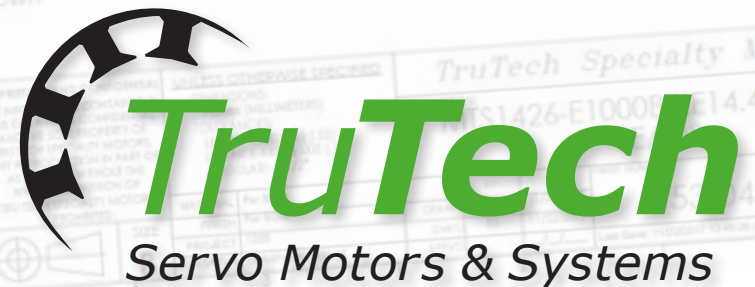


Optimizing Servo Motors for Increased Machine Performance

White paper guide for better performing equipment in today's ultra-competitive environment

Karl A. Meier



Optimizing Servo Motors for Increased Machine Performance

This white paper describes the evolution and implementation of electric motors in machine designs. With ever increasing expectations for additional machine performance, OEM designs today require more in-depth consideration of motors needed to perform required control and motion. There are a variety of rotary and linear motors available including AC or DC motor variants with several different winding technologies. Nearly all are available in varying forms and each have a place when fulfilling specific motion functionality as required.

The focus here will be on the advantages of rotary permanent magnet synchronous motors (PMSM) whether they are configured as AC variants, labeled as permanent magnet AC (PMAC) typically without feedback, or as DC versions, commonly referred as brushless DC (BLDC) with feedback devices. These motors are more prevalent than all others when providing machine control for discrete manufacturing and processing. With the updated set of methodologies and processes for supplying these servo motors, modern OEM designs can expect superior machine performance and with an increased competitive advantage when PMSM servo motors are utilized.

The choice of implementing servos already includes the most efficient and dynamic motors the market can offer. This potential allows OEM machine designers to extend that performance to their respective customers. Further, as those designers have many different motor choices available, all too often they want to gravitate to familiar vendor choices to ease development. Although this may seem a logical choice at first, it could be contrary to the best choices possible for maximizing machine operation.

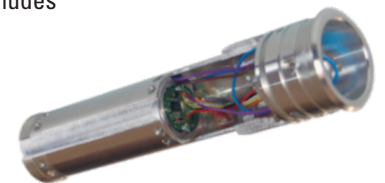
This document is intended to be a PMSM servo motor considerations process as laid out with the goal of providing machine designers and mechanical engineers best possible information for motor optimization. The factors outlined will allow a maximization of design efforts, regardless of the machine they are entrusted to design and deliver.

Re-examining Motor Choices at the Earliest Stage of Design

For any type of machinery or equipment that incorporates moving parts, the inclusion of electric motors has increasingly become a requirement. As such, there are regulated and mandated standards depicting energy efficiencies with pending requirements whereby implementing any electric motor can be quite an arduous task. Engineers and designers alike know that core to most machine's performance are motors as its most essential element. Given that, it is imperative that all options be reviewed early in the design process to maximize motor implementation.

In machine designs when motors are a part, whether for complete motion control or simply the control of motion (...these definitions can be vastly different and basically determined by what drives the motor and how that is controlled), often chosen is by what's available on the open market. Motor selection can be for a number of reasons: 1.) units are readily

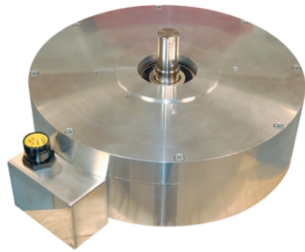
available, 2.) technical information of the motor selected can easily be found for overall machine incorporation, 3.) maintaining the expected motor 'envelope' might be simple to achieve with many selections possible. Regardless, rarely is a second thought given which typically concludes continued motor consideration. However, does a selection such as that result in the best possible choice? In many more cases than not, the answer is "No!" Better alternatives are more than possible and are becoming more essential to the selection process.



Small frame, assembly tool arm integrated PMSM motor used in the manufacturing process for tightening fasteners.

Mechanical engineers and/or machine designers have many decisions to make during the design of a machine. As motors are a portion of the design task with only calculated or given references for speed and torque requirements, along with perhaps a minimal set of electrical and mounting criteria, the selection process may seem to be straightforward. Where readily available motor(s) meet those basic concerns, a decision can easily be made to merely choose something and continue with the remaining machine design needs. Though, an important review point here would be to know if that decision would result in the best possible outcome? The answer can have significant impact on the machines

overall fit, form, function and resulting design that would ultimately follow. For instance, did that choice: 1.) limit overall performance capabilities, 2.) revise the potential of reducing machine size, 3.) impede or constrain needed environmental operations, or 4.) alter choices where many other machine design parameters may no longer be achievable? All are valid concerns needing resolution well in advance of final motor selection.



IP67, 330mm (O.D.) PMSM motor used in submersible water pumps optimized for delivering high torque at low speeds.

PMSM servo motors are compact, cost-effective, come in various form factors, perfect in controlled motion applications and typically implemented anywhere from 10's of Watts up to 30 kW of power as required.



AGV hub traction assembly utilizing standard frame PMSM motor and gearhead (gearhead courtesy of Auburn Gear).

The simple fact is that PMSM servo motors provide the machine or equipment with a lifetime of constant start and stop motion, deliver extremely fast speeds with exceptional acceleration/deceleration performance.

Implementing PMSM servo motor technology has allowed machine and equipment builders to achieve unparalleled process throughput and higher levels of quantity output. PMSM servo motors are now being tailored to equipment to keep them more than competitive and with typical 'best-in-class' performance.



IP68, Autonomous Underwater Vehicle PMSM motor including purging ports.

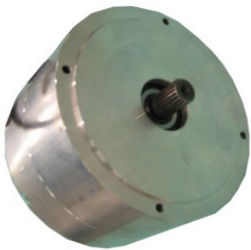
Taking a Fresh, New Look at PMSM Motor Optimization and Implementation

PMSM servo motors have been on the market now for over 30 years. In that time, they have become a standard in allowing machines to flawlessly perform in a variety of applications. Known for their extended lifetimes and providing increased performance compared to other technologies, PMSM servo motors have grown to become the new standard across several industries including: robotics, assembly automation, medical and healthcare, packaging, food processing, defense and security, material handling, entertainment, automated warehousing, machine tool, metal working and many, many more.



Low voltage, IP67, PMSM motor specifically designed for submersible use.

No longer considered for indoor factory machinery use only, new markets and applications continue to be presented with PMSM delivered solutions for mobile and portable equipment with operation in severe or caustic environmental conditions. Previous solutions were considered unobtainable but then PMSM servo motors implemented with high ingress protection construction and other internal containment considerations, solutions are now a reality. Another trend has been to replace pneumatics and hydraulics where possible as equipment energy efficiencies are vastly improved. PMSM replacement solutions in these cases lead to longer-lasting hardware with lowered operational costs resulting in vast savings over the life of equipment.



AGV hub traction integrated PMSM motor subassembly needed to reduce overall profile length.

To get to an ultimate solution where PMSM servo motors are desired or required, some of the first questions to ask should be much broader than... "I wonder what's available out of a catalog?" On many occasions, simple catalog selection returns a compromise of performance. Not the least of which is that it met the minimum of set of requirements! The real questions machine designers and mechanical engineers need to ask, among a host of others, include:

"Will simple motor selection(s) end exploration of other options for best possible machine performance?"

"How does implementation of the motor(s) have an effect over the entire system or process?"

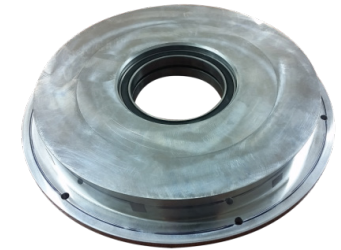
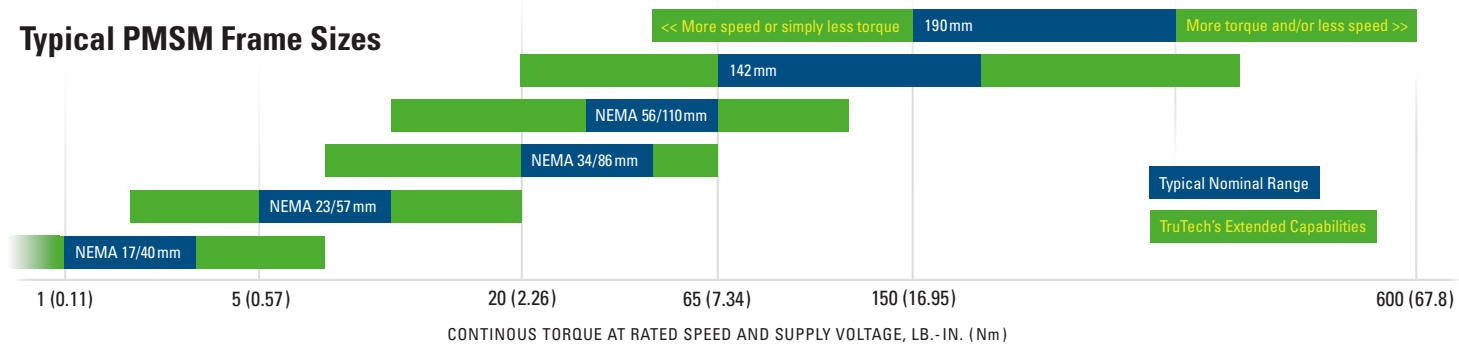
"Does my motor selection eliminate possible machine size reduction or performance capabilities through continued evolution from a different motor's inclusion?"

"Would this motor selection lead to a void in further consideration for best possible machine functionality when ignoring alternatively tailored solutions?"

All answers lead to important decision criteria. The design of machines simply should not stop because a motor might come from a catalog as this could essentially lead to a compromise of overall potential. As engineers and designers uncover requirements, it is inherent to explore and expand the possibilities as the result could allow for the best design possible.

For instance, if market available frame sizes are desired but speed/torque requirements differ, results are still very possible. Figure 1 (next page) is indicative of typical frame sizes where speed/torque can easily be altered within a given form factor by focusing on the application while still accommodating similar mounting needs. Seemingly 'non-typical', simple solutions like these have been more than achievable and delivered by supplying companies that know how to partner with their customers.

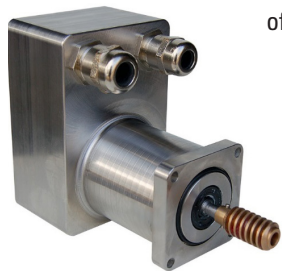
Typical PMSM Frame Sizes



IP67, 300mm (O.D.) hollow shaft, high voltage and torque, outer rotational PMSM motor used in food processing.

FIGURE 1

Further, design requirements for machines or similar equipment that already have many more constraints and atypical of any given frame size, such as food processing or sub-sea deployment, available choices will not be satisfactory or meet expected operation. Mechanical engineers and/or machine designers automatically consider alternative possibilities as they already know that meeting design objectives from alternative solutions will be required. These results are fully optimized PMSM servo motor solutions that not only meet or exceed their expectations but also allows them to extend design benefits to other portions of the machine during the design. For example, multiple benefits can also be realized when implementing a frame integrated motor as it shortens and lightens the overall machine size and weight. Respectively, so too is a reduction of overall costs.



IP 68 seamless enclosure, stainless-steel housing PMSM servo motor with watertight cable entry glands and customer specified pitched screw shaft adapter for harsh environment compliance.

In many cases, simply asking additional questions leads to the incorporation of more aspects and considerations. Given a machine with overall execution requirements and pending environmental operation, a PMSM motorized solution may ultimately be conceived that not only includes performance gains but also a reduced set of componentry. After all, this is

an exciting aspect of engineer's and designer's duties that incorporates motors while also leading to the best possible solution across the machine's platform. Not just considering the minimal aspects of the axes involved.

OEMs strive for best-in-class machinery but are not always sure how to get there. Tailoring PMSM servo motor solutions is one method to achieve that. OEM's customers worldwide have proven to appreciate in advance designs that encapsulate higher performing, longer lasting, smaller sized, lighter weight and lower cost machine solutions.

To help designers and engineers achieve this, listed here are the major criteria with additional considerations that dictate a final PMSM servo motor system's design to allow for delivery of the best machine available. For the most part, exacting technical details are not needed as anything is conceptually possible (...except those that defy the laws of physics!) Once a concept is presented with basic information given, specific results can quickly be generated and prepared for complete review. A PMSM servo motor supplier that is established with a corresponding flexible operation can easily produce optimized motors, thereby maximizing any OEM's machine's or equipment's capabilities.

PMSM Servo Motor System Considerations and Design Criteria

SPEED – The applied voltage to a motor is directly proportional to motor speed. Where higher or lower speeds are required, applied motor voltage may limit desired outcome. However, stator windings can easily be made to specifications that allow for increased or decreased speeds given the voltage requirement, with consideration for torque. This factor is called K_e and given in Volts/krpm and can have a wide range of possibilities.

TORQUE – Available current to a motor is directly proportional to motor torque. Where increased or decreased torque is needed, available current may not always be in line. As well with speed, the stator winding specification can easily be made to increase the torque for lowered available current, with consideration for speed. This factor is called K_t and given in Nm/Amp. Another option to increase torque, where plenty of current is available and overall length is not an issue, is to add to the stator length and/or number of stacks while retaining the frame size.

VOLTAGE – The nominal or expected voltage sourced to the motor will determine the speed (see above). The windings in the motor are produced knowing that applied voltage. Since power electronics are in the system, i.e. servo drives, the resulting voltage the motor observes is considered DC, whether the power to the electronics is connected to a DC source or rectified DC from an AC line. Motor windings can therefore explicitly be specified for any voltage, including 10 to 80 VDC for low voltage needs, typical: 90, 120, 240, 480, 525 VACs line sources or higher! Knowing supply voltage is critical to any application success.

INERTIA – The overall design of the rotor results in the angular mass and determines needed torque while accommodating targeted acceleration/ deceleration aspects. Considering in advance all aspects of design and materials, load inertia matching can be key specifications to a given application. Mismatches in inertia can be of large concern given overall momentum of the load.

FRAME SIZE – Sizing is typically predicated by the torque requirements. As standards are always available, so too come with them the general constraints of housing sizes. When defining specifications to any given application, these can readily be opened for ‘best fit’ considerations while not having to follow any ‘standard’ as desired for operation. As well, frameless motors allow for stators to become a part of the machine frame itself and are increasingly popular while driving down overall costs/size.

IP RATING – Ingress Protection ratings afford the application proper sealed motor enclosures as required. Increased protection comes with vastly improved sealing, and with multiple methods, for both the housing portions and bearings where required.

MOUNTING – Again, standards are readily available but can also be expanded where additional requirements may be desired. Not having to follow a pre-determined mechanical interface allows for increased options.

SHAFT – Typically, these are stainless steel with available standards defining potential interface to the motor. However, multiple alterations of material and configuration can be specified as deemed necessary by the developer/application. This ranges widely and includes specifics for diameter differences, shape variations, keying, etc.

HOUSING MATERIAL – With housings typically made from aluminum, or powder coated external laminations, and the fact that they can see differing environmental conditions, dictates reviewing all types of variations to match application needs. Metals and coatings can be specified as required to match expected use.

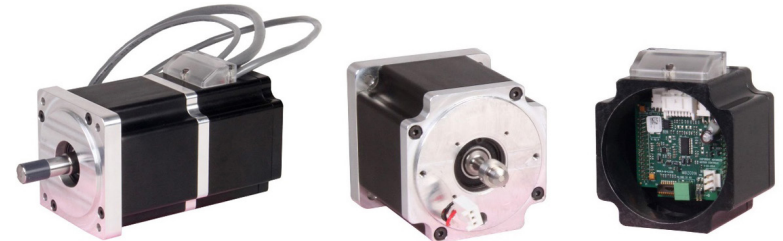
WIRING / CONNECTION – Multiple variations for termination of wiring to the motor can be made. Available components can readily be applied or, specifying both wire and connector types, can easily be adapted.

GEARBOX / ACTUATOR – As the motor itself becomes part of a larger assembly, incorporating other mechanical aspects such as gearing or actuation, the new ‘system’ can be made to stand alone. This further reduces size and unit costs to be inclusive as an ‘all-in-one’ component.

BRAKE – As another optional component to ensure proper application solution, adding brakes to a motor can easily be achieved where necessary and included as part of the motor system.

FEEDBACK – Many market encoding devices are available and can be specified as required for the application. Usually rear mounted, this portion of the rotor’s shaft can be altered as needed and the end cap of the motor modified to fit overall motor design.

ELECTRONICS: DRIVES / NETWORKS – Incorporating the drive’s power electronics and digital network is another trend in servo motor technology. This further reduces not only the number of machine components overall but also the complexity of the wiring. In the age of Industry 4.0, the ability to incorporate intelligent electronics in the motor is here to stay.



Integrated servo drive-PMSM motor assembly; separated to show component blocks (drive courtesy of ADVANCED Motion Controls).

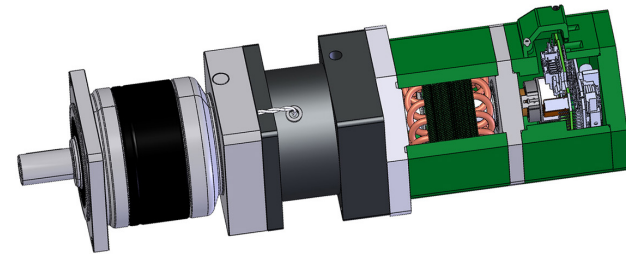
When considering a PMSM servo motor as a part of the entire machine design, most motor design parameters are alterable and can be tailored to the requirements as desired. A systematic and considerations process approach can overcome most limitations and deliver a best possible solution. End results can quickly be prototyped, and production units made readily available.

Concluding with Optimized PMSM Servo Motor Knowledge and Selection

In nearly every case, implementation of a PMSM servo motor is an excellent solution for any motion system. It can also be a key aspect and/or concern for overall machine performance and appearance. Often, completely optimized solutions come as an extension of existing designs and/or previous know-how. Providing an optimized servo motor solution that is completely integral to overall machine design allows for greater flexibility in the end and an increased possibility for those machines to surpass competitor's offerings within the marketplace.

Along with proven various examples and images throughout this paper, the goal here was to help broaden the perspective of mechanical engineers and machine designers alike and provide input as to how any machine design can be improved by accurately assessing PMSM servo motors and their selection. By noting additional considerations should really be the first choice when reviewing PMSM servo motor requirements, solutions for the overall machine design itself could greatly be increased. Applying realized potential while adding more benefit and value, all areas of the design should be considered. Avoiding this could

cause limitations when using standard motors. With fast turn-around, optimized PMSM servo motor designs that are manufactured with similarly engaged production practices, machine designers can now rely on motors that are tailored to their designs. This affords more design flexibility and, quite often, lowered capital and machine production costs that exceed original expectations.



Realized concept of integrated PMSM servo motor assembly including servo drive with CANopen networking, magnetic encoder, mechanical holding brake and planetary gearhead.

ABOUT THE AUTHOR

Karl A. Meier is the Executive Vice President at TruTech Servo Motors & Systems. He has worked in the controls industry for over 35 years and has a BS in Electrical Engineering with an MS in Computer Science. He can be reached at kmeier@trutechmotors.com