Finite Element Method in modal analysis of the IO 220 kV high voltage Circuit breaker structure

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Abstract: This paper present a Finite Element model of the high-voltage circuit breaker type IO–240 kV made by using ANSYS program and the modal analysis of this model. The study was made in order to simulate the behavior of this type of circuit breaker during different types of earthquakes. The modal analysis is the first step in earthquake F.E.M. simulation. The results presented are the first 8 natural frequencies and the corresponding vibration modes. This F.E.M. model was validated by experimental results and can be used in earthquake simulation by performing a F.E.M. spectrum analysis.

Key-Words: - Seism Simulation, Modal Analysis, Finite Element Method, ANSYS, Circuit Breaker

1 Introduction

The IO 240kV high voltage circuit breakers are expensive and vital equipments, therefore it is necessary the safe functioning of these equipments, especialy during limit conditions, like earthquakes.
One of the principal difficulties of the high-voltage circuit breaker producers consist in reconciling flexibility and resistance of the structure in order to make it possible for the cable to support millions of torsion movements, resonance and extreme climatic conditions.

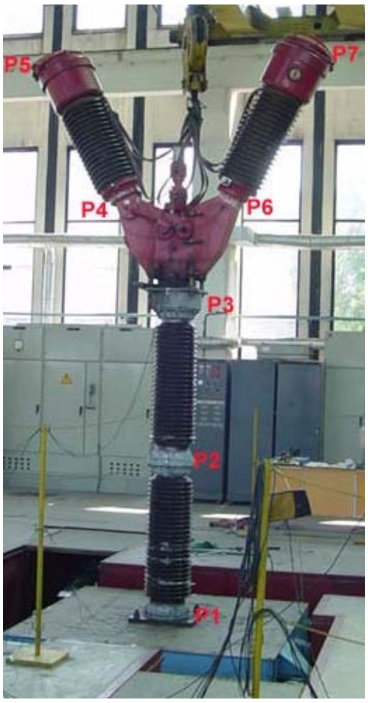


Fig.1 High voltage circuit breaker IO 240 kV (during experiments)

Also, the circuit breaker structure must be reliant during different types of earthquake because the damage of a high-voltage circuit breaker determined by earthquake has determinant implications in breaking the power supply for large territorial areas or even in producing fire disasters by letting the power cables to fall down on the earth.
For a complete test of the seismic capability it is necessary to perform an experimental study combined with a Finite Element Method simulation because the experiment is expensive and not so flexible regarding the simulation of all types of limit conditions of earthquakes.
The first steps in this study are the construction of the FEM model, the modal analysis of the model and the comparison of the FEM results with the experimental results in order to validate the FEM model.
The computational simulation was made using F.E.M. and ANSYS program which permit to perform a modal analysis on the F.E.M. model of the circuit breaker.

2 Problem Formulation

The modal analysis of a F.E.M. model is used for natural frequency and mode shape determination.
The equation of motion for an undamped system, expressed in matrix notation is:

$$[M]\{\ddot{u}\} + [K]\{u\} = \{0\} \tag{1}$$

where: [M] - the mass matrix;
[K] - the stiffness matrix

For a linear system, free vibrations will be harmonic of the form:

$$\{u\} = \{\Phi\}_i \cos \omega_i \, t \qquad (2)$$

where: $\{\Phi\}_i$ = eigenvector representing the mode shape of the ith natural frequency;

ω_i = i^{th} natural circular frequency (radians per unit time);

t = time.

Thus, equation (1) becomes:

$$\left(-\omega_i^2 [M] + [K]\right)\{\Phi\}_i = \{0\} \qquad (3)$$

and the solution is:

$$|\,[K] - \omega^2 [M]\,| = 0 \qquad (4)$$

This is an eigenvalue problem which may be solved for up to n values of ω^2 and n eigenvectors $\{\Phi\}_i$ which satisfy equation (3) where n is the number of DOFs.

The natural frequencies (f) are:

$$f_i = \omega_i / 2\pi \qquad (5)$$

where f_i = i^{th} natural frequency (cycles per unit time).

3 Modal analysis by F.E.M.

The model of circuit breaker structure was made entirely in ANSYS program.

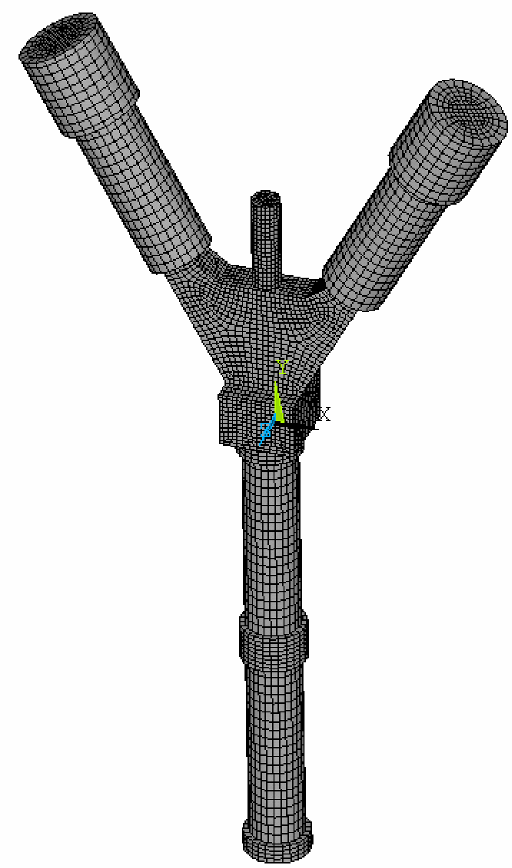
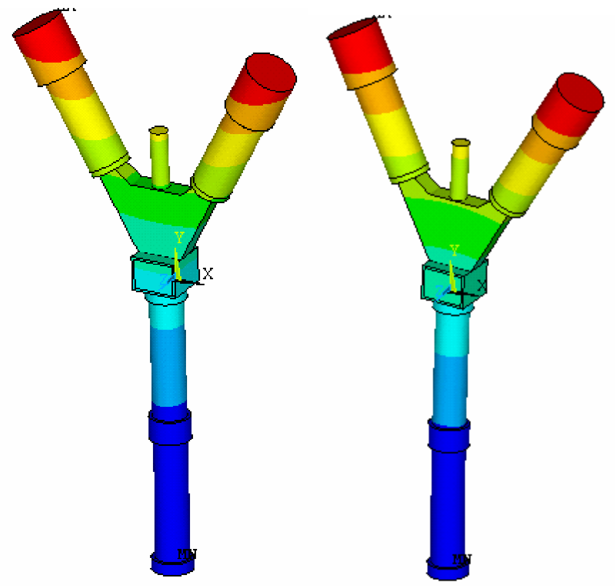


Fig. 2 Finite Element Method model of the IO 220 kV Circuit Breaker

The program has several methods to perform modal analysis of a FEM model, but the best results of the simulation are offered by the Block Lanczos method which is indicated to process models with big number of elements. The model of circuit breaker has over 11.000 finite elements.

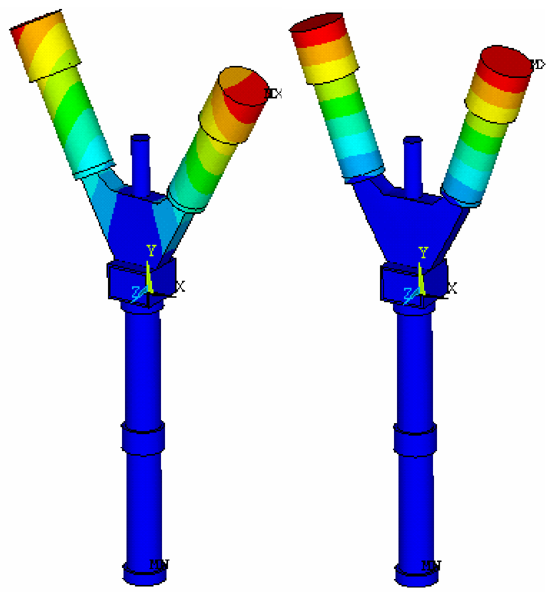
The results of the modal analysis simulation are presented bellow.



frequency = 2,31 Hz Mode no. 1   frequency = 2,4 Hz Mode no.2

Fig. 3 Vibration modes no. 1 and no. 2

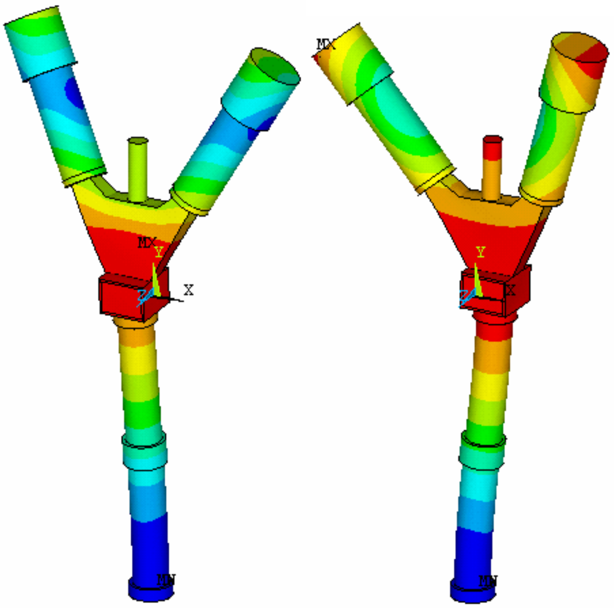
We can observe that first vibration mode is a translation about Oz axis and the second mode is a translation about Ox axis.



frequency = 5,38 Hz Mode no. 3   frequency = 11,63 Hz Mode no.4

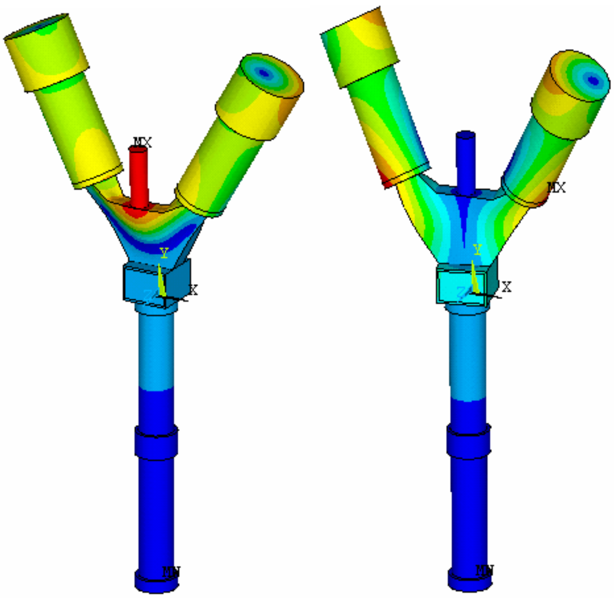
Fig. 4 Vibration modes no. 3 and no. 4

The third vibration mode is the rotation of the poles about Oy axis and the forth mode is the translation of the poles about Oy axis



frequency = 13,73 Hz frequency = 14,23 Hz
Mode no. 5 Mode no.6
Fig. 5 Vibration modes no. 5 and no. 6

The fifth vibration mode is the translation of the column about Oz axis and the sixth mode is the translation of the column about Ox axis.



frequency = 27,89 Hz frequency = 32,47 Hz
Mode no. 7 Mode no.8
Fig. 6 Vibration modes no. 7 and no. 8

The seventh vibration mode is the translation of the poles support about Oz axis and the mode no. 8 is the rotation of the pole support about Oy axis.

4 Experimental measurements

The measuring equipment have a portable construction, “diplomat” type, and the component parts are:

-acquisition interface type µDaq – USB-30A16 (16 analogical channel, 500 kHz , 16 bit resolution);
-support board for 16 galvanic isolated and amplification modules type MB;
-piezoelectric acceleration transducers with electronic integrated circuit type 353B32;
-piezoelectric force transducers with electronic integrated circuit type 208C04;
-signal conditioners type 480B21 with three channel for supply of transducer type 353B32 and type 208C04.

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

Fig. 7 Excitation and measuring Points (P1…P7)

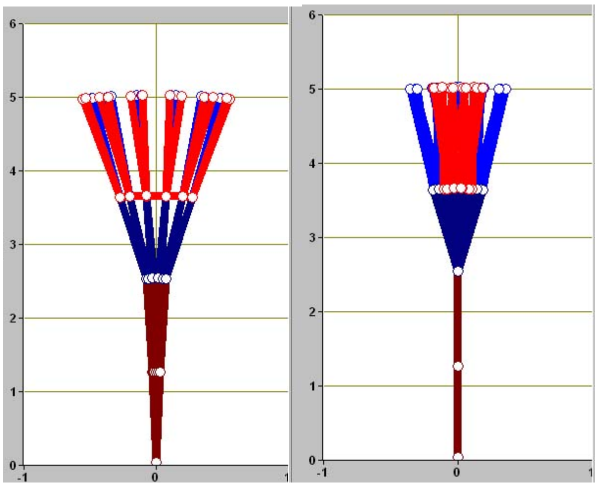
During the tests was maintain all connections between the poles system and measuring instrument.

The fig. 7 presents the circuit breaker under test and the map of excitation and measuring points.

The spatial model of the circuit breaker is represented in the TestPoint application made by authors, by bar elements, with the nodes positioned in the connection points.

This model cover all the necessary, taking into account that the interested frequency range is in the seismic domain of 0.5...35 Hz and that the vulnerable seismic elements are isolators column which have the eigenfrequency over the seismic frequencies, and they could be considered as rigid bar elements.

The excitation of the equipment was made only on transversal direction, and the measuring of the response was made on the same direction.



Frequency = 2.39 Hz Frequency = 5.278 Hz

Fig. 8 Vibration modes no. 1 and no. 3

The experiment couldn't get all the vibration modes because the measuring was made only on transversal direction. We have measured only the vibration modes which determine displacements on the same direction. Some of these modes are presented in fig. 8.

We can see, by comparing the modes determined by experiment with those simulated with F.E.M. that they are identical, and the values of the natural frequencies are very similar.

Table 1 – Comparison between computational and experimental results

Mode No.	Frequency by FEA	Freq. by Experiment	Error
1	2.31 Hz	2.39 Hz	5.9 %
2	2.4 Hz	-	-
3	5.38 Hz	5.278 Hz	1.9 %
4	11.63Hz	-	-
5	13.72Hz	12.697	7.4 %
6	14.22Hz	-	-
7	27.89Hz	-	-
8	32.4 Hz	-	-

4 Conclusion

The results obtained using simulation with F.E.M. of the modal behavior of the circuit breaker are very similar with those obtained by experiment. The maximal error of 7.4% validates the F.E.M. model which simulate the dynamics of the IO 220 kV circuit breaker structure.

We can conclude that the simulation with F.E.M. is correct and the designed F.E.M. model can be used in a future FEM simulation of the seismic behavior of the circuit breaker, in order to measure the seismic capability of this equipment.

These results are useful in the optimization design process of high voltage circuit breakers.

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