A physical criterion for validating the method used to design mechanical impedance matchers for Mario Schenberg's transducers

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Abstract. This work reports improvements made in the modelling of mechanical impedance matchers with mushroom shape using the finite elements method when shell elements type were used instead of tetrahedron elements type. Also, it is presented here an original methodology which makes use of the symmetry of the system and its influence on the mechanical vibrational modes to validate the modelling that was the base for the simulations performed.

1. Introduction

“Mario SCHENBERG”[1, 2, 3, 4, 5] is a spherical resonant-mass gravitational wave (GW) detector weighting 1.15ton, being built in the Department of Materials Physics at the University of Sao Paulo (Brazil). The sphere, with 65cm in diameter, is made of an alloy with 94% copper and 6% aluminum (94%Cu-6%Al). In a spherical resonant-mass detector the signal is generated when the GW passes through it and causes vibrations in the spherical mass.

The distribution of six sensors on the surface of the sphere is chosen purposefully [6, 7]: they are arranged on the sphere surface in a half-dodecahedron distribution. These transducers are located as if in the center of the 6 connected pentagons in a dodecahedron surface.

The resonant frequencies of this array will be around 3.2 kHz with a bandwidth of about 200Hz. Each transducer amplifies the motion of the region of the sphere where it is attached to. By analyzing the signal of such transducers the intensity and the direction of the incoming gravitation wave can be obtained.

The impedance mechanical matchers, which are part of such transducers, filter and amplify part of the movement of the region of the sphere to which they are connected. Thus the transducer project is of great importance in order to guarantee that the transducer is tuned to the frequency of the sphere (quadrupole mode), that resonates with the GW.

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The improvements obtained in the modeling of mechanical impedance matchers were confirmed by the validation method used. The symmetry of the antenna system relative to its vertical axis "z" made possible the validation procedure used here, which would be impossible to be made experimentally. There would be no other way to do this validation, since an experimental procedure is not viable. Far as the authors of this paper know such a procedure to validate the simulation method used is new. We believe that this method can be used to validate other simulations of systems that have symmetries, using the finite element method or other method of numerical simulation.

2. Mechanical Impedance Matchers

In Schenberg each transducer has a 2-mode mechanical impedance matcher [9]. This study used 1-mode mechanical impedance matchers [9, 10] with mushroom shape, arranged in the same way as on the Schenberg detector (figure 1). The design of the mechanical impedance matchers with a mushroom shape was made using the finite elements method [11].

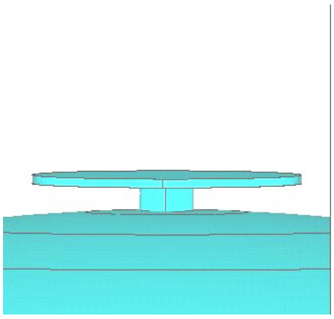

Figure 1. The illustration shows a mushroom impedance matcher attached on the sphere surface. The diaphragm has diameter of 50mm, thickness from 0.5 to 2.5mm and height of 7 mm.

3. Initial phase of this study

In the first phase of this study only tetrahedral elements type were used in the preparation of models for the simulations with the finite element method (FEM). The reasons for this choice were the good results obtained in the simulations with the bare resonant-mass sphere (the sphere without impedance matchers) [12]. The values found were close to the experimental values obtained modeling the sphere with holes that will be used to house the transducers[13]. Furthermore, the standard deviation of the values found was 0.03%, which suggests that the modes are degenerate.

The best outcome of this phase of the study can be seen in figure 2, which shows, through 66 snapshots, the maximum amplitudes of each of the six mushrooms coupled to the sphere, in the 11 normal modes of vibration of the sphere-mushrooms array or sphere-mechanical impedance matchers.

In figure 3 is shown the graph of the frequencies obtained for the normal modes of the sphere-mushrooms array.

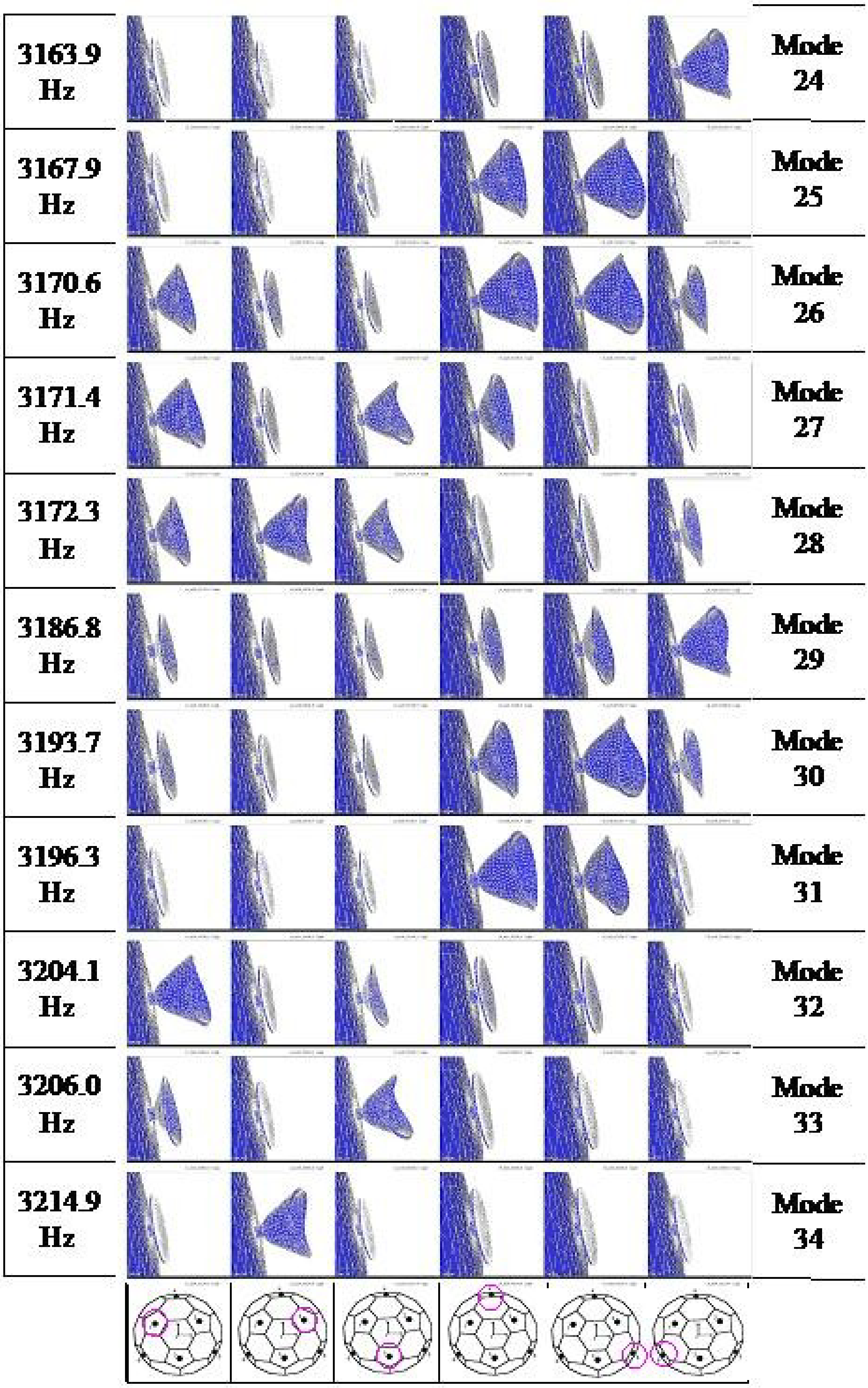

Figure 2. From the first phase of this study: snapshots obtained in models for which only tetrahedral elements type were used. Shown is the maximum amplitude of each of the six mushrooms coupled to the sphere, in the 11 normal modes of vibration of the sphere-mushrooms array. The 11 frequencies of the modes are shown at the left side of this figure. The location of the mushroom is shown in the lower part of the figure.

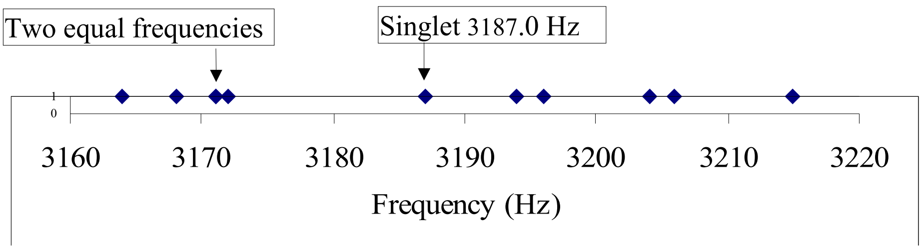

Figure 3. From the first phase of this study: the frequencies of the 11 modes of the sphere-mushrooms array.

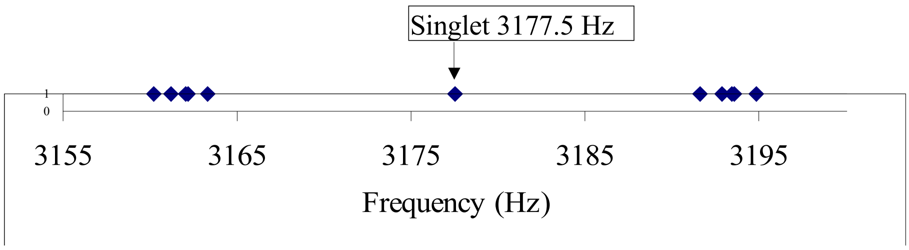

Figure 4. From the current phase of this study: the frequencies of the 11 modes of the sphere-mushrooms array.

4. Current phase of this study

In the current phase of this study the models for the sphere used in the simulations using the finite elements method have also been developed using elements of the tetrahedral type. However, in developing the models for the diaphragms of the mushrooms, shell-type elements were used.

The best outcome of this phase of the study can be seen in figures 4 and 5.

In figure 4 is shown the graph of the frequencies obtained for the normal modes of the sphere-mushrooms array

Figure 5 shows, through 66 snapshots, the maximum amplitude of each of the mushrooms – 6 coupled to the sphere, in the 11 normal modes of vibration of the sphere-mushroom array.

5. Results

Unlike the results obtained in the initial phase of the study (figures 2 and 3), the results obtained in the simulations made with the models developed with shell-type elements (figures 4 and 5) were quite symmetrical.

As the system has several vertical planes of symmetry, all parallel to the vertical axis z of the reference system, an asymmetrical result relative to the frequencies of normal vibrational modes of the system were not expected, as the one obtained in the first phase of this study.]

Another aspect arising from this symmetry can be seen in snapshots in Figure 5. Mushrooms on both sides of the sphere tend to have their maximum amplitudes in the same mode. Notice the amplitudes of mushrooms 1 and 5, or 2 and 6, or 3 and 4 in the same mode (same line) and compare with other mushrooms of the same mode in Figure 2.]

We believe that these symmetries were obtained because the model was appropriate for the current system and the principles of mechanical vibration [14] involved.]

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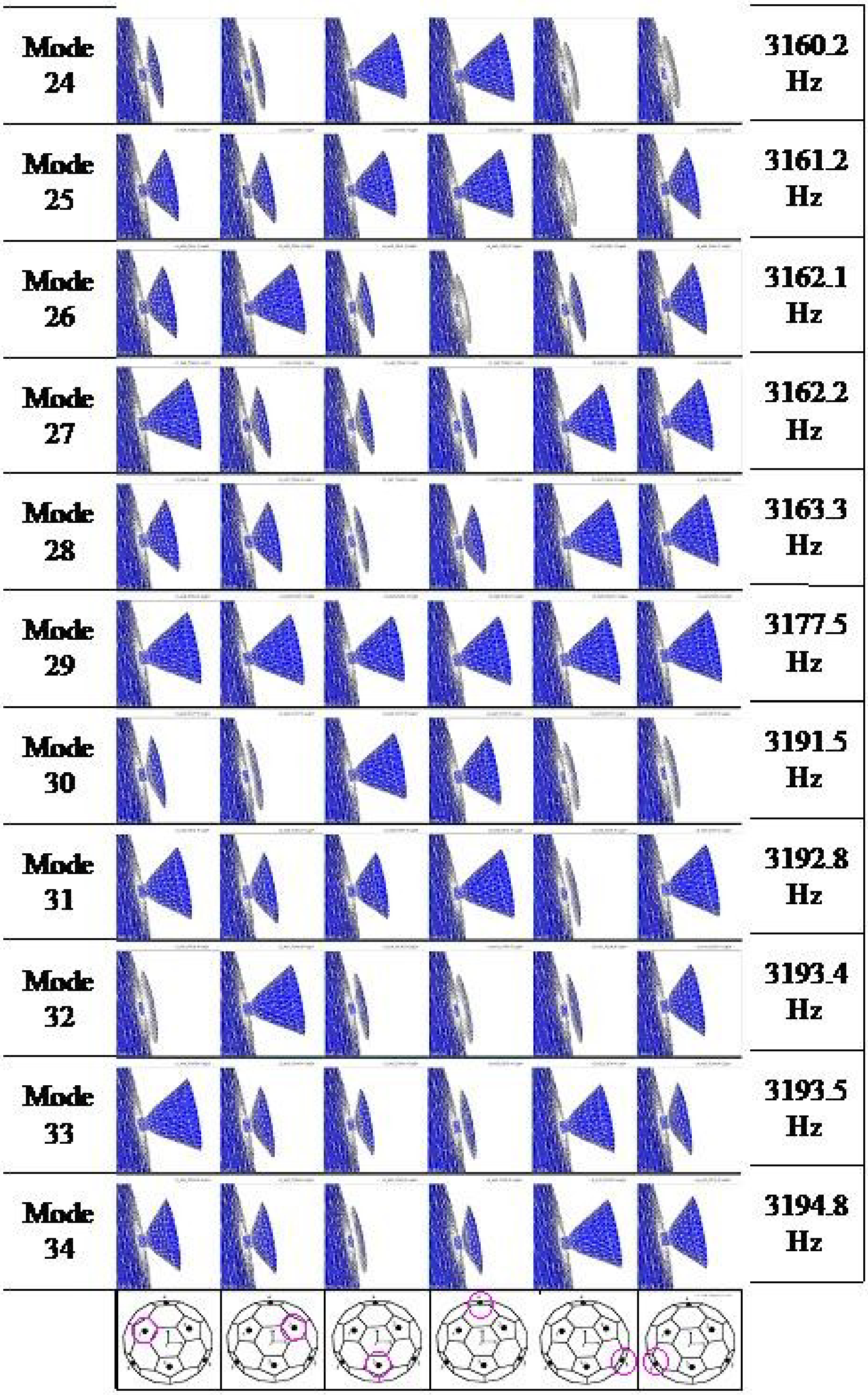

Figure 5. From the current phase of this study: snapshots obtained with models that used shell-type elements in the diaphragms of the mushroom. Shown is the maximum amplitude of each of the six mushrooms coupled to the sphere, in the 11 normal modes of vibration of the sphere-mushrooms array. The 11 frequencies of the modes are shown at the right side of this figure. The location of the mushroom is shown in the lower part of the figure.

References

[1]Aguiar O D et al. 2008 The Schenberg spherical gravitational wave detector: the first commissioning runs *Classical and Quantum Gravity* **25** 114042
[2]Frajuca C, Magalhaes N S, Bortoli F S and Horiguti A M 2008 Study of six mechanical impedance matchers on a spherical gravitational wave detector *Journal of Physics. Conference Series (Online)* **122** 012029
[3]Aguiar O D et all 2005 The Brazilian gravitational wave detector Mario Schenberg: progress and plans *Classical and Quantum Gravity* **22** S209-14
[4]Aguiar O D et al. 2004 The Brazilian spherical detector: progress and plans *Classical and Quantum Gravity* **21** n. 5 S457-63
[5]Frajuca C 2001 (in Portuguese) Mario Schenberg Gravitational Wave Detector *Sinergia - Revista do Centro Federal de Educação Tecnológica de São Paulo* **2** n. 1 14-8
[6]Merkowitz S M and Johnson W W 1993 *Phys. Rev. Lett.* **70** 2367
[7]Magalhaes N S, Aguiar O D, Johnson W W and Frajuca C 1997 *Gen. Relat. Grav.* **29** 1511
[8]Frajuca C 1996 (in Portuguese) *Optimization of two Mechanical Modes Transducers for Gravitational Wave Detectors* Ph.D. thesis (Sao Paulo, SP, Brazil: Sao Paulo University)
[9]Frajuca C and Bortoli F S 2006 Planning to improve the mechanical quality factor in the transducer impedance matchers for Mario Schenberg detector *Journal of Physics. Conference Series* **32** 315-8
[10]Frajuca C, Bortoli F S and Magalhaes N S 2005 Resonant transducers for spherical gravitational wave detectors *Brazilian Journal of Physics* (São Paulo, SP: Brasilian Society of Physic) **35** n. 4B 1201-3
[11]Frajuca C, Bortoli F S and Magalhaes N S 2006 Studying a new shape for mechanical impedance matchers in Mario Schenberg transducers *Journal of Physics. Conference Series* **32** 319-22
[12]Bortoli F S 2006 (in Portuguese) *Study of Mechanical Impedance Matchers for Microwave Parametric Transducers on a Spherical Gravitational Waves Detector* M.Sc. dissertation, (Sao Paulo, SP, Brazil: Sao Paulo University)
[13]Aguiar O D et al 2004 *Classical Quantum Gravity* **21** 457
[14]Marion J B 1975 (in Spanish) *Dinámica Clasica de las Particulas y Sistemas* (Barcelona: Reverte)