KOFORD
ENGINEERING, LLC

1.30” (33mm) Series

• High performance slotless brushless precison motors for aerospace, military, electric power tools, medical, and industrial applications

•Outstanding servo performance, cog free, low inertia, low inductance

•Rated power to 430 watts, peak to 1,900 watts, speeds up 50,000 rpm

• Vacuum versions suitable for high vacuum applications

• Highest power density

•4 pole design

• High temperature ML (220°C) insulation for the ultimate in ruggedness

• Available with hall sensors, or sensorless

• Up to 94% efficiency

• Available with high efficiency (94%) long life planetary gearboxes with hardened steel gears and all antifriction bearings

• Available with temperature sensors, or internal overtemperature protection

• Long life premium synthetic bearing lube with -73C to 149C temperature range.

•Ceramic bearings available

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1.30" (33mm) Slotless Brushless motor.

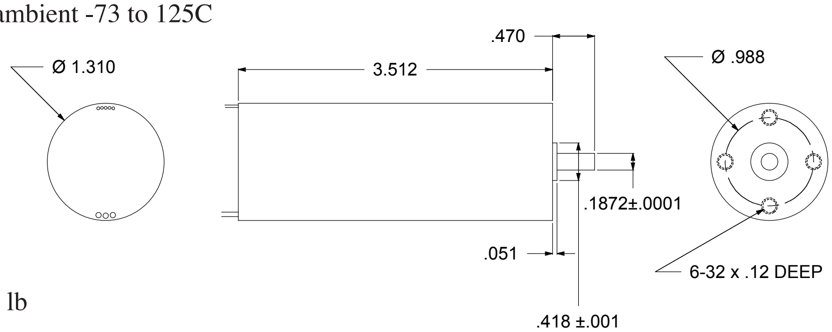
•Up to 19,756 rpm •Rated power 430 watts •4 pole

4 pole ultra high performance, rugged, slotless design provides unmatched power density,high continuous and peak torque and is cog free. 240°C rated ML wire and 205°C rated thermosetting thermally conductive resin are used for the windings for the ultimate in ruggedness. Available in hall and sensorless versions. Lamination materials are ultra low loss for maximum performance. Outstanding servo performance due to cog free design, low inerta, and low inductance. Available with high performance gearboxes, thermistor temperature sensors, and self resetting overtemperature protection (available on hall versions only). Vacuum versions and versions with ceramic hybrid bearings available. Custom winding or modified shafts can be provided.

Motor Data

Winding		410	411	412
Nominal supply voltage	volts	24	36	48
no load speed	rpm ±12%	9,840	14.796	19,756
speed/torque slope	rpm/oz-in	66	74	81
Stall torque	oz-in	275	413	551
Continuous torque case 20°C/no h.s.	oz-in	99/34	99/33	98/32
Continuous current case 20°C/no h.s.	amps	30.4/10.6	30.3/10.3	30.2/10.0
Motor constant Km	oz-in/√w	6.14	6.14	6.14
Winding resistance	ohm±15%	.285	.285	.285
Peak output	watts	275	600	1,000
No load current	amp±50%	.10	.12	.14
Damping factor	oz-in/krpm	.013	.013	.013
Static friction	oz-in	.20	.20	.20
Velocity constant	rpm/volt	411	411	412
Torque constant Kt	oz-in/amp	3.28	3.28	3.28
Stall current	amps	84	126	168
Maximum efficiency	%	93	94	94
Winding inductance	mH	.11	.11	.11
Mechanical time constant	ms	1.4	1.4	1.4
Rotor inertia	10^{-4}oz-in-sec^2	3.90	3.90	3.90
Thermal res. winding to case	°C/W	.49	.49	.49
Thermal case to ambient	°C/W	3.3	3.3	3.3

Weight 11.9 oz 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



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

Example: Part Number 33 H 410 A / A3 / P7

Motor dia. — 33
Type S=sensorless H=120°halls — H
Winding number — 410
Modifications A=none T=temperature sensor O=overtemperature protection, V=vacuum, B=ceramic hybrid bearings — A
Encoder A=256lines (1024 count), A3=360lines(1,440 count) — A3
Gearhead P7=6.75:1, P46=45.56:1, P307=307.54:1 — P7

Test Data
Total System Performance
33H410A with H24V20A Controller at 24 volts

Rpm	Torque Oz-in	Watts Out	Efficiency %	Amps
9950	0.00	0.00	0.00	0.13
9787	3.12	22.58	94.10	1.00
9528	6.36	44.82	93.40	2.00
9118	12.86	86.76	90.40	4.00
8690	19.71	126.78	88.00	6.00
8258	26.70	163.20	84.00	8.10
7846	33.31	193.41	81.40	9.90
7389	39.93	218.34	75.80	12.00
6959	46.75	240.78	71.20	14.10
6417	53.10	252.19	65.70	16.00
6203	59.92	275.06	63.70	18.00
5550	66.77	274.26	57.10	20.00

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
Total System Performance
33H412A with H48V20A Controller at 48 volts

Rpm	Torque Oz-in	Watts Out	Efficiency %	Amps
19875	0.00	0.00	0.00	0.17
19520	2.59	37.44	78.00	1.00
19280	6.04	86.21	88.50	2.03
19033	9.46	133.31	91.40	3.04
18783	12.94	179.88	92.30	4.06
18549	16.16	221.79	92.20	5.01
18246	19.65	265.37	91.80	6.02
18011	23.07	307.52	91.00	7.04

Dyno test results of a motor and drive combination with voltage held to 48v 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.

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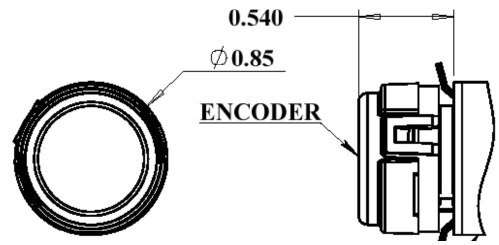
Optical Encoders

A2=256 lines, A3=360 lines. A and B channels in quadrature. Combined this gives 1024 and 1440 counts per shaft revolution.Mating connector Molex 51021-400/50079 . Supply voltage 5±.5V. Rpm 60,000 max. Inertia .07 x10^{-4}oz-in-sec^2



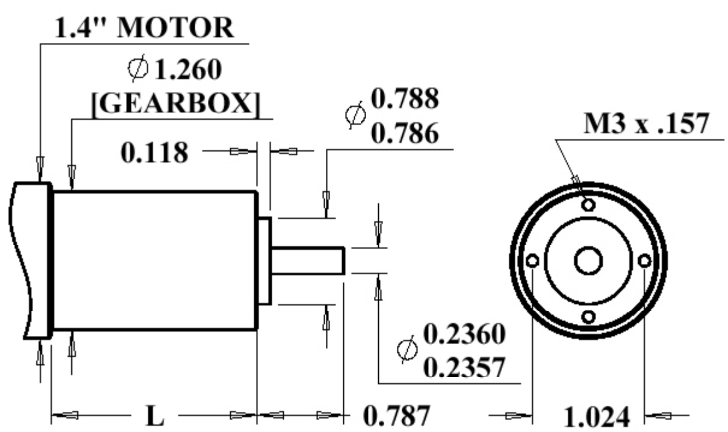
Planetary Gearheads

Construction is planetary with case hardened alloy steel gears, needle bearings on planets and double sheilded 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. Maximum input speed 60,000 rpm.
45.56:1 L=1.510 478 oz-in peak /319 cont. 89% eff. Maximum input speed 60,000 rpm.
307.54:1 L=1.884 957 oz-in peak /638 cont. 85%eff. Maximum input speed 60,000 rpm.

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 x 10-^{4}oz-in-sec^2
All gears are precision hobbed hardened alloy steel. Output is dual sheilded ball bearings.



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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

°F -32 ÷1.8=°C example: 212°F=100°C, °C x1.8+32=°F example: 100°C=212°F, in x 25.40=mm, mm x.03937= in., oz x 28.3495=g, oz-in x 7.06=mNm, mNm x .142=oz-in, Nm x .142=oz-in, Ncm x 1.42=oz-in, rpm x .1047=rad s^{-1}, V/R/S x .1047=volts/rpm, 746 watts=1hp, lb-in^2 x .04144=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 sensititive. 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 dynamicially 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 x weight (oz.)/ rpm=unbalance in milli oz-in. If the components have appreciable length they must be balance in 2 planes.

Motor technology

The Koford 33mm 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 (50,000+rpm), can operate in a vacuum, and will not introduce comtamination 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 higher voltages and speeds then shown on the data sheet. Motors should not be operated above 50,000 rpm.

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) x 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, or Sensorless 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.

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 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 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 x 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. 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 to 20°C and the second with no cooling in still air. Most applications will fall somewhere between these two extreemes. 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 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. Contact the factory if your application requires a frameless version of one of the motors listed in the catalog.

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 5,000μF 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 then 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 in not any noticable 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 then 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 then 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 then 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 x 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).