Progress in Soft-X-Ray Fourier Transform Spectrometry

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Introduction

The Soft X-Ray Fourier Transform Spectrometer (FTSX) on bend magnet beamline 9.3.2 is a modified Mach-Zender interferometer spectrometer designed for ultra-high resolution spectrometry in the 10-20nm (120-60eV) range. The theoretical resolving power ($\frac{E}{\triangle E}$) of this instrument, as with all spectrometers, is proportional to the number of waves of incident light in the maximum path length difference introduced by the instrument to the beam. The FTSX has a design travel of 1 centimeter, giving a theoretical resolving power of the order of a million. The instrument is designed for high resolution exploration of the autoionizing states of helium.

Instrument Design

The mechanical layout of the modified Mach-Zender interferometer system is outlined in figure 1 below. It consists of a sixteen point cartwheel flexure rectilinear motion stage which was EDM machined from a single block of Vascomax 300 maraging steel. The rectilinear motion is achieved by external hydraulic ram, and the position is monitored by means of a commercial HP laser interferometer. Beam splitters are mounted to the stationary part of the stage. The four mirrors are optically contacted to a rhombus prism which is attached to the moving stage.[1]

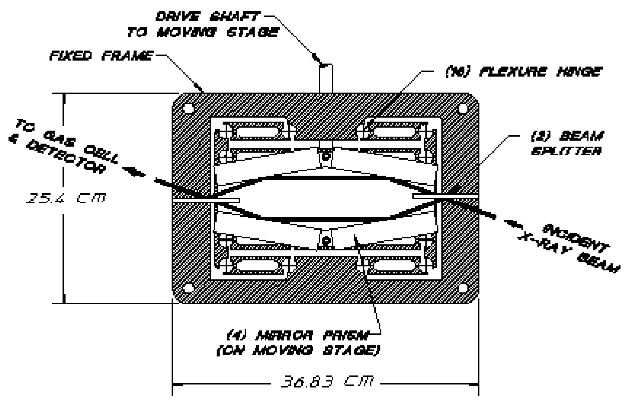

Figure 1 FTSX Schematic

Accomplishments to Date

The construction and assembly of the FTSX has required the design and manufacture of a number of components to new levels of precision. The translation stage itself was a considerable engineering feat. The total allowed pitch error over the full motion of the flexure hinge stage was calculated to be on the order of 0.5 μrad.[2] The stage, as delivered, was substantially out of specification; extra slots had to be machined, and taper pins added and adjusted to correct the tilt errors. After corrections, the stage tilt errors were measured to be 0.38 μrad over the full travel of the mirrors[3].

The beamsplitters are the first of their kind. They were manufactured by RocketDyne from a single crystal of silicon. A set of 50 μm wide, 15mm long slots were photolithographically etched into the surface with a 100 μmperiod, then coated with molybdenum to make a wavefront dividing, soft X-ray beamsplitter. The surface roughness of these beamsplitters was measured with the ALS Optical Metrology Lab (OML) Wyco Micromap phase-shifting interferometer, and found to have an RMS roughness of less than 5 angstroms. The surface figure of the beamsplitters as measured by the OML Long Trace Profiler was found to be flat to below 0.5 μrad. The four mirrors, manufactured by Photon Sciences and coated with molybdenum, are also of exceptional quality; showing a flat surface figure to within 0.6 μrad and a surface roughness of only 2 angstroms RMS. The alignment tolerance was ascertained to be 1.5 microradians of error between the relative tilts of the wavefront[2], hence a total of 1.5 microradians of error in the alignment of all of the optical surfaces. The mirrors were aligned to each other by optical contacting to a prism base. This was measured by Photon Sciences using Hadinger fringes to be aligned to less than 0.6μrad of error, leaving a beamsplitter to mirror alignment tolerance of about a microradian[1].

Previous Results

In the original conception of the workings of the instrument the beamsplitters themselves were held in place and aligned via a system of 6-32 screws held in place by set screws pressing against 0.5 to 1.5 ft.-lb. spring loaded pins; gross adjustments were to be performed outside of the vacuum chamber by using the LBNL Coordinate Measuring Machine (CMM) facilities.. Two leaf spring flexures with picomotor adjustments were added for *in-situ* fine adjustment of downstream beamsplitter "roll" and "yaw" when aligning at the XUV. It was hoped that this mounting would be sufficiently stable to hold at least a rough alignment. Unfortunately, the laboratory CMM machine was located on the opposite side of the campus, so the instrument was subjected to various unpredictable forces on its trip back from CMM alignment to its ALS vacuum chamber on beamline 9.3.2.

More problematic, if more predictable; there were problems with screw backlash, walking of the screws upon application of their set screws, and the overall crudeness of adjustment using this rough grade screw, which made any adjustments of these settings largely irreproducible. The operator made the adjustment by counting Hadinger fringes as the screws were nudged in one or another direction, and noting their relative quality. Worse, the set screws were not sufficient to hold the alignment screws in place. This was not clear until the instrument was aligned well enough to obtain an interferogram of visible partially coherent neon light (see figure 1 below). The alignment which produced this interferogram was lost as the instrument sat static overnight.

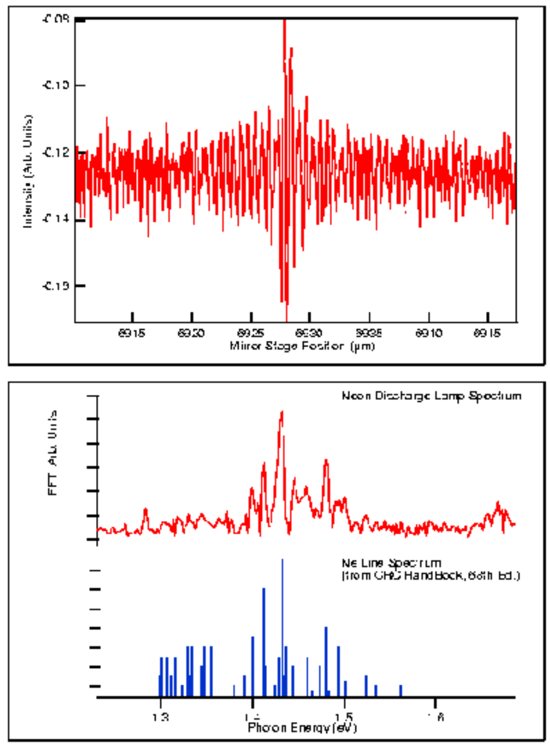

Figure 2 Interferogram from neon discharge lamp and associated spectra

Modifications to Beamsplitter Mounts

The beamsplitter mounts were modified to use New Focus picomotors with 1/4-80 threaded screws. According to the sales literature[4] these are able to move a step as small as 40 nanometers via a 2 mrad rotation, and also grasp the screw itself when the piezo actuator is in the relaxed position. Unfortunately, these devices do not function like stepper motors; i.e. sending a pulse to a picomotor does not move the motor by a reproducible step; it may not move at all on a given pulse!

As such, some kind of position monitor was needed to close the loop of the beamsplitter position adjustment subsystem. We chose to use Linear Variable Differential Transformers (LVDT) from Macrosensors as our position monitor. The use of LVDT in combination with picomotors had already been pioneered by Paul Denham et. al. on CXRO metrology beamline 12. These devices had a number of advantages over rotary encoders; among them, low cost, a relatively simple wiring scheme, small size (as small as 0.75" long by 3/8" diameter), excellent stability, good vacuum qualities and good, direct linear position resolution. Some simple aluminum mounts were fabricated, set pins were attached to the LVDT cores, the beamsplitter mount was fitted for the LVDT mountings, and the same spring loaded pins were used to keep the set pin/LVDT core pressed against the beamsplitter at final assembly. A modified version of the CXRO controller box, which was essentially a shielded box and power supply for several Analog Devices AD698 LVDT Signal Conditioner IC chips, was used. This chip generates a waveform which can be selected for amplitude, frequency and scaling factors to match the individual LVDT, then converts the return signal into a DC voltage. In its present form, the LVDT controller box output is read by a simple 12 bit A/D converter in the VME Crate which gives an overall resolution of about 2.5mV. The LVDT controller box output seems to be about a factor of 10 more sensitive, so more resolution is available should we decide to use this controller with a GPIB voltmeter rather than the simple ADC.

In tests with micrometers, the LVDTs were found to have a sensitivity of about 300nm per millivolt. When calibrating the LVDT output to the actual angular change using the OML Autocollimator, the rough adjustments of the beamsplitter mounts were found to have a resolution of about 14 μrad on the yaw axis, and $40\mu rad$ on the roll axis. The downstream beamsplitter leaf-spring flexure reduction axes have a resolution of about 0.21 μrad on the yaw axis and 0.27 μrad on the roll axis. These resolutions should be sufficient to align the beamsplitters to their $1\mu rad$ tolerance. As implied before, these resolutions can be improved upon using a more sensitive voltage measuring device such as a GPIB voltmeter, and taking some steps to reduce the system noise.

Should it be deemed useful at some point to return to the old CMM alignment methodology, the LVDTs will certainly prove useful in not only retaining the best possible CMM alignment, but also forming something of a non-indexing CMM, once the LVDTs are locked down and calibrated with respect to the position measurements of the CMM itself.

Modifications to Software

The computer control for this instrument consists of several levels of hardware. At the heart of the system is the VME crate and the Motorola 68040 CPU MVME167 controller card running the VxWorks realtime operating system. This card controls various other cards on the VME Bus, including several I/O cards, the H.P. laser position monitor controller card and a dual DSP subsystem for realtime signal processing. A Sun IPX workstation running SunOS release 4.1.4 was used as a development platform for the VxWorks code, as well as providing a Labview user interface.

In the prior software configuration, a TCP socket interface was used to communicate between the Labview and VxWorks code across a standard ethernet connection. This code had a number of bugs which occasionally caused the system to hang during datataking. The nature of this socket level code also made it difficult to develop new data or control channels as the controller code and the instrument itself increased in complexity. With the recent addition of computer control for the hydraulics, the picomotors and the LVDT sensors, it was decided to use the higher level Sun "Remote Procedure Call" (RPC)[5] in order to facilitate quicker network software development cycles, as well as providing a cleaner "client/server" software model for multithreading of the main VxWorks control program. The data streaming from VxWorks to Labview is also presently being changed from a streaming "ring buffered" model to an interrupt driven, block buffered model to increase reliability, data transfer speed and overall VxWorks code efficiency. Rather than relying on the speed and reliability of the Labview software in accepting the data on the IPX end, the new code also uses operating system level, hence faster and more reliable, SunOS RPC Network File Server (NFS) calls to write the interferogram data to the IPX workstation.

Conclusions and Expectations of Performance

At present, there are no mechanical restraints or software problems which will prevent the successful alignment of the interferometer. All mechanical specifications of the individual components have been met. Several proven methodologies for *in-situ* and out of chamber CMM alignment of the beamsplitters with respect to the mirror planes exist. The addition of picomotor actuators as well as LVDT position measuring sensors for the beamsplitters will provide a reliable mechanism for finding and keeping beamsplitter alignment with respect to the mirror plane, even while the spectrometer is under vacuum. This was the last major remaining engineering hurdle to the commissioning of the FTSX on ALS beamline 9.3.2.

Acknowledgements

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