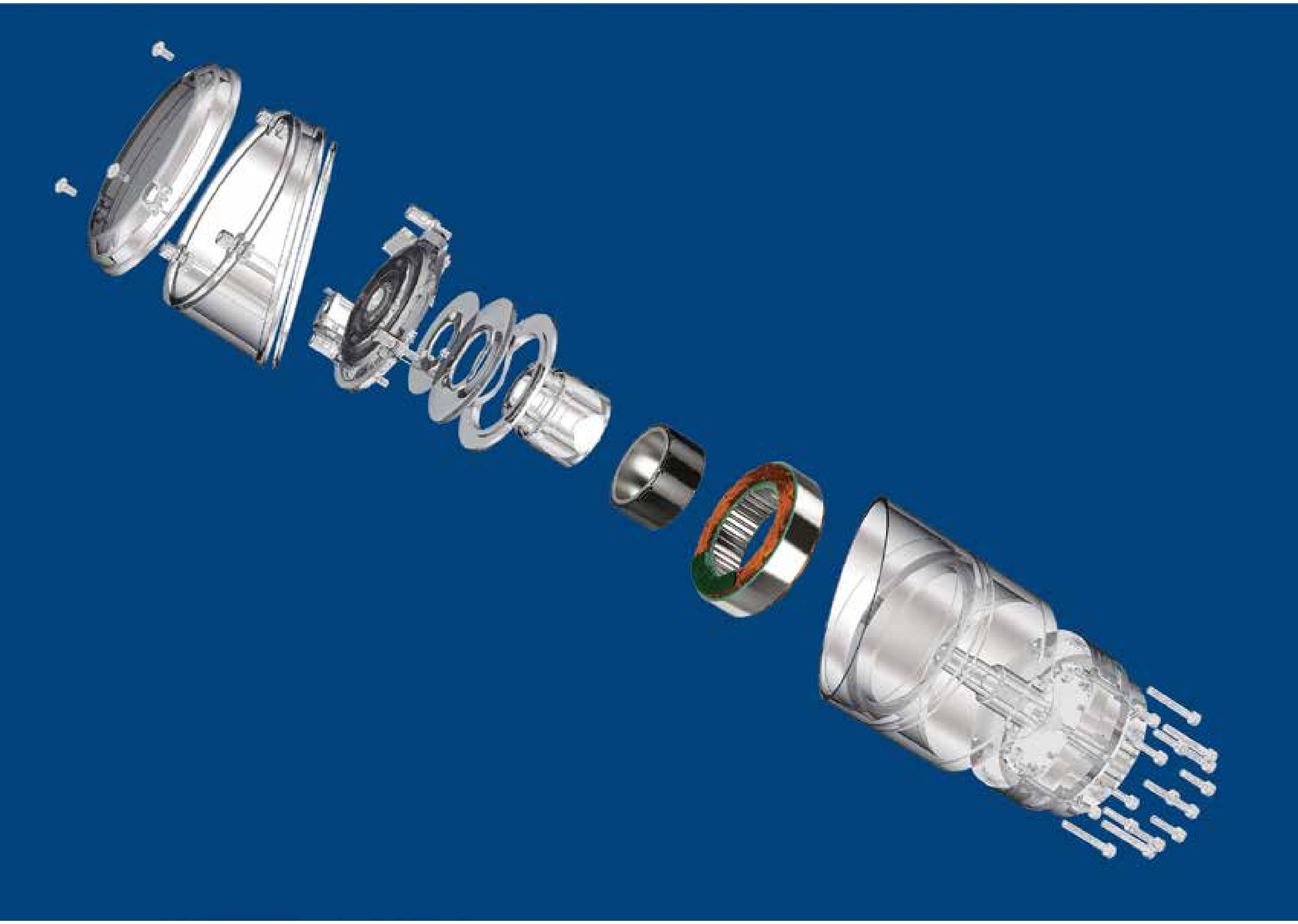
ROBOTICS BUSINESS REVIEW

WHITEPAPER



Demystifying the Use of Frameless Motors in Robotics

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EXECUTIVE SUMMARY: THE VALUE OF FRAMELESS MOTORS IN ROBOTICS

The use of frameless motors in robotics is often driven by the same factors that demand usage in other applications where a standard servo motor won't work. The most common factor behind a decision to use frameless motors is the need for a compact form or environmental demands, yet a requirement for high power and torque density.

There are additional benefits to be had from going with a frameless motor design, such as efficiency in many regards, greater system bandwidth, and a smaller footprint. When the application calls for a small, lightweight motor that delivers significant power and torque, frameless is the way to go.

In this whitepaper, we will seek to eliminate barriers to choosing frameless motors, as well as help robotic engineers build out their specifications so that when it's time to start talking to motion companies, the conversation can move along efficiently.

For example, with a thorough understanding of size, gearing, thermal, and mechanical needs, our team can quickly walk you through the options that are available, whether that be a motor we already produce, one that needs minor adjustments or perhaps a completely new design.

Understanding the economics of these options is also critical, so engineers can work with you to examine specific areas in which savings can be found with minimal impact on your design.

ENGINEERS: WHY IS THIS ARTICLE FOR YOU?

As more organizations and companies implement lean manufacturing processes and incorporate the use, as well as the design of robotic joints in daily operations, frameless motors are at the center of innovative solutions across the industry.

From cleaner assemblies and reduced maintenance to greater efficiency and less downtime, there are many advantages to incorporating frameless motors in your applications. In addition, frameless motors are much easier to mount and install than many believe.

Whether you have MathCAD or similar tools available to calculate torque and speed requirements or you need some support in that area, an engineer with a variety of application experience and the knowledge to help you optimize around factors beyond mechanical considerations can be invaluable to moving forward.

Today, speed to prototype is often the most important problem to solve, so a solution consisting of standard parts, as opposed to a fully custom design can shave weeks off of your timeline. Understanding trade-offs in terms of time versus optimization, as well as speed and torque versus thermal considerations, can help you achieve the best solution the first time and move forward with your application.

ADVANTAGES OF FRAMELESS MOTORS

There are many reasons to include direct-drive frameless motors in your design. They offer clean mechanical assembly, and are easier to mount than many believe. There are fewer parts and less maintenance to think about given their lack of belts that need tightening and adjustments, not to mention the gearing lubrication requirements and overall wear. This all translates into less downtime, as well.

But aside from the cleanliness and maintenance aspect, the improvement in performance that they deliver is absolutely worth considering. There is no need for inertia matching to ensure stable performance.

Frameless motors are much quieter than servo motors, operating at or above 6,000 rpm by as much as 20 decibels. So if you've been wondering if it's worth it to incorporate a frameless motor, the answer is a resounding yes.

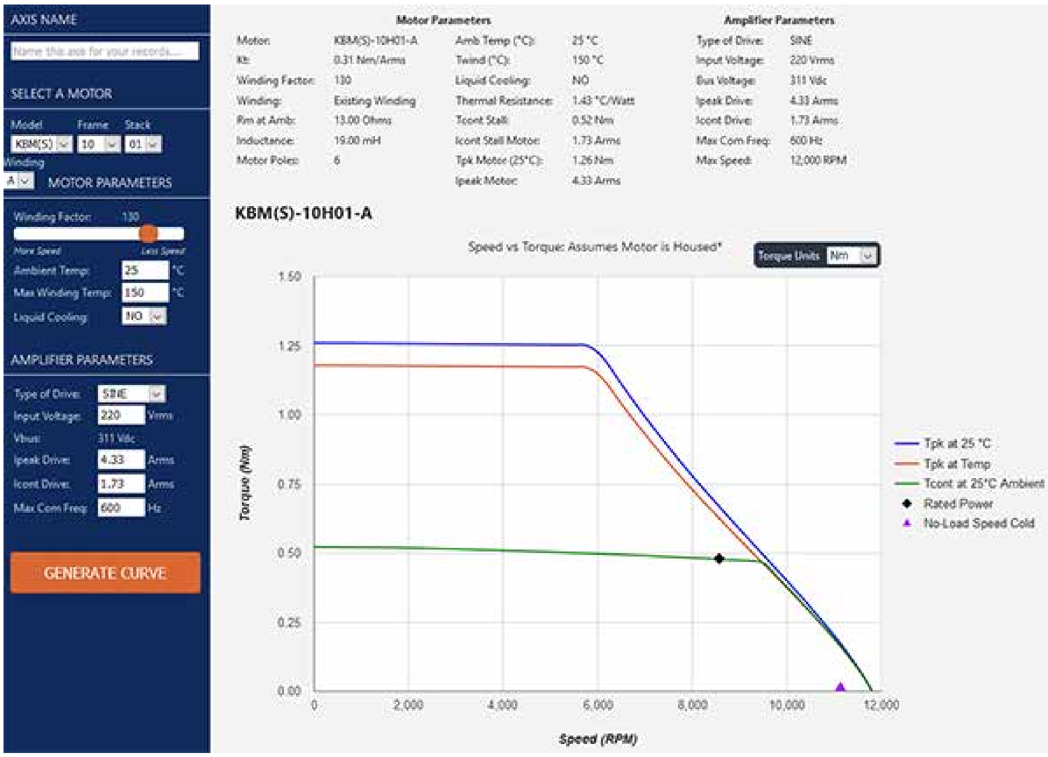
BUILDING OUT YOUR SPECIFICATIONS

Sizing your motor begins during the design phase. As you consider the work that the robot application will be expected to perform, you'll need to think about the speed, torque, and voltage required to make it happen. Understanding factors such as load inertia, friction, and acceleration will help you determine speed and torque. However, there are options as to how you can think about the size and dimensions of your motor to handle these factors and produce consistent, efficient power.

It cannot be understated how much form factor matters when planning and designing your project. One example of how to think about form factor and how it can influence your overall design is the D^2L Rule.

The D^2L rule simply states that, in general, when you double the axial length of the motor armature, you'll get an increase of continuous torque and power that is proportional to that increase. Basically, if you double the length, you double the continuous torque.

However, if instead of doubling the length, you double the diameter of the rotor moment arm, the increase in torque would be squared. You would have four times the continuous torque capacity by moving to the larger diameter.



Kollmorgen's Performance Curve Generator can help designers optimize an overall system.

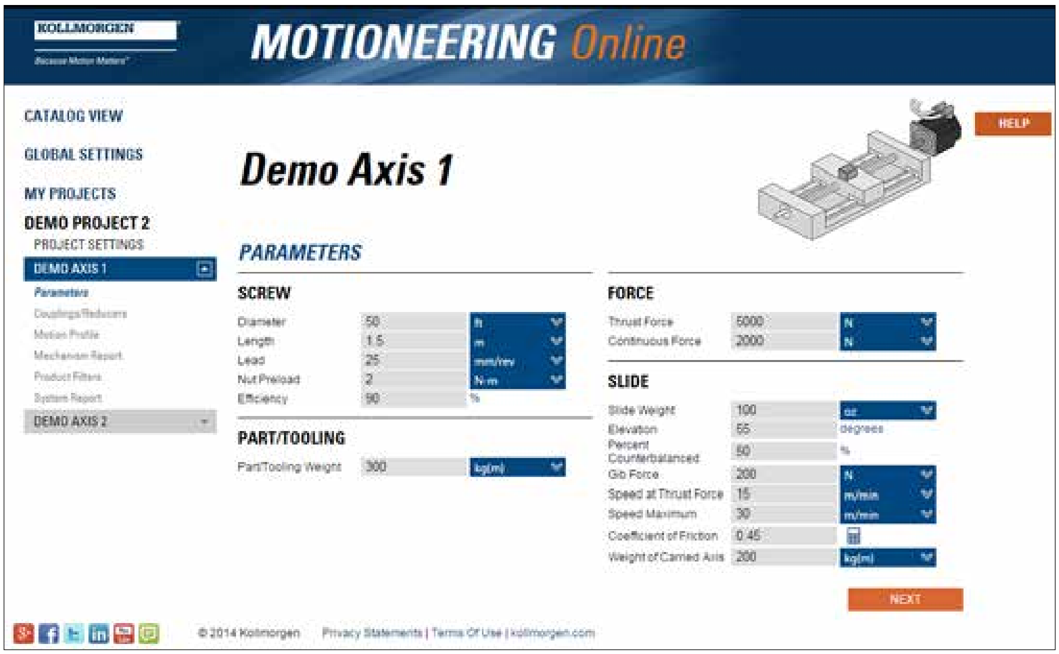
Factors such as the D^2L Rule are why sizing your motor begins with the design phase because you can dramatically optimize the form factor of your motor.

Over the years, unique tools have been created to help customers quickly optimize motors to their needs. For example, this Performance Curve Generator by Kollmorgen can be used to optimize your overall system and experiment with how a different bus voltage might change system performance or gain an understanding of how different amplifier current ratings impact motor performance.

The Performance Curve Generator even allows a design engineer to evaluate ambient and maximum motor winding temperature options. Continuous torque enhancement using Liquid Cooling is also a part of the modelling options available.

Another such tool from Kollmorgen is MOTIONEERING Online, which has been revamped and modernized, and is now one of the most respected application-sizing programs of the past 20 years. This tool gives you access to sizing and selection tools wherever you have access to the Internet.

MOTIONEERING works by collecting your data inputs, then comparing results against a catalog of motor systems. If you're not sure what your torque and speed needs are as you work through the Application Profile Questions, this tool can help you figure them out, and then you can take the relevant 3D models to reach model validation.



Kollmorgen's MOTIONEERING Online is useful for calculating application sizing for frameless motors.

Many clients have their own tools and processes for determining torque and speed requirements. Even in those cases, it's a great idea to input your numbers into these tools to assist with selecting the appropriate motor to meet your application needs.

Whether this is the first time you've thought through motor and drive requirements, or you've been doing it for years, a checklist of considerations can be a helpful tool. At the end of this article, you will find a list of Application Profile Questions that you or your team can use to prepare for a conversation with a support engineer.

You'll find important questions related to the mechanical envelope, motor type, minimum and maximum temperatures in operating and ambient conditions, maximum speed and torque, operating speed and torque, and duty cycle.

WHAT COMES NEXT?

Once you've got an idea of the performance needs of your motor, that's when a team of engineers and product specialists can get to work. There are three ways in which engineers can work with you to determine the perfect frameless motor for each application.

At Kollmorgen, for example, they would begin by matching your requirements against a standard catalog of motors that may just fit your need directly.

If a standard option isn't exactly right, the next step is to look at simple modifications such as changing the windings and making other mechanical customizations.

In addition, if your application demands certain materials to withstand harsh environmental conditions, material changes can be incorporated into an existing design. Either way, you have the option to choose from smaller or larger diameters, changing the windings, changing the stack length and more.

If what you need doesn't match up to a standard option or requires more than a simple modification, the final option is to pull out a clean sheet of paper and work from scratch. Even in these instances, many of the elements of existing motors can be incorporated, while custom parts are designed in response to things like a unique form factor or unusual environmental conditions.

Another option if you know your form factor, torque, and speed requirements is to use an additional online tool from Kollmorgen: the Direct Drive Rotary Motor Selector. While many customers rely on product catalogs, this online tool works very well.

You're able to start with torque, speed and bus voltage information as inputs on the product selector, which will give you a strong starting point. This is actually a good time to return to the performance curve generator as you can use it to optimize your product selection further.

Once you've generated a range of product possibilities through the selection tool, this is also an excellent time to engage with an experienced applications engineer who can walk you through many of the same optimization steps that the performance curve generator uses.

You'll also receive the benefit of application expertise to steer you in the right direction, often resulting in a faster solution in terms of how quickly you can get to a prototype with a motor that will deliver the torque and speed necessary to do the job, even if it isn't perfectly optimized for your exact needs.

Those optimized solutions could take time to deliver, whereas a standard design may work on a prototype to prove your concept while maintaining the integrity of your performance needs. With time to prototype playing such a critical role in the success of many projects, the time-savings to be had through readily available parts could be critical.

For a deeper dive into how this process works, let's look at how Kollmorgen works with robotics applications, specifically, frameless motors in a collaborative robotic joint.

A joint design requires many considerations. For this report, let's examine the following elements in more detail: payload capacity, speed, thermal management, and gearing considerations.

The payload capacity of a robotic joint application will likely be determined by the design for performance of the system. Usually, the reflected torque loads of such a design are modeled in CAD and give the designer some flexibility in determining how the "what if" system characteristic needs reflect to the motor requirements.

In the case of many collaborative type robotic arms, there is a particular small payload as set by industry-accepted "standards" as the norm. Depending on the length of the "arms" and the dynamics of the motion needed, the RMS and Peak motor torque can be determined from such CAD models.

The speed of the payload, or the distance it must travel per second, will be determined by the safety considerations and dynamics of the controller and mechanical system design. These design parameters will also be determined in the CAD-based models.

Often, the robotic system designer has a unique safety or control design element that is the heart of their "secret sauce," and perhaps their strength is not in the mechatronics portion of the design. This is where Kollmorgen's expertise can help reduce your design time and iterations.

The need for a design to take into account thermal management comes from several different considerations. Due to the close proximity of the robot in the work cell to humans, there is a need to maintain a "touch-proof" level of surface temperature of the robot relative to possible human interaction. Thermal insulation or padding could be added to a robotic design, but weight and bulk may be limiting to other performance or aesthetic considerations.

There may also be limitations for heat in proximity to other system elements such as gearing, feedback devices, and bearings. If a robotics designer looks to a motor vendor's standard catalog listings for maximum temperature ratings of their motor windings, he or she would nominally find temperatures of 155°C, as this reflects the industry-standard insulation systems used in conventional frameless and housed servo motors.

Even if the housing supporting the frameless motor includes significant thermal heat sink mass, the temperature within an inch or two of the motor armature may only be 15°C to 20°C lower than the motor winding temperature.

Many encoder feedback devices will want to keep opto-electronic components to a maximum of 100°C to 120°C, while most gearing solutions may have a 65°C temperature limitation. Possible solutions to this thermal limitation issue range from:

- Increasing the thermal heat sink mass that requires a trade-off of increased weight and reduced payload capacity
- Greater axial distance to bearings, encoder, or gearing, which also requires a trade-off of increased weight and reduced payload capacity
- Reduce the maximum winding temperature limit of the frameless motor design, which also reduces the available torque from the motor

If a gearbox in use has a maximum temperature rating of 65°C and a 15°C higher maximum winding temperature for the nearby motor, this would require a maximum winding temperature rating of 80°C. This information will then be used later in the motor selection process when evaluating actual motor capability using the Performance Curve Generator tool.

The robotic design engineer is able to see the actual continuous and peak torque and speed capability of a frameless motor using the Performance Curve Generator. The motor performance requirement data from the system CAD design can now be easily compared to the selected motor.

Due to the relatively low-speed nature of the rotation requirement in collaborative robotic joints, the use of gearing is very practical as long as the system backlash can be maintained at zero. The zero backlash and moderate stiffness capabilities seen in strain wave gearing lend themselves well to these applications.

Be sure to take into account the dynamic efficiency of torque transfer in the different gearing designs (often seen in the range of 60% to 70%).

Also, be aware of the

Kollmorgen's KBM series frameless motors provide high performance in a compact space.

thermal limitation of the lubrication required for any gearing type used, as the relative proximity of the gearbox to the motor may be close enough to limit system performance to stay within the manufacturer's recommended operating temperature range.

The benefit of a relatively high ratio gearing (typically about 100:1) is seen not only in the ability to increase available torque at the output, but also the significant reduction in reflected load inertia to the motor. The load inertia of a fully extended robotic arm with a maximum payload can be substantial.

The square of the gear ratio will reduce the load inertia value seen at the motor. In the case of a 100:1 gearing, the reflected inertia to the motor is 1/10,000th of the inertia of the load. Mechanical efficiency, thermal considerations, and system life expectancy all reflect on gearing type and ratio to be chosen in a robotic joint application.

With so many factors potentially affecting the operation and lifecycle of robotic motors, robotics manufacturers that make collaborative robots require a flexible and durable solution. The TBM series is an innovative direct drive frameless motor technology provided by Kollmorgen.

The TBM (Torquer Brushless Motor) series is designed for high-power, motion-critical applications such as robotic joints, medical robots, and sensor gimbals.

The frameless kit motors offer mechanical and plant engineering teams a wide range of solutions for creating applications with a maximum degree of flexibility, power density, dynamics, and durability.

In addition to the technical advantages provided, Kollmorgen's KBM and TBM platforms include a wide range of 17 frame sizes and many pre-engineered standard options. For robotics companies, from startups to those growing and expanding into new markets, this is a critical aspect of operations.

APPLYING AND VALIDATING YOUR SOLUTION

There can be little argument that the demands of today's marketplace don't leave much margin for error. Whether you're facing time constraints, demands for better performance, or even if you're already thinking about the next generation of equipment while the current one is being built, a variety of innovative motion solutions can rise to the challenge.

Working with quality tools and engineers can help make the difference in moving you from design to prototype to production, while ensuring that factors such as feedback, thermal, bearing, and gearing considerations don't get left out.

After all of the tools have been used and the 3D models put together and tested, the actual work of installing and validating your motor system is all that's left. The good news here is that there really isn't anything to fear when you're incorporating high-performance frameless motors into your machine design. Installation is relatively easy, since the shaft that the frameless motor will be mounted upon will be machined to tolerances well within the range required for robust performance.

CONCLUSION

A properly planned, specified and installed frameless motor can open the door to innovative solutions. While there may be a little more work involved in selecting and optimizing a frameless motor for your application over a standard servo motor, the results are worth it.

Working with a dedicated team of engineers from the beginning is the best way to prevent problems and ensure that no aspect of your application is overlooked. Whether you're trying to push the envelope and make something that's never been done before, or you simply want to make sure that your application is running at the peak of efficiency, the tools and the team at your service through Kollmorgen will make it possible.

APPLICATION PROFILE QUESTIONS

These are a range of design elements that should be discussed during the design process.

MOTOR REQUIREMENTS

Motor Type

- ☐ Housed
- ☐ Frameless
- ☐ Feedback options
  - ☐ Encoder
  - ☐ Resolver
  - ☐ Hall sensors
  - ☐ Other

Operating Environment

Operating temp: Min ____________ Max ____________________

Ambient temp: Min ____________ Max ____________________

Other: ____

Performance Data

Max speed: ____

Max torque: ____

Operating speed: _______________________________________

Operating torque: ______________________________________

Duty cycle: ____

Mechanical Envelope

Mounting requirements: __________________________________

Dimensional requirements: _______________________________

Inside dimensions: Min _____________ Max ________________

Outside dimensions: Min ____________ Max ________________

Weight requirements: ____________________________________

Available cooling: ______________________________________

Other requirements: _____________________________________

CONTROL / DRIVE REQUIREMENTS

Supply Voltage, AC/DC: ______________________________

Peak and Continuous Current: ________________________

Commutation Type

☐ Sinusoidal

☐ Six-step

Control Loop Type

☐ Torque

☐ Velocity

☐ Position

Operating Environment

Operating temp: Min __________ Max ________________

Ambient temp: Min __________ Max ________________

Other: ____

Other requirements: _________________________________