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Laser scale systems improve feedback in aerospace and other precision industries

Internationally the demand for new aircraft is at extremely high levels, driven by the increasing boom in leisure travel and economic development in emerging markets. This is bringing immense pressures to beat on the manufacturing capabilities of the world's manufacturers, increasing the need to use automated and jigless assembly techniques within build processes.

This is also happening at a time that manufacturers are striving to reduce both component cost and weight - the benefits of lighter aircraft in reduced fuel costs and extra passenger load capability throughout the life of an aircraft are immense. All these changes are reasons why there is an increasing demand to improve the dimensional accuracy of large aircraft fuselage and wing components.

The two main sources of machining inaccuracies are found in the axis positioning system and the dimensional changes in the workpiece caused by fluctuating environmental conditions. Existing positioning systems, such as rotary encoders or linear glass scales work well on short axes, but on large machines are susceptible to mechanical components becoming worn, whilst cost and physical issues become critical. Options to counter thermal effects on the workpieces were either expensive, involving machine shop temperature control, or, as in the case of positioning compensation were no more than untried and unproven concepts.

Since the late 1980s, laser calibration systems have been available which achieve a linear accuracy approaching 1 part per million (1 micron per metre) over a range of up to 80 metres. Such systems are used for calibrating the accuracy of machine tools, measuring machines and other precision machinery as part of regular maintenance programmes. However, accuracy improvements achieved during machine calibration decay over time due to machine wear, and are affected by environmental changes, which affect both the machine and the workpiece.

The challenge has therefore been to take a laser calibration system and adapt it to become a permanent fixture to the machine tool in the hostile environment of a large machine shop. It has also been necessary to add correction for workpiece thermal changes so that parts machined in a variety of environments, where the temperature can vary by up to 30°C, precisely mate when assembled - a particular problem when working with aluminium, a popular lightweight material in the aerospace industry, but suffering from relatively high expansion coefficients.

As a market leader in laser calibration systems, Renishaw has been an early provider of one such solution to meet market requirements. Its HS10 laser scale system consists of a 633 nm HeliumNeon (HeNe) laser housed in a shop-hardened enclosure, with system components which enable lasers to be reliably employed in a machine shop environment. Issues of vibration proof mounting, beam protection from flying 'chips' and controller integration have all been overcome, resulting in a system that is available for fitment to new machines, and as a retrofit option for the large number of machines already in the field.

The system is claimed to provide position feedback at feedrates up to 60 metres per minute using either analogue or digital quadrature, with a range of user selection output resolutions.

An innovative approach was required to enable the system to instantaneously compensate for workpiece thermal growth. Aluminium presents major thermal growth issues, demanding the ability to 'track' its growth and reposition the cutting tool during the machining cycle.

To achieve a workable compensation system requires the skill of an experienced engineer and the sophistication of a compensator unit. A machine programmer can model (in CAD / CAM) the growth behaviour of a component and calculate multiple coefficients of expansion that accounts for different directions of component growth, in relation to both reference marks and fixturing points. The Renishaw system, which monitors and compensates for both air temperature refraction and machine / workpiece temperature changes, is then programmed with these different coefficients and can apply them at different user defined points along each axis. The machine controller therefore receives position information (square wave digital quadrature or sine wave analogue quadrature) which has already been compensated and handles the information as with any traditional encoder.

Tests on laser scale equipped machine tools working in the field have shown a system capable of positioning a machine to an accuracy of approximately 1 micron per metre. The consistency of machined aluminium components has improved to such an extent that Boeing, for example, now specify that all key wing components are manufactured under the control of this system.

A major benefit of using lasers for position control on machine tools is seen in improved machine dynamics. Through non-contact operation at high resolutions, lasers eliminate the traditional errors found in rack and pinion or ball screw feedback systems, such as hysteresis, backlash, mechanical wear and cyclic errors. The result is higher feedrates and dynamic responses giving improved profiling capabilities and surface finish.

Laser scale systems are also being migrated to other industries where a precise positioning system is a necessity. One such example is the co-ordinate measuring machines (CMM) which in many industries is the ultimate reference tool for positional accuracy.

A US based company, Resource Engineering Industries (REI) has recently produced a custom-built CMM using Invar as its main structural material and laser scale on the machine's X and Y-axes. The machine stand 4.4 metres tall, weighs 9980 kg and has axis travel of 2032 × 1524 × 1219 mm.

On CMMs or machine tools, the operating principle is the same: to measure linear distance a laser beam is shot through a beamsplitter and retroreflector that returns a reflected 'reference' beam parallel with the source beam. Two beams are actually sent to the detector on the HS10 laser head: the reference beam sent back directly and a measurement beam bounced off the reflector mounted on the moving axis member. As the axis moves and the distance between the optics changes, the detector counts the number of wavelengths' change. The result is an A/B quadrature square wave output, with switchable resolution.

The output is then fully corrected by the environmental compensator which takes data from multiple sensors, including temperature sensors for each axis, and an air pressure sensor. Based on the input from the environmental sensors and pre-programmed coefficient of expansion of expansion factors, the compensator adds or subtracts quadrature counts from the scale signals before sending them to the CMM's controller.

REI is currently using a third party PC-based DSP motion controller on the CMM. One advantage of laser scale technology, says REI, is that the standard quadrature output signal is transparent to just about any controller. "It would be possible to retro-fit a machine equipped with a glass scale or a steel scale, and the output from the laser system would appear the same, from a signal perspective."

During a typical ball bar test for CMM volumetric accuracy, temperature fluctuations must be given the utmost consideration as they impact the reliability of the test results, says REI. "We took our time - four days to be exact - because we were confident of the accuracy of the laser scales and the stability of our positioning platform. In fact, during calibration and test, the CMM was within three feet of the plant's main door, which was open to the 100-plus degree Arizona summer heat. We held phenomenal numbers, below spec, during the entire test. With the HS10 laser scale system, the CMM seemed not to 'move' at all. To achieve 5 microns over four days in the summer heat of Arizona is mind-boggling."

With results such as these, for both machine tools and CMMs, laser scale systems are now seen as a key enabling technology in the next generation of faster, lighter and more capable precision machinery.