# Improvement of Positional Accuracy of Developed Dicing Machine

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***Abstract*—An experimental procedure was performance on developed dicing machine to improve the positional accuracy and keep tolerances within acceptable range for precision manufacturing industry. The positional accuracy and repeatability of the developed dicing machine of the 5mm ball screw stage were studied and measured using laser interferometer. The values for positional accuracy and repeatability were performed and calculated according to ISO 230-2 standard for all three axes. Correction of pitch error compensation was performed. The results showed that the improvement of positional accuracy using pitch error compensation in this experiment was 5.49 µm, 9.41 µm and 1.35 µm in the X-axis, Y-axis and Z-axis, respectively.**

***Index Terms*—accuracy, precision dicing, positional, repeatability, compensation**

## I. Introduction

Precision Engineering is significantly important in the development of the micro-machining technology for improving the efficiency of quality control in manufacturing through higher machine accuracy. One of the greatest triumphs of precision engineering is to accomplish greater miniaturization. Future trends of precision engineering in high-technology industries such as optics, semiconductor, IC technology, and biomedical engineering, have a need for manufacturing processes of smaller features at smaller length scales and high precision. Since 1983, N. Taniguchi [1] has indicated in his curve see Fig. 1, that machining achievable in future will be in nano-accuracy

Miniaturization of devices in various fields currently requires production in micro and nanoscale components. Many studies have been carried out in previous years to fabricate micro-structures and micro-components. The properties of these components range from the sub-micron to a few hundred microns with high tolerance to many engineering materials [2, 3].

Without micro-machining technology, fabrication of miniature components is impossible on micrometer range dimensions. Hence the need towards special machines with submicron even down to nanometer accuracy is growing to meet the demands of new invention in high-technology industries [4, 5].

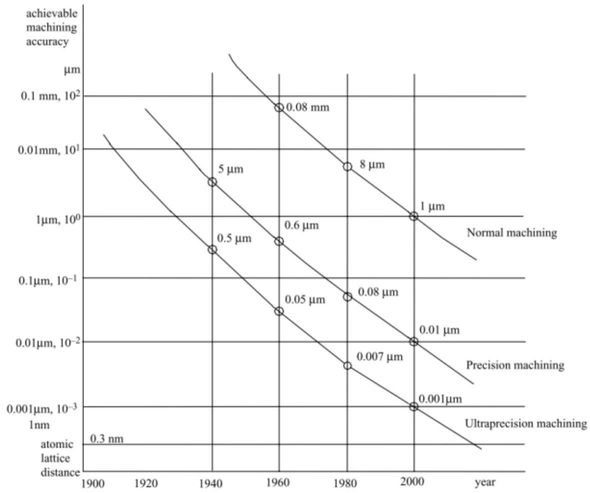


Figure 1. Taniguchi curve[1].

There is demand for machining operation for the multi-layer material of thickness less than 1 mm with minimal material damage. According to L.G. Carpenter et al. [6], the previous study has shown that precision dicing technologies are essential methods, to obtain the highest form accuracy and surface quality. For these types of precision machining, it is necessary to measure and compensate motional deviations.

R. Theska et al. [7] stated that in order to be able to develop superior precision machines, it is essential to identifying and quantitatively determine various error sources at the earliest stages of the design process and the machines performance parameters. The accuracy of the machine relies on many error sources. These can cause changes in the geometry of the machine component assembly such as spindle shaft, the bearings, the housing, the guideways and frame, the drives and the tool and work-holding fixtures. Due to the changes will affect the positioning and orientation error of the machine [8,9].

General definition of accuracy and repeatability in position accuracy can be referred in international standards such as ISO 230-2, JIS B6201-1993, and ASME B5.54. These standards describe both test procedures and methods for calculating the accuracy and repeatability under unloaded conditions for linear and rotary machine tool motions. This paper presents an inspection and acceptance testing of the improvement of

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positional accuracy of dicing machine using pitch error compensation followed the ISO 230-2 standard.

## II. Experimental Setup

A laser interferometer is used to measure the machine positioning properties. This laser-based measurements method using interferometric techniques are suitable for high-precision measurement such as length measurement. Renishaw Standard ML10 laser interferometer used in this experiment, with linear measurement optics uncertainty of ±0.7 µm/m. It is equipped with EC10 environmental compensation unit, integrating air pressure sensor and relative humidity sensor, while air and material temperature sensor are separated in order to be mounted on machine tool to have exact values. This makes it possible to perform accurate measurement of position in workshop conditions. Laser10 software and EC10 environmental compensation unit also used in data acquisition process as shown in Fig. 2(a). Furthermore, this experiment also takes consideration of environment condition by integrating with air compensation sensor (air pressure sensor and relative humidity) as shown in Fig. 2(b). It has separate air and material temperature sensor mounted on the machine body to measure the exact values of accurate measurement in the room condition.

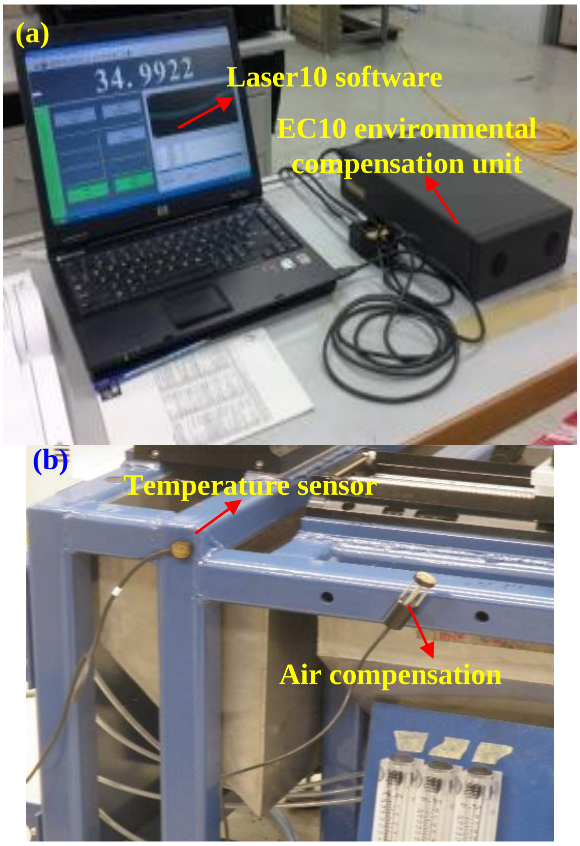


Figure 2. (a) Laser10 software and EC10 environmental compensation unit (b) temperature and air compensation sensor

Machine set-up for measuring linear position is shown in Fig. 3(a). Laser head ML10 was placed outside of the machine and stably mounted on the tripod. The laser and the linear optics was adjusted to the axis of travel measured; one linear reflector is secured to the beam-splitter, to form the fixed length reference arm of the interferometer. The other linear reflector moves about the beam-splitter and forms the variable length measurement arm. This is shown at the side view of Fig. 3(b). The laser system then tracks any change in the separation between the measurement arm linear reflector and beam-splitter. The axis under test was moved from the first target to the last target and the beam was aligned so that the signal strength meter remains constant over the range of the travel. The warm-up cycle was done before starting the axis measurement to simulate the machine operating condition. All measurement has been performed in a controlled environment of temperature 20°C and all heat source is removed. All of the measurement is under no load condition and does not indicate the machine performance under machining conditions.

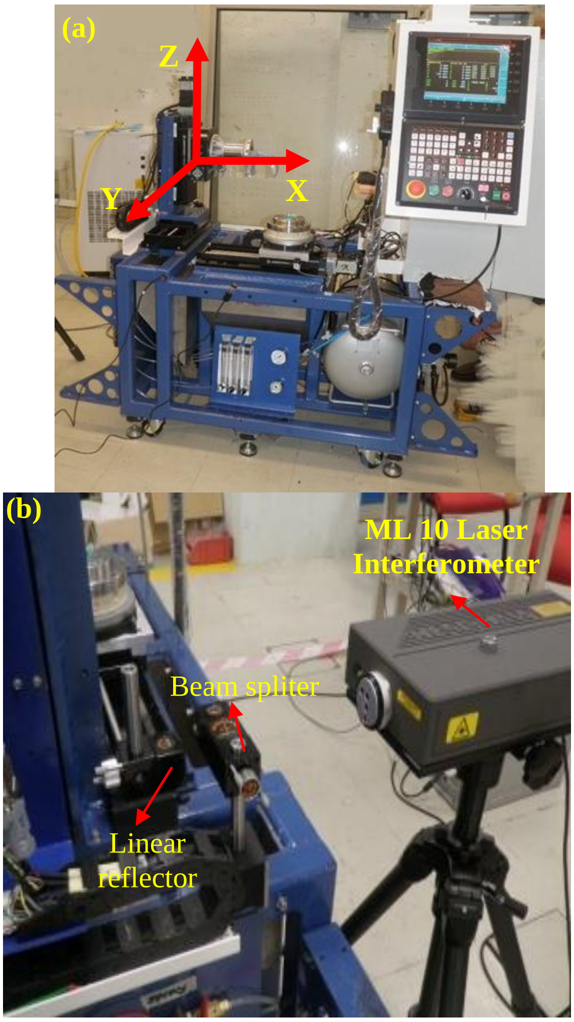


Figure 3. Machine set-up for measuring linear axis using a laser interferometer (a) Front view (b) Side view

The environment data is shown in Table I. The EC10 measures the variation in environmental conditions; then the unit calculates the actual laser wavelength using Edlen's equation. The EC10 received data from up to three material sensors, which measure the temperature of the machine to compensate for a machine's thermal expansion.

TABLE I. ENVIRONMENT DATA

| Data | Initial | | After | |
|---|---|---|---|---|
| | Start | End | Start | End |
| Air Temperature | 19.62$^{0}$C | 19.31$^{0}$C | 19.21$^{0}$C | 19.14$^{0}$C |
| Air Pressure | 1004.48 mbar | 1004.02 mbar | 1003.86 mbar | 1003.87 mbar |
| Rel. Humidity | 65.96% | 65.30% | 65.30% | 65.26% |
| Material Temp. | 20.59$^{0}$C | 20.06$^{0}$C | 19.95$^{0}$C | 19.81$^{0}$C |
| Exp. Coefficient | 11.70 ppm/$^{0}$C | 11.70 ppm/$^{0}$C | 11.70 ppm/$^{0}$C | 11.70 ppm/$^{0}$C |
| Environment factor | 0.316407 | 0.316409 | 0.316410 | 0.316410 |

Linear positional error measurements were carried out by direct measurement of each linear axis X-axis, Y-axis, and Z-axis on the machine. All measurement is according to the standard ISO 230-2 which have followed their characteristics condition [ISO 230-2] :

i - Uniform temperature
ii - Warm-up cycle
iii - Uni- and bi-directional approaches
iv - Number of target points: linear axes require at least five (5) target points per meter.
v - Number of measurements per target point: each test requires at least five (5) cycles of forward and reverse direction.

When applying laser interferometer based techniques to the machine, there are several errors affected the measurement need to be considered. Errors in the laser wavelength of the interferometric methods are transferred directly into the errors in the length measurement. Due to the errors in the frequency stabilization, the laser wavelength may change or different from normal.

For the compensation, the interval length of 5 mm was set in the machine parameters. To run the compensation, the initial parameter must be consider before calculating a new table of compensating parameters, the deviation value, and the multiplication factor. The parameters used for measurements of the positional errors are shown in Table II. The parameter is then manually inserted in the machine controller, and then the machine reads the implementation of the compensate deviation parameter for the axis. The machine reference point are X-axis = 0 mm, Y-axis = 0 mm, and Z-axis = 0 mm, A = 0$^{o}$, C = 0$^{o}$ were setup as origin. First step was carried out beam alignment with linear stage axis where by the reflected beam achieved maximum power at all three axes. During linear measurements, one of the optical components remains stationary, while the other moves along the linear axis. A positional measurement is produced by monitoring the changes in optical path difference between the measurement and reference beams. The travel lengths of the axes were tested by bidirectional approach in 7 cycles.

TABLE II. PARAMETERS OF MEASUREMENTS

| Measurement Axis | X | Y | Z |
|---|---|---|---|
| Length | 200mm | 140mm | 90mm |
| Accuracy (from the manufacturer) | ±8 µm | ±8 µm | ±6 µm |
| Bidirectional Repeatability (from manufacture) | ±1.0 µm | | |

| | |
|---|---|
| Drive System of Linear Motion Stage | 5 mm lead ball screw |
| Type of scale | Ball screw and rotary encoder |
| Feed rate | 100mm/min |
| Dwell time at each target position | 4 sec |
| Interval length | 5 mm |
| Number of the test cycle | 7 |

## III. RESULT

The initial measurement taken at X-axis have shown that the mean bidirectional positional deviation value of the X-axis has improved from 19.150 µm to 5.493 µm and the reversal error was decreasing from 3.914 µm to 0.971 µm after the initial errors have been compensated. The software calculated the reversal error as the difference of mean unidirectional positional deviation of 'forward' and 'backward' direction for an axis and this is the value of mean backlash or mean repeatability. Errors measured were compensated using extracted error compensation values from the software. The compensation of errors included the pitch and backlash values. Fig. 4 shown measurement value at X-axis before and after compensation respectively.

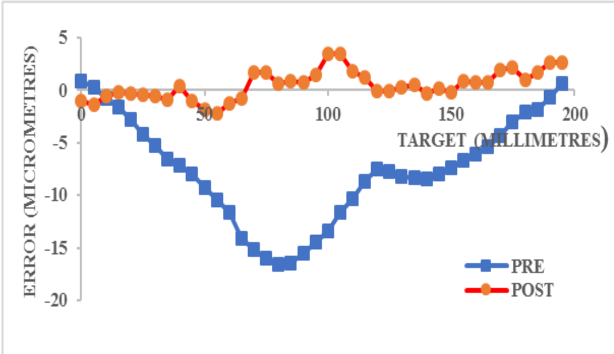


Figure 4. Positional error of the X-axis before and after correction of the pitch error compensation.

Similar set-up was used for Y-axis. Fig. 5 shows the initial state of Y-axis. It shows the mean bidirectional positional deviation values decrease from 20.450 µm to 10.907 µm after first compensation. The reversal error was also decreased from 3.214 µm to 0.714 µm. Results from the initial accuracy and repeatability measurements of Y-axis are not as good as X-axis. Thus, the Y-axis was measured for the second time where measured compensation values from the first compensation were manually transferred into the controller's compensation table to reduce the error. The result from the second compensation has shown that the mean bidirectional positional deviation value is able to decrease from 10.907 µm to 9.807 µm, but the reversal error was increased from 0.714 µm to 1.014 µm. The third compensation was carried out to reduce the error further, in which the compensation value was extracted from the second compensation. The third compensation has reduced the error value more, the mean bidirectional positional deviation values decrease after third compensation from 9.807 µm to 9.407 µm, while the reversal error was increased from 1.014 µm to 1.200 µm. Each round of compensation there was an improvement in the unidirectional accuracy. However, repeatability was slightly increased for both directions.

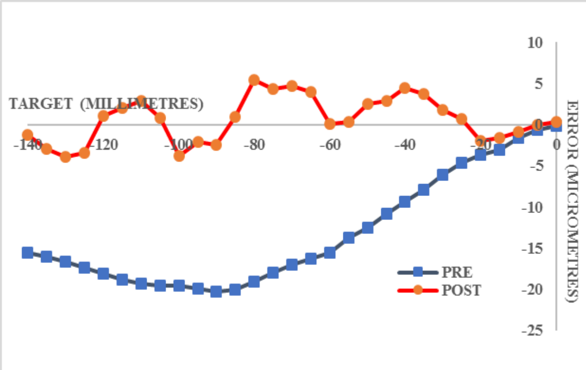


Figure 5. Positional error of the Y-axis before and after correction of the pitch error compensation.

For Z-axis, as shown in Fig. 6, the mean bidirectional positional deviation values decreased from 57.800 µm to 1.350 µm after compensation, and the reversal error was decreased from 2.457 µm to 0.600 µm. It shows an improvement in the unidirectional accuracy and repeatability.

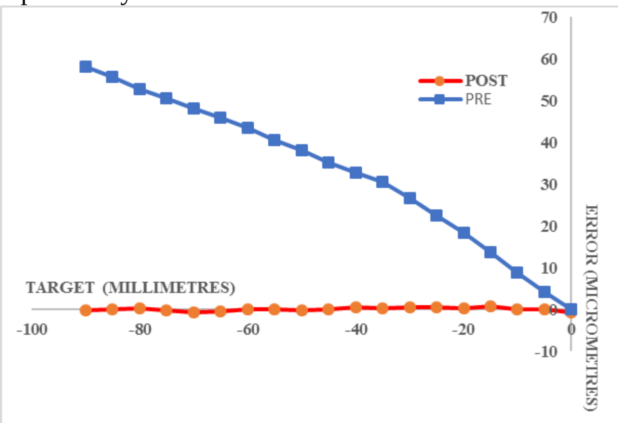


Figure 6. Positional error of the Z-axis before and after correction of the pitch error compensation.

Table III. shows a summary of the positional error of the X, Y and Z axis of the pitch error compensation. Reversal value of the Y-axis exceed 1.0 µm, that means there is backlash movement, due to linear stages. The imperfections of the moving component in the machine or it the guiding system will cause linear positioning error in the linear axis. After compensation take place, the improvement for the X-axis, Y-axis and Z-axis was 5.49 µm, 9.41 µm and 1.35 µm respectively. It clearly shows a huge improvement by doing this compensation.

TABLE III. Positional Error of the X, Y, Z-axis Before and After Correction of the Pitch Error Compensation

| Axis | Axis lengths (mm) | | Before Comp. | After Comp. | Percentage Improvement (%) |
|---|---|---|---|---|---|
| X | 200 | Accuracy (µm) | 19.150 | 5.493 | 349 |
| | | Reversal (µm) | 3.914 | 0.971 | |
| Y | 140 | Accuracy (µm) | 20.450 | 9.407 | 217 |
| | | Reversal (µm) | 3.214 | 1.200 | |
| Z | 90 | Accuracy (µm) | 57.800 | 1.350 | 4281 |
| | | Reversal (µm) | 2.457 | 0.600 | |

## IV. Conclusion

An experimental improvement procedure was used for dicing machine to minimize positional errors of linear scale. The improvement was based on the correction of the pitch error compensation table. According to this experiment, one correction was needed at X-axis and Z-axis, while three corrections were needed at Y-axis, in order to reduce the positional errors within ±8 µm range. More corrections were needed at Y-axis due to imperfections of the moving components in the machine. The experiment shows that there was an improvement in both directions for each round of compensation. The improvement of the bi-directional accuracy in this experiment was from 19.15 µm to 5.49 µm (349%), 20.45 µm to 9.41 µm (217%), 57.80 µm to 1.35 µm (4281%) in the X-axis, Y-axis and Z-axis, respectively. This research proved that high positional accuracy could be improved using pitch error compensation.


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