WHITE PAPER

The Bioprinter Manufacturer's Guide to Linear Motion Technology

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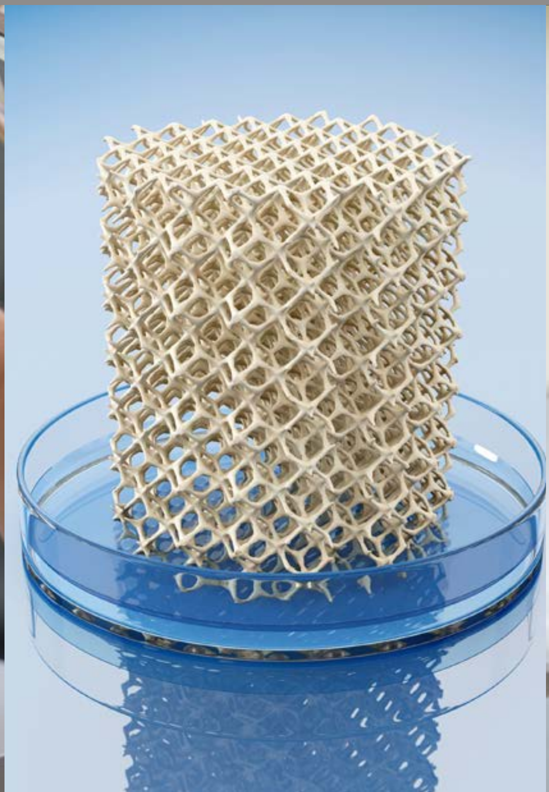
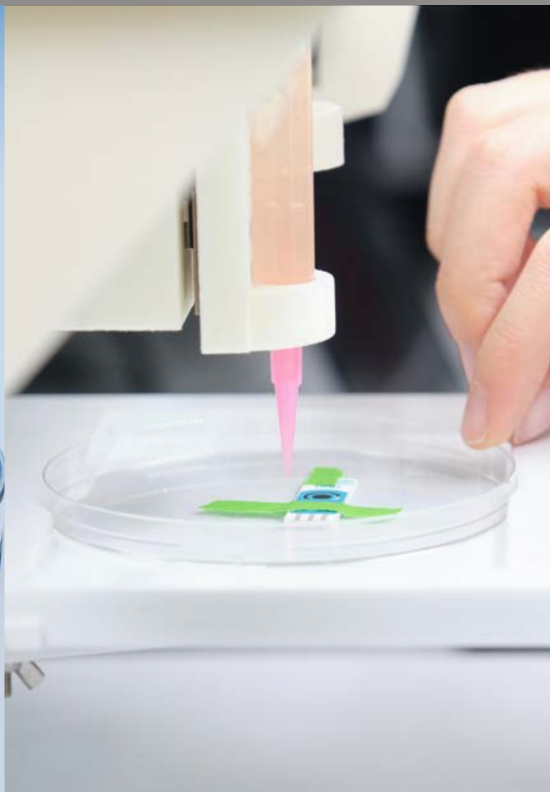




The Bioprinter Manufacturer's Guide to Linear Motion Technology

Introduction

At bioprinter original equipment manufacturers (OEMs), the product design engineers, mechanical engineers, and design engineering managers are charged with turning their visions, designs, and the potential of technology into the reality of equipment, systems, and solutions. The challenges include accuracy, precision, miniaturization, customization, biomaterials, and, always, biological safety.

Besides new bioprinting technologies and their myriad of current and future applications, designers must also stay abreast of new developments and essential functionalities in critical core components — including the linear motion systems that enable their printer components to function according to design.

Bioprinters and Linear Motion

Linear motion components play a critical part in the successful operation of a bioprinter. They must precisely guide the movement of the unit's print head, nozzle, laser, or electron beam — and sometimes also its material bed. It's a requirement that is true for every relevant additive manufacturing technology, including stereolithography and sintering, direct metal laser sintering, direct metal laser melting, and electron beam melting.

And it's no less more so than with bioprinters.

In the genre of low-cost bioprinters, new and modified desktop options still regulate linear movements using the exact mechanisms that 3D printing pioneers employed, such as bushings and belt drives or steel rods and basic ball bearings. This arrangement is inexpensive and provides adequate control for many more straightforward bioprinting tasks.

However, today, designers of even smaller bioprinters are turning instead to more advanced linear motion solutions, such as profiled linear guideways with ball bearings or rollers. They cost more than belt and rod systems — averaging 3x more expensive. But their advantages for more advanced bioprinting applications are decisive.

Their much higher degree of stiffness enables printing that virtually eliminates frustrating printer problems such as ringing or backlash. They also help avoid other issues of rod and belt arrangements, which are often too tight (so movement suffers from roughness or binding) or too loose (so movement is affected by excessive play in the mechanism).
Instead, a linear guideway's high-precision machined tolerances ensure ultra-smooth motion.

Once the application moves above the ability for accommodation by a desktop solution or beyond the need to create a one-of-a-kind prototype, modern printing technology is required to fulfill the challenges of complex bioprinting applications. Bioprinters dedicated to these applications require implementation at a whole new level of linear motion performance. As a result, OEM-contracted suppliers must furnish a linear motion solution with much higher degrees of critical characteristics such as rigidity, speed, and precision.

Two-axis positioning system used to position microscopes accurately.

Modern motion components often applied to bioprinters include profiled guideways with balls, profiled miniature guideways, miniature balls screws, and linear motion systems.

Integration is a continuing trend. Why buy a rail or a slide plus a separate encoder and then encounter difficulties in trying to align them? Specifying the guideway with an integrated encoder/measuring system can save setup time and trouble while reducing the total cost of ownership.

Maintenance is likewise a vital issue. To simplify maintenance, focus on features such as integrated long-term lubrication features or materials with extended wear resistance.

Successful Partnering for Critical Expertise

While bioprinter OEMs are experts in their own right, many have limited resources when the challenge rests in the specifics of linear motion technology. Partnering with an experienced linear motion supplier can, in effect, extend your engineering team. Shape working supplier relationships to build the best basis for a successful project:

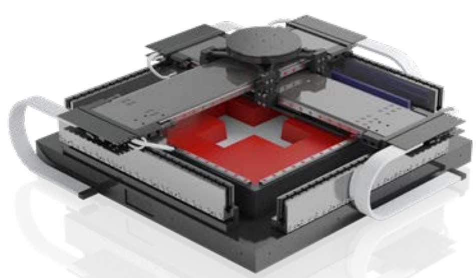
1. Start early. Call in the supplier near the start of the design process, arrange a nondisclosure agreement (NDA), and leverage the supplier to scope and quantify linear motion requirements upfront. This gives the supplier maximum time and scope to recommend the right solution, from initial planning to final design freeze.

2. Design to performance. Expect the supplier to quickly pinpoint any motion issues and opportunities a given design may present. Expert suppliers can identify trade-offs and suggest alternatives. The goal: Avoid pitfalls now to prevent performance shortcomings later when they are harder to correct.

3. Design to cost. In the real world, budgets are always a prime concern. Share the intended market price of the printer with the supplier. An experienced supplier will strive to meet it without sacrificing quality or extended service life. The ultimate goal is to strike the best balance of delivering optimal performance with the lowest total cost of ownership over the printer's lifetime.

4. Explore custom options. Many times, standard, off-the-shelf components won't fit or can't deliver the proper performance for a specific design. Keep the options open. Avoid "take-it-or-leave-it" supplier relationships. The right partner will tailor their solutions to the unique specifications and demands of the design and application. Customized linear motion components and systems can improve the design process, the performance, and the total cost of ownership.

Besides expertise with customization, the right supplier will bring a wide array of linear motion offerings to the challenge. OEM engineers can benefit from their versatility of drawing on a range of linear solutions — such as anti-friction guideways, profile linear guideways, bearings and racks, positioning systems, linear ball bearings, and ball screws. Such components can be intelligently combined in a system with the rigidity, speed, and precision to deliver the performance demanded in bioprinting.



Twin gantry positioning system used for biomedical/medical applications, such as microscopy, bioprinting tissue, and organ regeneration.

Rigidity

The performance of a bioprinter's linear motion system rests, literally and figuratively, on its base.
Wherever high performance is required, sufficient rigidity or stiffness demands close attention to factors such as thickness, frame construction, and materials. All must be consistent with the final performance specifications you want to achieve.
Rigidity affects factors such as flatness and straightness. For example, a manufacturer may attempt to attach a linear motion rail made of stainless steel, of required thickness and suitably rigid design, to an aluminum plate that's thinner than the rail. The inevitable result: deflection. (Linear motion components are typically designed to resist forces along the X, Y, and Z axes to prevent this.) Here, the deflection would mean that the rail could curve, however slightly, in the direction dictated by any force applied. This affects smooth travel and repeatability, which in turn can degrade the uniformity of the printed product.

But even the most advanced linear motion products can't deliver superior speed or precision if they rest on a base that allows extraneous movement. Traditionally, most 3D printers have been mounted on structures such as sheet metal cabinets or aluminum tables. Unfortunately, these bases won't deliver the acceptable rigidity demanded by modern bioprinter manufacturing equipment. So instead, the recommendation is for strongly built steel or iron structures or granite bases.

Another innovative choice is a substructure composed of minerals and epoxy resins. These mineral cast bases furnish printer beds with excellent vibration dampening, strong chemical resistance, and excellent thermal stability. In addition, they can be formed to accommodate any contours and dimensions a given printer requires, including custom-shaped openings, spaces, and wiring channels. They also offer clear technological, economic, and ecological advantages over steel, gray iron, or cast iron.

Discuss expected loads and printer configuration with the linear motion supplier early so that the resulting system is designed from the start to withstand all the forces and conditions and meet all the accuracy and precision requirements of its intended application.

Speed

The travel speed of a linear motion system essentially defines the printer's production speed.

Relatively slow speeds are required for some tasks on some bioprinters to prevent such issues as deformation. On others, excessive travel acceleration can create problems from ringing to ghosting to lack of layer adhesion to filament blobbing. In most cases, manufacturers ask linear motion suppliers to deliver maximum speed wherever possible.

Three-axis positioning system for ultra-high precision medical scanning and processing.

When the highest productivity or output is required, it's essential that a linear motion element can accelerate as rapidly as possible. But settle time is often another key metric: how long it takes the rail or other component attached to the moving part (print or beam head, material bed, etc.) to come to rest without appreciable vibration after each acceleration step.

However, such factors greatly depend upon the printer design, the material, shape, thickness, resolution, and other characteristics of the specific item that the printer is producing; and which linear motion components have been employed.

Generally speaking, in an optimum configuration, some of today's high-performance linear motion systems can attain constant velocities with step-and-settle intervals — even at exact positions — of as low as 50 milliseconds. That would allow extremely rapid travel to support the fastest industrial printers available today, which operate at up to 1000 millimeters a second. A discussion between manufacturer and supplier is required to determine what can be achieved in any specific application.

Precision

The choice of linear motion equipment directly impacts the degree of positional accuracy and repeatability — the precision — that an operating bioprinter demands. Therefore, the linear motion technology employed will impact critical performance requirements for the end application, including accuracy, repeatability, and resolution.

If the end-user in a bioprinting process employs after-print finishing steps to attain given tolerances or flatness/smoothness specifications, extreme precision in primary printing may not be necessary. However, a good linear motion system for this range of printers might deliver positional precision down to plus or minus 50 or 100 microns.

However, internal features of the finished item may not be easily accessible after completion. Additionally, bioindustry-leading OEMs are evolving their approaches to minimize extra finishing. Thus, an extremely accurate linear motion may be required to achieve precise dimensions and shapes at every point.

Many bioprinter applications are now exceeding the level of linear motion equipment precision traditionally required by high-performance machine tools. And as biomanufacturing technologies continue to evolve, expect many applications to demand even higher degrees of precision — such as leading linear motion suppliers design into ultra-precise nanoscale equipment for semiconductor manufacturing. For bioprinter requirements that fall into these latter groups, a linear technology supplier must be willing and able to consult on specific requirements and compare the exact capabilities of possible linear motion solutions to enable a manufacturer to achieve such a whole new level of precision.

Much depends on the specific printer design and on the item that must be bio-printed. Beyond, a linear tech supplier must address issues from the linear motion system's stiffness, flatness, load/preload, and construction materials to its operating temperatures and vibration/resonance potential, as well as considering factors such as constant velocity and stroke length. But under the right conditions, a superior linear motion system today can enable certain bioprinters to attain repeatable accuracy from 0.5 down to 0.1 microns

Moving into the Future of Bioprinter Manufacturing

Today's advanced linear motion systems can, and are, delivering the precision that bioprinting applications can demand.

As bioprinter manufacturing continues its explosive development, speeds will increase, efficiencies will grow, and the use of biomaterials will proliferate.

There is ample room for bioprinters' linear motion capabilities to grow. For instance, precisely controlling the movement of dispensing elements on smaller and smaller scales can empower bioprinters to manufacture ever-finer somatic structures. Vein tissue was first successfully printed in 2016. Fully functional 3D-printed human organs are predicted in the not-so-distant future.

The result: an increasing number of bioprinter OEMs are exploring the benefits of advanced linear motion solutions for their challenging, cutting-edge, and in many cases, unique products. The right supplier can overcome concerns and obstacles to help deliver advantages such as expert design, acceptable lead times, reduced cost of ownership, reliable quality, and rewarding partnership. In addition, the right linear technology can provide critical characteristics such as rigidity, speed, accuracy, precision, miniaturization, customization, material compatibility, and biosafety that enable truly high-performance bioprinting.

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