Pushing The Precision Level of Mechanical Alignment System Into The Nano Meter Region

Neville K. S. Lee, Z. Q. Li
Dept. of IEEM, Hong Kong University of Science and Technology
Clear Water Bay, Kowloon, Hong Kong

Abstract  With the advance of MEMS and NEMS technology, assembly of micro device may some day become important. The quality of the assembled micro device would depend on the accuracy of the alignment process. Optical Alignment System (OSA) for semiconductor industry has very high level of precision. But the system is too expensive, and the size of the marker is too big for practical application in the area of micro assembly. On the other hand, the alignment resolution of typical vision type of optical alignment system, limited by the wavelength of the light, is difficult to push too much beyond the um range. Therefore it is the objective of this presentation to discuss the finding of our investigation for an alternative low cost method that can operate in the tens of Nano Meter (nm) Range, and have the potential extending further into nm range.

Mechanical alignment system (MAS) is widely used in industry because of its simplicity, low cost and easy to use. However, there is a fairly common notion in the industry that MAS is relatively crude, and is not suitable for precision manufacturing. To certain extend, there are some reasons leading to that kind of erroneous conclusion. Some of the MAS used in the industry may indeed perform rather poorly with resolution merely in the tens of micron meter (um). The level of precision of MAS depends strongly on the design of the MAS and the operating condition of the MAS.

One of the difficulties in the understanding of the level of precision achievable in MAS is due to the lack of a multi-dimensional position monitoring device with high enough resolution. In this paper, we will discuss the development and the performance characteristics of a new multi-dimensional positioning monitoring system with resolution better than 10nm. Using this multi-dimensional ultra-high resolution positioning monitoring system, the performance of two different types of MAS commonly used in industry has been studied. For our preliminary study, only alignment of macroscopic parts has been studied due to their availability. But in fact, smaller system should perform better. Even with our present macroscopic system, performance level at 60-70nm has already been demonstrated.

In the presentation, we will discuss the key design issues and key operation factors that can significantly affect the accuracy of the MAS as well as some of the detail of our investigation.

Key Word:  Precision Alignment System, Mechanical Alignment System, Ultra-Precision Multi-dimensional Position Monitoring System.

1. INTRODUCTION
Manufacturing precision is important since it affects the product quality and production yield. With global competitions, manufacturers are increasingly facing the challenge of producing high precision products while keeping the production costs low. Therefore, precision manufacturing can no longer be an expensive, luxury item. In fact, low cost manufacturing processes are a fundamental requirement for participating in design and manufacturing hi-tech products.

Assembly processes in contemporary manufacturing have the workpiece assembled together and subject to certain inspection activities to assure the quality of the final product. Therefore, how good the assembly task is performed in assembly process is one of the important factors that will greatly affect the assembly quality. Considerable research effort has been done in the past to deal with the problem. Xie et al.[1] have proposed to determine the reasonable alignment position before the real starting of the whole assembly work by using robot’s functions and measurement on a small amount of practical run with the assembly line and then teach the right alignment position to the robot. Derby [2] developed an end-effector that dramatically improved the accuracy and repeatability of the robot to which it was attached.
Slocum and Weber [3] developed a passive mechanical wafer alignment technique that is based on the principle of elastic averaging and uses mating pyramid and groove elements to passively align wafers to each other as they are stacked. By their approach, an alignment accuracy of 0.47µm was observed for kinematic couplings. Lee et al. [5-7] investigated the effect of how a datum is secured in a mechanical alignment system with the aid of a high-resolution multidimensional optical position monitoring system, an alignment accuracy of 0.246µm was achieved for fixed cylindrical datum system by their approach. They also studied the performance of different MAS in terms of assembly accuracy in the presence of the form error, surface waviness and surface roughness of the references surface, and analysed the effect of imperfections of the workpiece on the manufacturing precision.

In manufacturing industry, there was some common belief that the low cast mechanical alignment method, in which the mechanical datum are used to align the reference surfaces of the workpiece for each setup, is cheap but not precise. In this respect, the aim of this study is to understand the ultimate level of the performance of a well-performing assembly with mechanical alignment system. Furthermore, the factors that adversely affect precision, and the means to counteract these effects, have been investigated.

2. CAPACITIVE MEASUREMENT SYSTEM

The shape of a capacitive sensor used in our test is the rectangular with area of $3.18 \times 8\, mm^2$. To reduce the noise and improve the stability of the sensor, the area of sensor is surrounding by a guard-rectangle which is separated from the sensor by a narrow gap and grounded. In this way the noise will be virtually eliminated and the ideal situation may be approached very closely [8].

To identify the relationship between output voltage $V_o$ and the resolution of the system, the sensor with an area of $3.18 \times 8\, mm^2$ is tested. The experiment condition as follow:
1. Signal: square wave, $V_s = 10.75V$, frequency $f = 40\, KHz$
2. Noise of the system: $\Delta V_{noise} = \pm 0.1mV$
3. Observed resolution of the meter: $\Delta V_o = 0.1mV$

For a small space between sensor and workpiece, the sensitivity and the resolution of the system may be defined as

$$sensitivity = \frac{dV_o}{dD}, \quad res = \frac{\Delta V_o}{sensitivity} \quad (2.1)$$

Figure 1(a) shows the measured relationship of output voltage and the space between the sensor and workpiece. At a gap of $\delta = 0.05\, mm$, which was used to measure the position of workpiece in our test, a quite high resolution of $7.16\, nm$ will be achieved (Fig. 1(b)).

3. EXPERIMENTAL SET UP

The experiment setup for measuring displacement in $x$ direction is shown in Fig. 1(c). The idea for this situation is that, after calibration of the system, the workpiece can be removed and then restored to the same position for each test. In this respect, two kinds of mechanical alignment datums are designed for repeatability experiment.

1. Three steel balls with diameter of 8mm were embedded into the platform and formed a three semi-ball datum system. These three semi-balls act as a reference and are used to located the $L$ shape workpiece with two crossed V-grooves as shown in Fig. 1(d). A screw locates at the centroid of the triangle formed by the three semi-balls and is used to exert a contact force between the balls and the grooves.
2. In this procedure, three stainless dowel pins with diameter of 12mm were fixed on the platform by pressing them into the bored holes whose diameters were slight smaller than that of the pins. The $L$ shape workpiece is located on the platform via a 3-2-1 scheme of cylindrical datum system formed by the pins as shown in Fig. 1(e). Two screws are used to fasten the workpiece to prevent any displacement after it is alignment.
A sensor frame is mounted on a $xyz$ stage and can be moved freely in $x$ direction to calibrate the system. Three sensors $s_1$, $s_2$ and $s_3$ with an area of $3.18 \times 8 \text{mm}^2$ are located on the frame (Fig. 1(c)).

4. EXPERIMENTAL RESULTS
A series of repeatability experiments for two datum systems were conducted at room temperature (23°C). Our study shows that, for a good design, the high alignment precision can be achieved by a low cost mechanical alignment system. The average errors for cylindrical datum and three-ball kinematic coupling are 143nm and 67nm, respectively.

The three-ball kinematic coupling datum system exhibits a better alignment accuracy than that of the cylindrical datum system. The mechanism for this difference is not fully understood since many factors, such as surface roughness of the workpiece and datum, the elastic indentation, magnitude of the holding force, etc. will affect the precision of the alignment. It also implies that what kind datum is chosen in mechanical alignment system is a significant factor contributing to the accuracy of workpiece alignment in MAS.

7. CONCLUSION
Statistical experiment and data analysis have been performed to study the alignment precision of the mechanical alignment system with two alignment setups. The following major conclusions could be drawn on the displacement of workpiece under different alignment conditions:
1. A real-time multidimensional capacitive position monitoring system (CPMS) with a high resolution up to 7.16nm has been developed as the tool for characterizing the alignment precision.
2. Our data shows that the high alignment precision can be achieved by a low cost mechanical alignment system. The average errors for cylindrical datum and three-ball kinematic coupling are 143nm and 67nm, respectively.
3. The three-ball kinematic coupling datum system exhibits a better alignment accuracy than that of the cylindrical datum system. The results suggest that what kind datum is chosen in mechanical alignment system is indeed a significant factor contributing to the accuracy of workpiece alignment in MAS.

Acknowledgement
This work has been supported by an RGC Grant from the Government of the HKSAR (Project No. HKUST 6224/01E).

Reference
Fig. 1. (a) The relationship of output voltage and the gap; (b) The variation of resolution of system at different gaps; (c) Experiment setup; (d) Three-balls datum system; (e) cylindrical datum system.