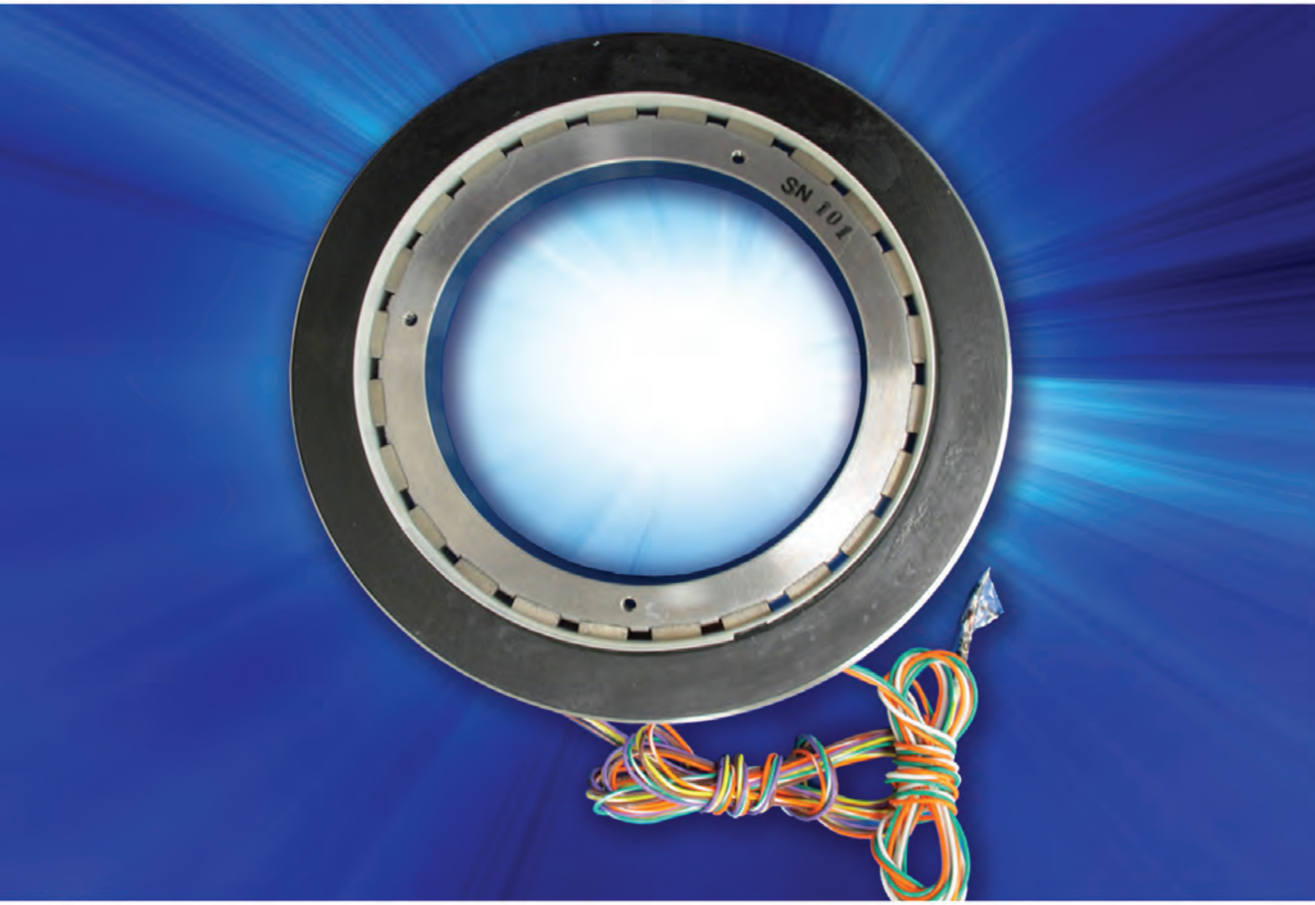
GENERAL DYNAMICS
Mission Systems



Brushless DC Motors Handbook

General Dynamics Mission Systems (GDMS) Precision Pointing and Motion Systems is experienced and ready to build a high-quality system solution for your specific application.

GENERAL DYNAMICS
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Selection Guide Tables

User's Guide

The GDMS Brushless DC Motor Manual is organized in a manner which makes it easy to access the product performance information. Starting with the Design Guides, you should be able to locate the specific brushless motor which best suits your needs.

The Selection Guide is the first page in each brushless motor section.The Selection Guide lists the products featured, basic parameters, and the page where the datapage can be found. Immediately following the Selection Guide are the individual datapages. On each datapage are end and cutaway views of the product, as well as winding and performance data.

Sample Datapage

Model Number

GENERAL DYNAMICS
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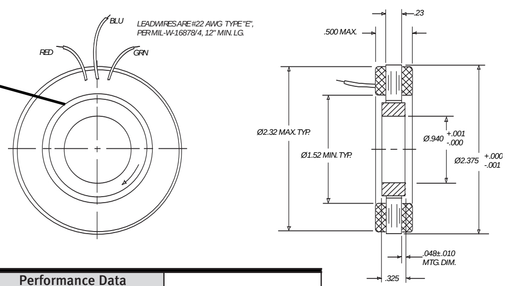
2375H-050
Brushless DC Motors

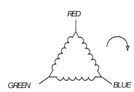
Motor Drawing



Performance Data

Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	60
Power at T_p (P_p)	watts	160
Motor Constant (K_m)	oz-in/$\sqrt{W}$	4.74
Electrical Time Constant (τ_e)	milli-sec	0.54
Mechanical Time Constant (τ_m)	milli-sec	10.0
Damping Factor (F_o)	oz-in/rad/sec	0.160
Moment of Inertia (J_m)	oz-in-sec^2	0.0016
Total Breakaway Torque (T_f)	oz-in	1.0
Temperature Rise (TPR)	°C/watt	4
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	5.5
Number of Poles		8
Number of Phases		3

ROTATION: FIELD ROTATES CW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: RED+, GREEN-; BLUE+, GREEN-; BLUE+, RED-.



SCHEMATIC

Winding Constants

Winding Constants						
Parameter	**UNITS**	**TOL.**	**-013**	**-033**	**-052**	**-131**
Resistance (R)	ohms	±12.5%	1.3	3.3	5.2	13.1
Voltage at T_p (V_p)	volts	Nominal	14.4	23.3	29.2	46.5
Current at T_p (I_p)	amps	Nominal	11.1	6.90	5.50	3.45
Torque Sensitivity (K_t)	oz-in/amp	±10%	5.40	8.70	10.9	17.4
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.039	0.061	0.076	0.120
Inductance (L)	millihenries	±30%	0.7	1.8	2.8	7.1

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Motion Control Packages

For decades, GDMS has provided solutions for complex applications such as ultrasonic imaging systems, semiconductor process, mechanisms, aircraft actuation and missile guidance systems. The mechanism section of the GDMS Brushless DC Motor Manual gives a brief overview.

Design Guides

At the end of this catalog, you will find a DC Motor Design Guide, which prompts you to answer the necessary questions about your current motor requirements. The Design Guide is especially useful when your project calls for a custom solution. We recommend you make copies of it to use as worksheets when deciding on your brushless motor requirements.

GDMS Motion Control Products Introduction

Heritage

GDMS has been serving the commercial,industrial and defense motion control industries for 40 years, supplying high performance components and systems that stand up to the most rigorous environments. We supply high performance products that withstand 700 g's of shock, 15,000 lbs of pressure, and temperature ranges from -55°C to +200°C, for applications from aerospace to medical, textile to robotics.

From our inception, GDMS has continuously challenged technological limitations, developing state-of-the-art motors, position feedback devices, and electromechanical assemblies for the rapidly evolving commercial, industrial, defense, aerospace, and medical industries. Equipped for innovation, with a world-class team of engineers and a global support network, GDMS is uniquely able to apply this high performance technology to your system needs, at a competitive cost.

Design and Manufacturing

Your GDMS design begins with a detailed review of your specifications by our engineers. If you have not established formal specifications, our engineers will help develop them with you. We use computer aided design programs, design, and process control specifications to assure the product will meet your specifications.

GDMS manufacturing cycle brings with the establishment of a Materials Requirements Plan (MRP). With the aid of an integrated computer planning/scheduling system, detailed production schedules are generated to ensure on-time material delivery, optimal output, and inventory levels.

Customer Service

At GDMS, service does not end with the delivery of your products. Service and support are our most important responsibilities, and we meet them with our network of technical support staff that stretches around the world. Our engineering, manufacturing and quality experts - in fact, all employees in our entire organization - are ready to serve you from concept, through development, to order delivery, and beyond.

Quality Assurance

We have established the internal quality systems required for high-reliability commercial and defense programs. GDMS Quality System is certified to AS9100.

Manufacturing Operation

GDMS has a modern 60,000 square foot facility in San Diego, staffed by dedicated employees.We can easily accommodate contracts from the development phase through full-scale production.

We encourage factory tours. Our operations include an extensive CNC machine shop, automated armature winding station, organized work centers, and environmental and performance testing equipment.

Brushless DC Motors

The mechanical switching of current associated with brush motors is replaced with electronic switching in brushless motors. Brushless DC motors are not simply AC motors powered by an inverter, instead these devices use rotor feedback devices so that the input wave forms are kept in proper timing with the rotor position. Some form of electronic commutation switching is necessary for all motors, except in the limited angle devices.

Brushless DC motors with suitable control electronics can be directly substituted for similarly-sized brush DC motors. Brushless DC motors provide several advantages:

1. Brushless units may be operated at much higher speeds and at full torque at these speeds, resulting in a motor with considerable power output for its size. High speed operation is especially difficult for conventional DC motors because the high energy that must be switched by the brushes is destructive and shortens motor life. In brushless motors this energy can be handled by the drive circuits.

2. The stator, which is wound member, may be mounted in a substantial heat sink to minimize temperature rise and prolong bearing life.

3. Where long life is a requirement, the absence of brushes normally increases the motor's life expectancy to that of the bearings.

4. In high-cleanliness applications, unacceptable brush wear particles are eliminated.

5. The EMI (Electromagnetic Interference)normally associated with the arcing of the brush commutator interface is eliminated in the brushless motor. Brushless DC controllers are generally free of major EMI contributors.

6. For explosive environments, a brushless motor can be used without special housing elements necessary to explosion-proof a conventional DC motor.

7. Although brushes have been used extensively in space environments, their preparation is expensive and time consuming.The brushless motor requires much less preparation.

Typical Applications

Brushless DC motors have the same electrical performance operating (transfer function) characteristics as brush-commutated DC motors, and can be used in the same applications.They provide high starting torque, variable bi-directional speed operation, and precision position and velocity servo loop capabilities. They can also replace AC motors in spindle and rotary table drives where the higher torque DC motor can drive the spindle directly, eliminating the need for a belt and pulley.

Basic Components

A brushless motor system consists of four basic subassemblies:

1. A stator wound with electromagnetic coils which are connected in single and poly-phase configurations.

2. A rotor consisting of a soft iron core and permanent magnet poles.

3. A rotor position sensor providing rotor

The gearless DC motor drive is ideally suited to high acceleration applications requiring improved response for rapid start/stop actions.

Applications	Equipment	Brushless DC Advantage
Velocity Servos	Disk Memory Spindle Drive	Long Life, Low-EMI
	Video Tape Recorder	High Speed, No Brush Debris
	Silicon Water Spinner	High Speed, Long Life
	CAT Scanner	Low-EMI, Low Audible Noise
	Infrared Imager	High Speed, Low-EMI
	Artificial Hearts	Long Life, No Brush Debris
	Cryogenic Compressor	No Brush Debris
	Fuel Pump	No Arching No Brush Debris
	Air Bearing Spindle	No Brush Debris High Speed
Position Servos	Space Vehicle	Vacuum Operation Low-EMI
	Optical System	No Brush Debris
	Stable Platform	Low-EMI
High Power Density	Robot	Low Thermal Resistance
	Airborne Actuator	Low Thermal Resistance Vacuum Operation

position to the required resolution.

4. Commutation logic and switching electronics to covert rotor position information to the proper stator phase excitation.

Stator

The stator for a brushless DC motor is a laminated steel core with coils of magnet wire embedded and connected in two or more phases so that by sequentially exciting these phase winding, a rotating electromagnetic field can be generated.

Since both iron and copper losses in the brushless DC motor take place in the stator, generated heat is easily transferred to the surroundings. A motor with an inner rotor is better in this regard due to the larger stator area in contact with the mounting surfaces.

Rotors

In all continuous rotation brushless DC motors, the permanent magnetic field is on the rotor. The winding supplying the rotating electromagnetic field are in the stator. The rotor can be designed inside of the stator, as in a conventional motor, or outside of the stator. See Figure 1A and 1B. The inner rotor design is generally used in incremental motion application where low inertia and fast response are required. The outer rotor configuration provides a more rigid structure for the permanent magnets and has higher inertia. It is used in high speed applications where a stiff structure is required to counter the centrifugal forces acting on the permanent magnets, in velocity loop applications where the additional rotor inertia is desired for velocity stabilization, or when the additional inertia is insignificant relative to the total inertia as in a memory disk drive.

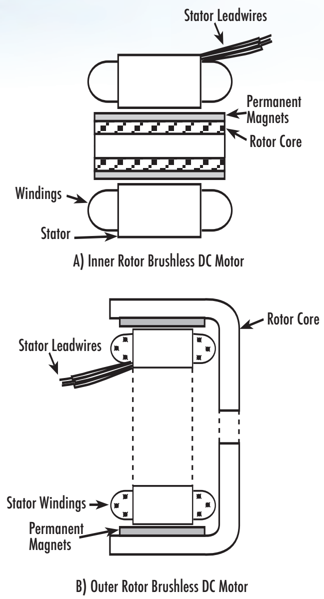


Fig. 1 Brushless Motor Configurations

Position Sensors

There are several ways to sense brushless rotor position. Rotor position sensing is necessary so the stator winding excitation can be controlled to keep the electromagnetic field in leading quadrature with respect to the rotor field. These methods fall into three categories: photo-electronic, electromagnetic, and magnetic.

PhotoElectronic

A set of photo-transistors and LEDs are coupled across a shutter which is keyed to the rotor and has windows in the proper pattern to control the phase excitation. If a shaft angle encoder is required in the system for normal shaft position sensing, a separate pattern track can be included on the disk for motor commutation. The output of an absolute encoder can also be used in a sine cosine ROM or as input to a digital comparator to develop the commutation waveform.

Electromagnetic

Electromagnetic sensors use a soft iron target and a set of wound coils. Changes in the coil inductance are sensed and decoded to verify rotor position. Eddy current devices using metallic targets can also be used in the same manner. Brushless resolver are commonly used in sine cosine systems as the source of the phase quadrature waveform.

Magnetic

Hall effect sensors, magneto-resistors, or magneto-diodes are used in magnetic sensors. These devices work directly off of the rotor poles so that the alignment of the sensors can be accomplished during the manufacture of the stator. They become a part of the stator assembly so that the user need only install the rotor to have an aligned system.

Electronics

The electronics module, which can be internal to the motor housing or placed on an external printed circuit board, receives the signals form the position sensors and uses digital logic to develop the wave-forms that are used to control the switches. These switches are usually power MOSFET, IGBT, or bipolar transistor devices. The selection of the type of power switch depends largely on the application and includes factors such as the motor voltage, peak motor current, PWM frequency, and the operating characteristics of the motor.

In general, power MOSFET'S, because of the very low "on" resistance exhibited by this type of device, are the switches of choice while IGBT'S are most common in high voltage brushless motors driver where the motor voltages are on the order of several hundred volts.

Also, for high power applications, most modern three phase brushless drivers are designed to operate directly off of the 230 VAC or 440 VAC power line, eliminating the need for separate power supply lines, and the need for a separate power supply to generate the switch bus voltages. These drive systems almost always use IGBT power devices because of the high voltages encountered and the high efficiency achieved with direct line powered operation.

In a sine-cosine system, the electronics module is a two phase bipolar amplifier. The sensor output are first decoded or demodulate (if required), and then amplified by a four quadrant power amplifier. To reduce power dissipation in the amplifier, pulsewidth modulation is often used. This type of system is more costly than the digitally switched system. For this reason, is used only when the applications needs the smooth, low ripple torque of a sinusoidally-commutated brushless motor.

Brushless DC motor controllers offer many power levels and commutation options. Standard controller products are available providing closed loop control of speed or torque, accepting Hall sensor, optical encoder or resolver position sensor signals. Often in low power applications, the control electronic are an integral part of the motor and range from single commutation and switching circuits to complete speed control systems. Many IC's combining commutation, current sensing, fault detection, and power switch drive functions provide cost effective Brushless DC motor control.

Commutating Brushless DC Motors

Torque and Winding Characteristics

The basic torque waveform of a brushless DC motor has a sinusoidal or trapezoidal shape. It is the result of the interaction between the rotor and stator magnetic fields, and is defined as the output torque generated relative to rotor position when a constant DC current is applied between two motor leads. This torque waveform is qualitatively equivalent to the voltage generated waveform at the two motor leads when the motor is driven at a constant speed by another motor. The frequency is equal to the number of pole pairs in the motor times the speed in revolutions per second.

The brushless DC motor will exhibit torque speed characteristics similar to a conventional DC motor when the stator excitation is in proper alignment with the rotor's magnetic field. The stator excitation may be square wave or sinusoidal. Ideally, the stator excitation may be square wave or sinusoidal. Ideally, the stator excitation should be applied in a sequence to provide a constant output torque due to the finite commutation angle. The commutation angle is the angle the rotor rotates through before the winding are switched. Ripple torque is typically expressed as a percentage of average to peak torque ratio. It is present whenever the winding are switched by a step function either electrically via solid state switches or mechanically via brushes.

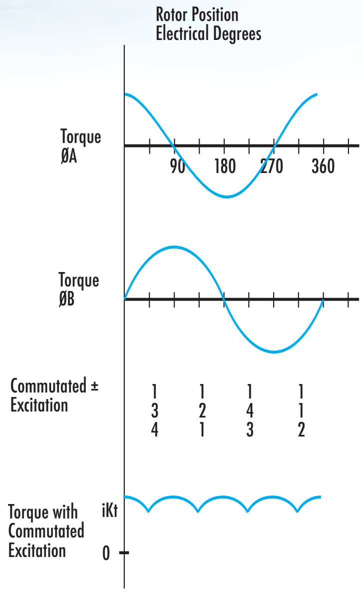


Figure-2. Switch mode commutation of a two phase brushless DC motor.

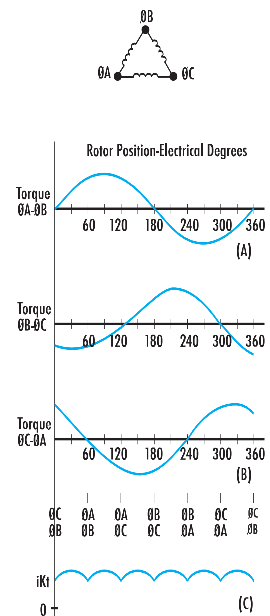


Figure-3. Switch mode commutation of a three phase delta wound brushless DC motor.

In brushless DC motors designed for square wave excitation, the ripple torque can be reduced by reducing the commutation angle by using a higher number of phases, which also improves motor efficiency. Figure 2 shows the commutation points and output torque for a two phase brushless motor.The commutation angle is 90 electrical degrees which yields the largest ripple torque of about 17% average to peak.A three phase delta system is shown in Figure 3.The commutation angle is 60 degrees and the ripple toque is approximately 7% average to peak. Since two-thirds of the available winding are used at any one time, compared to one-half for the two phase system is more efficient.

The torque waveform indicated in Figure 2 and 3 have a sinusoidal shape.A trapezoidal torque waveform can be obtained by using a salient pole structure in conjunction with the necessary lamination/ winding configuration. In practice, the trapezoidal torque waveform does not have a perfectly flat top. Manufacturing and other cost considerations result in an imperfect trapezoidal waveform. An example is Figure 4 where the generated voltage waveform across two terminals of a brushless motor designed for trapezoidal torque generation is Shown. Figure 5 is an example of a 12 phase brushless motor with a trapezoidal torque waveform. With the center terminal of the phases connected to the supply voltage, the phases are switched to ground during the indicated commutation angle of 30 electrical degrees. Only three phases are "on" at any one time. This motor was designed to satisfy the requirements of high efficiency and minimum ripple torque for a precision pointing and tracking space gimbal application. In applications requiring smooth

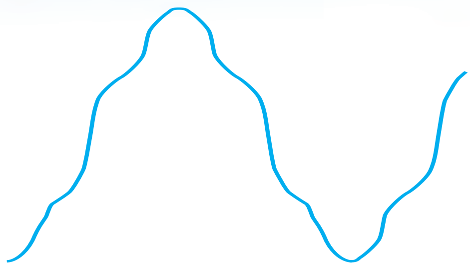


Figure-4. BEMF Trapezoidal waveform.

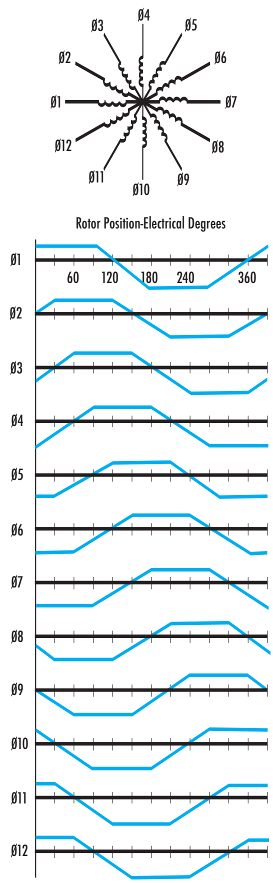


Figure-5.Torque waveform for 12 phase brushless DC motor.

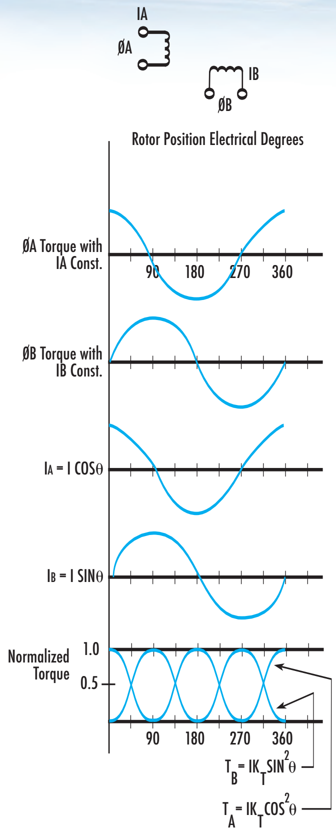


Figure-6.Two phase sinusoidal excitation.

operation at low speed, or where the motor is operated in a position loop, a sinusoidal drive system should be considered. Figure 6 is an example of a two phase motor designed for sine wave drive.
The torque output of each phase is:

$T_A = I_A K_T \cos\theta$
$T_B = I_B K_T \cos\theta$
Where

I_A = current in phase A
I_B = current in phase B
K_T =torque sensitivity of motor
θ = rotor position in electrical degrees

If the motor currents are supplied in the following relationships:

$I_A = I \cos\theta$
$I_B = I \sin\theta$

The torque output of the motor is:

$T = T_A + T_B$
$T = I K_T(\sin^2\theta + \cos^2\theta)$
$T = I K_T$

This analysis indicates that the sinusoidally driven brushless motor has linear characteristics similar to a conventional DC motor and has minimum ripple torque. Three phrase winding can be connected in either wye or delta configuration. Excitation can be switch mode or sinusoidal drive. The switch mode drive is the most commonly used system because it results in the most efficient use of the electronics. Two switches per phase terminal are required for the switch mode drive system. Therefore, only six switches are required for either the wye or delta configuration.

The delta winding form a continuous loop, so current flows through all three winding regardless of which pair of terminals is switched to the power supply. Since the internal resistance of each phase is equal, the current divides unequally, with two-third of the total current from one winding to another as the winding are commutated.

For the wye connection, current flows through the two winding between the switched terminals. The third winding is isolated and carries no current. As the winding are commutated, the full load current must be switched from terminal to terminal. Due to the electrical time constant of the winding, it takes a finite amount of time for the current to reach full value. At high motor speeds, the electrical time constant may limit the switched current from reaching full load value during the commutation interval, and thus limits the generated torque. This is one of the reasons the delta-configuration is preferred for applications requiring high operating speed. Other considerations are manufacturing factors which permits the delta configuration to be fabricated with lower BEMF constant, resistance, and inductance. A lower BEMF constant allows the use of more common low voltage power supplies, and the solid state switches will not be required to switch high voltage. For other than high speed applications, the wye connection is preferred because it provides grater motor efficiency when used in conjunction with brushless motors designed to generate a trapezoidal torque waveform.

Sensor Timing and Alignment

A brushless DC motor duplicates the performance characteristics of a DC motor only when its winding are properly commutated. Proper commutation involves the timing and sequence of stator winding excitation. Winding excitation must be timed to coincide with the rotor position that will produce optimum torque. The excitation sequence controls the polarity of generated torque, and therefore the direction of rotation.

Rotor position sensors provide the information necessary for proper commutation. Sensor output is decoded by the commutation logic electronics. The logic signals are fed to the power drive circuit which activates the solid state switches to commutate the winding.

The commutation points and output torque for a two phase brushless motor were shown in Figure 2. The commutation angle is 90 electrical degrees, and the winding are switched "on: 45 electrical degrees before the peak torque position. The current polarity must be reversed for negative torque peaks. The commutation waveform for this motor are shown in Figure 7. Sensor output and alignment is shown in figure 7A. The S1 output leads the phase B torque position by 45 electrical degrees.

There are several methods for aligning the S1,2 sensors with respect to the stator winding. As shown in Figure 2, the peak torque position of phase B coincides with the zero torque position of phase A and vice versa. Sensor S1 can be aligned to the phase B winding by applying a constant current to phase A. The rotor will rotate to phase A's zero torque position. S1 should be positioned so that its output just switches from a low to high logic state at 45 electrical degrees counter-clockwise from phase A's zero torque position.

Another method is to align the position sensors to the BEMF waveform. Since the BEMF waveform is qualitatively equivalent to the torque waveform, the motor can be driven at a constant speed by another motor, and the position sensors aligned to the generated BEMF waveform. The sensor transition points relative to the BEMF waveform should be as indicated in Figures 2 and 7. For critical applications which require the commutation points to be optimized, the motor should be operated at its rated load point, and then the position sensors should be adjusted until the average winding current is at its minimum value. To facilitate sensor alignment, GDMS can supply stators

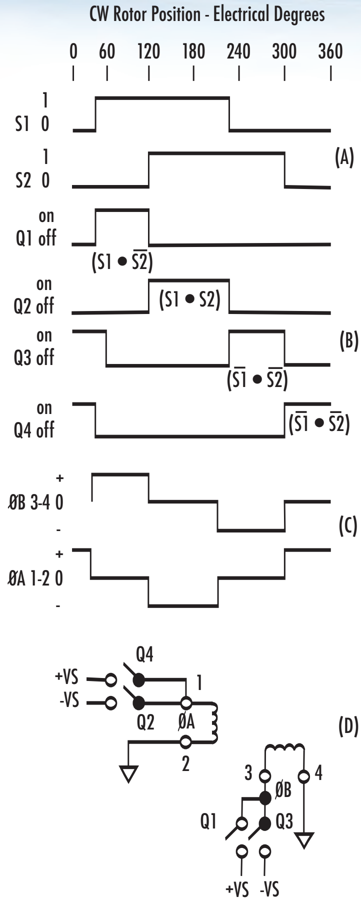


Figure-7. Sensor output, commutation logic, and and winding excitation waveform for a two phase brushless DC motor.

with reference marks to which the position sensors can be aligned.

The commutation points and output torque for a three phase brushless motor was shown in Figure 3.The commutation angle is 60 electrical degrees, and the winding are switched "on" at 30 electrical degrees before the peak torque position, and switched "off " at 30 electrical degrees after the peak torque position. The current polarity for

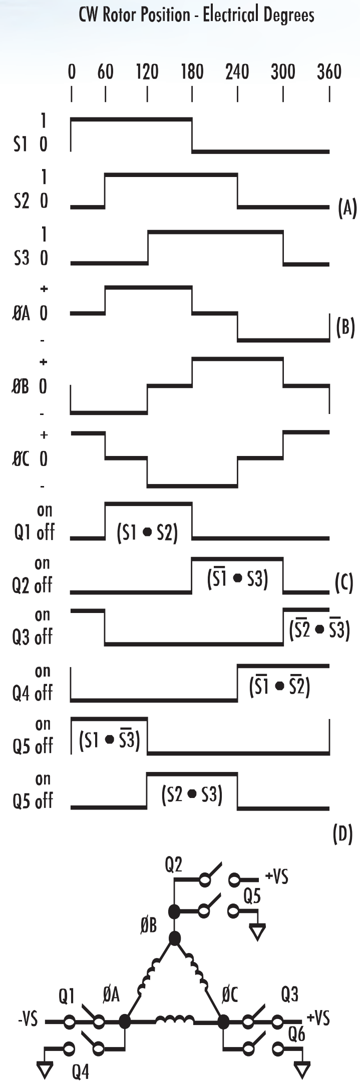


Figure-8. Sensor output, commutation logic and winding excitation waveform for a three phase brushless DC motor.

each phase during each commutation segment is shown in Figure 3B. The commutated output torque versus motor position(in electrical degrees) is shown in Figure 3C.

To identify each of the 6 commutation terminals, a minimum of three logic signals are required. The commutation waveform are shown in Figure 8. The three sensors are spaced 60 electrical degrees apart, and have a 50% duty cycle.

As indicated in Figure 3 and 8, sensor S1 can be aligned to the ∅A-∅B zero torque position.

This can be accomplished by applying a constant current to the ∅A-∅B terminals. The rotor will rotate to the ∅A-∅B zero torque position. Then S1 should be positioned so that its output just switches from a low to high logic state S2 and S3 should be positioned 60 and 120 electrical degrees respectively from S1. Other alignment considerations are as previously discussed for the two phase motor.

Sine Wave Drive

The sine wave drive control scheme is the best choice when the brushless motor is required to duplicate the performance characteristics of a conventional DC torque motor. Brushless DC torque motors designed to provide sinusoidal torque waveform have the additional advantage of minimum ripple torque and high reliability when

compared to the brush-commutated DC torque motor.

The basic equations for controlling motor current and the resulting output torque for a two phase Brushless DC torque motor were shown in Figure 7. The control method consists of developing drive currents that are a sinusoidal function of the rotor position. AS mentioned previously, position information can be obtained from a variety of

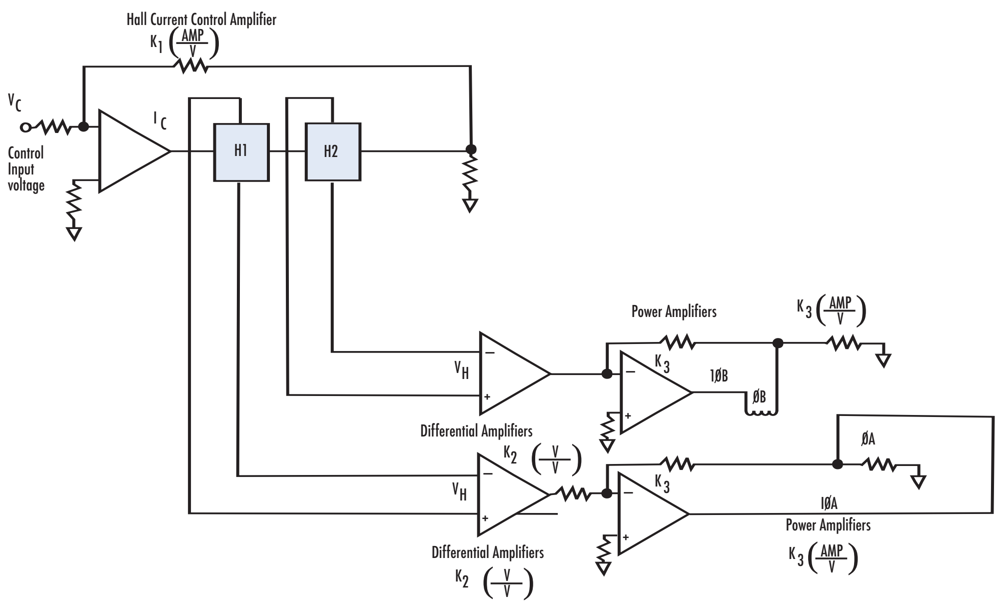


Figure-9. Functional control circuit for a two phase brushless DC torque motor with Hall Effect rotor positioning sensing.

devices. Hall effect elements, sine cosine resolvers, optical encoder, electromagnetic and electrostatic pickups, magneto-resistors, and magneto-diodes are currently being used as rotor position sensors.

The specific requirements of each application usually dictate the position sensing system selections. The linear Hall effect ele ment is the sensing systems most frequently used because of its small size, low cost, and simplified processing electronics. Figure 9 is a functional control circuit for a two phase brushless DC torque motor with linear Hall effect rotor positions sensing. To obtain Hall device output voltages proportional to the sine and cosine of the rotor's position, the Hall devices are mechanically displaced 90 electrical degrees from each other, and are then align with the stator's BEMF or torque waveform. The magnitude and direction of the motor drive current is regulated by varying the magnitude and polarity of the Hall device control current.

The control equations are as follows:

(Refer to Fig. 9**)**

$I_C = K_I V_C$
$V_H = K_H I_C B \cos\theta$

Where
Ic = Hall device control current(Amp)
Vc = Input control Voltage (Volt)
K1 = Current amplifier gain (Amp/Volt)
V_H = Hall device output voltage (Volt)
K_H = Hall constant (Volt/Amp-KGauss)
B = Rotor permanent magnet field vector

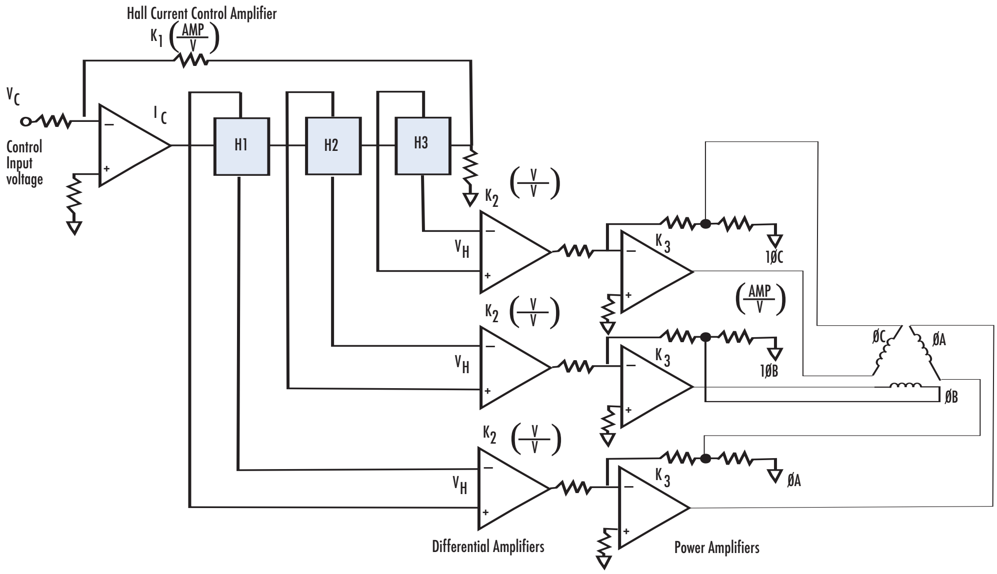


Figure-10. Functional control circuit for a three phase brushless DC torque motor with Hall Effect positioning sensor. positioning sensing.

θ = Angle between the plane of the Hall element and the rotor permanent magnet field vector(degrees)

The current in ∅A winding is:

$I_{\varnothing A} = V_H K_2 K_3$

$= K_2 K_3\ K_H I_C B \text{ Cos } \theta$

$= K_2 K_3\ K_H K_1 B V_C \text{ Cos } \theta$

Similarly, the current in ∅B winding is:

$I_{\varnothing B} = K_2 K_3 K_H I_C B V_C \text{ Sin } \theta$

The torque output of each phase is:

$T_{\varnothing A} = I_{\varnothing A} K_T \text{ Cos } \theta$

$T_{\varnothing B} = I_{\varnothing B} K_T \text{ Sin } \theta$

Substituting for $I_{\varnothing A}$ and $I_{\varnothing B}$

$T_{\varnothing A} = V_C K_1 K_2 K_3\ K_H K_T B \text{ Cos}^2\ \theta$

$T_{\varnothing B} = V_C K_1 K_2 K_3\ K_H K_T B \text{ Sin}^2\ \theta$

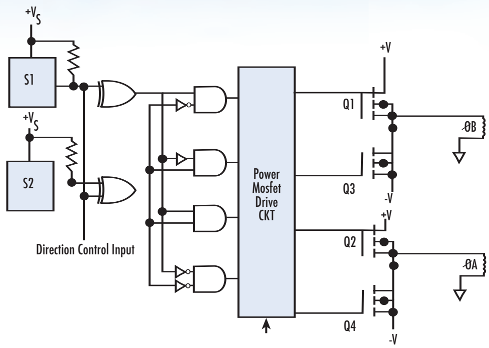


Figure-11. Functional drive circuit for bidirectional control of a two phase brushless DC motor.

Let $K_C = K_1 K_2 K_3\ K_H K_T B$

Then the motor's output torque is:

$T = T_{\varnothing A} + T_{\varnothing B} = V_C K_C\ (\text{Cos}^2\ \theta + \text{Sin}^2\ \theta)$

$T = V_C K_C$

Therefore, the output torque is directly pro–

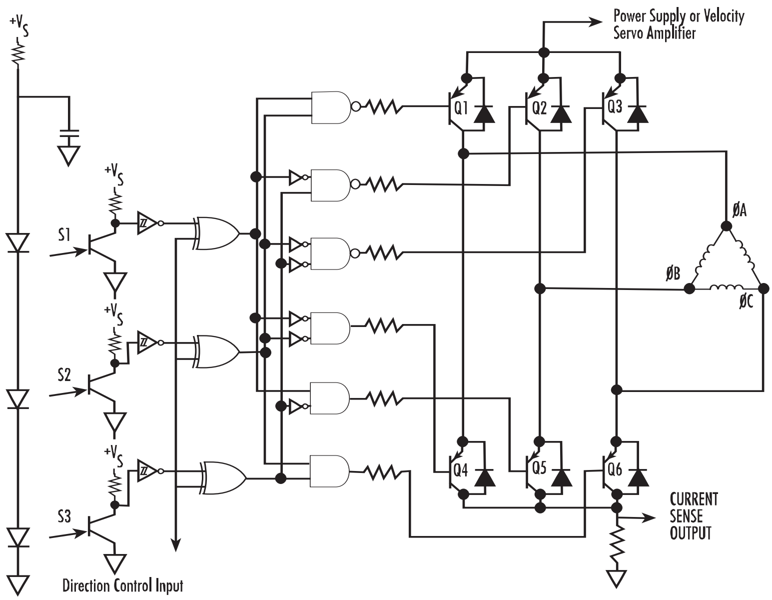


Figure-12. Functional drive circuit for bidirectional control of a three phase brushless DC motor.

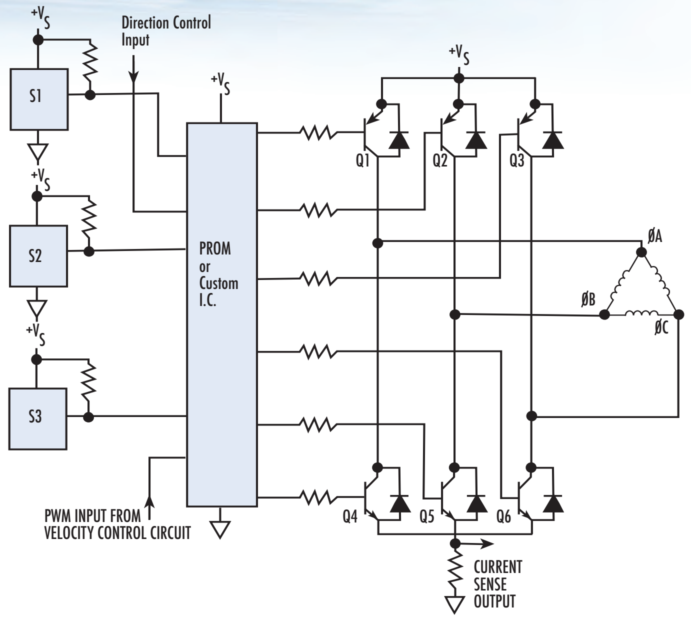


Figure-13. Functional drive circuit for bi-directional control of a three phase brushless DC motor.

portional to the input control voltage. The same control scheme can be applied to a three phase brushless DC torque motor as shown in Figure 10. The Hall devices are mechanically displaced 120 electrical degrees from each other and are aligned with the BEMF waveform of each phase. The control equations are as previously derived for the two phase system, except the output torque is:

$$T = V_C K_C (\sin^2 \theta + \sin^2 \theta (0 + 120) + \sin^2 (\theta - 240))$$
$$T = 1.5 V_C K_C$$

and, as before, the output torque is directly proportional to the input control voltage.

Square Wave Drive

A square wave drive system provides the most efficient utilization of the control electronics, and yields the lowest system cost. Power dissipation in the output stage is minimized by operating the power switch devices in the complete OFF or fully ON stage. The output stage can be interfaced directly with the commutation logic circuit, and the whole system can be digital. This allows the use of lower cost digital integrated circuits to decode the position sensor output and to sequence the drive circuit power semiconductors.

Figure 11 shows a simplified drive circuit for bi-directional control of a two phase brushless DC motor. The timing and excitation waveform for this motor were shown in Figure 7. The rotor position sensors are Hall effect switches and their outputs are processed by Exclusive OR gates. This feature allows the direction of rotation to be reversed. A logic “1” on the direction con-

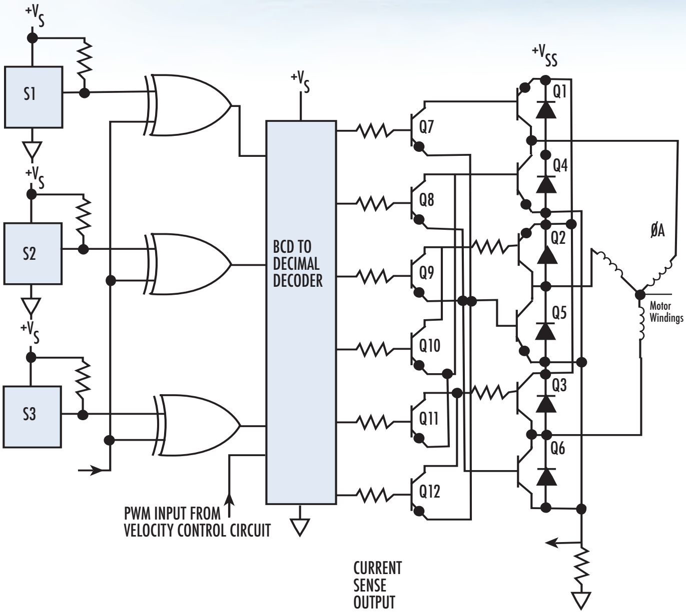


Figure-14. Functional drive circuit for bi-directional control of a three phase brushless DC motor.

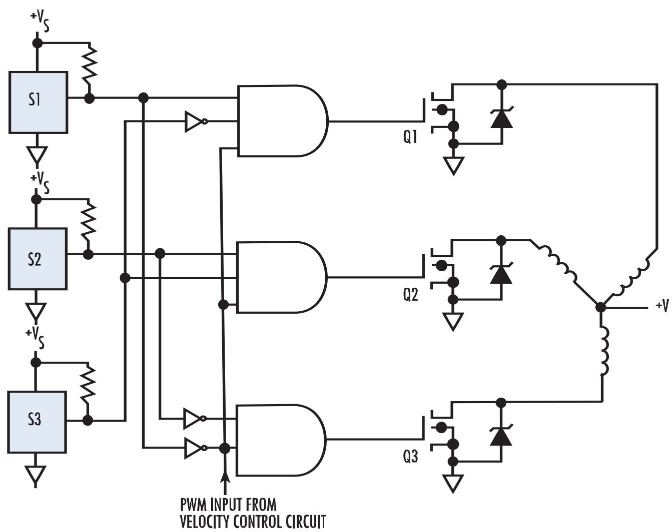


Figure-15. Functional drive circuit for bi-directional control of a three phase brushless DC motor.

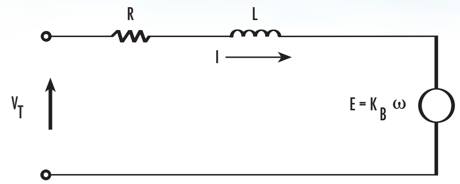


Figure-16. Equivalent electrical circuit of the Brushless DC motor.

trol input will invert the sense of the position sensor output. Referring back to Figure 7, we note that inverting the sensor polarity will reverse the polarity of excitation on each motor terminal thus making it produce torque in the opposite direction.

The logic statements shown in Figure 7b are implemented with AND and INVERT gates. Power MOSFETS are used to switch the motor winding. Speed control is obtained by pulse width modulating the power MOSFET during its ON commutation period.The MOSFET drive circuit consists of the gate drive and appropriate level shifting for the "P" and "N" channel devices.

A functional drive circuit for bi-directional control of a three phase brushless DC motor is shown in Figure 12.The timing and excitation waveform for this motor was shown in Figure 8. The main features of this control scheme are:

1. Rotor position feedback is obtained from three LED-photo-transistors.

2. Schmit-trigger inventers are used to shape the photo transistors output waveform.

3. AND and INVERT gates are used to implement the logic statements of Figure 8B.

4. PNP and NPN power Darlington transistors are used to switch the motor winding.

5. Flyback diodes across each transistors provide a transient path for the commutated winding inductive energy.

6. Speed control is achieved by "servoing" the supply voltage to the transistor bridge.

A single PROM or custom integrated circuit can be used to replace the EXCLUSIVE OR,AND, and INVERT logic ICs. This is shown in Figure 13.

The required logic can also be implemented with a BCD-to-decimal decoder as shown in Figure 14. Since the decoder output has only one unique "high" output state for any combination of logic inputs, both the PNP and NPN power transistors must be switched OFF and ON simultaneously for each commutation point.This control function is performed by driver transistors Q7 through Q12.

A simple low-cost drive used to control the brushless DC spindle motor in a disk drive is shown in Figure 15. Only three power MOSFETS are required to commutate the wye connected winding with the center tap connected to the supply voltage.The winding are switched over 120 electrical degrees. Due to the relatively high inertial load, the increased ripple torque has negligible impact on system performance.

Clamping zener diodes are used to protect the power MOSFETS from over-voltage transients produced when the inductive winding are switched OFF.

Brushless Servo Systems

The brushless DC motor, when properly commutated, will exhibit the same performance characteristics as a brushcommutated DC motor, and for servo analysis the brushless motor can be represented by the same motor parameters. It can be modeled by the equivalent circuit of Figure 16. This model can be used to develop the electrical and speed-torque characteristics equations for brushless DC motors.

The electrical equation is:

$V_T = I_R + Ldl/dt + K_B(\omega)$ (1)

Where

V_T = the terminal voltage across the active commutated phase
I = the sum of the phase currents into the motor
R = the equivalent input resistance of the active commutated phase
L = the equivalent input inductance of the active commutate phase
K_B = the back EMF constant of the active
ω = the angular velocity of the rotor

If the electrical time constant of the brushless DC motor is substantially less than the period of commutation, the steady state equation describing the voltage across the motor is:

$V_T = IR+K_B\omega$ (2)

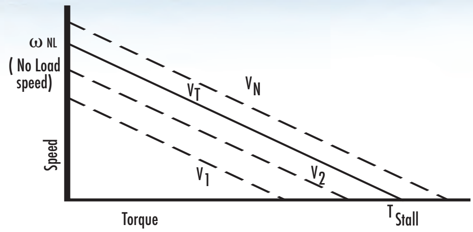


Figure-17 Speed torque characteristic curves.

The torque developed by the brushless DC motor is proportional to the input current.

$T = I\ K_T$

Where K_T = the torque sensitivity (oz-in/amp)

If we solve for I and substitute into Equation (2) we obtain:

$V_T = T/K_T R + K_B(\omega)$ (3)

The first term represents the voltage required to produce the desired torque, and the second term represents the voltage required to overcome the back EMF of the winding at the desired speed. If we solve (3) for rotor speed, we obtain:

$\omega = V_T/K_B - TR/K_B K_T$ (4)

which is the speed-torque equation for a permanent magnet DC motor.

A family of speed-torque curves represented by Equation (4) is shown in Figure 17.

The no-load speed can be obtained by substituting T=0 into (4).

$\omega_{NL} = V_T/K_B$

Stall torque can be determined by substituting ω=0 in (4)

$T_{STALL} = K_T V_T/R = IK_T$

The slopes of the parallel straight line speed torque curves of Figure 17 can be expressed by:

$R/K_BK_T = \omega_{NL}/T_{STALL}$

Since the speed-torque curves are linear, their construction is not required; the servo designer can calculate all needed information from the basic motor parameters.

Application Example

A typical constant velocity application such as the spindle in a memory disk drive may have the following requirements:

Operating speed	ω = 3600 RPM = 377 rad/sec
Load Torque	T_L = 12 oz-in
Available supply	V_S = 24V ± 10%
Max Voltage drop across switching transistors	$V_{CE(MAX)}$ = 1.5 V

The requirement is to select an appropriate motor and verify that it will meet operating speed torque requirements under worst case parameter conditions.

The motor selected has the following parameters:

K_T = 5.4 ± 10% oz-in/amp
K_B = 0.038 ± 10% Volts rad/sec
R = 0.90 ± 12.5% ohms

Assume the motor has an internal loss torque. T_{LOSS} = 0.5 oz-in, and the winding will see a maximum temperature rise (ambient plus internal heating) of 25° C.

The minimum voltage available to the motor is:

$V_{T(MIN)} = V_{S(MIN)} - 2V_{CE(MAX)} = 21.6 - 3.0 = 18.6\,V$

The maximum resistance of the winding including tolerance and temperature rise is:

$R_{MAX} = R\,(1 + 12.5\%)\{1 + (0.00393)(\Delta T)\}$

$R_{MAX} = 0.9(1.125)\{1 + (0.00393)(25)\} = 1.11$ ohm

The maximum voltage across the motor with worst case parameters is:

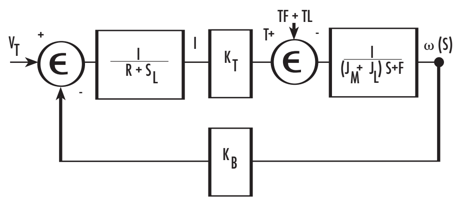


Figure-18 Block diagram of brushless DC motor model.

$V_{T(MAX)} = (R_{MAX})(T_L + T_{LOSS})/(K_{T(MAX)}) + K_{B(MAX)}\omega$

$V_{T(MAX)} = (1.11)(12.5 + 0.5)/(5.94) + (0.0418)(377)$

$V_{T(MAX)} = 18.1\,V$

Therefore, the motor selected will meet the requirements under worst case conditions. The block diagram and transfer function for a brushless DC motor when coupled to a load can be constructed from Equation (1) and the following dynamic torque equation:

$$T = (J_M + J_L))d\omega/dt + F\omega + T_F + T_L \quad (5)$$

Where
J_M = the motor moment of inertia
J_L = the load moment of inertia
F = the damping factor representing all motor and load viscous friction
T_F = the motor friction torque
T_L = the load friction torque

Taking the Laplace transform of (1) and (5) yields:

$$V_T = IR + SL + K_B\,\omega(S) \quad (6)$$

$$T = (J_M + J_L))S + F\omega(S) + T_F + T_L \quad (7)$$

Figure 18 is a block diagram representing Equations (6) and (7) and is identical to the model used for the brush commutated DC motor.

Some Common Pitfalls

Motor windings are inductive. This gives rise to two considerations that should not be overlooked. The first is motor speed. Since the winding electrical time constants are in the area of one millisecond, commutating frequencies above several hundred hertz need special treatment. Commutating frequency is equal to the number of pole pairs in the machine times the speed in revolutions per second. For units that must operate at higher speeds some provision for shifting the commutation points must be made. This can be done either mechanically or electronically. Also, the motor inductance causes high voltage spikes to appear across the power transistors as they are switched off. These must be allowed for in the design either by use of high voltage transistors or protective zener diodes or other transient suppressors. Almost all brushless motor systems require current limiting to avoid inadvertent demagnetization of the permanent magnet rotor during starting and fast reversals. The logic system must be examined for possibility of improper outputs during power application. For instance, if the logic states are such that both the transistors at one corner of the three phase delta are turned on, the resulting short circuit will be disastrous. An easy and fruitful test during bread boarding is to step the logic through its sequence and note that the motor steps through its rotation with no reversals or long steps. This assures that the logic is correct and that the motor is connected properly. If this is not done, it is possible that the motor will run, but that during one segment of its rotation its torque will be reversed or non-existent. High current will result, but may be overlooked inadvertently.

A Simple Test Method

Many of our customers have found that an incoming test of the motor torque is expensive to instrument and perform. In these cases we have suggested that the incoming electrical inspection be made on the back EMF constant of the motor (Kb). This parameter is directly proportional to the torque sensitivity and is more easily measured. The technique involves driving the motor at a constant speed and measuring the generated voltage at the motor terminals. Acceptance limits can be set based on the back EMF constant and assurance of a compliant motor is given by this test.

Thermal Considerations

On each of the following data pages, the maximum allowable winding temperature is specified. The maximum operating temperature of the winding depends on the load duty cycle and the thermal paths to system heat sinks. The value given for motor resistance and resistance dependent parameters on the data sheets are defined at 25°C winding temperature. If the winding is operated at a different temperature, the temperature coefficient of copper (0.4% per °C) must be taken into consideration.

Handling, Storage, Installation

The motors in this Source Book are all designed with rare earth magnets and require careful handling. These magnets have very strong attractions to magnetic materials. Without cautious handling, injury could occur.

When motors are stored in their original shipping container, they are well protected for normal storage conditions. Those motors that are housed have permanently lubricated bearings and do not require changing the bearings unless storage packaging has been damaged. The device should be closely inspected to see if damage or contamination has occurred.

Installation of brushless motors has only a handling problem. As the size of the motor increases, not only does the weight affect handling, but the magnetic attraction is a problem. If the motor is shipped with the magnet assembly inside the armature, it should be left this way to keep from damaging the magnets. There is a nonmagnetic shim placed in the air gap to keep the magnet assembly close to the center of the armature. This helps to align the motor to the mating mounting diameters. The mounting diameters of the housing and hub or shaft should have chamfers to help during installation. Once the motor is in place, the shim is removed and the motor should be free to rotate. It is always recommended to inspect the area of the air gap looking for any chips from magnets or magnetic chips that may have adhered to magnets and removed before operating the motor.

Glossary

Commutation – Sequenced switching of electrical power so that it is properly distributed in place and time to a motor winding. This function is performed by carbon brushes and a copper commutator in a conventional DC motor.

Electrical Degree – An angular measure dimensioned so that one pole pair contains 360 electrical degrees. In a two pole machine an electrical degree equals a mechanical degree. The number of pole pairs in a machine equals the number of electrical degrees in a mechanical degree.
Exclusive OR gate – An electronic logic element in which the output is on when either of the two inputs is on but not when both are on or off. It can be seen that if one input is held off the state of the output is the same as the state of the second input but if the first input is held on the state of the second input is reversed at the output.

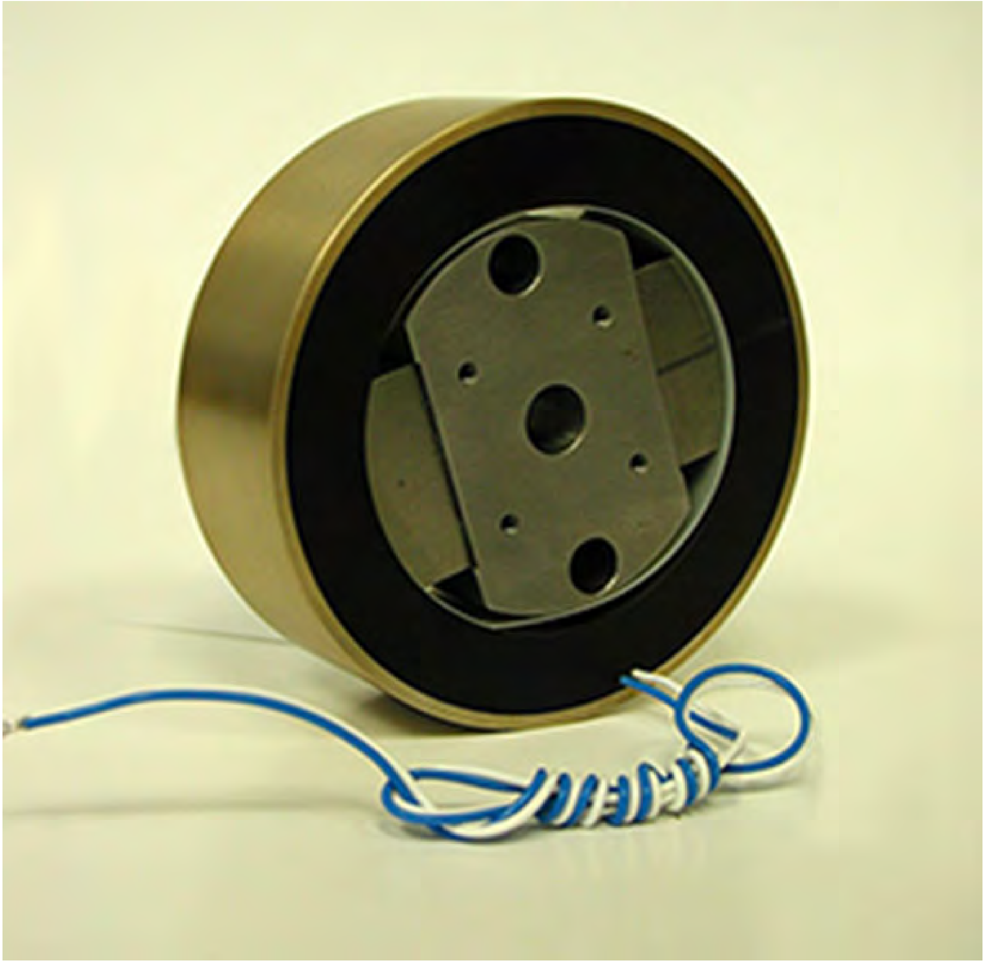
Hall Effect Element – Semiconductor which produces an output voltage proportional to the magnetic flux density perpendicular to the surface of the semiconductor and an input control current. It is commonly packaged with signal conditioning electronics to provide a linear or digital output.

LED (Light-Emitting Diode) – A two terminal electronic component that emits light from its semiconductor junction when electrical current flows through it.

Mounting – The information given on each data page are user requirements for correct axial and concentric orientation of the motor components. It is required to preserve the specified performance characteristics.

Phase – A motor winding which will set up magnetic poles in a specific position in the motor when a current is flowing in the winding. There is usually more than one phase in a brushless motor. The pole positions for each phase are angularly displaced from one another so that a moving magnetic field may be set up in a stationary component.

Photo Transistor – A semiconductor device in which the electrical current flowing through it is controlled by the amount of light falling in on the junction. When there



GDMS DC torque motors are designed using premium materials that offer unique space and weight savings while generating maximum power output. Limited angle torque motors do not require commutation elec-tronics and have near zero cogging.

is no light the current is very small.
A greater amount of light increases the current flow.

PROM – A programmable read only memory is an integrated circuit where data is entered by field programming techniques in which fusible links are blown, or in which some other permanent modification is made to the device structure. They can be employed to eliminate conventional combinational logic circuits.

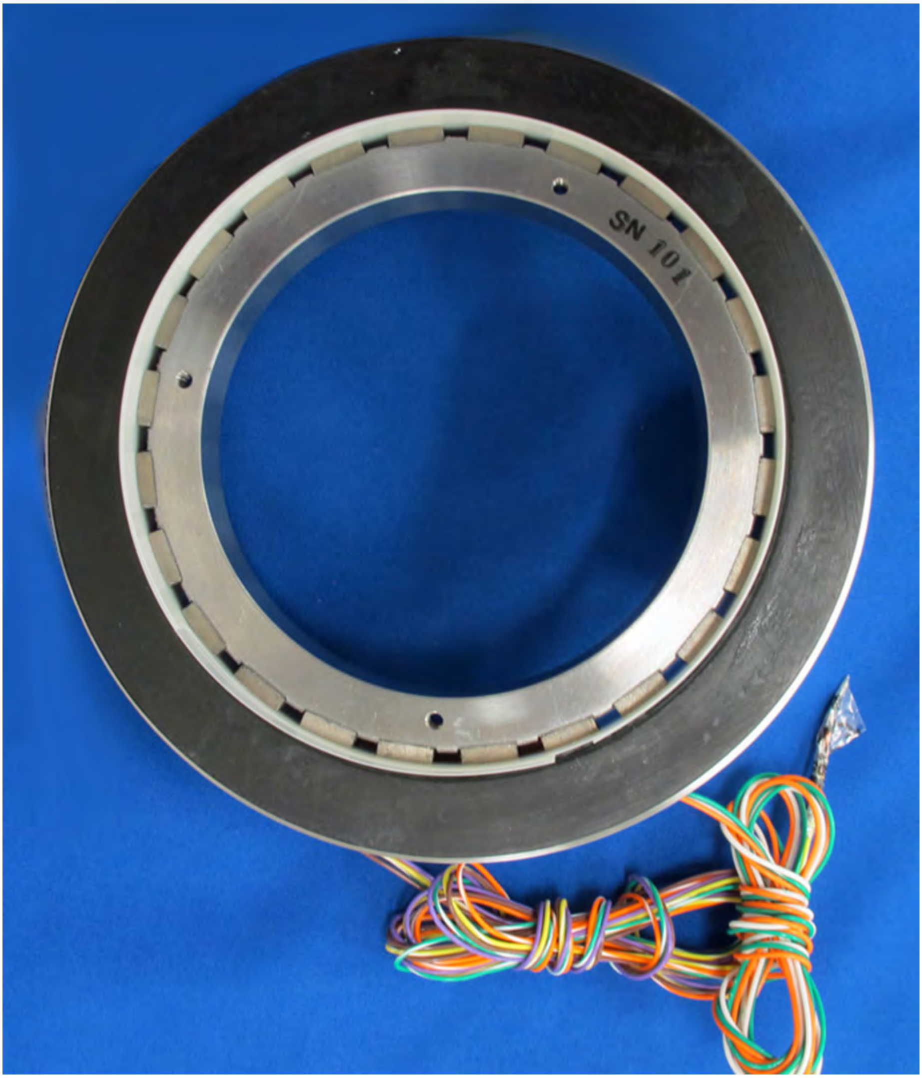
Rotor – Rotating element that drives the load.

Solid State Switch – A semiconductor device which is used to switch the power to the motor windings. Commonly used devices are transistors and MOSFETS.

Stator – Stationary element.

Conversion Table

To Convert:	From	To	Multiply by
Weight	ounces (force) ounces (force) pounds (force) pounds (force)	grams (force) Newtons grams (force) Newtons	28.35 0.278 453.6 4.448
Distance	inches inches feet	centimeters meters meters	2.54 2.54×10^{-2} .3048
Torque	ounce-inches ounce-inches pound-feet	gram-centimeters Newton-meters Newton-meters	72.01 7.061×10^{-3} 1.356
Angular Velocity	RPM degrees/second rev/second	radians/second radians/second radians/second	0.1047 1.745×10^{-2} 6.283
Inertia	ounce-inch-sec^2 pound-feet-sec^2	gram-cm square Kgram-cm square	7.06×10^4 0.367
Power Rate	ounce-inch/sec^2	kilowatts/second	7.061×10^{-3}



GDMS produces a wide range of brushless DC motors in both standard and custom models.

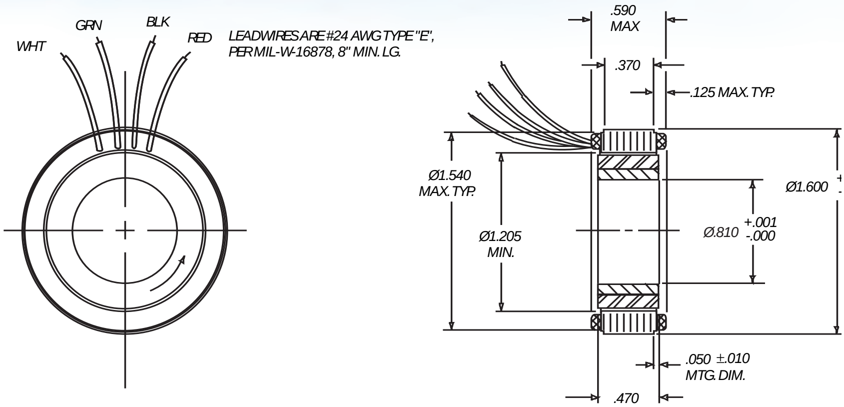
Selection Guide : by Peak Torque – 2 Phase Brushless Motors								
Model Number	Rotation Inner/Outer	Peak Torque (oz-in.)	Power@T_P (watts)	K_m (oz-in/$\sqrt{\text{watts}}$)	O.D. (in.)	I.D. (in.)	Axial Length (in.)	Page
4500C-080C	I	384	120	35	4.500	2.770	0.800	30
1600C-059	I	20	58	2.64	1.600	0.810	0.590	29

Other sizes are available. Contact GDMS for your specific requirements.

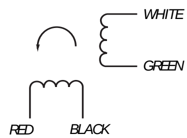
1600C-059

Brushless DC Motor / Inside Rotor

GENERAL DYNAMICS
Mission Systems



ROTATION: FIELD ROTATES CCW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: BLACK & WHITE LEADS COMMON & A POSITIVE VOLTAGE APPLIED TO GREEN LEAD THEN TO RED LEAD.



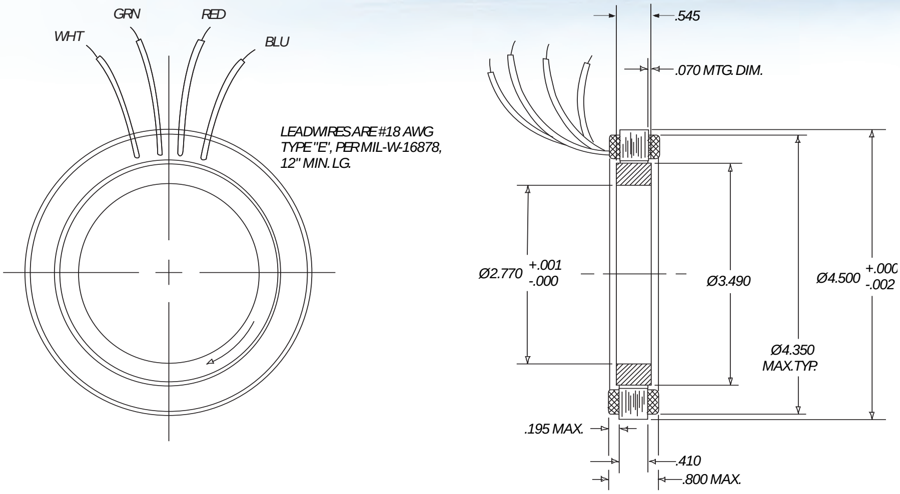
SCHEMATIC

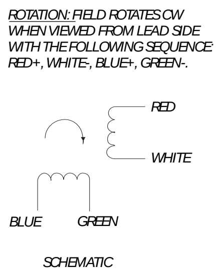
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	20
Power at T_p (P_p)	watts	58
Motor Constant (K_m)	oz-in/$\sqrt{W}$	2.64
Electrical Time Constant (τ_e)	milli-sec	0.43
Mechanical Time Constant (τ_m)	milli-sec	20
Damping Factor (F_o)	oz-in/rad/sec	0.05
Moment of Inertia (J_m)	oz-in-sec^2	0.001
Total Breakaway Torque (T_f)	oz-in	1.0
Temperature Rise (TPR)	°C/watt	4
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	2.6
Number of Poles		8
Number of Phases		2

Winding Constants						
Parameter	**UNITS**	**TOL.**	**-004**	**-010**	**-066**	**-104**
Resistance (R)	ohms	±12.5%	0.4	1.2	6.6	10.4
Voltage at T_p (V_p)	volts	Nominal	4.9	8.1	19.6	24.5
Current at T_p (I_p)	amps	Nominal	11.8	7.07	2.94	2.35
Torque Sensitivity (K_t)	oz-in/amp	±10%	1.70	2.83	6.80	8.50
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.012	0.020	0.049	0.061
Inductance (L)	millihenries	±30%	0.2	0.5	2.9	4.5

4500C-080C

Brushless DC Motors / Inside Rotor





Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	384
Power at T_p (P_p)	watts	120
Motor Constant (K_m)	oz-in/$\sqrt{W}$	35
Electrical Time Constant (τ_e)	milli-sec	0.42
Mechanical Time Constant (τ_m)	milli-sec	5.0
Damping Factor (F_o)	oz-in/rad/sec	8.7
Moment of Inertia (J_m)	oz-in-sec^2	0.043
Total Breakaway Torque (T_f)	oz-in	9.6
Temperature Rise (TPR)	°C/watt	5.0
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	22
Number of Poles		20
Number of Phases		2

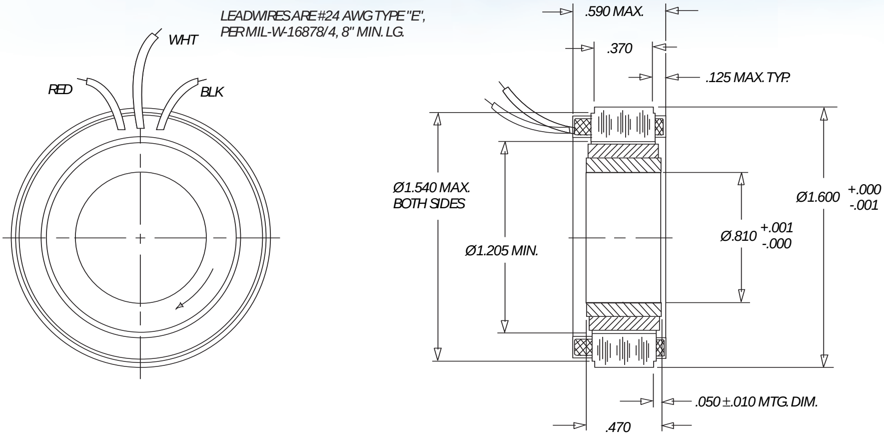
Winding Constants						
Parameter	**UNITS**	**TOL.**	**-016**		**-033**	**-062**
Resistance (R)	ohms	±12.5%	1.69		3.34	6.18
Voltage at T_p (V_p)	volts	Nominal	14.26		20	27.28
Current at T_p (I_p)	amps	Nominal	8.44		6	4.41
Torque Sensitivity (K_t)	oz-in/amp	±10%	45.5		64	87
Back E.M.F. (K_b)	volts/rad/sec	±10%	.321		.452	0.614
Inductance (L)	millihenries	±30%	0.69		1.4	2.59

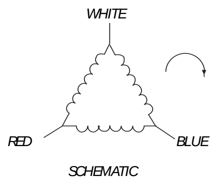
Brushless DC Motors

Selection Guide: by Peak Torque - 3 Phase Brushless Motors								
Model Number	Rotation Inner/Outer	Peak Torque (oz-in)	Power@Tp (watts)	Km (oz-in/√watts)	O.D. (in)	I.D. (in)	Axial Length (in)	Page
1600C-059J	I	20	57	2.64	1.600	0.810	0.590	32
1600M-060	I	20	46.3	2.94	1.600	0.360	0.600	33
2375H-050	I	60	158	4.78	2.375	0.940	0.500	34
2376-057	I	68	68	8.25	2.376	0.800	0.570	35
2376-064	I	68	68	8.25	2.376	0.800	0.640	36
3730H-071	I	187	100	18.7	3.730	1.811	0.708	37
4500C-080	I	384	116	35.6	4.500	2.770	0.800	38
4750J-110	I	856	282	51	4.750	3.000	1.100	39
6000S-146	I	2100	360	110.7	6.000	4.000	1.460	40
6000S-210	I	2100	360	110.7	6.000	4.000	2.100	41
6000S-360	I	5280	384	269.4	6.000	4.000	3.600	42
6000S-400	I	5280	384	269.4	6.000	4.000	4.000	43
8338-157	I	2124	106	206	8.338	6.417	1.575	44
8860B-330	I	15294	1020	479	8.860	5.000	3.300	45
8860B-475	I	35520	3712	583	8.860	5.000	4.750	46

1600C-059J

Brushless DC Motor / Inside Rotor





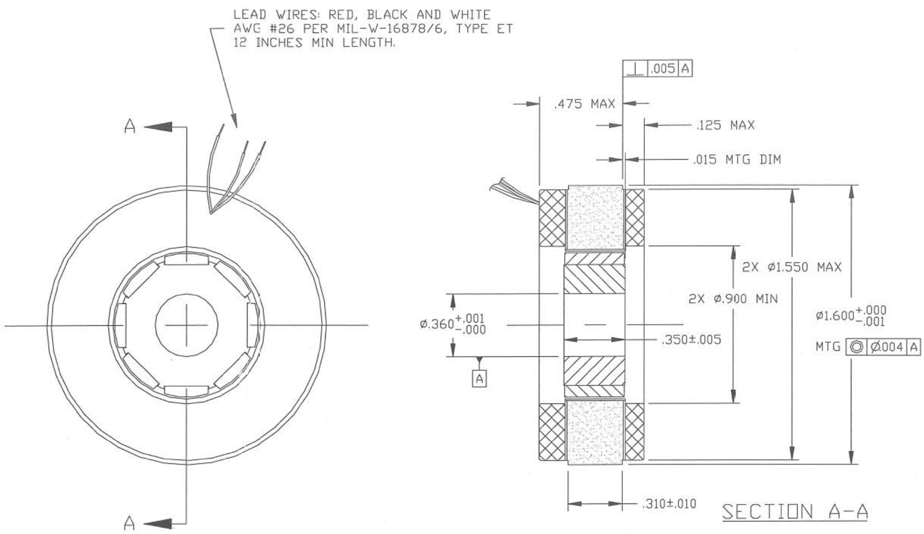
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	20
Power at T_p (P_p)	watts	57
Motor Constant (K_m)	oz-in/$\sqrt{W}$	2.64
Electrical Time Constant (τ_e)	milli-sec	0.06
Mechanical Time Constant (τ_m)	milli-sec	20.4
Damping Factor (F_o)	oz-in/rad/sec	0.049
Moment of Inertia (J_m)	oz-in-sec^2	0.001
Total Breakaway Torque (T_f)	oz-in	0.40
Temperature Rise (TPR)	°C/watt	8
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	2.6
Number of Poles		8
Number of Phases		3

Winding Constants						
Parameter	**UNITS**	**TOL.**	**-004**	**-011**	**-028**	**-068**
Resistance (R)	ohms	±12.5%	0.4	1.1	2.8	6.8
Voltage at T_p (V_p)	volts	Nominal	4.9	7.8	12.4	19.2
Current at T_p (I_p)	amps	Nominal	11.7	7.41	4.65	2.99
Torque Sensitivity (K_t)	oz-in/amp	±10%	1.71	2.70	4.30	6.70
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.012	0.020	0.032	0.050
Inductance (L)	millihenries	±30%	0.02	0.06	0.16	0.39

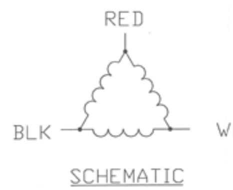
1600M-060-[***]

GENERAL DYNAMICS
Mission Systems

3 Phase Brushless DC Motor / Inside Rotor Motor only



Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	20
Power I^2R @ Tp:	watts	P	46.3
Continuous Stall Torque:	oz-in	Tcs	6
Motor Constant:	oz-in/$\sqrt{W}$	Km	2.94
Electrical Time Constant:	ms	Te	0.36
Mechanical Time Constant:	ms	Tm	3.3
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	0.06
Max Breakaway Torque:	oz-in	Tf	0.4
Rotor Inertia:	oz-in-sec^2	Jm	0.0002
Number of Poles:		p	8
Weight:	OZ	WT	2.4
Rated Winding Temperature :	^oC	Temp.	155
Thermal Resistance:	$^oC/W$	tpr	22



Notes:

1) Direction of rotation CW when viewed from lead exit with excitation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

*** Order this Winding Designator

	UNITS	TOL.	SYMBOL	- 029	- 110	- 278	
Design Voltage:	Volts	Nominal	**Vp**	**11.6**	**22.6**	**35.9**	**Winding Constants**
Resistance:	ohms	+/- 12.5%	R	2.9	11	27.8	
Inductance:	mH	+/- 30%	L	1	4	10	
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	5	9.75	15.5	
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	0.035	0.069	0.109	
Peak Current @Tp:	Amps	Nominal	Ip	4	2	1.29	

All constant values at 25 ^oC ambient temperature

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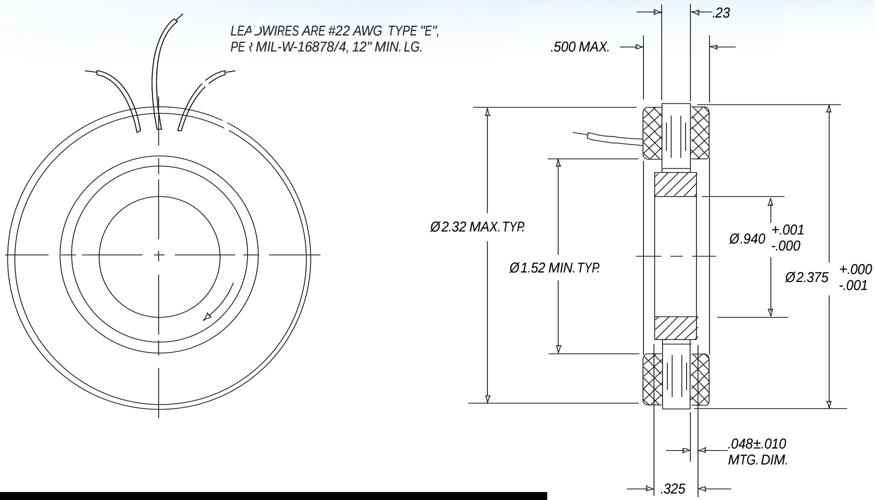
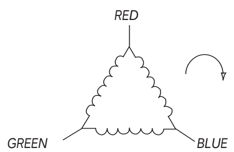
2375H-050

Brushless DC Motor / Inside Rotor



Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	60
Power at T_p (P_p)	watts	158
Motor Constant (K_m)	oz-in/$\sqrt{W}$	4.78
Electrical Time Constant (τ_e)	milli-sec	0.23
Mechanical Time Constant (τ_m)	milli-sec	9.9
Damping Factor (F_o)	oz-in/rad/sec	0.16
Moment of Inertia (J_m)	oz-in-sec^2	0.0016
Total Breakaway Torque (T_f)	oz-in	1.0
Temperature Rise (TPR)	°C/watt	14.5
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	4.2
Number of Poles		8
Number of Phases		3

ROTATION: FIELD ROTATES CW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: RED+, GREEN-; GREEN+, BLUE-; BLUE+, RED-.



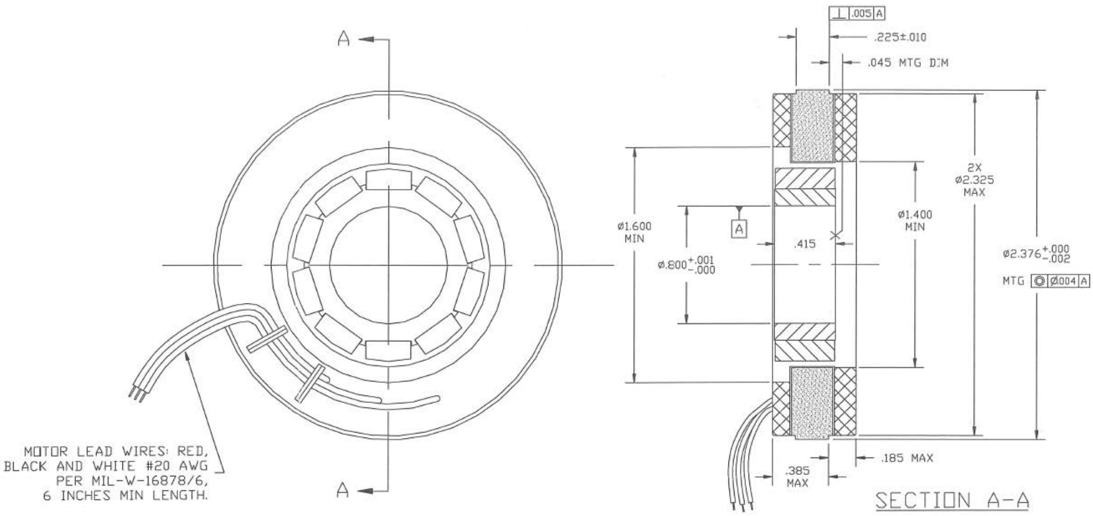
SCHEMATIC

Winding Constants						
Parameter	**UNITS**	**TOL.**	**-013**	**-033**	**-052**	**-131**
Resistance (R)	ohms	±12.5%	1.3	3.3	5.2	13.1
Voltage at T_p (V_p)	volts	Nominal	14.44	22.77	28.3	45.2
Current at T_p (I_p)	amps	Nominal	11.11	6.9	5.5	3.45
Torque Sensitivity (K_t)	oz-in/amp	±10%	5.4	8.7	10.9	17.4
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.038	0.061	0.077	0.123
Inductance (L)	millihenries	±30%	0.30	0.76	1.2	3.0

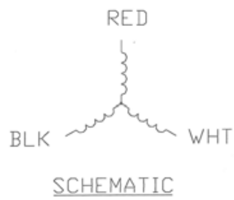
2376-057-[***]

3 Phase Brushless DC Motor / Inside Rotor Motor Only

GENERAL DYNAMICS
Mission Systems



Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	68
Power I^2R @ Tp:	watts	P	68
Continuous Stall Torque:	oz-in	Tcs	22
Motor Constant:	oz-in/$\sqrt{W}$	Km	8.25
Electrical Time Constant:	ms	Te	0.85
Mechanical Time Constant:	ms	Tm	2.3
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	0.48
Max Breakaway Torque:	oz-in	Tf	1.3
Rotor Inertia:	oz-in-sec^2	Jm	0.0011
Number of Poles:		p	10
Weight:	OZ	WT	5.5
Rated Winding Temperature :	°C	Temp.	155
Thermal Resistance:	°C/W	tpr	13



Notes:

1) Direction of rotation CW when viewed from lead exit with excitation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

*** Order this Winding Designator

	UNITS	TOL.	SYMBOL	- 018	- 082	- 180	
Design Voltage:	Volts	Nominal	**Vp**	**11.1**	**23.6**	**35**	Winding Constants
Resistance:	ohms	+/- 12.5%	R	1.52	8.19	18	
Inductance:	mH	+/- 30%	L	1.54	6.96	15.3	
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	11.1	23.6	35	
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	0.078	0.167	0.247	
Peak Current @Tp:	Amps	Nominal	Ip	6.13	2.88	1.94	

All constant values at 25 °C ambient temperature

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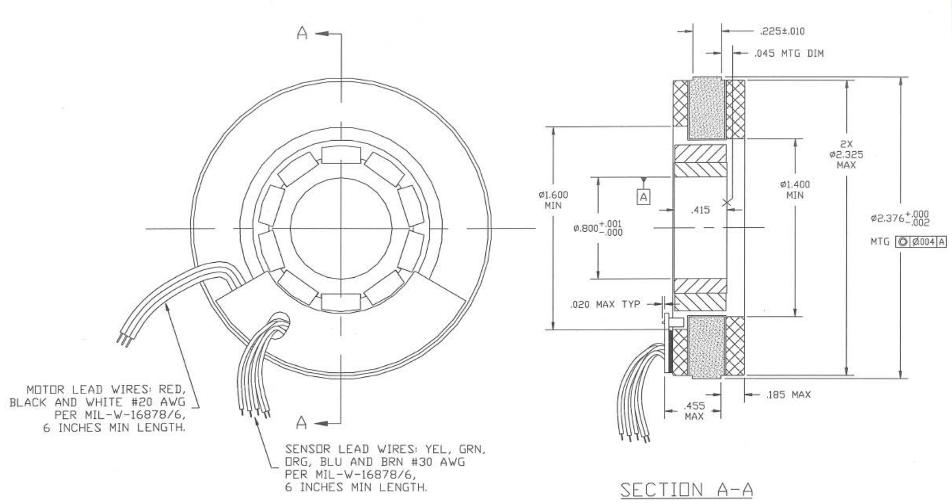
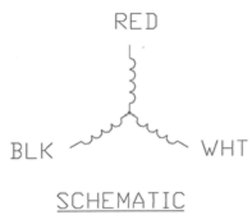
2376-064-[***]

3 Phase Brushless DC Motor / Inside Rotor Motor with Hall sensors



Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	68
Power I^2R @ Tp:	watts	P	68
Continuous Stall Torque:	oz-in	Tcs	22
Motor Constant:	oz-in/$\sqrt{W}$	Km	8.25
Electrical Time Constant:	ms	Te	0.85
Mechanical Time Constant:	ms	Tm	2.3
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	0.48
Max Breakaway Torque:	oz-in	Tf	1.3
Rotor Inertia:	oz-in-sec^2	Jm	0.0011
Number of Poles:		p	10
Weight:	OZ	WT	6
Rated Winding Temperature :	°C	Temp.	155
Thermal Resistance:	°C/W	tpr	13



Notes:

1) Direction of rotation CW when viewed from lead exit with excitation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

***** Order this Winding Designator**

Winding Constants	UNITS	TOL.	SYMBOL	- 018	- 082	- 180
Design Voltage:	Volts	Nominal	**Vp**	**11.1**	**23.6**	**35**
Resistance:	ohms	+/- 12.5%	R	1.52	8.19	18
Inductance:	mH	+/- 30%	L	1.54	6.96	15.3
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	11.1	23.6	35
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	0.078	0.167	0.247
Peak Current @Tp:	Amps	Nominal	Ip	6.13	2.88	1.94

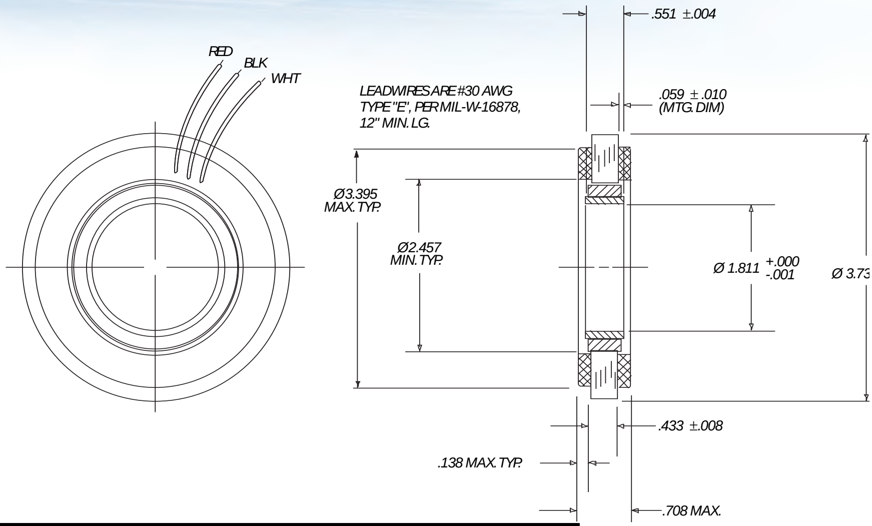
All constant values at 25 °C ambient temperature

Ver. 12/2012

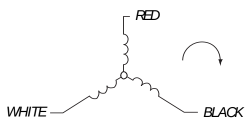
3730H-071

Brushless DC Motor / Inside Rotor

GENERAL DYNAMICS
Mission Systems



ROTATION: FIELD ROTATES CW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE RED+, BLACK-; WHITE+, BLACK-; WHITE+, RED-.



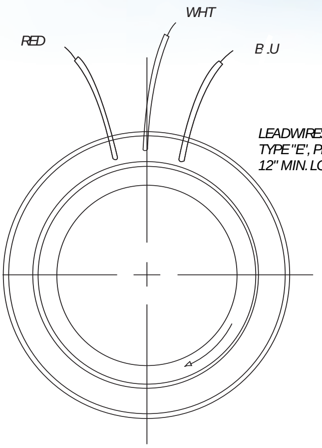
SCHEMATIC

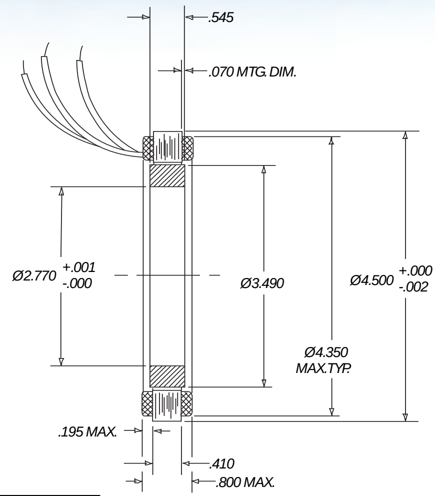
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	187
Power at T_p (P_p)	watts	100
Motor Constant (K_m)	oz-in/$\sqrt{W}$	18.7
Electrical Time Constant (τ_e)	milli-sec	0.5
Mechanical Time Constant (τ_m)	milli-sec	5.1
Damping Factor (F_o)	oz-in/rad/sec	2.5
Moment of Inertia (J_m)	oz-in-sec^2	.0125
Total Breakaway Torque (T_f)	oz-in	6.4
Temperature Rise (TPR)	°C/watt	5.8
Max. Allowable Wdg. Temp.	°C	155
Weight	lbs	1.2
Number of Poles		14
Number of Phases		3

Winding Constants						
Parameter	**UNITS**	**TOL.**	**-034**	**-051**	**-082**	**-125**
Resistance (R)	ohms	±12.5%	3.5	5.16	8.95	12.5
Voltage at T_p (V_p)	volts	Nominal	18.7	22.7	29.9	35.4
Current at T_p (I_p)	amps	Nominal	5.34	4.40	3.34	2.83
Torque Sensitivity (K_t)	oz-in/amp	±10%	35.0	42.5	56.0	66.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.247	.300	.395	.466
Inductance (L)	millihenries	±30%	1.75	2.6	4.5	6.2

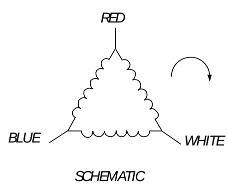
4500C-080

Brushless DC Motor / Inside Rotor





ROTATION: FIELD ROTATES CW
WHEN VIEWED FROM LEAD SIDE
WITH THE FOLLOWING SEQUENCE:
RED+, WHITE-, BLUE+,
WHITE-; BLUE+, RED-.



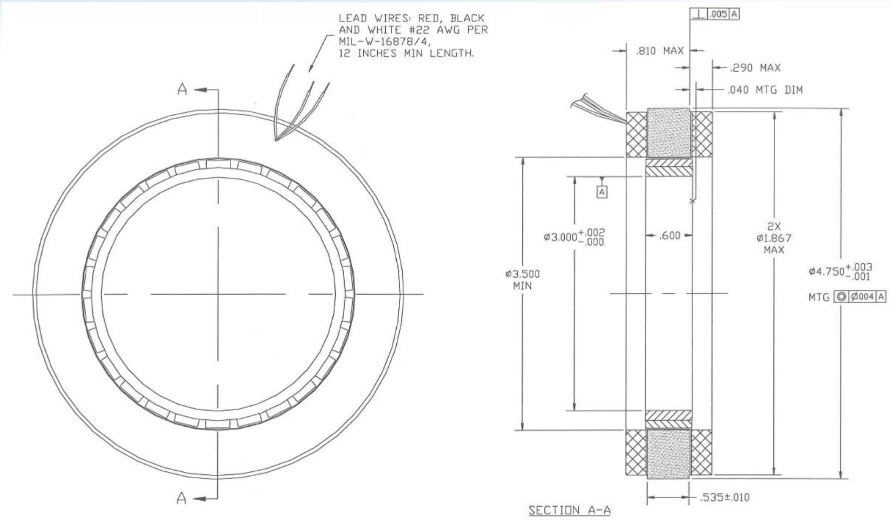
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	384
Power at T_p (P_p)	watts	116
Motor Constant (K_m)	oz-in/$\sqrt{W}$	35.6
Electrical Time Constant (τ_e)	milli-sec	0.50
Mechanical Time Constant (τ_m)	milli-sec	4.75
Damping Factor (F_o)	oz-in/rad/sec	8.97
Moment of Inertia (J_m)	oz-in-sec^2	0.0426
Total Breakaway Torque (T_f)	oz-in	9.6
Temperature Rise (TPR)	°C/watt	4.9
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	22
Number of Poles		20
Number of Phases		3

Winding Constants						
Parameter	**UNITS**	**TOL.**	**-008**	**-020**	**-031**	**-048**
Resistance (R)	ohms	±12.5%	0.84	2.0	3.0	4.8
Voltage at T_p (V_p)	volts	Nominal	9.89	15.24	18.7	23.6
Current at T_p (I_p)	amps	Nominal	11.77	7.62	6.23	4.92
Torque Sensitivity (K_t)	oz-in/amp	±10%	32.6	50.4	61.7	78.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	.230	.356	.436	.551
Inductance (L)	millihenries	±30%	0.42	1.0	1.5	2.4

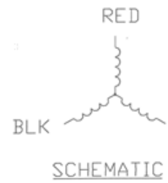
4750J-110-[***]

GENERAL DYNAMICS
Mission Systems

3 Phase Brushless DC Motor / Inside Rotor Motor only



Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	856
Power I^2R @ Tp:	watts	P	282
Continuous Stall Torque:	oz-in	Tcs	308
Motor Constant:	oz-in/$\sqrt{W}$	Km	51
Electrical Time Constant:	ms	Te	0.8
Mechanical Time Constant:	ms	Tm	2.1
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	18.4
Max Breakaway Torque:	oz-in	Tf	12
Rotor Inertia:	oz-in-sec^2	Jm	0.0039
Number of Poles:		p	26
Weight:	LBS	WT	1.75
Rated Winding Temperature :	°C	Temp.	220
Thermal Resistance:	°C/W	tpr	3.7



Notes:

1) Direction of rotation CCW when viewed from lead exit with excitation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

*** Order this Winding Designator

Winding Constants	UNITS	TOL.	SYMBOL	-018	-044	-069	-203
Design Voltage:	Volts	Nominal	**Vp**	**22.7**	**35.2**	**44.1**	**75.6**
Resistance:	ohms	+/- 12.5%	R	1.83	4.4	6.9	20.3
Inductance:	mH	+/- 30%	L	1.45	3.5	5.5	16.3
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	69	107	134	230
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	0.487	0.756	0.946	1.624
Peak Current @Tp:	Amps	Nominal	Ip	12.4	8	6.39	3.72

All constant values at 25 °C ambient temperature

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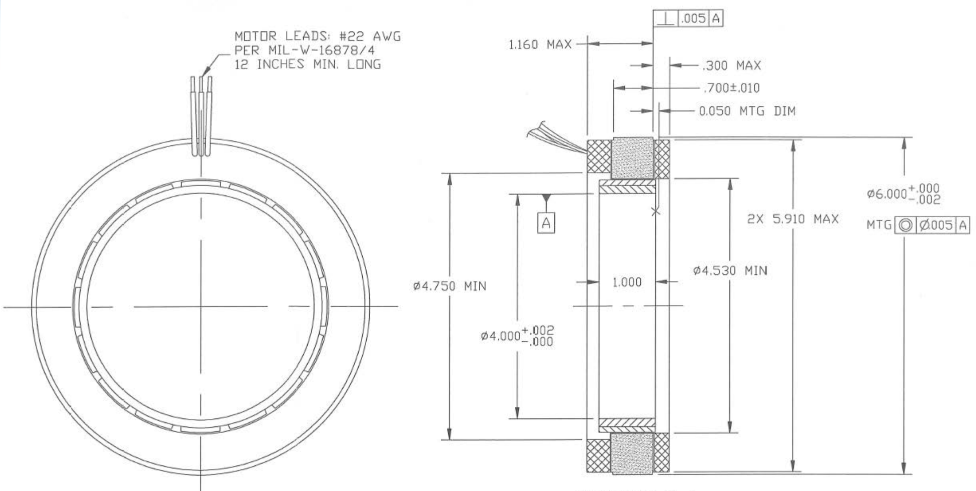
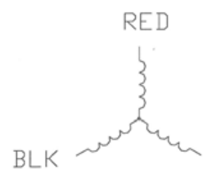
6000S-146-[***]

GENERAL DYNAMICS
Mission Systems

3 Phase Brushless DC Motor / Inside Rotor Motor Motor Only



SECTION A-A



SCHEMATIC

Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	2100
Power I^2R @ Tp:	watts	P	360
Continuous Stall Torque:	oz-in	Tcs	882
Motor Constant:	$oz\text{-}in/\sqrt{W}$	Km	110.7
Electrical Time Constant:	ms	Te	1.56
Mechanical Time Constant:	ms	Tm	1.91
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	86.5
Max Breakaway Torque:	oz-in	Tf	20
Rotor Inertia:	$oz\text{-}in\text{-}sec^2$	Jm	0.165
Number of Poles:		p	16
Weight:	LBS	WT	4.0
Rated Winding Temperature :	°C	Temp.	220
Thermal Resistance:	°C/W	tpr	2.28

Notes:

1) Direction of rotation CCW when viewed from lead exit with excitation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

*** Order this Winding Designator

Winding Constants	UNITS	TOL.	SYMBOL	-016	-064	-162
Design Voltage:	**Volts**	**Nominal**	**Vp**	**24**	**48**	**76.5**
Resistance:	ohms	+/- 12.5%	R	1.6	6.4	16.2
Inductance:	mH	+/- 30%	L	2.5	10	26
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	140	280	445
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	0.989	1.977	3.142
Peak Current @Tp:	Amps	Nominal	Ip	15	7.5	4.72

All constant values at 25 °C ambient temperature

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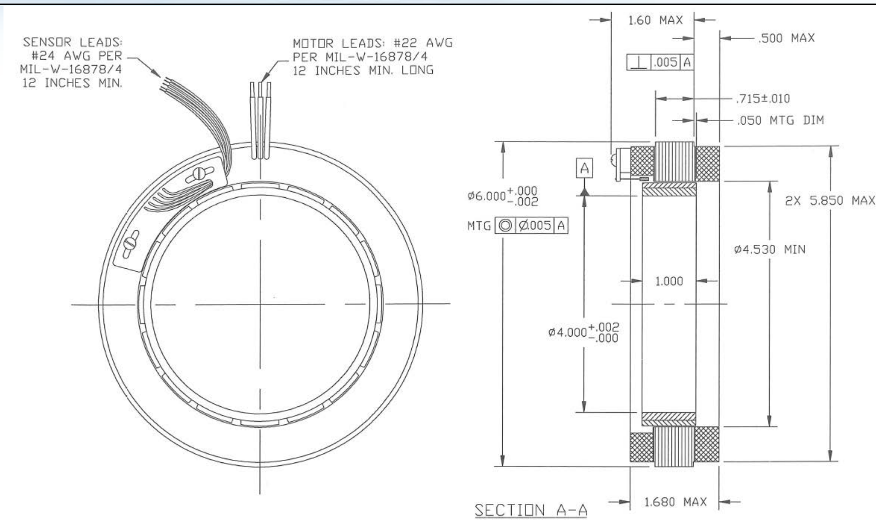
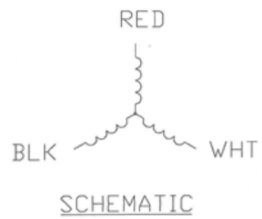
6000S-210-[***]

GENERAL DYNAMICS
Mission Systems

3 Phase Brushless DC Motor / Inside Rotor Motor with Hall sensors



Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	2100
Power I^2R @ Tp:	watts	P	360
Continuous Stall Torque:	oz-in	Tcs	882
Motor Constant:	$oz\text{-}in/\sqrt{W}$	Km	110.7
Electrical Time Constant:	ms	Te	1.56
Mechanical Time Constant:	ms	Tm	1.91
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	86.5
Max Breakaway Torque:	oz-in	Tf	20
Rotor Inertia:	$oz\text{-}in\text{-}sec^2$	Jm	0.165
Number of Poles:		p	16
Weight:	LBS	WT	4.0
Rated Winding Temperature :	^oC	Temp.	220
Thermal Resistance:	$^oC/W$	tpr	2.28



Notes:

1) Direction of rotation CCW when viewed from lead exit with excitation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

*** Order this Winding Designator

	UNITS	TOL.	SYMBOL	-016	-064	-162	
Design Voltage:	**Volts**	**Nominal**	**Vp**	**24**	**48**	**76.5**	**Winding Constants**
Resistance:	ohms	+/- 12.5%	R	1.6	6.4	16.2	
Inductance:	mH	+/- 30%	L	2.5	10	26	
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	140	280	445	
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	0.989	1.977	3.142	
Peak Current @Tp:	Amps	Nominal	Ip	15	7.5	4.72	

All constant values at 25 ^oC ambient temperature

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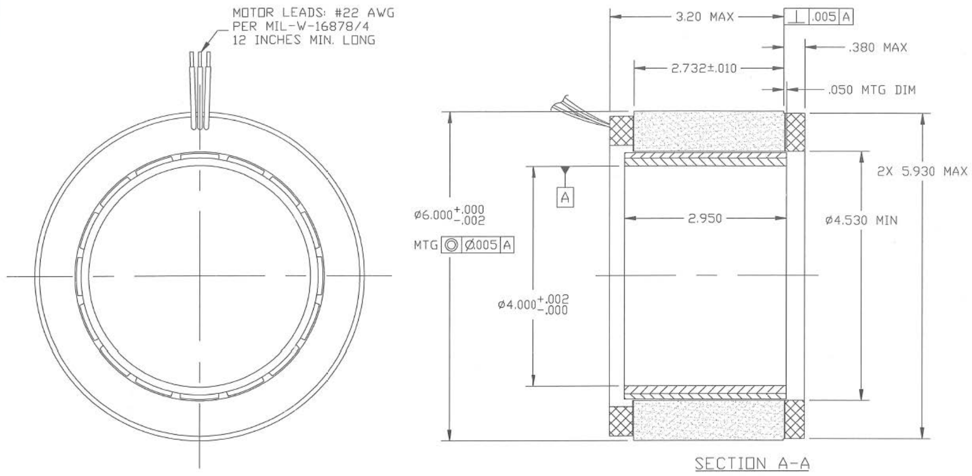
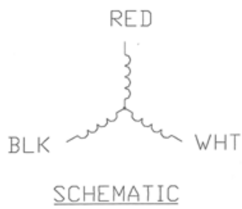
6000S-360-[***]

3 Phase Brushless DC Motor / Inside Rotor Motor only



Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	5280
Power I^2R @ Tp:	watts	P	384
Continuous Stall Torque:	oz-in	Tcs	3115
Motor Constant:	$oz\text{-}in/\sqrt{W}$	Km	269.4
Electrical Time Constant:	ms	Te	2.5
Mechanical Time Constant:	ms	Tm	1.0
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	513
Max Breakaway Torque:	oz-in	Tf	70
Rotor Inertia:	$oz\text{-}in\text{-}sec^2$	Jm	0.51
Number of Poles:		p	16
Weight:	LBS	WT	12
Rated Winding Temperature :	°C	Temp.	220
Thermal Resistance:	°C/W	tpr	1.1



Notes:

1) Direction of rotation CCW when viewed from lead exit with excitation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

***** Order this Winding Designator**

Winding Constants	UNITS	TOL.	SYMBOL	-015	-060	-154
Design Voltage:	**Volts**	**Nominal**	**Vp**	**24**	**48**	**77**
Resistance:	ohms	+/- 12.5%	R	1.5	6	15.4
Inductance:	mH	+/- 30%	L	3.8	15	38.5
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	330	660	1056
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	2.330	4.661	7.457
Peak Current @Tp:	Amps	Nominal	Ip	16	8	5

All constant values at 25 °C ambient temperature

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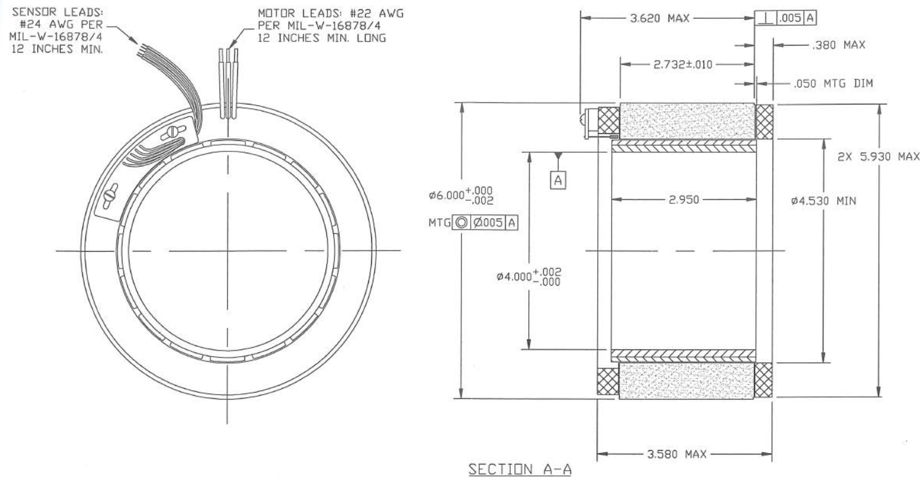
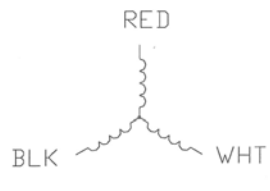
6000S-400-[***]

3 Phase Brushless DC Motor / Inside Rotor Motor with Hall sensors



Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	5280
Power I^2R @ Tp:	watts	P	384
Continuous Stall Torque:	oz-in	Tcs	3115
Motor Constant:	oz-in/$\sqrt{W}$	Km	269.4
Electrical Time Constant:	ms	Te	2.5
Mechanical Time Constant:	ms	Tm	1.0
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	513
Max Breakaway Torque:	oz-in	Tf	70
Rotor Inertia:	oz-in-sec^2	Jm	0.51
Number of Poles:		p	16
Weight:	LBS	WT	12.7
Rated Winding Temperature :	^{o}C	Temp.	220
Thermal Resistance:	^{o}C/W	tpr	1.1



SCHEMATIC

Notes:

1) Direction of rotation CCW when viewed from lead exit with excitation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

*** Order this Winding Designator

	UNITS	TOL.	SYMBOL	-015	-060	-154	
Design Voltage:	**Volts**	**Nominal**	**Vp**	**24**	**48**	**77**	Winding Constants
Resistance:	ohms	+/- 12.5%	R	1.5	6	15.4	
Inductance:	mH	+/- 30%	L	3.8	15	38.5	
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	330	660	1056	
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	2.330	4.661	7.457	
Peak Current @Tp:	Amps	Nominal	Ip	16	8	5	

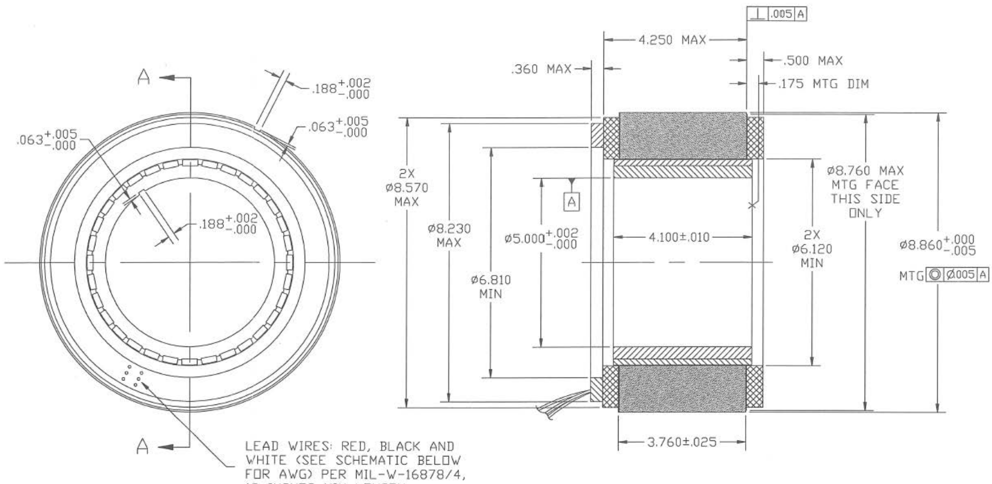
All constant values at 25 ^{o}C ambient temperature

Ver. 12/2012

GENERAL DYNAMICS
Mission Systems

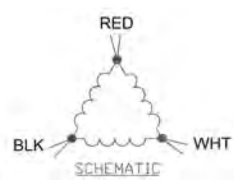
8860B-475-[***]

3 Phase Brushless DC Motor / Inside Rotor Motor Only



SECTION A-A

Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	35520
Power I^2R @ Tp:	watts	P	3712
Continuous Stall Torque:	oz-in	Tcs	9590
Motor Constant:	oz-in/$\sqrt{W}$	Km	583
Electrical Time Constant:	ms	Te	3.8
Mechanical Time Constant:	ms	Tm	0.96
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	2402
Max Breakaway Torque:	oz-in	Tf	312
Rotor Inertia:	oz-in-sec^2	Jm	2.3
Number of Poles:		p	32
Weight:	LBS	WT	41.5
Rated Winding Temperature :	°C	Temp.	220
Thermal Resistance:	°C/W	tpr	0.52



WINDING DESIGNATOR	# OF LEADS PER PHASE	AWG
-002 & -006	2	# 12
-023	1	# 12
-064 & -170	1	# 16

Notes:

1) Direction of rotation CW when viewed from lead exit with exciation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

*** Order this Winding Designator

	UNITS	TOL.	SYMBOL	-002	-006	-023	-064	-170	
Design Voltage:	Volts	Nominal	**Vp**	**23.2**	**46.4**	**92.8**	**154.6**	**252**	
Resistance:	ohms	+/- 12.5%	R	0.145	0.58	2.32	6.44	17	Winding Constants
Inductance:	mH	+/- 30%	L	0.55	2.2	8.8	24.4	64	
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	222	444	888	1480	2400	
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	1.57	3.14	6.27	10.45	17	
Peak Current @Tp:	Amps	Nominal	Ip	160	80	40	24	14.8	

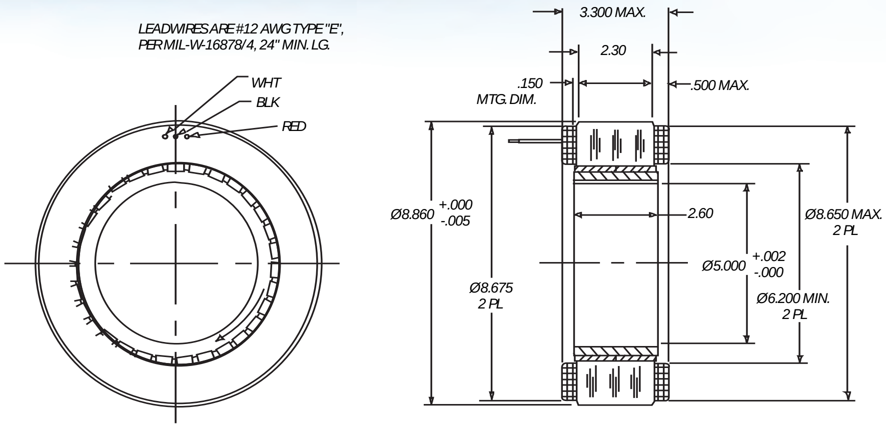
All constant values at 25 °C ambient temperature

Ver. 12/2012

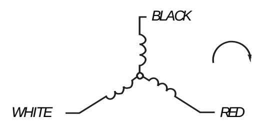
8860B-330

Brushless DC Motor / Inside Rotor

GENERAL DYNAMICS
Mission Systems



ROTATION: FIELD ROTATES CW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: BLACK+, WHITE-; BLACK+, RED-; WHITE+, BLACK-.



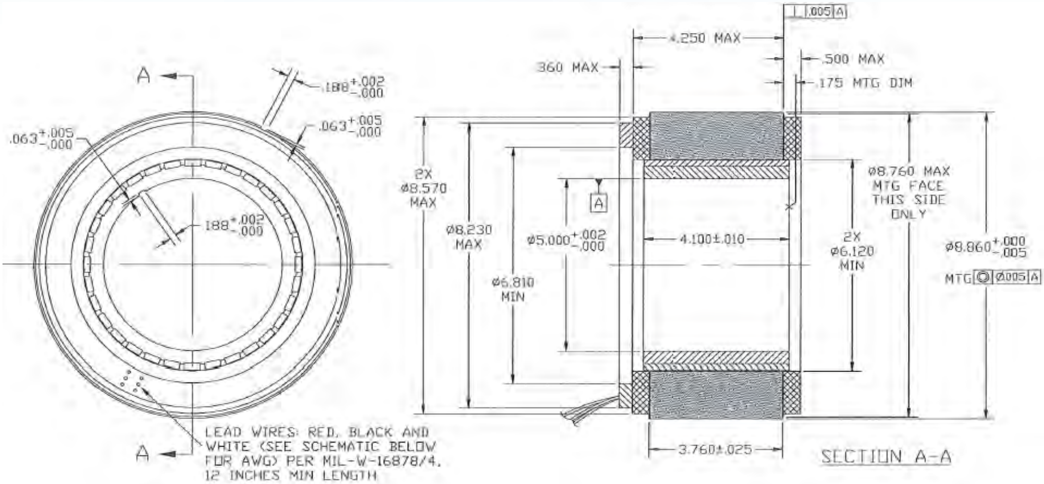
SCHEMATIC

Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	15,294
Power at T_p (P_p)	watts	1020
Motor Constant (K_m)	oz-in/$\sqrt{W}$	480
Electrical Time Constant (τ_e)	milli-sec	3.2
Mechanical Time Constant (τ_m)	milli-sec	1.0
Damping Factor (F_o)	oz-in/rad/sec	1635
Moment of Inertia (J_m)	oz-in-sec^2	1.62
Total Breakaway Torque (T_f)	oz-in	160
Temperature Rise (TPR)	°C/watt	0.4
Max. Allowable Wdg. Temp.	°C	155
Weight	lb	24
Number of Poles		32
Number of Phases		3

Winding Constants						
Parameter	**UNITS**	**TOL.**				**-058**
Resistance (R)	ohms	±12.5%				5.8
Voltage at T_p (V_p)	volts	Nominal				75.4
Current at T_p (I_p)	amps	Nominal				13.0
Torque Sensitivity (K_t)	oz-in/amp	±10%				1176.5
Back E.M.F. (K_b)	volts/rad/sec	±10%				8.33
Inductance (L)	millihenries	±30%				18.5

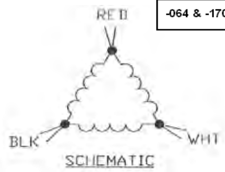
8860B-475-[***]

3 Phase Brushless DC Motor / Inside Rotor Motor Only



Size Constants	UNITS	SYMBOL	VALUE
Peak Torque, Stalled @ Vp:	oz-in	Tp	35520
Power I^2R @ Tp:	watts	P	3712
Continuous Stall Torque:	oz-in	Tcs	9590
Motor Constant:	oz-in/$\sqrt{W}$	Km	583
Electrical Time Constant:	ms	Te	3.8
Mechanical Time Constant:	ms	Tm	0.96
Damping Factor: *(zero impedance)*	oz-in/ (rad/sec)	Fo	2402
Max Breakaway Torque:	oz-in	Tf	312
Rotor Inertia:	oz-in-sec^2	Jm	2.3
Number of Poles:		p	32
Weight:	LBS	WT	41.5
Rated Winding Temperature :	°C	Temp.	220
Thermal Resistance:	°C/W	tpr	0.52

WINDING DESIGNATOR	# OF LEADS PER PHASE	AWG
-002 & -006	2	# 12
-023	1	# 12
-064 & -170	1	# 16



Notes:

1) Direction of rotation CW when viewed from lead exit with exciation sequence of: RED(+)/WHT(-), WHT(+)/BLK(-) and BLK(+)/RED(-)

*** Order this Winding Designator

	UNITS	TOL.	SYMBOL	-002	-006	-023	-064	-170	
Design Voltage:	Volts	Nominal	**Vp**	**23.2**	**46.4**	**92.8**	**154.6**	**252**	Winding Constants
Resistance:	ohms	+/- 12.5%	R	0.145	0.58	2.32	6.44	17	
Inductance:	mH	+/- 30%	L	0.55	2.2	8.8	24.4	64	
Torque Sensitivity:	oz-in/A	+/- 10%	Kt	222	444	888	1480	2400	
Back EMF Constant:	V/(rad/sec)	+/- 10%	Kb	1.57	3.14	6.27	10.45	17	
Peak Current @Tp:	Amps	Nominal	Ip	160	80	40	24	14.8	

All constant values at 25 °C ambient temperature

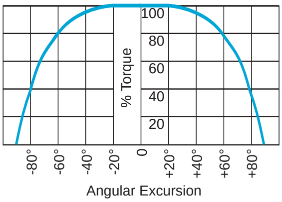
Ver. 12/2012

Selection Guide: by Peak Performance - Limited Angle Slotless Motors (Toroidally Wound)

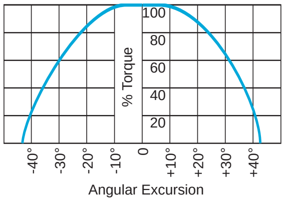
Model Number	Peak Torque (oz-in)	Power@ T_P (watts)	K_m (oz-in/√watts)	Ang. Excusion (± degrees)	O.D. (in.)	I.D. (in.)	Axial Length (in.)	Page
BTM10-AD	1.7	20	0.383	60	1.000	0.187	0.350	50
BTM10-N-2	1.8	21	0.395	20	1.000	0.125	0.350	51
BTM10-S	6.0	84	0.653	60	0.960	0.125	0.700	49
BTM14-E	6.0	38	0.968	30	1.374	0.500	0.375	52
BTM16-B	6.0	25	1.20	22.5	1.600	0.810	0.350	54
BTM18-G	18	39	2.89	25	1.718	0.250	0.700	55
BTM18-L	20	60	2.59	50	1.719	0.187	0.943	56
BTM15-C	22	159	1.75	15	1.500	0.375	0.500	53
BTM30-E	63	72	7.42	60	3.000	0.500	1.000	57
BTM35-B	165	118	15.2	20	3.500	1.000	0.950	60
BTM34-S	170	430	8.20	50	3.400	0.380	1.100	59
BTM34-Q-B	180	100	18.0	5	3.350	0.800	1.726	58
BTM48-B	220	245	14	5	4.759	2.676	0.600	61

Typical Performance Curves

Torque vs. Angular Excusion



X



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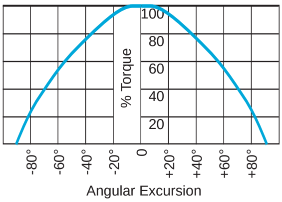

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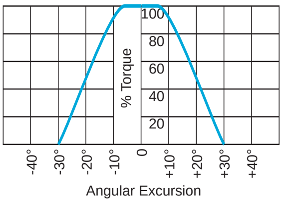
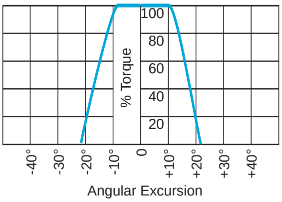


6 Pole

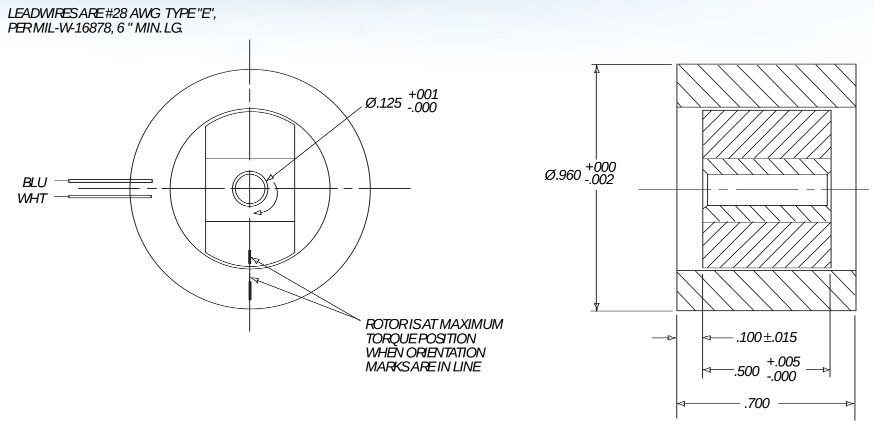


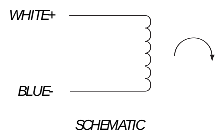
8 Pole

BTM10-S

GENERAL DYNAMICS
Mission Systems

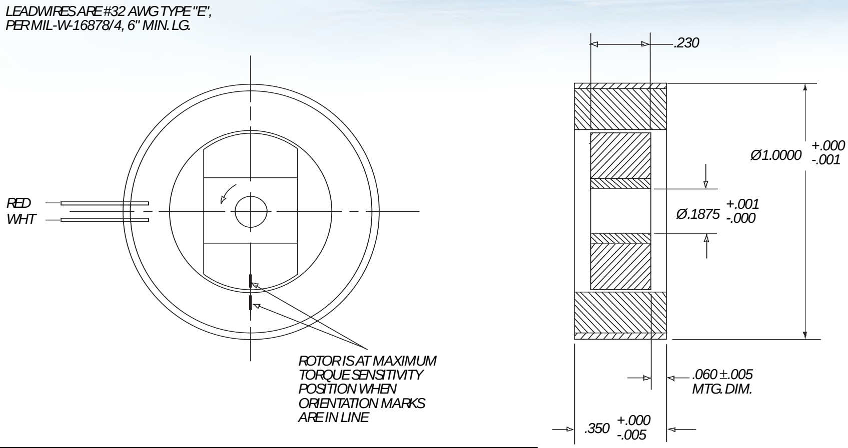
Brushless DC Motors





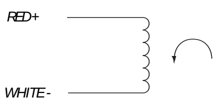
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	6.0
Power at T_p (P_p)	watts	84
Motor Constant (K_m)	oz-in/$\sqrt{W}$	0.653
Constinuous Torque (T_c)	oz-in	1.5
Power at Constinuous Torque	watts	5.3
Input Volts at Constinuous Torque	volts	5.6
Electrical Time Constant (τ_e)	milli-sec	0.25
Mechanical Time Constant (τ_m)	milli-sec	13.8
Damping Factor (F_o)	oz-in/rad/sec	0.0029
Rotor Inertia (J_m)	oz-in-sec^2	0.00004
Angular Excursion (Page 50, Curve X)	degrees	±60
Total Breakaway Torque (T_f)	oz-in	0.03
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	1.1

Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	6.0
Voltage at T_p (V_p)	volts	Nominal	22.5
Current at T_p (I_p)	amps	Nominal	3.75
Torque Sensitivity (K_t)	oz-in/amp	±10%	1.60
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.011
Inductance (L)	millihenries	±30%	1.5



Performance Data

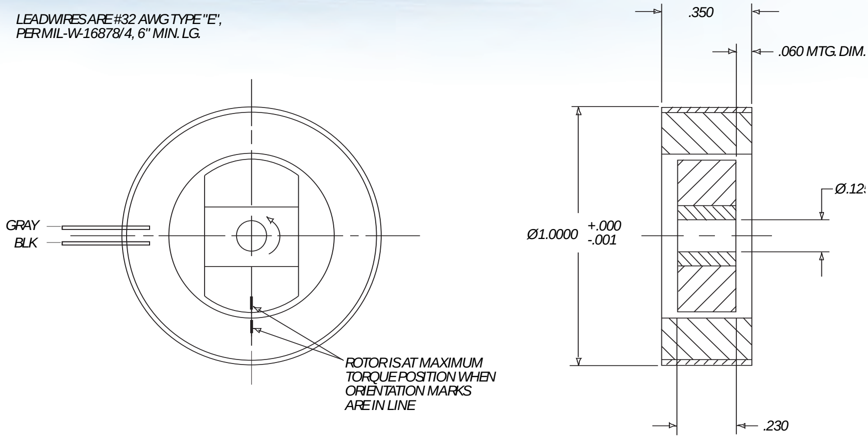
Parameter	Units	Value
Peak Torque (T_p)	oz-in	1.7
Power at T_p (P_p)	watts	20
Motor Constant (K_m)	oz-in/$\sqrt{W}$	0.383
Constinuous Torque (T_c)	oz-in	0.5
Power at Constinuous Torque	watts	2.4
Input Volts at Constinuous Torque	volts	7.5
Electrical Time Constant (τ_e)	milli-sec	0.15
Mechanical Time Constant (τ_m)	milli-sec	23
Damping Factor (F_o)	oz-in/rad/sec	0.0008
Rotor Inertia (J_m)	oz-in-sec^2	0.000018
Angular Excursion (Page 50, Curve X)	degrees	±60
Total Breakaway Torque (T_f)	oz-in	0.04
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	0.6



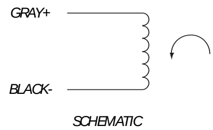
SCHEMATIC

Winding Constants

Parameter	UNITS	TOL.	Value
Resistance (R)	ohms	±12.5%	33.0
Voltage at T_p (V_p)	volts	Nominal	25.0
Current at T_p (I_p)	amps	Nominal	0.773
Torque Sensitivity (K_t)	oz-in/amp	±10%	2.20
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.012
Inductance (L)	millihenries	±30%	5.0



Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	1.8
Power at T_p (P_p)	watts	21
Motor Constant (K_m)	oz-in/$\sqrt{W}$	0.395
Constinuous Torque (T_c)	oz-in	0.6
Power at Constinuous Torque	watts	2.3
Input Volts at Constinuous Torque	volts	9.6
Electrical Time Constant (τ_e)	milli-sec	0.30
Mechanical Time Constant (τ_m)	milli-sec	16.4
Damping Factor (F_o)	oz-in/rad/sec	0.0011
Rotor Inertia (J_m)	oz-in-sec^2	0.000018
Angular Excursion (Page 50, Curve Z)	degrees	±20
Total Breakaway Torque (T_f)	oz-in	0.10
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	0.8

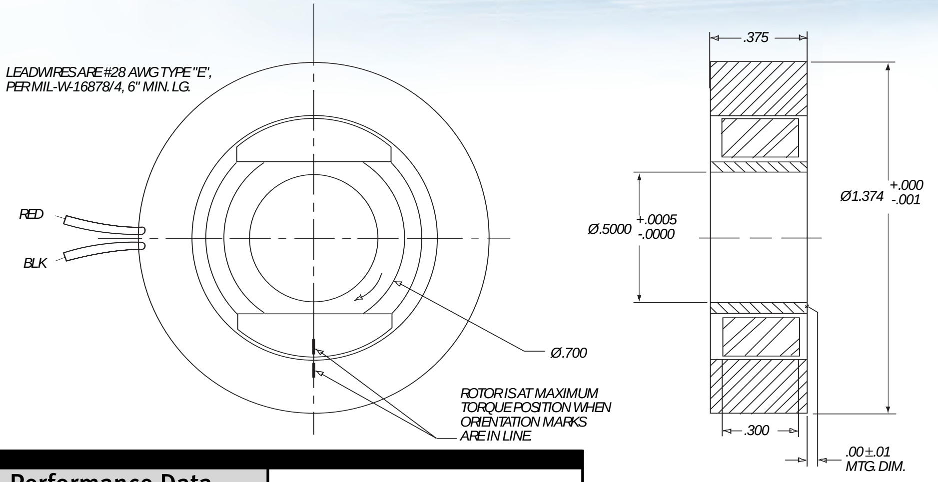


SCHEMATIC

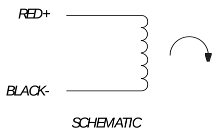
Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	40.0
Voltage at T_p (V_p)	volts	Nominal	28.8
Current at T_p (I_p)	amps	Nominal	0.720
Torque Sensitivity (K_t)	oz-in/amp	±10%	2.50
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.018
Inductance (L)	millihenries	±30%	12

BTM14-E

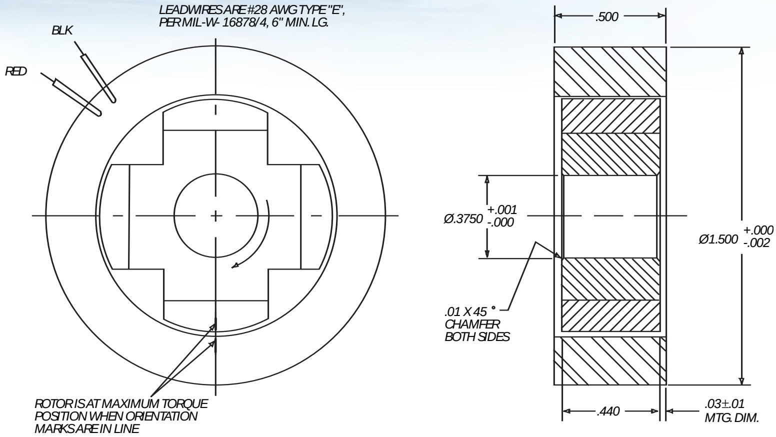
Brushless DC Motors

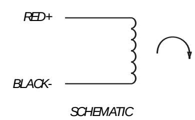


Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	6.0
Power at T_p (P_p)	watts	38
Motor Constant (K_m)	oz-in/$\sqrt{W}$	0.968
Constinuous Torque (T_c)	oz-in	2.1
Power at Constinuous Torque	watts	4.7
Input Volts at Constinuous Torque	volts	6.7
Electrical Time Constant (τ_e)	milli-sec	.42
Mechanical Time Constant (τ_m)	milli-sec	33
Damping Factor (F_o)	oz-in/rad/sec	0.0066
Rotor Inertia (J_m)	oz-in-sec^2	0.000022
Angular Excursion (Page 50, Curve Y)	degrees	±30
Total Breakaway Torque (T_f)	oz-in	0.04
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	1.7



Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	9.6
Voltage at T_p (V_p)	volts	Nominal	19.2
Current at T_p (I_p)	amps	Nominal	2.00
Torque Sensitivity (K_t)	oz-in/amp	±10%	3.00
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.021
Inductance (L)	millihenries	±30%	4.0



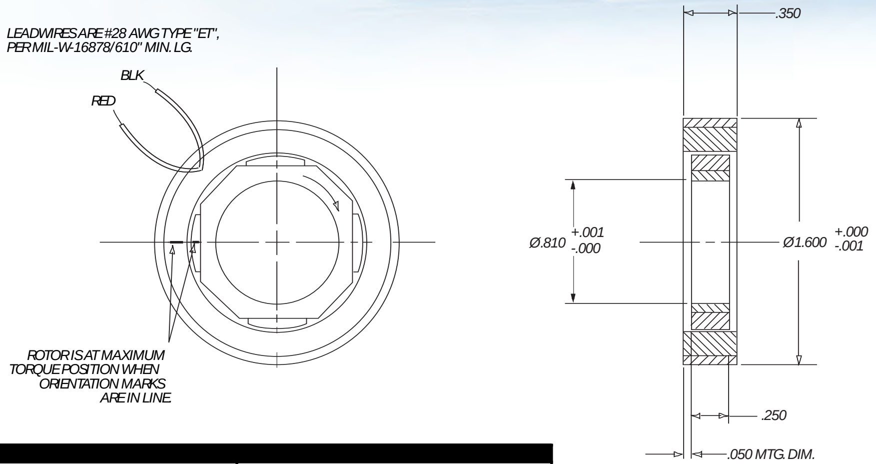


Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	22
Power at T_p (P_p)	watts	159
Motor Constant (K_m)	oz-in/$\sqrt{W}$	1.75
Constinuous Torque (T_c)	oz-in	4.5
Power at Constinuous Torque	watts	6.6
Input Volts at Constinuous Torque	volts	7.8
Electrical Time Constant (τ_e)	milli-sec	.23
Mechanical Time Constant (τ_m)	milli-sec	19.0
Damping Factor (F_o)	oz-in/rad/sec	0.0021
Rotor Inertia (J_m)	oz-in-sec^2	0.0004
Angular Excursion (Page 50, Curve Y)	degrees	±15
Total Breakaway Torque (T_f)	oz-in	0.5
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		4
Weight	oz	2.5

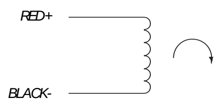
Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	9.2
Voltage at T_p (V_p)	volts	Nominal	38.2
Current at T_p (I_p)	amps	Nominal	4.15
Torque Sensitivity (K_t)	oz-in/amp	±10%	5.30
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.036
Inductance (L)	millihenries	±30%	2.1

BTM16-B

Brushless DC Motors

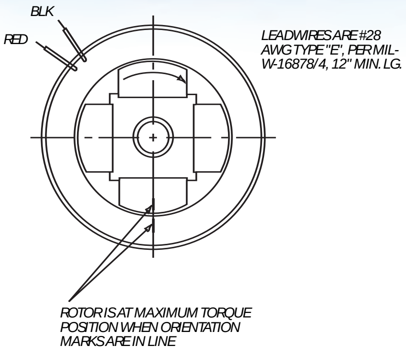


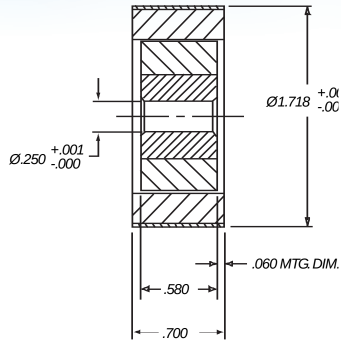
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	6.0
Power at T_p (P_p)	watts	25
Motor Constant (K_m)	oz-in/$\sqrt{W}$	1.20
Constinuous Torque (T_c)	oz-in	1.7
Power at Constinuous Torque	watts	2
Input Volts at Constinuous Torque	volts	5.6
Electrical Time Constant (τ_e)	milli-sec	0.30
Mechanical Time Constant (τ_m)	milli-sec	33.3
Damping Factor (F_o)	oz-in/rad/sec	0.0099
Rotor Inertia (J_m)	oz-in-sec^2	0.00033
Angular Excursion (Page 50, Curve Y)	degrees	±22.5
Total Breakaway Torque (T_f)	oz-in	0.08
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		4
Weight	oz	1.5



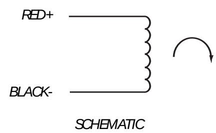
SCHEMATIC

Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	14.8
Voltage at T_p (V_p)	volts	Nominal	19.3
Current at T_p (I_p)	amps	Nominal	1.30
Torque Sensitivity (K_t)	oz-in/amp	±10%	4.60
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.032
Inductance (L)	millihenries	±30%	4.4

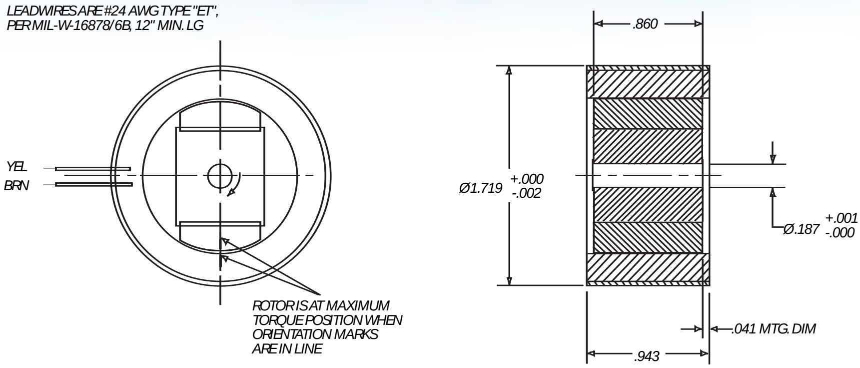




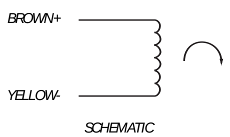
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	18
Power at T_p (P_p)	watts	39
Motor Constant (K_m)	oz-in/$\sqrt{W}$	2.89
Constinuous Torque (T_c)	oz-in	8
Power at Constinuous Torque	watts	7.7
Input Volts at Constinuous Torque	volts	9.6
Electrical Time Constant (τ_e)	milli-sec	.58
Mechanical Time Constant (τ_m)	milli-sec	14
Damping Factor (F_o)	oz-in/rad/sec	0.0059
Rotor Inertia (J_m)	oz-in-sec^2	0.00084
Angular Excursion (Page 50, Curve Y)	degrees	±25
Total Breakaway Torque (T_f)	oz-in	0.30
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		4
Weight	oz	4.8



Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	12.0
Voltage at T_p (V_p)	volts	Nominal	21.6
Current at T_p (I_p)	amps	Nominal	1.80
Torque Sensitivity (K_t)	oz-in/amp	±10%	10.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.071
Inductance (L)	millihenries	±30%	7.0



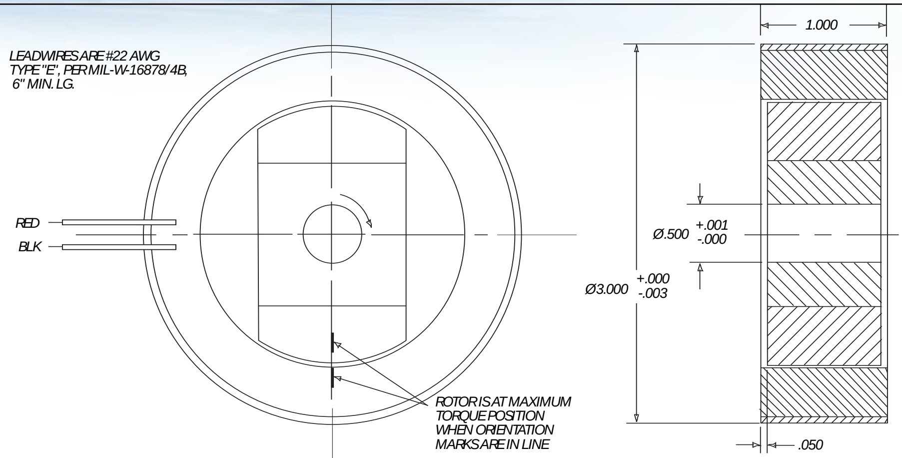
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	20
Power at T_p (P_p)	watts	60
Motor Constant (K_m)	oz-in/$\sqrt{W}$	2.59
Constinuous Torque (T_c)	oz-in	6.0
Power at Constinuous Torque	watts	8.5
Input Volts at Constinuous Torque	volts	8.5
Electrical Time Constant (τ_e)	milli-sec	.77
Mechanical Time Constant (τ_m)	milli-sec	25
Damping Factor (F_o)	oz-in/rad/sec	0.048
Rotor Inertia (J_m)	oz-in-sec^2	0.0012
Angular Excursion (Page 50, Curve X)	degrees	±50
Total Breakaway Torque (T_f)	oz-in	0.60
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	5.6



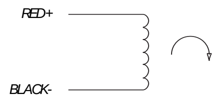
Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	6.5
Voltage at T_p (V_p)	volts	Nominal	19.7
Current at T_p (I_p)	amps	Nominal	3.03
Torque Sensitivity (K_t)	oz-in/amp	±10%	6.60
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.047
Inductance (L)	millihenries	±30%	5.0

BTM30-E
Brushless DC Motors

GENERAL DYNAMICS
Mission Systems

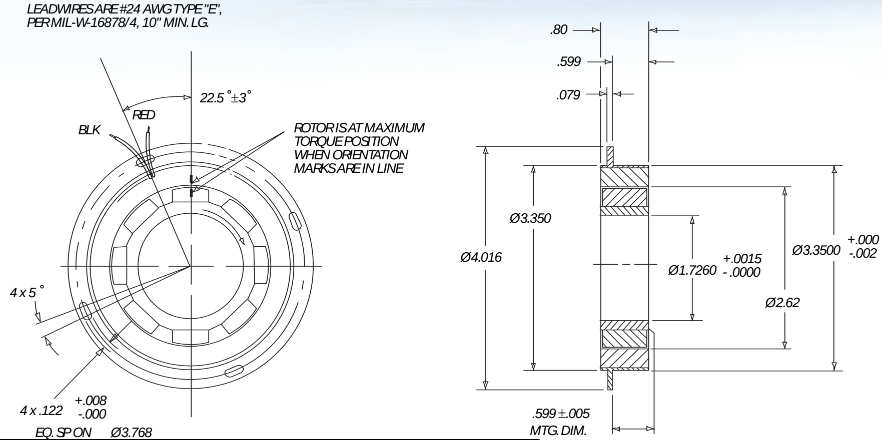


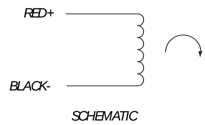
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	63
Power at T_p (P_p)	watts	72
Motor Constant (K_m)	oz-in/$\sqrt{W}$	7.42
Constinuous Torque (T_c)	oz-in	20
Power at Constinuous Torque	watts	7.3
Input Volts at Constinuous Torque	volts	7.6
Electrical Time Constant (τ_e)	milli-sec	2.3
Mechanical Time Constant (τ_m)	milli-sec	46
Damping Factor (F_o)	oz-in/rad/sec	0.4
Rotor Inertia (J_m)	oz-in-sec^2	0.018
Angular Excursion (Page 50, Curve X)	degrees	±60
Total Breakaway Torque (T_f)	oz-in	0.80
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	22



SCHEMATIC

Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	8.0
Voltage at T_p (V_p)	volts	Nominal	24.0
Current at T_p (I_p)	amps	Nominal	3.00
Torque Sensitivity (K_t)	oz-in/amp	±10%	21.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.148
Inductance (L)	millihenries	±30%	18

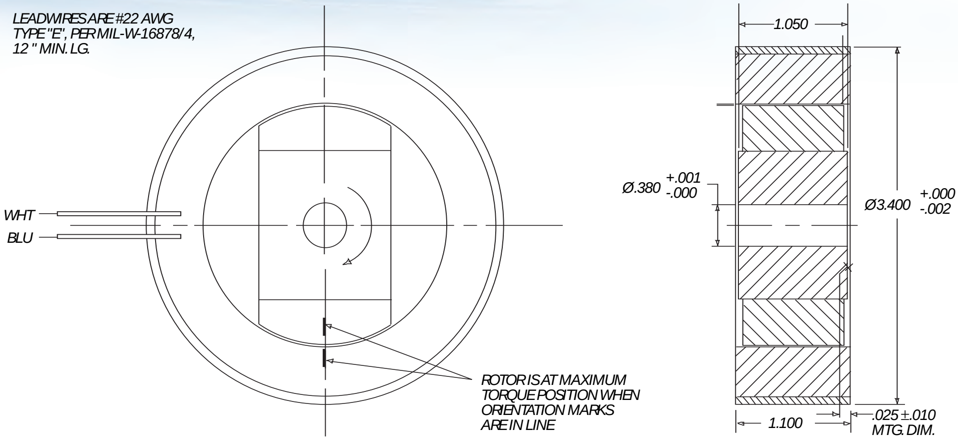




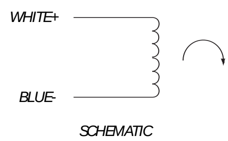
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	180
Power at T_p (P_p)	watts	100
Motor Constant (K_m)	oz-in/$\sqrt{W}$	18.0
Constinuous Torque (T_c)	oz-in	70
Power at Constinuous Torque	watts	30
Input Volts at Constinuous Torque	volts	9
Electrical Time Constant (τ_e)	milli-sec	0.50
Mechanical Time Constant (τ_m)	milli-sec	13
Damping Factor (F_o)	oz-in/rad/sec	2.29
Rotor Inertia (J_m)	oz-in-sec^2	0.0029
Angular Excursion (Page 50, Curve 8 Pole)	degrees	±5
Total Breakaway Torque (T_f)	oz-in	1.50
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		8
Weight	oz	20

Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	4.0
Voltage at T_p (V_p)	volts	Nominal	20.0
Current at T_p (I_p)	amps	Nominal	5.00
Torque Sensitivity (K_t)	oz-in/amp	±10%	36.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.254
Inductance (L)	millihenries	±30%	2.0

GENERAL DYNAMICS
Mission Systems



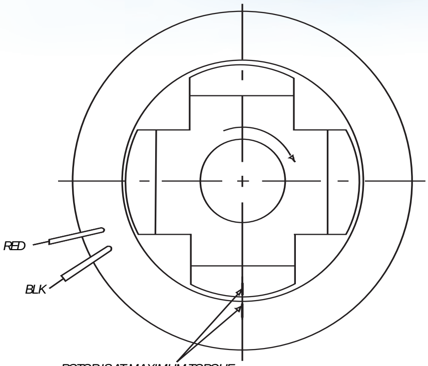
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	170
Power at T_p (P_p)	watts	430
Motor Constant (K_m)	oz-in/$\sqrt{W}$	8.20
Constinuous Torque (T_c)	oz-in	49.5
Power at Constinuous Torque	watts	36.5
Input Volts at Constinuous Torque	volts	7.1
Electrical Time Constant (τ_e)	milli-sec	1.6
Mechanical Time Constant (τ_m)	milli-sec	38
Damping Factor (F_o)	oz-in/rad/sec	0.48
Rotor Inertia (J_m)	oz-in-sec^2	0.018
Angular Excursion (Page 50, Curve X)	degrees	±50
Total Breakaway Torque (T_f)	oz-in	1.50
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	28

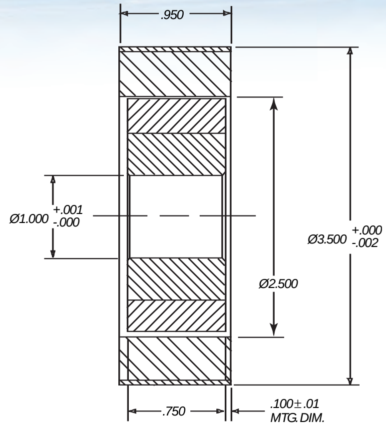


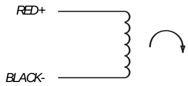
Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	1.4
Voltage at T_p (V_p)	volts	Nominal	24.5
Current at T_p (I_p)	amps	Nominal	17.5
Torque Sensitivity (K_t)	oz-in/amp	±10%	9.70
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.069
Inductance (L)	millihenries	±30%	2.2

BTM35-B

Brushless DC Motors







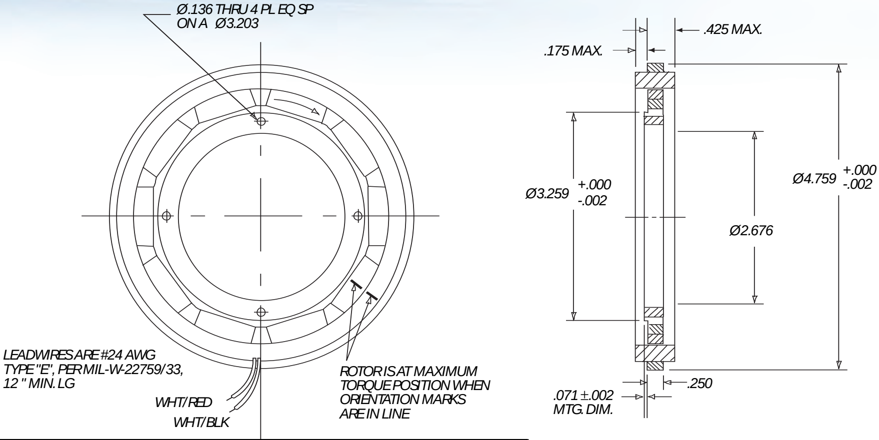
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	165
Power at T_p (P_p)	watts	118
Motor Constant (K_m)	oz-in/$\sqrt{W}$	15.2
Constinuous Torque (T_c)	oz-in	61
Power at Constinuous Torque	watts	16.1
Input Volts at Constinuous Torque	volts	9
Electrical Time Constant (τ_e)	milli-sec	1.6
Mechanical Time Constant (τ_m)	milli-sec	15
Damping Factor (F_o)	oz-in/rad/sec	1.6
Rotor Inertia (J_m)	oz-in-sec^2	0.024
Angular Excursion (Page 50, Curve Y)	degrees	±20
Total Breakaway Torque (T_f)	oz-in	2.00
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		4
Weight	oz	23

Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	5.0
Voltage at T_p (V_p)	volts	Nominal	24.3
Current at T_p (I_p)	amps	Nominal	4.85
Torque Sensitivity (K_t)	oz-in/amp	±10%	34.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.235
Inductance (L)	millihenries	±30%	8.0

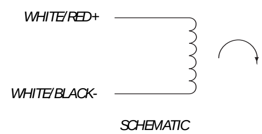
BTM48-B

Brushless DC Motors

GENERAL DYNAMICS
Mission Systems



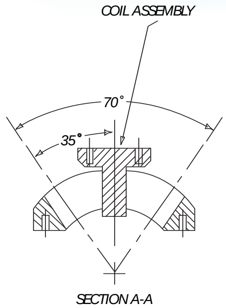
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	220
Power at T_p (P_p)	watts	245
Motor Constant (K_m)	oz-in/$\sqrt{W}$	14
Constinuous Torque (T_c)	oz-in	40
Power at Constinuous Torque	watts	8
Input Volts at Constinuous Torque	volts	17.2
Electrical Time Constant (τ_e)	milli-sec	0.50
Mechanical Time Constant (τ_m)	milli-sec	25.0
Damping Factor (F_o)	oz-in/rad/sec	1.6
Rotor Inertia (J_m)	oz-in-sec^2	0.04
Angular Excursion (Page 50, Curve 8 Pole)	degrees	±5
Total Breakaway Torque (T_f)	oz-in	2.00
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		10
Weight	oz	9

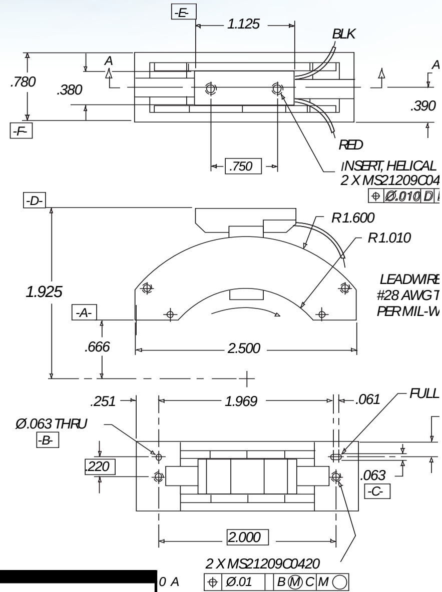


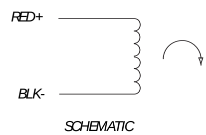
Winding Constants			
Parameter	**UNITS**	**TOL.**	**Value**
Resistance (R)	ohms	±12.5%	36.5
Voltage at T_p (V_p)	volts	Nominal	94.5
Current at T_p (I_p)	amps	Nominal	2.59
Torque Sensitivity (K_t)	oz-in/amp	±10%	8.5
Back E.M.F. (K_b)	volts/rad/sec	±10%	.664
Inductance (L)	millihenries	±30%	20

Selection Guide: Limited Angle Moving Coil Motors

Model Number	Rotation Inner/Outer	Peak Torque (oz-in.)	Continuous Torque (oz-in.)	Actuator Constant (oz-in/$\sqrt{\text{watts}}$)	Angular Excursion (degrees)	O.D.	I.D.	Axial Length	Page
RA2500A-077	I	7	3.7	2.63	+/-35	See Drawing			63
RA2500B-078	I	9	4.6	1.84	+/- 35	See Drawing			64
RA6240B-119	0	80	43	10.5	+/- 20	See Drawing			65
RA6800-119	0	110	-	23	+/- 10	See Drawing			66







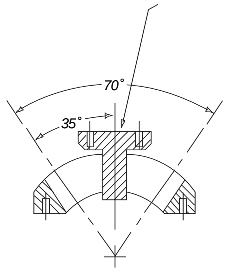
Performance Data

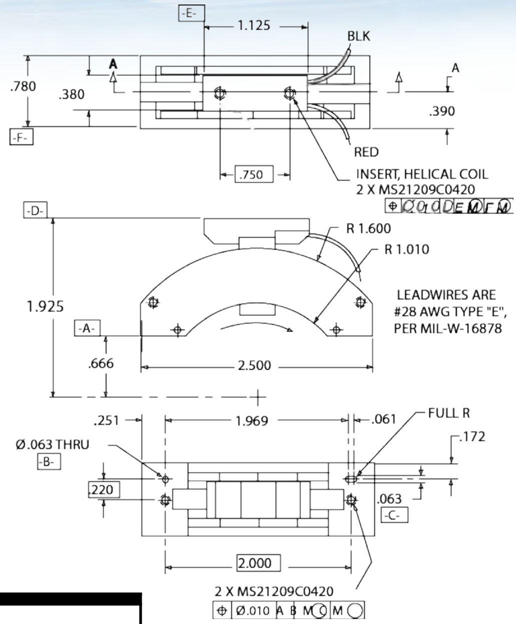
Parameter	Units	Value
Peak Torque (T_p)	oz-in	7
Power at T_p (P_p)	watts	7.1
Actuator Constant (K_a)	oz-in/ sqrt W	2.63
Continuous Torque (T_c)	oz-in	3.7
Electrical Time Constant (τ_e)	milli-sec	0.345
Stroke	degrees	±35.5
Clearance	mm	0.381
Temperature Rise (TPR)	°C/watt	22
Maximum Winding Temp.	°C	155
Weight of coil assembly	oz	.451
Total Weight	oz	5.3

Winding Constants

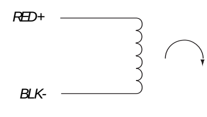
Parameter	UNITS	TOL.	-110
Resistance (R)	ohms	±12.5%	11.0
Voltage at T_p (V_p)	volts	Nominal	8.8
Current at T_p (I_p)	amps	Nominal	0.8
Torque Sensitivity (K_t)	oz-in/amp	±10%	8.75
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.044
Inductance (L)	millihenries	±30%	3.8

RA2500B-078
Brushless DC Motors



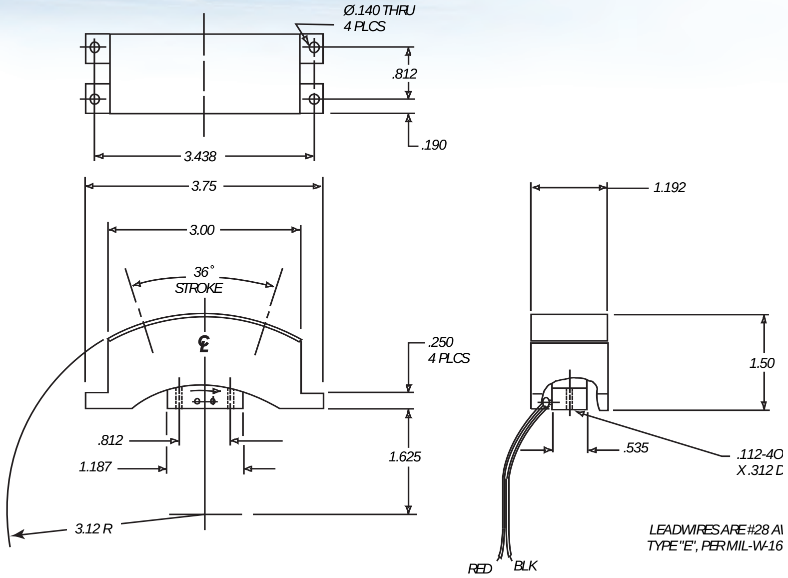


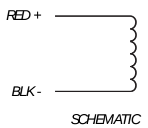
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	9
Power at T_p (P_p)	watts	23.8
Actuator Constant (K_a)	oz-in/ sqrt W	1.84
Continuous Torque (T_c)	oz-in	4.6
Electrical Time Constant (τ_e)	milli-sec	0.357
Stroke	degrees	±35
Clearance	inch	.015
Temperature Rise (TPR)	°C/watt	14
Maximum Winding Temp.	°C	155
Weight of coil assembly	oz	0.63
Total Weight	oz	4.4



Winding Constants			
Parameter	**UNITS**	**TOL.**	**-056**
Resistance (R)	ohms	±12.5%	5.6
Voltage at T_p (V_p)	volts	Nominal	11.5
Current at T_p (I_p)	amps	Nominal	2.1
Torque Sensitivity (K_t)	oz-in/amp	±10%	4.36
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.031
Inductance (L)	millihenries	±30%	2

GENERAL DYNAMICS
Mission Systems



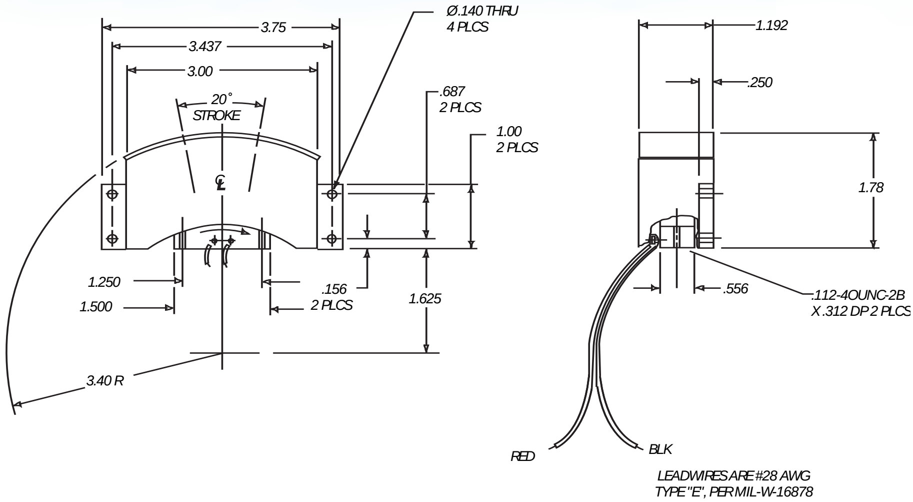


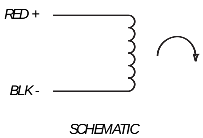
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	80
Power at T_p (P_p)	watts	58.1
Actuator Constant (K_a)	oz-in/ sqrt W	10.5
Continuous Torque (T_c)	oz-in	43
Electrical Time Constant (τ_e)	milli-sec	0.25
Stroke	degrees	± 20
Clearance	inch	.037
Temperature Rise (TPR)	°C/watt	5.1
Maximum Winding Temp.	°C	155
Weight of coil assembly	oz	0.21
Total Weight	oz	14.6

Winding Constants			
Parameter	**UNITS**	**TOL.**	**-011**
Resistance (R)	ohms	±12.5%	1.1
Voltage at T_p (V_p)	volts	Nominal	8
Current at T_p (I_p)	amps	Nominal	7.27
Torque Sensitivity (K_t)	oz-in/amp	±10%	11
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.078
Inductance (L)	millihenries	±30%	.275

RA6800-119

Brushless DC Motors





Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	110
Power at T_p (P_p)	watts	23
Actuator Constant (K_a)	oz-in/ sqrt W	23
Continuous Torque (T_c)	oz-in	-
Electrical Time Constant (τ_e)	milli-sec	0.660
Stroke	degrees	±10
Clearance	inch	0.02
Temperature Rise (TPR)	°C/watt	-
Maximum Winding Temp.	°C	155
Weight of coil assembly	oz	0.75
Total Weight	oz	16

Winding Constants			
Parameter	**UNITS**	**TOL.**	**-035**
Resistance (R)	ohms	±12.5%	3.5
Voltage at T_p (V_p)	volts	Nominal	8.96
Current at T_p (I_p)	amps	Nominal	2.56
Torque Sensitivity (K_t)	oz-in/amp	±10%	43
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.3
Inductance (L)	millihenries	±30%	2.3

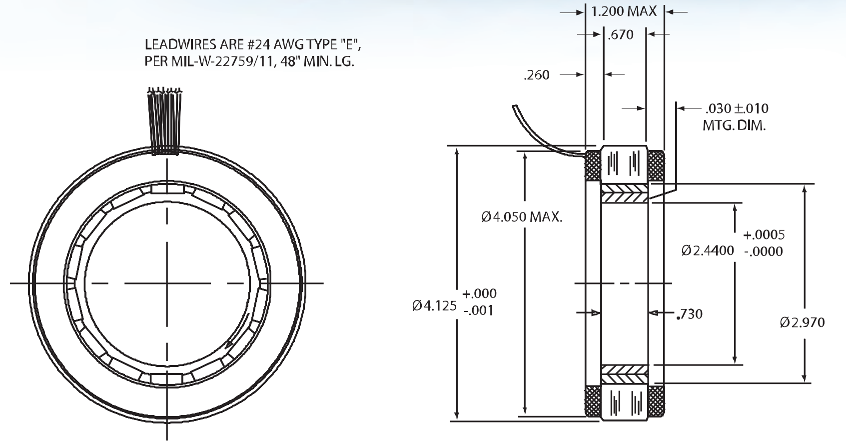
Selection Guide: Dual Winding Motors

Motor Type	Model Number	Rotation Inner/Outer	Peak Torque (oz-in.)	Power@TP (watts)	Km (oz-in/$\sqrt{\text{watts}}$)	O.D. (in.)	I.D. (in.)	Axial Length (in.)	Page
2-Phase	**4125-120**	I	82.5	12.5	33	4.125	2.440	1.200	68
3-Phase	**6700-154**	I	500	31.1	90	6.700	5.250	1.850	69
3-Phase	**8700-100**	0	150	10.5	50.3	8.700	7.500	1.000	70

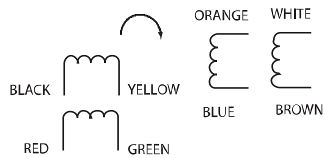
GENERAL DYNAMICS
Mission Systems

4125-120

Brushless DC Motor / Inside Rotor



ROTATION: FIELD ROTATES CW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: PRIMARY: RED+, GREEN-, BLUE+, ORANGE -; SECONDARY: BLACK+, YELLOW-, BROWN+, WHITE-.



SCHEMATIC

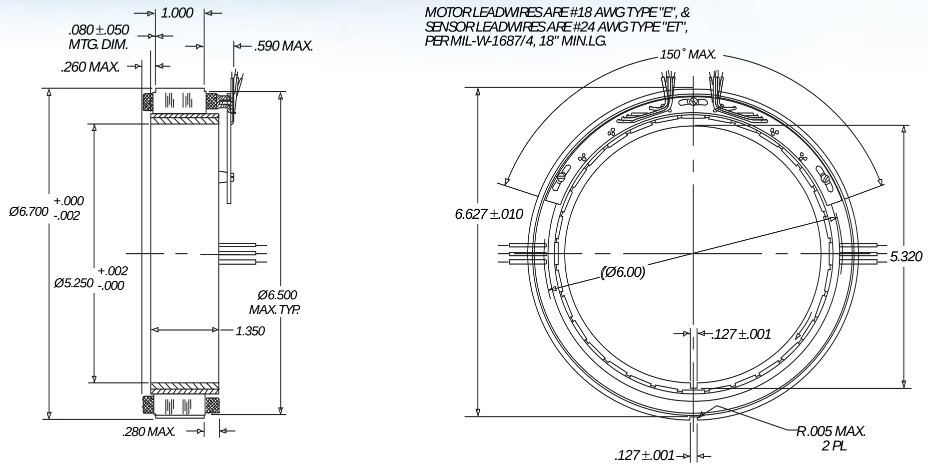
Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	82.5
Power at T_p (P_p)	watts	12.5
Motor Constant (K_m)	oz-in/$\sqrt{W}$	33
Electrical Time Constant (τ_e)	milli-sec	.5
Mechanical Time Constant (τ_m)	milli-sec	8.93
Damping Factor (F_o)	oz-in/rad/sec	3.92
Moment of Inertia (J_m)	oz-in-sec^2	0.035
Total Breakaway Torque (T_f)	oz-in	5.0
Temperature Rise (TPR)	°C/watt	2.4
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	29
Number of Poles		14
Number of Phases		2

Winding Constants						
Parameter	**UNITS**	**TOL.**				**-500**
Resistance (R)	ohms	±12.5%				50.0
Voltage at T_p (V_p)	volts	Nominal				25
Current at T_p (I_p)	amps	Nominal				0.500
Torque Sensitivity (K_t)	oz-in/amp	±10%				165
Back E.M.F. (K_b)	volts/rad/sec	±10%				1.16
Inductance (L)	millihenries	±30%				25

6700-154

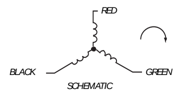
GENERAL DYNAMICS
Mission Systems

Brushless DC Motor with Hall Sensors / Inside Rotor

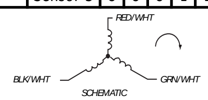


Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	500
Power at T_p (P_p)	watts	31.1
Motor Constant (K_m)	oz-in/$\sqrt{W}$	90.0
Electrical Time Constant (τ_e)	milli-sec	.37
Mechanical Time Constant (τ_m)	milli-sec	7.7
Damping Factor (F_o)	oz-in/rad/sec	57.7
Moment of Inertia (J_m)	oz-in-sec^2	0.440
Total Breakaway Torque (T_f)	oz-in	20
Temperature Rise (TPR)	°C/watt	1.2
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	67
Number of Poles		32
Number of Phases		3

Commutation Table (PRIMARY)									
Step		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Color**
Motor	Phase A	+	+	Off	-	-	Off	+	RED
	Phase B	-	Off	+	+	Off	-	-	BLK
	Phase C	Off	-	-	Off	+	+	Off	GRN
Sensor	Sensor 1	1	1	0	0	0	1	1	YEL
	Sensor 2	0	1	1	1	0	0	0	RED
	Sensor 3	0	0	0	1	1	1	0	ORG



Commutation Table (SECONDARY)									
Step		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Color**
Motor	Phase A	+	+	Off	-	-	Off	+	RED / WHT
	Phase B	-	Off	+	+	Off	-	-	BLK / WHT
	Phase C	Off	-	-	Off	+	+	Off	GRN / WHT
Sensor	Sensor 1	1	1	0	0	0	1	1	YEL /WHT
	Sensor 2	0	1	1	1	0	0	0	RED / WHT
	Sensor 3	0	0	0	1	1	1	0	ORG / WHT

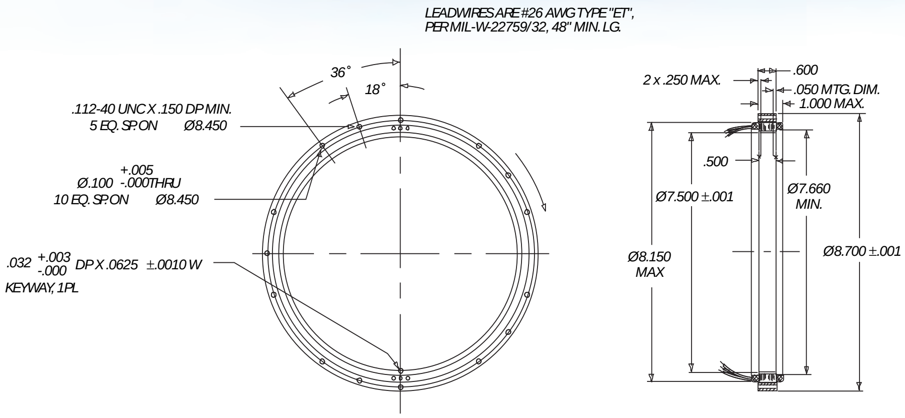


ROTATION: CW WHEN VIEWED FROM LEAD SIDE

Winding Constants						
Parameter	**UNITS**	**TOL.**	**-019**			
Resistance (R)	ohms	±12.5%	1.9			
Voltage at T_p (V_p)	volts	Nominal	7.7			
Current at T_p (I_p)	amps	Nominal	4.03			
Torque Sensitivity (K_t)	oz-in/amp	±10%	124			
Back E.M.F. (K_b)	volts/rad/sec	±10%	.876			
Inductance (L)	millihenries	±30%	1.3			

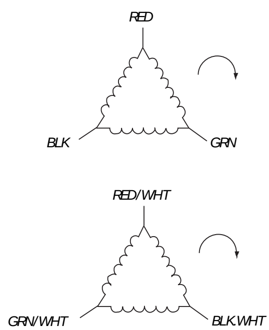
8700-100

Brushless DC Motor/Outside Rotor



Performance Data		
Parameter	**Units**	**Value**
Peak Torque (T_p)	oz-in	150
Power at T_p (P_p)	watts	10.5
Motor Constant (K_m)	oz-in/$\sqrt{W}$	50.3
Electrical Time Constant (τ_e)	milli-sec	.31
Mechanical Time Constant (τ_m)	milli-sec	47.5
Damping Factor (F_o)	oz-in/rad/sec	17.9
Moment of Inertia (J_m)	oz-in-sec^2	.850
Total Breakaway Torque (T_f)	oz-in	10
Temperature Rise (TPR)	°C/watt	1.4
Max. Allowable Wdg. Temp.	°C	155
Weight	lbs	2.95
Number of Poles		40
Number of Phases		3

ROTATION: FIELD ROTATES CW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: RED+, GREEN-, GREEN+, BLACK-, BLACK+, RED-. AND RED/WHT+ GRN/WHT- GRN/WHT+, BLK/WHT- BLK/WHT+, RED/WHT-.



SCHEMATIC

Winding Constants						
Parameter	**UNITS**	**TOL.**	**-800**			
Resistance (R)	ohms	±12.5%	80			
Voltage at T_p (V_p)	volts	Nominal	29			
Current at T_p (I_p)	amps	Nominal	.363			
Torque Sensitivity (K_t)	oz-in/amp	±10%	450			
Back E.M.F. (K_b)	volts/rad/sec	±10%	3.178			
Inductance (L)	millihenries	±30%	80			

Mechanisms

Direct Drive Motor Assemblies

GDMS produces custom-designed motion control packages and assemblies. Brushless torque motors can be integrated with matching resolvers to provide smooth commutation and high accuracy, absolute positioning. These products provide efficient solutions in demanding motion control applications from industrial robot drives to space mechanisms. Our customers enjoy the performance, cost and logistics benefits of procuring integrated component sets from a single source.

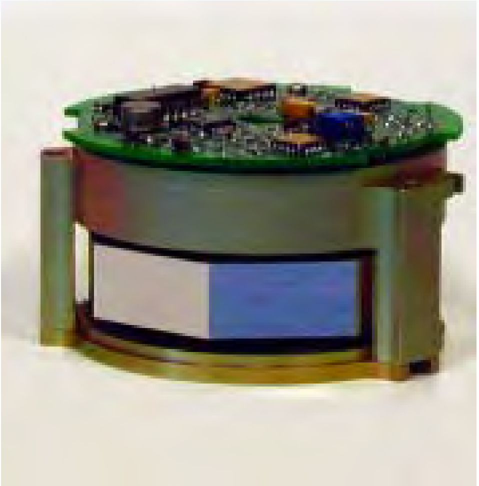
High torque brushless motor-resolver assembly with integral ferrofluid seal for vacuum semiconductor process mechanism provides high positioning accuracy and speeds up to 1200 RPM.

Scanners

GDMS is a leading supplier of rotary and oscillating scanners for defense IR imaging applications.

These scanners incorporate proprietary control electronics to provide high scan rates and linearity.

Typical Performance Characteristics
Rotary Scanners
Wobble: 30 arc-seconds
Jitter: 1.5 micro-seconds
Oscillating Scanners:
Active Scan Angle: 7.5 deg
Scan Rate: 60 Hz
Linearity: .5 micro-seconds

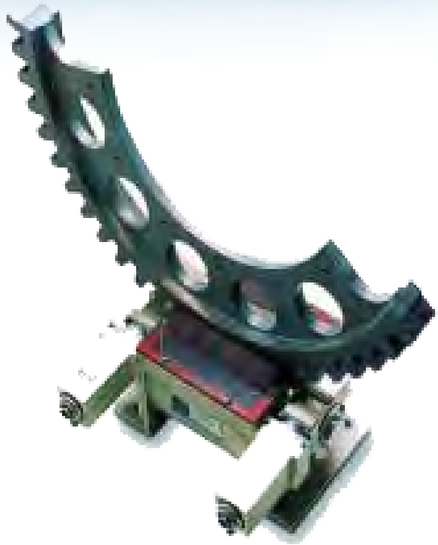


Rotating scanner.

Oscillating scanner.

Actuators

GDMS produces custom linear and rotary actuators for a space, defense and commercial.



Redundant drive actuator for space deployment mechanism.

Focus actuator with integral control electronics for IR imaging telescope positions to 6x10-4 inches.

Feedback Packages

GDMS provides resolvers in custom housings,creating special application-specific feedback packages.

Resolver-based feedback package for commuter jet flap drive mechanism.

Capabilities

Overview

- DC Motors - Direct Drive/Brushless and Brush Type
- AC and Stepper Motors
- DC and AC Tachometers
- Resolvers/Synchros
- Scanners - Oscillating and Rotary
- Actuators - Linear and Rotary
- Packages, Assemblies and Servosystems

GDMS comprehensive component design and manufacturing capabilities are unique in the motion control industry, with expertise developed over more than three decades.This experience allows GDMS to provide high performance motion control and measurement solutions using the most advanced and reliable technology available. GDMS offers a wide array of both standard and custom components, which can be combined as a system to offer opti-mal solutions for your motion control needs. By incorporating standard components into a single housing, for example, we can provide the most economical and technically sound solution to many motion control problems. Standard or custom-engineered components, sub-assemblies, or entire systems– GDMS has what you need. The following information offers a brief description of each of our product lines, plus examples of how they can be combined into assemblies and systems to meet your motion control needs

DC Motors

Direct Drive / Brushless and Brush Type Performance Features

GDMS complete line of MAGTECH® direct drive brushless and brush type torque motors and servomotors are sure to include a motor that meets your system's requirements.

The direct drive motor is equivalent to a conventional servomotor-gearhead, but features improved response characteristics. This gearless DC motor drive is ideally suited for high acceleration applications with rapid starts and stops. The absence of gearing also eliminates errors caused by friction, backlash, and other inaccuracies, making possible a very high threshold sensitivity - to one arc second in high performance positioning systems.

DC torque motors have a space-saving "pancake" shape, i.e. they are axially short compared to the diameter and can be conventionally mounted around a shaft or other load. Limited angle torque motors do not require commutation electronics and have no cogging.

Characteristics

Brushless

- Outer diameters 0.5" to 33"
- Torque up to 1,650 ft-lbs
- Housed or frameless
- Rare earth magnets
- 2- or 3- phase winding

Brush

- Outer diameters 1" to 20"
- Torque up to 465 ft-lbs
- Housed or frameless
- Rare earth magnets
- 2-wire control (+/-)

Brushless, Limited Angle Torque Motors

- Outer diameters 0.8" to 14"
- Torque up to 24 ft-lbs
- Angular excursion: to ±60°
- No slot effects

Brushless, Moving Coil, Segmented

- Radius up to 10"
- Torque up to 200 oz-in
- Extremely low cogging
- No commutation required

DC Brushless and Brush Motors, Housed and Frameless Motors, Segment Motors, Brushless Limited Angle Torque Motors, and Large Ring Torque Motors.

AC and Stepper Motors

Performance Features

GDMSs' AC and stepper motors maintain constant speed without feedbackdevices, reducing system cost and complexity. Hysteresis synchronous AC motors are small, light-weight, low-inertia motors that ensure tight speed control under varying loads. They also feature fast ramp up, proven reliability, and cost-effective design. Induction AC motors also offer high reliability and low cost, with non-sparking operation. They can meet stringent torque and starting voltage specifi-cations. Stepper motors provide accurate position using a predefined angular step, and are suitable in lighter load applications.

Characteristics

Hysteresis Synchronous AC Motors

- Motor speeds to 12,000 rpm
- Power output to 250 watts
- Speed stability to .001%
- Available with or without gearhead
- Fixed wobble is 100 arcseconds maximum, phase to phase
- Random wobble is 7 arcseconds total maximum

Induction AC Motors

- Outer diameters 0.5" to 2.5"
- Motor speeds to 24,000 rpm
- Power output to 75 watts
- 12 to 230 VAC / 60 to 400Hz
- Single and double-shaft extensions

Stepper Motors

- Outer diameters 0.5" to 4"
- 7.5, 15, 30, 45 and 90 degree steps
- Slow speeds to 1,500 PPS
- Permanent magnet and variable reluctance

DC and AC Tachometers

Performance Features

GDMS - MAGTECH® electromagnetic tachometer generators provide precise velocity feedback by supplying output voltage directly proportional to speed. With these very high output voltage to speed ratios, GDMS tachometers allow stable voltage output over a wide range of speeds. Their fast response to high-rate velocity changes aid overall system stability. They can be coupled directly to the load to eliminate drive train inaccuracies. A wide dynamic range allows for low speed operation. GDMS engineers its tachometers to withstand high shock and vibration levels.

Tachometer Generators.

Characteristics

- Outer diameter 1" to 20"
- Velocity change response less than 100 microsec time constants
- Dynamic range up to 50,000 to 1
- Output ripple as low as 0.03%
- Speed range 1 rpm to 6000 rpm
- AC or DC configurations

Resolvers/Synchros

Performance Features

GDMS exceptionally reliable single, multi-speed and segment resolvers are absolute position sensors, providing a high degree of angular accuracy and extremely high resolution. They are available in transmitter, differential, or receiver functions. These maintenance-free, high-precision resolvers are specifically designed to withstand environments containing dirt, grease, oil or other contaminants. They are available housed or unhoused, in a variety of configurations, with either analog or digital outputs.

They are compact, low weight, easy to install and feature a low noise/signal ratio. The segmented resolver, a patented invention, offers cost savings over full rotation resolvers by providing highly accurate performance in situations that require only limited angle measurements.

Brushless Resolvers, Multispeed Resolvers, Segmented Resolvers, Synchros and Induction Potentiometers.

Characteristics

- Single or multispeed, up to 64 speed
- Accuracy to 5 arcseconds
- Outer diameters 0.7" to 13" - custom sizes available
- Input excitation frequency from 60 to 20,000 Hz
- Null voltages 1 to 3 mV/Volt output
- Speeds to 20,000 rpm
- Bare, hub and sleeve housings, or fully housed with bearings available
- Rotor or stator primary
- Compensated windings available
- Brushless versions available
- Transmitter, receiver or differential available

Scanners

Performance Features

GDMS high precision scanners are designed and manufactured in both open and closed loop configurations. These sophisticated scanners are capable of performing with precision and reliability under harsh envi-ronmental conditions. They are used in mil-itary, medical, printing, guidance tracking, and thermal imaging system applications requiring precision performance. Low jitter, low power consumption, high stability and high band width with precision velocity and position feedback, are salient features of our scanning systems. Our scanners incor-porate state-of-the-art control techniques covered by several patents.

Rotating and Oscillating Scanners.

Characteristics

Open Loop Configuration

- **Hysteresis Synchronous Scanner**
  - Speeds up to 100,000 rpm
  - Low jitter, high efficiency and low heat dissipation
- Brushless DC Scanner
  - Speeds up to 50,000 rpm
  - Low ripple, high efficiency, low jitter and noise

Closed Loop Configurations

- Rotary polygon, oscillating and co-axial configurations
- 1,200-3,000 pulses per scanner revo-lution
- Typical tilt and wobble 10 arcseconds
- Scanner speeds between 300-50,000 rpm
- MTBF = 100,000 hrs @ 25°C

Actuators

Transducer Selection

GDMS designs and manufactures several con-figurations of rotary and linear actuators. GDMS actuators serve a large market includ-ing the military, aerospace, medical, and industrial sectors.They are typically found in electro-optical pointing systems, missile fin actuator systems, commercial avionics con-trol surfaces, as well as in robotic and special industrial applications. GDMS actuators are available with either AC or DC power sys-tem options. Prime mover choices include either Brush DC motor, brushless DC motor, stepper motor, or induction motor. The actuator's prime movers can vary to meet individual application requirements.

Linear/Rotary Electromechanical Actuators, Drive Electronics and Control Systems.

Characteristics

- High precision, high efficiency gear boxes –spur and planetary types are typical
- Available for both rotary and linear displacement
- Operating torques 5 in-oz to 5000 oz-in
- Available in both open loop and closed loop configurations with or without drive electronics
- Positional accuracy of .0002" achiev-able with linearity and repeatability up to 2%, under extreme environmen-tal conditions

Packages, Assemblies and Servosystems

Custom Assembly.

Assemblies

Packaging several electromechanical components onto a common shaft is one way to provide greater system accuracy at lower cost. GDMS can assemble components such as motors, potentiometers, resolvers, encoders, gearheads, or magnetic brakes and clutches into a single housing to save space and increase system reliability. Customers also save procurement, assembly and testing costs, and gain one source accountability, on-time delivery of all parts, and a single documentation package. The result: a ready-to install servomechanism optimized for the application, and backed by GDMS. guaranteed quality and service.

Systems

In addition to custom sub-assemblies, GDMS also provides complete servosystems consisting of motor, velocity feedback, position feedback, gear reduction, electronic control units, motor drivers and amplifiers. Like custom subsystems, complete servosystems provide ready-to-install products uniquely optimized for the application. The result is lower cost, greater accuracy, and all the advantages of single-source accountability.

DC Motor Design Guide

Application______________________________
____
____
____
____

Physical Requirements:

- ❏ Brushless
- ❏ Brush
- ❏ Inner Rotating
- ❏ Outer Rotating
- ❏ Limited Angle
- ❏ Frameless
- ❏ Housed
- ❏ Maximum OD
- ❏ Maximum Length
- ❏ Minimum ID

For Housed Motors Only:

OD ______________________________
Length ____________________________
Shaft OD __________________________
Shaft Length ________________________

For Brushless Motors Only:

Commutation:
❏ Hall Sensors ❏ Resolver
❏ Encoder ❏ None

Drive Output Waveform:
❏ 6 Point Trapezoidal ❏ Sinusoidal

Winding:
❏ Single Phase ❏ 2-Phase ❏ 3-Phase
❏ Delta ❏ Wye ❏ Open Delta

Performance/Winding Data:

Peak Torque:
______________ ❏oz-in ❏ N-m
Motor Constant:
______________ ❏oz-in/$\sqrt{W}$ ❏N-m/$\sqrt{W}$
Torque Sensitivity:
______________ ❏oz-in/Amp ❏N-m/Amp
Back EMF________________ Volt/rad/s
Power ________________ Watt
Current ________________ Amp
Voltage ________________ Volt
Resistance ________________ Ohms
Inductance ________________ mH

Max Winding Temperature: 155°C is standard for Brush type, 220°C is standard for Brushless type.
Other Max. Winding Temperature if required ______________________ °C

Environmental Requirements:

Temperature of Operation:
Minimum _____°C Maximum _____°C
Shock ____________________________
Vibration __________________________
Altitude ___________________________
Other _____________________________

Requested by:

Name ____________________________
Title _____________________________
Company __________________________
Address ___________________________
City ______________________________
State _____________________________
Zip ______________________________
Country ___________________________
Phone ____________________________
Fax ______________________________
Email _____________________________

GENERAL DYNAMICS
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