KOLLMORGEN
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WHITE PAPER

# Incorporating Frameless Motors Into an Environmentally Resilient Design

**Motion systems are often deployed into extreme environmental conditions—deep-ocean pressures, high-radiation and high-vacuum conditions, extreme washdown, hazardous atmospheres and more.**

To protect components and achieve ultimate reliability, consider embedding frameless motors directly into your application design. Frameless servo motors allow engineers to create mechanical designs with unsurpassed compactness, precision and environmental resilience.

## Compact applications

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, enabling the most compact footprint without compromising performance.

## Precise performance

In many applications, this tight integration of stator and rotor also eliminates the need for compliant and backlash-prone transmission components, instead driving the load directly. For applications that benefit from torque multiplication and reduced speed, frameless motors are also ideal for use with zero-backlash harmonic drive (strain wave) gearing or with stiff, low-backlash planetary or cycloidal gear sets.

## Environmental resilience

As the focus of this white paper, frameless motors also allow for the most environmentally resilient motion designs. There are three principal reasons for this. First is the simplicity of the motor itself, eliminating the wear points of a housed motor such as rotor bearings and shaft seals.

Second, many frameless motors can be supplied with highly specialized materials designed for superior resilience—for example, to prevent the degradation of insulation when exposed to high-radiation environments and to minimize outgassing in high-vacuum environments.

Third, lacking its own dedicated housing, a frameless motor allows the application engineer to design the housing characteristics needed to protect motion components in specific environmental conditions, such as high-pressure washdown, deep-sea submersion or explosive atmospheres.

## Environmental Challenges and Solutions

**Let's take a closer look at the extreme environmental challenges motion-system designers must contend with, and how frameless motors can help solve them. We'll follow that discussion with an overview of design considerations for successfully incorporating frameless motors into your specific application.**

### Extreme washdown

When manufacturing and packaging food, beverage and pharmaceutical products, it's essential to maintain a hygienic environment at all times. Frequent, high-pressure washdowns with highly acidic or caustic chemicals are crucial to avoid dangerous pathogen outbreaks, expensive recalls and reputational damage that can be difficult to repair.

Traditionally, these washdowns require stopping all machines, letting them cool down, and spraying every surface with high-pressure cleaning fluids. Since these fluids can quickly damage bearings and other components within a housed motor, these motors must be protected by shields or bags during the washdown process and individually cleaned by hand—a time- and labor-intensive process that is liable to be performed inadequately or even entirely skipped.

To avoid these costly disruptions, manufacturers are increasingly adopting clean-in-place practices (CIP), which eliminate the need to bag motors, remove and reinstall motor guards, physically move stations to a separate cleaning area, or in some cases even to shut down the operation.

Frameless motors are ideal for processing and packaging machines designed for CIP. The machine can be built so that no vulnerable components are exposed either to the product or to washdown chemicals. The motor housing is an integral part of the machine design, so it can be configured to provide complete, seamless protection of the motor—even while the machine is running to continue production or to facilitate cleaning of moving parts.

## Submersible vehicles; underwater and downhole tools

Remotely operated submersible vehicles perform crucial energy exploration and production tasks, such as opening and closing valves on deep-sea oil distribution pipelines. And ROVs have many other applications: inspecting ship hulls, maintaining subsea infrastructure, performing scientific research, inspecting fuel-storage tanks and more—all while sparing human divers from engaging in potentially hazardous work.

These and other applications—such as underwater tools and downhole oil and gas tools—require specialized designs to protect motors, bearings, electronics and other components from ingress of the fluids that they operate in. In a deep-sea ROV application, for example, contamination by saltwater would short electrical systems, rapidly destroying thrusters and electrically operated tools. At great depths, pressures up to 30,000 psi can easily overcome the seals and even crush a conventional housed motor.

These failure modes can be prevented by using a housed motor like Kollmorgen's Goldline S submersible servo motor, which uses an oil-filled housing to compensate for external pressures at ocean depths up to 20,000 feet. Unlike air, the hydraulic fluid used in these motors is noncompressible, so even at extreme pressures seawater can't penetrate seals or implode the motor housing.

When compactness, direct drive precision and energy efficiency are paramount, however, frameless motors can offer an even better solution. For example, a thruster mechanism can be designed with an oil-filled, pressure-compensated housing to protect the frameless stator and rotor, with the rotor mated to a drive shaft that directly couples to the impeller.

This enables the most compact design possible in a submersible mechanism that is impervious to high-pressure seawater, requires little or no maintenance, and delivers exceptional efficiency—an important consideration not just for battery-operated ROVs, but also for higher-voltage tethered systems where the available current is significantly attenuated as it passes through extremely long cables.

## High-vacuum environments

In addition to satellites and other space vehicles, there are many earthbound applications that operate under partial-vacuum conditions—for example, semiconductor wafer and chip manufacturing processes, mass spectrometers, electron microscopes, X-ray diffraction instruments and more. Vacuum levels can range from 10E–5 or more in artificially created partial vacuums to as much as 10E–10 in deep space applications.

In all of these settings, there is a strong tendency for certain materials—such as the insulation, encapsulation and magnet materials found in a conventional motor—to break down on a microscopic level. This can significantly reduce the motor's service life. Of even greater concern, however, the outgassing of these materials can condense on and contaminate optical systems, precision electronics, sensor devices and other critical system components.

Frameless motors are often an ideal choice in these applications for two reasons. First, a frameless motor leaves it up to the application engineer to choose the optimum, outgassing-resistant materials used in bearings, seals and all the other components that would otherwise be integral to a housed motor.

Second, with the motor itself reduced to the essential components of stator and rotor, a motor manufacturer who understands the challenges of high-vacuum operation may offer modified versions that replace standard materials with outgassing-resistant versions.

For example, Kollmorgen's TBM, KBM, and RBE series frameless motors are all optionally provided with specialized materials known for low to virtually zero outgassing in high-vacuum conditions. Secondary processes may then be applied to assembled motor components to drive out any residual volatile compounds.

Our cost-effective modifications meet NASA-STD-6016A outgassing standards, and we have been delivering spaceworthy motors ever since the early years of crewed and uncrewed space exploration. Kollmorgen motors prove their reliability in space every day, from low Earth orbit satellites to the surface of Mars.


## High-radiation environments

In many environments—for example medical imaging centers, nuclear medicine departments, uranium mines and nuclear power plants—levels of ionizing radiation can substantially exceed normal background levels. Multiple forms of ionizing radiation are also a problem for orbiting satellites and especially for deep-space vehicles.

When conventional motors are exposed to high radiation levels, the crosslinked polymers in insulation, encapsulation, adhesive and other materials can rapidly degrade and lead to motor failure. In the case of space vehicles, disintegrated materials can also float around and contaminate other systems, similar to the outgassing problem discussed above.

Fortunately, material science can be applied to solve the radiation problem too. In fact, many of the same materials and processes used to prevent outgassing also result in a radiation-hardened motor that performs reliably over a long lifespan, whether in radiation-exposed applications on Earth or in space.

## Classified hazardous locations

Kollmorgen offers a range of housed explosion proof of motors for use in hazardous locations,  such as mines, oil & gas production and refining operations, flour mills, grain elevators, textile mills, and industrial paint booths. However, to achieve the most compact and powerful application, it may be desirable to specify a frameless motor as the core motion control component of a purpose-built design that achieves the exact certifications you require.

Using a frameless motor, you can design and build a housing that uses your preferred protective methods and meets the relevant UL, ATEX, IECEx, CSA or other hazardous location standards. Kollmorgen can provide the documentation you need to support these certifications with regard to the design and construction of the frameless motor components.

## 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 other considerations.

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 either avoided or engineered to be appropriately oversized for best practices in machine design.

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, the TBM2G 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.


### Explosion proof enclosures

For an explosion proof design used in hazardous locations potentially exposed to ignitable gases, dust or fibers, you will need to ensure that the motor enclosure is capable of withstanding an internal explosion, includes flame paths that prevent any internal flame or spark from reaching the outside environment, and that surface temperatures can never become hot enough to ignite hazardous materials.

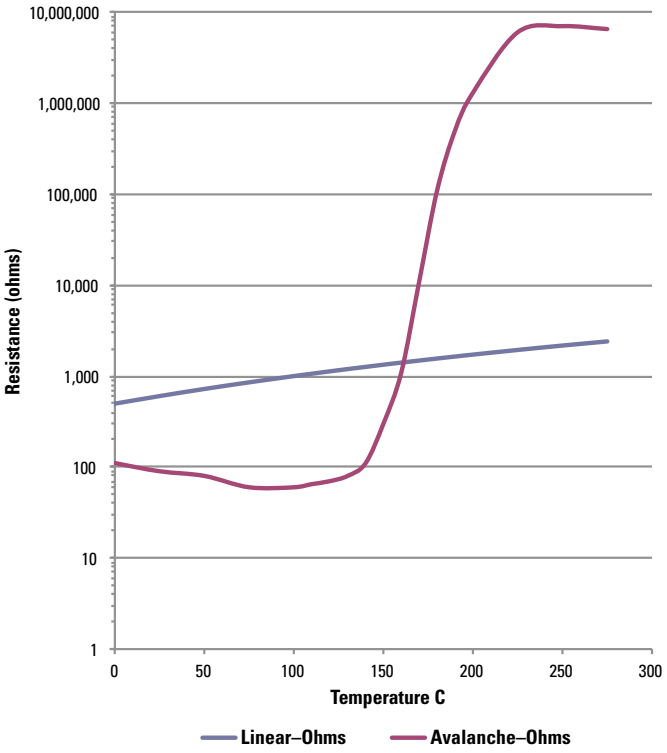
Your application must be designed, tested and certified according to all applicable standards for your region and particular hazardous location. A complete discussion of the topic is beyond the scope of this white paper, but you can contact a Kollmorgen Engineer for guidance on the appropriate resources to consult.

## 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.




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

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.

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 sensor 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 kit has no shaft or bearings. Instead, the application design includes its own output shaft. The machine designer already understands the bearing load requirements for the mechanism and simply needs to find a point on that shaft to mount the rotor to be added, and then to design a housing element in the machine to support the stator based on that rotor location.

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. Resolvers are often preferred, for example, in applications such as submersible vehicles and spacecraft. However, be aware that resolvers provide lower resolution—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 applications 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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