Large-sized Granite XY Stage

Makoto Takahashi*

1. Introduction

With recent trends toward larger-sized and higher-definition flat-screen televisions, FPD manufacturing equipment is getting larger and more accurate at an accelerated pace. Multifunctionality is also demanded for more intensive functions, along with higher speed for higher productivity.

Given this situation, manufacturing equipment involving positioning devices require large, high-accuracy, multi-spindle, rapid-movement stages. This forces stage manufacturers to meet specifications more difficult to satisfy.

This paper describes how stages have evolved to meet such diversified needs, what some of the problems are with the current manufacturing of large stages, and what some of the issues are in responding to larger substrates, while giving a general explanation of stages.

2. Basic Stage Structure

The basic structure of stages can be roughly divided into the following three types.

Figure 1-2 Appearance of a Gantry Type Stage

All of these types have orthogonal X and Y axes and are generally called XY stages.

① Gantry type (See Figures 1-1 and 1-2)

This type spread around the world ever since the fifth generation as trends toward larger stages began to appear.

This type of stage has a gate-shaped movable axis (Y). Another axis (X) is provided on the gate and it moves in

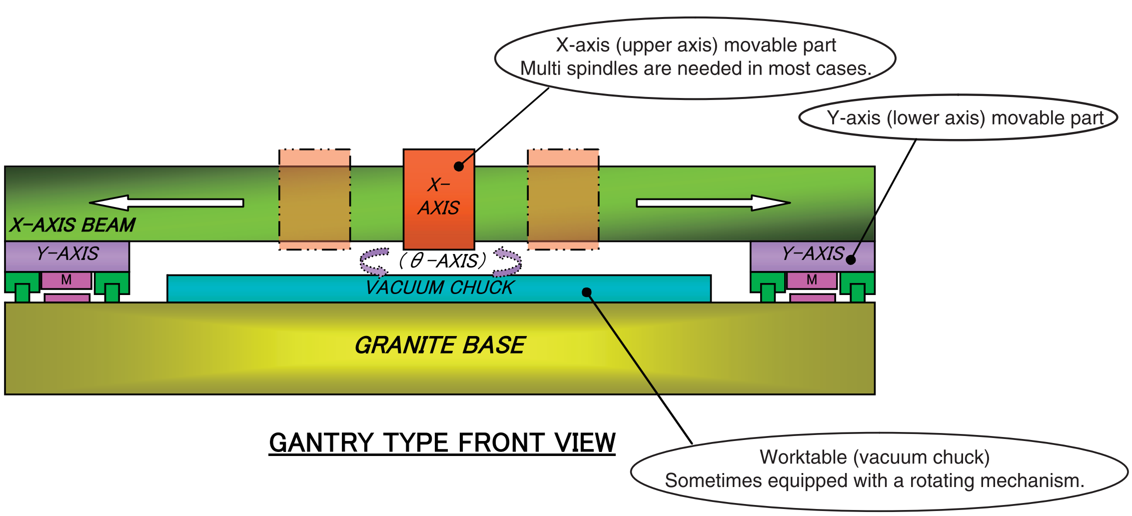

Figure 1-1 Image of the Gantry Type

* Sigma-Technos Co., Ltd.
(URL) http://www.sigma-technos.co.jp/

the direction perpendicular to the direction of the gate's motion.

To respond to many users'need for multi-spindle stages (especially on the X-axis), Sigma-Technos has manufactured gantry stages with up to 14 spindles on the X and Y axes. (The largest number of spindles we have integrated in a stage was 38 on X, Y and other movable axes.)

A stationary worktable is installed on or integrated into a main base made of granite.

Axes are guided by air bearings (static guide) when speed ripple accuracy is required, otherwise metal direct-acting bearings (rolling guide) are used.

Linear motors are generally used to drive the system and they operate by receiving feedback from optical high-resolution linear encoders. (Closed loop)

The gate-shaped movable axis is synchronously controlled using linear encoders attached to both ends. This is considered to be a theoretically optimized method.

This type has been manufactured in larger quantities than the other types over the last few years.

・Equipment for which the gantry type is predominantly used.

Height measuring equipment, XY measuring equipment, laser repair equipment, slit coaters, and more

・Features of the gantry type

This type of stage can be manufactured with minimized dimensions and weight, but these stages are inferior to other types in rigidity and accuracy due to their movable gate structure.

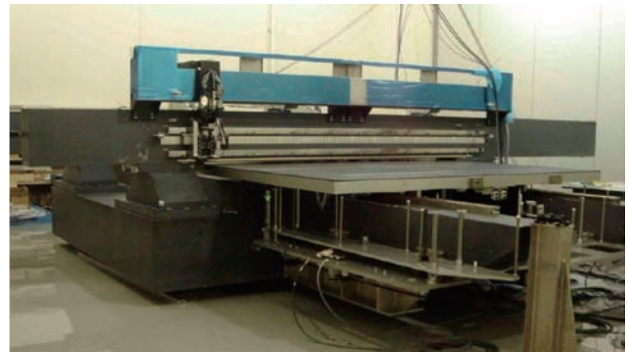

Figure 2-2 Appearance of a Bridge Type Stage

This type can be manufactured at relatively low cost.

② Bridge type (See Figures 2-1 and 2-2)

This type of stage consists of a movable worktable (Y) with a vacuum chuck; a stationary gate mounted on a main base in a direction perpendicular to the movable worktable; and an axis (X) mounted on the gate, which can move in a direction perpendicular to the Y-axis.

The main base must be made thick and strong enough to minimize the influence of disturbances and minimize deformation due to deadweight during movement.

Worktables are mainly provided for dynamic continuous reciprocating movement, and most of them are manufactured with one spindle only, but many users demand multi spindles on the perpendicular X-axis.

Axes are guided by air bearings (static guide) on the Y-axis serving as a worktable in order to improve the speed ripple and to allow for heat generation at bearings

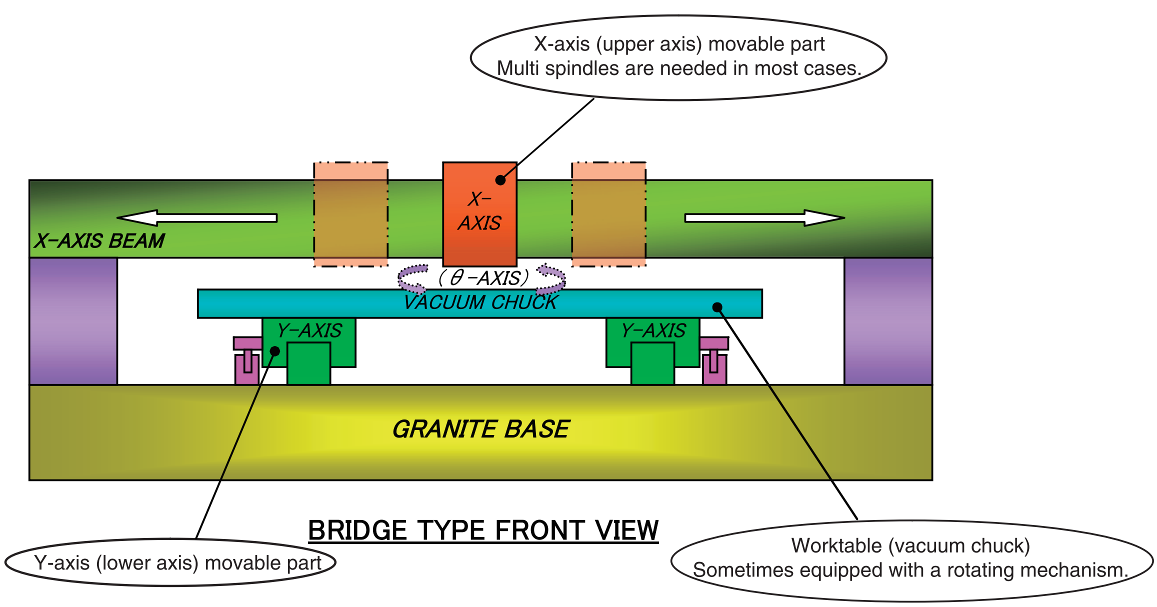

Figure 2-1 Image of the Bridge Type

during continuous reciprocating movement. They are also guided by metal bearings (rolling guide) on the X-axis.

Linear motors are generally used as drive sources and they operate by receiving feedback from optical high-resolution linear encoders.

When high-precision positioning is required, a laser interferometer can be mounted to give feedback for absolute positioning to cancel disturbances.

- **Equipment for which the bridge type is predominantly used.**

Laser processing equipment, ink jet coaters, slit coaters, and more

- **Features of the bridge type**

This type can be manufactured with high rigidity and the highest accuracy, but requires an installation area twice as large as that of a gantry stage. An eighth generation bridge stage has a weight of over 50 tons, flying in the face of space saving. Nonetheless, some applications are only satisfied by this structure and this type is in high demand for equipment that gives top priority to stage accuracy.

③ Table type (See Figures 3-1 and 3-2)

This type of stage consists of a movable worktable (Y) with a vacuum chuck and another axis (X) that can move in a direction perpendicular to the worktable. The axes are stacked or assembled flush with each other. This type has no movable axis above the workpieces.

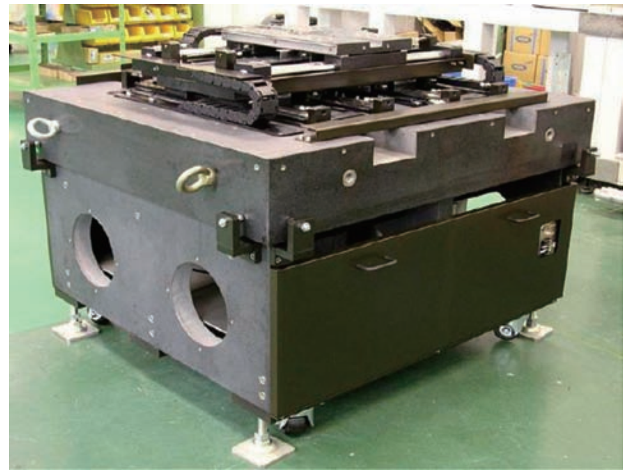

Figure 3-2　Appearance of a Table Type Stage

Stages designed for larger substrates have shapes similar to the stages of the gantry type mentioned above in ①.

In most cases, X and Y axes have one spindle each.

Axes are guided by air bearings when speed ripple accuracy is required, otherwise metal bearings are used.

Linear motors are generally used as drive sources, and they operate by receiving feedback from optical high-resolution linear encoders.

- **Equipment for which the table type is predominantly used.**

Exposure equipment and substrate alignment equipment

- **Features of the table type**

Due to the trend toward larger substrates, this type

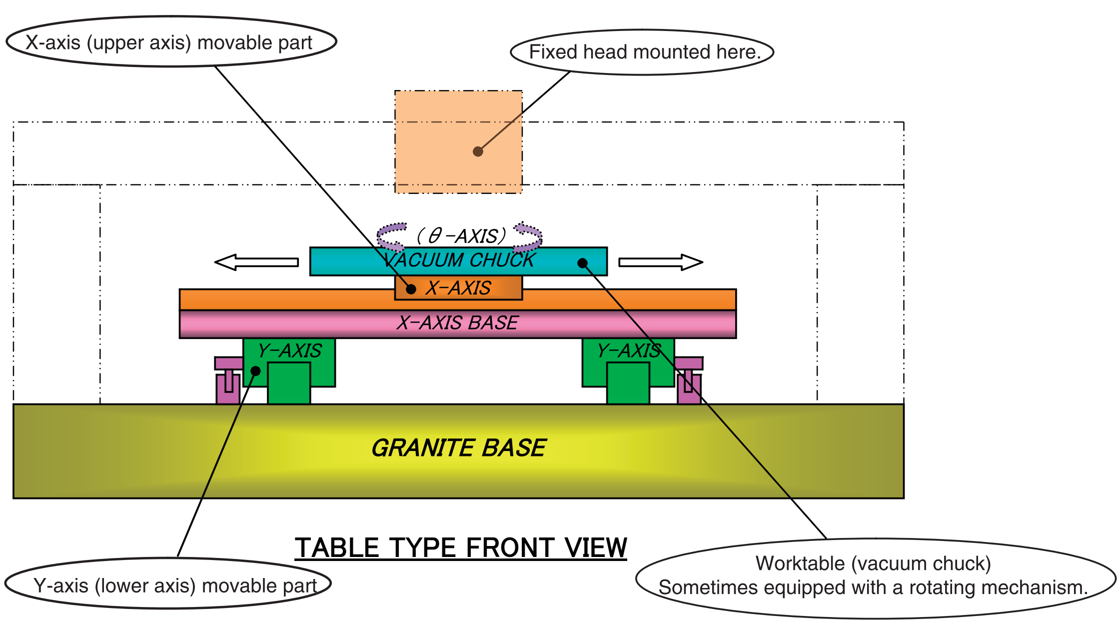

Figure 3-1　Image of the Table Type

has become the most unpopular. This is because its total movement area is a maximum of four times as large as the substrate area.

This type is inferior to the bridge type in accuracy due to its unbalanced table movement.

This type is used for equipment that has a head containing a system which must never be moved.

3. Air Bearings (Static Guide)

This section describes the characteristics of air bearings used for stages.

The basic structures of air bearings are roughly divided into the following two types.

① Orifice air bearings

This is an old type of air bearing. Compressed air is injected from outside into a bearing, and fed to a bearing sliding surface through some holes and grooves on the sliding surface, which have dimensions of several tenths of a millimeter, to generate air gaps.

This type is not so efficient, as it consumes much air due to the pressure gradient that occurs in positions away from orifices.

It also has disadvantages in that when the bearing surface inclines, the surface pressure significantly drops, rigidity is lost, and vibration occurs (hammering).

It has an advantage in that air bearings can be processed directly on granite. For this reason, only this type of air bearings is manufactured at Sigma-Technos, and they are rigidly assembled to stages.

This type ensures sufficient bearing surface pressures for large stages.

② Porous air bearings

This is a new type of air bearing. Compressed air is injected from outside into a bearing and fed uniformly to the entire bearing surface through innumerable holes in a porous material to generate air gaps.

This type is efficient and consumes little air because air is discharged from the entire bearing surface.

Unlike the orifice type, this type is structured to keep a certain level of rigidity and hardly causes vibration even when the bearing surface inclines.

This type has become disadvantageous because it cannot be manufactured in large sizes.

3.1 Air Gap

Bearing rigidity increases as the air gap narrows (to be exact, the air gap is compressed). Rigidity decreases as the air gap widens.

If air bearings are rigidly assembled on opposite sides and air gaps are too narrow, the bearings easily bite rails when a moment is applied.

It is necessary to determine the optimum amount of air gap that satisfies specifications for a stage and other conditions, taking into account the close relationship among rigidity, safety and accuracy.

3.2 Accuracy Improved by Using Air Bearings

Air bearings cause no waving because they are not directly affected by slight disturbances on a sliding surface and they have no ball, roller or other rotating mechanism as is found in metal bearings.

Therefore, air bearings improve speed ripple and angular error accuracies much more than metal bearings.

Air bearings minimize absolute positioning errors because there is no difference between the coefficient of static friction and the coefficient of kinetic friction.

These bearings cause no sticking or slipping, and thus they are especially useful for open-loop controlled positioning systems using ball screws.

3.3 Design Value for Adoption of Air Bearings

When calculating a bearing area or selecting a bearing pad for air bearings used for stages, the bearing efficiency of 50% is used for calculations, allowing for pressure losses and leakage from peripheries of bearings.

When the supplied compressed air pressure value of 0.5Mpa is the standard condition, the input value is set to 0.3Mpa as a safety value, and the load weight is divided by the pressure value and then multiplied by 50% to determine the design value.

3.4 Advantages of Using Air Bearings

Air bearings are non-contact bearings, which cause no friction or abrasion of bearing and rail surfaces, and thus they are effective for increasing service life of stages.

Air bearings cause little friction heat, having no adverse influence on stage accuracy.

Air bearings need no grease or lubrication.

3.5 Disadvantages of Using Air Bearings

Air bearings require higher levels of processing and assembling techniques and thereby require more man-hours than metal bearings. Air bearings also require many peripheral parts and materials to make the bearings work and so are very expensive.

If a power supply is shut off during stage movement, an inertial force remains and bearings collide against stoppers at high speed.

At present, we use electromagnetic valves to forcibly shut off air supply to air bearings to consume the kinetic energy. But this generates strong friction between bearings and guide surfaces, and it is not considered to be the best method in view of the damage done to the stage.

4. Stage Designing

Sigma-Technos has the following principles for stage designing.

① Determining a cross section of granite depending on accuracy, strength and weight balance

We determine the deformation tolerance of granite based on the required accuracy, and calculate a required cross section depending on loading conditions and movement patterns.

Similarly, we determine a required cross section to keep strength depending on loading conditions and movement patterns, and determine an ideal size.

② Reducing weights of parts and materials

Being aware of the recent need for higher speed stages, we try to minimize the weights of parts and materials used for movable parts.

Reduction in weight enables movement at a higher speed and reduces the settling time. Moreover, downsizing of linear motors and other parts contributes to cost reduction.

③ Adhering to the ideal support point (Bessel point)

Support points of main parts and materials are positioned at Bessel points as much as possible, and support points of parts and materials positioned vertically to the main parts and materials are aligned with the Bessel points as much as possible.

④ Positioning a drive system allowing for Abbe's errors

As part of the measures for improving the positioning accuracy, the drive system parts and materials are positioned as close as possible to workpieces.

This is effective, particularly, for linear encoders.

Linear motors are positioned as close as possible to workpieces in consideration for thrust balance due to their relations to bearings.

⑤ Amount of heat generated by linear motors

Linear motors generate heat, which adversely affect high-accuracy stages.

In particular, large stages have long strokes and are significantly affected by heat and result in non-negligible problems.

To avoid these problems, we need to calculate the amount of generated heat based on operating conditions, and estimate the influence on surrounding parts.

If the amount of heat is large enough to deteriorate the required accuracy, we consider using a heat exchanging system such as a thermo chiller.

5. Large Granite Processing Issues

What is most affected by increased stage size is the granite processing process. Increase in weight makes it more difficult to handle the stage and increases in plane area and length make it more difficult to achieve the required accuracy.

Most stages are required to have high accuracy, regardless of their large sizes, or rather, the requirement seems to become increasingly severe the larger the stage.

For these reasons, we cannot determine the time required for granite processing from only an increase in size, but all we have to go on is the actual data of the man-hours as an index. This makes it more difficult for us to control processes for newly designed products.

6. Anti-vibration Systems

Stages for vibration-sensitive equipment need to be insulated from vibration generated by factory floors or other structures.

Granite itself attenuates vibration to an extent, but if it is insufficient, we install an anti-vibration system with air springs below the main base to protect the stage against vibration interference.

In most cases, we adopt passive anti-vibration systems with control valves, rather than expensive active anti-vibration systems.

Recent large stages have heavy movable bodies (exceeding 5 tons for the eighth generation) and high acceleration. When a passive isolator is used alone for such a stage, it cannot control the vibration sufficiently to suppress reaction forces generated during acceleration and deceleration and cannot stop vibration generated by the stage itself.

This problem can be solved by adopting active anti-vibration systems, but as mentioned above, they are too expensive to adopt in view of the selling prices of stages.

Therefore, it is essential to create passive anti-vibration systems with vibration control properties enhanced by using oil dampers and mechanical dampers for large stages.

7. Changes in the Transport of Large Stages

Due to limitations in the width of cargo for land transport inside and outside the country, non-stop transportation is not available for stages in the eighth generation or later. So we have changed stage structures to split structure design (patent pending), allowing for disassembly for transport.

For example, a tenth generation bridge type stage, for which we need to plan transport soon, has a core, or a worktable, larger than the allowable width for transport. It may need to be disassembled and tilted in order to transport it.

The product is large and heavy, but requires micron-order accuracy. We need to elaborately design a carriage for transport.

In most cases, there is no large crane available for a clean room in which a stage is to be installed. We need to design stages that can be reassembled without using a crane. To this end, we also need to fabricate transport jigs and purchase required equipment and materials. This will increase the cost even though it is not for the stage itself, and we are concerned about this issue.

8. Conclusion

We have always been and will continue to address the issue of how fast and at how low a price we can supply stages, meeting the needs of the times, for processing the ever-larger substrates at higher speeds and at higher degrees of accuracy.

As equipment becomes larger, it must have longer service life than conventional equipment. Improvement in durability is also an important factor in designing stages.

We need to evolve stage designing, manufacturing and processing techniques to stay up-to-date while adhering to basic design principles.