Research on high-speed measurement accuracy of coordinate measuring machines

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Abstract. Modern manufacturing technology has put forward a more exacting demand of speed and accuracy on Coordinate Measuring Machines (CMMs). However, with the increase of speed, the dynamic accuracy will decrease since dynamic errors will have a great impact on accuracy and act as a barrier to the measuring cycle time. In this paper, the influence of velocity parameters on dynamic performance of CMMs is studied. The main dynamic error sources of CMMs are identified and a method for evaluating the positioning accuracy under different dynamic conditions using a laser interferometer on a moving bridge type CMM is designed and analyzed, which might be utilized to realize dynamic error compensation.

1. Introduction
In recent years, demands for ultra-high accuracy and high-speed CMMs have arisen. However, with the increasing of measuring speed, dynamic errors will have a greater influence on the accuracy. And so far, investigations of dynamic errors of CMMs are still inadequate. Therefore, more study on dynamic errors of CMMs is pressing.

2. Dynamic characteristics of CMMs
The structure of the CMM in our study is shown in Figure 1. A typical touch-trigger probe is used in this bridge-type CMM. The driving system of x is located on the right side of bridge. The bridge travels along the x-guideway, the y-carriage travels along the y-traverse and the ram together with the probe travels along the z direction.

In the measurement process, on a computer-controlled machine the probe is commanded to approach the workpiece at a constant speed (positioning velocity) when it comes within the probe approach distance. There is no trigger signal when the probe tip just meets the surface of workpiece. The probe will continue to move with probing velocity. When probing force builds in the probe mechanism between the probe tip and the workpiece and reaches a threshold setting, a trigger signal is generated.
which is used by the CMM to latch the machine’s position at that moment and to command the machine to slow down and back off the surface.

Figure 2 shows the velocity and acceleration change in a typical point measurement using HP5529 laser interferometer time-base measurement on an MC850 bridge-type CMM equipped with Renishaw MHI20 touch-trigger probe (with a 20-mm stylus and 3-mm tip diameter) under different DCC (Direct computer control) parameters [1]. In Figure 2a positioning velocity \( v_1 \) is 20mm/s, probing velocity \( v_2 \) is 2mm/s, in Figure 2b \( v_1 = 80 \text{mm/s}, v_2 = 10 \text{mm/s} \).

![Figure 2](image)

**Figure 2. Touch-trigger probing process under different DCC parameters.**

### 3 Main dynamic error sources

Dynamic errors may vary from one type of CMM to the next. But based on the general structure of CMMs (shown in Figure 1), several components can be identified as the main dynamic error sources.

#### 3.1 Machine loop

The machine loop is made up of the machine structure, air bearing and guideway systems. All the moving elements are jointed with air bearings. During the process of fast probing when acceleration or deceleration constantly occurs, large inertial forces from the distributed mass of components (the bridge, y-carriage and the ram) will be imposed on the structure of the bridge. Because of improper performance of the guide system, the bridge will yield rotational errors around the joints of the air bearings. Under inertial forces, the bridge will also yield elastic deformation.

![Figure 3](image)

**Figure 3. Schematic arrangement of comparison approach.**
From the structure of this CMM, we know that the measuring line does not coincide with the scale line, so an Abbe offset exists. Therefore these rotational errors can bring about a translation error at the probe. In addition, there will also be oscillations due to machine dynamics.

3.2 Probe system (Touch-trigger probe)
Advances in machine accuracy, speed and tighter part tolerances leave pre-travel as one of the major error sources on CMMS using touch trigger probes, especially under high speed conditions. The three parameters (chosen in figure 2) have great impact on dynamic probe error, among which the influence of approaching velocity and distances are greater than positioning speed [2]. When the approaching distance increases and meanwhile the approaching speed decreases, the deformation and oscillation will be damped out before probing, thus brings less dynamic errors. Therefore in the day-to-day measuring process of CMM, the velocity parameters set at calibration should accord with the parameters used in measurement. If not, it will bring much dynamic probing error although it is always neglected by CMM users.

3.3 Servo-control system
To minimize the impact of dynamic error, the high capacity of the servo control system is also very important. How quickly it can accelerate to attain the target scanning speed and the machine’s ability to hold at a programmed speed depends much on the control parameters and the electromechanical performance of the drive system. Tightening the motion control of the CMM to provide a stiff servo loop is one way to tackle the dynamic performance barrier.

3.4 Measuring system
The impact of the above error sources ultimately leads to the improper reading of measuring system (usually slide system), and then impacts the quality of measured data, thus dynamic errors are generated. Because of dynamic effects, which are inherent during machine working affect, original reading of slide can be used as nominal position to compare with the actual position captured dynamically by laser interferometer system on a time basis as the quill moves continuously along the machine axis on test. The A-quad-B pulses produced by the encoder can be picked up and sent to the A-quad-B connector of the laser card [3]. In this way, the two groups of data can be connected synchronously. Then the difference of the two groups of data is dynamic error, which can be utilized for the purpose of software compensation. A criticism of this approach is that it omits effects of probing errors. This is due to the fact that the cube-corner was mounted in the probe head instead of the usual stylus. The schematic of the principle of this method is shown in Figure 4.

Figure 5. An example of the experimental data.

This experiment is carried out along three axes at seven different positions (p1 to p7) on a bridge-type CMM. Each axis with a certain velocity at a certain position is repeated five times back and forth. The axis velocity is set to 9 different values from 20mm/sec to 100mm/sec, Figure 5 shows an example of the experiment data. Abscissa is axis velocity (unit: mm/sec), y-axis is reading the difference between the laser interferometer system and slide system (dynamic error, unit: um). It apparently is made up of high-frequent and low-frequent data components. The dynamic error of one position is along x axis and the velocity of the moving axis is 30mm/s. In figure 5, X1-5 is five times measuring data respectively, X is the average value curve. The p2 and p3 line is the four-order spline curve and shape-presenting curve used to fit the average value curve. The six groups of curves in Figure 6 show the relation between the accuracy parameters of each axis with axis velocity at seven positions in
according with ISO230/2 standard. In these figures below, A presents unidirectional accuracy of positioning of an axis, B is reversal difference of unidirectional data, E is unidirectional positioning systematic deviation, R is unidirectional repeatability of positioning. Slope represents slope of one-element regression curves used to fit average value curve.

![Graphs showing dynamic accuracy index comparison](image)

(a) (b) (c)

(d) (e)

Figure 6. Comparison of dynamic accuracy index at different position.

From this experimental data, we can easily see the characteristics of the dynamic errors of CMM: repeatable, space-relevant, and increase with axis velocity, although more data analysis and processing are needed in order to pursue further study. Now, on the basis of this error data, the manufacturer can implement compensation software so as to correct the measurements performed by the machine.

4 Conclusion

In this paper machine the dynamic characteristics of a bridge-type CMM using a touch-trigger probe is studied. Several experiments are carried out to analyze the effect of the main dynamic error sources related to velocity parameters.

References

[1] Dong C S, Zhang C, Wang B, Zhang G. X 2000 Orlando FL. J. Proceedings of the ASME. 11 55

[2] Fei Y T, Zhao J, 2004 Hangzhou China The fourth straits forum on manufacturing technology. 277

[3] Castro H E F, Burdekin M 2003 J. Machine Tools and Manufacture. 43 947