

# KOFORD

ENGINEERING, LLC



## 1.4 inch (36mm) Series

- High performance slotless brushless motors for military, aerospace, medical, and commercial applications.
- Cog free design ideal for precision motion
- 2 and 4 pole designs
- Highest power density
- High temperature ML insulation
- Available with hall sensors, sensorless, and integral electronics
- Up to 90% efficiency
- Available with planetary gearboxes featuring all case hardened alloy steel gears
- Needle bearings on planets and ball bearings on output shaft.
- Long life premium synthetic bearing lube with -73C to 149C temperature range

## 1.4" (36mm) Hi Performance 4 Pole Slotless Brushless DC motor.

•9,960 rpm no load

•Rated power 58 watts

High performance design uses special low loss lamination material. Four pole design is optimum for positioning applications using hall signals for speed feedback because it offers twice the resolution, as well as increased power and speed compared to two pole motors. Slotless design is cog free for maximum smoothness and positioning accuracy. ML insulation is used for the greatest possible durability. Available with optical encoders and gearheads. 150°C rated Neo rare earth magnets standard. These motors can be used with sinusoidal drives (brushless AC) to provide smooth ripple free torque at low speeds. Custom versions with modified shaft or custom windings can be provided on request.

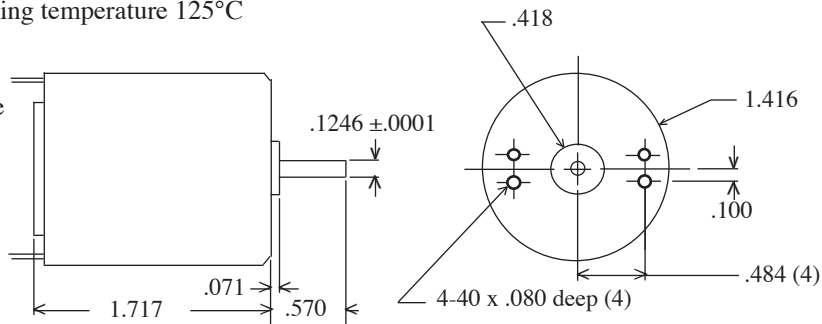


### Motor Data

Winding		415
Nominal supply voltage	volts	24
No load speed	rpm	9,960
Speed/torque slope	rpm/oz-in	130
Maximum efficiency	%	90
Continuous torque heat sink/no h.s.	oz-in	23.7/9.5
Motor constant Km	oz-in/√w	3.66
Resistance	ohm±15%	.80
Peak output	watts	160
No load current	amp±50%	.12
Damping factor	oz-in/krpm	.03
Static friction	oz-in	.07
Velocity constant	rpm/volt±12%	415
Torque constant Kt	oz-in/amp	3.25
Stall current	amps	30
Stall torque	oz-in	97
Winding inductance	mH	.29
Mechanical time constant	ms	3
Rotor inertia	10 <sup>-4</sup> oz-in-sec <sup>2</sup>	3.1
Thermal res. winding to case	°C/W	1.9
Thermal res case to ambient	°C/W	5.7
Bearing rating radial (dynamic)	lb.	71
Bearing rating axial (static)	lb.	29

Weight 7 oz. Maximum winding temperature 125°C

Values based on winding and magnet temp. of 20°C, heat sink values assume case cooled to 20C. Lead wire resistance 11.8mΩ if used at full length. Leads are 12" minimum. Phase leads are 18 gauge, hall leads are 28 gauge, all TFE



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

**Ordering Information:** mail@koford.com • phone 330-315-3061 • fax 937-695-0237 • www.koford.com

**Example:** Part Number 36 H 415 A / A5 / P7

Motor dia. \_\_\_\_\_  
 Type S=sensorless H=120°halls \_\_\_\_\_  
 Winding number \_\_\_\_\_  
 Gearhead P7=6.75:1, P46=45.56:1, P307=307.54:1  
 Encoder w index A5=500line(2000 count)  
 Modifications A=none, T=thermistor

Test Data  
 Total System Performance  
 36H415A with H24V10A Controller at 24 volts

Rpm	Torque Oz-in	Watts Out	Efficiency %	Amps
9600	0.00	0.00	0.00	0.13
9475	1.02	7.18	69.60	0.43
9345	2.01	13.87	80.30	0.72
9221	3.00	20.46	85.30	1.00
9090	4.03	27.12	86.90	1.30
8930	5.02	33.18	87.50	1.58
8802	6.03	39.29	87.54	1.87
8690	6.91	44.46	86.97	2.13
8540	8.02	50.71	86.95	2.43
8421	9.02	56.19	86.10	2.72
8296	10.01	61.36	85.79	2.98
8066	11.94	71.26	83.64	3.55
7820	13.88	79.71	81.80	4.06
7225	17.90	95.64	75.90	5.25
6642	22.06	108.42	70.70	6.39
6010	26.08	115.98	63.60	7.60

Dyno test results of a motor and drive combination with voltage held to 24v at input of drive using remote voltage sense on the power supply. Winding temperature is held below 40C by running test quickly and/or allowing motor to cool between tests. Test were conducted at room temperature.

•3,936 to 8,184 rpm no load

•Rated power 40 watts

Four pole design is optimum for positioning applications using hall signals for speed feedback because it offers twice the resolution, as well as increased power and speed compared to two pole motors. Slotless design is cog free for maximum smoothness and positioning accuracy. ML insulation is used for the greatest possible durability. Available with optical encoders and gearheads. 150°C rated Neo rare earth magnets are standard. These motors can be used with sinusoidal drives (brushless AC) to provide smooth ripple free torque at low speeds. Custom versions with modified shaft or custom windings can be provided on request. Please contact factory.

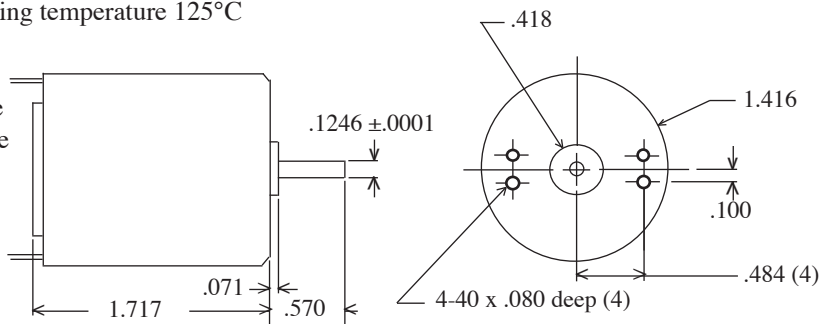


**Motor Data**

Winding		328	329
Nominal supply voltage	volts	12	24
No load speed	rpm±12%	3,936	7,704
Speed/torque slope	rpm/oz-in	113	124
Continuous torque heat sink/no h.s.	oz-in	22/9.8	21/8.4
Maximum efficiency	%	81	84
Motor constant Km	oz-in/√w	3.66	3.66
Winding resistance	ohm±15%	1.26	1.26
Peak output	watts	25	100
No load current	amp±50%	.09	.14
Damping factor	oz-in/krpm	.067	.058
Static friction	oz-in	.076	.076
Velocity constant	rpm/volt±12%	340	341
Torque constant Kt	oz-in/amp	4.11	4.11
Stall current	amps	9.5	19.0
Winding inductance	mH	.17	.17
Mechanical time constant	ms	4	4
Rotor inertia	10 <sup>-4</sup> oz-in-sec <sup>2</sup>	3.1	3.1
Thermal res. winding to case	°C/W	1.9	1.9
Thermal res case to ambient	°C/W	5.7	5.7
Stall torque	oz-in	39	78
Bearing rating radial (dynamic)	lb.	71	71
Bearing rating axial (static)	lb.	29	29

Weight 7 oz. Maximum winding temperature 125°C

Values based on winding and magnet temp. of 20°C, heat sink values assume case cooled to 20C. Lead wire resistance 11.8mΩ if used at full length. Leads are 12" minimum. Phase leads are 18 gauge, hall leads are 28 gauge, all TFE



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

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**Example:** Part Number 36 H 329 A / A5 / P7

Motor dia. \_\_\_\_\_ Gearhead P7=6.75:1, P46=45.56:1, P307=307.54:1  
 Type S=sensorless H=120°halls \_\_\_\_\_ Encoder w index A5=500line(2000 count)  
 Winding number \_\_\_\_\_ Modifications A=none, T=Thermistor

•4,992 to 30,000 rpm no load

•Rated power 100 watts

Slotless design is cog free, cost effective, and provides high efficiency and cool operation at high speed. ML insulation is used for the greatest possible durability. Available with optical encoders and gearheads. 150°C rated Neo rare earth magnets standard. 2 pole design is preferred for higher speeds. Available with hall sensors for positioning and reversing applications or heavy inertial loads and sensorless for use with sensorless drives, with encoder controlled commutation or use as a generator. These motors exhibit exceptional smoothness when driven by encoder controlled sinusoidal drives. Motor can be wound to different rpm and voltages than the standard winds. High temperature 200C rated magnets, and custom output shafts can be provided. Also available

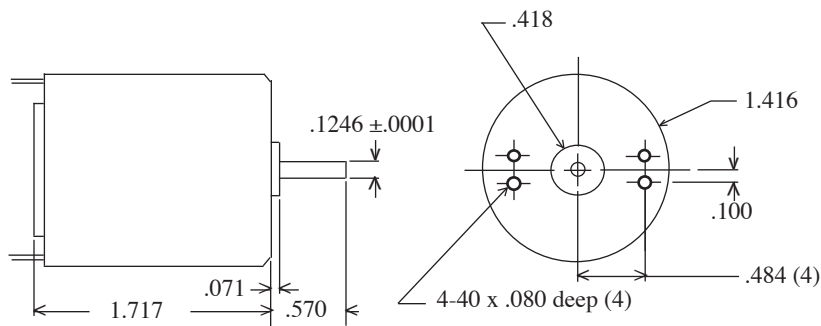


**Motor Data**

Winding		416	1250	2500	1251	792	417
Nominal supply voltage	volts	12	12	12	24	24	24
No load speed	rpm	4,992	15,000	30,000	30,000	19,000	10,000
Maximum efficiency	%	77	80	81	83	81	80
Continuous torque	heat sink/no h.s. oz-in	19.7/8.3	17.4/0	9.8/0	9.5/0	15.3/0	19.7/6.0
Motor constant Km	oz-in/√w	2.98	3.06	2.39	3.06	2.86	3.14
Winding resistance	ohm±15%	1.15	.122	.049	.122	.348	1.04
Peak output	watts	30.3	263	583	1,052	391	121
No load current	amp±50%	.15	1.1	2.4	1.5	.71	.25
Damping factor	oz-in/krpm	.075	.073	.040	.050	.059	.072
Static friction	oz-in	.076	.076	.076	.076	.076	.076
Velocity constant	rpm/volt±12%	416	1250	2,500	1251	792	417
Torque constant Kt	oz-in/amp	3.20	1.07	.53	1.07	1.69	3.20
Stall current	amps	10.4	98.4	245	196	68.9	23.0
Stall torque	oz-in	33.0	95.7	145	191	112	66.1
Winding inductance	mH	.432	.059	.012	.059	.111	.432
Mechanical time constant	ms	6	6	8	6	6	6
Rotor inertia	10 <sup>-4</sup> oz-in-sec <sup>2</sup>	3.1	3.1	3.1	3.1	3.1	3.1
Thermal res. winding to case	°C/W	1.9	1.9	1.9	1.9	1.9	1.9
Thermal res case to ambient	°C/W	5.7	5.7	5.7	5.7	5.7	5.7
Bearing rating dynamic	lb	71	71	71	71	71	71
Bearing rating axial (static)	lb	29	29	29	29	29	29
Maximum winding temperature	°C	125	125	125	125	125	125

Weight 7 oz

Values based on winding and magnet temp. of 20°C  
heat sink values assume case cooled to 20C  
Lead wires resistance 11.8mΩ if used at full length. Leads are 12" minimum Phase leads are 24 gauge, hall leads are 28 gauge, all TFE



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

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**Example:** Part Number 36 H 417 A / A5 / P7 — Gearhead P7=6.75:1, P46=45.56:1, P307=307.54:1

Motor dia. \_\_\_\_\_ Encoder w index A5=500lines(2000 count)  
Type S=sensorless H=120°halls \_\_\_\_\_ Modifications A=none, T=thermistor  
Winding number \_\_\_\_\_

Test Data  
Total System Performance  
36H792T/P7 gearmotor with H24V10A Controller at 24 volts

RPM	Torque Oz-in	Watts out	Efficiency %	Amps
2818	0.00	0.00	0.0	0.45
2703	8.22	16.44	56.6	1.21
2678	16.03	31.77	70.0	1.89
2633	24.27	47.29	74.4	2.65
2590	32.70	62.67	78.2	3.34
2553	40.12	75.81	79.2	3.99
2511	48.85	90.76	79.4	4.76
2489	51.53	94.94	79.9	4.95
2454	57.75	104.89	79.5	5.50
2423	66.03	118.39	79.0	6.24
2365	74.22	129.90	77.3	7.00
2318	82.26	141.13	75.4	7.80
2260	90.96	152.15	74.6	8.50
2220	95.15	156.36	72.4	9.00

Dyno test results of a motor and drive combination with voltage held to 24v at input of drive using remote voltage sense on the power supply. Winding temperature is held below 40C by running test quickly and/or allowing motor to cool between tests. Test were conducted at room temperature.

Test Data  
Continuous Duty Total System Performance  
36H792T/P7 gearmotor with H24V10A Controller at 24 volts

RPM	Torque oz-in	watts out	Efficiency (%)	Amps	$\Delta T$ ( $^{\circ}$ C)	Final temp( $^{\circ}$ C)
2773	5.09	10.45	48.4	0.90	32.5	55.9
2750	9.90	20.13	64.0	1.31	33.4	57.2
2732	14.81	29.84	71.5	1.74	35.2	59.3
2710	19.88	39.87	75.5	2.20	38.6	62.9
2689	25.03	49.85	78.1	2.66	41.7	66.1
2659	32.76	64.46	79.9	3.36	49.2	73.9
2613	41.11	79.52	79.6	4.16	56.0	81.6

Motor was run at load until winding temperature stabilized. Motor was attached to a heavy aluminum mounting bracket. Test was run at room ambient 23-26C. Note that there is no drop in output power as the motor heats up.

•Maximum rpm 10,100

•Continuous torque 4 oz-in.

Integral electronics operate at either 12 volts or 24 volts and are ideal for pump, blower and filter wheel, and beam chopper applications where long life is required, electrical noise cannot be tolerated, or brush dust is not acceptable.. These units have higher continuous and maximum torque ratings than similarly sized integral electronic motors. Speed varies linearly with applied voltage. Optional encoder lead outputs a voltage equal to the input voltage and with a frequency of 1 pulse per revolution. Speed can be read directly with a scope, multimeter with frequency function, or can be interfaced with a microcontroller. Standard rotation is clockwise as viewed from the output shaft, with counter clockwise rotation an option. Slotless design provides for smooth motor rotation and high efficiency. Housing is CNC machined anodized aluminum for the highest possible heat transfer. Motor life is limited only by the life of the ball bearings. Custom modifications such as special winding with different rpm per volt, or special shafts can be provided. Maximum allowable current is 2 amps.



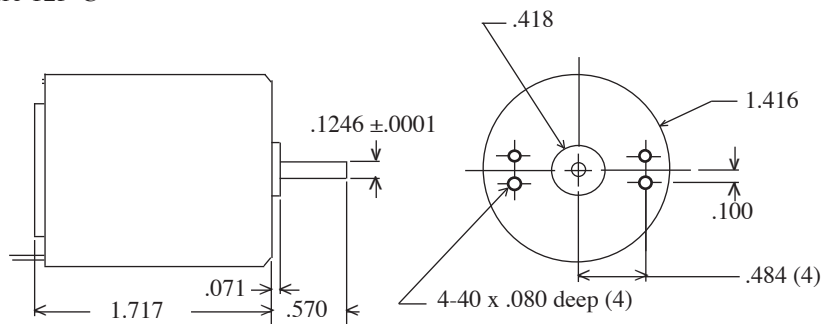
## Motor Data

Winding		I420	I210	I421
Nominal supply voltage	volts	12	24	24
Absolute maximum voltage	volts	30	30	30
No load speed	rpm±12%	5,040	5,040	10,100
Maximum torque	oz-in	5	11	5
Continuous torque case 50°C/no h.s.	oz-in	5/4	7/4	5/0
rpm gradient	rpm/oz-in	-327	-562	-327
Motor constant Km	oz-in/√w	2.0	1.8	2.0
Resistance	ohm	1.8	8.8	1.8
Peak output	watts	78	65	312
No load current	amp±50%	.2	.1	.3
Damping factor	oz-in/krpm	.1	.1	.1
Static friction	oz-in	.14	.14	.14
Velocity constant	rpm/volt	420	210	421
Torque constant Kt	oz-in/amp	3.21	6.42	3.21
Maximum current	amps	2.0	2.0	2.0
Thermal res. winding to case	°C/W	1.9	1.9	1.9
Thermal res case to ambient	°C/W	5.7	5.7	5.7
Bearing rating dynamic	oz	1136	1136	1136
Bearing rating axial (static)	oz	464	464	464

Weight 7 oz

Maximum winding temperature 125°C

Motor data based on winding  
and magnet temp. of  
20°C



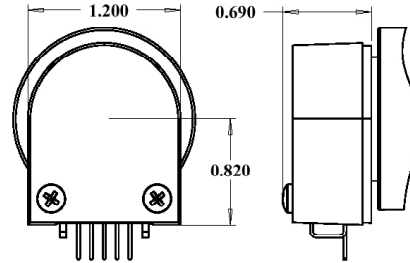
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**Example:** Part Number 36 I420 A

Motor dia. \_\_\_\_\_  
Winding number \_\_\_\_\_  
A=clockwise, B=clockwise with 1 ppr encoder

# Optical Encoders

Mating connector AMP103977-4. Supply voltage  $5 \pm .5V$ .  
Rpm 60,000 max. Weight .5 oz, inertia  $.08 \times 10^{-4} \text{oz-in-sec}^2$



# Planetary Gearheads

Construction is planetary with case hardened alloy steel gears, needle bearings on planets and double shielded ball bearings on output. Bearing lube rated for -35C to 140C. Low temp lube rated for -60 to 130C available on special order.

### For 1.4" (36mm) motors

6.75:1 L=1.136 159 oz-in peak/108 cont. 94% eff.

45.56:1 L=1.510 478 oz-in peak /319 cont. 89% eff.

307.54:1 L=1.884 957 oz-in peak /638 cont. 85% eff.

Weight 6.75:1=5.6 oz, 45.56:1=7.4 oz

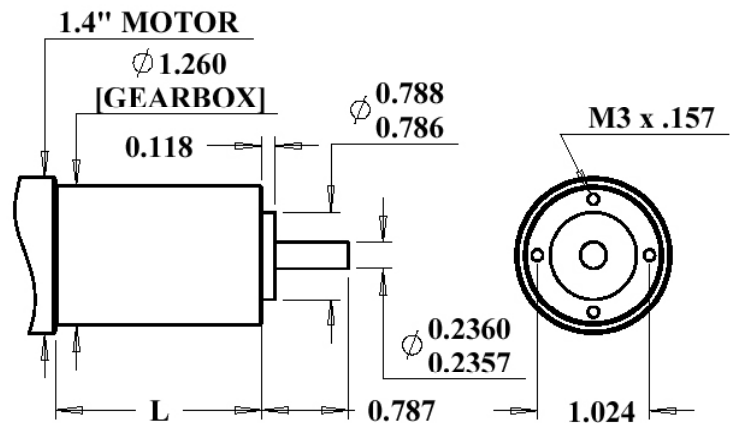
307.54:1=9.3 oz

Maximum backlash 6.75:1=1.5°, 45.56:1=2°,

307.54:1=3°

inertia  $= .13 \times 10^{-4} \text{oz-in-sec}^2$

All gears are precision hobbled hardened alloy steel. Output is dual shielded ball bearings.



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

### 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 36 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 (200,000+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 and also at somewhat higher voltages and speeds then shown on the data sheet. For example 24 volt motors can be run on 28 volt system. Running a 24 volt motor on a 36 volts system is not recommended.

### 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 56kHz or higher are recommended for best performance. Drives which use ASIC's for transistor switching will perform better then drives which use DSP's or Micro's for this function due to more accurate phase switching. For the highest performance Koford drives are recommended. Drives which have a pwm frequency of less then 56kHz will need inductors for proper drive 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 more then 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 then  $(5-1.0) \times 3.0 = 12 \text{ oz-in}$ . 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, or integral electronics**

The most common motor configuration is the hall sensor design. They 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. In certain frameless hermetic pump applications hall sensor designs are not possible and sensorless motors must be used. Integral electronic motors are available in some larger sizes and simplify connection and mounting. In general integral electronic motors will have a lower power rating for a given motor size.

### **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 then half of the peak torque of a Koford motor with the same specifications. The stall torque of Koford motors is equal to the  $K_t$  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 then the stall current so this is not an issue.

### **Speed torque calculations**

A motors 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 8,695 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. If the ambient temperature is above 20°C then the continuous duty torque is reduced. If the data sheet shows the heat rise at a given torque and rpm then that rise can be added to the ambient temperature to determine if the motor is suitable for the application. Keep in mind that the temperature rise tests are with the motor mounted to an thick aluminum bracket. Many 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) where the interior of the motor is filled with refrigerant or water/glycol. 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 then 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.

### **Vacuum Applications**

All Koford motors are suitable for low vacuum applications. For high vacuum applications (option V) contact the factory. Vacuum grade motors are made with low outgassing material and baked before shipping. A vacuum bake by the customer immediately prior to use may be desirable to reduce pump down time. 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 loss-

es, 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 (56kHz or above) are recommended.

### **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).