

AIGO High Performance Compact Vibration Isolation System

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Abstract. We present a completed prototype of the AIGO seismic vibration isolation system. The design has been developed to satisfy the isolation requirements for the next generation of interferometric GW detectors. The system relies on passive isolation and includes multiple Ultra Low Frequency (ULF) stages to achieve minimal low frequency residual motion. Two complete isolators are being installed at the high power test facility located in Gingin, Western Australia. The performance of individual mechanical stages is continually being tested and improved. Currently it is expected that residual motion close to 1 nm at 0.3 Hz will be achieved.

1. Introduction

A high performance vibration isolation system is being developed for advanced gravitational wave detectors at the AIGO High Optical Power Interferometer Facility in Gingin, Western Australia. The system is distinguished by a relatively compact height, three stages of pre-isolation, an all passive design and the use of several novel isolation techniques.

In addition to high performance isolation within the detection bandwidth, it is critical to the interferometer operation that the isolator provides minimal residual motion at low frequencies in order to facilitate cavity locking and to minimise noise input through actuation forces. Because pendulum systems inherently have large Q-factors, it is necessary to damp the normal modes of the suspension system. Current isolator designs developed for GEO [1], LIGO [2], TAMA [3, 4] and VIRGO [5, 6] have approached this problem with a variety of techniques, using passive and active damping designs. The isolator reported here relies on a novel passive damping technique, and a double horizontal pre-isolation design to achieve nanometre residual motion at low frequencies.

This system consists of a three dimensional pre-isolator [7, 8]; (from Figure 2) (a) the inverse pendulum, (b) the LaCoste linkage, and (c) the Roberts linkage [9, 10]. After the pre-isolation stages an isolation stack is suspended which consists of three low frequency three-dimensional isolator stages [11, 12]. In this paper we review the AIGO isolation design and report on isolation performance measurements and tuning. Individual stage measurements have shown near ideal performance. Measurements on multistage systems always quickly reach sensitivity limit due to sensor noise and reference frame noise. Thus the ultimate noise performance is not easily verified, but the critical issue of normal mode performance and residual motion can be determined. These aspects are presented here. The design of the isolator and concepts behind these techniques are reviewed in section 2. The experimental results and tuning progress are presented in section 3. Finally we report in section 4 on the status of the development of the isolation system at the AIGO site in Gingin, Western Australia.

2. Isolation Techniques

The AIGO mechanical vibration isolator consists of multiple stages as shown in Fig 1 which uses several different techniques to attenuate seismic noise. Anti-Spring geometries are implemented into various stages to reduce fundamental mode frequencies [12, 13].

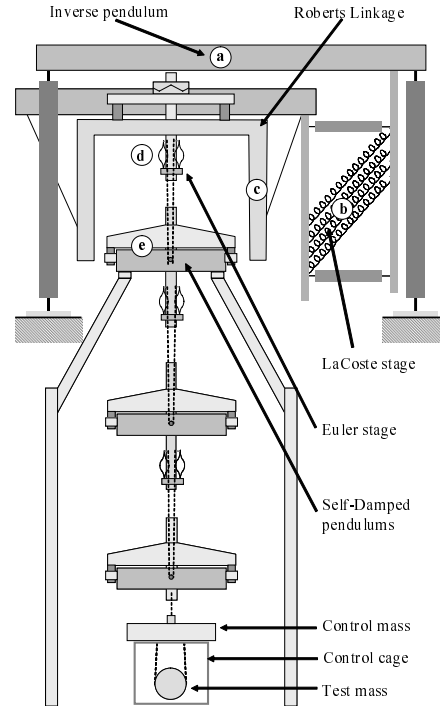


Figure 1. Isolation stages of the AIGO suspension chain. The pre-isolation stages include a, b and c. The isolation stack is defined as the three identical stages of self-damped pendulums with Euler stages; a) Inverse pendulum pre-isolator [7] b) LaCoste Linkage [7] c) Roberts Linkage [10] d) Euler springs [12] e) Self-damped pendulums [11]

The pre-isolator consists of several stages, the inverse pendulum, the LaCoste linkage and the Roberts linkage, each with their resonant frequencies below 0.1 Hz. The inverse pendulum pre-isolation stage or sometimes called the wobbly table is effectively a table top supported at each corner by inverse pendulums. Vertical pre-isolation is provided by the LaCoste linkage [7] which is a combination of inverse pendulums and coil springs supporting the load. The Roberts linkage is a relatively simple design as illustrated in Fig 2. A cube frame is suspended by 4 wires which are hung off the vertical pre-isolation stage. The load is suspended at about the same height that the Roberts linkage wires are attached from, resulting in a very low fundamental resonant frequency [9, 11].

A low frequency isolation stack is suspended from the Roberts Linkage consisting of three almost identical stages (see Figure 1). A 40kg mass load is suspended from each stage in a self-damped pendulum arrangement as illustrated in Fig 3. The self-damping concept consists of viscously coupling different degrees of freedom of the pendulum mass and is discussed in the paper by Dumas [11]. The Euler spring vertical stage shown in Fig 4 is used to further attenuate the vertical component of seismic noise. Euler spring stages can be tuned with anti-spring geometries to achieve good low frequency performance within a very compact design as reported by Chin [12]. Each of the stages comprise of the combination of a self damped pendulum and an Euler spring vertical stage in an arrangement as illustrated in Fig 5.

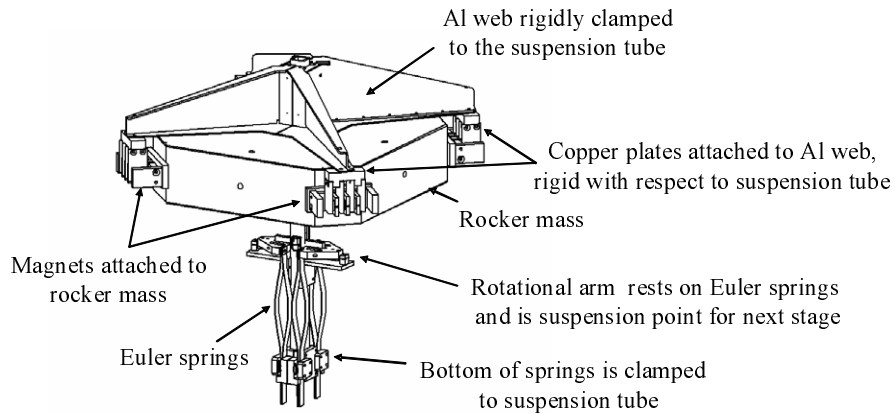


Figure 5. The combined 3D isolator stage [11]

3. Experimental and theoretical results

The assembly of a full scale prototype vibration isolator was completed at the university of Western Australia. The transfer functions of the inverse pendulum in the pre-isolator was measured in both the horizontal and vertical planes. These results are presented in the paper by Lee [15] along with the implementation of the Proportional-Integral-Differential (PID) control. The performance of the Roberts linkage was also recently tested and tuned. This was done by sensing the motion output from point at which the 3D stack is suspended from the Roberts linkage. The shaking was done by actuating upon the inverse pendulum. The tuning of the roberts linkage is a meticulous process best explained by a theoretical model as presented in a previous publication by Dumas [10] showing the effect of varying the suspension point height (point P increases in height where C and D remain fixed, *see Fig 2*). Not only is the normal mode frequency affected but also the high frequency isolation floor. Fig 6 shows the transfer function results of increasing the suspension point P . Moving this point influences the centre of percussion of the Roberts linkage structure which determines the isolation floor (the concept is described in [10]). The third curve shows a vast improvement in both the normal mode frequencies and the roll off above 2.3 Hz. Increasing the mass of the structure decreases the resonant mode frequency. Also, by placing the additional mass close to the suspension point, the radius of gyration decreases thereby improving the performance. It is shown that there is a 20 dB improvement at 7 Hz compared with the untuned curve (see Fig 6 (a) vs. (b) and (c)). However at 10 Hz we see a peak appearing as we progressively improved the isolation floor level. Further investigations are being done in an effort to find the real source of the peak. The low frequency isolation stack has also been extensively tuned and tested, with results reported elsewhere [11, 12]. We have obtained satisfying results in which experimental curves compared well with theory .

The horizontal transfer function of the complete 3D isolation system has been simulated and is shown in Fig 7. It can be seen that all normal vibration modes are below 2 Hz. The isolation performance provides 120 dB of attenuation at 2 Hz and rapidly rolls off, so that the detector could operate as low as 5 Hz. The RMS residual motion is also shown in Fig 8. We expect an RMS residual motion of 1 nm at 0.3 Hz. This level of attenuation would improve the ease with which to acquire cavity locking [16].

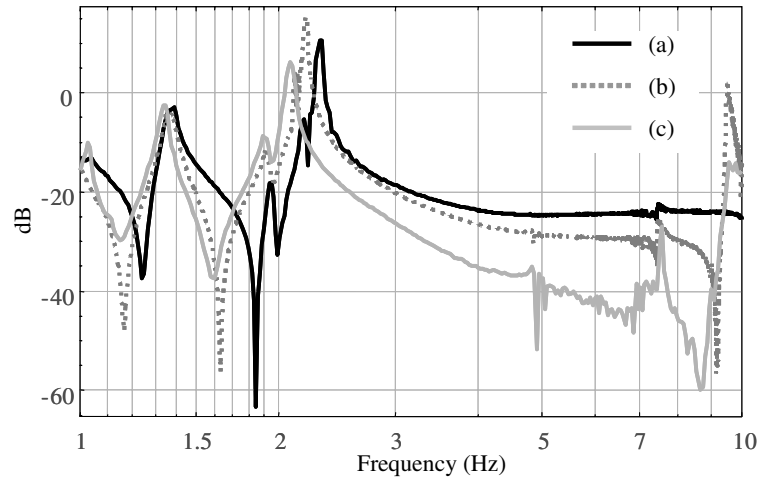


Figure 6. Robert Linkage Frequency Response under different tuning conditions: a) Load suspended at point P b) Load suspended 12 cm higher c) Load suspended 12 cm higher and with a 5 kg tuning mass

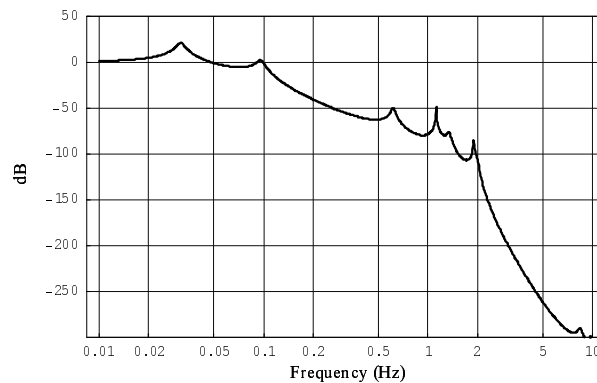


Figure 7. Transfer function theoretical curve

4. Isolator Progress in AIGO

Efforts are made to install two full vibration isolator systems at the test facility of AIGO. The isolators are assembled in a clean room environment in the central laboratory in Gingin. Each mechanical part is UHV cleaned under stringent conditions. The first system is nearing completion. Immediately following this the assembly of the second will commence to eventually form a 80 meter long East arm cavity.

Performance testing of the full isolators is planned later in the year after the completion of the cavity. This will be done in UHV conditions where the cavity can be laser locked. The error signal of the locked cavity will be used to test the performance of the control system and to obtain transfer functions of the vibration isolators.

Acknowledgments

We would like to acknowledge the Australian Research Council for their support of this work. This project is part of the research program of the Australian Consortium for Interferometric

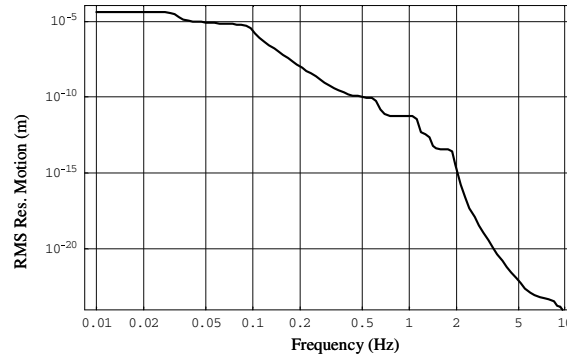


Figure 8. RMS Residual motion theoretical curve

Gravitational Astronomy.

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