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Operational and Performance Characteristics of Dynamically Aligned Interferometers

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KEY WORDS

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Interferometer
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Spectral resolution
Digital signal processor (DSP)
Rapid scan

INTRODUCTION

The performance of Fourier transform spectrometers, including mid-IR, Raman and near-IR systems, continues to improve with advances in electronics, digital signal processor (DSP) control and optical technology. The role of the DSP is to monitor and maintain interferometer alignment. This continuous, high-speed intrascan alignment process is referred to as dynamic alignment.[1] A dynamically aligned interferometer optimizes spectral stability, resolution, signal-to-noise performance and band shapes. The performance advantages that dynamic alignment brings are so clear that it has been employed on all of the highest performance research spectrometers for the past decade. Although dynamic alignment was developed as a tool for research spectrometers, performance and stability improvements can be used on any system. Nicolet employs dynamic alignment to achieve performance enhancement on all of our spectrometer systems. This note describes the basic operational features and performance characteristics of the dynamically aligned interferometers used in Nicolet spectrometers.

The interferometer (Figure 1) is the heart of an FT spectrometer. A collimated beam of light originating from the source is directed onto a beamsplitter that reflects a portion of the energy to the fixed mirror and transmits a portion to the moving mirror. Increasing the maximum path difference between the two mirrors provides higher spectral resolution. Maintaining perfect alignment of the fixed and moving mirrors relative to each other, through individual and multiple scans provides consistent results and low noise.

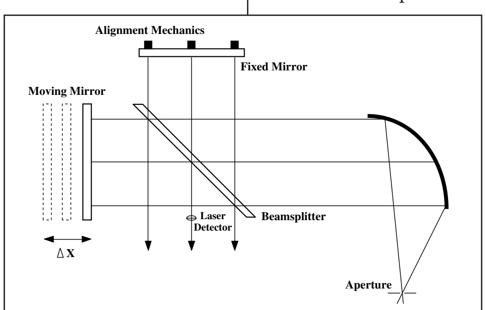

Figure 1: Optical Layout of an Interferometer

The stability, spectral resolution and performance of the system are dependent upon precise perpendicular alignment between the fixed and moving mirrors. Deviations from perfect alignment due to tilt, shear or sag reduce both spectral resolution and throughput, especially at shorter wavelengths. Some mechanical interferometer designs are utilized which can minimize the effects of one or two of these factors, but these do not eliminate, and may even exacerbate, the remaining factors. Dynamic alignment improves the performance of any interferometer by actively checking for any misalignments at speeds of up to 130,000 times per second! Any corrections are made in real-time.

Dynamic alignment is the ***only*** known mechanism that can actively correct for optical misalignment due to changes in temperature, which affects the interferometer beamsplitter. On systems without dynamic alignment, even small temperature changes cause the beamsplitter to expand and contract enough to lead to alignment to shift.

The basic principles of dynamic alignment are equivalent on either Nicolet's Avatar or Nexus spectrometers. Dynamic alignment continually measures and adjusts the relative position of the mirrors to maintain perfect alignment for each scan. This is achieved by monitoring, in real-time, the phase relationship of three laser signals as shown in Figure 2. As the coincident infrared and reference laser beams exit the interferometer, a sensor detects X, Y, and R (reference) laser signals. A DSP continuously monitors the phase relationship of these three laser signals, which define the alignment plane of the mirrors orthogonally. The DSP can then adjust mirror position in real-time through electromagnetic transducers on the mirror mount.

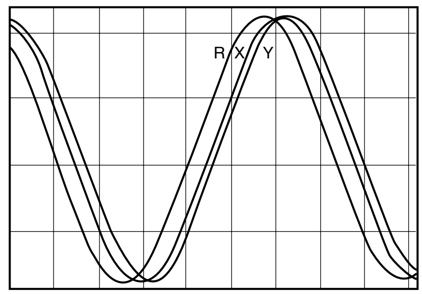

Figure 2: Laser Phases Continuously Maintained by DSP

The performance benefits of a dynamically aligned interferometer are significant: exceptional long-term and short-term spectral stability, and enhanced spectral resolution with excellent band shapes.

SPECTRAL STABILITY

The FT-IR spectrum results from the ratio of sample to background energy curves collected sequentially. Small changes in alignment of the fixed and moving mirrors due to mechanical tilt, shear or sag can produce large shifts in the ratioed spectrum. With dynamic alignment, the energy from the interferometer is constantly maintained, enhancing spectral stability. To measure the stability of the Nexus spectrometer using its dynamically aligned interferometer, spectra were collected over an 8-hour time period. The data in Figure 3 were collected at 4 cm^{-1} resolution using 128 scans for sample and background spectra.

The Nexus spectrometer was configured with a KBr beamsplitter, DTGS detector, and Ever-Glo™ mid-IR source using a scanning velocity of 0.63 cm/sec (10 KHz). A sample and background spectrum were collected at t=0 hours and subsequent sample spectra were collected at 1 hour time intervals to the last at t=8 hours. All sample spectra were ratioed to the original background spectrum at t=0 hours.

Figure 3 shows the excellent long-term stability of a Nexus spectrometer using its dynamically aligned interferometer. Note that over the 8 hour time period of the experiment the spectra remain flat, horizontal and very close to the 100% position.

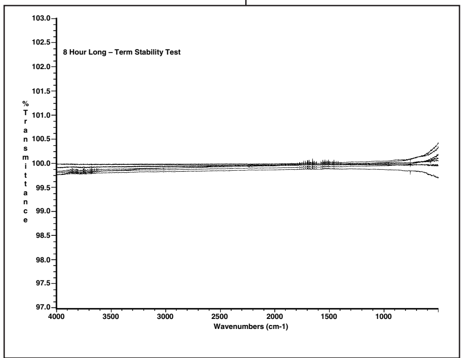

Figure 3: Long-Term Spectral Stability with Dynamic Alignment

System alignment is even more critical in the near-IR spectral region[2]. In Figure 4, we show performance and alignment effects in the near vs mid-IR spectral regions. For this experiment we used the Nicolet XT-KBr™ beamsplitter[3], the DTGS detector and the tungsten-halogen, white light source.

Spectra A through I show 100% lines for the spectral region of 11,000-2,000 cm^{-1} collected over an 8 hour time period. Note that during this 8 hour time period of the near-IR stability test the spectra deviation was less than 0.5%T at 11,000 cm^{-1}.

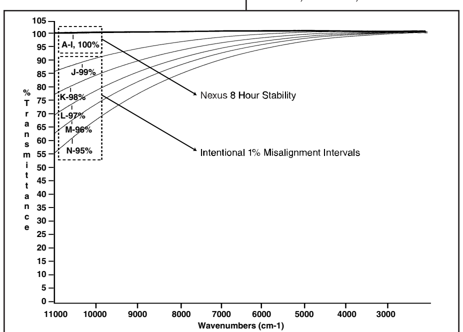

Figure 4: Near-IR Spectral Stability

Spectra J through N were also ratioed to the original background spectrum. However, the interferometer was deliberately misaligned in steps equivalent to 1% decreases in peak-to-peak interferometer voltage to simulate the "drift over time" commonly seen in instruments lacking dynamic alignment. The effect of interferometer misalignment is most pronounced in the near-IR spectral region. For example, for the 5% reduction in interferogram voltage in spectrum N, we see a 45% loss of energy at 11,000 cm^{-1}.

The high performance DSP used in Nicolet systems maintains dynamic alignment even at rapid scan speeds. Figure 5 shows 16 cm^{-1} resolution rapid scan data collected over a period of 5 minutes at a rate of 38.7 scans per second. The 128-scan background spectrum for all ratioed spectra is collected prior to the experiment. Each of the single scan sample spectra was automatically ratioed to the original background spectrum. The percent transmittance value at 2000 cm^{-1} of the spectrum at 12-second time segments is shown in the plot.

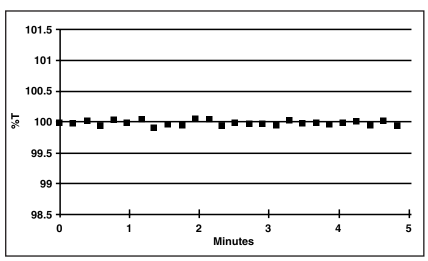

Figure 5: Rapid Scan Spectral Stability with Dynamic Alignment

There is virtually no spectral deviation from 100% even at rapid scan velocities. These data show that dynamic alignment provides excellent spectral stability for standard and high-speed applications.

Spectral Resolution, Band Shape & Intensity

Spectral resolution is also effected by interferometer alignment. Loss of alignment of the mirrors degrades spectral resolution and spectral line shape. The best theoretical spectral resolution is defined from the inverse of the maximum path difference of the moving and fixed mirrors[1]. The industry standard measurement for spectral resolution is computed from the full width at half height (FWHH) of carbon monoxide gas. In Figure 6, we show the effect of good and bad alignment on spectral resolution and line shape.

Figure 6 shows spectra of 4 torr carbon monoxide gas measured in a 10 cm gas cell collected at nominal 1/8 cm^{-1} resolution using a high sensitivity MCT-A detector. All collection and processing parameters were identical using 128 scans and boxcar apodization. Spectrum A was collected with the system operating in its normal fully aligned mode with dynamic alignment. Spectrum B again simulates an interferometer without dynamic alignment since it is collected with a purposely misaligned system. We can see the effect of precision interferometer alignment; spectral resolution is increased from 0.198 cm^{-1} to 0.078 cm^{-1}, the band intensity is increased from 0.125 to 0.398 absorbance units, and the spectral line shape is symmetric. A well tuned, dynamically aligned interferometer provides excellent resolution, band intensity and line shape.

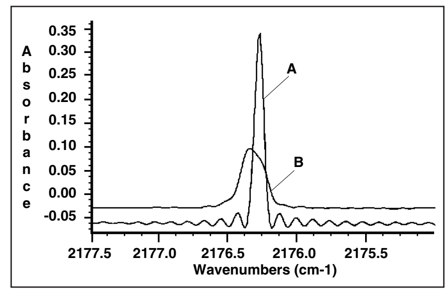

Figure 6: Spectral Resolution as a Function of Interferometer Alignment; spectrum A with dynamic alignment, spectrum B with purposely misaligned interferometer

Conclusions and Discussion

A dynamically aligned interferometer maintains perfect alignment. Dynamic alignment improves short and long-term spectral stability, enhances spectral resolution, improves band shapes and optimizes signal-to-noise performance in any FT based interferometer system. Dynamic alignment benefits all of Nicolet's spectrometer systems including entry-level, QC/QA and NIR Avatar systems, research-grade Nexus spectrometers and FT-Raman instruments.

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