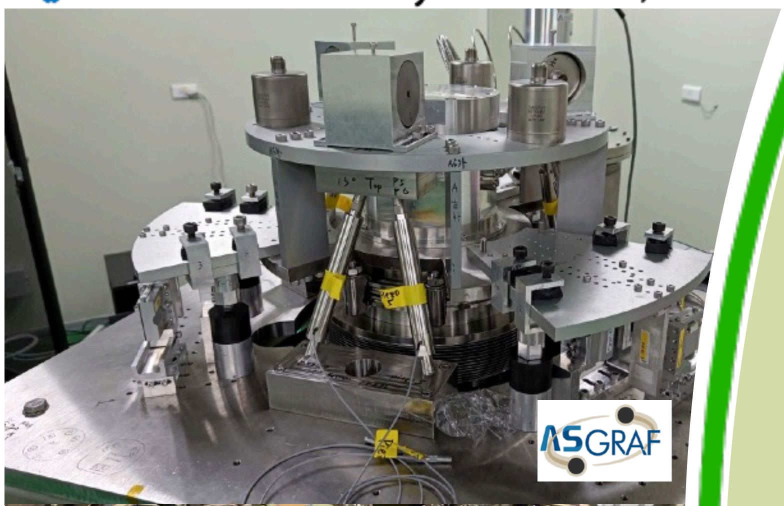
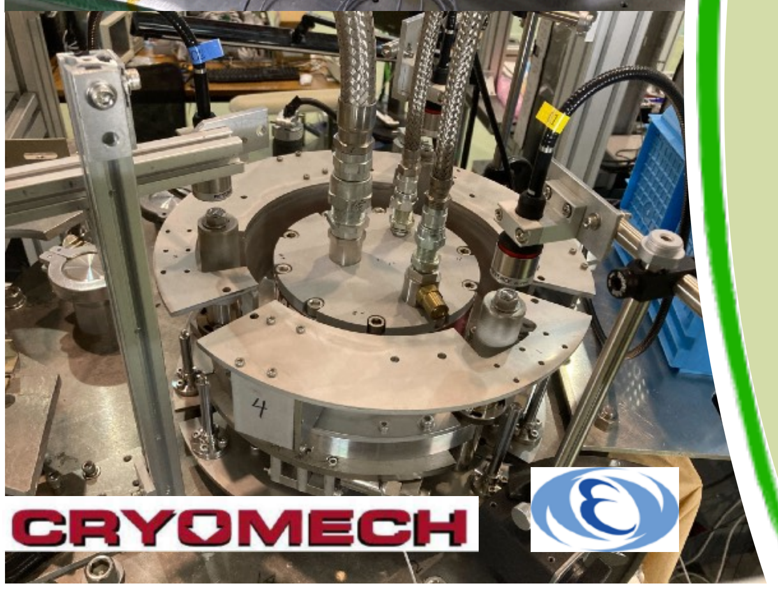
Development and Characterization of active damping cryogenic system for astronomical telescope

Yuki Inoue[1,2,3], Ma'arif Miftahul[1], Hsiang-Chieh Hsu[2], Masaya Hasegawa[3,4], Satoru Igarashi[3], Daisuke Kaneko[4], Takahiro Kanayama[3], Junichi Suzuki[3] Daiki Tanabe[2], Henry.T Wong[2]

National Central University[1], Academia Sinica[2], KEK[3], QUP[4]

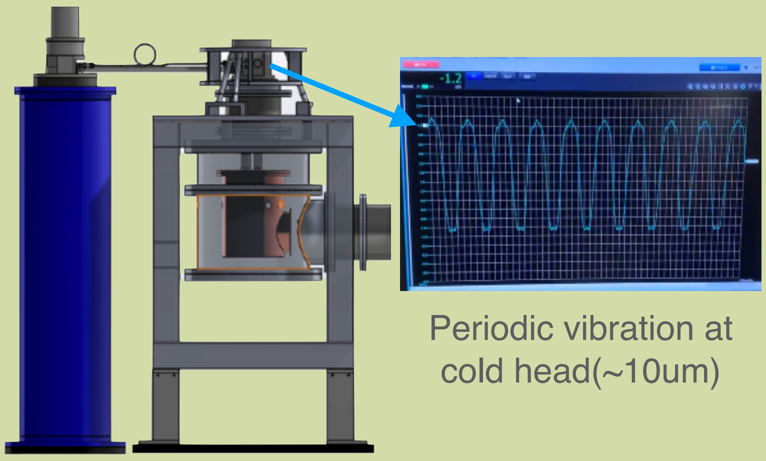
Sumitomo Heavy Industries, Ltd.





1.Introduction

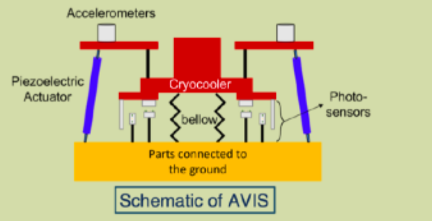
Current astronomical observations are supported by cryogenic technologies. However, there is a suggestion that the vibrations of the cryogenic unit itself may introduce noise during the process of using the cryogenic system. Therefore, we are incorporating active vibration suppression techniques from gravitational wave experiments into the cryogenic unit and developing technology to suppress vibrations. In this study, we are particularly aiming to demonstrate this technology, focusing on cryogenic units from Sumitomo Heavy Industries and CRYOMECH.



Periodic vibration at cold head(~10um)

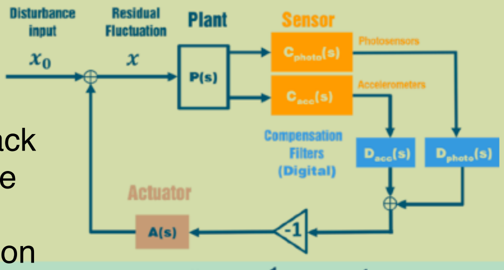
2.Active vibration isolation system

Sensors and actuators are utilized to construct an active vibration suppression system for the cryogenic system. Vibration suppression is achieved by providing feedback to these signals at appropriate frequencies. The research specifically focuses on vibration evaluation in the ambient temperature portion of the cryogenic system.



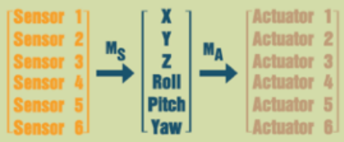
Schematic of AVIS

- Plant: 2-stage pulse-tube cryocooler (the system to be controlled).
- Ground: parts connected to the ground.
- Actuators: connect Plant and Ground.
- Sensor: detect the vibrations in 6 DoF (2 different types of sensors).
- → Control "relative motion" between Plant & Ground based on the signal from sensors.



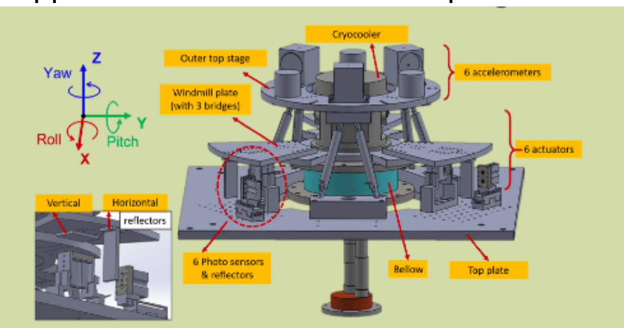
$$x = x_0 - PCDAx \Rightarrow \frac{x}{x_0} = \frac{1}{1+PCDA} = \frac{1}{1+G}$$

- G: open-loop transfer function (G=PCDA)
- The original disturbance is suppressed by a factor 1/(1+G)



3.Instruments

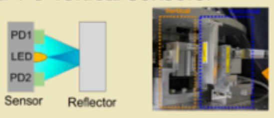
The system is divided into sensors, actuators, and a digital feedback system. The progress of the development of these components is summarized below.
In particular, the digital control system has been miniaturized, considering its application in Chile and South pole.



Sensor 2 types of sensors aim for different frequency bands.

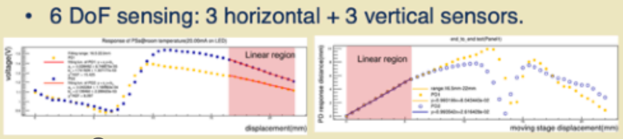
High-frequency (> 5Hz)

→ **Accelerometers:**
- Seismic, high sensitivity, ceramic flexural ICP® sensor.
- Typical sensitivity: ~10.0 V/g (1.02 V/(m/s^2)) with ±5% uncertainty.
- 6 DoF sensing: 3 horizontal + 3 vertical sensors.



Low-frequency (DC - 5Hz)

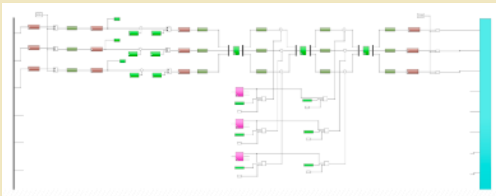
→ **Photo sensors**: a reflective optical sensor comprised of one LED and two photodiodes (PD).
- Well calibrated and can reconstruct the displacement with an error lower than 0.1 %.
- 6 DoF sensing: 3 horizontal + 3 vertical sensors.



Sensor

Digital Feedback system

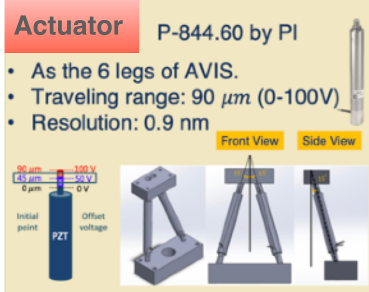
- OS: Debian10
- Digital I/O sytem (16 bit)
- Synchronized with FPGA clock signal
- Nyquist frequency: 8192Hz
- Create Infinite Impulse responce filter
- Managed by EPICS
- Free software developed by LIGO (installed by apt)
- Design the digital feedback filter byMatlab simulink



Feedback loop design on Matlab simulink

Actuator P-844.60 by PI

- As the 6 legs of AVIS.
- Traveling range: 90 μm (0-100V)
- Resolution: 0.9 nm

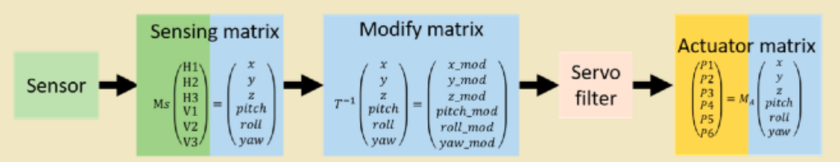


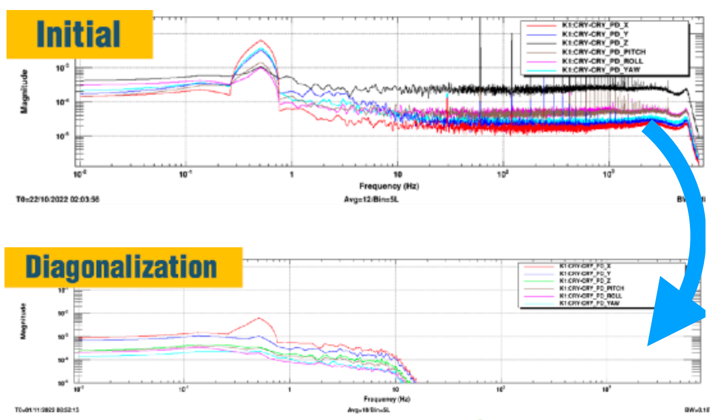
4.Feedback control

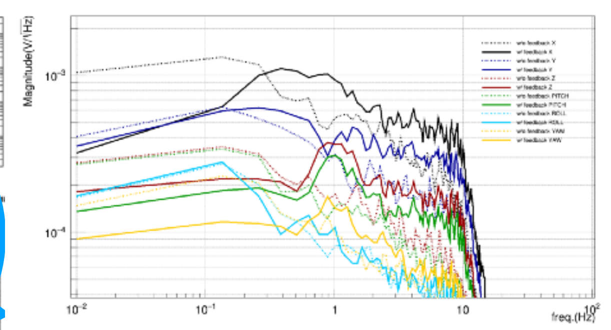
Diagonalization

Actual Input Matrix (A) = Adjustment Matrix (T) ★ Ideal Input Matrix (M)

- Ideally (perfect case), the Actual input matrix (A) should be identical to the ideal input matrix (M) and the adjustment matrix should (T) be an identity matrix. However, we observe the non-diagonality in our instrument.
- Method: 1.) Find T from the measurement. 2.) Cancel it by inverse matrix T^{-1}







Noise spectrum with feedback

5.Discussion and Summary

This study is expected to be applied to future gravitational wave and astronomical telescopes for vibration suppression. The system has already been implemented at KEK and ASGRAF in Taiwan, where evaluation tests are ongoing. While this study focused on vibration suppression in the room temperature section, efforts are currently being made to extend vibration suppression to low-temperature environments. As a method for cryogenically adapting the vibration suppression, the initial plan is to enable the reading of sensor data at low temperatures.

Reference

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2. Ayaka Shoda, 'Development of a High-Angular-Resolution Antenna for Low-Frequency Gravitational-Wave Observation'
3. ASGRAF: Academia Sinica Gravitational Physics Research Facility(PI: Yuki Inoue)