PROCEEDINGS OF SCIENCE

Control of Laser Interferometer for DECIGO and B-DECIGO

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DECIGO (DECi-hertz Interferometer Gravitational-wave Observatory) is a space-based gravitational wave detector that has a good sensitivity at low frequencies from 0.1 Hz to 10 Hz. DECIGO can detect gravitational wave signals from intermediate mass black hole binary mergers and gravitational wave background. It leads to the verification of the formation scenario of supermassive black holes and inflation theories in the early universe. DECIGO is a triangular-shaped laser interferometer consisting of 3 satellites that are in a precise formation flight. By controlling and measuring the distance between each satellite, the interferometer detects distortion of space caused by gravitational waves. Each side of the triangular laser interferometer is an optical cavity, and its length is designed to be 1000 km for DECIGO and 100 km for B-DECIGO. This cavity is called Dual-Pass Fabry-Perot cavity because the laser beams from satellites on both sides are incident on it. It is necessary to protect the interferometer from disturbances such as solar wind in space, and to control the position and alignment of the mirrors that consist of Dual-Pass Fabry-Perot cavity. In this presentation, we introduce the methods to sense and control these mirrors (called Pound-Drever-Hall technique for length control, WaveFront Sensor and Beam Pointing Control for alignment control), and an experiment for demonstration and verification of them. As the result, we succeeded in a simultaneous control 2 dofs of length and 12dofs of alignment which are all dofs of Dual-Pass Fabry-Perot cavity.

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1. Introduction

DECIGO (DECi-hertz Interferometer Gravitational-wave Observatory)[1] is a space-based gravitational wave detector. 3 satellites are precisely controlled and form a triangle-shaped laser interferometer. DECIGO aims at gravitational waves whose frequency is from 0.1 Hz to 10 Hz. This frequency region is lower than the target of ground-based gravitational wave detectors LIGO[2], Virgo[3], and KAGRA[4, 5]. Each side of the triangle-shaped interferometer of DECIGO and B-DECIGO is an optical cavity as shown in figure 1. The length of the cavity is planed to be 100 km for B-DECIGO, and 1000 km for DECIGO. Each satellite has a laser and laser beams are incident on the Fabry Perot cavity from both sides. We call this optical configuration of the cavity "Dual-Pass Fabry Perot cavity(DPFP cavity)".

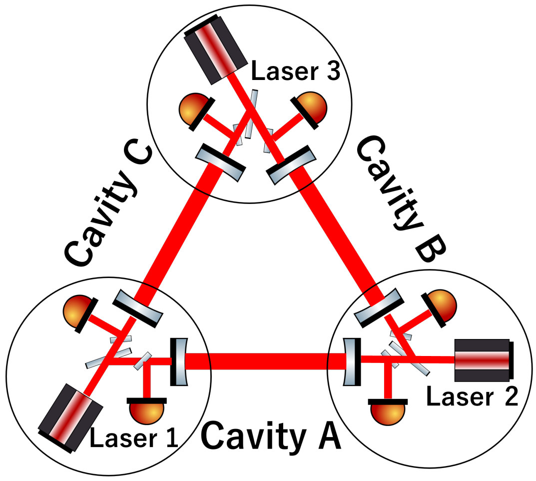

Figure 1: Laser Interferometer of DECIGO and B-DECIGO

To realize DECIGO and B-DECIGO, we need to verify and demonstrate the control method of DPFP cavity on the ground. For this purpose, We did an experiment and demonstrated the sensing and control of Dual-Pass Fabry Perot cavity is successfully done by Pound-Drever-Hall technique, WaveFront Sensor, and Beam Pointing Control.

This article is organized as follows. In Section 2, we explain the control scheme of Dual-Pass Fabry Perot cavity and how many degrees of freedom are needed to control. We introduce the experimental setup for the demonstration in Section 3. Section 4 shows the results of the experiment and WFS and BPC suppress the angular noises of the cavity. Finally, We summarize this work and discuss next steps in Section 5.

2. Control scheme of Dual-Pass Fabry-Perot cavity

We can distinguish the control of the Dual-Pass Fabry Perot cavity into two, Length Sensing and Control and Alignment Sensing and Control. Length Sensing and Control(LSC) of the two lasers is achieved using Pound-Drever-Hall technique[6, 7]. Figure 2 shows a misaligned DPFP cavity. This is a general situation without any controls. To align Dual-Pass Fabry Perot cavity, we need to align 4 axes. 2 are incident beam axes of the two lasers(Blue and red lines in Figure 2), Anothor is a cavity axis which is defined by the curvature centers of the two mirrors. The other is

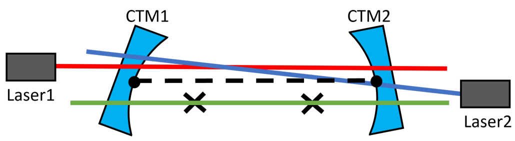

Figure 2: Misaligned Dual-Pass Fabry Perot cavity. The cross symbols are the curvature centers of two mirrors. The dot symbols are the rotational centers of two mirrors

a standard line which is defined by the rotational centers of the two mirrors. Against the standard line, we have two kinds of errors, shifted error and tilted error for the other three axes. moreover we have to consider there are two directions, Pitch and Yaw, orthogonal to the optical beam axis. To sum up, we need to control 12 degrees of freedom for alignment. Alignment Sensing and Control(ASC) of these degrees of freedom test masses(CTMs) and steering mirrors (STMs) are achieved by WaveFront Sensor(WFS)[8–10] and Beam Pointing Control(BPC)[11].

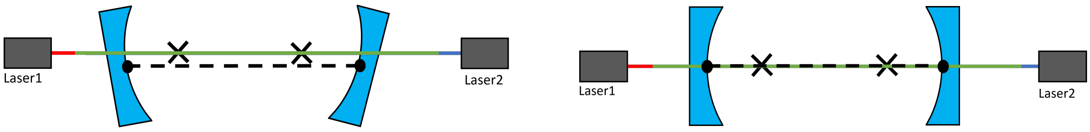

Figure 3: Left: 3 axes are aligned by WFS. The red and blue axes are the incident axis of each laser and the green axis is the cavity mode which is defined by the curvature centers of the two mirrors. These three axes are aligned by WFS. **Right**: All 4 axes are aligned by both, BPC and WFS. Beam Pointing Control detects the error between the cavity axis (Green solid line) and the standard axis (Black dashed line). After BPC is implemented, these two axes should be aligned. Moreover, Incident axes of the two lasers (Red and Blue) follow the green cavity axis by WFS. As a result of WFS and BPC, all 4 axes are aligned.

3. Experiment

Figure 4 shows a schematic of the experimental setup for the verification of control of Dual-Pass Fabry Perot cavity. Two mirrors that form the Fabry Perot cavity are suspended by a well-damped pendulum and installed in a vacuum tank(see Figure 5).

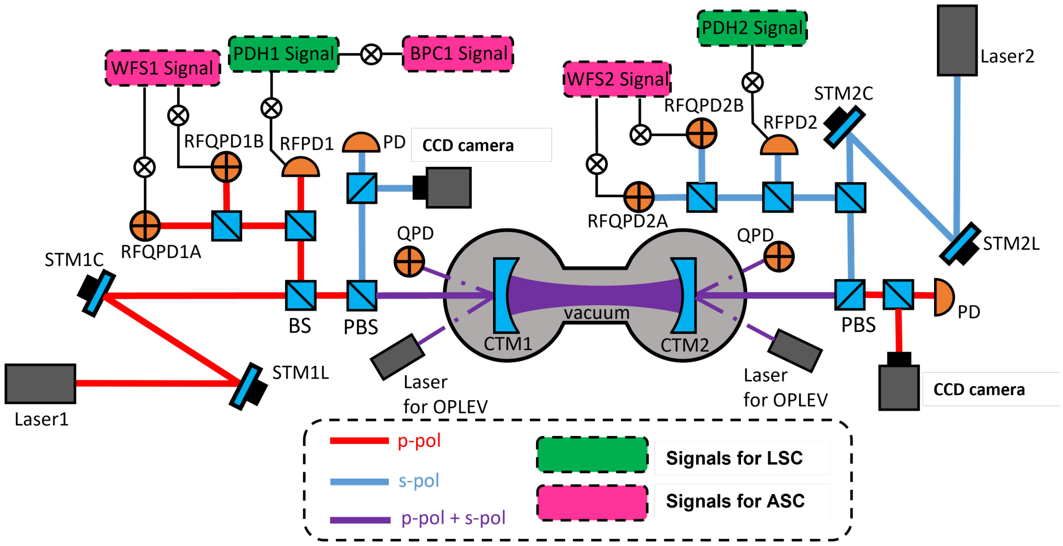

Figure 4: Schematic of the experimental setup

Two lasers are incident on the cavity from both sides. To distinguish the two laser beams, p-polarization of laser 1 is incident on the cavity while s-polarization of laser 2 is incident on the cavity from the opposite side. We can actuate incident beams by driving Steering mirrors that are attached to PZT. Moreover, RF Diodes and RF Quad-diodes are installed in the reflection area to detect PDH signals and WFS signals. In transmission port, we installed CCD cameras and photodiodes to monitor the spherical modes of the beam and transmitted powers.

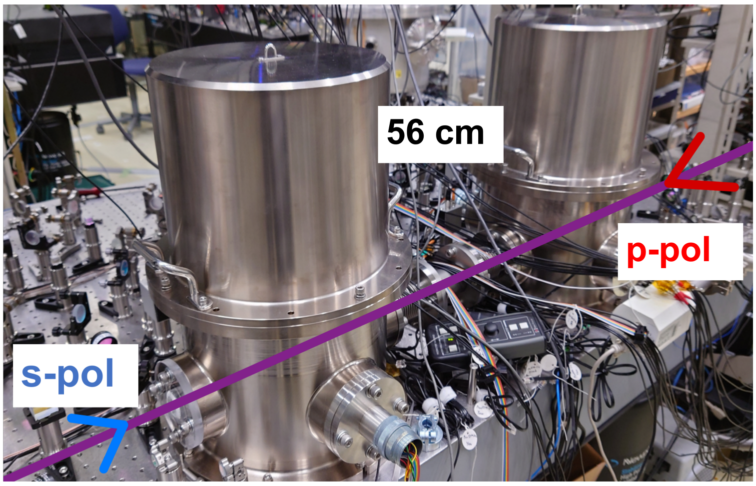

Figure 5: Schematic of the experimental setup

4. Result

As a result, the figure 6 shows angular noises of CTMs are reduced by WaveFront Sensor. Blue curves are angular fluctuations before we implement WFS and Orange curves are those after WFS is implemented. It can find the angular noise at low frequencies between 0.1 Hz and 10 Hz is suppressed.

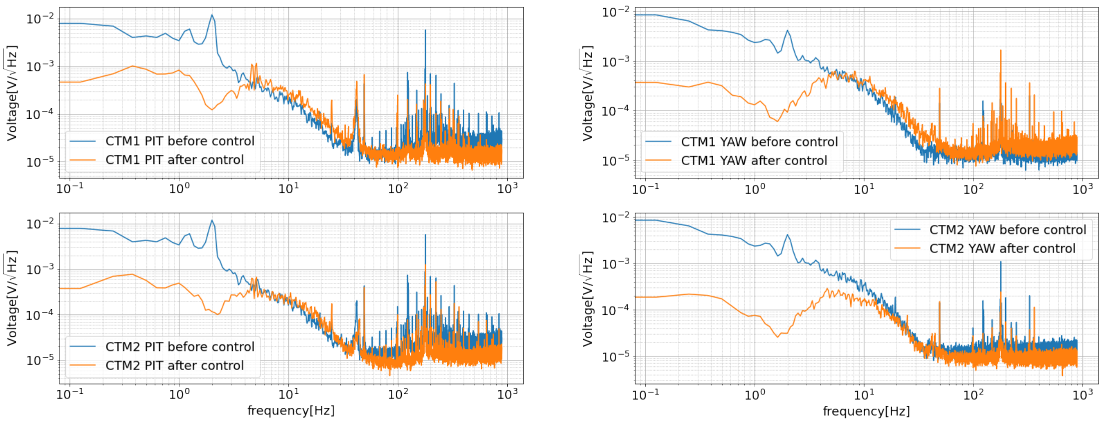

Figure 6: Angular noise reduction on CTMs (Top: CTM1, Bottom: CTM2, Left:Pitch, Right:Yaw). The blue curves show the angular fluctuation before WFS is implemented and the orange curves show that after WFS is implemented.

As shown in the figure 7, We dithered CTMs at 200 Hz, 225 Hz, 330 Hz, 365 Hz for detecting the error of beam spots of the 2 CTMs in the direction of pitch and yaw. after BPC is implemented. It can find the dithered peak is suppressed because the distance between beam spots and rotational centers get to be small. The Blue curve in the figure 8 shows an error signal of laser1 without alignment control and The orange curve is that with WFS control. Around 10 to 100 Hz, it can find the error signal got to be worse after WFS. This result means the source of this noise is the alignment control noise. The green plot is the error signal of the laser after WFS and BPC. we can find the alignment control noise is suppressed. it is because the beam spots matched the rotational centers of the cavity mirrors due to BPC, and the length movement and the angular movement of the mirrors are decoupled.

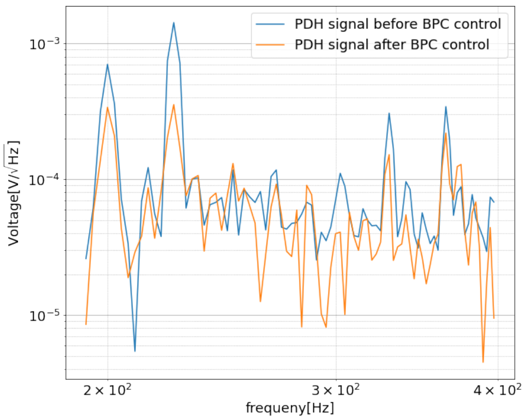

Figure 7: Peak suppression on PDH singal

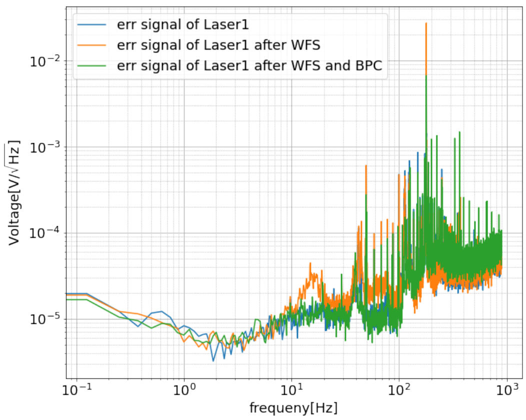

Figure 8: Alignment Control Noise reduction by BPC

5. Summary

DECIGO is the triangle-shaped laser interferometer and each side of the triangle is a linear optical cavity. Each satellite on both sides has a laser and the beams of the two lasers are incident on the Fabry Perot cavity from its both sides. We call this interferometric configuration Dual-Pass Fabry Perot cavity.One Dual-Pass Fabry Perot cavity has 14 degrees of freedom of controlling. 2 are for the length of the cavity. 12 are for the alignment of the cavity and incident beam axes. We successfully controlled all 14 degrees of freedom by Pound-Drever-Hall technique, WaveFront Sensor and Beam Point Control and demonstrated the control of Dual-Pass Fabry Perot cavity is possible by these three methods. For next steps, we will work on the decoupling of degrees of freedom and numerical assessment of the residual noises.

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