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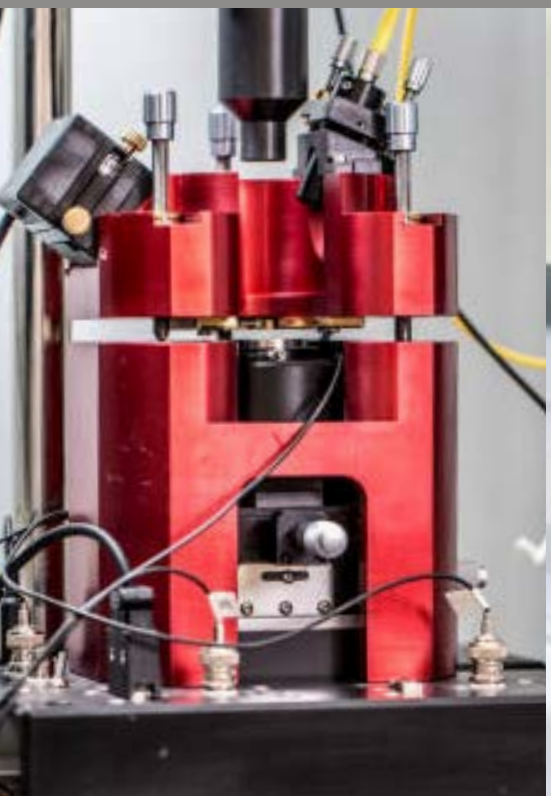
Advancing Life Science and Biomedical Manufacturing through Linear Motion: The OEM's Guide



Advancing Life Science and Biomedical Manufacturing through Linear Motion: The OEM's Guide

Introduction

To meet colossal competitive pressures and exponential market growth, life science and biomedical original equipment manufacturers (OEMs) must constantly pursue improvements in technology, processes, workflows, and yield. But improvements cannot only be about expanding success. They must also prevent in-use failures of such advanced equipment utilized in research, scientific, medical, and other critical applications.

Neglecting improvements and safeguards in one seemingly minor component of these instruments — in-process linear motion systems — can generate consequences ranging from inconvenient to catastrophic. So, the OEMs which manufacture these instruments, as well as its users, must remain vigilant.

This report highlights how next-generation linear motion systems can be specified, designed, installed, and maintained to advance life science and biomedical research and capital equipment manufacturing.

Consequences

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

From a prevention standpoint, this means that both capital equipment manufacturers and equipment users must monitor even relatively rare failure risks in linear motion components or systems throughout the process. This concern includes equipment ranging from DNA sequencing to bio-printing to atomic force microscopes (AFMs).

The stakes are enormous.

Failure of a single part or system can cost equipment users hundreds of thousands of dollars for even a relatively short-duration downtime event. Depending on location, severity, and response time for repair or replacement, 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 to electrical shock.

Specification and Design

To begin with, obviously, it is essential that the linear motion manufacturing facility be fully ISO-certified to ensure consistency in all its key processes. In addition, meticulous prototype builds help uncover steps that are key to maintaining the performance and, or the reliability of the finished motion component or system. Missing, or not correctly performing, any of many small, crucial steps in assembly or testing could ultimately lead to a failed system in the field. So, makers of biomedical and life science tools must make sure they are dealing with the right high-quality, experienced linear motion supplier.

In addition, many life science and biomedical equipment manufacturers establish targets that translate into 5 to 7 — and potentially many more — years of reliable service before they will replace the equipment with a next-generation platform that is extensively updated and/or redesigned. Calculations of component service life should be appropriately performed. Because duty cycles may vary from application to application, service life is stated in terms of kilometers traveled for many linear motion components. The linear motion maker must then translate that calculation into various 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 correctly sized, particulates falling from the cable or stress on the cable tracks or connectors could conceivably cause early failure in the process (especially where maintenance schedules are not strictly observed).

Consider Customization

Off-the-shelf parts play a critical role in many assemblies that capital equipment manufacturers build for life science and biomedical applications. One concern, for example, is that a stock linear motion stage element may not have been designed and constructed to work with the precise combination of other components and structures that the supplier is assembling. Unexpected incompatibilities may arise.

The question is: Will issues 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 objectives of specific performance requirements. They allow the capital equipment manufacturer to focus on the design aspects of the stage that the application requires — specifically 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.

Life science and biomedical 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 vital to anticipating and eliminating product shortcomings, avoiding roadblocks in integration — and preventing failures throughout.

Specify products with the precise size, shape, coating, or material the job demands. And insist on solutions that meet the 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). At the same time, ceramic bearings may be a viable solution for specific lubrication issues.

Surface preparation for a linear motion component

Handle with Care

Once a linear motion component that is destined for a specific life science or biomedical application 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 the track in its travel. This might 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 a slight degradation of performance in the process to burnt-out motors and major downtime events. Surface preparation also merits close attention. Tolerances must match in all particulars. In some cases, a manufacturer building tools for these processes 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. For example, this may cause binding of the bearings resulting in premature wearing of the bearings, additional forces on the ball screw, or higher power requirements from linear motors resulting in excessive overheating and potential failure.

Get Grounded

Ensuring that all components in the linear motion system have proper electrical grounding is another precaution that OEMs can undertake to prevent a future problem. Such an oversight might result in electrical shock risks for operators. But it can also have an impact on system performance.

A ground loop in the system that feeds back through the ground path could 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, positional accuracy may result in errors in the instruments readings leading to inaccurate analysis.

Ensure Efficient Integration

To provide their customers with the highest-reliability product, life science and biomedical capital equipment manufacturers must think big, long-term, and preventively. In many situations, risk can be eliminated before a moving part arrives at the loading dock.

Do not think in terms of buying even the best single component. Instead, focus on creating a complete metrology solution from the floor up to the point of measurement. Besides highest-performance cross roller bearings to provide extreme smoothness and speed, seek a solution that takes "ownership" of the entire assembly. This would include not just the stage but the properly isolated frame to which it is mounted. This also includes state-of-the-art active dampening measures. This kind of integrated technology helps ensure rock-solid control of both component movement and any ancillary vibration.

In terms of manufacture, 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 can crop up and need to be guarded against, as they must in other parts of the build. But it is 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 all

Linear motion component system integration

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 the 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 application. 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 motor burnout. Suppose the limits are not correctly specified, and during travel, a motor-driven component such as a stage or table is physically impeded by an unexpected object on the rail (a fallen screw, an operator's hand, its end of travel, etc.). In this case, the motor may draw more and more amperage until it burns out. The results: equipment shutdown, disassembly, and service or replacement — all with the major downtime and costs for that part of the application.

An even subtler problem may arise if the control designers neglect to consider every possible condition that could occur 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. Not accounted for in planning, this could include hitting a nearby post or holder or dispenser.

The problem is this: 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.

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Transport and Installation

The relatively low resistance of linear motion systems to impact loading was discussed earlier. The points of most significant 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 process floor and installation.

A reliable, experienced linear motion supplier can significantly decrease the chance of shock damage during the first phase. Supplier experts can ascertain manufacturing space constraints early, so they do not design a stage that is too large or too heavy to be easily assembled in the medical 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.

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 operations.

Lubrication

Although linear motion systems usually run 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.

In the Clean Room

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 the 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.

Every linear motion system supplier ships their product with a specified re-lubrication service cycle. Yet, human nature being what it is, many problems 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.

Other lubrication issues include premature failure of the bearings resulting in reductions in performance such as straightness, flatness, pitch, roll and yaw.

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

Linear motion in a cleanroom environment

Caution: Use only the correct grease on each machine. Take great care never to mix incompatible oils or greases. This includes using different greases when servicing a machine from one cycle to the next. This will change the required viscosity — often resulting in the buildup of a gummy, cement-like material that is the last thing to desire in delicate equipment. If the material also includes particulates from an over flexed cable, a cable carrier, or even elsewhere, usually rail failure will soon result.

Performance Roadmap

In response to demands from capital equipment manufacturers, linear motion equipment makers are continually working to push the envelope in performance. First, ensure that any improvements do not inadvertently increase the risk of linear motion failures.

A good linear motion supplier will supply a "performance roadmap" highlighting elements of the system that can be designed not just for current requirements but with the performance capacity for next-generation use. This commitment is especially critical in the manufacture of advanced technology life science and biomedical research equipment.

Conclusion

Linear motion process systems may not be the most prominent elements in most life science and biomedical equipment. Nor are they typically a top-of-mind concern for most instrument users. But their failure can have severe consequences for both. Fortunately, proper attention to design, installation, operation, and maintenance can ensure linear motion systems play a vital role in the continuing critical — and perhaps even life-saving — successful operation of the most advanced life science and biomedical equipment.

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