A new Instrumented Baffle for Advanced Virgo

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On behalf of the Virgo Collaboration

The 8th KAGRA International Workshop
Hosted by the Korea Astronomy and Space Science Institute
July 7 - 9, 2021 | Online Workshop
Outline

• Stray Light @ Virgo
• Instrumented baffle
• Installation
• Performance, first results
• Phase II

• Final notes
About 100 W would be diffused light in the interferometer (80% for 125 W input)

- Most of the light at small angles close to the mirrors → Dictated by the mirror maps/defects
- Larger angles going to core-optics/cryo stations
- Scattered light in long tube much smaller → but can kill the GW signal if not mitigated.
Use case for smart baffle

- Efficient alignment of ITF → maximize sensitivity
- Dynamic mapping of mirror surfaces
- Monitoring of developing laser high modes
- Correlate with ITF glitches

- Sensors on 1064 nm (IR)
- UHV (10^{-9} mbar)
- No active cooling possible
- Solid against baked out (100 C)
- Reflectivity less than 0.5%
- Total scattering under control
- Limited RO cabling → wireless RO
- Negligible induced EM noise near mirrors
- ......
LVK Schedule

LIGO
- O1: 80 Mpc
- O2: 100 Mpc
- O3: 105-130 Mpc
- O4: 160-190 Mpc
- O5: Target 330 Mpc

Virgo
- O1: 30 Mpc
- O2: 50 Mpc
- O3: 90-120 Mpc
- O4: 150-260 Mpc

KAGRA
- O1: 8-25 Mpc
- O2: 25-130 Mpc
- O3: 130+ Mpc

LIGO-India
- O1: Target 330 Mpc

Smart baffle @ IMC tower
Smart baffle @ test masses
Baffle in IMC

Plan to redesign the payload for the Input Mode Cleaner mirror and the installation of new mirror

→ Opportunity to integrate an instrumented baffle in a suspended area to demonstrate the feasibility
Simulations

Simulations were used to optimize the sensor layout and determine the level of light power to be exposed to.

We performed also studies on miss-aligned cavities.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Mirror + baffle</th>
<th>Baffle</th>
<th>Photodiode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonance</td>
<td>$1.35 \times 10^4$ W</td>
<td>0.20 W</td>
<td>$3.2 \times 10^{-3}$ W</td>
</tr>
<tr>
<td>Misaligned (10 μrad)</td>
<td>$1.19 \times 10^4$ W</td>
<td>0.17 W</td>
<td>$3.0 \times 10^{-3}$ W</td>
</tr>
<tr>
<td>Extremely misaligned</td>
<td>-</td>
<td>-</td>
<td>$2.1 \times 10^{-2}$ W</td>
</tr>
<tr>
<td>Mechanical drift</td>
<td>390 W</td>
<td>-</td>
<td>130 (for 10 ms)</td>
</tr>
</tbody>
</table>

We are not repeating the simulations with the new mirror.

A. Romero-Rodríguez et al, 2021, Class. Quantum Grav. 38 045002
Conceptual Design

Photo-sensors located behind plate

- Number of sensors 76 (38 in each 1/2 baffle)
- Sensors mounted in large PCBs
- Sensors active area 0.49 cm²
- Light reaches sensors through conical (12°) holes of 4 mm of diameter (in the polished side)

→ Avoid scattering in edges and hide PCB from light
→ Knife like edges in holes and inner aperture
First Integration test @ EGO

A first (successful) integration test with the new IMC payload took place in October 2020

→ Indicated the perfect balance of the mechanics
→ Certified the integration with electronics and connections
→ Indicated the real integration @ vacuum tower would be smooth
New Hamamatsu Sensors

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>7.37 x 7.37 mm²</th>
</tr>
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<tbody>
<tr>
<td>Sensitive area</td>
<td>6.97 x 6.97 mm²</td>
</tr>
<tr>
<td>Operation temperature</td>
<td>-40 to 100 °C</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>50 mW</td>
</tr>
<tr>
<td>Optical coating</td>
<td>Anti-reflective (1.8%)</td>
</tr>
<tr>
<td>Photosensitivity</td>
<td>600 mA/W</td>
</tr>
</tbody>
</table>

Thanks to 2-years long R&D with Hamamatsu we developed Si-based sensors UHV compatible and with a reflectivity of about 1.2% - 1.8% reflectivity (v3 sensors)

→ First attempts to reduce to < 1 % led to non-linearity and slower sensors (v4 sensors)
Vacuum Tests

First test at ALBA and EGO satisfactory

Intense collaboration with CERN Vacuum Department led to a stringent certification

Outgassing after 100°C@24h -48h bake out: in the range $10^{-7} - 10^{-9}$ mbar l/s

Tests with fully powered electronics

→ Very good heat dissipation (golden PCBs)
Front End Calibration

Ongoing campaign to obtain a precise absolute calibration of the baffle signals

- Inter-calibration at the level of < 2%
- First absolute calibration at the < 5% level:
  ADC count → 6.2 μW +/- 0.2 μW
Installation @ IMC end mirror (1/2)
After a delicate installation the integrity of the detector was checked in situ (with a visible laser) before closing the tower and restoring the vacuum.
Commissioning

- The IMC baffle has been taking data for more than a month at EGO without observing any effect on the IMC cavity performance.
- Injection of wireless signal does not affect the IMC feedback loops.
- Temperature stable @ max 27 C
- Running serial readout mode @ 2Hz (→ nominally would reach 10 Hz) now integrating over 500 ms
- Wireless readout yet to be commissioned

Plan to run the system in O4 (more than one year from now)
Performance

Laser off (pedestals)

Laser on @ 40 W

Very quiet detector with laser off

Very stable response with laser on

Able to see glitches
(temporarily unlocks of cavity)

Good thermal behavior in UHV
→ PCBs working with 2V
→ Golden PCB dissipates heat
→ Never beyond 27 C
→ Good for longevity and
for the mirror/suspension preservation
First results

The fist data indicates a tilted phi distribution pointing to a potential astigmatism of the end mirror with the principal RoCs tilted
→ Somehow confirm by tilted HOMs (next slide)
→ Ongoing simulations with new mirror map
→ Tilt of the dihedron (?) → too big

![Graph showing phi distribution counts](image)

- **Preliminary**
- Points are cumulative
- Legend:
  - Yellow: Inner row only
  - Green: Two inner rows
  - Light green: Three inner rows
  - Dark green: All rows

![Image of laser setup](image)

- Faraday isolator
- 130W laser
- 143 m distance

![Image of experimental setup](image)
**Miss-alignments**

- Special run was taken with miss-aligned IMC cavity (ad hoc) to show the sensitivity of the instrumented baffle to the status of the cavity.

- The baffle demonstrates sensitivity to the situation of the cavity and the development of HOMs.
End Mirror Baffles

<table>
<thead>
<tr>
<th></th>
<th>Ø (cm)</th>
<th>Baffle inner Ø (cm)</th>
<th>Baffle outer Ø (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMC</td>
<td>14</td>
<td>14</td>
<td>35</td>
</tr>
<tr>
<td>Input mirror</td>
<td>35</td>
<td>33</td>
<td>80</td>
</tr>
<tr>
<td>End mirror</td>
<td>55</td>
<td>52</td>
<td>80</td>
</tr>
</tbody>
</table>

- New large mirrors (100kg) for O5
- Completely new payload and baffling
- New instrumented baffles being defined now
  - O(200) sensors v5 (being explored with Hamamatsu)
  - New DAQ at 1kHz / serial + wireless readout
  - Further Improvements on polished material (?)
    (considering ultra polished Nickel coating instead of SSTL+AR)
Final notes

The installation of the first instrumented baffle in Virgo has demonstrated that active monitoring of the stray light at the core optics of interferometers is feasible.

It is being operated at Virgo with no impact in the interferometer.

It will provide precious data to calibrate simulations and to improve the understanding of the stray light inside the experiment.

Instrumented baffles at the main arms offer extra handles on alignment, optimization/operation of the Fabry-Perot cavities, developing mirror defects, and correlation with glitches.

Thanks for your attention

Very busy two years ahead of us to build the new devices