Fibre laser position metrology techniques for commercial spectrometers

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Background

Blue Sky Spectroscopy Inc. has a long heritage in the development of custom Fourier transform spectrometers (FTS) and the associated data acquisition and analysis software for both ground and space-based astronomy. Blue Sky Spectroscopy Inc. was proud to host the Data Processing and Science Analysis Software (DAPSAS) for the SPIRE FTS on the European Space Agency's (ESA) Herschel Space Observatory, launched in 2009. This ground-breaking observatory produced our first unbiased view of the far-infrared (FIR) universe and has been an outstanding success. It has caused astronomers to re-examine their theories of star formation, provided our first large scale view of distant galaxies, and garnered several national and international awards.

Recognizing the immense gain in sensitivity that can be achieved by cooling a Herschel type telescope, ESA and the Japan Aerospace Exploration Agency (JAXA) have joined forces to develop the Space Infrared telescope for Cosmology and Astrophysics (SPICA). Blue Sky Spectroscopy Inc. is proud to announce that it has been awarded Canadian Space Agency (CSA) funding under the Space Technology Development Program to develop a data processing framework for post-dispersed polarizing FTS, a necessary first step in the development of DAPSAS that could be a strong candidate for the SPICA/SAFARI instrument.

In collaboration with ITER-India, Blue Sky Spectroscopy Inc. is contributing an FTS for the measurement of electron cyclotron emission as a diagnostic tool in the ITER thermonuclear reactor, which is the largest nuclear fusion experiment ever attempted. Blue Sky Spectroscopy Inc. is exploring new and unique designs for the ITER FTS and is proudly at the forefront of Canadian contributions to ITER.

References

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"ITER – the way to new energy." https://www.iter.org/.

Previous Metrology Systems

In previous work I designed, constructed, and tested two laser position metrology systems for applications at Blue Sky Spectroscopy Inc.

ITER FTS Laser Metrology

The temperature inside a nuclear reactor must be measured 100× faster than an FTS typically employed in space-based applications, and the initial implementation was a high-speed incremental laser fringe counter. A free space Michelson interferometer was constructed using a 1550 nm diode laser and beamsplitter cube. A plane mirror attached to the FTS translation stage was probed in the measurement arm of the interferometer. A data acquisition board sampled an electrically rectified interferogram from a photodetector at 2 MHz and the data was processed offline by a PC. A resolution of 388 nm was achieved by this system.

Frequency Modulation Laser Metrology

A frequency modulation fibre laser metrology system was constructed for short range, high accuracy, general purpose and cryogenic applications. The schematic of the frequency modulation interferometer is shown in Figure 1.

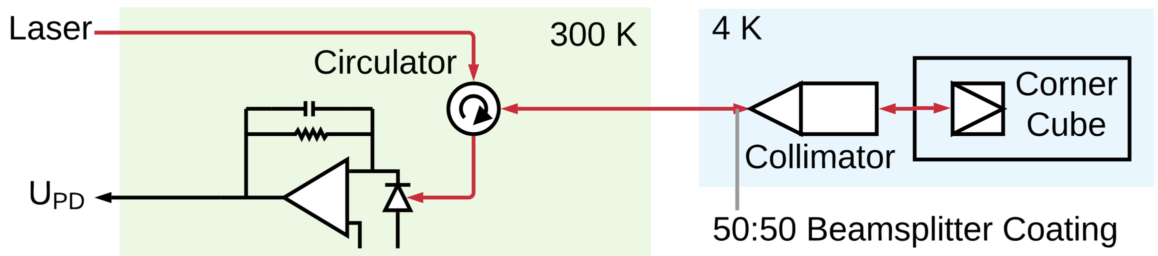

Figure 1: Frequency modulation laser interferometer schematic.

For cryogenic operation, illustrated in Figure 1, a 1550 nm laser at room temperature is frequency modulated sinusoidally. The signal is guided to a <4 K vacuum chamber via optical fibre which terminated with a 50:50 beamsplitter coating. Half the power is reflected and becomes the reference signal, and half is launched by a collimator to probe a corner cube retroreflector mounted on the moving target. The probing signal returns to the fibre and interferes with the reference signal at the photodetector. The detected signal is sampled by an ADC on an FPGA, which performs demodulation to recover the encoded position and achieved 31 nm rms accuracy in a 20 Hz bandwidth. This system serves a demonstrator for the cryogenic position metrology technique adopted by the SPICA/SAFARI instrument, and shows that the technique is viable at temperatures <4 K. This design can be extended to provide simultaneous multiple axes measurements using a single laser and photodetector.

Commercial FTS Metrology

Blue Sky Spectroscopy Inc. requires a commercially viable incrementally encoded range-resolved interferometer for use in their commercial FTSs, which must satisfy the following requirements:

- 1 µm accuracy
- Up to 100 mm/s mechanical velocity
- Up to 500 mm range
- Position synchronous output
- Vacuum operation
- Retrofittable to existing FTS

The requirement for the metrology to be retrofittable implies a fibre coupled system, which allows a probing laser signal to be easily guided through existing harnesses in the FTS vacuum chamber. Commercially available solutions may satisfy these requirements; however, they can be difficult to operate in a small evacuated chamber. Blue Sky Spectroscopy Inc. is currently exploring in-house solutions that can be retrofitted to an exiting system.

ITER FTS Metrology

To provide position metrology for the ITER FTS, Blue Sky Spectroscopy Inc. requires a high-speed incrementally encoded range-resolved laser interferometer with the following requirements:

- 1 µm accuracy
- Up to 775 mm/s mechanical velocity (1 MHz fringe rate)
- 50 mm range
- Position synchronous output
- Vacuum operation
- Must operate with a plane mirror reflector

Building upon the initial ITER FTS laser metrology design, a fibre laser will be used to allow for simple and secure routing of the laser interferometer into the evacuated chamber. The similarity in requirements between high-speed and commercial FTS laser metrology systems may enable the development of a single laser position metrology system, allowing Blue Sky Spectroscopy to accommodate high-speed metrology in every FTS.

Development Plan

My partnership with Blue Sky Spectroscopy Inc. will see the development of laser position metrology systems for applications in Blue Sky Spectroscopy Inc. commercial FTSs and its ITER FTS. I will develop both systems in parallel following a sequential development process, outlined below.

Phase 1: Research

- Survey existing solutions and how cost and performance compare to potential in-house solutions
- Provide an analysis to determine if Blue Sky Spectroscopy Inc. should offer the laser metrology system as a standalone product

Phase 2: Design

- Design of potential laser metrology systems, including the mechanical, optical, electrical, and signal processing components
- Complete an error analysis to explore the trade-off space between cost and performance

Phase 3: Construction

- Procurement of parts
- Mechanical, optical, and electrical construction
- Programming of signal processing hardware

Phase 4: Verification

- Characterization of precision, accuracy, range, and velocity
- Testing of system reliability and robustness
- Collaboration with the University of Lethbridge to use a proprietary laser interferometer I have constructed to test infrared laser metrology against a HeNe laser measurement with a common optical path