

METHODS FOR DETERMINING AN OPTIMIZED SCALING ACCELERATION VALUE

A motorized system consists of the motor controller, the stage, and the payload to be moved. The theoretical stage acceleration can be calculated based on the motor parameters, motor driver power output capacity, and the mass of the load to be moved. However, the real motion system has an acceleration that is restricted by the motor driver, motor ratings, and motion system limitations. The controller uses this predicted acceleration and acceleration limit to generate a motion profile. This motion profile accomplishes the desired move from point A to point B with a given velocity and acceleration. In the stages.ini file, the parameter for theoretical stage acceleration for brushless and linear motor stages is Scaling Acceleration, and the limited acceleration is the Acceleration Limit.

Finding the correct Scaling Acceleration value enables the motorized stage to perform at an optimized level. It is analogous to calibrating a magnetic compass for the local magnetic declination. If you want to move north (toward the Geographic North Pole) using a magnetic compass, but with only occasional location verification by a more absolute methods (e.g., map, GPS, etc.), then you must first calibrate the direction measurement system. Otherwise, when you check your progress along your planned route, you will need to correct for the deviations from moving towards geographic north.

The Scaling Acceleration parameter indicates the expected system response for a given payload. If the scaling acceleration value does not correspond to the actual value, then the feedback loop system will need to perform extra corrections to best achieve the desired movement. The feedback loop monitors the position during a move and correction signals are needed to match the actual performance of the moving stage with the pre-move calculated motion profile.

The following are three empirical methods for finding the appropriate Scaling Acceleration for a given load. Appendix A presents the theoretical method for determining the Scaling Acceleration and Acceleration Limit based on motor specifications and load characteristics. For Newport stages with linear or brushless motors, reference graphs and formulas are presented in Appendix B.

I. Open loop, current acceleration optimization

If reliable PID parameters are unknown, then first determining the Scaling Acceleration in open loop is necessary. After finding a good value for the parameter, optimize the PID settings. Then, one of the two closed loop Scaling Acceleration optimization methods (sections II and III) can be used to further optimize the Scaling Acceleration value.

In this example, an unknown load is assumed with limited knowledge of the motor parameters. Ideally, the current acceleration will match the setpoint acceleration when the motion system is optimized. An initial scaling acceleration of 75,000 mm/s² was used. Figure 1 shows the current acceleration and setpoint acceleration data that was gathered during a 10 mm move. During the beginning stage acceleration, the setpoint acceleration is 2,500 mm/s², and the current acceleration is approximately 1,000 mm/s². The ratio between the actual and setpoint acceleration values is 0.4. Multiplying the Scaling Acceleration value of 75,000 mm/s² by this ratio yielded a new Scaling Acceleration value of 30,000 mm/s². Figure 2 shows the gathered acceleration values with a Scaling Acceleration of 30,000 mm/s². The performance improved, but more refinement was needed. Figure 3 shows the acceleration values with a Scaling Acceleration of 32,400 mm/s².

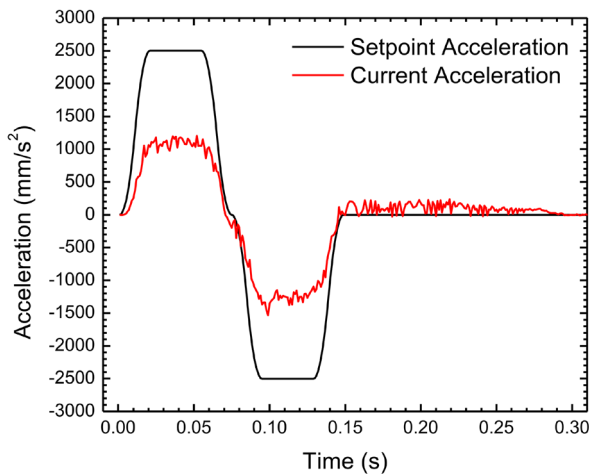


Figure 1. Current acceleration with an initial Scaling Acceleration value of 75,000 mm/s². The value is not optimized

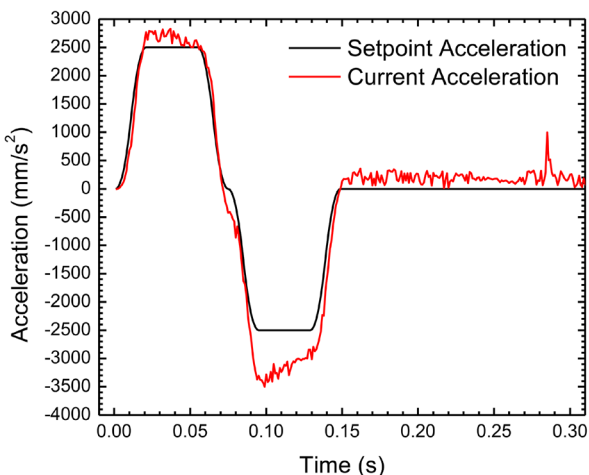


Figure 2. Current acceleration with a Scaling Acceleration value of 30,000 mm/s². The response has improved compared to the initial observation.

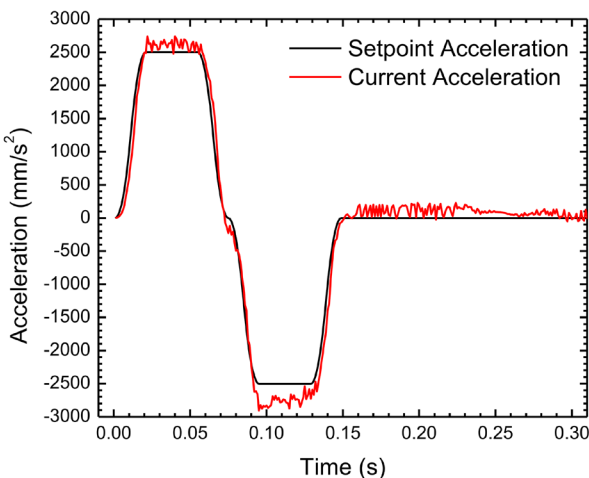


Figure 3. Current acceleration with a Scaling Acceleration value of 32,400 mm/s². The response has improved again when compared to the performance observed in Fig. 2.

Steps:

1. If needed, from the Stage / Modify webpage, set the following parameter for the stage to be optimized,

HomeSearchSequenceType = CurrentPositionAsHome

and reboot the XPS so the parameter is loaded in memory.

2. Navigate to the Tuning tab on the XPS webpage.
3. Verify that the Closed Loop setting = 0.
4. By hand, (if possible), move the stage to the starting position.
5. Initialize the stage.
6. Home the stage.
7. Input or verify that the motion parameters (velocity, acceleration, jerk time, etc.) are correct for the desired move.
8. Configure data gathering for Current Acceleration and Setpoint Acceleration.
9. Configure the gathering number of points and frequency.
10. Move the stage.
11. From the presented data, find a region of time that has constant setpoint acceleration.
12. Calculate the ratio between the current acceleration and the setpoint acceleration and the subsequent new Scaling Acceleration value. If the current acceleration oscillates or is not stable, attempt to determine an average or otherwise expected steady-state value.

$$\text{New_ScalingAccl} = \text{Old_ScalingAccl} * (\text{CurrentAccl} / \text{SetAccl})$$

13. From the Stage / Modify webpage, find the stage of interest and click Modify.

14. In the parameter list, locate ScalingAcceleration = and enter the calculated value. Note: the Acceleration Limit value must be less-than or equal to the Scaling Acceleration value.
15. Reboot the XPS.
16. Goto step 2, and repeat the move-and-gather.
17. Determine if the Scaling Acceleration value is optimized. A reasonable optimization would be a measured Current Acceleration value in the range +/- 5% of the Setpoint Acceleration. If optimized, end the procedure. If not optimized, goto step 11.

II. Closed loop, corrector output optimization

The stage to be optimized was a Newport XMS50. The load on the XMS50 was approximately 6.0 kg. Unless otherwise noted, the movement parameters for the optimization test were velocity = 300 mm/s, acceleration = 2,500 mm/s², minimum and maximum jerk time = 0.02 s, and travel distance = 20 mm.

When the default Scaling Acceleration value of 56,740 mm/s² and a load of 6.0 kg was used, the corrector output for this motion system was unoptimized. Figure 4 shows the corrector output and setpoint acceleration data that was gathered during the 20 mm move. Ideally, the corrector output will match the setpoint acceleration when the motion system is optimized. Here, the XPS detected that the real acceleration did not match the expected acceleration. Therefore, the corrector output does not match the setpoint acceleration. During the initial constant stage acceleration, the setpoint acceleration is 2,500 mm/s², however, the corrector output is approximately 16,000 mm/s². The ratio between the setpoint and corrector output value is 0.156. Multiplying the Scaling Acceleration value of 56,740 mm/s² by this ratio yielded a new Scaling Acceleration value of 8,851 mm/s².

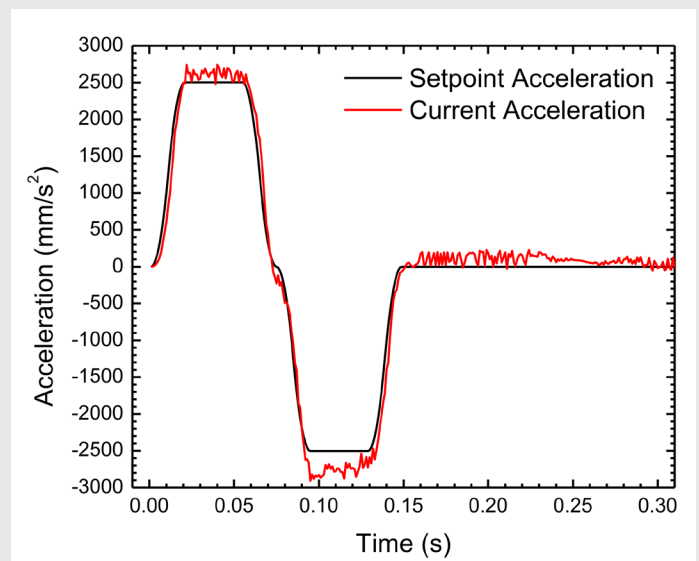


Figure 4. Corrector output with the default Scaling Acceleration value of 56,740 mm/s². The value is not optimized and the system responds wildly.

After entering the newly found Scaling Acceleration value in the stages.ini parameter file, rebooting the XPS, and performing the same move, the gathered data is shown in Figure 5. The new value better corresponds to the actual performance of the motion system.

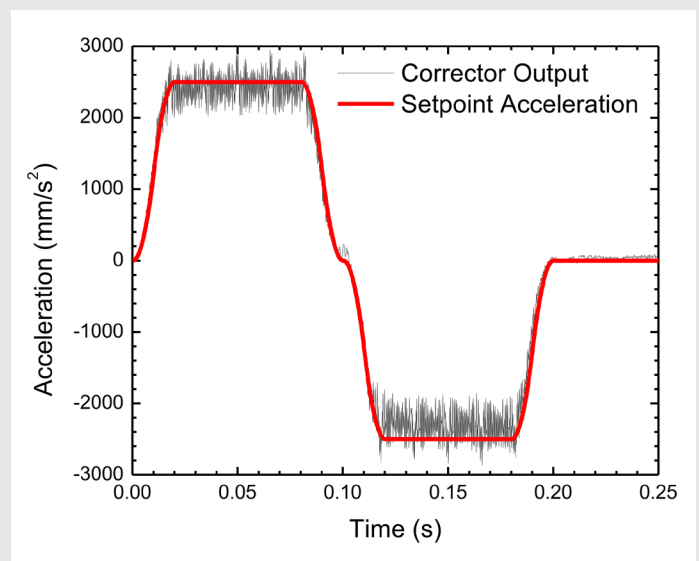


Figure 5. Corrector output with the calculated Scaling Acceleration value of 8,851 mm/s². The value is optimized and the system responds as expected.

Steps:

1. Navigate to the Tuning tab on the XPS webpage.
2. Verify that the Closed Loop setting = 1.
3. Move the stage to the starting position.
4. Input or verify that the motion parameters (velocity, acceleration, jerk time, etc.) are correct for the desired move.
5. Configure data gathering for Corrector Output and Acceleration Setpoint.
6. Configure the gathering number of points and frequency.
7. Move the stage.
8. From the presented data, find a region of time that has constant setpoint acceleration.
9. Calculate the ratio between the setpoint acceleration and the corrector output and the subsequent new Scaling Acceleration value. If the current acceleration oscillates or is not stable, attempt to determine an average or otherwise expected steady-state value.

$$\text{New_ScalingAccl} = \text{Old_ScalingAccl} * (\text{SetAccl} / \text{CorrectorOutput})$$
10. From the Stage / Modify webpage, find the stage of interest and click Modify.
11. In the parameter list, locate Scaling Acceleration = and enter the calculated value. Note: the Acceleration Limit value must be less-than or equal to the Scaling Acceleration value.
12. Reboot the XPS.
13. Goto step 1, and repeat the move-and-gather.
14. Determine if the Scaling Acceleration value is optimized. A reasonable optimization would be a measured Corrector Output value in the range +/- 5% of the Setpoint Acceleration. If optimized, end the procedure. If not optimized, goto step 8.

III. AutoScaling

When the system is close to being optimized, AutoScaling can be used to automatically calculate the Scaling Acceleration value. An example situation would be when the system was previously optimized and the load was changed only a small amount.

Steps:

1. Navigate to the Tuning tab on the XPS webpage.
2. Click on AutoScaling button. Note, if the stage was previously initialized, kill the initialization first.
3. Determine if the calculated value is consistent with the change in load (more load decreases the scaling acceleration value and vice-versa).
4. Save if desired.
5. Use gathering as described in the closed loop section to verify the optimization.

Appendix A: Scaling Acceleration and Acceleration Limit theoretical calculations

Scaling Acceleration is the theoretical maximum stage acceleration when a full 10 V signal is input to the motor driver. The value can be calculated initially for the no-friction case with the equation,

$$\text{ScalingAcceleration} = \frac{1}{\sqrt{2}} * \frac{\text{MotorForceConst} * 10 * \text{TransimpedanceDriver}}{\text{Mcar} + \text{Load}}$$

- 1) MotorForce Constant: A specification provided by the motor manufacturer. The units are specified as Newtons/Amp. (Current in Amps is the RMS value).
- 2) TransImpedance Driver: A characteristic of the driver card. For the XPS-DRV02, the value is 0.5 Amp/Volt.
- 3) Mcar: Mass of the carriage. The units are specified in kg. The carriage is defined as the part of the stage that moves and can carry a Load.
- 4) Load: User-supplied payload on the stage's carriage. The units are specified in kg.

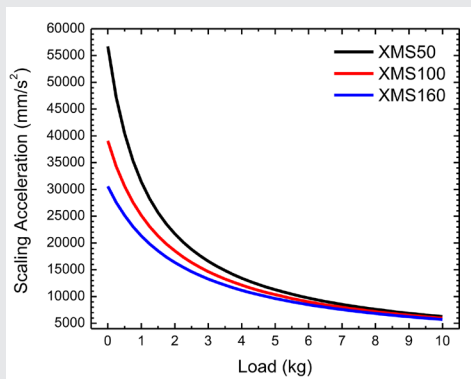
Note: The equation will result in m/s² as the units for linear stages. However, the XPS units is typically mm/s².

Acceleration Limit is the maximum allowed stage acceleration determined by the stage's safe operating parameters. This limit prevents overheating and other dynamic errors. The value is defined for direct drive stages by the equation,

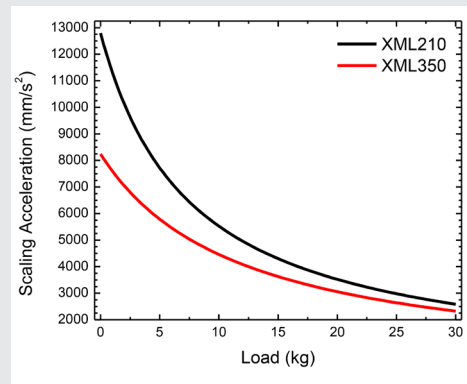
$$AccelerationLimit = ScalingAcceleration * \frac{StagePeakCurrent}{MaxDriverCurrent} * 0.95$$

- 1) Scaling Acceleration: The previously determined scaling acceleration value (above). The units are mm/s².
- 2) MaxDriverCurrent (Imax): A characteristic of the driver card. 5 Amps for XPS-DRV02 and 6.4 Amps for XPS-DRV11.
- 3) StagePeakCurrent: A maximum safe current supplied to the motor. The units are specified in Amps.

Appendix B: Scaling Acceleration value formulas and calculated graphs for Newport stages used with the XPS-DRV02 driver card. If a different driver card is used, scale the determined value by the factor Imax / 5 Amp where Imax is the maximum current output from your driver card. L represents the added load (kg).



$$\begin{aligned} \text{XMS50} \\ SA &= \frac{70,357 \text{ mm}}{L + 1.24 \text{ s}^2} \\ \text{XMS100} \\ SA &= \frac{70,357 \text{ mm}}{L + 1.80 \text{ s}^2} \\ \text{XMS160} \\ SA &= \frac{70,357 \text{ mm}}{L + 2.3 \text{ s}^2} \end{aligned}$$

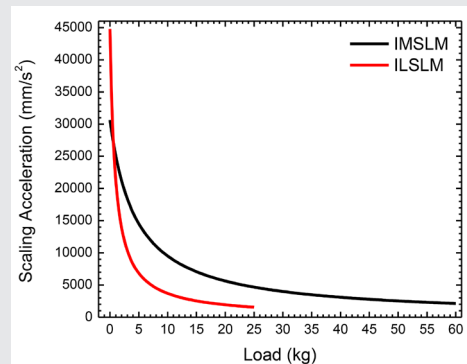


$$\begin{aligned} \text{XML210} \\ SA &= \frac{97,227 \text{ mm}}{L + 7.6 \text{ s}^2} \\ \text{XML350} \\ SA &= \frac{97,227 \text{ mm}}{L + 11.8 \text{ s}^2} \end{aligned}$$

If the XPS-DRV02 driver card is not used, then scale the calculated value by the factor Imax / 5 Amp where Imax is the maximum current output from your motor driver.

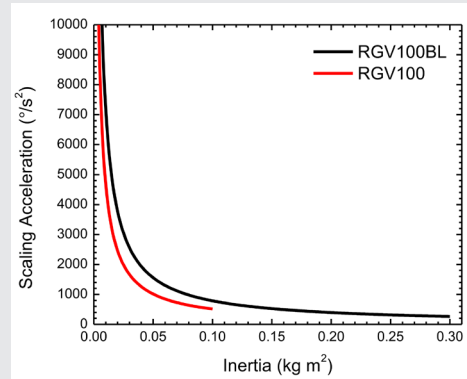
Figure 6. Calculated Scaling Acceleration (SA) values for different loads (L) for the XMS and XML series of linear stages with the XPS-DRV02 driver card.

Figure 8. Calculated Scaling Acceleration (SA) values for different inertial payloads (I) for the RGV series of rotation stages with the XPS-DRV02 driver card



$$\begin{aligned} \text{IMSLM} \\ SA &= \frac{137,534 \text{ mm}}{(L + 4.5) \text{ s}^2} \\ \text{ILSLM} \\ SA &= \frac{40,305 \text{ mm}}{(L + 0.9) \text{ s}^2} \end{aligned}$$

Figure 7. Calculated Scaling Acceleration (SA) values for different loads (L) for the IMS and ILS Linear Motor series of linear stages with the XPS-DRV02 driver card.



$$\begin{aligned} \text{RGV100BL} \\ SA &= \frac{83.652}{I + 0.001035 \text{ s}^2} \\ \text{RGV100} \\ SA &= \frac{51.74}{I + 0.001035 \text{ s}^2} \end{aligned}$$

If the XPS-DRV02 driver card is not used, then scale the calculated value by the factor Imax / 5 Amp where Imax is the maximum current output from your motor driver.

Figure 8. Calculated Scaling Acceleration (SA) values for different inertial payloads (I) for the RGV series of rotation stages with the XPS-DRV02 driver card

Addendum -

List of Scaling Acceleration and Acceleration Limit formulas

To ease the process of deriving Scaling Acceleration (SA) and Acceleration Limit (AL) parameters described above, we came up with ready to go formulas.

All that is needed is to plug in the payload value instead of L parameter:

IDL-LM Family

IDL165 @ XPS-DRV02P

$$SA = \frac{77,711 \text{ mm}}{L + 2.5 \text{ s}^2}, AL = 0.8686 * SA$$

IDL165 @ XPS-EDBL

$$SA = \frac{277,540 \text{ mm}}{L + 2.5 \text{ s}^2}, AL = 0.2432 * SA$$

IDL225 @ XPS-DRV02P

$$SA = \frac{155,424 \text{ mm}}{L + 7 \text{ s}^2}, AL = 0.8686 * SA$$

IDL225 @ XPS-EDBL

$$SA = \frac{555,085 \text{ mm}}{L + 7 \text{ s}^2}, AL = 0.2432 * SA$$

IDL280 @ XPS-DRV02P

$$SA = \frac{237,896 \text{ mm}}{L + 10.8 \text{ s}^2}, AL = 0.95 * SA$$

IDL280 @ XPS-EDBL

$$SA = \frac{848,535 \text{ mm}}{L + 10.8 \text{ s}^2}, AL = 0.266 * SA$$

IDL560 @ XPS-DRV02P

$$SA = \frac{389,054 \text{ mm}}{L + 25.6 \text{ s}^2}, AL = 0.95 * SA$$

IDL560 @ XPS-EDBL

$$SA = \frac{1,389,480,535 \text{ mm}}{L + 25.6 \text{ s}^2}, AL = 0.266 * SA$$

MLT Family

MLT25 @ XPS-DRV11

$$SA = \frac{25000}{0.5 + L}, AL = 0.98 * SA$$

MLT50 @ XPS-DRV11

$$SA = \frac{25000}{0.6 + L}, AL = 0.98 * SA$$

MLT100 @ XPS-DRV11

$$SA = \frac{25000}{0.8 + L}, AL = 0.98 * SA$$

MLT200 @ XPS-DRV11

$$SA = \frac{25000}{1.3 + L}, AL = 0.98 * SA$$

MLT250 @ XPS-DRV11

$$SA = \frac{25000}{1.6 + L}, AL = 0.98 * SA$$

ILS-LM Family

ILS-LM@XPS-DRV02

$$SA = \frac{40,305 \text{ mm}}{L + 0.9 \text{ s}^2}, AL = 0.741 * SA$$

IMS-LM Family

IMS-LM@XPS-DRV02

$$SA = \frac{137,534 \text{ mm}}{L + 4.5 \text{ s}^2}, AL = 0.95 * SA$$

XM Family

XMS50@XPS-DRV02

$$SA = \frac{70,357 \text{ mm}}{L + 1.24 \text{ s}^2}, AL = 0.4769 * SA$$

XMS100@XPS-DRV02

$$SA = \frac{70,357 \text{ mm}}{L + 1.8 \text{ s}^2}, AL = 0.4769 * SA$$

XMS160@XPS-DRV02

$$SA = \frac{70,357 \text{ mm}}{L + 2.3 \text{ s}^2}, AL = 0.4769 * SA$$

XML210@XPS-DRV02

$$SA = \frac{97,227 \text{ mm}}{L + 7.6 \text{ s}^2}, AL = 0.7942 * SA$$

XML350 @XPS-DRV02

$$SA = \frac{97,227 \text{ mm}}{L + 11.8 \text{ s}^2}, AL = 0.7942 * SA$$

RGV Family

RGV100BL @XPS-DRV02

$$SA = \frac{83.865}{L + 0.001035} \frac{dg}{s^2}, AL = 0.57 * SA$$

RGV100HL@XPS-DRV02

$$SA = \frac{301.835}{L + 0.001234} \frac{dg}{s^2}, AL = 0.5244 * SA$$

RGV160BL @XPS-EDBL

$$SA = \frac{2240.465}{L + 0.02411} \frac{dg}{s^2}, AL = 0.5054 * SA$$

RGA Family

RGA150 @ XPS-DRV11

$$SA = \frac{277.441}{0.00622 + L}, AL = 0.8906 * SA$$

Notes:

1. If using XPS-DRV11, multiply the calculated SA and AL values by a factor of 1.28 (Imax/5Amp=6.4/5=1.28), except MLT and RGA families.
2. Please contact Newport division of MKS Instruments for further assistance , if the specific Stage@drivercard combination you are using is not listed in this document.

