Forces using LCC

Force and Current limits on LCC

The configuration file contains settings that limit the current and determine how the current values are represented. The most important setting (which you should never change after loading the config file) is the **Motor rated current**. The Motor rated current is expressed in [mA]. All other currents and forces are related to the Motor rated current.
The motor rated current is the current that the motor/actuator can maintain over long periods of time without becoming too hot (@ $T_{ambient}$ = 25^{o}C, not enclosed)

The **Max force** is given in per thousand of Motor rated current. In other words: if the Max force is 3000, the maximum current to generate force will be 3 times the Motor rated current

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The Max force and the Max current have the same value in the config file. In a program you can use this by first setting the max current to a lower value for process purposes and reset it later to its original value by copying the max force value to the max current value.

The **Positive** and **Negative force limit** can be used to provide an force/current limit that is asymmetrical around zero. This can be useful if the actuator is vertical and the moving mass is creating a force downwards. If you want to make a softland that is lower in force than the moving mass, these Positive and Negative force limits can be used to create this. Note that in this case a force offset can help in improving position control.

Example:

Config file is loaded in controller; parameters are shown in tuning tab of SMAC control center

Max force	4833	‰ of rated
Max current	4833	‰ of rated
Positive force limit	4833	‰ of rated
Negative force limit	-4833	‰ of rated
Motor rated current	479	mA

This means that the maximum current through the motor is 479 mA * 4.833 = 2315 mA = 2.3 A. Currents above this value of 2.3 A will not be allowed by the controller. If it is required by the control loop it will be maximised to 2.3 A. Note that the limit that is set with the lowest value will limit the current through the actuator.

Calculate Actuator Forces from LCC Currents

In order to calculate the actual generated force of an actuator the following parameters must be known:

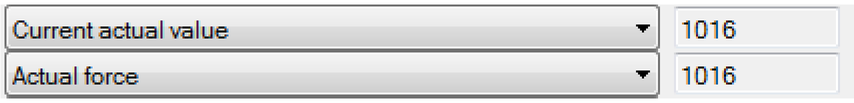
- Motor rated current [mA]
- Measured Actual Current or Measured Actual Force [‰ of rated current]
- Force constant of the actuator [N/A]
- Friction Force and Gravity forces of moving mass.

First step is to determine the measured current. For this you need to multiply the measured actual current or the measured actual force with the motor rated current. Then you multiply this measured current with the force constant in order to know the force generated by the actuator. Part of the force might be used to overcome friction if the force measurement is at a constant speed. Also the gravity forces of the moving mass can affect the actual force value that the actuator gives to your process under test.
Note that the actual current and the actual force contain the same value. They might appear different if the moment of sampling is slightly different.

Example:

The Motor rated current can be found at the Tuning Tab of the Control Center:

The actual current or actual force can be measured in the Run Programs Tab:



The force constant can be found on the motor specification. For this example we take a force constant of 30 N/A.
We take the friction force to be 1N and the moving mass of the actuator plus what is mounted to the shaft is 500 gram (≈ 5 N)
Assume the actuator shaft is moving with the shaft downwards onto an object .

The actual force can be calculated by:
Actual current through actuator = Motor rated current * Actual force
Actual current through actuator = 479 * 1.016 = 487 mA
The Force generated by the actuator = Actual current * force constant
The Force generated by the actuator = 0.487 * 30 = 14.6 N
Since the actuator is helped by the moving mass gravity the force increases with 5N.
Since the friction works against the movement the 1N needs to be reduced.
This results in a force on the object = 14.6 + 5 -1 = 18.6 N

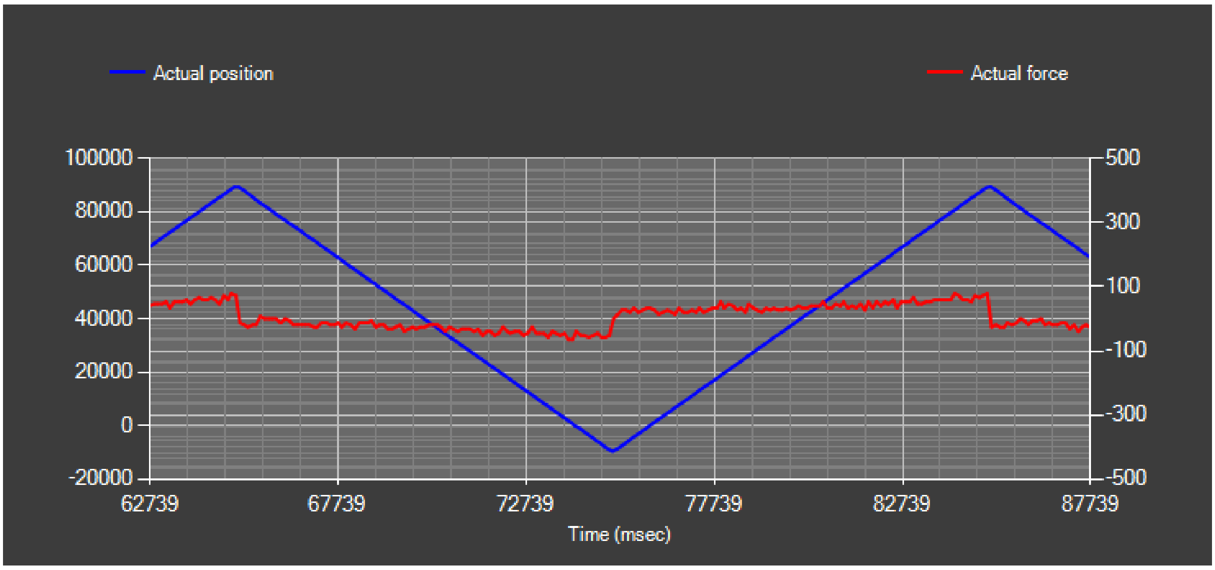
Force Accuracy

The force calculated has a tolerance. This tolerance can be determined by taking the following factors in account.

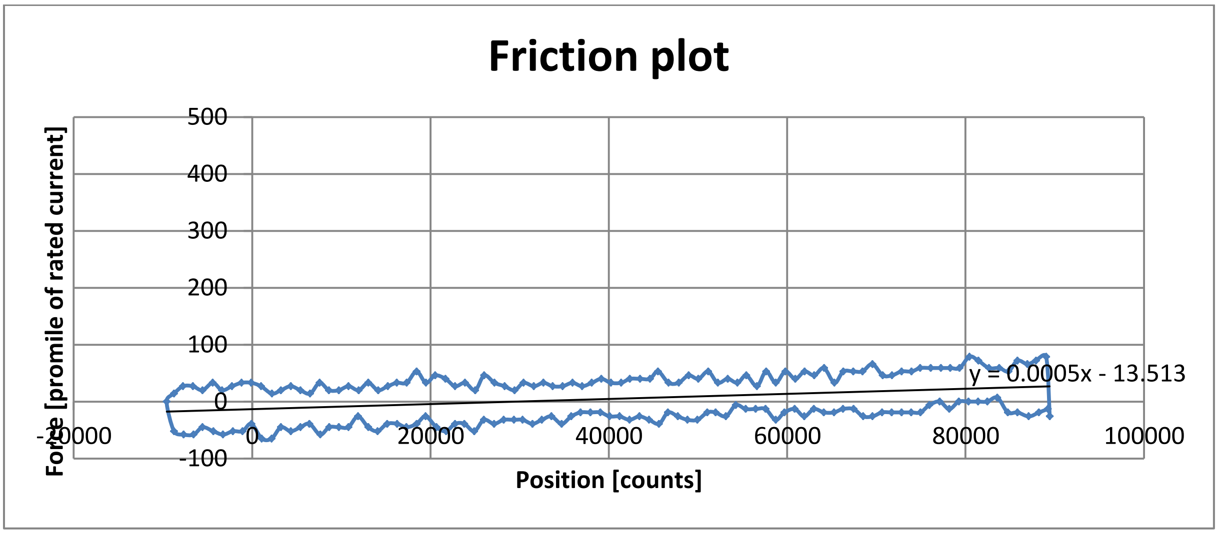
Friction noise
The friction is not always and everywhere the same. The friction can vary from 0 to 1 N for most linear guides used in SMAC's actuators. Note that this variation affects the accuracy only during motion. To identify the friction of an actuator you can use a simple extend and retract repetitive move as shown in the program section below.

0		MacroNumber	1	Repetitive Extrend and Retract move
4	1-1	PositionMove	Absolute,Target=90000,Vel=10000,Acc=,Change_immediate	Extend move to position + 9 mm (with a 0.1 micron encoder)
3	1-2	Wait	Trajectory_generator_ready	
3	1-3	PositionMove	Absolute,Target=-10000,Vel=,Acc=,Change_immediate	Retract move to position -1 mm (with a 0.1 micron encoder)
3	1-4	Wait	Trajectory_generator_ready	
1	1-5	Macro	Repeat,RepeatCount=0	keep repeating this macro

In the run programs tab the position and force can be logged as shown below.



If you then save this log to a .csv file, you can visualise the two variables position and force in an xy-plot as shown in the next page.



The upper blue line is the force required to move to extend and the lower is the force to retract. The fitted line (thin black with the formula y = 0.0005x -13.513) shows the forces required if friction would be 0. The distance to between the fitted line and the blue line is the friction. The average distance between these two lines in this example is 35 ‰ of rated current and the standard deviation is 9 ‰ of rated current. The motor rated current for this actuator is 408 mA and the force constant for this unit is 8N/A (= 8 mN/mA). So the average friction force is 35/1000 * 408 * 8mN = 114 mN = 0.114N. The standard deviation of this unit is 9/1000 *408 *8mN = 30 mN = 0.03N. What you can also see is that there is a slight angle in the force related to the position. This is stiffness inside the actuator which is caused (in this case) by the relatively small radius of the flex cables. The unit in this example is a cross roller demo unit with a 0.1 micron encoder.

At stand still the forces are equal to the fitted line (the friction has almost no influence on the static forces.

Force constant accuracy

Force constant can be is slightly different at different locations. Generally this differs not more than 5% over full stroke for any single pole actuator. The force can be slightly lower at the beginning and the end of stroke. At a single location the force constant is repeatable. Multipole actuators can vary more, ranging up to 2 N for an LCA50 or 1.5 N for an LCA25. This is called force ripple of the multipole actuator. Force ripple has been minimized the firmware 2.x versions.

Accuracy of moving masses

Moving mass can be measured exactly by weighing the moving mass. When the actuator is assembled this is not possible anymore. The best way of weighing moving mass is then to hold the moving part of the actuator vertically onto a scale, move it gradually (constant speed) up and down. You will get two different readings on the scale. The difference between the two readings is twice the friction; the average of the two readings is the moving mass.

Measurement accuracy

The current sensing system of the standard LCC controller has a resolution of 2mA for a single pole actuator and 10mA for a multipole actuator.
If your single pole actuator has a force constant of 30N/A this results in a tolerance of
0.002 * 30 = 0.06 N (6 gram).
If your multipole actuator has the same force constant it would result in a tolerance of
0.01 * 30 = 0.3N (30 gram).

Calibrating a force at a certain position will take away all tolerances but the measurement accuracy. When moving through that position, the friction noise still needs to be accounted for.

Maximum Force of the Actuator

Theoretical the maximum force can be calculated by taking the max current times the force constant. Another theoretical approach is to divide the applied voltage by the resistance of the coil (gives current) and multiply this with the force constant. Both methods result in too optimistic values.

There are a few limiting factors to this theoretical maximum force:

1) The driver of the controller has a certain yield. This yield can be due to threshold voltages of the power bridge or due to the required dead time for switching the PWM. These effects takes care that you lose a few volts for powering the actuator. For the LCC this voltage loss can be 2 to 3 V at 24Vdc supply or 4 to 5 V at 48Vdc supply.
2) The resistance of the coil is dependent of the temperature. The resistance of the coil increases in resistance if the temperature of the coil increases. This effect can rise up to 16% resistance increase (= max force decrease) if the coil gets 40C warmer.
   (R increase = 0.4% per ^{o}C)
3) Magnetic force reduction due to temperature rise. If the magnetic housing rises in temperature for 20 C the magnetic field will reduce by 2%.
   (B decrease = 0.1 % per ^{o}C)

Considering these factors it is safe to calculate the max force using the mentioned theoretical method with a reduction of about 27%