

# KOFORD

ENGINEERING, LLC



## **.63" (16mm) Series**

- High performance slotless brushless motors for military, aerospace, medical/dental, and industrial applications
- Large .125 shaft and bearings
- Speeds up to 53,040 rpm
- Cog free design ideal for precision motion
- Highest power density
- High temperature ML (220°C) insulation
- Available with hall sensors, or sensorless
- Long life premium synthetic bearing lube with -73C to 149C temperature range
- Frameless configuration available

•Up to 53,040 rpm •Rated power up to 20 watts •2 pole

16mm diameter but with larger shaft, more robust bearings and higher efficiency and power density than other 16mm motors. High efficiency, speed and power. Slotless design is cog free, cost effective, and provides high efficiency and cool operation. Available with optical encoders and gearheads. 150°C rated Neo rare earth magnets standard. ML(240°C) insulation is standard for highest reliability. Available with hall sensors for positioning, reversing, or applications involving heavy inertial loads and sensorless for use with our sensorless controllers, or for use with encoder controlled commutation. These motors exhibit exceptional smoothness at low speed when driven by encoder controlled sinusoidal drives. Custom versions available including custom windings for different no load rpm or input voltage. Modified shafts can also be provided. Winding temperature sensor (thermistor) can be provided on sensorless versions only.



### Motor Data

		2209	2784	3507	4420	1925
Winding number		2209	2784	3507	4420	1925
Ball Bearing type		stainless	stainless	stainless	stainless	stainless
Nominal supply voltage	volts	12	12	12	12	24
no load speed	rpm ±12%	26,515	33,409	42,095	53,040	46,200
speed/torque slope	rpm/oz-in	11,790	12,050	12,200	12,413	12,413
Stall torque	oz-in	2.4	3.0	3.7	4.7	4.7
Continuous torque case 60°C/no h.s.	oz-in	.73/.68	1.8/.68	1.8/.61	1.8/.58	1.8/.58
Continuous current case 60°C/no h.s.	amps	1.2/1.1	3.8/1.4	4.8/1.6	6.0/1.9	3.0/95
Motor constant Km	oz-in/√w	.335	.335	.335	.335	.335
Winding resistance	ohm±15%	3.11	1.96	1.23	.776	3.11
Peak output	watts	12	19	30	44	44
No load current	amp±50%	.06	.09	.13	.19	.07
Damping factor	oz-in/krpm	.001	.001	.0009	.0009	.0009
Static friction	oz-in	.01	.01	.01	.01	.01
Velocity constant	rpm/volt	2209	2784	3507	4420	2210
Torque constant Kt	oz-in/amp	.61	.48	.38	.30	.70
Stall current	amps	3.9	6.1	9.8	15.4	5.8
Maximum efficiency	%	77	77	78	79	79
Winding inductance	mH	.060	.038	.024	.015	.060
Mechanical time constant	ms	4.0	4.0	4.0	4.0	4.0
Rotor inertia	10 <sup>-4</sup> oz-in-sec <sup>2</sup>	.034	.034	.034	.034	.034
Thermal res. winding to case	°C/W	2.0	2.0	2.0	2.0	2.0
Thermal case to ambient	°C/W	18	18	18	18	18

Weight 1.2 oz (34g) Maximum winding temperature 150°C (hall and magnet temp limited), ambient -73 to 125C

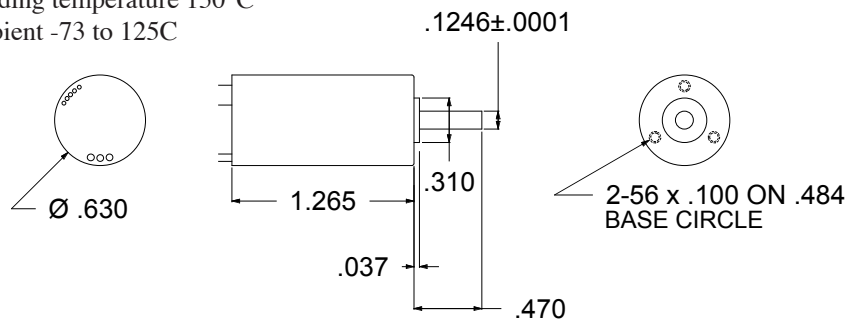
values based on winding and magnet temperature of 20°C  
Winding resistance does not include lead resistance of .052Ω. Leads are TFE 12" minimum 24 gauge phase and 28 gauge hall.

Maximum axial bearing force 20 lb

**Ordering Information:** mail@koford.com • www.koford.com

**Example:** Part Number 16 H 2209 A

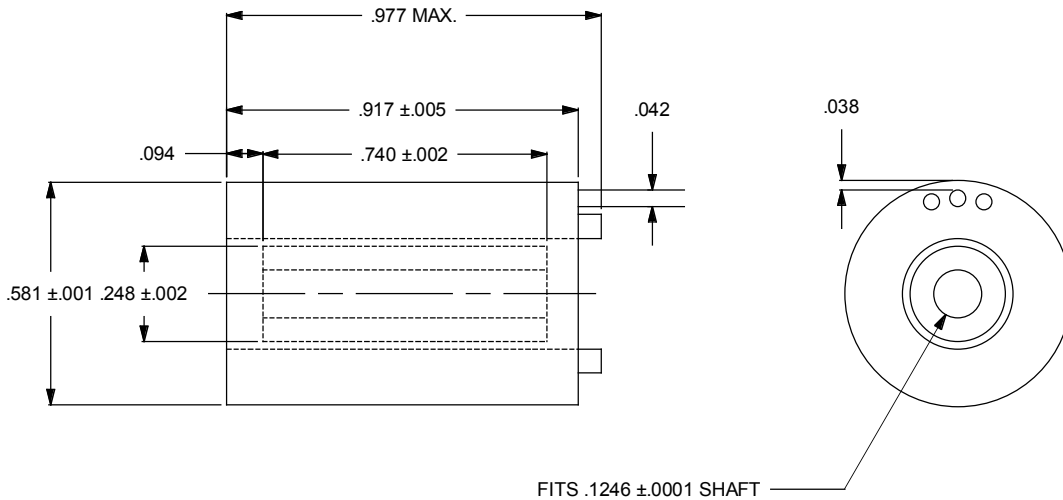
Type S=sensorless H=120°halls  
Winding number  
Modifications A=none, T=Thermistor



Leads	
Blue	Phase A
White	Phase B
Brown	Phase C
Red	+5 volts
Black	Ground
Yellow	Sensor A
Orange	Sensor B
Green	Sensor C

# .63" (16mm) Frameless Slotless Brushless DC motor.

Frameless motors are used for the construction of products such as hermetic compressors, canned pumps and specialty machining spindles where a housed motor cannot be used. Frameless motor can only be provided in the sensorless configuration at this time. These units can also be used with air or magnetic bearings where the large air gap due to the slotless design greatly reduces the negative magnetic stiffness improving bearing performance and stability. A magnetized single piece magnet is supplied ready for the customer to epoxy to his shaft and balance (for higher speeds). Do not use Anaerobic or acrylic adhesives. Do not attempt press fitting, this will destroy the rotor. The stator should be attached to the housing with epoxy using a bond gap of around .001". The minimum bondline thickness of the epoxy to be used must be determined as some material contain large particle size fillers and cannot achieve a .001" bondline. For heat cure (recommended) Koford Engineering has a line of high performance epoxies (see the epoxy section of our web site), for room temperature cure 3M DP-460 works well as long as care is taken to ensure the correct mix ratio (don't use the static mixer and dispense a large enough quantity of material that the correct amount from both components is dispensed). If the stator must be removable a heat shrink mounting is recommended but careful matching is required to achieve reliable mounting and prevent the stator from spinning. Do not attempt press fitting as this will destroy the stator. The data provided in this catalog can be used as a guide to motor performance, however some variations will result due to variations between motor bearings, housing clearances, and thermal resistances. For the best performance the motor housing should be nonmagnetic and have the maximum practical clearance to the rotor magnet. The motor bearings should also be spaced as far away from the rotor as possible to reduce drag. Custom winds and rotors for other shaft sizes can be provided on special orders (minimum quantities may apply).



For the frameless version of a motor put F in the part number, for example 16F2209A.

## Thermistor resistance for Koford motors

Temp [degree C]	Temp [degree F]	Rt/R25	Temp Coef [%/C]	Resistance [ohm]
-50	-58	66.970	7.10	334850
-45	-49	47.250	6.86	236250
-40	-40	33.740	6.62	168700
-35	-31	24.370	6.40	121850
-30	-22	17.800	6.19	89000
-25	-13	13.130	5.99	65650
-20	-4	9.776	5.80	48880
-15	5	7.347	5.63	36735
-10	14	5.570	5.46	27850
-5	23	4.257	5.30	21285
0	32	3.279	5.10	16395
5	41	2.550	4.95	12750
10	50	1.998	4.81	9990
15	59	1.576	4.68	7880
20	68	1.252	4.55	6260
25	77	1.000	4.43	5000
30	86	0.804	4.31	4019
35	95	0.650	4.20	3249
40	104	0.528	4.09	2641
45	113	0.432	3.99	2158
50	122	0.355	3.74	1773
55	131	0.295	3.63	1474
60	140	0.247	3.54	1233
65	149	0.207	3.44	1035
70	158	0.175	3.35	874
75	167	0.148	3.26	741
80	176	0.126	3.18	631
85	185	0.108	3.10	539
90	194	0.092	3.03	462
95	203	0.080	2.95	398
100	212	0.069	2.86	344
105	221	0.060	2.78	299
110	230	0.052	2.70	261
115	239	0.046	2.63	228
120	248	0.040	2.56	200
125	257	0.035	2.50	177
130	266	0.031	2.44	156
135	275	0.028	2.37	138
140	284	0.025	2.31	123
145	293	0.022	2.26	110
150	302	0.020	2.20	98

### Unit conversions

$^{\circ}\text{F} - 32 \div 1.8 = ^{\circ}\text{C}$  example:  $212^{\circ}\text{F} = 100^{\circ}\text{C}$ ,  $^{\circ}\text{C} \times 1.8 + 32 = ^{\circ}\text{F}$  example:  $100^{\circ}\text{C} = 212^{\circ}\text{F}$ ,  $\text{in} \times 25.40 = \text{mm}$ ,  
 $\text{mm} \times 0.03937 = \text{in.}$ ,  $\text{oz} \times 28.3495 = \text{g}$ ,  $\text{oz-in} \times 7.06 = \text{mNm}$ ,  $\text{mNm} \times .142 = \text{oz-in}$ ,  $\text{Nm} \times .142 = \text{oz-in}$ ,  
 $\text{Ncm} \times 1.42 = \text{oz-in}$ ,  $\text{rpm} \times .1047 = \text{rad s}^{-1}$ ,  $\text{V/R/S} \times .1047 = \text{volts/rpm}$ ,  $746 \text{ watts} = 1\text{hp}$ ,  $\text{lb-in}^2 \times$   
 $.04144 = \text{oz-in-sec}^2$

### Understanding Data Sheets

When comparing Koford motors to data sheets for other motors be careful to note the conditions associated with the rated torque listed. For example many manufactures list continuous torque at stall or at rpm less then the maximum. This specsmanship results in unrealistically high continuous torque ratings for these motors. Attempting to operate these motors continuously at the nominal operating voltage will often result in overheating even if the motor is unloaded.

### Hall Sensors

Like other semiconductor components hall sensors are electrostatic sensitive. Hall motors are supplied in electrostatic safe packaging and should be kept in the packaging until use. When trimming wire length, adding connectors, and hooking up motors, workers should be grounded to prevent electrostatic damage to the sensors.

### Balancing

Components attached to the motor shaft should be dynamically balanced to G6.3 or better and located as close to the motor body as possible. This is especially critical over 20,000 rpm. G6.3 is equal to  $0.64 \times \text{weight (oz.)} / \text{rpm} = \text{unbalance in milli oz-in}$ . If the components have appreciable length they must be balance in 2 planes.

### Motor technology

The Koford 16 mm brushless series of motors are slotless sintered rare earth permanent magnet motors with unique technology. Compared to brush motors they have much longer life (up to 25,000 hours +), much higher speed capability (53,000+rpm), can operate in a vacuum, and will not introduce contamination from brush dust. Compared to conventional slotted bonded rare earth magnet with the same no load speed and phase resistance Koford motors are smaller, lighter, have higher efficiency, higher peak torque (equal to stall torque), and are cog free. Compared to other slotless motors they have higher speed capabilities, better efficiency, lighter weight and more durable construction (ML Class 220C wire insulation bonded with solventless Class 205 thermoset resin) compared to the low temp bondable wire used in other slotless motors which will soften and fail under thermal overload.

### Operating speed

Motors can be operated at any lower voltage then shown on the data sheet.

### Motor selection

Motors for continuous duty applications such as pumps, blowers etc. should in most cases be selected to operate at about 10% of stall torque. This point is close to peak efficiency. Keep in mind that the drive used has a great effect on motor operating temperature. The lowest motor temperature rise will occur with the drive pwm duty cycle at 100% (maximum speed). Using a higher speed winding then necessary and reducing the speed through the drive will result in higher motor and drive operating temperatures then if a winding is selected that will run as close as possible to full speed. During variable speed operation, when the motor is operating at less then full speed, both the motor and drive operating temperature will be influenced by the drive frequency. Drive pwm frequencies of 37kHz or higher are recommended for best performance. For the highest performance Koford drives are recommended. Drives which have a pwm frequency of less then 37kHz can be used with inductors for improve operation and to prevent overheating when used with higher speed motor. Koford drives do not require inductors.

For variable speed applications where the motor does not operate continuously, the safest approach is to specify the motor with the continuous operating torque equal to the maximum load. If the maximum load is not known then the continuous motor current rating should be if possible more than the current limit of the drive. This will prevent the possibility of overload. For example if the current rating of the drive is 5 amps, the motor Kt is 3.0 and the no load current is 1.0 amps, continuous torque rating should be more than  $(5-1.0) \times 3.0=12$  oz-in. If the duty cycle is known then the equivalent continuous torque can be estimated. Keep in mind that the resistance losses are a function of the current squared so reducing the duty cycle to fifty percent will only allow the torque to be increased by 41% not 100%.

When comparing Koford motors to data sheets for other motors be careful to note the conditions associated with the rated torque listed. For example many manufactures list continuous torque at stall or at 10,000 rpm. Usually this is because these motors will overheat if run continuously at full speed even with no load.

### **Selection of Hall, Sensorless Commutation**

Typically pumps and blowers use sensorless commutation while motion control applications which involve controlling position rather than speed use hall sensors. Also if the motor needs to start up instantly with no delay then hall sensors are used. Hall sensors will operate down to zero speed and have no start up delay. Sensorless motors have only three leads which can be helpful in applications where the motor must be hundred or thousands of feet away from the drive. It also makes for a more flexible cable for surgical or dental handpieces. In addition sensorless motors operate with higher efficiency especially at speeds above 60,000 rpm. Sensorless motor also have a easier hook up having only three leads and there is no concern about electrostatic damage to hall sensors by touching the sensor leads.

### **Linear characteristics**

Koford motors exhibit highly linear behavior. This is not the case with slotted motors and even some slotless motors. A slotted motor with the same rpm and phase resistance may only be capable of less than half of the peak torque of a Koford motor with the same specifications. The stall torque of Koford motors is equal to the Kt times the current. However keep in mind that at stall the winding will heat up rapidly increasing the resistance so the full stall torque may only be available for a fraction of a second. In most cases the current limit of the drive is much less than the stall current so this is not an issue.

### **Speed torque calculations**

A motor's no load speed is equal to the supply voltage times the velocity constant (rpm/v). Under load the rpm will drop. To determine the approximate speed, use dyno data if listed, or use the speed torque slope from the data sheet. For example if the supply voltage is 28 volts and the rpm/volt is 500 then the no load speed will be 14,000 rpm. If the speed torque slope is 800 rpm/oz-in and a 5 oz-in load is applied to the shaft then the speed will be  $14,000-(5 \times 800) = 10,000$  rpm. If there is extra wiring between the drive and the motor, or the supply and the drive, then the speed will drop at a more rapid rate due to the voltage drop in the wiring. A design margin of at least 15% should be used to allow for motor tolerances, so for example with the above motor the rpm can be expected to be at least 8,500 rpm.

### **Motor cooling**

The continuous output torque which can be achieved from a motor is limited by the allowable maximum temperature. This in turn is determined by the cooling provided by the user, and the ambient temperature. In the case of some high speed motors the continuous output torque is shown as zero if the motor does not have heat sinking. In these cases the motor can only be used in intermittent duty applications unless appropriate heatsinking is used. The data sheet lists continuous torque with a 20°C (68°F) ambient and full rated voltage with 100% duty cycle and block commutation. Two values are listed, the first with the motor case cooled using customer supplied heat sinking to 60°C and the second with no cooling in still air. Most applications will fall somewhere between these

two extremes. If the ambient temperature is above 20°C then the continuous duty torque is reduced. Sensorless motors are available with temperature sensors and this can be useful during prototyping to evaluate cooling. The actual limitation is the rotor (magnet) temperature, but since the windings surround the rotor, the temperature can be assumed to be the same in most cases. One exception is in pump applications (frameless or housed) if the motor is immersed in refrigerant. In these applications the rotor temperature can be expected to closely follow the fluid temperature. For applications in air the allowable output torque can be increased by mounting the motor to a thick aluminum plate with surface area several times larger than the surface area of the motor. Further improvements can be obtained with the use of a fan directed at the body of the motor. Even higher performance can be obtained by the use of a refrigerant cooled sleeve around the outside diameter of the motor coupled with heatsink grease. If the motor housing can be cooled below 20°C then improved performance above data sheet values can be obtained. If only natural convection is used and the motor is mounted to plastic or a low thermal conductivity material such as steel then consideration should be given to ensuring free flow of air over the motor. Placing the motor in a small enclosed space with poor thermal connection to the outside ambient can result in considerable reduction in the amount of output power possible without overheating. When performing temperature rise calculations remember that the resistance of the copper windings increases with temperature. You must use the resistance at the operating temperature not at 20C.

### **Frameless motors**

Frameless motors are useful for certain specialized applications where housed motors cannot be used. These include air bearing or magnetic bearing motors, and pump applications where the rotor and impeller are part of a single assembly with the working fluid inside of the motor. All Koford motors can withstand continuous exposure to refrigerants. Frameless motors should be avoided for any application where a housed motor can be used. The use of water without corrosion inhibitors inside the motor requires special magnets. In many cases sleeve bearings are used with water instead of ball bearings so as to prevent corrosion and the possibilities of particles from jamming the ball bearings. Contact the factory if your application requires a frameless version of one of the motors listed in the catalog.

### **Vacuum Applications**

All Koford motors are suitable for low vacuum applications. For high vacuum applications contact the factory. An important consideration is that in a vacuum there is no heat removal by air contacting the motor housing. Therefore the mounting of the motor should be made of highly thermally conductive material, such as copper or aluminum, should be of as heavy a cross section as possible, and should connect to a large surface exposed to the outside air.

### **Motor hook up**

Koford hall sensor motors typically separate the phase and sensor wires. These wires should be kept apart and away from other wires. The leads should be trimmed as short as possible to reduce EMI and power losses. Where electrical noise is a consideration the phase wires may be twisted or braided with each other or enclosed in a shielded jacket. The same can be done with the hall leads to prevent their picking up EMI from noise sources.

### **EMI**

Koford drives and motors have low levels of emi relative to other motors but in sensitive applications the following steps are suggested. First keep the phase wires as short as physically possible and twist or braid them together and if necessary add a shield jacket terminated at one end. Add a 5,000 $\mu$ F cap at the input to the drive along with a common mode inductor. Add small inductors to each of the phase wires. If possible vary the input voltage to the drive rather than using the speed control. Place the drive and motor as close together as possible. Also consider enclosing the drive or motor and drive in a metal enclosure.

### **Sine Drives**

Koford motors are especially suitable for sine drives due to their exceptionally low harmonic distortion (typically

well under 1%). Sine drives are useful for very accurate motion around zero speed. At higher speeds e.g. above 3,000 rpm there is not any noticeable difference in noise/vibration/velocity accuracy with sine drives. The use of Sine drives results in lower power output and reduced efficiency compared to standard drives (block commutation) when compared with the same motor.

### **Permanent Magnet Synchronous motors, DC Brushless motors, AC Permanent Magnet motors**

These are all different names for the same type of motor.

### **System efficiency**

The system efficiency is different than the motor efficiency. The system efficiency takes into account motor losses, drive losses, wiring losses, and gearbox losses. The choice of a drive will make a large difference in the total system efficiency. The data sheet value for maximum motor efficiency is at maximum speed. At less than 100% speed efficiency will be reduced. For example if a motor is operated at 12 volts with the speed control turned all of the way up, the efficiency will be better than if the motor is operated with 24 volts into the drive and the speed set at 50%. Although the motor speed is the same, there are additional losses in the drive and motor to drop the 24 volts down to 12 volts. The amount of these losses is determined by the drive and motor design. High frequency drives (37 kHz or above) provide slightly better overall efficiency than 18kHz drives. Drives with a pwm frequency below 18kHz are not recommended for slotless motors.

### **PWM basics**

Variable speed drives operate using PWM where the voltage to the motor is rapidly turned on and off. This is the same as a switching power supply where the motor is the filter. A PWM drive operates like a transformer, for example if the motor pulls 20 amps at 12 volts and the input to the drive is 36 volts then the input current to the drive will be  $12/36 \times 20$  or 6.66 amps (neglecting losses). A drive rated at 20 amps will only pull 20 amps from the power supply or battery if the speed is turned all of the way up (no PWM).



