Linear Synchronous Motor Repeatability Tests

by

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Linear Synchronous Motor Repeatability Tests (U)

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EXECUTIVE SUMMARY

A cart system using linear synchronous motors is being considered for use in the material transport system to transport material between and within gloveboxes in the Modern Pit Facility (MPF). The only moving parts in this system are the cart itself and the wheels on the cart. The only components inside containment are two magnet arrays, the cart and the wheels. The linear motor primaries are located outside containment. This makes the linear synchronous motor system very desirable from a maintenance standpoint. One of the important characteristics of a transport system is its repeatability. In the case of a cart in a transport system, repeatability is the variability in positioning when the cart is moved to a specific position. A cart system using linear synchronous motors has been installed in the Savannah River Technology Center. This system was tested to determine its repeatability.

The tests determined that the repeatability for the linear synchronous motor cart system when stopping on the center of a motor with a range of gross weight from 125 to 675 lbs. was $\pm$ 0.073 inches ($\pm$1.8 mm). This is excellent repeatability for a cart carrying such a wide range of loads. This repeatability can be improved to $\pm$0.028 inches ($\pm$0.7 mm), if the load stops at a position completely on a motor unit and always approaches the point from a fixed distance from the same direction.

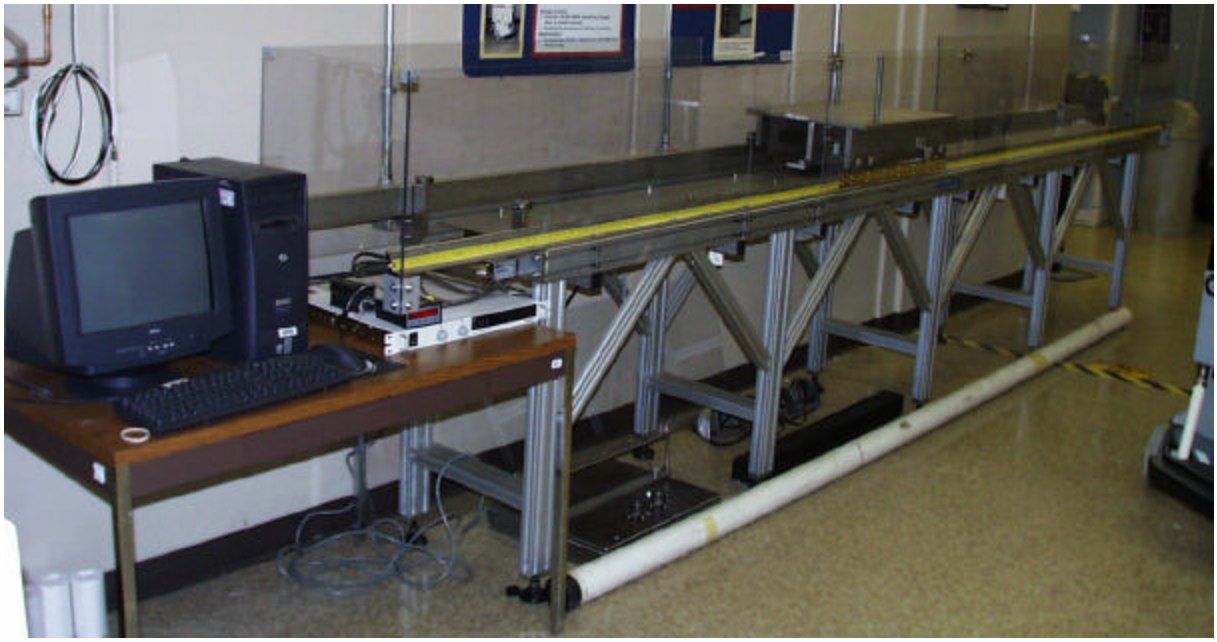
INTRODUCTION

A cart system using linear synchronous motors was being considered for the Plutonium Immobilization Plant (PIP). One of the applications in the PIP was the movement of a stack of furnace trays, filled with the waste form (pucks) from a stacking/unstacking station to several bottom loaded furnaces. A system was ordered to perform this function in the PIP Ceramic Prototype Test Facility (CPTF). This system was installed and started up in SRTC prior to being installed in the CPTF. The PIP was suspended and then canceled after the linear synchronous motor system was started up. This system was used to determine repeatability of a linear synchronous motor cart system for the Modern Pit Facility.

DISCUSSION

The PIP cart system was built to carry a relatively large payload for a glovebox system, 600 lbs. To interface with the bottom loaded furnace the cart had to be approximately 7 ½ inches off of the glovebox floor. The cart also had to be approximately 18 inches wide and 25 ½ inches long to accommodate the furnace trays and furnace bottom. This made the cart rather large and heavy. It weighs approximately 125 lbs. To simulate a stack of furnace trays and the furnace bottom in SRTC, eleven plates, each weighing approximately 50 lbs., were provided. For the PIP application the cart had to travel a distance of over 12 feet, so the track is

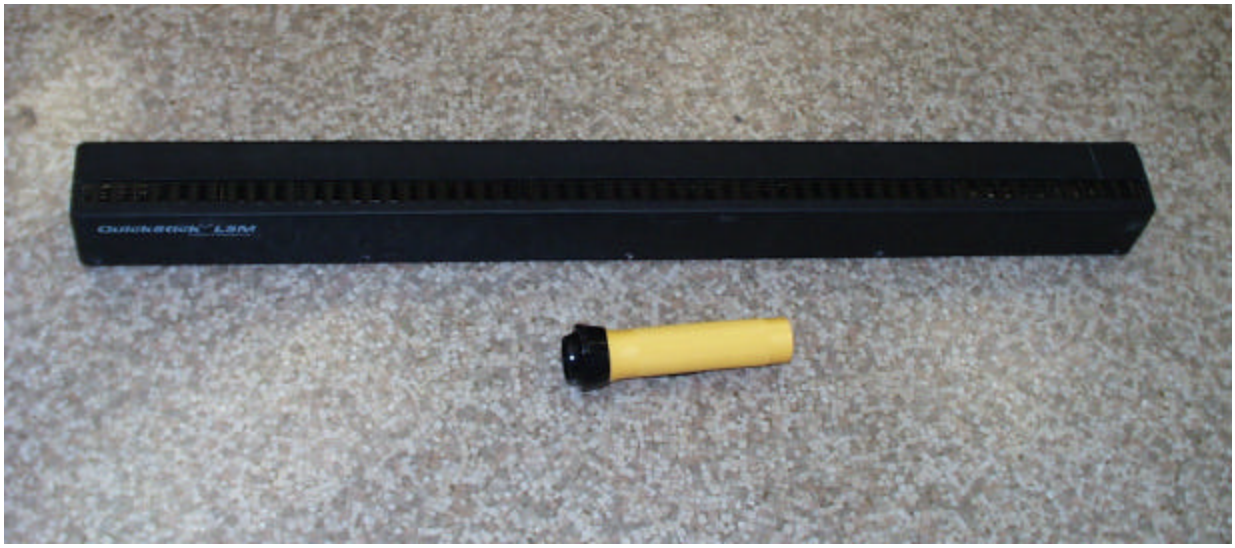
approximately 13 feet, 4 inches long to accommodate the 25 ½ inch long cart. The system is shown in Figure 1. A close-up of the cart is shown in Figure 2.



PIP Linear Synchronous Motor System
Figure 1.

Linear Synchronous Motor Cart
Figure 2.

Below the cart is a 3/16" thick, 304L stainless steel plate to represent the glovebox floor. Two magnet arrays are attached to a plate suspended from the center of the cart. One magnet array is the motor secondary and is only about 1/16 inch above the glovebox floor. The second magnet array provides position feed back to the system and is about 3/8 inch above the floor. There are four linear synchronous motor primaries in the PIP system, called QuickSticks™ by their manufacturer, MagneMotion. Each motor primary is one meter long. There is a one inch gap between each motor to simulate the ability to span a glovebox flange, air lock door or fire door. A QuickStick™ is shown in Figure 3 beside a standard flashlight for comparison. The QuickStick™ primaries are connected via a single "daisy chained" power and communications cable to a personal computer. Custom motion control software communicates with each uniquely addressable QuickStick™ primary to coordinate cart movement within and between primaries.



Linear Synchronous Motor Primary (with flashlight for comparison)
Figure 3.

A Balluff Micropulse™ linear transducer, model BTL-5-P1-M3606-4-S32, was installed to independently determine the position of the cart. The transducer is a magnetostrictive device. The position of a magnet moved axially along the transducer is displayed on a digital readout. The transducer has a resolution of 0.002 inch (0.05 mm). The repeatability of the transducer was checked by manually moving the cart against a solid end stop at each end of the track. At each end the same reading was produced in each of 10 cycles. To confirm the accuracy of the transducer, the cart was moved 3 meters (as measured by a metal tape measure installed below the cart) and the transducer displayed an increase of 3 meters.

In each of the first six repeatability tests the cart was sent to a specific position from a long distance from the left, a short distance to the left, a long distance from the right and a short distance from the right. This represents the range of locations from which

the cart could be sent to a specific position. In each test the cart was sent from these four locations, in order, to a specific position 30 times. Since the repeatability could be different with different payloads on the cart, the tests were conducted with no weight on the cart (a gross weight of 125 lbs.), 300 lbs. on the cart (a gross weight of 425 lbs.) and 550 lbs. on the cart (a gross weight of 675 lbs.). Since the repeatability could be different depending on whether the specific position was in the center of a motor, or in the gap between motors, tests were completed for each weight with the specific position on the center of the motor and between motors.

TEST RESULTS

Eight repeatability tests were conducted. The details of each test are presented in Attachments 1-8. The results from the first six tests are summarized in Table 1.

Ranges of all moves to center of motor

	0 weight	300 lbs.	550 lbs.	0,300,550	0,300
high (mm)	1151.18	1150.90	1152.45	1152.45	1151.18
low (mm)	1150.38	1149.59	1148.74	1148.74	1149.59
difference (mm)	0.80	1.31	3.71	3.71	1.59
difference (in.)	0.031	0.052	0.146	0.146	0.063

Ranges of short from right moves to center of motor

	0 weight	300 lbs.	550 lbs.	0,300,550	0,300
high (mm)	1150.62	1150.24	1149.68	1150.62	1150.62
low (mm)	1150.48	1149.96	1149.21	1149.21	1149.96
difference (mm)	0.14	0.28	0.47	1.41	0.66
difference (in.)	0.006	0.011	0.019	0.056	0.026

Ranges of all moves to gap between motors

	0 weight	300 lbs.	550 lbs.	0,300,550	0,300
high (mm)	656.93	657.01	657.91	657.91	657.01
low (mm)	655.41	654.57	654.90	654.57	654.57
difference (mm)	1.52	2.44	3.01	3.34	2.44
difference (in.)	0.060	0.096	0.119	0.131	0.096

Ranges of short from right moves to gap between motors

	0 weight	300 lbs.	550 lbs.	0,300,550	0,300
high (mm)	655.98	656.97	657.62	657.62	656.97
low (mm)	655.84	656.35	657.20	655.84	655.84
difference (mm)	0.14	0.62	0.42	1.78	1.13
difference (in.)	0.006	0.024	0.017	0.070	0.044

Table 1.

As shown in the table, the difference in the high and low readings (the range) is very low for no weight on the cart. The repeatability is one half of the range. The range for all moves to a position in the middle of a motor with no weight on the cart is 0.031 inches or a repeatability of $\pm$0.016 inches. If the cart with no weight approaches a

position in the middle of a motor from a short distance to the right, the range improves to 0.006 inches or a repeatability of ±0.003 inches (about 1/5). The range (and repeatability) increases as weight on the cart increases. For example, the range of all moves to a position in the middle of a motor with 550 lbs. on the cart is 0.146 inches. This is almost five times greater than with no weight on the cart. The ranges for all moves on a motor with the three different weights is the same as for 550 lbs. because the ranges coincide. However, for all other cases the ranges don't coincide and, therefore, the range for the three different weights is greater than the range for 550 lbs.

Since the range for 550 lbs. on the cart generally is greater than the range for no weight or 300 lbs. on the cart, and doesn't coincide with the other ranges, the range for all moves or short moves is better (about ½) for the cart with no weight and 300 lbs. than for all three weights. For example, the range for moves from a short distance to the right to a position in the middle of a motor is 0.056 inches for all three weights, but improves to 0.026 inches (about ½), if only no weight and 300 lbs. on the cart are considered. In the MPF no weight to 300 lbs. or less may be a sufficient range in weight. Handling greater than 300 lbs. (425 lbs. gross weight) in a glovebox would be extremely unusual. In the PIP only the trays and furnace bottom application required weights above this range.

For most cases the range for the tests with the cart centered on the gap between motors, is not as good as the same tests on the center of the motor. The one exception is all moves on a motor gap, but otherwise the ranges are about double the equivalent tests on the center of a motor.

Most of the tests were programmed in move commands. In move commands the maximum speed can be programmed, but accelerations and decelerations cannot. With the software provided by MagneMotion, changes in programmed maximum speed produced no perceivable change in actual maximum speed, even when extremely low maximum speeds were programmed. The maximum speed for all move commands was measured to be about 200 ft./minute.

With profile commands, the maximum speed, acceleration and deceleration can be programmed. This is traditional servo motion control. The maximum speed is actually controlled properly by profile commands. To determine if profile commands could improve repeatability over move commands, tests using profile commands were conducted. One test was run with 550 lbs. on the cart, stopping in the center of a motor with three different maximum speeds (0.1 m/sec, 0.5 m/sec and 1.0 m/sec). The accelerations and decelerations for all three were numerically about half of the maximum speed. The results are shown in Attachment 7. The ranges were not as good as the corresponding test using move commands as shown in Attachment 5. This is especially true if the fast from left or fast from right moves are compared, since the fast speed in a profile command (1 m/sec) is equivalent to the actual speed (200 ft./min) with a move command. A second test was conducted using the moderate maximum speed, 0.5 m/sec and three different decelerations (-0.050

m/sec^2, -0.200 m/sec^2, and -1.000 m/sec^2). Again, the ranges were not as good as the corresponding test using move commands.

Some of the programs would stop during the first cycle or the first few cycles during the initial testing. In these cases, intermediate stop positions in the program (not the final stop position to determine repeatability) were changed until the program would run reliably. This changed the distance from which the cart would approach the final stop position. After the test was completed, it was determined that the program would stop because the cart was not positioned within the acceptable stop limit set in other software. The acceptable stop limit was increased and several programs that previously would not run continuously ran continuously.

CONCLUSIONS

Repeatability of the linear synchronous motor cart system was excellent. The tests determined that the repeatability for all moves for the cart system when stopping on the center of a motor with a range of gross weight from 125 to 675 lbs. was $\pm$ 0.073 inches ($\pm$1.8 mm). This is excellent repeatability for a cart carrying such a wide range of loads. This repeatability can be improved to $\pm$0.028 inches ($\pm$0.7 mm), if the load stops at a position completely on a motor unit and always approaches the point from a fixed distance from the same direction. If the gross weight only varies from 125 lbs. to 300 lbs., the repeatability on the motor can be further improved to $\pm$0.013 inches ($\pm$0.3 mm). This may be more indicative of the MPF weight range requirements.

Repeatability of the cart when stopping over a one inch gap between motors is about double that for similar situations when stopping over the center of a motor. However, the one inch gap is to allow for flanges between gloveboxes sections, air lock doors or fire doors. For the PIP, MPF and other glovebox facilities, it is unlikely that the cart would need to stop at all in these areas and it is extremely unlikely that the cart would need to stop accurately in these areas. In an actual application, the motors can be installed without gaps in a processing glovebox. Unfortunately, eliminating one or more gaps in the SRTC system to test repeatability with this configuration would require significant mechanical modification of the system and a substantial change in software by the vendor, MagneMotion. So repeatability at the joint between motors, with no significant gap was not tested. Theoretically, no gaps between motors should make the joint between motors insignificant, so repeatability should be similar to repeatability at the center of a motor.

The profile command did not produce as good a repeatability as the move command, even though the profile command allows the accelerations and decelerations to be changed.

The changes in the maximum velocity of the cart in move commands make no perceivable change in the actual maximum velocity of the cart. In fact the actual

maximum velocity is about 200 feet/sec and is much faster than is probably desired in a glovebox system. The vendor software used for this test was the preliminary issue, since the QuickStick™ was a new product at the time of purchase. This software inadequacy needs to be corrected before it can be used in an actual glovebox system.

SUMMARY

The linear synchronous motor cart system has an advantage over conventional cart systems for a glovebox system because it has no moving parts other than the cart and wheels inside the glovebox. The repeatability tests documented in this report indicate that the linear synchronous motor cart system also has excellent repeatability. By always approaching a desired position from a short distance in one direction the repeatability for gross loads from 125 lbs. to 425 lbs. can be $\pm$0.013 inches. The linear synchronous motor cart system should continue to be considered for use in the Modern Pit Facility.

LSM repeatability test, no weight on cart, moves to center of motor

cycle no.	long from left	short from left	long from right	short from right
1	1150.81	1150.76	1150.38	1150.53
2	1150.76	1150.81	1150.38	1150.53
3	1150.81	1150.76	1150.38	1150.48
4	1150.67	1150.67	1150.57	1150.48
5	1150.81	1150.76	1150.38	1150.48
6	1151.14	1150.81	1150.57	1150.53
7	1150.81	1150.76	1150.53	1150.48
8	1150.81	1151.09	1150.48	1150.48
9	1150.81	1150.86	1150.38	1150.48
10	1151.09	1151.18	1150.38	1150.48
11	1150.86	1150.81	1150.38	1150.48
12	1151.04	1151.09	1150.38	1150.48
13	1150.86	1150.81	1150.38	1150.53
14	1151.09	1150.76	1150.48	1150.53
15	1151.04	1150.86	1150.43	1150.53
16	1150.81	1150.86	1150.38	1150.48
17	1150.81	1150.86	1150.43	1150.53
18	1151.04	1150.81	1150.43	1150.48
19	1150.86	1150.81	1150.43	1150.48
20	1150.76	1150.86	1150.38	1150.53
21	1151.09	1151.09	1150.43	1150.57
22	1150.81	1150.81	1150.43	1150.48
23	1150.81	1150.86	1150.48	1150.48
24	1150.81	1150.76	1150.43	1150.48
25	1150.86	1150.76	1150.38	1150.48
26	1150.81	1150.86	1150.43	1150.48
27	1151.09	1150.81	1150.43	1150.48
28	1150.81	1151.04	1150.43	1150.62
29	1150.81	1150.81	1150.43	1150.48
30	1150.67	1150.81	1150.43	1150.48
high	1151.14	1151.18	1150.57	1150.62
low	1150.67	1150.67	1150.38	1150.48
diff.	0.47	0.51	0.19	0.14
stdev.	0.132	0.121	0.055	0.034

	total
	1151.18
	1150.38
	0.80

Program			
motor test			
1 move	0.500	0.500	NA
2 move	1.500	0.500	NA
3 wait	NA	NA	4.000
4 move	1.000	0.500	NA
5 move	1.500	0.500	NA
6 wait	NA	NA	4.000
7 move	3.500	0.500	NA
8 move	1.500	0.500	NA
9 wait	NA	NA	4.000
10 move	1.600	0.500	NA
11 move	1.500	0.500	NA
12 wait	NA	NA	4.000

ATTACHMENT 1

LSM repeatability test, no weight on cart, moves to gap between motors

cycle no.	long from left	short from left	long from right	short from right
1	656.73	656.78	655.46	655.60
2	656.73	656.73	655.41	656.56
3	656.73	656.64	656.46	656.56
4	656.73	656.73	656.51	656.60
5	656.73	656.73	656.56	656.65
6	656.59	656.59	656.51	656.60
7	656.73	656.73	656.60	656.70
8	656.68	656.68	656.51	656.65
9	656.73	656.73	656.51	656.65
10	656.73	656.68	656.56	656.65
11	656.73	656.73	656.74	656.88
12	656.73	656.73	656.65	656.74
13	656.73	656.73	656.65	656.79
14	656.64	656.68	656.56	656.70
15	656.73	656.73	656.65	656.79
16	656.73	656.73	656.74	656.88
17	656.73	656.73	656.65	656.79
18	656.73	656.73	656.60	656.74
19	656.73	656.73	656.56	656.70
20	656.73	656.68	656.74	656.84
21	656.73	656.73	656.74	656.88
22	656.73	656.73	656.65	656.84
23	656.73	656.73	656.65	656.79
24	656.73	656.73	656.74	656.88
25	656.73	656.73	656.74	656.84
26	656.73	656.73	656.84	656.93
27	656.73	656.73	656.79	656.88
28	656.73	656.73	656.74	656.93
29	656.68	656.73	656.84	656.93
30	656.64	656.73	656.84	656.93
high	656.73	656.78	656.84	656.93			656.93
low	656.59	656.59	655.41	655.60			655.41
diff.	0.14	0.19	1.43	1.33			1.52
stdev.	0.035	0.035	0.328	0.244			

Program			
gap test1			
1 move	2.500	0.500	NA
2 move	1.000	0.500	NA
3 wait	NA	NA	4.000
4 move	1.100	0.500	NA
5 move	1.000	0.500	NA
6 wait	NA	NA	4.000
7 move	0.400	0.500	NA
8 move	1.000	0.500	NA
9 wait	NA	NA	4.000
10 move	0.900	0.500	NA
11 move	1.000	0.500	NA
12 wait	NA	NA	4.000

ATTACHMENT 2

LSM repeatability test, 6 plates on cart (~300 lbs.), moves to center of motor

cycle no.	long from left	short from left	long from right	short from right
1	1149.91	1150.10	1150.81	1150.10
2	1149.91	1150.20	1150.81	1150.15
3	1149.82	1150.10	1150.76	1150.15
4	1149.77	1150.15	1150.76	1150.06
5	1149.82	1150.20	1150.76	1150.20
6	1149.82	1150.15	1150.86	1150.24
7	1149.73	1150.06	1150.81	1150.24
8	1149.77	1150.10	1150.90	1150.20
9	1149.82	1150.01	1150.86	1150.20
10	1149.77	1150.15	1150.90	1150.20
11	1149.54	1149.96	1150.76	1150.20
12	1149.77	1150.15	1150.62	1150.01
13	1149.77	1150.15	1150.81	1150.15
14	1149.77	1150.15	1150.86	1150.20
15	1149.77	1150.01	1150.76	1150.20
16	1149.73	1150.20	1150.76	1150.15
17	1149.73	1150.10	1150.90	1150.29
18	1149.77	1150.10	1150.76	1149.96
19	1149.77	1150.15	1150.76	1150.15
20	1149.77	1150.20	1150.71	1150.06
21	1149.77	1150.24	1150.71	1150.10
22	1149.77	1150.15	1150.71	1149.96
23	1149.73	1150.15	1150.86	1150.20
24	1149.82	1150.15	1150.67	1150.10
25	1149.59	1150.15	1150.81	1150.10
26	1149.73	1150.10	1150.67	1150.06
27	1149.77	1150.20	1150.76	1149.96
28	1149.73	1150.10	1150.62	1149.96
29	1149.73	1150.10	1150.57	1150.01
30	1149.73	1150.24	1150.67	1150.01
high	1149.91	1150.24	1150.90	1150.24
low	1149.59	1149.96	1150.57	1149.96
diff.	0.32	0.28	0.33	0.28
stdev.	0.072	0.065	0.087	0.095

	Program			
	motor test			
1	move	0.500	0.500	NA
2	move	1.500	0.500	NA
3	wait	NA	NA	4.000
4	move	1.000	0.500	NA
5	move	1.500	0.500	NA
6	wait	NA	NA	4.000
7	move	3.500	0.500	NA
8	move	1.500	0.500	NA
9	wait	NA	NA	4.000
10	move	1.600	0.500	NA
11	move	1.500	0.500	NA
12	wait	NA	NA	4.000

high	1150.90	
low	1149.59	
diff.	1.31	
stdev.		

ATTACHMENT 3

LSM repeatability test, 6 plants on cart (~300 lbs.), moves to gap between motors

cycle no.	long from left	short from left	long from right	short from right
1	655.88	656.78	657.01	656.97
2	655.79	655.93	656.92	656.59
3	656.07	655.98	656.87	656.64
4	655.98	656.03	656.83	656.64
5	656.07	656.17	656.83	656.68
6	656.12	656.17	656.73	656.45
7	656.07	656.12	656.78	656.50
8	656.07	655.23	656.78	656.45
9	656.12	656.35	656.83	656.54
10	656.07	656.21	656.92	656.54
11	656.17	656.35	656.83	656.50
12	656.17	656.21	656.83	656.59
13	656.21	656.31	656.83	656.59
14	656.17	656.45	656.92	656.64
15	656.17	656.31	656.92	656.59
16	656.07	656.17	656.78	656.50
17	656.31	656.35	656.83	656.54
18	656.26	656.31	656.83	656.45
19	656.4	656.21	656.68	656.40
20	654.57	654.9	656.59	656.45
21	656.21	656.4	656.73	656.35
22	656.26	656.35	656.68	656.40
23	656.35	656.21	656.73	656.45
24	656.26	656.26	656.73	656.40
25	656.12	656.26	656.83	656.45
26	656.12	656.21	656.78	656.40
27	656.07	656.17	656.87	656.45
28	656.07	656.03	656.73	656.40
29	656.03	656.12	656.78	656.45
30	656.12	656.17	656.73	656.35
high	656.40	656.78	657.01	656.97			657.01
low	654.57	654.90	656.59	656.35			654.57
diff.	1.83	1.88	0.42	0.62			2.44
stdev.	0.312	0.340	0.088	0.126			

Program			
gap testA			
1 move	2.500	0.500	NA
2 move	1.000	0.500	NA
3 wait	NA	NA	4.000
4 move	1.500	0.500	NA
5 move	1.000	0.500	NA
6 wait	NA	NA	4.000
7 move	0.400	0.500	NA
8 move	1.000	0.500	NA
9 wait	NA	NA	4.000
10 move	**0.550**	0.500	NA
11 move	1.000	0.500	NA
12 wait	NA	NA	4.000

ATTACHMENT 4

LSM repeatability test, 11 plates on cart (~550 lbs.), moves to center of motor

cycle no.	long from left	short from left	long from right	short from right
1	1149.02	1149.82	1152.13	1149.40
2	1149.11	1150.10	1152.13	1149.30
3	1149.16	1150.20	1152.17	1149.30
4	1149.02	1150.29	1152.31	1149.30
5	1149.11	1150.15	1152.36	1149.40
6	1149.07	1150.10	1152.36	1149.44
7	1149.11	1150.10	1152.27	1149.35
8	1149.02	1150.01	1152.27	1149.40
9	1148.97	1150.10	1152.22	1149.40
10	1148.97	1150.10	1152.08	1149.21
11	1149.02	1150.06	1152.31	1149.35
12	1149.02	1150.10	1152.03	1149.35
13	1148.83	1150.24	1152.03	1149.35
14	1149.07	1150.15	1152.06	1149.44
15	1149.02	1150.06	1152.13	1149.35
16	1149.02	1150.01	1152.08	1149.35
17	1148.97	1149.77	1152.27	1149.54
18	1148.97	1149.77	1152.17	1149.68
19	1149.07	1149.87	1152.17	1149.44
20	1149.02	1149.68	1152.22	1149.59
21	1149.07	1149.91	1152.27	1149.35
22	1148.93	1149.82	1152.22	1149.49
23	1148.97	1150.01	1152.22	1149.44
24	1149.02	1149.82	1152.17	1149.40
25	1148.97	1149.82	1152.22	1149.40
26	1149.07	1149.62	1152.36	1149.49
27	1149.02	1150.24	1152.22	1149.35
28	1148.97	1149.77	1152.22	1149.44
29	1148.74	1149.59	1152.36	1149.54
30	1148.83	1149.68	1152.45	1149.59
high	1149.16	1150.29	1152.45	1149.68
low	1148.74	1149.59	1152.03	1149.21
diff.	0.42	0.70	0.42	0.47
stdev.	0.088	0.199	0.107	0.101

	total
	1152.45
	1148.74
	3.71

Program			
motor test			
1 move	0.500	0.500	NA
2 move	1.500	0.500	NA
3 wait	NA	NA	4.000
4 move	1.000	0.500	NA
5 move	1.500	0.500	NA
6 wait	NA	NA	4.000
7 move	3.500	0.500	NA
8 move	1.500	0.500	NA
9 wait	NA	NA	4.000
10 move	1.600	0.500	NA
11 move	1.500	0.500	NA
12 wait	NA	NA	4.000

ATTACHMENT 5

LSM repeatability test, 11 plates on cart (~550 lbs.), moves to gap between motors

cycle no.	long from left	short from left	long from right	short from right
1	654.80	657.01	657.77	657.30
2	654.90	656.92	657.77	657.20
3	654.90	657.06	657.86	657.39
4	654.94	657.01	657.91	657.34
5	654.94	656.92	657.91	657.25
6	654.94	656.87	657.95	657.44
7	655.04	656.87	657.81	657.34
8	654.94	656.83	657.86	657.44
9	655.13	656.92	657.81	657.30
10	655.04	656.92	657.81	657.34
11	654.99	656.83	657.77	657.34
12	655.04	656.87	657.81	657.39
13	655.18	656.73	657.72	657.48
14	655.18	656.64	657.62	657.48
15	655.18	656.64	657.77	657.44
16	654.99	656.78	657.81	657.44
17	655.18	656.54	657.67	657.48
18	655.18	656.54	657.58	657.53
19	656.18	656.54	657.72	657.58
20	655.23	656.59	657.62	657.53
21	655.23	656.50	657.67	657.53
22	655.13	656.50	657.72	657.39
23	655.18	656.54	657.67	657.44
24	655.13	656.54	657.53	657.44
25	655.18	656.45	657.58	657.48
26	655.27	656.45	657.62	657.58
27	655.32	656.50	657.62	657.62
28	655.23	656.50	657.62	657.58
29	655.32	656.50	657.72	657.62
30	655.37	656.50	657.62	657.58
high	656.18	657.06	657.91	657.62
low	654.80	656.45	657.53	657.20
diff.	1.38	0.61	0.38	0.42
stdev.	0.243	0.200	0.111	0.110

Program				
gap test				
1 move		2.500	0.500	NA
2 move		1.000	0.500	NA
3 wait	NA		NA	4.000
4 move		1.500	0.500	NA
5 move		1.000	0.500	NA
6 wait	NA		NA	4.000
7 move		0.400	0.500	NA
8 move		1.000	0.500	NA
9 wait	NA		NA	4.000
10 move		0.900	0.500	NA
11 move		1.000	0.500	NA
12 wait	NA		NA	4.000

total
657.91
654.90
3.01

ATTACHMENT 6

LSM repeatability test, 11 plates on cart (~550 lbs.), moves to center of motor

cycle no.	slow from left	med from left	fast from left	slow from right	med from right	fast from right
1	1151.98	1150.62	1150.01	1149.63	1151.51	1149.44
2	1152.45	1150.62	1150.86	1150.01	1150.90	1151.61
3	1152.36	1150.81	1149.44	1149.63	1151.09	1150.62
4	1152.22	1150.86	1149.77	1149.91	1150.95	1152.03
5	1152.27	1151.00	1149.68	1149.59	1151.14	1149.59
6	1152.27	1151.23	1149.73	1149.44	1150.71	1152.13
7	1152.36	1151.18	1149.59	1149.59	1151.00	1152.69
8	1152.13	1151.51	1149.82	1149.68	1151.33	1151.61
9	1152.64	1150.67	1150.20	1149.73	1151.14	1152.17
10	1152.69	1150.86	1149.73	1149.68	1151.09	1152.17
11	1152.74	1151.23	1149.63	1149.63	1151.00	1152.55
12	1152.41	1151.00	1149.63	1149.63	1151.00	1151.94
13	1152.17	1151.23	1149.82	1149.63	1151.23	1152.60
14	1152.27	1151.18	1149.96	1149.96	1151.09	1152.50
15	1152.27	1150.90	1149.96	1149.82	1151.90	1151.94
16	1152.22	1151.04	1150.06	1149.63	1150.86	1152.08
17	1152.41	1150.81	1149.77	1149.59	1150.86	1152.55
18	1152.31	1151.18	1149.73	1149.59	1150.86	1151.61
19	1152.03	1151.14	1149.77	1149.63	1151.04	1152.03
20	1152.27	1150.53	1150.24	1149.59	1151.14	1149.26
21	1152.36	1150.57	1150.24	1149.59	1150.71	1149.49
22	1152.03	1150.43	1150.34	1149.44	1150.53	1150.20
23	1151.98	1150.29	1150.29	1149.26	1150.53	1150.20
24	1152.03	1150.43	1150.48	1149.68	1150.67	1150.62
25	1152.08	1150.86	1150.62	1149.59	1150.81	1151.47
26	1152.22	1150.71	1150.20	1149.30	1150.71	1149.73
27	1151.80	1150.95	1150.43	1149.26	1150.43	1149.73
28	1151.84	1151.18	1150.10	1149.26	1150.53	1151.33
29	1151.84	1150.86	1150.10	1149.30	1150.43	1149.68
30	1151.98	1151.47	1150.01	1149.21	1150.20	1149.54
high	1152.74	1151.51	1150.86	1150.01	1151.51	1152.69
low	1151.80	1150.29	1149.44	1149.21	1150.20	1149.26
diff.	0.94	1.22	1.42	0.80	1.31	3.43
stdev.	0.238	0.309	0.335	0.204	0.348	1.182

Program					
motor test prof.					
1 move	0.500	0.500	NA		
14 prof	1.500	0.100	0.050	-0.050	
3 wait	NA	NA	4.000		
4 move	0.500	0.500	NA		
3 prof	1.500	0.500	0.200	-0.200	
6 wait	NA	NA	4.000		
7 move	0.500	0.500	NA		
15 prof	1.500	1.000	0.400	-0.400	
9 wait	NA	NA	4.000		
10 move	2.500	0.500	NA		
14 move	1.500	0.500	NA		
12 wait	NA	NA	4.000		
13 move	2.500	0.500	NA		
3 prof	1.500	0.500	0.200	-0.200	
15 wait	NA	NA	4.000		
16 move	2.500	0.500	NA		
15 prof	1.500	1.000	0.400	-0.400	
18 wait	NA	NA	4.000		

ATTACHMENT 7

LSM repeatability test, 11 plates on cart (~550 lbs.), moves to center of motor

cycle no.	slow decel from left	med decel from left	fast decel from right
1	1150.90	1149.87	1150.86
2	1150.81	1149.73	1150.62
3	1150.71	1150.06	1151.00
4	1150.90	1150.24	1150.34
5	1150.81	1150.15	1150.71
6	1150.86	1150.15	1150.67
7	1150.76	1149.91	1150.53
8	1150.71	1150.06	1150.86
9	1150.57	1149.87	1150.71
10	1150.62	1150.10	1150.01
11	1150.81	1150.01	1150.48
12	1151.28	1150.20	1150.76
13	1150.62	1150.34	1150.38
14	1150.86	1150.34	1150.86
15	1151.28	1150.67	1150.20
16	1150.81	1150.24	1150.34
17	1151.02	1150.38	1150.43
18	1150.86	1150.34	1150.53
19	1151.14	1150.01	1151.00
20	1150.81	1150.06	1150.57
21	1151.23	1149.96	1150.76
22	1151.47	1150.20	1150.62
23	1151.37	1150.43	1150.48
24	1151.37	1149.87	1150.95
25	1151.14	1149.87	1150.71
26	1150.95	1150.20	1150.34
27	1151.09	1149.87	1151.23
28	1151.18	1151.01	1150.71
29	1150.86	1150.06	1151.56
30	1150.76	1150.15	1150.53
high	1151.47	1151.01	1151.56
low	1150.57	1149.73	1150.20
diff.	0.90	1.28	1.36
stdev.	0.246	0.263	0.311

	Program				
	motor test prof. Decel				
1	move	0.500	0.500	NA	
17	prof	1.500	0.500	0.200	-0.050
3	wait	NA	NA	4.000	
4	move	0.500	0.500	NA	
3	prof	1.500	0.500	0.200	-0.200
6	wait	NA	NA	4.000	
7	move	0.500	0.500	NA	
16	prof	1.500	0.500	0.200	-1.000
9	wait	NA	NA	4.000	

ATTACHMENT 8