Real-time straightness measurement system using 1Dplus linear scale by applying two-probe method for large flat-panel manufacturing stage

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INTRODUCTION
To enable large-sized high-resolution flat panel displays, manufacturing equipments need sub-micron repeatability over wide working area. The straightness error of the scan stage is one of the main error sources. It is impossible to assemble the scan stage with sub-micron straightness error, especially when the travel range exceeds several meters to cover large glass size. Therefore we have to measure and compensate straightness error to guarantee sub-micron repeatability. Traditionally reversal method and laser calibrator have been used, but these cannot be applied to long travel stage due to limited accuracy and repeatability. In addition, off-line mechanism limits real-time measurement during operation. The real-time straightness measurement method using position sensitive diode was proposed [1]. They measured straightness using collimated laser beam, multiple retro-reflector and a PSD. But PSDs have inherently drift problem so long-term repeatability cannot be guaranteed. Error separation methods, so called two-probe and three-probe methods, were proposed to separate the straightness error from surface profile of reference block [2]. The straightness profile can be determined under on-line machine conditions. However the usage of capacitive probes and target block limits measuring area. The autocollimator used for measuring yaw has drift issue so long-term repeatability cannot be guaranteed.

In this paper, we propose a new real-time straightness measuring system using the 1Dplus linear scale and multiple encoder heads by applying two-probe method. We implement the system into the 8G high resolution flat-panel manufacturing machine to verify the effectiveness.

STRAIGHTNESS MEASUREMENT METHOD
Two Probe Straightness Measurement Method
Figure 1 shows the principle of the two probe method schematically. Two probes are installed to fixed frame and target is attached to a scan stage. Assume the profile of target surface is described by \( f(x) \). Let \( d \) be the distance between probes. The outputs of probe \( A \) and \( B \) can be expressed as follows:

\[
\begin{align*}
    m_a(x_n) &= f(x_n) + t(x_n) \quad (1) \\
    m_b(x_n) &= f(x_n + d) + t(x_n) + d \times \theta(x_n). \quad (2)
\end{align*}
\]

Here, \( t(x) \) is the straightness profile and \( \theta(x) \) is yaw error of the scan stage. The increment of surface profile is calculated by eliminating \( t(x) \),

\[
\Delta f(x_n) = f(x_n + d) - f(x_n) - m_a(x_n) + m_b(x_n) \quad (3)
\]

An approximate derivative \( \Delta f(x_n) \) can be defined as follows:

\[
\Delta f(x_n) = \frac{\Delta f(x_n)}{d}. \quad (4)
\]

Profile of target surface \( f(x) \) can be determined by \( 1^{st} \) approximation

\[
f(x_{n+1}) = f(x_n) + \Delta f(x_n) \cdot x \cdot (x_{n+1} - x_n). \quad (5)
\]

Consequently, straightness error is calculated by

\[
l(x_n) = m_a(x_n) - f(x_n). \quad (6)
\]

**FIGURE 1. Schematics of the two-probe method**

**Proposed Measuring Setup using 1Dplus scale**

The 1Dplus scale is a kind of linear scale from Heidenhain which can measure both x and y position simultaneously. It has gratings in x and y directions. The grating for y-direction is same with conventional linear scale measuring long y-dir scan motion. The grating for x-direction measures transverse motion in short range when stage moves along y-direction. The scale is made from zeroDur so that high thermal stability is assured.

We implemented straightness measuring system using 1Dplus linear scale into 8G high resolution flat panel manufacturing stage. The measuring system is shown in Figure 2. A 1Dplus scale was mounted on a side of the chuck. Since the scale is located near the glass and the height of scale is the same with the glass, it measures the...
motion of the glass accurately without Abbe error. An encoder head assembly was attached below metrology frame. It consists of six encoder heads. The left three encoder heads are for the first scan and the right three heads are for the second scan measurements. During each scan, one encoder head measures y-dir displacement and the other two heads measure x-dir displacement to apply the two-probe algorithm. To measure yaw error, we installed another 1Dplus scale and encoder head assembly on the opposite side of chuck and metrology frame, respectively. The length of the 1Dplus scale was 2600 mm and the resolution was 10 nm with interpolation. With this straightness measuring system we can always monitor straightness error of the scan stage during on-line operating condition and compensate it when the error becomes larger than allowable level. The proposed system can measure straightness error at even high speed scan because the distance between the scale and encoder heads is just 1 mm so that the signal is negligibly affected by environment change such as air turbulence and temperature variation.

MEASUREMENT RESULT
The position of the scan stage was controlled using laser interferometers with resolution of 5 nm. The positioning stability in x and y direction was 60 nm in 3 sigma. We set the distance between two x-encoder heads as 17 mm and sampling period as 1 mm. Figure 3 shows the straightness profile calculated by applying two-probe algorithm. The straightness error was 22 um with 2nd order curved shape over 2500 mm travel. Although the 1Dplus scale was deformed by 200 um when installed, the straightness profile was measured accurately independently of scale deformation. The straightness profile was caused by surface profile of bar mirror used for laser interferometer measurement. The straightness error can be compensated by applying the measured profile to x-dir command. The long-term repeatability of the straightness profiles was measured during on-line operating condition. During 24 hours 120 profiles were measured and the result is shown in Figure 4. The maximum value was less than 0.15 um and mean value of the 3 sigma value was 100 nm.

CONCLUSION
We proposed a real-time straightness measuring system using the 1Dplus linear scale by applying two-probe algorithm. The proposed method has several advantages: real-time measurement in on-line condition, high resolution over long travel, high stability even at high scan speed. We implemented that into 8G size high resolution flat panel display manufacturing system. We verified the effectiveness of the system by measuring the straightness error and the repeatability of profiles.

REFERENCES