LASER SENSING AND NEW STATOR DESIGNS FOR A LINEAR SLIDER

Hideki Kawakatsu, Hannes Bleuler, Takashi Saito, Takahisa. Yahiro, Michihito. Watanabe
Institute of Industrial Science, University of Tokyo, Tokyo, Japan
Roland Siegwart
Swiss Federal Institute of Technology, Zurich, Switzerland

ABSTRACT
This paper introduces the use of laser beams for guiding a linear slider along the track with magnetic levitation. The paper will focus on the optical and magnetic design, control, and possible applications. Three parallel laser beams are positioned along the stator to define a plane along which the slider should be guided. The beams are reflected from the slider by three corner cubes, whose lateral displacements are then detected by three four-segment photodiodes situated on the stator side. The configuration allows the slider to be free of electrical components and possible source of contaminant. Introduction of digital control allows increased flexibility. For example, by feedback of the position of the slider along the track, it becomes possible to guide the slider along a designated plane or a curved surface. The system is applicable to sample transport in ultrahigh vacuum and clean rooms.

INTRODUCTION
Magnetic suspension has the potential of providing wear and contaminant free sample handling and/or transportation. It has already been applied to areas where ultrahigh vacuum or cleanliness is needed[1]. For rotational designs, with some exceptions[2], gap sensors are commonly used for feedback control of the magnetic bearing. This does not cause major problems, since the sensors could be situated on the stator side. However, in the case of linear magnetic suspension, detection of the suspension gap becomes an issue that decides the basic configuration of the system. For example, if the slider carries the gap sensors, the slider will either have to: (i) carry active electromagnets and its power source or obtain power without contact from the stator side or; (ii) send the measured gap sensor signals to the stator side by some wireless technique for control of the active stator magnets. On the other hand, if the sensors are situated on the stator side, the system is likely to require; (iii) many probe type gap sensors; and , (iv) calibration and wiring of the gap sensors. If the slider is required to satisfy a given accuracy of linear guidance, a plane-reference satisfying the requirements will have to be incorporated to serve as the gap sensor target, or as the reference for calibration. Commercially available linear magnetic suspension systems for clean rooms have adopted such configurations as; (i) gap sensor, active magnets, and batteries on the slider[3]. Some incorporate zero power control for prolonged battery life[4], (ii) gap sensor and active magnets on the stator side, which are enclosed in a metal tube to keep contaminants within the stator side[5], (iii) gap sensor and active magnets on the slider, with contactless energy transportation from the stator side by electrical induction[6].

We have introduced the use of laser beams for detecting the position of the slider[7]. Since the method requires only a few optical parts to be attached to the slider, the system is expected to be used in clean rooms and ultrahigh vacuum. The system also allows accurate linear guidance in the submicrometer range without high demand for machining accuracy of the mechanical components. The paper will focus on the optical design, some magnetic designs, the control system and possible applications. Detection technique of the lateral movement of the laser beam can be found in publications on atomic force microscopy[8]. Existing technique of using light to detect the position of a suspended object can be found in another publication[9].

EXPERIMENTAL

Design of the laser sensing system
We have adopted a laser sensing system that uses three parallel beams, corner cubes and four segment photodiodes. Other optical designs are also possible. Different

optical designs and their comparison can be found in another publication[7].

Figure 1 depicts the optical design used for the experiments. A laser beam from a laser diode is split into three parallel beams by beam splitters and a right angle prism. Each beam enters corner cubes attached to the slider. The beams reflected from the corner cubes enter four segment photodiodes on the stator side. Since corner cubes return beams parallel to the incident beam, the laser beams will stay on the detectable range of the photodiode even in the case of large yaw or pitching of the slider. The requirement for precision of parallelism of the laser beams and their parallelism to the stator is in the order of 0.5 mm per meter. However, the requirement becomes lower by the use of digital control, which enables easy compensation of tilt of the laser beam(s) from parallelism. It is possible to calibrate the slider at two ends of the guiding track, and interpolate to redefine a plane of guidance. The sensor system had a resolution of 0.1μm, and measured fluctuation of the gap value was 0.3 μm p-p for a stationary slider, regardless of the stator design. Trueness of linear guidance was not yet measured. It is expected that non-parallelism of the laser beams could be compensated by sensing the position of the slider along the track, which can be done also by an optical approach. Compensation of error becomes more difficult if the amount of error from an ideal plane of guidance is not linear to the position of the slider. Such error are expected to rise from bad collimation of the laser beams or broadening of the beam waist. We will need to incorporate a high sensitivity laser interferometry system to check the validity of compensating for the above mentioned non-linear effects with control.

Design of the magnetic circuit

Three types of stator design were used with the optical sensing system. All had active stator coils. Figure 2 depicts the three types. Figure 2 (a) depicts a type with stator 'tooth' with a coil wound on each tooth. The slider core had a length long enough to cover three pitch of the stator tooth, enabling control of pitch and yaw. Photo interrupters situated along the stator were used to detect the position of the slider along the track, whose signals were used to switch energizing currents to the appropriate coils.

Figure 2 (b) depicts a design which consists of a long 'U' shaped stator, with energizing coil at the end. By such a configuration, it is possible to eliminate electrical components along the guiding track of the system. For example, by placing the coils on one side of a vacuum chamber flange, the chamber need only contain the magnetic cores and three corner cubes. As expected, the design showed bad efficiency, since the magnetic circuit short circuits itself along the long U-shaped stator core. Attractive

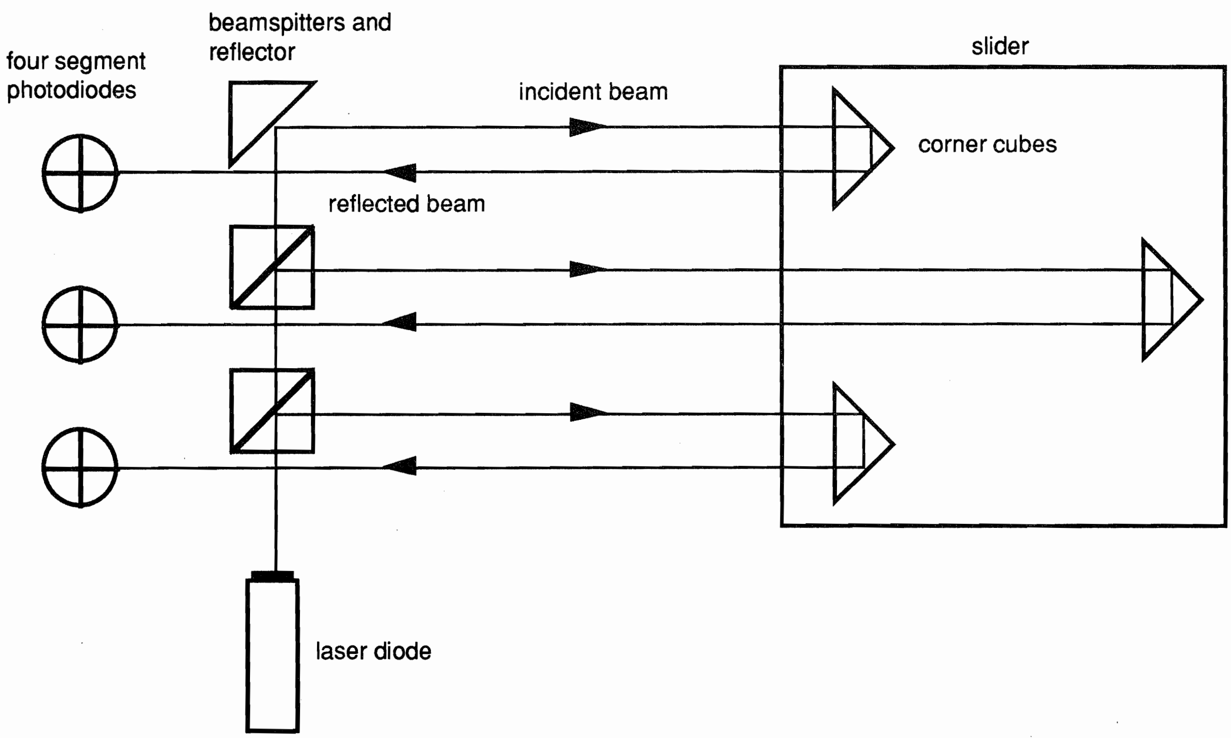

FIGURE 1. Schematic of the laser sensing system for detecting the position and attitude of the linear slider.

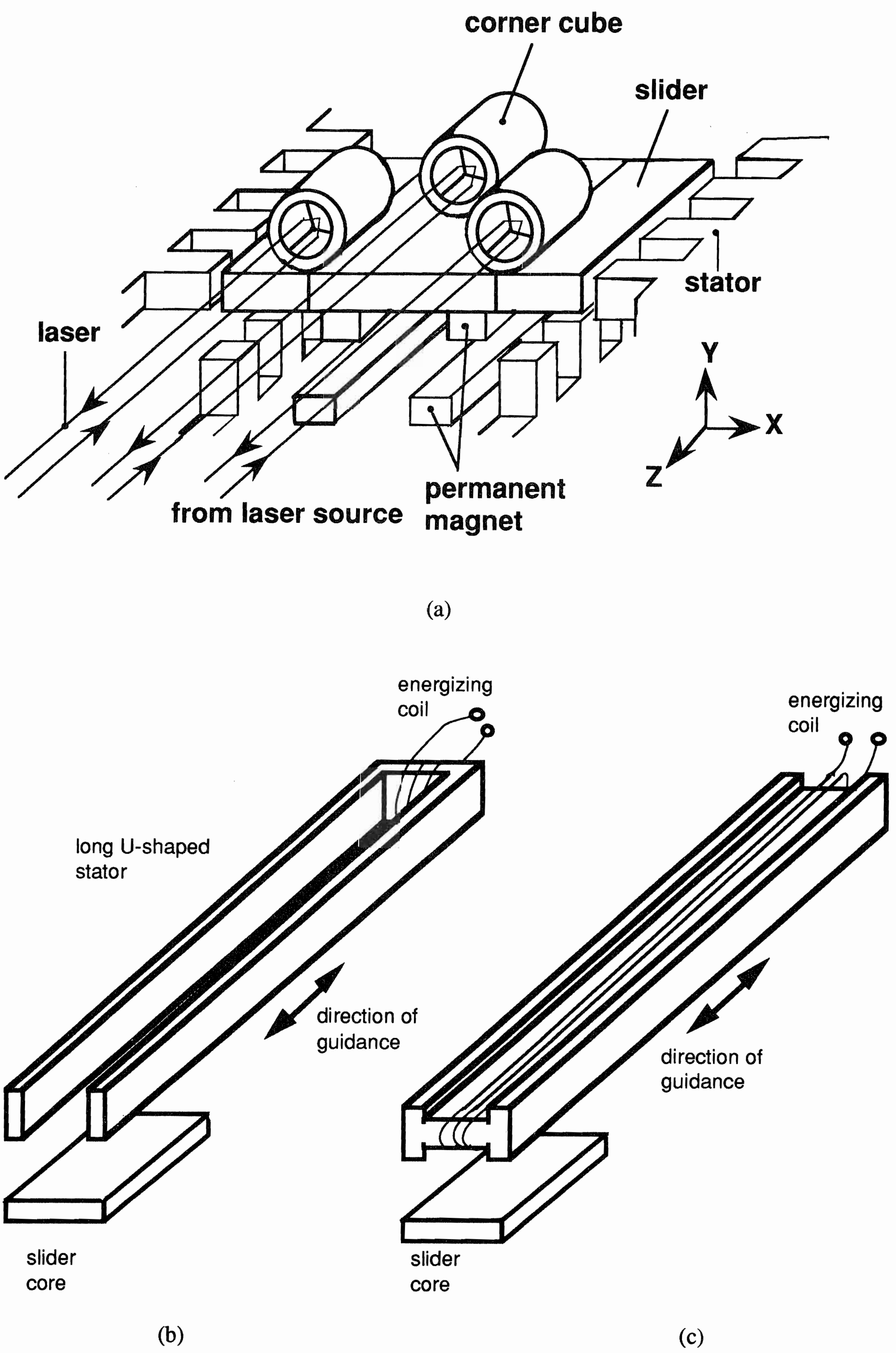

FIGURE 2.(a) Schematic of the magnetic core design with toothed pole stators and coils wound on each tooth. (b) magnetic core design with long U-shaped stators. The design has no electrical component along the guiding track of the slider. (c) magnetic core design with long stator coils. It is best suited for high accuracy suspension and guidance. Figures (b) and (c) are simplified to one degree of freedom.

force between the stator and the slider core decreased rapidly as the slider moved away from the coils. Experiments showed that using energizing coils with a large diameter, around ten times the perimeter of the stator core was effective in achieving increase of force at points further away from the coils. No analytical study on the magnetic design has yet been carried out. Stable suspension of a 1 kg slider was achieved 200 mm from the coils. Accuracy of suspension was also in the 0.1 μm order. Movable span of around 800 mm seems possible by the use of coils with larger diameters.

Figure 2 (c) depicts a design with long energizing coils along the stator. The attractive force between the slider and the stator should in principle be independent of the position of the slider along the track. The design allows high accuracy of linear guidance, since there is no cogging due to commutation of the slider from one stator tooth to the other. Accuracy of linear guidance is expected to be close to the 0.1 μm suspension accuracy. One problem of the stator design is the relative high resistance of the stator coils. Due to the relatively long copper wiring used in the coils, for example, 150 turns for a 1 m track becomes 300 meters of wiring per coil, relatively large amount of ohmic loss needs to be considered at the designing stage. Suspension control was simple to implement since there was no commutation between the stator coils.

Control methods

Both analog and digital control were used in the experiments. For analog control, proportional-differential (PD) control was executed with operational amplifiers, where feedback parameters and offset adjustments were done by adjusting potentiometers or mechanical screws. Commutation of the slider from one stator pole to the other was implemented by using C-MOS analog switches, which reconnected the flow of the analog signals as the slider moved along the stator. Stable commutation was observed. However, to make the most of the simplicity and accuracy of the laser sensing system, adoption of digital control was strongly needed.

A digital signal processor was used for implementing digital control. At the moment, we have achieved stable suspension of the sliders with PD control. Adjustments prior to suspension were performed with ease due to software setting of the offset and the parameters. At the moment, we are developing software which compensates for slight non parallelism of the laser beams and the stator to achieve truer linear guidance. As for the control of the U-shaped stator type, changing the feed back parameters according to the position of the slider along the track seems effective in compensating for the change of attractive force along the stator.

CONCLUSION

An optical sensing system was introduced to detect five or six degrees of freedom of a linear slider. The design requires only a few optical components and three four-segment photodiodes, and is in principle very clean, or ultrahigh vacuum compatible. Three types of stator design were discussed and experimented. The toothed pole stator type, showed maximum efficiency since only the energizing coils around the slider are activated. The configuration has such problems as: (i) use of many coils; (ii) slight fluctuation of suspension gap during commutation; and, (iii) necessity to detect the position of the slider along the guiding track. The long U-shaped stator design allows maximum compatibility to very clean environment and extremely high vacuum, since the energizing coils can be situated outside the vacuum chamber. Use of large diameter energizing coils were found to be effective in increasing attractive force when the slider is further away from the coils. The third design with long energizing coils does not have commutation problems and requires only a small number of coils. The design is the best choice for making most of the high accuracy of the laser sensing system. Some drawbacks are the relatively high ohmic loss due to the long wiring of the coils. We will work on high precision linear slider systems and also on conveyor systems which allows a number of sliders to move on a single track.

ACKNOWLEDGMENTS

Hideki Kawakatsu thanks Tatsuo Komori and Atsushi Horikoshi of Nippon Seiko Co. LTD for the analog control circuitry, Yasunori Ueki of Epson Co. LTD for the permanent magnets used in the toothed stator type, and Hirochika Ueyama of Koyo Seiko Co. LTD for making the long-coil type stator. This research was partially supported by the Foundation for Promotion of Advanced Automation Technology (PAAT).

REFERENCES

1. J. K. Fremery, J. Vac. Sci. Technol., A3, 1715, (1985).
2. D. Visher and H. Bleuler, in Proc. of the Second International symposium on Magnetic Bearings, Tokyo, Japan, (1990).
3. for example, Daifuku Co. LTD.
4. for example, Toshiba Co. LTD.
5. for example, SEIKO SEIKI Co. LTD.
6. for example, Daifuku Co. LTD.
7. H. Kawakatsu and M. Kawai, in Proc. of the Third Int. Symp. on Magnetic Bearings, Virginia, USA, 360, (1992).
8. G. Meyer and N. Amer, Appl. Phys. Lett., 53, 1045, (1988).
9. R.L.Hollis, A.P. Allan, and S. Salcudean, in Proc. of the Fourth Int. Symp. on Robotics Research, Santa Cruz, Ca., USA, (1987).