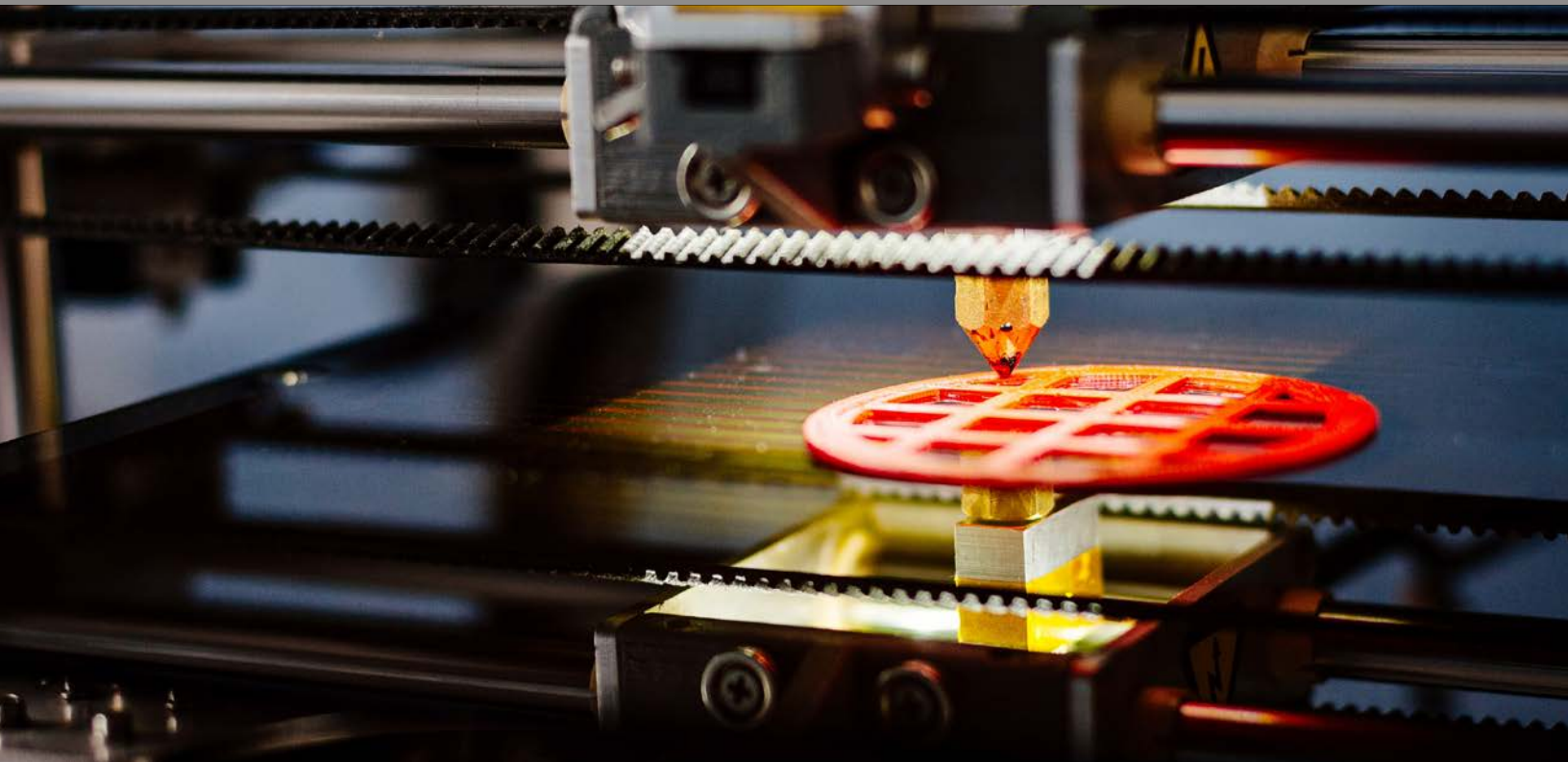


WHITE PAPER

The 3-D Printer  
Manufacturer's Guide to

# High-Performance Linear Motion

SCHNEEBERGER Inc., U.S.A.



# The 3-D Printer Manufacturer's Guide to High-Performance Linear Motion

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## Introduction

**3D printing is on the move.** As additive manufacturing expands so explosively — with new printers and applications debuting almost daily — it can be challenging for product design engineers, mechanical engineers, and design engineering managers at 3D printer OEMs to keep up.

Besides new printing technologies and their myriad of uses, designers must also stay abreast of new developments and essential functionalities in a core component: the linear motion systems that make their printers move.

This report examines the state of the art in high-performance linear motion, how it contributes specifically to industrial 3D printing — and how to be sure that the linear motion system you choose delivers the new levels of rigidity, speed, and precision you need.

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## Background

Linear motion components play a critical part in the successful operation of a 3D printer. They must precisely guide the movement of the unit's print head, nozzle, laser, or electron beam — and sometimes also its material bed. That's true for every relevant additive manufacturing technology, including stereolithography and sintering, direct metal laser sintering, direct metal laser melting, and electron beam melting.

It's true that early 3D printers did not demand the utmost in precision. And today, many desktop models still regulate linear movements using the same 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 simpler printing tasks. However, today, designers of even some

smaller printers are turning instead to more advanced linear motion solutions, such as profiled linear guideways with ball bearings or rollers.

These cost more than belt and rod systems — averaging 3x more expensive. But their advantages for many printing applications are decisive.

Their much higher degree of stiffness enables printing that virtually eliminates frustrating printer problems such as ringing or backlash. And they help you 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 you move above the desktop level, or beyond printers used simply to create one-of-a-kind prototypes, modern 3D printers are often dedicated to complex industrial uses. They typically turn out parts — often at high production volumes, and always with great consistency — for machine tool, aerospace, automotive, and bio-medical uses, and more.

When your printer is dedicated to these applications, you must make sure it implements a whole new level of linear motion performance. So you must demand that your supplier furnish a linear motion solution with much higher degrees of critical characteristics such as rigidity, speed, and precision.

Modern motion components that are often applied to industrial printers like yours in-

# The 3-D Printer Manufacturer's Guide to High-Performance Linear Motion

clude 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 your total cost of ownership.

Also buy with an eye on simplifying maintenance. Look for options such as integrated long-term lubrication features, or materials with extended wear resistance.

## Ask the Linear Motion Experts

Many 3D printing OEMs have limited resources. Partnering with an experienced linear motion supplier can in effect extend your engineering team. Shape your working relationship with the supplier to build the best basis for a successful project:

### 1. Start early.

Call in your supplier near the start of your process, arrange a nondisclosure agreement (NDA), and get your linear motion requirements quantified and understood as quickly as possible. That gives the supplier maximum time and scope to come up with just the right solution, from initial planning to final design freeze.

### 2. Design to performance.

The supplier should work to quickly pinpoint any motion issues and opportunities that a given printer design may present. They can identify trade-offs and suggest alternatives. The goal: help you avoid any pitfalls now —

to prevent performance shortcomings later, when they're harder to correct.

### 3. Design to cost.

Budgets are always a prime concern. Give your supplier your intended market price or target. The right supplier will strive to meet it, without sacrificing quality or long service life. The ultimate goal is to strike the best balance: optimal performance with the lowest total cost of ownership over the lifetime of your printer.

### 4. Explore custom options.

Some standard, off-the-shelf components won't fit, or can't deliver the right performance for your specific design. Keep your options open. Avoid "take-it-or-leave it" suppliers; look instead for partners that can tailor solutions to your unique specifications. Customized linear motion components and systems can improve the design process, the performance, and the total cost of ownership of your 3D printer.

Besides expertise with customization, find a supplier with a wide array of linear motion offerings. You want the versatility to draw on a range of products such as anti-friction guideways, profile linear guideways, bearings and racks, positioning systems, linear ball bearings, and ball screws. Components like these can be intelligently combined in a system with the rigidity, speed, and precision to deliver the performance you demand.

## Rigidity

The performance of a 3D printer's linear motion system rests, literally and figuratively, on its base.

Where high performance is called for, 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, printer makers 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 actually 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 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.

Even the finest linear motion products can't deliver superior speed or precision if they rest on a base that allows any extraneous movement. Traditionally, most 3D printers have been mounted on structures such as sheet metal cabinets or aluminum tables. These won't deliver acceptable rigidity for most of today's industrial additive manufacturing equipment. Many linear motion suppliers instead recommend strongly built steel or iron structures, or granite bases.

Another innovative choice: a substructure composed of minerals and epoxy resins. These mineral cast bases furnish printer beds with superlative vibration dampening, strong chemical resistance, and excellent thermal stability. They can be formed to accommodate any contours and dimensions a given printer requires, including

# The 3-D Printer Manufacturer's Guide to High-Performance Linear Motion



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 your linear motion supplier early, so that your system can be designed to withstand all the forces and conditions of your specific operation.

## Speed

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

Of course, for some tasks on some printers, fairly slow speeds are necessary to prevent problems such as deformation. On others, excessive travel acceleration can create issues from ringing to ghosting to lack of layer adhesion to filament blobbing. In most cases, additive manufacturers ask their linear motion suppliers to maximize speed wherever possible. So for some applications, it's important that a linear motion element accel-

erate as rapidly as possible for the highest productivity. 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. Of course, these factors are greatly dependent upon your printer's design; the material, shape, thickness, resolution, and other characteristics of the specific piece the printer is making; and which linear motion components you choose.

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 highly precise 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.

Consult your supplier for what they can achieve in your specific application.

## Precision

When you choose linear motion equipment, consider the degree of positional accuracy and repeatability — the precision — that your 3D printer / additive manufacturing design demands. This will impact several critical areas of your final performance, including accuracy, repeatability, and resolution.

If your work process includes after-print finishing steps to attain given tolerances or flatness/smoothness specifications, extreme precision in primary printing may not be necessary. 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 work piece may not be easily accessible after completion. Additionally, OEMs at the forefront of the industry are evolving their approaches to minimize extra finishing.

So you may well require extremely accurate linear motion to achieve precise dimensions and shapes at every point.



# The 3-D Printer Manufacturer's Guide to High-Performance Linear Motion

In fact, a number of 3D printing applications are moving to the level of linear motion equipment precision traditionally required by high-performance machine tools. Now, if you're used to building a printer to achieve only 100-micron exactness, you may not be sure how to improve that significantly. And as additive manufacturing technologies evolve, some applications demand even higher degrees of precision — like those that leading linear motion suppliers design into ultra-precise nanoscale equipment for semiconductor manufacturing. If your 3D printer falls into these latter groups, find a supplier that's willing and able to consult on your specific requirements, compare the exact capabilities of possible linear motion solutions, and help you achieve that whole new level of precision.

Much depends on your specific printer design, and on the piece that must be printed. Beyond that, your supplier must address issues from your linear motion system's stiffness, flatness, load/preload, and materials of construction 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 3D printers to attain repeatable accuracy from 0.5 down to 0.1 micron.

## Success Stories

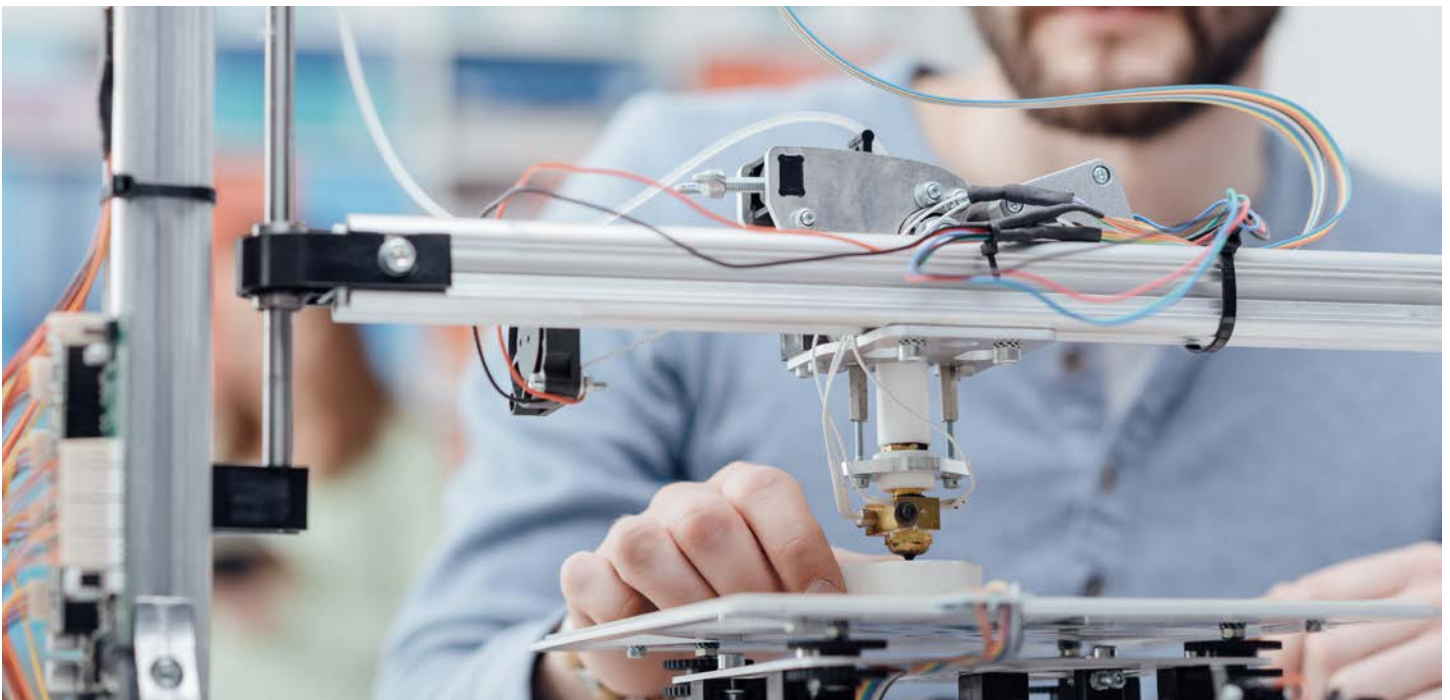
As 3D printing becomes suitable for more complex industrial uses, it can take advantage of qualities that have made advanced linear motion a vital part of manufacturing in machine tools, metrology, auto-

mation, medical / life sciences, and more.

For example: SCHNEEBERGER, a long-established global supplier based in Switzerland, has provided a wide array of linear motion components and systems for these and other uses. Today, it's applying its unmatched knowledge and experience to solve an array of issues for additive manufacturing OEMs. In cases where other suppliers may say that initial specifications can't be met, SCHNEEBERGER experts can often find a way.

### Example 1: Tight envelope, existing design

A leading digital manufacturing solutions company needed a compact linear motion unit to fit into a tight space within one of their existing 3D printer tooling offerings. But using most suppliers' standard



# The 3-D Printer Manufacturer's Guide to High-Performance Linear Motion

product, however compact, would have meant redesigning the tool architecture around it — adding time and requiring substantial use of the customer's precious engineering/design resources to accommodate this one component. Fortunately, SCHNEEBERGER experts were able to customize a special linear bearings cross-roller stage. It precisely fit the constricted space, while fully integrating the necessary electronics and printed circuit boards.

## **Example 2: Lower cost, higher speed, better quality**

A manufacturing-centric 3D printer maker was designing a newer, larger, faster printer targeted to machine shops that were considering making the switch from traditional CNC tools. The OEM's design required a linear motion product that could help reduce costs and increase operational speed — while still maintaining or even improving print quality. SCHNEEBERGER linear motion experts recommended a size 15 MONORAIL ball guideway. Its cost-effective design provided high traveling speeds, while offering low friction values and smooth running to ensure consistently high quality of print output.

## **Example 3: Better tolerances, less vibration, lower cost**

An additive manufacturing company was encountering issues with the overall accuracy of its industrial metal printing product. Too often, tolerances could not meet specifications, causing end products to fail quality tests. Repeated set-ups, manufacturing, and testing were wasting precious time and money. The company turned to SCHNEEBERGER.

Examining the problematic printer, SCHNEEBERGER engineers traced the problem to the machine's granite base. A premium product chosen for ultimate stability, it was instead allowing excessive vibration. Solution: a mineral cast base that could provide ensured vibration damping plus greater structural stability — all at a lower cost.

## **Example 4: high precision for bioprinting**

Various established and startup 3D printing companies are exploring what's needed to produce ceramic parts that can strengthen bone structures, or intricate polymer scaffolding to support the growth of living human cells for transplanted organs. Working with these biomedical printing OEMs from their early design phases, SCHNEEBERGER is demonstrating it has the products and experience to

deliver the ultra-precise linear motion solutions they require. Even the most advanced previous generations of printers needed only good linear motion functionality, with acceptable speed, plus positioning precision in the range of perhaps 50 or 100 microns. But these innovative bioprinting applications demand whole new levels of performance. SCHNEEBERGER experts are combining the right designs and materials to deliver utmost rigidity, extreme flatness of surface and straightness of travel, high constant velocity, and repeatable from 0.5 down to 0.1 micron, for stages from 50 to 100 mm and accuracy between 1 and 20 microns for the same distance. — with step-and-settle rates that ensure no vibration within 50 milliseconds after each movement.

## **Moving into the Future of Additive Manufacturing**

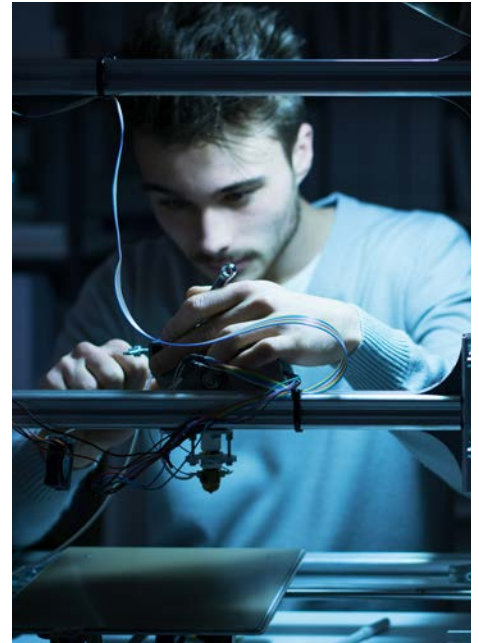
Today's advanced linear motion systems can actually deliver more precision than existing 3D printing technologies can use.

As additive manufacturing continues its explosive development, speeds will increase, efficiencies will grow, and materials will proliferate. Certainly the tipping point is near when more 3D printers will produce metals than plastics.

# The 3-D Printer Manufacturer's Guide to High-Performance Linear Motion

So there's ample room for printers' linear motion capabilities to grow. For instance, the ability to precisely control 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.

Or on an industrial scale, high-precision linear motion equipment could help enable 3D printers to produce surfaces characterized by extreme smoothness. This would permit production of pieces flat enough to function in bearings, seals, or other parts that demand closely mating surfaces — without requiring additional finish machining. 3-D printers for prosthetic appliances, virtual reality-controlled equipment, and many more.



## Conclusion

An increasing number of 3D printing / additive manufacturing OEMs are exploring the benefits of advanced linear motion solutions for their 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. And the right products can provide critical characteristics such as the rigidity, speed, and precision that enable truly high-performance printing.

## SCHNEEBERGER COMPANIES

## SWITZERLAND

SCHNEEBERGER AG  
Lineartechnik  
St. Urbanstrasse 12  
4914 Roggwil/BE

+41 62 918 41 11  
+41 62 918 41 00  
info-ch@schneeberger.com

## JAPAN

Nippon SCHNEEBERGER K.K.  
Crane Toranomon Bldg 7F  
3-20-5 Toranomon, Minato-ku  
Tokyo 105-0001

日本シュネーベルガー株式会社  
〒105-0001  
東京都港区虎ノ門3-20-5  
クレイン虎ノ門ビル7階

+81 3 6435 7474  
+81 3 6435 7475  
info-j@schneeberger.com

## GERMANY

SCHNEEBERGER GmbH  
Gräfenau  
75339 Höfen/Enz

+49 7081 782 0  
+49 7081 782 124  
info-d@schneeberger.com

## CHINA

SCHNEEBERGER  
(Shanghai) Co., Ltd.  
Rm 606, Shang Gao International  
Building  
No. 137 XianXia Road  
200051 Shanghai

施耐博格 (上海) 传动技术有限公司  
上海市长宁区  
仙霞路137号盛高国  
际大厦606室, 上海 200051

+86 21 6209 0027  
+86 21 6209 0102  
info-cn@schneeberger.com

## ITALY

SCHNEEBERGER S.r.l.  
Via Soldani 10  
21021 Angera (VA)

+39 0331 93 20 10  
+39 0331 93 16 55  
info-i@schneeberger.com

## KOREA

SCHNEEBERGER Korea Ltd.  
Garden5 Tool  
10, Chungmin-ro,  
Songpa-gu, Seoul,  
Korea 05840

슈니베르코리아 유한회사  
05840 서울시 송파구 중민로 10  
가든파인빌 10층

+82 2 554 2971  
+82 2 554 3971  
info-kr@schneeberger.com

## USA

SCHNEEBERGER Inc.  
44 Sixth Road,  
Woburn, MA 01801-1759

+1 781 271 0140  
+1 781 932 4127  
info-usa@schneeberger.com

## SINGAPORE

SCHNEEBERGER Linear  
Technology Pte. Ltd.  
38 Ang Mo Kio Industrial Park 2  
#01-04, Singapur 569511

+65 6841 2385  
+65 6841 3408  
info-sg@schneeberger.com

## INDIA

SCHNEEBERGER India Pvt. Ltd.  
406, Satra Plaza,  
Palm Beach Road, Sector 19D  
Vashi,  
400 703 New Mumbai

+91 73 0454 0119  
info-in@schneeberger.com



www.schneeberger.com