Planning to improve the mechanical quality factor in the transducer impedance matchers for Mario Schenberg detector

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"Mario Schenberg" is a spherical resonant-mass gravitational wave (GW) detector that will be part of a GW detection array of two detectors. Another one is been built in The Netherlands. Their resonant frequencies 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 much more complex. Some studies indicated that using low mass mechanical resonators (used for impedance matching to the parametric transducer, in a cold damping regime) allow the detector to reach the standard quantum limit. In this work we describe the procedures that are being developed to quickly test the mechanical quality factor of a very small resonator in the quest to find the best machining method and thermal annealing for the impedance matching resonator, one key part that makes a good coupling between the sphere and the transducer. The main goal is to optimize the mechanical quality factor in a reasonable time.

1. Introduction

"Mario Schenberg" is a spherical resonant-mass gravitational wave detector cooled down to 20 millikelvin 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 [1] with 94% Cu and 6% Al. The distribution of motion sensors in the surface of the sphere will be based on the work of Merkowitz and Johnson [2]. Motion sensors are devices that monitor the motion of the sphere surface. The detector will have six motion sensors, also called 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 these sensors the intensity and the direction of the incoming gravitation wave could be obtained [3].

Another similar detector is been built in the Netherlands called "MiniGrail" [4]. Together these two detectors will form an array of GW detectors sensitive to frequencies around 3.2 kHz with a bandwidth of about 200Hz.

The Brazilian group has decided to use as motion sensors microwave parametric transducers, as the ones used in the GW resonant-mass detector NIOBE by the Australian GW group [5]. The detection system can be seen in Figure 1. For each of the six transducers, a resonator with two mechanical modes will be used as an impedance match between the sphere surface and a microwave cavity. The first of these modes, the one connected to the sphere, will be called intermediate mode and the second one will be called final mode, all made in a Copper-Aluminum monolithic structure. In this work we present some preliminary results on the investigation of these mechanical impedance matchers.

2. The multimode transducer

A multi-mode transducer would have several advantages over the single mode transducer, as has been well discussed several times [6, 7, 8]. These advantages include increasing the detector's bandwidth and improving the electro-mechanical coupling. In order to improve these characteristic it is necessary to keep the mass-ratio between the sphere effective mass [2] and the effective mass of the intermediate resonator mode equal to the ratio between the mass of the intermediate and the mass of the final resonator modes.

Using the procedures presented in [9] with a lump element model, we calculated for different mass-ratios the sensitivity of the detector, and we chose the mass-ratio that implies with best sensitivity
and has a good size to be machined. By performing these calculations, and assuming a sphere mass of 1150 kg (the effective mass is 280 kg), one can find the right masses for the two modes of the impedance matcher.

3. The mechanical impedance matcher design

Using the concepts of a very compact design and a manufacturing process that uses as less machining processes as possible, a very simple design came up as can be seen on Figure 2. On the top left three disks can be seen, these disks connected by smaller disks, the purpose of these is to make a suspension that will isolate the two beams located at the bottom right of the figure 2, these beams will have the detection frequency (around 3.2 kHz). This monolithic structure will be hang by a very thin titanium wire inside a small experimental chamber, where a very good vacuum will be made, and this small chamber will be put directly inside a liquid helium dewar suspended by a stainless steel tube and the mechanical quality factor of the part will be measured, like the procedure used in [10] (in this case another kind of measure where made).

Calculations in finite element programs are made to evaluate the correct dimensions in order to obtain the correct frequencies for the resonator. One example of these calculations can be seen in figure 3.

4. Comments and future work

The Schenberg detector is expected to attain a noise temperature close to 1 µK [11]. This will be possible if several goals are met, including a mechanical quality factor of 10 million for all the components (the sphere and the two impedance matcher modes). For the sphere that limit doesn’t seem to be a problem, but because the mechanical quality factor seems to decreases with the resonator mass, this will require many tests trying to find the best machining and annealing methods to improve the mechanical quality factor.

The next step in the development of the impedance matcher is to machine many of such structures in different way, test them, and then with the best result, try different thermal annealings trying to reach the best mechanical quality factor. This work is the very first step in the quest to find the best mechanical quality factor for this alloy in a reasonable time.

![Figure 1: The detection system.](image-url)
**Figure 2:** The impedance matcher design.

**Figure 3:** Example of the calculation for the natural frequencies in finite elements model.
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