Armel Industrial Systems

Voice Coil Actuator Application Guide

Armel Industrial Systems

Armel Industrial Systems, Magnetics Div. LLC was founded in order to provide the US OEM and Industrial Market Place with the state of the art Linear and Rotary Solutions. The primary products are Voice Coil Based Linear and Rotary Actuators, and Linear Motors. For the actuator market, Armel Industrial Systems is able to provide both a standard distribution product and also high volume custom solutions.

With many years of experience, our international engineering and supporting staff is able to provide you the latest advancements in the motion technologies. Armel Industrial Systems is based in the US with manufacturing centers in Asia.

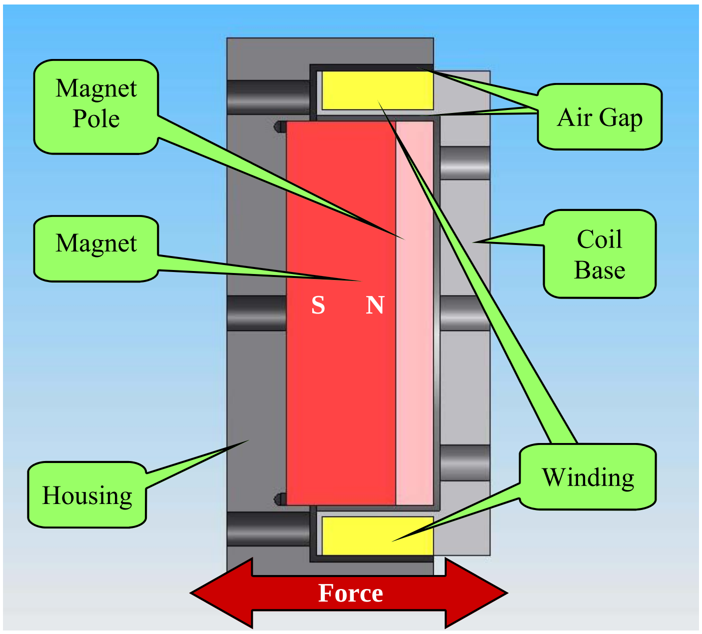
Voice Coil Actuators, VCAs, are devices that convert electrical energy into a mechanical force. They movements can be of either linear or limited angle rotary motion. VCAs utilize the interaction of powerful magnetic fields from permanent magnets and the coils of current carrying conductors to produce a force over a limited motion range. The Linear Actuators can produce forces that can exceed 5000 Newtons and strokes are available up to 175 mm. Rotary Actuator can product torques greater than 100 N-m and stroke angles greater than 90 degrees.

Because the VCAs manufactured by Armel Industrial Systems are a non commutated motion device, the positioning accuracy is limited only to the feedback sensor and the controller – not the Voice Coil Actuator. Positioning accuracies to 10nm are easily achievable with the appropriate position feedback sensor. Accelerations of more than 300 g are possible; of course the actual acceleration is dependant on the inertia of the load being accelerated.

VOICE COIL ACTUATOR BASICS

Voice Coil Actuators, VCAs, are available from Armel Industrial Systems in many different styles. Whether it is a Linear Actuators or a Rotary Actuators the basic operating principles are the same. A current carrying conductor in a magnetic field will product a force perpendicular to the direction of the current and the magnetic field. The magnitude of the force is dependent on the length of the conductor in the magnetic field, the strength of the magnetic field and the current. A VCA converts an applied current to a linear force or torque. The force / torque is proportional to the applied current.

The figure above is a cut away of a LAR series actuator. The magnet pole focuses and directs the magnetic field from the magnet face through the air gap and the windings. The magnetic field is then returned to the opposite magnetic pole through the housing. The windings are the current carrying conductors. The coil base supports the windings, it is manufactured from low mass non-magnetic materials, either aluminum or plastic. The coil base also assists in dissipating the heat produced by the windings.



The force that a Voice Coil Actuator (VCA) will produce is dependant upon the design and the current.

$$F = \beta L I$$

F = Force in Newtons (N)
β = Magnetic field strength in Tesla (T)
L = Length of the conductor in Meters (m)
I = Current in Amps (A)

The magnetic field strength and the length of the conductors are a function of the VCA design. The amount of the current applied is the means of controlling the force / torque produced. The design rating for the Current vs. Force relationship for a Linear VCA model is the Force Sensitivity K_F and Torque Sensitivity K_T for rotary actuators. Armel Industrial Systems rates the Force Sensitivity (K_F) in Newtons / Amp - (N/A) and Torque Sensitivity in Newton-meter / Amp (N-m/A). A Newton is the SI unit for force and is a measurement of how much a device either pushes or pulls. VCA are a simple non-communicated analog device that converts a current flow into a force. Because of this the position and force resolution is only limited by the position feedback device and the controller – not by the VCA.

LINEAR MOTION

For a liner motion:

$$\text{Force} = \text{Current} \times K_F$$

The basic definition for a Newton in SI units is:

$$1 \text{ Newton (N)} = 1 \text{ Kg } \cdot \text{ m / sec}^2$$

Newtons are the equivalent unit of measurement to: Pound-force, Ounce-force, Dyne and Kilogram Force.

Basic conversions for Newtons

1Newton = 0.225 LB_F

1Newton = 3.597 Oz_F

1Newton = 0.102 Kg_F

1Newton = 100000 Dyne

If VCA with a K_F rating of 10 N / A is supplied with a current of 5 Amps, it will produce a force of 50 Newtons. The same actuator when supplied with a current of 2 Amps, the force produced will be 20 Newtons. If the current is reversed the direction of the produced force is in the opposite direction. Therefore a simple current controller can control the force produced by a Linear VCA.

Newtons Second Law States:

If a force is applied to a given mass it will be accelerated in the direction of the force.

$$F = m\,a \qquad \text{or} \qquad a = F / m$$

Where:

F = the force in Newtons

m= the mass in kg

a = the acceleration in m / second^2

Linear Motion Equations:

$x = v\,t$

$v = v_o + a\,t$

$x = v_o\,t + ½\,a\,t^2$

$v^2 = v_o^2 + 2\,a\,x$

Where:

x = Distance in meters

These Linear Motion Equations when combined with the force constant of the Voice Coil Actuator yields the following:

$F = K_F\,I$

$a = K_F\,I / (m_{VCA} + m_{LOAD})$

$v = \sqrt{(2 \times K_F\,I / (m_{VCA} + m_{LOAD}))}$

$x = ½\,t^2\,K_F\,I / (m_{VCA} + m_{LOAD})$

Where:

K_F = Force Sensitivity

I = The current applied

m_{VCA} = mass of the coil

m_{LOAD} = mass of the load

When sizing a linear motion solution using VCAs the Peak Force, Stroke and the Continuous Force ratings must be taken into account. The Continuous Force rating is dependent on the heat produced (Load Dependent) and the heat removal (VCA dependant).

$$\text{Force}_{RMS} = \sqrt{\frac{(F_1^2 t_1 + F_2^2 t_2 + F_3^2 t_3 \ldots F_N^2 t_N)}{t_1 + t_2 + t_3 + \ldots t_N}}$$

Where:

$F_1, F_2, \ldots, F_N$ are the forces

$t_1, t_2, \ldots, t_N$ are the time that the forces are applied.

The VCA must have a continuous rating greater than the Force_{RMS} .

Armel Industrial Systems has developed the

“ Armel Industrial Systems Linear Actuator Sizing Program “

to assist with these calculations.

ROTARY MOTION

For a rotary motion:

Torque = Current x K_T

The basic definition for a Newton - m in SI units is:

1 Newton –meter (N-m) = 1 Kg-m^2 rad / sec^2

A radian (rad) is a measurement of angular displacement.

360 degrees = 2π Radians   360 degrees ≈ 6.28 Rad

Newtons are the equivalent unit of measurement to: Foot Pound-force, Ounce-force inch, Dyne cm and Kilogram-Force meter.

Basic conversions for Newton meters:

1N-m = 0.7376 foot - LB$_F$
1N-m = 141.6 Oz$_F$ - inch
1N-m = 0.102 Kg$_F$ - meter
1N-m = 1000000 Dyne - cm

If VCA with a K_T rating of 0.1 N –m / A is supplied with a current of 5 Amps, it will produce a torque of 0.5 N-m. The same actuator when supplied with a current of 2 Amps, the torque produced will be 0.2 N-m. If the current is reversed the direction of the produced torque is in the opposite direction. Therefore a simple current controller can control the force produced by a Rotary VCA.

Newtons Second Law States: $\tau = I\,\alpha$

Where

τ = the torque in Newton – meters
I = the moment of inertia in kg – m^2
α= the angular acceleration in radians / second

Rotary Motion Equations:

$$\theta = \omega\, t$$
$$\omega = \omega_o + \alpha\, t$$
$$\theta = \omega_o\, t + \alpha\, t^2$$
$$\omega^2 = \omega_o^2 + 2\,\alpha\,\theta$$

Where:

θ = the angular displacement in radians
ω = the angular velocity radians / second

These Rotary Motion Equations when combined with the torque constant of the Voice Coil Actuator yields the following:

$$\tau = K_T\, I$$
$$\alpha = K_T\, I / (I_{VCA} + I_{LOAD})$$
$$\omega = \sqrt{(2 \text{ x } K_T\, I / (I_{VCA} + I_{LOAD}))}$$
$$\theta = \tfrac{1}{2}\, t^2\, K_F\, I / (I_{VCA} + I_{LOAD})$$

Where:

K_T = Torque Sensitivity
I = The current applied
I_{VCA} = Moment of Inertia of the coil
I_{LOAD} = Moment of Inertia of the load

When sizing a rotary motion solution using VCAs the Peak Torque, Stroke and the Continuous Torque ratings must be taken into account. The Continuous Torque rating is dependent on the heat produced (Load Dependent) and the heat removal (VCA dependant).

$$\text{Torque}_{RMS} = \sqrt{\frac{(\tau_1^2 t_1 + \tau_2^2 t_2 + \tau_3^2 t_3 \ldots \tau_N^2 t_N)}{t_1 + t_2 + t_3 + \ldots t_N}}$$

Where $\tau_1, \tau_2, \ldots, \tau_N$ are the torques and $t_1, t_2, \ldots, t_N$ are the time that the torques are applied.
The VCA must have a continuous rating greater than the Torque$_{RMS}$.

Armel Industrial Systems has developed the
" Armel Industrial Systems Rotary Actuator Sizing Program "
to assist with these calculations.

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LINEAR vs ROTARY MOTION

LINEAR MOTION			ROTARY MOTION		
	Units	Linear Motion	Rotary Motion	Units	
Position	m, mm	x	θ	Degree , rad	Angular Position
Velocity	m/s	v	ω	Degree /s, rad/s	Angular Velocity
Acceleration	m/s^2	a	α	Degree $/s^2$, rad/s^2	Angular Acceleration
Linear Motion Equations		$x = v\ t$	$\theta = \omega\ t$		Rotary Motion Equations
		$v = v_o + a\ t$	$\omega = \omega_o + \alpha\ t$		
		$x = v_o\ t + \frac{1}{2}\ a\ t^2$	$\theta = \omega_o\ t + \alpha\ t^2$		
		$v^2 = v_o^2 + 2\ a\ x$	$\omega^2 = \omega_o^2 + 2\ \alpha\ \theta$		
mass	g kg	m	I	$g\text{-}cm^2$ $kg\text{-}m^2$	inertia
Newton's Second Law Force	$N = kg\ m/s^2$	$F = m\ a$	$\tau = I\ \alpha$	$N\text{-}m = kg\ m^2\ rad/s^2$	Newton's Second Law Torque

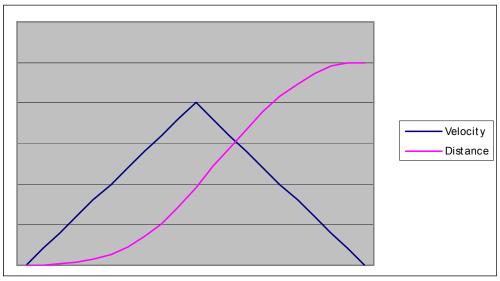
Comparison of Motion Profiles

The shown below are examples for two different types of motion profiles: Triangular and Trapezoidal. Both have the same movement distance and time.

Given:

Load Mass	200 g	Move Time	10 msec
Distance	10 mm	Dwell Time	10 msec

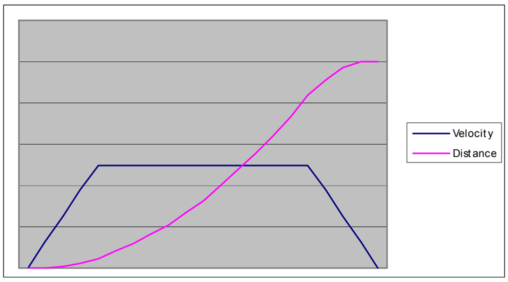
Triangular Motion



Vavg = Distance / Time	1 m/sec
Vmax = 2 Vavg	2 m/sec
Accel = Vmax / Accel time	400 m / sec^2
Force = Accel x Mass	80 N
RMS Force	56.36 N

The Triangular Motion Profile will require a lower peak force but will require a higher RMS force

Trapezoidal Motion



Vavg = Distance / Time	1 m/sec
Vmax = 4/3 Vavg	1.33 m/sec
Accel = Vmax / Accel time	533 m / sec^2
Force = Accel x Mass	106 N
RMS Force	53.3 N

The Trapezoidal Motion Profile requires a higher Peak Force but a lower RMS force. Also, as the maximum velocity is lower the voltage required to overcome the BEMF will also be lower.

DATA SHEET PARAMETERS

Winding Constant	**Symbol**	**Units**	**Notes**
Resistance	R	Ω	
Voltage @ FP	V_{FP}	V	Voltage at Peak
Current @ FP	I_{FP}	A	Current at Peak
Force Sensitivity (Linear)	K_F	N / A	Force Sensitivity at mid-stroke
Torque Sensitivity (Rotary)	K_T	N-m / A	Torque Sensitivity at mid-stroke
Back EMF (Linear)	K_B	V / m / sec	Back EMF at mid-stroke
Back EMF (Rotary)	K_B	V/Rad/sec	Back EMF at mid-stroke
Inductance	L	mh	
Actuator Constants	**Symbol**	**Units**	**Description**
Peak Force (Linear)	F_P	N	Peak Force rated at 10 second duty
Peak Torque (Rotary)	T_P	N-m	Peak Torque rated at 10 second duty
Continuous Force (Linear)	F_C	N	Continuous Force rated at ambient of 25 C and max winding temperature
Continuous Force with Heat Sink (Linear)	F_{CH}	N	Continuous Force rated at ambient of 25 C and max winding temperature with 250 mm x 250 mm x 10 mm Aluminum Heat Sink
Continuous Torque	T_C	N-m	Continuous Torque rated at ambient of 25 C and max winding temperature
Continuous Torque with Heat Sink (Rotary)	T_{CH}	N-m	Continuous Torque rated at ambient of 25 C and max winding temperature with 250 mm x 250 mm x 10 mm Aluminum Heat Sink
Actuator Constant (Linear)	K_A	N / √w	
Actuator Constant (Rotary)	K_A	N-m / √w	
Electrical Time Constant	Te	msec	
Peak Power @ FP (Linear)	P_P	w	
Peak Power @ TP (Rotary)	P_P	w	
Total Stroke (Linear)	S	mm	
Total Stroke (Rotary)	S	Degree	
Coil Clearance	CL	mm	Clearance between coil and field assemblies. For un-housed actuators must be maintained externally.
Thermal Resistance	θ_{TH}	C / w	
Thermal Resistance with Heat Sink	θ_{THH}	C / w	Thermal Resistance with 250 mm x 250 mm x 10 mm Aluminum Heat Sink
Max Winding Temperature	T_{MAX}	C	
Weight of Coil Assembly	Wt_C	g	
Moment of Inertia of Coil Assembly (Rotary)	I_C	g-cm^2	
Weight of Field Assembly	Wt_F	g	
Weight of Actuator	Wt_A	g	

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All VCA Series

LAR Series

The LAR Series of Cylindrical Actuators constitute nearly 70% of the market. They can produce a high force with a high acceleration rates. Peak Forces range for 0.7 N to 2000 N. Typically, their stroke length is less than 50 mm. LAR Series Actuator Applications include Valve Actuators, Z Axis pick and place, small accurate positive displacement metering pumps, and both vibrators and active vibration dampening systems. Markets include Medical, Semiconductor, Aerospace and Automotive.

LAS Series

LAS Series Rectangular Actuators have a lower force per weight than the cylindrical actuators. But they also have a much longer strokes. Forces range up to 1000 N and strokes to 250 mm.

Rectangular Actuators are the ideal solution for X –Y Axis movements and their major market is in the semiconductor and micro machine tool industries.

LAP Series

LAP Series Planer Actuators have a lower stroke length per size than rectangular. But they also have a lower height profile. Forces range up to 500 N and strokes to 15 mm.

LAP Series Planer Actuators are the ideal solution for very small stroke X –Y Axis movements and their major market is in the semiconductor and micro machine tool industries

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RAS Series

RAS Series Rotary Actuators have taken the technology of the rectangular linear actuator and bent them to provide a high resolution limited angle positioning system. Typical stroke angles exceed 100 degrees and torques to 50 N-m.

Rotary Actuators are typically utilized as mirror position actuators for laser technologies, rotary valve and damping actuators, rotary positioning systems and flight control actuators. Rotary Actuator markets include semiconductor, automotive, industrial and aerospace industries

LAH / RAH Series

The LAR and RAS series actuators may be readily adapted to a housed / sealed unit with bushings or bearings.

Custom

For large OEMs, if our standard products to not meet your exact requirements we may be able to design and manufacture a custom device that will meet you exact requirements. Just send us an e-mail with your specifications and volume requirements and our staff will review it and quickly respond your request.

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