Control Technologies, Inc

Direct Drive Cog-Less Brushless DC Motor Catalog

Innovative Designs, Responsive Solutions

Avior Control Technologies, Inc
2000 Pike Road, Unit B
Longmont CO, 80501
+1 720-491-3708
www.AviorControls.com

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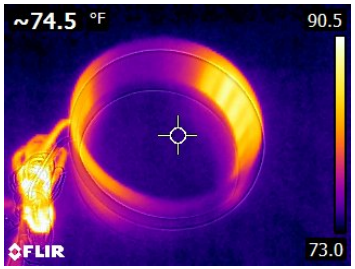
Section 1 - Introduction

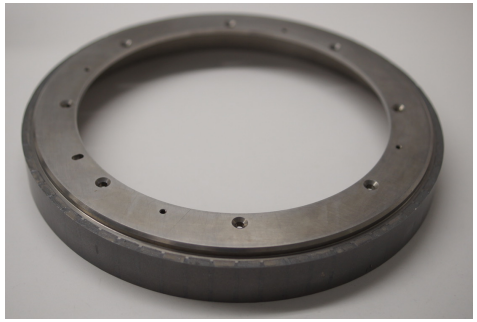
This catalog is separated into two types of direct drive motors typically used in the Aerospace community. **Section 2** tabulates our Slot-less, Cog-less (Type CL) line of motors. These motors offer low disturbance and low-total harmonic distortion back emf, ideal for pointing and tracking applications. These motors offer extremely low magnetic coulomb or "drag" torque, and extremely low cross-sectional configuration. For "Conventional Toothed" Motors (Avior Type CM), refer to our CM Motor Catalog.

Magnet Material: *All* motors feature high-reliability, high-temperature Samarium Cobalt (SmCo) magnets which are much more reliable than Neodymium Iron Boron Magnets (NeFeBn). SmCo magnets have much higher operating temperature, significantly improved corrosion resistance and offer increased temperature stability, compared to NeFeBn magnets. Avior also offers as an option totally encapsulated rotor assemblies (shown to the right) which provides a higher level of reliability and handling robustness compared to exposed magnet assemblies. Our encapsulated magnet assemblies minimize handling and installation issues as well as provide particulate containment. It is recommended to take extreme care in handling and installation of the rotor assemblies.



Redundancy: Any of our CL motors may be provided with electrical redundancy. Tabulated performance herein provides the "Simplex" or "Redundant" performance for each configuration. Our "*Colorado-Quadrant Redundant*" Technology for redundant winding configurations offers desired features over other designs. Most competitive technologies use "Half-Moon" redundancy, where the primary motor winding encompasses one-half of the stator body diameter, and the redundant the other half. While there is no overlap of the motor windings, in the half-moon design, necessarily this configuration results in unbalanced thermal gradients in the motor assembly. Our Colorado-Quadrant-Redundancy balances the heat more uniformly across the assembly by winding the redundancy in quadrants. The IR image to the left shows a thermal image of a powered Colorado-Quadrant Redundant Motor.

Windings and Voltages: There are far more options for motor winding performance, operational voltages and torque constant configurations than we are able to tabulate in this catalog. The motor winding performance for DC resistance and Torque Constants tabulated herein are calculated for 24 Volts Input (V_{IN}). **Refer to Engineering Section 3 to approximate dynamic performance as well as project other motor winding configurations, drive methods and / or supply voltages.**

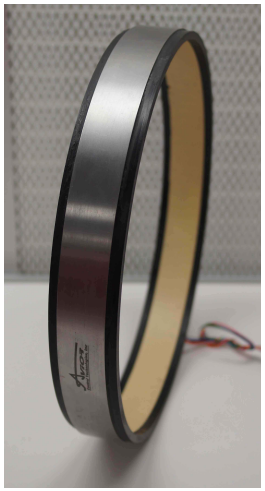


Optional Mounting Provisions: Particularly with the CL Motor configuration, Avior recommends we integrate and assemble any mounting flange provision. This allows Avior to conduct the final bore machining with respect to your custom mounting provisions, thereby eliminating accumulated tolerances, and providing a more precise assembly. The customer may provide the hardware as Customer Furnished Material (CFM), or Avior may manufacture the parts in-house, your prints.

Other Notables: Cog-less type CL motors offer smoother control, lower harmonic distortion and thin cross-sectional area, compared to Conventional Toothed Direct Drive Motors (Avior Type CM). For a given outside diameter, however, Type CM Motors are more efficient and can handle higher temperatures, compared to the CL line of motors.

Although it is not a requirement, it is recommended to use sinusoidal drive for cog-less motors. See the **Section 3**, Engineering for further information about Trapezoidal versus Sinusoidal. Type CL motors may be provided in either a two phase or three phase winding configuration. Simplex or Quadrant-Redundant windings, as well as integral mounting provisions may be provided on request. Avior may also provide custom sizes and stack-heights for specific applications.

This catalog tabulates common motor sizes from 1.0" (25.40 mm) through 10.0" in diameter (254 mm). The unit shown to the left is our type CL-10.0-1.0R configuration. While we have tabulated a range of configurations and motor winding options, custom diameters, operational voltages and stack-heights are available on request. Avior manufacturers each of our motors to specific Customer's requirements, it is standard for our process to optimize the motor your your specific system application.



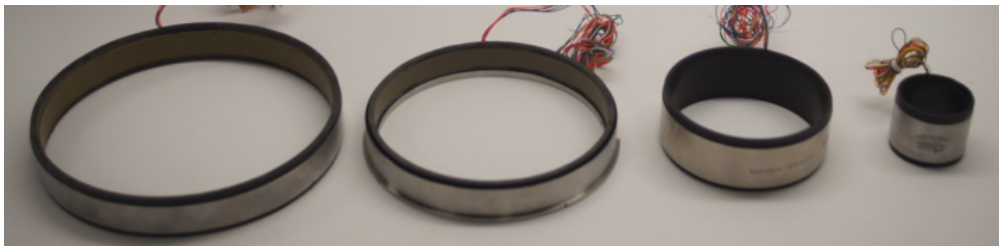
Avior's standard CL line of motors offer High-Temperature magnet wire and lead-wire insulation. Additionally, the end-turn dimensions provided herein include high temperature, low-outgassing potting material for handing robustness and added structural integrity. Soldering standards are in accordance with IPC-J-STD-002, Space Addendum with J-STD-006 materials. Compliance with EEE-INST-002 Magnet Wire and Lead Wire is available for Class 1 missions.

Outside Rotor Configuration: This catalog tabulates performance for baselined sizes from 1.0" to 10.0" in diameter. Avior may also provide "Outside-In" assemblies, where the motor windings are on the inside, and the rotational magnet assembly is on the outside of the motor assembly. This catalog will be amended in the near future to incorporate the Outside-In motor options and performance.

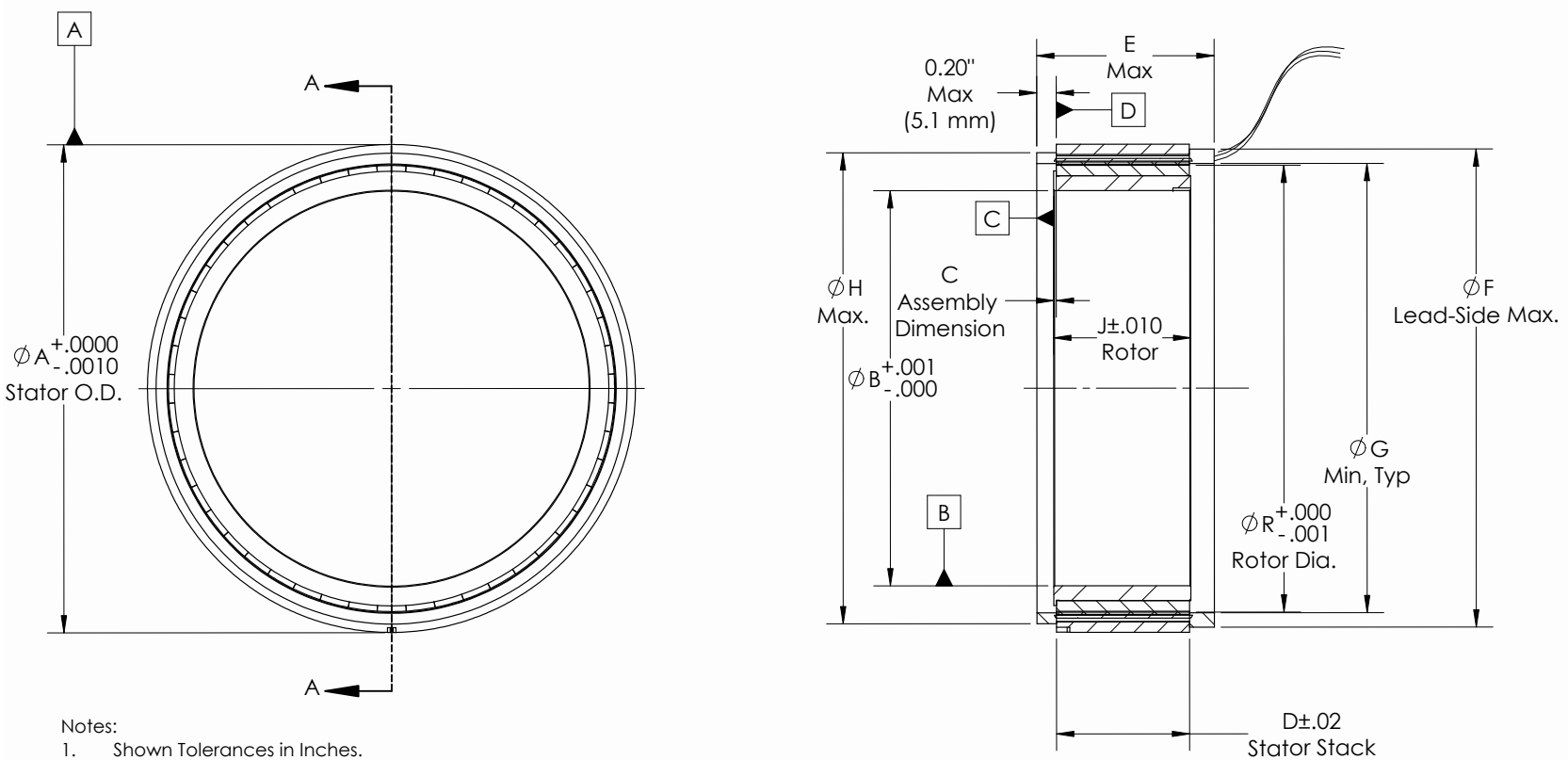
Motor Code Nomenclature: Our motor code designations indicate the configuration, outside diameter, stack height and redundancy option. A CL-3.5-.75R is a Cog-less, 3.5" Outside Diameter, and 0.75" stack height. If a special winding resistance is requested, simply add the resistance after the code. For instance, a CL-3.5-.75R-50 would have a 50 Ohm winding, rather than our tabulated 80 ohm. See Section 3 for more information on calculating other winding options. The Customer must also specify two phase or three phase. All data represented herein is approximate and subject to change without notice.

Thermal Considerations: Mounting configuration and thermal system characteristics play a large part of the thermal temperature rise characteristics of Cog-less motors. Avior will work with Customer system engineers to support thermal modeling of our motors in system environment conditions.

Note: Custom Motor Diameters, Stack Lengths, Mounting Configurations and Winding Options are Available on Request



Section 2 - Cog-Less Motors (Type CL)



Notes:
1. Shown Tolerances in Inches.
2. Assure clearance around windings to any electrically conductive surface to be 0.031" (.8 mm), minimum.
3. Assembeled Concentricity of -A- to -B- to be within 0.004" (0.10 mm), maximum.
4. Assembeled Alignment of -C- to -D- (Dimension C) to be within ± 0.016" (±.40 mm).
5. Assembeled Perpendicularity of -C- to -A- to be within ±0.003" (0.08mm).

Figure 1 - CL-ICD

Table CL-1.0 - Cog-Less Motor Data

PARAMETER	UNITS	Table CL-1.0 - Motor Data (+25ºC)							
		CL-1.0-.25S	CL-1.0-.25R	CL-1.0-.38S	CL-1.0-.38R	CL-1.0-.50S	CL-1.0-.50R	CL-1.0-.75S	CL-1.0-.75R
A Outside Diameter	Inches	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	mm	25.40	25.40	25.40	25.40	25.40	25.40	25.40	25.40
B Through Bore	Inches	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
	mm	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35
C Stator to Rotor Location	Inches	0.050	0.050	0.050	0.050	0.050	0.050	0.075	0.075
	mm	1.270	1.270	1.270	1.270	1.270	1.270	1.905	1.905
D Stack Length	Inches	0.252	0.252	0.378	0.378	0.504	0.504	0.756	0.756
	mm	6.40	6.40	9.60	9.60	12.80	12.80	19.20	19.20
E Max Length	Inches	0.772	0.822	0.898	0.948	1.024	1.074	1.276	1.326
	mm	19.61	20.88	22.81	24.08	26.01	27.28	32.41	33.68
F Lead-Side Max End Turn O.D.	Inches	0.980	0.980	0.980	0.980	0.980	0.980	0.980	0.980
	mm	24.89	24.89	24.89	24.89	24.89	24.89	24.89	24.89
G End-Turn Min I.D.	Inches	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	mm	18.80	18.80	18.80	18.80	18.80	18.80	18.80	18.80
H Max End-Turn Dia (Non-Lead side)	Inches	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
	mm	23.88	23.88	23.88	23.88	23.88	23.88	23.88	23.88
J Rotor Length	Inches	0.352	0.352	0.478	0.478	0.604	0.604	0.906	0.906
	mm	8.94	8.94	12.14	12.14	15.34	15.34	23.01	23.01
R Rotor Outside Diameter	Inches	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625
	mm	15.88	15.88	15.88	15.88	15.88	15.88	15.88	15.88

PARAMETER	UNITS	Table CL-1.0 - Motor Data (+25ºC)							
		CL-1.0-.25S	CL-1.0-.25R	CL-1.0-.38S	CL-1.0-.38R	CL-1.0-.50S	CL-1.0-.50R	CL-1.0-.75S	CL-1.0-.75R
Coulomb Torque (Fc)	Lbf-In	1.00E-03	1.00E-03	1.50E-03	1.50E-03	2.00E-03	2.00E-03	3.00E-03	3.00E-03
	Nm	1.13E-04	1.13E-04	1.69E-04	1.69E-04	2.26E-04	2.26E-04	3.39E-04	3.39E-04
Mass	Lbs	0.060	0.060	0.075	0.075	0.100	0.100	0.150	0.150
	kg	0.027	0.027	0.034	0.034	0.045	0.045	0.068	0.068
Number of Poles (#P)	-	8	8	8	8	8	8	8	8
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	3.20E-06	3.20E-06	4.80E-06	4.80E-06	6.40E-06	6.40E-06	9.60E-06	9.60E-06
	kg-m^2	3.62E-07	3.62E-07	5.42E-07	5.42E-07	7.23E-07	7.23E-07	1.08E-06	1.08E-06
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**0.046**	**0.033**	**0.070**	**0.049**	**0.093**	**0.066**	**0.121**	**0.085**
	Nm / √watt	5.20E-03	3.73E-03	7.91E-03	5.59E-03	1.05E-02	7.46E-03	1.37E-02	9.66E-03
No-Load Speed (Reference)	RPM	5,092	5,019	3,741	3,742	3,085	3,074	2,653	2,654
	Rad/Sec	533	526	392	392	323	322	278	278
Theoretical Stall Torque (T_S)	Lbf-In	0.149	0.075	0.253	0.126	0.368	0.185	0.535	0.268
	Nm	0.017	0.009	0.029	0.014	0.042	0.021	0.060	0.030
Max Power Output Torque (T_{PO})	Lbf-In	0.074	0.038	0.127	0.063	0.184	0.092	0.268	0.134
	Nm	0.008	0.004	0.014	0.007	0.021	0.010	0.030	0.015
Motor Resistance (Ω)	Ohms	**75**	**150**	**60**	**120**	**50**	**100**	**40**	**80**
Torque Constant (Kt)	Lbf-In/Amp	0.398	0.404	0.542	0.542	0.658	0.660	0.765	0.765
	Nm/Amp	0.045	0.046	0.061	0.061	0.074	0.075	0.086	0.086

Table CL-1.5 - Cog-Less Motor Data

Parameter	Units	Table CL-1.5 - Motor Data (+25ºC)							
		CL-1.5-.38S	CL-1.5-.38R	CL-1.5-.50S	CL-1.5-.50R	CL-1.5-.75S	CL-1.5-.75R	CL-1.5-1.0S	CL-1.5-1.0R
A Outside Diameter	Inches	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500
	mm	38.10	38.10	38.10	38.10	38.10	38.10	38.10	38.10
B Through Bore	Inches	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625
	mm	15.88	15.88	15.88	15.88	15.88	15.88	15.88	15.88
C Stator to Rotor Location	Inches	0.05	0.05	0.05	0.05	0.075	0.075	0.075	0.075
	mm	1.27	1.27	1.27	1.27	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.378	0.378	0.504	0.504	0.756	0.756	1.008	1.008
	mm	9.60	9.60	12.80	12.80	19.20	19.20	25.60	25.60
E Max Length	Inches	0.898	0.948	1.024	1.074	1.276	1.326	1.528	1.578
	mm	22.81	24.08	26.01	27.28	32.41	33.68	38.81	40.08
F Lead-Side Max End Turn O.D.	Inches	1.480	1.480	1.480	1.480	1.480	1.480	1.480	1.480
	mm	37.59	37.59	37.59	37.59	37.59	37.59	37.59	37.59
G End-Turn Min I.D.	Inches	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
	mm	31.50	31.50	31.50	31.50	31.50	31.50	31.50	31.50
H Max End-Turn Dia (Non-Lead side)	Inches	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
	mm	36.58	36.58	36.58	36.58	36.58	36.58	36.58	36.58
J Rotor Length	Inches	0.478	0.478	0.604	0.604	0.906	0.906	1.158	1.158
	mm	12.14	12.14	15.34	15.34	23.01	23.01	29.41	29.41
R Rotor Outside Diameter	Inches	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125
	mm	28.58	28.58	28.58	28.58	28.58	28.58	28.58	28.58

PARAMETER	UNITS	Table CL-1.5 - Motor Data (+25ºC)							
		CL-1.5-.38S	CL-1.5-.38R	CL-1.5-.50S	CL-1.5-.50R	CL-1.5-.75S	CL-1.5-.75R	CL-1.5-1.0S	CL-1.5-1.0R
Coulomb Torque (Fc)	Lbf-In	2.50E-03	2.50E-03	3.33E-03	3.33E-03	5.00E-03	5.00E-03	6.67E-03	6.67E-03
	Nm	2.82E-04	2.82E-04	3.77E-04	3.77E-04	5.65E-04	5.65E-04	7.53E-04	7.53E-04
Mass	Lbs	0.150	0.150	0.200	0.200	0.300	0.300	0.400	0.400
	kg	0.068	0.068	0.091	0.091	0.136	0.136	0.182	0.182
Number of Poles (#P)	-	12	12	12	12	12	12	12	12
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	4.73E-05	4.73E-05	6.30E-05	6.30E-05	9.45E-05	9.45E-05	1.89E-04	1.89E-04
	kg-m^2	5.34E-06	5.34E-06	7.12E-06	7.12E-06	1.07E-05	1.07E-05	2.14E-05	2.14E-05
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**0.152**	**0.107**	**0.193**	**0.136**	**0.276**	**0.195**	**0.352**	**0.265**
	Nm / √watt	1.72E-02	1.21E-02	2.18E-02	1.54E-02	3.12E-02	2.20E-02	3.98E-02	2.99E-02
No-Load Speed (Reference)	RPM	1,541	1,541	1,214	1,214	849	849	665	625
	Rad/Sec	161	161	127	127	89	89	70	65
Theoretical Stall Torque (T_S)	Lbf-In	0.491	0.246	0.624	0.312	0.892	0.446	1.138	0.606
	Nm	0.056	0.028	0.070	0.035	0.101	0.050	0.129	0.068
Max Power Output Torque (T_{PO})	Lbf-In	0.246	0.123	0.312	0.156	0.446	0.223	0.569	0.303
	Nm	0.028	0.014	0.035	0.018	0.050	0.025	0.064	0.034
Motor Resistance (Ω)	Ohms	**75**	**150**	**75**	**150**	**75**	**150**	**75**	**150**
Torque Constant (Kt)	Lbf-In/Amp	1.316	1.316	1.671	1.671	2.390	2.390	3.048	3.246
	Nm/Amp	0.149	0.149	0.189	0.189	0.270	0.270	0.344	0.367

Table CL-2.0 - Cog-Less Motor Data

PARAMETER	UNITS	Table CL-2.0 - Motor Data (+25ºC)							
		CL-2.0-.38S	CL-2.0-.38R	CL-2.0-.50S	CL-2.0-.50R	CL-2.0-.75S	CL-2.0-.75R	CL-2.0-1.0S	CL-2.0-1.0R
A Outside Diameter	Inches	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
	mm	50.80	50.80	50.80	50.80	50.80	50.80	50.80	50.80
B Through Bore	Inches	1.0625	1.0625	1.0625	1.0625	1.0625	1.0625	1.0625	1.0625
	mm	26.99	26.99	26.99	26.99	26.99	26.99	26.99	26.99
C Stator to Rotor Location	Inches	0.05	0.05	0.05	0.05	0.075	0.075	0.075	0.075
	mm	1.27	1.27	1.27	1.27	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.378	0.378	0.504	0.504	0.756	0.756	1.008	1.008
	mm	9.60	9.60	12.80	12.80	19.20	19.20	25.60	25.60
E Max Length	Inches	0.898	0.948	1.024	1.074	1.276	1.326	1.528	1.578
	mm	22.81	24.08	26.01	27.28	32.41	33.68	38.81	40.08
F Lead-Side Max End Turn O.D.	Inches	1.980	1.980	1.980	1.980	1.980	1.980	1.980	1.980
	mm	50.29	50.29	50.29	50.29	50.29	50.29	50.29	50.29
G End-Turn Min I.D.	Inches	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74
	mm	44.20	44.20	44.20	44.20	44.20	44.20	44.20	44.20
H Max End-Turn Dia (Non-Lead side)	Inches	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94
	mm	49.28	49.28	49.28	49.28	49.28	49.28	49.28	49.28
J Rotor Length	Inches	0.478	0.478	0.604	0.604	0.906	0.906	1.158	1.158
	mm	12.14	12.14	15.34	15.34	23.01	23.01	29.41	29.41
R Rotor Outside Diameter	Inches	1.6250	1.625	1.6250	1.625	1.6250	1.625	1.6250	1.625
	mm	41.28	41.28	41.28	41.28	41.28	41.28	41.28	41.28

PARAMETER	UNITS	Table CL-2.0 - Motor Data (+25ºC)							
		CL-2.0-.38S	CL-2.0-.38R	CL-2.0-.50S	CL-2.0-.50R	CL-2.0-.75S	CL-2.0-.75R	CL-2.0-1.0S	CL-2.0-1.0R
Coulomb Torque (Fc)	Lbf-In	6.00E-03	6.00E-03	8.00E-03	8.00E-03	1.20E-02	1.20E-02	1.60E-02	1.60E-02
	Nm	6.78E-04	6.78E-04	9.04E-04	9.04E-04	1.36E-03	1.36E-03	1.81E-03	1.81E-03
Mass	Lbs	0.210	0.210	0.280	0.280	0.420	0.420	0.560	0.560
	kg	0.095	0.095	0.127	0.127	0.191	0.191	0.255	0.255
Number of Poles (#P)	-	16	16	16	16	16	16	16	16
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	1.80E-04	1.80E-04	2.28E-04	2.28E-04	3.42E-04	3.42E-04	4.56E-04	4.56E-04
	kg-m^2	2.03E-05	2.03E-05	2.58E-05	2.58E-05	3.86E-05	3.86E-05	5.15E-05	5.15E-05
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**0.190**	**0.134**	**0.250**	**0.177**	**0.350**	**0.247**	**0.450**	**0.318**
	Nm / √watt	2.15E-02	1.52E-02	2.82E-02	2.00E-02	3.95E-02	2.80E-02	5.08E-02	3.59E-02
No-Load Speed (Reference)	RPM	1,378	1,379	1,048	1,048	1,058	1,058	823	823
	Rad/Sec	144	144	110	110	111	111	86	86
Theoretical Stall Torque (T_S)	Lbf-In	0.687	0.343	0.904	0.452	1.789	0.894	2.300	1.150
	Nm	0.078	0.039	0.102	0.051	0.202	0.101	0.260	0.130
Max Power Output Torque (T_{PO})	Lbf-In	0.343	0.172	0.452	0.226	0.895	0.447	1.150	0.575
	Nm	0.039	0.019	0.051	0.026	0.101	0.051	0.130	0.065
Motor Resistance (Ω)	Ohms	**60**	**120**	**60**	**120**	**30**	**60**	**30**	**60**
Torque Constant (Kt)	Lbf-In/ Amp	1.472	1.472	1.936	1.936	1.917	1.917	2.465	2.464
	Nm/Amp	0.166	0.166	0.219	0.219	0.217	0.217	0.278	0.278

Table CL-2.5 - Cog-Less Motor Data

Parameter	Units	Table CL-2.5 - Motor Data (+25ºC)							
		CL-2.5-.50S	CL-2.5-.50R	CL-2.5-.75S	CL-2.5-.75R	CL-2.5-1.0S	CL-2.5-1.0R	CL-2.5-1.5S	CL-2.5-1.5R
A Outside Diameter	Inches	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500
	mm	63.50	63.50	63.50	63.50	63.50	63.50	63.50	63.50
B Through Bore	Inches	1.625	1.625	1.625	1.625	1.625	1.625	1.625	1.625
	mm	41.28	41.28	41.28	41.28	41.28	41.28	41.28	41.28
C Stator to Rotor Location	Inches	0.05	0.05	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.27	1.27	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.504	0.504	0.756	0.756	1.008	1.008	1.498	1.498
	mm	12.80	12.80	19.20	19.20	25.60	25.60	38.05	38.05
E Max Length	Inches	1.024	1.074	1.276	1.326	1.528	1.578	2.018	2.068
	mm	26.01	27.28	32.41	33.68	38.81	40.08	51.26	52.53
F Lead-Side Max End Turn O.D.	Inches	2.480	2.480	2.480	2.480	2.480	2.480	2.480	2.480
	mm	62.99	62.99	62.99	62.99	62.99	62.99	62.99	62.99
G End-Turn Min I.D.	Inches	2.230	2.230	2.230	2.230	2.230	2.230	2.230	2.230
	mm	56.64	56.64	56.64	56.64	56.64	56.64	56.64	56.64
H Max End-Turn Dia (Non-Lead side)	Inches	2.440	2.440	2.440	2.440	2.440	2.440	2.440	2.440
	mm	61.98	61.98	61.98	61.98	61.98	61.98	61.98	61.98
J Rotor Length	Inches	0.604	0.604	0.906	0.906	1.158	1.158	1.648	1.648
	mm	15.34	15.34	23.01	23.01	29.41	29.41	41.86	41.86
R Rotor Outside Diameter	Inches	2.170	2.170	2.170	2.170	2.170	2.170	2.170	2.170
	mm	55.12	55.12	55.12	55.12	55.12	55.12	55.12	55.12

PARAMETER	UNITS	Table CL-2.5 - Motor Data (+25ºC)							
		CL-2.5-.50S	CL-2.5-.50R	CL-2.5-.75S	CL-2.5-.75R	CL-2.5-1.0S	CL-2.5-1.0R	CL-2.5-1.5S	CL-2.5-1.5R
Coulomb Torque (Fc)	Lbf-In	1.90E-02	1.90E-02	2.85E-02	2.85E-02	3.80E-02	3.80E-02	5.70E-02	5.70E-02
	Nm	2.15E-03	2.15E-03	3.22E-03	3.22E-03	4.29E-03	4.29E-03	6.44E-03	6.44E-03
Mass	Lbs	0.300	0.300	0.450	0.450	0.600	0.600	0.900	0.900
	kg	0.136	0.136	0.205	0.205	0.273	0.273	0.409	0.409
Number of Poles (#P)	-	16	16	16	16	16	16	16	16
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	6.10E-04	6.10E-04	9.15E-04	9.15E-04	1.22E-03	1.22E-03	1.83E-03	1.83E-03
	kg-m^2	6.89E-05	6.89E-05	1.03E-04	1.03E-04	1.38E-04	1.38E-04	2.07E-04	2.07E-04
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**0.478**	**0.338**	**0.552**	**0.390**	**0.749**	**0.530**	**1.048**	**0.741**
	Nm / √watt	0.054	0.038	0.062	0.044	0.085	0.060	0.118	0.084
No-Load Speed (Reference)	RPM	600	600	581	581	458	458	353	353
	Rad/Sec	63	63	61	61	48	48	37	37
Theoretical Stall Torque (T_S)	Lbf-In	1.893	0.946	2.444	1.222	3.545	1.772	5.357	2.678
	Nm	0.214	0.107	0.276	0.138	0.401	0.200	0.605	0.303
Max Power Output Torque (T_{PO})	Lbf-In	0.946	0.473	1.222	0.611	1.772	0.886	2.679	1.339
	Nm	0.107	0.053	0.138	0.069	0.200	0.100	0.303	0.151
Motor Resistance (Ω)	Ohms	**50.0**	**100.0**	**40.0**	**80.0**	**35.0**	**70.0**	**30.0**	**60.0**
Torque Constant (Kt)	Lbf-In/Amp	3.38	3.38	3.49	3.49	4.43	4.43	5.74	5.74
	Nm/Amp	0.382	0.382	0.394	0.394	0.501	0.501	0.649	0.648

Table CL-3.0 - Cog-Less Motor Data

PARAMETER	UNITS	Table CL-3.0 - Motor Data (+25ºC)							
		CL-3.0-.50S	CL-3.0-.50R	CL-3.0-.75S	CL-3.0-.75R	CL-3.0-1.0S	CL-3.0-1.0R	CL-3.0-1.5S	CL-3.0-1.5R
A Outside Diameter	Inches	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
	mm	76.20	76.20	76.20	76.20	76.20	76.20	76.20	76.20
B Through Bore	Inches	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
	mm	50.80	50.80	50.80	50.80	50.80	50.80	50.80	50.80
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.502	0.502	0.756	0.756	1.008	1.008	1.498	1.498
	mm	12.75	12.75	19.20	19.20	25.60	25.60	38.05	38.05
E Max Length	Inches	1.022	1.072	1.276	1.326	1.528	1.578	2.018	2.068
	mm	25.96	27.23	32.41	33.68	38.81	40.08	51.26	52.53
F Lead-Side Max End Turn O.D.	Inches	2.980	2.980	2.980	2.980	2.980	2.980	2.980	2.980
	mm	75.69	75.69	75.69	75.69	75.69	75.69	75.69	75.69
G End-Turn Min I.D.	Inches	2.74	2.74	2.74	2.74	2.74	2.74	2.74	2.74
	mm	69.60	69.60	69.60	69.60	69.60	69.60	69.60	69.60
H Max End-Turn Dia (Non-Lead side)	Inches	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94
	mm	74.68	74.68	74.68	74.68	74.68	74.68	74.68	74.68
J Rotor Length	Inches	0.652	0.652	0.906	0.906	1.158	1.158	1.648	1.648
	mm	16.56	16.56	23.01	23.01	29.41	29.41	41.86	41.86
R Rotor Outside Diameter	Inches	2.6250	2.6250	2.6250	2.6250	2.6250	2.6250	2.6250	2.6250
	mm	66.68	66.68	66.68	66.68	66.68	66.68	66.68	66.68

PARAMETER	UNITS	Table CL-3.0 - Motor Data (+25ºC)							
		CL-3.0-.50S	CL-3.0-.50R	CL-3.0-.75S	CL-3.0-.75R	CL-3.0-1.0S	CL-3.0-1.0R	CL-3.0-1.5S	CL-3.0-1.5R
Coulomb Torque (Fc)	Lbf-In	2.30E-02	2.300E-02	3.45E-02	3.45E-02	4.60E-02	4.60E-02	6.90E-02	6.90E-02
	Nm	2.60E-03	2.60E-03	3.90E-03	3.90E-03	5.20E-03	5.20E-03	7.80E-03	7.80E-03
Mass	Lbs	0.360	0.360	0.540	0.540	0.750	0.750	1.125	1.125
	kg	0.164	0.164	0.245	0.245	0.341	0.341	0.511	0.511
Number of Poles (#P)	-	20	20	20	20	20	20	20	20
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	1.25E-03	1.25E-03	1.88E-03	1.88E-03	2.50E-03	2.50E-03	3.75E-03	3.75E-03
	kg-m^2	1.41E-04	1.41E-04	2.12E-04	2.12E-04	2.82E-04	2.82E-04	4.24E-04	4.24E-04
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**0.580**	**0.410**	**0.686**	**0.485**	**0.840**	**0.594**	**1.220**	**0.863**
	Nm / √watt	0.066	0.046	0.078	0.055	0.095	0.067	0.138	0.097
No-Load Speed (Reference)	RPM	903	903	854	854	764	764	588	588
	Rad/Sec	95	95	89	89	80	80	62	62
Theoretical Stall Torque (T_S)	Lbf-In	4.193	2.096	5.545	2.772	7.438	3.718	12.077	6.038
	Nm	0.474	0.237	0.626	0.313	0.840	0.420	1.365	0.682
Max Power Output Torque (T_{PO})	Lbf-In	2.097	1.048	2.772	1.386	3.719	1.859	6.039	3.019
	Nm	0.237	0.118	0.313	0.157	0.420	0.210	0.682	0.341
Motor Resistance (Ω)	Ohms	**15**	**30**	**12**	**24**	**10**	**20**	**8**	**16**
Torque Constant (Kt)	Lbf-In/Amp	2.246	2.246	2.376	2.376	2.656	2.656	3.451	3.450
	Nm/Amp	0.254	0.254	0.268	0.268	0.300	0.300	0.390	0.390

Table CL-3.5 - Cog-Less Motor Data

Parameter	Units	Table CL-3.5 - Motor Data (+25ºC)							
		CL-3.5-.75S	CL-3.5-.75R	CL-3.5-1.0S	CL-3.5-1.0R	CL-3.5-1.5S	CL-3.5-1.5R	CL-3.5-1.8S	CL-3.5-1.8R
A Outside Diameter	Inches	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500
	mm	88.90	88.90	88.90	88.90	88.90	88.90	88.90	88.90
B Through Bore	Inches	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500
	mm	63.50	63.50	63.50	63.50	63.50	63.50	63.50	63.50
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.498	1.498	1.750	1.750
	mm	19.20	19.20	25.60	25.60	38.05	38.05	44.45	44.45
E Max Length	Inches	1.276	1.326	1.528	1.578	2.018	2.068	2.270	2.320
	mm	32.41	33.68	38.81	40.08	51.26	52.53	57.66	58.93
F Lead-Side Max End Turn O.D.	Inches	3.480	3.480	3.480	3.480	3.480	3.480	3.480	3.480
	mm	88.39	88.39	88.39	88.39	88.39	88.39	88.39	88.39
G End-Turn Min I.D.	Inches	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24
	mm	82.30	82.30	82.30	82.30	82.30	82.30	82.30	82.30
H Max End-Turn Dia (Non-Lead side)	Inches	3.44	3.44	3.44	3.44	3.44	3.44	3.44	3.44
	mm	87.38	87.38	87.38	87.38	87.38	87.38	87.38	87.38
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.648	1.648	1.900	1.900
	mm	23.01	23.01	29.41	29.41	41.86	41.86	48.26	48.26
R Rotor Outside Diameter	Inches	3.125	3.125	3.125	3.125	3.125	3.125	3.125	3.125
	mm	79.38	79.38	79.38	79.38	79.38	79.38	79.38	79.38

PARAMETER	UNITS	Table CL-3.5 - Motor Data (+25ºC)							
		CL-3.5-.75S	CL-3.5-.75R	CL-3.5-1.0S	CL-3.5-1.0R	CL-3.5-1.5S	CL-3.5-1.5R	CL-3.5-1.8S	CL-3.5-1.8R
Coulomb Torque (Fc)	Lbf-In	0.039	0.039	0.055	0.055	0.083	0.083	0.110	0.110
	Nm	4.35E-03	4.35E-03	6.21E-03	6.21E-03	9.32E-03	9.32E-03	1.24E-02	1.24E-02
Mass	Lbs	0.67	0.67	0.95	0.95	1.43	1.43	1.90	1.90
	kg	0.302	0.302	0.432	0.432	0.648	0.648	0.864	0.864
Number of Poles (#P)	-	24	24	24	24	24	24	24	24
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	3.25E-03	3.25E-03	4.30E-03	4.30E-03	6.50E-03	6.50E-03	8.00E-03	8.00E-03
	kg-m^2	3.67E-04	3.67E-04	4.86E-04	4.86E-04	7.34E-04	7.34E-04	9.04E-04	9.04E-04
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**0.780**	**0.551**	**0.950**	**0.672**	**1.520**	**1.075**	**2.027**	**1.433**
	Nm / √watt	8.81E-02	6.23E-02	1.07E-01	7.59E-02	1.72E-01	1.21E-01	2.29E-01	1.62E-01
No-Load Speed (Reference)	RPM	411	411	390	390	298	298	316	317
	Rad/Sec	43	43	41	41	31	31	33	33
Theoretical Stall Torque (T_S)	Lbf-In	3.45	1.73	4.86	2.43	9.52	4.76	17.95	8.97
	Nm	0.390	0.195	0.549	0.274	1.075	0.538	2.028	1.014
Max Power Output Torque (T_{PO})	Lbf-In	1.727	0.863	2.428	1.214	4.758	2.379	8.974	4.486
	Nm	0.195	0.098	0.274	0.137	0.538	0.269	1.014	0.507
Motor Resistance (Ω)	Ohms	**40**	**80**	**30**	**60**	**20**	**40**	**10**	**20**
Torque Constant (Kt)	Lbf-In/Amp	4.93	4.93	5.20	5.20	6.80	6.80	6.41	6.41
	Nm/Amp	0.557	0.557	0.588	0.588	0.768	0.768	0.724	0.724

Table CL-4.0 - Cog-Less Motor Data

PARAMETER	UNITS	Table CL-4.0 - Motor Data (+25ºC)							
		CL-4.0-.75S	CL-4.0-.75R	CL-4.0-1.0S	CL-4.0-1.0R	CL-4.0-1.5S	CL-4.0-1.5R	CL-4.0-2.0S	CL-4.0-2.0R
A Outside Diameter	Inches	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
	mm	101.60	101.60	101.60	101.60	101.60	101.60	101.60	101.60
B Through Bore	Inches	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
	mm	76.20	76.20	76.20	76.20	76.20	76.20	76.20	76.20
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.498	1.498	2.002	2.002
	mm	19.20	19.20	25.60	25.60	38.05	38.05	50.85	50.85
E Max Length	Inches	1.276	1.326	1.528	1.578	2.018	2.068	2.522	2.572
	mm	32.41	33.68	38.81	40.08	51.26	52.53	64.06	65.33
F Lead-Side Max End Turn O.D.	Inches	3.980	3.980	3.980	3.980	3.980	3.980	3.980	3.980
	mm	101.09	101.09	101.09	101.09	101.09	101.09	101.09	101.09
G End-Turn Min I.D.	Inches	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
	mm	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00
H Max End-Turn Dia (Non-Lead side)	Inches	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94
	mm	100.08	100.08	100.08	100.08	100.08	100.08	100.08	100.08
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.648	1.648	2.152	2.152
	mm	23.01	23.01	29.41	29.41	41.86	41.86	54.66	54.66
R Rotor Outside Diameter	Inches	3.563	3.563	3.563	3.563	3.563	3.563	3.563	3.563
	mm	90.50	90.50	90.50	90.50	90.50	90.50	90.50	90.50

PARAMETER	UNITS	Table CL-4.0 - Motor Data (+25ºC)							
		CL-4.0-.75S	CL-4.0-.75R	CL-4.0-1.0S	CL-4.0-1.0R	CL-4.0-1.5S	CL-4.0-1.5R	CL-4.0-2.0S	CL-4.0-2.0R
Coulomb Torque (Fc)	Lbf-In	0.054	0.054	0.072	0.072	0.108	0.108	0.144	0.144
	Nm	6.10E-03	6.10E-03	8.13E-03	8.13E-03	1.22E-02	1.22E-02	1.63E-02	1.63E-02
Mass	Lbs	0.916	0.916	1.221	1.221	1.832	1.832	2.442	2.442
	kg	0.416	0.416	0.555	0.555	0.833	0.833	1.110	1.110
Number of Poles (#P)	-	32	32	32	32	32	32	32	32
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	4.80E-03	4.80E-03	6.20E-03	6.20E-03	9.10E-03	9.10E-03	1.21E-02	1.21E-02
	kg-m^2	5.42E-04	5.42E-04	7.00E-04	7.00E-04	1.03E-03	1.03E-03	1.37E-03	1.37E-03
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**0.985**	**0.696**	**1.170**	**0.827**	**1.650**	**1.167**	**2.210**	**1.562**
	Nm / √watt	1.11E-01	7.87E-02	1.32E-01	9.35E-02	1.86E-01	1.32E-01	2.50E-01	1.77E-01
No-Load Speed (Reference)	RPM	461	461	448	448	389	389	335	335
	Rad/Sec	48	48	47	47	41	41	35	35
Theoretical Stall Torque (T_S)	Lbf-In	6.17	3.08	8.46	4.23	14.61	7.30	22.60	11.30
	Nm	0.697	0.348	0.956	0.478	1.651	0.825	2.553	1.276
Max Power Output Torque (T_{PO})	Lbf-In	3.084	1.542	4.229	2.114	7.305	3.652	11.298	5.648
	Nm	0.348	0.174	0.478	0.239	0.825	0.413	1.276	0.638
Motor Resistance (Ω)	Ohms	**20.0**	**40.0**	**15.0**	**30.0**	**10.0**	**20.0**	**7.5**	**15.0**
Torque Constant (Kt)	Lbf-In/Amp	4.41	4.40	4.53	4.53	5.22	5.22	6.05	6.05
	Nm/Amp	0.498	0.498	0.512	0.512	0.590	0.589	0.684	0.684

Table CL-4.5 - Cog-Less Motor Data

Parameter	Units	Table CL-4.5 - Motor Data (+25ºC)							
		CL-4.5-.75S	CL-4.5-.75SR	CL-4.5-1.0S	CL-4.5-1.0R	CL-4.5-1.5S	CL-4.5-1.5R	CL-4.5-2.0S	CL-4.5-2.0R
A Outside Diameter	Inches	4.500	4.500	4.500	4.500	4.500	4.500	4.500	4.500
	mm	114.30	114.30	114.30	114.30	114.30	114.30	114.30	114.30
B Through Bore	Inches	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500
	mm	88.90	88.90	88.90	88.90	88.90	88.90	88.90	88.90
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.498	1.498	2.002	2.002
	mm	19.20	19.20	25.60	25.60	38.05	38.05	50.85	50.85
E Max Length	Inches	1.276	1.326	1.528	1.578	2.018	2.068	2.522	2.572
	mm	32.41	33.68	38.81	40.08	51.26	52.53	64.06	65.33
F Lead-Side Max End Turn O.D.	Inches	4.480	4.480	4.480	4.480	4.480	4.480	4.480	4.480
	mm	113.79	113.79	113.79	113.79	113.79	113.79	113.79	113.79
G End-Turn Min I.D.	Inches	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24
	mm	107.70	107.70	107.70	107.70	107.70	107.70	107.70	107.70
H Max End-Turn Dia (Non-Lead side)	Inches	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44
	mm	112.78	112.78	112.78	112.78	112.78	112.78	112.78	112.78
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.648	1.648	2.152	2.152
	mm	23.01	23.01	29.41	29.41	41.86	41.86	54.66	54.66
R Rotor Outside Diameter	Inches	4.063	4.063	4.063	4.063	4.063	4.063	4.063	4.063
	mm	103.20	103.20	103.20	103.20	103.20	103.20	103.20	103.20

PARAMETER	UNITS	Table CL-4.5 - Motor Data (+25ºC)							
		CL-4.5-.75S	CL-4.5-.75SR	CL-4.5-1.0S	CL-4.5-1.0R	CL-4.5-1.5S	CL-4.5-1.5R	CL-4.5-2.0S	CL-4.5-2.0R
Coulomb Torque (Fc)	Lbf-In	0.06825	0.06825	0.091	0.091	0.1365	0.1365	0.182	0.182
	Nm	7.71E-03	7.71E-03	1.03E-02	1.03E-02	1.54E-02	1.54E-02	2.06E-02	2.06E-02
Mass	Lbs	1.125	1.125	1.500	1.500	2.250	2.250	3.000	3.000
	kg	0.511	0.511	0.682	0.682	1.023	1.023	1.364	1.364
Number of Poles (#P)	-	32	32	32	32	32	32	32	32
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	4.63E-03	4.63E-03	6.08E-03	6.08E-03	8.89E-03	8.89E-03	1.18E-02	1.18E-02
	kg-m^2	5.23E-04	5.23E-04	6.87E-04	6.87E-04	1.00E-03	1.00E-03	1.33E-03	1.33E-03
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**1.15**	**0.81**	**1.35**	**0.95**	**1.91**	**1.35**	**2.56**	**1.81**
	Nm / √watt	0.130	0.092	0.153	0.108	0.216	0.153	0.289	0.204
No-Load Speed (Reference)	RPM	455	456	425	425	388	388	354	354
	Rad/Sec	48	48	45	45	41	41	37	37
Theoretical Stall Torque (T_S)	Lbf-In	8.31	4.16	10.69	5.34	19.53	9.76	32.06	16.03
	Nm	0.939	0.470	1.208	0.604	2.206	1.103	3.622	1.811
Max Power Output Torque (T_{PO})	Lbf-In	4.157	2.078	5.346	2.672	9.764	4.881	16.028	8.013
	Nm	0.470	0.235	0.604	0.302	1.103	0.551	1.811	0.905
Motor Resistance (Ω)	Ohms	**15.0**	**30.0**	**12.5**	**25.0**	**7.5**	**15.0**	**5.0**	**10.0**
Torque Constant (Kt)	Lbf-In/Amp	4.45	4.45	4.77	4.77	5.23	5.23	5.72	5.72
	Nm/Amp	0.503	0.503	0.539	0.539	0.591	0.591	0.647	0.647

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Table CL-5.0 - Cog-Less Motor Data

Parameter	Units	Table CL-5.0 - Motor Data (+25ºC)							
		CL-5.0-.75S	CL-5.0-.75R	CL-5.0-1.0S	CL-5.0-1.0R	CL-5.0-1.5S	CL-5.0-1.5R	CL-5.0-2.0S	CL-5.0-2.0R
A Outside Diameter	Inches	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
	mm	127.00	127.00	127.00	127.00	127.00	127.00	127.00	127.00
B Through Bore	Inches	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
	mm	101.60	101.60	101.60	101.60	101.60	101.60	101.60	101.60
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.498	1.498	2.002	2.002
	mm	19.20	19.20	25.60	25.60	38.05	38.05	50.85	50.85
E Max Length	Inches	1.276	1.326	1.528	1.578	2.018	2.068	2.522	2.572
	mm	32.41	33.68	38.81	40.08	51.26	52.53	64.06	65.33
F Lead-Side Max End Turn O.D.	Inches	4.980	4.980	4.980	4.980	4.980	4.980	4.980	4.980
	mm	126.49	126.49	126.49	126.49	126.49	126.49	126.49	126.49
G End-Turn Min I.D.	Inches	4.74	4.74	4.74	4.74	4.74	4.74	4.74	4.74
	mm	120.40	120.40	120.40	120.40	120.40	120.40	120.40	120.40
H Max End-Turn Dia (Non-Lead side)	Inches	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94
	mm	125.48	125.48	125.48	125.48	125.48	125.48	125.48	125.48
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.648	1.648	2.152	2.152
	mm	23.01	23.01	29.41	29.41	41.86	41.86	54.66	54.66
R Rotor Outside Diameter	Inches	4.532	4.532	4.532	4.532	4.532	4.532	4.532	4.532
	mm	115.11	115.11	115.11	115.11	115.11	115.11	115.11	115.11

PARAMETER	UNITS	Table CL-5.0 - Motor Data (+25ºC)							
		CL-5.0-.75S	CL-5.0-.75R	CL-5.0-1.0S	CL-5.0-1.0R	CL-5.0-1.5S	CL-5.0-1.5R	CL-5.0-2.0S	CL-5.0-2.0R
Coulomb Torque (Fc)	Lbf-In	0.086	0.086	0.115	0.115	0.173	0.173	0.230	0.230
	Nm	9.74E-03	9.74E-03	1.30E-02	1.30E-02	1.95E-02	1.95E-02	2.60E-02	2.60E-02
Mass	Lbs	1.322	1.322	1.763	1.763	2.645	2.645	3.526	3.526
	kg	0.601	0.601	0.801	0.801	1.202	1.202	1.603	1.603
Number of Poles (#P)	-	48	48	48	48	48	48	48	48
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	1.13E-02	1.13E-02	1.51E-02	1.51E-02	2.27E-02	2.27E-02	3.02E-02	3.02E-02
	kg-m^2	1.28E-03	1.28E-03	1.71E-03	1.71E-03	2.56E-03	2.56E-03	3.41E-03	3.41E-03
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**1.30**	**0.92**	**1.48**	**1.05**	**2.15**	**1.52**	**2.87**	**2.03**
	Nm / √watt	0.147	0.104	0.167	0.118	0.243	0.172	0.324	0.229
No-Load Speed (Reference)	RPM	493	493	485	485	385	385	354	354
	Rad/Sec	52	52	51	51	40	40	37	37
Theoretical Stall Torque (T_S)	Lbf-In	11.528	5.763	14.651	7.325	24.577	12.286	40.133	20.064
	Nm	1.302	0.651	1.655	0.828	2.777	1.388	4.534	2.267
Max Power Output Torque (T_{PO})	Lbf-In	5.764	2.882	7.326	3.662	12.288	6.143	20.067	10.032
	Nm	0.651	0.326	0.828	0.414	1.388	0.694	2.267	1.133
Motor Resistance (Ω)	Ohms	**10.0**	**20.0**	**8.0**	**16.0**	**6.0**	**12.0**	**4.0**	**8.0**
Torque Constant (Kt)	Lbf-In/Amp	4.117	4.117	4.186	4.185	5.266	5.266	5.733	5.732
	Nm/Amp	0.465	0.465	0.473	0.473	0.595	0.595	0.648	0.648

Table CL-5.5 - Cog-Less Motor Data

PARAMETER	UNITS	Table CL-5.5 - Motor Data (+25ºC)							
		CL-5.5-.75S	CL-5.5-.75R	CL-5.0-1.0S	CL-5.5-1.0R	CL-5.5-1.5S	CL-5.5-1.5R	CL-5.5-2.0S	CL-5.5-2.0R
A Outside Diameter	Inches	5.500	5.500	5.500	5.500	5.500	5.500	5.500	5.500
	mm	139.70	139.70	139.70	139.70	139.70	139.70	139.70	139.70
B Through Bore	Inches	4.500	4.500	4.500	4.500	4.500	4.500	4.500	4.500
	mm	114.30	114.30	114.30	114.30	114.30	114.30	114.30	114.30
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.700	0.700	1.008	1.008	1.498	1.498	2.002	2.002
	mm	17.78	17.78	25.60	25.60	38.05	38.05	50.85	50.85
E Max Length	Inches	1.220	1.270	1.528	1.578	2.018	2.068	2.522	2.572
	mm	30.99	32.26	38.81	40.08	51.26	52.53	64.06	65.33
F Lead-Side Max End Turn O.D.	Inches	5.480	5.480	5.480	5.480	5.480	5.480	5.480	5.480
	mm	139.19	139.19	139.19	139.19	139.19	139.19	139.19	139.19
G End-Turn Min I.D.	Inches	5.24	5.24	5.24	5.24	5.24	5.24	5.24	5.24
	mm	133.10	133.10	133.10	133.10	133.10	133.10	133.10	133.10
H Max End-Turn Dia (Non-Lead side)	Inches	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44
	mm	138.18	138.18	138.18	138.18	138.18	138.18	138.18	138.18
J Rotor Length	Inches	0.850	0.850	1.158	1.158	1.648	1.648	2.152	2.152
	mm	21.59	21.59	29.41	29.41	41.86	41.86	54.66	54.66
R Rotor Outside Diameter	Inches	5.032	5.032	5.032	5.032	5.032	5.032	5.032	5.032
	mm	127.81	127.81	127.81	127.81	127.81	127.81	127.81	127.81

PARAMETER	UNITS	Table CL-5.5 - Motor Data (+25ºC)							
		CL-5.5-.75S	CL-5.5-.75R	CL-5.0-1.0S	CL-5.5-1.0R	CL-5.5-1.5S	CL-5.5-1.5R	CL-5.5-2.0S	CL-5.5-2.0R
Coulomb Torque (Fc)	Lbf-In	0.089	0.089	0.127	0.127	0.19	0.19	0.253	0.253
	Nm	1.00E-02	1.00E-02	1.43E-02	1.43E-02	2.15E-02	2.15E-02	2.86E-02	2.86E-02
Mass	Lbs	1.400	1.400	2.000	2.000	3.000	3.000	4.000	4.000
	kg	0.636	0.636	0.909	0.909	1.364	1.364	1.818	1.818
Number of Poles (#P)	-	48	48	48	48	48	48	48	48
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	1.44E-02	1.44E-02	1.92E-02	1.92E-02	2.88E-02	2.88E-02	3.84E-02	3.84E-02
	kg-m^2	1.63E-03	1.63E-03	2.17E-03	2.17E-03	3.25E-03	3.25E-03	4.34E-03	4.34E-03
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**1.55**	**1.10**	**1.76**	**1.24**	**2.52**	**1.78**	**3.36**	**2.38**
	Nm / √watt	0.175	0.124	0.199	0.141	0.285	0.201	0.380	0.268
No-Load Speed (Reference)	RPM	414	414	408	408	329	329	302	302
	Rad/Sec	43	43	43	43	34	34	32	32
Theoretical Stall Torque (T_S)	Lbf-In	13.72	6.86	17.42	8.71	28.81	14.40	47.04	23.52
	Nm	1.551	0.775	1.968	0.984	3.255	1.627	5.315	2.657
Max Power Output Torque (T_{PO})	Lbf-In	6.862	3.431	8.712	4.355	14.403	7.200	23.520	11.758
	Nm	0.775	0.388	0.984	0.492	1.627	0.814	2.657	1.328
Motor Resistance (Ω)	Ohms	**10.0**	**20.0**	**8.0**	**16.0**	**6.0**	**12.0**	**4.0**	**8.0**
Torque Constant (Kt)	Lbf-In/Amp	4.90	4.90	4.98	4.98	6.17	6.17	6.72	6.72
	Nm/Amp	0.554	0.554	0.562	0.562	0.697	0.697	0.759	0.759

Table CL-6.0 - Cog-Less Motor Data

PARAMETER	UNITS	Table CL-6.0 - Motor Data (+25ºC)							
		CL-6.0-.75S	CL-6.0-.75R	CL-6.0-1.0S	CL-6.0-1.0R	CL-6.0-1.5S	CL-6.0-1.5R	CL-6.0-2.0S	CL-6.0-2.0R
A Outside Diameter	Inches	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
	mm	152.40	152.40	152.40	152.40	152.40	152.40	152.40	152.40
B Through Bore	Inches	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
	mm	127.00	127.00	127.00	127.00	127.00	127.00	127.00	127.00
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.498	1.498	2.002	2.002
	mm	19.20	19.20	25.60	25.60	38.05	38.05	50.85	50.85
E Max Length	Inches	1.276	1.326	1.528	1.578	2.018	2.068	2.522	2.572
	mm	32.41	33.68	38.81	40.08	51.26	52.53	64.06	65.33
F Lead-Side Max End Turn O.D.	Inches	5.980	5.980	5.980	5.980	5.980	5.980	5.980	5.980
	mm	151.89	151.89	151.89	151.89	151.89	151.89	151.89	151.89
G End-Turn Min I.D.	Inches	5.74	5.74	5.74	5.74	5.74	5.74	5.74	5.74
	mm	145.80	145.80	145.80	145.80	145.80	145.80	145.80	145.80
H Max End-Turn Dia (Non-Lead side)	Inches	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94
	mm	150.88	150.88	150.88	150.88	150.88	150.88	150.88	150.88
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.648	1.648	2.152	2.152
	mm	23.01	23.01	29.41	29.41	41.86	41.86	54.66	54.66
R Rotor Outside Diameter	Inches	5.532	5.532	5.532	5.532	5.532	5.532	5.532	5.532
	mm	140.51	140.51	140.51	140.51	140.51	140.51	140.51	140.51

Parameter	Units	Table CL-6.0 - Motor Data (+25ºC)							
		CL-6.0-.75S	CL-6.0-.75R	CL-6.0-1.0S	CL-6.0-1.0R	CL-6.0-1.5S	CL-6.0-1.5R	CL-6.0-2.0S	CL-6.0-2.0R
Coulomb Torque (Fc)	Lbf-In	0.113	0.113	0.150	0.150	0.225	0.225	0.300	0.300
	Nm	1.27E-02	1.27E-02	1.69E-02	1.69E-02	2.54E-02	2.54E-02	3.39E-02	3.39E-02
Mass	Lbs	1.650	1.650	2.200	2.200	3.300	3.300	4.400	4.400
	kg	0.750	0.750	1.000	1.000	1.500	1.500	2.000	2.000
Number of Poles (#P)	-	48	48	48	48	48	48	48	48
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	1.88E-02	1.88E-02	2.50E-02	2.50E-02	3.75E-02	3.75E-02	5.00E-02	5.00E-02
	kg-m^2	2.12E-03	2.12E-03	2.82E-03	2.82E-03	4.24E-03	4.24E-03	5.65E-03	5.65E-03
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**1.82**	**1.29**	**2.48**	**1.75**	**3.30**	**2.33**	**4.42**	**3.12**
	Nm / √watt	2.06E-01	1.45E-01	2.80E-01	1.98E-01	3.73E-01	2.64E-01	4.99E-01	3.53E-01
No-Load Speed (Reference)	RPM	352	353	289	289	251	251	229	230
	Rad/Sec	37	37	30	30	26	26	24	24
Theoretical Stall Torque (T_S)	Lbf-In	16.115	8.056	24.551	12.274	37.722	18.858	61.880	30.935
	Nm	1.821	0.910	2.774	1.387	4.262	2.131	6.991	3.495
Max Power Output Torque (T_{PO})	Lbf-In	8.057	4.028	12.275	6.137	18.861	9.429	30.940	15.468
	Nm	0.910	0.455	1.387	0.693	2.131	1.065	3.496	1.748
Motor Resistance (Ω)	Ohms	**10.0**	**20.0**	**8.0**	**16.0**	**6.0**	**12.0**	**4.0**	**8.0**
Torque Constant (Kt)	Lbf-In/Amp	5.755	5.754	7.014	7.013	8.083	8.082	8.840	8.839
	Nm/Amp	0.650	0.650	0.792	0.792	0.913	0.913	0.999	0.999

Table CL-6.5 - Cog-Less Motor Data

PARAMETER	UNITS	Table CL-6.5 - Motor Data (+25ºC)							
		CL-6.5-.75S	CL-6.5-.75R	CL-6.5-1.0S	CL-6.5-1.0R	CL-6.5-1.5S	CL-6.5-1.5R	CL-6.5-2.0S	CL-6.5-2.0R
A Outside Diameter	Inches	6.500	6.500	6.500	6.500	6.500	6.500	6.500	6.500
	mm	165.10	165.10	165.10	165.10	165.10	165.10	165.10	165.10
B Through Bore	Inches	5.500	5.500	5.500	5.500	5.500	5.500	5.500	5.500
	mm	139.70	139.70	139.70	139.70	139.70	139.70	139.70	139.70
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.489	1.498	2.000	2.000
	mm	19.20	19.20	25.60	25.60	37.82	38.05	50.80	50.80
E Max Length	Inches	1.276	1.326	1.528	1.578	2.009	2.068	2.520	2.570
	mm	32.41	33.68	38.81	40.08	51.03	52.53	64.01	65.28
F Lead-Side Max End Turn O.D.	Inches	6.480	6.480	6.480	6.480	6.480	6.480	6.480	6.480
	mm	164.59	164.59	164.59	164.59	164.59	164.59	164.59	164.59
G End-Turn Min I.D.	Inches	6.24	6.24	6.24	6.24	6.24	6.24	6.24	6.24
	mm	158.50	158.50	158.50	158.50	158.50	158.50	158.50	158.50
H Max End-Turn Dia (Non-Lead side)	Inches	6.44	6.44	6.44	6.44	6.44	6.44	6.44	6.44
	mm	163.58	163.58	163.58	163.58	163.58	163.58	163.58	163.58
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.639	1.648	2.150	2.150
	mm	23.01	23.01	29.41	29.41	41.63	41.86	54.61	54.61
R Rotor Outside Diameter	Inches	6.032	6.032	6.032	6.032	6.032	6.032	6.032	6.032
	mm	153.21	153.21	153.21	153.21	153.21	153.21	153.21	153.21

PARAMETER	UNITS	Table CL-6.5 - Motor Data (+25ºC)							
		CL-6.5-.75S	CL-6.5-.75R	CL-6.5-1.0S	CL-6.5-1.0R	CL-6.5-1.5S	CL-6.5-1.5R	CL-6.5-2.0S	CL-6.5-2.0R
Coulomb Torque (Fc)	Lbf-In	1.41E-02	1.41E-02	1.88E-02	1.88E-02	2.82E-02	2.82E-02	3.76E-02	3.76E-02
	Nm	1.59E-03	1.59E-03	2.12E-03	2.12E-03	3.19E-03	3.19E-03	4.25E-03	4.25E-03
Mass	Lbs	1.80	1.80	2.40	2.40	3.60	3.60	4.80	4.80
	kg	0.82	0.82	1.09	1.09	1.64	1.64	2.18	2.18
Number of Poles (#P)	-	48	48	48	48	48	48	48	48
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	2.49E-02	2.49E-02	3.32E-02	3.32E-02	4.98E-02	4.98E-02	6.64E-02	6.64E-02
	kg-m^2	2.81E-03	2.81E-03	3.75E-03	3.75E-03	5.63E-03	5.63E-03	7.50E-03	7.50E-03
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**2.30**	**1.63**	**3.10**	**2.19**	**4.45**	**3.15**	**5.93**	**4.19**
	Nm / √watt	2.60E-01	1.84E-01	3.50E-01	2.48E-01	5.03E-01	3.55E-01	6.70E-01	4.74E-01
No-Load Speed (Reference)	RPM	312	312	267	267	228	228	242	242
	Rad/Sec	33	33	28	28	24	24	25	25
Theoretical Stall Torque (T_S)	Lbf-In	22.77	11.38	35.44	17.72	62.30	31.15	117.41	58.70
	Nm	2.572	1.286	4.004	2.001	7.039	3.519	13.265	6.631
Max Power Output Torque (T_{PO})	Lbf-In	11.384	5.691	17.718	8.858	31.150	15.573	58.704	29.348
	Nm	1.286	0.643	2.002	1.001	3.519	1.759	6.632	3.316
Motor Resistance (Ω)	Ohms	**8.0**	**16.0**	**6.0**	**12.0**	**4.0**	**8.0**	**2.0**	**4.0**
Torque Constant (Kt)	Lbf-In/Amp	6.505	6.504	7.593	7.592	8.900	8.899	8.386	8.385
	Nm/Amp	0.735	0.735	0.858	0.858	1.006	1.005	0.947	0.947

Table CL-7.0 - Cog-Less Motor Data

Parameter	Units	Table CL-7.0 - Motor Data (+25ºC)							
		CL-7.0-.75S	CL-7.0-.75R	CL-7.0-1.0S	CL-7.0-1.0R	CL-7.0-1.5S	CL-7.0-1.5R	CL-7.0-2.0S	CL-7.0-2.0R
A Outside Diameter	Inches	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000
	mm	177.80	177.80	177.80	177.80	177.80	177.80	177.80	177.80
B Through Bore	Inches	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
	mm	152.40	152.40	152.40	152.40	152.40	152.40	152.40	152.40
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.498	1.498	2.002	2.002
	mm	19.20	19.20	25.60	25.60	38.05	38.05	50.85	50.85
E Max Length	Inches	1.276	1.326	1.528	1.578	2.018	2.068	2.522	2.572
	mm	32.41	33.68	38.81	40.08	51.26	52.53	64.06	65.33
F Lead-Side Max End Turn O.D.	Inches	6.980	6.980	6.980	6.980	6.980	6.980	6.980	6.980
	mm	177.29	177.29	177.29	177.29	177.29	177.29	177.29	177.29
G End-Turn Min I.D.	Inches	6.74	6.74	6.74	6.74	6.74	6.74	6.74	6.74
	mm	171.20	171.20	171.20	171.20	171.20	171.20	171.20	171.20
H Max End-Turn Dia (Non-Lead side)	Inches	6.94	6.94	6.94	6.94	6.94	6.94	6.94	6.94
	mm	176.28	176.28	176.28	176.28	176.28	176.28	176.28	176.28
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.648	1.648	2.152	2.152
	mm	23.01	23.01	29.41	29.41	41.86	41.86	54.66	54.66
R Rotor Outside Diameter	Inches	6.535	6.535	6.535	6.535	6.535	6.535	6.535	6.535
	mm	165.99	165.99	165.99	165.99	165.99	165.99	165.99	165.99
Coulomb Torque (Fc)	Lbf-In	0.166	0.166	0.221	0.221	0.332	0.332	0.442	0.442
	Nm	1.87E-02	1.87E-02	2.50E-02	2.50E-02	3.75E-02	3.75E-02	4.99E-02	4.99E-02

PARAMETER	UNITS	Table CL-7.0 - Motor Data (+25ºC)							
		CL-7.0-.75S	CL-7.0-.75R	CL-7.0-1.0S	CL-7.0-1.0R	CL-7.0-1.5S	CL-7.0-1.5R	CL-7.0-2.0S	CL-7.0-2.0R
Mass	Lbs	2.041	2.041	2.721	2.721	4.082	4.082	5.442	5.442
	kg	0.928	0.928	1.237	1.237	1.855	1.855	2.474	2.474
Number of Poles (#P)	-	64	64	64	64	64	64	64	64
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	3.30E-03	3.30E-03	4.40E-03	4.40E-03	6.60E-03	6.60E-03	8.80E-03	8.80E-03
	kg-m^2	3.73E-04	3.73E-04	4.97E-04	4.97E-04	7.46E-04	7.46E-04	9.94E-04	9.94E-04
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**2.80**	**1.98**	**3.69**	**2.61**	**5.30**	**3.75**	**5.80**	**4.10**
	Nm / √watt	0.316	0.224	0.417	0.295	0.599	0.423	0.655	0.463
No-Load Speed (Reference)	RPM	256	256	224	224	191	191	247	247
	Rad/Sec	27	27	24	24	20	20	26	26
Theoretical Stall Torque (T_S)	Lbf-In	27.7	13.9	42.2	21.1	74.2	37.1	114.8	57.4
	Nm	3.13	1.57	4.77	2.38	8.38	4.19	12.97	6.49
Max Power Output Torque (T_{PO})	Lbf-In	13.859	6.929	21.090	10.543	37.100	18.547	57.417	28.704
	Nm	1.566	0.783	2.383	1.191	4.192	2.095	6.487	3.243
Motor Resistance (Ω)	Ohms	**8.0**	**16**	**6.0**	**12.0**	**4.0**	**8.0**	**2.0**	**4.0**
Torque Constant (Kt)	Lbf-In/Amp	7.920	7.918	9.039	9.037	10.600	10.598	8.202	8.201
	Nm/Amp	0.895	0.895	1.021	1.021	1.198	1.197	0.927	0.927

Table CL-7.5 - Cog-Less Motor Data

Parameter	Units	Table CL-7.5 - Motor Data (+25ºC)							
		CL-7.5-.75S	CL-7.5-.75R	CL-7.5-1.0S	CL-7.5-1.0R	CL-7.5-1.5S	CL-7.5-1.5R	CL-7.5-2.0S	CL-7.5-2.0R
A Outside Diameter	Inches	7.500	7.500	7.500	7.500	7.500	7.500	7.500	7.500
	mm	190.50	190.50	190.50	190.50	190.50	190.50	190.50	190.50
B Through Bore	Inches	6.500	6.500	6.500	6.500	6.500	6.500	6.500	6.500
	mm	165.10	165.10	165.10	165.10	165.10	165.10	165.10	165.10
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.498	1.498	2.002	2.002
	mm	19.20	19.20	25.60	25.60	38.05	38.05	50.85	50.85
E Max Length	Inches	1.276	1.326	1.528	1.578	2.018	2.068	2.522	2.572
	mm	32.41	33.68	38.81	40.08	51.26	52.53	64.06	65.33
F Lead-Side Max End Turn O.D.	Inches	7.480	7.480	7.480	7.480	7.480	7.480	7.480	7.480
	mm	189.99	189.99	189.99	189.99	189.99	189.99	189.99	189.99
G End-Turn Min I.D.	Inches	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24
	mm	183.90	183.90	183.90	183.90	183.90	183.90	183.90	183.90
H Max End-Turn Dia (Non-Lead side)	Inches	7.44	7.44	7.44	7.44	7.44	7.44	7.44	7.44
	mm	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.648	1.648	2.152	2.152
	mm	23.01	23.01	29.41	29.41	41.86	41.86	54.66	54.66
R Rotor Outside Diameter	Inches	7.035	7.035	7.035	7.035	7.035	7.035	7.035	7.035
	mm	178.69	178.69	178.69	178.69	178.69	178.69	178.69	178.69

PARAMETER	UNITS	Table CL-7.5 - Motor Data (+25ºC)							
		CL-7.5-.75S	CL-7.5-.75R	CL-7.5-1.0S	CL-7.5-1.0R	CL-7.5-1.5S	CL-7.5-1.5R	CL-7.5-2.0S	CL-7.5-2.0R
Coulomb Torque (Fc)	Lbf-In	0.20	0.20	0.26	0.26	0.39	0.39	0.52	0.52
	Nm	2.20E-02	2.20E-02	2.94E-02	2.94E-02	4.41E-02	4.41E-02	5.87E-02	5.87E-02
Mass	Lbs	2.329	2.329	3.105	3.105	4.658	4.658	6.210	6.210
	kg	1.059	1.059	1.411	1.411	2.117	2.117	2.823	2.823
Number of Poles (#P)	-	64	64	64	64	64	64	64	64
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	3.83E-03	3.83E-03	5.10E-03	5.10E-03	7.65E-03	7.65E-03	1.02E-02	1.02E-02
	kg-m^2	4.32E-04	4.32E-04	5.76E-04	5.76E-04	8.64E-04	8.64E-04	1.15E-03	1.15E-03
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**3.15**	**2.23**	**4.10**	**2.90**	**6.15**	**4.35**	**8.21**	**5.80**
	Nm / √watt	3.56E-01	2.52E-01	4.63E-01	3.27E-01	6.95E-01	4.91E-01	9.28E-01	6.56E-01
No-Load Speed (Reference)	RPM	228	228	202	202	165	165	175	175
	Rad/Sec	23.8	23.8	21.2	21.2	17.3	17.3	18.3	18.3
Theoretical Stall Torque (T_S)	Lbf-In	31.183	15.589	46.867	23.430	86.100	43.043	162.550	81.263
	Nm	3.523	1.761	5.295	2.647	9.728	4.863	18.365	9.181
Max Power Output Torque (T_{PO})	Lbf-In	15.592	7.795	23.433	11.715	43.050	21.522	81.275	40.631
	Nm	1.762	0.881	2.648	1.324	4.864	2.432	9.182	4.591
Motor Resistance (Ω)	Ohms	**8.0**	**16**	**6.0**	**12.0**	**4.0**	**8.0**	**2.0**	**4.0**
Torque Constant (Kt)	Lbf-In/Amp	8.910	8.908	10.043	10.041	12.300	12.298	11.611	11.609
	Nm/Amp	1.007	1.006	1.135	1.134	1.390	1.389	1.312	1.312

Table CL-8.0 - Cog-Less Motor Data

Parameter	Units	Table CL-8.0 - Motor Data (+25ºC)							
		CL-8.0-.75S	CL-8.0-.75R	CL-8.0-1.0S	CL-8.0-1.0R	CL-8.0-1.5S	CL-8.0-1.5R	CL-8.0-2.0S	CL-8.0-2.0R
A Outside Diameter	Inches	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
	mm	203.20	203.20	203.20	203.20	203.20	203.20	203.20	203.20
B Through Bore	Inches	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000
	mm	177.80	177.80	177.80	177.80	177.80	177.80	177.80	177.80
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.498	1.498	2.002	2.002
	mm	19.20	19.20	25.60	25.60	38.05	38.05	50.85	50.85
E Max Length	Inches	1.276	1.326	1.528	1.578	2.018	2.068	2.522	2.572
	mm	32.41	33.68	38.81	40.08	51.26	52.53	64.06	65.33
F Lead-Side Max End Turn O.D.	Inches	7.980	7.980	7.980	7.980	7.980	7.980	7.980	7.980
	mm	202.69	202.69	202.69	202.69	202.69	202.69	202.69	202.69
G End-Turn Min I.D.	Inches	7.565	7.565	7.565	7.565	7.565	7.565	7.565	7.565
	mm	192.15	192.15	192.15	192.15	192.15	192.15	192.15	192.15
H Max End-Turn Dia (Non-Lead side)	Inches	7.850	7.850	7.850	7.850	7.850	7.850	7.850	7.850
	mm	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.648	1.648	2.152	2.152
	mm	23.01	23.01	29.41	29.41	41.86	41.86	54.66	54.66
R Rotor Outside Diameter	Inches	7.534	7.534	7.534	7.534	7.534	7.534	7.534	7.534
	mm	191.36	191.36	191.36	191.36	191.36	191.36	191.36	191.36

PARAMETER	UNITS	Table CL-8.0 - Motor Data (+25ºC)							
		CL-8.0-.75S	CL-8.0-.75R	CL-8.0-1.0S	CL-8.0-1.0R	CL-8.0-1.5S	CL-8.0-1.5R	CL-8.0-2.0S	CL-8.0-2.0R
Coulomb Torque (Fc)	Lbf-In	0.18	0.18	0.24	0.24	0.36	0.36	0.48	0.48
	Nm	2.03E-02	2.03E-02	2.71E-02	2.71E-02	4.07E-02	4.07E-02	5.42E-02	5.42E-02
Mass	Lbs	3.65	3.65	4.867	4.867	7.300	7.300	9.733	9.733
	kg	1.659	1.659	2.212	2.212	3.318	3.318	4.424	4.424
Number of Poles (#P)	-	64	64	64	64	64	64	64	64
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	4.75E-02	4.75E-02	6.25E-02	6.25E-02	9.38E-02	9.38E-02	1.25E-01	1.25E-01
	kg-m^2	5.37E-03	5.37E-03	7.06E-03	7.06E-03	1.06E-02	1.06E-02	1.41E-02	1.41E-02
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**3.70**	**2.62**	**4.93**	**3.49**	**7.03**	**4.97**	**9.37**	**6.62**
	Nm / √watt	0.418	0.296	0.557	0.394	0.794	0.562	1.059	0.748
No-Load Speed (Reference)	RPM	194	194	168	168	144	144	153	153
	Rad/Sec	20.3	20.3	17.6	17.6	15.1	15.1	16.0	16.0
Theoretical Stall Torque (T_S)	Lbf-In	36.6	18.3	56.4	28.2	98.4	49.2	185.5	92.7
	Nm	4.14	2.07	6.37	3.19	11.12	5.56	20.96	10.48
Max Power Output Torque (T_{PO})	Lbf-In	18.314	9.156	28.196	14.096	49.210	24.601	92.758	46.372
	Nm	2.069	1.034	3.186	1.593	5.560	2.779	10.480	5.239
Motor Resistance (Ω)	Ohms	**8.0**	**16**	**6.0**	**12.0**	**4.0**	**8.0**	**2.0**	**4.0**
Torque Constant (Kt)	Lbf-In/Amp	10.5	10.5	12.1	12.1	14.1	14.1	13.3	13.2
	Nm/Amp	1.18	1.18	1.37	1.37	1.59	1.59	1.50	1.50

Table CL-9.0 - Cog-Less Motor Data

PARAMETER	UNITS	Table CL-9.0 - Motor Data (+25ºC)							
		CL-9.0-.75S	CL-9.0-.75R	CL-9.0-1.0S	CL-9.0-1.0R	CL-9.0-1.5S	CL-9.0-1.5R	CL-9.0-2.0S	CL-9.0-2.0R
A Outside Diameter	Inches	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
	mm	228.60	228.60	228.60	228.60	228.60	228.60	228.60	228.60
B Through Bore	Inches	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
	mm	203.20	203.20	203.20	203.20	203.20	203.20	203.20	203.20
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
	mm	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
D Stack Length	Inches	0.756	0.756	1.008	1.008	1.498	1.498	2.002	2.002
	mm	19.20	19.20	25.60	25.60	38.05	38.05	50.85	50.85
E Max Length	Inches	1.276	1.326	1.528	1.578	2.018	2.068	2.522	2.572
	mm	32.41	33.68	38.81	40.08	51.26	52.53	64.06	65.33
F Lead-Side Max End Turn O.D.	Inches	8.975	8.975	8.975	8.975	8.975	8.975	8.975	8.975
	mm	227.97	227.97	227.97	227.97	227.97	227.97	227.97	227.97
G End-Turn Min I.D.	Inches	8.730	8.730	8.730	8.730	8.730	8.730	8.730	8.730
	mm	221.74	221.74	221.74	221.74	221.74	221.74	221.74	221.74
H Max End-Turn Dia (Non-Lead side)	Inches	8.950	8.950	8.950	8.950	8.950	8.950	8.950	8.950
	mm	227.33	227.33	227.33	227.33	227.33	227.33	227.33	227.33
J Rotor Length	Inches	0.906	0.906	1.158	1.158	1.648	1.648	2.152	2.152
	mm	23.01	23.01	29.41	29.41	41.86	41.86	54.66	54.66
R Rotor Outside Diameter	Inches	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
	mm	203.20	203.20	203.20	203.20	203.20	203.20	203.20	203.20

PARAMETER	UNITS	Table CL-9.0 - Motor Data (+25ºC)							
		CL-9.0-.75S	CL-9.0-.75R	CL-9.0-1.0S	CL-9.0-1.0R	CL-9.0-1.5S	CL-9.0-1.5R	CL-9.0-2.0S	CL-9.0-2.0R
Coulomb Torque (Fc)	Lbf-In	0.289	0.289	0.385	0.385	0.578	0.578	0.770	0.770
	Nm	3.26E-02	3.26E-02	4.35E-02	4.35E-02	6.52E-02	6.52E-02	8.70E-02	8.70E-02
Mass	Lbs	3.65	3.65	4.867	4.867	7.300	7.300	9.733	9.733
	kg	1.659	1.659	2.212	2.212	3.318	3.318	4.424	4.424
Number of Poles (#P)	-	64	64	64	64	64	64	64	64
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	0.071	0.071	0.093	0.093	0.142	0.142	0.185	0.185
	kg-m^2	8.02E-03	8.02E-03	1.05E-02	1.05E-02	1.60E-02	1.60E-02	2.09E-02	2.09E-02
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**4.53**	**3.20**	**6.17**	**4.36**	**8.25**	**5.83**	**10.93**	**7.73**
	Nm / √watt	0.512	0.362	0.697	0.493	0.932	0.659	1.235	0.873
No-Load Speed (Reference)	RPM	158	158	147	147	142	142	152	152
	Rad/Sec	16.6	16.6	15.4	15.4	14.9	14.9	15.9	15.9
Theoretical Stall Torque (T_S)	Lbf-In	44.8	22.4	77.3	38.6	133.4	66.7	249.9	124.9
	Nm	5.07	2.53	8.73	4.36	15.07	7.53	28.23	14.11
Max Power Output Torque (T_{PO})	Lbf-In	22.422	11.209	38.630	19.312	66.684	33.337	124.940	62.461
	Nm	2.533	1.266	4.364	2.182	7.534	3.766	14.116	7.057
Motor Resistance (Ω)	Ohms	**8.0**	**16**	**5.0**	**10.0**	**3.0**	**6.0**	**1.5**	**3.0**
Torque Constant (Kt)	Lbf-In/Amp	12.8	12.8	13.8	13.8	14.3	14.3	13.4	13.4
	Nm/Amp	1.45	1.45	1.56	1.56	1.61	1.61	1.51	1.51

Table CL-10.0 - Cog-Less Motor Data

PARAMETER	UNITS	Table CL-10.0 - Motor Data (+25ºC)							
		CL-10.0-1.0S	CL-10.0-1.0R	CL-10.0-1.5S	CL-10.0-1.5R	CL-10.0-2.0S	CL-10.0-2.0R	CL-10.0-3.0S	CL-10.0-R
A Outside Diameter	Inches	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
	mm	254.00	254.00	254.00	254.00	254.00	254.00	254.00	254.00
B Through Bore	Inches	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
	mm	228.60	228.60	228.60	228.60	228.60	228.60	228.60	228.60
C Stator to Rotor Location	Inches	0.075	0.075	0.075	0.075	0.075	0.075	0.125	0.125
	mm	1.91	1.91	1.91	1.91	1.91	1.91	3.18	3.18
D Stack Length	Inches	1.008	1.008	1.498	1.498	2.002	2.002	2.996	2.996
	mm	25.60	25.60	38.05	38.05	50.85	50.85	76.10	76.10
E Max Length	Inches	1.528	1.578	2.018	2.068	2.522	2.572	3.516	3.566
	mm	38.81	40.08	51.26	52.53	64.06	65.33	89.31	90.58
F Lead-Side Max End Turn O.D.	Inches	9.975	9.975	9.975	9.975	9.975	9.975	9.975	9.975
	mm	253.37	253.37	253.37	253.37	253.37	253.37	253.37	253.37
G End-Turn Min I.D.	Inches	9.730	9.730	9.730	9.730	9.730	9.730	9.730	9.730
	mm	247.14	247.14	247.14	247.14	247.14	247.14	247.14	247.14
H Max End-Turn Dia (Non-Lead side)	Inches	9.950	9.950	9.950	9.950	9.950	9.950	9.950	9.950
	mm	252.73	252.73	252.73	252.73	252.73	252.73	252.73	252.73
J Rotor Length	Inches	1.158	1.158	1.648	1.648	2.152	2.152	3.246	3.246
	mm	29.41	29.41	41.86	41.86	54.66	54.66	82.45	82.45
R Rotor Outside Diameter	Inches	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
	mm	228.60	228.60	228.60	228.60	228.60	228.60	228.60	228.60

PARAMETER	UNITS	Table CL-10.0 - Motor Data (+25ºC)							
		CL-10.0-1.0S	CL-10.0-1.0R	CL-10.0-1.5S	CL-10.0-1.5R	CL-10.0-2.0S	CL-10.0-2.0R	CL-10.0-3.0S	CL-10.0-R
Coulomb Torque (Fc)	Lbf-In	0.521	0.521	0.7815	0.7815	1.042	1.042	1.563	1.563
	Nm	5.89E-02	5.89E-02	8.83E-02	8.83E-02	1.18E-01	1.18E-01	1.77E-01	1.77E-01
Mass	Lbs	6.125	6.125	9.1875	9.1875	12.25	12.25	18.375	18.375
	kg	2.784	2.784	4.176	4.176	5.568	5.568	8.352	8.352
Number of Poles (#P)	-	72	72	72	72	72	72	72	72
Motor Rotor Inertia (Jm)	Lbf-In-sec^2	0.105	0.105	0.130	0.130	0.201	0.201	0.260	0.260
	kg-m^2	1.19E-02	1.19E-02	1.47E-02	1.47E-02	2.27E-02	2.27E-02	2.94E-02	2.94E-02
Simplex or Redundant	-	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant	Simplex	Redundant
Motor Constant (Km)	Lbf-In/ √watt	**7.25**	**5.13**	**9.80**	**6.93**	**13.07**	**9.24**	**17.55**	**12.41**
	Nm / √watt	0.819	0.579	1.107	0.783	1.477	1.044	1.983	1.402
No-Load Speed (Reference)	RPM	114	114	111	111	110	110	116	116
	Rad/Sec	12.0	12.0	11.6	11.6	11.5	11.5	12.1	12.1
Theoretical Stall Torque (T_S)	Lbf-In	82.9	41.4	146.7	73.3	258.8	129.4	491.4	245.7
	Nm	9.36	4.68	16.57	8.28	29.24	14.62	55.52	27.75
Max Power Output Torque (T_{PO})	Lbf-In	41.437	20.715	73.336	36.663	129.386	64.683	245.700	122.831
	Nm	4.682	2.340	8.286	4.142	14.618	7.308	27.759	13.877
Motor Resistance (Ω)	Ohms	**6.0**	**12**	**3.5**	**7.0**	**2.0**	**4.0**	**1.0**	**2.0**
Torque Constant (Kt)	Lbf-In/Amp	17.8	17.8	18.3	18.3	18.5	18.5	17.6	17.5
	Nm/Amp	2.01	2.01	2.07	2.07	2.09	2.09	1.98	1.98

Section 3 - Engineering

3.1 Motor Sizing Example & Performance Equations:

Often times the motor size is primarily driven by the allowable envelope of the system. The performance data tabulated herein is provided to guide the design engineer to determine the required performance. This section will present the information to optimize a motor for your specific application, and meet all the requirements for Torque Margin and reliability for the most demanding space-rated applications. Other motor manufacturers in the industry ofter tabulate motor torque constants and DC resistances far too low for most applications. The consequence is increased motor current requirements that increases line losses and has EMI / EMC implications. Avior offers the flexibility of optimization of performance to minimize system current requirements while meeting all motor performance requirements. This section walks the engineer though sizing and optimization of a motor.

The critical requirements for a motor selection include:

- Load Moment of Inertia (J_L)
- Load Static Friction (F_C)
- Load Viscous Load Losses (B_{VL})
- Load Max Acceleration Requirements (α_L)
- Load Maximum Velocity Requirements (ω_L)
- Minimum Supply Voltage (V_{IN})

As an example, an Avior Type **CL-5.5-1.5R** has the following motor characteristics:

- Motor Constant (K_M): 1.78 Lbf-In/√Watt (0.201 Nm/√Watt)
- Torque Constant (K_T): 6.17 Lbf-In/Amp (.697 Nm/Amp)
- DC Resistance (Ω_{25}): 12.0 ± 10% Ohms
- No Load Speed (ω_{NL}): 329 RPM (34 Rad/sec)
- Stall Torque (T_{S25}): 14.4 Lbf-In (1.63 Nm)
- Minimum Supply Voltage (V_{IN}): 24 VDC
- Rated Temperature Performance (t): +25° C
- Motor Drag Torque (F_{CM}): 0.19 Lbf-In (0.02 Nm)
- Motor Inertia (J_M): 2.88E-02 Lbf-In-sec2 (3.25 kgm^2)

In our theoretical application, the CL-5.5-1.5R mechanically fits, but we require the following performance:

- Operational Velocity ω_M: 200 RPM (20.94 Rad/sec)
- Load Bearing Static Friction (F_{CL}): 0.5 Lbf-In (0.056 Nm)
- Load Viscous Friction (B_{VL}): 2.5E-3 Lb-in/RPM (2.7E-05 Nm-sec/rad)
- Minimum Input Voltage (V_{IN}): 24 VDC
- Load Inertia (J_L): 0.05 Lbf-in-sec^2
- Acceleration (α_L): 10 Rad/sec^2
- Max Temperature (t_2): +60° C

Table 3.1 Brushless Motor Performance Equations

Parameter	Symbol	Imperial / SI Units	Equation Or Data Location
Motor Inertia	J_M	Lbf-In-sec^2 / kg-m^2	(See Tabulated Motor Data)
Stall Power Input at Holding (at +25º C)	P_S	Watts	$P_S = (T_S / K_M)^2$
Motor Constant at 25ºC	K_M	Lbf-In / √Watt / Nm / √Watt	$T_{S25} / \sqrt{P_{S25}}$ (See Tabulated Motor Data)
Motor Constant at 25ºC (alternate equation)	K_M	Lbf-In / √Watt / Nm / √Watt	$K_T / \sqrt{\Omega_{25}}$ (See Tabulated Motor Data)
DC Resistance (+25º C)	Ω_{25}	Ohms	Nominal, See Data Sheet $\Omega_{25} = (K_T \div K_M)^2$
DC Current at Stall (+25º C)	I_{S25}	Amps	$I_s = V / \Omega_{25}$
DC Resistance at other Temperature (t_2)	Ωt_2	Ohms	$\Omega t_2 = \Omega_{25}(1 + 0.004 (t_2-25))$
DC Current at Stall at t_2	$I_{S(t2)}$	Amps	$I_{S(t2)} = V_{IN} / \Omega_{t2}$
Torque Constant	K_T	Lbf-In/ Amp / Nm/ Amp	$K_T = T_S / I_S$
Back emf Constant	K_B	V/Rad/Sec	$K_B = K_T$ In Nm/Amp (SI)
Stall Torque at Motor at +25º C	T_{S25}	Lbf-In / Nm	$T_S = K_T * I_{S25}$
Stall Torque at Motor at Max Temperature (t_2)	$T_{S(t2)}$	Lbf-In / Nm	$T_{S(t2)} = K_T * I_{S(t2)}$
No Load Speed (Reference)	ω_{NL}	RPM / Rad/sec	V_{IN}/K_B / $(Vin/K_B)*9.55$

Table 3.1 Brushless Motor Performance Equations			
Parameter	Symbol	Imperial / SI Units	Equation Or Data Location
Operational Velocity at Motor	ω_M	RPM / Rad/sec	**Customer Driven Requirement**
Available Torque at Operational Velocity - At t_2	$T_{\omega A}$	Lbf-In / Nm	$T_{\omega A} = ((\omega_{NL} - \omega_M) * T_{S(t2)}) / \omega_{NL}$
Required Torque at Operational Velocity (Per GSFC-STD-7000)	$T_{\omega R}$	Lbf-In / Nm	$T_{\omega R} = (F_{CL}(K_V))+((J_M+J_L)*(\alpha_L(K_C)) + (B_{VL}*\omega_M)(K_V))+ (F_{CM}(K_c))$
Margin of Safety (must be >0)	MoS	-	$MoS = (T_{\omega A}/T_{\omega R}) - 1$

Per GSFC-STD-7000, Factors of Safety are dependent on the nature of the torque requirements, and the stage of the program they are required. "Known" factors of safety are values that cannot change over time or wear, such as torque to accelerate inertia, non-contacting magnetic coulomb or motor hysteresis torques. "Variable" factors are items such as bearing drag or contacting friction torques. As the program matures, the required margins reduce. Note: F_{CL} is load bearing friction and B_{VL} is the load viscous (dynamic) losses.

Table 3.2 – Applied Factors of Safety to Torque Components per GSFC-STD-7000		
Program Phase	Known Factor of Safety (K_C)	Variable Factor of Safety (K_V)
Preliminary Design Review	2.00	4.0
Critical Design Review	1.50	3.0
Acceptance / Qualification Test	1.50	2.0

Calculating for our theoretical example for PDR level requirements, and using $T_{\omega R}$ equation from table 3.1, we calculate the following REQUIRED torque at speed (ω_M).

$$T_{\omega R} = (0.5(4.0)+(((2.88E\text{-}2+5.0E\text{-}2)*10)(2)))+((2.5E\text{-}3*200)(4))+(0.19*(2))$$

This results in a Required Torque of **$T_{\omega R}$ = 4.156 Lbf-**In at 200 RPM.

To calculate the AVAILABLE torque under worst-case conditions (Min voltage, maximum resistance, maximum temperature), we must calculate the resistance at temperature (t_2):

$$\Omega t_2 = 13.2(1+.004(60\text{-}25)$$

Which gives us a Ω_{t2} = 15.05 Ohms. Therefore the Theoretical Stall Torque at t_2 is equal to:

$$T_{S(t2)} = 6.17\ (24/15.05)$$

Which provides $T_{S(t2)}$ = 9.84 Lbf-In. Our no load speed, for intents and purposes, is unaffected by temperature. So our AVAILABLE torque at 200 RPM is:

$$T_{\omega A} = ((329 - 200)*9.84)/329$$

Our **Available** torque at 200 RPM for our CL-5.5-1.5R is **$T_{\omega A}$ = 3.86**, while we require greater than **4.156 Lbf-In.** This analysis shows that the desired motor will not produce the required margined torque at speed. In order to achieve positive margin at speed, we must reduce the Torque Constant (K_T) by at least the square root of the ratio of 3.86 / 4.156 or about 5%. If we reduce the K_T by 10%, we get a modified K_T' of 5.55 Lbf-In/Amp (0.628 Nm/Amp). Since the K_M does not change, we calculate a new nominal resistance of:

$$\Omega_{25}' = (K_T' / K_M)^2$$

Giving us a new *nominal* resistance of 9.73 Ohms. Recalculating performance:

$$\Omega_{t2}'=(9.73*1.1)(1+.004(60\text{-}25))$$
$$\Omega_{t2}'=12.20\ \text{Ohms}$$

$$\omega_{NL}' = (24/.628)*9.55$$
$$\omega_{NL}' = 365\ \text{RPM}$$

$$T_{S(t2)}' = 5.55(24/12.2)$$
$$T_{S(t2)}' = 10.91\ \text{Lbf-In}$$

$$T_{\omega A}'= ((365\text{-}200)*10.91)/365$$
$$T_{\omega A}'= 4.93\ \text{Lbf-In}$$

Providing a positive PDR **M**argin of **S**afety of:

$$MoS = (4.93 / 4.156) -1$$
$$MoS = 0.18$$

Note: The above analysis ignores some secondary losses such as motor hysteresis, Ldi/dt (which are typically very low in Cog-less motors), IR voltage drops, as well as motor temperature rise affects. This analysis, however, does provide an accurate "first cut" of motor performance. As a standard process, Avior runs a full Finite Element Analysis motor performance simulation to assure system requirements will be met before hardware is built.

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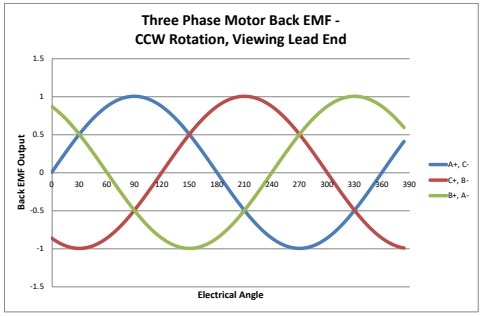
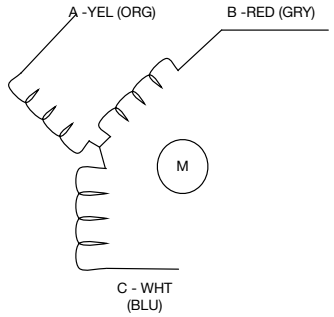
There usually is no cost impact for a motor winding options, other than tabulated herein. If our calculations had shown for *too much* available torque, we would recommend an increase of the K_T to minimize required motor currents. It is not desirable to have too low of a Torque Constant, since low K_T means higher phase current, adding potential line losses and EMI challenges.

3.2 Schematic and Phasing

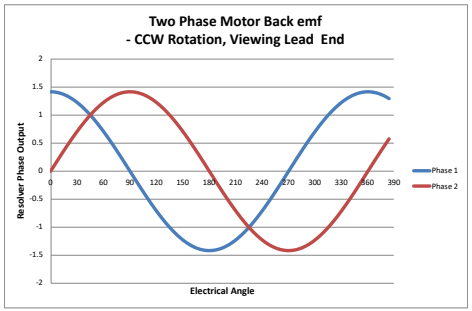
Redundant Lead colors shown in parenthesis.

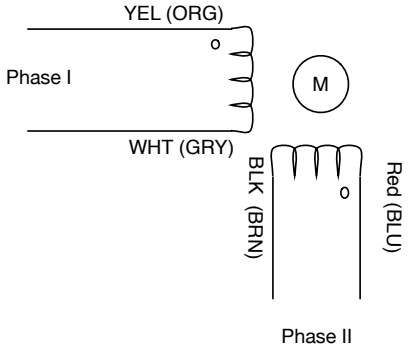
3.2.1 Three Phase Phasing





3.2.2 Two Phase Phasing





3.3 Two Phase Versus Three Phase Sinusoidal

Generally speaking, it is easier to manufacturer a three phase Cog-Less Motor, as compared to a two phase Cog-Less, due to winding manufacturing techniques. There may also be some efficiencies gained by the vectorial math of a three phase motor over a two phase motor. Some system engineers prefer two phase sinusoidal control, because it is easier to control two independent H bridges. Our CL line of motors may be wound for two phase or three phase control. Inherently, CL motor back emf is sinusoidal, so it is rare to drive these units via a trapezoidal methodology.

For a Sinusoidal three phase motor, due to the torque vector mathematics, the *phase currents are actually 0.816 times (1/√1.5) the calculated current from the Table 3.1 values.* There are multiple papers available online that provide the mathematical background. It is important to note, however, *that the performance simulations calculated per Table 3.1 are largely similar, and fairly accurate, whether you drive Two Phase or Three Phase, sinusoidally*. Avior runs detailed FEA simulations to predict actual performance for each specific application. There is a performance penalty for Stall Torque and Dynamic Running Torque if CL motors are trapezoidally driven, due to the sinusoidal back emf. This is discussed in more detail in the next section.

3.4 Sinusoidal Versus Trapezoidal:

Sinusoidal commutation is used by the vast majority of Cog-Less applications. However, it is not a requirement to sinusoidally drive Cog-Less motors. The performance tabulated herein is assumes sinusoidal commutation is used. However, if the Customer elects to use three phase trapezoidal commutation, there will be a reduction in operational torque between commutation points, due to torque ripple. The Stall Torque should be reduced by a factor of 0.866. Dynamically, the torque loss due to ripple averages out to about a 7% (0.93) reduction factor.

Avior's Conventional "Toothed" Direct Drive Motors (Type CM), are much more conducive to trapezoidal drives. Generally speaking, trapezoidal drives are commonplace for higher power output applications. In addition to the CM motors having significantly higher K_M to outside diameter ratio, the toothed configuration and minimal magnetic air-gap allows for trapezoidal back-emf profile, which reduces torque ripple and increases performance further.

3.5 Finite Element Analysis (FEA):

For detailed FEA analysis, conservative preliminary runs are performed pre-contract, while more high-fidelity analyses are conducted after contract award. Optional detailed performance analysis reports are often required by the Customer as a contract deliverable. The following FEA outputs show some of the detailed information available.

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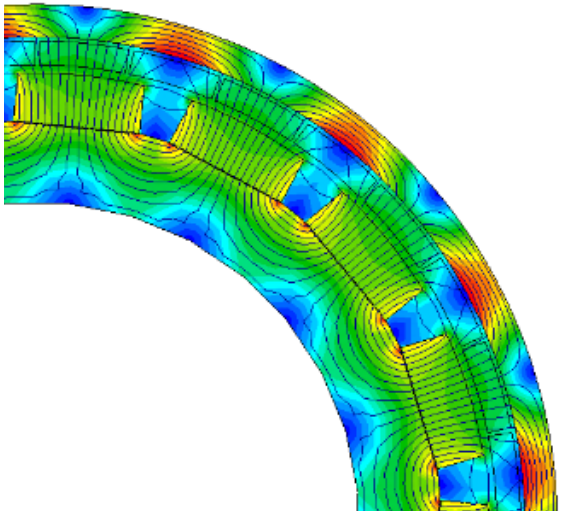
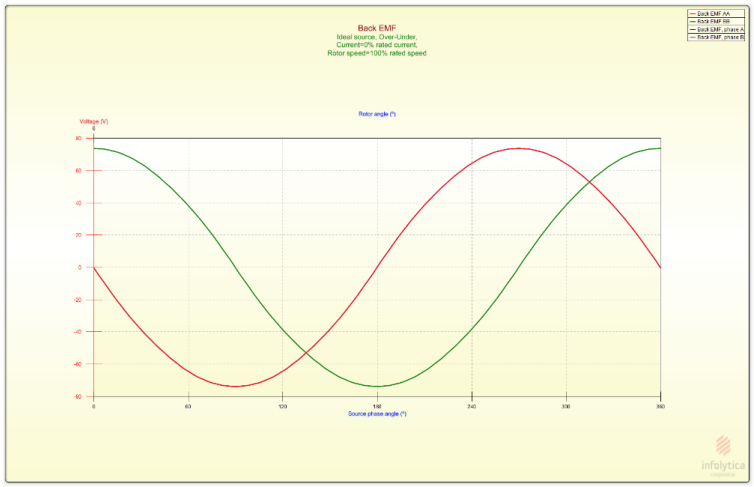
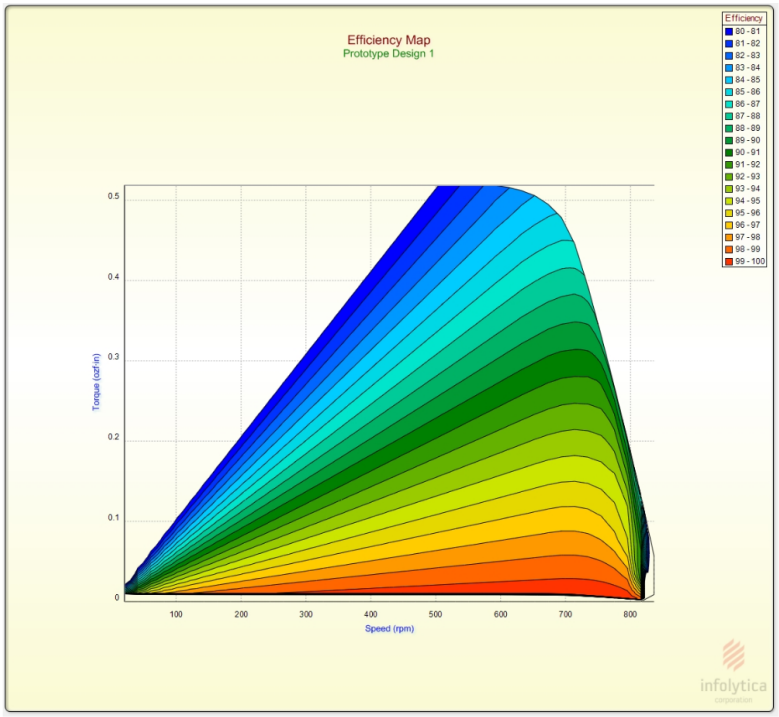
Flux function (Wb/mm)
Flux density (T)



	1	2	3	4
RMS current (A)	0.75	1.5	2.25	3
RMS current (% of rated)	50	100	150	200
Kt (derived from Ke) (N·m/A)	0.356	0.356	0.356	0.356
Ke (peak line-line Back-EMF over speed) (V/krpm)	30.5	30.5	30.5	30.5
Lmax (maximum per phase self-inductance) (mH)	0.0668	0.0668	0.0668	0.0668
Llmax (maximum line-line inductance) (mH)	0.149	0.149	0.149	0.149
Rs (stator phase resistance) (Ω)	1.01	1.01	1.01	1.01
Back-EMF (peak line-line) (V)	11.9	11.9	11.9	11.9



Efficiency Map, Prototype Design 1



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3.6 Servo-System Acceleration Feedback Option:

Inner loop velocity feedback is typically used for servo-system transfer function manipulation to provide damping which increases response, bandwidth and stability. The rate signals are typically accomplished by differentiating the position with respect to time. Higher order transfer function manipulation may be accomplished with a Permanent Magnet Rotary Accelerometer integrated into the system. While this option adds another mechanical component into the system, the potential advantages of electronically making the system inertia look higher are significant. Since differentiation inherently introduces noise, starting with a passive acceleration signal offers significant advantages. In systems where the load inertia about the rotation axis can change significantly over position, the ability to stabilize the transfer function and significantly increase bandwidth and gain is highly desirable. For high echelon systems requiring extreme pointing and tracking capabilities, Rotary Accelerometer Feedback (RAF) may offer many benefits.

Rotary Acceleration Feedback (RAF) Compensation Benefits:

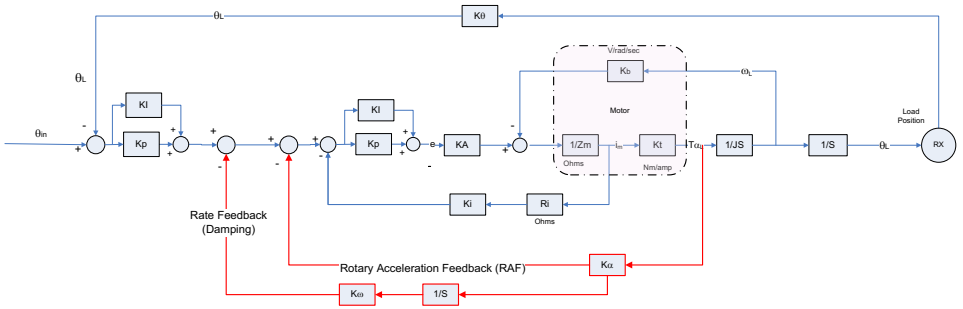
RAF Affects Higher Order Term of Transfer Function

- Ax^2+Bx+C
  - –A = Inertial Term (Mechanical + Electrical)
  - –B = Damping (Mechanical + Electrical)
  - –C = Stiffness

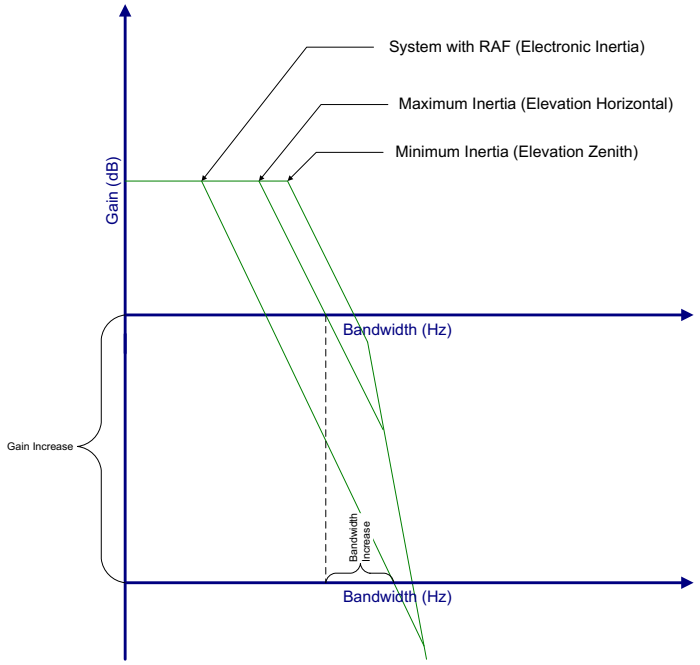
• Provides electronic “Inertia” to servo equations without adding mass or power consumption
• Allows higher forward loop gain to achieve maximum bandwidth
• Increases system stiffness and robustness of servo system
• May make inertia “look” constant regardless of load position
• Provides analog damping term through op-amp integrated acceleration signal
• Provides electronic “Damping”
• Preferred to differentiated (and highly filtered) rate signal from position processing
• Reduces torque ripple
• Automatic feedback from Accelerometer compensates disturbances for ultra-smooth performance
• If bearing characteristics change over life, RAF automatically compensates

System integrators must consider that Rotary Accelerometers will pick up noise through Pulse Width Modulation of motor currents. A simple low pass filter below the PWM frequency will allow the useful signal to be available. Typically, Avior can provide a Rotary Accelerometer in the same Outside / Inside Diameter configuration as the type CL motor assembly. Contact Avior’s Engineering department for further information and options of our Permanent Magnet Rotary Accelerometers.

Simplified Gimbal Controller Block Diagram
With Rotary Acceleration Feedback and Rate Damping



Bode Plot Example of Second Order System



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