**Tuning a 2.4 meter telescope... blindfolded**

The Automated Planet Finder

The APF is the newest telescope sited at Lick Observatory, 32 kilometers east of San Jose near California's central coast. The APF is an alt-azimuth telescope with a 2.4 meter mirror, enclosed in a co-rotating dome; the dome was designed and fabricated by Electro Optical Systems of Australia, and the telescope by EOS Technologies in Tucson, Arizona. The Levy spectrometer is installed at the left Nasmyth port, mounted directly to the telescope yoke; the instrument was designed and fabricated by University of California Observatories. The design objective for this telescope and spectrometer is high resolution Doppler spectroscopy. Instability in the servo control system of the telescope was a major roadblock for the commissioning of the facility; this paper describes some of the problems encountered, and the solutions deployed.

![Open APF dome with the Shane telescope in the background](image1)

![Model of the APF telescope showing the light path to the Levy Spectrometer](image2)

![Schematic showing the major components of the Levy spectrometer](image3)

Delta Tau PMAC servo tuning

The tuning process first addressed components that could be isolated: zero point offsets, the current loop and gain in the servo amplifiers, and basic acceleration parameters; the process then moved to the traditional proportional, integral, and derivative servo control loop implemented on a Delta Tau Turbo PMAC motor controller. Adding an aggressive low-pass filter and maximizing the servo update rate were two key modifications that enabled the best performance for the APF. Using a combination of software from Delta Tau and EOST followed by on-sky testing, we implemented enough stiffness and precision in the control loop to meet or exceed the performance requirements of the telescope, with following errors tightly controlled at less than a tenth of an arc second at tracking speeds, and no uncontrollable oscillations at any speed.

![Delta Tau step move test, showing rapid acceleration and well controlled error correction](image4)

![Delta Tau parabolic move test, showing minimal following error while accelerating at low speed](image5)

![Following error and DAC output while tracking at a constant speed of 0.1 degrees per second](image6)

Alignment of Heidenhain linear encoders

The alignment of the Heidenhain linear read head met the tolerances established by the manufacturer, but a significant nonlinearity in the quadrature output emerged. This manifested itself as a perfectly repeatable oscillation with a characteristic frequency determined by the line spacing on the encoder tape and the velocity of the read head. Using test gear manufactured by Heidenhain and custom electronics to divide down the output from the encoder interpolators, UCO personnel were able to improve the alignment of the read heads from 2.3 degrees deviation down to 0.5-2 degrees; this reduced the amplitude of the oscillations, but did not eliminate them entirely. Only by adjusting undocumented potentiometers inside the interpolators themselves could the signal nonlinearity, and thus the persistent oscillations, be eliminated.

![Adjustable mount for Heidenhain LiDA 30C linear encoder read head](image7)

![For the oscilloscope traces below, the quadrature output from the encoder read head are the plots which are white and green; the voltage inputs below are divided down to the interpolator. All the traces are triggered from two overlaid passes. 180 degrees out of phase.](image8)

You don't need to wear a blindfold...

Get the documentation.

When contracting with a third party, you have no institutional memory to lean on when the time comes to extend, improve, or repair your facility. Mechanical designs, electrical schematics, software architecture overviews, thorough descriptions of key maintenance operations and procedures; they all play an essential role in streamlining the long-term success of your facility. Proper documentation should be an explicitly required deliverable in your overall contract and statement of work.

Get the source code.

Source code is effectively the ultimate documentation for any software delivered for your facility. Questions that go unanswered in the delivered documentation may have answers tucked away in the source code; in effect, the source code is the most direct and relevant example for how to properly interface with discrete hardware subsystems. Even if there is no intent to augment or otherwise modify the software, the source code retains enormous practical value as a detailed design document.

Analysis before empirical testing.

Complex systems are not necessarily amenable to direct empirical exploration of the solution space. In the case of servo tuning, it is easy to mistakenly convince oneself that a locally stable solution is globally stable. Independent analyses of the systems such as a swept-sine analysis, can expose chronic problems that could severely impact probing of the solution space. Determine in advance the aspects of your system that can be isolated, and explore those areas before moving on to more complex issues.

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Shane 3-meter and APF 2.4 meter telescopes at Lick Observatory

APF at twilight, with the lights of San Jose in the distant background

APF telescope in Tucson before delivery to Mt. Hamilton

Spectral format of the Levy spectrometer; this is a polar spectrum with later color

Principal engineer Matt Radkovich

Project scientist Steve Vogt

Extending the APF dome at twilight; don’t forget to turn off the lights!

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