Direct Drive Pick and Place System with Reduced Moving Mass

FIELD OF THE INVENTION

The present invention relates to a pick and place system that is used for picking and placement of micro devices, such as semiconductor IC packages or optical devices. Ideally, such a pick and place system would be generic and flexible to enable it to be used in different applications or on different micro devices. Hence, programmability of the system without the need for hardware modifications or set up for picking different micro devices is a desirable feature. Moreover, an integrated vacuum suction system should also be included in the system to enable picking and placement of different micro devices with a vacuum suction pad.

DISCUSSION OF PRIOR ART

Pick and Place Systems are used extensively in automation applications all over the world. Many different types of pick and place systems have been designed, with most of them being designed for very specific applications. The basic function of a pick and place system is to pick a part from one position and accurately place it onto another position. The most common pick and place application would involve a vertical motion axis (Z motion) which is carried by another X axis or/and Y axis as in a XY stage. In applications which involve picking and placement of micro devices, there is also an increasing need for a rotary motion (Theta rotation). The Z motion is required to pick up a part and place down the part at another position. The Theta motion is required to rotate the part into the correct orientation. The accuracy of placement can range from millimeters to a few microns. Such a pick and place operation may also sometimes involve other processes, such as bonding after placement. An example of a pick and place application is the picking a semiconductor die from a wafer and placing it onto a substrate followed by bonding of the die onto the substrate. Another example would be in Surface Mount Machines (SMT) where components are picked and placed onto PCBs at high speed. With so many different types of devices, it is the object of this invention to have a flexible pick and place system which provides Z motion and Theta rotation, and at the same time include an integrated vacuum system for

suction and placement of parts. The system is also designed for high performance, low moving mass, compact size, high placement accuracy and good dynamic response.

U.S. Patent No. 6,364,387 B1 issued to Bolotin discloses a pick and place system that uses an air cylinder with a piston which is actuated through electrical pneumatic valves to provide an up down motion for the pick and place probe. This system is limited to two fixed position control - an upward position and a downward position. As there is no closed loop feedback, it is also not possible to control the motion smoothly or have various stopping positions. When the pick and place unit needs to be used for devices with different heights, some form of mechanical adjustment or set up will be necessary. This means down time when changing product devices. In addition, the pick and place unit does not cater for orientation adjustment. There is no rotary axis on this unit.

U.S. Patent No. 5,422,554 issued to Rohde discloses a pick and place unit which uses a lead screw coupled to a stepper motor to provide a Z axis movement. While the stepper motor operates as an open loop actuator, a load cell is provided which senses the force applied, thereby giving feedback to the controller. With a stepper motor, this actuator will be limited in dynamic response and high speeds and accelerations will not be feasible. This system also does not provide theta correction for orientation of parts.

U.S. Patent No. 5,953,812 issued to Ferrante discloses a pick and place system with a Z servo axis carrying a theta axis. The theta axis shaft is driven by a belt system connected to a servomotor offset from the rotary axis. The entire mass of the theta axis has to be carried up and down when the nozzle head has to be moved. This limits the dynamics of the system as the moving mass includes the entire rotary actuator and the attached mechanism. With the theta axis not driven directly, there will also be backlash, resulting in poor accuracy. The head is also constructed with a vacuum chamber and the fit between the nozzle and the bushing forms a seal to define the vacuum chamber. This requires precise machining of the parts to provide tight tolerances and good fit, therefore the cost of manufacturing will not be trivial.

U.S. Patent No. 5,315,189 and 5,446,323 issued to Neff discloses an actuator comprising translation and rotational control. The system uses a linear voice coil actuator to provide linear force. A voice coil actuator is basically a single phase motor with one winding, ending with 2 wires. When the coil is being placed in a magnetic field produced by permanent magnets, a force is produced when current flows through the coil. By reversing the direction of the current, an opposite force is produced. Position feedback is provided by an LVDT or a linear optical encoder. Rotational torque is provided by a rotary motor connected through a linkage, either a belt/pulley mechanism, a gear system, or with a stator mounted around the grip/rod. The linkages introduce additional inertia and friction to the rotary motion and also decrease the accuracy with the introduction of backlash which is inherent in gears and pulleys. Moreover, in all the configurations, the entire motor mass and the mass of the mechanism has to be carried up and down every time the actuator probe is moved up and down. This limits the dynamic performance of the system.

U.S. Patent No. 5,789,830 issued to Portegies discloses an in-line rotational drive mechanism which provides both translation and rotary motion. The system also uses a linear voice coil actuator to provide linear force. Instead of mounting the motor at a distance offset from the actuator probe, and having linkages to transfer rotational torque from the motor shaft to the actuator probe, the rotary motor is mounted in coaxial alignment with the actuator probe. This minimizes uneven lateral forces on the actuator probe which cause it to wobble. However, with this design, a flexible coupling is needed to connect the motor shaft to the actuator probe. The flexible coupling is needed to accommodate misalignments in the two shafts. Such a coupling reduces the stiffness of the system, thereby reducing the dynamic performance. This will be apparent in applications where very high angular accelerations are required, such as those involving very small angular movements but in a very short time, and involving a tight position tolerance or error margin when motion is complete. Any flexibility or low stiffness in the rotary shaft can cause vibrations and the shaft will take a longer time to settle down at the end of motion. In this design, the entire motor mass also has to be carried by the linear axis, moving up and down every time the actuator probe picks and places a part. The mass of the moving piston, the rotary motor and the mechanism is significantly larger than the mass of the part to be picked and place. Moreover, with this in line design where the motor and the

actuator probe are mounted coaxially, in order to provide for a vacuum to the actuator probe, a fluid chamber needs to be provided. This fluid chamber is disclosed in U.S. Patent No. 5,685,214 issued to Neff. A cylindrical sleeve formed with a plurality of ports and air tight seals formed by O ring seals are required to enable the vacuum in the hollow rod to flow from the vacuum ports connected to the vacuum source. The seals introduce friction to the motion and this may vary over time due to the wear and tear of the seals, affecting the control performance of the system. With the wear and tear, the seals will deteriorate over time and needs to be replaced, especially when such pick and place systems are designed for very high usage, typically thousands of cycles per day or millions of cycles over a few years.

SUMMARY OF INVENTION

A direct drive flexible pick and place system provides Z motion and Theta rotation, and at the same time includes an integrated vacuum system for suction and placement of parts using a three phase ironless brushless linear motor providing a linear force and a three phase brushless rotary motor providing rotary motion, with the stator coil of the motor being fixed to the housing and the rotor being built directly into the actuator shaft.

The invention thus has high performance, low moving mass, compact size, high placement accuracy and good dynamic response.

A first object of the direct drive pick and place system is a system comprising

a brushless rotary motor;
a brushless linear motor;
a pick and place probe;
a vacuum means;
a rotor; and
a stator

wherein the brushless linear motor and brushless rotary motor provides a linear motion and a rotational motion respectively, said brushless linear motor and brushless rotary motor being integrated with a pick and place probe, said probe moving along a vertical

axis from the stator while the rotor rotates the pick and place probe on its own axis.

Preferably, the rotor has arc magnets on it, said arc magnets designed according to the requirements of the maximum linear stroke with the relationship:

Maximum linear stroke = Rm – Rc

Where
Rm is the length of the arc magnet
Rc is the length of the stator

Preferably the linear motor coil length and magnet track length must also fulfill the relationship:

Lm – Lc > Rm – Rc (maximum linear stroke)

Where
Lm is the length of the linear motor magnet track,
Lc is the length of the linear motor coil

Preferably the brushless linear motor and brushless rotary motor use analog hall sensors, which are integrated in the brushless linear motor and brushless rotary motor to tap on the sinusoidal magnetic flux density signals which are inherently produced by the alternating poles of magnets for position feedback, thereby eliminating the need for external feedback devices such as linear encoders or rotary encoders.

Preferably the pick and place probe consisting of a hollow shaft with a vacuum means and a suction cup to pick up objects and to place objects.

Preferably the vacuum means consisting of a vacuum supply near one end of the hollow shaft, a through hole within hollow shaft for vacuum to flow and a suction cup at the other end of the hollow shaft to pick up objects and to place objects.

Preferably the vacuum means is operable so when vacuum supply is withdrawn from the through hole in the hollow shaft, said suction cup picks an object and when vacuum supply is sent through the through hole, said suction cup releases the picked object .

Preferably the brushless linear motor; brushless rotary motor and stator are enclosed in a housing.

Preferably the stator consisting of coil, coil back iron and stator casing fixedly mounted onto the housing.

Preferably the brushless linear motor; brushless rotary motor, pick and place probe, rotor are controlled by a motion controller which moves the said pick and place system to pick up objects and place said objects.

Preferably the picking up and placing of objects by the pick and place system is controlled by a motion controller and further operated by programmable software.

A second object of the invention is a direct drive pick and place system wherein the pick and place probe moves from a first position to pick an object, said suction cup place on object, vacuum supply withdrawn from the through hole in the hollow shaft, wherein said suction cup picks the object and pick and place probe moves to a second position, said pick and place probe places object when vacuum supply is sent through the through hole, wherein said suction cup releases the picked object at the second position.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, its advantages, and the objects attained by its use, reference should now be made to the accompanying drawings. The accompanying drawings illustrate one or more embodiments of the invention and together with the description herein, serve to explain the workings and principles of the invention.

Fig. 1 is a cross sectional diagram illustrating an embodiment of the invention with the position of the linear motor coil, moving carriage and shaft at the extreme top position.

Fig. 2 is a cross sectional diagram illustrating an embodiment of the invention with the position of the linear motor coil, moving carriage and shaft at the extreme downward position.

Fig. 3 is a cross section view of the system.

Fig. 4 is an illustration of a pick and place system of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Fig 1 shows the design of this invention. Casing (1) forms the base of this pick and place system where all other components are mounted. By using single solid piece of aluminum as a base, the rigidity, straightness and flatness are greatly improved. An ironless brushless linear motor with moving coil (2) and magnet track (3) is installed to provide linear force. This ironless linear motor has very a short coil but very high force, resulting in a large force/size density ratio, as described in Singapore Patent P-No. 125972, (Leow, Yong Peng et al). The referred patent also describes the unique winding technique and placement of the coils which enables the placement of hall sensors (4a,4b) on the moving coil (2). In this design, analog hall sensors (4a,4b) are placed on the moving coil (2). The alternating poles of the magnets (15) on the stationary magnet track (3) (North-South-North-South and so on) results in a SINCOS magnet flux density signal (sinusoidal in shape) that can be read by the analog hall sensors (4a,4b) and used for position feedback on many commercially available motion controllers, such as ELMO's CEL 5/60 I controller. The controller is able to read these signals and interpolate them into digital pulses. A final linear position resolution of 1 micron can be achieved. The linear motor coil (11) is used to drive a moving carriage (5), which is guided on linear bearings on rail (6). By connecting a hollow shaft (7) to the moving carriage (5) through bearing housings (8a,8d), the hollow shaft (7) will move linearly up and down together with the moving carriage (5). The hollow shaft (7) allows a vacuum suction cup (14) to be fixed to the bottom end and vacuum supply from the top end of the hollow shaft (7), thereby acting as an actuator pick and place probe (24). With arc magnets

(15) attached to the hollow shaft (7), the hollow shaft (7) also acts as the rotor (28) of a brushless rotary motor (20), with the stator (30) being built into the base. This stator (30) is fixed and does not move up and down with the rotor (28). It may already be observed that Fig 1 shows the position of the linear motor coil (11), moving carriage (5) and hollow shaft (7) at the extreme top position whereas Fig 2 shows the position of the linear motor coil (11), moving carriage (5) and hollow shaft (7) at the extreme downward position. Fig 3 shows a cross section view of the system, clearly revealing the coil (11) and coil back iron (12) of the stator (30) of the brushless rotary motor (20). By switching the relevant phase on the coil (11) through the motion controller, the hollow shaft (7) will rotate accordingly, being guided by the bearings (13a,13b) which are mounted on bearing housings (8a,8b) respectively. Analog hall sensors (4a,4b) are also installed in the stator (30) to detect the SINCOS signal produced by the alternating poles of magnets (15). With this signal, a rotary resolution of 0.02 degrees can be achieved after interpolation in the electronics. By translating and rotating the hollow shaft (7), a pick and place operation involving vertical placement and orientation can be achieved accurately.

Referring to Fig 3, the arc magnets (15) are designed to be longer than the stator (30) to enable the brushless rotary motor (20) to work properly throughout the complete linear range of the system, from the top most position to the extreme downward position. In fact, the length of the magnets (15) can be determined by the desired maximum stroke of the pick and place system with the following relationship:

Maximum linear stroke = Rm – Rc

Where
Rm is the length of the arc magnet (15),
Rc is the length of coil 11 of the stator (30)

Moreover, the linear motor coil (11) length and magnet track (3) length must also fulfill the relationship:

Lm – Lc > Rm – Rc (maximum linear stroke)

Where
Lm is the length of the linear motor magnet track (3),

Lc is the length of the linear motor coil (11)

A person skilled in the art would observe that the actual working length of the coil (11) of the brushless rotary motor (20) would actually be Rec rather than be Rc, where Rec is the effective working length of the coil (11). This is the portion of the coil (11) which will generate a torque on the hollow shaft (7) as the coil (11) is energized. Hence, theoretically the arc magnets (15) need not extend beyond the coil (11) length Rec. However, it has been observed that the end portions of the coil (11) outside Rec will cause small linear forces in the vertical direction, even though the coil back iron (12) does not extend to these end portions of the coil (11). These small linear forces can interfere with the linear force produced by the linear motor coil (11). By having the arc magnets (15) extending its length to cover coil (11) completely (Rc), we are able to eliminate completely any resultant linear force coming from the brushless rotary motor (20).

Unlike conventional designs where pulleys, gears or flexible couplings are used to transmit forces and torques from the actuator to the moving load, this system uses direct drive without any mechanical transmission device. This not only simplifies the design by using less parts but also results in a more rigid system, thereby giving better dynamic performance. Vibrations at the settling positions are also significantly reduced or eliminated, especially when performing high acceleration and deceleration motions.

Fig. 4 is an illustration of a pick and place system of the invention.

Since the invention uses lesser number of moving parts partly by design and because of the use of direct drive, the pick and place system of the invention is less prone to frequent breakdowns and results also in lower maintenance costs.

Unlike U.S. Patent No. 5,789,830 issued to Portegies where the entire rotary axis motor is carried up and down, the arrangement of the inventive system enables only translation of the rotor (28) part of the rotary motor. The stator (30) which comprises the coil (11), coil back iron (12) and stator casing are all fixed. It has been found that in a typical brushless rotary motor (20), the stator (30) constitutes 65-80 percent of the total mass of the entire motor, whereas the rotor (28) constitutes the remainder. This is

due to the relatively high density of copper in the coils (11) and the steel coil back iron (12) that forms the stator (30) of a motor. Copper has a density of 8.9 g/mm3 and steel has a density of 7.8 g/cm3. By fixing the stator (30) and moving only the rotor (28), the invention is able to achieve a lower moving mass. This inventive arrangement improves the dynamics of the system and allows higher acceleration with the same amount of force.

By using a design where a brushless linear motor (22) and a brushless rotary motor (20) are integrated, the invention is able to use analog hall sensors (4a,4b) to tap on the sinusoidal magnetic flux density signals which are inherently produced by the alternating poles of magnets (15), both on the linear motor and the rotor (28) of the rotary motor for position feedback. This eliminates the need for costly linear optical encoders where glass scales are typically etched used to produce similar sinusoidal signals. The rotary feedback through analog hall sensors (4a,4b) is also preferred over rotary encoders as commercially available rotary encoders are not very compact and/or do not allow a hollow shaft to go through them.

By using a brushless linear motor (22) instead of a linear voice coil actuator to generate linear force for the vertical motion, it allows the stroke to be scaleable just by increasing the length of the linear motor magnet track (3). In a voice coil actuator, when the stroke needs to be increased, the size of the actuator has to grow in all 3 directions to correspond to the increase in stroke in order to maintain similar force. In a brushless linear motor (22), only the length of the magnet track (3) needs to be increased, in proportion to the stroke required, while at the same time maintaining the same amount of force it can produce. This allows for flexibility in design and the stroke is completely scaleable.

Moreover, unlike conventional systems where seals have to be used to prevent vacuum leakage in vacuum chambers or the vacuum flow system, this feature of using a hollow shaft (7) which has a through hole for vacuum to flow in the hollow shaft (7) eliminates the use of seals. This use of the hollow shaft (7) also eliminates friction caused by the seals which are again susceptible to wear and tear. Standard off-the-shelf hollow shafts (7) can be used, thereby reducing costs of the system. Without the need for seals and complicated vacuum chambers or vacuum

flow paths or systems, the reliability of the invention is greatly enhanced. Maintenance costs and downtime are also reduced.

OTHER EMBODIMENTS

The pick and place probe (24) is essentially any hollow shaft (7) with vacuum means (26). Since the pick and place system has reduced moving mass, it is used for picking and placement of micro devices, such as semiconductor IC packages or optical devices, other similar with similar elongate and hollow devices besides a hollow shaft (7) can be substituted e.g. hollow cylinder, hollow pole or hollow rod.

It is envisaged that similar devices could be used for the same purposes as intended with or without modifications for the invention to work in such a scenario.

Having described preferred embodiments of the invention with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention as defined in the claims.

ADVANTAGEOUS EFFECTS OF THE INVENTION

The invention uses less moving parts and is a more rigid system, thereby giving better dynamic performance. Vibrations are also significantly reduced or eliminated, especially when performing high acceleration and deceleration motions.

This would also result in lesser frequency of breakdowns with associated downtime costs. Use of less parts and lesser number of moving parts and seals results in reduced moving mass. Overall, this translates into lower annual maintenance costs.

Claims:

1. A direct drive pick and place system with reduced mass and having both translation and rotary motion, the pick and place system comprising

a brushless rotary motor (20);
a brushless linear motor (22);
a pick and place probe (24);
a vacuum means (26);
a rotor (28); and
a stator (30)

wherein the brushless linear motor (22) and brushless rotary motor (20) provides a linear motion and a rotational motion respectively, said brushless linear motor (22) and brushless rotary motor (20) being integrated with a pick and place probe (24), said pick and place probe (24) moving along a vertical axis from the stator (30) while the rotor (28) rotates the pick and place probe (24) on its own axis.

2. The rotor (28) of a pick and place system as claimed in Claim 1 wherein the rotor (28) has arc magnets (15) on it, said arc magnets (15) designed according to the requirements of the maximum linear stroke with the relationship:

Maximum linear stroke = Rm – Rc

Where
Rm is the length of the arc magnet (15)
Rc is the length of the stator (30)

3. A brushless linear motor (22) for a pick and place system as claimed in Claim 1, wherein the linear motor coil length and magnet track length must also fulfill the relationship:

Lm – Lc > Rm – Rc (maximum linear stroke)

Where
Lm is the length of the linear motor magnet track (3),
Lc is the length of the linear motor coil (11)

4. The brushless linear motor (22) and brushless rotary motor (20) of a pick and place system as claimed in Claim 1 wherein the brushless linear motor (22) and brushless rotary motor (20) use analog hall sensors (4a,4b), which are integrated in the brushless linear motor (22) and brushless rotary motor (20) to tap on the sinusoidal magnetic flux density signals which are inherently produced by the alternating poles of magnets (15) for position feedback, thereby eliminating the need for external feedback devices such as linear encoders or rotary encoders.

5. A pick and place probe (24) as claimed in Claim 1, the pick and place probe (24) consisting of a hollow shaft (7) with a vacuum means (26) and a suction cup (14) to pick up objects and to place objects.

6. A vacuum means (26) as claimed in Claim 1, said vacuum means (26) consisting of a vacuum supply near one end of the hollow shaft (7), a through hole within said hollow shaft (7) for vacuum to flow and a suction cup (14) at the other end of the hollow shaft (7) to pick up objects and to place objects.

7. A vacuum means (26) as claimed in Claim 1, said vacuum means (26) operable so when vacuum supply is withdrawn from the through hole in the hollow shaft (7), said suction cup (14) picks an object and when vacuum supply is sent through the through hole, said suction cup (14) releases the picked object .

8. A direct drive pick and place system as claimed in Claim 1, wherein said brushless linear motor (22); brushless rotary motor (20) and stator (30) are enclosed in a housing.

9. A direct drive pick and place system as claimed in Claim 1, wherein said stator (30) consisting of coil (11), coil back iron (12) and stator casing are fixedly mounted onto the housing.

10. A direct drive pick and place system as claimed in Claim 1, wherein the brushless linear motor (22); brushless rotary motor (20), pick and place probe (24), rotor (28) are controlled by a motion controller which moves the said pick and place system from one position to another position, to pick up objects and place said objects.

11. A direct drive pick and place system as claimed in Claim 1, wherein the said picking up and placing of objects by the pick and place system is controlled by a motion controller and further operated by programmable software.

12. A method of picking and placing of objects using a direct drive pick and place system as claimed in any one of the preceding claims wherein

the pick and place probe (24) moves from a first position to pick an object;
said suction cup (14) is placed on object;
vacuum supply withdrawn from the through hole in the hollow shaft (7), so that suction cup (14) picks an object;
pick and place probe (24) moves to a second position, with object;
vacuum supply is sent through the through hole;
suction cup (14) releases the picked object at the second position; and
pick and place probe (24) moves back to the first position to repeat the picking and placing of objects