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# A novel stylus profiler without nonlinearity and parasitic motion for FPD inspection system

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**Abstract**

There are increasing needs to inspect micro-pattern of flat panel display (FPD) device such as PDP and LCD. The inspection system should be able to measure over large size mother glass with high productivity and accuracy. Stylus profilers are adopted as an inspection system. To scan over large and heavy FPD device specimen, a "tip-scanning" head for stylus profiler is required. A simple method to realize a tip-scanning system is to miniaturize the whole scanning unit. In this study, a novel stylus profiler is proposed as a tip-scanning stylus profiler. The novel stylus profiler has leaf spring instead of conventional lever and pivot. To measure position of stylus an optical senor is used. Linear variable differential transformer is applied to feed-back scanning stage displacement. The stage is actuated by a voice coil motor (VCM). Target performances of the stylus profiler head are in the stroke over 20 μm with high accuracy. Specifications of xy-scanning stage are over 250 μm×250 μm and high bandwidth over 20 Hz. The magnetic and elastic characteristics of the mechanism are designed based on finite element (FE) analysis. After fabrication of the head and stage, they are integrated. Current amplifier and feedback controller are also developed. The performance of the stylus profiler is also validated by inspecting standard sample.

*Keywords*: Stylus profiler; Tip scanning; Scanning stage; Leaf spring

## 1. Introduction

The functional performance of stylus profilers is usually compared to that of atomic force microscopes (AFM) as shown in Table 1. [1] The two measurement equipments are widely used in semiconductor and flat panel display (FPD) industry. Especially in FPD industry, the bigger equipment and factory are required because the larger size of mother glass is processed. This caused so severe vibration and noise that complex vibration control and isolation system are needed to apply AFM. The system should be redesigned if the operating condition is changed. The cost of vibration control and isolation system is more than that of the measurement equipment. The lifetime of tip of AFM is also shorter than that of stylus profiler. If we lower the damage to sample and make the resolution high, the stylus profiler can be adopted to FPD industry as measurement equipment.

In this study, we propose a novel stylus profiler and design a scanning stage for the stylus. The stylus and stage can measure and investigate FPD with low damage, high speed and required resolution. For the high resolution, leaf spring stage with nearly no nonlinearity and parasitic motion is designed. Parasitic motion can also cause damage on the sample.

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Table 1. Stylus profiler vs. AFM.

| | Stylus Profiler | AFM |
|---|---|---|
| Resolution | Several nm | Several Å |
| Robustness to environment | Sensitive | Highly sensitive |
| Damage to sample. | A little | Little |
| Force to sample | $10^{-1} \sim 10^{-4}$ N | $10^{-7} \sim 10^{-8}$ N |
| Working Range | <1mm | <10um |
| Lifetime of Tip (Continuous operation) | 1~20 month | 1~30 day |

## 2. Conventional stylus profiler

A conventional stylus profiler head adopts the pivot & lever mechanism, sample stage and capacitive sensor as presented in Fig. 1 [2]. This mechanism causes friction and nonlinearity. The friction is inherent in pivot. It makes the sample damaged because the friction force is delivered to the surface. The circular motion of tip arise the nonlinearity while ideal one is translational. If the sample surface is wide like mother glass in FPD industry, the sample stage should be larger. The capacitive sensor has also inherently drift property and is sensitive to noise.

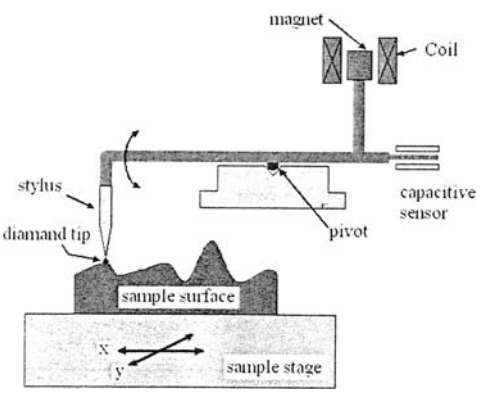



Fig. 1. Conventional stylus profiler.

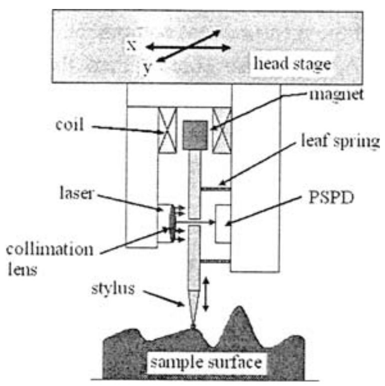



Fig. 2. Schematics of novel stylus profiler.

## 3. Novel stylus profiler

A novel stylus profiler is proposed as depicted in Fig. 2. The system has leaf spring instead of lever & pivot, head stage in place of sample stage, and optical sensor for capacitive one. This sensor has less drift and is more robust to noise compared to capacitive one.

Multi-head stage presented in Fig. 3 can scan over whole mother glass in spite of small sized head stage [3]. If the conventional stylus shown in Fig. 1 is utilized, it is hard to move the mother glass stage over long range of the glass size. Although multi-head stage mechanism is adapted to the conventional stylus, it is also hard to control the mother glass stage with high speed because of its heavy weight and large size. Potential configuration of the novel stylus profilers has many head which can move with high speed and high resolution in small range. All the profilers have "tip-scanning" scheme. A simple method to realize a tip-scanning system is to miniaturize the whole scanning unit.

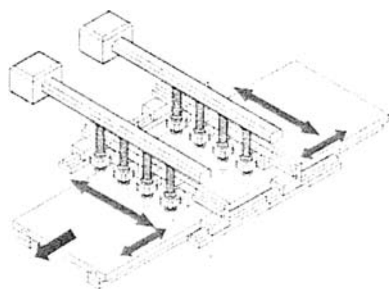


Fig. 3. Schematics of multi-head profiler.

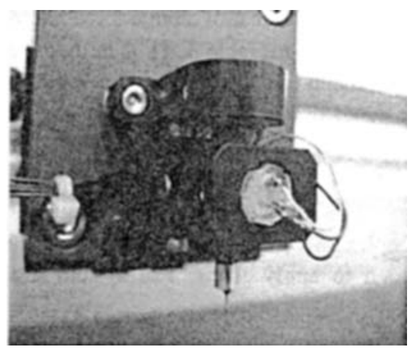


Fig. 4. Fabricated stylus profiler head.

### 3.1 Stylus profiler head

The optical sensor has laser, collimation lens, pinhole and position sensitive photodiode detector (PSPD). If the stylus moves, the pinhole position is varied and consequently laser spot position on PSPD is changed. The position change of spot is detected by the PSPD as shown in Fig. 2. Working range of the stylus head is 20 μm and measurement resolution is about 100 nm.

### 3.2 Scanning stage

#### 3.2.1 Double compound linear spring mechanism

Double compound linear spring structure has no nonlinearity, no parasitic motion & no friction. It has small mass. Dashed line displays deformed spring by actuating force according to the direction of arrow. Symmetric structure has many advantages such as robustness against environmental change and manufacturing error. Therefore, we adopt 8 spring mechanisms as a guide mechanism of tip scanning stage as shown in Fig. 5.

Target specifications of scanning stage are listed in Table 2. They are for investigating colour filter of liquid crystal display (LCD). After colour filter process, there should not be protrusion defect over height of 2.0 μm and diameter of 10 μm. One pixel of LCD is about 100 μm×100 μm. From this information, the specifications of scanning stage are determined as Table 3.

The first candidate of guide and spring mechanism of xy-scanning stage is flexure hinge. The length of each spring should be lower than 25 mm because of size limitation of head stage. Width between 2 hinges should be also smaller than 40 mm. It is designed that the radius of notch is 1.0 mm, length of the spring is 24 mm and thickness of the whole stage is 5 mm. Then the working range requirement is satisfied from actuating force of voice coil motor (VCM) that will be mentioned in the following section. But the thickness of notch is 0.1 mm which needs expensive wire electro-discharge machining. After finite element analysis, the static deformation and vibration mode shape for the flexure hinge are presented in Figs. 6 and 7.

The second candidate of guide and spring mechanism of xy-scanning stage is leaf spring. Design constraints on the size are the same as the flexure hinge. It is designed that thickness of leaf spring is 0.6 mm, length of the spring is 21 mm and thickness of the whole stage is 5 mm. Then the working range requirement is satisfied from actuating force of the VCM. After finite element analysis, static deformation and vibration mode shape for the leaf spring mechanism are presented in Figs. 8 and 9.

Table 2. Target specifications of scanning stage.

| | Target | Unit |
|---|---|---|
| Working range of scanning stage | 250×250 | $\mu m^2$ |
| Bandwidth of scanning stage | 20 | Hz |
| Resolution of scanning stage | 100 | nm |

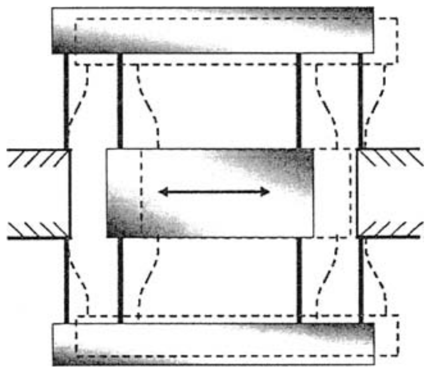


Fig. 5. Double compound linear spring.

Using the second candidate, we fabricated two double compound liner spring mechanisms for x- and y-motion, respectively The leaf spring is made of stainless steel, SUS304 because of its high Young's modulus. If the spring constant of the linear spring mechanism is high, system bandwidth of scanning stage is also high.

#### 3.2.2 Voice coil motor as an actuator

Actuator of the scanning stage is voice coil motor (VCM). It has magnet, yoke and coil winding as depicted in Fig. 10. If the coil windings are energized by current, magnetic actuating force is generated by Lorenz's principle. In this study VCM has specifications listed in Table 3 [4].

#### 3.2.3 Fabrication of scanning stage

Using the designed above, we fabricate and assemble the scanning stage presented as described in Figs. 11, 12, and 13. Except leaf springs, other body is made of Al6061 for easy machining. The leaf springs are carefully machined for its dimensional accuracy.

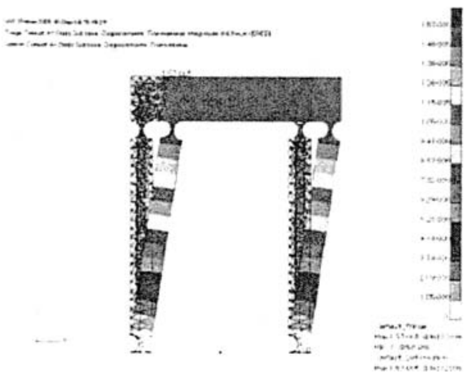


Fig. 6. Deformation of flexure hinge.

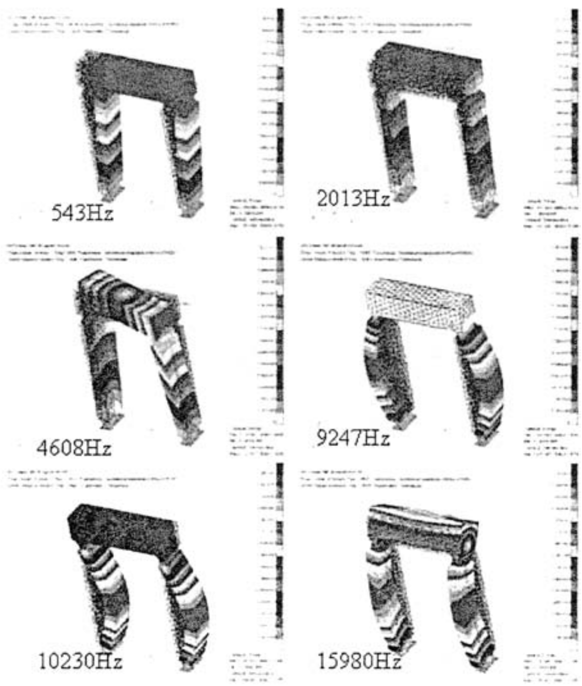



Fig. 7. Vibration mode of flexure hinge.

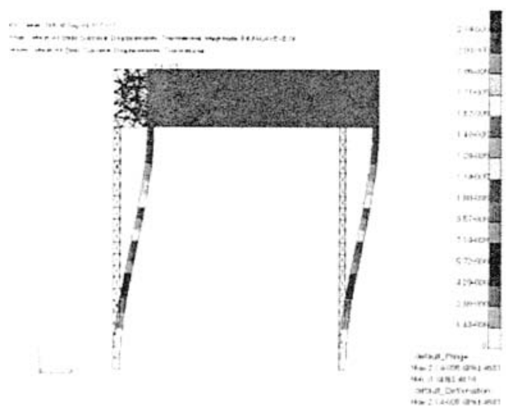


Fig. 8. Deformation of leaf spring.

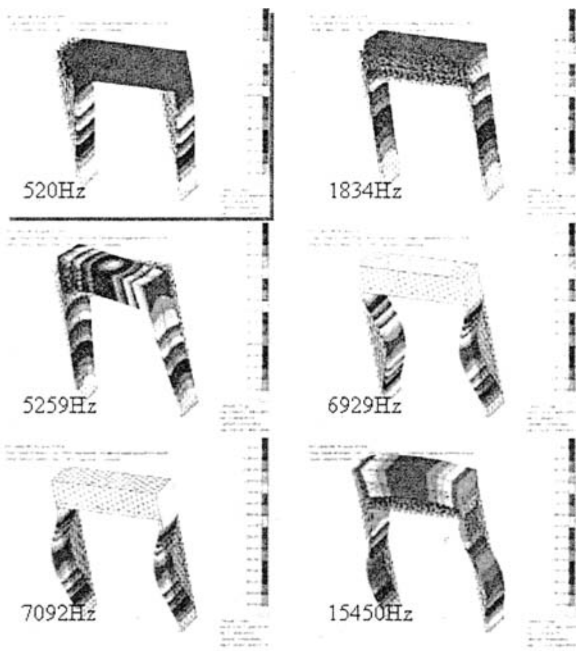



Fig. 9. Vibration mode of leaf spring.

Table 3. Specifications of voice coil motor.

| | Spec. | Unit |
|---|---|---|
| Magnetic flux density in air gap | 0.679 | T |
| Maximum actuating force | 13.1 | N |
| Number of coil turns | 600 | turns |
| Resistance of coil | 18.2 | Ω |
| Inductance of coil | 26.3 | mH |
| Force constant | 9.91 | N/A |

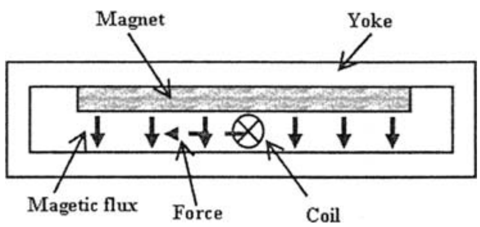



Fig. 10. Voice coil motor.

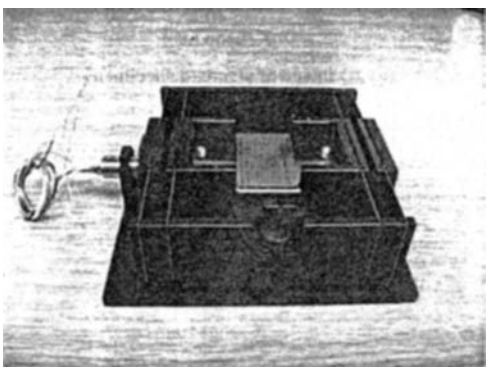


Fig. 11. Assembly for x-motion.

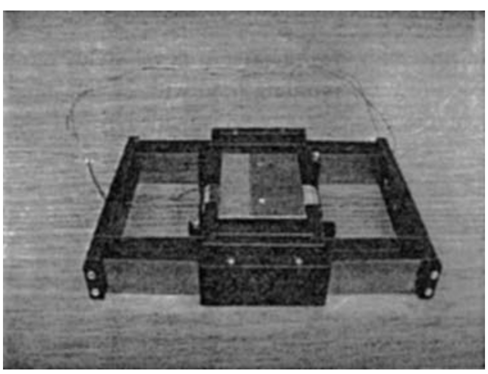


Fig. 12. Assembly for y-motion.

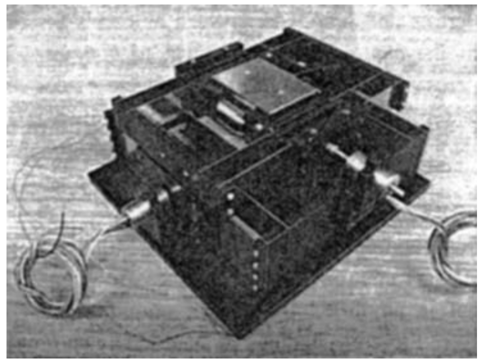


Fig. 13. Fabricated scanning stage with LVDT.

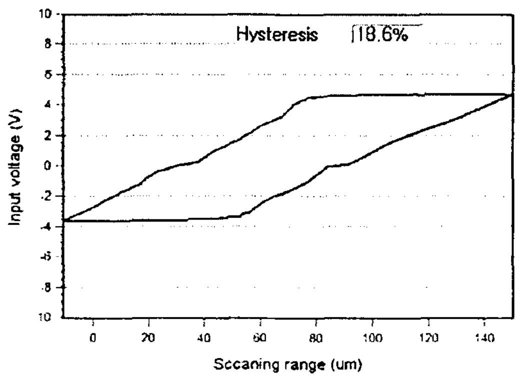



Fig. 14. Hysteresis of stage by deviation.

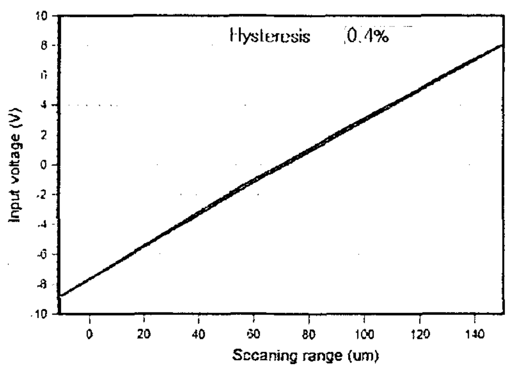



Fig. 15. Improved hysteresis of stage.

All the springs are assembled with position pins not to transgress dimensional tolerance. The two stages are also connected with position pins.

Precision motion of the stage is measured and feed-backed by a linear variable differential transformer (LVDT) because of its low cost. The LVDT plays a role of non-contact position senor. Its core is mounted on the stage and its coil module is fixed on ground. There are many sources that make the sensor have hysteresis and non-linearity such as core's deviation from the center line and contact to coil unit. The hysteresis is presented in Fig. 14. It can be corrected by assembling core with high care as shown in Fig. 15. Non-linearity of the stage is under 1.0 %.

### *3.2.4 Controller and amplifier*

Host computer commands DSP (digital signal processor) controller to generate control signal. The signal is amplified by current amplifier and then delivered to coil windings in stages. The current and magnet moves the stylus head and stage against the spring force of leaf spring. The motion of stylus and stage are feed-backed to DSP controller via low noise signal conditioner. The control block diagram is depicted in Fig. 16. Amplifier for VCM and LVDT is fabricated as shown in Fig. 17.

For voltage input of 4~14 V, moving rage of xy-stage is 250 μm. Resonant frequency of the stage is 23.0 Hz. System bandwidth is generally higher than the resonant frequency, therefore, requirement of bandwidth is satisfied.

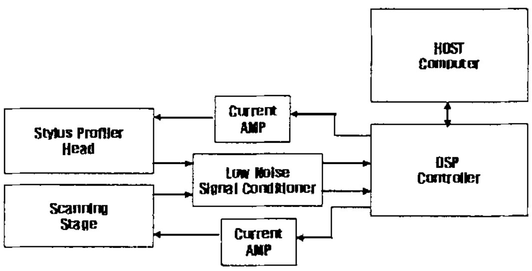



Fig. 16. Block diagram of control system.

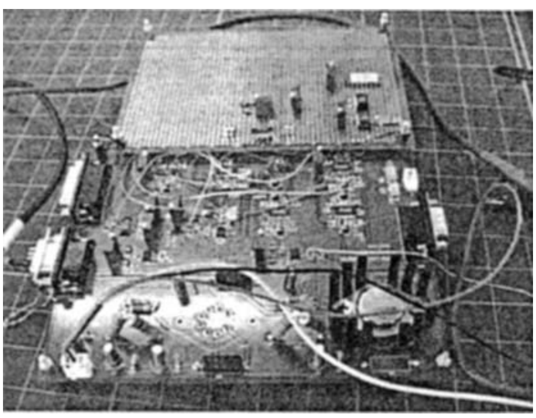
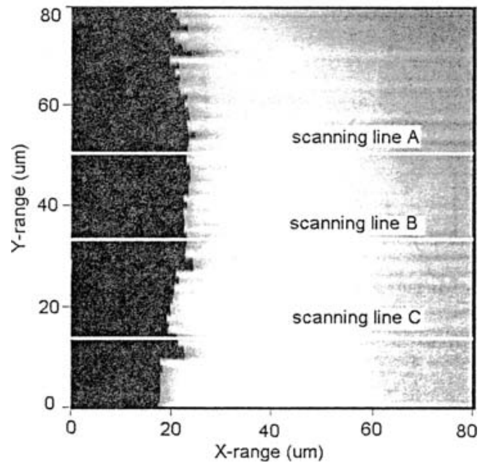


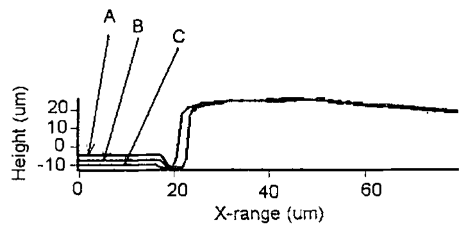
Fig. 17. Fabricated amplifier for VCM and LVDT.

## 4. Experimnets and results

In order to evaluate proposed stylus profiler, we scanned a standard specimen with 20 μm step. Results are presented in Fig. 18. The 2D image is deviated from the straight line, however, measured step height is almost the same. The deviation is due to drift characteristics of LVDT sensor, therefore, compensation is required.




(a) 2D image of standard specimen




(b) Profile of standard specimen for scanning lines

Fig. 18. Scanning results of proposed profiler.

## 5. Conclusions

In this study, we propose a novel stylus profiler. The profiler has profiling head with 20 μm range in height direction. The motion is guided by leaf spring. This can suppress parasitic motion from pivot and lever mechanism. The head also has optical sensor instead of capacitive sensor which has inevitably drift problem.

Tip scanning stage is designed and fabricated. The stage has voice coil motors as actuator and double compound linear spring mechanisms as guide. The VCM and guide also designed to satisfy requirements. Its performance ranges are 250 μm×250 μm and bandwidth over 20 Hz. Non-linearity and hysteresis of the motion were negligible.

Fabricated novel stylus profiler can measure standard specimen with satisfiable accuracy, however, there is drift problem of scanning stage. Its imperfection can be compensated by future work.

The proposed stylus profiler can be applied to multi-head inspection equipments for FPD.

## Aknowledgement

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