Resonant Transducers for Spherical Gravitational Wave Detectors

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(Received on 15 October, 2005)

”Mario Schenberg” is a spherical gravitational wave (GW) detector that will be part of a GW detection array of two detectors. Another one is been built in The Netherlands. Spherical gravitational wave detector is a resonant-mass detector, which signal comes when the GW passes through and causes vibrations in a spherical mass. The resonant frequencies of this array will be around 3.2 kHz with a bandwidth of about 200 Hz. This range of frequencies is new in a field where the typical frequencies lay below 1 kHz, making the transducer development some more complex. In this work we made a series of fine element studies in sphere coupled to a resonant mushroom shape resonator that will work as a mechanical impedance matcher between the sphere and the transducer. We describe the search for a shape in the impedance matcher that will improve the performance of the detector.

I. INTRODUCTION

“Mario Schenberg” [1, 2] is a spherical resonant-mass gravitational wave detector weighting 1.15 ton, being built in the Department of Materials and Mechanics at the University of Sao Paulo.The sphere with 65 cm in diameter will be made of a copper-aluminum alloy [3] with 94Al. The distribution of motion sensors in the surface of the sphere will be based on the work of Merkowitz and Johnson [4]. Transducers are motion sensors that monitor the motion of the sphere surface transforming the mechanical oscillation in electrical signal [5, 6]. The detector will have six transducers, arranged in the sphere surface in a half-dodecahedron distribution; the sensors will be located as if in the center of the 6 connected pentagons in a dodecahedron surface. By analyzing the signal of such sensors the intensity and the direction of the incoming gravitation wave can be obtained [7–9].

Another similar detector is been built in the Netherlands called ”MiniGrail” [10]. Together these two detectors will form an array of GW detectors sensitive to frequencies around 3.2 kHz with a bandwidth of about 200Hz. Transducers are used to measure the vibration of the sphere surface. The Brazilian group has decided to use as such motion sensors microwave parametric transducers, as the ones used in the GW resonant-mass detector NIOBE by the Australian GW group [11], where a superconducting cavity is pumped with monochromatic resonant microwaves, when the size of the cavity changes by the vibration, it changes the size of the cavity (one of the cavity wall is connected to the sphere by the mechanical impedance matcher) and creates two side band in the microwave signal that leaves the cavity, the amplitude of the side band is proportional to the amplitude of the sphere vibration. A multi-mode impedance matcher for the transducer would have several advantages over the single mode transducer, as has been well discussed several times [12].

II. THE FIRST THREE IMPEDANCE MATCHERS

The start of this work is by choosing a design to the impedance matcher very ease to model in a finite element program, the idea in this first work is to learn how to deal with the finite element program. We choose a mechanical impedance matcher with a mushroom shape. This shape consists of a disk diaphragm with a cylinder in the center that connects the diaphragm to the sphere. Figure 1 shows the five different impedance matchers tested, the drawings are on scale. The fist three are identical with the diaphragm having 100 mm of diameter and different thickness, respectively, 6.063mm, 5.869 mm and 5.161 mm, they all have 30 mm for the diameter of the center cylinder. Figure 2 shows a closer look of the first drawing in Figure 1.

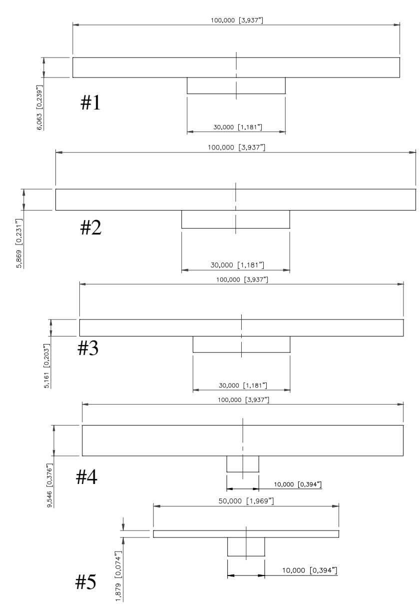
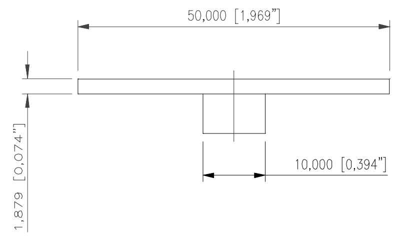


FIG. 1: The impedance matchers.

The intention of this first tests was to tune the impedance matcher at the same frequency of the sphere quadrupole modes in the way that it will work as a resonant transducer, but when the dimensions were changed, a very interesting feature appeared, as can be seem in Figures 3, 4 and 5, the shape of the vibration didn’t follow the expectation (a example of the



#5

FIG. 2: An example of the impedance matcher drawing.

expected shape can be seem on the bottom of Figure 5), most of the modes, seems to be deformed, or even worse, it seems to have the wrong vibration mode (as can be seem on the first mode in Figure 5). In any case, this is very inconvenient, because of the deformed vibration, the transducers will have a problem in the calibration, or even worse, the wrong mode that appears in Figure 5, don't give any signal in a capacitive or inductive transducer.

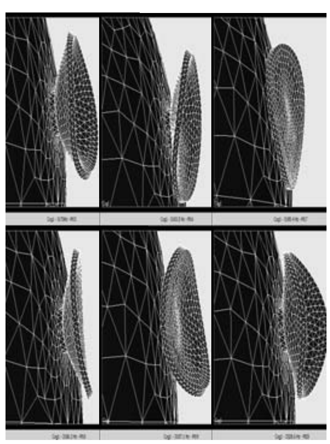


FIG. 3: The first impedance matcher.

The explanation find for the deformed modes was, that the base of the impedance matcher was too big, in a way that amplifies the differential movements on the sphere surface, the attempt to correct this was to decrease the size of the cylinder base.

III. THE FOURTH AND FIFTH IMPEDANCE MATCHER

The diameter of the impedance matcher was changer to 10 mm, the diameter of the diaphragm was kept in 100 mm and

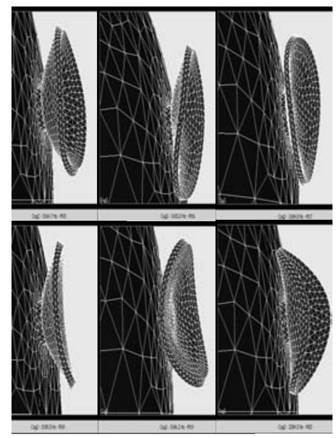


FIG. 4: The second impedance matcher.

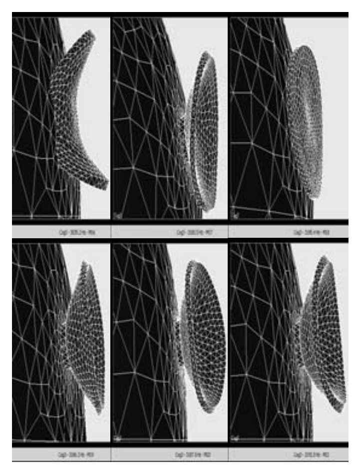


FIG. 5: The third impedance matcher.

the thickness choose was 9.548 mm. This first attempt showed to be quite unfortunate, the frequency of the desired mode (the mushroom mode) is very close to the other mode, called the rocking mode (as can be seem in Figure 6, the two top left and one bottom right). The only way to change this correlation is to change the diaphragm diameter and then it was decrease to a diameter of 50 mm and the thickness changed to 1.879 mm.

The results of this can be seem in Figure 7, all the modes have the same shape, there is still some small deformation but much smaller than in the other cases. All the modes won't have calibration problems and will give signal in capacitive or inductive transducers.

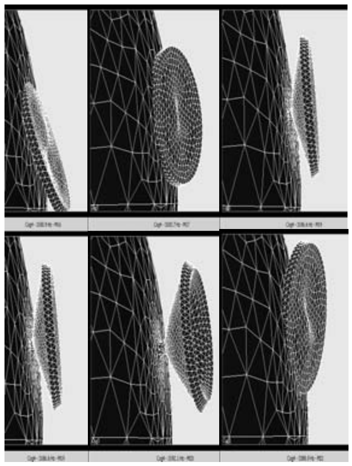


FIG. 6: The fourth impedance matcher.

IV. CONCLUSION AND FUTURE WORK

After a series of changes in the design of the impedance matcher, we could find one which all the modes have similar shapes and could be calibrated in the same way. It was learned that is not straight forward find a mechanical oscillator to right frequency of the quadrupole modes and it will work as a good impedance matcher for a spherical gravitational wave detector.

Next step is to model the six impedance matchers (similar to the one named #5) on the sphere surface on a half-dodecahedron distribution and study the behavior of them coupled to the sphere quadrupole modes. After that, the real impedance matchers for the Schenberg detector will start to be analyzed. A multimode impedance matchers will be discussed in a further work.

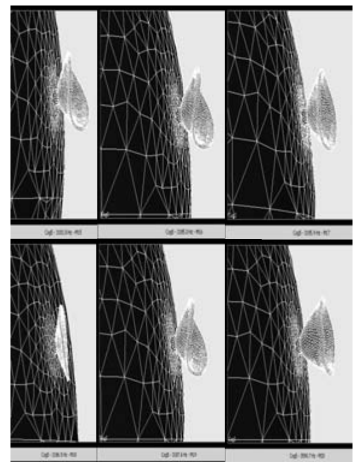


FIG. 7: The fifth impedance matcher.

Acknowledgements

CF. acknowledges FAPESP (grants #98/13458-9) for the financial support.

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