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# HIGH PRECISION $X$-$Y$ STAGE FOR PRODUCTION AND INSPECTION EQUIPMENT OF ORGANIC LIGHT-EMITTING DIODE DISPLAY

**MYUNG-JIN CHUNG[1], SUNG-YONG SON[2] and YANG-HEE YEE[1]**

[1]Department of Mechatronics Engineering
Korea Polytechnic University
Shihung, 429-793
Korea
e-mail: mjchung@kpu.ac.kr
yhyee@kpu.ac.kr

[2]Department of Information and Communication Engineering
Kyungwon University
Seongnam, 461-791
Korea
e-mail:xtra@kyungwon.ac.kr

## Abstract

Recently, there is an increasing requirement for controlling linear motion from several ten nanometers to a few hundred of millimeter strokes in the area of the organic light-emitting diode (OLED) display production and inspection equipment. Linear positioning system with direct driving method such as piezoelectric drive and permanent magnet motor could offer significant advantages over conventional linear actuation technologies. Among these direct driving methods, high precision $X$-$Y$ stage using linear motor is a proper method for long stroke and high accuracy.

Keywords and phrases: linear motor, organic light-emitting diode, plane type $X$-$Y$ stage, production and inspection.

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In this work, plane type $X$-$Y$ stage having air bearing guide system is proposed for using in the production and inspection equipment of OLED display. The configurations of high precision $X$-$Y$ stage for production and inspection equipment of OLED display is as follows, $X$- and $Y$- axis using linear motor, air bearing guide system using hollow guide beam mounted by linear motor, isolation system supporting the base of $X$-$Y$ stage, and control system. Each component of high precision $X$-$Y$ stage is designed and constructed according to requirement of production and inspection equipment of OLED display.

The developed high precision $X$-$Y$ stage is verified by the performance test. From the performance test, moving stroke is 720mm for $X$- axis and 920mm for $Y$- axis, repeatability is less than 200nm for $X$- axis and 300nm for $Y$- axis, straightness variation is less than 700nm for $X$- axis and 300nm for $Y$- axis, flatness is less than 4.6μm for $X$- axis and 0.8μm for $Y$- axis, velocity ripple is 0.19% for $X$- axis and 0.47% for $Y$- axis at 50mm/sec, and in-position stability is ±69nm for $X$- axis and ±59nm for $Y$- axis.

## 1. Introduction

Recently, there is an increasing requirement for controlling linear motion from several ten nanometers to a few hundred of millimeter strokes in the area of the organic electro luminescence display (OLED) production and inspection equipment. Linear positioning system with direct driving method such as piezoelectric drive, and permanent magnet motor could offer significant advantages over conventional linear actuation technologies, such as motors driven by cams, linkages and pneumatic rams, in terms of efficiency, operating bandwidth, speed and thrust control, stroke and positioning accuracy with low kinematical complexity [1, 3-5]. Among these direct driving methods, high precision $X$-$Y$ stage using linear motor is a proper method for long stroke and high accuracy [2].

The requirements of the high precision $X$-$Y$ stage are low trajectory following error and high positioning accuracy. To satisfy these requirements, it has to be designed with the minimum velocity ripple and maximum acceleration.

In this work, plane type $X$-$Y$ stage having air bearing guide system is proposed, where each axis using linear motor is mounted on the hollow guide beam, isolation system, and control system are used for performance requirement. The developed high precision $X$-$Y$ stage is verified by performance test.

## 2. Configuration of High Precision $X$-$Y$ Stage

The configurations of high precision $X$-$Y$ stage using for production and inspection equipment of OLED is as follows, $X$- and $Y$-axis using linear motor, air bearing guide system using hollow guide beam mounted by linear motor, isolation system supporting the base of $X$-$Y$ stage, and control system as showed in Figure 1.

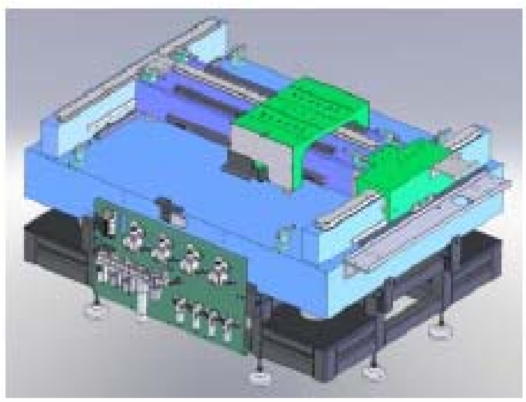


**Figure 1.** Configuration of high precision $X$-$Y$ stage.

## 3. Development of High Precision $X$-$Y$ Stage

Each component of high precision $X$-$Y$ stage is designed and constructed as follows.

### 3.1. $X$- axis

The requirement of $X$- axis is that stroke is 720mm, maximum velocity is 0.5m/sec, and maximum acceleration is 0.3G in the condition of 40kg payload and 25°C coil temperature. In the design of $X$- axis driving system, coreless type linear motor (SGLGW 40A 253BP) is used as driving method to reduce the velocity ripple, and hollow guide beam is used to minimize the moving mass. Figure 2 shows the developed $X$- axis.

**Figure 2.** Driving system of $X$- axis.

### 3.2. $Y$- axis

The requirement of $Y$- axis is that stroke is 920mm, maximum velocity is 0.5m/sec, and maximum acceleration is 0.1G in the condition of 38kg payload and 25°C coil temperature. In the design of $Y$- axis driving system, coreless type linear motor (SGLGW 40A 253BP) is used as driving method to reduce the velocity ripple, and hollow guide beam is used to minimize the moving mass. Figure 3 shows the developed $Y$- axis, where two linear motor and synchronized command is used.

**Figure 3.** Driving system of $Y$- axis.

### 3.3. Air bearing guide system

In the design of air bearing guide system, porous type air bearing is used, and magnet preload (127.5N) is used to increase the stiffness and flatness. Figure 4 shows the developed air bearing guide system.

**Figure 4.** Air bearing guide system.

Air bearing stiffness ($K$) according to air gap thickness is calculated as follows:

$$K = \frac{P_s \cdot A}{2 \cdot h}, \tag{1}$$

where $P_s$ denotes the supply pressure, $A$ is the area of pad, and $h$ denotes the air gap thickness. Designed air bearing stiffness is $7.017 \times 10^2$ N/μm.

### 3.4. Isolation system

In the design of isolation system, pneumatic auto leveling control system (PAL) isolator is used, and allowable load is 3,600kg in the supporting condition by four isolators. Figure 5 shows the used PAL isolator. This PAL isolator has natural frequency from 1.5Hz to 2.7Hz for vertical direction.

**Figure 5.** Pneumatic auto leveling control system isolator.

### 3.5. Granite base

In the design of granite base for support and guide of $X$-$Y$ stage, surface characteristic is important component in the mechanical precision of $X$- and $Y$- axis. Table 1 lists the design specifications of granite base.

**Table 1.** Design specifications of granite base

| | |
|---|---|
| Size ($mm^3$) | $1920 \times 1420 \times 250$ |
| Flatness (μm/0.3m) | ±1 |
| Straightness (μm/0.3m) | ±1 |
| Parallelism (arc sec) | ±3 |

**3.6. Control system**

The control system is constructed with motion controller, servo amplifier, linear encoder, and control panel.

As motion controller, UMAC controller having functions such as 80MHz DSP56303 CPU, 2048 I/O port, 16bit resolution, and 4096 analogue encoder interpolations is used.

As servo amplifier, servo star power block (CP 303250) having functions such as direct digital PWM input to UMAC controller and 1kW capacity is used.

As linear encoder, RSF electronic reflective scanning linear encoder (MS61.04) having functions such as grating pitch 40μm, maximum velocity 4m/sec, and minimum resolution 9.8nm by 4096 interpolation for 40μm pitch is used. $X$- and $Y$- axis are using the same linear encoder. Figure 6 shows the linear encoder system used for $Y$- axis.

As control panel, double sealed control cable (UL20276-SX) is used to reduce the nose effect.

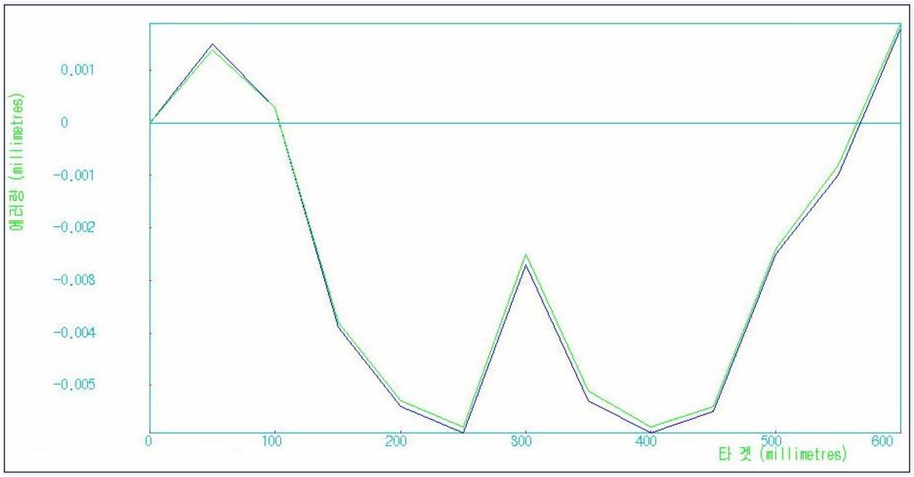
**Figure 6.** Linear encoder system used for $Y$- axis.

## 4. Experimental Results

The performance test is conducted with developed precision $X$-$Y$ stage as showed in Figure 7. In the performance test, laser interferometer (ML10) having 1nm resolution is used to measure the displacement of the $X$-$Y$ stage in the condition of forward and backward motion.

**Figure 7.** Developed high precision $X$-$Y$ stage.

From the performance test, moving stroke is measured as 720mm for $X$- axis and 920mm for $Y$- axis. Figure 8 shows the measured repeatability, where $X$- axis repeatability is less than 200nm and $Y$- axis one is less than 300nm. From Figure 8, average error can be compensated by mapping process. Figure 9 shows the measured straightness, where $X$- axis straightness variation is less than 700nm and $Y$- axis one is less than 300nm. From Figure 9, average straightness variation can be compensated by mapping process. Figure 10 shows the flatness, where $X$- axis flatness is less than $4.6\mu m$ and $Y$- axis one is less than $0.8\mu m$.

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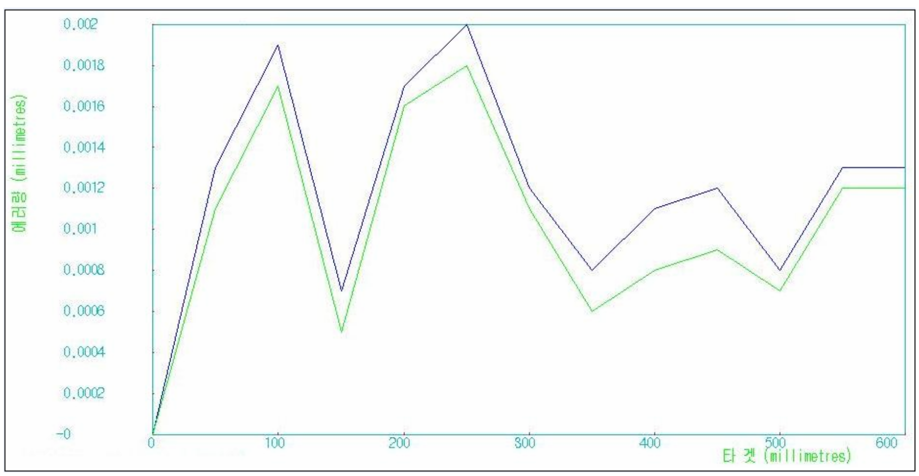
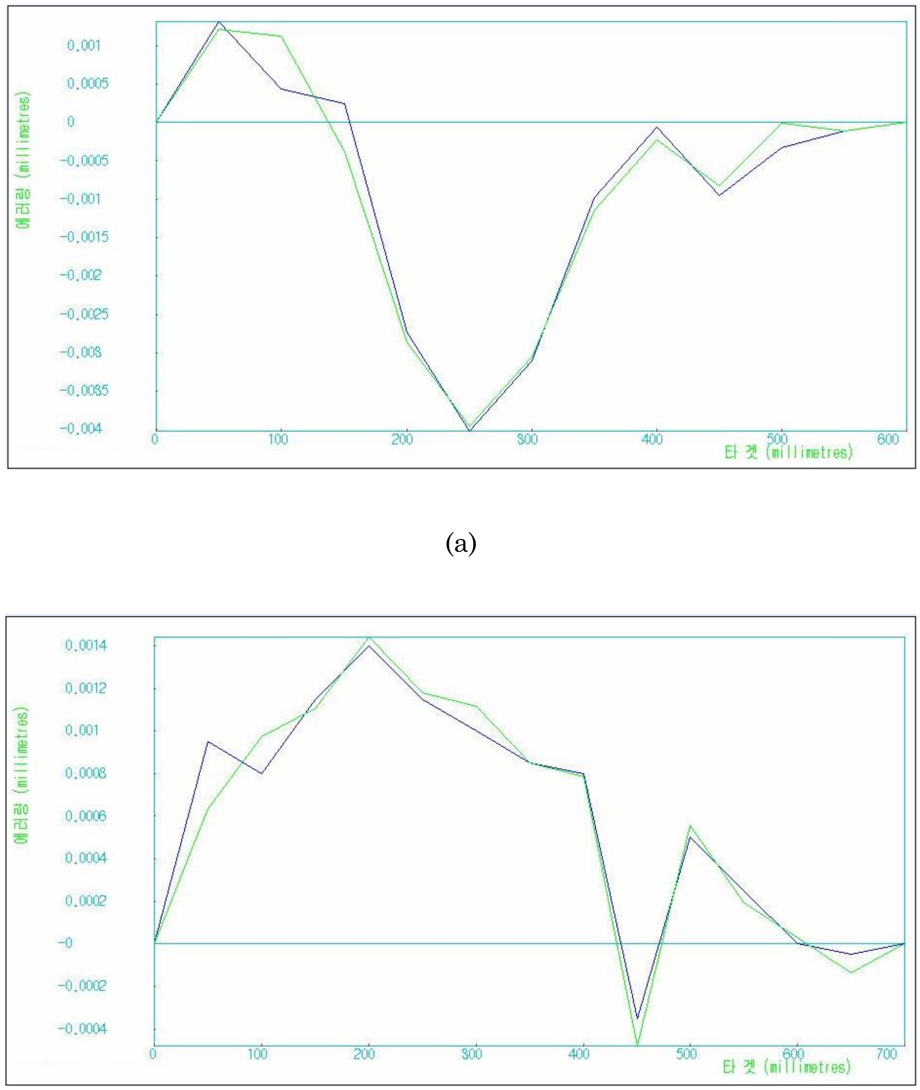



(b)

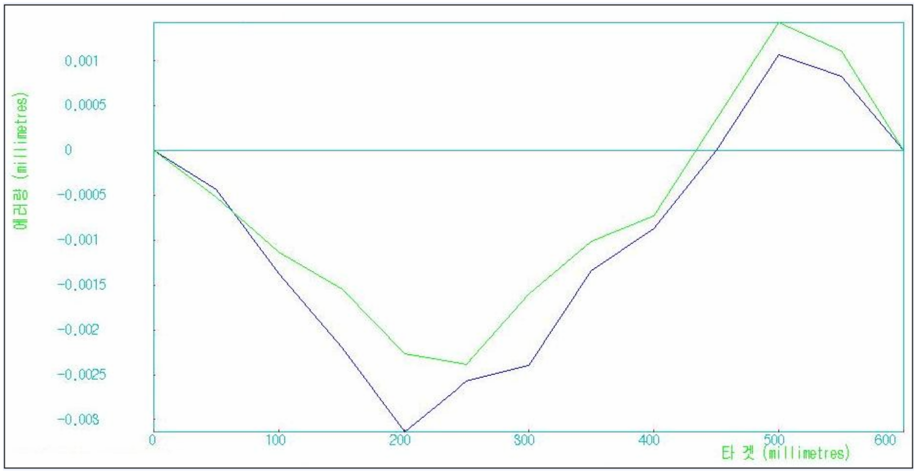
**Figure 8.** Repeatability of (a) $X$- axis, (b) $Y$- axis.




(a)

(b)

**Figure 9.** Straightness of (a) $X$- axis, (b) $Y$- axis.

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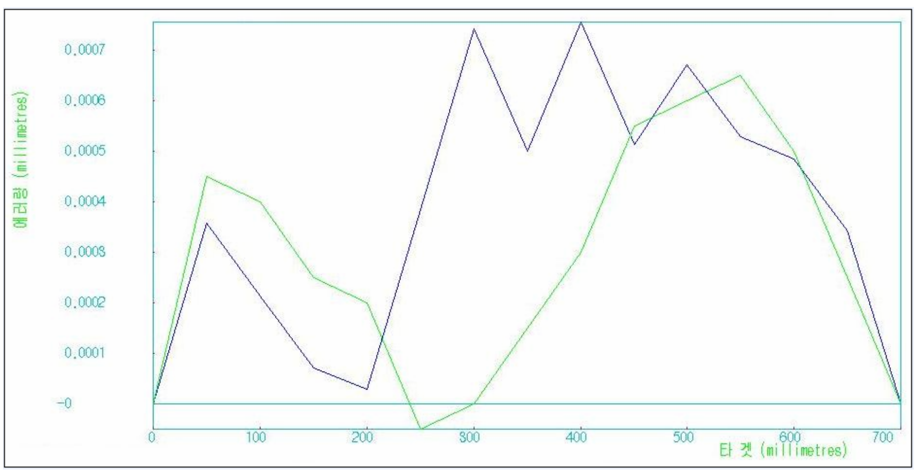
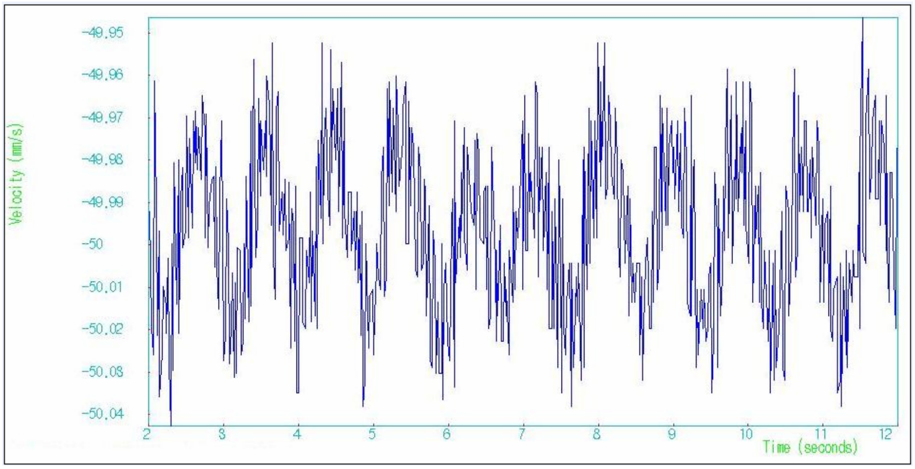



(b)

**Figure 10.** Flatness of (a) $X$- axis, (b) $Y$- axis.

Figure 11 shows the velocity ripple, where $X$-axis velocity ripple is 0.19% and $Y$-axis one is 0.47% at the velocity of 50mm/sec for each direction. Figure 12 shows the in-position stability, where $X$-axis in-position stability is $\pm 69$nm and $Y$-axis one is $\pm 59$nm.

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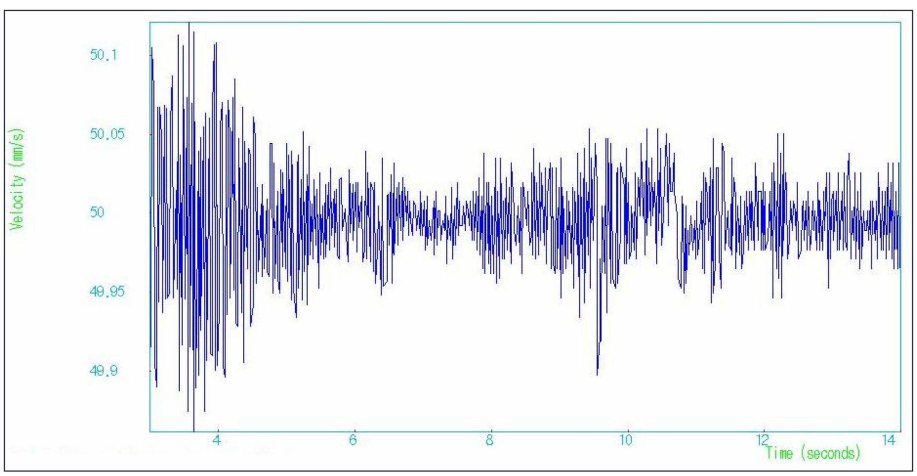
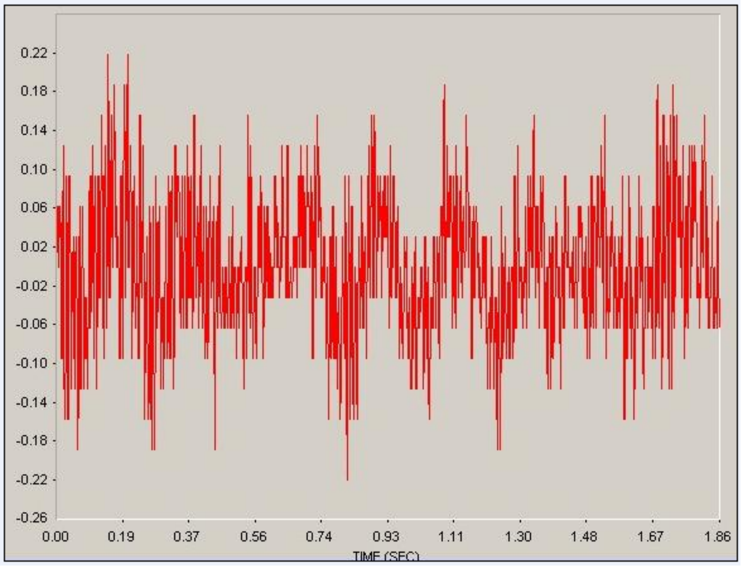



(b)

**Figure 11.** Velocity ripple of (a) $X$-axis, (b) $Y$-axis.

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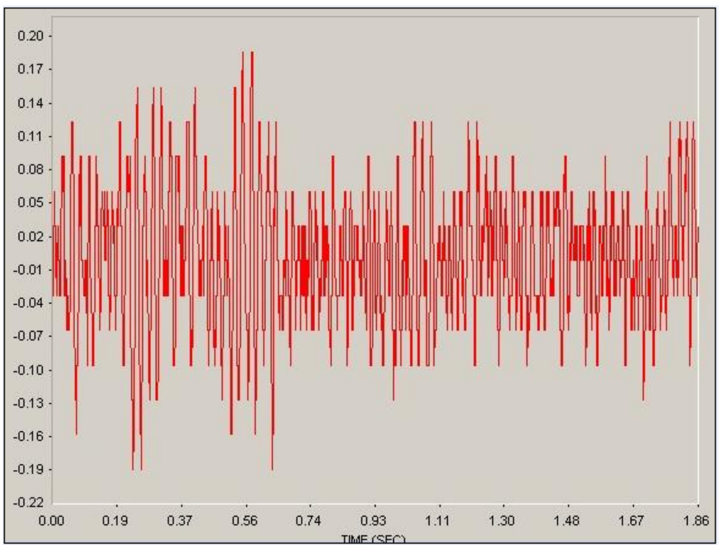



(b)

**Figure 12.** In-position stability of (a) $X$- axis, (b) $Y$- axis.

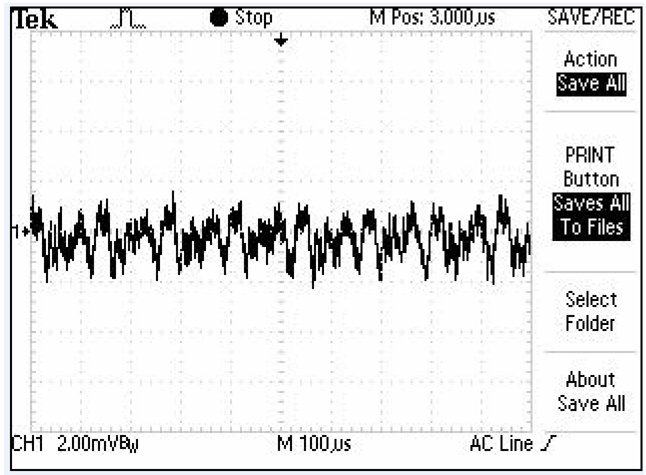
In Figure 12, displacement is measured by linear encoder attached in $X$-$Y$ stage. Table 2 lists the measured specifications of developed $X$-$Y$ stage. Figure 13 shows the reduction of vibration coming from ground at the granite base according to isolation system employment.

**Table 2.** Measured specifications of developed $X$-$Y$ stage

| | |
|---|---|
| Stroke ($mm^2$) | 720 × 920 |
| Repeatability (nm) | < 300 |
| Straightness (μm) | < 5.3 |
| Flatness (μm) | < 4.6 |
| Velocity ripple (%) | 0.47 at 50mm/sec |
| In-position stability (nm) | < 140 |

## 5. Conclusions

In this work, the plane type $X$-$Y$ stage having air bearing guide system is proposed, where each axis using linear motor is mounted on the hollow guide beam, isolation system, and control system are used for performance requirement. The developed high precision $X$-$Y$ stage is verified by the performance test. From the performance test, moving stroke is 720mm for $X$-axis and 920mm for $Y$-axis, repeatability is less than 200nm for $X$-axis and less than 300nm for $Y$-axis, straightness variation is less than 700nm for $X$-axis and less than 300nm for $Y$-axis, flatness is less than 4.6μm for $X$-axis and less than 0.8μm for $Y$-axis, velocity ripple is 0.19% for $X$-axis and 0.47% for $Y$-axis at 50mm/sec at each direction, and in-position stability is ±69nm for $X$- axis and ±59nm for $Y$-axis. From the performance test, developed $X$-$Y$ stage is applicable for the OLED production and inspection equipment.

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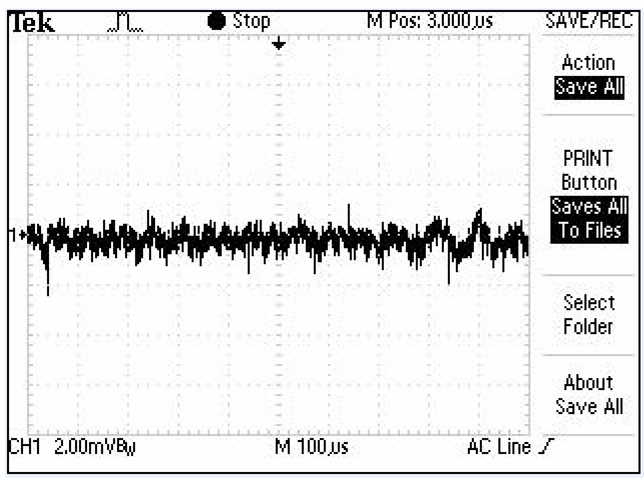


(b)

**Figure 13.** Vibration at the granite base (a) isolation system inactivated, (b) isolation system activated.

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