A Bilateral Comparison of NIST And PTB Laser Power Standards for Increased Calibration Confidence at LIGO

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The Laser Interferometric Gravitational Wave Observatory (LIGO) calibrates gravitational strain measurements using photon momentum, with laser power serving as the measurand. Calibration of its laser power meters is currently traceable to the International System of Units through a primary standard maintained by the United States' National Metrology Institute (NMI). Disparity between NMIs indicated in the EUROMET 2010 study impacts confidence in Gravitational Wave (GW) event parameters such as mass, distance and location.

INTRODUCTION

Displacement of mirrored test masses at the extrema of the LIGO interferometer arms is calibrated through photon momentum. Accordingly, uncertainty in the power incident on the mirror is directly proportionate to the uncertainty in the interferometer strain [1].

The EUROMET 2010 study [2] suggests disagreement between various NMIs detector-based representation of the optical watt that exceed stated uncertainties. Inequivalence between NMIs decreases confidence in the absolute accuracy of any given nation's power scale realization.

PREVIOUS INTERNATIONAL COMPARISON

The EUROMET 2010 comparison [2] results for calibrations at 1 W, 1064 nm show discrepancy between calibrations performed by NIST and PTB exceed the 95% measurement confidence interval as described in Table 1. The agreement between NIST and PTB at 514 nm contrasted with the inequivalence at 1064 nm suggests an unaccounted spectral-responsivity. We suggest the discrepancy may be attributable to characteristics of the thermopile transfer standards

Table 1. Comparison of EUROMET 2010 results for PTB and NIST

Thermopile	1064 nm C.F. Discrepancy	1064 nm Bilateral Uncertainty
Ophir	1.03%	1.03%
Molectron	1.15%	1.10%
Thermopile	**514 nm C.F. Discrepancy**	**514 nm Bilateral Uncertainty**
Ophir	0.12%	0.99%
Molectron	0.01%	0.99%

THERMOPILE TRANSFER STANDARD INEQUIVALENCE CONTRIBUTIONS

During the EUROMET study NIST applied 1 W for 200 s while PTB applied the same power and wavelength for 600 s. The disparity in injection period, when applied to an uncompensated thermopile such as those used in the EUROMET study, yields an inequivalence of approximately 0.1 % due to increased cold-junction temperature. Figure 1 below depicts decreasing (interpolated) responsivity due to cold-junction heating.

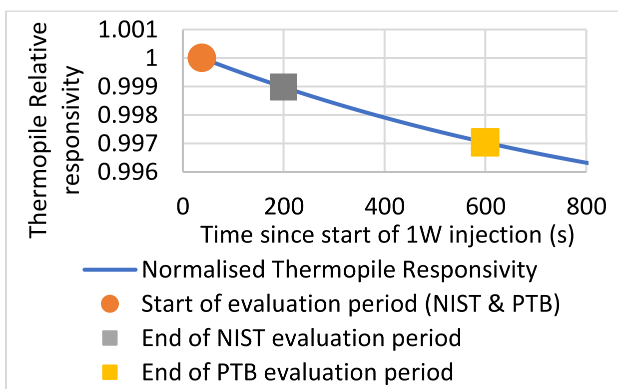

Figure 1. Thermopile relative responsivity versus injection time

Spatial nonuniformity for a thermopile similar to those used during the EUROMET 2010 study, depicted in Figure 2 below, suggests a 2 mm alignment discrepancy can readily yield a responsivity variation exceeding 1 %.

The inequivalence attributable to differing injection periods and spatial nonuniformity suggests the cause of the apparent laboratory inequivalence.

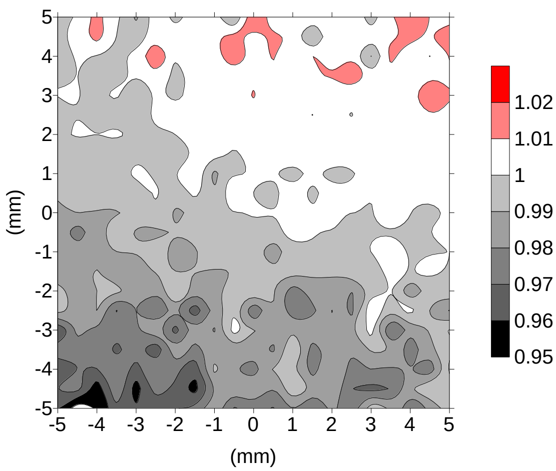

Figure 2. Typical thermopile relative spatial non-uniformity

AN INTEGRATING SPHERE DETECTOR AS AN ALTERNATIVE TRANSFER STANDARD

Integrating sphere detectors, with baffles and apertures configured for laser power measurement, offer an alternative tool for a watt-level comparison between NIST and PTB. For this study, LIGO's calibration group provided a 100 mm fluoropolymer-lined integrating sphere identical to their Photon Calibrator detectors [3]. The spatial non-uniformity of this integrating sphere depicted in Figure 3 is an order-of-magnitude below that of a thermopile. Empirically, the temperature sensitivity coefficient for the system is 0.02 % to 0.1 % per Kelvin [4].

RESULTS AND DISCUSSION

To be presented upon measurement completion at NEWRAD.

CONCLUSION

Observed inequivalence contributions arising from different laser power injection times and typical laser alignment discrepancies combined with spatial non-uniformity

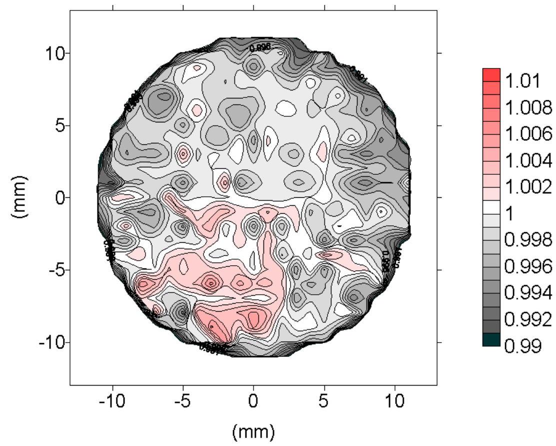

Figure 3. Integrating sphere transfer standard relative spatial non-uniformity

of the transfer standards used in the EUROMET 2010 study suggest the cause of measurement discrepancy between NMIs. Resolution of measurement discrepancy between NIST and PTB validates the competency of both laboratories and the use of integrating spheres as transfer standards. For future comparisons, integrating sphere detectors may be used as transfer standards together with well-matched laboratory environments to reduce these uncertainty contributions by a factor of 10. Successful completion of this bilateral comparison enables a larger comparison validating the power scale of National Metrology Institutes for other GW observatory host countries to serve as an ongoing validation of the LIGO calibration program.

REFERENCES

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