GENERAL DYNAMICS
Ordnance and Tactical Systems

BRUSH TYPE DC MOTORS | HANDBOOK

General Dynamics Ordnance and Tactical Systems has a diverse customer base and provides motion control solutions to the Department of Defense, NASA, Defense Contractors, Aerospace Companies and Original Equipment Manufacturers (OEMs).

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INTRODUCTION

The General Dynamics Ordnance and Tactical Systems' standard product presented in this brochure provides the servomechanism designer an opportunity to select brush type DC torque motors with high performance. These motors are tooled and designed for producibility. High energy product Samarium Cobalt (SmCo) magnets combined with optimum motor windings provide the maximum torque and performance available in a broad range of frame sizes (1.125" - 5.125" OD). Using General Dynamics Ordnance and Tactical Systems product in your designs will give you the advantage of availability today and the long-term benefits of high performance throughout your products life cycle. Should you require a more specialized design or design with a housing please use the "DC Motor Design Guide" on page 53 of this manual. With over 45 years of experience General Dynamics Ordnance and Tactical Systems' engineering is ready to satisfy the most demanding specification with thousands of models from our proven design data base.

DC TORQUE MOTOR CHARACTERISTICS

One of the most useful rotating components available to the control system design engineer is the direct-drive DC torque motor. This versatile control element is a permanent magnet, armature-excited, continuous rotation motor with the following features especially suited to servo system drive and actuation applications:

No gear train
Direct mounting on the driven shaft
High torque at low speeds
High torque-to-inertia ratio
High torque-to-power ratio
Linear torque speed characteristics
Low electrical time constant
Convenient form factors
Simple, rugged construction
Smooth operation

These features make it possible for the designer to obtain such system performance characteristics as:

- High coupling stiffness
- Fast response
- Precise positioning
- High tracking accuracy
- Improved system reliability
- Excellent stability
- Low input power
- Smooth and quiet operation
- Compact assembly

DIRECT DRIVE

The DC torque motor is equivalent to a conventional servo motor plus gearhead, except for the torque motor's improved response characteristics. Because reflected output torque in a geared system varies directly with gear reduction, while reflected output inertia varies as the square of the reduction, torque-to-inertia ration (acceleration) is higher in a gearless system by a factor equal to the gear reduction. The gearless DC torque motor drive is therefore ideally suited to high acceleration applications with rapid starts and stops.

The absence of gearing also eliminates errors caused by friction, backlash, and other gear inaccuracies, thereby making possible a very high threshold sensitivity to one arc second in high performance positioning systems. Positioning accuracy depends primarily on the error-detecting transducer, which should be directly coupled to the load. Direct-drive systems also feature smooth following, freedom from noise caused by bearing play, gear tooth resilience, and similar disturbing factors. For practical purposes, the performance-limiting residual nonlinearities, so common in conventional servomechanisms, are almost absent when DC torque motors are used.

DC VS AC

The direct-drive DC torque motor is probably the most linear kind of servo actuator. The common motor parameters - stall torque and no-load speed - are almost perfectly linear functions of applied voltage. The family of speed-torque characteristics is a parallel set of straight lines and doesn't exhibit the loss in damping at low control voltages, which is characteristic of AC servo motors (see Fig. 1).

For the DC torque motor, the damping is a constant. For the AC servo motor, damping varies with speed and control voltage. It is a minimum at zero speed and zero control voltage. This is critical stability region for the positioning servo systems.

Performance of the DC torque motor in a servo system may be calculated very accurately using the conventional assumptions of linear servo systems. The mechanical time constants measured in milliseconds are about the same as the catalog values listed for small AC motors. However the effective time constants of small AC motors in slow speed positioning systems are 2 to 5 times catalog value; and these higher values are the determining factor in establishing system stability. On the other hand, the electrical time constants of DC torque motors are very low, down to fractions of a millisecond. In a second-order high performance system, it is electrical time constant which cuts into phase margin, thereby leading to instability.

Because of its smooth linear characteristics, the direct-drive DC torque motor is recommended where accurate tracking over speed ranges of several thousand-to-one are required. This dynamic range is about ten times that of conventional AC servo motors.

For example, torque motors are capable of speed ranges of 0.1 to 600 degrees per second with a uniformity within ±0.1%. Some units even go down to 0.001 degree per second with better than 0.5% uniformity. This performance is quite difficult to achieve with other types of drive units.

DC torque motors for most applications have a space-saving “pancake” shape; i.e. they are axially thin compared with their diameter, but for some specialized applications, General Dynamics Ordnance and Tactical Systems has designed motors that are axially long compared to the diameter. Units are usually supplied without stator housing, rotor shaft and bearings, since they are most conveniently mounted directly around the driven load. This allows flexibility in packaging, leading to a compact system assembly, and reduces the number of rotating components and linkages.

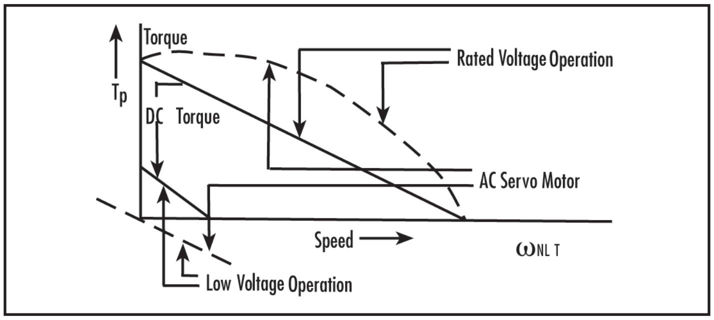

Fig. 1 Torque-speed characteristics of a DC torque motor and an AC servomotor. The slope represents inherent motor damping

MOTOR OPERATION THEORY

(See page 13 for performance parameter definitions.)

BASIC EQUATIONS

Since the DC torque motor is a permanent-magnet field, armature-excited DC motor, the basic equations for DC motors can be used to establish torque motor characteristics.

$$V = E + IR \quad (1)$$
$$E = K_b\,\omega \quad (2)$$
$$T = K_t I \quad (3)$$

Where:

V = applied voltage (volts)
E = back EMF (volts)
I = current (amps)
R = DC resistance (ohms)
T = torque (oz-in)
K_t = torque sensitivity
K_b = back EMF constant
ω = speed (rad/sec)

Substitution into Eq (1) leads to the speed torque characteristic for a given motor:

$$V = K_b\omega + \frac{TR}{K_t} \quad (4)$$

The first term represents the voltage required to overcome the back EMF of the motor at the desired speed and the second term represents the voltage required to produce the desired torque.

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Torque motors may be wound to operate suitably at any practical voltage level. This can be accomplished with no change whatsoever in performance. In a set of similar units, power, torque, and time constants are unchanged. The DC resistance and armature inductance vary as the square of the voltage rating; the current varies inversely with voltage rating.

The equivalent circuit of the DC torque motor is shown in Fig. 2.

POWER RELATIONSHIPS

We can derive some further important relationships from Eq (1):

$$V = E + IR$$

by multiplying each term by I to set up a power equation.

$$VI = EI + I^2R \qquad (5)$$

Since the first term represents input power and the last term represents copper loss, EI must be the mechanical power developed at the shaft, in watts (including friction and armature iron loss). Relating EI to developed shaft power gives:

$$EI = \frac{T\omega}{141.612} \qquad (6)$$

Stall torque (T_p), stall power (P_p), and no-load speed (ω_{NLT}) are inter-related parameters of DC servo motors. If any two of the three are defined, the third parameter is automatically defined. Eq(7) illustrates this relationship:

$$P_P = \frac{T_P\,\omega NLT}{141.612} \qquad (7)$$

Where ω_{NLT} is the theoretical no-load speed which does not include the effect of losses.

DAMPING

By manipulating Eq (7), the following equation for servo motor damping (F0) is derived.

$$F_o = \frac{141.612}{R}\left(\frac{V_P}{\omega NLT}\right) \qquad (8)$$

Here V_P/ω_{NLT} is, of course, the volts per rad/sec of back EMF (the voltage that would be developed if the torque motor were used as a tachometer). R is armature resistance (ohms) and F_0 is the damping in oz-in per rad/sec. The restrictions imposed by Eq (7) and Eq. (8) are fundamental in setting up consistent specifications for high performance torque motors.

If voltage and ω_{NLT} are not available, Fo can be calculated using back EMF constant and torque sensitivity.

$$Fo = \frac{Kb{*}Kt}{R}$$

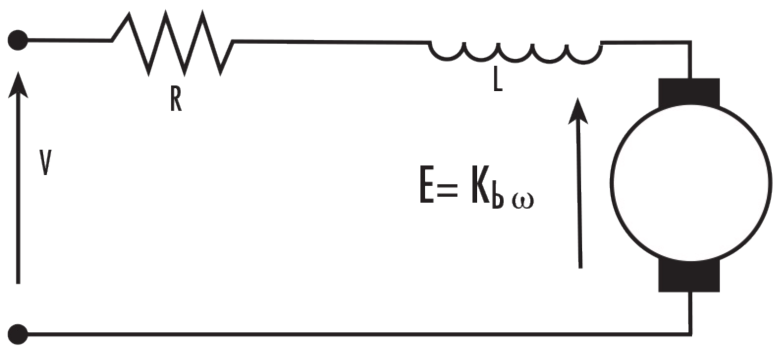

Fig. 2 Equivalent circuit of the Brush Type DC motor. Here L/R constitutes the electrical time constant. The component L, in the circuit, represents armature inductance, and can be minimized by careful design of the magnetic circuit.

DIRECT-DRIVE SYSTEMS

MOTOR TRANSFER FUNCTION

A DC torque motor can be represented by the following transfer function for simplified servo analysis. This transfer function ignores motor induction, friction and shaft resonances.

$$\frac{\omega}{V} = \frac{1/K_b}{(T_m S+1)}$$

ω = speed
V = voltage
Kb = back EMF constant
T_m = mechanical time constant

To include the effect of motor inductance, the transfer function is modified to include an additional term.

$$\frac{\omega}{V} = \frac{1/Kb}{(T_m S+1)\ (T_e S+1)}$$

T_e = electrical time constant

This function assumes that the mechanical time constant is much larger than the electrical time constant and that friction is negligible.

High response DC motors occasionally have mechanical time constants that approach their electrical time constants. In this case it is necessary to use the following transfer function.

$$\frac{\omega}{V} = \frac{1/K_b}{(T_m T_e S^2+1)\ (T_m T_e)S+1}$$

For detailed analysis of more complex systems terms for friction, shaft resonances, and ripple torque components should be added if they are likely to have an effect of noticeable proportion. The following diagram shows the Bode plot for the second transfer function give (see Fig. 3).

$$f_c = \frac{1}{T_m(2\pi)} H_z \qquad f_r = \frac{1}{T_e(2\pi)} H_z$$

The phase plot of the motor also can be derived from the transfer function (see Fig. 4)

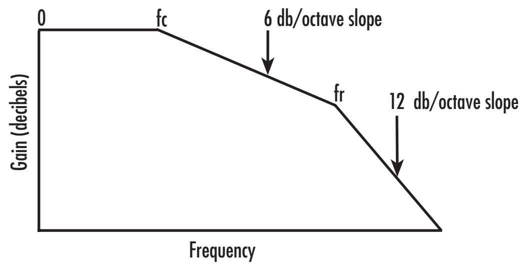

Fig. 3 Mode Bode Plot

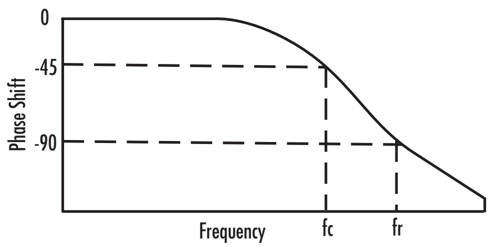

Fig. 4 Motor Phase Plot

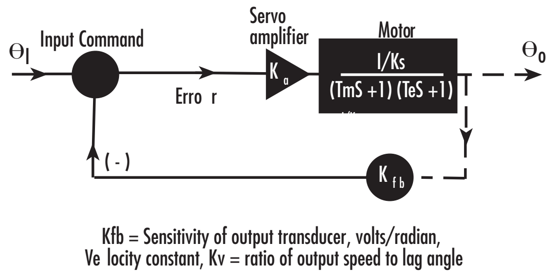

Fig. 5 System Block Diagram

GAIN DETERMINATION

A simple servo system containing a DC torque motor is shown below (see Fig. 5).

Assume the servo loop is opened at the mechanical input to the feedback transducer and a one radian deflection is applied to the transducer and a one radian deflection is applied to the transducer input. The transducer output K_{fb} is amplified by K_a thereby applying $K_a K_{fb}$ volts to the motor. If V_p is the rated motor voltage and ω_{NLT} is the no-load speed at this voltage, then:

$$K_{fb} K_a \omega_{NLT} = \omega \text{ (rad/sec)}$$

This expression equals the velocity constant (K_s) since it represents the output velocity per unit of error.

Therefore: solving for K_a

$$K_s = \frac{K_{fb} K_a \omega_{NLT}}{V_p} \qquad K_a = \frac{K_s V_p}{K_{fb} \omega_{NLT}}$$

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To determine the stiffness, or the torque per radian deflection of the output shaft when the loop is closed.

$$T = \frac{K_{fb}K_a}{V_p} T_p$$

Since T_p / ω_{NLT} represents the motor damping factor, the stiffness (K) becomes:

$$K = K_s F_o$$

The basic design approach, even for complex systems is as follows:

1. Combine characteristics of motor and load to arrive at overall figures for inertia and damping.

2. Using conventional servo system analysis procedure, draw the open-loop Bode plot representing the desired system velocity constant, band width, and stability margins.

3. Determine amplifier gain and stiffness from the equations developed above.

4. Check to see that the stiffness is adequate by comparing with the system friction to establish threshold error.

AMPLIFIER CONSIDERATIONS

Because the torque motor operates on direct current, it follows that at least the power stage of the servo amplifier must be a DC amplifier. If the feedback transducer is an AC device, demodulation is required at some point in the system.

DC motors may require large currents under transient conditions and during reversing, therefore careful attention must be paid to the peak current ratings of the motor and the power amplifier. Current limiters should be considered to overcome this problem.

The power amplifier should have a low output impedance to make best use of the internal damping of the motor. Note that damping torque is inversely proportional to resistance, which must include the amplifier output resistance. The output resistance of the amplifier under saturated conditions may be a factor in analyzing dynamic response. SCR-type amplifiers are popular for these applications in spite of their one-cycle transport lag and the troublesome EMI they generate in the power lines. Somewhat more complex, but superior in performance, are pulse-width modulated amplifiers where power transistor conveniently switched at one or more kHz, to minimize ripple in the generated torque. The driving amplifier may be modified by current feedback to deliver a current rather than a voltage proportional to error. This is equivalent (theoretically) to an infinite output impedance. Damping vanishes, and the open-loop Bode plot falls at 12db/octave at low frequencies. The electrical time constant L/R similarly vanishes, and all damping must be externally supplied. Amplifier circuits with high output impedance lead to characteristic Type 2 servo system with essentially an infinite velocity constant. It is useful when available current is limited, and appreciable power output is required at the motor shaft.

NETWORK COMPENSATION

The normal methods of network compensation, lead networks, lag networks, lag-lead networks, and differentiating networks in the tachometer feedback loop can be readily applied in direct-drive servo systems. Since direct current is required for the motor drive, simple DC networks can be used in the amplifier input stages. Circuit simplification can usually be effected by putting networks in the feedback circuits of DC pre-amplifiers, using well known design principles. These often lead to more convenient sizes for stabilization capacitors. Furthermore, when integrating characteristics are required, the saturation of the amplifiers limits the maximum value of the integrated error, leading to a much reduced overshoot in the response to a large step input. This is especially important in very high gain systems where large overshoots and settling lags of several seconds may be intolerable.

Tachometer damping is less convenient than network compensation because it requires an additional rotating component, but it does provide the smoothest slow-speed tracking, and avoids saturation effects which would disable stabilization networks.

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TACHOMETER STABILIZATION

Since the DC torque motor makes an excellent tachometer generator, it is natural to use tachometer damping as a way of increasing the accuracy of direct-drive servos, especially those designed for very low speed operation.

Tachometer damping reduces the system mechanical time constant by increasing the effective damping. It also reduces loop gain in the same proportion. Thus, if it is desired to multiply band width by decreasing the effective time constant by a factor of 5 for example, the amplifier gain must be increased by a factor of 25 to maintain the phase margin unchanged (see Fig. 6). Relatively high amplifier gains are required in tachometer-damped loops. However, these lead to proportionally higher static stiffness, a very desirable servo feature.

It should be kept in mind that the electrical time constant has been ignored in this brief analysis. If a final check indicates significant phase lag from this source at the zero-db cross-over point on the Bode plot, a corrective reduction in gain must be made. As a matter of fact, the limitation to tachometer feedback occurs when the electrical time constant prevents achievement of an adequate phase margin. A practical upper limit for cross-over frequency would be one half the electrical time constant corner frequency. The band width of a typical tachometer stabilized servo system with about 60° open-loop phase margin is about 40 to 50 cycles per second.

EMI CONSIDERATIONS

The switching action of the commutator in DC motors usually causes some arcing which results in electrical noise. Although careful design can minimize torque motor brush noise, some arcing noise can get into sensitive control circuits and interfere with proper operation.

Such EMI can be transmitted from a source to a sensitive location by direct conduction along wires; capacitive coupling between leads; inductive coupling between wires; and direct radiation from exposed shafts due to an antenna effect. The first three of these methods of transmitting RFI are important in torque motor applications.

Noise voltages are conducted along the motor supply leads from the power amplifier and transferred to nearby tachometer generator leads by capacitive coupling. The tachometer generator leads terminate at the input of a preamplifier where only a few microvolts may be enough to interfere with proper system operation.

The simplest remedy is to keep motor leads separated from the generator leads. If this is not enough to reduce the noise or if it is not feasible to separate the cable, a shielded twisted pair can be used for the tachometer leads. This shield has to be grounded at the preamplifier, end only. Sometimes it may be desirable to use a shielded lead pair for the motor as well. A common ground for preamplifier, amplifier and cables is very important to the elimination of brush noise. Brush noise may be reduced by a filter across the terminals, as close to the brush assembly as possible.

THERMAL CONSIDERATIONS

On each of the following data pages there is a value for input power at stall torque. This power is dissipated as heat in the armature winding. The thermal resistance value given on the motor data pages can be used to determine the steady state temperature increase of the armature above ambient. The thermal resistance is theoretical with the motor suspended in the air. Air movement and a mounting structure can be used to improve a motor's thermal resistance.

The capacity of the motor to handle the load must also take into account the duty-cycle which affects motor heating. A small motor with the capacity to drive the load intermittently may be inadequate when driving the same load under a more rigorous duty-cycle. Special care must be given to the thermal analysis of rare earth magnet motors since they can achieve peak torques which may cause excessive armature temperatures under continuous operation.

THERMAL EQUATIONS

The following equations can be used to calculate the final temperature of the motor winding in a given application. The RMS torque must be known so that average power dissipation at 25°C can be calculated.

$$P_{25} = (T_{RMS}/K_t)^2 (R_{25}) \text{ watts}$$

Where:

P_{25} = power dissipation @ 25°C
R_{25} = resistance @ 25°C
Kt = torque constant
T_{RMS} = RMS torque

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If the product of this power and the thermal resistance of the motor is greater than 253 then a steady state temperature will never be reached. A thermal runaway condition will exist.

The final temperature in a nonrunaway system is:

$$T_F = .9212\ P_{25} \text{ x tpr} + T_{AMB}(1 - .00394\ P_{25} \text{ x tpr})$$

Where:

T_F = final temperature

tpr = thermal resistance

T_{AMB} = ambient temperature

If the final temperature is greater than the allowable winding temperature, then cooling must be provided or a larger motor must be selected.

Standard torque motor armatures are supplied with a maximum winding temperature capability of 155°C. Our design and manufacturing methods allow availability of special units with temperature capability of 220°C, if required.

MATCHING MOTORS TO REQUIREMENT

Matching motors to requirements frequently involves operating a motor below peak torque ratings. In such cases a simple derating procedure will permit selection of a standard motor.

SIGNIFICANCE OF K_M

The ability of a permanent-magnet DC torque motor to convert electric power input to torque is proportional to the product of total magnetic flux linking to the winding from the field and the magnetomotive forces established by the excited armature winding. This ability can be represented by

$$Km = \text{torque} / \sqrt{\text{power input (watts)}}$$

and is a valid figure of merit to compare torque motors in their ability to produce torque per unit of input power. This basic motor constant is included for each motor in the selection chart. If the motor K_M > the required $T/\sqrt{\text{watts}}$ the motor performance will equal or exceed the demands of the application. Note also that Km is close to the required value, motor size or weight generally will be at minimum.

EXAMPLE PROCEDURE

The following example illustrates the procedure for using the motor constant Km to select a motor where the input power is constrained.

Problem: Develop 50 oz-in torque at or near stall. Maximum amplifier output is 26 volts at 1 ampere, or 26 watts.

Solution: Using the motor performance index (K_m) relationship:

$$Km = T/\sqrt{\text{watts}} = 50/\sqrt{26} = 9.8$$

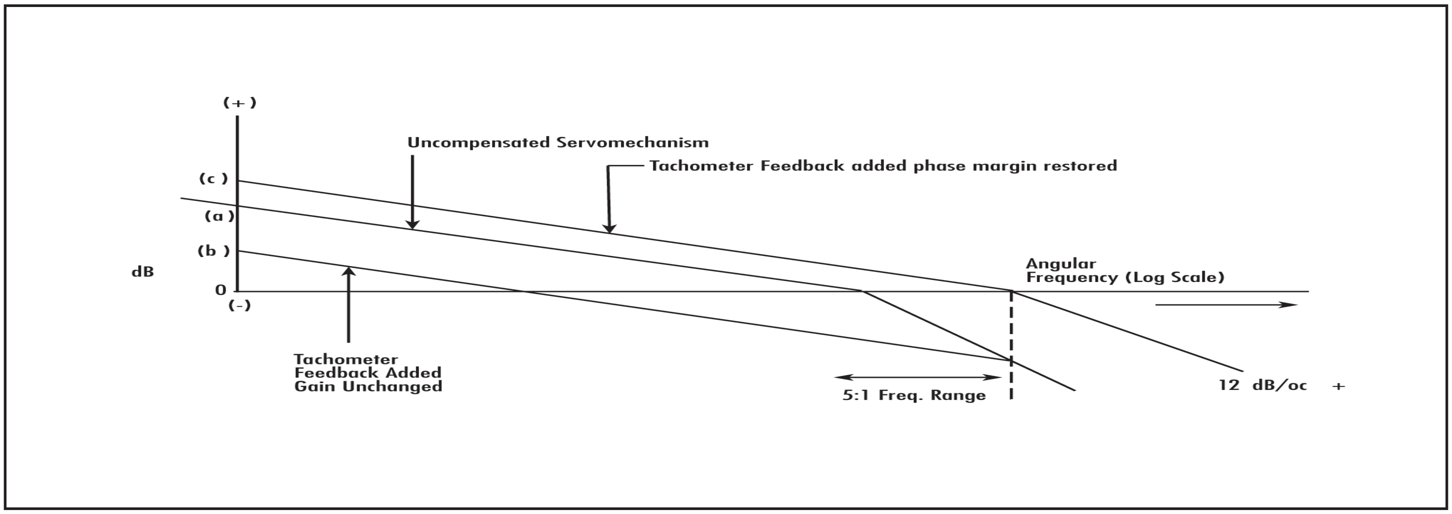

Fig.6 Open loop asymptotic attenuation characteristics for a tachometer damped servo system. (a) Original servo with a gain of Ka (b) Tachometer feedback, with a gain of Ka (c) Tachometer feedback, with a gain of 25Ka.

Model	Peak Torque (oz-in)	Motor Constant (Km)	Torque @ 40 watts $T=Km\sqrt{watts}$	OD (in)	Length (in)	Weight (oz)
1500V-040	14	1.58	9.99	1.500	0.40	1.5
1375V-062	22	2.67	16.89	1.375	0.62	2.5
1500V-062	28	2.91	18.40	1.500	0.62	2.7

Fig. 7 Example of three models using torque vs. power derating @ 40 watts

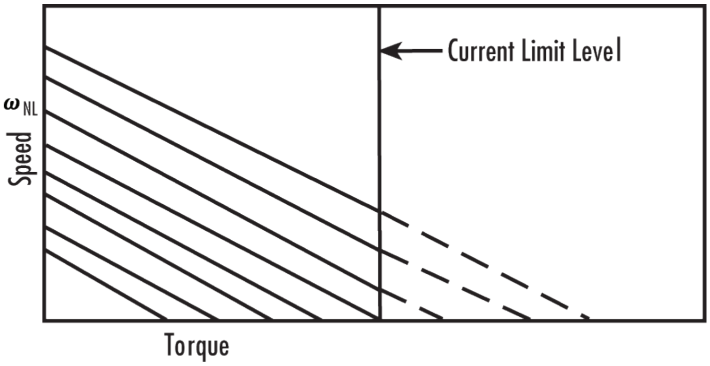

Fig. 7A Family of speed-torque curves.

Motors with a Km greater than 9.8 can meet the required torque-to-power condition. Also a torque output can be calculated on a selected motor with 26 watts input by making the equation equal to torque.

$$\text{Torque} = Km\sqrt{\text{watts}} = Km\sqrt{26}$$

Fig. 7 illustrates torque vs. power derating for three motors. Using this information will facilitate the process of selecting a motor when constrained by power supply ratings. Example: A motor is needed to operate at peak torque of 14 oz-in with a 40 watt input. Model 1500V-040, while rated at a peak torque of 14 oz-in cannot meet torque requirements with a 40 watt input. Figure 7, under the torque calculation column, two other models exceeding the required torque can be selected.

Motor selection can be made to optimize weight or configuration. Note the wide variations available in motor diameter, axial length and weight.

This procedure illustrates the trade-offs normally encountered when derating because of power supply limits. In some situations, thermal considerations rather than power supply limits make derating necessary. Installation heat transfer paths and duty-cycles sometimes dominate selection criteria.

If a torque motor is derated for power input, the damping coefficient

$$(Fo = Tp/\omega_{NLT})$$

remains constant and therefore for all practical purposes a speed torque characteristic for a model can be drawn for any DC torque motor by plotting a straight line between the values for peak torque and no-load speed. (Fig. 7A)

OVER-SPEED OPERATION

An application sometimes calls for operating a motor above its normal maximum speed-torque curve. This presents some problems due to the fact that torque motors are designed for good commutation at slow speeds and high torques, therefore some points above the speed-torque curve are points where bad commutation and the resultant decrease in brush life occur. In order to avoid this eventuality, it is generally true that the motor should not be operated above the shaft power output that is represented by the following equation.

$$\text{Power} = \left(\frac{T_P}{2K_m}\right)^2 \text{ or } 1/4\ P_P$$

If more shaft power is desired modifications may be possible that will improve commutation within acceptable limits.

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TYPICAL MOTOR APPLICATIONS

A common problem is to determine the torque required to move a load from one position to another in a given amount of time.

The torque required can be calculated:

$$T = T_f + \alpha\,(J_M + J_L)$$

Where:
T = torque needed (oz-in)
α = acceleration (rad/sec^2)
JM = motor moment of inertia (oz-in/sec^2)
JL = load moment of inertia (oz-in/sec^2)
Tf = total system friction torque (oz-in)

If the total angle through which the motor must travel is θ radians and the time required for the step is t seconds the acceleration required of the motor is

$$\alpha = \frac{4\theta}{t^2} \quad \frac{\text{rad}}{\text{sec}^2}$$

This equation assumes a triangular velocity profile constant applied torque which will result in minimum acceleration for the job as shown in Fig. 8.

MINIMUM POWER SOLUTION

If the energy dissipation is of more concern that minimum acceleration a trapezoidal velocity profile can be used, as shown in Fig. 9.

One third of the time is used for acceleration; the speed is held constant for one third of the time and the last third is used for deceleration. In this case there is a 15% saving in dissipated energy, but the acceleration required is:

$$\alpha = \frac{4.5\theta}{t^2} \quad \frac{\text{rad}}{\text{sec}^2}$$

VOLTAGE AND CURRENT REQUIREMENTS

Using the motor winding constants the voltage and current required may now be calculated.

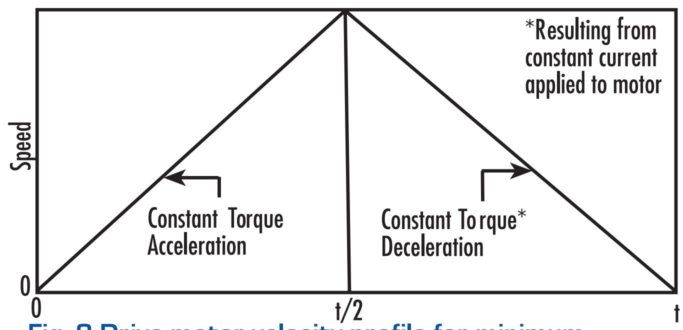


Fig. 8 Drive motor velocity profile for minimum required acceleration in a point-to-point step.

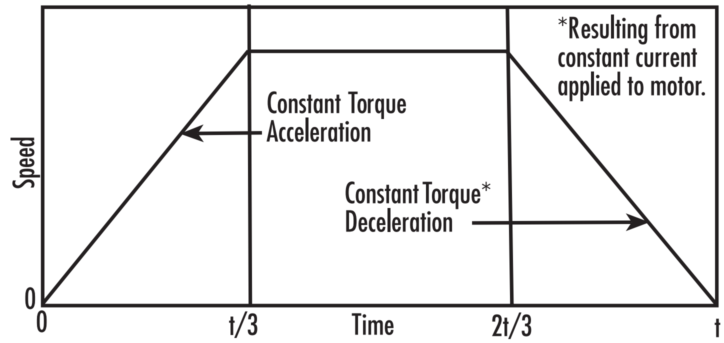


Fig. 9 Drive motor velocity profile for minimum energy dissipation in a point-to-point step.

$$I = \frac{T}{K_T}$$

$$V = IR + \frac{K_b \alpha t}{2}$$

for triangular velocity profile

$$V = IR + \frac{K_b \alpha t}{3}$$

for trapezoidal velocity profile where
K_T = torque sensitivity in oz-in/amp
K_b = back EMF in volts/rad/sec
R = motor resistance in ohms
α and t are defined previously

An amplifier can now be selected which is capable of supplying the calculated voltage and current simultaneously. If the winding that was chosen for the calculations indicates a voltage or current that is not available in existing amplifiers, a special amplifier or motor winding should be considered. For this task it is important to know that the voltage is directly proportional to the torque sensitivity of the winding and that the current is inversely proportional to the torque sensitivity.

EXCEEDING VOLTAGE/SPEED RATINGS

When the terminal voltage is above the voltage at peak torque it is necessary to put a current limiter in the circuit so that the motor will not be overheated by over currents. The motor may be run at speeds above the specified no-load speed as long as the torque required is below the specified peak torque. An amplifier with a current limit is a requirement for this type of operation. It should be noted that operation above the speed-torque curve decreases motor brush life.

MOTION CONVERSION

In many applications it is necessary to couple the motor to the load through a motion converting system, such as gear train, belt and pulley, rack and pinion or lead screw. If it is necessary to minimize the energy consumed by the system the coupling ratio must be optimized. It can be shown that the optimum coupling ratio is the ratio which matches the reflected load inertia to the motor inertia. The optimum ratio, N, is found by the following equation:

$$N = \sqrt{\frac{J_L}{g\,J_M}}$$

This equation assumes that the system friction losses at the motor shaft are negligible. For other types of couplings the inertia matching techniques also minimizes energy consumption. For example in the lead screw system:

$$P = \frac{1}{2\pi}\sqrt{\frac{m}{J_M}}$$

Where:

P = lead screw pitch (turns/in)

m = weight of load (oz)

J_M = motor moment of inertia (oz-in/sec^2)

g = 386 in/sec^2

PERFORMANCE PARAMETERS

DEFINITIONS

On each of the following pages, data on a single motor model is presented. Electrical, physical, and mechanical data applying to each model are given.

Definition of the terms used in these data pages are given below.

MOTOR DATA:

(P_p) Peak Torque. This is the maximum useful (non continuous) torque (in ounce-inches) that can be obtained at maximum recommended current input.

(K_M) Motor Constant. This is the ability of a servo motor to convert electric power input to torque-a kind of figure of merit that can be used to compare motors in their ability to produce torque per unit of power input. It is the ratio of torque to the square-root of the power input

($T/\sqrt{\text{power input (watts)}}$).

(T_e) Electric Time Constant.

The ratio of armature inductance to its resistance is the electrical time constant of a torque motor (in seconds).

$$T_e = \frac{L}{R}$$

(T_m) Mechanical Time Constant.

The ratio of the motor moment of inertia to the damping factor with a zero-impedance power source gives the mechanical time constant of the motor. In direct-drive systems, load inertia and damping factor have to be added to the motor inertia and damping factor to determine the mechanical time constant.

$$(T_M = \frac{R \star J_M}{K_t \star K_b})$$

(P_P) Power at Peak Torque. This is the input power (in watts) required to produce peak torque at stall and at 25°C winding temp.

(F_o) Damping factor. ($F_o = T_p/\omega NLT$) The ratio of the stall torque to the no-load speed (oz-in/rad/sec). The value of Fo is governed by the total amount of resistance in the armature circuit which must include any driving power amplifier's output resistance as well. The damping effect of Fo is usually insufficient for control system stability in most applications.

(Continued on page 14)

(Continued from page 13)

Added stabilization is provided by tachometer-generator damping or by circuit compensation.

(T_F) Total Breakaway Torque. The friction contributed by the motor to the system determines the total breakaway torque (in ounces-inches). It is the sum of the brush-commutator friction, plus the magnetic retarding torques such as hysteresis drag and slot effect drag.

(JM) Moment of Inertia. The moment of inertial of the armature is measured about the torque motor's axis of rotation.

(ω_{NLT}) No-Load Speed. This is the maximum speed of the motor (in radians per second) at no-load when the voltage that is required to produce peak torque is applied.

(α) Maximum Theoretical Acceleration. The acceleration developed by the motor alone, from stand-still, at the moment when maximum voltage is applied is the maximum theoretical acceleration in radians per second. It is equal to the ratio Tp/Jm.

(tpr) Thermal Resistance. This is the ratio of winding temperature rise to average power continuously dissipated from the armature. The tpr values are based on the average I^2R loss in an armature suspended in air without heat sink or forced air cooling. In normal applications the actual value can be 1/2 to 1/3 of the listed tpr because the armature may be mounted on a shaft with good heat conductivity.

(fR) Ripple Frequency. The number of ripple cycles in one revolution of the armature is the ripple frequency (in cycles per revolution). A higher frequency component caused by the brush phasing also is present, but the fundamental frequency is determined by the number of commutator bars.

(T_R) Ripple Torque. A small change in torque with armature position is caused by the switching action of the commutator. The armature rotates through a small angle before its field is returned to its original position through commutation. This variation is known as ripple torque and is usually expressed in percent of torque level.

(WT) Weight. Weight of the servo motor is the sum of the weights of the armature, the field, and the brush assembly. It does not include the weight of the mounting hardware.

(R) DC Resistance. This is the DC resistance (in ohms) measured at 25°C between the motor terminals. It is the sum of the winding and brush resistances. This resistance is usually measured at 1/3 to 1/5 of peak current.

(V_p) Voltage at Peak Torque. This is the voltage required to produce peak torque (Tp) where the motor is at standstill and the winding temperature is 25°C.

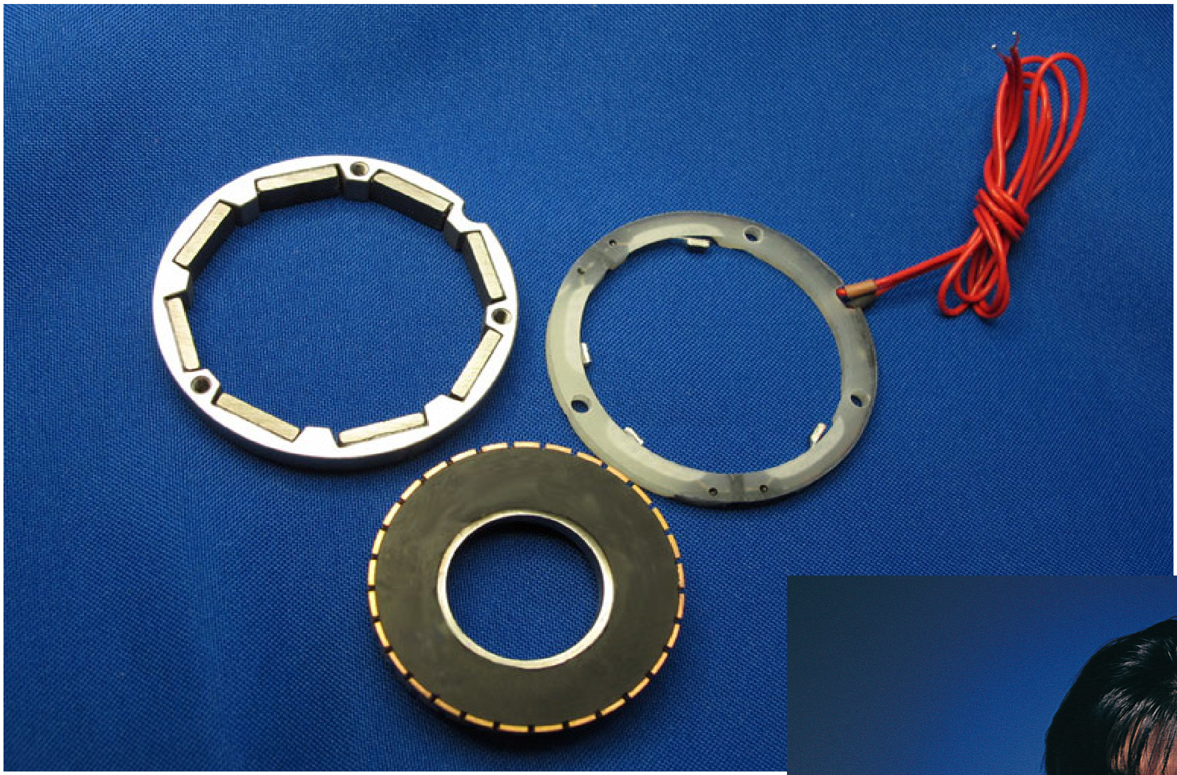
(I_p) Current at Peak Torque. This is the current required to obtain peak torque (Tp) from the motor. It is given in amperes.

(K_T) Torque sensitivity. This is in torque output of the motor per ampere of motor input current. It is given in ounce-inches per ampere.

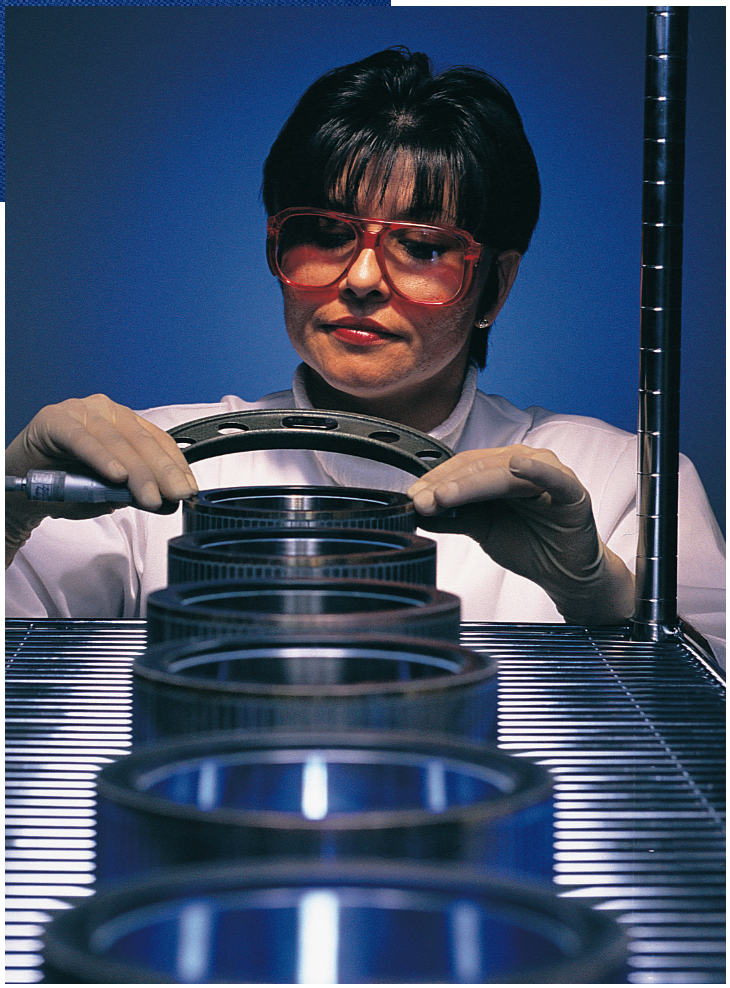
(K_b) Back EMF. This is the voltage generated by the armature as it rotates in the permanent magnetic field and is proportional directly to the speed. It is numerically equal to the torque sensitivity (K_T) multiplied by a constant. It is given in volts/rad/sec.

(L_M) Inductance. This is the inductance of the motor armature as measured at the motor terminals. It is given in millihenries, measured at 1kHz.

(P) Power Rate. The ratio of peak torque squared to inertia which is useful in applications where the acceleration of a load through a gear train is the prime consideration. An initial motor selection is made which has a power rate of at least 4 times the product of the load inertia and the load acceleration required. A gear ratio is then chosen which will match the motor and load inertia.



General Dynamics' motors incorporate rare earth magnets with outer diameters ranging from 1.0" to 24" and provide peak torques up to 262 ft-lbs.



General Dynamics' DC torque motors are designed using premium materials that offer unique space and weight savings while generating maximum power output. Space-rated versions of most motors are available.

(Continued on page 16)

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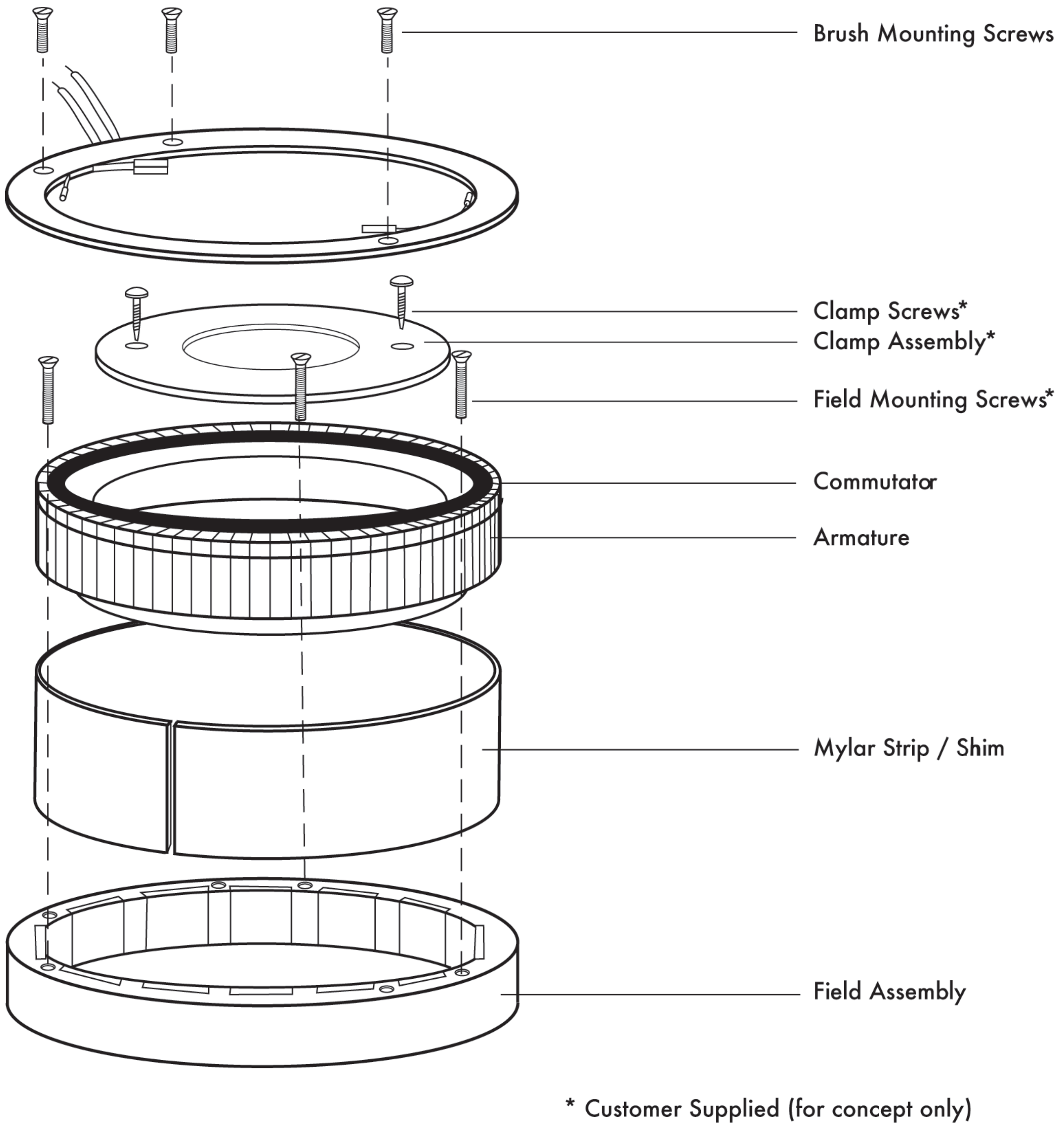
TORQUE MOTOR ASSEMBLY

COMPONENT PARTS



DEFINITIONS

Armature - The element containing the windings and commutator. This is the rotating element of a brush type motor.

Commutator - A conductive segmented copper ring on the armature. Allows transfer of electrical power to the windings from the stationary brush assembly.

Field - The stationary element containing permanent magnets.

Brush Assembly - The stationary insulating ring supporting spring loaded electrical contacts (brushes) which slide on the commutator to transfer the DC power.

OD - The outside diameter of the outer element.

ID - The inside diameter of the inner element.

Width - The overall axiall length of the motor.

Mounting - Mounting dimension (shown as MTG DIM on every drawing) is the user controlled distance from the mounting face of the field to the mounting face of the armature. This dimension must be maintained within the required tolerance to insure that the brushes align with the commutator. Correct mounting is required to preserve the specified performance characteristics.

ASSEMBLY

MOUNTING

1. Component Parts

The brush type torque motor consists of three major components: A permanent magnet field, an armature and a brush assembly, are packaged together in serialized sets. The brush ring assembly is protected by a separate container. Brush installation hardware is included.

2. Field placement and installation

Position the permanent magnet field over the surface on which it will be mounted. Align the field mounting holes with the mounting bolt pattern, push the field into place and install the mounting screws at this time.

3. Protective strip

In order to protect the amature finish and commutator surface a MYLAR® strip is placed inside the field at this time. If will be removed later, so it should be sized so that it extends above the armature for grasping and removal.

4. Armature installation

(Caution: high magnetic forces may cause damage or injury.)

Slip the armature inside the MYLAR® strip with the commutator end facing you. Push the armature onto the mounting hub. Make sure that it is seated firmly against the shoulder. Clamp the armature in place. The common method uses a clamp ring and screws. Other installation methods utili-tze a threaded clamp ring, servo clamps or cements for fastening the armature to the hub.

5. Install brush ring assembly

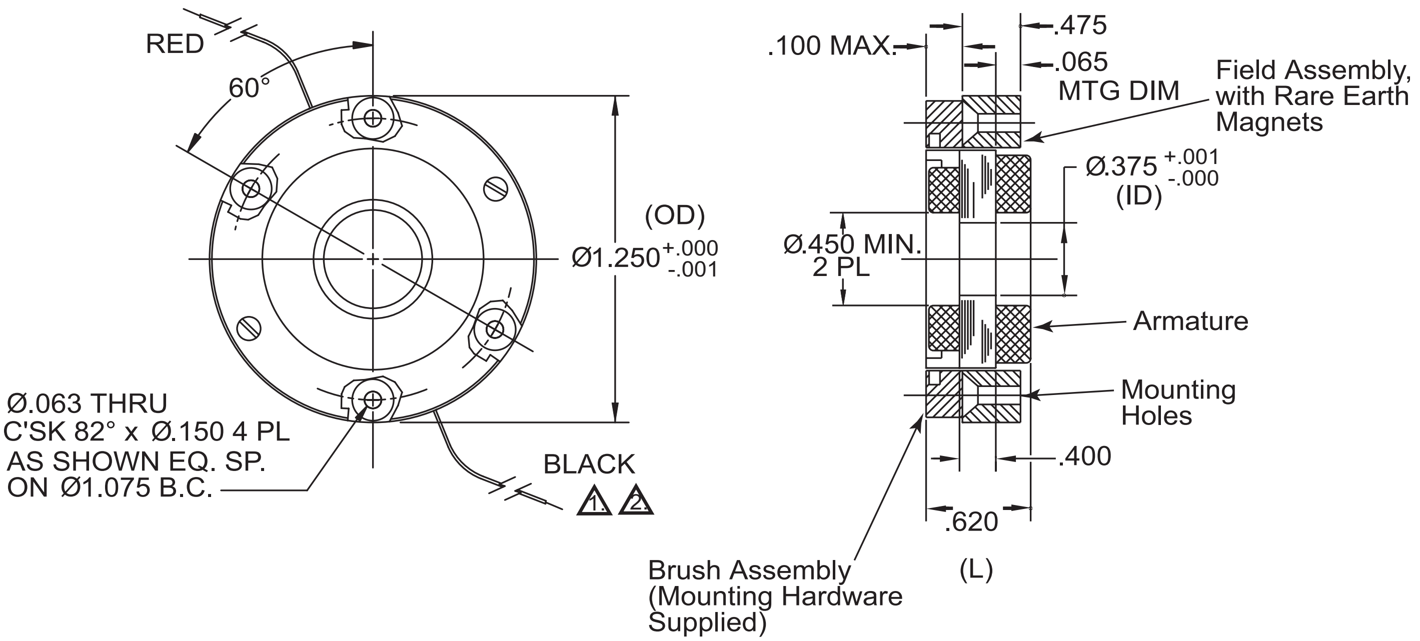
The brush assembly may be installed by hand. Positon one set of the brushes on the MYLAR® strip, then gently compress the remaining brush springs and slide them onto the motor.

6. Assembled motor

Remove the MYLAR® strip. Position the lead exits properly (reference line up marks) and align the mounting holes. Fasten the brush ring to the field using the supplied hardware. Insure that the brushes are on the commutator, and that the armature rotates freely within the field, the assembly is complete.

General Dynamics Ordnance and Tactical Systems' complete line of brushless and brush type torque motors and servomotors are sure to include a motor that meets your system's requirements, or together we can develop a device to meet your specifications.

DRAWING AND PART NUMBER EXPLANATION



1250 V-062-075			
Meaning:	1.250 inches in diameter	0.62 inches in axial length	wound as a 7.5 Ω winding

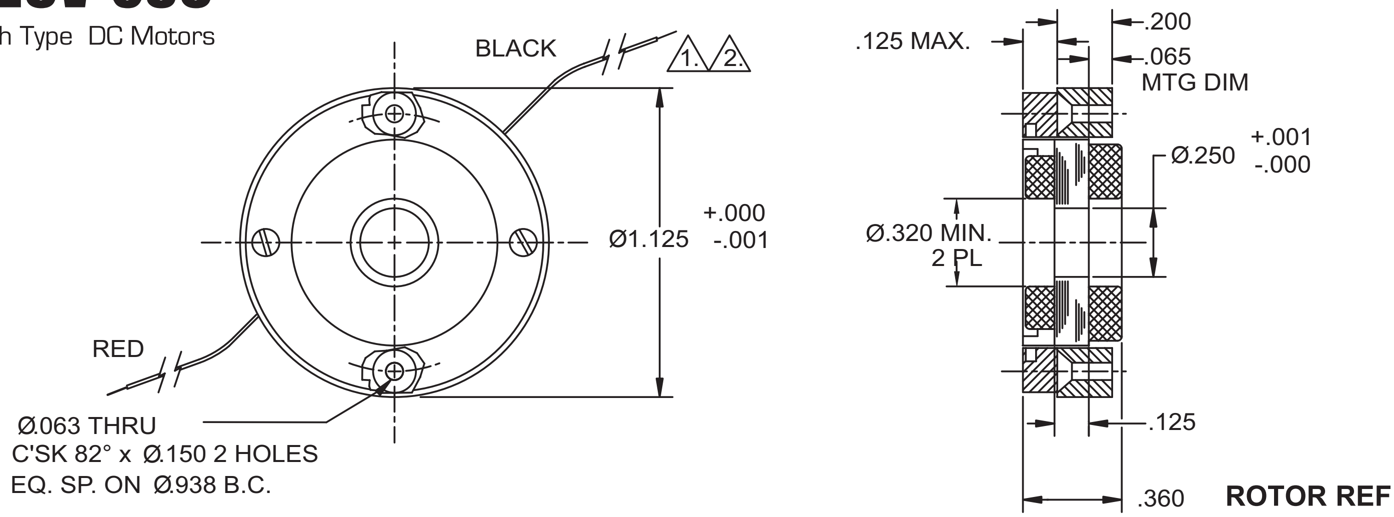
Selection Guide

Part Number:	Peak Torque @ Stall		Motor Constant	No Load Speed	Electrical Time Constant	Breakway Torque	Rotor Inertia	Thermal Resistance	Physical Dimensions			Weight
	T_P oz-in	P_P watts	K_M oz-in/√W	ωNL rad/sec	T_e millisec	T_F oz-in	J_M oz-in-sec²	θ_{th} °C/watt	OD in	ID in	L in	WT. oz
1125V-036	4	78	0.45	2638	0.12	0.25	.000068	45	1.125	0.250	0.360	0.8
1125V-071	12	95	1.23	1072	0.19	0.45	.00016	30	1.125	0.250	0.710	2
1250V-039	6	59	0.78	1323	0.09	0.45	.00012	41	1.250	0.375	0.390	1.1
1250V-062	12	68	1.45	767.8	0.11	0.55	.00022	32.4	1.250	0.375	0.620	2.1
1375V-039	11	52	1.53	633	0.14	0.60	.00034	35.6	1.375	0.500	0.390	1.4
1375V-062	22	68	2.67	416	0.19	0.75	.00061	27.5	1.375	0.500	0.615	2.5
1500V-040	14	79	1.58	757.6	0.13	0.65	.00044	31.6	1.500	0.625	0.400	1.5
1500V-062	28	93	2.91	447	0.19	0.85	.00077	24	1.500	0.625	0.620	2.7
1500V-085	42	121	3.81	389.5	0.22	1.1	.0011	18	1.500	0.625	0.850	3.9
1700V-045	16	66	2.0	554	0.20	0.8	.00082	30	1.700	0.800	0.450	1.9
1700V-090	48	95	4.92	266.6	0.28	1.2	.0019	16	1.700	0.800	0.900	4.8
2125V-072	70	109	6.72	208.2	0.28	2.4	.0039	17.1	2.125	1.125	0.720	5.3
2125V-097	105	143	8.77	183.2	0.31	3.0	.0055	13.3	2.125	1.125	0.970	7.6
2375V-096	120	140	10.14	156.8	0.42	3.0	.0075	12.1	2.375	1.250	0.960	9.5
2625V-044	45	51	6.30	153	0.36	1.5	.0059	16.2	2.625	1.375	0.440	4.4
2625V-069	90	69	10.83	103	0.48	2.0	.0103	12.1	2.625	1.375	0.690	7.9
2625V-094	135	70	16.11	69.8	0.56	2.5	.0147	9.7	2.625	1.375	0.940	11.5
2813V-046	55	73	6.44	189	0.34	2.5	.0105	15.1	2.813	1.500	0.460	6
2813V-096	165	85	17.88	69.2	0.62	3.5	.018	9.0	2.813	1.500	0.960	14.5
3000V-053	75	89	7.94	159.6	0.32	2.5	.01	13.5	3.000	1.750	0.530	6.5
3000V-083	150	98	15.13	88	0.39	3.5	.0175	9.7	3.000	1.750	0.830	11.5
3181V-091	200	187	14.61	126.3	0.34	5.0	.022	8.8	3.181	2.000	0.910	12.1
3375V-051	125	142	10.49	153	0.23	4.0	.0155	11.7	3.375	2.125	0.510	7.1
3375V-095	300	177	22.55	79.2	0.38	6.5	.035	7.4	3.375	2.125	0.950	16.3
3625V-054	150	154	12.08	138	0.37	4.5	.0228	10.1	3.625	2.250	0.540	8.5
3625V-084	300	184	22.13	82.5	0.41	6.5	.0396	7.3	3.625	2.250	0.840	15.5
3730V-115	525	321	29.29	82.3	0.39	9.5	.0554	5.7	3.730	2.400	1.150	22.8
4500V-056	325	248	20.64	102.8	0.59	8.0	.0593	6.9	4.500	2.750	0.560	14
4500V-086	650	275	39.19	56.8	0.78	12.0	.1013	5.2	4.500	2.750	0.860	24.6
4500V-146	1300	370	67.56	38.3	1.05	20.0	.1854	3.5	4.500	2.750	1.460	46.5
5125V-058	400	245	25.55	86.7	0.46	12.0	.151	5.7	5.125	3.500	0.580	22
5125V-088	800	248	50.84	41.6	0.76	16.0	.1758	4.3	5.125	3.500	0.880	28
5125V-148	1600	350	85.49	29.5	0.83	24.0	.3198	2.9	5.125	3.500	1.480	52

General Dynamics Ordnance and Tactical Systems designs custom components to meet a customer's specific requirements. Here are some standard Motors which may satisfy your requirements. Should you require a new design or modifications, please contact General Dynamics Ordnance and Tactical Systems.

1125V-036

Brush Type DC Motors



NOTES:

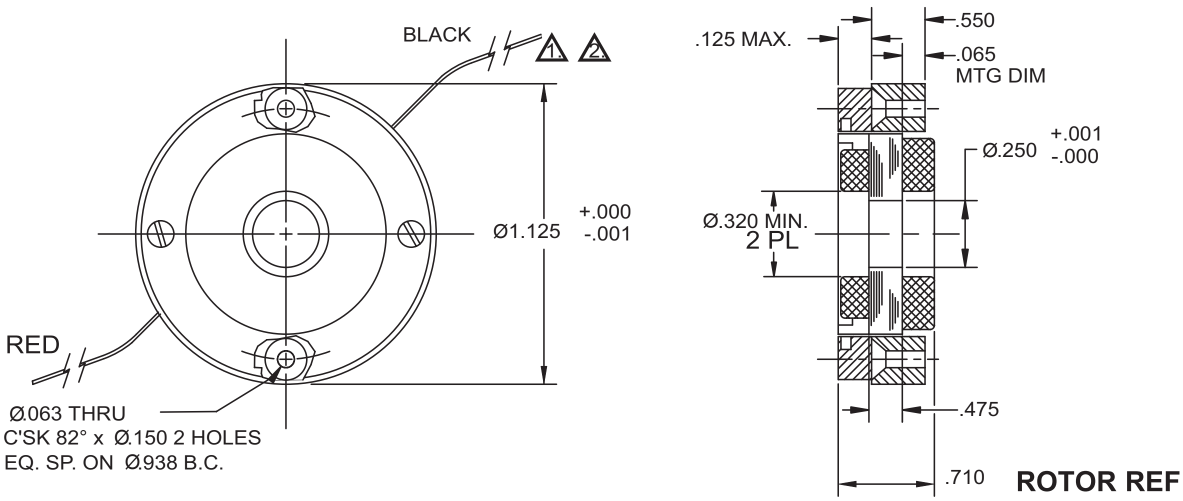
1. LEADS: #28 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	4
Power I^2R @Tp:	watts	P	78
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	0.45
Electrical Time Constant	ms	Te	0.12
Mechanical Time Constant	ms	Tm	47.02
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.001
Break Away Torque	oz-in	Tf	0.25
Rotor Inertia	oz-in-sec²	Jm	0.000068
Theoretical Acceleration @ Tp	rad/sec²	α_t	58824
Ripple Frequency	cycles/rev	f_R	13
Ripple Torque	% (ave to peak)	T_R	10
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	2638
Weight	oz	WT	0.8
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	45.0

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-011	-042	-098
Resistance	ohms	+/-12.5%	R	1.27	4.68	10.9
Inductance	mH	+/-30%	L	0.15	0.57	1.32
Torque Sensitivity	oz-in/A	+/-10%	Kt	0.51	0.98	1.5
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.004	0.007	0.011
Peak Voltage @ Tp	Volts	Nominal	Vp	10.0	19.1	29.1
Peak Current @ Tp	Amps	Nominal	Ip	7.84	4.08	2.67

1125V-071

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	12
Power I^2R @Tp:	watts	P	95
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	1.23
Electrical Time Constant	ms	Te	0.19
Mechanical Time Constant	ms	Tm	15.00
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.011
Break Away Torque	oz-in	Tf	0.45
Rotor Inertia	oz-in-sec^2	Jm	0.00016
Theoretical Acceleration @ Tp	rad/sec^2	α_t	75000
Ripple Frequency	cycles/rev	f_R	13
Ripple Torque	% (ave to peak)	T_R	10
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	1072.4
Weight	oz	WT	2.0
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	30.0

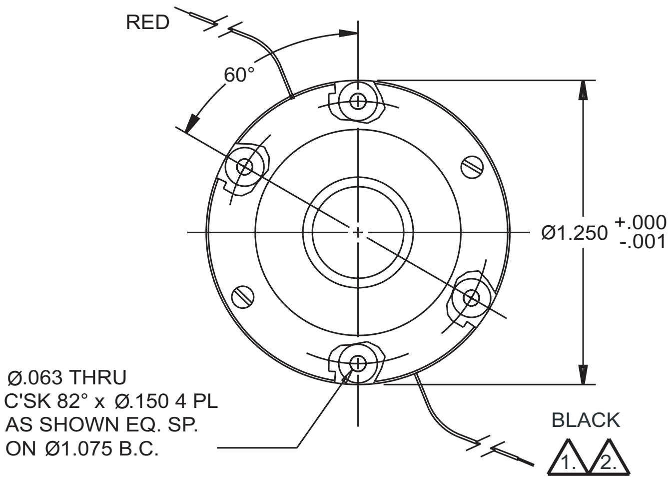
NOTES:

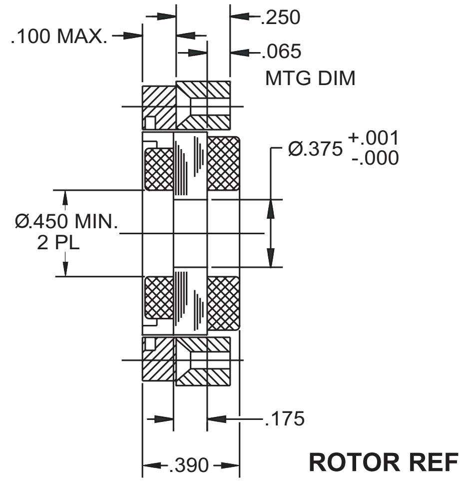
1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-011	-041	-100
Resistance	ohms	+/-12.5%	R	1.26	4.72	11.4
Inductance	mH	+/-30%	L	0.24	0.88	2.12
Torque Sensitivity	oz-in/A	+/-10%	Kt	1.38	2.67	4.15
Back EMF Constant:	V(rad/sec)	+/-10%	Kb	0.010	0.019	0.029
Peak Voltage @ Tp	Volts	Nominal	Vp	11.0	21.2	32.9
Peak Current @ Tp	Amps	Nominal	Ip	8.70	4.49	2.89

1250V-039

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	6
Power I²R @Tp:	watts	P	59
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	0.78
Electrical Time Constant	ms	Te	0.09
Mechanical Time Constant	ms	Tm	27.85
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.004
Break Away Torque	oz-in	Tf	0.45
Rotor Inertia	oz-in-sec²	Jm	0.00012
Theoretical Acceleration @ Tp	rad/sec²	α_t	50000
Ripple Frequency	cycles/rev	f_R	23
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	1322.9
Weight	oz	WT	1.1
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	41.0

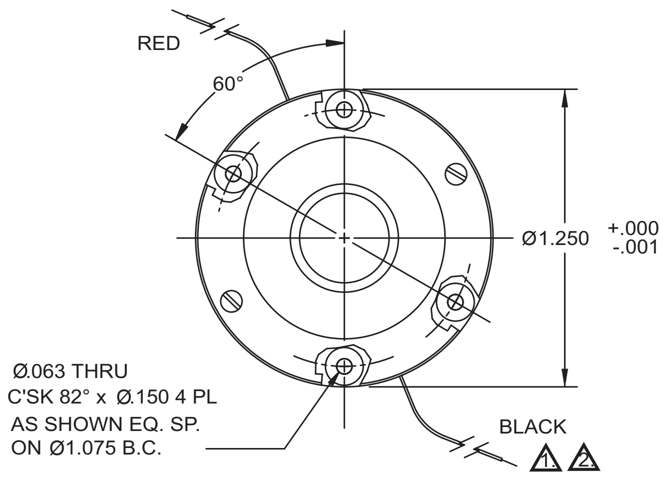
NOTES:

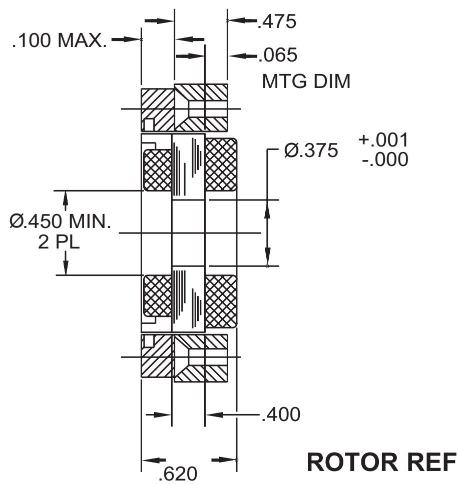
1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-022	-079	-213
Resistance	ohms	+/-12.5%	R	2.36	8.40	21.7
Inductance	mH	+/-30%	L	0.21	0.74	1.93
Torque Sensitivity	oz-in/A	+/-10%	Kt	1.20	2.26	3.64
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.008	0.016	0.026
Peak Voltage @ Tp	Volts	Nominal	Vp	11.8	22.3	35.8
Peak Current @ Tp	Amps	Nominal	Ip	5.00	2.65	1.65

1250V-062

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	12
Power I^2R @Tp:	watts	P	68
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	1.45
Electrical Time Constant	ms	Te	0.11
Mechanical Time Constant	ms	Tm	14.78
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.015
Break Away Torque	oz-in	Tf	0.55
Rotor Inertia	oz-in-sec^2	Jm	0.00022
Theoretical Acceleration @ Tp	rad/sec^2	α_t	54545
Ripple Frequency	cycles/rev	f_R	23
Ripple Torque	%(ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	767.8
Weight	oz	WT	2.1
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	32.4

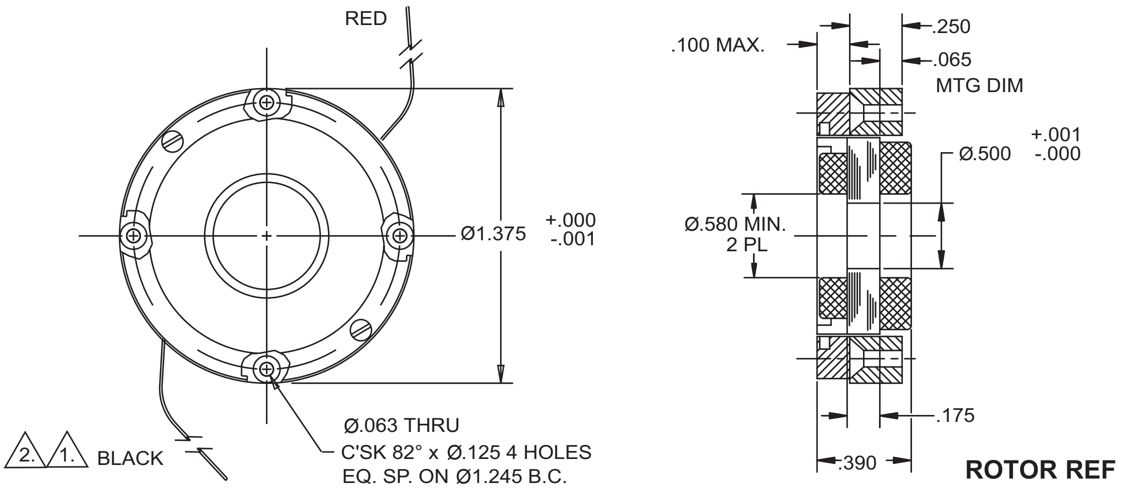
NOTES:

1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-019	-075	-176
Resistance	ohms	+/-12.5%	R	1.86	7.80	18.3
Inductance	mH	+/-30%	L	0.20	0.84	1.98
Torque Sensitivity	oz-in/A	+/-10%	Kt	1.98	4.05	6.21
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.014	0.029	0.044
Peak Voltage @ Tp	Volts	Nominal	Vp	11.3	23.1	35.3
Peak Current @ Tp	Amps	Nominal	Ip	6.06	2.96	1.93

1375V-039

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	11
Power I^2R @Tp:	watts	P	52
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	1.53
Electrical Time Constant	ms	Te	0.14
Mechanical Time Constant	ms	Tm	20.65
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.016
Break Away Torque	oz-in	Tf	0.60
Rotor Inertia	oz-in-sec²	Jm	0.00034
Theoretical Acceleration @ Tp	rad/sec²	α_t	32353
Ripple Frequency	cycles/rev	f_R	29
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	632.9
Weight	oz	WT	1.4
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr.	35.6

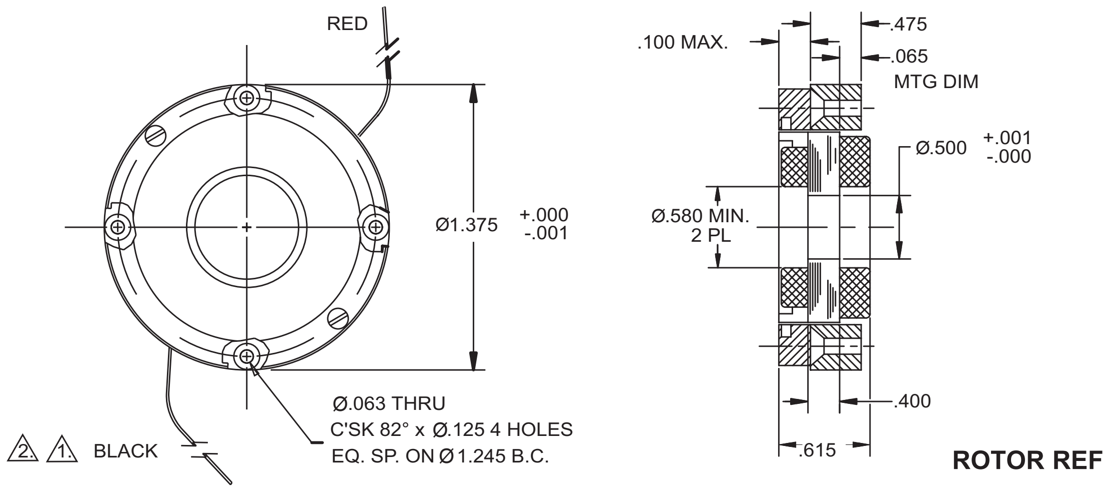
NOTES:

1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	UNITS	TOL.	Symbol	-046	-110	-264
Resistance	ohms	+/-12.5%	R	4.90	11.8	28.4
Inductance	mH	+/-30%	L	0.70	1.70	3.93
Torque Sensitivity	oz-in/A	+/-10%	Kt	3.38	5.25	8.14
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.024	0.037	0.057
Peak Voltage @ Tp	Volts	Nominal	Vp	15.9	24.8	38.3
Peak Current @ Tp	Amps	Nominal	Ip	3.25	2.10	1.35

1375V-062

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	22
Power I^2R @Tp:	watts	P	68
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	2.67
Electrical Time Constant	ms	Te	0.19
Mechanical Time Constant	ms	Tm	12.13
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.050
Break Away Torque	oz-in	Tf	0.75
Rotor Inertia	oz-in-sec^2	Jm	0.00061
Theoretical Acceleration @ Tp	rad/sec^2	α_t	36066
Ripple Frequency	cycles/rev	f_R	29
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	416.0
Weight	oz	WT	2.5
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	27.5

NOTES:

1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

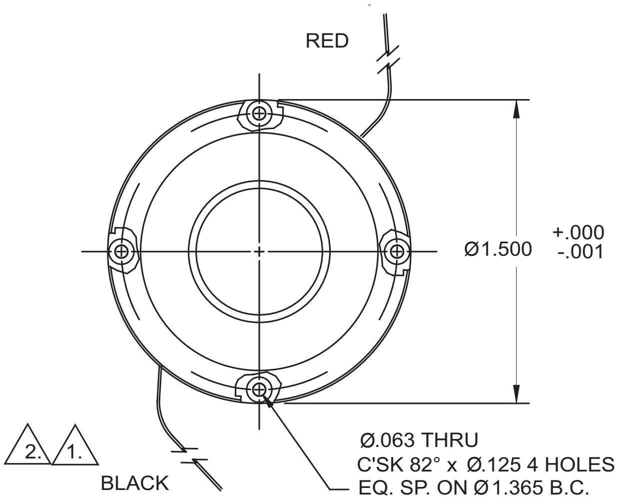
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

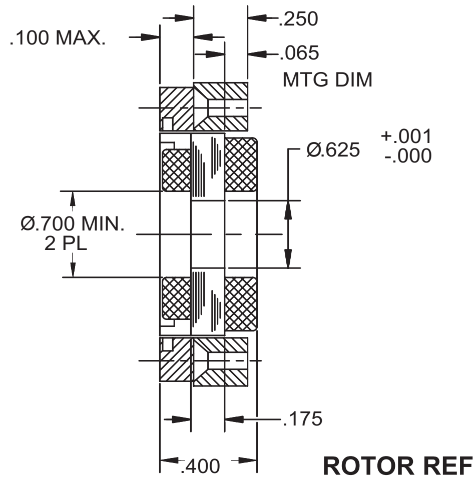
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-017	-064	-156
Resistance	ohms	+/-12.5%	R	1.81	6.72	16.4
Inductance	mH	+/-30%	L	0.34	1.25	3.10
Torque Sensitivity	oz-in/A	+/-10%	Kt	3.59	6.92	10.8
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.025	0.049	0.076
Peak Voltage @ Tp	Volts	Nominal	Vp	11.1	21.4	33.5
Peak Current @ Tp	Amps	Nominal	Ip	6.13	3.18	2.04

1500V-040

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	14
Power I^2R @Tp:	watts	P	79
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	1.58
Electrical Time Constant	ms	Te	0.13
Mechanical Time Constant	ms	Tm	25.03
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.018
Break Away Torque	oz-in	Tf	0.65
Rotor Inertia	oz-in-sec^2	Jm	0.00044
Theoretical Acceleration @ Tp	rad/sec^2	α_t	31818
Ripple Frequency	cycles/rev	f_R	29
Ripple Torque	%(ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	757.6
Weight	oz	WT	1.5
Maximum Allowable Temperature	°C(at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	31.6

NOTES:

1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

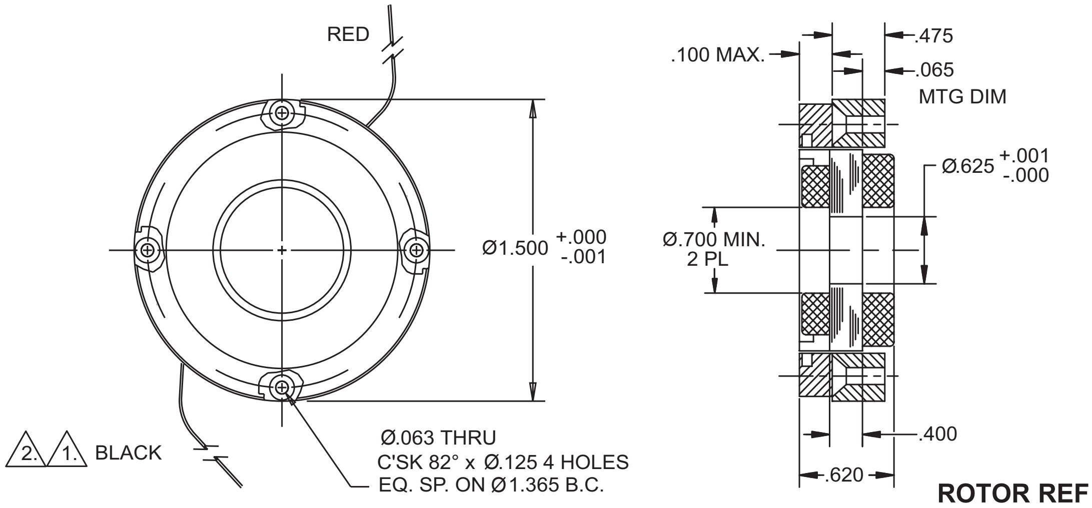
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-013	-049	-121
Resistance	ohms	+/-12.5%	R	1.45	5.41	13.7
Inductance	mH	+/-30%	L	0.19	0.70	1.79
Torque Sensitivity	oz-in/A	+/-10%	Kt	1.90	3.67	5.84
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.013	0.026	0.041
Peak Voltage @ Tp	Volts	Nominal	Vp	10.7	20.6	32.9
Peak Current @ Tp	Amps	Nominal	Ip	7.37	3.81	2.40

1500V-062

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	28
Power I^2R @Tp:	watts	P	93
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	2.91
Electrical Time Constant	ms	Te	0.19
Mechanical Time Constant	ms	tm	12.9
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.060
Break Away Torque	oz-in	Tf	0.85
Rotor Inertia	oz-in-sec^2	Jm	0.00077
Theoretical Acceleration @ Tp	rad/sec^2	α_t	36364
Ripple Frequency	cycles/rev	f_R	29
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	447.1
Weight	oz	WT	2.7
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	24.0

NOTES:

1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

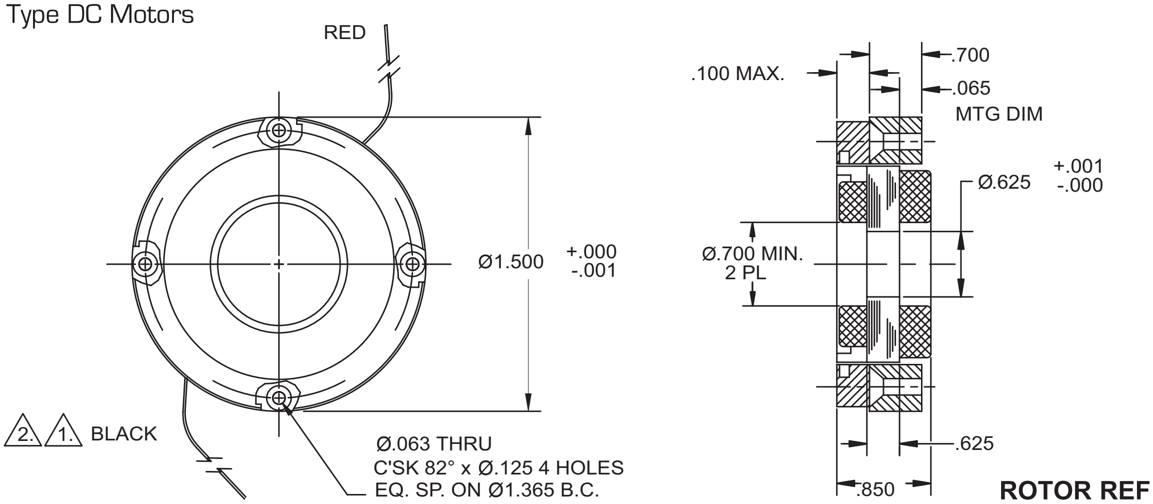
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-012	-043	-105
Resistance	ohms	+/-12.5%	R	1.25	4.77	11.3
Inductance	mH	+/-30%	L	0.24	0.92	2.17
Torque Sensitivity	oz-in/A	+/-10%	Kt	3.25	6.35	9.77
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.023	0.045	0.069
Peak Voltage @ Tp	Volts	Nominal	Vp	10.8	21.0	32.4
Peak Current @ Tp	Amps	Nominal	Ip	8.59	4.41	2.87

1500V-085

Brush Type DC Motors



Size Constants:	Units	Symbol	Value
	(all values at 25° C ambient temperature)		
Peak Torque, stalled @Vp:	oz-in	Tp	42
Power I^2R @Tp:	watts	P	121
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	3.81
Electrical Time Constant	ms	Te	0.22
Mechanical Time Constant	ms	tm	10.71
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.103
Break Away Torque	oz-in	Tf	1.1
Rotor Inertia	oz-in-sec^2	Jm	0.0011
Theoretical Acceleration @ Tp	rad/sec^2	α_t	38182
Ripple Frequency	cycles/rev	f_R	29
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	389.5
Weight	oz	WT	3.9
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	18.0

NOTES:

1. LEADS: #26 AWG TYPE “ET” TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

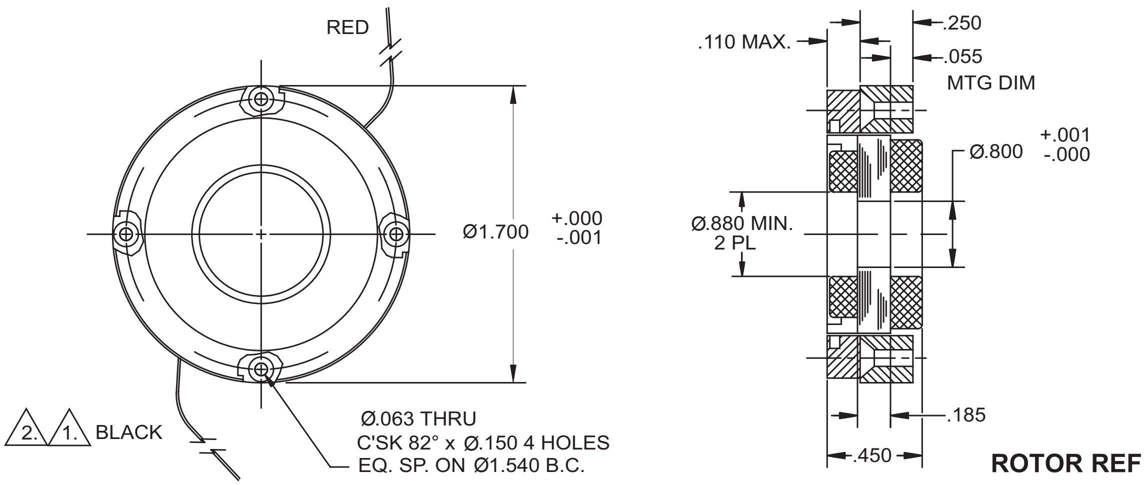
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	Units	TOL.	Symbol	-015	-034	-084
	(all values at 25° C ambient temperature)					
Resistance	ohms	+/-12.5%	R	1.63	3.88	9.62
Inductance	mH	+/-30%	L	0.36	0.85	2.14
Torque Sensitivity	oz-in/A	+/-10%	Kt	4.87	7.51	11.83
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.034	0.053	0.084
Peak Voltage @ Tp	Volts	Nominal	Vp	14.1	21.7	34.2
Peak Current @ Tp	Amps	Nominal	Ip	8.62	5.59	3.55

1700V-045

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	16
Power I^2R @Tp:	watts	P	66
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	2.00
Electrical Time Constant	ms	Te	0.20
Mechanical Time Constant	ms	Tm	29.94
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.027
Break Away Torque	oz-in	Tf	0.8
Rotor Inertia	oz-in-sec^2	Jm	0.00082
Theoretical Acceleration @ Tp	rad/sec^2	α_t	19512
Ripple Frequency	cycles/rev	f_R	31
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	554.1
Weight	oz	WT	1.9
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	30.0

NOTES:

1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

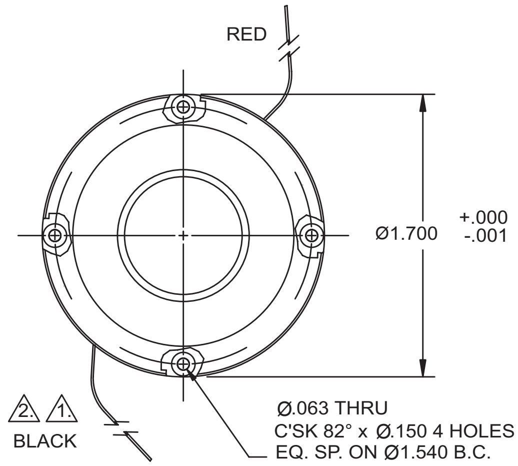
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

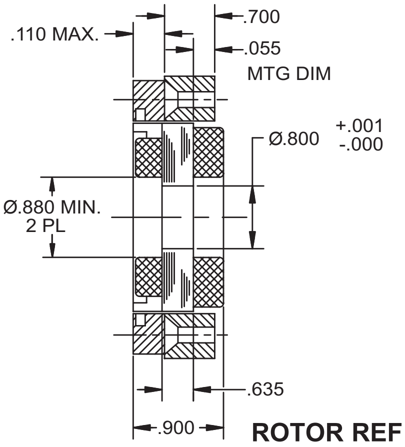
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-054	-137	-319
Resistance	ohms	+/-12.5%	R	5.72	14.3	34.1
Inductance	mH	+/-30%	L	1.13	2.88	6.70
Torque Sensitivity	oz-in/A	+/-10%	Kt	4.71	7.45	11.5
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.033	0.053	0.081
Peak Voltage @ Tp	Volts	Nominal	Vp	19.4	30.7	47.4
Peak Current @ Tp	Amps	Nominal	Ip	3.40	2.15	1.39

1700V-090

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	48
Power I^2R @Tp:	watts	P	95
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	4.92
Electrical Time Constant	ms	Te	0.28
Mechanical Time Constant	ms	Tm	11.12
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.171
Break Away Torque	oz-in	Tf	1.2
Rotor Inertia	oz-in-sec^2	Jm	0.0019
Theoretical Acceleration @ Tp	rad/sec^2	α_t	25263
Ripple Frequency	cycles/rev	f_R	31
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	266.6
Weight	oz	WT	4.8
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	16.0

NOTES:

1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

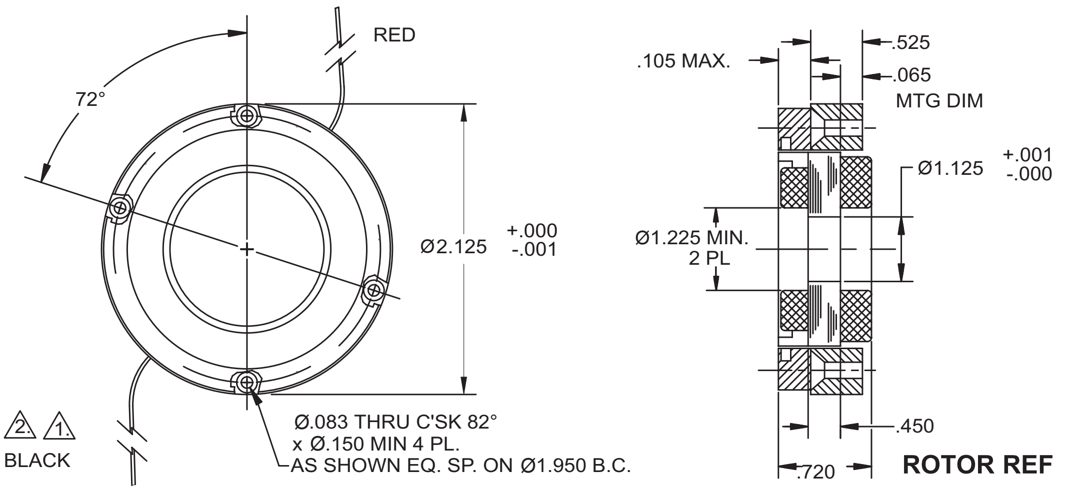
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-038	-090	-229
Resistance	ohms	+/-12.5%	R	4.00	9.54	23.8
Inductance	mH	+/-30%	L	1.13	2.67	6.71
Torque Sensitivity	oz-in/A	+/-10%	Kt	9.84	15.2	24.0
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.069	0.107	0.169
Peak Voltage @ Tp	Volts	Nominal	Vp	19.5	30.1	47.6
Peak Current @ Tp	Amps	Nominal	Ip	4.88	3.16	2.00

2125V-072

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	70
Power I^2R @Tp:	watts	P	109
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	6.72
Electrical Time Constant	ms	Te	0.28
Mechanical Time Constant	ms	Tm	12.24
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.319
Break Away Torque	oz-in	Tf	2.4
Rotor Inertia	oz-in-sec^2	Jm	0.0039
Theoretical Acceleration @ Tp	rad/sec^2	α_t	17949
Ripple Frequency	cycles/rev	f_R	41
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	208.2
Weight	oz	WT	5.3
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	17.1

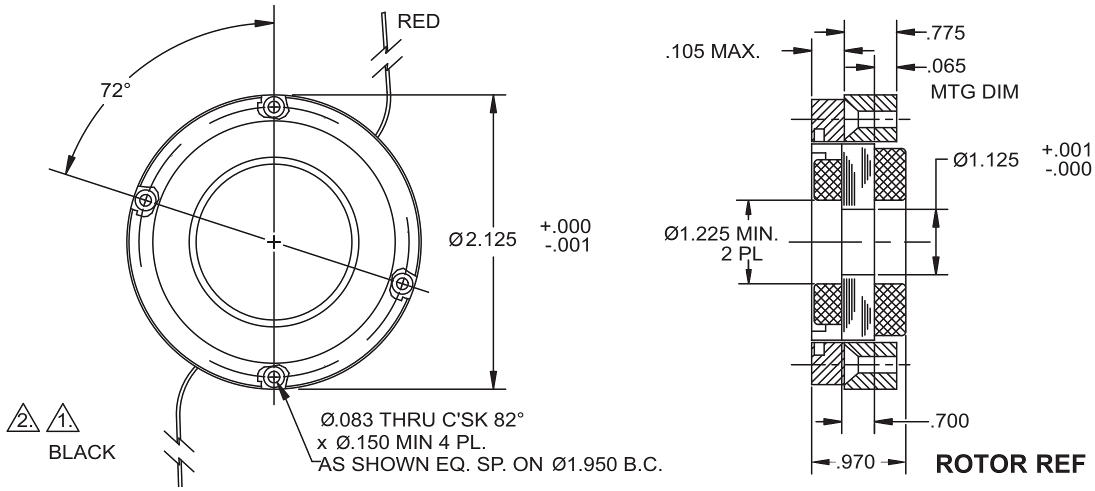
NOTES:

1. LEADS: #24 AWG TYPE “ET” TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-019	-069	-173
Resistance	ohms	+/-12.5%	R	2.00	7.34	17.9
Inductance	mH	+/-30%	L	0.56	2.07	5.05
Torque Sensitivity	oz-in/A	+/-10%	Kt	9.50	18.2	28.4
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.067	0.129	0.201
Peak Voltage @ Tp	Volts	Nominal	Vp	14.7	28.3	44.0
Peak Current @ Tp	Amps	Nominal	Ip	7.37	3.85	2.46

2125V-097

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	105
Power I^2R @Tp:	watts	P	143
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	8.77
Electrical Time Constant	ms	Te	0.31
Mechanical Time Constant	ms	Tm	10.13
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.543
Break Away Torque	oz-in	Tf	3.0
Rotor Inertia	oz-in-sec^2	Jm	0.0055
Theoretical Acceleration @ Tp	rad/sec^2	α_t	19091
Ripple Frequency	cycles/rev	f_R	41
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	183.2
Weight	oz	WT	7.6
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	13.3

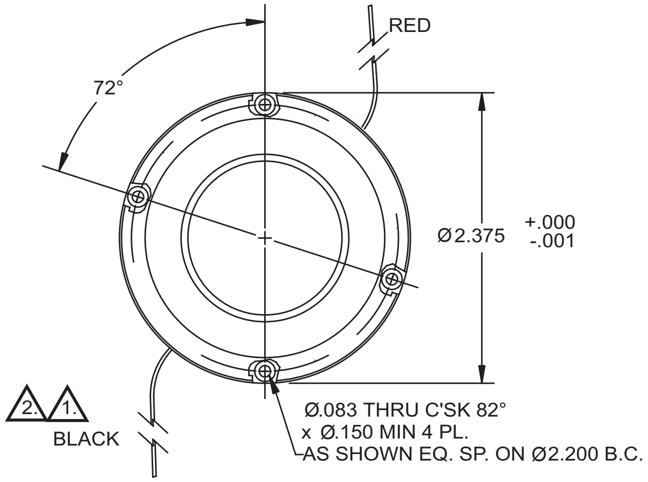
NOTES:

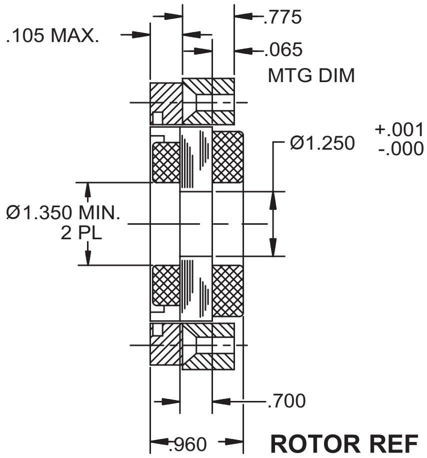
1. LEADS: #24 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-016	-056	-130
Resistance	ohms	+/-12.5%	R	1.75	6.07	13.4
Inductance	mH	+/-30%	L	0.54	1.89	4.15
Torque Sensitivity	oz-in/A	+/-10%	Kt	11.6	21.6	32.1
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.082	0.153	0.227
Peak Voltage @ Tp	Volts	Nominal	Vp	15.8	29.5	43.8
Peak Current @ Tp	Amps	Nominal	Ip	9.05	4.86	3.27

2375V-096

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	120
Power I^2R @Tp:	watts	P	140
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	10.14
Electrical Time Constant	ms	Te	0.42
Mechanical Time Constant	ms	Tm	10.33
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.726
Break Away Torque	oz-in	Tf	3.0
Rotor Inertia	oz-in-sec^2	Jm	0.0075
Theoretical Acceleration @ Tp	rad/sec^2	α_t	16000
Ripple Frequency	cycles/rev	f_R	41
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	156.8
Weight	oz	WT	9.5
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	12.1

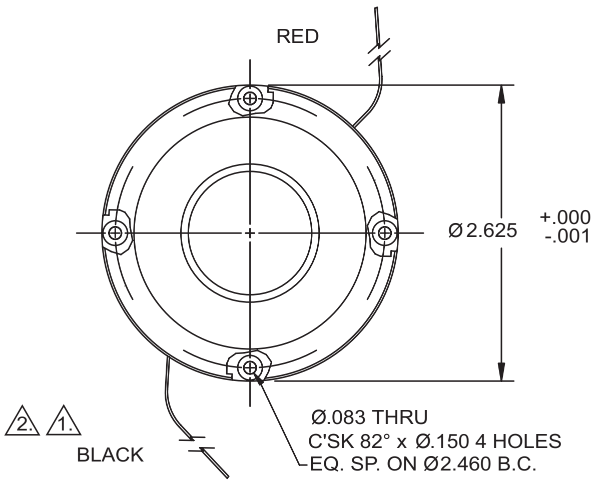
NOTES:

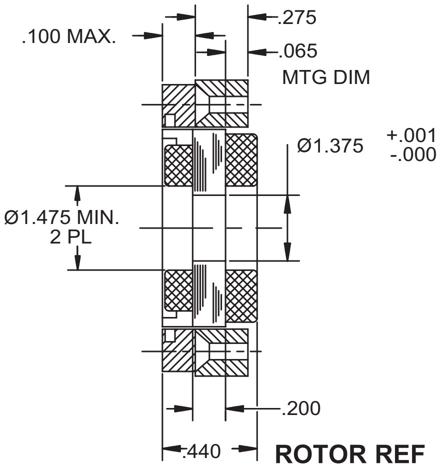
1. LEADS: #24 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-018	-065	-149
Resistance	ohms	+/-12.5%	R	1.88	7.09	16.1
Inductance	mH	+/-30%	L	0.79	2.98	6.76
Torque Sensitivity	oz-in/A	+/-10%	Kt	13.9	27.0	40.7
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.098	0.191	0.287
Peak Voltage @ Tp	Volts	Nominal	Vp	16.2	31.5	47.5
Peak Current @ Tp	Amps	Nominal	Ip	8.63	4.44	2.95

2625V-044

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	45
Power I^2R @Tp:	watts	P	51
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	6.30
Electrical Time Constant	ms	Te	0.36
Mechanical Time Constant	ms	Tm	21.05
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.280
Break Away Torque	oz-in	Tf	1.5
Rotor Inertia	oz-in-sec^2	Jm	0.0059
Theoretical Acceleration @ Tp	rad/sec^2	α_t	7627
Ripple Frequency	cycles/rev	f_R	49
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	152.9
Weight	oz	WT	4.4
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	16.2

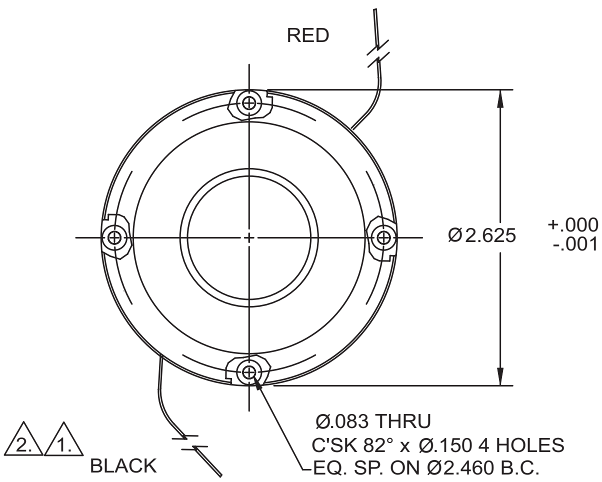
NOTES:

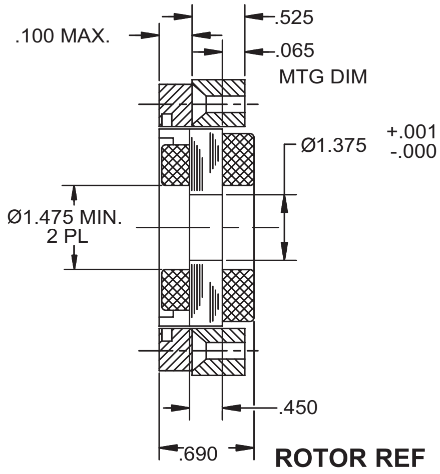
1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)						
	Units	TOL.	Symbol	-039	-090	-141	-226
Resistance	omhs	+/-12.5%	R	4.39	10.1	15.5	24.7
Inductance	mH	+/-30%	L	1.58	3.64	5.58	8.90
Torque Sensitivity	oz-in/A	+/-10%	Kt	13.2	20.0	24.8	31.3
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.093	0.141	0.175	0.221
Peak Voltage @ Tp	Volts	Nominal	Vp	15.0	22.7	28.1	35.6
Peak Current @ Tp	Amps	Nominal	Ip	3.41	2.25	1.81	1.44

2625V-069

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	90
Power I²R @Tp:	watts	P	69
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	10.83
Electrical Time Constant	ms	Te	0.48
Mechanical Time Constant	ms	Tm	12.42
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.829
Break Away Torque	oz-in	Tf	2.0
Rotor Inertia	oz-in-sec²	Jm	0.0103
Theoretical Acceleration @ Tp	rad/sec²	α_t	8738
8738Ripple Frequency	cycles/rev	f_R	49
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	103
Weight	oz	WT	7.9
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	12.1

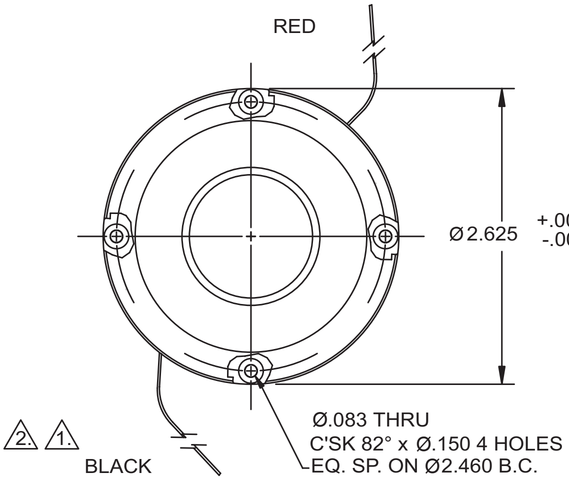
NOTES:

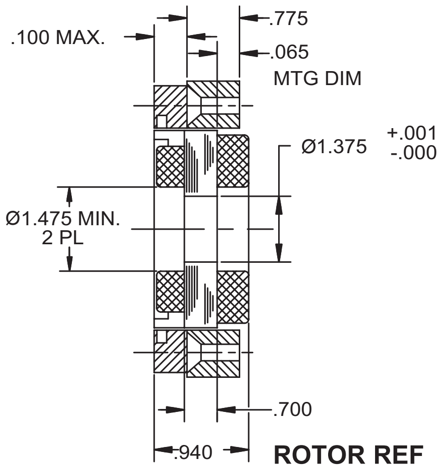
1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-033	-091	-192
Resistance	ohms	+/-12.5%	R	3.65	9.06	21.3
Inductance	mH	+/-30%	L	1.77	4.35	10.2
Torque Sensitivity	oz-in/A	+/-10%	Kt	20.7	32.6	50.0
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.146	0.230	0.353
Peak Voltage @ Tp	Volts	Nominal	Vp	15.9	25.0	38.3
Peak Current @ Tp	Amps	Nominal	Ip	4.35	2.76	1.80

2625V-094

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	135
Power I^2R @Tp:	watts	P	70
Continuous Stall Torque	oz-in	Tcs	36.4
Motor Constant	oz-in/$\sqrt{W}$	Km	16.11
Electrical Time Constant	ms	Te	0.56
Mechanical Time Constant	ms	Tm	8.02
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	1.833
Break Away Torque	oz-in	Tf	2.5
Rotor Inertia	oz-in-sec^2	Jm	0.0147
Theoretical Acceleration @ Tp	rad/sec^2	α_t	9184
Ripple Frequency	cycles/rev	f_R	49
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	69.8
Weight	oz	WT	11.5
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	9.7

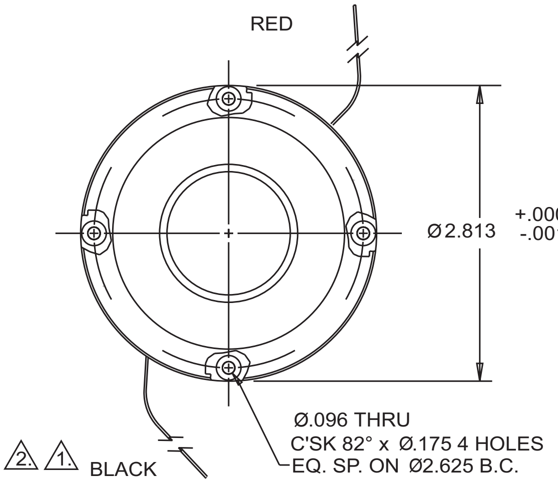
NOTES:

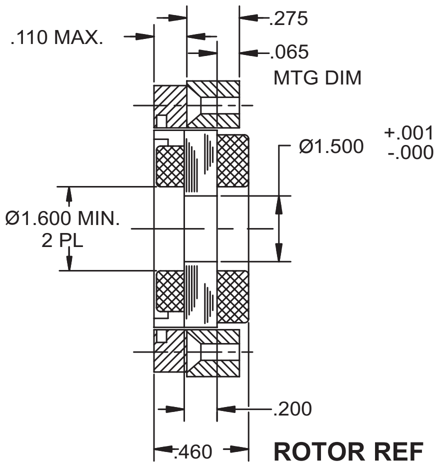
1. LEADS: #26 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-012	-042	-102
Resistance	ohms	+/-12.5%	R	1.29	4.40	10.5
Inductance	mH	+/-30%	L	0.72	2.47	5.90
Torque Sensitivity	oz-in/A	+/-10%	Kt	18.3	33.8	52.2
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.129	0.239	0.369
Peak Voltage @ Tp	Volts	Nominal	Vp	9.6	17.6	27.2
Peak Current @ Tp	Amps	Nominal	Ip	7.38	4.00	2.59

2813V-046

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	55
Power I^2R @Tp:	watts	P	73
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	6.44
Electrical Time Constant	ms	Te	0.34
Mechanical Time Constant	ms	Tm	36
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.293
Break Away Torque	oz-in	Tf	2.5
Rotor Inertia	oz-in-sec^2	Jm	0.0105
Theoretical Acceleration @ Tp	rad/sec^2	α_t	5238
Ripple Frequency	cycles/rev	f_R	49
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	189
Weight	oz	WT	6.0
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	15.1

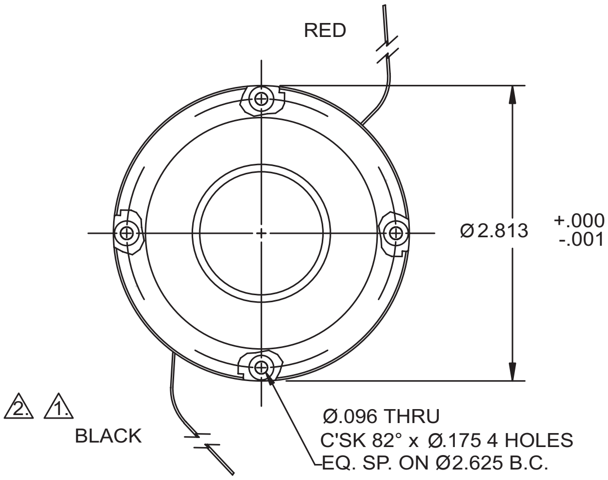
NOTES:

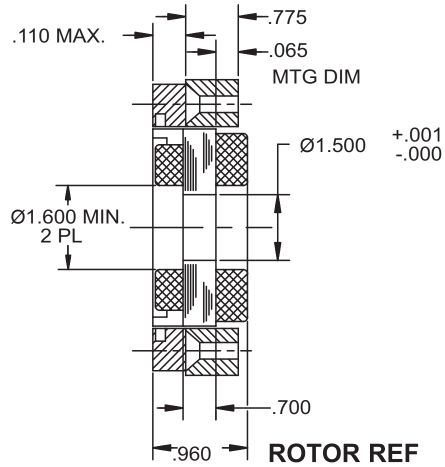
1. LEADS: #24 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-008	-029	-069
Resistance	ohms	+/-12.5%	R	1.03	3.53	8.61
Inductance	mH	+/-30%	L	0.35	1.21	2.91
Torque Sensitivity	oz-in/A	+/-10%	Kt	6.54	12.1	18.9
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.046	0.085	0.133
Peak Voltage @ Tp	Volts	Nominal	Vp	8.66	16.1	25.1
Peak Current @ Tp	Amps	Nominal	Ip	8.41	4.55	2.91

2813V-096

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	165
Power I^2R @Tp:	watts	P	85
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	$oz\text{-}in/\sqrt{W}$	Km	17.88
Electrical Time Constant	ms	Te	0.62
Mechanical Time Constant	ms	Tm	7.98
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	2.257
Break Away Torque	oz-in	Tf	3.5
Rotor Inertia	$oz\text{-}in\text{-}sec^2$	Jm	0.018
Theoretical Acceleration @ Tp	rad/sec^2	α_t	9167
Ripple Frequency	cycles/rev	f_R	49
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	69.2
Weight	oz	WT	14.5
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	9.0

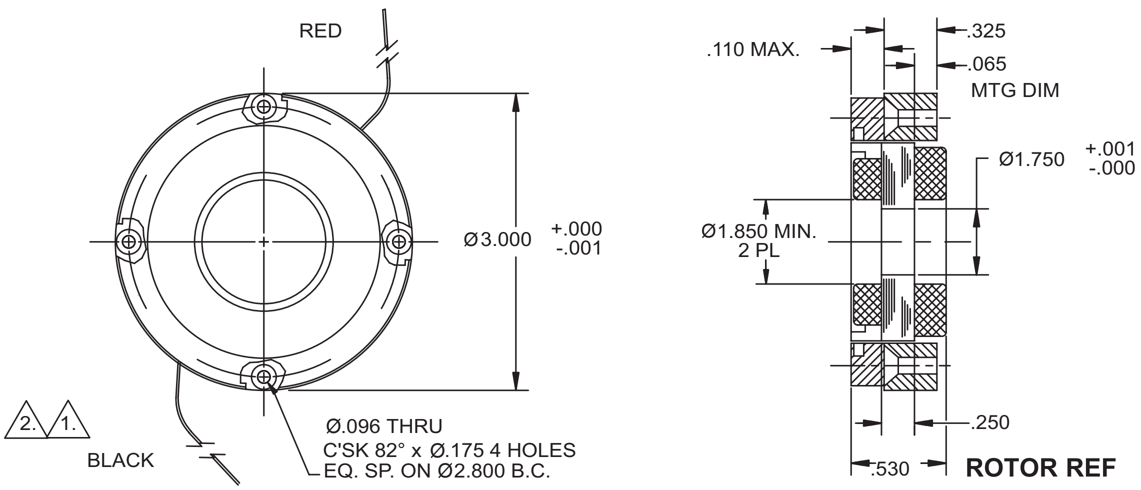
NOTES:

1. LEADS: #24 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-013	-048	-117
Resistance	ohms	+/-12.5%	R	1.38	5.13	12.1
Inductance	mH	+/-30%	L	0.9	3.18	7.50
Torque Sensitivity	oz-in/A	+/-10%	Kt	21.0	40.5	62.2
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.148	0.286	0.439
Peak Voltage @ Tp	Volts	Nominal	Vp	10.8	20.9	32.1
Peak Current @ Tp	Amps	Nominal	Ip	7.86	4.07	2.65

3000V-053

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	75
Power I^2R @Tp:	watts	P	89
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	7.94
Electrical Time Constant	ms	Te	0.32
Mechanical Time Constant	ms	Tm	22.47
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.445
Break Away Torque	oz-in	Tf	2.5
Rotor Inertia	oz-in-sec^2	Jm	0.01
Theoretical Acceleration @ Tp	rad/sec^2	α_t	7500
Ripple Frequency	cycles/rev	f_R	49
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	159.6
Weight	oz	WT	6.5
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	13.5

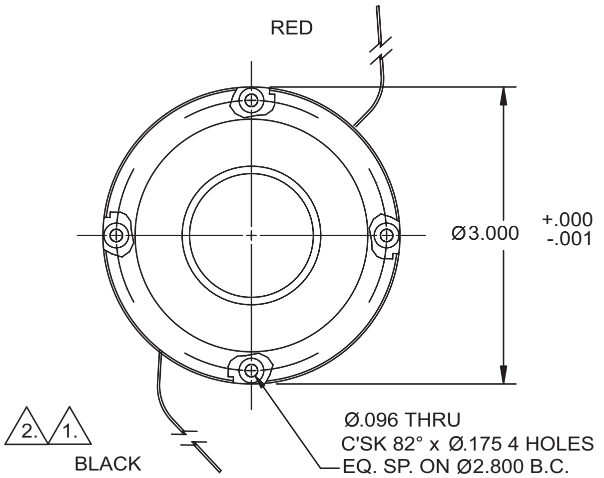
NOTES:

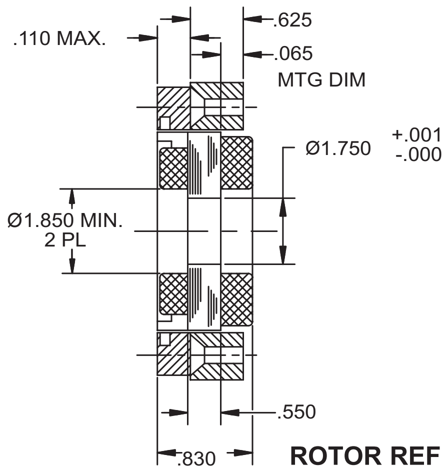
1. LEADS: #24 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-012	-045	-105
Resistance	ohms	+/-12.5%	R	1.34	4.86	11.4
Inductance	mH	+/-30%	L	0.43	1.57	3.67
Torque Sensitivity	oz-in/A	+/-10%	Kt	9.19	17.5	26.8
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.065	0.124	0.189
Peak Voltage @ Tp	Volts	Nominal	Vp	10.9	20.8	31.9
Peak Current @ Tp	Amps	Nominal	Ip	8.16	4.29	2.80

3000V-083

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	150
Power I^2R @Tp:	watts	P	98
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	15.13
Electrical Time Constant	ms	Te	0.39
Mechanical Time Constant	ms	Tm	10.82
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	1.617
Break Away Torque	oz-in	Tf	3.5
Rotor Inertia	oz-in-sec^2	Jm	0.0175
Theoretical Acceleration @ Tp	rad/sec^2	α_t	8571
Ripple Frequency	cycles/rev	f_R	49
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	88.1
Weight	oz	WT	11.5
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	9.7

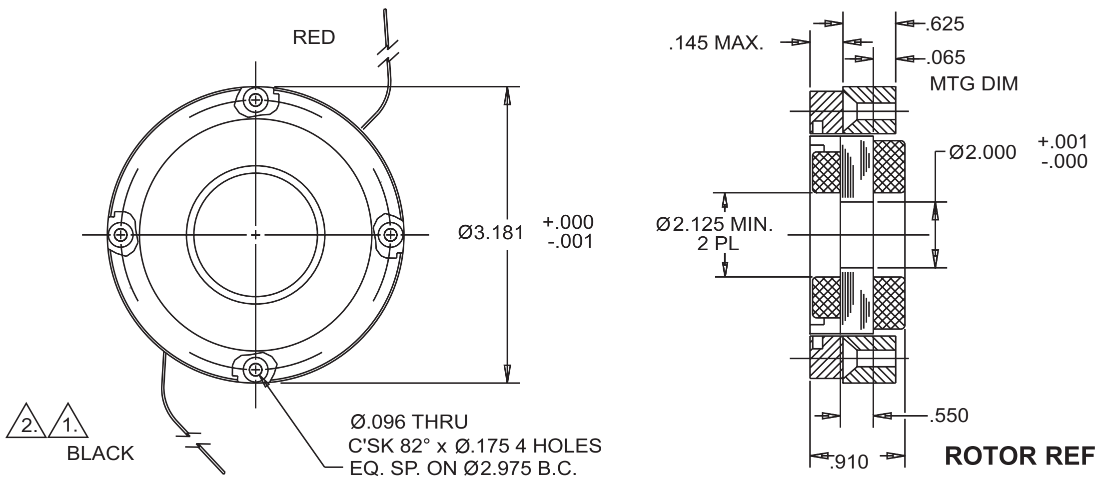
NOTES:

1. LEADS: #24 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-016	-038	-094
Resistance	ohms	+/-12.5%	R	1.80	4.17	10.4
Inductance	mH	+/-30%	L	0.70	1.62	4.04
Torque Sensitivity	oz-in/A	+/-10%	Kt	20.3	30.9	48.8
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.143	0.218	0.345
Peak Voltage @ Tp	Volts	Nominal	Vp	13.3	20.2	31.9
Peak Current @ Tp	Amps	Nominal	Ip	7.39	4.85	3.07

3181V-091

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	200
Power I^2R @Tp:	watts	P	187
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	14.61
Electrical Time Constant	ms	Te	0.34
Mechanical Time Constant	ms	Tm	14.6
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	1.507
Break Away Torque	oz-in	Tf	5.0
Rotor Inertia	oz-in-sec^2	Jm	0.022
Theoretical Acceleration @ Tp	rad/sec^2	α_t	9091
Ripple Frequency	cycles/rev	f_R	49
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	126.3
Weight	oz	WT	12.1
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	8.8

NOTES:

1. LEADS: #22 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

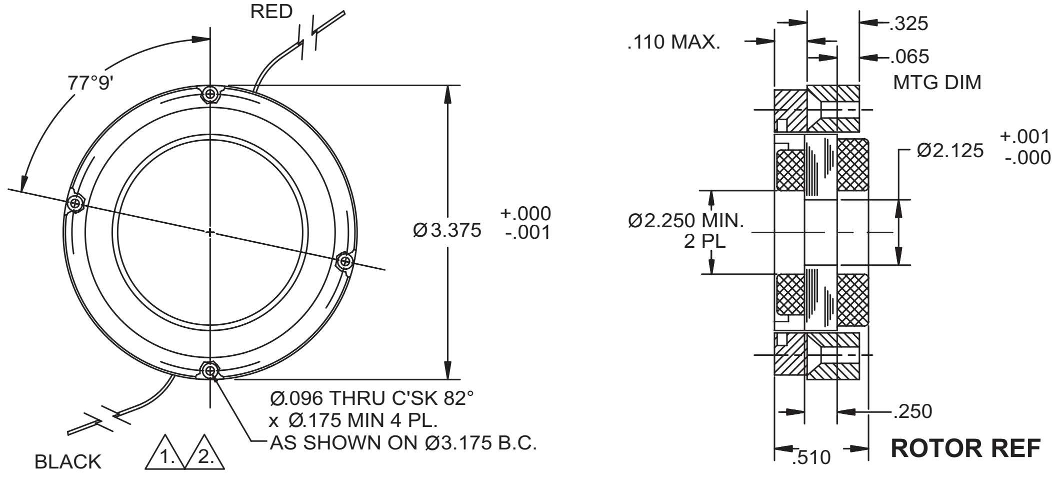
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-018	-068	-157
Resistance	ohms	+/-12.5%	R	1.80	6.62	14.7
Inductance	mH	+/-30%	L	0.61	2.25	4.97
Torque Sensitivity	oz-in/A	+/-10%	Kt	19.6	37.6	56.0
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.138	0.266	0.395
Peak Voltage @ Tp	Volts	Nominal	Vp	18.4	35.2	52.5
Peak Current @ Tp	Amps	Nominal	Ip	10.20	5.32	3.57

3375V-051

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	125
Power I²R @Tp:	watts	P	142
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	10.49
Electrical Time Constant	ms	Te	0.23
Mechanical Time Constant	ms	Tm	19.950
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	0.777
Break Away Torque	oz-in	Tf	4.0
Rotor Inertia	oz-in-sec²	Jm	0.0155
Theoretical Acceleration @ Tp	rad/sec²	α_t	8065
Ripple Frequency	cycles/rev	f_R	55
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	153.1
Weight	oz	WT	7.1
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	11.7

NOTES:

1. LEADS: #22 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

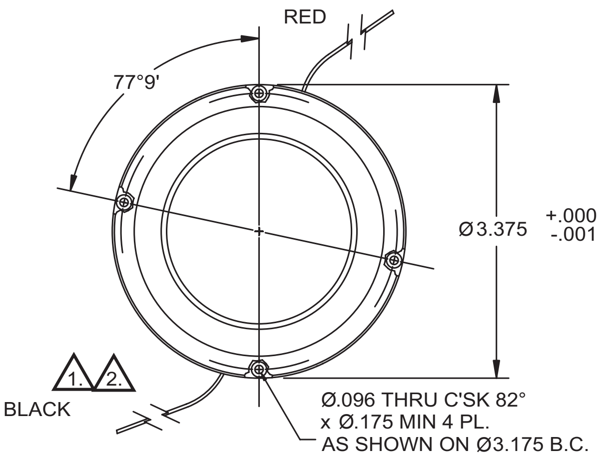
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

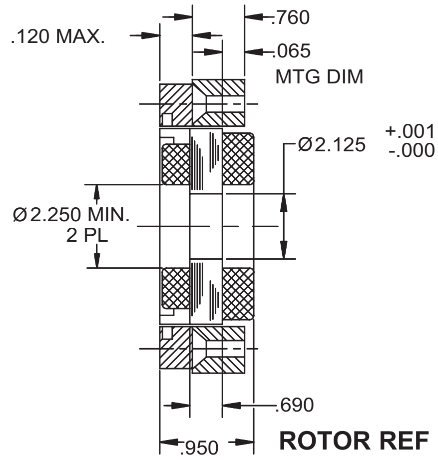
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-018	-045	-105
Resistance	ohms	+/-12.5%	R	2.10	4.64	11.9
Inductance	mH	+/-30%	L	0.49	1.07	2.76
Torque Sensitivity	oz-in/A	+/-10%	Kt	15.2	22.6	36.2
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.107	0.160	0.256
Peak Voltage @ Tp	Volts	Nominal	Vp	17.3	25.7	41.1
Peak Current @ Tp	Amps	Nominal	Ip	8.22	5.53	3.45

3375V-095

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	300
Power I^2R @Tp:	watts	P	177
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	22.55
Electrical Time Constant	ms	Te	0.38
Mechanical Time Constant	ms	Tm	9.75
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	3.589
Break Away Torque	oz-in	Tf	6.5
Rotor Inertia	oz-in-sec^2	Jm	0.035
Theoretical Acceleration @ Tp	rad/sec^2	α_t	8571
Ripple Frequency	cycles/rev	f_R	55
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	79.2
Weight	oz	WT	16.3
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	7.4

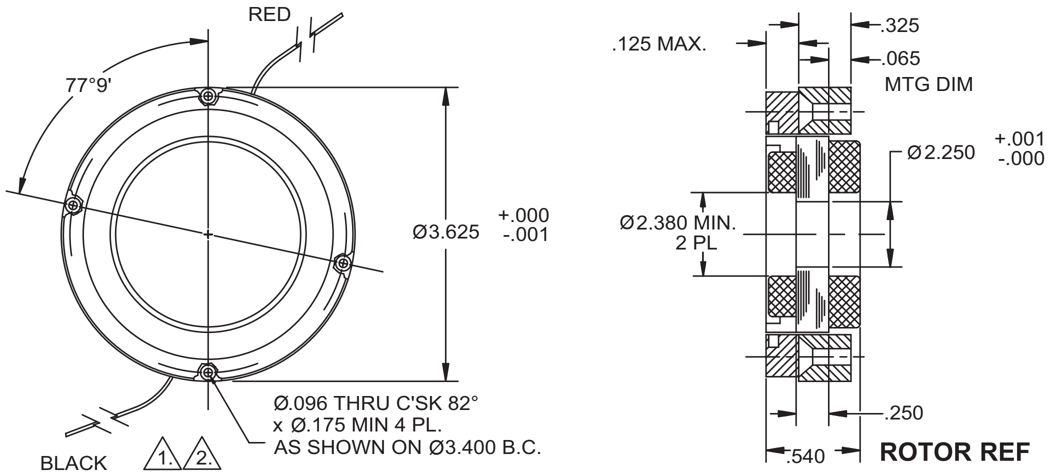
NOTES:

1. LEADS: #22 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-012	-045	-090
Resistance	ohms	+/-12.5%	R	1.35	4.42	9.47
Inductance	mH	+/-30%	L	0.46	1.68	3.60
Torque Sensitivity	oz-in/A	+/-10%	Kt	24.8	47.4	69.3
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.175	0.335	0.489
Peak Voltage @ Tp	Volts	Nominal	Vp	16.33	28	41.0
Peak Current @ Tp	Amps	Nominal	Ip	12.1	6.33	4.33

3625V-054

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	150
Power I²R @Tp:	watts	P	154
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	12.08
Electrical Time Constant	ms	Te	0.37
Mechanical Time Constant	ms	Tm	22.13
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	1.030
Break Away Torque	oz-in	Tf	4.5
Rotor Inertia	oz-in-sec²	Jm	0.0228
Theoretical Acceleration @ Tp	rad/sec²	α_t	6579
Ripple Frequency	cycles/rev	f_R	55
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	138.0
Weight	oz	WT	8.5
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	10.1

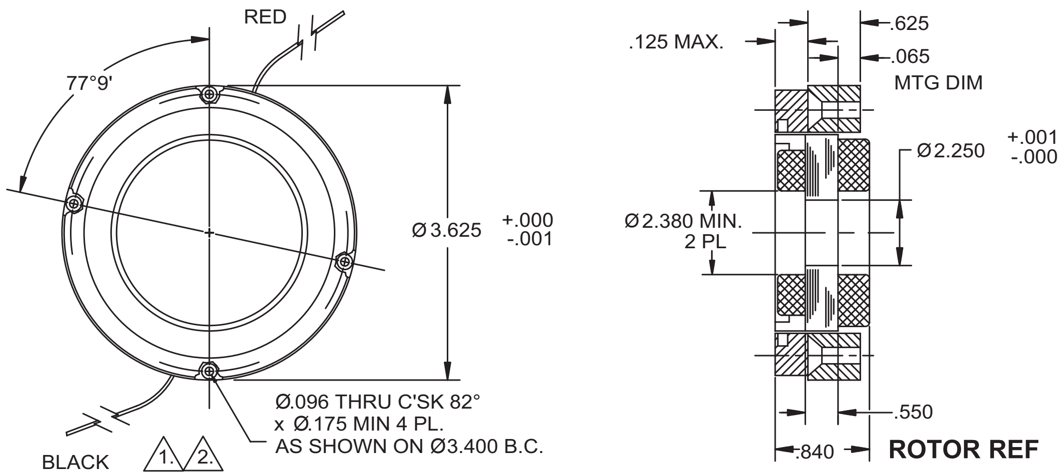
NOTES:

1. LEADS: #22 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-027	-063	-147
Resistance	ohms	+/-12.5%	R	2.58	6.04	14.0
Inductance	mH	+/-30%	L	0.96	2.23	5.18
Torque Sensitivity	oz-in/A	+/-10%	Kt	19.4	29.7	45.2
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.137	0.210	0.319
Peak Voltage @ Tp	Volts	Nominal	Vp	19.9	30.5	46.5
Peak Current @ Tp	Amps	Nominal	Ip	7.73	5.05	3.32

3625V-084

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	300
Power I^2R @Tp:	watts	P	184
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	22.13
Electrical Time Constant	ms	Te	0.41
Mechanical Time Constant	ms	Tm	11.45
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	3.458
Break Away Torque	oz-in	Tf	6.5
Rotor Inertia	oz-in-sec^2	Jm	0.0396
Theoretical Acceleration @ Tp	rad/sec^2	α_t	7576
Ripple Frequency	cycles/rev	f_R	55
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	82.5
Weight	oz	WT	15.5
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	7.3

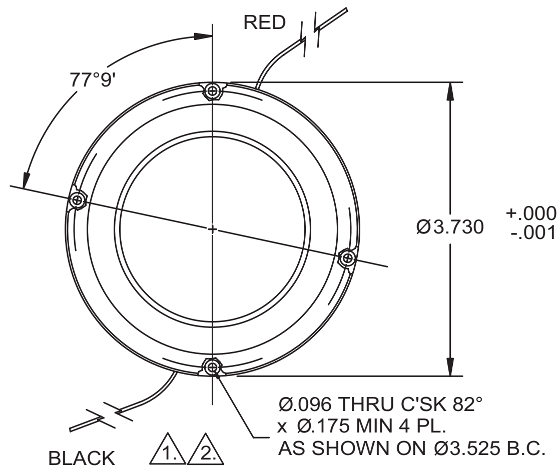
NOTES:

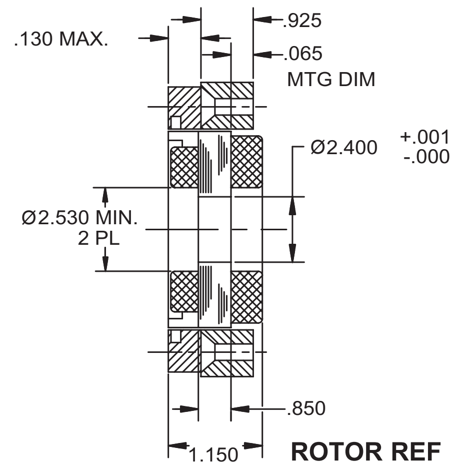
1. LEADS: #22 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-022	-053	-130
Resistance	ohms	+/-12.5%	R	2.17	5.25	13.0
Inductance	mH	+/-30%	L	0.89	2.14	5.32
Torque Sensitivity	oz-in/A	+/-10%	Kt	32.6	50.7	79.8
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.230	0.358	0.564
Peak Voltage @ Tp	Volts	Nominal	Vp	20.0	31.1	48.9
Peak Current @ Tp	Amps	Nominal	Ip	9.20	5.92	3.76

3730V-115

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	525
Power I^2R @Tp:	watts	P	321
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	29.29
Electrical Time Constant	ms	Te	0.39
Mechanical Time Constant	ms	Tm	9.15
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	6.056
Break Away Torque	oz-in	Tf	9.5
Rotor Inertia	oz-in-sec^2	Jm	0.0554
Theoretical Acceleration @ Tp	rad/sec^2	α_t	9477
Ripple Frequency	cycles/rev	f_R	55
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	82.3
Weight	oz	WT	22.8
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	5.7

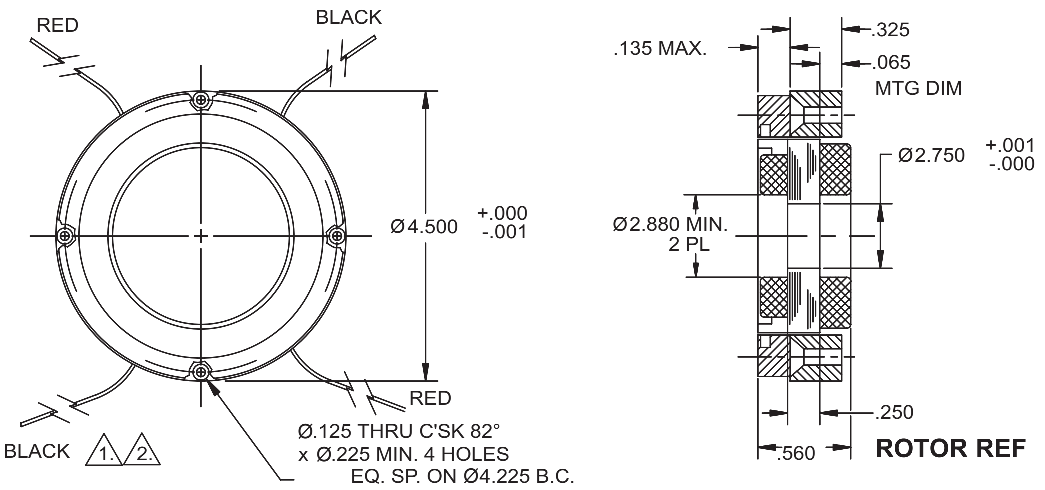
NOTES:

1. LEADS: #20 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-018	-041	-064
Resistance	ohms	+/-12.5%	R	1.81	4.10	6.59
Inductance	mH	+/-30%	L	0.71	1.59	2.56
Torque Sensitivity	oz-in/A	+/-10%	Kt	39.4	59.3	75.2
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.278	0.419	0.531
Peak Voltage @ Tp	Volts	Nominal	Vp	24.1	36.3	46.0
Peak Current @ Tp	Amps	Nominal	Ip	13.32	8.85	6.98

4500V-056

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	325
Power I^2R @Tp:	watts	P	248
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	20.64
Electrical Time Constant	ms	Te	0.59
Mechanical Time Constant	ms	Tm	19.7
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	3.009
Break Away Torque	oz-in	Tf	8.0
Rotor Inertia	oz-in-sec^2	Jm	0.0593
Theoretical Acceleration @ Tp	rad/sec^2	α_t	5481
Ripple Frequency	cycles/rev	f_R	65
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	102.8
Weight	oz	WT	14.0
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	6.9

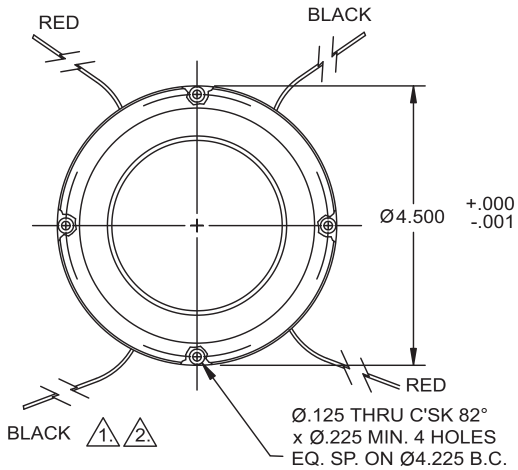
NOTES:

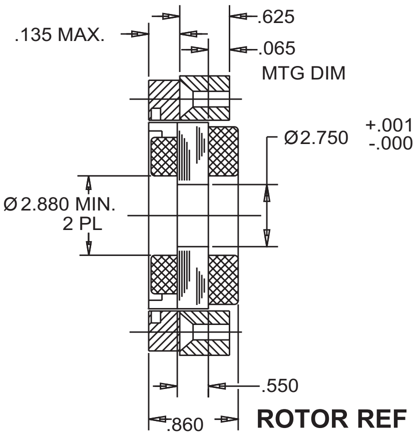
1. LEADS: #22 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)						
	Units	TOL.	Symbol	-013	-050	-082	-121
Resistance	ohms	+/-12.5%	R	1.42	5.43	8.59	12.1
Inductance	mH	+/-30%	L	0.84	3.19	5.04	7.10
Torque Sensitivity	oz-in/A	+/-10%	Kt	24.6	48.1	60.5	71.8
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.174	0.340	0.427	0.507
Peak Voltage @ Tp	Volts	Nominal	Vp	18.8	36.7	46.1	54.8
Peak Current @ Tp	Amps	Nominal	Ip	13.21	6.76	5.37	4.53

4500V-086

Brush Type DC Motors





Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	650
Power I^2R @Tp:	watts	P	275
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	39.19
Electrical Time Constant	ms	Te	0.78
Mechanical Time Constant	ms	Tm	9.34
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	10.847
Break Away Torque	oz-in	Tf	12.0
Rotor Inertia	oz-in-sec^2	Jm	0.1013
Theoretical Acceleration @ Tp	rad/sec^2	α_t	6417
Ripple Frequency	cycles/rev	f_R	65
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	56.8
Weight	oz	WT	24.6
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	5.2

NOTES:

1. LEADS: #22 AWG TYPE “ET” TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

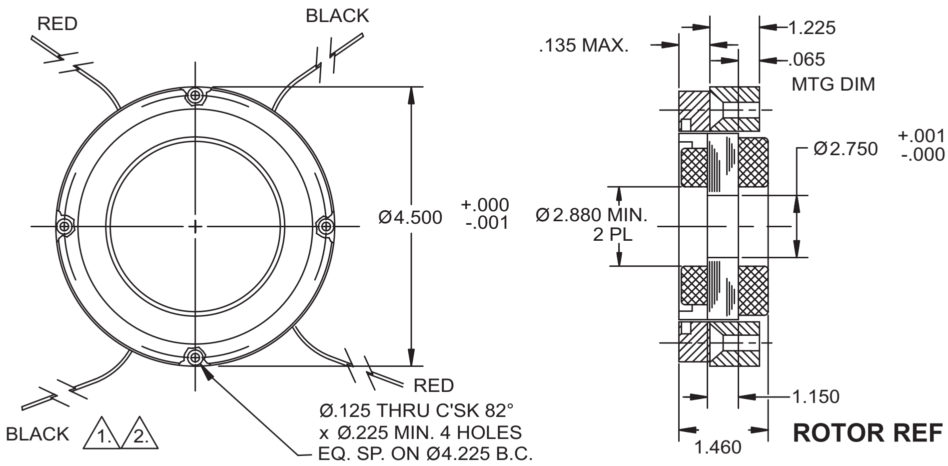
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-012	-028	-066
Resistance	ohms	+/-12.5%	R	1.33	3.10	6.68
Inductance	mH	+/-30%	L	1.04	2.43	5.24
Torque Sensitivity	oz-in/A	+/-10%	Kt	45.2	69.0	101.3
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.319	0.487	0.715
Peak Voltage @ Tp	Volts	Nominal	Vp	19.1	29.2	42.9
Peak Current @ Tp	Amps	Nominal	Ip	14.38	9.42	6.42

4500V-146

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	1300
Power I^2R @Tp:	watts	P	370
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	67.56
Electrical Time Constant	ms	Te	1.05
Mechanical Time Constant	ms	Tm	5.75
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	32.232
Break Away Torque	oz-in	Tf	20.0
Rotor Inertia	oz-in-sec^2	Jm	0.1854
Theoretical Acceleration @ Tp	rad/sec^2	α_t	7012
Ripple Frequency	cycles/rev	f_R	65
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	38.3
Weight	oz	WT	46.5
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	3.5

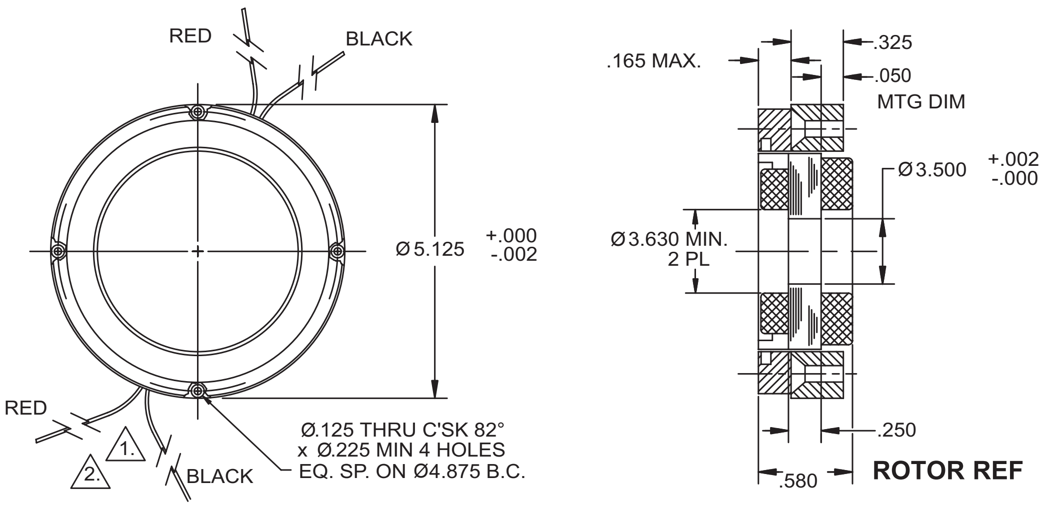
NOTES:

1. LEADS: #22 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)						
	Units	TOL.	Symbol	-011	-042	-066	-100
Resistance	ohms	+/-12.5%	R	1.19	4.38	6.42	10.2
Inductance	mH	+/-30%	L	1.25	4.60	6.74	10.7
Torque Sensitivity	oz-in/A	+/-10%	Kt	73.7	141.4	171.2	215.8
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.520	0.999	1.209	1.524
Peak Voltage @ Tp	Volts	Nominal	Vp	21.0	40.3	48.7	61.4
Peak Current @ Tp	Amps	Nominal	Ip	17.64	9.19	7.59	6.02

5125V-058

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	400
Power I^2R @Tp:	watts	P	245
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	25.55
Electrical Time Constant	ms	Te	0.46
Mechanical Time Constant	ms	Tm	32.7
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	4.61
Break Away Torque	oz-in	Tf	12.0
Rotor Inertia	oz-in-sec^2	Jm	0.151
Theoretical Acceleration @ Tp	rad/sec^2	α_t	2649
Ripple Frequency	cycles/rev	f_R	79
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	86.7
Weight	oz	WT	22
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	5.7

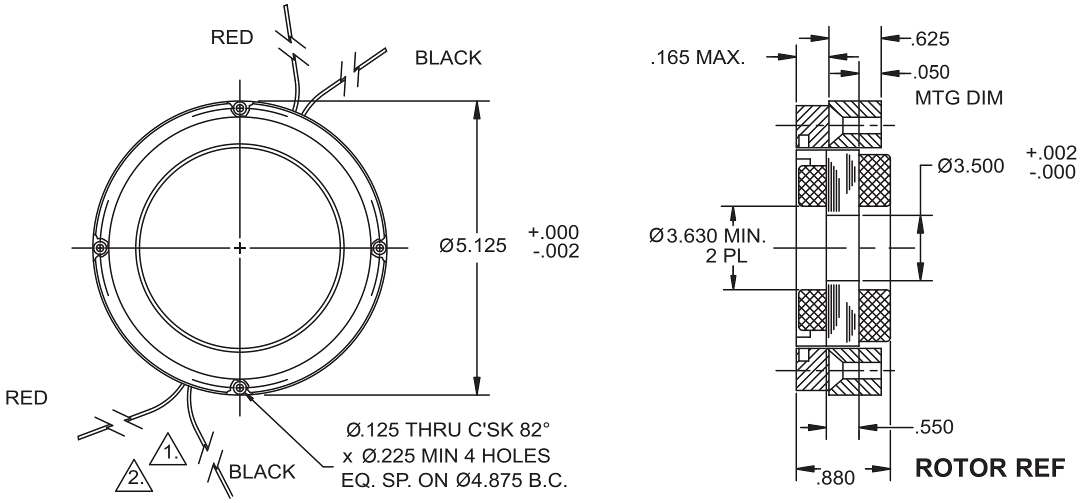
NOTES:

1. LEADS: #20 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)						
	Units	TOL.	Symbol	-005	-016	-060	-148
Resistance	ohms	+/-12.5%	R	0.65	1.93	6.92	16.3
Inductance	mH	+/-30%	L	0.30	0.89	3.19	7.50
Torque Sensitivity	oz-in/A	+/-10%	Kt	20.6	35.5	67.2	103.2
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.145	0.251	0.475	0.729
Peak Voltage @ Tp	Volts	Nominal	Vp	12.6	21.8	41.2	63.2
Peak Current @ Tp	Amps	Nominal	Ip	19.42	11.27	5.95	3.88

5125V-088

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	800
Power I^2R @Tp:	watts	P	248
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	50.84
Electrical Time Constant	ms	Te	0.76
Mechanical Time Constant	ms	Tm	9.63
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	18.255
Break Away Torque	oz-in	Tf	16.0
Rotor Inertia	oz-in-sec²	Jm	0.1758
Theoretical Acceleration @ Tp	rad/sec²	α_t	4551
Ripple Frequency	cycles/rev	f_R	79
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	41.6
Weight	oz	WT	28.0
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	4.3

NOTES:

1. LEADS: #20 AWG TYPE “ET” TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.

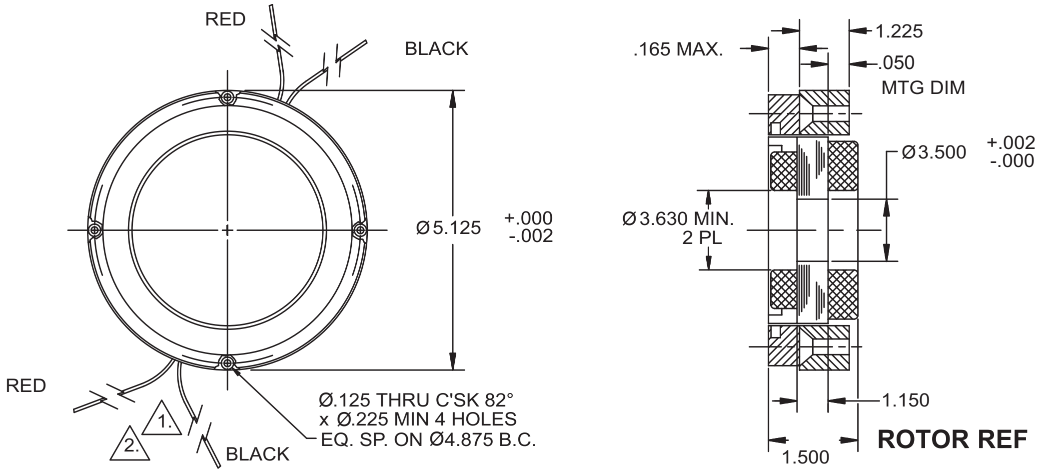
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.

3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)						
	Units	TOL.	Symbol	-013	-021	-050	-120
Resistance	ohms	+/-12.5%	R	1.43	2.36	5.12	12.0
Inductance	mH	+/-30%	L	1.09	1.80	3.91	9.17
Torque Sensitivity	oz-in/A	+/-10%	Kt	60.8	78.1	115	176.1
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.429	0.552	0.812	1.244
Peak Voltage @ Tp	Volts	Nominal	Vp	18.8	24.2	35.6	54.5
Peak Current @ Tp	Amps	Nominal	Ip	13.16	10.24	6.96	4.54

5125V-148

Brush Type DC Motors



Size Constants:	(all values at 25° C ambient temperature)		
	Units	Symbol	Value
Peak Torque, stalled @Vp:	oz-in	Tp	1600
Power I^2R @Tp:	watts	P	350
Continuous Stall Torque	oz-in	Tcs	-
Motor Constant	oz-in/$\sqrt{W}$	Km	85.49
Electrical Time Constant	ms	Te	0.83
Mechanical Time Constant	ms	Tm	6.20
Damping Factor (zero impedance)	oz-in/(rad/sec)	Fo	51.606
Break Away Torque	oz-in	Tf	24.0
Rotor Inertia	oz-in-sec^2	Jm	0.3198
Theoretical Acceleration @ Tp	rad/sec^2	α_t	5003
Ripple Frequency	cycles/rev	f_R	79
Ripple Torque	% (ave to peak)	T_R	7
Theoretical No Load Speed @ Vp	rad/sec	ω_{NLT}	29.5
Weight	oz	WT	52.0
Maximum Allowable Temperature	°C (at winding)	Temp.	155
Thermal Resistence	°C/W	tpr	2.9

NOTES:

1. LEADS: #20 AWG TYPE "ET" TEFLON COATED PER MIL-W-16878,12" MINIMUM LENGTH.
2. MOTOR TO ROTATE CW VIEWED FROM BRUSH END WITH POSITIVE VOLTAGE APPLIED TO RED LEADWIRE WITH RESPECT TO THE BLACK.
3. MOUNTING: MOTOR I.D. CONCENTRIC TO MOTOR O.D. WITHIN .004 TIR

Winding Constants	(all values at 25° C ambient temperature)					
	Units	TOL.	Symbol	-009	-031	-074
Resistance	ohms	+/-12.5%	R	0.90	3.19	7.46
Inductance	mH	+/-30%	L	0.75	2.65	6.21
Torque Sensitivity	oz-in/A	+/-10%	Kt	81.1	152.7	233.5
Back EMF Constant:	V/(rad/sec)	+/-10%	Kb	0.573	1.078	1.649
Peak Voltage @ Tp	Volts	Nominal	Vp	17.8	33.4	51.1
Peak Current @ Tp	Amps	Nominal	Ip	19.73	10.48	6.85

DC MOTOR DESIGN GUIDE

Application ______________________________
____
____
____
____

PHYSICAL REQUIREMENTS:

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

FOR HOUSED MOTORS ONLY:

OD ______________________________
Length ______________________________
Shaft OD ______________________________
Shaft Length ______________________________

FOR BRUSHLESS MOTORS ONLY:

Commutation:
☐ Hall Sensors ☐ Resolver
☐ Encoder ☐ None

Drive Output Waveform:
☐ 6 Point Trapezoidal ☐ Sinusoidal

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

PERFORMANCE/WINDING DATA:

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

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

ENVIRONMENTAL REQUIREMENTS:

Temperature of Operation:
Minimum ________ °C Maximum ________ °C
Shock ______________________________
Vibration ______________________________
Altitude ______________________________
Other ______________________________

REQUESTED BY:

Name ______________________________
Title ______________________________
Company ______________________________
Address ______________________________
City ______________________________
State ______________________________
Zip ______________________________
Country ______________________________
Phone ______________________________
Fax ______________________________
Email ______________________________