Harmonic cancellation cuts positioning errors

A British instrument manufacturer has used a harmonic cancellation algorithm to cut positioning errors dramatically in a new instrument. Simon Smith of Aerotech explains how.

Prescott Instruments' Rheo-Line multi-function rheometer (above) is used to test rubber and elastomer materials. It is based on a frameless and brushless torque motor (left) with a high-resolution optical encoder and integrated servo drive and motion controller

PRESCOTT INSTRUMENTS, the Tewkesbury-based specialist test instrument designer and manufacturer, recently introduced a multi-function rheometer for testing rubber and elastomer materials. The instrument incorporates a direct-drive brushless servomotor to deliver sinusoidal motion that improves its flexibility and supports a wider range of test conditions.

The rheometer can provide tests at lower frequencies than usual to improve the study of polymer processability, as well as performing more traditional moving-die rheometer testing and dynamic mechanical analyses to evaluate the cured properties of materials.

The new rheometer uses a single-axis frameless and brushless torque motor with a peak rating of around 20Nm, in combination with a high-resolution optical encoder and Aerotech's Soloist HPe integrated servo drive and motion controller. The sinusoidal motion is used to oscillate the sample under test at selected low frequencies and is delivered in combination with a fast output pattern from the drive. This gives the instrument the time-vs-angular position information that is critical for the in-phase and out-of-phase measurements recorded by the machine's sensors.

The synchronisation between the motion and output needs to be extremely accurate, with a working specification of a few thousandths of a degree.

When developing and commissioning their machines, Prescott's engineers use the advanced tuning tools and algorithms available in Aerotech's dynamic controls toolbox. This toolbox works with the Soloists' IDE software – a Windows-based GUI that provides diagnostic, development, and analysis tools that share a common theme with all of Aerotech's motion control software platforms.

The Rheo-Line's performance is helped by a harmonic cancellation algorithm which reduces positional errors dramatically on systems with the periodic trajectory commands or cyclic disturbances typically found in oscillating trajectories.

The full effect of harmonic cancellation for this application can be seen from the screenshots generated by the IDE software, including the dynamics controls toolbox.

The first screenshot (Fig. 1) is an initial loop transmission test that shows a well-tuned system. The crossover frequency is at 108Hz and the gain and phase margin indicate a system which satisfies stability criteria. An increase in low-frequency gains could affect the stability criteria adversely.

The machine test required an oscillation of one degree at 33.5Hz. As can be seen from Fig. 2 (produced using an oscilloscope utility), there is a phase shift at this frequency that causes a position error of almost the commanded amplitude. The position feedback plot shows that the sinewave is far from achieving the commanded value. This phase shift is due to the large inertial load and the controller's inability to track the commanded frequency with the stable gains.

Using a Fast Fourier Transform (FFT) utility on the position feedback, Fig. 3 shows that the input command frequency of 33.5Hz is the dominant frequency, however the plot also indicates a less significant peak at 100.5Hz. Using the dynamic controls toolbox, the harmonic cancellation is selected for frequency and applied at 33.5Hz.

Looking again at the 'scope view, Fig. 4 shows that the position error has reduced from ±0.5 degrees, to less than ±0.005 degrees – an improvement of 100 times the original error. At this point, the phase shift

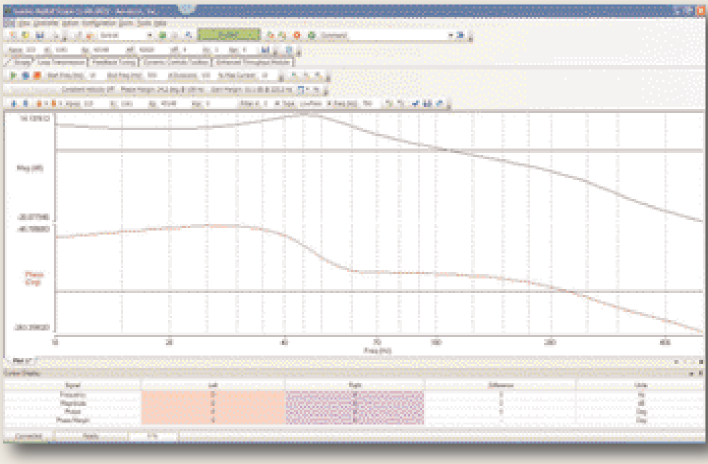

Fig. 1: the initial loop transmission test

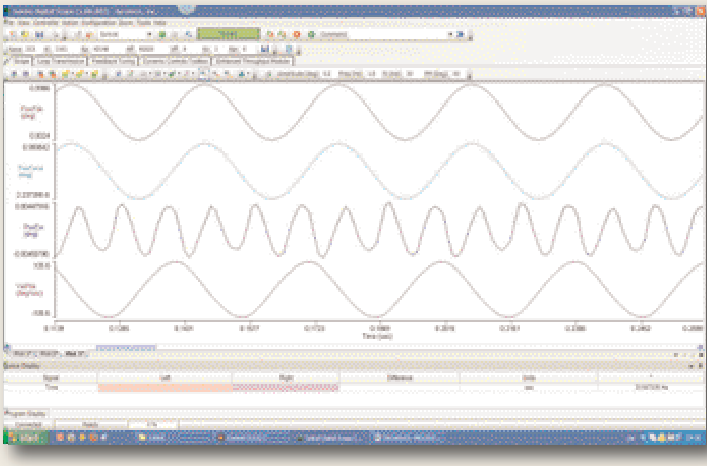

Fig. 4: the position feedback plot now shows a 100x reduced error

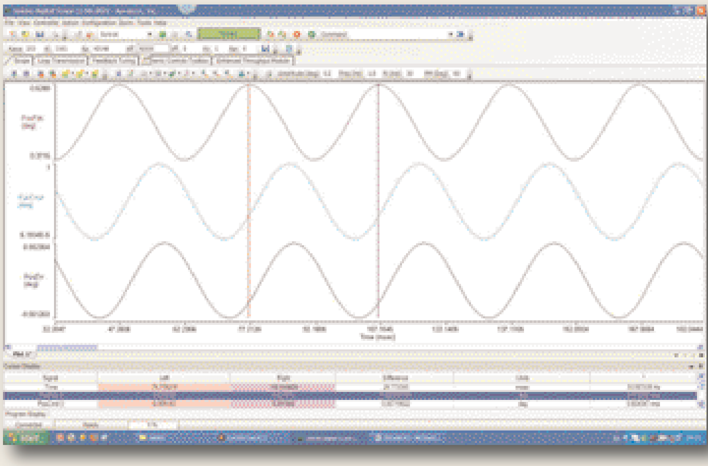

Fig. 2: a position feedback plot showing an error of almost one degree

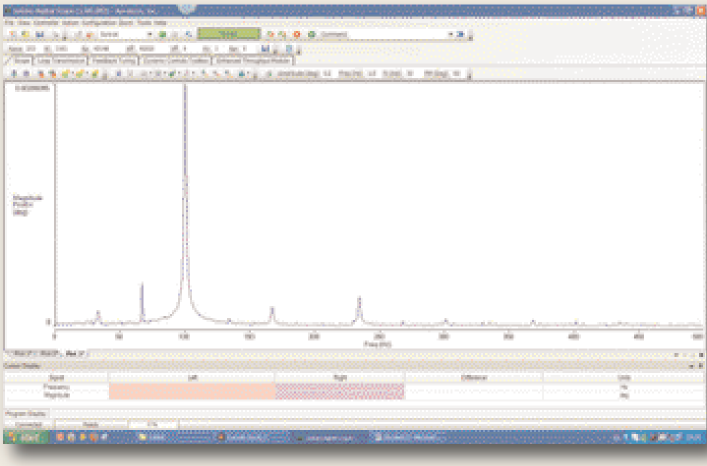

Fig. 5: FFT now shows a dominant frequency at the third harmonic peak of 100.5Hz

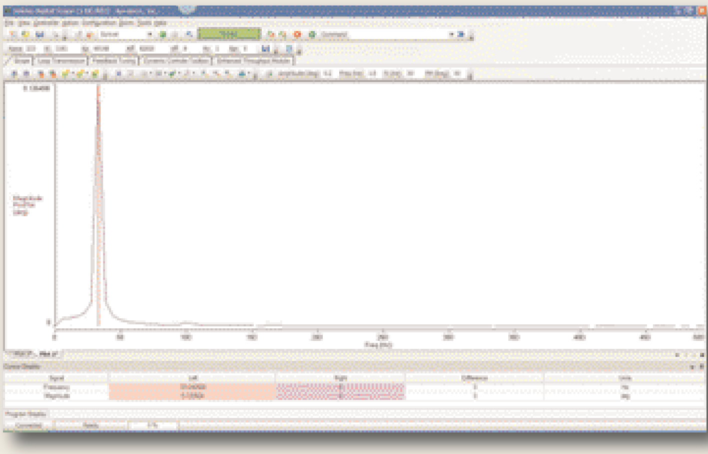

Fig. 3: FFT shows the dominant frequency at 33.5Hz and a third harmonic peak at 100.5Hz

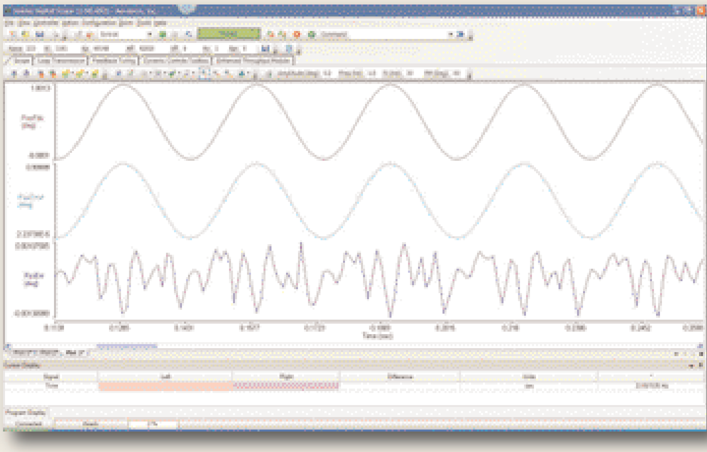

Fig. 6: the position tracking error is now ±0.0013 degrees

is effectively eliminated.

The FFT of the position error (Fig. 5) now shows that the original 33.5Hz harmonic has been eliminated and the third harmonic is now dominant (100.5Hz). To improve the system response further, harmonic cancellation is now applied at 33.5Hz as well as the third harmonic of 100.5Hz.

The resulting position error is now reduced from ±0.5 degrees to ±0.0013 degrees (Fig. 6). This gives a 385x improvement in position tracking from the original error and falls well within the original specification.

The harmonic cancellation algorithm is extremely effective where a motion profile is repeated continually – such as the sinusoidal oscillation required for the rheometer. Other applications that could benefit include sensor testing of accelerometers, gyroscopes and other inertial measurements. The algorithm may also be useful for multi-axis positioning systems where a periodic or rotational motion on one axis leads to unwanted error motions on the other axes.

This problem is exhibited to some degree by machine tools, tracking systems, semiconductor wafer processing equipment, and spin stands for data storage. The harmonic cancellation algorithm can adapt to such disturbances that are periodic on the position of another axis, even if the speed of that axis – and thus time-based frequency – changes.

Another tool that can improve machine accuracy and increase speed and throughput is an "enhanced throughput module" – a software- and sensor-based hardware system that measures the unwanted motion in several directions on the machine base, sending the information to the controller which modifies acceleration/deceleration and other factors. This results in significantly improved move-and-settle times and contouring performance which, in turn, increases the throughput of existing and new machines, and reduces the effects of frame motion on the servo system. D&C