

# KOFORD

ENGINEERING, LLC



## **.91" (23mm) Series**

- High performance slotless brushless motors for military, aerospace, medical/dental, specialty power tool, and commercial applications.
- Speeds up to 40,000 rpm and autoclavable versions for surgical/dental applications
- \*Vacuum versions available
- 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
- Hardened and ground stainless steel shaft
- Available with planetary gearboxes featuring all case hardened alloy steel gears
- Long life premium synthetic bearing lube with -73C to 149C temperature range

•No Load RPM up to 23,232

•Maximum Stall torque 90 oz-in.

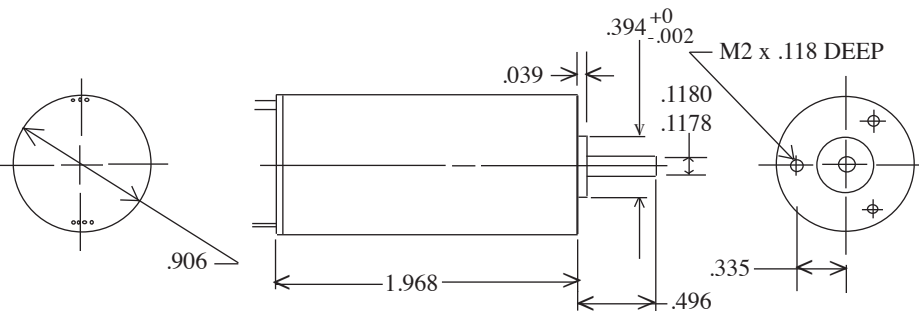
4 pole ultra high performance, rugged, slotless design provides unmatched power density, high continuous and peak torque and is cog free. Available with optical encoders and gearheads (contact factory). 240°C ML wire and Kapton® ground insulation are used for the ultimate in ruggedness. Leads are Teflon® insulated. Lamination materials are special low loss materials for maximum performance. Motors are available with hall sensors for servo applications. For applications such as pumps and blowers sensorless versions are available for use with Koford sensorless drives.



### Motor Data

<u>Winding</u>		519	968
Nominal supply voltage	volts	24	24
No load speed	rpm	12,456	23,232
Speed torque slope	rpm/oz-in	342	700
Stall torque (theoretical)	oz-in	53.6	90.6
Continuous torque case 20°C/no h.s.	oz-in	18/5.8	12.7/4.1
Continuous current case 20°C/no h.s.	amps	8.6/2.3	9.4/3.2
Thermal time constant	minutes	16	16
Motor constant Km	oz-in/√w	2.36	2.29
Resistance	ohm±15%	1.16	.368
Peak output	watts	95	330
No load current	amp±50%	.09	.25
Damping factor	oz-in/krpm	.015	.013
Static friction	oz-in	.041	.041
Velocity constant	rpm/volt±12%	519	968
Torque constant Kt	oz-in/amp	2.60	1.39
Stall current	amps	20.6	65.2
Maximum efficiency	%	87	88
Winding inductance	mH	.22	.06
Mechanical time constant	ms	1.4	1.5
Rotor inertia	10 <sup>-4</sup> oz-in-sec <sup>2</sup>	.57	.57
Thermal res. windings to case	°C/W	1.9	1.9
Thermal res. case to ambient	°C/W	8.5	8.5
Bearing rating dynamic	lb	59	59
Maximum axial force on shaft	lb	22	22
Design temperature limits winding	°C	150	150
Design temperature limits case	°C	-73C to +100C	-73C to +100C
Weight	oz.	3.8	3.8

Leads are 12" minimum  
Phase leads are 24 gauge, hall leads are 28 gauge, all TFE insulation. Untrimmed leads add .051Ω. Motor data at 20°C. No load current is motor only and does not include customer supplied drive



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

**Ordering Information:** phone 937-695-1275 • fax 937-695-0237 • www.koford.com • mail@koford.com

**Example:** Part Number 23 H 519 A / A3 / P25

Motor dia. \_\_\_\_\_  
Type S= sensorless, H=120° halls \_\_\_\_\_  
Winding number \_\_\_\_\_  
Gearbox P4=3.70:1, P25=25.01:1  
Encoder A3=360 lines, A1=100 lines  
Modifications A=none, T=thermistor (sensorless only) H= .040 bore hollow shaft S=sealed bearings

Test Data  
 Total System Performance  
 23S519T with S24V10A Controller at 24 volts

RPM	Torque Oz-in	Watts out	Efficiency %	Amps
12580	0.00	0.00	0.00	0.08
12216	1.11	10.05	82.11	0.51
12017	1.72	15.26	85.92	0.74
11768	2.37	20.65	86.04	1.00
10867	5.11	41.13	84.42	2.03
9955	7.86	57.92	79.13	3.05
9035	10.28	68.76	71.98	3.98
8018	13.23	78.51	64.78	5.05

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 ambient.

Test Data  
 Continuous Duty Total System Performance  
 23S519T with S24V10A Controller at 24 volts

RPM	Torque oz-in	watts out	$\Delta T$ (° C)	Final motor temp (° C)
12243	0.99	8.94	4.5	26.9
11946	2.00	17.62	6.9	28.8
11626	2.99	25.63	8.5	31.3
11301	3.99	33.25	11.9	34.7
10960	5.06	40.89	16.1	39.8
10601	6.00	46.90	23.5	45.5
10265	6.99	52.91	30.6	53.2
9860	8.20	59.62	39.6	63.1
9540	9.10	64.02	54.3	77.5
9210	10.13	68.80	76.6	99.4
8840	11.08	72.23	97.8	121.9

Motor was run at load until winding temperature stabilized. Motor was attached to a heavy aluminum mounting bracket. Test was run at room ambient 22-24C. At 12 oz-in temperature reached 150°C temperature limit after 5 minutes and test was stopped to prevent exceeding magnet temperature limit. Note that there is no drop in output power as the motor heats up.

•2 pole

•Maximum rpm 16,800

•Maximum Stall torque 36.7 oz-in.

Slotless design is cog free, cost effective, and provides high efficiency and cool operation at high speed. Available with optical encoders and gearheads. 150°C rated Neo magnets are standard, along with a hardened stainless steel shaft. 240°C ML wire and Kapton® ground insulation are used for the ultimate in ruggedness. Leads are Teflon® insulated. Motors are available with hall leads for positioning and reversing applications and sensorless for use with our sensorless controllers or for use with encoder controlled commutation. Modified shafts with shorter lengths or reduced diameter ends can be provided. Custom windings with different input voltages or different rpm can also be provided.



### Motor Data

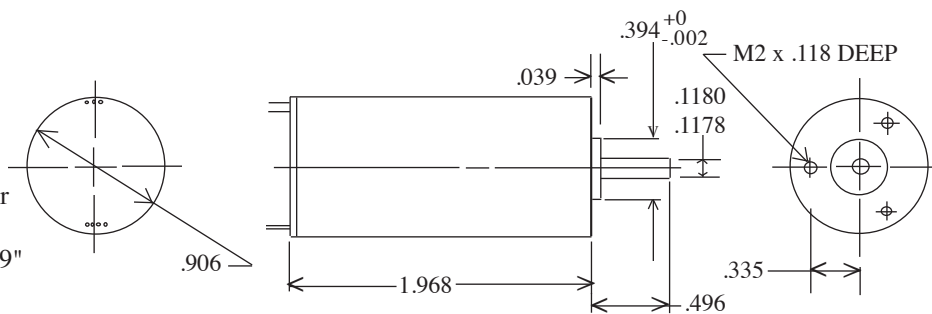
Winding		699	349	440	700
Nominal supply voltage	volts	12	24	24	24
no load speed	rpm	8,388	8,376	10,560	16,800
Stall torque (theoretical)	oz-in	18.8	18.8	23.7	36.7
Continuous torque heat sink/no h.s.	oz-in	12/4.8	12/4.8	12/4.8	11/4.3
Motor constant Km	oz-in/√w	1.74	1.74	1.74	1.74
Resistance*	ohm±15%	1.23	4.92	3.10	1.23
Peak output	watts	24	24	36	80
No load current	amp	.08	.04	.07	.14
Damping factor	oz-in/krpm	.007	.007	.007	.007
Static friction	oz-in	.14	.14	.14	.14
Velocity constant	rpm/volt±12%	699	349	440	700
Torque constant Kt	oz-in/amp	1.93	3.86	3.06	1.93
Stall current	amps	10	4.9	7.7	19
Maximum efficiency	%	78	78	82	83
Winding inductance	mH	.23	.92	.58	.23
Mechanical time constant	ms	3	3	3	3
Rotor inertia	10 <sup>-4</sup> oz-in-sec <sup>2</sup>	.66	.66	.66	.66
Thermal res.windings to case	°C/W	1.9	1.9	1.9	1.9
Thermal res case to ambient	°C/W	8.5	8.5	8.5	8.5
Bearing rating dynamic	oz	944	944	944	944
Bearing axial (static)	oz	352	352	352	352
Maximum winding temp.	°C	150	150	150	150

Weight oz. 3.8

Values based on winding and magnet temp. of 20°C

Ambient temperature -73C to 100C, contract factory for higher or lower temperature applications.

\*Not including .052Ω 12.9" length leads



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 23 H 603 A / A3 / P25

Motor dia. \_\_\_\_\_  
 Type S=sensorless, H=120°halls \_\_\_\_\_  
 Winding number \_\_\_\_\_  
 \_\_\_\_\_ Gearbox P4=3.70:1, P25=25.01:1  
 \_\_\_\_\_ Encoder A3=360cpr  
 \_\_\_\_\_ Modifications A=none H= .040 bore hollow shaft S=sealed bearings

Test Data  
Total System Performance  
23S700A with S24V10A Controller at 24 volts

Rpm	Torque Oz-in	Watts Out	Efficiency %	Amps
17160	0.00	0.00	0.0	0.21
16151	1.47	17.51	76.0	0.96
15760	2.08	24.17	78.7	1.28
15183	2.94	32.91	79.7	1.72
14853	3.50	38.36	79.1	2.02
14580	3.94	42.36	78.1	2.26
14049	4.73	49.00	77.0	2.65
13160	6.04	58.60	73.8	3.31
12388	7.19	69.80	69.2	3.92
11709	8.21	70.89	66.0	4.47
11005	9.27	75.23	62.7	5.00
10472	10.04	77.53	59.8	5.40
9607	11.28	79.91	55.0	6.05

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 ambient.

Test Data  
Total System Performance  
23S349A with S24V10A Controller at 24 volts

Rpm	Torque Oz-in	Watts Out	Efficiency %	Amps
8497	0.00	0.00	0.0	0.09
7924	1.09	6.31	73.0	0.36
7640	1.67	9.35	78.0	.50
7110	2.54	13.27	76.9	.72
6864	3.04	15.34	74.3	.86
6570	3.53	17.05	72.5	.98
6243	4.14	19.00	69.8	1.14
5975	4.65	20.44	66.8	1.28
5781	5.04	21.40	65.3	1.37
5525	5.48	22.24	62.6	1.48
5172	6.13	23.29	58.8	1.65
4908	6.52	23.51	56.0	1.75

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 ambient.

•2 pole

•Maximum rpm 40,000

•Maximum Stall torque 24 oz-in.

Slotless design is cog free, cost effective, and provides high efficiency and cool operation at high speed. Available with optical encoders and gearheads. 150°C rated Neo magnets are standard, along with a hardened stainless steel shaft. 240°C ML wire and Kapton® ground insulation are used for the ultimate in ruggedness. Leads are Teflon® insulated. Motors are available with hall leads for positioning and reversing applications and sensorless for use with our sensorless controllers or for use with encoder controlled commutation. Modified shafts with shorter lengths or reduced diameter ends can be provided. Custom windings with different input voltages or different rpm can also be provided.



### Motor Data

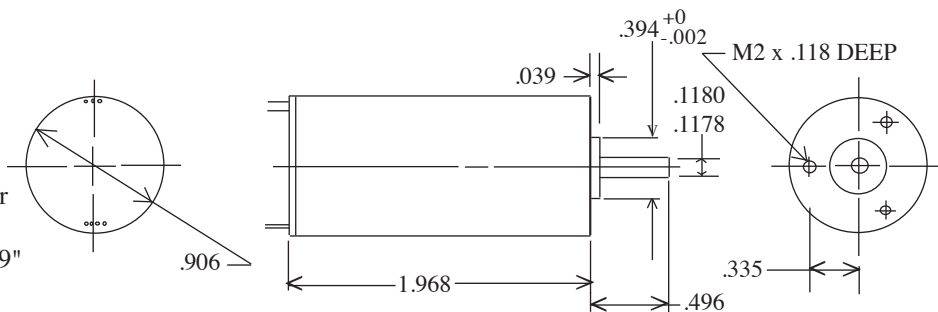
Winding		3333	1666
Nominal supply voltage	volts	12	24
no load speed	rpm	40,000	40,000
Stall torque (theoretical)	oz-in	24.0	24.0
Continuous torque heat sink/no h.s.	oz-in	5.7/1.6	5.7/1.6
Motor constant Km	oz-in/√w	.95	.95
Resistance*	ohm±15%	.18	.73
Peak output	watts	176	176
No load current	amp	.38	.19
Damping factor	oz-in/krpm	.002	.002
Static friction	oz-in	.041	.041
Velocity constant	rpm/volt±12%	3,584	1,792
Torque constant Kt	oz-in/amp	.40	.81
Stall current	amps	66	32
Maximum efficiency	%	84	85
Winding inductance	mH	.02	.08
Mechanical time constant	ms	7	7
Rotor inertia	10 <sup>-4</sup> oz-in-sec <sup>2</sup>	.37	.37
Thermal res. windings to case	°C/W	1.9	1.9
Thermal res. case to ambient	°C/W	8.5	8.5
Bearing rating dynamic	oz	944	944
Bearing axial (static)	oz	352	352
Maximum winding temp.	°C	150	150

Weight oz. 3.8

Values based on winding and magnet temp. of 20°C

Ambient temperature -73C to 100C, contract factory for higher or lower temperature applications.

\*Not including .052Ω 12.9" length leads



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 23 H 1666 A / A3

Motor dia. \_\_\_\_\_  
 Type S=sensorless, H=120°halls \_\_\_\_\_ Encoder A1=100 lines  
 Winding number \_\_\_\_\_ Modifications A=none H=.040 bore hollow shaft S=sealed bearings

•Autoclavable

•2 pole

•176 watts peak

Slotless design is cog free, cost effective, and provides high efficiency and cool operation at high speed in surgical/dental handpieces. Samarium cobalt magnets, hardened stainless shaft, and corrosion resistant lamination materials are used. 240°C ML wire and Kapton® ground insulation are used for the ultimate in ruggedness. Leads are Teflon® insulated. Typical life exceeds 1,000 autoclave cycles. Motors are available in sensorless configuration for use with our sensorless controllers which only require 3 leads and have the coolest operation or with hall sensors for quick start up and the widest speed range. Modified shafts with features such as cross pins can be provided. Custom windings can also be provided.



### Motor Data

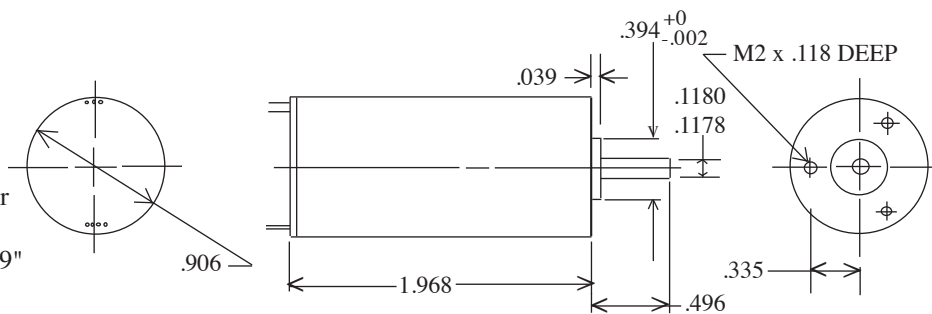
Winding		3584	1792
Nominal supply voltage	volts	12	24
no load speed	rpm	43,000	43,000
Stall torque (theoretical)	oz-in	24.0	24.0
Continuous torque heat sink/no h.s.	oz-in	5.6/1.6	5.6/1.6
Motor constant Km	oz-in/√w	.88	.88
Resistance*	ohm±15%	.18	.73
Peak output	watts	176	176
No load current	amp	.38	.19
Damping factor	oz-in/krpm	.002	.002
Static friction	oz-in	.041	.041
Velocity constant	rpm/volt±12%	3584	1,792
Torque constant Kt	oz-in/amp	.38	.75
Stall current	amps	66	32
Maximum efficiency	%	84	85
Winding inductance	mH	.02	.08
Mechanical time constant	ms	7	7
Rotor inertia	10 <sup>-4</sup> oz-in-sec <sup>2</sup>	.37	.37
Thermal res. windings to case	°C/W	1.9	1.9
Thermal res. case to ambient	°C/W	8.5	8.5
Bearing rating dynamic	oz	944	944
Bearing axial (static)	oz	352	352
Maximum winding temp.	°C	150	150

Weight oz. 3.8

Values based on winding and magnet temp. of 20°C

Ambient temperature -73C to 100C, contract factory for higher or lower temperature applications.

\*Not including .052Ω 12.9" length leads



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 23 S 1792 C

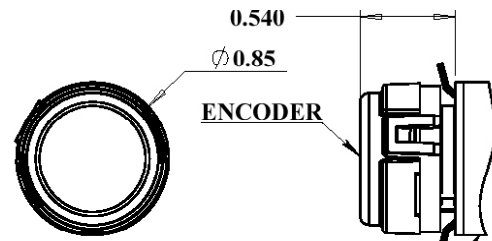
Motor dia. \_\_\_\_\_  
 Type S=sensorless, H=120°halls \_\_\_\_\_  
 Winding number \_\_\_\_\_

Cobalt magnet and corrosion resistant laminations H= .040 bore hollow shaft S=sealed bearings

## Optical Encoders

A3=360 lines. A and B channels in quadrature. Combined this gives 1440 counts per shaft revolution. Mating connector Molex 51021-400/50079 . Supply voltage  $5 \pm .5V$ . Rpm 16,000 max. Inertia  $.07 \times 10^{-4}$  oz-in-sec<sup>2</sup>. -20°C to 100°C.

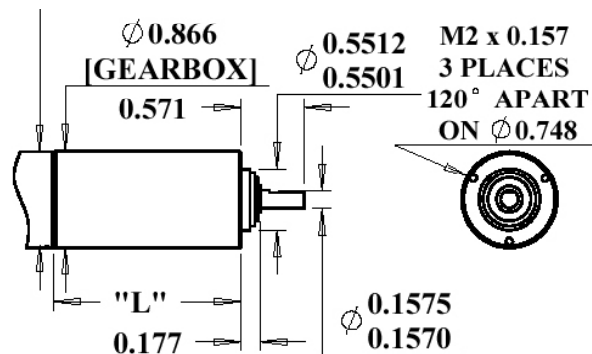
A1=100 lines. A and B channels in quadrature. Combined this gives 400 counts per shaft revolution. Mating connector Molex 51021-400/50079 . Supply voltage  $5 \pm .5V$ . Rpm 60,000 max. Inertia  $.07 \times 10^{-4}$  oz-in-sec<sup>2</sup>. -20°C to 100°C.



## Planetary Gearheads

Construction is planetary with case hardened alloy steel gears, and double shielded ball bearings on output. Input speed for best life is 6,000 rpm or lower. Bearing lube rated for -35C to 140C. Low temp lube rated for -60 to 130C available on special order. Other ratios are available on special order.

3.70:1 L=.775 127 oz-in peak 85 oz-in cont.  
90% eff.  
25.01:1 L=1.039 149 oz-in peak 99 cont.  
80% eff.  
92.70:1 L=1.303 168 oz-in peak 112 cont.  
70% eff.  
Weight 3.70:1=1.7 oz, 25.01:1=2.1 oz,  
92.70:1=2.6 oz  
Max backlash 3.70:1=1.5°, 25.01:1=2°,  
92.70:1=2.5°  
Inertia  $10^{-4}$  oz-in-sec<sup>2</sup> = .05





## 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. Usually this is because these motors will overheat if run continuously at full speed even with no load.

### **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 23mm 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 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, 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 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. 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

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.

### **Motors for surgical and dental tools**

Surgical and dental tool motors typically operate at high speed so high efficiency is important to prevent the tool from heating up excessively in the users hand. Sensorless motors are popular for this application due to cooler operation especially over 60,000 rpm, and since only three wires are required, the cord to the tool can be smaller and more flexible. However there is approximately a 0.25 seconds of delay in start up with a sensorless motor. Also the speed range is approximately 35% to 100% of maximum. If these characteristics are not acceptable then a hall sensor motor should be used. If the design of the tool requires the motor to withstand being placed in a sterilizer (autoclave) then an autoclavable motor is recommended. Because high pressure steam is highly corrosive a standard motor will only withstand about 100 autoclave cycles of twenty minutes at temperature. The number of cycles will increase when the motor is placed in an housing. The greater thermal mass the housing has, the more the motor is sealed against steam pressure, and the shorter the autoclave cycle used the more cycles that can be obtained. For long life eg. 1000 cycles an autoclavable motor should be used. This is option C which is available on a number of motors. These motors are made with highly corrosion resistant magnet, shaft and lamination materials and the polymeric materials are polyimide, Teflon®, or high performance heat cured epoxy.

### **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 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).