij}^k and V_{ij}^k defined by:

$$\frac{\psi_i^k\cdot\psi_j^k}{a_k}=U_{ij}^k+i\cdot V_{ij}^k \quad \text{şi} \quad \frac{\overline{\psi}_i^k\cdot\overline{\psi}_j^k}{\overline{a}_k}=U_{ij}^k-i\cdot V_{ij}^k \quad [3]$$

Using these notations we can determine the system admittance, $\alpha_{ij}(\omega)$, defined as the rapport between the displacement response and the force excitation:

$$\alpha_{ij}(\omega)=\sum_{k=1}^{n}\left[\frac{U_{ij}^k+i\cdot V_{ij}^k}{-\mu_k+i\cdot(\omega-\nu_k)}+\frac{U_{ij}^k-i\cdot V_{ij}^k}{-\mu_k+i\cdot(\omega+\nu_k)}\right] \quad [4]$$

In the approximations made during the realisation of mathematical model, it was used the concept of discrete system with concentrated mass in 'n' material points. For a precise approximation of the real system by discrete system, 'n' must have a high value ($n\rightarrow\infty$). This is not possible because of excitation and response measurement technique and also because of necessary time for data processing. In applications the frequencies domain is limited to a reasonable width determined by the major resonances of the analysed equipment and the frequency domain of application goal. In these conditions the sum from relation (4) is reduced to several components, notated in the following with 'n' too. The contributions of inferior and superior modes are included in two correction factors known as "inferior modal admittance", $-\frac{1}{M_{ij}^{'}\omega^2}$ (for inferior modes) and "residual flexibility", $S_{ij}^{'}$ (for superior modes). The system admittance will be written as:

$$\alpha_{ij}(\omega)=\frac{-1}{M_{ij}^{'}\cdot\omega^2}+\sum_{k=1}^{n}\left(\frac{U_{ij}^k+i\cdot V_{ij}^k}{-\mu_k+i\cdot(\omega-\nu_k)}+\frac{U_{ij}^k-i\cdot V_{ij}^k}{-\mu_k+i\cdot(\omega+\nu_k)}\right)+S_{ij}^{'} \quad [5]$$

So, an eigenmode is defined by a set of 4n+2 parameters:

$$\mu_k, \nu_k, U_{ij}^k, V_{ij}^k, -\frac{1}{M_{ij}^{'}}, S_{ij}^{'}, \quad k = 1,2,...,n$$

Using equation (2) it is possible to calculate the system response to different excitation types, which are:

- Seismic motion applied to base, when the concentrated forces are $\{Q(\omega)\} = -a_0(\omega) \cdot [M]$ where $a_0(\omega)$ represents the soil acceleration.

- Electrodynamic concentrated forces, due to commutation phenomena;

- Distributed forces, due to the wind.

The problem consists in determination of the modal parameters based on the tests made on equipment bring up in a controlled excitation state, with simultaneous determination of the excitation and response. For the high voltage equipment placed in the working conditions the excitation can be realized by one of the following low energetic level methods: relaxed level force or excitation with force impulse.

2.1. Identification of modal parameters

It is made by following the next steps:

1. Determination of the frequency response functions, for all pairs of excitation points / response points.

2. The approximate localization of the resonances and determination in initial approximation of the modal parameters $\mu_k \; and \; \nu_k, \quad k = 1,2,...,n$

3. The first stage identification of modal parameters $\mu_k, \nu_k, U_{ij}^k, V_{ij}^k, -\frac{1}{M_{ij}^{'}}, S_{ij}^{'}$, on limited frequency domains. The identification is made using linear procedure of recursive approximation, determining those modal parameters which inserted in relation [5] generate theoretical characteristics which approximate with minimal error the experimentally determined frequency response functions.

4. The final identification of the modal parameters

$$\mu_k, \nu_k, U_{ij}^k, V_{ij}^k, -\frac{1}{M_{ij}^{'}}, S_{ij}^{'}, \quad k = 1,2,...,n,$$

over entire frequency domain. The identification is made using nonlinear procedure of recursive approximation, determining those modal parameters which inserted in relation [5] generate theoretical characteristics which approximate with minimal error the experimentally determined frequency response functions.

2.2. The evaluation of response at seismic loads

It is made in time or frequency domain, function of the definition mode of entry accelerograms.

For evaluation of the response at seismic loads it is necessary to know the modal parameters as well as the geometrical and material characteristics of the equipment to be analyzed.

The mathematical equation which describes the motion of the system subject to seismic loads is:

$$[M]\{\ddot{x}(t)\} + [C]\{\dot{x}(t)\} + [K]\{x(t)\} = -[M]\{\ddot{u}_0(t)\} \quad [6]$$

Equation [6] is identical with motion equation [1], considering the generalized seismic forces:

$$\{Q(t)\} = -[M] \cdot \{\ddot{u}_0(t)\} \quad [7]$$

In these conditions the entire model of identification and evaluation of the response to imposed loads remain the same as in the case of loads applied in distinct points, with replacements regarding the applied loads.

The system response at the imposed motion applied to base characterized by Fourier Transform of base acceleration $\ddot{U}_0(\omega)$ is determined with the equation:

$$X_i(\omega) = \sum_{j=1}^{m} \left\{ \sum_{k=1}^{n} \left[\frac{U_{ij}^k + iV_{ij}^k}{(-\mu_k + i(\omega - \nu_k))} \right] \cdot (m_j) \right\} \cdot \ddot{U}_0(\omega) + \sum_{j=1}^{m} \left\{ \sum_{k=1}^{n} \left[\frac{U_{ij}^k - iV_{ij}^k}{(-\mu_k + i(\omega + \nu_k))} \right] \cdot (m_j) \right\} \cdot \ddot{U}_0(\omega) \quad [8]$$

$X_i(\omega)$ represents the Fourier Transform of the relative displacements of "i" degree of freedom.

For defining the time response it is expressed the response function at unit impulse, hij(t), function of modal parameters by the following equation:

$$h_{ij}(t) = \sum_{k=1}^{n} \left[(U_{ij}^k + iV_{ij}^k) e^{(\mu_k + i\nu_k) \cdot t} + (U_{ij}^k - iV_{ij}^k) e^{(\mu_k - i\nu_k) \cdot t} \right] \quad [9]$$

So the response function at the unit impulse is determined by a sum of modal contribution, every modal contribution consisting of two terms which can be represented as two sinusoidal spirals which are rotating in time in opposed ways such as at every moment the imaginary part of one cancels the imaginary part of the other. The response function at unit impulse is a real function.

Knowing the response function at unit impulse it is determined the response in point "i" of the system at seismic loads applied to the base, characterized by entry acceleration $\ddot{u}_0(t)$, by following relation:

$$x_i(t) = \sum_{j=1}^{m} m_j \left\{ \int_0^t \ddot{u}_0(\tau) \cdot \left\{ \sum_{k=1}^{n} \left[(U_{ij}^k + iV_{ij}^k) e^{(\mu_k + i\nu_k)\cdot(t-\tau)} \right] \right\} d\tau \right\} + \sum_{j=1}^{m} m_j \left\{ \int_0^t \ddot{u}_0(\tau) \cdot \left\{ \sum_{k=1}^{n} \left[(U_{ij}^k - iV_{ij}^k) e^{(\mu_k - i\nu_k)\cdot(t-\tau)} \right] \right\} d\tau \right\} \quad [10]$$

The discrete response of the linear system, to actions of seismic motion given by the sequence of acceleration data entry $\{\cdots 0, \ddot{u}_0(0), \ddot{u}_0(T_0), \ddot{u}_0(2T_0), \cdots\}$ is determined by the following relation:

$$x_i(n) = \sum_{j=1}^{m} m_j \left\{ \sum_{l=0}^{M-1} \left\{ \ddot{u}_0(n-l) \cdot \left\{ \sum_{k=1}^{n} \left[(U_{ij}^k + iV_{ij}^k) e^{(\mu_k + i\nu_k)\cdot(l)} \right] \right\} \right\} \right\} + \sum_{j=1}^{m} m_j \left\{ \sum_{l=0}^{M-1} \left\{ \ddot{u}_0(n-l) \cdot \left\{ \sum_{k=1}^{n} \left[(U_{ij}^k - iV_{ij}^k) e^{(\mu_k - i\nu_k)\cdot(l)} \right] \right\} \right\} \right\} \quad [11]$$

where $x_i(n)$ represents the response of "i" degree of freedom at the moment $n \cdot T_0$.

For evaluation of the seismic response it must follow the next steps:

1. To calculate the modal vectors and of norm contents.

2. Graphically representation of equipment in their eigenmodes. Knowing the geometry data of the equipment and the modal vectors, it is graphically represented the evolution of the equipment in vibration modes, during a cycle of 3600.

3. To evaluate the seismic response. For assessment of the seismic response it is necessary to know the modal parameters, the geometry and material data and the seismic loads given in time or frequency domain. Function of the seismic defining mode, it can be used one of the relations [8] or [11].

Frequency (Hz)	*Amplitude (m/s²) / Damping (%)*			
	2%	5%	10%	20%
0,5	2,6	1,8	1,4	0,5
1	6,1	3,2	2,3	1,6
2,4	8,5	5,1	3,8	2,9
9	8,5	5,1	4,2	3,6
20,0	4,5	4,1	3,8	3,1
25	3,0	3,0	3,0	3,0
35	3,0	3,0	3,0	3,0

Tab.1: Required response spectra for ground mounted equipment. Qualification level AF3

Table 1 presents the response spectra of a seism type AF3 according to IEC 61166/1993 norm.

In a similar fashion are defined the required response spectra type AF2 and AF5 having the "zero" period acceleration of 2 m/s2 respectively 5 m/s2.

Using relations [8] or [11] it can be determined the acceleration and displacement response in points in which it was determined the vibration response of the equipment $\ddot{x}_i$, $i=1,2,...10$ during the test.

Considering a linear distribution of accelerations on the equipment structure, by linear interpolation it can be determined the distribution of seismic acceleration or displacement on the equipment structure.

Knowing the geometry and material characteristics and the acceleration distribution, it is determined separately the distributions on equipment of the seismic force, seismic bending moment and stress.

The seismic force on the level „j" is determined with:

$$F_j = m_j * \ddot{x}_j \quad [12]$$

The seismic bending moment on the level „j" is:

$$M_j = \sum_{k=0}^{j} F_k * l_k \quad [13]$$

The stress on the level „j" it is determined with:

$$\sigma_j = \frac{M_j * Y_{\max j}}{I_j} \quad [14]$$

3. Measuring equipment for seismic capability assessment of the electrical equipment

The measuring equipment has a portable construction, "diplomat" type, and the component parts are:

-acquisition interface type µDaq – USB-30A16 (16 analogical channel, 250 kHz , 14 bit resolution);

-support board for 16 galvanic isolated and amplification modules type MB (41, 38, etc.);

-power sources of 5Vcc/3A and 24Vcc/1A for external transducers;

-piezoelectric accelerometers type 353B32;

-piezoelectric force transducer type 208C04;

-signal conditioners type 480B21 with three channels for supply of transducer type 353B32 and type 208C04.

Fig. 1. MultiTester MT01 equipment for seismic qualification of the high voltage electric equipment.

Electrical signals entry in the measuring equipment is done by amplification modules type MB, which assure the working in a hardly conditions that characterize the electric stations.

4. Software for seismic capability assessment by experimental modal analysis

The package programs contain four modules realized under TestPoint programming environment.

'ModalAch.tst' is a program for controlling the data acquisition on 16 channels using a notebook and MultiTester MT01.

'IdModal.tst' is a program for computing of the frequency response functions and for evaluating of the modal parameters, according to pct.2.1. For modal identification it is used a linear system model with *n.d.o.f.* with generalized viscous damping. The program performs different actions which can be started by acting the corresponding action objects like as:

-*Orig_D* –graphical visualization and selection of the entry characteristics.

-*FRF* – calculates the frequency response functions.

-*Mod_0* –partial numerical identification in the "0" order aproximation of the modal parameters μ_k şi ν_k

-*Mod_In* - partial numerical identification in the first order aproximation of the modal parameters μ_k şi ν_k

-*Mod_Part* - Partial numerical identification of the modal parameters µk, νk, Uk,Vk

-*Mod_Fin* – Final numerical identification of 4n modal parameters: $\mu_k ; \nu_k ; U_{jl}^{k} ; V_{jl}^{k} \;\; k = 1,2...n$,

-*Print* – Writes in the file the modal parameters.

'RspModalTime.tst' calculates, according to 2.2., the equipment eigenmodes; graphically represents the equipment in their eigenmodes and assess the equipment seismic response *in time domain*, at a seismic excitation given according to IEC 61166/1993.

'RspModalSpectru.tst' calculates, according to 2.2., the equipment eigenmodes; graphically represents the equipment in their eigenmodes and assess the equipment seismic response *in frequency domain*, at a seismic excitation given according IEC61166/1993.

5. Application of experimental modal analysis on a 400 kV / 2500 A disconnecting switchgear

5.1. Testing procedure

The disconnecting switchgear SMEP–400 kV has a flexible construction made by two isolator columns fixed on a metallic frame which is fixed on two concrete columns. In fig. 5.1 it is represented the test mounting, and the measuring and excitation points' distribution. To the excitation and measurements points choosing it was taking into account the necessary for mathematical modelling. Each column isolators of the SMEP – 400 kV is made by two columns that are mane by three isolators creating at the base an equilateral triangle with the edge of 290 mm. This geometry assures for the disconnector's columns a relatively high inertia moment and a high flexibility.

Currently, the spatial model for this type of equipment is represented by bar type elements, having the nodes positioned in the fixing places of the columns, and the element mass concentrated in nodes at the end of the elements.

This model covers the current necessity, because the seismic frequency domain is lower than eigenfrequencies of the vulnerable elements that are the isolator columns. So in the seismic frequencies domain of 1…35 Hz, the isolator columns can be considered as rigid bar elements.

For disconnecting switchgear excitation was used the impact excitation method, the excitation being applied successively in several representative nodes. The response was determined in all nodes where it is necessary to determine the seismic response. For test we have used 5 accelerometers type 353 B32, coupled with the signal conditioner of 480 B21 type. For excitation force measurement was used an impactor of cca. 7 Kg endowed with a force transducer with strain gauge of 350 Ω resistances in complete bridge connected at a MB 38 module - Strain Gauge Module.

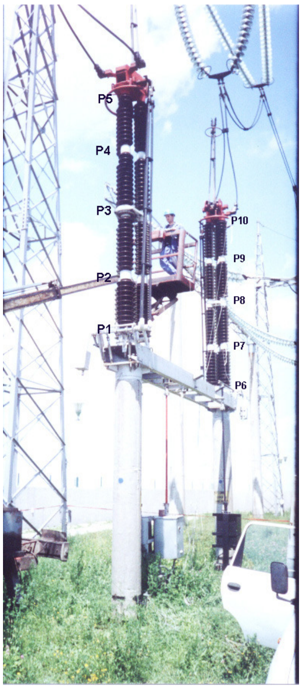


Fig.2: The position of excitation and measurement points for SMEP400kV

The accelerometers were positioned successively in the measuring points P1...P5 and P6...P10, covering the necessary for simultaneous measurement on each column. The excitation was successively applied in the P1…P10 points and simultaneously was measured the excitation force and accelerations response. The fig. 3 presents the recorded characteristics for excitation in the 3 point and response measuring on column 1. In the bottom part it is presented a zoom of the start part of the recording.

It is used an own custom graphic with two cursors. In the inferior displays it is shown the characteristics value at the time moments corresponding to the cursors. The graphic permits the representations of maximum 32 curves, only 8 of them will be defined by colour, type, line width and values of other axis. The curves multiple of 8 have the characteristics of the base curves.

5.2. Modal parameters identification

The modal parameters identification is made successively for each pairs of excitation points – measuring points. In the first step it is calculated the frequency response function (FRF). The fig. 4 presents, in Cartesian and polar coordinate, the frequency response characteristics corresponding to excitation point 3, measuring point 5.

the theoretical and experimental characteristics because of the complexity of the investigated equipment and because in a configuration excitation point – measuring point, not all vibration modes have significant power, some of them being hardly detected from the noise. Generally, are considered only the relevant modes.

In the seismic domain of frequency the SMEP 400 kV has 9 eigenmodes corresponding to the following frequencies:18.51 rad/s(2.94 Hz), 20.18 rad/s(3.21 Hz), 59.12 rad/s(9.4 Hz), 64.99 rad/s(10,34 Hz), 75.77 rad/s (12,06 Hz), 85.60 rad/s(13,62 Hz), 146.67 rad/s(23,34 Hz), 162.47 rad/s(25.85 Hz), 185.48 rad/s(29,52 Hz).

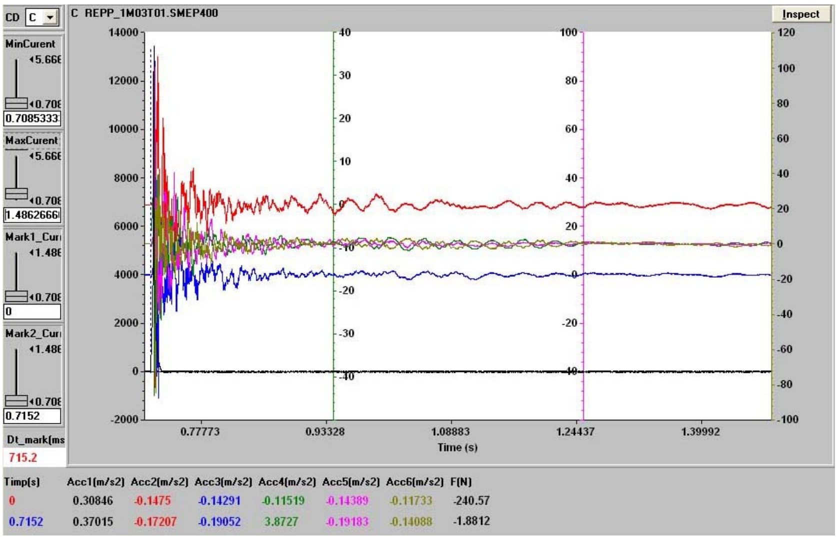


Fig.3: Time characteristic. ExcPoint 03 – MsrCol 1.

The characteristics contain the amplitude (black curve), real part (red curve), imaginary part (blue curve), power spectral density of excitation (green curve), and power spectral density of the response (magenta curve). It follows the next steps of identification described in the chapter 2.1. (*Mod_0, Mod_In, Mod_Part*), and in the final step, *Mod_Fin,* after a cycle of successively approximations, determines the modal parameters in final approximation. The iterations cycle stops when it is considered that achieved an enough precision of the approximation of experimental characteristics by theoretically characteristics generated with equation [5].

The fig. 5 presents, reported to the same axis, the theoretical and experimental characteristics. The curve order is: Re_theoretic– continuous red curve, Im_theoretic – continuous blue curve, Re_experimental – discontinuous red curve, Im_experimental – discontinuous blue curve. There are small differences between

5.3. Seismic response assessment

With the modal parameters identified and knowing the geometry and material characteristics, it can make the assessment of the response at seismic solicitation applied to equipment's base, according to IEC61166/93 norm. A typical example is the above defined type AF3 solicitation, corresponding to a seism with "zero acceleration" of 3 m/s^2.

In the first step it is calculated and graphically represented the structure in their eigenmodes. In the fig. 6.1…6.4. are represented the SMEP 400 kV disconnector in the first 4 eigenmodes. The figures represent the modes corresponding to the transversal direction, the most seismic vulnerable direction. The blue curve represents the column no. 1 (corresponding to P1…P5 points), and the red curve represents the column 2 (corresponding to P6…P10 points).

Are determined the acceleration and displacement seismic spectra entry, corresponding to the analysed equipment.

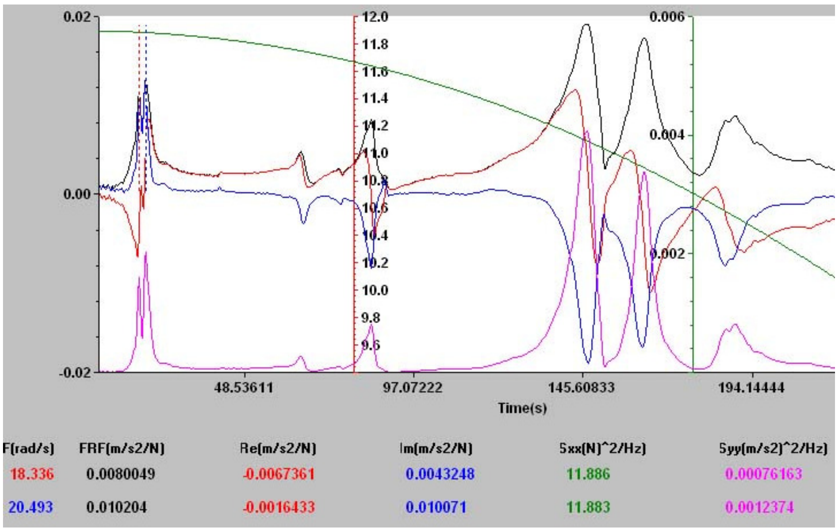
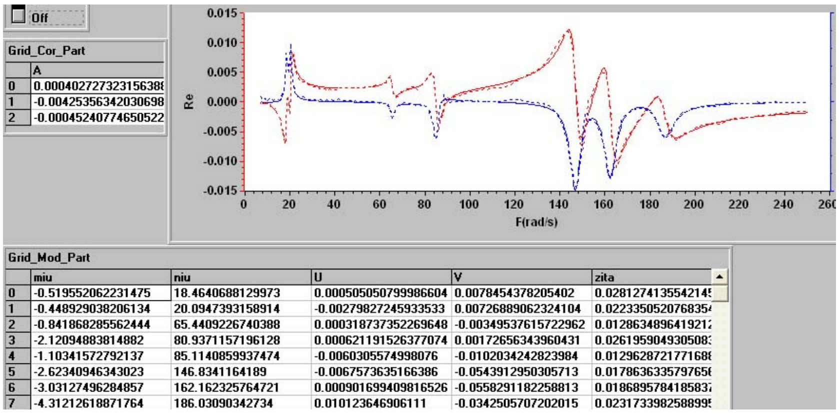


Fig.4: Frequency Response Function. Exc.03 - Msr.05



Grid_Cor_Part

	A
0	0.00040272732315638
1	-0.00425356342030698
2	-0.00045240774650522

Grid_Mod_Part

	miu	niu	U	V	zita
0	-0.519552062231475	18.4640688129973	0.000505050799986604	0.0078454378205402	0.028127413554214
1	-0.448929038206134	20.0947393158914	-0.00279827245933533	0.00726889062324104	0.022335052076835
2	-0.841868285562444	65.4409226740388	0.000318737352269648	-0.00349537615722962	0.012863489641921
3	-2.12094883814882	80.9371157196128	0.000621191526377074	0.00172656343960431	0.026195904930508
4	-1.10341572792137	85.1140859937474	-0.0060305574998076	-0.0102034242823984	0.012962872177168
5	-2.62340946343023	146.8341164189	-0.0067573635166386	-0.0543912950305713	0.017863633579765
6	-3.03127496284857	162.162325764721	0.000901699409816526	-0.0558291182258813	0.018689578418583
7	-4.31212618871764	186.03090342734	0.010123646906111	-0.0342505707202015	0.023173398258899

Fig.5: Modal parameters in the final approximation.

Applying the relation [8] are determined the Fourier transforms, $\ddot{X}_i(\omega)$ and $X_i(\omega)$, of the "i" point acceleration and displacement, i=1,2,...10. The figures 7.1 and 7.2 represent the spectral response of both columns of disconnector to a AF3 type spectrum, corresponding to a 7 degree Richter seism.

By making the inverse Fourier decomposition, considering the equipment eigenfrequencies, it is determined the time acceleration and displacement base movement. Using the relation [11] are determined the time domain response of equipment in acceleration and displacement. By linear interpolation is determined the distribution of the acceleration and displacement on equipment structure.

According to chapter 2.3, knowing the geometry and material characteristics and the acceleration distribution are successively determined the seismic force distribution, the seismic bending moment and the stress distribution on the equipment surface.

The homogenous parts of the structure are divided in 20 elements each, and at each division „j" level it is calculated the mass distribution m_j and the lengths x_j. It is calculated the distribution of geometric and material characteristics: elasticity coefficient E_j, inertia moment I_j, the maximal displacement $Y_{\max j}$. By linear interpolation it is calculated the accelerations distribution $\ddot{X}_j(m/s^2)$ and displacement distribution $X_j(m/s^2)$ on equipment structure.

Using relations [12, 13 and 14] are determined the seismic force distribution $Fs(N)$, the seismic bending moment $M(N \cdot m)$, and stress distribution $\sigma(N/m^2)$. It was applied the seismic loads type AF2, AF3, AF5. The table 2 presents the the bending moments and the stresses, on the bottom division level of each inferior column where it is obtained the maximal seismic load.

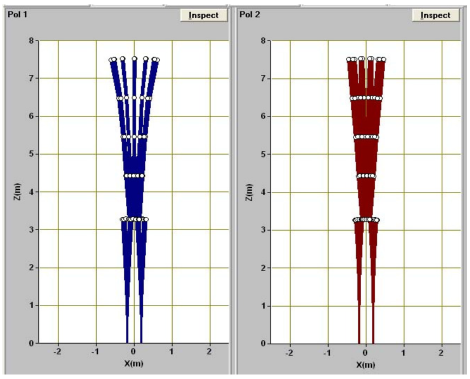


Fig.6.1: The 1st eigenmodes
Fq=18.51 rad/s (2.94 Hz)

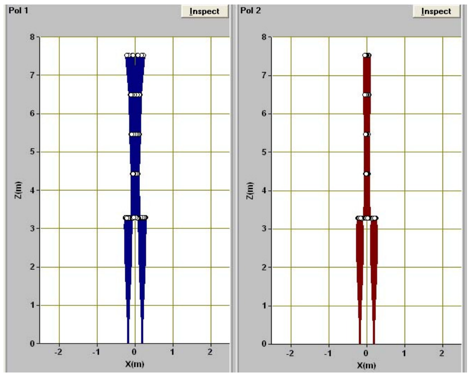


Fig.6.2: The 2nd eigenmodes
Fq= 20.18 rad/s (3.21 Hz)

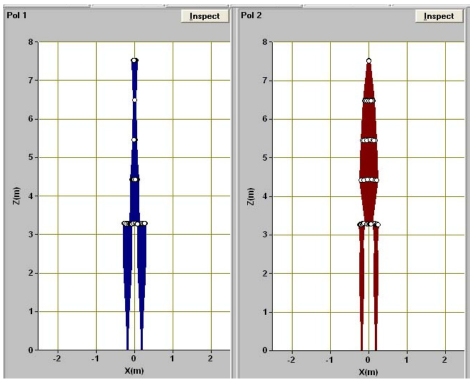


Fig.6.3: The 3rd eigenmodes
Fq= 59.12 rad/s (9.4 Hz)

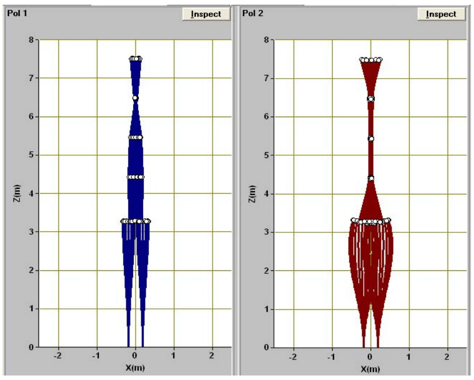


Fig.6.4: The 4th eigenmodes
Fq=64.99 rad/s (10,34 Hz)

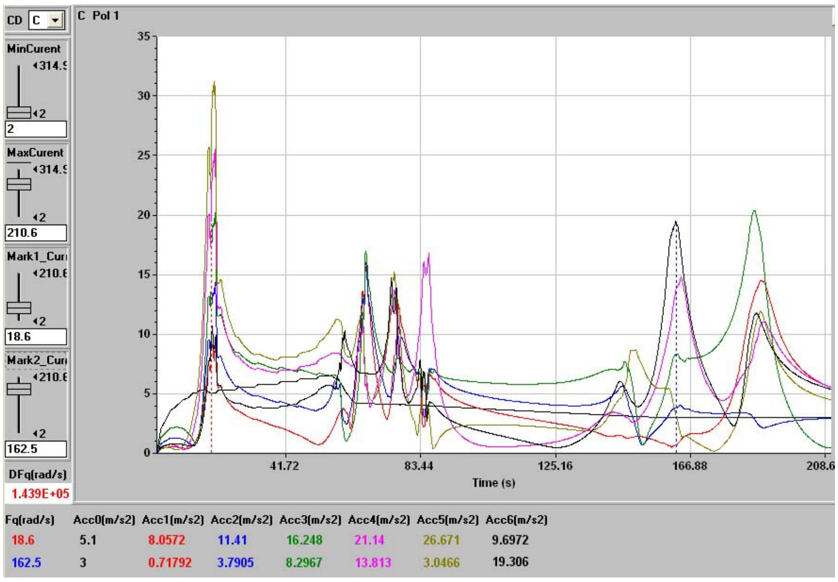


Fig.7.1: Acceleration response spectra of the column 1 to an AF3 type seism

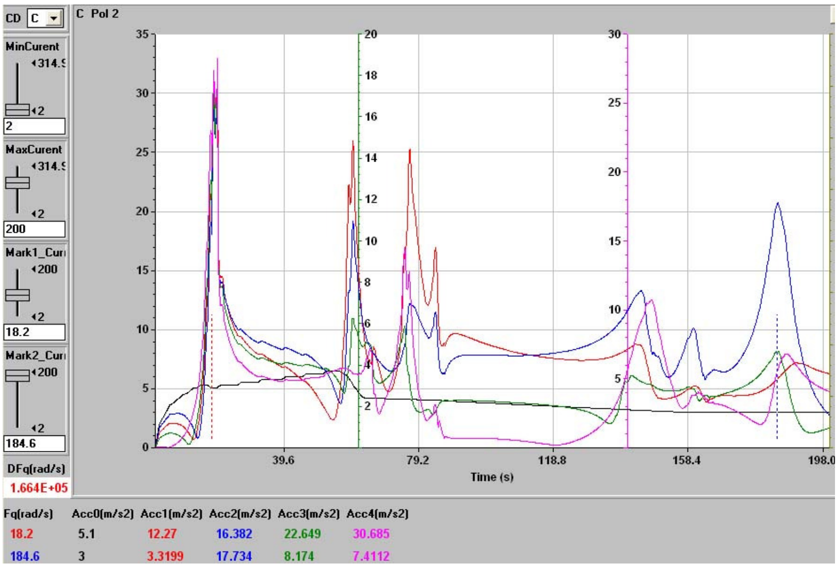


Fig.7.2: Acceleration response spectra of the column 2 to an AF3 type seism

Seism Type	Col 1		Col 2	
	$\sigma(N/m^2)$	$M(N \cdot m)$	$\sigma(N/m^2)$	$M(N \cdot m)$
AF2	$0,61 \cdot 10^7$	$1,4 \cdot 10^5$	$0,75 \cdot 10^7$	$0,28 \cdot 10^5$
AF3	$0,85 \cdot 10^7$	$2,0 \cdot 10^5$	$1.05 \cdot 10^7$	$0,40 \cdot 10^5$
AF5	$1.32 \cdot 10^7$	$3,0 \cdot 10^5$	$1.65 \cdot 10^7$	$0,64 \cdot 10^5$

Tab.2: Seismic response at the base of inferior column

By comparing the stresses obtained by modal analysis with the admissible stresses given by the producer, it is determined which is the maximal seismic load which can be supported by the equipment. For the case of SMEP 400kV disconnector, the vulnerable elements are the isolator columns made from eletrotechnic porcelain CER 110 with the admissible stress $\sigma_{\min} = 6 \cdot 10^7 (N/m^2)$. Analysing the eigenmodes and the data presented in the table 2 the conclusion is that the SMEP 400kV disconnecting switchgear can stand out to an AF5 type seism, corresponding to a seism greater then 7 Richter degrees.

6. Conclusions

6.1. The experimental modal analysis represents a powerfully instrument for the manufacturers of the high voltage equipment. The manufacturers can test and optimize the new equipment even from the prototype phase, using the most efficient constructive solutions. In the parallel it is recommended to use the finite element analysis methods implicating the validation of the mathematical model by experimental modal analysis.

6.2. For the users of electrical equipment, the experimental modal analysis is the singular solution for assessment of equipment capability to stand out to seism, storms or short-circuit events. It is recommended to be applied to equipment of the high importance when the safety functioning queries exist.

6.3. It is recommended the use of experimental modal analysis at every reception of the new equipment as a validation method of the mounting conditions and for the verification of the equipment – foundation - soil interaction.

Bibliografie

[1] Ewins D.J. - Modal testing. Theory and Practice; Bruel & Kjaer 1987

[2] Manea I. – Experimental Modal Analysis, Universitaria – Craiova, 2006

[3] IEC 60068-3-3:1991, Environmental testing–Part 3: Seismic test methods for equipment;

[4] IEC 61166:1993, High voltage alternating current circuit-breakers – Guide for seismic qualification of high voltage alternating current circuit breakers;

[5] IEC TS 61463:2000, Bushings – Seismic qualification.

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