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A novel laser micro/nano-machining system for FPD process

Kihyun Kim [a], *Young-Man Choi* [a], *Dea-Gab Gweon* [a], *Moon G. Lee* [b,*]

[a] *Department of Mechanical Engineering, KAIST, Republic of Korea*
[b] *Division of Mechanical Engineering, Ajou University, San 5, Woncheon-Dong, Yeongton-Gu, Suwon-City, Gyeonggi-Do 305-701, Republic of Korea*

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ABSTRACT

Laser machining technology has potential to be adopted as micro- and nano-fabrication equipments in the field of flat panel display (FPD) industry. The equipments repair short, open or protrusion defects by cutting and welding using high-power laser. The equipments should be able to carry large sized mother glass and have high productivity and accuracy. To meet the requirements, the equipment should travel long range with higher speed and higher precision than the conventional. In this paper, a high precision decoupled dual-stage is proposed to transfer and position FPD mother glass. The dual-stage system consists of coarse stage actuated by linear motor and fine stage by moving magnet type voice coil motor. The control and design of the two stages are required to be considered independently if possible in order to take advantage of modular approach. In order to suppress disturbance from the coarse to fine stage, they are designed without mechanical connections. Dual-servo tracking controller is applied by adding fine controller to conventional coarse controller. Reaction force between fine and coarse stages is compensated by a force compensator (FC) because it is detrimental to positioning and scanning. By simulation and experiment, the performance of dual-stage is evaluated and compared.

1. Introduction

Laser machining technology has potential to be applied to FPD industry. The equipments repair short, open or protrusion defects by cutting and welding by laser, which are found after display inspection in FPD process. In order to repair micro- and nano-pattern for FPD device such as plasma display panel (PDP) and liquid crystal display (LCD) as shown in Fig. 1, the equipments should be able to carry large sized mother glass and have high productivity and accuracy. To meet the requirements of next generation FPD process, the equipment should travel long range with higher speed and precision than the conventional.

Dual-servo *XY* stages are generally used to satisfy the requirements of equipments. The stage consists of coarse and fine stages. The coarse stage moves the fine stage and laser head to long distance with high speed. The fine stage rejects the disturbance with wide bandwidth and high resolution. Linear motor is introduced as a coarse actuator and voice coil motor (VCM) as a fine actuator. Using the laser machining, the protrusion defect in color filter of LCD can be repaired. The size of defects is 10–30 μm in diameter and 5–10 μm in height.

The conventional dual-stages researched up to now has two stages connected in series, for example, a ball-screw drive or a linear motor (LM) and a PZT-driven flexure stage (Lee and Kim, 1997; Elfizy et al., 2005; Guo et al., 1998). In other words, the stages have been mechanically coupled with flexure structure. The performance of a coarse stage is generally limited by system vibration, thermal deformation, guide imperfection, mass, and frictions. These disturbances of a coarse stage

* *Corresponding author*. Tel.: +82 31 219 2338; fax: +82 31 213 7108.
E-mail addresses: khkim12@kaist.ac.kr (K. Kim), moongulee@ajou.ac.kr (M.G. Lee).
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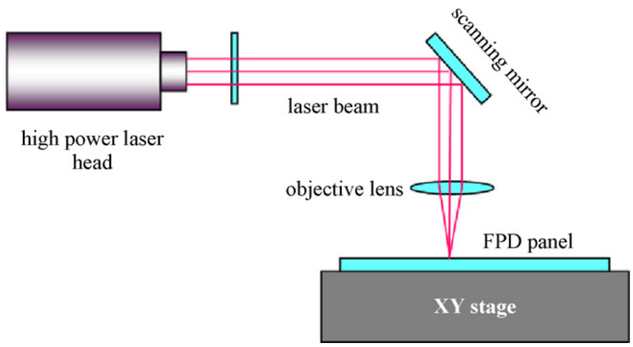

Fig. 1 – Working principle of a laser repair.

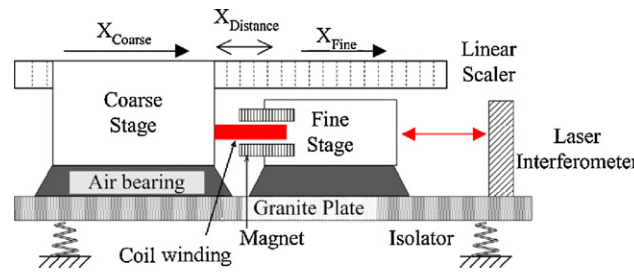

Fig. 2 – Concept of dual-stage.

are directly delivered to a fine stage through the mechanical connections. In order to compensate these disturbances, the controller of fine stage should be complex.

These methods are not requiring the modular approach because design and control of two stages are inextricably interconnected inevitably. Especially, field engineers want to update their conventional single-servo LM stage toward dual-stage with appending fine stage. In the case, the modular approach of design and control is essential.

In this paper, we propose and design a new type of dual-stage: a mechanically decoupled-type dual-stage (MDDS). A linear motor (LM) and a moving magnet voice coil motor (MMVCM) are used as actuators for the stage of MDDS. The design and control of the two stages are carried out as independently as possible. Minimization of reaction force between the fine and coarse stages is achieved by no mechanical connections between the stages. Both stages are guided and suspended, respectively, by air bearings which float on a granite surface for frictionless movement.

By adding fine controller to conventional coarse controller, dual-servo tracking controller is realized for the modular approach philosophy. This paper applies a dual-servo algorithm. Despite the modular design, reaction force between fine and coarse stages is generated by magnetic coupling, which is detrimental to positioning and scanning even resulting in collision between the stages. Therefore, we propose a simple but effective force compensator (FC) that compensates the reaction force.

2. Design of mechanically decoupled dual-stage

2.1. *Dual-stage configuration*

As shown in Fig. 2, the proposed dual-stage is made up of a coarse stage which is actuated by LM and guided by air-bearing and a fine stage which is actuated by MMVCM and also guided by air-bearing. In general, LM has velocity ripples due to commutation mismatch between current and magnetic flux. VCM has smooth motions without velocity ripples because it does not need any commutations. It has longer working range than PZT actuator. Guide systems with guide bar, granite surface and air bearing are capable of sustaining a high load and make the dual-stage be frictionless. There is magnetic coupling but no mechanical connection through the VCM because the coil windings are mounted on coarse stage and magnets attached to fine stage. The magnets are moving freely over the windings by Lorentz force. Due to the mechanically decoupled mechanism, the transferred disturbance from the coarse stage to the fine stage can be more minimized than the mechanism which has mechanical coupling. As position sensors of the coarse and fine stages, a linear scale and a laser interferometer are used, respectively.

In order to design, maintain, and update equipment, modular design approach is recommended. The system in Fig. 3 has two module, coarse stage with LM and fine stage with MMVCM. This modular approach is essential in workshop, to field engineer and for safety of the workpiece. The coarse and fine stages can work independently with their separate controller and position sensor. If one of them is broken, the other should work in workshop. The two stages can be fabricated and tested independently, which save lead time.

The LM of the coarse stage is an actuator for its hundreds of mm stroke. It consists of a stator (magnet) and a mover (coil winding). The stator is fixed on the guide bar of coarse stage. Therefore, *x*-motions of the coarse stage are decided by the displacements of the mover. And each VCM consists of coil windings which are attached to coarse stage and magnets on the fine stage. The fine stage is guided by air-bearing on granite surface, and actuated by four VCMs (x_1, x_2, y_1, and y_2,), respectively. Each VCM consists of a coil winding, four rare-earth magnets (Star Group, Ni coated N-40, Hc = 923 kA/m and Br = 1.25 T), and two yokes made of permeable material, S10C.

Generally, moving coil type VCM are used in many industry fields: an optical disk drive, a hard disk drive, a linear motor, etc. Heat generation from the coil results in thermal deformation. On the contrary, a moving magnet type VCM

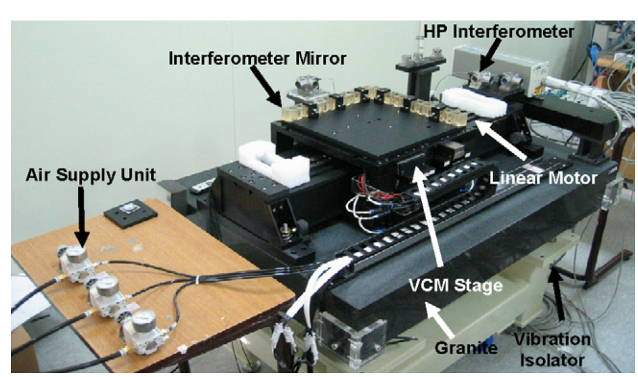

Fig. 3 – Fabricated mechanically decoupled dual-stage.