MODELLING AN EXPERIMENT TO MEASURE THE SPEED OF GRAVITY IN SHORT DISTANCES USING ROTATING MASSES

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Abstract: An experiment to measure the speed of gravitational signals using rotating masses in short distances has been developed with the intention to study its behaviour when a medium different from air is allocated between the emitter and the detection and check if the speed of the interaction changes. The experiment is composed of two masses rotating at incredible rotation (the goal is rotate the masses at rotation speed higher than 600,000 RPM, that excites a saphire bar called the detector. The amplitude of the central device (detector) is monitored by an ultralow phase noise microwave signal using resonance in the whispering gallery modes and cooled down at 4.2 K. Between the rotating masses and the detector, a different medium will be placed, and then the speed is measured and compared with the case where the medium is pure air. The modelling of the experiment is made assuming the detector as a spring-mass system. The results show that the detection is achievable.

Key words: Controlling Device, Variable Reluctance Motors, Gravimeters.

1. Introduction

The Graviton Group is a research group in Brazil for the study of gravity, as part of these studies Gravitational Waves (GW) is the central focus of research, As neutron stars are candidate GW source this is the reason the group also include this topic as the study of Pulsar [1].

GW existence got a very strong evidence with measurements of the pulsar binary system PSR B1913+16 (known also as Hulse–Taylor binary) which orbital period changes with time due the emission of GW [5]. The first experiments to directly detect GW started in the early sixties [6] with the resonant mass GW detectors [7,8,9,10]. The first detection of GW is the result of experiments planned in 2010 [2]. In 2016 the first GW was achieved [3,4].

The Graviton Group efforts for detection of GW are centered on the Schenberg detector which is a 65 cm Cu 6%Al alloy sphere with six microwave transducers on the surface sphere in a semi dodecahedron distribution. The transducer amplifies the radial vibration on the surface of the sphere, the mechanically
amplified vibration is measured in microwave resonant cavity. Once these vibrations are measured the direction of the GW can be determined [11,12,13]. The Graviton Group efforts can be seen in references [14-36]. The Brazilian detector design is shown in Figure 1.

The knowledge developed with GW gave the group the expertise and the eagerness to understand gravity. Keeping that in mind the group is developing an experiment to measure the speed of gravity and to do it in short distances. To reach such a detection a quadrupolar distribution of masses will rotate at very high speeds and very stable in time. In the next section the strength of the signal will be shown, and a proposal for the engine and the control system. After that the limits of the experiment will be calculated.

2. Gravitational signal generation
The experiment first was proposed by Frajuca and Ruiz [37] and a schematics can be seen in Figure 2 where the two bodies of mass 'M' are rotating with a specific radius 'r' around at a distance 'a' from the detector. This scheme is used to calculate the forces between the emitter and the detector. The detector is modelled by two masses 'm' connected by a spring.
Making the calculation of the force acting in the two masses of the detector and making an approximation for a bigger than b and r and making the difference of forces in the two masses of the detector:

\[ f_2 - f_1 = \frac{-4b}{a} + \frac{6b^2}{a^2} + \frac{2}{a^3} + \frac{10(b^4 + 6b^2c^2)}{a^4} + \mathcal{O}(1/a^5) \]  

where \( x = r \cos(wt) \), \( w \) is the angular velocity of rotation in the emitter.

Keeping only the non constant term, the highest term order is:

\[ f_2 - f_1 \approx \frac{24Gm \cos^2(wt)}{a^5} \]  

Applying the force in a harmonic oscillator, the amplitude in the detector will be

\[ \Delta b/b = \frac{24GMQr^2}{(w^2a^5)} \]  

where \( Q \) is the mechanical quality factor.

Using:

\[ M_{eff} = 1\,\text{kg}; \]

Distance between the masses = 5 m;

\[ Q = 10^9; \]

\[ G = 6.67 \times 10^{-11} \text{m}^3\text{kg}^{-1}\text{s}^{-2}; \]

\[ A = 10^{-4} \text{ (Amplitude vibration of the bar devices)}; \]

\[ r = 0.1\,\text{m}; \]

\[ b = 1\,\text{m}; \]

\[ w = 10000\,\text{Hz}. \]

\[ \Delta b/b = 1.4 \times 10^{-15}. \]

\[ \Delta b = 1.4 \times 10^{-15}\,\text{m}. \]

3. SRM for the motorization

In SRM (Switched Reluctance Motor) only the stator has electric windings and the rotor does not have windings or magnets. with an extremely simple construction that does not use brushes or switches. The chosen configuration can be seen in Figure 3, more information can be seen in [38].
4. The proportional-integral controller
In speed control of motors the PI controller is used to increase the stability of the system.

With a PI controller it is possible to improve the stability because of the proportional and integral terms, the velocity is controlled by an appropriate excitation of the stator coils using PWM technique and using hall sensors to know its position. In Figure 4 the model of control is shown.

![Proposition of control model](https://people.ucalgary.ca/~aknigh/electrical_machines/images/oth/sr.jpg)

A position feedback loop is used. Knowing the position for feedback can be obtained using data derived from the position. The rotor position is measured using hall sensors and the motor is driven using voltage pulses and the position of the rotor[39,40]. The motor speed is controlled by variation of its voltage across the motor. The motor voltage variation is obtained by variation of the duty cycle of the PWM signal.

5. Quantum, equipment sensitivity and thermal noise limits
It follows the work in [41], instead the detector is a little different. Adding the following parameters:
Phase oscillator: -185 dBC/Hz at 1 kHz offset;
Frequency bandwidth BW = 3500 Hz;

\[
\hbar = 6,626,069 \cdot 10^{-34} \text{ J.s}
\]

5.1 The quantum limit
Corresponds to the smallest number of phonons that is a minimum limit, therefore:
\[\hbar w = \frac{1}{2} A^2 w^2 m \implies \hbar w = \frac{A^2 w^2 \text{Eff}}{2}\]
\[\Delta b_{QL} = A = \sqrt{\frac{2\hbar}{w \text{Eff}}} = \frac{2 \times 10^{-34}}{1.2 \times 10^5} = 10^{-19} m\]

(6)

5.2 Equipment sensitivity limit
Given by:
\[S_x(f) = \left(\frac{df}{dx}\right)^{-2} S_\phi(f) f^2\]
(7)
Using BW = 3500 Hz:
\[S_x = 3 \times 10^{-16} m\]
(8)

5.3 Thermal noise limit
\[\Delta_{xth} = \sqrt{\frac{KT}{2M_mwD}}\]
(9)
\[\Delta_{xth} = 10^{-20} m\]
(10)

6. Conclusion
The experiment is limited by the following values:
- Quantum limit: \(\Delta b_{QL} = 10^{-19} m\);
- Equipment sensitivity limit: \(S_x = 3 \times 10^{-16} m\);
- Thermal noise limit: \(\Delta_{xth} = 10^{-20} m\).

The value of amplitude to the measured is expected to be:
\[\Delta b = 1.4 \times 10^{-15} m\]
a value above the limits of the experiment then the experiment is quite viable.

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