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WHITE PAPER

Motion for Missiles: Optimizing Performance

Missile systems continue to evolve to meet specialized needs—from tactical guided missiles to longer-range strategic weapons, each designed for launch from a particular platform to reach an intended target. It's a fact of modern life that these weapons are needed to promote national and global security. In an uncertain world, they are needed in ever greater quantities, with more innovative capabilities than ever before.

The global market for rockets and missiles is projected to expand at a compound annual growth rate of more than 6% over the next several years, reaching a value of USD 77.4 billion by 2028.[1] Much of this growth is due to the need for—and ongoing development of—advanced new systems such as hypersonic missiles, which are projected to grow at 7.4% CAGR.

Although missiles are designed to be airborne for a relatively short time, the electric motors that control fin actuators, seeker head gimbals and other electromechanical systems must perform with absolute reliability. And they must be ready to deliver this performance at a moment's notice, instantly going from a standby state to extreme conditions of shock, vibration and temperature.

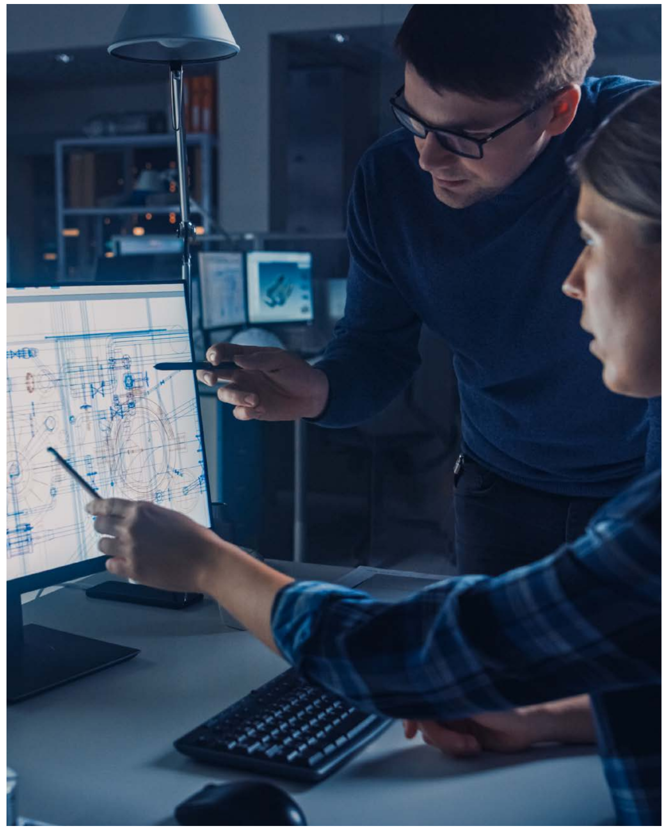
Missile engineers and builders face multiple challenges—creating ever more specialized missiles, fulfilling a rapidly growing demand for quantity, and in some cases helping to increase battle deployment capabilities by delivering missiles that are more compact and that can fly faster and farther without sacrificing performance. To meet these challenges, motion systems must be specified with the goal of fulfilling each application's unique performance, environmental and form factor requirements.

A collaborative process

At Kollmorgen, our engineers collaborate with aerospace and defense customers from the outset of every project to ensure that each motion solution is an ideal fit for its application. This collaborative relationship is built on extensive industry experience, expertise in electromechanical design and materials science, plus the proven ability to prototype, manufacture, deliver and support motors on the timeframe and in the quantities required for missile program success.

The collaborative process begins with discovery and documentation of the technical requirements of each electric motion application throughout the missile. This information can then be used to create motor specifications including installation footprint, performance requirements, component materials, thermal ratings and more.

Here is a high-level overview of the specification process. Note that these steps, while presented in sequential order, are actually highly interrelated. Because each decision affects others, all decisions must be approached as part of an organic whole.



Understanding motion system requirements

The biggest challenge—and the best opportunity for ensuring a successful program—is analyzing all the parameters that the motion systems must operate within and the performance characteristics they must deliver. Answer the following questions as thoroughly as possible early in the design process.

Know what space is available

Given the missile's overall design and the space available for each motion application, what is the motor's ideal length and diameter? How will the motor be integrated within the actuator system? Is a housed or frameless motor most appropriate? Consider that a housed motor provides the simplest installation, but a frameless motor integrated directly into the application's mechanical design can provide the greatest torque density in the most compact package.

A frameless motor is ideal for use with harmonic (strain-wave) gearing, an extremely compact, no-backlash transmission technology that is ideal for use in gimbal systems and other missile applications. A frameless motor also provides a central thru-bore to accommodate components such as microwave and slip ring rotary joints, allowing for an even more compact overall application design.

How large of a thru-bore do you need? Kollmorgen offers an extensive range of frameless motor technologies—including models that maximize the thru-bore aspect ratio—plus the expertise to help you choose the optimum form factor and performance characteristics for your specific application.

Know your available input power

Whether your missile uses conventional thermal batteries or an alternative power source, know all the applications that will draw on that power and what that means for the voltage range and the current—both continuous and peak—that will be available for each individual application. Kollmorgen offers low-voltage motors designed for battery-powered applications that deliver the same dynamic performance as standard motors.

Know your target performance profiles

What are the application's speed and torque requirements, on both a continuous basis and during peak loads? Due to the severe and unpredictable atmospheric forces encountered in subsonic, supersonic and hypersonic flight, the peak torque demands of control components can be extreme—even as course corrections must be performed instantaneously. Fin actuators require motors that can accelerate rapidly without losing significant torque at high speeds. Kollmorgen provides analytic tools and motor optimizations to help you achieve the ideal performance curves for your application.

Know your application's thermal requirements

Any missile is likely to experience a far wider range of temperatures than would ever be encountered in a typical factory environment. An extreme example is a hypersonic missile deployed in a subarctic environment at a temperature of –40°C or lower, which when fired through the atmosphere might reach surface temperatures of hundreds of degrees.

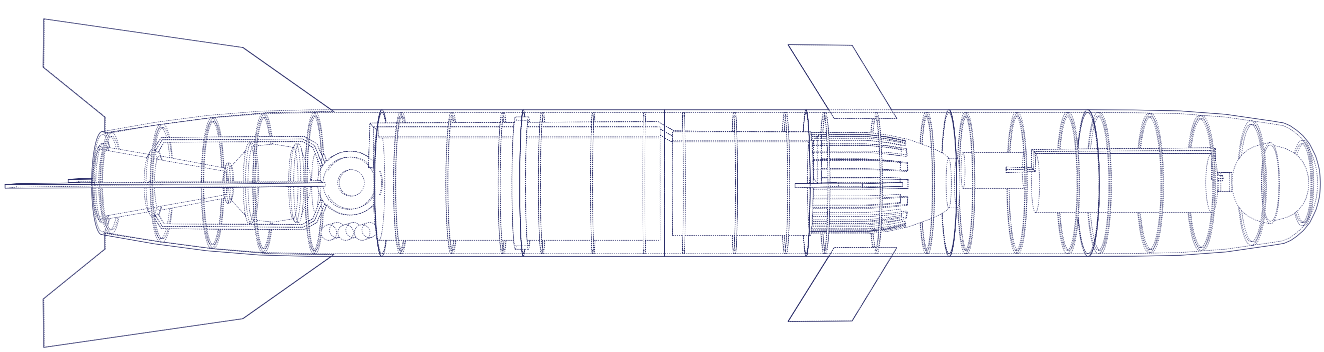
Although such a missile should be designed to provide thermal protection for temperature-sensitive components, motion systems still need to operate reliably across a wide temperature range. How will these temperature extremes, combined with the motor's own inherent thermal rise, affect performance? Based on your requirements, Kollmorgen can quickly calculate how a prototype design will perform at your application's temperature extremes, and we have the facilities to test that performance on the first physical prototypes.

Know your application's true duty cycle

Missile motors must perform flawlessly during the seconds or minutes between launch and impact, obviously. It's easy to imagine that this short performance window means very little risk of failure compared to the demands placed on motors in a 24/7 industrial environment. However, it's important to understand what will happen throughout the lifecycle of the missile, from when it's first deployed in the field to when it's either used or ultimately decommissioned.

This time interval could range from days to decades, and the missile must be in top condition at all times. Understanding what will happen throughout the life cycle will help ensure optimum motor selection and sizing—without the risk of under- or over-specification. For example, it's typical for shipboard missiles to be constantly at ready, with control fins, guidance systems and other motion-dependent components routinely tested to verify that they are operating correctly.

Will your missile be exercised on a daily basis? Does it need to be up and running at all times, whether in standby, ready or prefire mode? Given these requirements—in addition to actual flight conditions—how long will the motors be expected to perform at specific loads and speeds? Kollmorgen motors are engineered to endure in applications where failure is not an option.



Specify motor designs and materials to meet your performance and environmental targets

Every aspect of motor design and materials can be optimized to achieve particular performance and environmental goals. To meet the unique requirements of missile motion systems, which must deliver extreme performance under extreme conditions, the most important elements to optimize are the stator lamination stack and windings, the rotor permanent magnets, and the encapsulation and insulation materials.

Temperature ratings are important for motors used in missiles. However, note that the overall motor rating may be lower than the rating of component materials. For example, a motor rated at 155°C may be comprised of materials individually rated to 180°C or even 200°C. This provides a margin of safety when the motor is overdriven past its overall rating, helping ensure that it can handle extreme performance demands for a limited period of time without compromise. Also, note that motor ratings may be based on continuous operation for a longer period of time than a missile flight.

Laminations

Motor performance varies depending on whether the manufacturer uses high-performance versus standard stator laminations. Lamination design affects the properties of the magnetic flux generated in response to the changing electrical currents applied to the stator windings. Laminations can be designed to minimize the eddy currents produced by the magnetic fields rotating through the stator.

Thinner laminations can improve efficiency and minimize thermal rise by reducing energy losses to heat, especially when high switching frequencies are required to run the motor at higher speeds. Specialized lamination materials maximize the flux that can be generated without saturating the stator, allowing the motor to generate higher torque. Either or both of these design techniques could be advantageous, depending on the application needs.

Windings

Stator windings can be fine-tuned to optimize motor performance at specific bus voltages, including battery-operated missile applications, as well as at specific torque and speed levels. By precisely matching the winding design to the available input power and the performance requirements of the application, engineers avoid the risks of an undersized motor that can't handle the dynamic loads encountered in flight or an oversized motor that adds unnecessary size and weight to the missile design.

Insulation and permanent magnets

A key question for any missile design is how close the motors can approach the absolute, short-term performance demands placed upon them before being compromised. This includes maximizing the thermal time constant—the time it takes for the motor to reach 63% of its full, steady-state temperature—while pushing the motor's performance characteristics to the limits required by the application.

The longer a motor runs beyond its performance ratings, the greater the risk of materials degrading and potentially failing. This risk can be exacerbated by the missile's usage scenario and mitigated by its design.

For example, does the missile operate solely in the atmosphere, or is it launched from underwater, where the control surfaces encounter far greater resistance? If it's launched from an aircraft, must the fin actuators fight the buffeting of slipstream forces, or is there a mechanical lock that is only released upon launch?

If motors will be pushed to their limit and beyond, maximum reliability can be achieved by using higher-temperature solders, higher-temperature encapsulation and insulation systems, and in some cases higher-temperature magnets. Specialized permanent magnet alloys can also increase the torque that a motor can deliver without exceeding its thermal rating.

Collaborate with a motion expert

The partner you choose is as important as the motion technology. Kollmorgen works with you in the initial design phase to understand your exact requirements, then provides the engineering support you need to simplify product selection, sizing, configuration and optimization. Rapid prototyping, delivery and iteration of your solution can potentially save months in your development process.

When the final design is ready, Kollmorgen's AS9100 certified manufacturing facility applies lean manufacturing, repeatable processes and quality controls to enable a quick transition from prototype to full-rate production. You can expect motion solutions delivered on time, every time, as well as long-term support, in-region/for-region, throughout the lifecycle of your missile program.

As a Regal Rexnord brand, partnering with Kollmorgen also gives you access to the leader in highly specialized components in the aerospace and defense industry. Regal Rexnord provides expertise for virtually every missile subsystem along with the highest quality aerospace bearings, sealing solutions, electrical components, gearing systems and more.

Put your missile program on target

Contact Kollmorgen to discuss your needs and goals with a Kollmorgen expert for missile and other aerospace and defense applications.

1 "Rocket and Missile Market," Markets and Markets, September 2023. Specifications are subject to change without notice. It is the responsibility of the product user to determine the suitability of this product for a specific application. All trademarks are the property of their respective owners.

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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