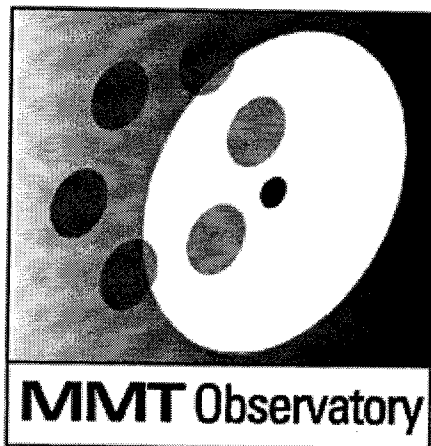


MMTO Conversion Technical Memorandum #98-2



Smithsonian Institution &
The University of Arizona®

The f/9 Hexapod Actuator Acceptance Testing

ADS Italia

August 1998

ACTUATORS ACCEPTANCE TESTING IN AMBIENT CONDITION

The linear actuators were subjected to an accuracy performances testing program in ambient conditions.

The following paragraph describes the test equipment used to conduct the tests and the tests results.

2.1 Test Equipment

The test equipment used for performance testing in ambient conditions is composed of:

- mechanical test bench able to support the linear actuator and the measuring system
- VME computer with acquisition and command units
- electronics box (signal conditioners, motor driver etc)
- PC integrating optical measuring system controller, AD converter, serial connection (RS-232) to control the remote VME computer.

The mechanical test bench is composed by the following elements (see figures in the next page):

- An aluminium frame to support the test bench;
- A stainless steel frame supporting the linear actuator and with the corresponding load application system. The fixed part of the actuator is connected to an end column of the support structure through bolts while the movable part of the actuator is connected through bolts to a flange mounted to a preloaded sliding carrier running on a high precision linear guide.
- A high precision measuring system to be used as reference for the actuator position measurements, consisting on a Heindehain optical linear incremental scale type MT101K (100 mm stroke, 0.1 μ m resolution) and the Heidenhain interpolation & digitizing electronics PC plug-in board).

The test bench is designed to conduct the following tests on the actuators:

- i) Lvdv noise test
- ii) Positioning accuracy
- iii) Brake's effects
- iv) Axial stiffness,

The tests can be performed using different load conditions (tension or compression, and load level from 20N to 300N)

The VME computer, based on a Motorola processor, is provided by the University Of Arizona and it contains all the electronics needed to acquire analog and digital signals sent by the actuator and send back the desired position

commands.

It also contains the control program that closes a position and velocity loop on the actuator. The computer works as a remote unit interfaced via RS-232 to the PC.

The electronics box, also provided by the University Of Arizona, works as an interface between the VME computer and the actuator. It contains several devices:

- the motor driver
- the lvdt signal conditioner
- the brake driver (designed by University Of Arizona)
- the encoder signal conditioner (designed by University Of Arizona)

The motor driver is a 211A model made by Copley Control Corp.

The Lvdt signal conditioner is a DCM-1000 direct current operated signal conditioner made by Macro Sensor, a division of Howard A. Schaevitz Technologies, Inc.

The PC used is an Intel Pentium® based computer, with two ISA additional cards:

- optic linear transducer controller, Heidenhain EXE 922
- 12 bit, variable gain ADC, made by Intelligent Instrumentation (PCI 20248 W1)

The PC is used as an advanced terminal, capable of self-driving (via RS-232 port) all the necessary tests. The main program permits to send a pre-selected list of sequential VME command (i.e. "moverel", "showstat" etc...) and read the VME echo; besides, it permits to access the data read by the internal boards.

Through the information carried by the echo strings and through the readings made by the internal boards and their relative transducers, it's possible to collect all the informations about the actuator status: absolute actuator position (by optical linear reference), lvdt position, (by VME "showp" echo), embedded rotating encoder position (by VME "showstat" echo), lvdt analog out [DC Volts] (by PC AD Converter) and all the system informations provided by the VME commands called "showstat", "showp", "showc"....

2.2 Test procedure

It's useful to report some definitions applicable to the actuator performances tests and measurements in order to have a common understanding to interpret and evaluate the test results.

a) Lvdt typical noise

It's defined as the standard deviation of the Lvdv DC analog out.

b) Positioning closed-loop accuracy of the actuator:

When a displacement is commanded to the actuator, the positioning accuracy of the actuator is defined as the difference between the actual position reached by the actuator (and measured by the optical linear scale of the test bench, considered as absolute reference for the measurement) and the position measured by the lvdv sensor.

The positioning closed-loop accuracy of the actuator depends on:

- the control law chosen, the sensors accuracy;
- the screw lead error distribution along the stroke;
- the roller screw behavior considered as a whole driving unit;
- motor and encoder angular resolution;
- hysteresis due to the inversion of motion;
- stick-slip phenomena;
- thermo-elastic deformation due to temperature gradients;
- changes in axial stiffness (therefore in elongation at constant applied load) depending on the actuator stroke;
- command discretization and controller error;
- other mechanical errors (misalignments, etc).

c) Brake induced error

It is defined as the actuator displacement, read by the optical linear external reference, due to the brake status commutation (On/Off).

d) Axial stiffness

It is the actuator axial stiffness, the ratio between the axial load and the displacement measured by the optical linear scale of the test bench.

Procedures

The tests were performed on each one of the seven (6+1) linear actuators.

i) Lvdv noise test

This test was performed to characterize the noise level of the Lvdv sensor. The test consists in acquiring the Lvdv analog out by the previously described acquisition card (PCI 20248 W1).

The test is arranged in two different configuration. In the first case only the Lvdv sensor and its conditioning electronic are supplied and the ADC reads a signal

relative to a fixed position of the actuator.

In the second case the same kind of measurement is performed after having:

- 1) powered the complete system
- 2) initialized the closed loop controller
- 3) killed the closed loop controller (open loop conditions)

Obviously, the actuator is perfectly still in both the cases but in the second one the noise level can be affected by electric crosstalk between the lvdt and the motor.

ii) Position accuracy test

This kind of test permits to obtain the position accuracy through twelve series of measures that cover all the screw length.

Each one of this series is composed by twenty independent absolute positioning commands between two fixed stations.

The first fixed position is always the same (A) for all tests, near the maximum actuator elongation, while the second one (B) moves from the maximum elongation point to the minimum one as the series number increases (see figure below).

Set 1 14000 to (14000+3000) lvdt counts A B

Set 2 14000 to (14000+6000) lvdt counts A B

... ..

Set 12 14000 to (14000+36000) lvdt counts A B

Because of the absence of an absolute positioning VME command, we used the "moverel" keyword in such a way that permits to arrange an absolute positioning.

This is possible because of another VME keyword: "showp".

In fact, as the Test Manager Program reads the new absolute commanded position (point A or B), it checks the current position ("showp") and calculates the distance between this position and the desired one.

After having sent a new command, the Test Manager waits for the complete positioning of the actuator and then reads the reached position through the optical linear reference.

For each set, the worst accuracy positioning achieved and the accuracy positioning standard deviation are evaluated.

Here is presented the test sequence performed by the Test Manager:

- read the desired absolute command from ascii file (JJJ)

- **SHOWP**
- read VME echo: **Chan 0: curp: CURPOS**
- store CURPOS (LvdT reading) that is the current absolute position
- calculate AAA to get (by MOVEREL AAA) the desired absolute position (JJJ) moving from CURPOS
- **MOVEREL AAA**
- read VME echo: **value = YYY**
- store YYY that represents the really commanded final position
-wait for the actuator positioning
- read Heidenhain linear reference (before)
- **SHOWP**
- read VME echo: **Chan 0: curp: XXX**
- store XXX (LvdT reading) that is the actual position
- read Heidenhain linear reference (after)
- calculate the average linear reference position $WWW=(\text{after}+\text{before})/2$
- store the generic step data: JJJ; XXX; WWW; YYY

The positioning error is defined as follows:

$$\text{Error} := \Delta \text{ YYY} / \text{sens} - \Delta \text{ WWW} * 1000$$

where:

[Δ YYY] = counts

[sens] = counts/micron

[Δ WWW] = mm

iii) Brake's effects test

The test is performed to evaluate the typical brake induced error. In fact the brake's action determines a perturbation of the current actuator position and the magnitude of this phenomena depends on the control system reactivity.

The measure we arranged is characterized by thirty status changes ("brake 0"/"brake 1"); after having initialized the closed loop controller, the actuator position is read before and after each status change (through the optical linear reference).

Once calculated the displacements caused by the brake's commutations (from 0 to 1), the brake induced error standard deviation and the biggest brake induced error are evaluated.

The test is performed in two different load conditions (traction load): 0 and 250 N.

The same kind of test has been repeated in open loop conditions. The informations provided by this kind of test are very useful because they are independent from the control law reactivity and permit to separate the brake's effect from the control law effects.

iv) Axial stiffness

This test permits to obtain the actuator axial stiffness through the measurement of two sets of displacements caused by a known set of axial load conditions. At first, the load set is applied to the actuator and a first set of displacement is measured. Then the same kind of load set is applied to a stainless steel beam of known stiffness, replacing the actual actuator. In this way it is possible to calculate the test bench stiffness and then the real actuator stiffness.

The displacements have been measured by the optical linear reference with a resolution of 0.1 micron while the loading masses have been evaluated with an accuracy of 0.01 kg.

The stiffness is calculated in two different system configuration:

- a) Switched off system, brake close
- b) Switched on system, brake close

The loading procedure, repeated three times for each of the two configurations, consists in a load increase course and a decreasing one.

The sequence of applied masses is the following:

0 - 2 - 4 - 6 - 8 - 9 - 11 - 13 - 14 - 16 - 18 - 23 - 18 - 16 - 14 - 13 - 11 - 9 - 8 - 6 - 4 - 2 - 0 Kg

In this way it is possible to show the hysteresis of the axial load response.

2.3 Test results

This paragraph summarizes settings and test results for the seven (6+1) linear actuators.

Actuators setting

In the following table the most significant setting values (lvdt counts, lvdt analog out, linear displacement) of each actuator, relative to the two limit switch positions, are reported.

Besides the lvdt sensitivity, in terms of counts/ μm and mV/ μm , is evaluated.

Before starting the initialization procedure, each actuator has been setted to its

nominal length (0.330 m) and then the lvdv bar position has been regulated so that the sensor DC out would be nearly 0 V.

| | Act. 1 SX | Act. 2 SX | Act. 3 SX | Act. 4 DX | Act. 5 DX | Act. 6 |
|---------------------------------|-------------------|-----------|-----------|-----------|-----------|--------|
| DX | Extra Act. | | | | | |
| Lvdt out volts ^ | -5.09 | -6.33 | -5.93 | -5.38 | | |
| Lvdt out volts * | 5.19 | 6.68 | 5.96 | 6.05 | | |
| Δ Lvdt [V] | 10.28 | 13.01 | 11.89 | 11.43 | | |
| Lvdt counts ^ | 16097 | 12041 | 13338 | 15129 | | |
| Lvdt counts * | 49748 | 54606 | 52270 | 52576 | | |
| Δ Lvdt counts | 33651 | 42565 | 38932 | 37447 | | |
| Δ x axial displ. μ m | 12573.0 | 15904.9 | 14800.4 | 14019.5 | | |
| Lvdt sens: count/ μ m | 2.67 | 2.67 | 2.63 | 2.67 | | |
| Lvdt sens: mV/ μ m | 0.817 | 0.817 | 0.803 | 0.815 | | |

(^) positive limit switch position; (*) negative limit switch position

Table xx. Actuators setting values

Results

Each test is discussed independently and then a final table is reported.

i) Lvdt noise

| σ [mV] | Act. 1 SX | Act. 2 SX | Act. 3 SX | Act. 4 DX | Act. 5 |
|---------------|------------------|-------------------|-----------|-----------|--------|
| DX | Act. 6 DX | Extra Act. | | | |
| Lvdt only | 1.29 | 1.21 | 1.33 | 1.04 | |
| Op. cond. | 3.72 | 12.50 | 12.40 | 3.71 | |

Though the actuator is perfectly still in both the cases (motor off and on), in the second one the noise level is a order of magnitude bigger.

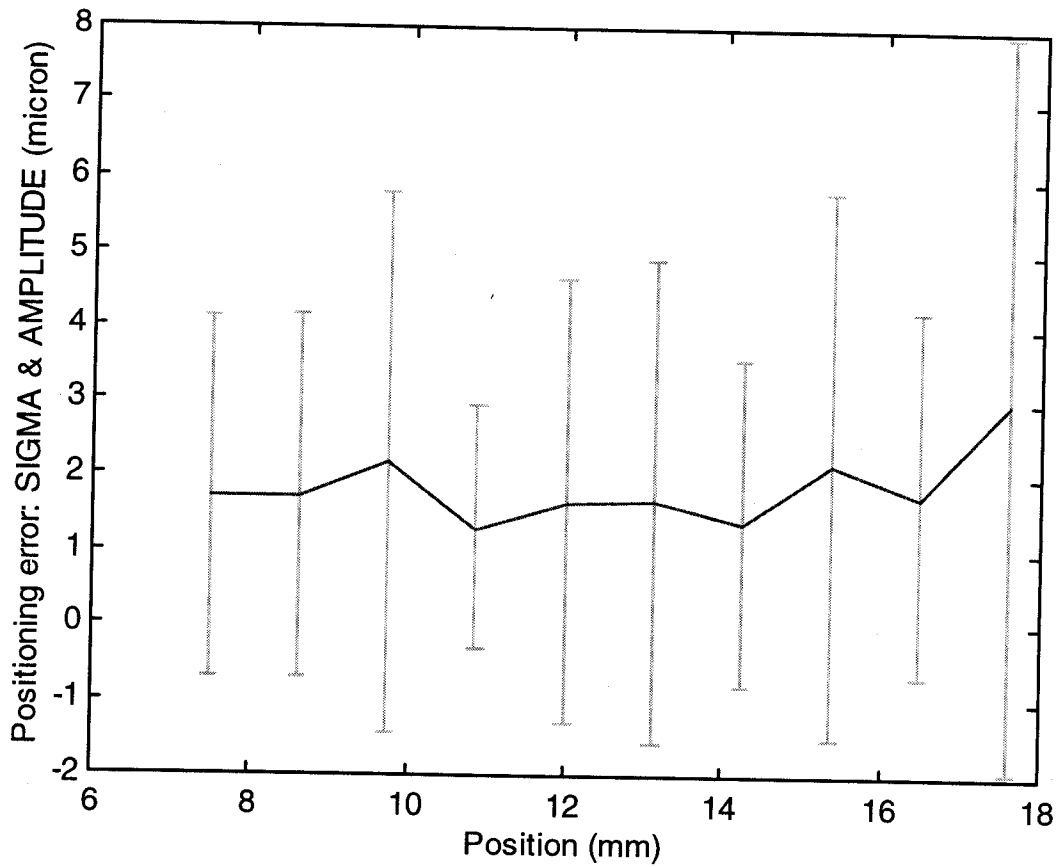
It's our opinion that this extra-noise depends on the grounding layout of the whole system, but we can't find a better test configuration than the test one.

This factor *strongly affects the overall system performances.*

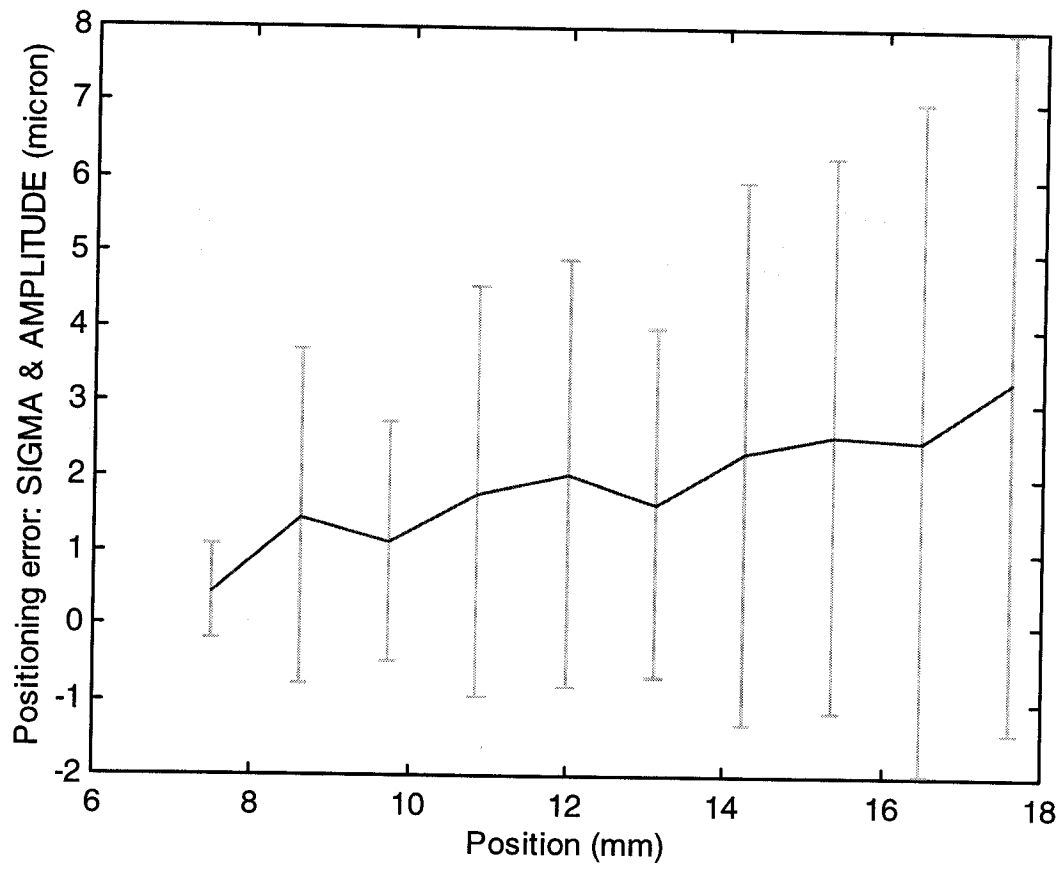
ii) Closed loop accuracy

The position accuracy achieved for each actuator is plotted. The continuous line is the positioning error standard deviation, computed over each set of movement that arrives to the same position on the screw starting.

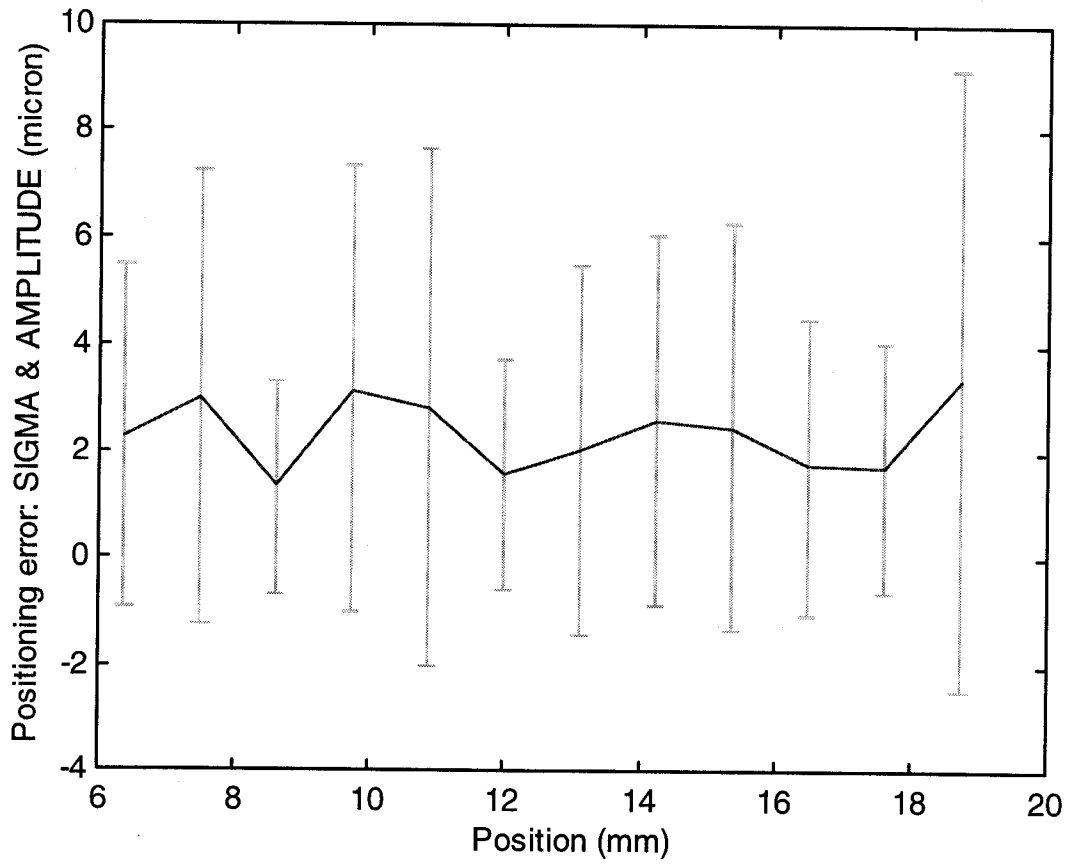
The error bar represent the delta between the smaller and the larger error around each nominal position.



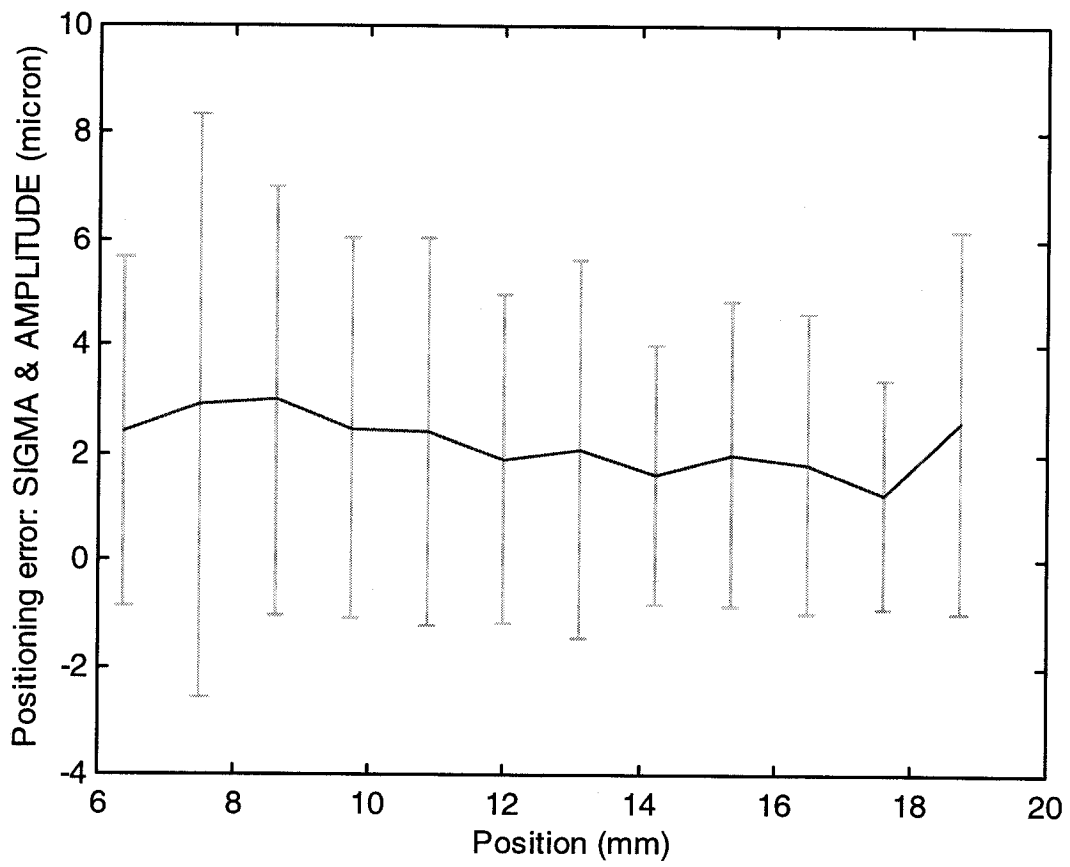
ACT1SX no load



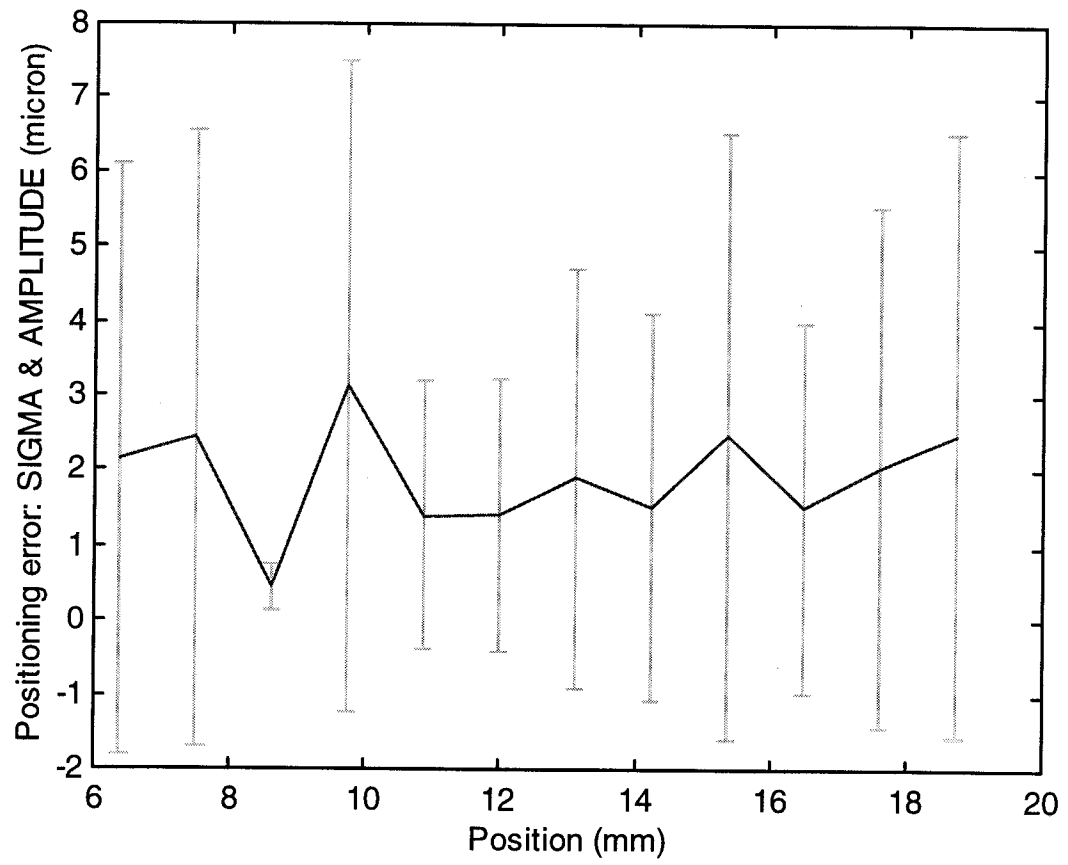
ACT1SX 250N load



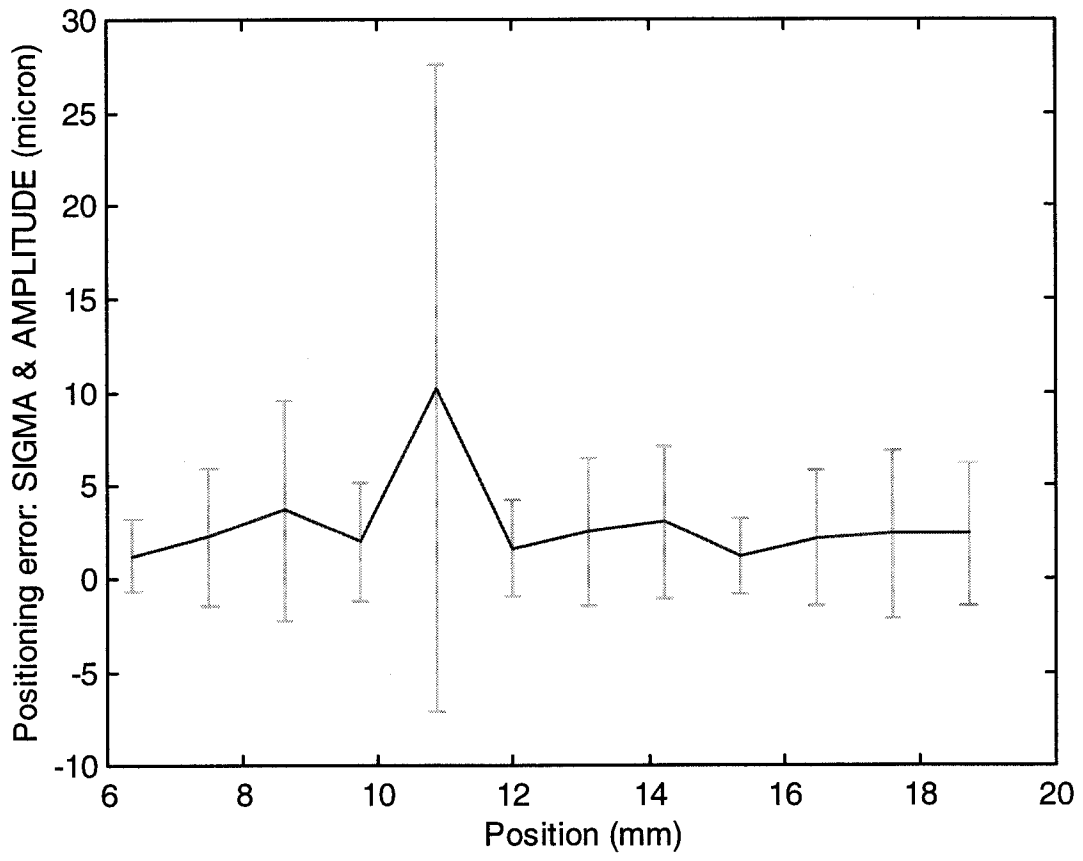
ACT3SX no load



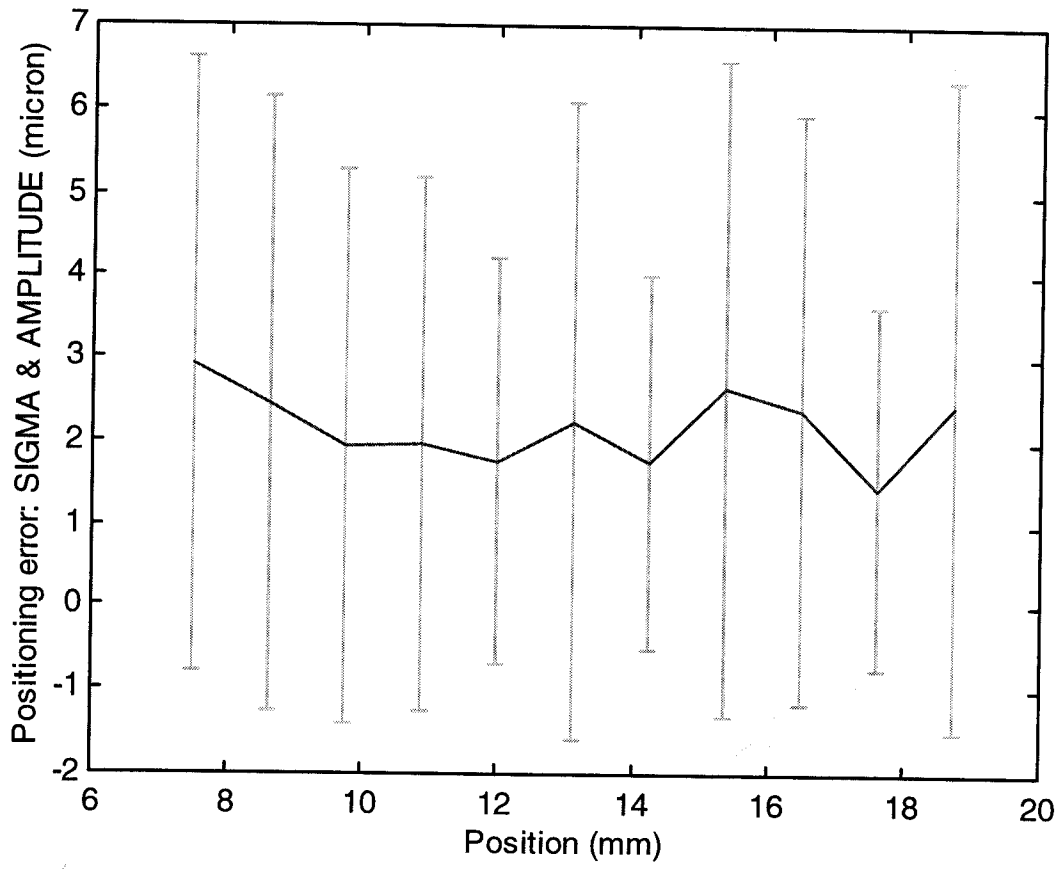
ACT3SX 250 N load



ACT4DX no load



ACT4DX 250 N load



ACT6DX no load