MAGTECH®

BRUSHLESS MOTOR

SOURCE BOOK

AXSYS TECHNOLOGIES

MOTION CONTROL PRODUCTS

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MOTION CONTROL PRODUCTS

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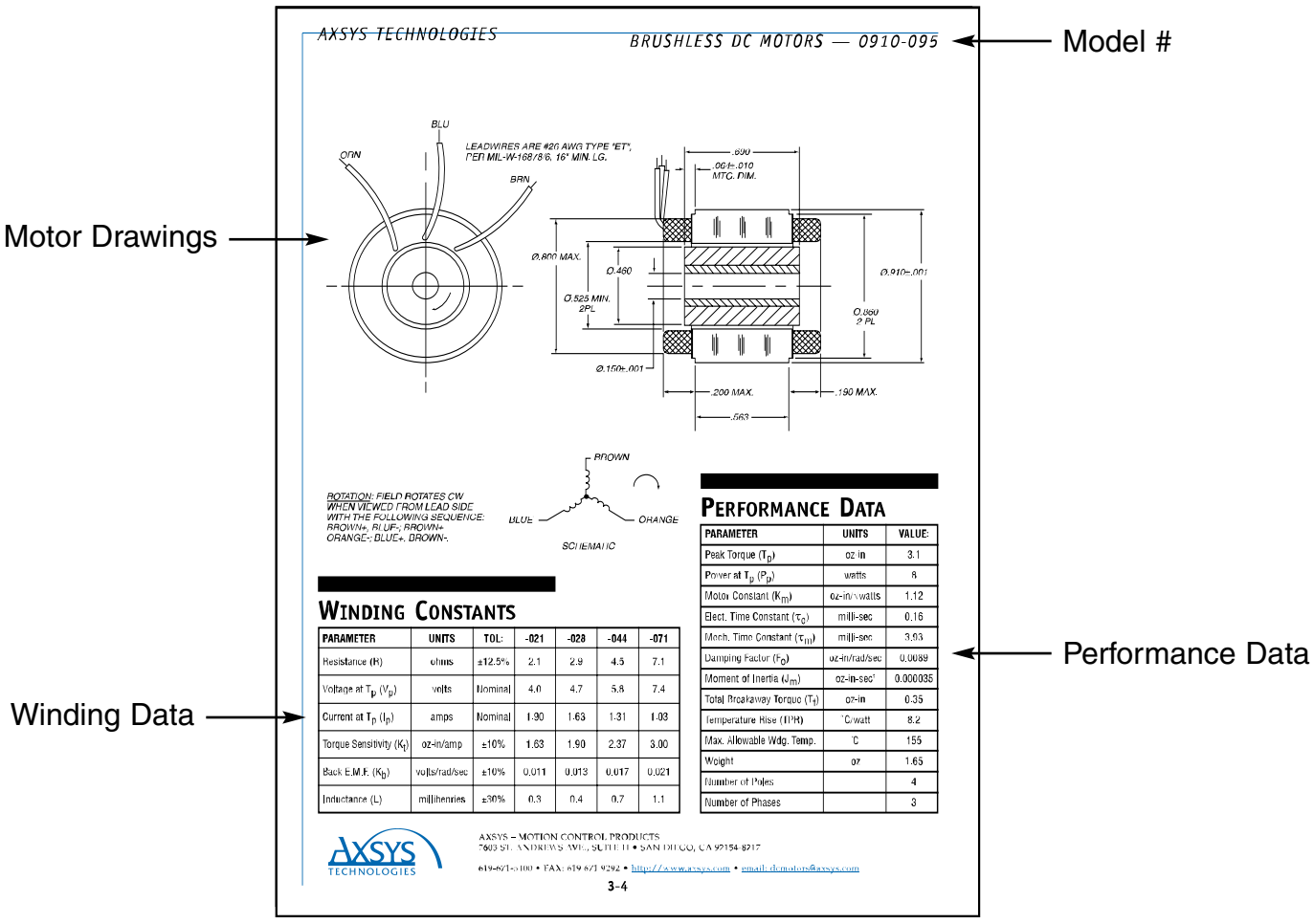
User's Guide

How to use the MAGTECH® Source Book

The MAGTECH® Source Book 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. Pages are identified with the section number followed by numeric order.

Sample Datapage



PARAMETER	UNITS	TOL:	-021	-028	-044	-071
Resistance (R)	ohms	±12.5%	2.1	2.9	4.5	7.1
Voltage at T_p (V_p)	volts	Nominal	4.0	4.7	5.8	7.4
Current at T_p (I_p)	amps	Nominal	1.90	1.63	1.31	1.03
Torque Sensitivity (K_t)	oz-in/amp	±10%	1.63	1.90	2.37	3.00
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.011	0.013	0.017	0.021
Inductance (L)	millihenries	±30%	0.3	0.4	0.7	1.1

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz in	3.1
Power at T_p (P_p)	watts	8
Motor Constant (K_m)	oz-in/√watts	1.12
Elect. Time Constant (τ_e)	milli-sec	0.16
Mech. Time Constant (τ_m)	milli-sec	3.93
Damping Factor (τ_D)	oz-in/rad/sec	0.0089
Moment of Inertia (J_m)	oz-in-sec²	0.000035
Total Breakaway Torque (T_f)	oz-in	0.35
Temperature Rise (TPR)	°C/watt	8.2
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	1.65
Number of Poles		4
Number of Phases		3

Motion Control Packages

For decades, Axsys MCP 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 MAGTECH® Source Book gives a brief overview.

Design Guides

At the end of the introduction, you will find a Brushless 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 take the Design Guide out of the binder and make copies for yourself to use as worksheets when deciding on your required brushless motor.

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Axsys MCP Introduction

Heritage

Axsys MCP 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, textiles to robotics.

From our inception, Axsys MCP 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, Axsys MCP is uniquely able to apply this high-performance technology to your system needs, at a competitive cost.

Design and Manufacturing

Your Axsys MCP 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.

Axsys MCP manufacturing cycle begins 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 Axsys MCP, 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.

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Quality Assurance

We have established the internal quality systems required for high-reliability commercial and defense programs. Axsys MCP is vigorously implementing ISO 9000-2000 quality guidelines. Our current quality levels are:

MIL-I-45208A
MIL-Q-9858A

Manufacturing Operation

Axsys MCP 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 operators include an extensive CNC machine shop, automated armature winding station, organized work centers, and environmental and performance testing equipment.

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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 save 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 the 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.

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The following table lists some applications:

Application	Equipment	Brushless DC Advantage
Velocity Servos	Disk Memory Spindle Drive	Long Life Low-EMI
	Video Tape Recorder	High Speed No Brush Debris
	Silicon Wafer 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
	Cryongenic Compressor	No Brush Debris
	Fuel Pump	No Arcing No Brush Debris
	Air Bearing Spindle	No Brush Debris High Speed
Position Servo	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

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Basic Components

A brushless motor system consists of four basic sub-assemblies:

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

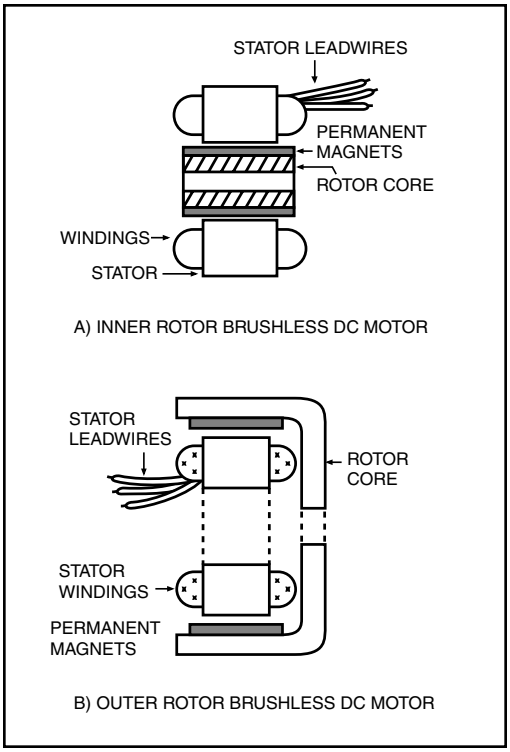

Figure-1 Brushless Motor Configurations

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 windings, 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 windings 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 Figures 1A and 1B. The inner rotor design is generally used in incremental motion applications 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 load inertia as in a memory disk drive.

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.

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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 waveforms.

ELECTROMAGNETIC

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

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 characteristic 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 motor 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 outputs are first decoded or demodulated (if required), and then amplified by a four quadrant power amplifier. To reduce power dissipation in the amplifier, pulse-width modulation is often used. This type of system is more costly than the digitally switched system. For this reason, is used only when the application 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.

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Often in low power applications, the control electronic are an integral part of the motor and range from simple 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 should be applied in a sequence to provide a constant output torque. Square wave excitation results in a small ripple in the output torque due to the finite commutation angle. The commutation angle is the angle the rotor rotates through before the windings are switched. Ripple torque is typically expressed as a percentage of average to peak torque ratio. It is present whenever the windings are switched by a step function either electrically via solid state switches or mechanically via brushes.

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 torque is approximately 7% average to peak. Since two-thirds of the available windings are used at

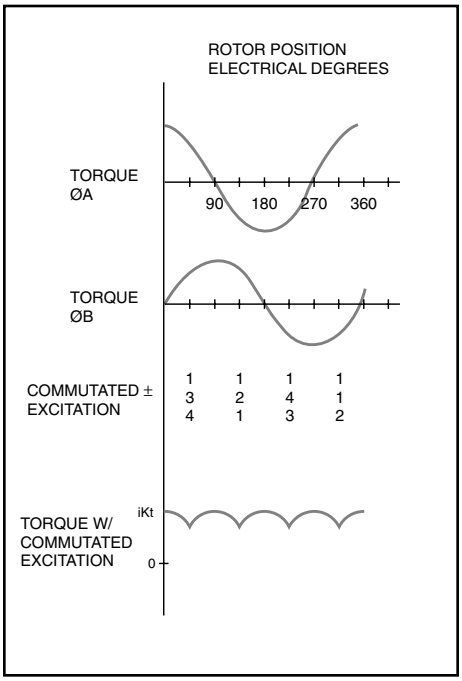

Figure-2 Switch mode commutation of a two phase brushless DC motor.

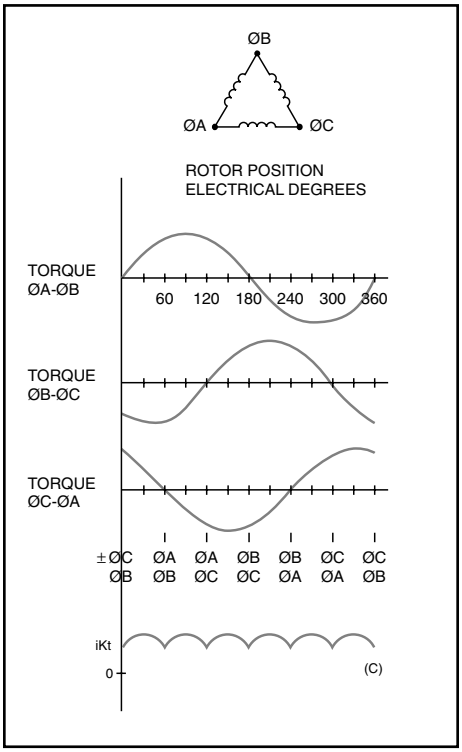

Figure-3 Switch mode commutation of a three phase delta wound brushless DC motor.

any one time, compared to one-half for the two phase winding, the three phase system is more efficient.

The torque waveforms indicated in Figures 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 in 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.

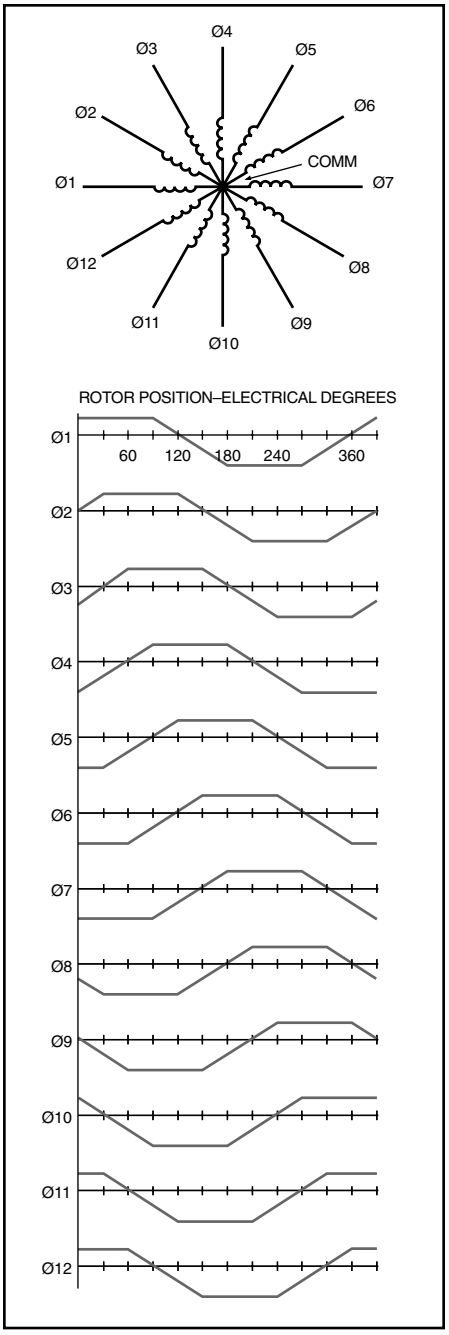

Figure-5 Torque waveform for 12 phase brushless DC motor.

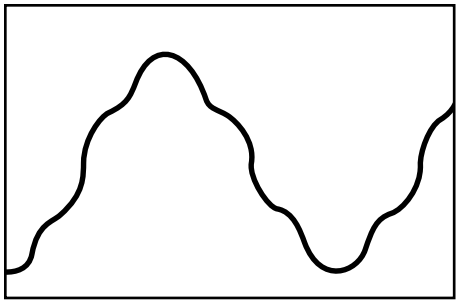

Figure-4 BEMF Trapezoidal waveform.

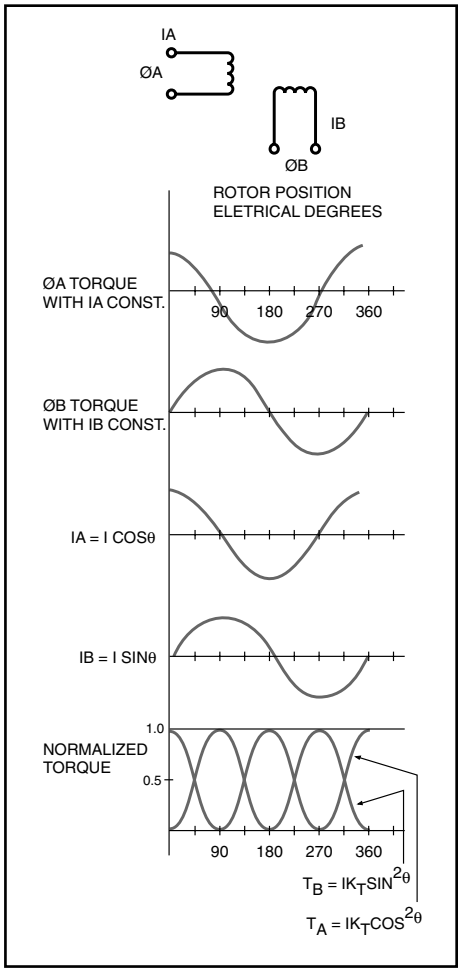

Figure-6 Two phase sinusoidal excitation.

In applications requiring smooth 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.

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The torque output of each phase is:

$T_A = I_A K_T \text{ Cos } \theta$
$T_B = I_B K_T \text{ Cos } \theta$
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:
$I_A = I \text{ Cos } \theta$
$I_B = I \text{ Sin } \theta$
The torque output of the motor is:
$T = T_A + T_B$
$T = I K_T(\text{Sin}^2 \theta + \text{Cos}^2 \theta)$
$T = I K_T$

This analysis indicates that the sinusoidally driven brushless motor has linear characteristics similar to a conventional DC motor and has minimum ripple torque.

Three phase windings 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 windings form a continuous loop, so current flows through all three windings 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-thirds flowing through the one winding connected directly between the switched terminals, and one-third flowing through the two series-connected windings paralleling it. This results in switching only one-third of the total current from one winding to another as the windings are commutated.

For the wye connection, current flows through the two windings between the switched terminals. The third winding is isolated and carries no current. As the windings are commutated, the full load current must be switched from terminal to terminal. Due to the electrical time constant of the windings, 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 permit 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 greater motor efficiency when used in conjunction with brushless motors designed to generate a trapezoidal torque waveform.

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Sensor Timing and Alignment

A brushless DC motor duplicates the performance characteristics of a DC motor only when its windings 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 windings are switched “on” 45 electrical degrees before the peak torque position. The current polarity must be reversed for negative torque peaks. The commutation waveforms 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.

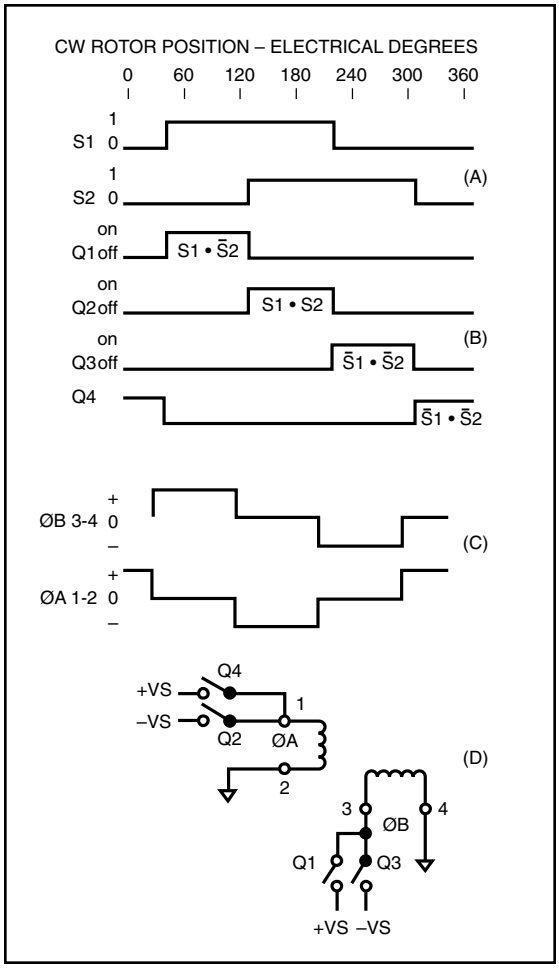

Figure-7 Sensor output, commutation logic, and winding excitation waveforms for a two phase brushless DC motor.

There are several methods for aligning the S1,2 sensors with respect to the stator windings. 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 sensor 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 waveforms 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, Axsys MCP can supply stators with reference marks to which the position sensors can be aligned.

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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 windings 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 must be reversed for negative torque peaks. The voltage polarity for 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 waveforms are shown in Figure 8. The three sensors are spaced 60 electrical degrees apart, and have a 50% duty cycle.

As indicated in Figures 3 and 8, sensor S1 can be aligned to the ØA-ØB zero torque position. This can be accomplished by applying a constant current to the ØA-ØB terminals. The rotor will rotate to the ØA-ØB 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.

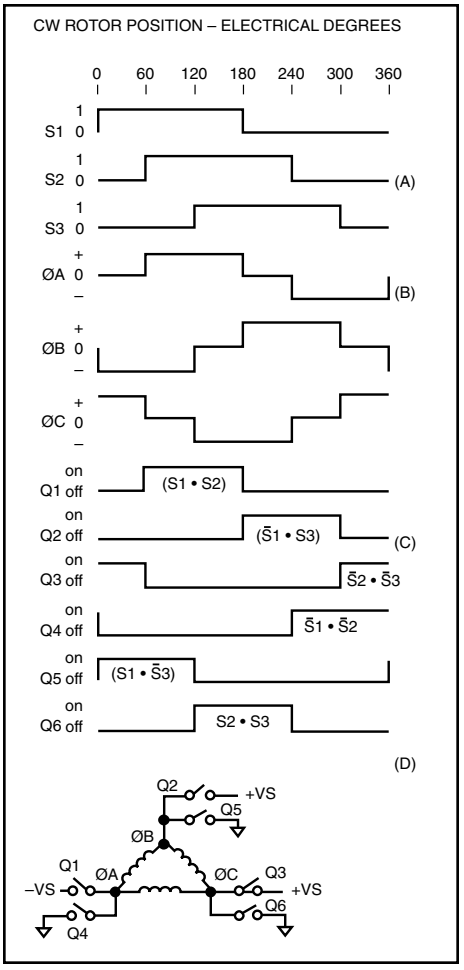

Figure-8 Sensor output, commutation logic, and winding excitation waveforms for a three phase brushless DC motor.

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 waveforms 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 on page 1-12. 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 devices. Hall effect elements, sine cosine resolvers, optical encoders, 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 element is the sensing system most frequently used because of its small size, low cost, and simplified processing electronics.

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Figure 9 is a functional control circuit for a two phase brushless DC torque motor with linear Hall effect rotor position 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 aligned 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.

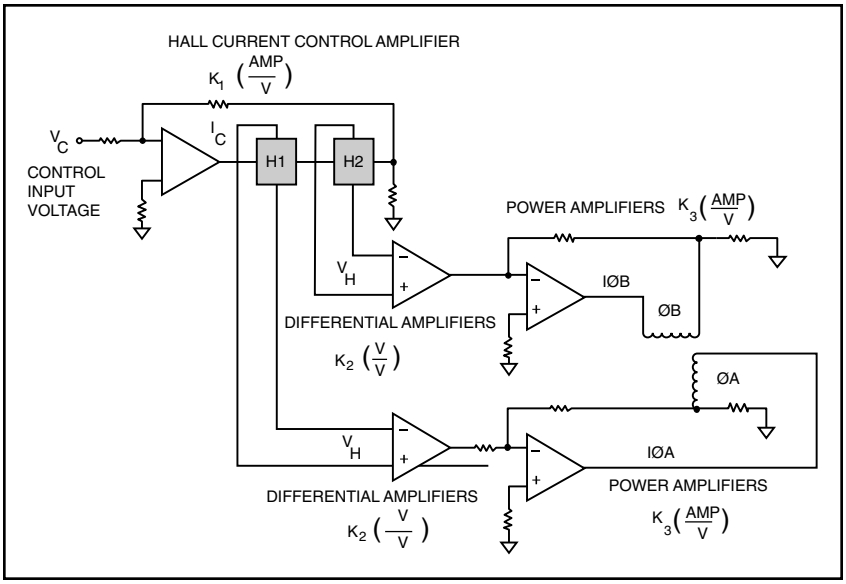

Figure-9 Functional control circuit for a two phase brushless DC torque motor with Hall Effect rotor positioning sensing.

The control equations are as follows: (Refer to Fig. 9)

$I_C = K_1 V_C$

$V_H = K_H I_C B \cos \theta$

Where

I_C = Hall device control current (Amp)

V_C = Input control Voltage (Volt)

K_1 = 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

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

The current in $Ø_A$ winding is:

$I_{ØA} = V_H K_2 K_3$

$= K_2 K_3 K_H I_C B \cos \theta$

$= K_2 K_3 K_H K_1 B V_C \cos \theta$

Similarly, the current in ØB winding is:

$I_{ØB} = K_2 K_3 K_H I_C B V_C \sin \theta$

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The torque output of each phase is:
$T_{\phi A} = I_{\phi A} K_T \cos \theta$
$T_{\phi B} = I_{\phi B} K_T \sin \theta$

Substituting for $I_{\theta A}$ and $I_{\theta B}$
$T_{\phi A} = V_C K_1 K_2 K_3 K_H K_T B \cos^2 \theta$
$T_{\phi B} = V_C K_1 K_2 K_3 K_H K_T B \sin^2 \theta$

Let $K_C = K_1 K_2 K_3 K_H K_T B$

Then the motor's output torque is:
$T = T_{\phi A} + T_{\phi B} = V_C K_C (\cos^2 \theta + \sin^2 \theta)$
$T = V_C K_C$

Therefore, the output torque is directly proportional 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:

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

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

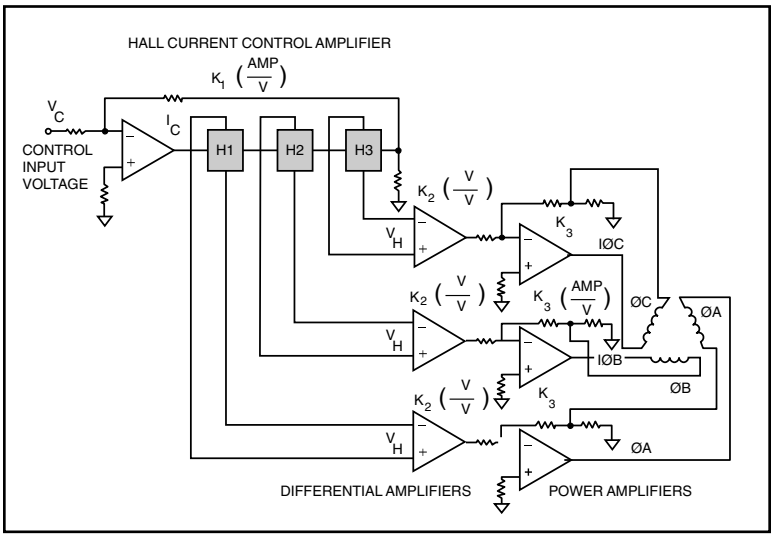

Figure-10 Functional control circuit for a three phase brushless DC torque motor with hall effect positioning sensing.

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 state. The output stage can be interfaced directly with the commutation logic circuit, and the whole system can be digital. This allows the use of low cost digital integrated circuits to decode the position sensor output and to sequence the drive circuit power semiconductors.

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Figure 11 shows a simplified drive circuit for bi-directional control of a two phase brushless DC motor. The timing and excitation waveforms 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 control 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.

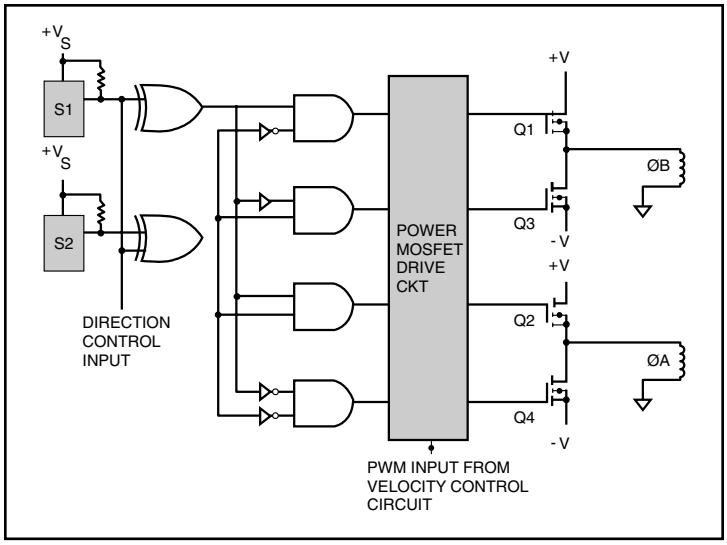

Figure-11 Functional drive circuit for bidirectional control of a two phase brushless DC motor.

The logic statements shown in Figure 7b are implemented with AND and INVERT gates.

Power MOSFETS are used to switch the motor windings. 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 waveforms 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 inverters are used to shape the photo-transistors output waveforms.

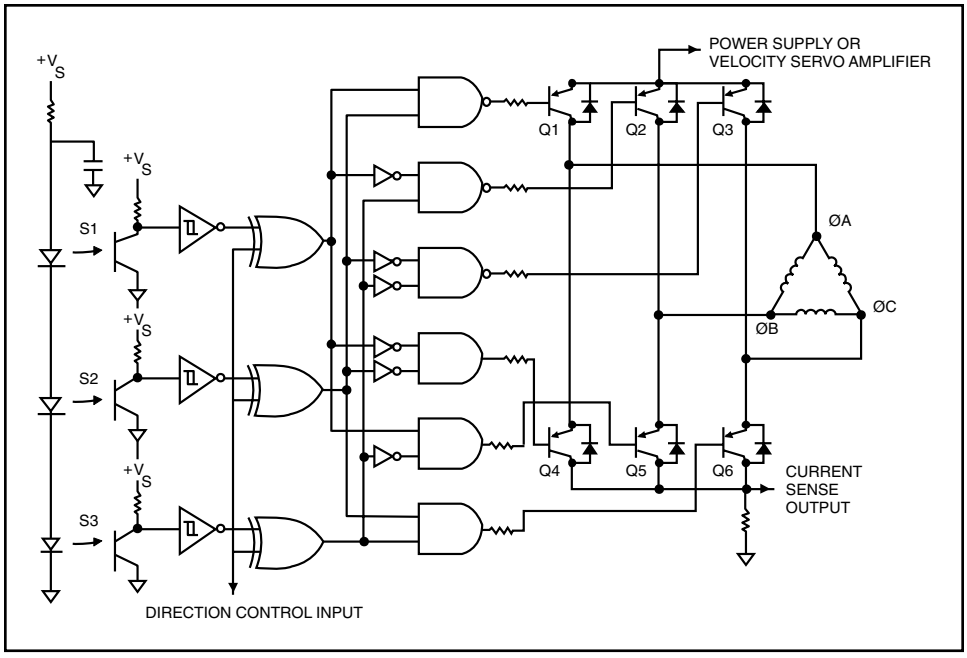

Figure-12 Functional drive circuit for bi-directional control of a three phase brushless DC motor.

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 windings.
5. Flyback diodes across each transistor provide a transient path for the commutated windings 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.

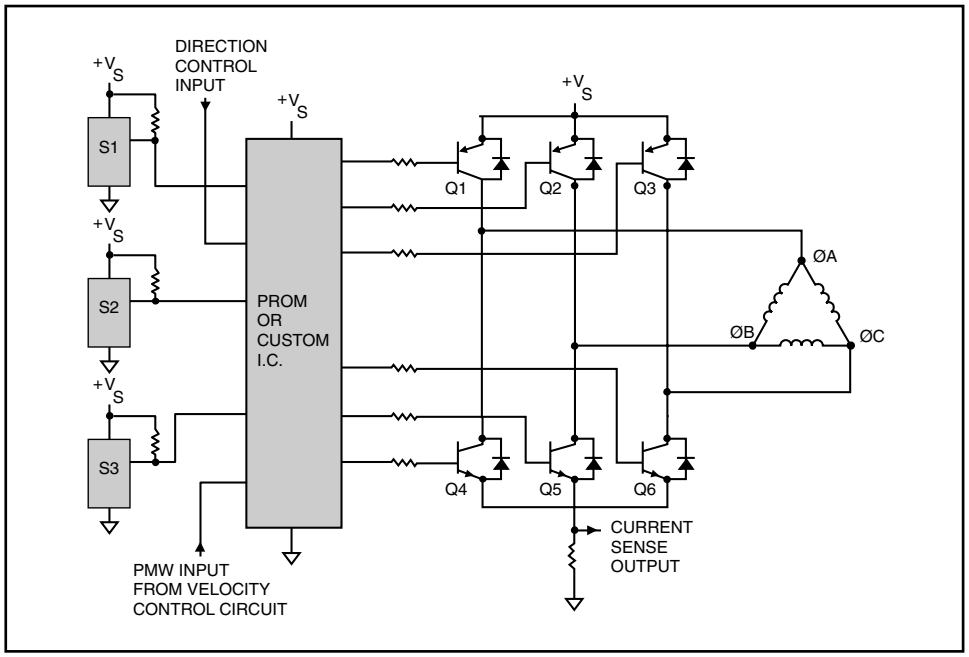

Figure-13 Functional drive circuit for bi-directional control of a three phase brushless DC motor.

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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 windings with the center tap connected to the supply voltage The windings 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 windings are switched OFF.

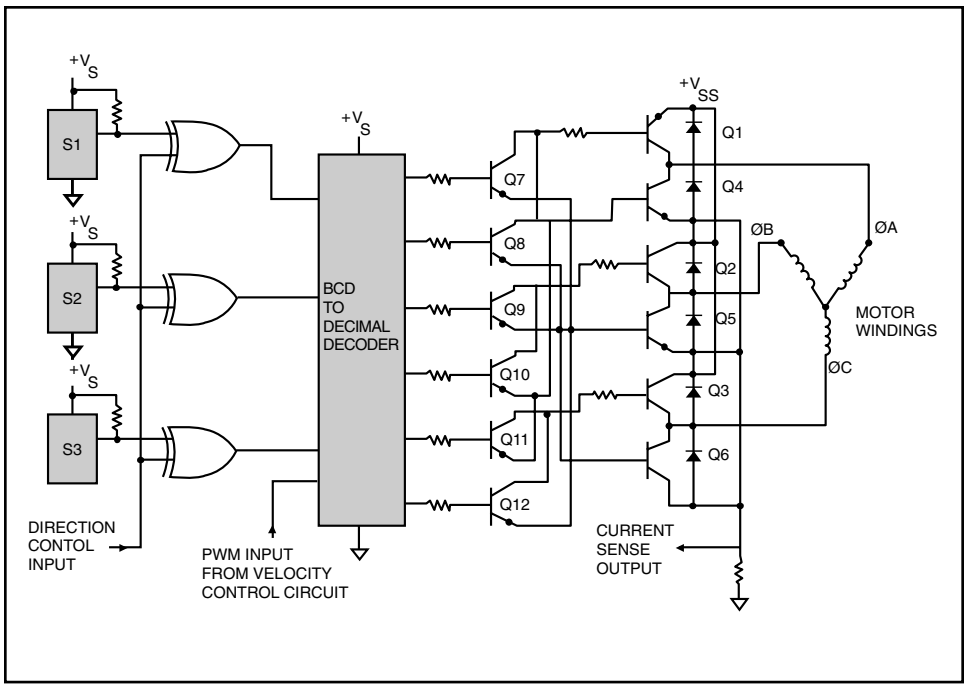

Figure-14 Functional drive circuit for bi-directional control of a three phase brushless DC motor.

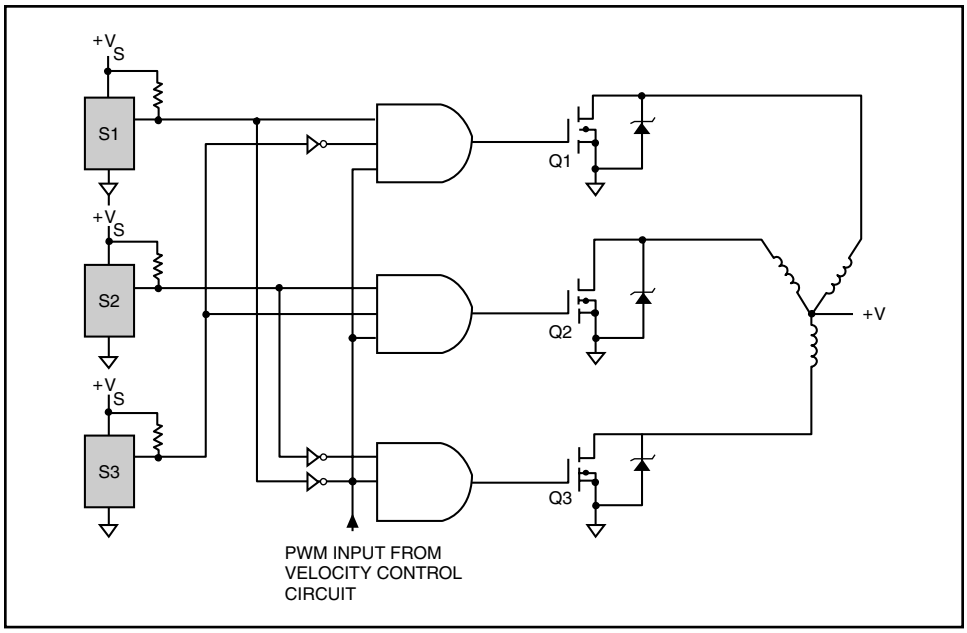

Figure-15 Functional drive circuit for bi-directional control of a three phase brushless DC motor.

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Brushless Servo Systems

The brushless DC motor, when properly commutated, will exhibit the same performance characteristics as a brush-commutated 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 characteristic equations for brushless DC motors.

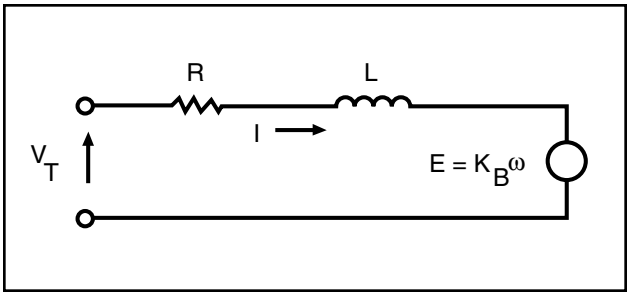

Figure-16 Equivalent electrical circuit of the brushless DC motor.

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 commutated phase
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:

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

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:

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

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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:

$\omega = V_T/K_B - TR/K_BK_T$ (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.

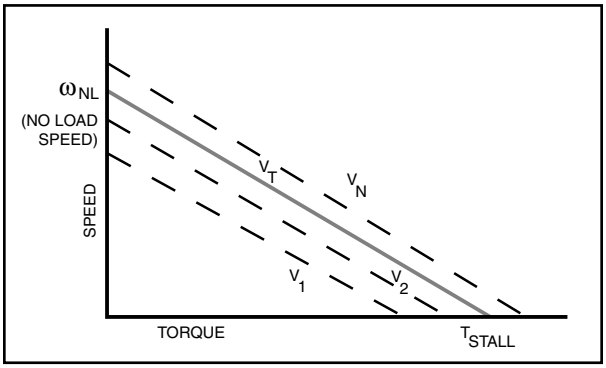

Figure-17 Speed torque characteristic curves.

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	Vs = 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.

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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:
$R_{MAX} = R\ (1 + 12.5\%)\{1 + (0.00393)(\ ^3T)\}$
$R_{MAX} = 0.9(1.125)\{1 + (0.00393)(\ 25)\} = 1.11$ ohm

The maximum voltage across the motor with worst case parameters is:
$V_{T(MAX)} = (\ R_{MAX})(T_L + T_{LOSS})/(K_{T(MAX)}) + K_{B(MAX)}\omega$
$V_{T(MAX)} = (\ 1.11)(12.5 + 0.5)/(5.94) + (0.0418)(377)$
$V_{T(MAX)} = 18.1$ 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:

$$V_T = IR + SL + K_B\ \omega(S) \quad (6)$$
$$T = (J_M + J_L))S + F\omega(S) + T_F + T_L$$

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

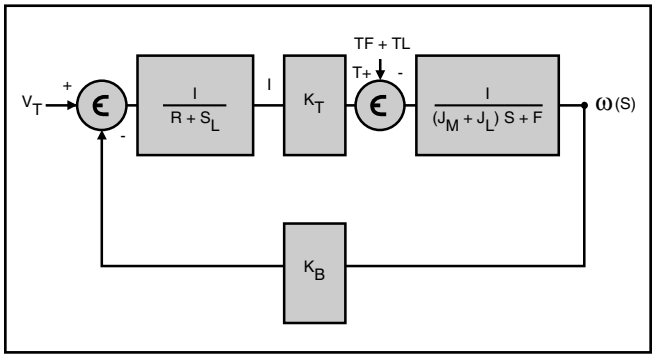

Figure-18 Block diagram of brushless DC motor model.

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 (K_b). 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.

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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.

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Glossary

BCD-to Decimal Decoder – An integrated circuit constructed so that an 8421 binary coded decimal on the four inputs provide a decimal (one-of-ten) decoded output. The device can be employed to provide sensor output decoding for commutation logic.

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

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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.

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Conversion Table

To Convert	From	To	Multiply by
Weight	ounces (force)	grams (force)	28.35
	ounces (force)	Newtons	0.278
	pounds (force)	grams (force)	453.6
	pounds (force)	Newtons	4.448
Distance	inches	centimeters	2.54
	inches	meters	2.54×10^{-2}
	feet	meters	0.3048
Torque	ounce-inches	gram-centimeters	72.01
	ounce-inches	Newton-meters	7.061×10^{-3}
	pound-feet	Newton-meters	1.356
Angular Velocity	RPM	radians/second	0.1047
	degrees/second	radians/second	1.745×10^{-2}
	rev/second	radians/second	6.283
Inertia	ounce-inch-sec^2	gram-centimeter^2	7.06×10^4
	pound-feet-sec^2	Kgram-centimeter^2	0.367
Power Rate	ounce-inch/sec^2	kilowatts/second	7.061×10^{-3}

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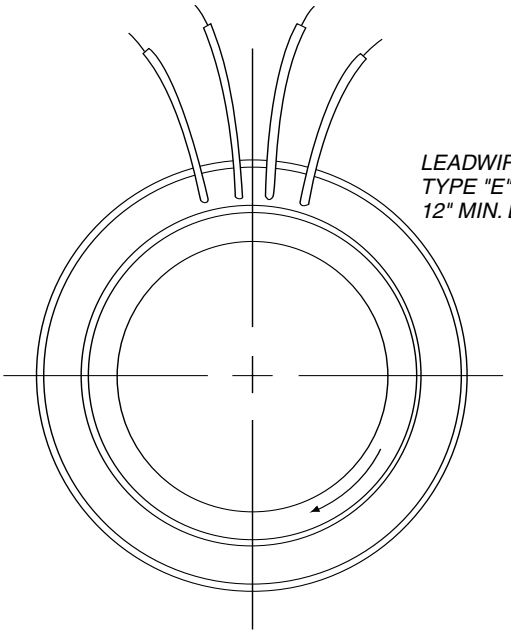
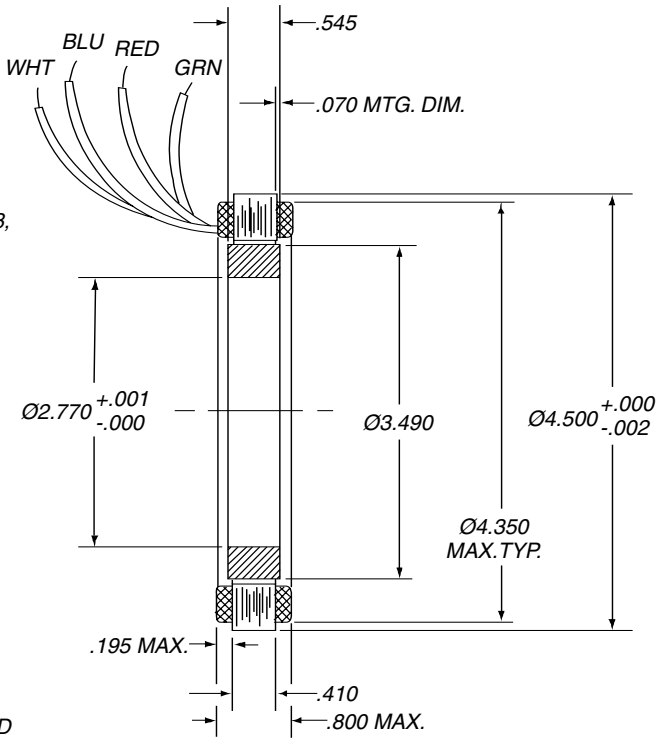
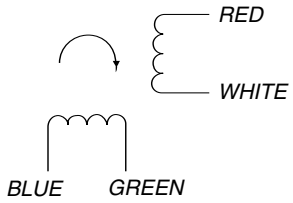


LEADWIRES ARE #18 AWG
TYPE "E", PER MIL-W-16878,
12" MIN. LG.





SCHEMATIC

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

WINDING CONSTANTS

PARAMETER	UNITS	TOL:	-008	-020	-031	-048
Resistance (R)	ohms	±12.5%	0.8	2.0	3.0	4.8
Voltage at T_p (V_p)	volts	Nominal	10.0	13.7	19.0	21.2
Current at T_p (I_p)	amps	Nominal	12.0	8.73	6.30	5.65
Torque Sensitivity (K_t)	oz-in/amp	±10%	32.0	44.0	61.0	68.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.242	0.424	0.459	0.659
Inductance (L)	millihenries	±30%	0.4	1.0	1.5	2.4

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/√watts	35.1
Elect. Time Constant (τ_e)	milli-sec	0.49
Mech. Time Constant (τ_m)	milli-sec	4.57
Damping Factor (F_o)	oz-in/rad/sec	9.33
Moment of Inertia (J_m)	oz-in-sec^2	0.0426
Total Breakaway Torque (T_f)	oz-in	3.5
Temperature Rise (TPR)	°C/watt	3.2
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	19
Number of Poles		20
Number of Phases		3

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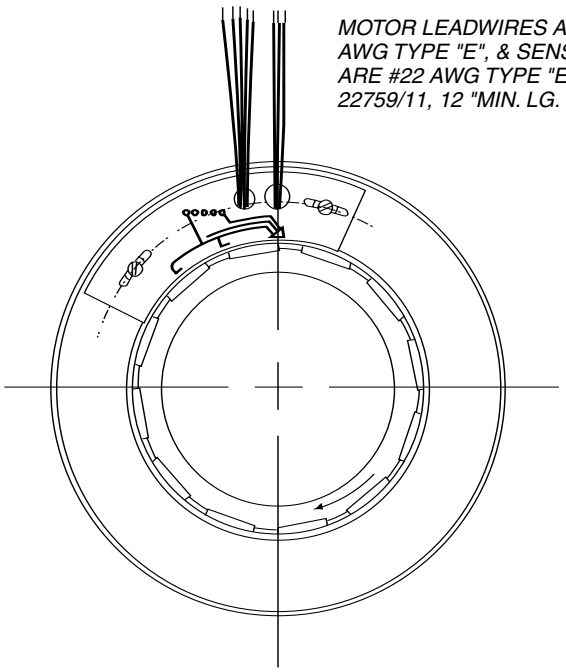
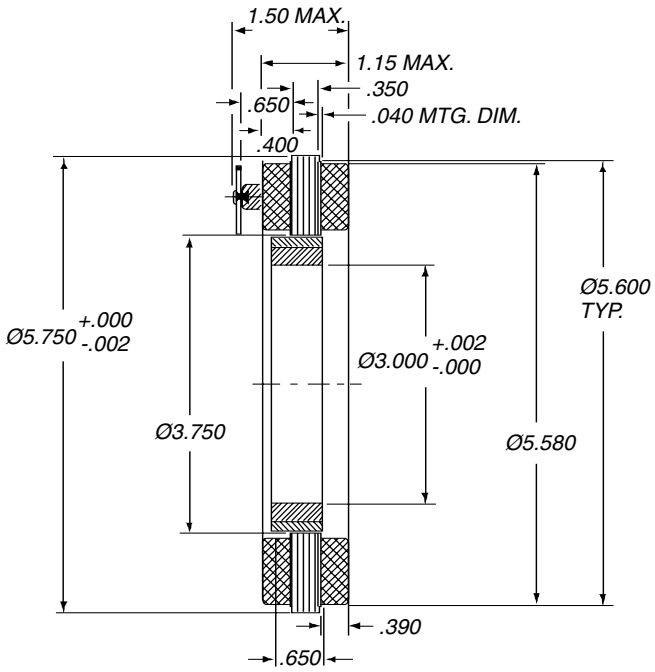
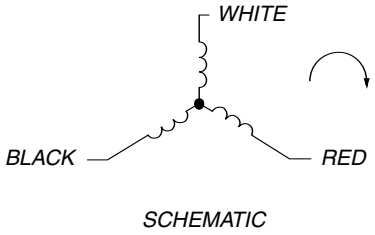


MOTOR LEADWIRES ARE #16 AWG TYPE "E", & SENSOR LEADWIRES ARE #22 AWG TYPE "ET", PER MIL-W-22759/11, 12 "MIN. LG.



COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	+	+	OFF	-	-	OFF	+	RED
	PHASE B	-	OFF	+	+	OFF	-	-	WHT
	PHASE C	OFF	-	-	OFF	+	+	OFF	BLK
SENSOR	SENSOR 1	1	1	0	0	0	1	1	YEL
	SENSOR 2	0	1	1	1	0	0	0	BRN
	SENSOR 3	0	0	0	1	1	1	0	ORG
	VIO								5-24 V DC
	BLK								DGND

ROTATION: CW WHEN VIEWED FROM LEAD SIDE



SCHEMATIC

Winding Constants

PARAMETER	UNITS	TOL:	-004	-009	-013	-021
Resistance (R)	ohms	±12.5%	0.4	0.9	1.4	2.1
Voltage at T_p (V_p)	volts	Nominal	6.0	8.4	11.4	13.5
Current at T_p (I_p)	amps	Nominal	15.0	10.7	7.89	6.67
Torque Sensitivity (K_t)	oz-in/amp	±10%	20.0	28.0	38.0	45.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.141	0.227	0.250	0.329
Inductance (L)	millihenries	±30%	0.5	1.0	1.5	2.4

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	300
Power at T_p (P_p)	watts	90
Motor Constant (K_m)	oz-in/√watts	31.6
Elect. Time Constant (τ_e)	milli-sec	1.1
Mech. Time Constant (τ_m)	milli-sec	8.5
Damping Factor (F_o)	oz-in/rad/sec	7.05
Moment of Inertia (J_m)	oz-in-sec^2	0.060
Total Breakaway Torque (T_f)	oz-in	5.0
Temperature Rise (TPR)	°C/watt	2.3
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	48
Number of Poles		12
Number of Phases		3

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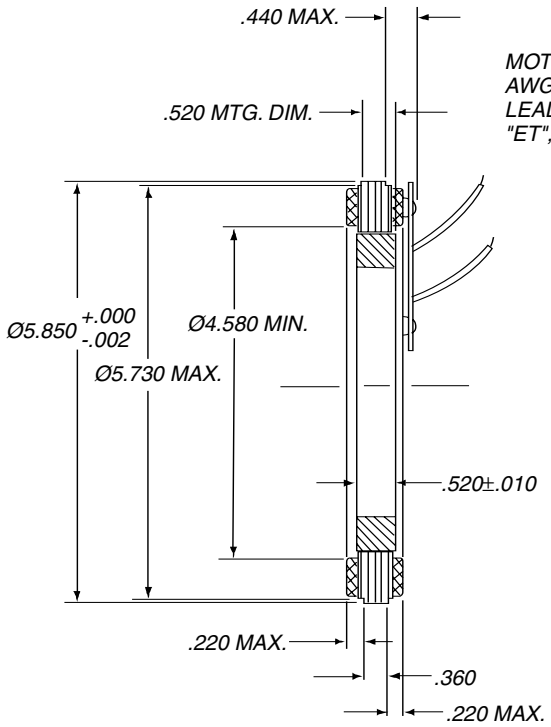
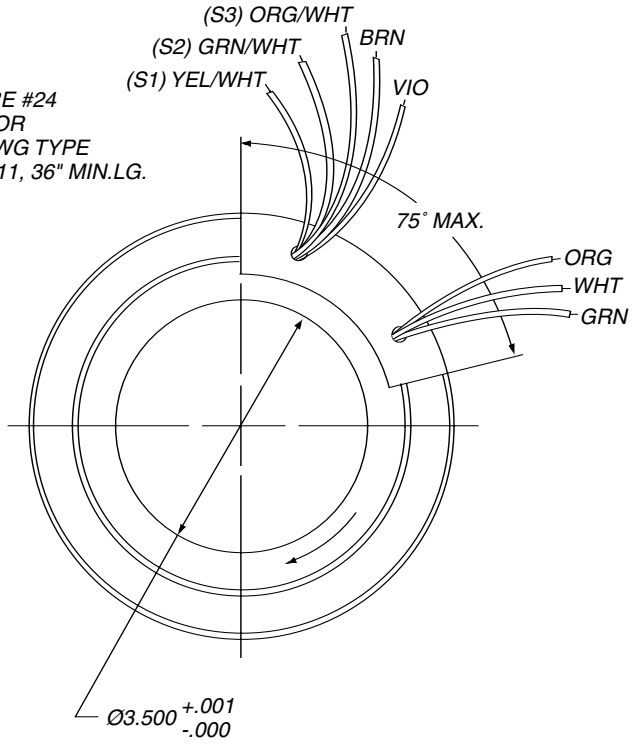
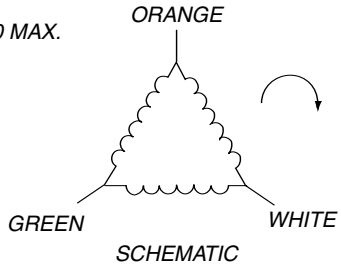


MOTOR LEADWIRES ARE #24 AWG TYPE "E", & SENSOR LEADWIRES ARE #26 AWG TYPE "ET", PER MIL-W-22759/11, 36" MIN.LG.



COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	OFF	+	+	OFF	-	-	OFF	ORG
	PHASE B	-	-	OFF	+	+	OFF	-	WHT
	PHASE C	+	OFF	-	-	OFF	+	+	GRN
SENSOR	SENSOR 1	0	0	0	1	1	1	0	(YELWHT)
	SENSOR 2	1	0	0	0	1	1	1	(GRN/WHT)
	SENSOR 3	1	1	0	0	0	1	1	(ORN/WHT)
	VIO								5-24V DC
	BRN								DGND

ROTATION: CW WHEN VIEWED FROM LEAD SIDE



WINDING CONSTANTS

PARAMETER	UNITS	TOL:	-082	-130	-205	-324
Resistance (R)	ohms	±12.5%	8.2	13.0	20.5	32.4
Voltage at T_p (V_p)	volts	Nominal	60.3	77.6	95.3	121.9
Current at T_p (I_p)	amps	Nominal	7.35	5.71	4.65	3.64
Torque Sensitivity (K_t)	oz-in/amp	±10%	136	175	215	275
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.959	1.18	1.52	1.87
Inductance (L)	millihenries	±30%	5.4	8.6	14	21

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	1000
Power at T_p (P_p)	watts	443
Motor Constant (K_m)	oz-in/√watts	47.5
Elect. Time Constant (τ_e)	milli-sec	0.659
Mech. Time Constant (τ_m)	milli-sec	9.1
Damping Factor (F_o)	oz-in/rad/sec	15.9
Moment of Inertia (J_m)	oz-in-sec^2	0.145
Total Breakaway Torque (T_f)	oz-in	10
Temperature Rise (TPR)	°C/watt	2.8
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	40
Number of Poles		24
Number of Phases		3

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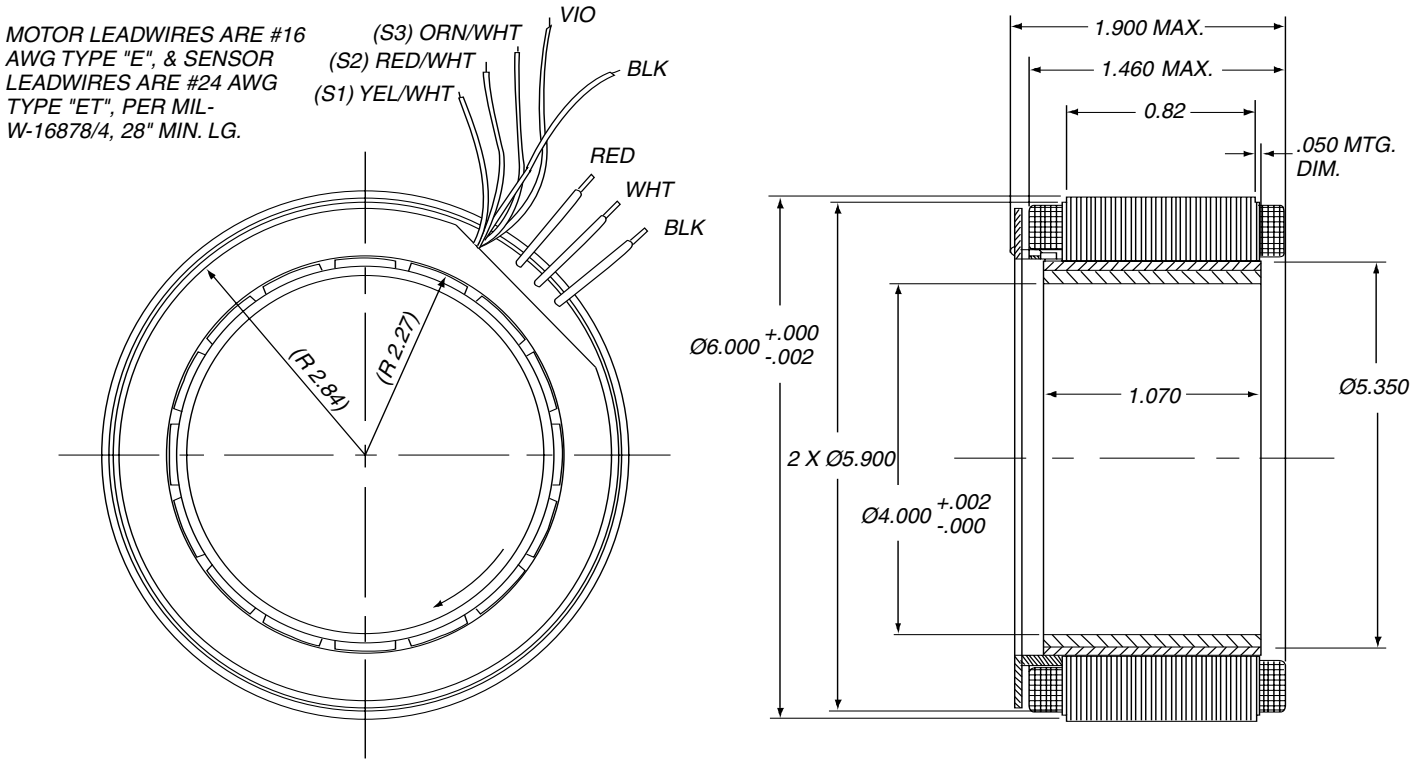
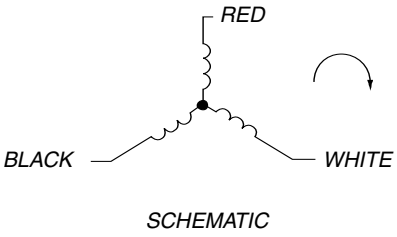


COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	+	+	OFF	-	-	OFF	+	RED
	PHASE B	-	OFF	+	+	OFF	-	-	WHT
	PHASE C	OFF	-	-	OFF	+	+	OFF	BLK
SENSOR	SENSOR 1	1	1	0	0	0	1	1	(YEL/WHT)
	SENSOR 2	0	1	1	1	0	0	0	(RED/WHT)
	SENSOR 3	0	0	0	1	1	1	0	(ORN/WHT)
	VIO								5-24V DC
	BLK								GND

ROTATION: CW WHEN VIEWED FROM LEAD SIDE



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Winding Constants

PARAMETER	UNITS	TOL:	-049	-075	-097	-120
Resistance (R)	ohms	±12.5%	4.9	7.5	9.7	12.0
Voltage at T_p (V_p)	volts	Nominal	34.0	41.9	48.5	53.6
Current at T_p (I_p)	amps	Nominal	6.94	5.64	4.87	4.41
Torque Sensitivity (K_t)	oz-in/amp	±10%	216	266	308	340
Back E.M.F. (K_b)	volts/rad/sec	±10%	1.57	1.95	2.17	2.44
Inductance (L)	millihenries	±30%	4.2	6.4	8.3	10

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	1500
Power at T_p (P_p)	watts	236
Motor Constant (K_m)	oz-in/√watts	97.6
Elect. Time Constant (τ_e)	milli-sec	0.86
Mech. Time Constant (τ_m)	milli-sec	3.33
Damping Factor (F_o)	oz-in/rad/sec	69.0
Moment of Inertia (J_m)	oz-in-sec^2	0.230
Total Breakaway Torque (T_f)	oz-in	12
Temperature Rise (TPR)	°C/watt	1.26
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	80
Number of Poles		16
Number of Phases		3

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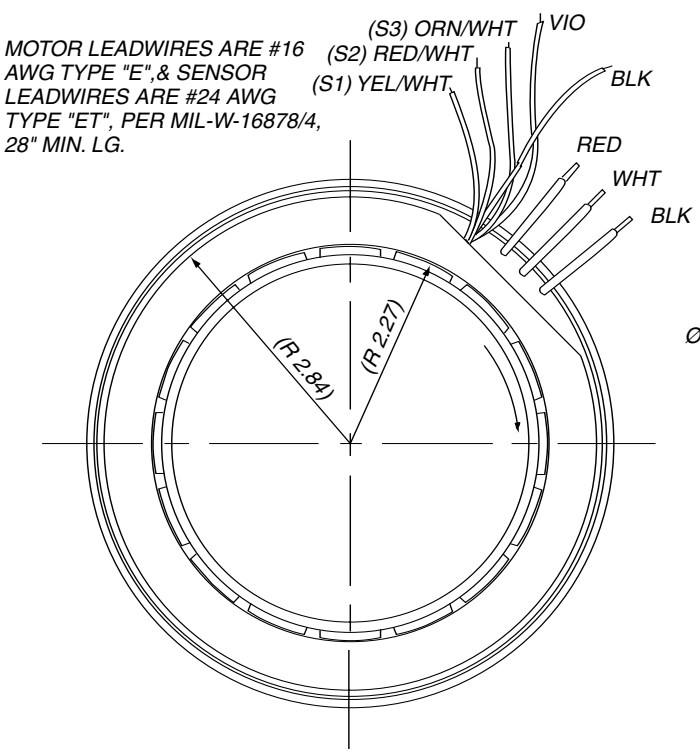
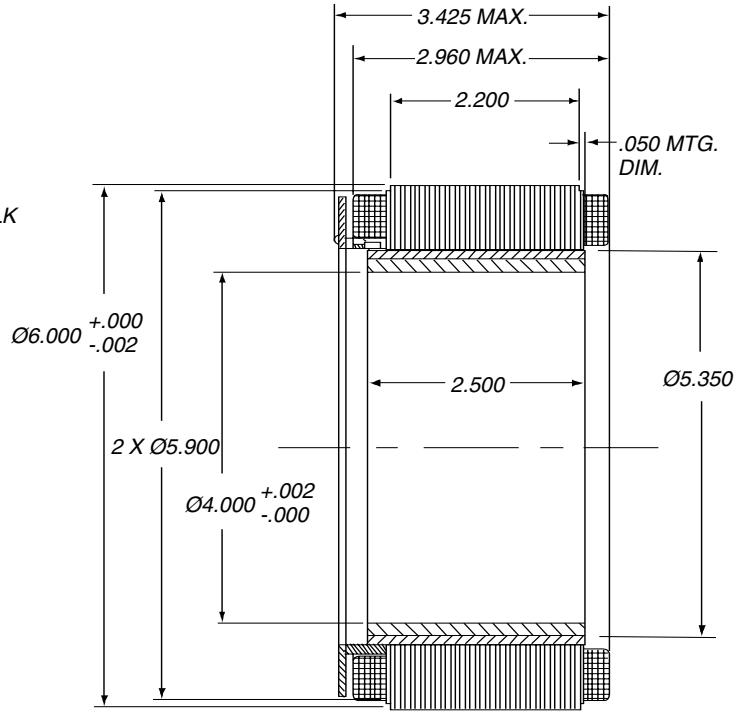
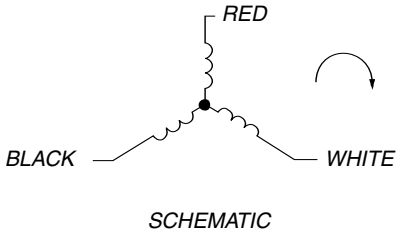




COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	+	+	OFF	-	-	OFF	+	RED
	PHASE B	-	OFF	+	+	OF	-	-	WHT
	PHASE C	OFF	-	-	OFF	+	+	OFF	BLK
SENSOR	SENSOR 1	1	1	0	0	0	1	1	(YEL/WHT)
	SENSOR 2	0	1	1	1	0	0	0	(RED/WHT)
	SENSOR 3	0	0	0	1	1	1	0	(ORN/WHT)
	VIO								5-24V DC
	BLK								GND

ROTATION: CW WHEN VIEWED FROM LEAD SIDE



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Winding Constants

PARAMETER	UNITS	TOL:	-021	-033	-050	-066
Resistance (R)	ohms	±12.5%	2.1	3.3	5.0	6.6
Voltage at T_p (V_p)	volts	Nominal	29.7	37.9	46.1	51.7
Current at T_p (I_p)	amps	Nominal	14.2	11.1	9.14	8.14
Torque Sensitivity (K_t)	oz-in/amp	±10%	300	382	465	522
Back E.M.F. (K_b)	volts/rad/sec	±10%	2.10	2.55	3.19	3.79
Inductance (L)	millihenries	±30%	1.3	2.0	3.1	4.1

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	4248
Power at T_p (P_p)	watts	421
Motor Constant (K_m)	oz-in/√watts	207
Elect. Time Constant (τ_e)	milli-sec	0.619
Mech. Time Constant (τ_m)	milli-sec	2.8
Damping Factor (F_o)	oz-in/rad/sec	300
Moment of Inertia (J_m)	oz-in-sec^2	0.850
Total Breakaway Torque (T_f)	oz-in	35.4
Temperature Rise (TPR)	°C/watt	0.4
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	168
Number of Poles		16
Number of Phases		3

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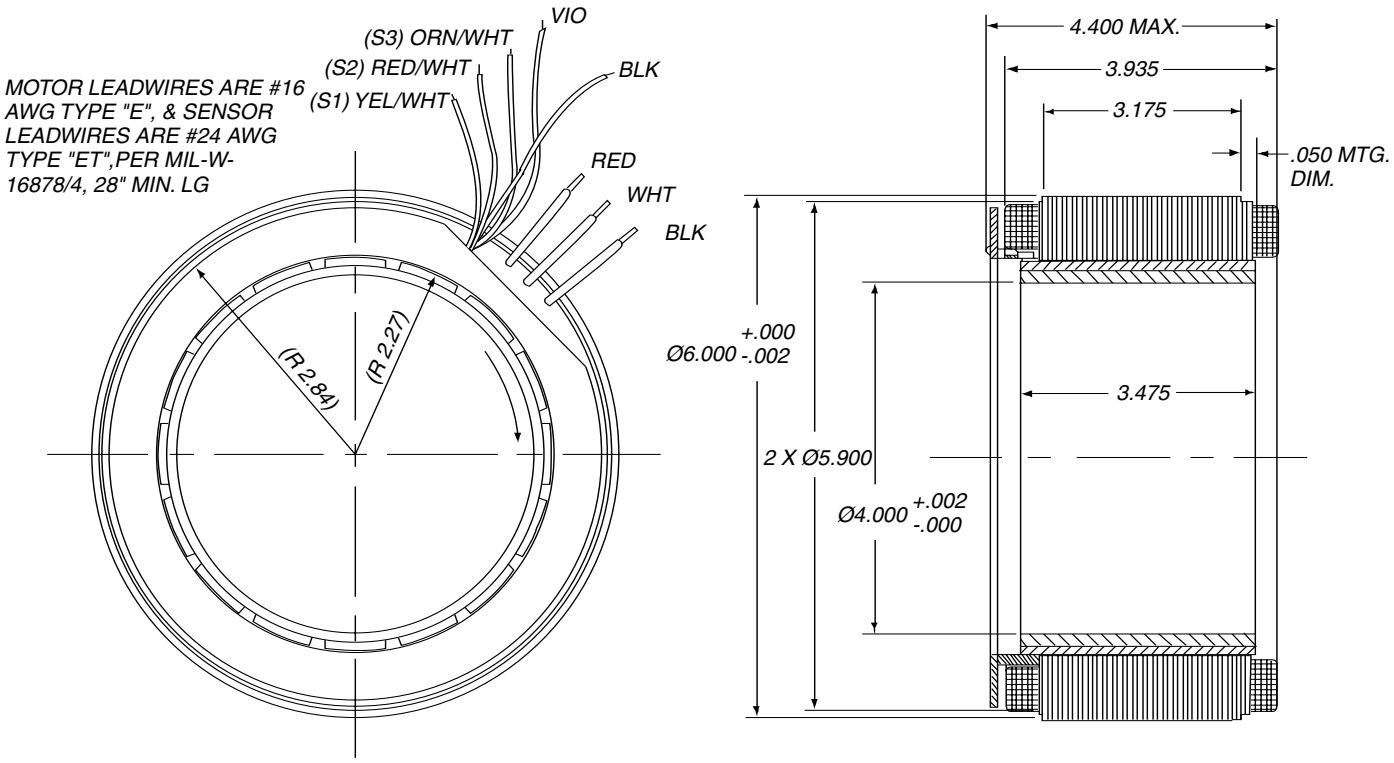
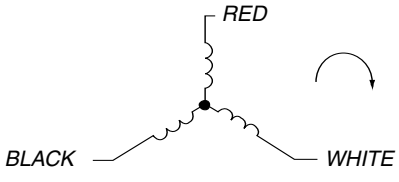


COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	+	+	OFF	-	-	OFF	+	RED
	PHASE B	-	OFF	+	+	OFF	-	-	WHT
	PHASE C	OFF	-	-	OFF	+	+	OFF	BLK
SENSOR	SENSOR 1	1	1	0	0	0	1	1	(YEL/WHT)
	SENSOR 2	0	1	1	1	0	0	0	(RED/WHT)
	SENSOR 3	0	0	0	1	1	1	0	(ORN/WHT)
	VIO								5-24V DC
	BLK								GND

ROTATION: CW WHEN VIEWED FROM LEAD SIDE



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Winding Constants

PARAMETER	UNITS	TOL:	-010	-017	-025	-040
Resistance (R)	ohms	±12.5%	1.0	1.7	2.5	4.0
Voltage at T_p (V_p)	volts	Nominal	24.9	32.1	39.0	49.7
Current at T_p (I_p)	amps	Nominal	24.9	19.3	15.9	12.5
Torque Sensitivity (K_t)	oz-in/amp	±10%	233	300	365	465
Back E.M.F. (K_b)	volts/rad/sec	±10%	1.61	2.13	2.57	3.23
Inductance (L)	millihenries	±30%	1.5	2.6	3.8	6.0

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	5800
Power at T_p (P_p)	watts	620
Motor Constant (K_m)	oz-in/√watts	233
Elect. Time Constant (τ_e)	milli-sec	1.5
Mech. Time Constant (τ_m)	milli-sec	2.0
Damping Factor (F_o)	oz-in/rad/sec	375
Moment of Inertia (J_m)	oz-in-sec^2	0.75
Total Breakaway Torque (T_f)	oz-in	50
Temperature Rise (TPR)	°C/watt	0.46
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	13
Number of Poles		16
Number of Phases		3

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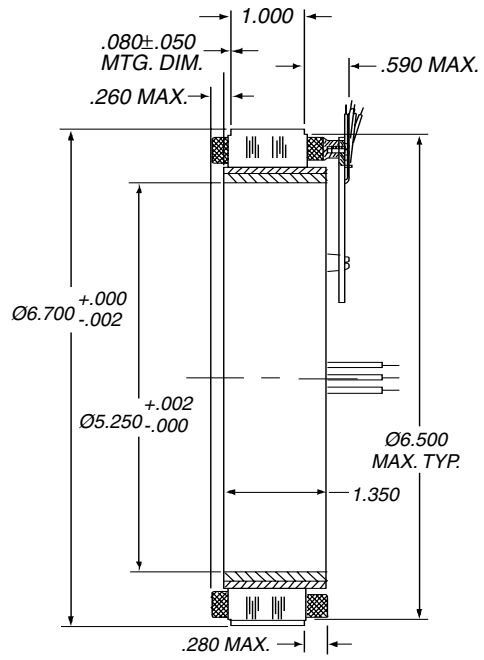
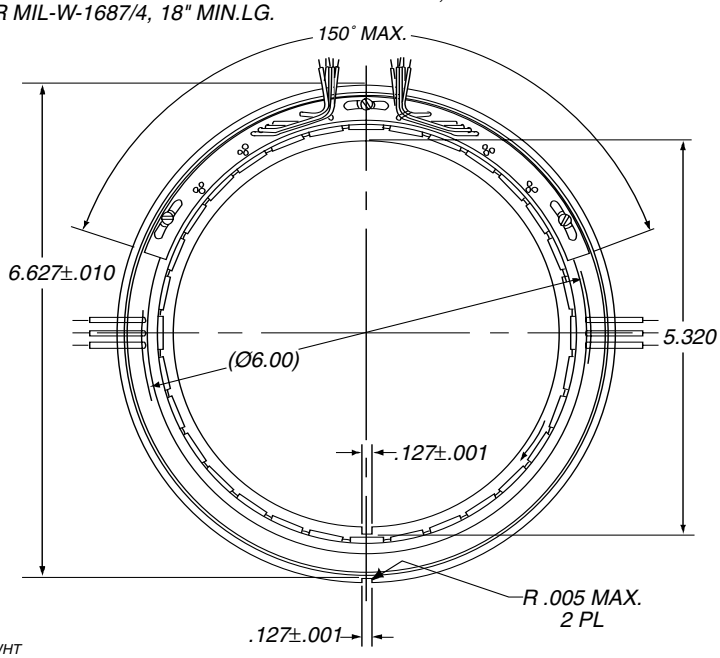
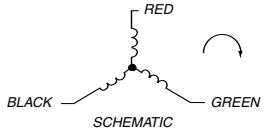


MOTOR LEADWIRES ARE #18 AWG TYPE "E", &
SENSOR LEADWIRES ARE #24 AWG TYPE "ET",
PER MIL-W-1687/4, 18" MIN.LG.





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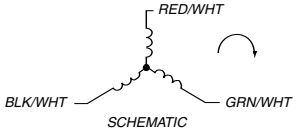

SCHEMATIC

COMMUTATION TABLE (PRIMARY)

STEP		1	2	3	4	5	6	1	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	1	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

Redundant Windings

WINDING CONSTANTS

PARAMETER	UNITS	TOL:	-019	-030	-049	-076
Resistance (R)	ohms	±12.5%	1.9	3.0	4.9	7.6
Voltage at T_p (V_p)	volts	Nominal	7.7	9.6	12.4	15.1
Current at T_p (I_p)	amps	Nominal	4.03	3.23	2.50	2.04
Torque Sensitivity (K_t)	oz-in/amp	±10%	124	155	200	245
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.876	1.11	1.40	1.77
Inductance (L)	millihenries	±30%	0.7	1.1	1.8	2.8

* DATA IS GIVEN PER SINGLE WINDING

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	500
Power at T_p (P_p)	watts	31
Motor Constant (K_m)	oz-in/√watts	90.0
Elect. Time Constant (τ_e)	milli-sec	0.37
Mech. Time Constant (τ_m)	milli-sec	7.69
Damping Factor (F_o)	oz-in/rad/sec	57.2
Moment of Inertia (J_m)	oz-in-sec^2	0.440
Total Breakaway Torque (T_f)	oz-in	10
Temperature Rise (TPR)	°C/watt	1.2
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	60
Number of Poles		32
Number of Phases		3

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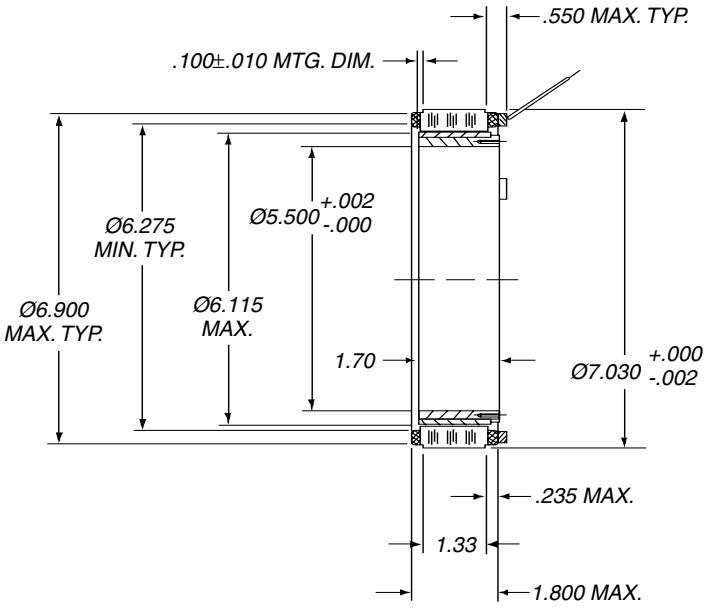
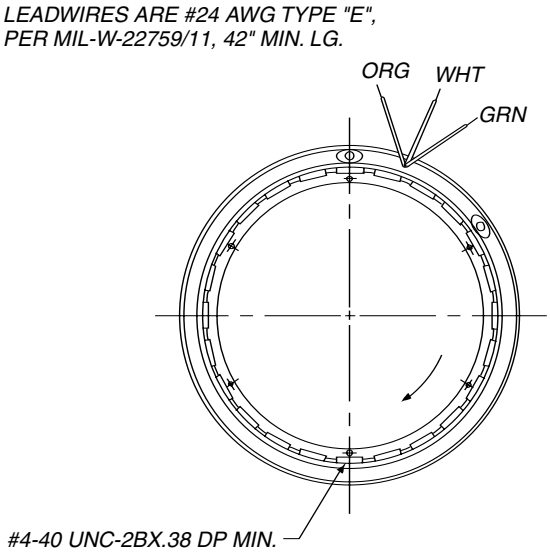
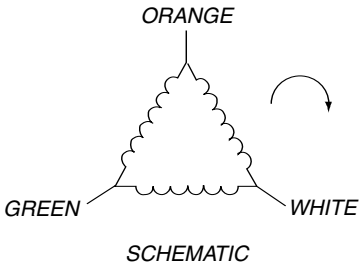




COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	OFF	+	+	OFF	-	-	OFF	ORN
	PHASE B	-	-	OFF	+	+	OFF	-	WHT
	PHASE C	+	OFF	-	-	OFF	+	+	GRN
SENSOR	SENSOR 1	0	0	0	1	1	1	0	(YEL/WHT)
	SENSOR 2	1	0	0	0	1	1	1	(GRN/WHT)
	SENSOR 3	1	1	0	0	0	1	1	(ORN/WHT)
	VIO								5-24V DC
	BRN								GND

ROTATION: CW WHEN VIEWED FROM LEAD SIDE



SCHEMATIC

Winding Constants

PARAMETER	UNITS	TOL:	-041	-100	-160	-200
Resistance (R)	ohms	±12.5%	4.1	10.0	16.0	20.0
Voltage at T_p (V_p)	volts	Nominal	41.8	64.0	80.3	93.9
Current at T_p (I_p)	amps	Nominal	10.2	6.67	5.32	4.55
Torque Sensitivity (K_t)	oz-in/amp	±10%	245	375	470	550
Back E.M.F. (K_b)	volts/rad/sec	±10%	2.34	3.73	4.77	5.09
Inductance (L)	millihenries	±30%	1.9	4.6	7.4	9.3

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	2500
Power at T_p (P_p)	watts	427
Motor Constant (K_m)	oz-in/√watts	121
Elect. Time Constant (τ_e)	milli-sec	0.46
Mech. Time Constant (τ_m)	milli-sec	5.57
Damping Factor (F_o)	oz-in/rad/sec	140
Moment of Inertia (J_m)	oz-in-sec^2	0.780
Total Breakaway Torque (T_f)	oz-in	46
Temperature Rise (TPR)	°C/watt	0.8
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	95
Number of Poles		24
Number of Phases		3

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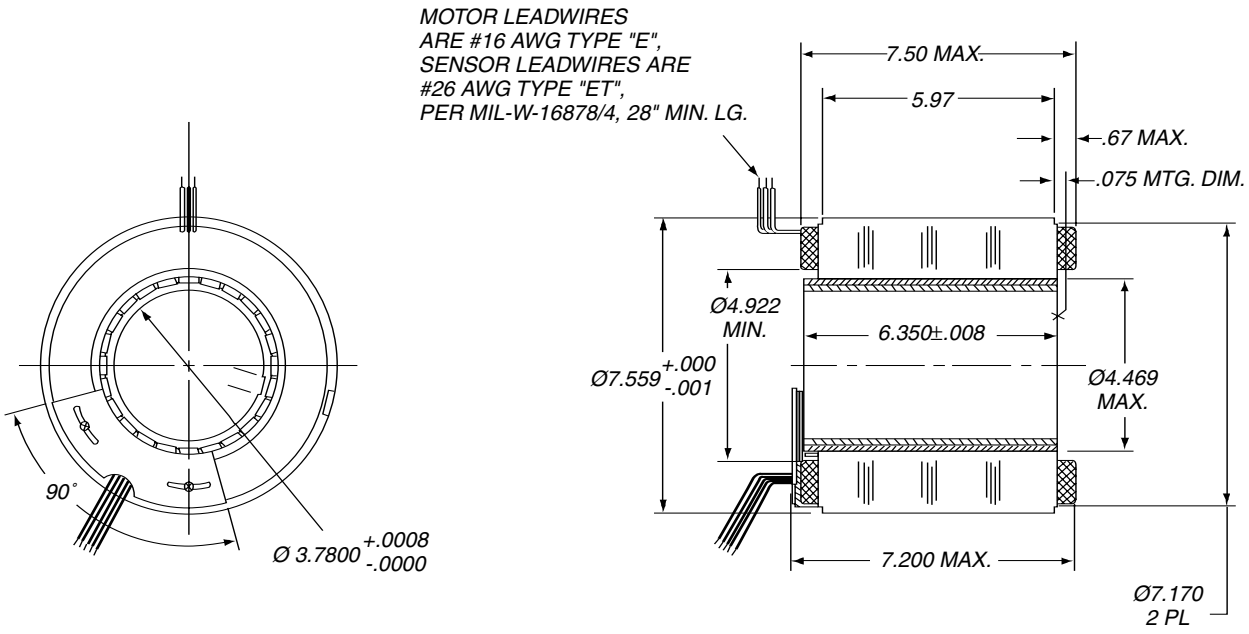
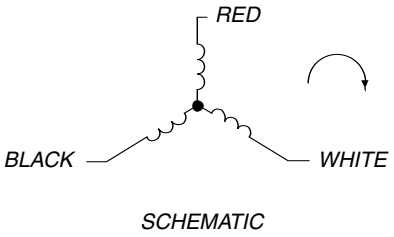


COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	+	+	OFF	-	-	OFF	+	RED
	PHASE B	-	OFF	+	+	OFF	-	-	WHT
	PHASE C	OFF	-	-	OFF	+	+	OFF	BLK
SENSOR	SENSOR 1	1	1	0	0	0	1	1	(YEL/WHT)
	SENSOR 2	0	1	1	1	0	0	0	(RED/WHT)
	SENSOR 3	0	0	0	1	1	1	0	(ORN/WHT)
	BLU								5-24V DC
	GRN								GND

ROTATION: CW WHEN VIEWED FROM LEAD SIDE



SCHEMATIC

Winding Constants

PARAMETER	UNITS	TOL:	-040	-061	-095	-155
Resistance (R)	ohms	±12.5%	4.0	6.1	9.5	15.5
Voltage at T_p (V_p)	volts	Nominal	71.7	85.9	107	138
Current at T_p (I_p)	amps	Nominal	17.9	14.9	12.0	9.33
Torque Sensitivity (K_t)	oz-in/amp	±10%	1585	1900	2375	3045
Back E.M.F. (K_b)	volts/rad/sec	±10%	10.6	13.4	16.8	21.5
Inductance (L)	millihenries	±30%	27	41	64	105

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	28400
Power at T_p (P_p)	watts	1284
Motor Constant (K_m)	oz-in/√watts	793
Elect. Time Constant (τ_e)	milli-sec	6.8
Mech. Time Constant (τ_m)	milli-sec	0.32
Damping Factor (F_o)	oz-in/rad/sec	4214
Moment of Inertia (J_m)	oz-in-sec^2	1.36
Total Breakaway Torque (T_f)	oz-in	180
Temperature Rise (TPR)	°C/watt	0.25
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	750
Number of Poles		24
Number of Phases		3

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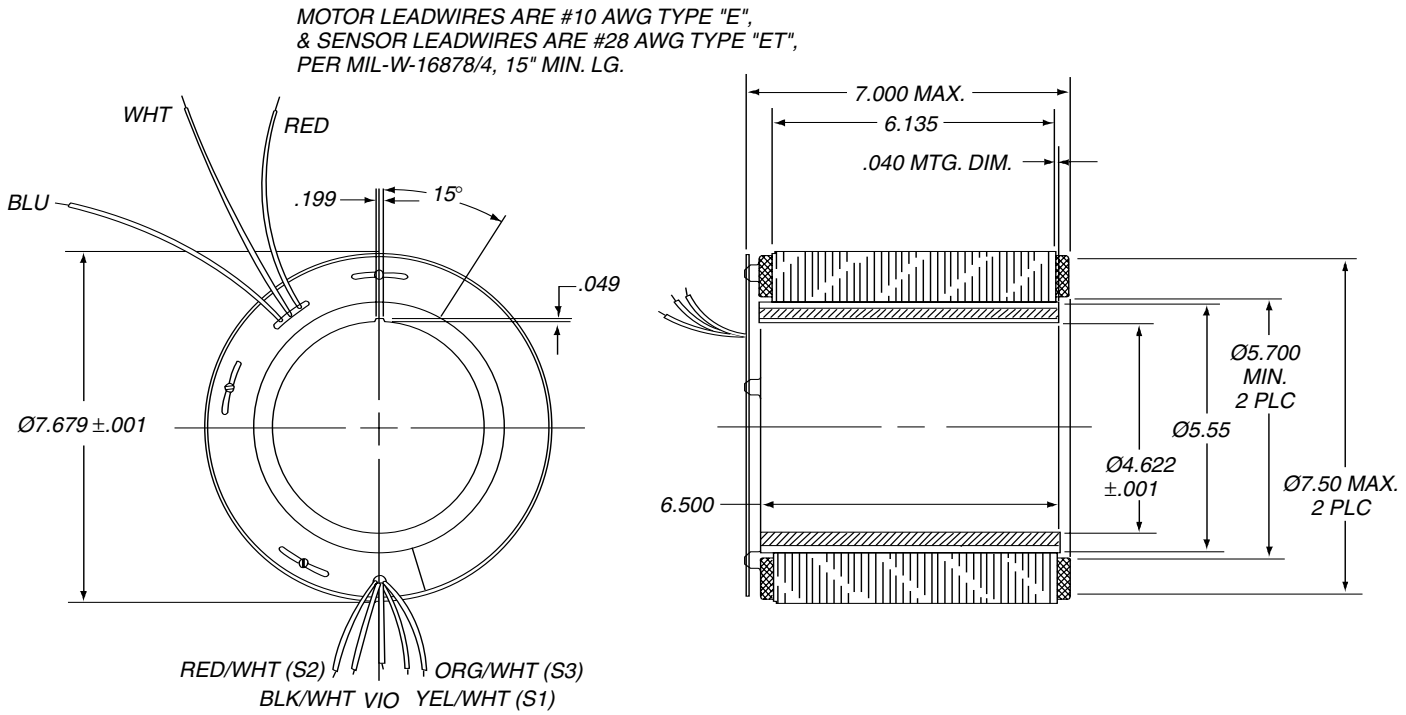
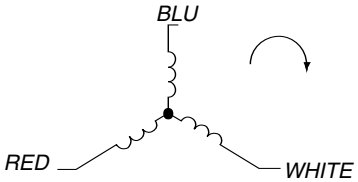


COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	OFF	+	+	OFF	-	-	OFF	RED
	PHASE B	-	-	OFF	+	+	OFF	-	WHT
	PHASE C	+	OFF	-	-	OFF	+	+	BLU
SENSOR	SENSOR 1	1	1	1	0	0	0	1	(YEL/WHT)
	SENSOR 2	0	0	1	1	1	0	0	(RED/WHT)
	SENSOR 3	1	0	0	0	1	1	1	(ORN/WHT)
	BLU								5-24V DC
	BLK/WHT								DGND

ROTATION: CW WHEN VIEWED FROM LEAD SIDE



WINDING CONSTANTS

PARAMETER	UNITS	TOL:	-022	-032	-054	-080
Resistance (R)	ohms	±12.5%	2.2	3.2	5.4	8.0
Voltage at T_p (V_p)	volts	Nominal	35.1	39.8	54.6	64.3
Current at T_p (I_p)	amps	Nominal	16.0	14.1	10.3	8.72
Torque Sensitivity (K_t)	oz-in/amp	±10%	794	900	1235	1454
Back E.M.F. (K_b)	volts/rad/sec	±10%	5.32	6.72	8.32	10.6
Inductance (L)	millihenries	±30%	27	39	66	98

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	12672
Power at T_p (P_p)	watts	560
Motor Constant (K_m)	oz-in/√watts	535
Elect. Time Constant (τ_e)	milli-sec	12
Mech. Time Constant (τ_m)	milli-sec	1.4
Damping Factor (F_o)	oz-in/rad/sec	1920
Moment of Inertia (J_m)	oz-in-sec^2	2.69
Total Breakaway Torque (T_f)	oz-in	164
Temperature Rise (TPR)	°C/watt	0.15
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	620
Number of Poles		24
Number of Phases		3

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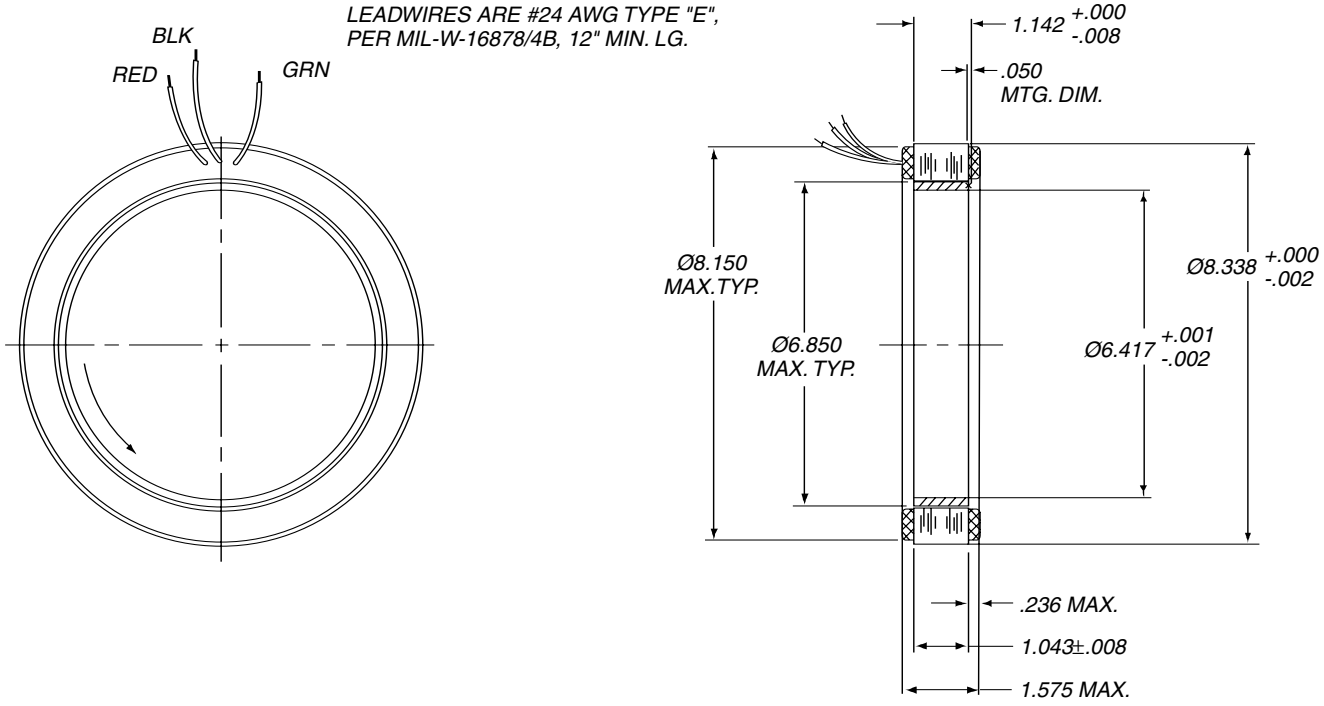

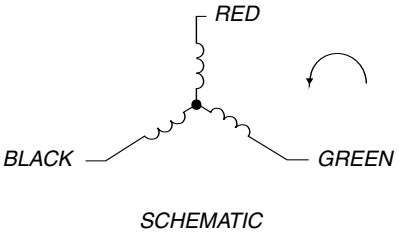

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ROTATION: FIELD ROTATES CCW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: RED+, GRN-; RED +, BLK-; GRN+, BLK-; GRN+, RED-; BLK+, RED-; BLK+, GRN-.

Winding Constants

PARAMETER	UNITS	TOL:	-043	-057	-071	-120
Resistance (R)	ohms	±12.5%	4.3	5.7	7.1	12.0
Voltage at T_p (V_p)	volts	Nominal	20.8	24.0	27.5	32.9
Current at T_p (I_p)	amps	Nominal	4.8	4.20	3.66	3.06
Torque Sensitivity (K_t)	oz-in/amp	±10%	439	506	581	694
Back E.M.F. (K_b)	volts/rad/sec	±10%	2.98	3.42	3.71	5.26
Inductance (L)	millihenries	±30%	5.7	7.6	9.4	16

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	2124
Power at T_p (P_p)	watts	101
Motor Constant (K_m)	oz-in/√watts	212
Elect. Time Constant (τ_e)	milli-sec	1.3
Mech. Time Constant (τ_m)	milli-sec	2.0
Damping Factor (F_o)	oz-in/rad/sec	304
Moment of Inertia (J_m)	oz-in-sec^2	0.600
Total Breakaway Torque (T_f)	oz-in	50
Temperature Rise (TPR)	°C/watt	0.9
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	104
Number of Poles		36
Number of Phases		3

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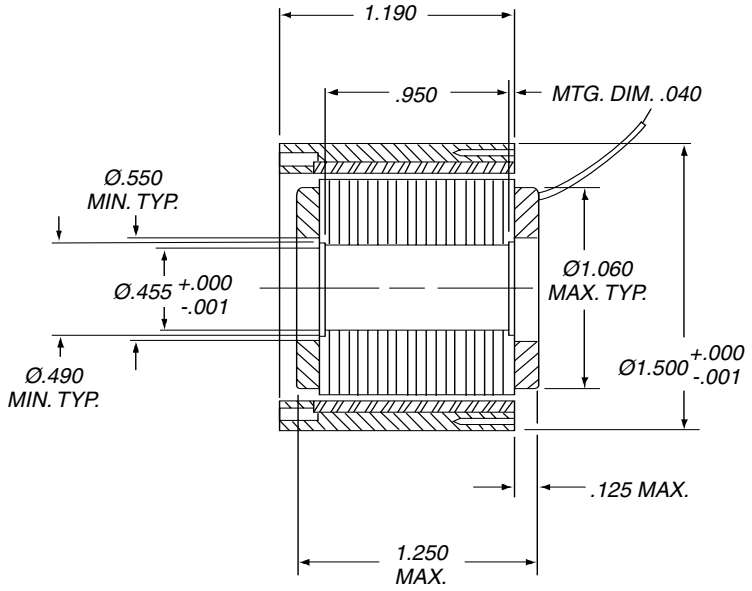
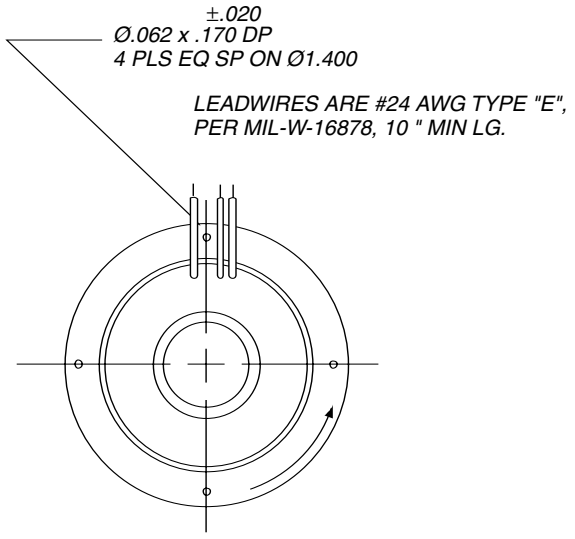
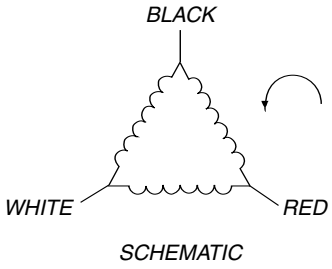




ROTATION: FIELD ROTATES CCW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: RED+, WHITE-; BLACK+, WHITE-; BLACK+, RED-.



SCHEMATIC

Winding Constants

PARAMETER	UNITS	TOL:	-023	-038	-061	-097
Resistance (R)	ohms	±12.5%	2.3	3.8	6.1	9.7
Voltage at T_p (V_p)	volts	Nominal	13.5	17.5	22.3	28.2
Current at T_p (I_p)	amps	Nominal	5.88	4.55	3.57	2.82
Torque Sensitivity (K_t)	oz-in/amp	±10%	8.50	11.0	14.0	17.7
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.060	0.076	0.096	0.121
Inductance (L)	millihenries	±30%	0.5	0.8	1.3	2.1

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	50
Power at T_p (P_p)	watts	80
Motor Constant (K_m)	oz-in/√watts	5.60
Elect. Time Constant (τ_e)	milli-sec	0.22
Mech. Time Constant (τ_m)	milli-sec	22.7
Damping Factor (F_o)	oz-in/rad/sec	0.22
Moment of Inertia (J_m)	oz-in-sec^2	0.005
Total Breakaway Torque (T_f)	oz-in	0.70
Temperature Rise (TPR)	°C/watt	4
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	6.2
Number of Poles		8
Number of Phases		3

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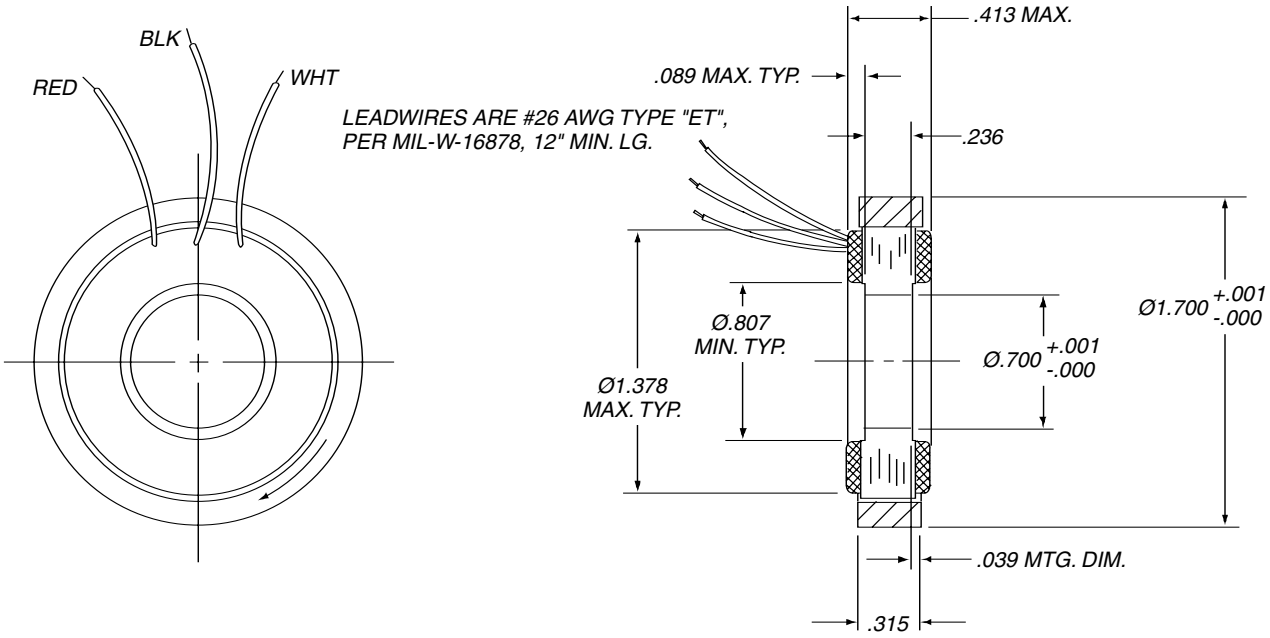
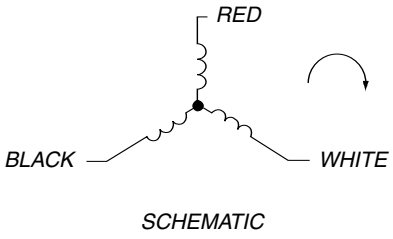


ROTATION: FIELD ROTATES CW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: RED+, BLACK-; WHITE +, BLACK-; WHITE+, RED-.



SCHEMATIC

Winding Constants

PARAMETER	UNITS	TOL:	-066	-100	-140	-220
Resistance (R)	ohms	±12.5%	6.6	10.0	14.0	22.0
Voltage at T_p (V_p)	volts	Nominal	14.4	17.5	21.6	27.6
Current at T_p (I_p)	amps	Nominal	2.18	1.79	1.45	1.13
Torque Sensitivity (K_t)	oz-in/amp	±10%	13.0	15.8	19.5	25.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.088	0.110	0.125	0.153
Inductance (L)	millihenries	±30%	0.6	0.9	1.3	2.1

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	28
Power at T_p (P_p)	watts	31
Motor Constant (K_m)	oz-in/√watts	5.06
Elect. Time Constant (τ_e)	milli-sec	0.094
Mech. Time Constant (τ_m)	milli-sec	6.90
Damping Factor (F_o)	oz-in/rad/sec	0.17
Moment of Inertia (J_m)	oz-in-sec^2	0.0012
Total Breakaway Torque (T_f)	oz-in	1.8
Temperature Rise (TPR)	°C/watt	15.5
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	2.5
Number of Poles		14
Number of Phases		3

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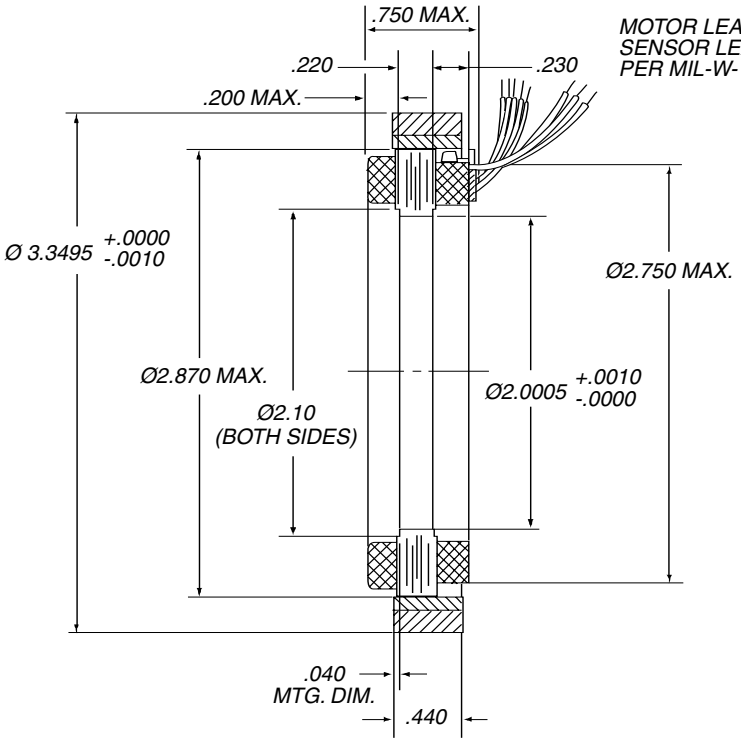
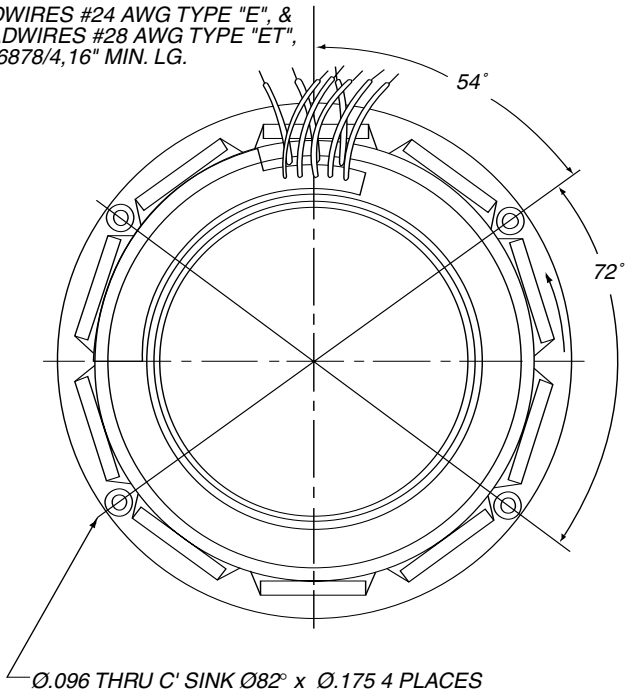
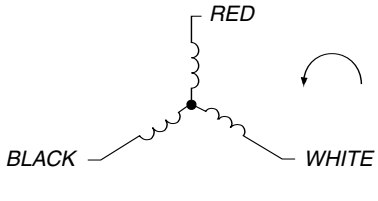




COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	OFF	-	-	OFF	+	+	OFF	(RED)
	PHASE B	+	+	OFF	-	-	OFF	+	(WHT)
	PHASE C	-	OFF	+	+	OFF	-	-	(BLK)
SENSOR	SENSOR 1	1	1	1	0	0	0	1	(YEL/WHT)
	SENSOR 2	0	0	1	1	1	0	0	(RED/WHT)
	SENSOR 3	1	0	0	0	0	1	1	(ORN/WHT)
	VIO								5-24V DC
	BLK								DGND

ROTATION: CCW WHEN VIEWED FROM LEAD SIDE



SCHEMATIC

Winding Constants

PARAMETER	UNITS	TOL:	-073	-111	-178	-280
Resistance (R)	ohms	±12.5%	7.3	11.1	17.8	28.0
Voltage at T_p (V_p)	volts	Nominal	11.1	13.8	17.8	22.2
Current at T_p (I_p)	amps	Nominal	1.52	1.23	0.95	0.76
Torque Sensitivity (K_t)	oz-in/amp	±10%	25.0	31.0	40.0	50.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.170	0.209	0.259	0.326
Inductance (L)	millihenries	±30%	1.1	1.7	2.7	4.2

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	38
Power at T_p (P_p)	watts	17
Motor Constant (K_m)	oz-in/√watts	9.25
Elect. Time Constant (τ_e)	milli-sec	0.15
Mech. Time Constant (τ_m)	milli-sec	42.9
Damping Factor (F_o)	oz-in/rad/sec	0.583
Moment of Inertia (J_m)	oz-in-sec^2	0.025
Total Breakaway Torque (T_f)	oz-in	1.60
Temperature Rise (TPR)	°C/watt	7.7
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	8.8
Number of Poles		10
Number of Phases		3

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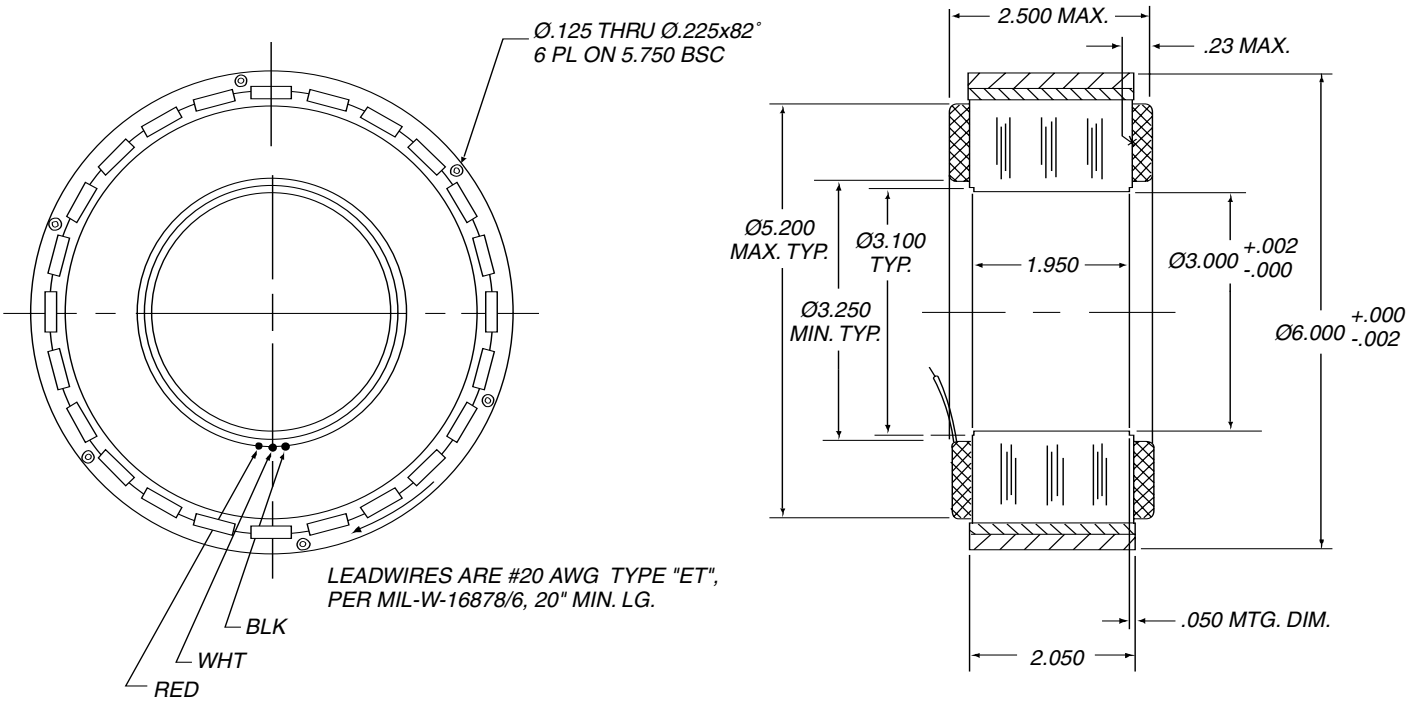

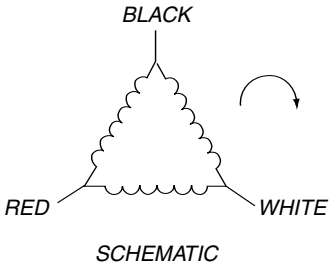

SCHEMATIC

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

Winding Constants

PARAMETER	UNITS	TOL:	-040	-050	-064	-096
Resistance (R)	ohms	±12.5%	4.0	5.2	6.4	9.6
Voltage at T_p (V_p)	volts	Nominal	37.6	42.6	47.6	59.7
Current at T_p (I_p)	amps	Nominal	9.39	8.28	7.40	5.90
Torque Sensitivity (K_t)	oz-in/amp	±10%	410	465	520	652
Back E.M.F. (K_b)	volts/rad/sec	±10%	2.90	3.32	3.66	4.37
Inductance (L)	millihenries	±30%	10	13	16	24

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	3850
Power at T_p (P_p)	watts	353
Motor Constant (K_m)	oz-in/√watts	205
Elect. Time Constant (τ_e)	milli-sec	2.5
Mech. Time Constant (τ_m)	milli-sec	4.8
Damping Factor (F_o)	oz-in/rad/sec	297
Moment of Inertia (J_m)	oz-in-sec^2	1.42
Total Breakaway Torque (T_f)	oz-in	75
Temperature Rise (TPR)	°C/watt	0.877
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	172
Number of Poles		24
Number of Phases		3

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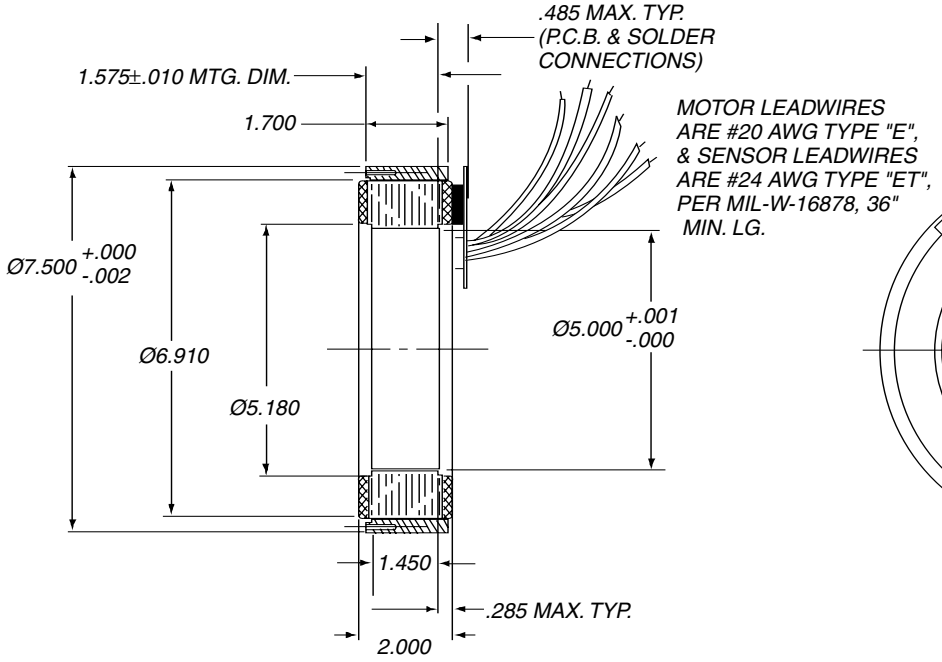
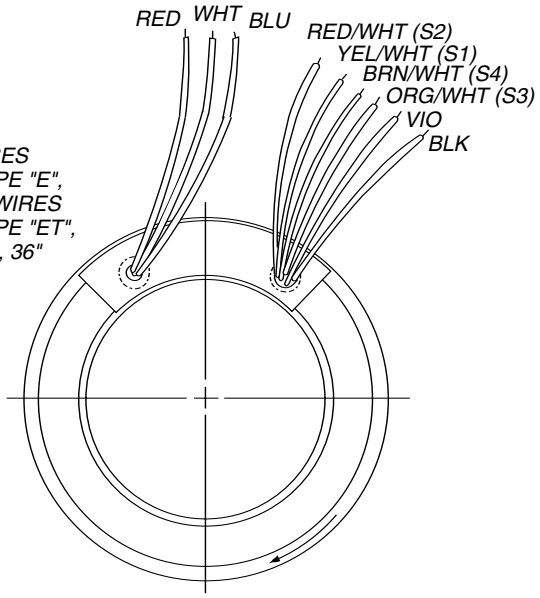
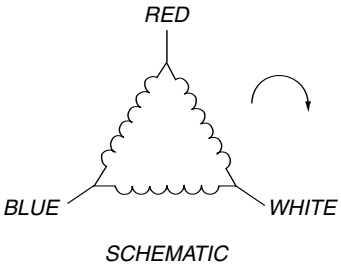




COMMUTATION TABLE									
STEP		1	2	3	4	5	6	7	COLOR
MOTOR	PHASE A	+	OFF	-	-	OFF	+	+	RED
	PHASE B	OFF	+	+	OFF	-	-	OFF	WHT
	PHASE C	-	-	OFF	+	+	OFF	-	BLU
SENSOR	SENSOR 1	1	0	0	1	1	1	1	(YEL/WHT)
	SENSOR 2	1	1	0	0	1	1	1	(RED/WHT)
	SENSOR 3	1	1	1	0	0	1	1	(ORN/WHT)
	SENSOR 4	1	1	1	1	0	0	1	(BRN/WHT)
	VIO								5-24V DC
	BLK								DGND

ROTATION: CW WHEN VIEWED FROM LEAD SIDE



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Winding Constants

PARAMETER	UNITS	TOL:	-015	-023	-037	-054
Resistance (R)	ohms	±12.5%	1.5	2.4	3.7	5.5
Voltage at T_p (V_p)	volts	Nominal	52.6	68.3	87.7	105
Current at T_p (I_p)	amps	Nominal	35.1	27.0	21.1	17.5
Torque Sensitivity (K_t)	oz-in/amp	±10%	285	370	475	570
Back E.M.F. (K_b)	volts/rad/sec	±10%	2.48	3.00	3.68	4.55
Inductance (L)	millihenries	±30%	4.1	6.4	10	15

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	10000
Power at T_p (P_p)	watts	1847
Motor Constant (K_m)	oz-in/√watts	233
Elect. Time Constant (τ_e)	milli-sec	2.7
Mech. Time Constant (τ_m)	milli-sec	2.8
Damping Factor (F_o)	oz-in/rad/sec	472
Moment of Inertia (J_m)	oz-in-sec^2	1.30
Total Breakaway Torque (T_f)	oz-in	50
Temperature Rise (TPR)	°C/watt	0.8
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	137
Number of Poles		22
Number of Phases		3

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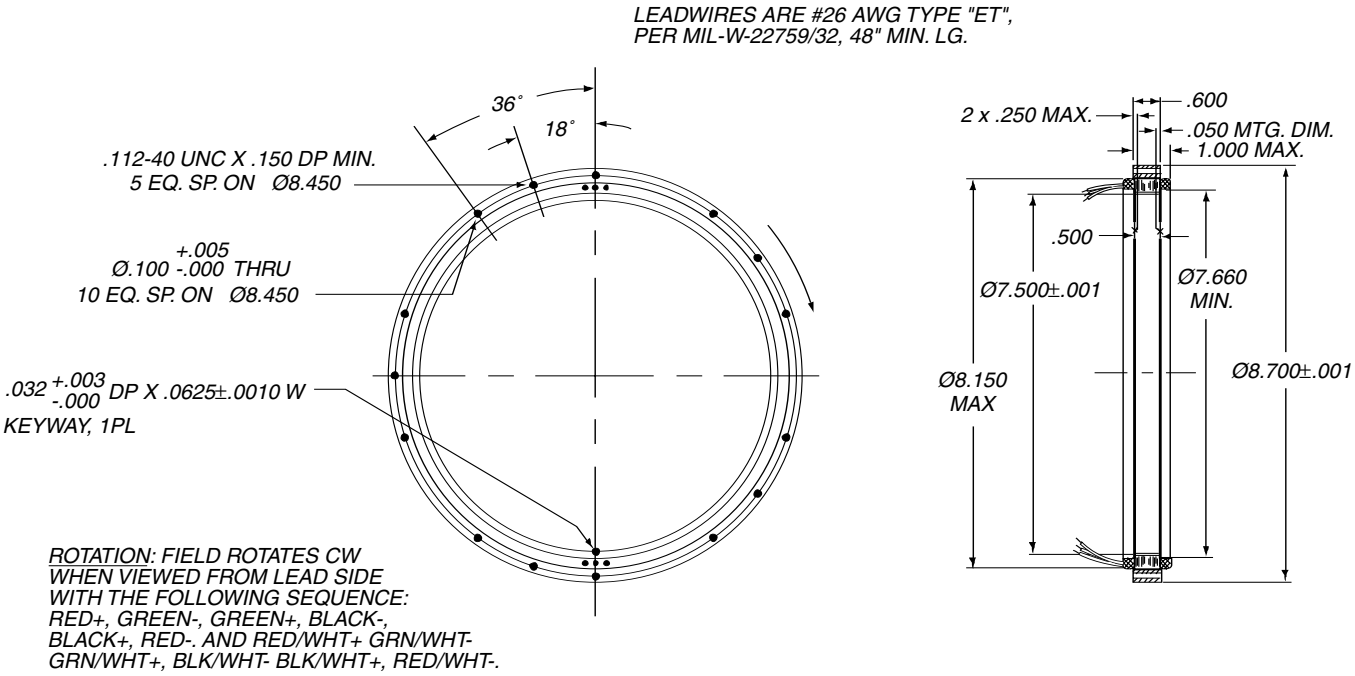
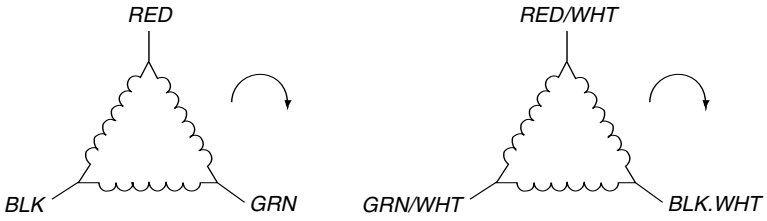


ROTATION: FIELD ROTATES CW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: RED+, GREEN-, GREEN+, BLACK-, BLACK+, RED-. AND RED/WHT+ GRN/WHT- GRN/WHT+, BLK/WHT- BLK/WHT+, RED/WHT-.



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Redundant Windings

Winding Constants

PARAMETER	UNITS	TOL:	-800	-1300	-1800	-3000
Resistance (R)	ohms	±12.5%	80	130	180	300
Voltage at T_p (V_p)	volts	Nominal	26.7	33.2	41.5	50.4
Current at T_p (I_p)	amps	Nominal	0.333	0.268	0.214	0.176
Torque Sensitivity (K_t)	oz-in/amp	±10%	450	560	700	850
Back E.M.F. (K_b)	volts/rad/sec	±10%	3.18	4.15	4.60	6.31
Inductance (L)	millihenries	±30%	10	16	23	38

* DATA IS GIVEN PER SINGLE WINDING

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	150
Power at T_p (P_p)	watts	8.9
Motor Constant (K_m)	oz-in/√watts	50.3
Elect. Time Constant (τ_e)	milli-sec	0.125
Mech. Time Constant (τ_m)	milli-sec	46
Damping Factor (F_o)	oz-in/rad/sec	17.9
Moment of Inertia (J_m)	oz-in-sec^2	0.820
Total Breakaway Torque (T_f)	oz-in	10
Temperature Rise (TPR)	°C/watt	1.4
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	2.95
Number of Poles		40
Number of Phases		3

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Selection Guide: by outside diameter
Limited Angle Slotted Motors (Series Wound)

Model Number	Rotation Inner/Outer	Peak Torque (oz-in)	Power @ T_p (watts)	K_m (oz-in/√watts)	Angular Excursion (± degrees)	O.D. (in)	I.D. (in)	Axial Length (in)	Page
2375H-050	I	60	235	3.92	5	2.375	0.940	0.500	4-1
2700C-061	I	60	70	7.19	5	2.700	1.250	0.610	4-2
3625-085	O	180	139	15.3	5	3.625	2.500	0.820	4-3
3730F-060	O	165	143	13.8	5	3.730	2.400	0.600	4-4
4600-075	O	65	10	20.8	2	4.600	3.000	0.750	4-5
4750C-106	O	800	254	50.2	5	4.750	2.077	1.061	4-6

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Selection Guide: by peak torque
Limited Angle Slotted Motors (Series Wound)

Model Number	Rotation Inner/Outer	Peak Torque (oz-in)	Power @ T_p (watts)	K_m (oz-in/√watts)	Angular Excursion (± degrees)	O.D. (in)	I.D. (in)	Axial Length (in)	Page
2375H-050	I	60	235	3.92	5	2.375	0.940	0.500	4-1
2700C-061	I	60	70	7.19	5	2.700	1.250	0.610	4-2
4600-075	O	65	10	20.8	2	4.600	3.000	0.750	4-5
3730F-060	O	165	143	13.8	5	3.730	2.400	0.600	4-4
3625-085	O	180	139	15.3	5	3.625	2.500	0.820	4-3
4750C-106	O	800	254	50.2	5	4.750	2.077	1.061	4-6

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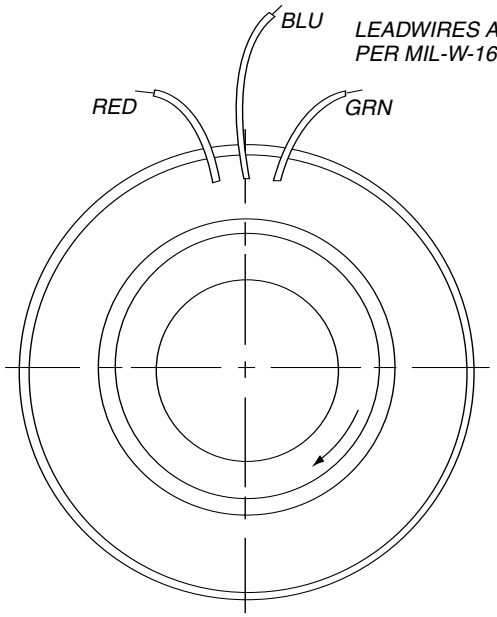
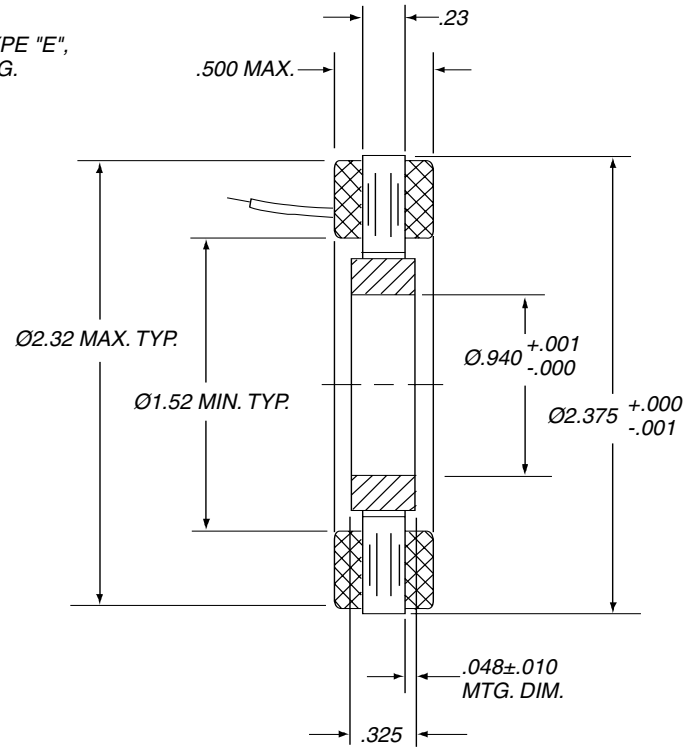
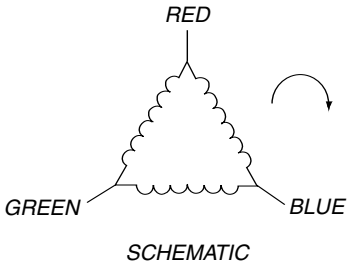


LEADWIRES ARE #22 AWG TYPE "E", PER MIL-W-16878/4, 12" MIN. LG.



Angular Excursion ±5°



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

Winding Constants

PARAMETER	UNITS	TOL:	-019	-031	-049	-078
Resistance (R)	ohms	±12.5%	1.9	31.0	4.9	7.8
Voltage at T_p (V_p)	volts	Nominal	21.1	27.0	35.2	43.0
Current at T_p (I_p)	amps	Nominal	11.1	8.70	6.67	5.45
Torque Sensitivity (K_t)	oz-in/amp	±10%	5.40	6.90	9.00	11.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.035	0.449	0.054	0.071
Inductance (L)	millihenries	±30%	1.0	16	2.6	4.1

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	60
Power at T_p (P_p)	watts	235
Motor Constant (K_m)	oz-in/√watts	3.92
Elect. Time Constant (τ_e)	milli-sec	0.53
Mech. Time Constant (τ_m)	milli-sec	16.0
Damping Factor (F_o)	oz-in/rad/sec	0.10
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		1

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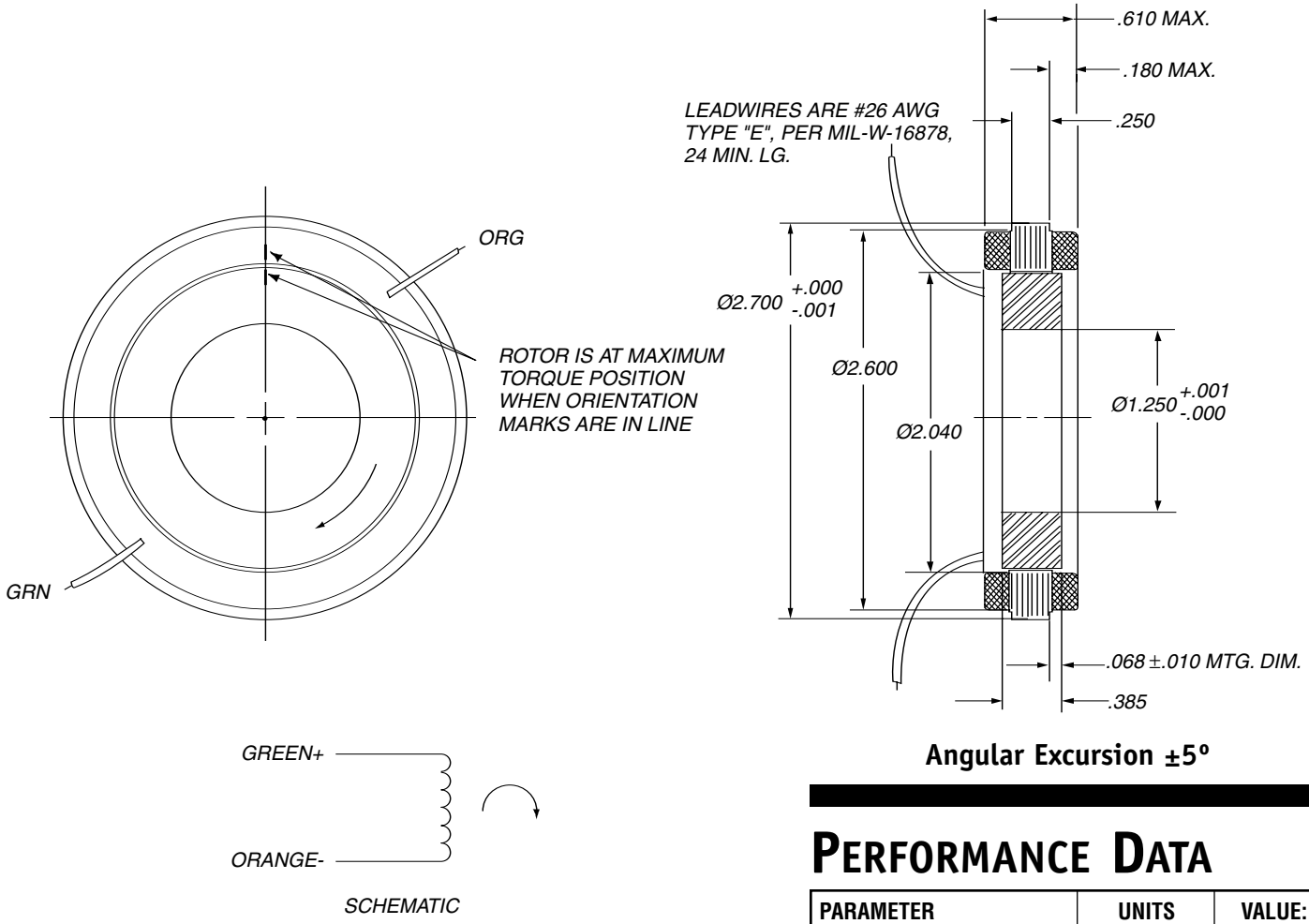

Angular Excursion ±5°

Winding Constants

PARAMETER	UNITS	TOL:	-060	-095	-122	-211
Resistance (R)	ohms	±12.5%	6.0	10.3	12.2	21.1
Voltage at T_p (V_p)	volts	Nominal	20.5	27.9	30.7	38.1
Current at T_p (I_p)	amps	Nominal	3.41	2.50	2.27	1.83
Torque Sensitivity (K_t)	oz-in/amp	±10%	17.6	24.0	26.4	32.8
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.136	0.172	0.185	0.257
Inductance (L)	millihenries	±30%	1.1	1.9	2.2	3.9

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	60
Power at T_p (P_p)	watts	70
Motor Constant (K_m)	oz-in/√watts	7.19
Elect. Time Constant (τ_e)	milli-sec	0.18
Mech. Time Constant (τ_m)	milli-sec	15.0
Damping Factor (F_o)	oz-in/rad/sec	0.40
Moment of Inertia (J_m)	oz-in-sec^2	0.006
Total Breakaway Torque (T_f)	oz-in	13
Temperature Rise (TPR)	°C/watt	3
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	7
Number of Poles		10
Number of Phases		1

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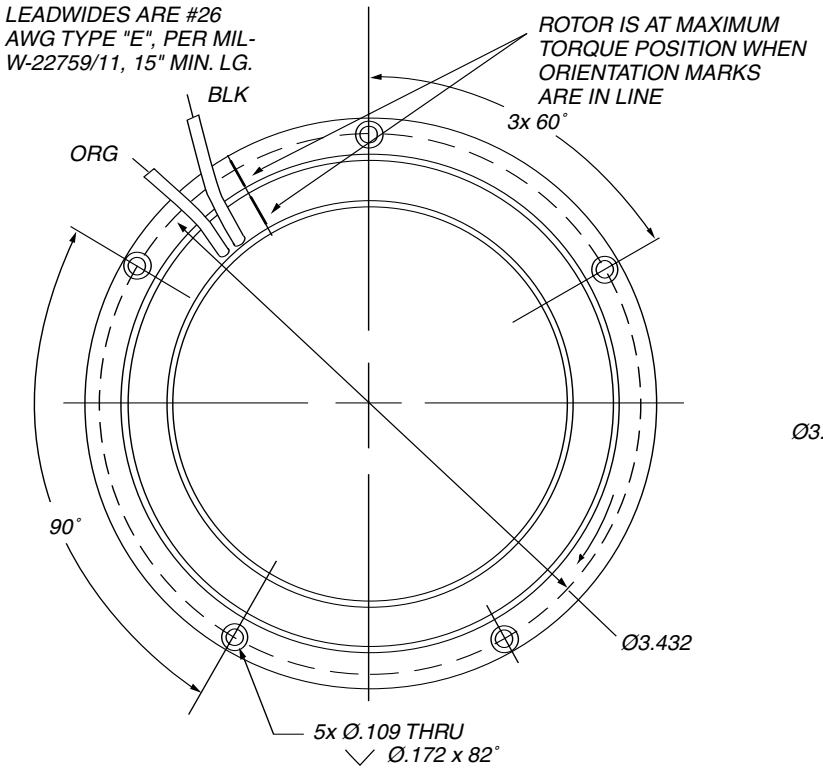
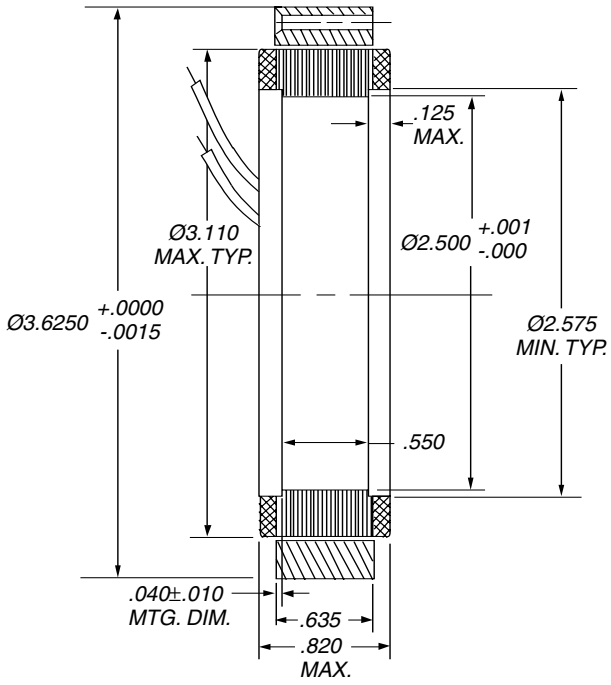
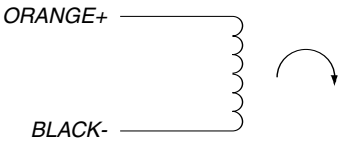




Angular Excursion ±5°



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Winding Constants

PARAMETER	UNITS	TOL:	-042	-068	-095	-155
Resistance (R)	ohms	±12.5%	4.2	6.8	9.5	17.0
Voltage at T_p (V_p)	volts	Nominal	24.2	30.6	33.8	43.2
Current at T_p (I_p)	amps	Nominal	5.75	4.53	4.11	3.21
Torque Sensitivity (K_t)	oz-in/amp	±10%	31.3	39.7	43.8	56.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.177	0.226	0.286	0.401
Inductance (L)	millihenries	±30%	1.1	1.8	2.5	4.5

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	180
Power at T_p (P_p)	watts	139
Motor Constant (K_m)	oz-in/√watts	15.3
Elect. Time Constant (τ_e)	milli-sec	0.26
Mech. Time Constant (τ_m)	milli-sec	25.8
Damping Factor (F_o)	oz-in/rad/sec	1.32
Moment of Inertia (J_m)	oz-in-sec^2	0.034
Total Breakaway Torque (T_f)	oz-in	3.0
Temperature Rise (TPR)	°C/watt	4
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	14
Number of Poles		12
Number of Phases		1

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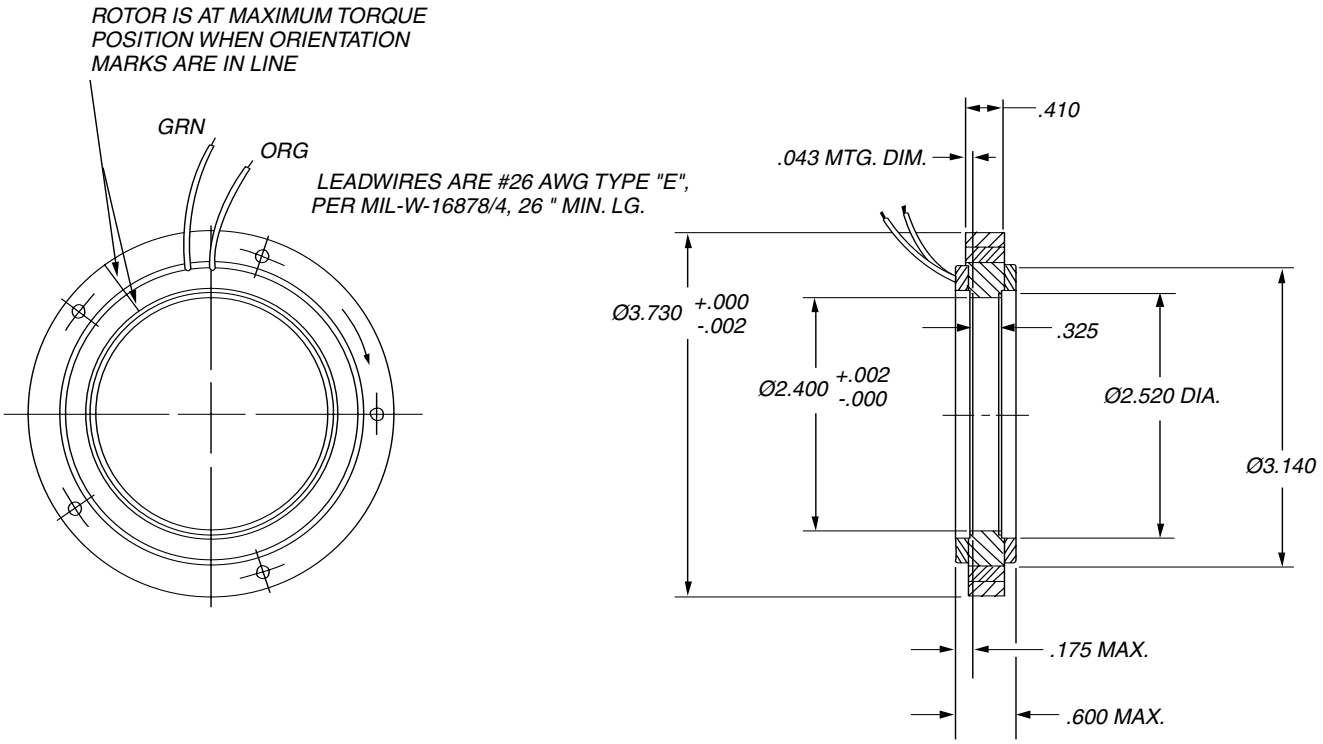

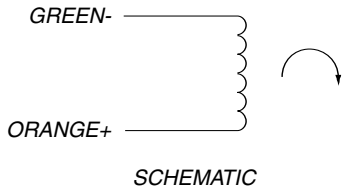

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Angular Excursion ±5°

Winding Constants

PARAMETER	UNITS	TOL:	-029	-043	-067	-104
Resistance (R)	ohms	±12.5%	2.9	4.3	6.7	10.4
Voltage at T_p (V_p)	volts	Nominal	20.4	24.3	29.8	37.5
Current at T_p (I_p)	amps	Nominal	7.02	5.89	4.80	3.81
Torque Sensitivity (K_t)	oz-in/amp	±10%	23.5	28.0	34.4	43.3
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.164	0.204	0.259	0.319
Inductance (L)	millihenries	±30%	2.7	4.0	6.2	9.7

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	165
Power at T_p (P_p)	watts	143
Motor Constant (K_m)	oz-in/√watts	13.8
Elect. Time Constant (τ_e)	milli-sec	0.93
Mech. Time Constant (τ_m)	milli-sec	27.1
Damping Factor (F_o)	oz-in/rad/sec	1.33
Moment of Inertia (J_m)	oz-in-sec^2	0.036
Total Breakaway Torque (T_f)	oz-in	3.0
Temperature Rise (TPR)	°C/watt	3
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	11
Number of Poles		10
Number of Phases		1

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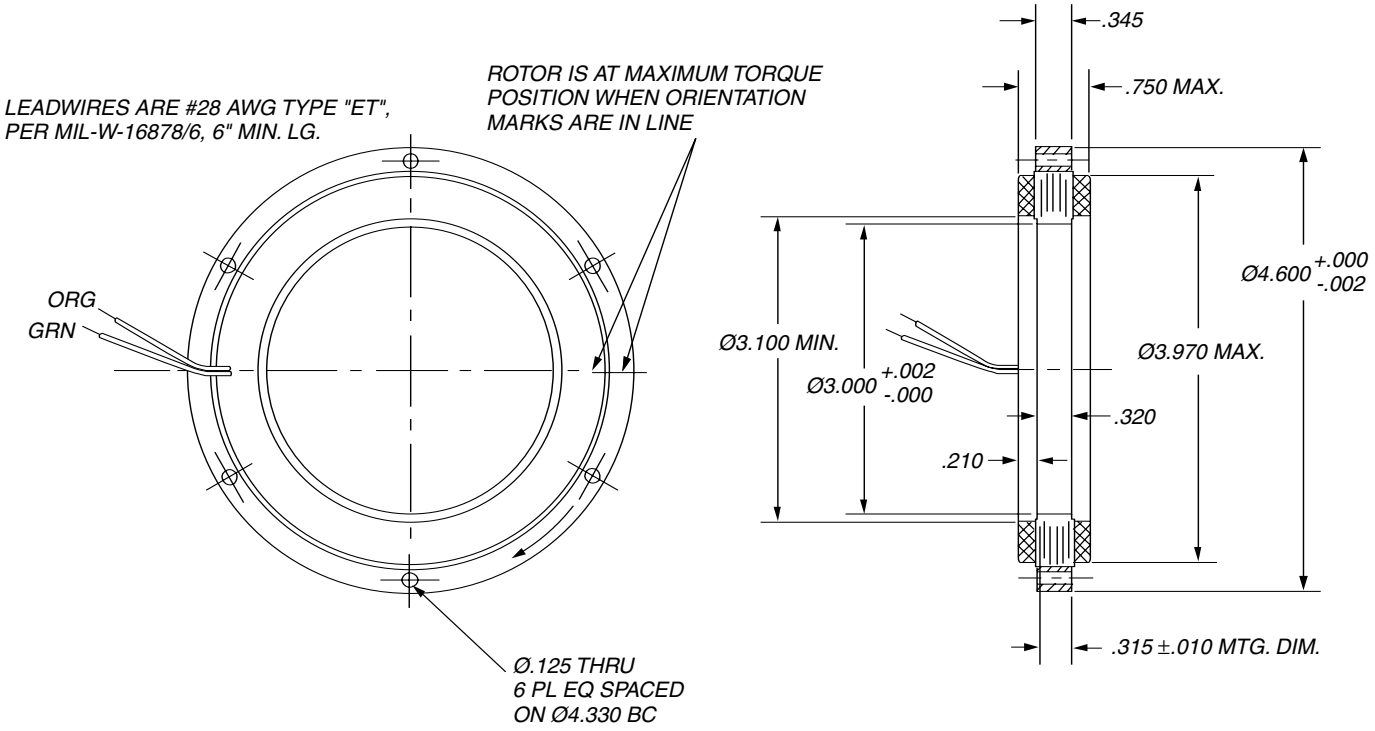

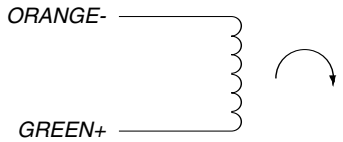

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Angular Excursion ±5°

Winding Constants

PARAMETER	UNITS	TOL:	-089	-137	-204	-345
Resistance (R)	ohms	±12.5%	8.9	13.7	20.4	34.5
Voltage at T_p (V_p)	volts	Nominal	9.3	11.4	14.2	18.1
Current at T_p (I_p)	amps	Nominal	1.05	0.855	0.688	0.542
Torque Sensitivity (K_t)	oz-in/amp	±10%	62.0	76.0	94.5	120
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.431	0.541	0.648	0.863
Inductance (L)	millihenries	±30%	4.3	6.6	9.9	17

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	65
Power at T_p (P_p)	watts	10
Motor Constant (K_m)	oz-in/√watts	20.8
Elect. Time Constant (τ_e)	milli-sec	0.48
Mech. Time Constant (τ_m)	milli-sec	24.3
Damping Factor (F_o)	oz-in/rad/sec	3.0
Moment of Inertia (J_m)	oz-in-sec^2	0.073
Total Breakaway Torque (T_f)	oz-in	2.0
Temperature Rise (TPR)	°C/watt	2
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	14
Number of Poles		12
Number of Phases		1

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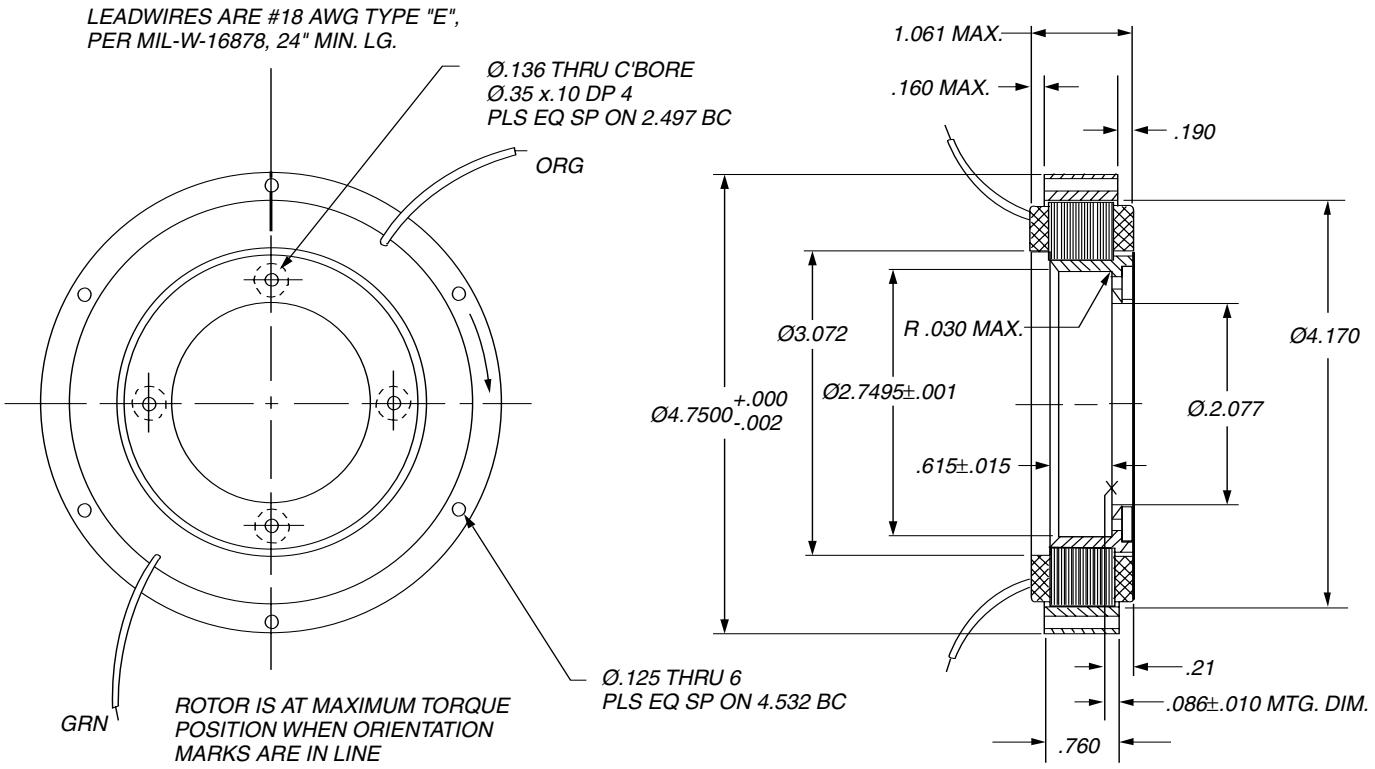
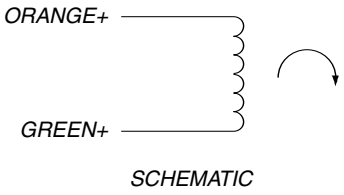


Angular Excursion ±5°



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Winding Constants

PARAMETER	UNITS	TOL:	-014	-023	-033	-054
Resistance (R)	ohms	±12.5%	1.4	2.3	3.3	5.4
Voltage at T_p (V_p)	volts	Nominal	18.7	24.9	29.2	37.4
Current at T_p (I_p)	amps	Nominal	13.6	10.2	8.70	6.78
Torque Sensitivity (K_t)	oz-in/amp	±10%	59.0	78.5	92.0	118
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.419	0.524	0.648	0.816
Inductance (L)	millihenries	±30%	1.4	2.3	3.4	5.5

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	800
Power at T_p (P_p)	watts	254
Motor Constant (K_m)	oz-in/√watts	50.2
Elect. Time Constant (τ_e)	milli-sec	1.0
Mech. Time Constant (τ_m)	milli-sec	10
Damping Factor (F_o)	oz-in/rad/sec	17.9
Moment of Inertia (J_m)	oz-in-sec^2	0.180
Total Breakaway Torque (T_f)	oz-in	18
Temperature Rise (TPR)	°C/watt	3
Max. Allowable Wdg. Temp.	°C	155
Weight	oz	36
Number of Poles		18
Number of Phases		1

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Selection Guide: by outside diameter
Limited Angle Slotless Motors (Toroidally Wound)

Model Number	Peak Torque (oz-in)	Power @ T_p (watts)	K_m (oz-in/√watts)	Angular Excursion (± degrees)	O.D. (in)	I.D. (in)	Axial Length (in)	Page
BTM9-C2	2.9	24	0.587	45	0.870	0.125	0.700	5-1
BTM10-S	6.0	84	0.653	60	0.960	0.125	0.700	5-2
BTM10-R-3	1.8	19	0.409	60	0.962	0.125	0.350	5-3
BTM10-AD	1.7	20	0.383	60	1.000	0.188	0.350	5-4
BTM10-A-5	2.9	81	0.323	60	1.000	0.125	0.350	5-5
BTM10-N-2	1.8	21	0.395	20	1.000	0.125	0.350	5-6
BTM10-L	14.5	418	0.710	40	1.000	0.125	1.000	5-7
BTM14-E	6.0	38	0.968	30	1.374	0.500	0.375	5-8
BTM15-C	22	159	1.75	15	1.500	0.375	0.500	5-9
BTM16-FA	6.0	29	1.12	22.5	1.600	0.187	0.350	5-10
BTM16-B	6.0	25	1.20	22.5	1.600	0.810	0.350	5-11
BTM16-A	7.0	26	1.39	7.5	1.600	0.600	0.350	5-12
BTM18-G	18	39	2.89	25	1.718	0.250	0.700	5-13
BTM18-L	20	60	2.59	50	1.719	0.187	0.943	5-14
BTM22-BA	12.5	25	2.50	60	2.125	0.875	0.500	5-15
BTM23-GA	37	36	6.17	13	2.270	0.250	1.000	5-16
BTM24-G	36	29	6.73	15	2.375	1.250	0.625	5-17
BTM28-EA	70	41	10.9	10	2.756	0.875	0.630	5-18
BTM30-E	63	72	7.42	60	3.000	0.500	1.000	5-19
BTM34-H-1	80	92	8.32	60	3.312	0.375	1.125	5-20
BTM34-L	75	253	4.71	60	3.313	0.250	0.625	5-21
BTM34-Q1	180	100	18.0	5	3.350	0.800	0.800	5-22
BTM34-U	345	998	10.9	45	3.375	0.627	2.000	5-23
BTM34-M	100	244	6.40	50	3.400	0.700	1.125	5-24
BTM34-S	170	430	8.20	50	3.400	0.380	1.100	5-25
BTM35-B	165	118	15.2	20	3.500	1.000	0.950	5-26
BTM40-B-3	255	199	18.1	30	4.000	0.750	1.500	5-27
BTM48-B	220	214	15.1	5	4.759	2.676	0.600	5-28
BTM52-B	708	502	31.6	25	5.250	0.700	1.700	5-29
BTM80-A	1882	383	96.2	5	8.000	1.000	2.000	5-30

All motors shown are inner rotating.

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Selection Guide: by peak torque
Limited Angle Slotless Motors (Toroidally Wound)

Model Number	Peak Torque (oz-in)	Power @ T_p (watts)	K_m (oz-in/√watts)	Angular Excursion (± degrees)	O.D. (in)	I.D. (in)	Axial Length (in)	Page
BTM10-AD	1.7	20	0.383	60	1.000	0.188	0.350	5-4
BTM10-R-3	1.8	19	0.409	60	0.962	0.125	0.350	5-3
BTM10-N-2	1.8	21	0.395	20	1.000	0.125	0.350	5-6
BTM9-C2	2.9	24	0.587	45	0.870	0.125	0.700	5-1
BTM10-A-5	2.9	81	0.323	60	1.000	0.125	0.350	5-5
BTM10-S	6.0	84	0.653	60	0.960	0.125	0.700	5-2
BTM14-E	6.0	38	0.968	30	1.374	0.500	0.375	5-8
BTM16-FA	6.0	29	1.12	22.5	1.600	0.187	0.350	5-10
BTM16-B	6.0	25	1.20	22.5	1.600	0.810	0.350	5-11
BTM16-A	7.0	26	1.39	7.5	1.600	0.600	0.350	5-12
BTM22-BA	12.5	25	2.50	60	2.125	0.875	0.500	5-15
BTM10-L	14.5	418	0.710	40	1.000	0.125	1.000	5-7
BTM18-G	18	39	2.89	25	1.718	0.250	0.700	5-13
BTM18-L	20	60	2.59	50	1.719	0.187	0.943	5-14
BTM15-C	22	159	1.75	15	1.500	0.375	0.500	5-9
BTM24-G	36	29	6.73	15	2.375	1.250	0.625	5-17
BTM23-GA	37	36	6.17	13	2.270	0.250	1.000	5-16
BTM30-E	63	72	7.42	60	3.000	0.500	1.000	5-19
BTM28-EA	70	41	10.9	10	2.756	0.875	0.630	5-18
BTM34-L	75	253	4.71	60	3.313	0.250	0.625	5-21
BTM34-H-1	80	92	8.32	60	3.312	0.375	1.125	5-20
BTM34-M	100	244	6.40	50	3.400	0.700	1.125	5-24
BTM35-B	165	118	15.2	20	3.500	1.000	0.950	5-26
BTM34-S	170	430	8.20	50	3.400	0.380	1.100	5-25
BTM34-Q1	180	100	18.0	5	3.350	0.800	0.800	5-22
BTM48-B	220	214	15.1	5	4.759	2.676	0.600	5-28
BTM40-B-3	255	199	18.1	30	4.000	0.750	1.500	5-27
BTM34-U	345	998	10.9	45	3.375	0.627	2.000	5-23
BTM52-B	708	502	31.6	25	5.250	0.700	1.700	5-29
BTM80-A	1882	383	96.2	5	8.000	1.000	2.000	5-30

All motors shown are inner rotating.

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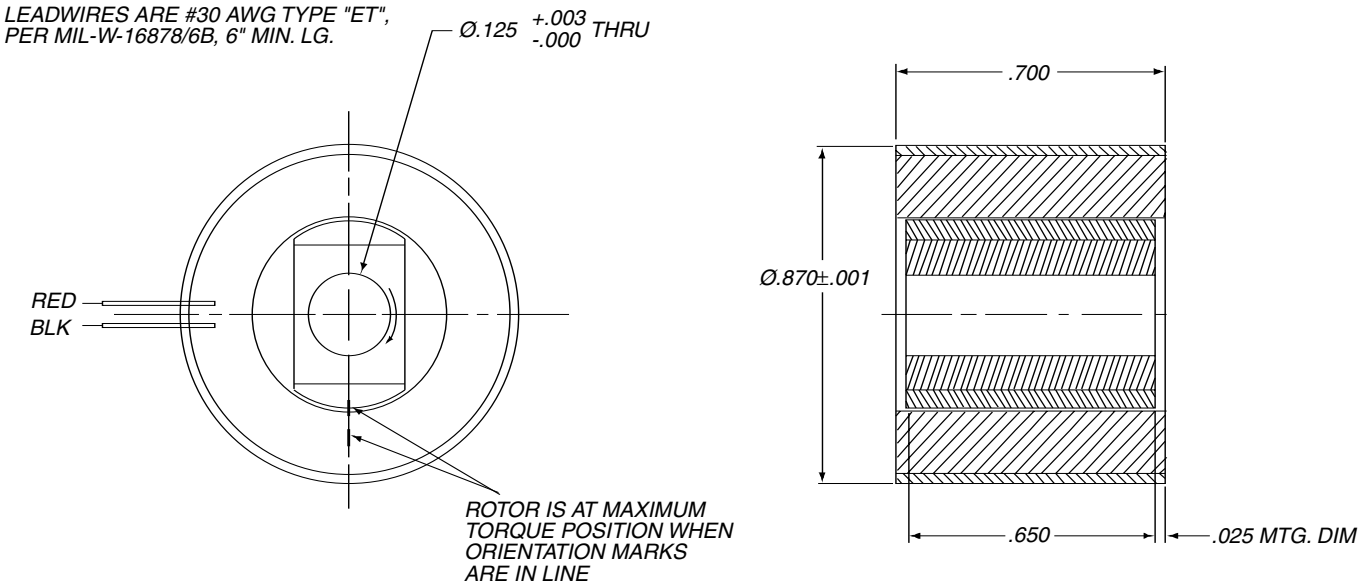

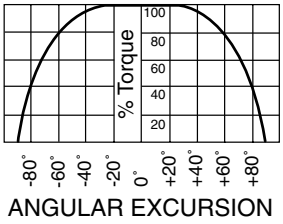

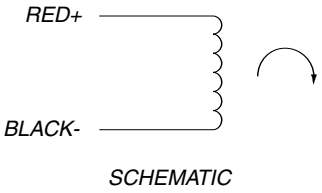

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	12.8
Voltage at Tp (V_p)	volts	Nominal	17.7
Current at Tp (I_p)	amps	Nominal	1.38
Torque Sensitivity (K_t)	oz-in/amp	±10%	2.10
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.015
Inductance (L)	millihenries	±30%	2.7

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	2.9
Power at Tp (P_p)	watts	24
Motor Constant (K_m)	oz-in/√watts	0.587
Continuous Torque (T_c)	oz-in	1.3
Power at Continuous Torque	watts	4.9
Input Volts at Continuous Torque	volts	7.9
Elect. Time Constant (τ_e)	milli-sec	0.21
Mech. Time Contstant (τ_m)	milli-sec	9.60
Damping Factor (F_o)	oz-in/rad/sec	0.0025
Rotor Inertia (J_m)	oz-in-sec^2	0.000024
Angular Excursion	degrees	±45
Total Breakaway Torque (T_f)	oz-in	0.05
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	1

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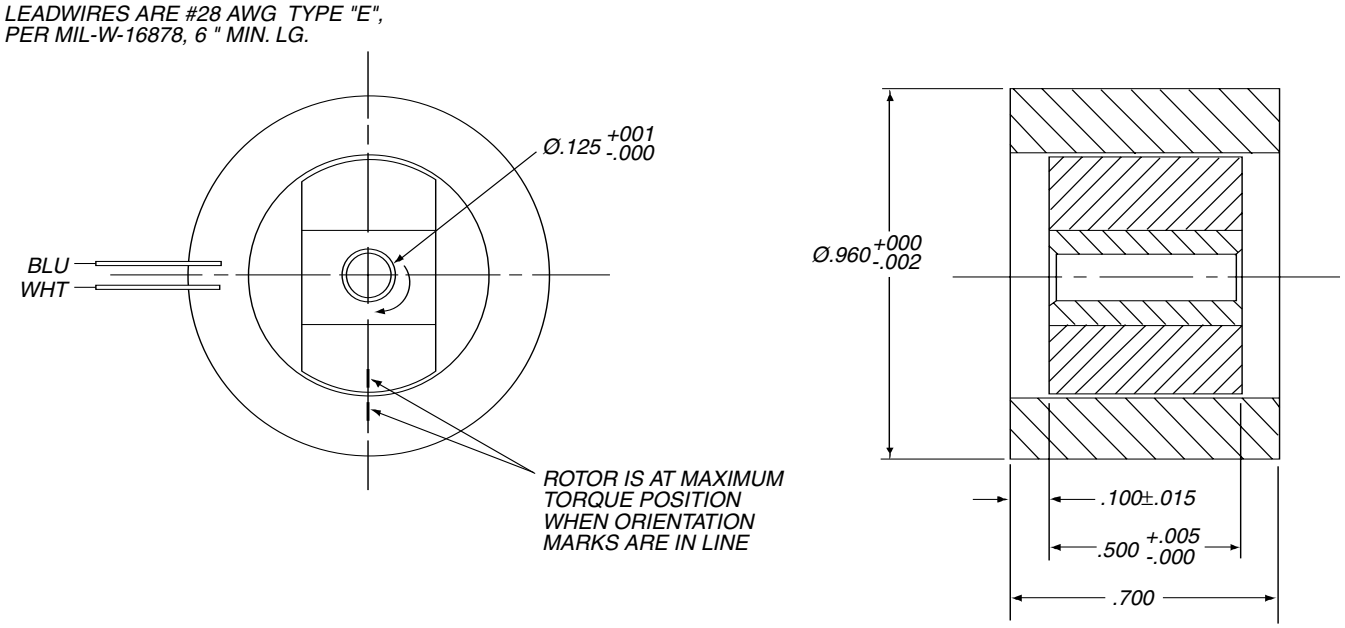

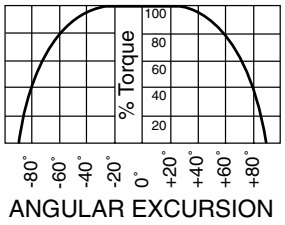

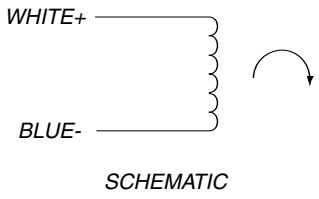

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	6.0
Voltage at Tp (V_p)	volts	Nominal	22.5
Current at Tp (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	6.0
Power at Tp (P_p)	watts	84
Motor Constant (K_m)	oz-in/√watts	0.653
Continuous Torque (T_c)	oz-in	1.5
Power at Continuous Torque	watts	5.3
Input Volts at Continuous Torque	volts	5.6
Elect. Time Constant (τ_e)	milli-sec	0.25
Mech. Time Contstant (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	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

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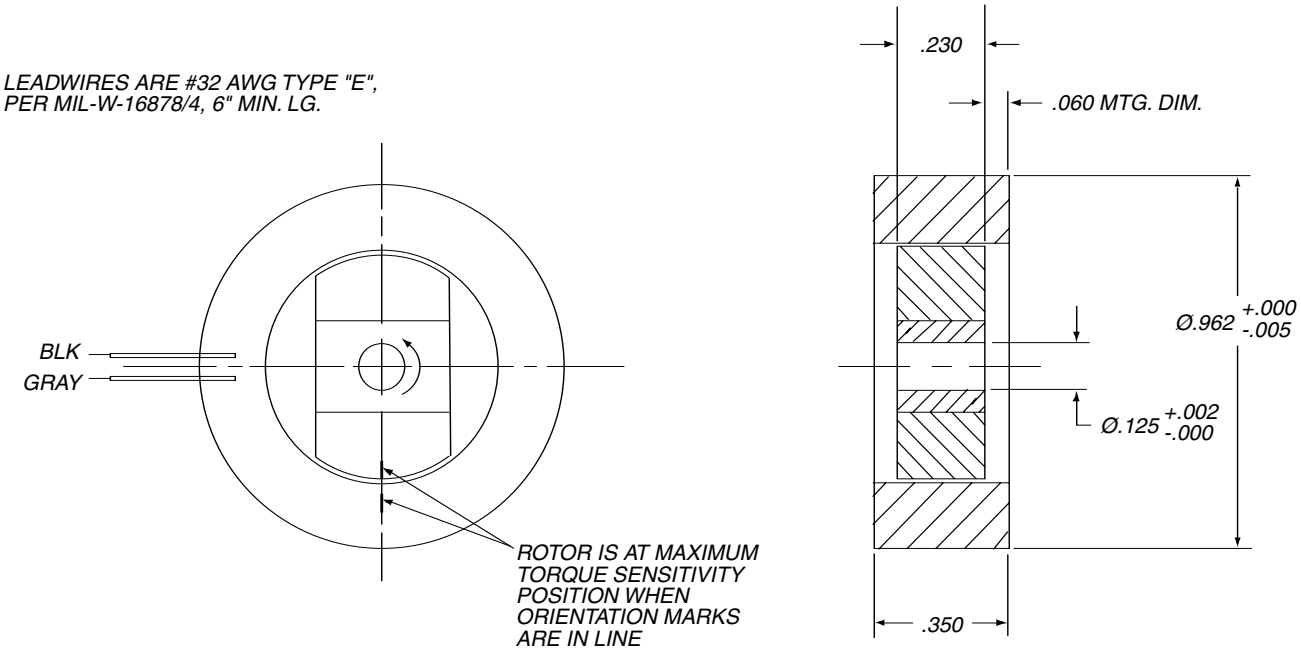

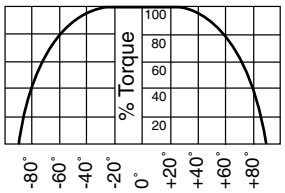

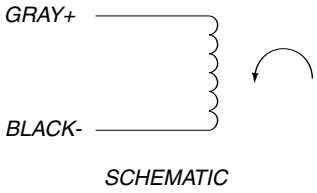

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	65.0
Voltage at Tp (V_p)	volts	Nominal	35.5
Current at Tp (I_p)	amps	Nominal	0.545
Torque Sensitivity (K_t)	oz-in/amp	±10%	3.30
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.024
Inductance (L)	millihenries	±30%	20

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	1.8
Power at Tp (P_p)	watts	19
Motor Constant (K_m)	oz-in/√watts	0.409
Continuous Torque (T_c)	oz-in	0.6
Power at Continuous Torque	watts	2.4
Input Volts at Continuous Torque	volts	11.8
Elect. Time Constant (τ_e)	milli-sec	0.30
Mech. Time Contstant (τ_m)	milli-sec	15.0
Damping Factor (F_o)	oz-in/rad/sec	0.0012
Rotor Inertia (J_m)	oz-in-sec^2	0.000018
Angular Excursion	degrees	±60
Total Breakaway Torque (T_f)	oz-in	0.03
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	0.7

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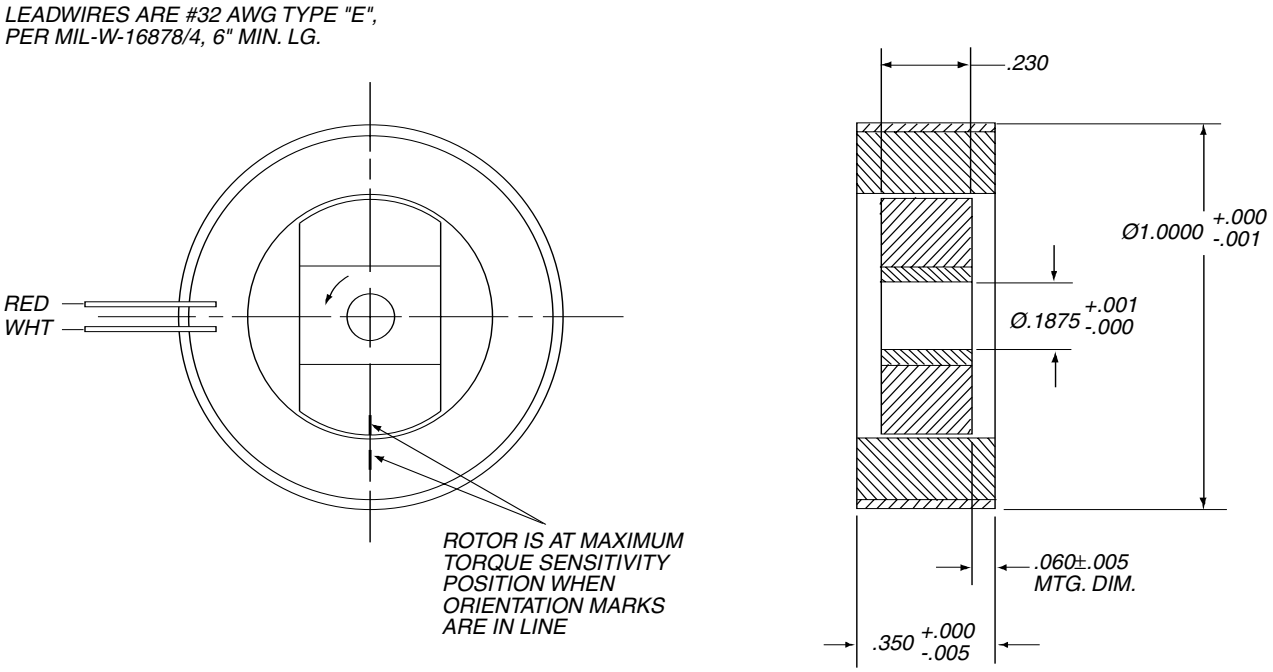

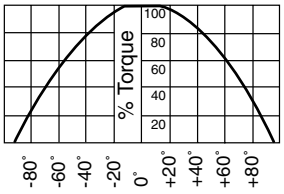

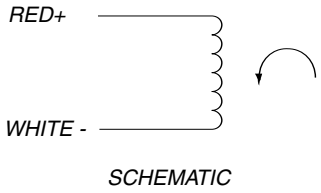

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	33.0
Voltage at Tp (V_p)	volts	Nominal	25.5
Current at Tp (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	1.7
Power at Tp (P_p)	watts	20
Motor Constant (K_m)	oz-in/√watts	0.383
Continuous Torque (T_c)	oz-in	0.5
Power at Continuous Torque	watts	2.4
Input Volts at Continuous Torque	volts	7.5
Elect. Time Constant (τ_e)	milli-sec	0.15
Mech. Time Contstant (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	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

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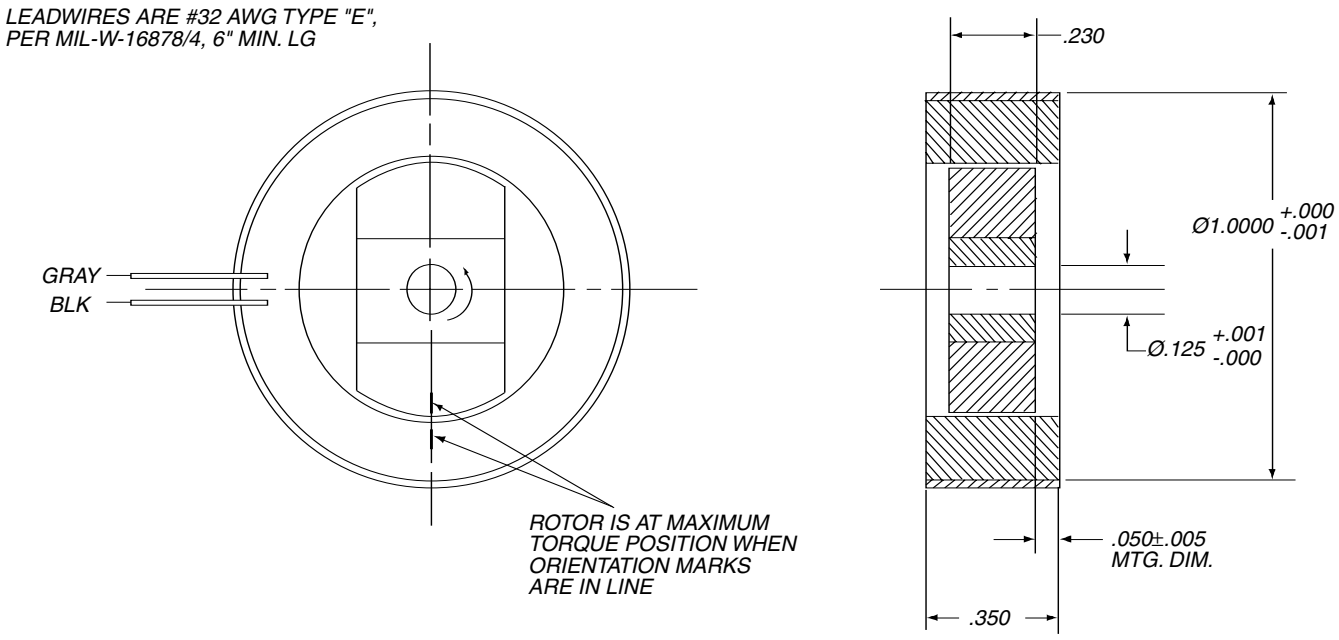

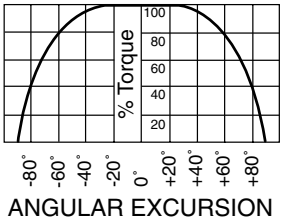

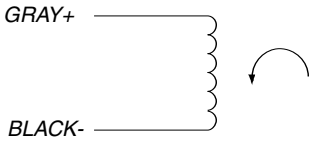

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	60.0
Voltage at Tp (V_p)	volts	Nominal	69.6
Current at Tp (I_p)	amps	Nominal	1.16
Torque Sensitivity (K_t)	oz-in/amp	±10%	2.50
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.192
Inductance (L)	millihenries	±30%	18

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	2.9
Power at Tp (P_p)	watts	81
Motor Constant (K_m)	oz-in/√watts	0.323
Continuous Torque (T_c)	oz-in	0.5
Power at Continuous Torque	watts	2.4
Input Volts at Continuous Torque	volts	12
Elect. Time Constant (τ_e)	milli-sec	0.30
Mech. Time Contstant (τ_m)	milli-sec	2.3
Damping Factor (F_o)	oz-in/rad/sec	0.008
Rotor Inertia (J_m)	oz-in-sec^2	0.000018
Angular Excursion	degrees	±60
Total Breakaway Torque (T_f)	oz-in	0.03
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	0.6

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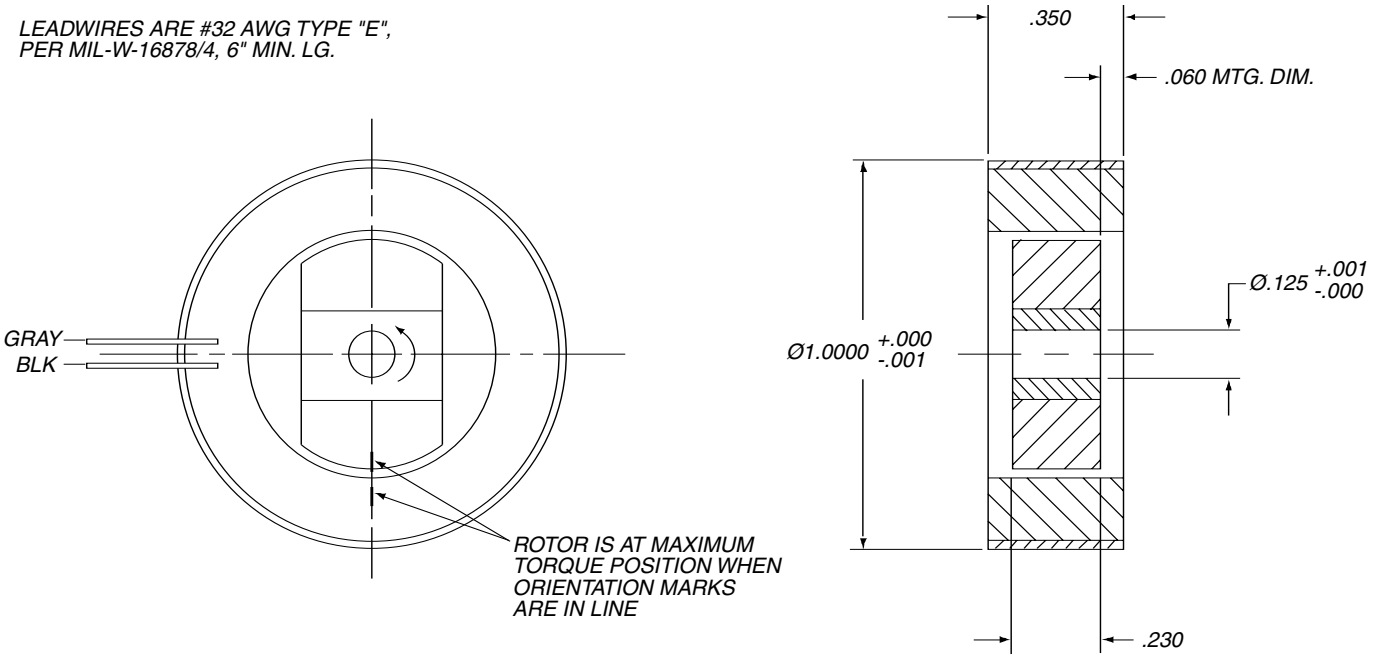

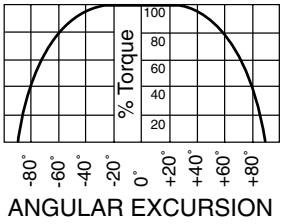

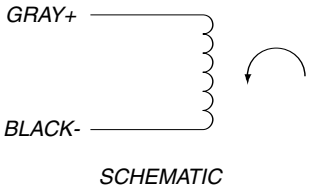

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	40.0
Voltage at Tp (V_p)	volts	Nominal	28.8
Current at Tp (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

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	1.8
Power at Tp (P_p)	watts	21
Motor Constant (K_m)	oz-in/√watts	0.395
Continuous Torque (T_c)	oz-in	0.6
Power at Continuous Torque	watts	2.3
Input Volts at Continuous Torque	volts	9.6
Elect. Time Constant (τ_e)	milli-sec	0.30
Mech. Time Contstant (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	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

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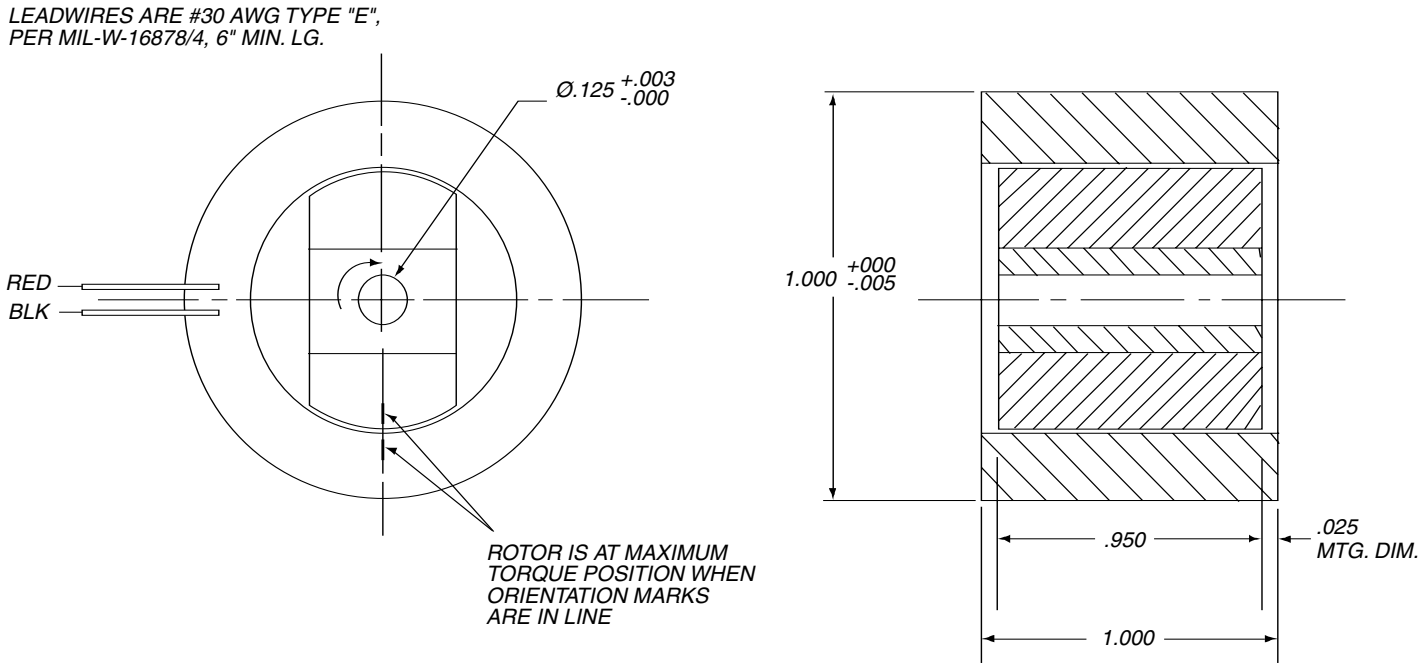

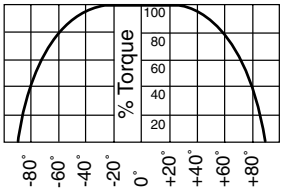

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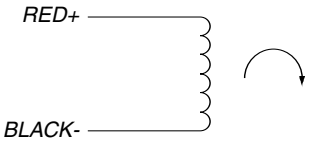

SCHEMATIC

WINDING CONSTANTS

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	16.7
Voltage at Tp (V_p)	volts	Nominal	83.5
Current at Tp (I_p)	amps	Nominal	5.00
Torque Sensitivity (K_t)	oz-in/amp	±10%	2.90
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.020
Inductance (L)	millihenries	±30%	2.2

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	14.5
Power at Tp (P_p)	watts	418
Motor Constant (K_m)	oz-in/√watts	0.710
Continuous Torque (T_c)	oz-in	1.7
Power at Continuous Torque	watts	5.7
Input Volts at Continuous Torque	volts	9.8
Elect. Time Constant (τ_e)	milli-sec	0.13
Mech. Time Contstant (τ_m)	milli-sec	34
Damping Factor (F_o)	oz-in/rad/sec	0.0035
Rotor Inertia (J_m)	oz-in-sec^2	0.00012
Angular Excursion	degrees	±40
Total Breakaway Torque (T_f)	oz-in	0.03
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	2.3

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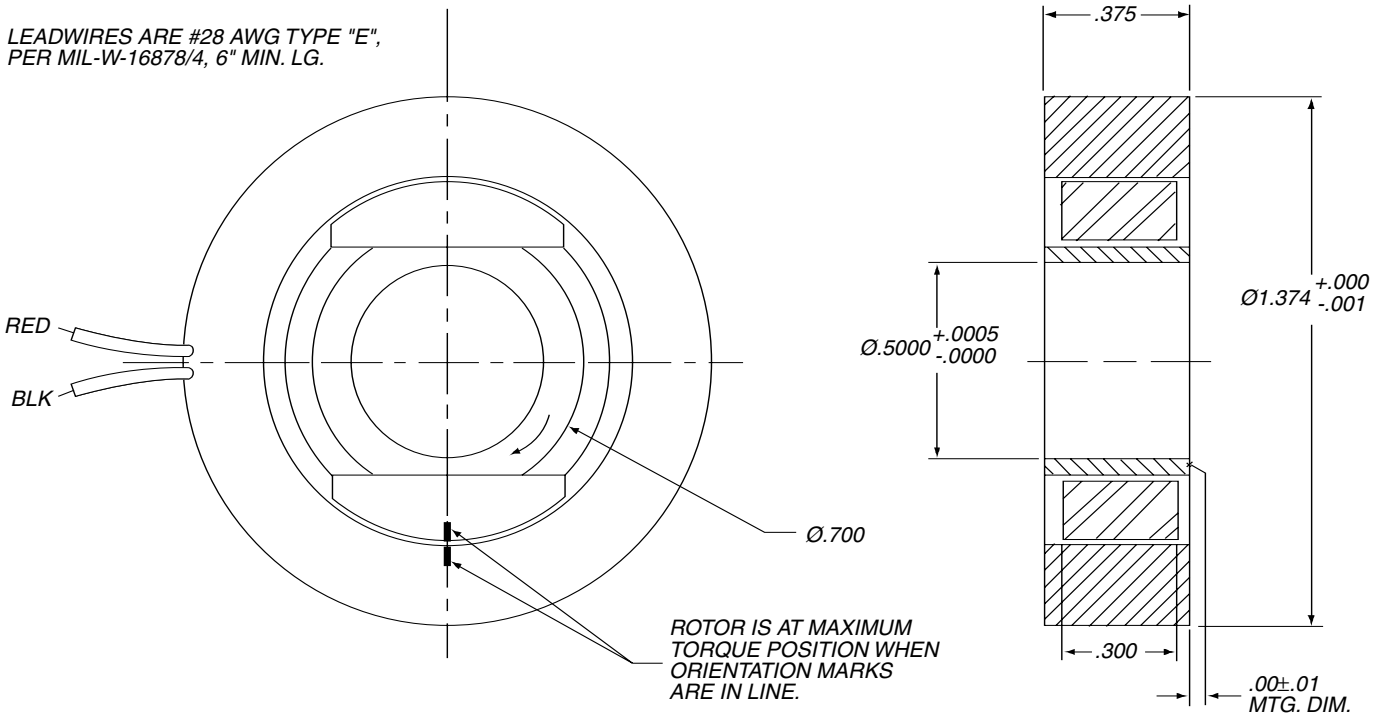

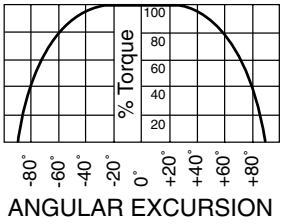

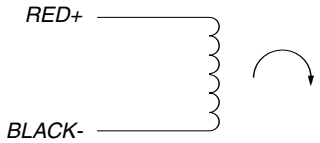

SCHEMATIC

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	9.6
Voltage at Tp (V_p)	volts	Nominal	19.2
Current at Tp (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%	5.8

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	6.0
Power at Tp (P_p)	watts	38
Motor Constant (K_m)	oz-in/√watts	0.968
Continuous Torque (T_c)	oz-in	2.1
Power at Continuous Torque	watts	4.7
Input Volts at Continuous Torque	volts	6.7
Elect. Time Constant (τ_e)	milli-sec	0.60
Mech. Time Contstant (τ_m)	milli-sec	33
Damping Factor (F_o)	oz-in/rad/sec	0.0066
Rotor Inertia (J_m)	oz-in-sec^2	0.00022
Angular Excursion	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

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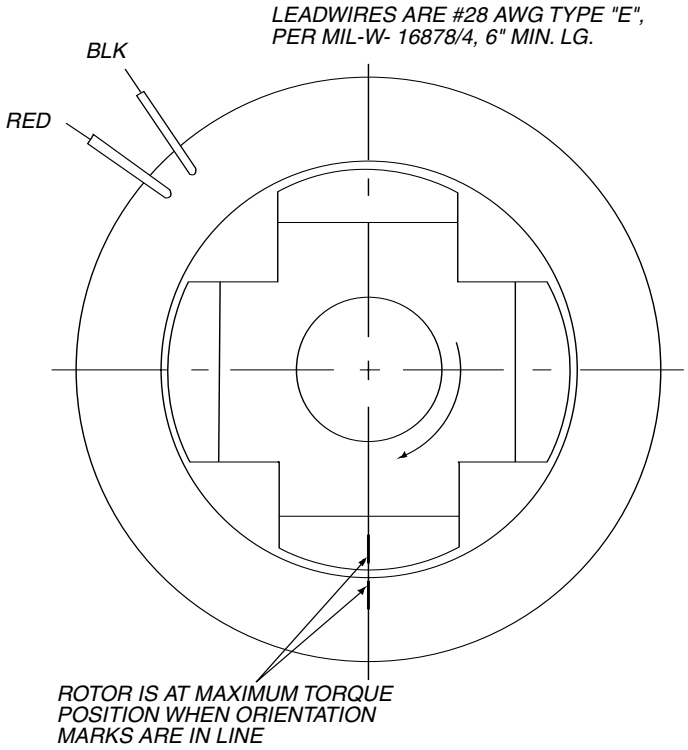

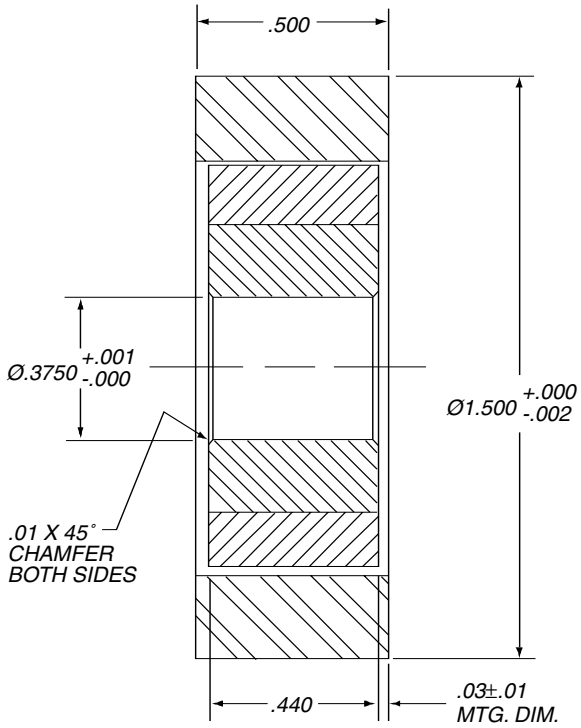

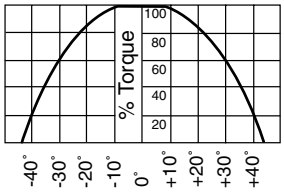

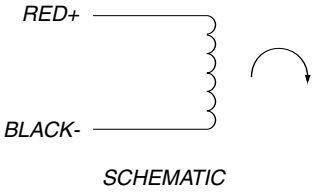

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	9.2
Voltage at Tp (V_p)	volts	Nominal	38.2
Current at Tp (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%	3.7

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	22
Power at Tp (P_p)	watts	159
Motor Constant (K_m)	oz-in/√watts	1.75
Continuous Torque (T_c)	oz-in	4.5
Power at Continuous Torque	watts	6.6
Input Volts at Continuous Torque	volts	7.8
Elect. Time Constant (τ_e)	milli-sec	0.40
Mech. Time Contstant (τ_m)	milli-sec	19.0
Damping Factor (F_o)	oz-in/rad/sec	0.021
Rotor Inertia (J_m)	oz-in-sec^2	0.0004
Angular Excursion	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

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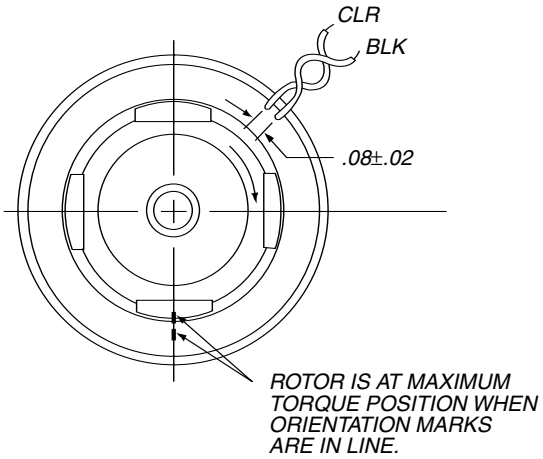
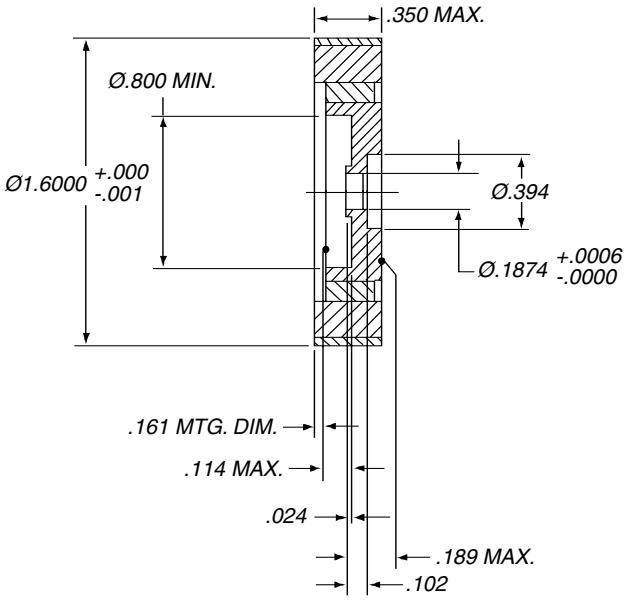
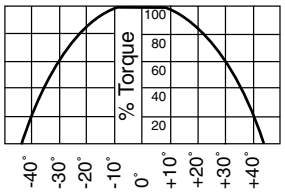
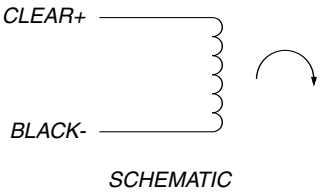
LEADWIRES ARE #32 AWG TYPE "ET", PER MIL-W-16878/4, 20" MIN. LG.









SCHEMATIC

WINDING CONSTANTS

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	6.3
Voltage at Tp (V_p)	volts	Nominal	13.5
Current at Tp (I_p)	amps	Nominal	2.14
Torque Sensitivity (K_t)	oz-in/amp	±10%	2.80
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.020
Inductance (L)	millihenries	±30%	1.8

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	6.0
Power at Tp (P_p)	watts	29
Motor Constant (K_m)	oz-in/√watts	1.12
Continuous Torque (T_c)	oz-in	1.5
Power at Continuous Torque	watts	2.4
Input Volts at Continuous Torque	volts	4.1
Elect. Time Constant (τ_e)	milli-sec	0.29
Mech. Time Contstant (τ_m)	milli-sec	36.7
Damping Factor (F_o)	oz-in/rad/sec	0.009
Rotor Inertia (J_m)	oz-in-sec^2	0.00033
Angular Excursion	degrees	±22.5
Total Breakaway Torque (T_f)	oz-in	0.08
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		4
Weight	oz	1.8

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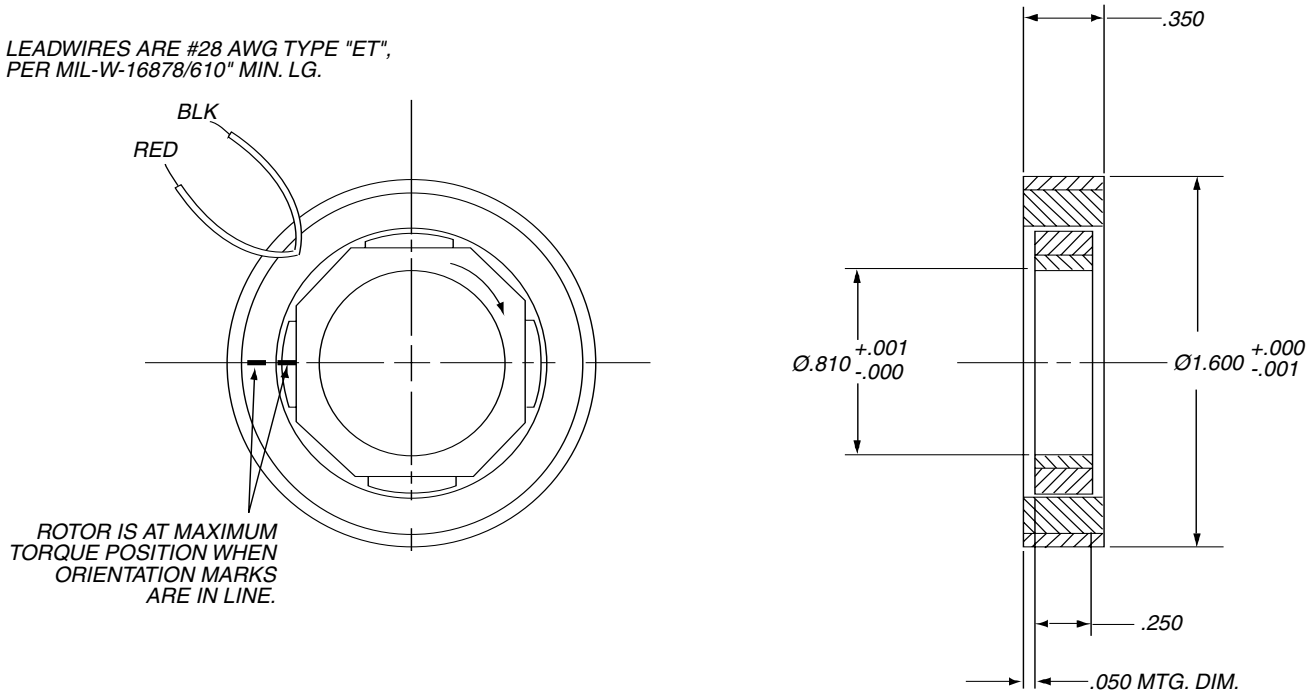

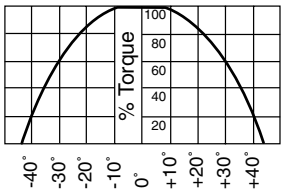

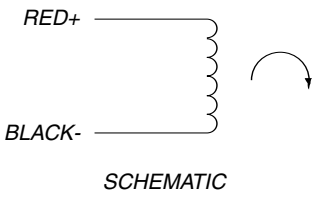

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	14.8
Voltage at Tp (V_p)	volts	Nominal	19.3
Current at Tp (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	6.0
Power at Tp (P_p)	watts	25
Motor Constant (K_m)	oz-in/√watts	1.20
Continuous Torque (T_c)	oz-in	1.7
Power at Continuous Torque	watts	2
Input Volts at Continuous Torque	volts	5.6
Elect. Time Constant (τ_e)	milli-sec	0.30
Mech. Time Contstant (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	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

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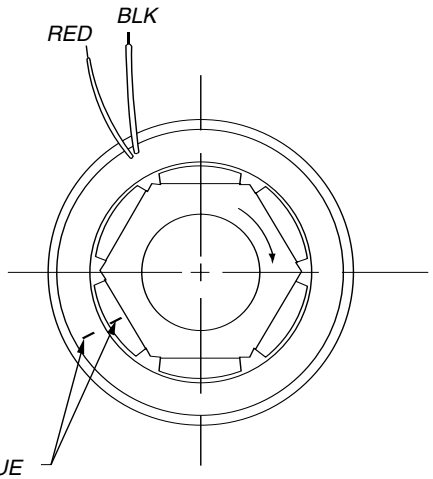
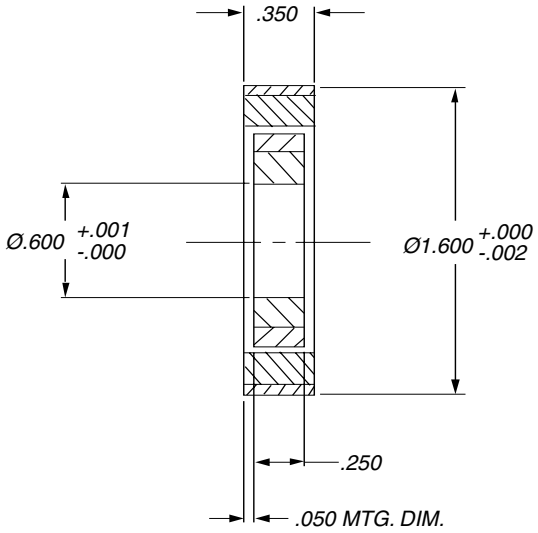
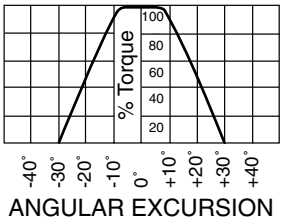
LEADWIRES ARE #28 AWG TYPE "ET", PER MIL-W-16878/6, 10" MIN. LG.

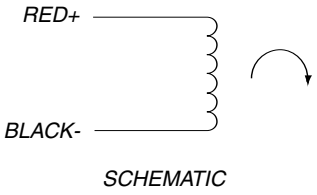


ROTOR IS AT MAXIMUM TORQUE SENSITIVITY POSITION WHEN ORIENTATION MARKS ARE IN LINE





ANGULAR EXCURSION



SCHEMATIC

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	12.0
Voltage at Tp (V_p)	volts	Nominal	17.5
Current at Tp (I_p)	amps	Nominal	1.46
Torque Sensitivity (K_t)	oz-in/amp	±10%	4.80
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.033
Inductance (L)	millihenries	±30%	1.7

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	7.0
Power at Tp (P_p)	watts	26
Motor Constant (K_m)	oz-in/√watts	1.39
Continuous Torque (T_c)	oz-in	2
Power at Continuous Torque	watts	2.1
Input Volts at Continuous Torque	volts	5
Elect. Time Constant (τ_e)	milli-sec	0.14
Mech. Time Contstant (τ_m)	milli-sec	3.03
Damping Factor (F_o)	oz-in/rad/sec	0.013
Rotor Inertia (J_m)	oz-in-sec^2	0.00004
Angular Excursion	degrees	±7.5
Total Breakaway Torque (T_f)	oz-in	0.08
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		6
Weight	oz	1.5

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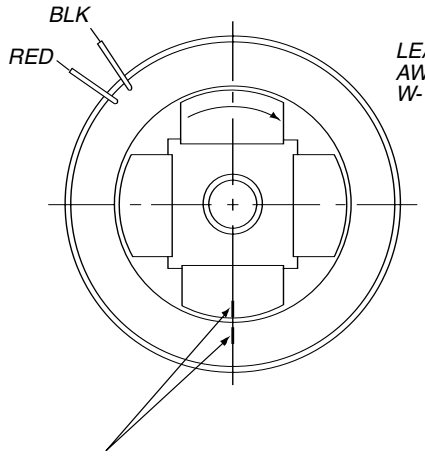

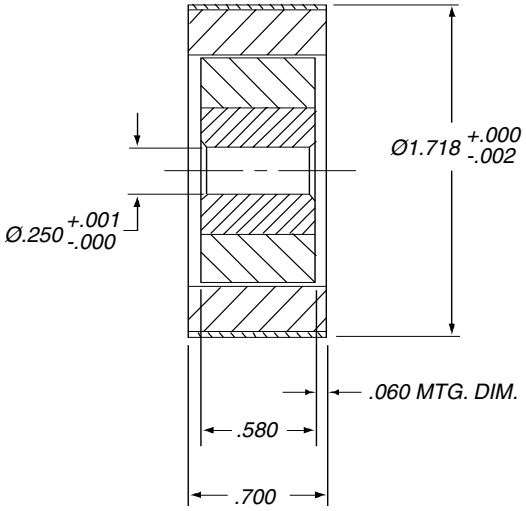

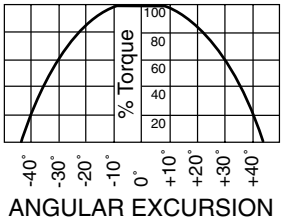

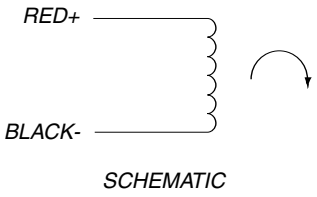

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	12.0
Voltage at Tp (V_p)	volts	Nominal	21.6
Current at Tp (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%	4.6

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	18
Power at Tp (P_p)	watts	39
Motor Constant (K_m)	oz-in/√watts	2.89
Continuous Torque (T_c)	oz-in	8
Power at Continuous Torque	watts	7.7
Input Volts at Continuous Torque	volts	9.6
Elect. Time Constant (τ_e)	milli-sec	0.38
Mech. Time Contstant (τ_m)	milli-sec	14
Damping Factor (F_o)	oz-in/rad/sec	0.059
Rotor Inertia (J_m)	oz-in-sec^2	0.00084
Angular Excursion	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

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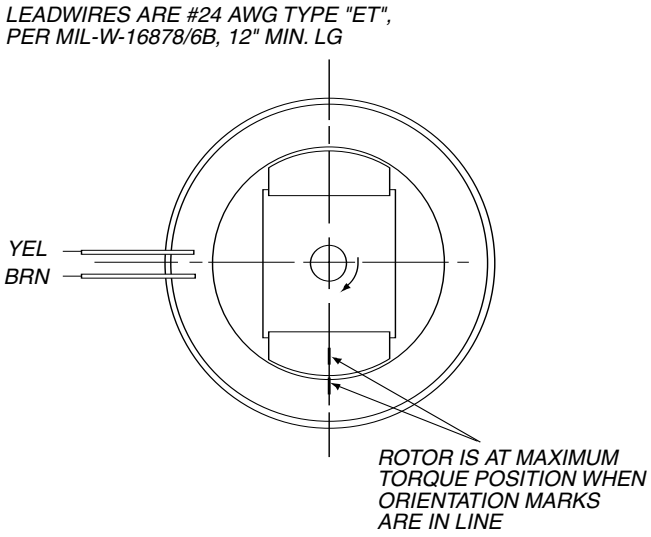
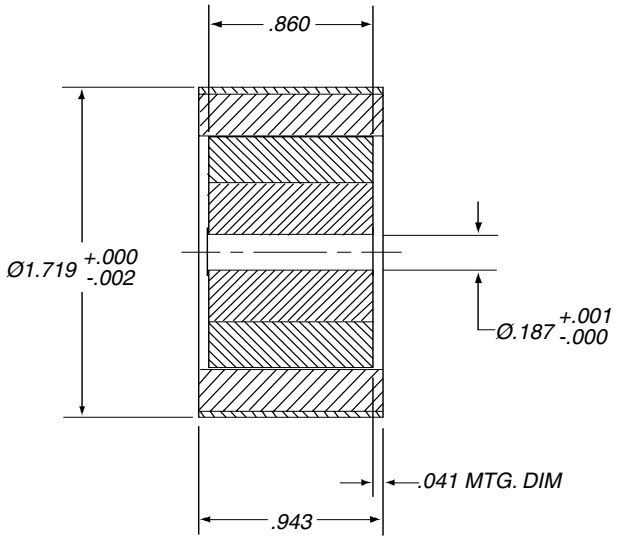
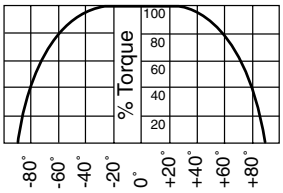
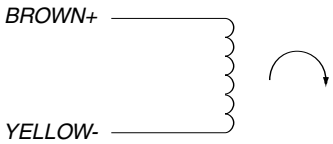






ANGULAR EXCURSION



SCHEMATIC

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	6.5
Voltage at Tp (V_p)	volts	Nominal	19.7
Current at Tp (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%	7.8

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	20
Power at Tp (P_p)	watts	60
Motor Constant (K_m)	oz-in/√watts	2.59
Continuous Torque (T_c)	oz-in	6.0
Power at Continuous Torque	watts	8.5
Input Volts at Continuous Torque	volts	8.5
Elect. Time Constant (τ_e)	milli-sec	1.2
Mech. Time Contstant (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	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

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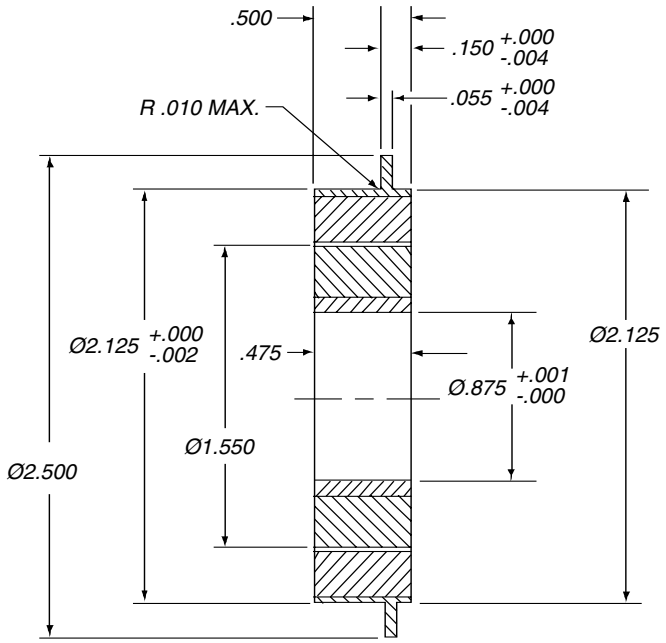

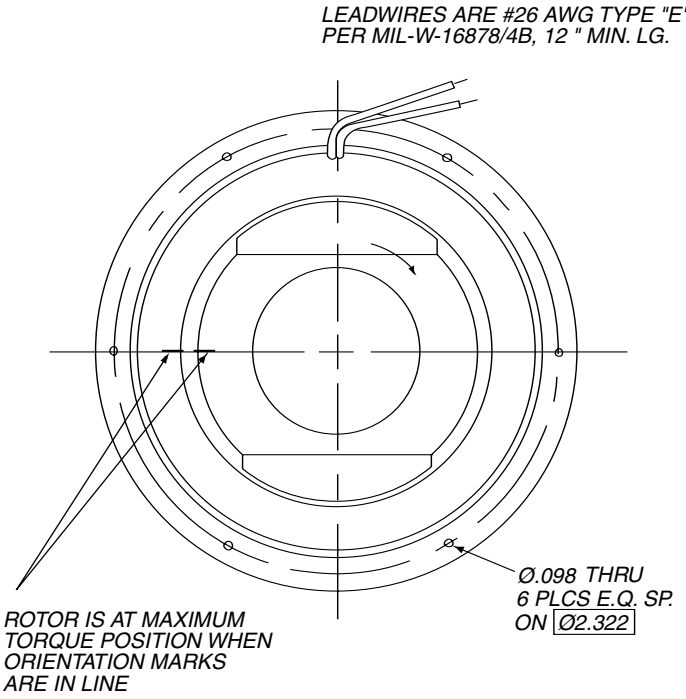

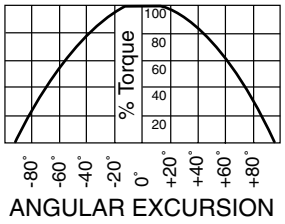

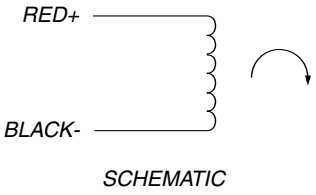

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	10.2
Voltage at Tp (V_p)	volts	Nominal	15.9
Current at Tp (I_p)	amps	Nominal	1.56
Torque Sensitivity (K_t)	oz-in/amp	±10%	8.00
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.056
Inductance (L)	millihenries	±30%	13

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	12.5
Power at Tp (P_p)	watts	25
Motor Constant (K_m)	oz-in/√watts	2.50
Continuous Torque (T_c)	oz-in	5
Power at Continuous Torque	watts	7
Input Volts at Continuous Torque	volts	10
Elect. Time Constant (τ_e)	milli-sec	1.25
Mech. Time Contstant (τ_m)	milli-sec	46
Damping Factor (F_o)	oz-in/rad/sec	0.044
Rotor Inertia (J_m)	oz-in-sec^2	0.002
Angular Excursion	degrees	±60
Total Breakaway Torque (T_f)	oz-in	0.50
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	10

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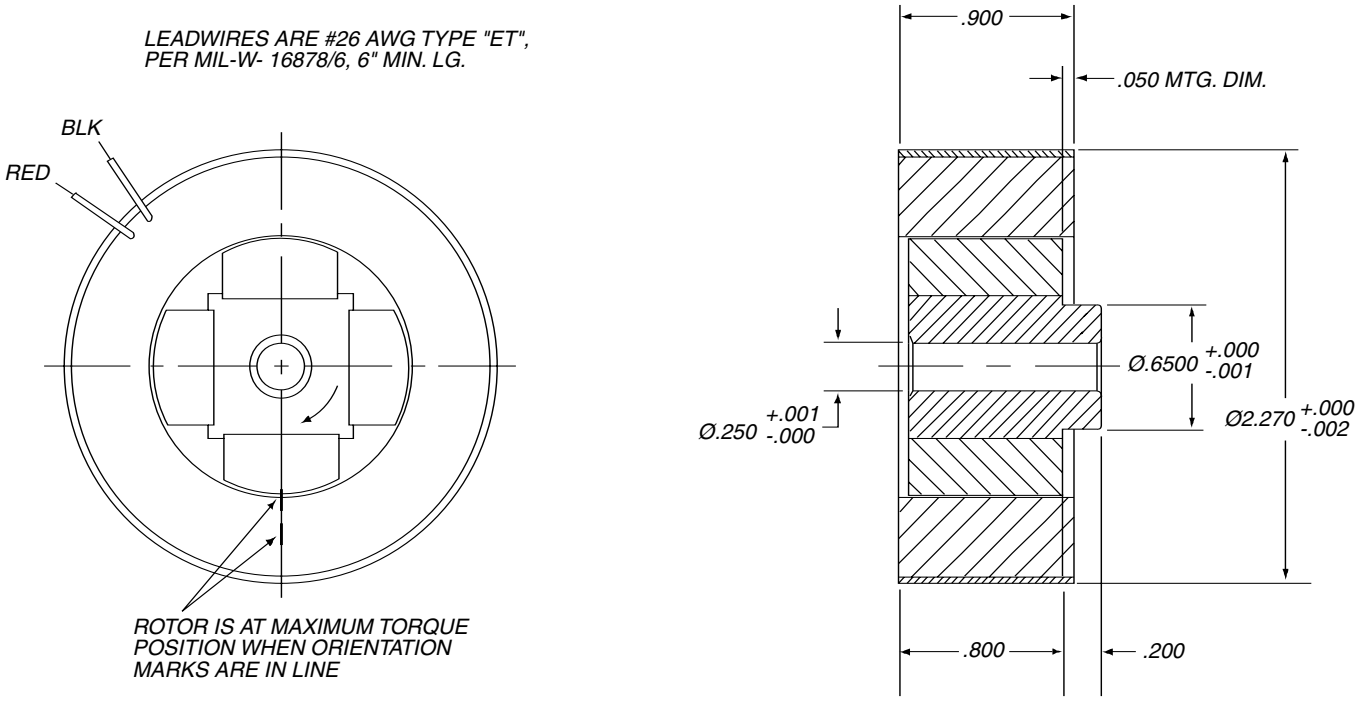

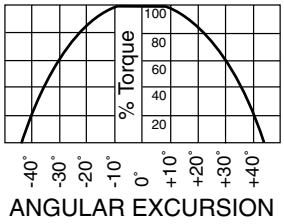

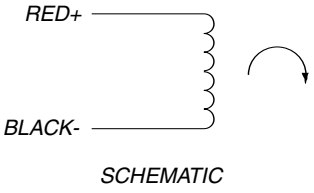

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	10.5
Voltage at Tp (V_p)	volts	Nominal	19.4
Current at Tp (I_p)	amps	Nominal	1.85
Torque Sensitivity (K_t)	oz-in/amp	±10%	20.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.143
Inductance (L)	millihenries	±30%	13

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	37
Power at Tp (P_p)	watts	36
Motor Constant (K_m)	oz-in/√watts	6.17
Continuous Torque (T_c)	oz-in	24
Power at Continuous Torque	watts	15.1
Input Volts at Continuous Torque	volts	13
Elect. Time Constant (τ_e)	milli-sec	1.2
Mech. Time Contstant (τ_m)	milli-sec	9.2
Damping Factor (F_o)	oz-in/rad/sec	0.272
Rotor Inertia (J_m)	oz-in-sec^2	0.0025
Angular Excursion	degrees	±13
Total Breakaway Torque (T_f)	oz-in	0.50
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		4
Weight	oz	14

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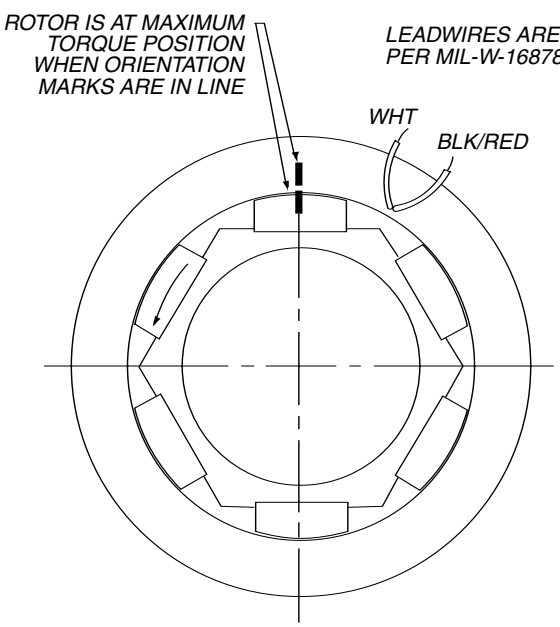
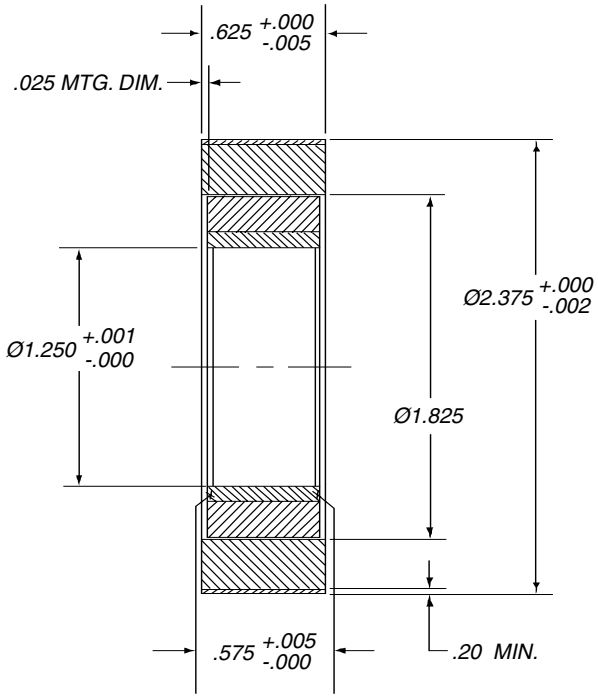
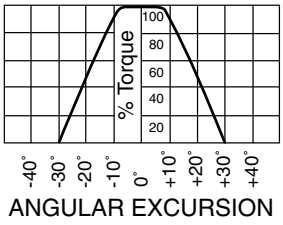
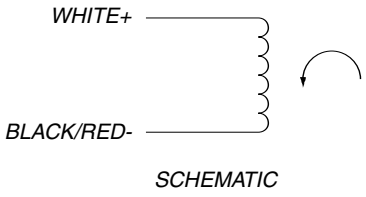






ANGULAR EXCURSION



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Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	36
Power at Tp (P_p)	watts	29
Motor Constant (K_m)	oz-in/√watts	6.73
Continuous Torque (T_c)	oz-in	20
Power at Continuous Torque	watts	12
Input Volts at Continuous Torque	volts	9.5
Elect. Time Constant (τ_e)	milli-sec	0.66
Mech. Time Contstant (τ_m)	milli-sec	14.2
Damping Factor (F_o)	oz-in/rad/sec	0.318
Rotor Inertia (J_m)	oz-in-sec^2	0.0045
Angular Excursion	degrees	±15
Total Breakaway Torque (T_f)	oz-in	1.00
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		6
Weight	oz	7

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	5.8
Voltage at Tp (V_p)	volts	Nominal	12.9
Current at Tp (I_p)	amps	Nominal	2.22
Torque Sensitivity (K_t)	oz-in/amp	±10%	16.2
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.114
Inductance (L)	millihenries	±30%	3.8

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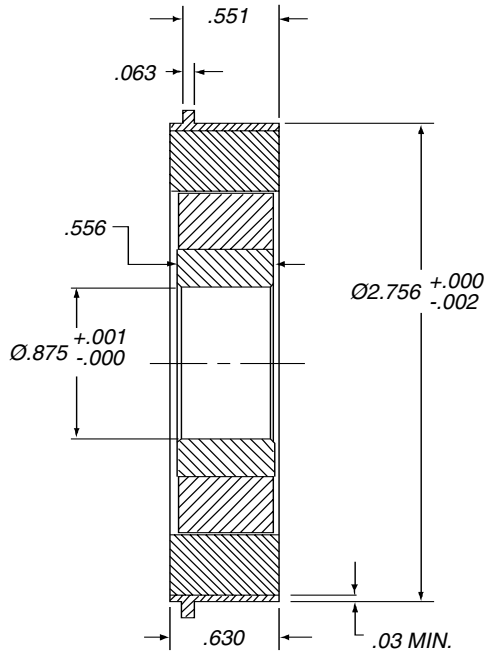
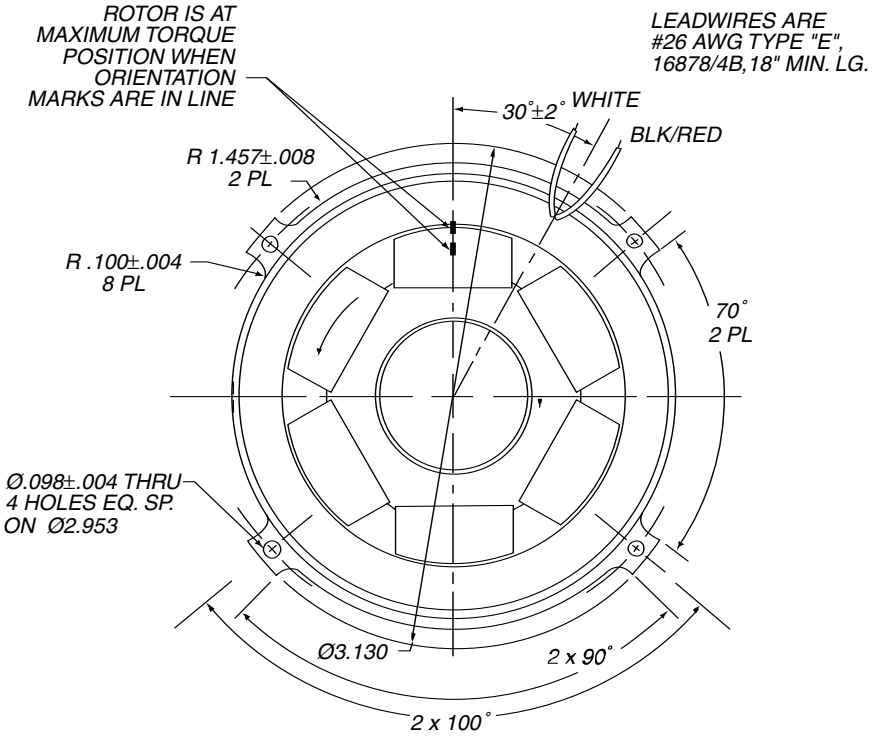
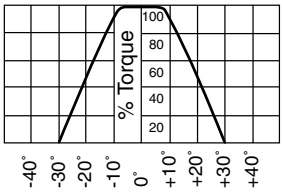
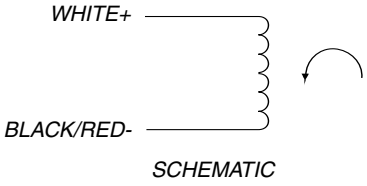






ANGULAR EXCURSION



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Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	19.0
Voltage at Tp (V_p)	volts	Nominal	28.0
Current at Tp (I_p)	amps	Nominal	1.47
Torque Sensitivity (K_t)	oz-in/amp	±10%	47.5
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.335
Inductance (L)	millihenries	±30%	18

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	70
Power at Tp (P_p)	watts	41
Motor Constant (K_m)	oz-in/√watts	10.9
Continuous Torque (T_c)	oz-in	45
Power at Continuous Torque	watts	20
Input Volts at Continuous Torque	volts	22
Elect. Time Constant (τ_e)	milli-sec	0.95
Mech. Time Contstant (τ_m)	milli-sec	11.9
Damping Factor (F_o)	oz-in/rad/sec	0.84
Rotor Inertia (J_m)	oz-in-sec^2	0.01
Angular Excursion	degrees	±10
Total Breakaway Torque (T_f)	oz-in	0.70
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		6
Weight	oz	8

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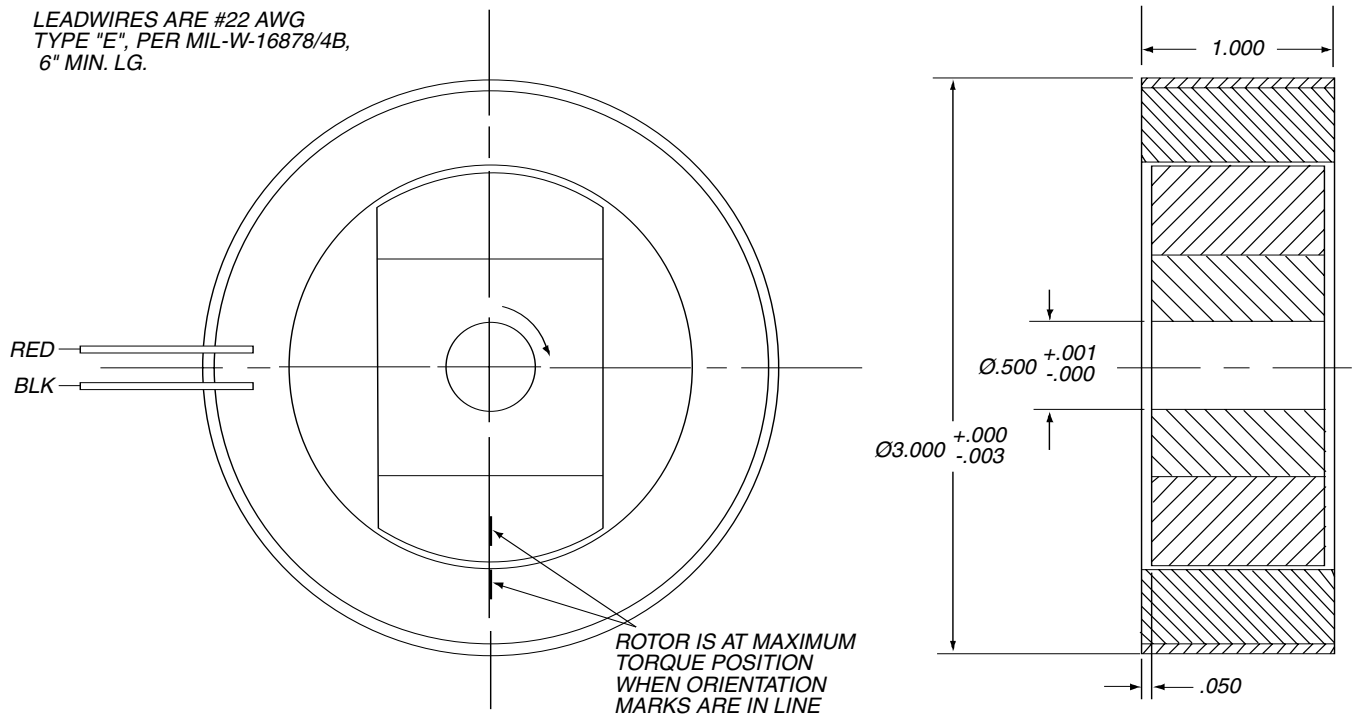

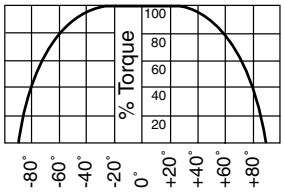

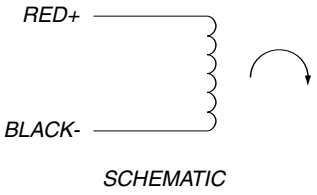

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	63
Power at Tp (P_p)	watts	72
Motor Constant (K_m)	oz-in/√watts	7.42
Continuous Torque (T_c)	oz-in	20
Power at Continuous Torque	watts	7.3
Input Volts at Continuous Torque	volts	7.6
Elect. Time Constant (τ_e)	milli-sec	2.3
Mech. Time Contstant (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	degrees	±60
Total Breakaway Torque (T_f)	oz-in	0.80
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	22

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	8.0
Voltage at Tp (V_p)	volts	Nominal	24.0
Current at Tp (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

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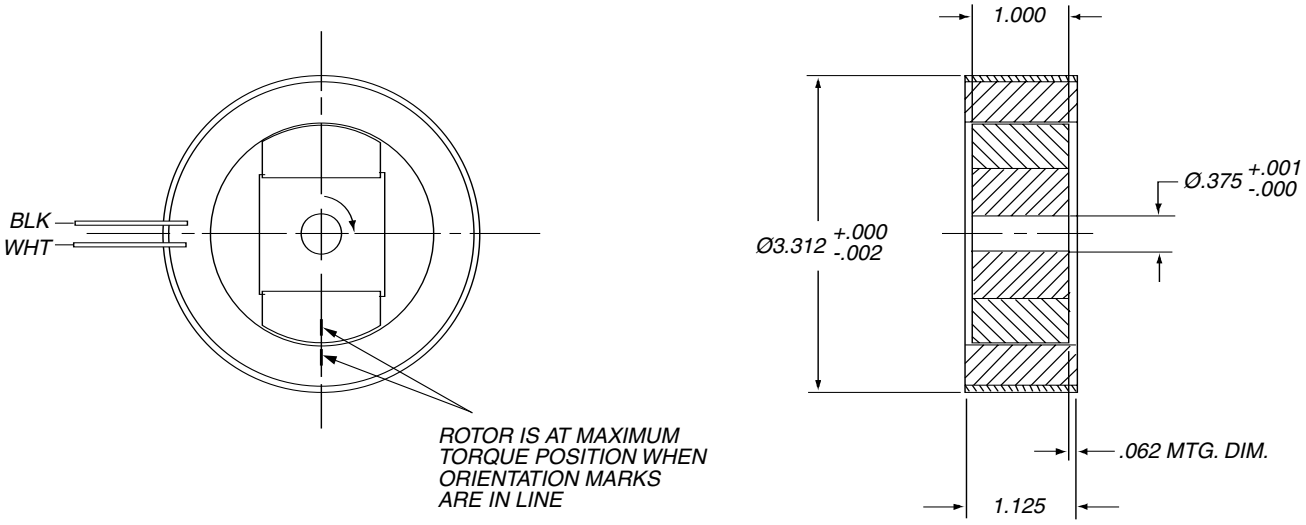
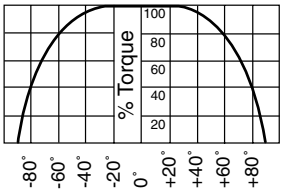
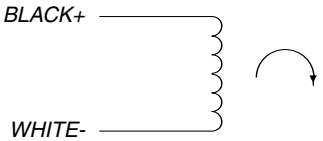
LEADWIRES ARE #24 AWG TYPE "ET",
PER MIL-W-16878/6, 12" MIN. LG.





ANGULAR EXCURSION



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Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	23.1
Voltage at Tp (V_p)	volts	Nominal	46.2
Current at Tp (I_p)	amps	Nominal	2.00
Torque Sensitivity (K_t)	oz-in/amp	±10%	40.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.282
Inductance (L)	millihenries	±30%	44

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	80
Power at Tp (P_p)	watts	92
Motor Constant (K_m)	oz-in/√watts	8.32
Continuous Torque (T_c)	oz-in	60
Power at Continuous Torque	watts	52
Input Volts at Continuous Torque	volts	34.7
Elect. Time Constant (τ_e)	milli-sec	1.9
Mech. Time Contstant (τ_m)	milli-sec	41
Damping Factor (F_o)	oz-in/rad/sec	0.49
Rotor Inertia (J_m)	oz-in-sec^2	0.02
Angular Excursion	degrees	±60
Total Breakaway Torque (T_f)	oz-in	2.00
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	28.5

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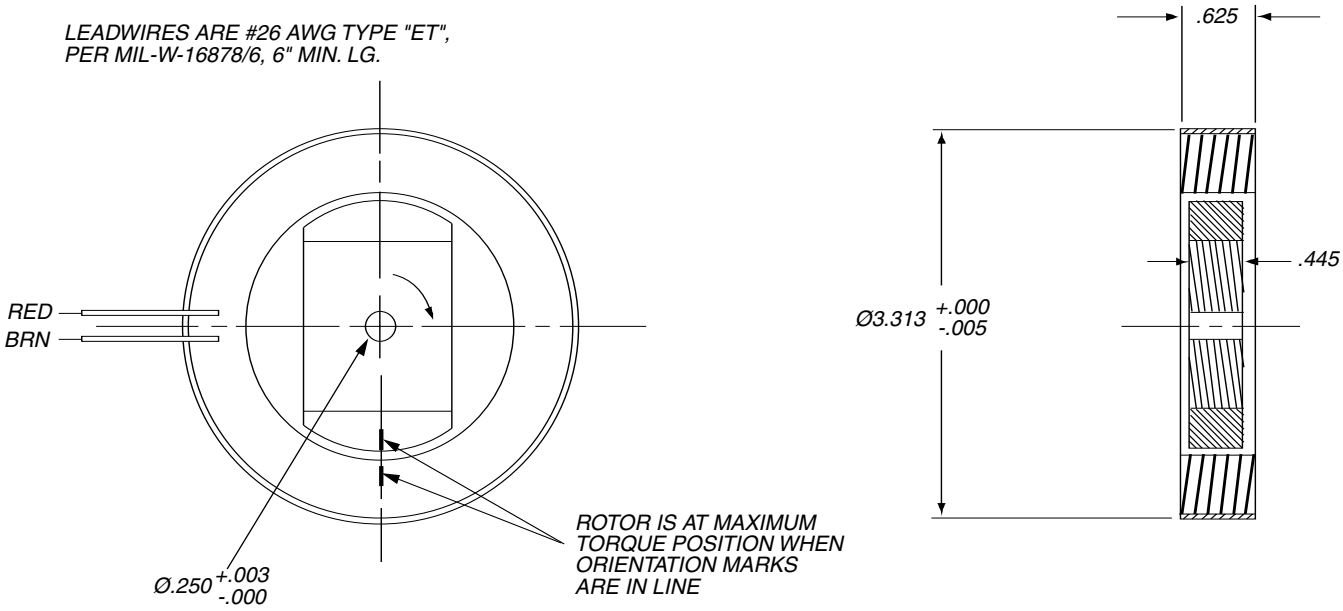

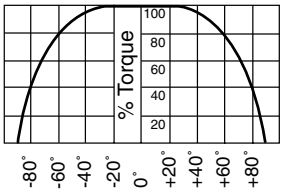

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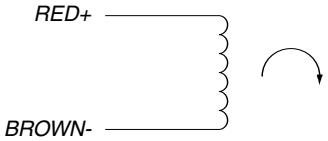

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Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	18.0
Voltage at Tp (V_p)	volts	Nominal	67.5
Current at Tp (I_p)	amps	Nominal	3.75
Torque Sensitivity (K_t)	oz-in/amp	±10%	20.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.014
Inductance (L)	millihenries	±30%	32

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	75
Power at Tp (P_p)	watts	253
Motor Constant (K_m)	oz-in/√watts	4.71
Continuous Torque (T_c)	oz-in	20
Power at Continuous Torque	watts	18
Input Volts at Continuous Torque	volts	18
Elect. Time Constant (τ_e)	milli-sec	1.80
Mech. Time Contstant (τ_m)	milli-sec	43.0
Damping Factor (F_o)	oz-in/rad/sec	0.0156
Rotor Inertia (J_m)	oz-in-sec^2	0.0067
Angular Excursion	degrees	±60
Total Breakaway Torque (T_f)	oz-in	0.50
Max. Allowable Wdg. Temp.	°C	130
Number of Poles		2
Weight	oz	12

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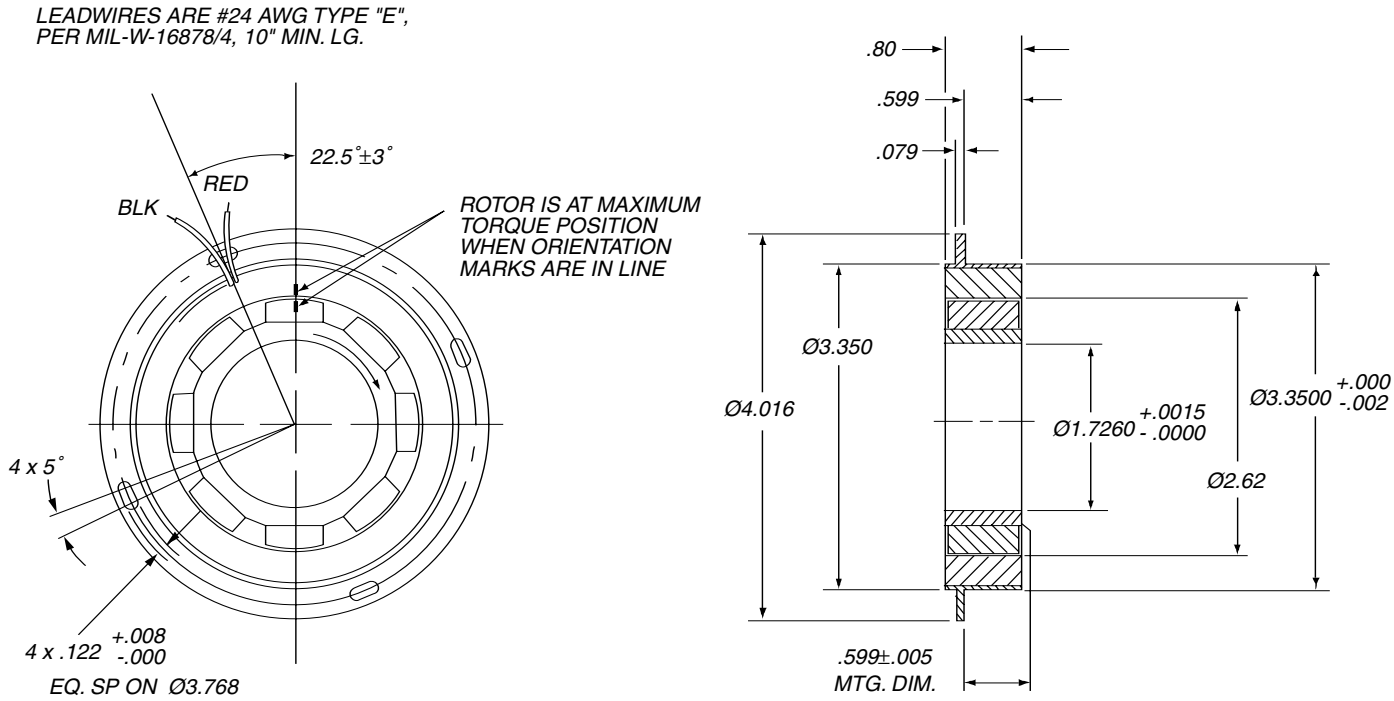
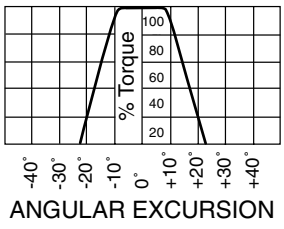
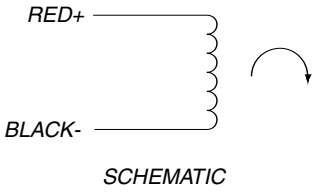




ANGULAR EXCURSION



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WINDING CONSTANTS

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	4.0
Voltage at Tp (V_p)	volts	Nominal	20.0
Current at Tp (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

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	180
Power at Tp (P_p)	watts	100
Motor Constant (K_m)	oz-in/√watts	18.0
Continuous Torque (T_c)	oz-in	70
Power at Continuous Torque	watts	30
Input Volts at Continuous Torque	volts	9
Elect. Time Constant (τ_e)	milli-sec	0.50
Mech. Time Contstant (τ_m)	milli-sec	13
Damping Factor (F_o)	oz-in/rad/sec	2.29
Rotor Inertia (J_m)	oz-in-sec^2	0.029
Angular Excursion	degrees	±5
Total Breakaway Torque (T_f)	oz-in	1.50
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		8
Weight	oz	20

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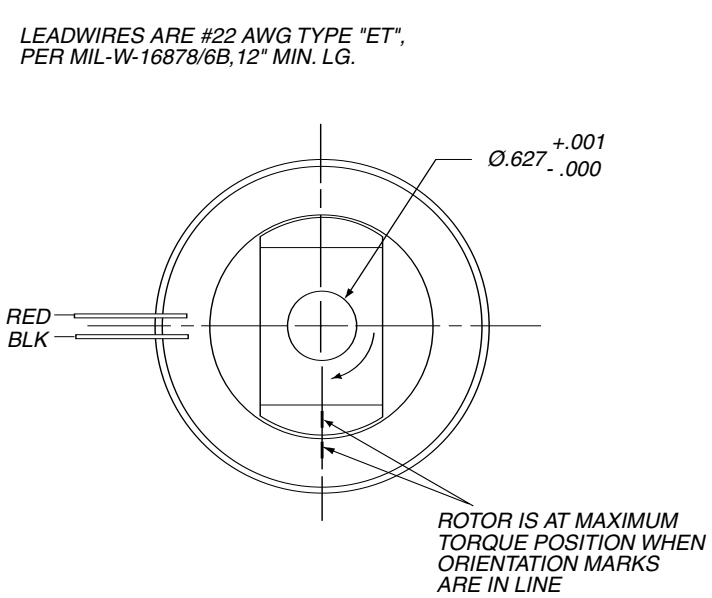

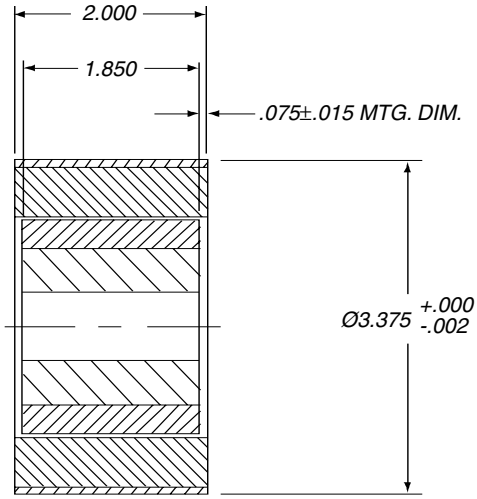

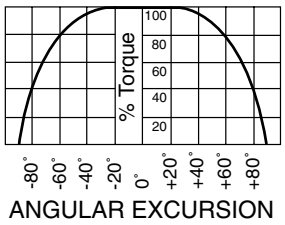

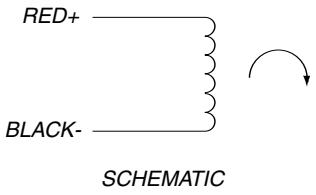

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	17.2
Voltage at Tp (V_p)	volts	Nominal	131
Current at Tp (I_p)	amps	Nominal	7.62
Torque Sensitivity (K_t)	oz-in/amp	±10%	45.3
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.320
Inductance (L)	millihenries	±30%	14

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	345
Power at Tp (P_p)	watts	998
Motor Constant (K_m)	oz-in/√watts	10.9
Continuous Torque (T_c)	oz-in	85
Power at Continuous Torque	watts	60.6
Input Volts at Continuous Torque	volts	32.3
Elect. Time Constant (τ_e)	milli-sec	0.80
Mech. Time Contstant (τ_m)	milli-sec	36
Damping Factor (F_o)	oz-in/rad/sec	0.843
Rotor Inertia (J_m)	oz-in-sec^2	0.03
Angular Excursion	degrees	±45
Total Breakaway Torque (T_f)	oz-in	3.50
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	40

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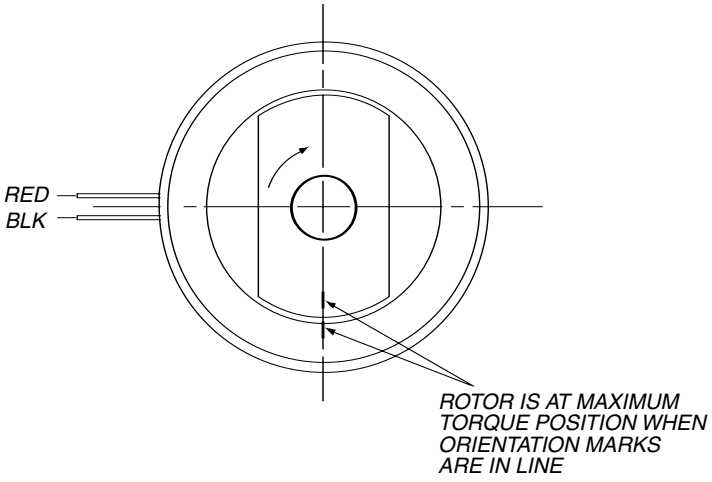
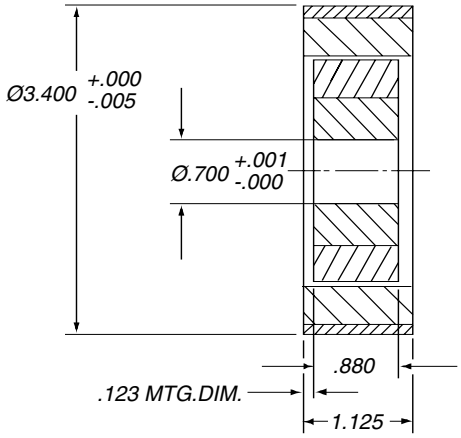
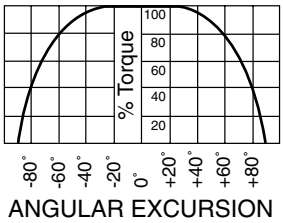
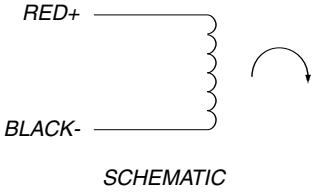
LEADWIRES ARE #22 AWG TYPE "ET",
PER MIL-W-16878, 18" MIN. LG.







ANGULAR EXCURSION



SCHEMATIC

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	100
Power at Tp (P_p)	watts	244
Motor Constant (K_m)	oz-in/√watts	6.40
Continuous Torque (T_c)	oz-in	40
Power at Continuous Torque	watts	39
Input Volts at Continuous Torque	volts	19
Elect. Time Constant (τ_e)	milli-sec	3.30
Mech. Time Contstant (τ_m)	milli-sec	48.3
Damping Factor (F_o)	oz-in/rad/sec	0.290
Rotor Inertia (J_m)	oz-in-sec^2	0.014
Angular Excursion	degrees	±50
Total Breakaway Torque (T_f)	oz-in	1.20
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	24

Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	9.2
Voltage at Tp (V_p)	volts	Nominal	47.4
Current at Tp (I_p)	amps	Nominal	5.15
Torque Sensitivity (K_t)	oz-in/amp	±10%	19.4
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.138
Inductance (L)	millihenries	±30%	30

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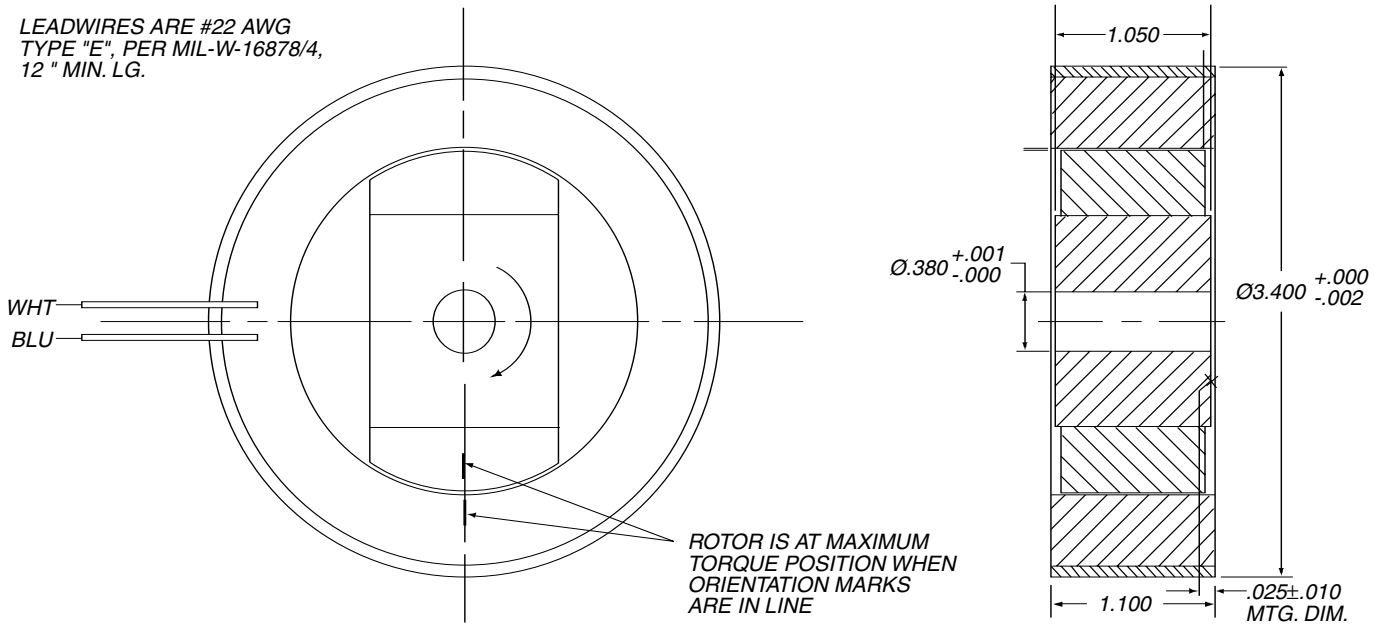

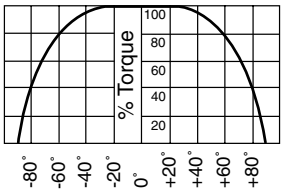

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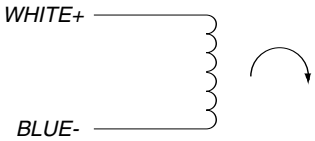

SCHEMATIC

WINDING CONSTANTS

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	1.4
Voltage at Tp (V_p)	volts	Nominal	24.5
Current at Tp (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

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	170
Power at Tp (P_p)	watts	430
Motor Constant (K_m)	oz-in/√watts	8.20
Continuous Torque (T_c)	oz-in	49.5
Power at Continuous Torque	watts	36.5
Input Volts at Continuous Torque	volts	7.1
Elect. Time Constant (τ_e)	milli-sec	1.6
Mech. Time Contstant (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	degrees	±50
Total Breakaway Torque (T_f)	oz-in	1.50
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	28

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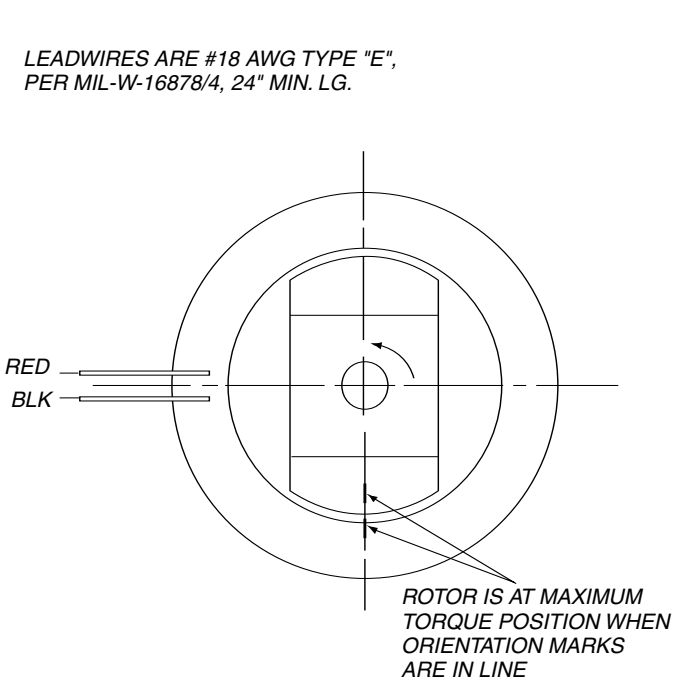

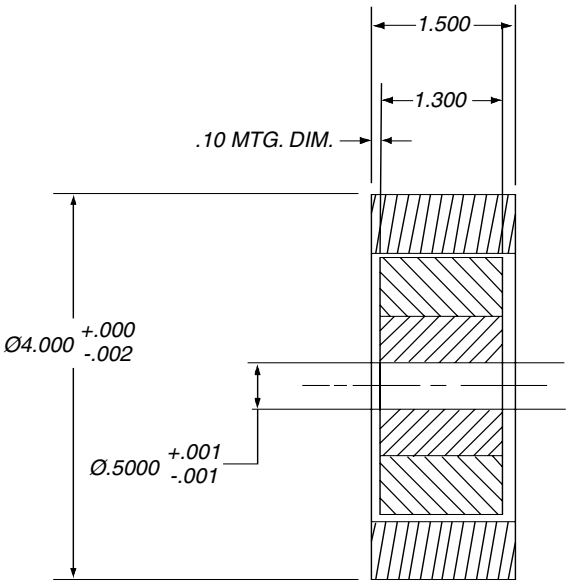

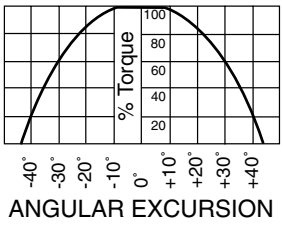

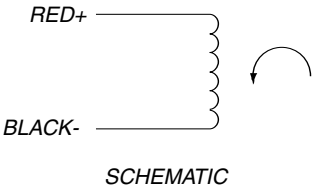

SCHEMATIC

WINDING CONSTANTS

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	5.0
Voltage at Tp (V_p)	volts	Nominal	24.3
Current at Tp (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

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	165
Power at Tp (P_p)	watts	118
Motor Constant (K_m)	oz-in/√watts	15.2
Continuous Torque (T_c)	oz-in	61
Power at Continuous Torque	watts	16.1
Input Volts at Continuous Torque	volts	9
Elect. Time Constant (τ_e)	milli-sec	1.6
Mech. Time Contstant (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	degrees	±20
Total Breakaway Torque (T_f)	oz-in	2.00
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		4
Weight	oz	23

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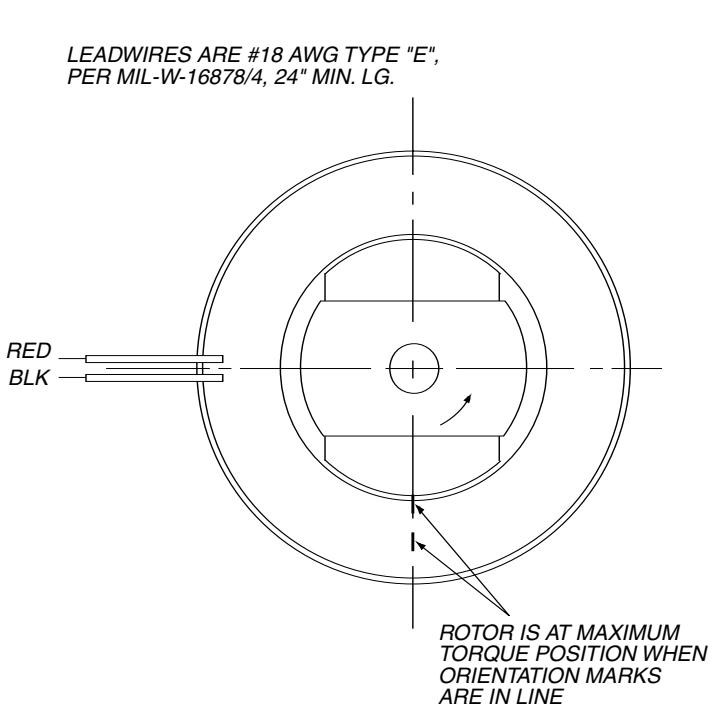
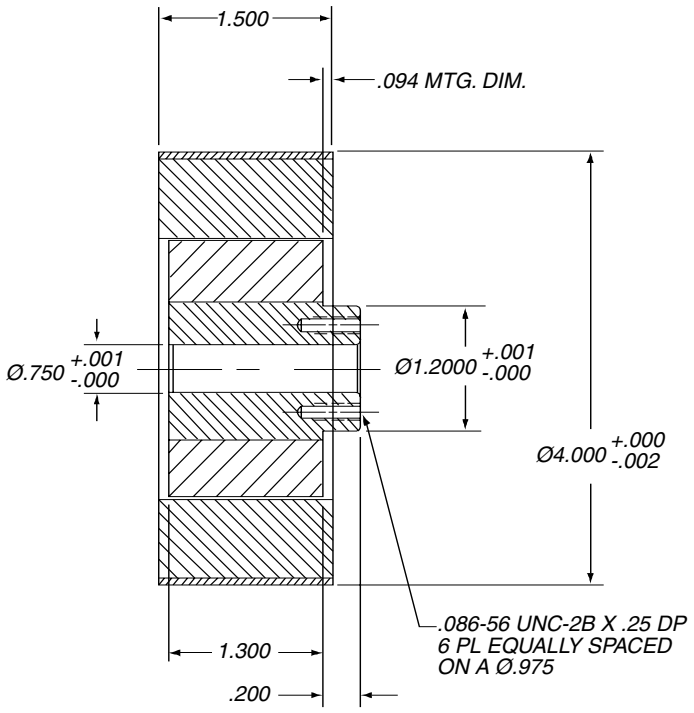
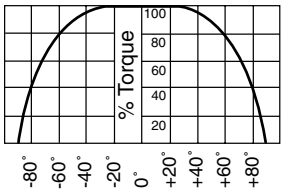
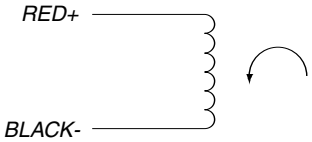






ANGULAR EXCURSION



SCHEMATIC

WINDING CONSTANTS

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	10.3
Voltage at Tp (V_p)	volts	Nominal	45.3
Current at Tp (I_p)	amps	Nominal	4.40
Torque Sensitivity (K_t)	oz-in/amp	±10%	58.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.410
Inductance (L)	millihenries	±30%	41

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	255
Power at Tp (P_p)	watts	199
Motor Constant (K_m)	oz-in/√watts	18.1
Continuous Torque (T_c)	oz-in	80
Power at Continuous Torque	watts	19.6
Input Volts at Continuous Torque	volts	14.2
Elect. Time Constant (τ_e)	milli-sec	4.0
Mech. Time Contstant (τ_m)	milli-sec	17
Damping Factor (F_o)	oz-in/rad/sec	2.31
Rotor Inertia (J_m)	oz-in-sec^2	0.04
Angular Excursion	degrees	±30
Total Breakaway Torque (T_f)	oz-in	1.00
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		2
Weight	oz	60

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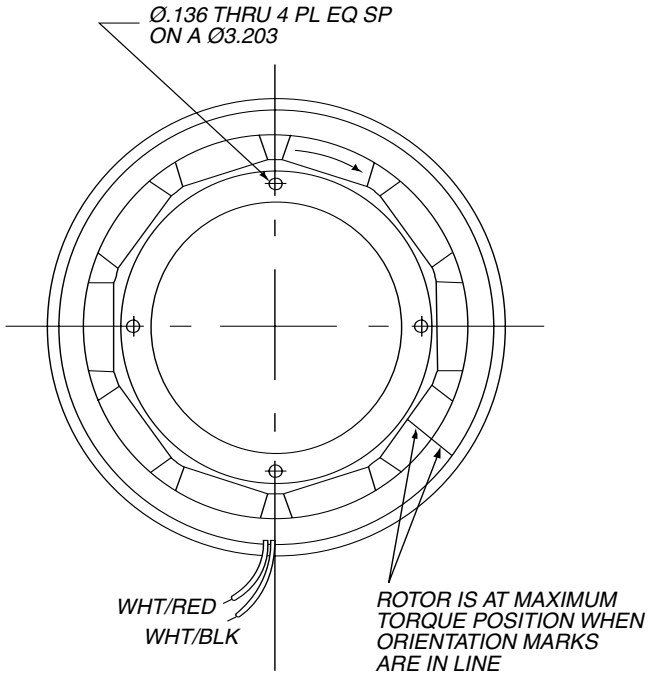
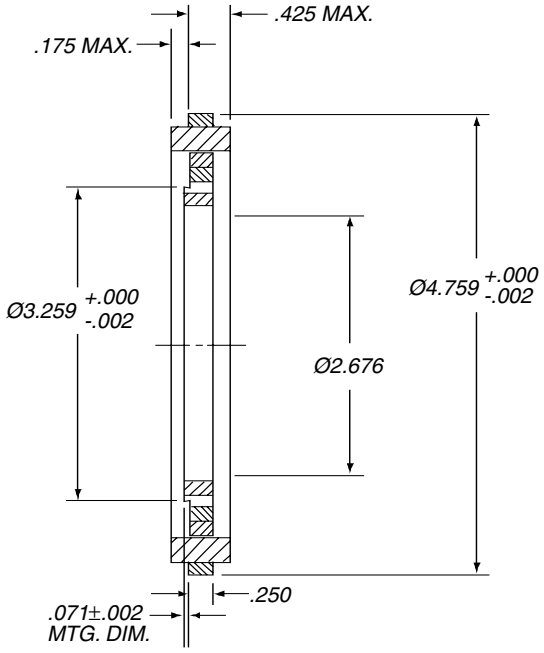
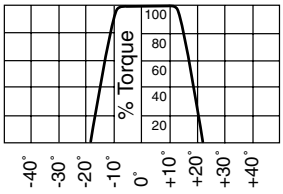
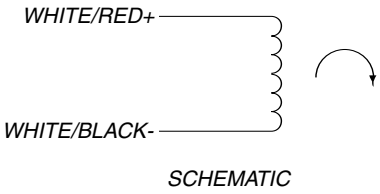




LEADWIRES ARE #24 AWG
TYPE "E", PER MIL-W-22759/33,
12 " MIN. LG





Winding Constants

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	39.0
Voltage at Tp (V_p)	volts	Nominal	91.3
Current at Tp (I_p)	amps	Nominal	2.34
Torque Sensitivity (K_t)	oz-in/amp	±10%	94.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.664
Inductance (L)	millihenries	±30%	20

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	220
Power at Tp (P_p)	watts	214
Motor Constant (K_m)	oz-in/√watts	15.1
Continuous Torque (T_c)	oz-in	40
Power at Continuous Torque	watts	7.1
Input Volts at Continuous Torque	volts	16.6
Elect. Time Constant (τ_e)	milli-sec	0.50
Mech. Time Contstant (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	degrees	±5
Total Breakaway Torque (T_f)	oz-in	2.00
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		10
Weight	oz	9

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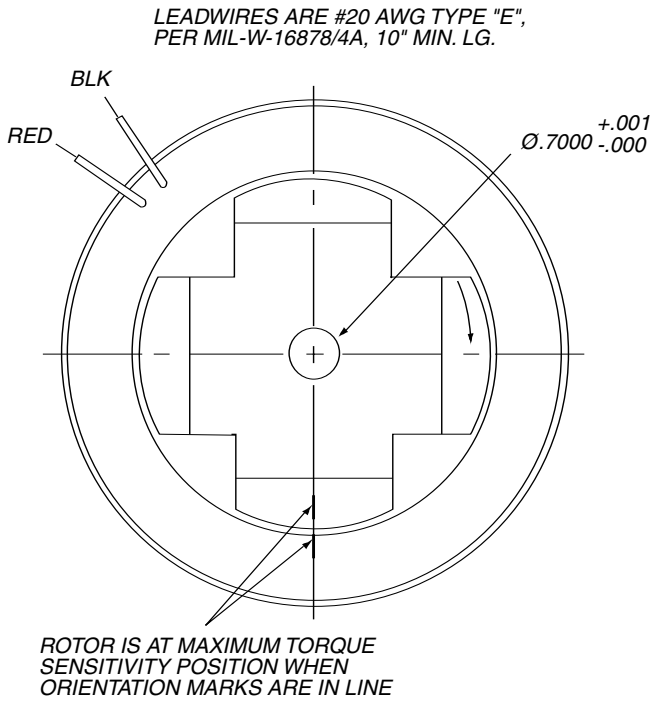
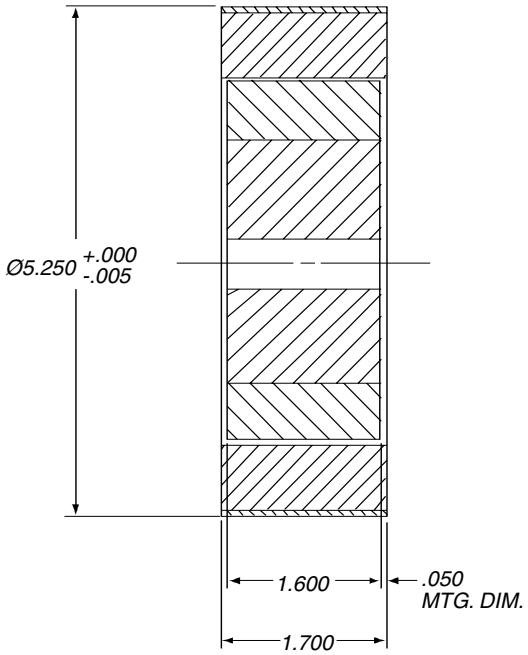
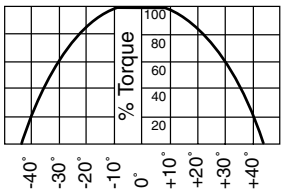
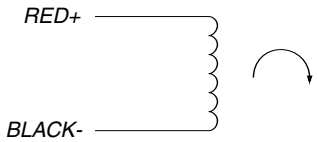






ANGULAR EXCURSION



SCHEMATIC

WINDING CONSTANTS

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	4.5
Voltage at Tp (V_p)	volts	Nominal	47.6
Current at Tp (I_p)	amps	Nominal	10.6
Torque Sensitivity (K_t)	oz-in/amp	±10%	67.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.473
Inductance (L)	millihenries	±30%	14

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	708
Power at Tp (P_p)	watts	502
Motor Constant (K_m)	oz-in/√watts	31.6
Continuous Torque (T_c)	oz-in	148
Power at Continuous Torque	watts	22
Input Volts at Continuous Torque	volts	9.9
Elect. Time Constant (τ_e)	milli-sec	3.0
Mech. Time Contstant (τ_m)	milli-sec	14
Damping Factor (F_o)	oz-in/rad/sec	7.04
Rotor Inertia (J_m)	oz-in-sec^2	0.10
Angular Excursion	degrees	±25
Total Breakaway Torque (T_f)	oz-in	3.60
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		4
Weight	oz	88

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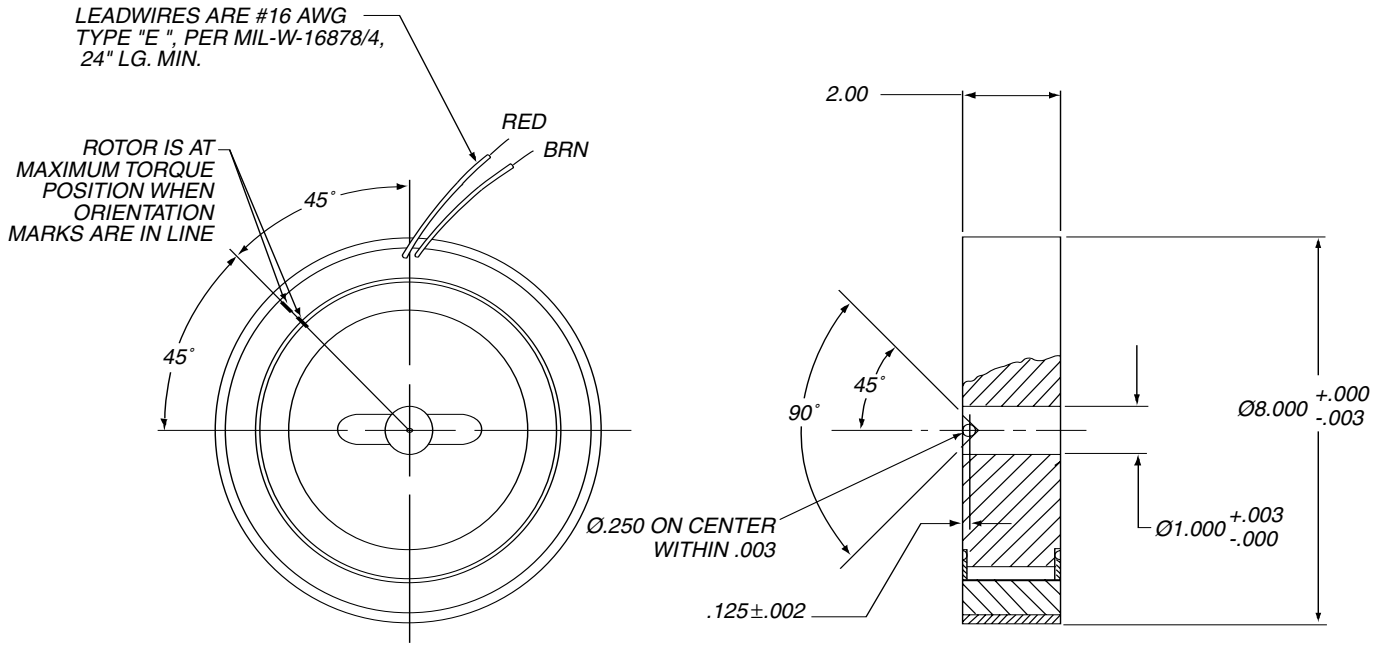
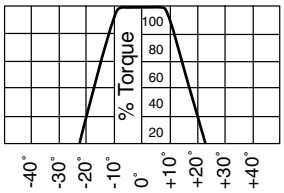
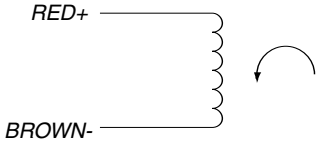




ANGULAR EXCURSION



SCHEMATIC

WINDING CONSTANTS

PARAMETER	UNITS	TOL:	Value
Resistance (R)	ohms	±12.5%	0.8
Voltage at Tp (V_p)	volts	Nominal	17.5
Current at Tp (I_p)	amps	Nominal	21.9
Torque Sensitivity (K_t)	oz-in/amp	±10%	86.0
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.618
Inductance (L)	millihenries	±30%	0.79

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	1882
Power at Tp (P_p)	watts	383
Motor Constant (K_m)	oz-in/√watts	96.2
Continuous Torque (T_c)	oz-in	1286
Power at Continuous Torque	watts	175
Input Volts at Continuous Torque	volts	11.8
Elect. Time Constant (τ_e)	milli-sec	0.99
Mech. Time Contstant (τ_m)	milli-sec	46.7
Damping Factor (F_o)	oz-in/rad/sec	66.4
Rotor Inertia (J_m)	oz-in-sec^2	3.10
Angular Excursion	degrees	±5
Total Breakaway Torque (T_f)	oz-in	45.0
Max. Allowable Wdg. Temp.	°C	155
Number of Poles		8
Weight	oz	355

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619-671-5400 • FAX: 619 671 9292 • http://www.axsys.com • email: dcmotors@axsys.com

Selection Guide: by outside diameter
Large Brushless Motors (LBM)

Model Number	Peak Torque (lb-in)	Power @ T_p (watts)	K_m (oz-in/√watts)	O.D. (in)	I.D. (in)	Axial Length (in)	Page
8860B-330	956	976	30.6	8.860	5.000	3.300	6-1
8860B-410	1505	1766	35.8	8.650	5.000	4.100	6-2
24000-370	6000	1224	64.5	24.000	20.000	3.700	6-3
28000-530	14400	1224	64.5	28.000	23.000	4.800	6-4
32000-850	30000	1224	64.5	32.000	24.000	8.500	6-5

All motors shown are inner rotating.

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Selection Guide: by peak torque
Large Brushless Motors (LBM)

Model Number	Peak Torque (lb-in)	Power @ T_p (watts)	K_m (oz-in/√watts)	O.D. (in)	I.D. (in)	Axial Length (in)	Page
8860B-330	956	976	30.6	8.860	5.000	3.300	6-1
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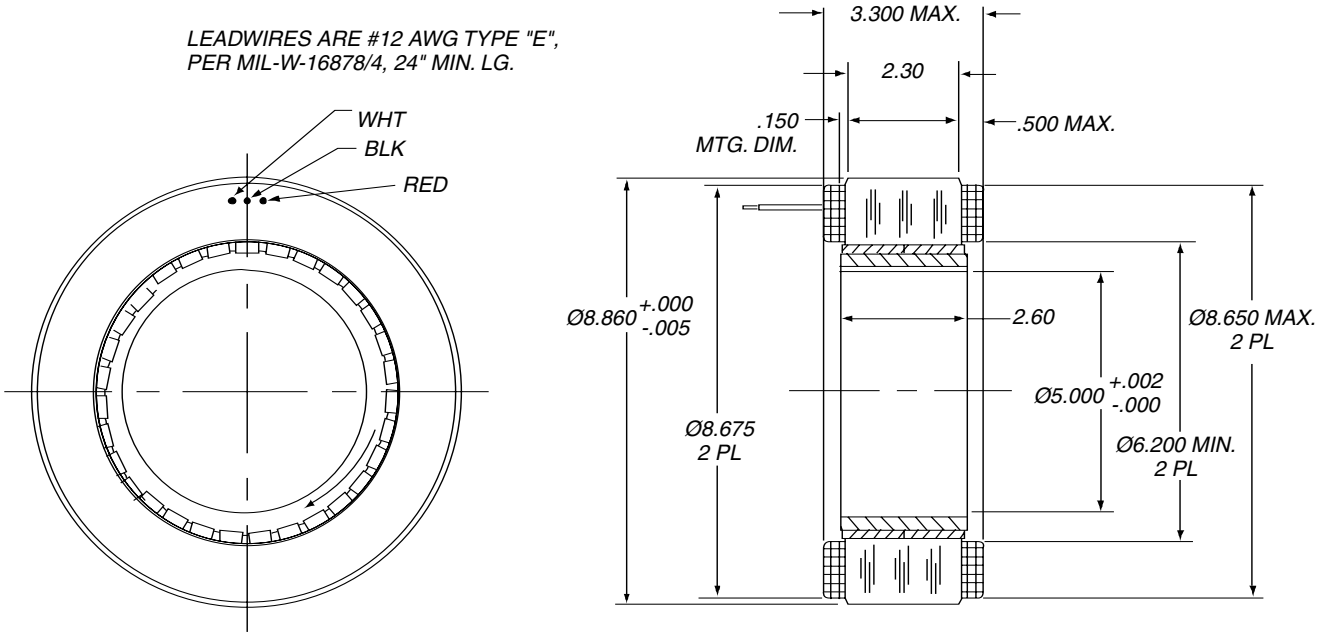

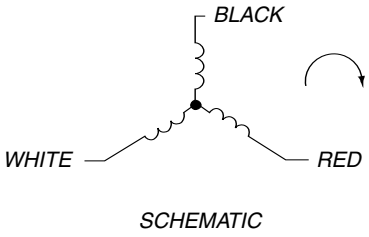

SCHEMATIC

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

Winding Constants

PARAMETER	UNITS	TOL:	-019	-025	-045	-058
Resistance (R)	ohms	±12.5%	1.9	2.5	4.5	5.8
Voltage at Tp (V_p)	volts	Nominal	43.5	50.2	67.4	75.2
Current at Tp (I_p)	amps	Nominal	23.1	20.1	15.0	13.0
Torque Sensitivity (K_t)	in-lb/amp	±10%	41.3	47.6	63.8	73.7
Back E.M.F. (K_b)	volts/rad/sec	±10%	4.64	5.36	7.19	8.03
Inductance (L)	millihenries	±30%	6.0	8.0	14	19

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	in-lb	956
Power at Tp (P_p)	watts	976
Motor Constant (K_m)	in-lb/√watts	30.6
Elect. Time Constant (τ_e)	milli-sec	3.2
Mech. Time Constant (τ_m)	milli-sec	1.0
Damping Factor (F_o)	in-lb/rad/sec	102
Moment of Inertia (J_m)	in-lb-sec^2	0.10
Total Breakaway Torque (T_f)	in-lb	10
Temperature Rise (TPR)	°C/watt	0.4
Max. Allowable Wdg. Temp.	°C	155
Weight	lb	23.4
Number of Poles		32
Number of Phases		3

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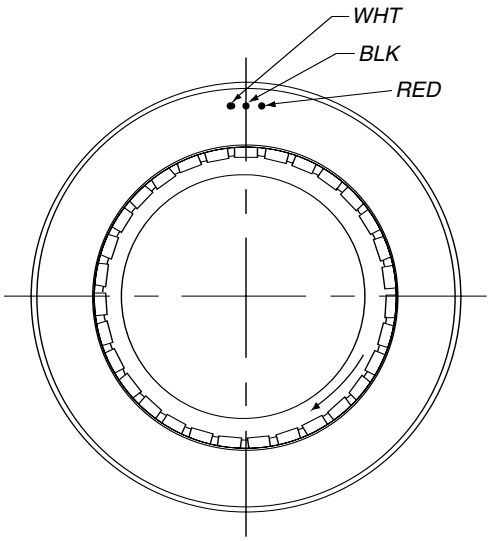
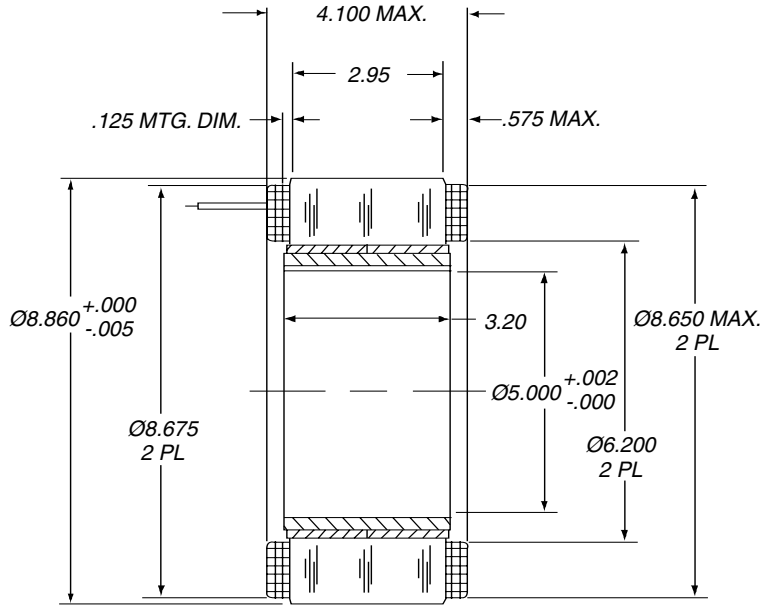
LEADWIRES ARE #12 AWG TYPE "E", PER MIL-W-16878/4, 24" MIN. LG.





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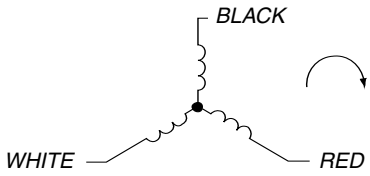

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Winding Constants

PARAMETER	UNITS	TOL:	-014	-022	-034	-086
Resistance (R)	ohms	±12.5%	1.4	2.2	3.4	8.6
Voltage at Tp (V_p)	volts	Nominal	48.8	61.3	77.1	120
Current at Tp (I_p)	amps	Nominal	36.2	27.9	22.7	13.9
Torque Sensitivity (K_t)	in-lb/amp	±10%	41.6	54.0	66.4	108
Back E.M.F. (K_b)	volts/rad/sec	±10%	4.71	5.91	7.43	11.6
Inductance (L)	millihenries	±30%	4.5	7.3	11	29

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	in-lb	1505
Power at Tp (P_p)	watts	1766
Motor Constant (K_m)	in-lb/√watts	35.8
Elect. Time Constant (τ_e)	milli-sec	3.33
Mech. Time Constant (τ_m)	milli-sec	0.90
Damping Factor (F_o)	in-lb/rad/sec	145
Moment of Inertia (J_m)	in-lb-sec^2	0.13
Total Breakaway Torque (T_f)	in-lb	12
Temperature Rise (TPR)	°C/watt	0.33
Max. Allowable Wdg. Temp.	°C	155
Weight	lb	29.7
Number of Poles		32
Number of Phases		3

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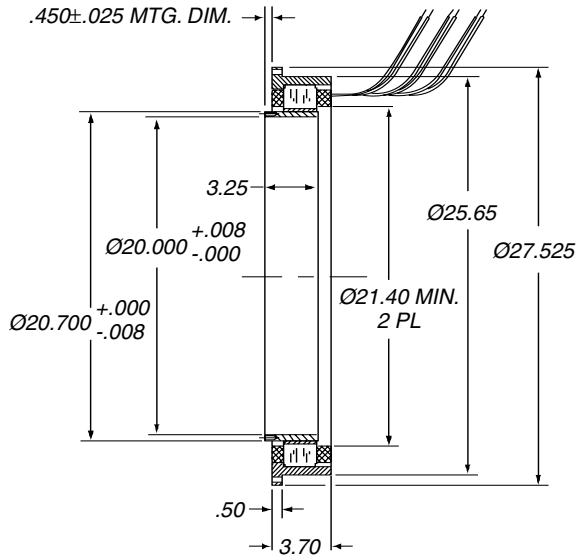
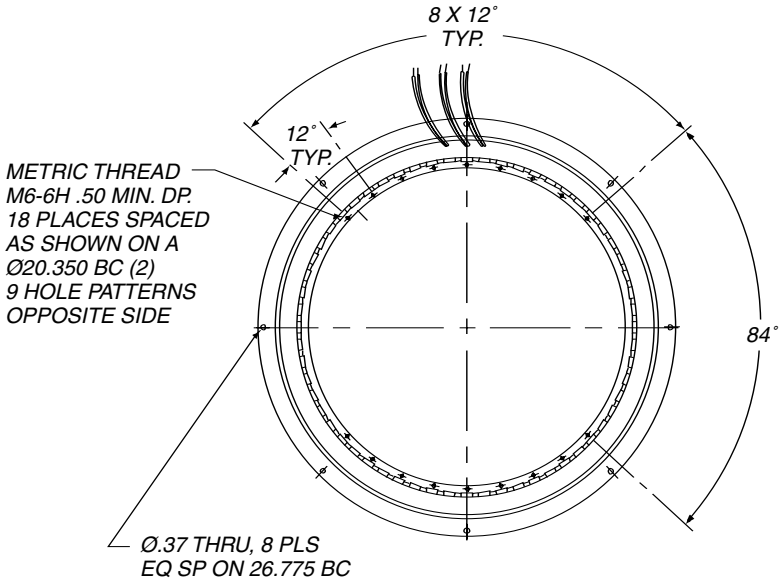
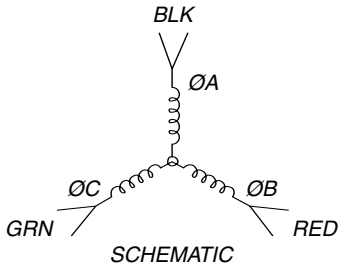




ROTATION: FIELD ROTATES CW
WHEN VIEWED FROM LEAD SIDE
WITH THE FOLLOWING SEQUENCE:
BLK+, RED-; GRN+, BLK-; BLK+, GRN-.



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Winding Constants

PARAMETER	UNITS	TOL:	-007	-011	-018	-029
Resistance (R)	ohms	±12.5%	0.7	1.1	1.9	2.9
Voltage at Tp (V_p)	volts	Nominal	28.2	32.6	44.9	55.3
Current at Tp (I_p)	amps	Nominal	38.2	29.7	24.3	19.1
Torque Sensitivity (K_t)	in-lb/amp	±10%	108	130	174	219
Back E.M.F. (K_b)	volts/rad/sec	±10%	6.71	8.69	10.7	13.6
Inductance (L)	millihenries	±30%	2.6	3.9	6.5	10

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	in-lb	6000
Power at Tp (P_p)	watts	1224
Motor Constant (K_m)	in-lb/√watts	64.5
Elect. Time Constant (τ_e)	milli-sec	3.51
Mech. Time Constant (τ_m)	milli-sec	9.55
Damping Factor (F_o)	in-lb/rad/sec	1798
Moment of Inertia (J_m)	in-lb-sec^2	9.36
Total Breakaway Torque (T_f)	in-lb	48
Temperature Rise (TPR)	°C/watt	0.15
Max. Allowable Wdg. Temp.	°C	155
Weight	lb	75.0
Number of Poles		64
Number of Phases		3

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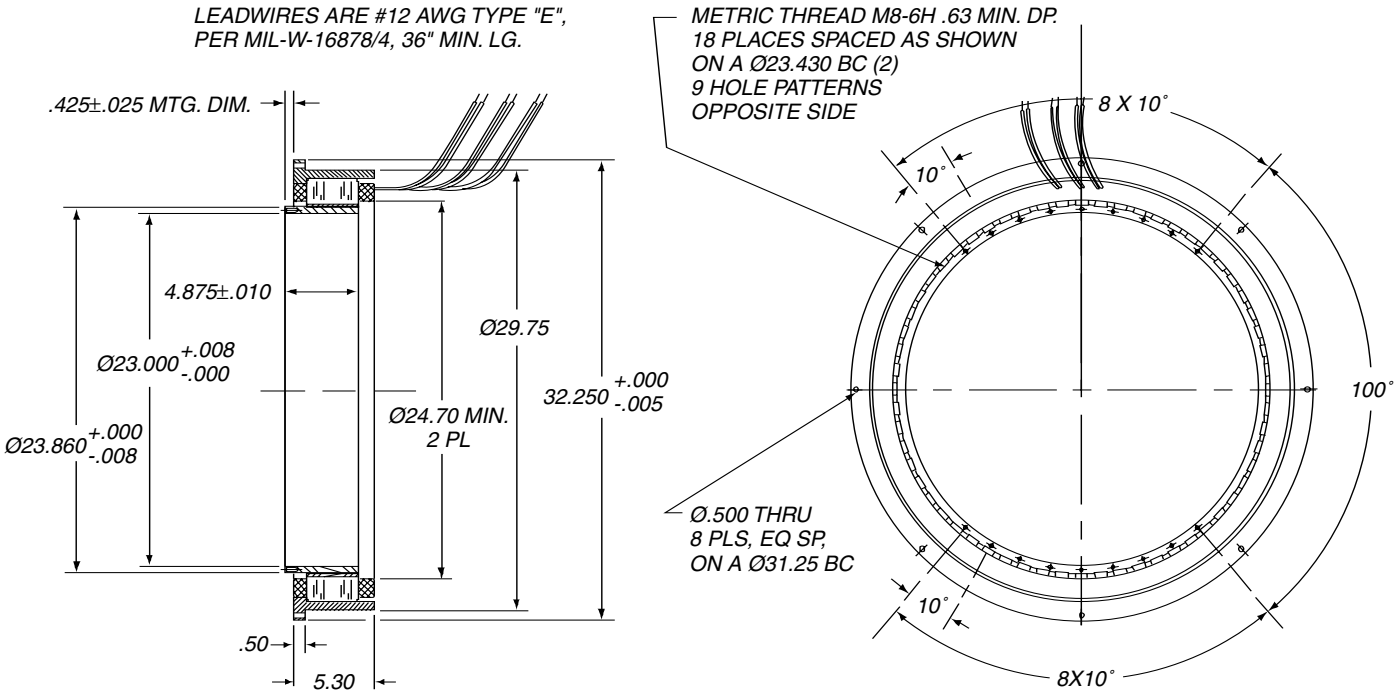

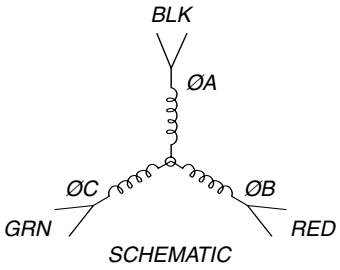

ROTATION: FIELD ROTATES CW
WHEN VIEWED FROM LEAD SIDE
WITH THE FOLLOWING SEQUENCE:
BLK+, RED-; GRN+, BLK-; BLK+, GRN-.

Winding Constants

PARAMETER	UNITS	TOL:	-005	-007	-011	-018
Resistance (R)	ohms	±12.5%	0.45	0.70	1.06	1.8
Voltage at Tp (V_p)	volts	Nominal	13.3	26.7	25.7	34.3
Current at Tp (I_p)	amps	Nominal	29.7	38.2	24.3	19.1
Torque Sensitivity (K_t)	in-lb/amp	±10%	212	265	320	428
Back E.M.F. (K_b)	volts/rad/sec	±10%	8.69	6.71	10.7	13.6
Inductance (L)	millihenries	±30%	3.0	4.6	7.0	12

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	in-lb	14400
Power at Tp (P_p)	watts	1224
Motor Constant (K_m)	in-lb/√watts	64.5
Elect. Time Constant (τ_e)	milli-sec	6.57
Mech. Time Constant (τ_m)	milli-sec	11.1
Damping Factor (F_o)	in-lb/rad/sec	11364
Moment of Inertia (J_m)	in-lb-sec^2	28.2
Total Breakaway Torque (T_f)	in-lb	114
Temperature Rise (TPR)	°C/watt	0.076
Max. Allowable Wdg. Temp.	°C	155
Weight	lb	180
Number of Poles		64
Number of Phases		3

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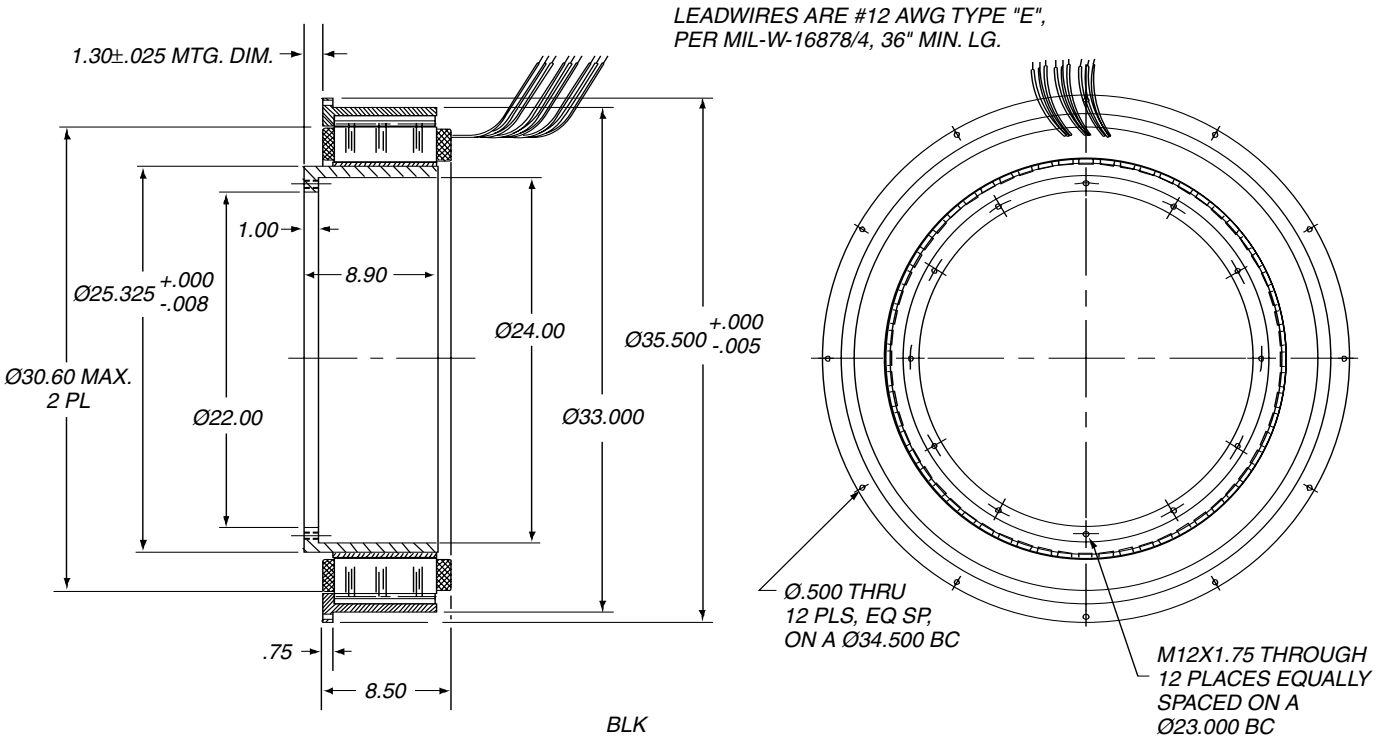

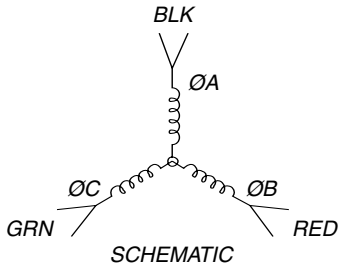

ROTATION: FIELD ROTATES CW WHEN VIEWED FROM LEAD SIDE WITH THE FOLLOWING SEQUENCE: BLK+, RED-; GRN+, BLK-; BLK+, GRN-.

Winding Constants

PARAMETER	UNITS	TOL:	-006	-010	-014	-018
Resistance (R)	ohms	±12.5%	0.6	1.0	1.4	1.8
Voltage at Tp (V_p)	volts	Nominal	23.7	28.5	32.8	33.4
Current at Tp (I_p)	amps	Nominal	38.2	29.7	24.3	19.1
Torque Sensitivity (K_t)	in-lb/amp	±10%	438	544	654	780
Back E.M.F. (K_b)	volts/rad/sec	±10%	6.71	8.69	10.7	13.6
Inductance (L)	millihenries	±30%	9.0	14	20	25

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	in-lb	30000
Power at Tp (P_p)	watts	1224
Motor Constant (K_m)	in-lb/√watts	64.5
Elect. Time Constant (τ_e)	milli-sec	14.5
Mech. Time Constant (τ_m)	milli-sec	16.4
Damping Factor (F_o)	in-lb/rad/sec	32856
Moment of Inertia (J_m)	in-lb-sec^2	78.0
Total Breakaway Torque (T_f)	in-lb	240
Temperature Rise (TPR)	°C/watt	0.04
Max. Allowable Wdg. Temp.	°C	155
Weight	lb	575
Number of Poles		64
Number of Phases		3

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Selection Guide:
Limited Angle Moving Coil Motors

Model Number	Rotation Inner/Outer	Peak Torque (oz-in)	Continuous Torque (oz-in)	Actuator Constant (oz-in/√watts)	Angular Excursion (degrees)	O.D.	I.D.	Axial Length	Page
RA2500A-077	I	7	4	1.9	35	See Drawing			7-1
RA2500B-078	I	9	4	1.9	35	See Drawing			7-2
RA6240B-119	O	80	43	10.5	18	See Drawing			7-3
RA6800-119	O	110	40	23	10	See Drawing			7-4

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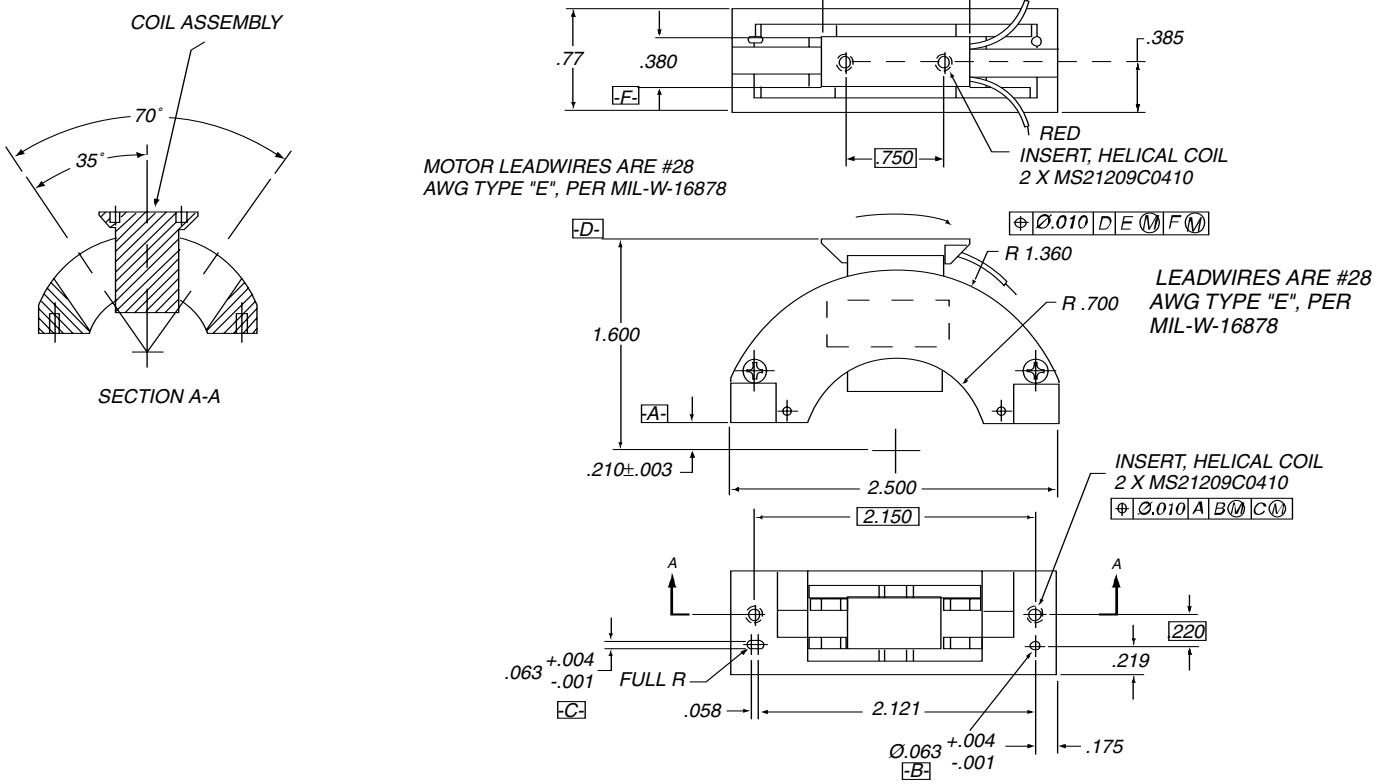

Winding Constants

PARAMETER	UNITS	TOL:	-110
Resistance (R)	ohms	±12.5%	11.0
Voltage at Tp (V_p)	volts	Nominal	8.8
Current at Tp (I_p)	amps	Nominal	0.8
Torque Sensitivity (K_t)	oz-in/amp	±10%	6.2
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.044
Inductance (L)	millihenries	±30%	3.8

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	7.1
Power at Tp (P_p)	watts	7.1
Actuator Constant (K_a)	oz-in/watts	1.9
Continuous Torque (T_c)	oz-in	4
Elect. 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	0.446
Total Weight	oz	5.24

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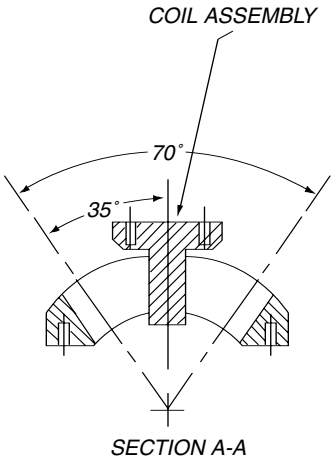

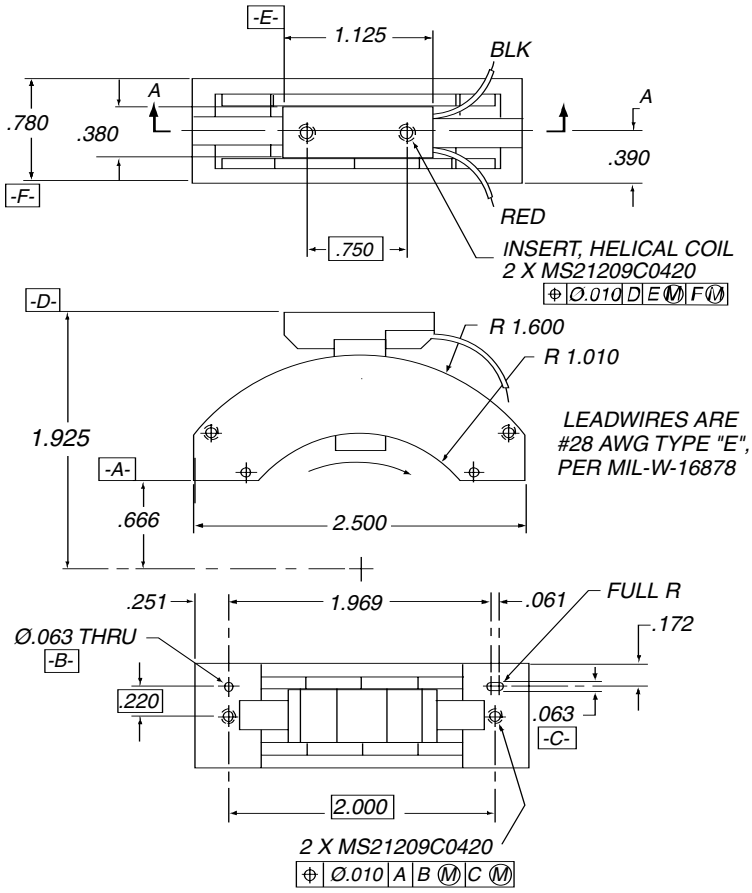

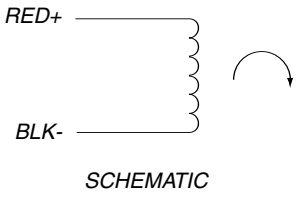

Winding Constants

PARAMETER	UNITS	TOL:	-056
Resistance (R)	ohms	±12.5%	5.6
Voltage at Tp (V_p)	volts	Nominal	11.5
Current at Tp (I_p)	amps	Nominal	2.1
Torque Sensitivity (K_t)	oz-in/amp	±10%	4.4
Back E.M.F. (K_b)	volts/rad/sec	±10%	0.031
Inductance (L)	millihenries	±30%	2

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	9
Power at Tp (P_p)	watts	23.8
Actuator Constant (K_a)	oz-in/watts	1.9
Continuous Torque (T_c)	oz-in	4
Elect. Time Constant (τ_e)	milli-sec	0.357
Stroke	degrees	±35
Clearance	mm	0.381
Temperature Rise (TPR)	°C/watt	14
Maximum Winding Temp.	°C	155
Weight of Coil Assembly	oz	0.62
Total Weight	oz	4.34

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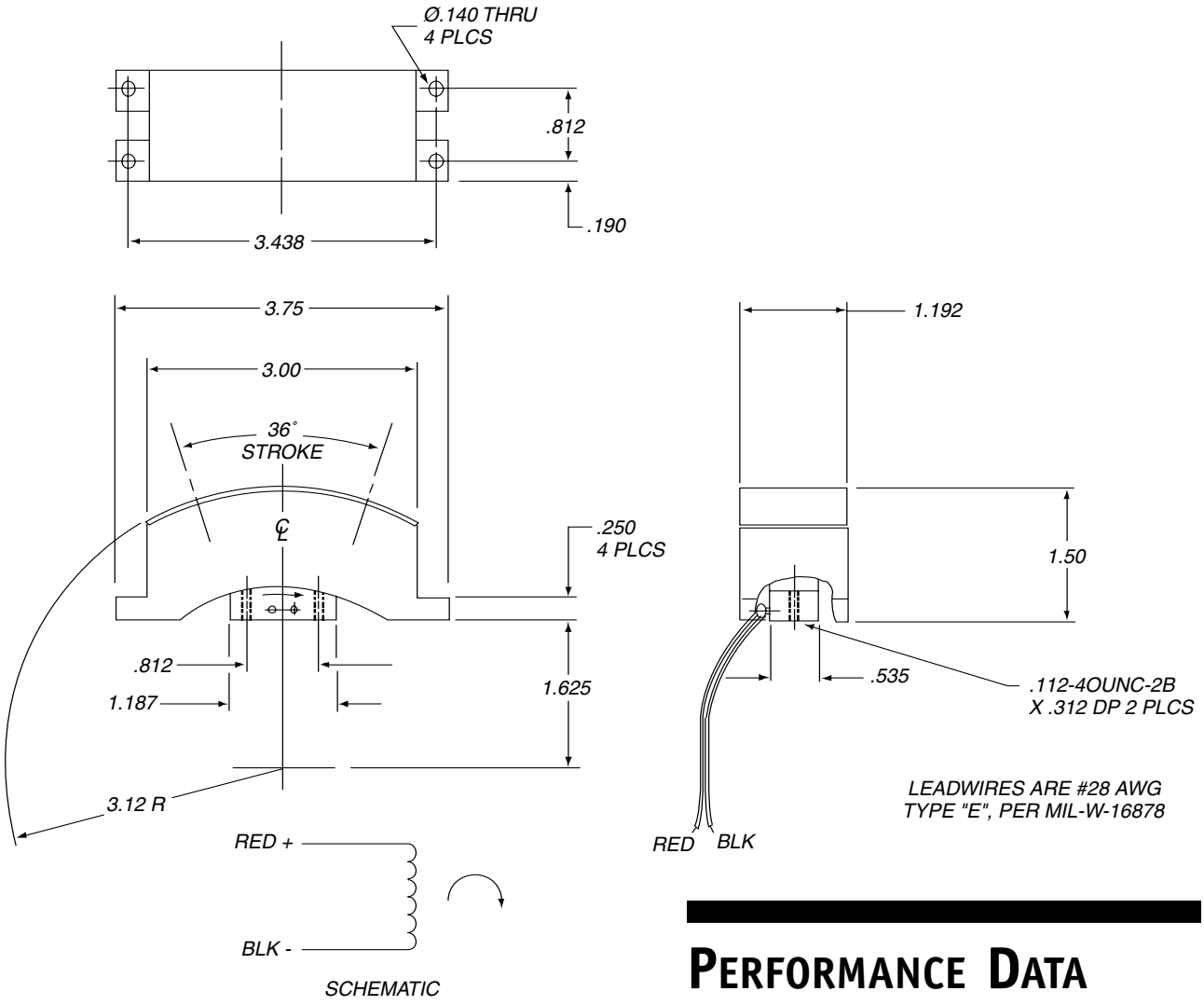

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WINDING CONSTANTS

PARAMETER	UNITS	TOL:	-011
Resistance (R)	ohms	±12.5%	1.1
Voltage at Tp (V_p)	volts	Nominal	8
Current at Tp (I_p)	amps	Nominal	7.3
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%	0.28

PERFORMANCE DATA

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	80
Power at Tp (P_p)	watts	58.1
Actuator Constant (K_a)	oz-in/watts	10.5
Continuous Torque (T_c)	oz-in	43
Elect. Time Constant (τ_e)	milli-sec	0.25
Stroke	degrees	±18
Clearance	mm	0.02
Temperature Rise (TPR)	°C/watt	5.1
Maximum Winding Temp.	°C	155
Weight of Coil Assembly	oz	0.21
Total Weight	oz	14.6

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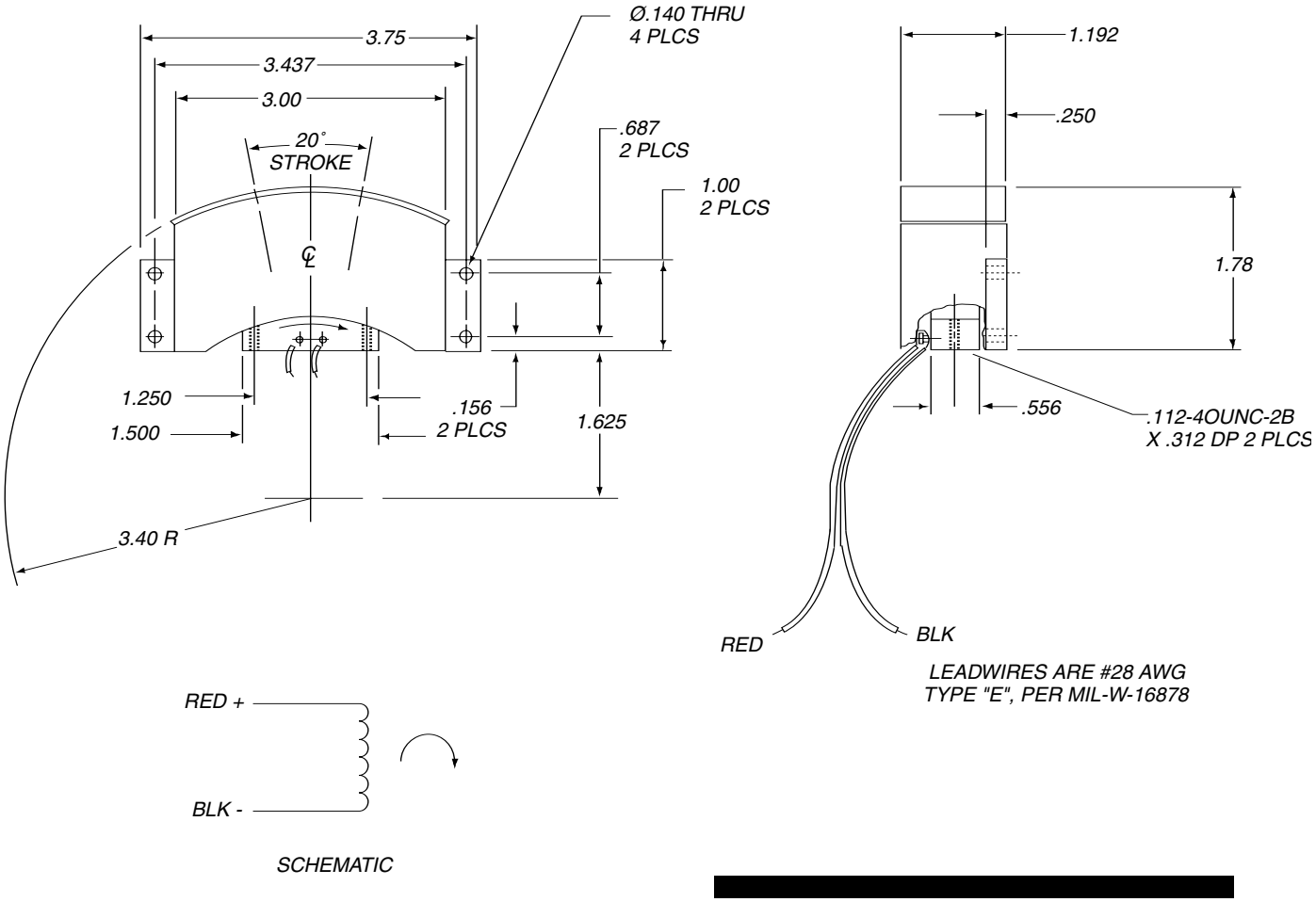

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Winding Constants

PARAMETER	UNITS	TOL:	-035
Resistance (R)	ohms	±12.5%	3.5
Voltage at Tp (V_p)	volts	Nominal	9.0
Current at Tp (I_p)	amps	Nominal	2.6
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

Performance Data

PARAMETER	UNITS	VALUE:
Peak Torque (T_p)	oz-in	110
Power at Tp (P_p)	watts	23
Actuator Constant (K_a)	oz-in/watts	23
Continuous Torque (T_c)	oz-in	40
Elect. Time Constant (τ_e)	milli-sec	0.660
Stroke	degrees	±10
Clearance	mm	0.02
Temperature Rise (TPR)	°C/watt	155
Maximum Winding Temp.	°C	155
Weight of Coil Assembly	oz	0.75
Total Weight	oz	16

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MAGTECH®
BRUSHLESS
MOTOR
SOURCE BOOK

AXSYS TECHNOLOGIES
MOTION CONTROL PRODUCTS

MECHANISMS

Direct Drive Motor Assemblies . . . . . 1 Link

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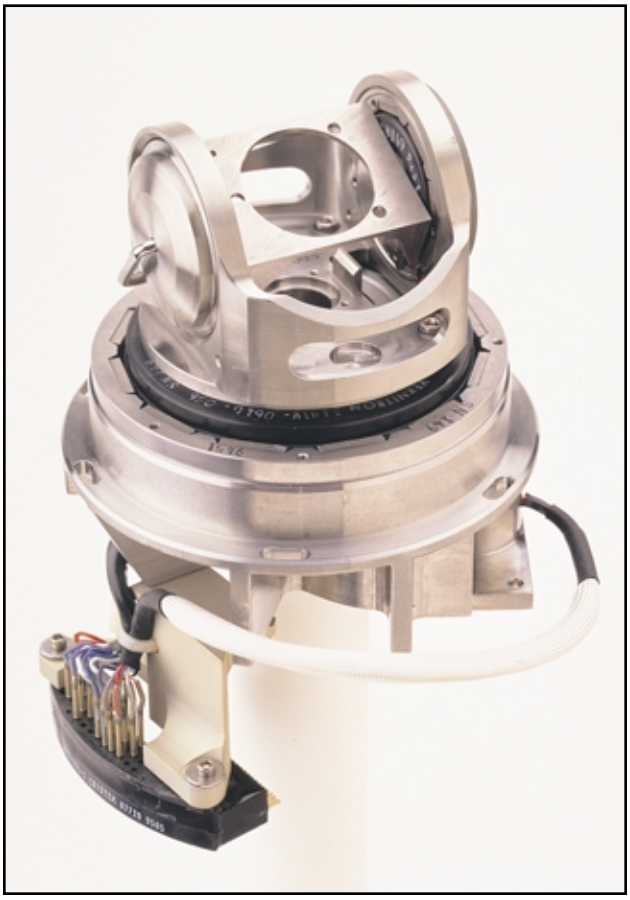
Feedback Packages . . . . . 4 Link

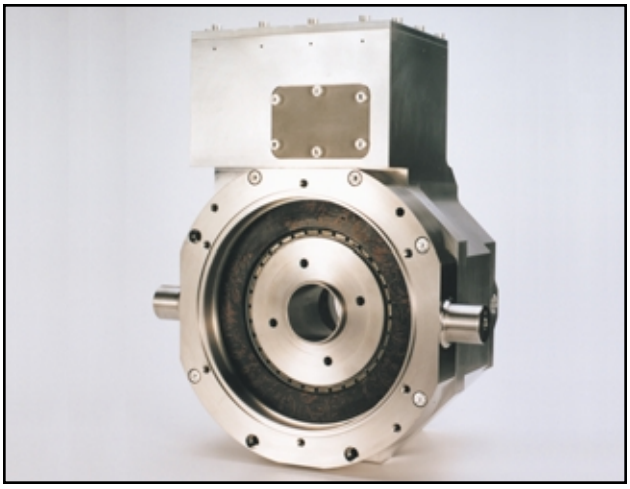
Direct Drive Motor Assemblies

AMCP 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.

Exploded view of 2 axis coaxial drive for robot application maximizes space efficiency and positioning accuracy. Unit incorporates 2 brushless motors and resolvers.



Gimbal assembly with a brushless motor, 2 D.C. brush motors, 2 resolvers, slip ring assembly, and associated structural hardware for a 2 axis missile seeker.



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.

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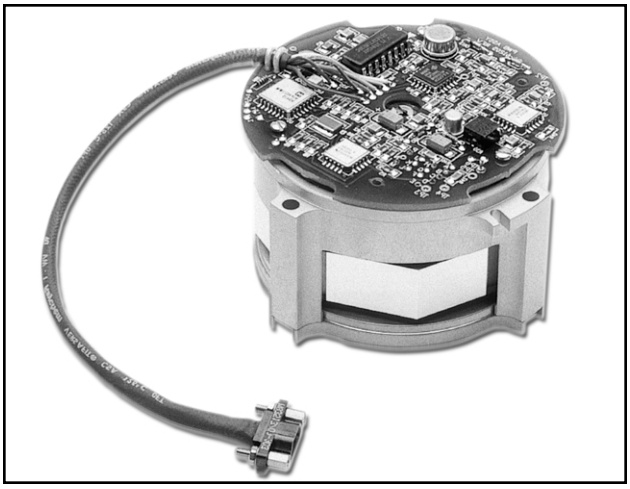
Scanners

AMCP 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.



Rotating scanner

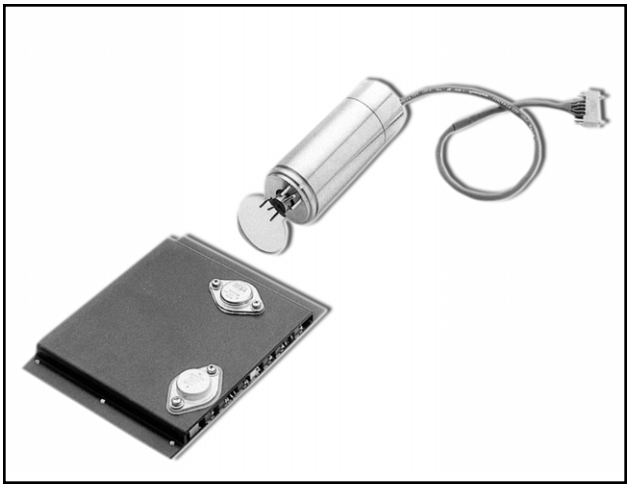
Typical Performance Characteristics

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



Oscillating scanner

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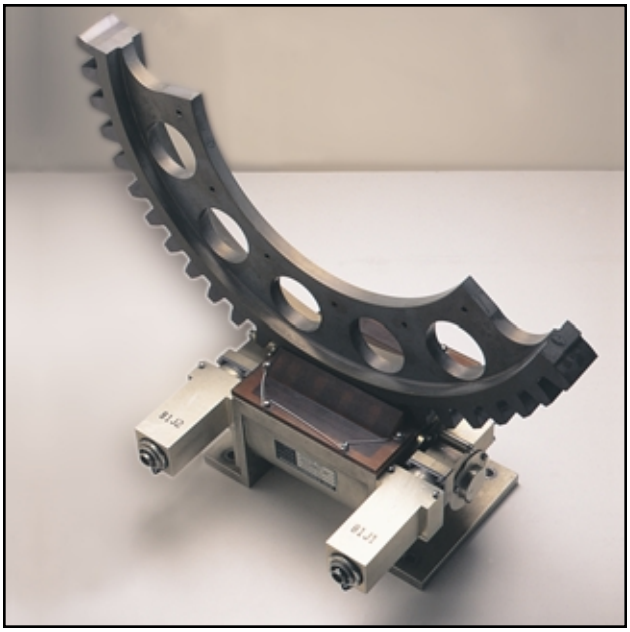
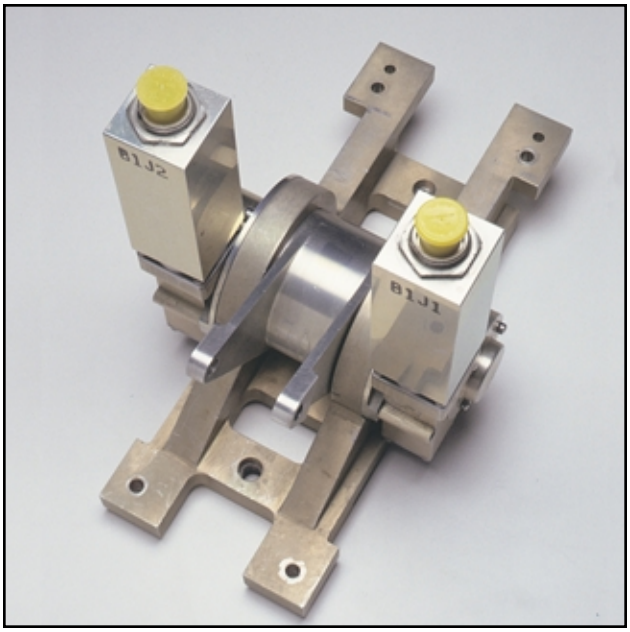
Actuators

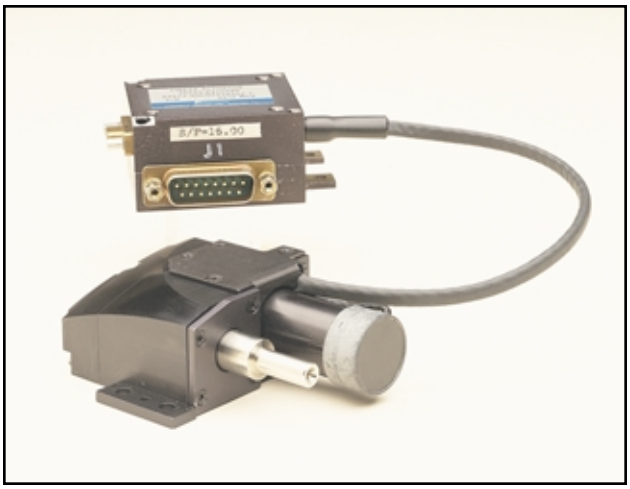
AMCP produces custom linear and rotary actuators for a variety of precision applications.



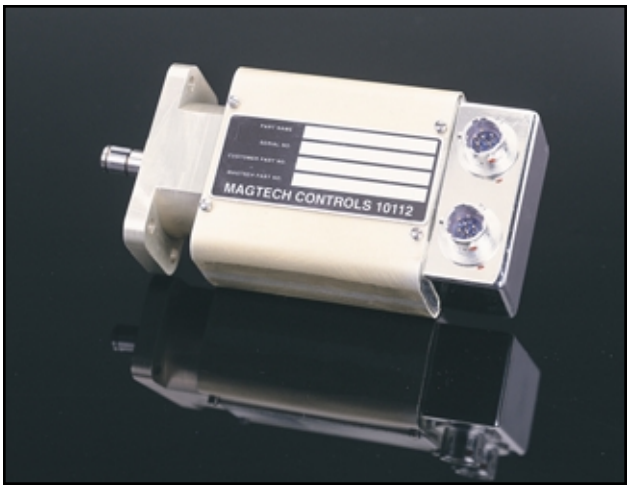
Redundant drive actuator for space deployment mechanism



Redundant drive actuator for space deployment mechanism



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



Redundant drive actuator for space deployment mechanism

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Feedback Packages

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

Resolver-based feedback package for commuter jet flap drive mechanism

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BRUSHLESS MOTOR SOURCE BOOK

AXSYS TECHNOLOGIES

MOTION CONTROL PRODUCTS

CAPABILITIES

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AC and Stepper Motors . . . . . 3 Link

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Scanners . . . . . 6 Link

Actuators . . . . . 7 Link

Packages, Assemblies and Servosystems . . . . . 8 Link

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

Axsys Technologies, Motion Control Product's comprehensive component design and manufacturing capabilities are unique in the motion control industry, with expertise developed over more than three decades. This experience allows Axsys MCP to provide high performance motion control and measurement solutions using the most advanced and reliable technology available.

Axsys MCP offers a wide array of both standard and custom components, which can be combined as a system to offer optimal 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–Axsys MCP 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.

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DC Motors

Direct Drive / Brushless and Brush Type

Performance Features

Axsys MCP's 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 (+/-)

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

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

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AC and Stepper Motors

Performance Features

VERNITECH® AC and stepper motors maintain constant speed without feedback devices, 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 specifications. Stepper motors provide accurate position using a predefined angular step, and are suitable in lighter load applications.

Characteristics

Hysteresis Synchronous AC Motors

- Outer diameters 0.5" to 2.5"
- 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

Hysteresis/Synchronous Motors, AC Servo Instrument Motors and Stepper Motors

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

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DC and AC Tachometers

Performance Features

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, Axsys MCP's 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. Axsys MCP engineers its tachometers to withstand high shock and vibration levels.

Characteristics

- Outer diameter 1" to 24"
- 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

Tachometer Generators

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Resolvers/Synchros

Performance Features

Axsys MCP's exceptionally reliable single, multispeed 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.

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 10,000 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

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

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Scanners

Oscillating and Rotary

Performance Features

Axsys MCP's 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 environmental conditions. They are used in military, 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 incorporate state-of-the-art control techniques covered by several patents.

Characteristics

Open Loop Configurations

- 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

Rotating and Oscillating Scanners

Closed Loop Configurations

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

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Actuators

Linear and Rotary

Performance Features

Axsys Technologies designs and manufactures several configurations of rotary and linear actuators. Axsys' actuators serve a large market including the military, aerospace, medical, and industrial sectors. They are typically found in electro-optical pointing systems, missile fin actuator systems, commercial avionics control surfaces, as well as in robotic and special industrial applications. Axsys' actuators are available with either AC or DC power system 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.

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" achievable with linearity and repeatability up to 2%, under extreme environmental conditions

Linear/Rotary Electromechanical Actuators, Drive Electronics and Control Systems

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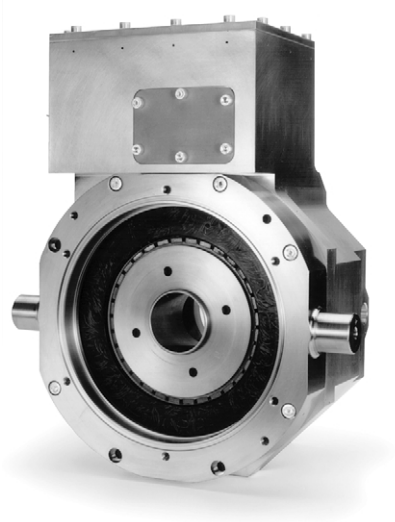
Packages, Assemblies and Servosystems

Assemblies

Packaging several electromechanical components onto a common shaft is one way to provide greater system accuracy at lower cost. Axsys MCP 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 Axsys MCP's guaranteed quality and service.

Systems

In addition to custom sub-assemblies, Axsys MCP also provides complete servosystems consisting of motor, velocity feedback, position feedback, gear reduction, electronic control units, motor drivers and amplifiers. Like custom sub-systems, 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.



Custom Assembly

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