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News from Renishaw

Technical note for editors: The dynamics of co-ordinate measuring machines (CMMs)

The dynamic performance barrier

Machine dynamics limit measurement accuracy at higher scanning speeds, creating a barrier to rapid measurement

Scanning is different to touch trigger probing in that the machine's dynamic performance is much more important than the static performance, the machine being under inertial load throughout. This leads to deflections in the structure that are very difficult to predict.

Conventional scanning systems achieve accuracy by moving slowly. This compromises inspection productivity and is what Renishaw calls the **dynamic performance barrier**.

An example of dynamic errors

Scanning induces inertial forces, which result in measurement errors if left uncorrected.

Traditionally, CMM builders have focussed on building a machine that can accurately measure the location of discrete points throughout its volume. This capability is captured in the static accuracy specification of the machine. Similarly, sensor makers have focussed on providing a repeatable sensor to facilitate such measurements.

These issues are still vitally important, but scanning has moved the goalposts by introducing another factor - **inertial forces**.

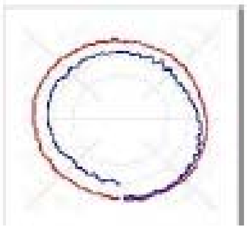
When measuring discrete points, these inertial forces are typically insignificant. In scanning, acceleration and hence inertial loads are ever-present. As speeds rise, the accelerations do too. In fact, accelerations increase much more quickly, varying with the square of scanning speed on a typical curved scan trajectory.

Inertial forces at low speeds are negligible, so it is in this zone that conventional scanning systems, which lack any form of dynamic compensation, are forced to operate. As speeds rise, dynamic forces quickly dominate the measurement performance of this system. However, most CMMs are used in a production environment where cycle times are important. There is clearly a great advantage to be had if measurements can be done more quickly.

An example

The plot shows the data acquired measuring the same feature at two different speeds. It illustrates how the dynamic forces build up as scanning speeds rise, resulting in an increase in form error.

The red plot shows the low-speed readings (10 mm/sec / 0.4 in/sec), which provide an accurate assessment of the size of the feature. The blue plot shows uncorrected high speed readings (150 mm/sec / 6 in/sec), which show the measured size of the bore decreasing as the centripetal forces on the quill build up as the measuring machine moves around the feature. At these speeds, inertial forces are up to 225 times higher than during the low speed scan!



Low and high speed scans

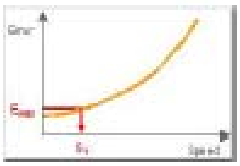
Dynamic errors increase with speed

As speeds rise, so do inertial errors, forming a barrier to high-speed measurement

Modern CMMs are capable of moving at high speeds - several hundred mm/sec - but typically scanning needs to be done at much slower speeds if accuracy is required. To get acceptable accuracy on tight tolerance parts, conventional scanning systems take measurements at low speeds - typically less than 20 mm/sec (0.8 in/sec).

Clearly there is potential to scan much faster than this, if only the dynamic errors induced by the deflection of the machine's structure could be overcome.

The error vs. speed chart shows error rising at an increasing rate with speed, since inertial forces are related to acceleration, which is related to the square of speed.



Dynamic error increases as scanning speeds rise

Emax is the maximum allowable error in the measurement of a particular feature. As a rule of thumb, this should be around 10% of the tolerance for that feature. By plotting this error on the graph we can see the maximum speed, S1, at which we should scan that feature.

What we need is a way to change the relationship between speed and accuracy, so that faster speeds can be reached whilst precision is maintained. Renishaw achieves this with **Renscan DC™**, a new patented dynamic compensation measurement technique.

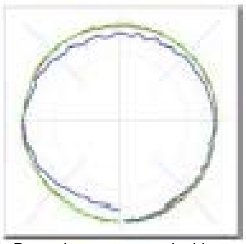
Components of the dynamic error

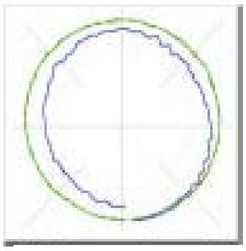
What are the factors that determine the dynamic error and which can be compensated?

The key characteristic of dynamic errors is their unpredictability. There are many factors affecting machine dynamics, making a predictive mapping approach impractical in all but the most constrained circumstances. These can be grouped as follows:

Factors that determine the **acceleration profile** of the machine during the scanning cycle, include:

- **Feature configuration** - the size, shape and orientation - which defines the path of the machine motion.
- **Scanning speed**, which defines the target velocity to be attained throughout the scan (bearing in mind that most scans will start with the speed at zero, so this speed is not maintained throughout the entire scan).
- The **machine's servo / motor performance** - how quickly can it accelerate to attain the target scanning speed?


Dynamic error near axis drive


Dynamic error away from axis drive

For each given acceleration profile, there are then factors that give rise to repeatable dynamic errors (inertial deflection) that can be compensated for by Renscan DC™:

- **'Macro' location** – the stiffness of the machine's structure, and therefore dynamic performance, varies throughout its operating range. The position of the feature being measured is therefore a significant factor.
- **Machine condition** - the state of the bearings and drive system, which could be a source of "slop" during scanning.

Although not predictable, these dynamic errors are repeatable. This means that compensation is possible, provided certain conditions are met.

There are also factors that give rise to smaller unrepeatable dynamic errors (system 'noise') for a given acceleration profile, that are not compensated by Renscan DC™:

- **Surface condition** - rough surfaces will cause vibration and some measurement error.
- **Servo noise / stability** - the machine's ability to hold at a programmed speed will depend on the control parameters and the electromechanical performance of the drive system.

These dynamic errors are more random in nature and are therefore not suitable for compensation. However, they are a small proportion of the total dynamic error.

Finally, there are factors that do not affect the dynamic error:

- **'Micro' position** - small variations about the nominal feature position, shape and size within the normal manufacturing and fixturing tolerances.
- **Temperature** - dynamic errors are immune to temperature. However, temperature variations may have an impact on static accuracy and hence measurement performance.

Error compensation

The full, feature-specific compensation provided by Renscan DC™ takes full account of these key dynamic variables. By effectively 'mapping' the dynamic errors that are induced for each feature on the component, subsequent parts can be measured accurately at high speeds, provided that they are nominally the same size and are located in the same part of the machine. This adaptability, to the machine and the measurement task, makes Renscan DC™ a highly flexible way to enhance the measurement performance of a CMM.