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Preventing Fab Failures Before They Start

Linear Motion Tips for Semiconductor Manufacturing Machinery OEMs and Fab Engineers

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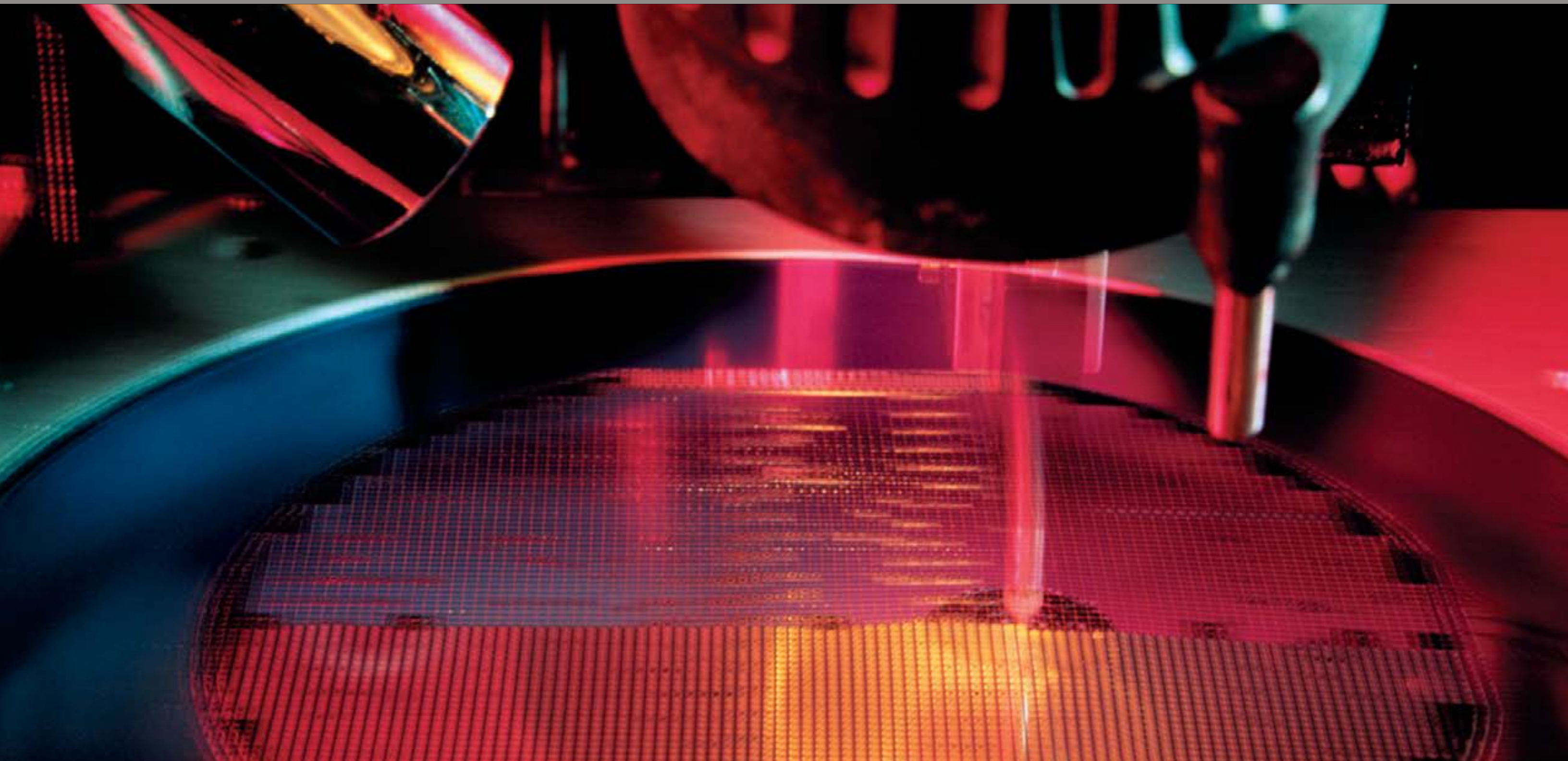

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Introduction

To meet colossal competitive pressures and exponential market growth, semiconductor makers must constantly pursue improvements in technology, processes, workflows, and yield. But improvements can't only be about expanding success. They must also prevent failures.

Neglecting improvements and safeguards in one seemingly minor class of equipment — in-process linear motion systems — can have consequences throughout the fabrication plant. These can range from fairly inconvenient to truly catastrophic. So fab managers, as well as the capital equipment manufacturers that supply them, must remain vigilant.

This report highlights how next-generation linear motion systems can be specified, designed, installed, and maintained to prevent problems before they start.

Consequences

Semiconductor engineering managers, engineering directors, and CTOs worldwide report that reliable linear motion is an absolute operational necessity.

From a prevention standpoint, this means that fab managers and capital equipment suppliers must monitor even relatively rare failure risks in linear motion components or systems throughout the process. That includes equipment used in metrology, wire or die-bonding, wafer dicing and scribing, or packaging.

The stakes are huge.

Failure of a single part or system can cost a fab hundreds of thousands of dollars for even a relatively short-duration downtime event. Depending on location, severity, and response time for repair or replacement, of course, costs could mount to a great deal more.

Personnel safety risk is another paramount concern. While rare, design flaws or failure to follow operational safeguards can lead to anything from pinch points to runaway stages — and cause damages from crushing injuries or electrical shock.

Specification and Design

To begin with, obviously it's important that the linear motion manufacturing facility be fully ISO-certified to ensure consistency in all its key processes — and thus consistent wafer yields in the fab itself. In addition, meticulous prototype builds help uncover steps that are key to maintaining performance and/or reliability of the finished motion component or system. Missing, or not properly performing, any of many small, crucial steps in assembly or testing could ultimately lead to a failed system in the field. So makers of capital equipment tools must make sure they're dealing with the right high-quality, experienced linear motion supplier.

In addition, calculations of component service life must be properly performed. Because duty cycles may vary from fab to fab — for many linear motion components, service life is stated in terms of kilometers traveled. The linear motion maker must then translate that into all sorts of decisions about the product. For example, one widely used cable specifies more than 10 million flex cycles if a 50-millimeter or greater bend radius is maintained. But if the bend radius is not sized properly, particulates falling from the cable, and/or stress on cable tracks or connectors could conceivably cause early failure in the fab (especially where maintenance schedules are not strictly observed).

Many capital equipment manufacturers establish targets that translate into 5 to 7 years of reliable service before they will replace the equipment with a next-generation platform that's extensively updated and/or redesigned.

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Consider Customization

Off-the-shelf parts play a critical role in many assemblies that capital equipment manufacturers build for semiconductor fabs. But one concern comes in the fact that, for instance, a stock linear motion stage element may not have been — could not have been — designed and constructed to work with the precise combination of other components and structures that the fab supplier is assembling. Unexpected incompatibilities may arise. Will they be caught in a good manufacturer's routine design, quality control, and inspection protocols?

Probably. But not certainly.

Often, only customized offerings can meet the ultimate objectives of a fab's specific performance requirements. They allow the capital equipment manufacturer to focus on exactly the design aspects of the stage the fab needs — precisely tailoring factors from speed to acceleration to stability. They can even reduce cost by eliminating unneeded features that come standard with an off-the-shelf stage. And they ensure an integrated solution without hidden incompatibilities.

Capital equipment suppliers should look for true "spec-sheet-to-prototype-build" control of their order from the linear motion manufacturer. Such intelligent customization is often vital to anticipating and eliminating product shortcomings, avoiding potential roadblocks in at-fab integration — and preventing failures all along the line.

Specify products with the precise size, shape, coating, or material your job demands. And insist on solutions that meet your unique targets for accuracy, speed, flatness, preloading (to increase stiffness by eliminating internal clearances), service life, maintenance levels, and price.

Sometimes, more innovative materials may also help reduce risks in specific custom designs. For example, carbon fiber construction can optimize structural strength, stiffness, and stability (despite its reduced weight and thickness), while ceramic bearings may be a viable solution for certain lubrication issues.

Handle with Care

Once a linear motion component that's ultimately destined for a semiconductor fabrication facility arrives on the capital equipment maker's floor, other risks can arise.

Linear motion manufacturers may be called in to solve a host of problems arising at this intermediate stage. A linear motor may suffer a binding problem, where the coil traveling inside the motor track is rubbing against that track at one point in its travel. This can be caused by a handling issue, due to jarring that slightly shifts the coil or the track out of alignment. Or the saddle — the moving stage segment — may get bumped, and suffer distortion. In building the larger tool, screws that are too long may be added, pushing through one linear motion plate into another, causing scratches and the risk of unpredictable forces during operation. Or a coil may be unscrewed from its mounting to allow access to run an additional cable, then re-screwed incorrectly. Mishaps like these run risks ranging from slight degradation of performance in the fab to burnt-out motors and major downtime events.

Surface preparation is another area that merits close attention. Tolerances must match in all particulars. In some cases, a manufacturer building tools for the fab may source a linear motion component constructed for flatness of travel of, say, 0.0005 inch (12.7 microns). But the toolmaker then bolts that component down to a larger assembly with flatness of only 0.005 inch (127 microns). The consequent twisting of the stage may be almost imperceptible. But if, for example, the tool will be stationed to perform wafer inspection via a high-precision camera, its focus may not meet the fab's desired specifications.

Get Grounded

Making sure that all components in the linear motion system have proper electrical grounding is another precaution that capital equipment makers can take to prevent later problems. Of course, overlooking something here might result in electrical shock risks for operators. But it can also have a more insidious effect on system performance.

A ground loop somewhere in the system that feeds back through the ground path could actually induce false readings in the encoder so that a component only travels 1 millimeter, but the controller registers travel of 100 millimeters. If such an oversight is not caught — for example, a scribing tool may make a cut in the wrong place — it could ruin the chip, or the entire wafer.

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Ensure Efficient Integration

To provide their fab customers with a highest-reliability product, capital equipment manufacturers need to think big, think long-term — and think preventively. In many situations, you can eliminate risk before a moving part arrives at your loading dock.

Don't think in terms of buying even the best single component. Instead, try to buy, for example, a complete metrology solution, from the floor up to the point of measurement. Besides highest-performance cross roller bearings to provide extremely smoothness and speed, you want a solution that takes "ownership" of the entire assembly. Not just the stage, but the properly isolated frame it mounts to — along with state-of-the-art active dampening measures. This kind of integrated technology helps ensure you get rock-solid control of both component movement and any ancillary vibration.

At the capital equipment end, though, perhaps the process that holds the most potential for causing mishaps down the line is designing and constructing the control element or elements that will direct the linear motion system. Issues such as improper wiring of course can crop up here and need to be guarded against, as they must in other parts of the build. But it's the myriad steps of programming the control and integrating the hardware and software that demand the most care.

Are all limit switches — with sensors that protectively trigger on or off states when the stage hits a point such as a hard stop for limit of travel — ordered as an option if a stage is a stock purchase? Were they all properly set, correctly oriented (with plus or negative limits sent to left or right pins, as applicable), suitably connected to the controller, and appropriately used?

Are limits for electrical current set to the proper levels? Is the stage correctly tuned? Is the velocity limited, so that it never exceeds the specified limits of any component in the system?

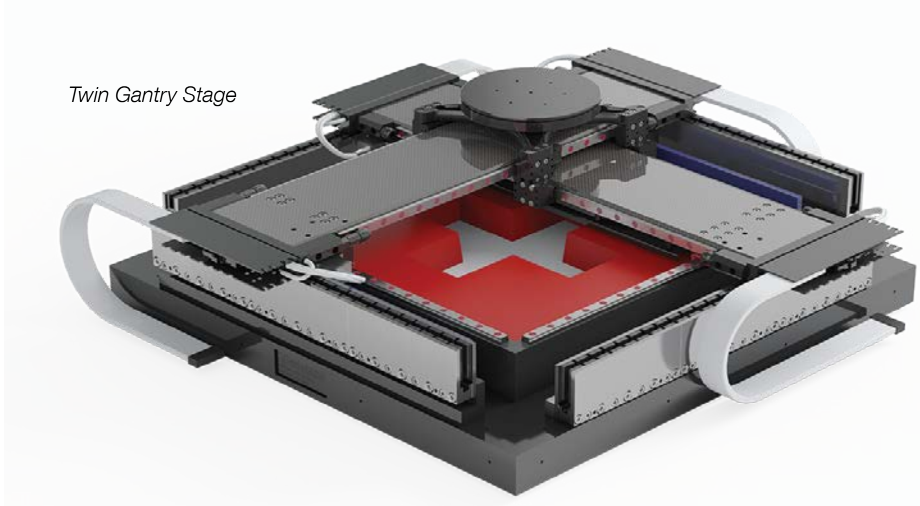
At the extreme, a mistake here might even lead to a runaway stage in the fab. The moving part loses communication with the controller and starts moving on its own volition, perhaps to the point where it goes beyond the desired end of travel and impacts another part of the machine.

But in a more likely scenario, a control design oversight could lead to an overcurrent situation and cause a motor burnout. If limits are not properly specified, and during travel a motor-driven component such as a stage or table is physically impeded by something unexpected on its rail — a fallen screw, an operator's hand, its end of travel, etc. — the motor may draw more and more amperage until it burns out. Results: equipment shutdown, disassembly, and service or replacement: all with major downtime and costs for that part of the fab.

An even subtler problem may arise if the control designers neglect to consider every possible condition that might obtain during linear motion equipment operation. For instance, a three-axis linear motion component might perform perfectly during all routine operations through thousands of iterations. But in what might be an exceptionally uncommon configuration with no limit switches set, such as when the X, Y, and Z axes all happen to be at their very lowest points of travel simultaneously — the moving component may run into a structure in its surrounding environment that was not accounted for in planning. So it hits a nearby post or holder or dispenser.

Problem: linear bearings are excellent at accommodating continuous dynamic and static loading. But not impact loading. If a linear motion component hits something at high velocity, it generates what could well be an out-of-spec impact load. Potentially, a single such hit could destroy every bearing in the system.

Twin Gantry Stage



Sweat the Small Stuff

To lessen risks, the capital equipment manufacturer should make sure that the linear equipment supplier gives proper attention to even small details that could cause significant problems in the fab.

Oil and residues should be pre-cleaned off all parts, to meet fab cleanroom standards. Even the smallest particulates can degrade or ruin vital processes during fab operation, from applying circuits on a wafer to inspecting them via metrology equipment. Pre-cleaning helps eliminate the risk of a smudge on high-resolution optics or a particle dropped in a circuit path.

Outgassing can cause an elastomeric substance to emit materials such as oils, additives, water, or other chemicals. Deposited as thin films on system components, these can wreak havoc on electronics internals, optical surfaces, and so on. Susceptible components should be pre-baked to prevent this.

Where appropriate, elements should be assembled using vented screw — to avoid trapping tiny, possibly contaminated air pockets at the screw tip.

Was it produced in a cleanroom? This is the first question to ask if a component forms part of a positioning system that must meet stringent ISO cleanroom requirements.

Finally, when evaluating integrated measurement systems, be sure they can be used in their intended operating environments without the need for expensive compressed-air purge systems. Their added mechanical complexity naturally adds a number of points of possible failure to the system.

Transport and Installation

Linear motion systems' relatively low resistance to impact loading was discussed earlier. The points of greatest risk naturally occur in three periods: 1) during transport from linear motion supplier to capital equipment tool maker; 2) during arrival and incorporation of the system into the capital equipment tool; and 3) during transport of the finished equipment assembly to the fab, and installation there.

A reliable, experienced linear motion supplier can greatly decrease the chance of shock damage during the first phase. Supplier experts can ascertain manufacturing space constraints early, so they don't design a stage that's too large or too heavy to be easily assembled in the clean room or manufacturing floor. They can also plan transport equipment usage (cranes, dollies, etc.) so that the stage can be safely transported from crate to tool, minimizing the risk of injury to onsite personnel, as well as the chance of damaging impacts.

For both the first and second phases, the linear motion supplier should follow best practices in constructing transport crates and bagging systems. One leading supplier envelops the system in two bags, one applied within a nitrogen atmosphere and the second in a cleanroom, for transport. They then provide special rigging and carts for delicate transport transfers.

In the third phase, if the system will be placed on the tool assembly from above, the tool makers' crane may suffice. If a more challenging sideload maneuver is necessary, the supplier provides a specialized chamber crate, which can be bolted to the side of the tool until mounting is accomplished.

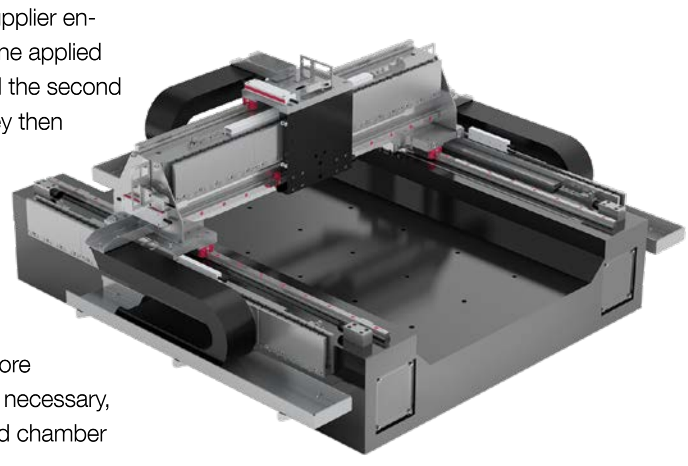
Finally, during installation, the linear motion system or the relevant portion of the tool can be equipped with the necessary passive isolation measures (such as elastomer feet or pads) or active isolation dampers (sensor-adjusted airbag systems) to reduce the chance of excessive shock or vibration during subsequent fab operations.

Vibration

As the unit undergoes normal operation, vibration — from other equipment on the fab floor, or even from sources outside the immediate environment, such as heavy machinery or passing trucks — is always a risk for many ultra-precise linear motion components. Even the process of adding a coating of a certain thickness to a wafer element can be disturbed by excessive vibration.

The active or passive isolation/damping systems mentioned above can be strategically deployed to greatly reduce this threat.

Single Gantry Stage



Lubrication

Although linear motion systems usually runs for cycle after cycle without trouble or extra attention, a small amount of regular maintenance is always critical. Here there are three keys to effective maintenance: lubrication, lubrication, and lubrication.

Every linear motion system supplier ships their product with a specified re-lubrication service cycle. Yet, human nature being what it is, many problems reported at fabs can be traced to simple failures to follow that recommended cycle. Without necessary lubrication, friction stresses mount and eventually cause extremely undesirable events — such as shutdowns or motor burnouts.

Another lubrication issue arises from the fact that a number of linear motion components in the fab work in vacuum chambers. This environment demands highly specialized vacuum greases.

However, not all vacuum greases are created equal. In fact, different systems may require different formulations, such as those marketed by Klüber, Barrierta, and Krytox.

Caution: Only the right grease should be used on each machine. Great care must be taken never to *mix* incompatible oils or greases, as when a machine that last cycle was serviced by one grease is later serviced by another. This will change the required viscosity — often resulting in buildup of a gummy, cement-like material that's the last thing you want in your delicate machine. If the material also includes particulates, from an overflexed cable or cable carrier or from a damaged wafer, usually rail failure will soon follow.

Performance Roadmap

In response to demands from capital tool manufacturers and the fabs themselves, linear motion equipment makers are always looking to push the envelope in performance. Of course, you must first make sure that any improvements don't actually *increase* the risk of those linear motion failures you're trying to prevent.

A good linear motion supplier will supply a "performance roadmap," highlighting element of the system that can be designed not just for the current generation of requirements, but also with performance capacity for use in the next generation of the tool in the fab.

Conclusion

Linear motion process systems are not the most prominent elements in most capital equipment manufacturers' products; nor are they typically a top-of-mind concern for a semiconductor fab's managers. But their failure can have serious consequences for both. Fortunately, reasonable attention to proper design, installation, operation, and maintenance can ensure they play a key role in a fab's continuing success.

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