QuickStick Repeatability Analysis

Purpose

This application note presents the variables that can affect the repeatability of positioning using a QuickStick system.

Introduction

Repeatability and accuracy are almost universally considered to be important attributes of any precision electro-motive system. The goal of this document is to provide information on how to design a track to optimize the repeatability of the Quickstick (QS) LSM. Throughout this document repeatability and accuracy are defined as follows:

> Repeatability – the tolerance within which the system will repeat a position
> Accuracy – the tolerance from the ordered position the system achieves

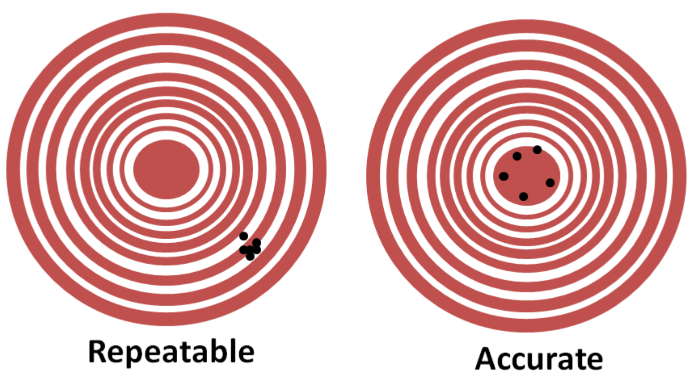

Figure 1: Repeatability and Accuracy

Within this document, we will consider both of these characteristics as internal to the system. This means that all distances are taken relative to the location commanded in software or to a point on the track. This can only be used in reference to an external reference point if the ordered location has already been determined experimentally and the system is fixed relative to the reference point. Repeatability is considered bi-directionally, with vehicles arriving from both directions being considered.

Repeatability and accuracy are key factors in many applications, especially those involving interactions with other machines. In many applications the repeatability is more important than accuracy since the accuracy of a high repeatability system can be improved by applying fixed adjustments to the motion command. For this reason, it is very useful to be able to determine how closely the vehicle can repeat a move to a position. Hence, the remainder of this document will focus on repeatability. There are two factors in determining the repeatability of movements on a system: the capabilities of the motors and the hardware configuration of the track.

The capabilities of the motor are the same on any track. Quick Stick motors employ Hall Effect Sensor (HES) technology for position feedback. The HES implementation has a theoretical resolution of less than one micron and a practical resolution of two microns when measurement noise is considered. In an ideal system, i.e. with no track to vehicle interaction, this is the positional repeatability for any single magnet array or vehicle to that position. The velocity accuracy has a theoretical resolution of less than 1 mm/s.

The hardware characteristics of the track are what determine the actual repeatability. Hardware selection can affect both positional repeatability and velocity variation for movements within a system. We will examine the effects of:

1. Friction
2. Guidance system selection
3. Vehicle construction tolerances
4. Track construction discrepancies
5. Track Rigidity
6. Payload
7. Motor Spacing

Static and Dynamic Friction

The difference between static and dynamic friction can induce variations in positioning. Dynamic friction determines the amount of force needed to keep the vehicle moving at a constant speed. Static friction determines the force necessary to start moving a vehicle from rest. In certain systems, the static friction can be significantly larger than the dynamic friction. This means that when starting or stopping, the two actions that determine repeatability, there is already a friction variation inherent in the system.

In a closed-loop system such as QS with PID controller, friction affects accuracy and repeatability by introduction of non-linearity into the servo system. In general higher degrees of system non-linearity require higher servo bandwidth from the PID controller which is employed in the QS control system if the same level of motion accuracy and repeatability performance is required. Variations in friction within the system will make it more difficult to tune for optimal repeatability.

As the friction in your system approaches the thrust limit of your motor, the consistency of the friction of your system plays a larger role. As the thrust produced by the motor is needed to both overcome friction and accelerate the vehicle, increasing the amount of thrust required to overcome friction will decrease the amount available for the quick acceleration needed for exactly positioning the vehicle. Therefore variations in friction near the high limit of the motor can result in insufficient thrust being available for fine vehicle positioning.

The following actions can compensate for friction and increase repeatability:

1. Tune the PID controller of your system for the friction that is present. A properly tuned system will result in improved repeatability.
2. Minimize static and dynamic friction. This will increase thrust available for dynamic adjustment and reduce the thrust requirements to break the hold of static friction, which makes tuning significantly easier. In the case of a theoretically perfect guidance system with no friction, the control loop would result in positional repeatability equal to the resolution of the motor.
3. Minimize the difference between static and dynamic friction. This will help ensure the friction remains constant even when approaching a stop. Using pre-loaded bearings can aid in this and keep friction curves smoother.
4. If not possible, keep dynamic friction consistent. This will ensure that the PID controller can be tuned far more exactly as it needs to account for less variation in thrust requirements.

Guidance System Selection

There are a variety of guidance systems that can be used to support a vehicle relative to the motors. These include many permutations of wheels on rails, a flat platform on rollers, a surface sliding on another surface, maglev, air tables, or many other options. The selection of a guidance system affects the friction present in a system. For example, a guidance system utilizing wheels and rails has a lower coefficient of friction than a surface sliding on another surface. This leaves more thrust available for precise vehicle control as noted in the previous section. The guidance system also affects the consistency of the friction applied.

As an example, consider a system using rails as opposed to a system using a flat platform riding on rollers.

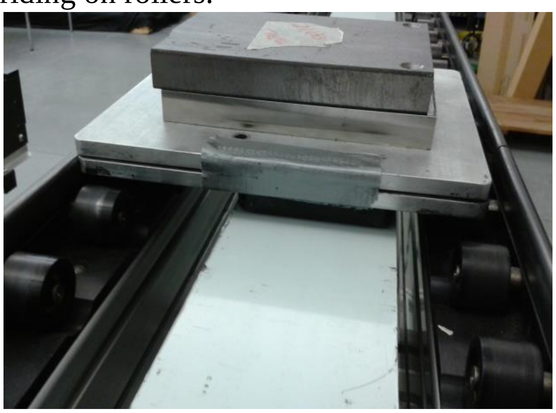

Figure 2: A Roller Based Guidance System

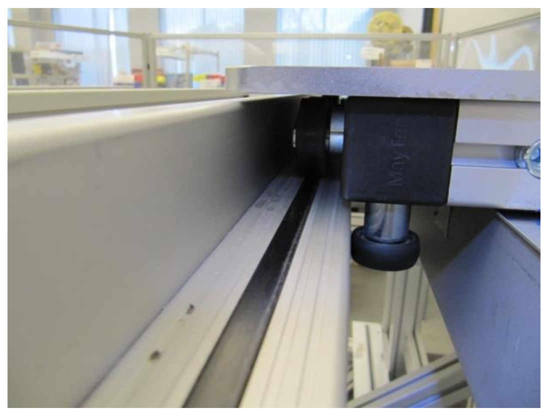

Figure 3: A Wheel and Rail Guidance System

The system using wheels on rails continuously experiences a more consistent friction. In the system using rollers, the vehicle intermittently impacts stopped rollers and is riding on different numbers of rollers at different times, resulting in changing friction and degrading repeatability.

The guidance system can also create settling points, which are areas where a vehicle will prefer to stop. These could be a gap between rails, a joint in a surface, or an area with higher than average friction as examples. If one of these areas is near a station, a vehicle might tend to settle into it, degrading repeatability.

Vehicle Construction Tolerances

In a system with multiple vehicles, differences between vehicles can affect repeatability. While the system may be calibrated using one vehicle, that one vehicle used for tuning or calibration may locate its payload differently than every other vehicle on the track. This is because design tolerances between the magnet array and the payload can affect the position of the payload relative to external tooling. These differences between vehicles can be noted and compensated for, either in hardware using a vehicle with an adjustable payload position or in software using a look-up table and slight variations in position orders based on which vehicle is being ordered.

Track Construction Discrepancies

Bumps in the rails, misaligned rails, loose bolts, and many other construction defects can affect the repeatability in a number of ways. An inconsistent track will produce inconsistent results.

Track Rigidity

The rigidity of the track becomes a factor when examining vibrations. Vehicles moving on a track will create vibrations. The magnitude of these vibrations can depend on vehicle weight, the interface with the track, and the dynamics of the maneuvers being performed. The vibrations can cause the entire track to shift, resulting in movement of a vehicle relative to the environment, even if the vehicle remains stationary relative to the track. If the track is sufficiently rigid or damped, these vibrations can be reduced.

Payload

The payload can affect the repeatability of the system in a number of ways. For example, a heavy payload reduces the linear dynamic range of the servo drive system, resulting in slower and less predictable responses which may lead to reduced motion repeatability. Payload also increases the effects of friction, as the coefficient of friction is multiplied by the weight of the vehicle. This means that a larger payload will be more sensitive to variations in friction.

Increasing the payload also reduces the control system sensitivities to force disturbance. With everything else being equal, this results in smoother motion and better positioning repeatability provided the system has the thrust needed to control the larger payload. In practice, achieving optimal repeatability performance requires trade-offs among payload, rail characteristics, and servo turning.

Motor Spacing

On the QuickStick Motors, reduced repeatability at the motor spacing is expected due to disruption in drive patterns. For this reason, it is preferable to have all repeatability critical operations occurring with full magnet array coverage over a motor, rather than over a space.

Summary

The track and vehicle construction play a very large role in the actual repeatability that a system can achieve. The same motors can have different motion quality on different tracks and from vehicle to vehicle. The best way to determine a system's movement characteristics is to build a prototype section of the type of track that will be used and test the vehicle on that prototype. This can help determine the effects of the bearing type, track material, motor spacing, and vehicle construction on repeatability.

Appendix 1: Example Data

On a system used at MagneMotion for testing, servo repeatability of less than 0.5 mm was achieved. When the PID function controlling positioning was tuned to the specific movement and the specific payload being transported, servo repeatability of less than 0.2mm was achieved.

The track for the system consisted of aluminum extrusion, attached together with T-nuts. The guidance method used was rubber wheels on riding on the aluminum extrusion. The entire rail for the observed path was a single piece of extruded aluminum with no joints. Horizontally oriented bearings with rubber wheels provided lateral guidance. The vehicles weighed roughly 7kg. Pictures of the vehicle and track are shown below.

Figure 4: Example System

Figure 5: Example Rails

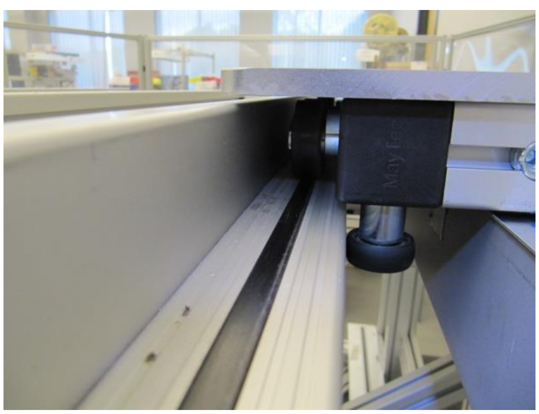

Figure 6: Example Guidance System

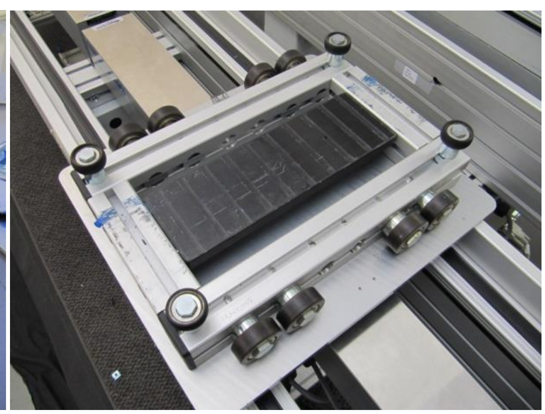

Figure 7: Example Vehicle

More Information
MagneMotion website: www.magnemotion.com
Questions & Comments: http://www.magnemotion.com/about-magnemotion/contact.cfm