FINAL REPORT

Student name: Alberto Donazzan
Cycle: XXX
Curriculum: ICT
Supervisor name: Maria Guglielmina Pelizzo
Thesis title (final): Heterodyne laser interferometers for the dimensional control of large ring-lasers.

PART 1 - COURSES, CONFERENCES AND MOBILITY

Courses for Ph.D. students

- S. Pupolin, "The FFT and its use in digital signal processing" (20h).
- G. Meneghesso, E. Zanoni, M. Meneghini, F. A. Marino, "Physics and operation of heterostructure-based electronic and optoelectronic devices" (20h).
- P. Villoresi, G. Vallone, "Introduction to Quantum Optics, Quantum Information and Quantum Communications" (20h).
- L. Finesso, "Statistical Methods" (24h).

Summer schools, short courses, tutorials

- "Adaptive School" (8h) at AOIM Workshop, Padova, 15/06/2015.
- M. De Dominicis, "Impactful Speeches: Effective communication in scientific disciplines" (5h), Padova, 01/03/2017.
- J. R. Leger, "Laser beam analysis, propagation and spatial shaping techniques" (3h) at CLEO Europe Conference, Munich, Germany, 06/2017.
- T. Udem, "Frequency combs and applications" (3h) at CLEO Europe Conference, Munich, Germany, 06/2017.

Seminars

- Niuko Srl, "Soft Skills Lab" at "Il Cubo Rosso", Padova, 16/02/2016.
- National Instruments Italy, LabVIEW Developer Days 2016, Padova, Italy, 16/11/2016.
- Confindustria Padova, "STEPS: Seminars Towards Enterprise for Ph.D. Students" (16h), Padova, 12/2015-02/2016. Visits to Unox SpA, Cadoneghe (PD) and Carraro SpA, Campodarsego (PD).

Participation to International Conferences and Workshops

- Xth International Workshop on Adaptive Optics for Industry and Medicine (AOIM), Padova, Italy, 06/2015
- 3rd IEEE International Workshop on Metrology for AeroSpace, Firenze, Italy, 06/2016 [speaker].
- SPIE Optical Engineering + Applications 2016, San Diego, USA, 08/2016 [speaker].
- 102° Congresso della Società Italiana di Fisica, Padova, Italy, 09/2016 [speaker].

- Final Conference on "Plastic Killer" EU LIFE+ Project, Padova, Italy, 05/04/2017.
- SPIE Optical Metrology 2017, Munich, Germany, 06/2017 [speaker].
- Conference on Lasers and Electro-Optics (CLEO)/Europe 2017, Munich, Germany, 06/2017.

Other learning activities

- National Instruments Italy, "LabVIEW Core 1" (24h), Padova, Italy, 07/2015.
- National Instruments Italy, "LabVIEW Core 2" (16h), Padova, Italy, 07/2015.
- National Instruments Italy, "Embedded control and monitoring using LabVIEW" (40h), Milano, Italy, 11/2016.

PART 2 - RESEARCH ACTIVITY

Summary of Research Topic and main Results

GINGER (Gyroscopes in General Relativity) is an experiment proposal for the detection of the Earth induced frame dragging in a ground based laboratory, by means of an array of large ring-lasers. The chance of achieving this goal relies directly on the degree of GINGER's mechanical stability. Active control of the geometrical parameters of a large ring-laser array is a challenging task, requiring the development of an accurate length monitoring system acting on the edges of this device. The proposed solution is a network of compact laser heterodyne interferometers, working together to keep the geometrical frame constantly well known (and stable) to nanometer accuracy. We took the first steps towards the realization of this device by focusing on its fundamental element, i.e. the compact heterodyne laser interferometer. A starting simplified prototype has been designed and assembled and is now under extensive test. The current experiment is meant to evaluate parts behavior, alignment issues and links between single components and overall gauge performances. The concerned distance is investigated by means of a reference and a measurement beam, obtained by spatial splitting of the heterodyne laser source. The phase shift between two heterodyne beatings provides a reliable signal for precise monitoring of the distance between two retroreflective fiducials.
The prototype now works reliably in athmospheric conditions and its long-term performances are limited only by unavoidable thermal and mechanical instabilities. Nevertheless the collected data report a noise floor of 0.05nm/√Hz for frequencies higher than 10Hz. The instrument sensibility then worsen to 0.3nm/√Hz at 1Hz and to tens of nanometers for lower frequencies. Gauge data consistency was tested by programmatic movements of one fiducial, which was mounted on a high precision nano-positioner for this purpose.

Performed activities (1st year)

The experiment is settled in a dedicated lab at CNR-IFN, which was equipped from scratch with a vibration isolated optical bench, laser safety gear and all the necessary hardware.

- Theoretical study of the laser heterodyne interferometer.
- Definition of specifications for the source unit.

- Study of laser source coherence and noise.
- Calculation of the required maximum linewidth.
- Numerical simulation of laser and AOMs phase noise.
- Study of the effects of (un)correlated noise on beats contrast.
- System power efficiency evaluation.

- Optical design
  - Cost vs Stability and Compactness evaluation.
  - Beam shaping and spatial splitting simulations (Zemax).
  - Design of a holey mirror with front-back coating.
  - Solutions of mounts clearance issues and footprint issues.
  - Simulation of beam magnification and collimation (Zemax).
- Opto-mechanical design of the whole set-up (Solidworks)
- Selection and purchase of components.

Performed activities (2nd year)

A fully working heterodyne source unit has been aligned and tested: a heterodyne beat with a widly tunable frequency (1Hz-10MHz) can be easily obtained and detected. The interferometric unit suffered some problems during the alignment procedures: beam spoiling and diffraction caused the reference and the measurement beams to mix each other. This was solved with the design of properly shaped blocking masks placed along the 2m test distance.

- Alignment and test of the heterodyne source unit
  - Laser source characterization (output power and polarization).
  - Fiber coupling of the laser source and connection to AOMs.
  - RF driver configuration and interfacing with AOMs and PC.
  - Test of AOMs coupling efficiency and determination of the heterodyne tuning range.
- Assembly and alignment of the free-space interferometric unit.
  - Alignment of fiber collimators and beam combiner.
  - Pre-alignment of 2D retroreflector.
  - Alignment of the drilled mirror and beam shape characterization after spatial splitting.
  - Study of beam propagation and diffraction along a 2m long racetrack.
  - Design of cleaning masks for beam mixing prevention (Zemax).
- Development of the detection unit
  - Alignment of detection lenses and PDs.
  - Analog signal collection with oscilloscope.
- Selection and purchase of a digital acquisition card.

Performed activities (3rd year)

The acquisition unit has been fully developed and the system performances characterized. The device can now provide reliable displacement measurements in order to estimate and stabilize the distance between a couple of retro-reflective fiducials.

- Development of the acquisition unit

- Completion of the analog acquisition chain (RF mixing and filtering of heterodyne channels) for testing the effectiveness of the cancelable circuit design.
- Data analysis: offline phase retrieval by hilbert transform and digital lockin (Matlab).
- Configuration and programming of the FPGA-based digital acquisition card (LabView): software backbone, network interface, FPGA-ADC module synchronization, FPGA-RT system communication, binary dataset disk streaming and automated export to external host, online lock-in algorithm implementation on FPGA.
- Lock-in algorithm debug by feeding the acquisition unit with wave-generators.

o Opto-mechanical system upgrade
- Custom design and manufacturing of: adapters for the correct matching between the xyz stage and the wide corner-cubes, mounts for coarse positioning of the 3D stage, low profile mounts for the holey mirror positioner.
- Full system alignment with added wide corner-cubes and 3D positioner.
- Contruction of a rigid plastic enclosure for attenuation of air turbulence.

o Full system performance test
- Continuous phase measurement up to 3h.
- Displacement noise characterization and clear detection of vibrations reduction due to the activation of the optical bench isolation system.
- Controlled displacement tests with 3D positioner.

o Selection and purchase of new components for future optical upgrade.

Other performed activities

In addition, other performed activities are connected with the topic of Optical Coatings and Materials Testing. A sensing system for Surface Plasmon Resonance (SPR) imaging has been developed in order to test metal/graphene chips. The metallic chips were realized by means of Electron-beam Physical Vapor Deposition. Worth mentioning is also the contribution to optical materials and graphene characterizations through the participation to a synchrotron beamline measurement campaign.

o Electron-beam Physical Vapor Deposition of various materials (Au, Pt, Pd, Ti) on Si wafers and on BK7 optical glass
o Reflectivity measurements on new and aged (ion bombarded) optical mirrors
o Development of a software application for the monitoring and control of a magnetron sputtering system (LabView).
o Full revision and upgrade of an automated data acquisition software for angular SPR measurements (LabView).
o Development of a switching SPR imaging system comprising an electrically tunable lens.
- Optical design and alignment of the SPR imaging system.
- Mechanical design of the incoherent source housing and the SPR chip slot.
- Software development for system calibration and data acquisition (Matlab).

PART 3 – PUBLICATIONS

List of publications on international journals

J1. A. J. Corso et al. “Room-temperature optical detection of hydrogen gas using palladium nano-islands” (under submission to *Nanotechnology* journal)

J2. A. Donazzan at al. “Characterization of nanometer displacement gauge for the dimensional control of large opto-mechanical structures” (under submission to OSA *Applied Optics* journal)

List of publications on conference proceedings

C1. A. Di Virgilio et al. “The GINGER Project and status of the ring-laser of LNGS”. In: *Proceedings of the XVI International Workshop on Neutrino Telescopes (NEUTEL2015)*. 2-6 March 2015, Palazzo Franchetti, Istituto Veneto, Venice, Italy (2015).

C2. M. Miszczak et al. “Multilayer adaptive optics development for the EUV wavefront control”. In: *Proceedings of the Xth International Workshop on Adaptice Optics for Industry and Medicine*, (2015), pp. 245–248.

C3. A. Ortolan et al. “GINGER: an array of ring lasers for testing fundamental physics”. In: *Proceedings of the MG14 Meeting on General Relativity*, Rome, Italy (2015)

C4. A. Ortolan et al. “The GINGER project and status of the GINGERino prototype at LNGS”. In: *Proceedings, 14th International Conference on Topics in Astroparticle and Underground Physics (TAUP 2015)*, J. Phys. Conf. Ser. 718(7), 072003 (2016).

C5. J. Belfi et al. “Very high sensitivity laser gyroscopes for general relativity tests in a ground laboratory”. In: *2016 European Frequency and Time Forum (EFTF)*, pp. 1-4, York (2016).

C6. A. Donazzan et al. “External Metrology System for the Stabilization of Large Ring-Lasers”. In: *2016 IEEE Metrology for Aerospace (MetroAeroSpace)*, pp. 266-270, Florence, Italy (2016).
[Oral presentation]

C7. A. Donazzan et al. “A network of heterodyne laser interferometers for monitoring and control of large ring-lasers”. In: *SPIE Optical Engineering + Applications*, Proc. SPIE 9960, Interferometry XVIII, 99600G–99600G-8, San Diego, USA (2016).
[Oral presentation]

C8. A. Donazzan et al. “Adaptive system able to switch between angular resolved SPR and SPR imaging”. In: *SPIE Optical Engineering + Applications*, Proc. SPIE 9921, Plasmonics XIV, 99213B-99213B-6, San Diego, USA (2016).
[Poster presentation]

C9. M. G. Pelizzo et al., "Qualification tests of optical coatings in space environment," *2017 IEEE International Workshop on Metrology for AeroSpace (MetroAeroSpace)*, Padua, Italy (2017), pp. 228-233; doi: 10.1109/MetroAeroSpace.2017.7999570

C10. A. Donazzan et al. “Study of the optical crosstalk in a heterodyne displacement gauge with cancelable circuit”. In: *SPIE Optical Metrology*, Proc. SPIE 10330, Modeling Aspects in Optical Metrology VI, 103300F, Munich, Germany (June 26, 2017); doi:10.1117/12.2270193
[Oral presentation]

C11. A. J. Corso et al. "Continuous palladium-based thin films for hydrogen detection". In: *SPIE Optical Sensors*, Proc. SPIE 10231, San Diego, USA (2017), doi:10.1117/12.2266472

C12. M. G. Pelizzo et al."Proton irradiation of optical components for applications in forthcoming space missions". In: *The 3rd International Conference on Frontiers of Optical Coatings (FOC2017)*, Optical thin film and coating technology, Guangzhou, China.

27-09-2017

Student signature

Supervisor signature