KAGRA

INSTRUMENTS SUMMARY

KAGRA photon calibrator

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Abstract

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The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too...

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2.1 Photon calibrator

One of the goals of the gravitational wave experiment is the accurate measurement of the gravitational waveform that is measured through the absolute displacement of the end test masses. A recent study that LIGO conducted in US showed that a displacement uncertainty could be controlled by the photon calibrator. The photon calibrator is one of the calibration tools to push the mirror surface using the photon pressure of the laser as shown in Fig XXX. The absolute displacement is described as

$$dx = \frac{P\cos\theta}{c}s(f)\left(1 + \frac{I}{M}\vec{a}\cdot\vec{b}\right),$$ (2.1)

where P is an absolute power of the laser, c is the speed of light, θ is an incident angle of the laser, I and M are moment of inertia and mass of test mass, $\vec{a}$ and $\vec{b}$ is position vector of photon calibrator lasers and interferometer laser. Then, $s(f)$ is transfer function of the test masses. We simulated the transfer function of test mass as shown in Fig. XXX. We assumed the masses, shapes and Young's modules of the each pendulum mass and fiber as shown in Fig.XXX. According to transfer function, we can regard the motion of high frequency as free mass due to higher than the natural frequency. Therefore, we are able to assume as follows:

$$s(f) = \frac{1}{M\omega^2},$$ (2.2)

where ω is the angular frequency of test mass.

2.2 Purpose of photon calibrator

2.2.1 Interferometer Calibration

2.2.2 Hardware injection test

2.2.3 Photon pressure actuator

2.3 Calibration line of KAGRA

Chapter 3

Instruments overview

3.1 Layout of Photon calibrator

The KAGRA photon calibrator is placed around EXA/EYA chamber, which is installed 36 m away from the end test mass (ETM). We push the mirror surface with the modulated photon pressure directly. Figure XXX shows the layout of the KAGRA photon calibrator. The photon calibrator consists of transmitter module (Tx module), receiver module (Rx module), periscope, and telephoto camera module (TCam module). We place the 20 W laser in Tx module, whose frequency is 1047 nm. The 1064 nm laser is not used due to avoid the coupling with main beams. The power of the laser is modulated by the optical follower servo (OFS). We split the beams in Tx module for pushing the drum head node points of the ETM due to elastic deformation. We transfer the beams to the ETM though the periscope. All the periscope structures are placed into the EXA/EYA chamber. The beam is received by the Rx module. We place a 6 inches integrating sphere for the accurate measurement of the laser power and two quadrant photo detector (QPD) for the beam position monitor. We also measure the beam position on the ETM surface using the telephoto camera (TCam). The Tcam is consists of the astronomical telescope, focuser, and high resolution digital camera. The specification of the Pcal system is shown in Table.XXXX. Details of instruments are described following section.

3.2 Transmitter (Tx) module

The Tx module is placed at the side of the EXA/EYA chamber. Figure XXX shows the view of Transmitter module. All the optical components are mounted on the $900 \, \text{mm} \times 900 \, mm$ breadboard (B9090L; Thorlabs). The bread board is placed on the support structure. The electrical module for the control and readout are hosed in the support structure.

Figure. XXX shows the optical layout of Tx module. All the optical components are listed in Table XXX.

3.2.1 Fiber laser

We employ the fiber laser made by the LER photonics as shown in Fig. XXX. The maximum power and frequency are 20 W and 1047 nm, respectively. The model number of the laser is CYFL-TERA-20-LP-1047-AM1-RGO-OM1-T305-C1. The maximum laser power of KAGRA Pcal is 10 times larger than that of LIGO. This is because that we need the high power laser for the injection test and photon pressure actuator technique. The typical beam width of the laser is 0.5 mm when we mount the isolator. We summarize the specification of the laser as shown in Table XXX.

3.2.2   Beam shutter

We have to pay attention to safety for the operation of the high power laser. In order to dump the beam, we use the beam shutter made by lasermet company. The model number of the shutter is LS-10-12. The aperture size and Max laser power are 15 mm and 20 W. These number meet our requirement due to the laser spot size and maximum power. We control the beam shutter on the GUI. The specification of the beam shutter is shown in Table. XXX.

3.2.3   Half wave plate

To control the polarization angle of incident beam, we employ the zero order half wave plate (HWP) made by the CVI laser optics. The model number of the HWP is QWPO-1047-05-2-R10 whose diameter are 12.7mm. The HWP is mounted on the rotation mount made by Thorlabs. The thick ness are optimized at 1047 nm. The specification of the HWP is listed in Table.XXX.

3.2.4   Polarizer

We place two polarizers to define the polarization angle accurately. This is because that the power of the laser is modulated by acousto-optic modulator (AOM) whose performance strongly depend on the incident polarization angle. One polarizer is placed behind HWP. Another one is placed after AOM. The Polarizer is made by Karl-Lambrecht. We purchased TFPC12-1047 that is optimized at 1047 nm.

3.2.5   Lens

We have dane a mode matching simulation using JamMt. We assumed laser beam to be gaussian distribution. We have to place the focus of the laser at the AOM. Thus, we decide the optimal position and focal length of the 1 inch lens (L1), where the assumed beam waist of the fiber laser and AOM are 0.5 mm and XXX mm, respectively. Furthermore, we place two lenses for placing the focus at the surface of the ETM. We employ the combination of 1 inch negative lens and 2 inch positive lens. The Gaussian beam can describe the following relation:

$$w(z) = \sqrt{(1+)}, \tag{3.1}$$

where λ is wavelength of the laser, w_0 is beam waist, z is direction from the focus. We estimate the minimum differential beam spot by changing beam waist because it make the alignment easier. The minimum beam spot is written by

$$\frac{dw(z = 36m)}{w_0} = 0. \tag{3.2}$$

The estimated beam waist and beam spot is 3.5 mm and 5.5 mm as shown in Fig. XXXX. We also place the lens at the front of the photo detector for the OFS. The parameters of the simulation results are listed in Table.XXXX. All lenses are made by CVI laser optics. The material of lenses are fused silica. The AR coating is placed at both surface.

3.2.6 Mirror

We employ nine 1 inch mirrors and four 2 inch mirrors. The 1 inch mirror is made by CVI laser optics. They place the HR coating on the surface of mirror. On the other hand, we use the HR coating on the fused silica disc of 2 inch in diameter. The coating and polishing the fused silica is made by Sigma-koki corporation. The reflectance of the mirror is shown in Figure. XXXX. The reflectance of HR coating depends on the incident angle and the polarization angle. We labeled mirrors as TxM1-TxM11, TxtM1-TxtM2, and TxbM1. The specification of mirrors are summarized in Table.XXXX. All mirror is aligned with optical mirror mount made by Newport company.

3.2.7 Beam splitter

To reduce the elastic deformation, we sepalate the beam with the beam splitter made by CVI laser optics. The diameter of the beam splitter is 2 inch. Figure. XXX shows the separation ratio of beam splitter.

3.2.8 Optical follower servo

3.2.9 beam sampler

3.2.10 2 inch integrating sphere

3.2.11 Structure

The breadboard is placed on the support structure. The material of this structure is SUS 306. This structure can be housed electrical devices, such as driver of the fiber laser, electronics of optical follower servo, and driver of laser shutter. We simulated the resonance frequency using ANSYS. The estimated frequency is XXX Hz.

3.3 Periscope

3.3.1 View window

3.3.2 Mirrors

3.3.3 Structure

3.3.4 Alignment

3.4 Receiver module

3.4.1 6inch Integrating sphere

3.4.2 Mirror

We employ four 2 inch mirrors. We place the HR coating made by Siguma-koki as shown in Fig. XXXX. For two mirrors, we make the AR coating on the back surface to pick up the beams. The specification of the mirrors are listed in Table XXXX.

3.4.3 QPD

3.4.4 Structure

The breadboard is placed on the support structure. The material of this structure is SUS 306. We simulated the resonance frequency using ANSYS. The estimated frequency is XXX Hz.

3.5 Camera module

3.5.1 Camera

3.5.2 Telecamera

3.5.3 Focuser

3.5.4 View window

3.5.5 Mirror

3.5.6 Structure

3.5.7 Illuminator

3.6 Summary

Chapter 4

Elastic deformation

Chapter 5

Absolute power calibration

5.1 Introduction

This section describes the in-situ calibration procedure of Photon Calibrator at each End station of KAGRA.

5.2 Theory of Operation

The Working Standard referred as WS is an integrating sphere with InGaAs photo detector, which has been calibrated against Gold Standard (GS) in the lab at LHO. The Gold Standard is calibrated by NIST. We will use this working standard to calibrate the Transmitter Module Photo Detector (TxPD) and Receiver Module Photo detector (RxPD), which are inside the Transmitter module and Receiver module of Photon calibrator respectively.

The following formula is used to obtain the calibration factor that will give the response of photodiodes in Photon calibrator modules in Watts/Volts:

$$\text{TxPD} = \frac{\text{TX}}{\text{WS}} * \frac{\text{WS}}{\text{GS}} * \text{GS} \tag{5.1}$$

$$\text{RxPD} = \frac{\text{RX}}{\text{WS}} * \frac{\text{WS}}{\text{GS}} * \text{GS} \tag{5.2}$$

5.3 Instrument Settings

5.3.1 DAC Calibration:

1. Provide a calibrated voltage using Martel voltage source and read it through the read back channel (`$(IFO):CAL-PCAL$(END)_WS_PD_INMON`). One unit voltage should give back 1638 counts. Provide 3 different voltages (0V, 1V and 2V) and record 15 seconds of data. Record the values in the Calibration Log (T1500062).

2. Check that the OFS loop is closed and stable.

5.3.2 Setting up the Current Amplifier

1. Plug the power cable of the Current Amplifier into a dedicated wall socket which no other equipment is using. It is very important that the Current Amplifier is on its own circuit as compromised data can result from using a shared power source.

2. Set the gain to 10E6 V/A

3. Set the Filter rise time = 100 ms

4. Turn filter on and make the sure the light is on.

5. Connect the BNC cable from the Working standard to the input and the BNC cable from the DAQ to the output.

6. Zero-check the instrument by pressing, " Shift " and " zero check " after the setup is complete and the laser is blocked at the Working Standard.

7. Make sure the " zero check " light is off before taking measurements.

8. Unplug the BNC cable from the Working Standard.

9. Remove small-side cover from TX module.

10. Place Working Standard into small-side of TX module. Take extra care when moving Working Standard from floor level to TX module.

11. Reconnect BNC cable to Working Standard.

5.3.3   Additional Checks

Do the following checks before proceeding to ratio measurements:

1. Check that the test mass is aligned, that the ISI is isolated with sensor correction turned off. Open the appropriate test mass suspension MEDM screen from the SITEMAP. The Guardian node `(SUS_ETM$(END))` is located at the top-center position of the MEDM screen. Select ALIGNED from the drop-down menu.

2. Check that the ISI sensor correction is off.

3. Check that both beams are entering the RX integrating sphere. If they are not, realignment is required before this procedure can be completed.

4. Turn off all excitations, including hardware injections. `$(IFO):CAL-PCAL(END)_OSC_SUM_ON` = 0, `$(IFO):CAL-PCAL(END)_SWEPT_SINE_ON` = 0, and `$(IFO):CAL-PINJ(END)_HARDWA` = OFF.

5. Let the Optical Follower Servo (OFS) stabilize before each reading. This is done by visual observation of the OFSPD signal (`$(IFO):CAL-PCAL(END)_OFS_PD_OUTMON`) on the MEDM screen.

6. Have the Calibration Log (T1500062) ready in front of you and follow the instruction in the Calibration Log to take the data.

7. For these measurements, the TxPD and RxPD are always in its original position whereas WS occupies two different positions, at TX just before the beam enters the vacuum system and at RxPD position, depending on the requirements.

5.4   Data Retrieval and Ratio calculation

5.4.1   Data Acquisition, Plots and Report

1. Make sure pcalEndstation is installed in the machine where you are trying to do the calibration calculation. You can check out the whole Pcal repository by following the instruction in T1500095.

2. From CDS computer you can access 'pcalEndStation' by going to this location:

   /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/.. scripts/pcalEndStation/

3. Do 'svn update' to make sure you have the latest version of the scripts.

4. Also 'kinit einstein@LIGO.ORG' to establish connection to external server. This will be required for obtaining data later

5. Open ' parametersforScript01.m ' script.

   (a) Enter appropriate calibration date, location and GPS time.
   (b) Make sure the workingcopy_location has appropriate path.
   (c) This parameter file is associated with Script01.

6. Run Script01_pcaldateandtime.m.

   (a) It will create a folder in 'DYYYYMMDD' format at appropriate location.
   (b) It also creates a matlab file named ' DYYYYMMDD_time.m ' with GPS time information within the folder.

7. Open ' parametersforScript02.m ' script.

   (a) Enter appropriate calibration date, location and GPS time (This is usually same as the one for first parameter file unless you are re-running the analysis code).
   (b) Make sure the workingcopy_location has appropriate path.
   (c) This parameter file is associated with Script02.

8. Run ' Script02_pcalDataandResults.m '.

   (a) This will fetch the data from the server; write it as txt files into the folder.
   (b) It also plots the ratios and saves the plots to the same folder. Make sure the plots are satisfactory before closing it.
   (c) Additionally it will save a 'DYYYYMMDD_Ratio.mat' and 'DYYYYM-MDD_Results.mat ' file that contains calibration results.

9. In Matlab Command window run the following command. pcalPublishReport(ifo_arm, outputFilename)

   (a) ifo_arm = 'LHOX' or 'LHOY' or 'LLOX' or 'LLOY'
   (b) outputFilename
       - '' (empty string will return default filename)
       - 'XXXXX.pdf'

5.5   End-station

5.6   Gold standard

5.7   Working standard

Chapter 6

Camera module

Chapter 7

Summary