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Hybrid low frequency seismic isolation system for the 3rd generation gravitational wave detectors

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Ultimate seismic isolation at low frequencies is necessary for the 3rd generation gravitational wave detectors. To isolate low-frequency seismic motion, we suggest the hybrid two-stage system with an inverted pendulum and a Roberts linkage. It is possible to tune each resonant frequency independently due to the different main parameters; load and center of gravity.

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1. Introduction

Some 3rd generation gravitational wave detectors are suggested. One of them, the Einstein Telescope (ET) employs a xylophone configuration which consists of a low-frequency interferometer (ET-LF) and a high-frequency one (ET-HF). The target sensitivity is $2 \times 10^{-23}/\sqrt{Hz}$ at 3 Hz in strain[1]. To obtain such a sensitivity, isolation of more than 200dB is required. Even if we employ a pendulum (filter) chain to increase the isolation ratio, two or more stage low-frequency pendulums are necessary.

We suggest the hybrid two-stage system with an inverted pendulum (IP)[2] and a Roberts linkage (RL)[3]. The IP was employed in the vibration isolation system of VIRGO and KAGRA. Their setup, tuning, and controls are established very well. The resonant frequency is tuned by the total load to the IP. The vibration isolation system using the RL has been developed by the UWA grope. The RL was employed in the 80-m prototype interferometer in Gingin. The resonant frequency is tuned by the position of the center of gravity. In the case of using a double IP, the tuning for the second stage affects the resonant frequency of the first stage. Because the load for the first stage was changed together when the load for the second stage was changed. In the case of using a combination of an IP in the first stage and an RL in the second stage, the tuning of the RL doesn't affect the resonant frequency of the IP. It is possible to tune each resonant frequency independently.

2. Roberts Linkage

RL is a horizontal isolation mechanism. It has a critical point that can move horizontally for small deviations. Fig.1 shows a 2D model of RL with a suspended payload. The distance between two suspension points (AB) is set to two times of the base length of the RL flame (CD); $AB = 2CD$. The center of mass of the RL flame, which is located at h a little bit smaller than H, moves with a small gravitational potential change. To keep the height of the center of gravity, the suspension point for the payload must be consistent with the center of mass of the RL flame ($d = 0$). In the case of $d \neq 0$, a rotation of the RL flame couples to the horizontal motion of the RL flame.

Fig.2 shows the calculated transfer functions from the ground displacement x_0 to the payload displacement x_2. The following parameters were used; the mass of the RL flame $m_1 = 37$ kg, the mass of the payload $m_2 = 30$ kg, the momentum of inertia of the RL flame $I_1 = 3.6\,\mathrm{kg\,m^2}$, the height of critical point $H = 0.65$ m, the height of center of mass $h = 0.64$ m, the pendulum length of payload $L = 0.92$ m. They came from the dimensions of the TAMA-SAS prototype (see the next section). The lowest mode frequency of the double pendulum depends on $H - h$. It is around 0.04 Hz in this case ($H - h = 0.01$ m). The isolation ratio (x_2/x_0) reach 10^{-6} at 5 Hz in the case of $d = 0$. The isolation at the higher frequency (> 2 Hz) became worse with increasing the offset d. When d went to the plus side, the lowest mode frequency became smaller. Because the center of gravity cross to the critical point.

3. Prototype test

The seismic attenuation system for TAMA300 (TAMA-SAS)[4] consists of the IP and the geometric anti-spring (GAS) filters to hang the payload which consists of the platform, the inter-

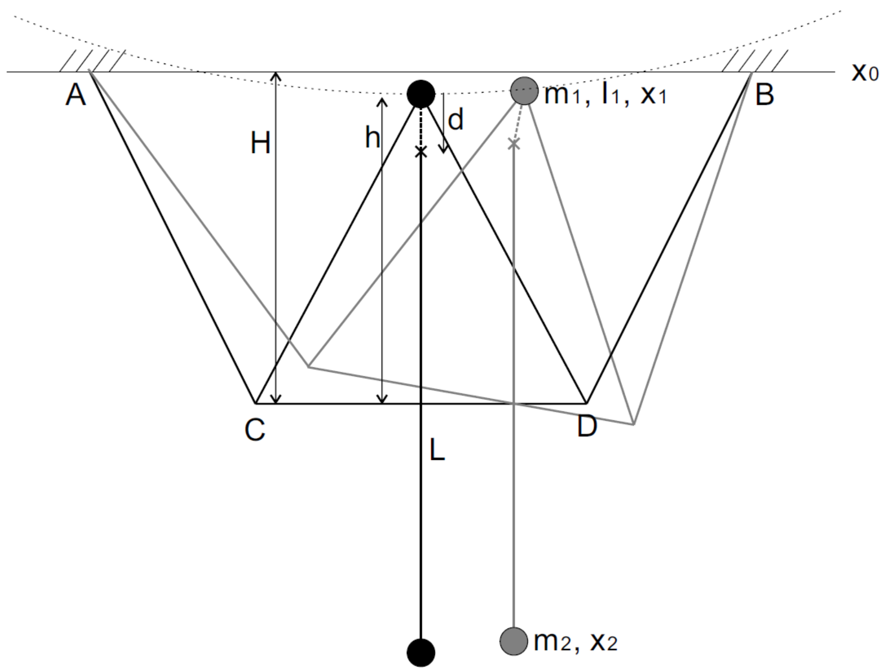

Figure 1: 2D model of RL with a suspended payload.

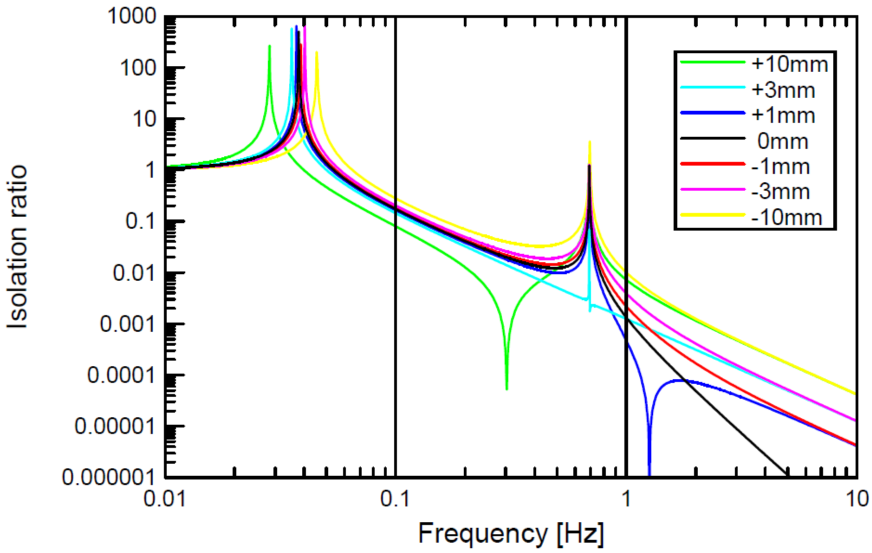

Figure 2: Calculated transfer functions from the ground displacement to the payload displacement in the 2D model. The isolation ratio depends on the suspension point of the payload. Some cases of the offset from the center of mass of the RL frame ($d = \pm 10$ mm) are shown.

mediate mass, and the test mass. We plan to test the hybrid seismic isolation system using the TAMA-SAS tower. The GAS filters are replaced with the RL. A simple test mass (TM) block with inertial sensors is used as the payload. Fig.3 shows the schematic view of the test configuration. The inverted pendulum is controlled with three LVDT displacement sensors and three magnet-coil actuators. The base plate of the RL frame is suspended with three tungsten wires from the top frame supported by the IP. The payload is suspended with a single managing steel wire from the top plate of the RL frame. The height of the suspension point is adjustable with stop screws. We can measure the transfer functions from the IP top to the TM. The displacement of the IP is measured by the LVDTs and the accelerometers (ACCs). The displacement of the TM is measured by laser sensors or inertial sensors.

4. Summary

We suggest the hybrid two-stage system with an inverted pendulum and a Roberts linkage to isolate the low-frequency seismic motion strongly. It is possible to tune the resonant frequency of RL by adjusting the height of the center of gravity without changing the load. It is necessary to make the suspension point consistent with the center of mass of the RL frame to avoid coupling due to the rotation of the RL frame. We plant the prototype test using the TAMA-SAS tower.

References

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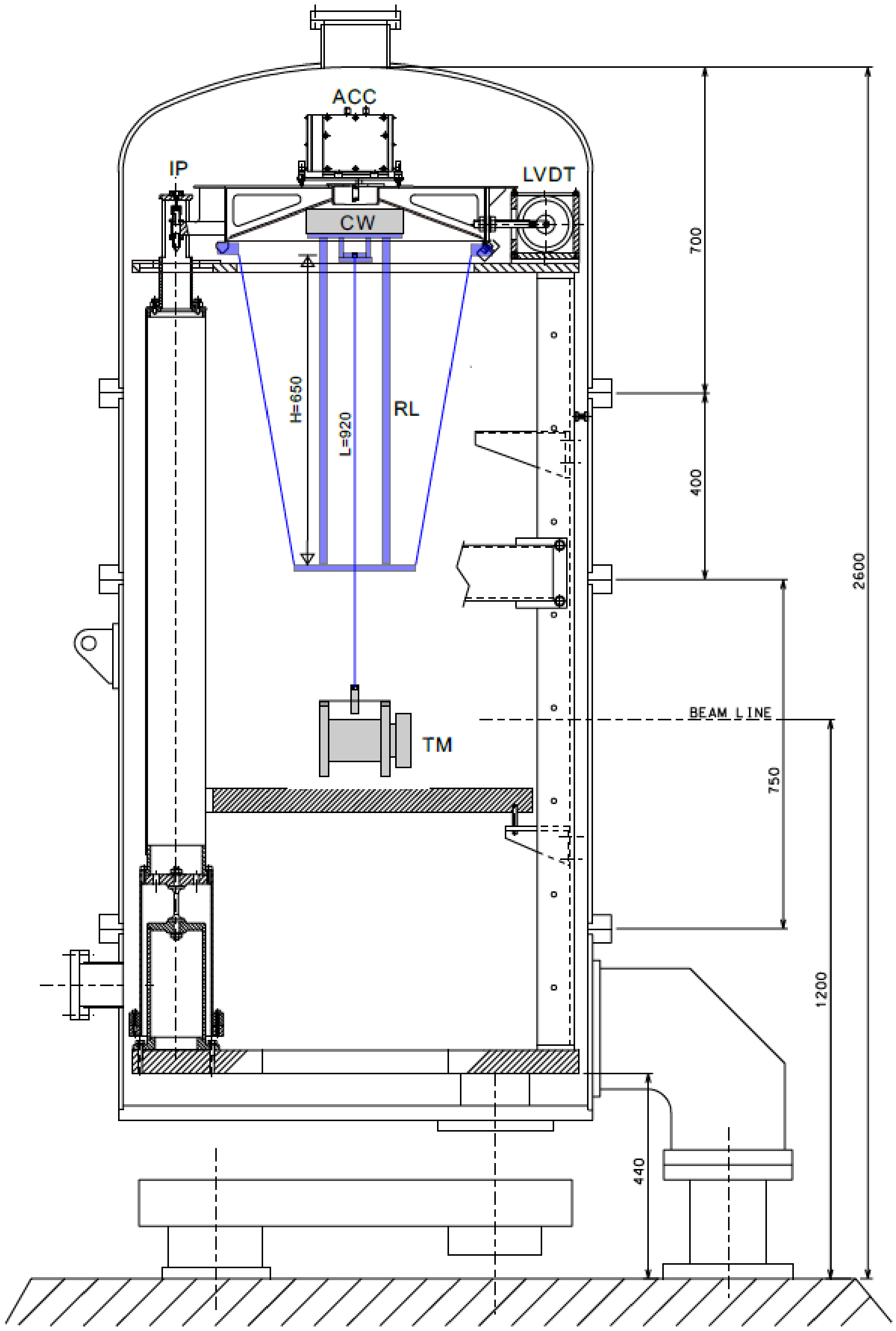

Figure 3: Schematic view of the test configuration using the TAMA-SAS tower. A counterweight (CW) is mounted on the top of the RL frame to make the center of mass cross the critical point.