Motion System Load Capacity

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Abstract
This application note offers a general discussion of the factors determining the maximum load controllable by a SmarAct motion system and provides support information for the load data presented in the motion system specific datasheets. In particular, factors that are determined by the load are elaborated followed by a discussion of the influence of the operating conditions of the motion system such as a non-horizontal mounting of the system.
Keywords
load, load mounting position, operating conditions, tilted motion system

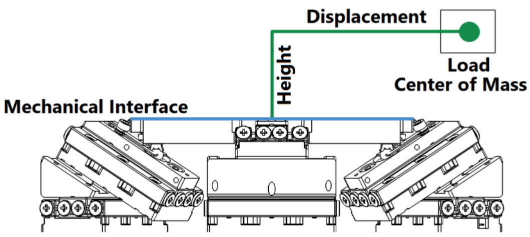

Figure 1. *The center of mass of the load is not centered at the mechanical interface of the motion system but is displaced and at a certain height.*

1. INTRODUCTION

The maximum load (referred to as load in the following) that can be controlled by a motion system depends on the mass of the load, the load distribution, and the operating conditions of the motion system. Here, load control refers to the entire accessible workspace of the motion system, i.e. if the load is supported then all poses (position and orientation) reachable by the mechanical interface of the motion system are supported.
Please note that the load simulation data shown in this application note and related load capacity datasheets represent a conservative estimation of the system's performance. In practice, the maximum load is given in the technical datasheet for each system, but also depends on the pose of the mechanical interface and the trajectory driven by the motion system as well as operating parameters such as closed loop control frequency (CLF) and velocity.
Typically, the load is not mounted at the center of the mechanical interface of the motion system, but is located at a certain distance, both horizontally (displacement) and vertically (height) from the mechanical interfaces center. This is illustrated in Figure 1 and the influence of a non-centered mounting will be discussed in section 2.
In this application note, the discussion is restricted to quasi-static situations i.e. the situation when the system is moving at very low velocities with a small closed loop control frequency so that dynamic effects (effects related to velocity and acceleration) are not relevant. However, in practice, higher velocities and closed loop control frequency are often possible see section 3. Therefore, the load can be treated as a point mass at the center of geometry of the load and the consideration of the moment of inertia is not required. Accordingly, throughout this application note, the load mounting position always refers to the position of the center of mass of the load with respect to the center of the mechanical interface of the motions system. In addition, we assume that no other external forces other than gravity are applied to the load.
In addition to the load mounting position, the operating conditions of the motion system (like atmospheric conditions and the mentioned positioner velocities and closed loop control frequency) are relevant influence factors for the maximum load controllable. A non-horizontal mounting of the motion system is a relevant factor as well. These aspects are discussed in section 3.
In this application note, a variant of the SmarPod 110.45 is discussed as the primary motion system example. However, in general, the results presented here apply to other SmarAct motion systems as well. Nonetheless, some considerations are specific to parallel kinematics motion systems with a three tower/three ball joint configuration shown in Figure 2 and Figure 7 with an exemplary SmarPod 110.45. The relevant mechanical components of such a configuration are discussed in the following subsection. For motion systems that do not feature this configuration the following subsection and all references to towers and ball joints can be ignored.

1.1 Common Motion System Components

Many parallel kinematics SmarAct motion systems (for example SmarPods and TriPods) consists of three towers which are a serial combination of active positioners and passive guideways with a ball joint at the end of each kinematic chain. The ball joints typically connect to the top plate of the motion system.

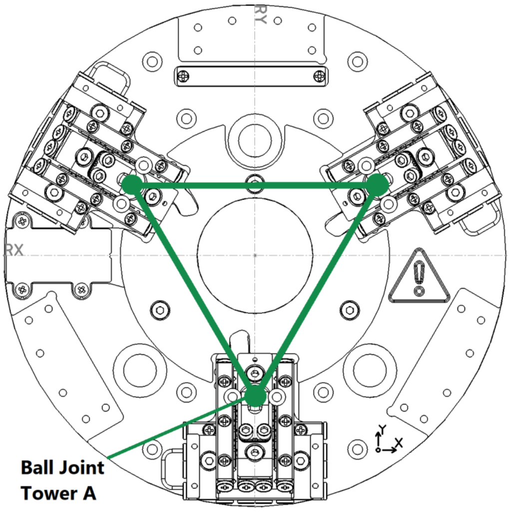

Figure 2. *Triangle formed by three ball joints which is a common configuration in many SmarAct motion systems.*

From a mechanical perspective, two main components of the motion system determine the load supported: The first is the force that can be generated by the positioners and the second is the force excerted on the three ball joints, see Figure 2. Here, the force on each ball joints should not exceed a certain joint type specific threshold.
In general, both factors limit the system in different situations: While for a load close to the center of the mechanical interface e.g. within the triangle formed by the supporting ball joints (shown in Figure 2) the positioner forces are the limiting factor (except for large heights) whereas for large displacements the ball joint limits are usually most restrictive.

2. LOAD MOUNTING POSITION

In this section, relevant load mounting position aspects are discussed for a motion system that is mounted horizontally.

2.1 Horizontal Load Displacement

The supported load mounting position can be visualized in a characteristic top view load capacity profile of the motion system for a fixed height. Here, top view refers to the motion systems mechanical interface in the zero pose, i.e. if the system is mounted non-horizontally (discussed in subsection 3.2) the view perspective remains the same. A typical load capacity profile is shown in Figure 3 where the lines indicate the valid load position area within which a load with a certain mass can be controlled by the motion system for the respective height.
As expected, the load area becomes smaller as the mass increases. In addition, the shape of the load capacity profile changes for 500g mass. This reflects the change in the limiting mechanical factor from ball joints to positioners, see subsection 1.1.

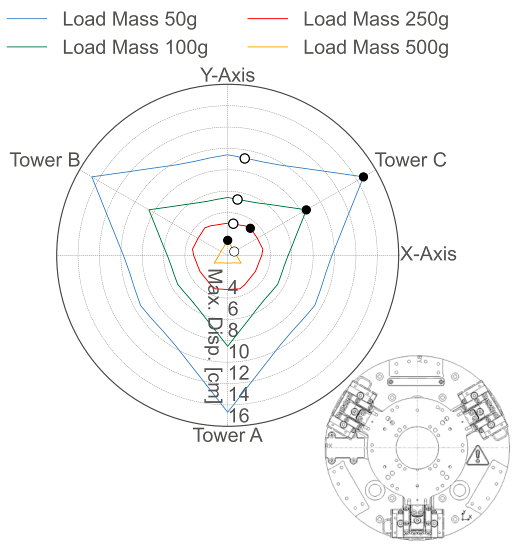

Figure 3. *Exemplary load capacity profile for a SmarPod 110.45. The load is at the height of the mechanical interface (height 0cm). For each mass an exemplary maximum (filled black dot) and minimum (hollow dot) are marked.*

It should be emphasized that the load capacity profile can look differently for different motion systems. An example load capacity profile for a SmarPod P-SLC-17 is shown in Figure 4. The most striking difference is the different triangle shape which is caused by the different ball joint arrangement.

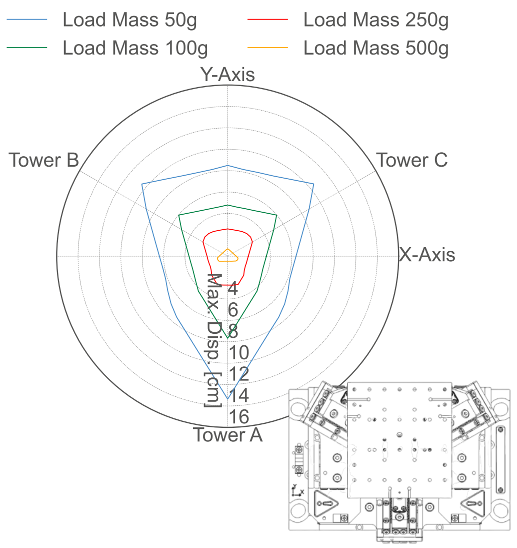

Figure 4. *Exemplary load capacity profile for a SmarPod P-SLC-17. The load is at the height of the mechanical interface (height 0cm).*

2.2 Load Height

Beside the specific motion system, the load height is a decisive factor as well, as Figure 5 reveals. This figure shows the identical situation as Figure 3, except that the load is at height 5cm with respect to the mechanical interface.

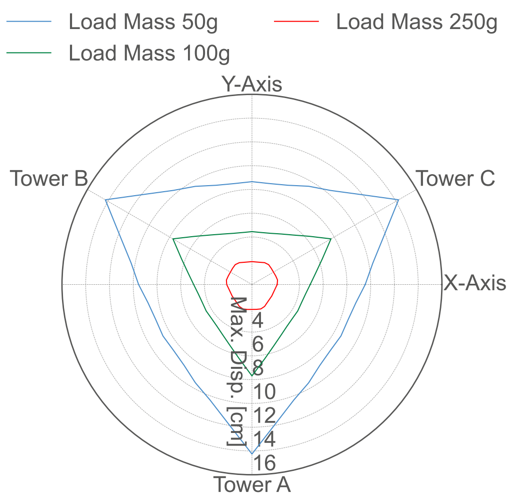

Figure 5. *Exemplary load capacity profile for a SmarPod 110.45. The load is at height 5cm with respect to the mechanical interface.*

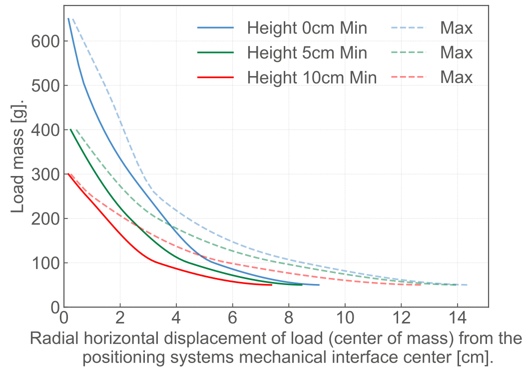

Figure 6. *Exemplary minimum and maximum load displacements for a SmarPod 110.45 for multiple masses and load heights (0,5, and 10cm). In Figure 3 the load displacement direction angles of the minima and maxima for the load height 0cm are shown for comparision.*

Compared to Figure 3, an overall reduced load capacity is found, in fact, the 500g load no longer controllable at this height. In addition, the shape of the load capacity profile changes slightly.
For multiple load heights, load capacity profiles obtained at different heights can be summarized in a plot where only the minimum and maximum possible displacement (taken over all load displacement direction angles) of the load are shown with respect to the center of the mechanical interface of the motion system. An example of such a plot is shown in Figure 6. It should be emphasized, that the load displacement direction angle for the minimum and maximum is in general a function of the load height and mass. For example, in Figure 3 a maximum is at a load displacement direction angle (counter-clockwise with respect to the X-Axis) at 30° for 50g, but at 90°for 500g. This change is a result of the fact that for higher masses the positioners become the limiting factor instead of the joints.

3. OPERATING CONDITIONS

In this section, the load capacity influence factors that are determined by the motion system are discussed, starting with a subsection on the general motion system operating conditions. The following subsection provides an analysis of the load capacity for tilted motion systems.

3.1 General operating conditions

In order for the load data presented in the motion systems datasheet to apply, the motion systems operating conditions are required to be within the positioner specifications which can be found in chapter 6 in [1] and an in depth discussion of the load influence on an individual positioner is available in Application Note 58 [2].
For motion systems the following aspects are of particular importance:

- The motion system should be in the range from standard atmospheric conditions to high vacuum conditions.
- In particular, the load data provided in the specification datasheet does not apply to cryogenic or ultra-high vacuum conditions, please do not hesitate to contact us if you require information for these application scenarios.
- Prolonged system movement generates heat in the positioners which needs to be considered, in particular in vacuum conditions, see [1].
- The velocity and closed loop control frequency of the motion system are required to be within the limits specified in the specific motion system test report for selected movements. Keep in mind that in general the load data provided in the datasheets applies to a quasi-static situation in general. Therefore, when an untested movement is performed it may be required to reduce the velocity, in particular, if the movement involves high acceleration forces. Please do not hesitate to contact us if you require information for your individual application.
- The motion system tilt should not exceed one degree in any direction, see the next section where the effect of the motion system tilt on the load capacity is discussed.

3.2 Motion System Tilt

SmarAct standard systems have been specified for horizontal operating conditions, either in bottom-up or upside-down configuration. A mounting that is not perfectly horizontal will lead to tilt angles of the overall motion system which will impact the resulting load capacity profiles.
Therefore, this subsection provides a discussion of the load capacity for a tilted motion system with a

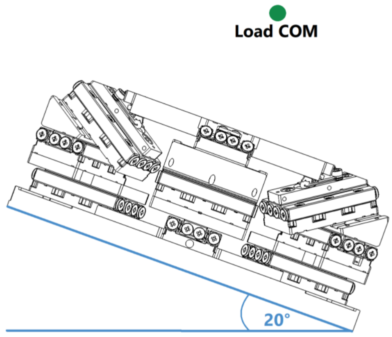

Figure 7. *A SmarPod 110.45 tilted 20° around the Y-Axis with a load at 5cm height.*

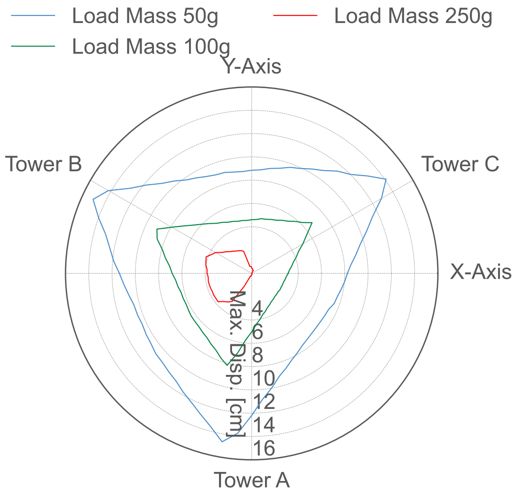

Figure 8. *Exemplary load capacity profile for a SmarPod 110.45 tilted 20° around the Y-Axis with a load at height 5cm with respect to the mechanical interface.*

load that is at non-zero height with respect to the mechanical interfaces center.
Figure 7 illustrates a motion system tilt of 20° around the Y-Axis with 5cm load height. The corresponding load capacity profile for this situation is shown in Figure 8.
It can be seen that there is a significant change in the load capacity profile compared to the load capacity profile of the system mounted horizontally, shown in Figure 3: The three main effects are:

- The load capacity profile is no longer symmetric.
- The load capacity profile is no longer centered at the mechanical interfaces center.
- The 500g load is no longer supported, as in Figure 5.

In addition to the degree of the system tilt, the tilt direction is a decisive factor. In general, the motion system should be mounted so that the most powerful side (a side with two towers, when using a motion system according to subsection 1.1) is elevated. However, as the significant changes in the load capacity profile in Figure 8 emphasize: The load is highly sensitive to motion systems tilt parameters, which makes an individual consideration of the specific situation recommended.

RECOMMENDATIONS

If your application requires an extended load range, the use of a counterweight can be considered if the ball joint limits are the restrictive factor for the load. This requires the total load (load and counterweight) to be within specifications.
Otherwise, the load capacity profile of a motion system can be designed to meet specific application requirements, for example, by the use of constant force springs, special tower and positioner alignments, repositioning of the mechanical interface, or, special ball joints. Application possibilities include motion systems for upside-down use or with a large system tilt, which includes systems mounted side-ways.
Please do not hesitate to contact us for specific information for your individual application requirements.

REFERENCES

[1] SmarAct GmbH. Stick-slip positioners assembly instructions. *Manual*.

[2] SmarAct GmbH. Influence of load in the direction of motion on linear stick-slip positioners. *Applicaton Note*, 58.

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