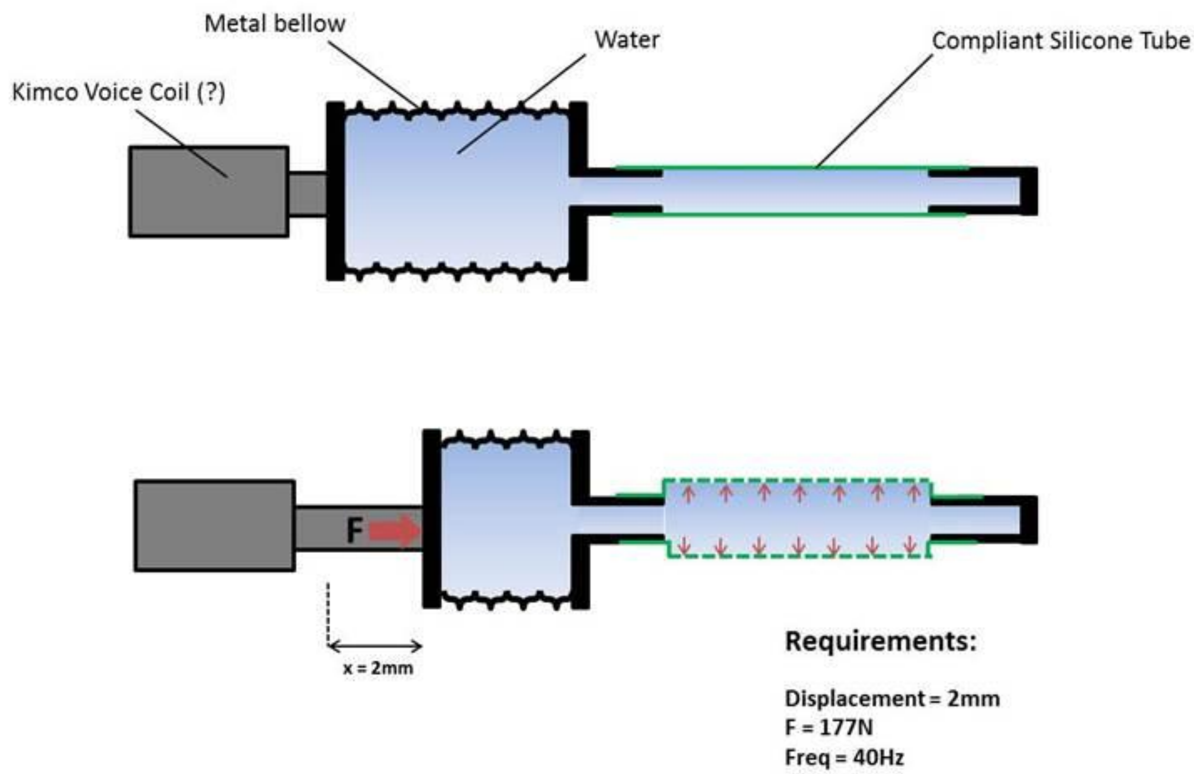
Metal Bellow-Pressure System

In brief, I require a linear actuator to displace a metal bellow. This metal bellow will in-turn displace a fluid, which is used to generate a required internal system pressure. This results in a diameter change of a compliant silicone tube (see figure below).



For my application, there are 3 criteria (such that the required ID change is achieved):

I. The pressure range must be 0 – 23kPa (i.e. at zero displ. = 0kPa, and at max. displ = 23kPa)
II. The compliant silicone tube must have a dynamic compliance of 3% IDΔ/100mmHg
III. Specific silicone tube dimensions

Based on these three criteria, it is possible to calculate:

1. The ID change of the silicone tube to corresponding to an internal pressure of 23kPa (based on tube compliance)
2. Volume change of silicone tube (based on ID change @ 23kPa, and assuming a fixed length)
3. Required bellow displacement to achieve volume change (based on bellow specifications)
4. Required force to displace bellow required distance (F_B, as governed by Hooke's Law)
5. Required force to achieve system pressure (F_P, as governed by Pascal's Law)

**Note:* the specifications of the bellow can be changed to best suit the application (i.e. effective area and spring constant can be changed). In preliminary work, a bellow with a large effective area (i.e. large ID) has been chosen to minimize required displacement such that higher frequencies are more feasible.

Using the above, it is possible to determine the total required applied force to the bellows (F_T) to achieve the required system pressure:

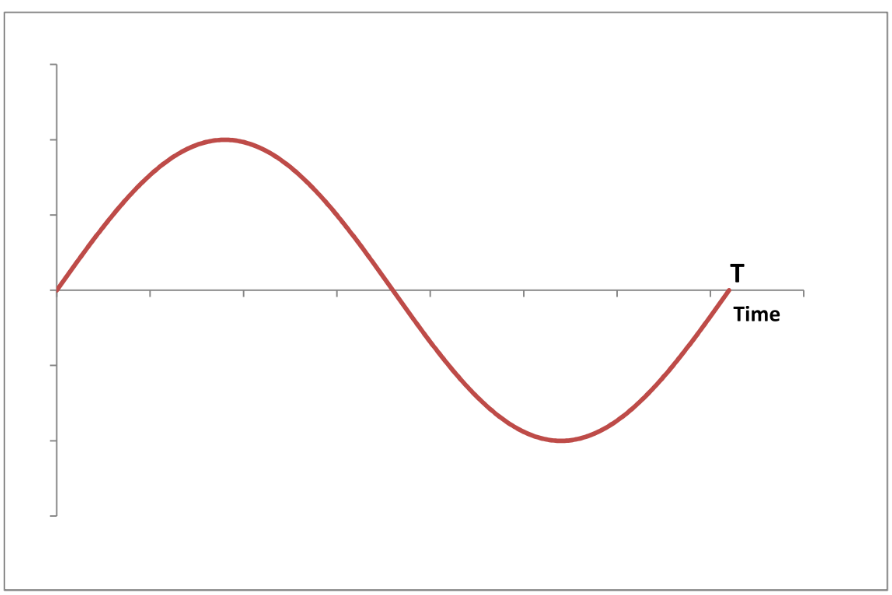
$$F_T = F_B + F_P$$

After initial calculations, I have determined that:

$$F_T = 177N$$

This is the force required to be applied to the bellow by the linear voice coil actuator to achieve the necessary system pressure of 23kPA. This will be achieved with a bellow displacement of 2mm (i.e. voice coil stroke length).

Additionally, I require a sinusoidal profile @ 40Hz (frequency is flexible, although the higher, the better).



Voice Coil Selection Theory:

This selection is based on the application guide provide by BEI Kimco Magnetics, as found at:
http://www.beikimco.com/pdf/VCA%20App%20Product%20Guide.pdf

$F_P = Peak\ Force$
$F_L = Force\ Due\ to\ Load$
$F_F = Force\ Due\ to\ Friction$
$F_m = Force\ Due\ to\ the\ Acceleration\ of\ Mass$
$M_{L+C} = Load\ Mass\ (incluicing\ actuator\ coil)$
$\alpha = load\ acceleration$
$F_{rms} = Root\ Mean\ Square\ Force = Average\ Continuous\ Force\ Requirement$
$t_1 = acceleration\ time$
$t_2 = run\ time$
$t_3 = deceleration\ time$
$t_4 = dwell\ time\ in\ a\ move\ profile$

$$F_P = F_L + F_F + F_m$$

$$F_m = M_{L+C} \times \alpha$$

$$F_{rms} = \sqrt{\frac{F_P^2 t_1 + (F_L + F_F)^2 t_2 + (F_m - F_L + F_F)^2 t_3}{t_1 + t_2 + t_3 + t_4}}$$

The nature of the application under consideration dictates the information required to properly select an actuator. For example, operating at a fixed force will have a different demand than operating at servo conditions. In general, four parameters will determine actuator selection:

1. Peak force requirement (F_P)
2. RMS force requirement (F_{rms})
3. Linear velocity (*v)*
4. Total stroke/move distance (D)

Peak Force Requirement

Peak force (F_P) is the sum of the force due to load (F_L), friction (F_F), and acceleration of mass (F_m).

Looking at the separate components, the force due to load is the force acting directly against the actuator at all times. For example, a vertically oriented actuator supporting a mass against gravity will always have the force of gravity as a load component (if not supported mechanically). The force due to friction is determined by the mechanical configuration of the complete motion assembly and includes factors such as bearings, grease, linkages, surface-to-surface contacts, etc. Finally, the force due to the acceleration of mass (F_m) is the product of the load mass (M_{L+C}; including the actuator coil) and the load acceleration (α).

RMS Force Requirement

Root-Mean-Square or RMS force (F_{rms}) requirement is used to approximate the average continuous force requirement of an application.

Linear Velocity

Velocity, *v*, is also dictated by the configuration of the mechanical system coupled to the actuator coil and by the type of move that is to be effected. For example, a constant force application would require an actuator with low velocity rating. A point-to-point positioning application would require an actuator with rated velocity higher than the average move velocity. The rated velocity would account for acceleration, deceleration, and run times of the motion profile. The figure below relates rated velocity to average velocity for point-to-point positioning move profiles.

DEFINITIONS

v_{max} = rated operating speed of actuator, in/Sec

v_{TRAP} = average speed of actuator required for a specified trapezoidal move, in/Sec

v_{TRI} = average speed of actuator required for a specified triangular move, in/Sec

D = total distance traveled, by moving coil

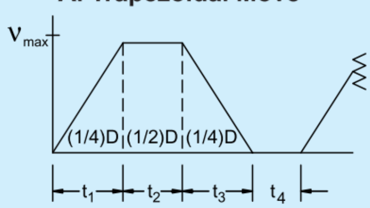
t_1 = acceleration time, seconds

t_2 = run time, seconds

t_3 = deceleration time, seconds

t_4 = dwell time, seconds

A. Trapezoidal Move



i) For acceleration portion of curve:

$$\frac{v_{max} + 0}{2} = (1/4)D/t_1 \qquad v_{max} = D/2t_1$$

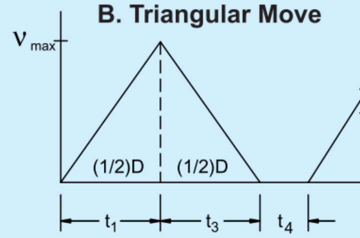
ii) For entire move:

$$v_{TRAP} = [(1/4)D+(1/2)D+(1/4)D]/(t_1+t_2+t_3) = D/3t_1$$

$$\text{iii)}\ \frac{v_{max}}{v_{TRAP}} = \frac{D/2t_1}{D/3t_1} = \frac{3}{2}$$

i.e., $v_{max} = 1.5\ v_{TRAP}$

B. Triangular Move



i) For acceleration portion of curve:

$$\frac{v_{max} + 0}{2} = (1/2)D/t_1 \qquad v_{max} = D/t_1$$

ii) For entire move:

$$v_{TRI} = [(1/4)D+(1/2)D+(1/4)D]/(t_1+t_2+t_3) = D/3t_1$$

$$\text{iii)}\ \frac{v_{max}}{v_{TRI}} = \frac{D/t_1}{D/2t_1} = 2$$

i.e., $v_{max} = 2\ v_{TRI}$

Stroke

Stroke may be specified as the total displacement from one end of travel to the other end, or as a plus/minus (±) displacement from a mid-stroke reference point. Force and stroke usually have an inverse relationship: high-force/short-stroke, low-force/long-stroke.

VCA Calculator

BEI has provided a "VCA Calculator" to be used to select the products they offer. It is found at: http://www.beikimco.com/actuators_linear.php under the "Products" tab.

BEI P/N	Linear VCA													
	Peak Force	Continuous Stall Force	Electrical Time Constant	Actuator Constant	Total Stroke	Operating Stroke	Actuator's Moving Part Mass	Load Moving Mass	Total Moving Mass	Maximum Theoretical Acceleration	Sin. Motion Maximum Theoretical Frequency @ desired stroke (10 sec. Max)	Triang. Motion Maximum Theoretical Frequency @ desired stroke (10 sec. Max)	Sin. Motion Maximum Theoretical Frequency @ desired stroke (cont. opn)	Triang. Motion Maximum Theoretical Frequency @ desired stroke (cont. opn)
	(N)	(N)	(msec)	(N/√watts)	(mm)	(mm)	(g)	(g)	(g)	(m/s^2)	Hertz	Hertz	Hertz	Hertz
LA28-22-000A	266.89	87.74	0.708	13.79	11.43	11.43	230.00	0.0	230.00	1160.4	71.72	79.68	41.12	45.69
LA28-43-000A	266.90	75.60	1.310	13.09	25.00	25.00	610.00	0.0	610.00	437.5	29.78	33.09	15.85	17.61
LA28-43-001A	266.90	75.60	1.310	13.09	25.00	25.00	740.00	0.0	740.00	360.7	27.03	30.04	14.39	15.99
LAH28-52-000A	220.00	75.60	1.310	13.09	25.00	14.00	740.00	0.0	740.00	297.3	32.80	36.44	19.23	21.36
LA30-48-000A	444.82	185.05	1.120	21.80	25.40	25.40	726.00	0.0	726.00	612.7	34.96	38.84	22.55	25.05
LA30-75-001A	444.82	96.24	1.070	17.79	50.80	40.00	680.00	0.0	680.00	654.1	28.78	31.98	13.39	14.88
LA34-37-000A	444.82	127.22	1.267	20.28	19.05	19.05	672.00	0.0	672.00	661.9	41.96	46.62	22.44	24.93
LA43-67-000A	######	282.91	0.485	28.02	31.75	31.75	498.90	0.0	498.90	2763.9	66.41	73.79	30.08	33.42
LA50-65-001Z	######	472.84	1.150	57.83	25.40	25.40	1450.00	0.0	1450.00	689.7	37.09	41.21	25.50	28.34
LA100-90-000A	######	1298.88	4.20	86.29	50.80	50.80	10260.00	0.0	10260.00	238.5	15.42	17.13	11.24	12.48

Selecting The Right Voice Coil

Having reviewed my system requirements, the VCA Application Guide, and VCA Calculator, I am looking for assistance in determining the following:

1. F_L = Force Due to Load
2. F_M = Force due to Acceleration of Mass

With Regards to F_L, the Application Guide defines it as "the force due to load is the force acting directly against the actuator at all times". The guide gives the example of a vertically oriented actuator supporting a mass against gravity as always having the force of gravity as a load component. As my application is horizontally arranged (i.e. no gravity component on actuator), ***is it correct to assume that the Force Due to Load is equal to total force required to achieve my system pressure*** (i.e. $F_T = F_B + F_P$ = 177N as stated above)?

With regards to F_M***, how is it possible to determine the "Load Mass"*** (or "Load Moving Mass" as listed in the VCA calculator); as my system will be in a horizontal arrangement, I need some clarification with this – is there some way to convert between Force due to Load, and "Load Mass"? Likewise, how is it possible to ***determine the acceleration (α) of the load mass for my system***, as it is in a sinusoidal profile.

Finally, as it is in a sinusoid profile, ***how are acceleration and deceleration times determined***?

Any help is hugely appreciated! Thanks!