KOLLMORGEN
A REGAL REXNORD BRAND

WHITE PAPER

Achieving Ultimate Motion Precision Using Frameless Servo Motors

Some motion applications only require "good enough" motion. Many more require a high degree of precision. And still other applications call for ultimate precision. For these, direct drive frameless servo motors are often the best choice.

These ultimate-precision applications include compact actuators used in high-end general automation applications, compact gimbals used to stabilize sensing and communications platforms, robotic workstations, precision machine tooling or any application where 18 bit or greater resolution may be required for highly repeatable positioning.

On factory floors, for example, human intervention in automated processes used to be required to move parts from work cell to work cell, placing them into a sequence of precision fixtures. These processes can now be performed much faster with collaborative robots that may require 6–7 degrees of freedom. Axes along the robot arm must deliver the torque needed to move, support and steady the rest of the assembly, and absolute precision is required to avoid an accumulation of positioning errors that could lead to unwanted scrap or downtime.

Or, consider a gimbal system that stabilizes and positions an electro-optical/infrared imaging system, as used for example to provide situational awareness and accurate targeting in aerospace & defense applications. The gimbal is a pivoting support that permits rotation of the EO/IR sensor around an axis, with additional degrees of freedom obtained by combining or nesting two or more gimbals, with their axes of rotation at 90° apart. The motors that drive these systems must react immediately and precisely to hold a steady image despite the extreme buffeting that occurs in high-speed flight.

There are many more examples of applications that depend on the ability to deliver high torque, responsive acceleration/deceleration and absolute precision in a compact form factor. Direct drive frameless motors are often the ideal choice for these applications.

Why frameless?

If you can find a housed motor that fits your application well, that's generally the best choice. But for applications that have specialized needs—such as an ultra-compact design, extreme precision and responsiveness of motion, or the need to protect the motor from harsh, potentially damaging environmental conditions—a frameless motor is often a better solution.

Frameless motors are precise and efficient

In a direct drive application, there is no mechanical compliance, backlash or lost motion. Even when a gearbox is used, frameless motors are best suited for use with zero- and low-backlash designs such as harmonic drive (strain wave), planetary and cycloidal gear sets. And with the highest torque density, frameless motors offer the most energy-efficient way to meet your application's torque and speed requirements.

Frameless motors are very compact

Frameless motor kits consist solely of a stator and rotor. All the other components associated with a traditional servo motor—the housing, endbells, bearings, output shaft and connectors—are instead designed into the application mechanism itself. Embedding a frameless motor into this mechanism design allows you to achieve the smallest possible footprint without compromising performance.

Frameless motors can provide superior environmental resilience

Because frameless motors are directly integrated into the application, they can be protected from environmental factors by design. In washdown applications, for example, a frameless motor can be embedded so that high-pressure fluids can never touch it. For a deep-sea propulsion system, the motor can be sealed in an oil-filled, pressure-compensated housing. In high-vacuum and high-radiation environments, specialized materials can be used to prevent outgassing or insulation degradation.

Frameless motors are available in a wide range sizes, shapes and performance characteristics

Design engineers can easily optimize application sizing in relation to required performance characteristics. For example, Kollmorgen's diverse frameless product lines offer both servo (axially longer) and torquer (axially shorter) form factors in standard diameters ranging from a few centimeters to nearly a meter. Bus voltages range from ≤ 48 VDC to 680 VDC (480 VAC rectified). Continuous torque capabilities range from a fraction to several thousand Nm.

With all these options, design engineers can determine the mass they need to move, the timing, application and space constraints, and any environmental challenges—and, working from that information, determine the product line and form factor that ideally suits the application.

Integrating frameless motors into your application

As mentioned earlier, a frameless motor kit consists of only a stator and rotor. All the other components normally associated with a housed servo motor must be built into the application mechanism. Here are some of the top-level considerations to address when designing that mechanism.

Housing

Unlike a housed motor with a mounting flange that is bolted to the machine, a frameless stator is typically bonded into a machined cylindrical cavity component that serves as the motor housing. This is mounted inside the machine in proximity to the driven shaft, allowing for the most compact design. Kollmorgen frameless motors are supplied with a detailed installation manual that covers machining tolerances, bonding agents, assembly sequences and more.

To ensure structural integrity and provide adequate heatsinking, the housing is typically fabricated of steel or aluminum with a minimum wall thickness of 4–6 mm. It's important to use a housing material that can effectively draw heat away from the motor, which is why these materials are preferred. Note that stainless steel has poor thermal conductivity and should be avoided or engineered to be appropriately oversized for best practices in machine design applications.

Kollmorgen provides a rich set of design tools. Customers can use our Frameless Motor Performance Curve Generator to gain insight into the details of motor speed and torque available under a wide range of specified thermal conditions. This allows engineers to properly size motors for each application, and it also aids in understanding the design requirements for stator housing dimensions as well as thermal considerations for closely mounted components such as bearings, gearing and feedback devices.

Also be aware that some frameless motors are designed to perform well at a significantly lower winding temperature than their maximum rating. For example, theTBM2G series delivers exceptional performance without exceeding 85°C, but is also capable of sustaining full performance at up to 155°C winding temperature on a continuous basis.

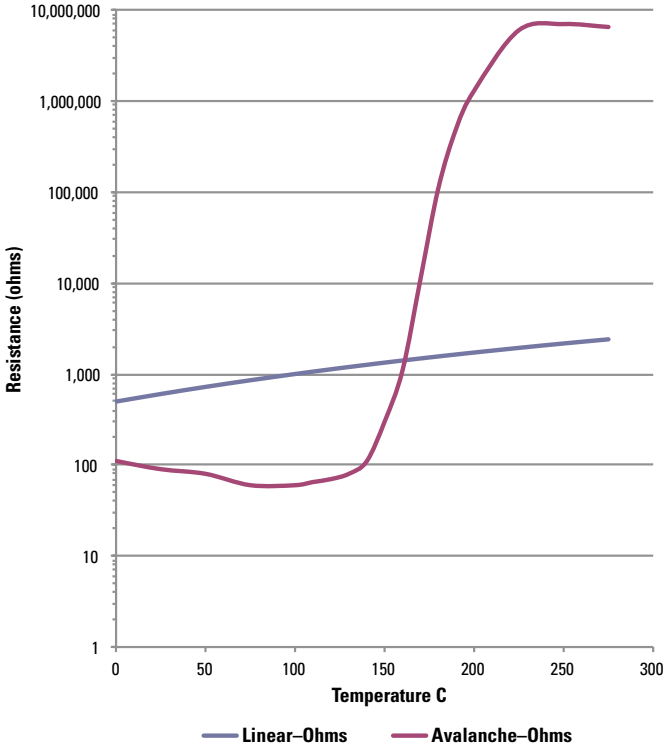
Thermal sensors

In the application design and prototyping phase, it's often useful to employ a **linear thermal sensor** to ensure that your motor can deliver the required continuous torque without exceeding an acceptable winding temperature.

Keep in mind that a motor running at its maximum winding temperature—for example, 155°C—can cause thermal damage to sensitive components positioned nearby, such as lubricants for bearings and gearing as well as thermally sensitive feedback device electronics. Excessive thermal rise can also be detrimental to the material being processed by the application if it is heat-sensitive.

A linear thermal sensor such as the widely used PT1000 can provide the information you need to correlate application performance levels with the winding temperature actually seen at the motor. This data may be compared to other thermally critical machine elements in the application. You may find that you can safely push your machine to higher performance levels with a given motor selection, or you may find that you can achieve the desired performance with a smaller motor.

In the final design, it may be advantageous to incorporate a **PTC or "avalanche" type thermal sensor.** A positive temperature coefficient sensor is a simple resistive device that changes resistance value rapidly when the temperature exceeds an established point, such as the maximum continuous temperature design limit for the motor windings. Most production applications don't need the level of detail provided by a linear thermal sensor unless there's some specialized function that requires it. But a simple PTC device wired to the drive can support various corrective actions in the event of overheating.



Response curve of linear vs. PTC ("avalanche") thermal sensor

For example, if a motor starts overheating and working too hard, the control system can be programmed to provide an alert, reduce current until the motor cools, or go through a slowing/stopping sequence—whatever makes the most sense for the health and productivity of the application and its process. A PTC provides an easy-to-implement and cost-effective protective element in your control system design.

Shaft and bearings

A traditional housed motor has internal bearings that allow the rotor to spin freely. These bearings are not intended to support the load, so one or more additional bearing sets external to the motor must be incorporated into the application for that purpose.

A frameless motor set has no shaft or bearings. Instead, the application design includes its own output shaft. Bearings on the shaft support both the rotor and the load. There's no need to change the overall machine design to accommodate a specific frameless motor. The machine designer already understands the bearing load requirements for the mechanism and simply needs to find a point on the shaft to mount the rotor to be added. Based on that rotor location, the housing element is designed into the machine to support the stator.

In other words, your design incorporates the already-existing shaft and bearing design that is required to perform a specific task, and you simply need to accommodate the rotor and stator elements appropriately onto that existing shaft. Keep in mind that the rotation of the rotor doesn't introduce any significant axial or radial loading forces on the bearings.

What this means is that the bearings on the shaft do support the frameless rotor in addition to the load, but they don't need to be specified with the motor in mind. Instead, select and size your bearings based on the axial and radial forces that the machine shaft will encounter as it moves the load. Using a frameless rather than a housed motor should have no effect on the shaft bearings you specify.

Feedback device

As with any brushless servo motor system, a feedback device for providing rotor position is used to control the timing and sequencing of the amplifier electronically controlling the power to the motor. In its simplest form, this commutation signal may be provided by a group of magnetic sensors known as Hall effect devices that may be offered as a standard option with the frameless motor part set.

Another option is to provide positioning feedback for a closed-loop control system using an incremental encoder that incorporates Hall-effect output tracks. Or, for harsh, high-shock environments that can be detrimental to an optical encoder, a resolver provides a rugged and reliable absolute position feedback alternative—although the resolution is lower at typically 12–16 bits.

Often the best solution, used in most frameless motor applications, is an absolute encoder, which provides the 18-bit or higher resolution required for automation systems that need the highest precision. Using an absolute encoder also eliminates the need for a separate Hall-effect device, allowing the drive to always know the exact rotor position even at system startup.

Gearing

Frameless motors are ideal for direct drive applications. But when it's desirable to increase torque while reducing speed, these motors can also be used with compact, zero-backlash harmonic drive (strain wave) gearing as well as cycloidal, spur and planetary gears. These gear sets maintain extreme precision while enabling high torque multiplication in a compact form factor.

For example, using harmonic drive gearing with a typical 100:1 reduction ratio, the load inertia reflected to the motor shaft is reduced by the square of the ratio, or a factor of 10,000, while barely affecting the overall dimensions of the application design.

These considerations can be important when, for example, you need the torque to accelerate a substantial load without hesitation—or when you want to achieve a specific amount of torque while using a smaller motor. Understanding the effect of gear reduction is critical to motor sizing. Kollmorgen engineers offer the experience to help you make the optimum choices.

Brakes

Some applications require electromagnetic or mechanical brakes. In vertical applications, for example, gravity is a load component that could cause the load to fall or move from its expected position if power to the motor is unexpectedly interrupted.

Another use for brakes is to maintain the integrity of the load's position when the motor is intentionally powered off. For example, a stabilized platform such as a UAV sensor gimbal may benefit from brakes to keep the load from shifting when the aircraft is in flight but the sensor isn't currently needed.

Brakes can be supplied as an integral component of many housed motors. However, with a frameless motor, they should be added to the primary driven shaft of the mechanism.

Design for manufacturability

It can be far too easy to design and build a prototype that meets your application's performance requirements—but to overlook the need for optimum performance on the factory floor and in the marketplace. To minimize risk and maximize success, consider that you need reliably sourced components, a straightforward assembly process and a design that can be easily serviced if needed.

When designing your application, think of the manufacturing process, the order of assembly and the total costs. For example, due to the high magnetic forces sometimes involved, consider whether you will need special fixtures to safely install the permanent-magnet rotor and shaft in proximity to the stator housing in the machine assembly.

If you expect the application to have extreme radial bearing loads that could shorten the typical life of the machine shaft bearings, you may wish to incorporate a means of disassembly for easy bearing replacement, while minimizing the cost and complexity of the frameless motor integration. These subtle design concepts are typically a part of the machine sustainability conversation that is a part of the standard design review process with Kollmorgen engineers.

By accounting for these and other factors from the beginning of your design process, you can avoid cost overruns, ensure that your manufacturing process can keep up with the demand, and greatly improve your prospects of marketplace acceptance.

Get the help and support you need

Designing and manufacturing an application that incorporates frameless motors doesn't need to be fraught with uncertainty. When questions or design challenges arise, know that there's always assistance available in the form of self-service resources as well as engineers with deep understanding of how to incorporate frameless motors in all kinds of applications.

Kollmorgen offers several tools to help you design and build a high-performance, highly manufacturable application:

- Frameless Motor Decision Tree. This interactive tool steps you through the questions you need to answer to determine whether a frameless motor is right for your application—and if so, which specific type of motor. There's also a printable pdf version.
- Frameless Motor Performance Curve Generator. Adjust the current, voltage, ambient temperature and winding factors to instantly generate performance curves and evaluate the best frameless motor options to suit your application requirements.
- Motioneering. Use this online guided selection tool to choose and size the optimum servo motion components for your project based on your actual motion profile needs that may be developed from a library of mechanical project types (ball screw, rack & pinion, belt drive, nip rollers, belt & pulley, direct drive) and loads characterized by your application timing and performance requirements.
- Other design tools. Compare and select motion products, generate 3D models, configure cables, calculate safe braking times and more with these powerful engineering tools.

Ready to move forward?

Contact Kollmorgen to discuss your needs and goals with a Kollmorgen frameless motor specialist.

About Kollmorgen

Kollmorgen, a Regal Rexnord Brand, has more than 100 years of motion experience, proven in the industry's highest-performing, most reliable motors, drives, AGV control solutions and automation platforms. We deliver breakthrough solutions that are unmatched in performance, reliability and ease of use, giving machine builders an irrefutable marketplace advantage.

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