1036

TECHNICAL MEMORANDUM
A3-228-AAMO-TM81-SOLAR-2

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DESIGN EVALUATION TEST REPORT, 1D22475-1 DRIVE UNIT, 2ND GENERATION HELIOSTAT

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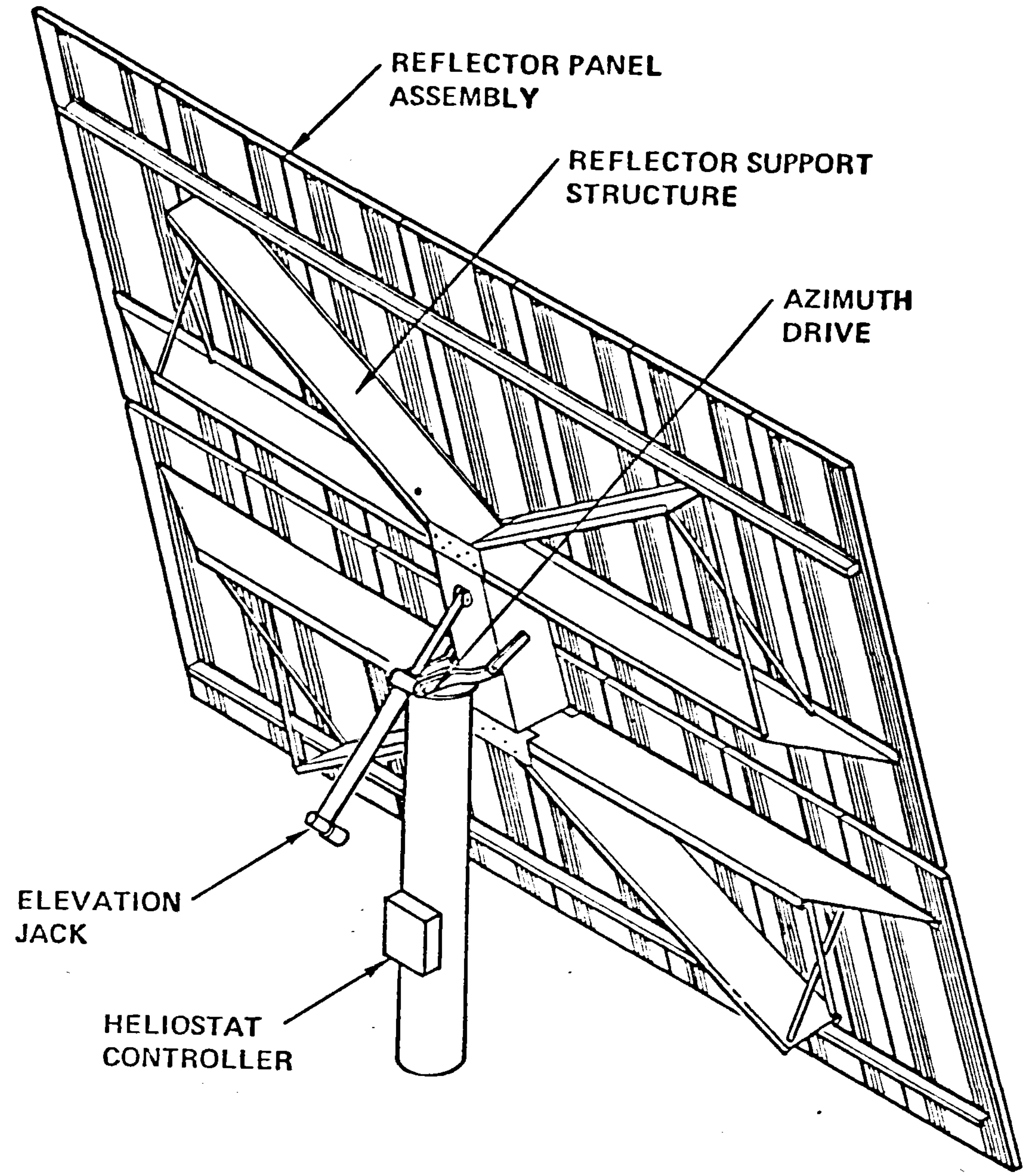
INTRODUCTION

McDonnell Douglas Astronautics Company-Huntington Beach (MDAC-HB) has designed a second generation heliostat for solar energy programs. The heliostat is shown in Figure 1, and has approximately 616 square feet of mirror surface. The heliostat uses an open-loop control system to track and reflect the sun's energy onto a central receiver. Each heliostat employs a drive unit capable of controlling rotation around the pedestal vertical centerline (azimuth) and a drive unit for control of mirror elevation.

The azimuth drive is a two-stage reduction device (see Figure 2). A 1/4 horsepower electric motor drives a helicon gear set for the primary reduction stage, and the helicon gear provides the input to a harmonic drive built by United Shoe Machinery Corporation for the output stage.

Similarly, the elevation drive is a two-stage linear actuator device (see Figure 3). The power source is a 1/3 horsepower electric motor driving a helicon gear set. The helicon gear set provides input to a drive screw with a translating ball nut. This device is built by Duff-Norton to MDAC-HB specification and is commonly referred to as the "jack" or "actuator".

Design of the drive system was the responsibility of the mechanical department and testing was required to verify that performance would meet design requirements. Testing was accomplished in the Structures Test Lab (Bldg. 30) in accordance with test documentation drawing 1T53864. This report summarizes and documents the test results.



- VERTICAL STOW
- HORIZONTAL SURVIVAL
- REFLECTIVE AREA - 612 FT^2 (57 M^2)
- 1.27-1 ASPECT RATIO

FIGURE 1

2ND GENERATION HELIOSTAT

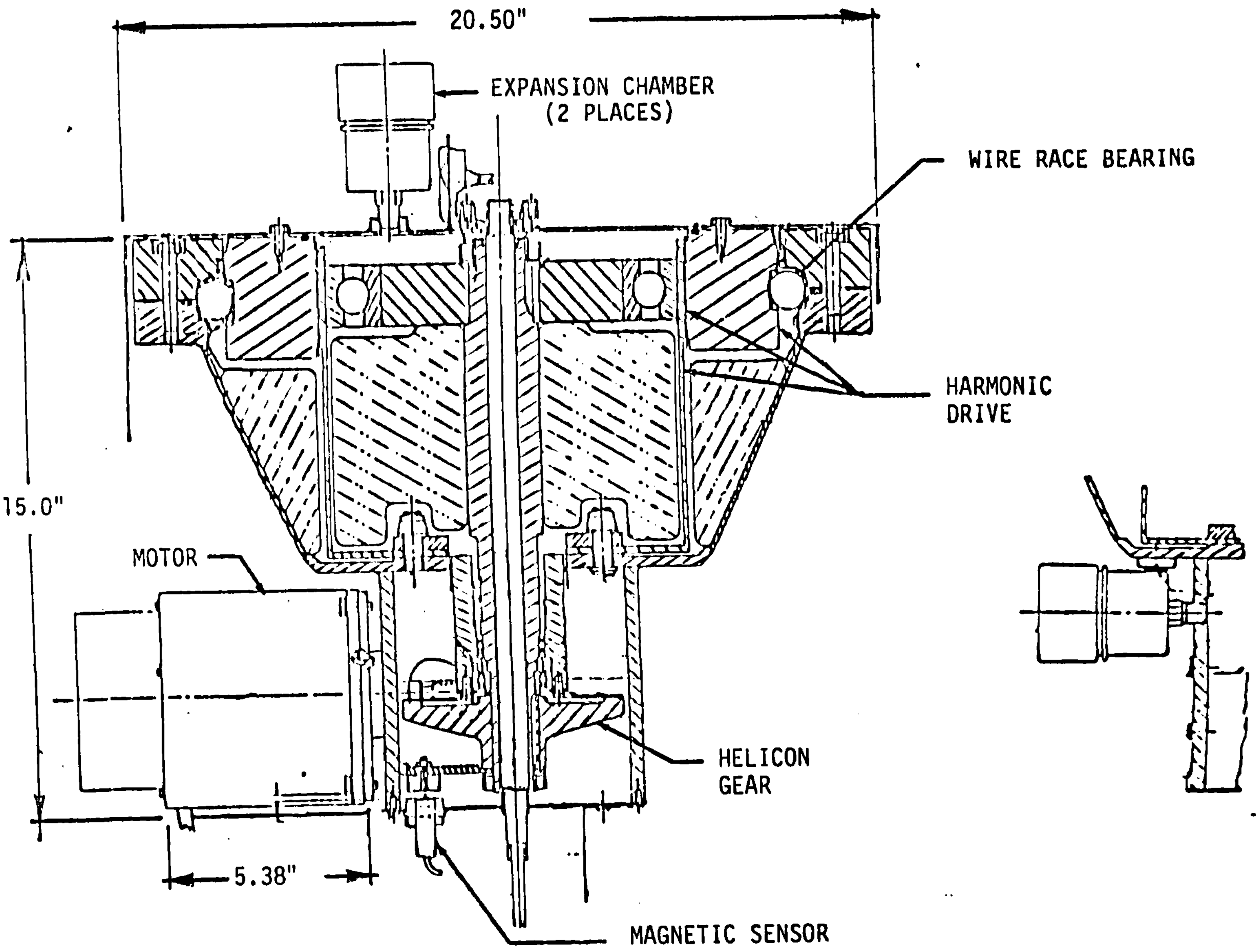


FIGURE 2 AZIMUTH DRIVE CROSS SECTION

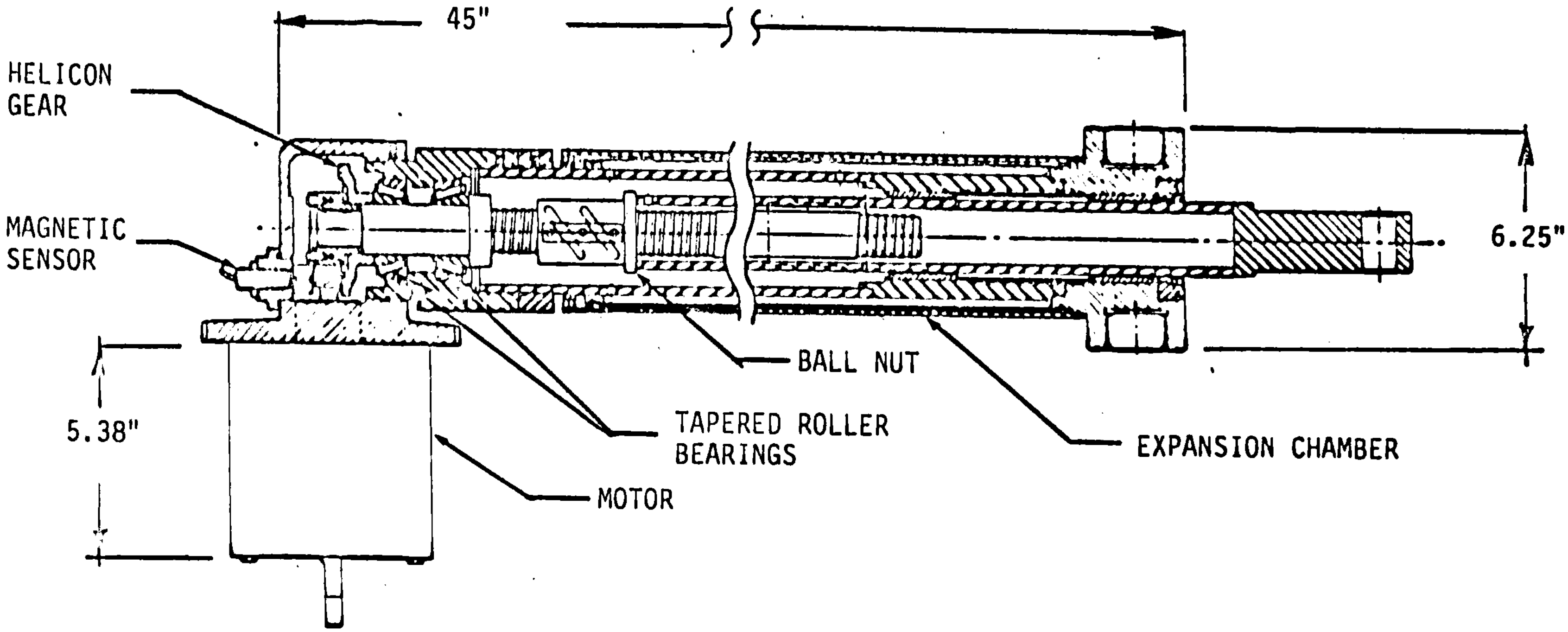


FIGURE 3

JACK CROSS SECTION

SUMMARY

This report documents design evaluation testing accomplished per 1T53864 to investigate and validate performance of the 2nd Generation Heliostat Drive Unit, MDAC P/N 1D22475-1. A test specimen, defined by 1D22436-1, was used for this purpose and a summary of testing accomplished is as follows.

A. Wire Race Bearing

1. Load deflection testing.

B. Elevation Drive

1. Starting torque at max operating load.
2. Efficiency.
3. Hysteresis testing at no-load and max operating loads.
4. Load deflection testing at max static loads.
5. System gain characteristics.

C. Azimuth Drive

1. Starting torque at max operating load.
2. Efficiency.
3. Hysteresis testing at no-load and max operating loads.
4. Load deflection testing at max static loads.
5. Reduction ratio.

During the latter part of the test effort, it was discovered that there was excessive input hysteresis (dead band) in the azimuth drive unit. The problem was traced to high friction in the wire race bearing and was fixed by reshimming the bearing.

This problem had not been anticipated and the shimming procedure did not adjust or test for excessive friction. Recommendations are made to revise the shimming procedure to preclude this potential problem.

Following rework, the unit was retested for those parameters which were influenced by reshimming. A summary of the final test results, including the unit design requirements, is presented in Figure 4.

Final conclusions are that the unit performed satisfactorily, all design requirements were met, and the structural integrity of the unit was proven. The drive unit is recommended for use on the 2nd Generation Heliostat.

FIGURE 4

2ND GENERATION HELIOSTAT DRIVE UNIT REQUIREMENTS/CAPABILITIES

Parameter	Azimuth		Elevation	
	Requirement	Capability	Requirement	Capability
Travel Time	180° in 15 Min.	180° in 12.5 Min.	90° in 7.5 Min.	Apx. 90° in 6.0 Min.
Survival Load (Face Up at 90 MPH)	99,500 In-Lbs	>212,500 In-Lbs	27,300 Lbs.	>44,000 Lbs.
Max Static Load (Any Orientation at 50 MPH)	144,000 In-Lbs	>212,500 In-Lbs	13,900 Lbs.	>18,600 Lbs.
Max Operational	80,900 In-Lbs	103,000 In-Lbs	10,816 Lbs.	>18,600 Lbs.
Deflection at 27 MPH	2.4 mrad at 41,900 In-Lbs	1.7 mrad at 42,000 In-Lbs	1.85 mrad at 52,900 In-Lbs and α = 20, 40°	1.6 mrad at 52,900 In-Lbs and α = 40°
Overturning Moment (At the Azimuth Drive Bearing Centerline)	401,000 In-Lbs with 9,400 Lb Axial and 4,500 Lb Radial	>512,000 In-Lbs		

DISCUSSION

Testing of the drive unit was accomplished in the MDAC-HB Structures Lab in accordance with 1T53864. The test specimen was built up on a short pedestal to the requirements of 1D22436 and is shown in Figure 5. Testing was broken into three categories: (1) testing to verify proper shimming of the wire race bearing; (2) testing to evaluate the elevation drive; and (3) testing to evaluate the azimuth drive.

1.0 Wire Race Bearing Evaluation

The wire race bearing was shimmed during assembly of the drive per the requirements of 1D22494. The procedure is to assemble the unit without o-rings or shims (see Figure 2) and torque the 3/8" bolts to 10 ± 1 in-lbs. The gap between the 1D22489-1 retainer and 1D22474-1 support is measured 4 places 90° apart and the shim sized to the average reading +.000/-.001.

The specimen was tested to determine compliance of the bearing at the max overturning moment of ± 401,000 in-lbs. Based on previous experience, the expected compliance was about ± 1.0 milliradian (mrad). The specimen was instrumented with dial indicators and measurements of load vs. deflection were recorded. These data are presented in Figure 6. The data show a deflection of ± 1.9 mrads which is unacceptable. The specimen was shimmed to 0.071" during assembly. It is postulated that 10 ± 1 in-lbs was not sufficient to overcome the running friction of the bolts and produce enough preload to seat the bearing components properly. This resulted in a loose fit up of the bearing causing excessive play as evidenced by the deflection hysteresis around the zero load point.

The specimen was disassembled and .006" of shim removed, leaving .065". The test was rerun and these data are given in Figure 7. Comparing Figures 6 and 7 shows that the compliance is now approximately ± 1.2 mrads. This was still greater than anticipated, so the specimen was disassembled and the shim peeled to .063". Data from test of this shim condition are

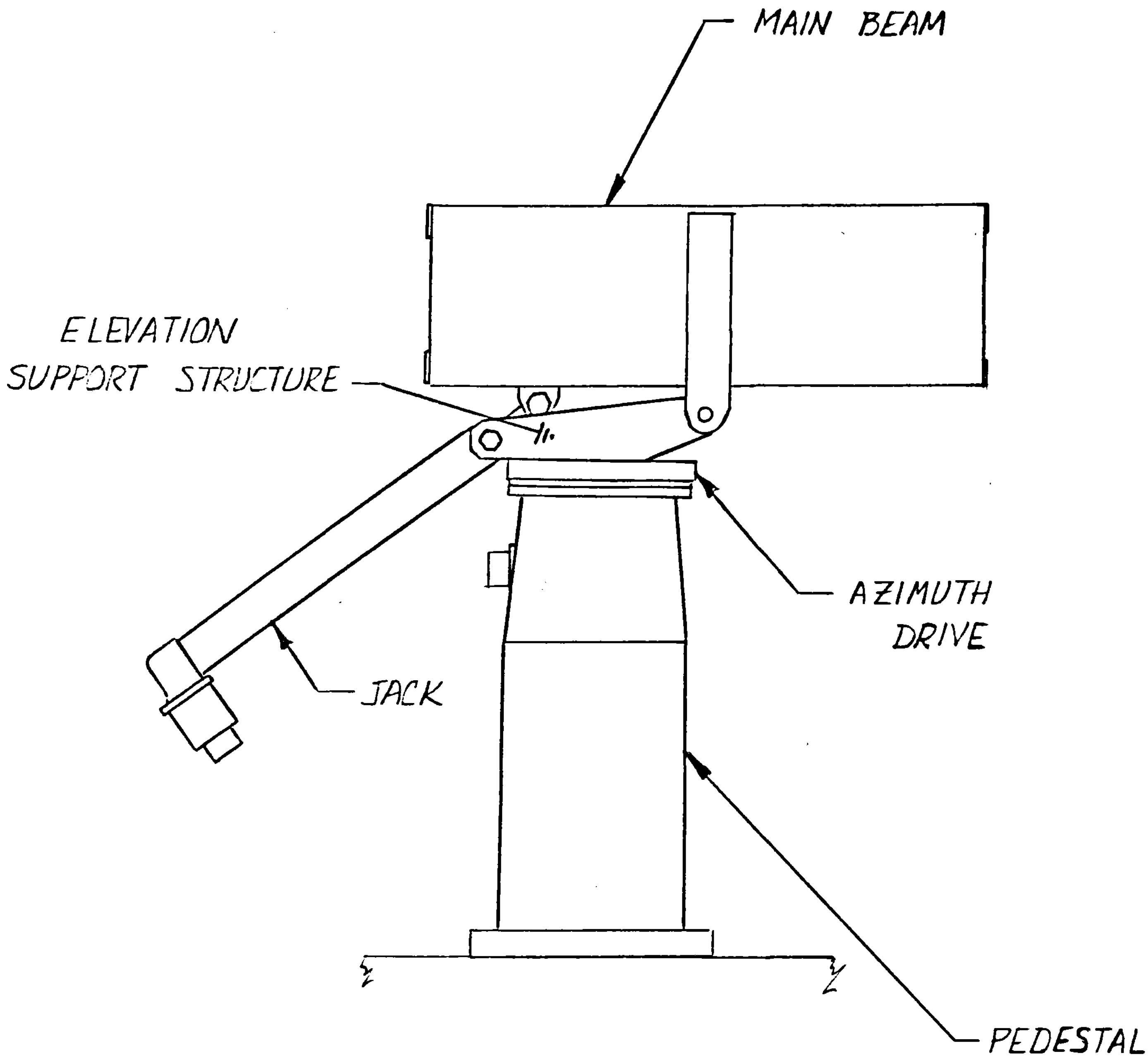
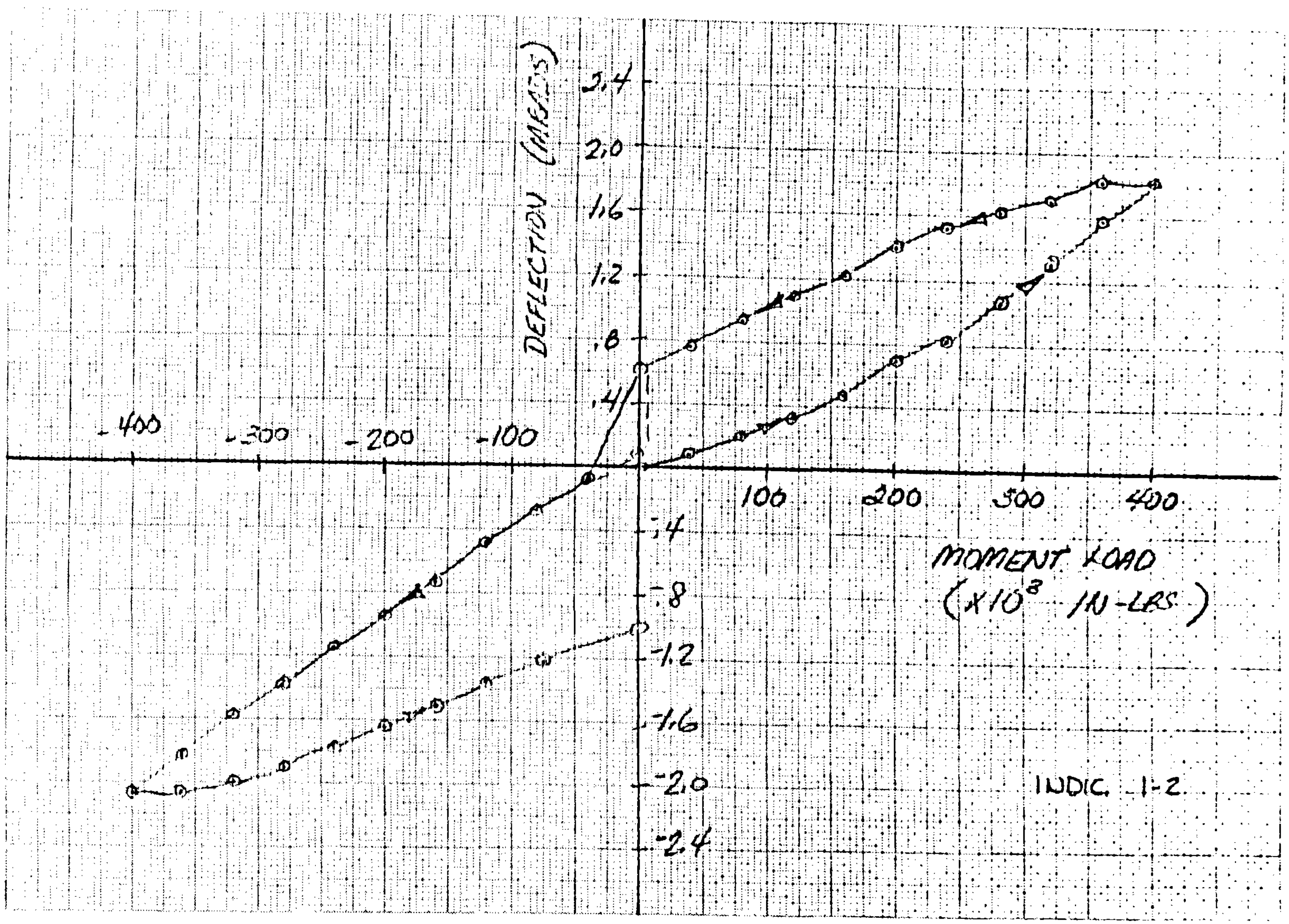


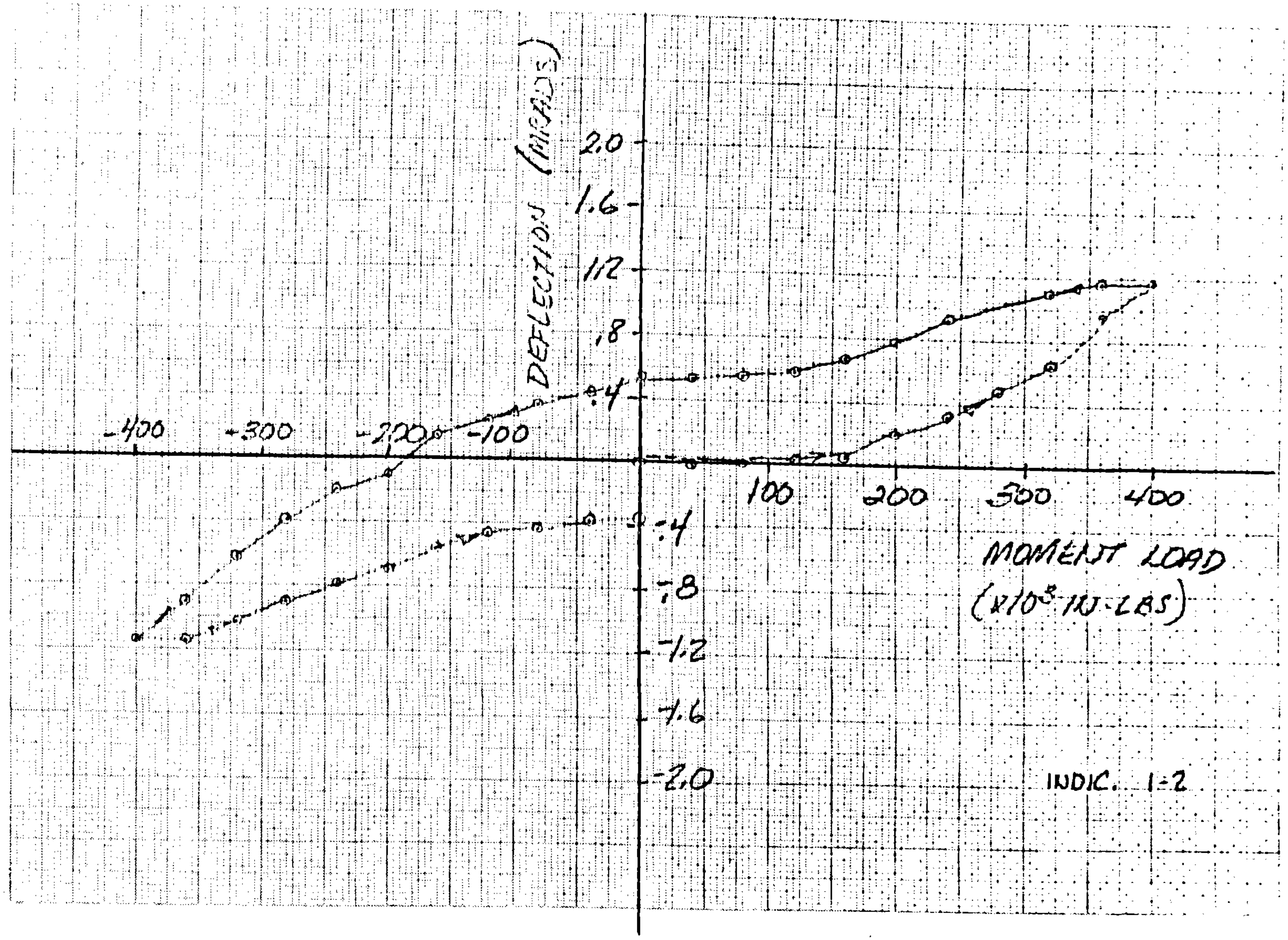
FIGURE 5

DRIVE UNIT TEST SPECIMEN



LOAD VS. DEFLECTION HELIOSTAT TEST SPECIMEN 7-15-80
OVERTURNING MOMENT ⊥ TO ELEV. DRIVE (.071" SHIM)

FIGURE 6



LOAD VS. DEFLECTION OT MOMENT ⊥ TO ELEV. DRIVE. HELIOSTAT TEST SPECIMEN (.065" SHIM) 7-16-83

FIGURE 7

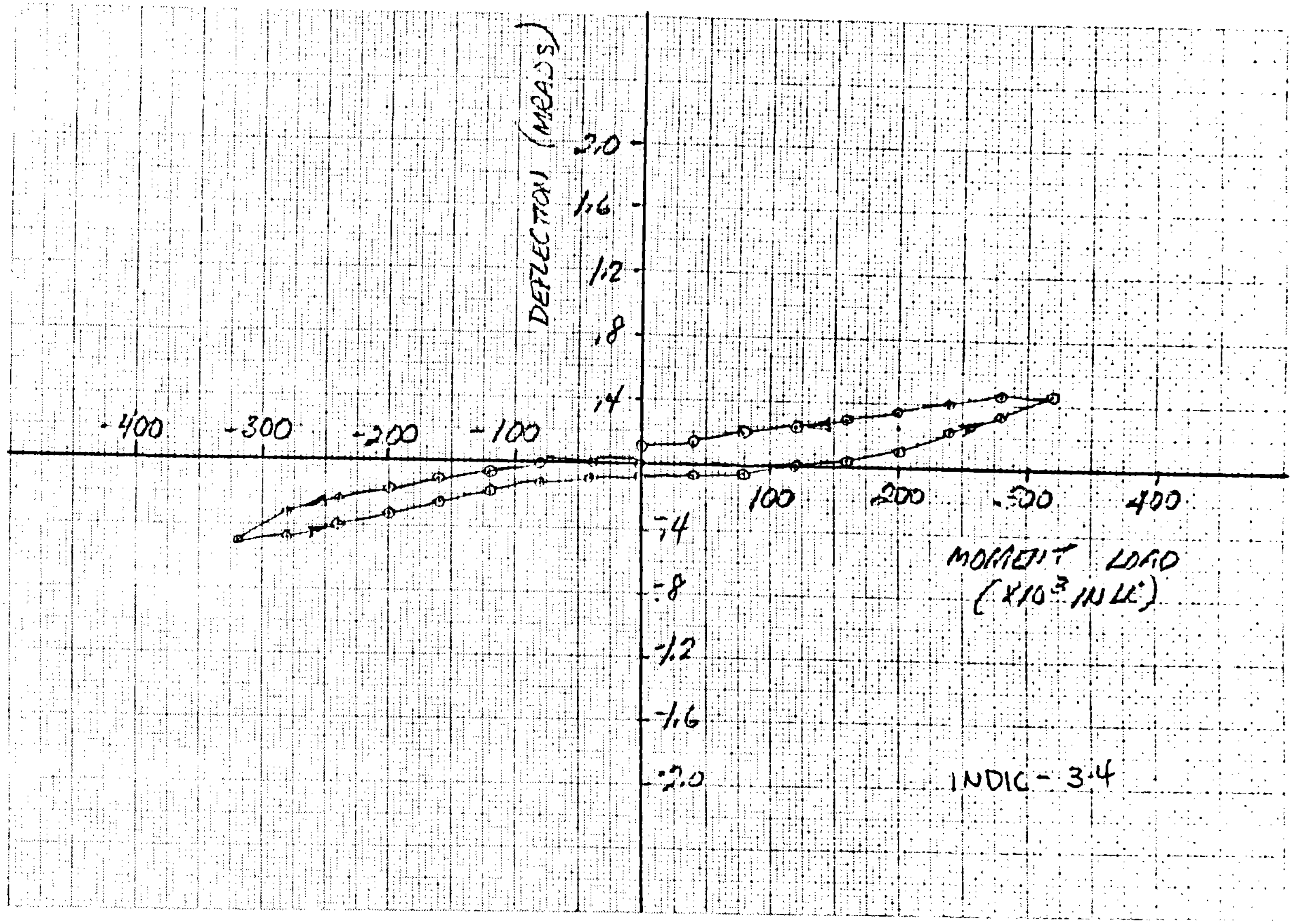
shown in Figure 8. Figure 8 is not directly comparable to Figures 6 or 7 since the data from Figure 8 are taken in the elevation plane, 90° from the axis used in Figures 6 and 7. However, these data indicate a tight bearing with a compliance of only ± 0.5 mrads.

During testing to determine the load deflection characteristics of the wire race bearing, the test specimen was inadvertently overloaded in the elevation axis. This resulted in a load of approximately 44,000 lb. tension applied to the jack. The jack design load is 28,100 lb. tension which means a 60% overload was applied. The specimen was not damaged as determined by visual inspection and dimensional checks of the jack and main beam structure following the incident. A load deflection test was run on the jack with the test specimen at the 40° attitude. The test results are shown in Figure 9. These data show a 0.011" backlash around the zero load point which is more than anticipated. The backlash in the ball nut, as measured at Duff-Norton, was .003 to .005 and the backlash in the helicon gear set would be negligable at the output. It is postulated that overloading the jack could have resulted in reseating the tapered roller bearings which react the axial loads in the jack. This would result in increased clearances in the bearing set and show up as backlash. Further investigation led to the conclusion that the jack was structurally sound and still operating properly. It was decided to continue testing as planned and no further troubles or anomalies arose due to this incident. Subsequent jack performance was acceptable.

This overload condition also resulted in an overturning moment of 512,000 in-lb on the wire race bearing. Continued testing and later disassembly showed no damage to this hardware.

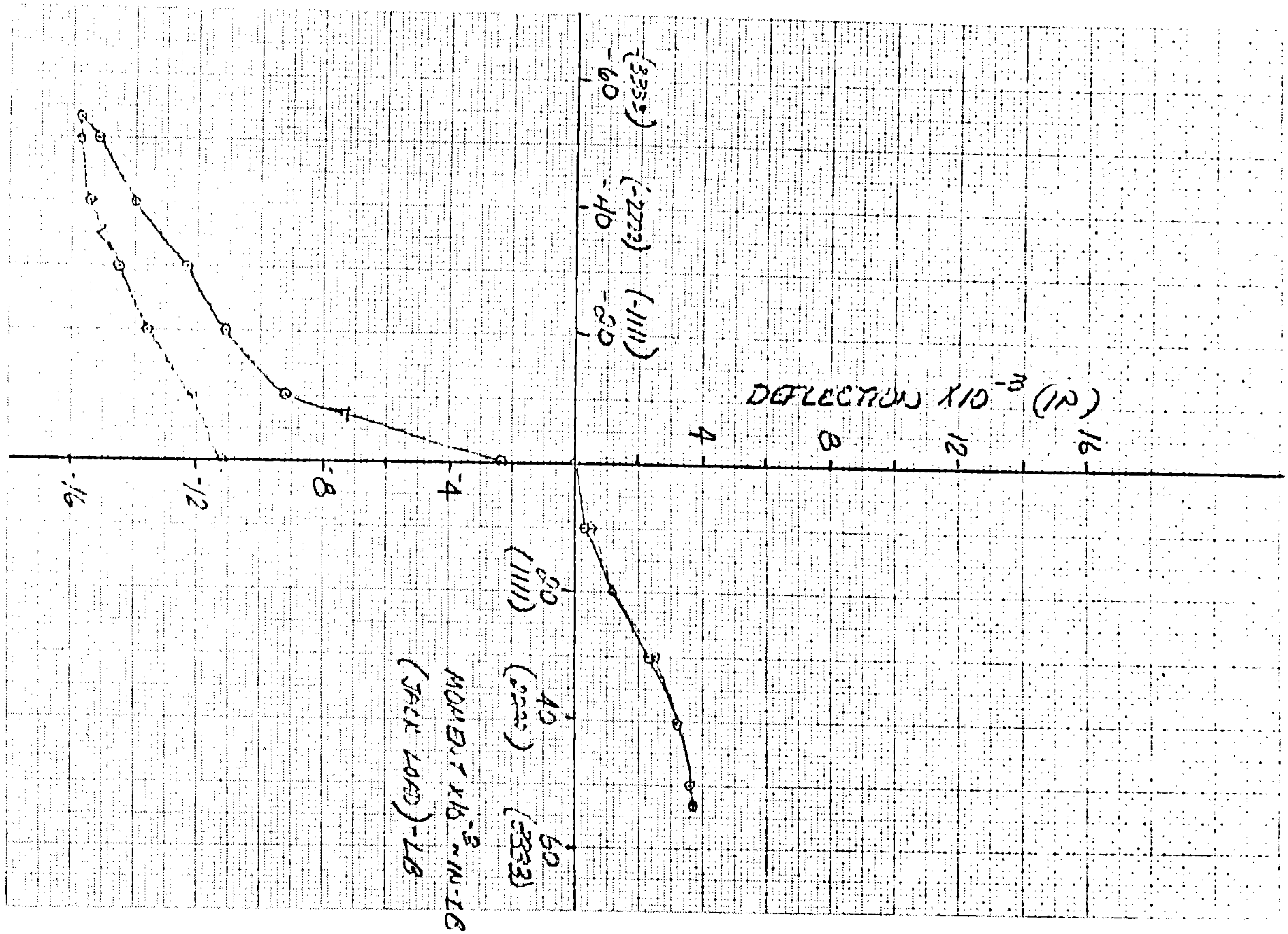
2.0 Elevation Drive Tests

Elevation drive testing was accomplished to determine starting torques, efficiencies, max operating hysteresis, and max static hysteresis. All external loads were applied to the test specimen using hydraulic cylinders.



LOAD VS. DEFLECTION ELEV. PLANE (.063" SHIM) 7-18-80

FIGURE 8



ELEV. DRIVE JACK DEFLECTION @ 40°

7-30-80

FIGURE 9

2.1 Starting Torque

This test was run with the specimen at a 90° elevation angle (main beam vertical) and at 10,816 lb. tension load applied to the jack (142,700 in-lb moment). This represents a worst case operational load for the elevation drive motor. A torque wrench was used to measure the torque required to breakout the motor with and against the load. Voltage was applied to the motor and increased until breakout occurred in both directions. In a second test, the external hydraulic loads were removed from the specimen leaving a dead weight moment of 10,400 in-lbs (790 lbs on the jack). Breakout torque and voltage were measured at this condition. The results of these tests are as follows:

Moment (In-Lbs)	Jack Load (Lbs)	Breakout Torque		Breakout Voltage	
		With	Against	With	Against
142,700	10,816 tension	8 in-lbs	23 in-lb	156	158
10,400	790 tension	50 in-oz	60-70 in-oz	157	157

Design calculations predicted a worst case startup torque of 28.8 in-lbs would be required for the jack motor. This value was calculated using manufacturers worst case efficiencies for the ball nut, bearings, and helicon gear set. The 23 in-lb actual measured value is well within this maximum.

2.2 Efficiencies

The elevation drive was loaded to 180,000 in-lbs at 40°, and 142,700 in-lbs at 90°, and power applied to the motor for 20 seconds to measure efficiency. The counter on the motor was used to determine the distance traveled and a power meter in the voltage supply to the motor gave a direct readout of voltage, current and power. The results are recorded in Figure 9.1 and show an efficiency of 15.3% and 18.4% working against the load. For the test conditions noted above, the jack efficiency should be almost the same. The load on the jack is 10,000 lb. and 10,816 lb., respectively, and the jack should perform with about the same efficiency in both cases. The only explanation for the difference would be tolerances in the applied load or test instrumentation and the fact that the ball nut inside the jack would be operating on a different portion of the drive screw.

FIGURE 9.1

1980

2ND GENERATION HELIOSTAT EFFICIENCIES

MOMENT LOAD (x1000 IN-LB)	MTR ROTATION WRT LOAD	VOLTS	CURRENT -AMPS A	B	C	WATTS	PWR IN (FT-LB/SEC)	PWR OUT (FT-LB/SEC)	EFFICIENCY (%)
AZIMUTH DRIVE									
80.9 CW	AGAINST	212	1.1	1.1	1.15	280	206.5	28.6	13.8
80.9 CW	WITH	212	0.9	0.9	0.9	110	81.1	–	–
40 CW	AGAINST	211	1.0	1.0	1.0	220	162.3	14.3	8.8
40 CW	WITH	212	0.9	0.9	0.9	100	73.8	–	–
80.9 CCW	AGAINST	212	1.1	1.15	1.15	320	236	28.7	12.2
80.9 CCW	WITH	212	0.9	0.9	0.9	105	77.4	–	–
40 CCW	AGAINST	212	0.95	1.0	1.0	220	162.3	14.3	8.8
40 CCW	WITH	212	0.9	0.9	0.9	100	73.8	–	–
ELEVATION DRIVE									
180 TENSION	AGAINST	212	1.6	1.5	1.39	420	310	56.9	18.4
@ 40°	WITH	212	1.15	0.95	0.93	156	115	–	–
42.7 TENSION	AGAINST	208	1.8	1.7	1.65	530	391	59.8	15.3
@ 90°	WITH	208	1.15	0.9	0.9	130	96	–	–

2.3 Operating Load Hysteresis

Load vs. deflection measurements were taken on the specimen in the elevation plane at angles of 0°, 40° and 90°. Hydraulic cylinders applied a moment of ± 53,000 in-lb (see Figure 10) to simulate a 27 mph wind load, and deflection readings were taken at intervals using electronic levels (see Figure 11).

Three minilevels (Wyler Co. Model #10H-150) were used. One mounted to the pedestal, one to the support structure, and one to the main beam. Data from these tests are presented in Figures 12, 13 and 14. The design requirement for the drive unit is 1.85 mrad average deflection at 40° in a 27 mph wind. Test results at 40° elevation angle show a deflection of 1.2 mrad for a moment load corresponding to 27 mph wind load.

Another test of elevation drive hysteresis and sensitivity was performed to quantify the unit performance. Input hysteresis was measured with the unit at 40° elevation by manually advancing the drive motor and monitoring the change in elevation using the minilevel. Data was taken at every 4 motor turns. The test was conducted at no-load (specimen dead weight only) and at 53,000 in-lbs tension and compression load. Data is plotted in Figures 15 through 17. Two motor turns was the maximum hysteresis noted as a measure of input sensitivity.

The control system budget for elevation drive backlash was originally targeted at 0.14 mrads which was recognized as optimistic. 0.14 mrads equates to 1.1 motor revolution at the optimum linkage gain. Further evaluation considering the total budget for beam pointing error (1.43 mrad rms) concluded that 2 motor turns backlash is acceptable.

2.4 Max Static Load Hysteresis

Deflection testing in the elevation plane continued up to loads simulating the max static capabilities of the drive unit. With the unit at 0° and 90° elevation, loads of ± 320,000 in-lb were applied and deflection readings taken at intervals. These data are presented in Figures 18 and 19.

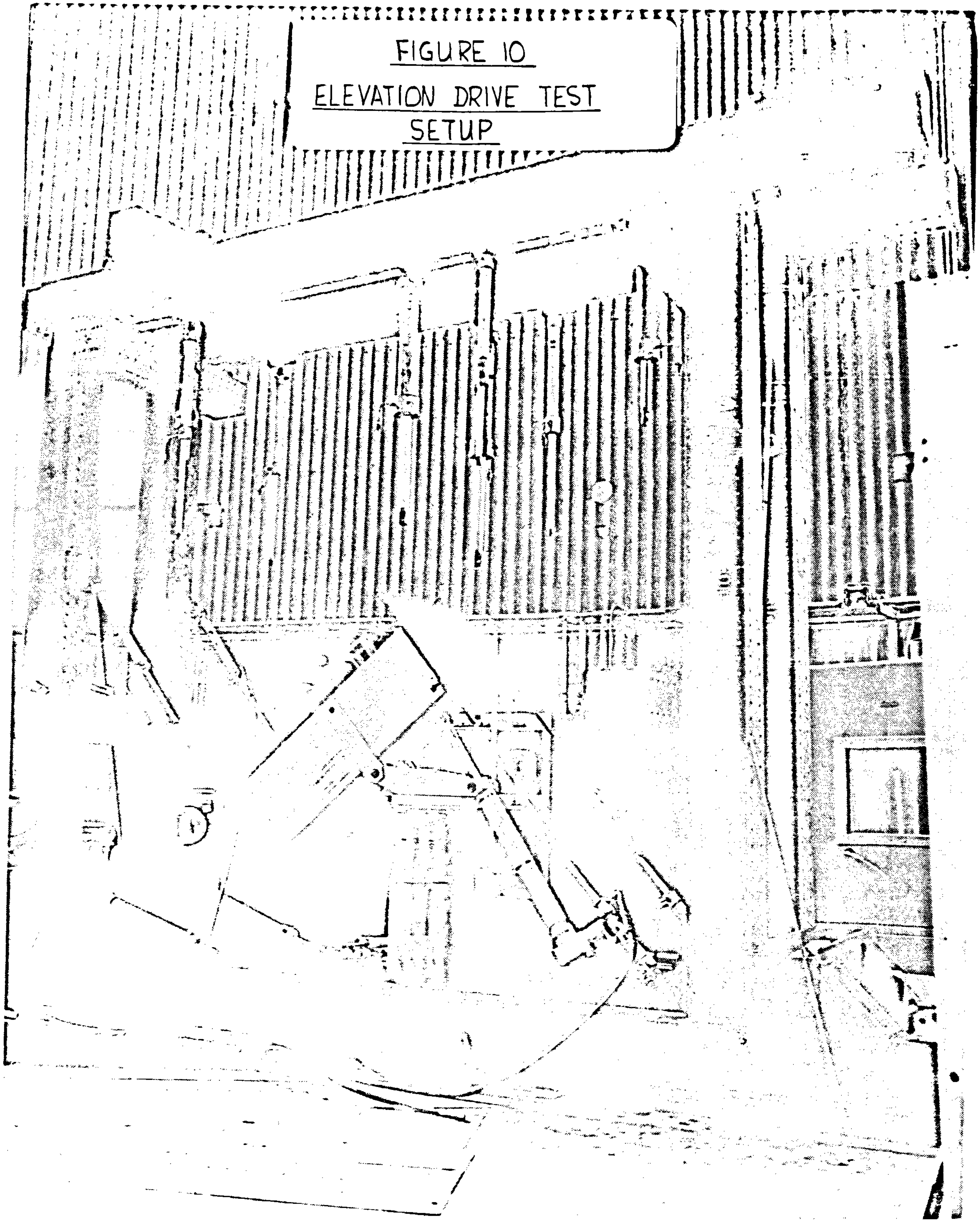


FIGURE 10

ELEVATION DRIVE TEST SETUP

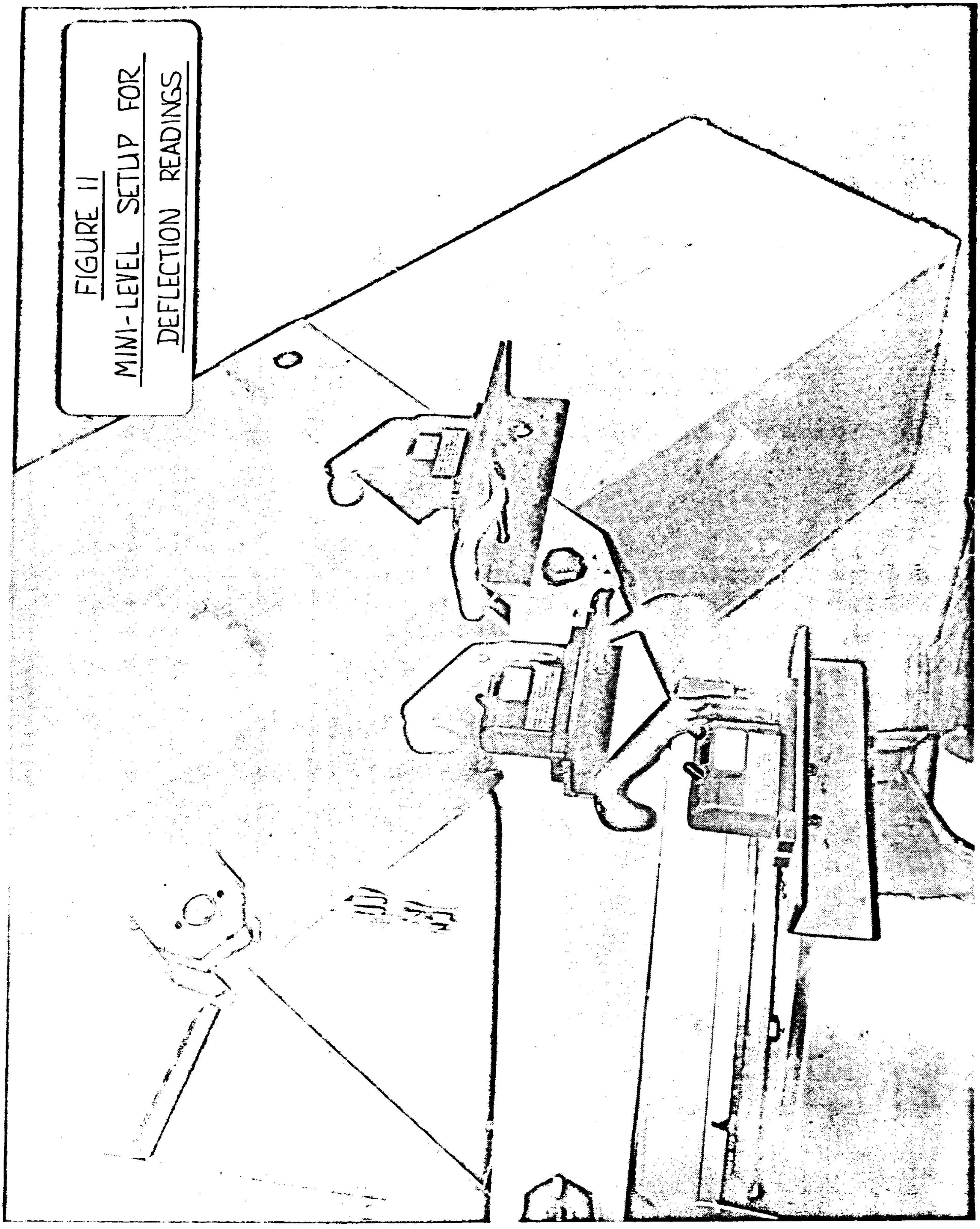
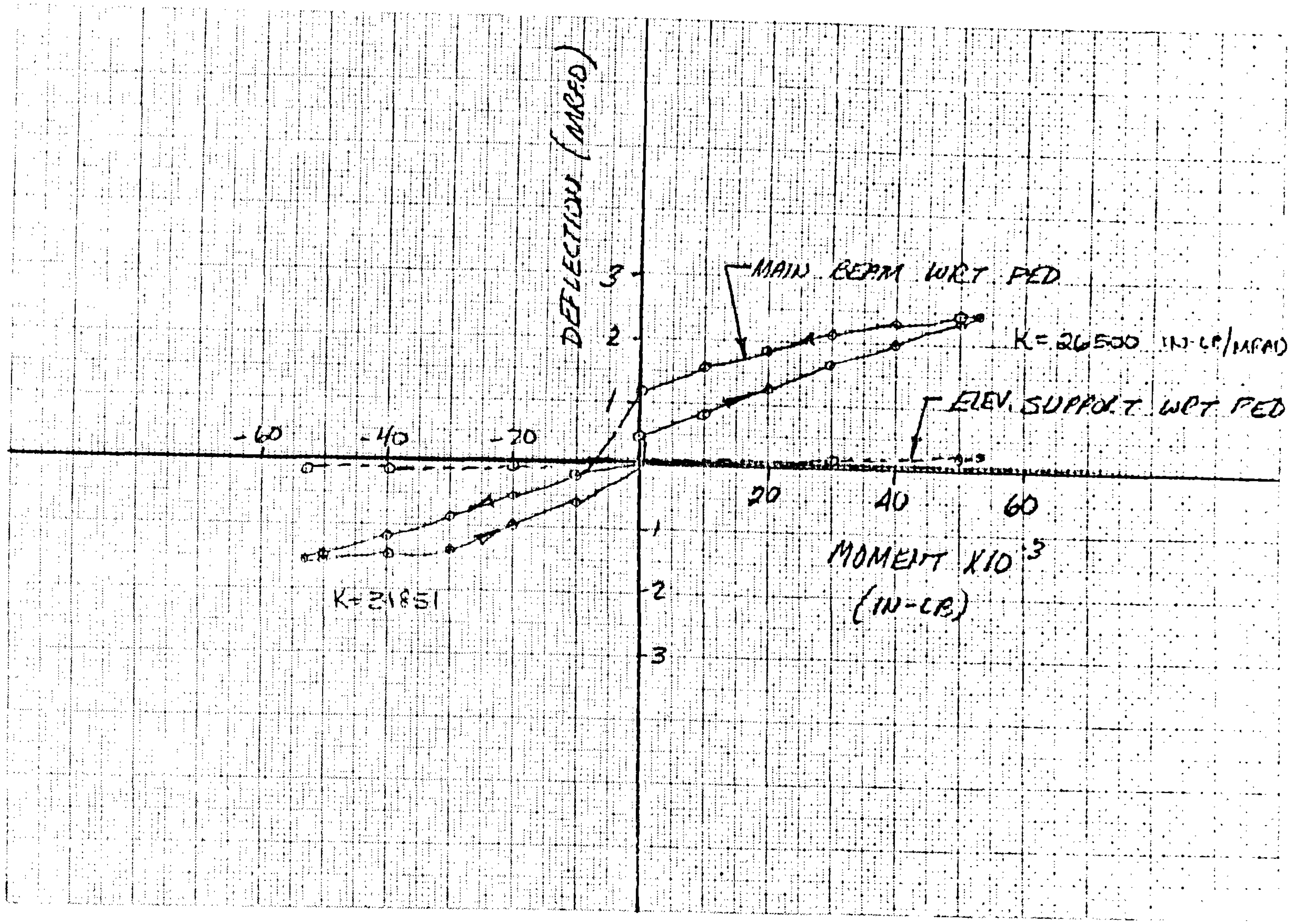


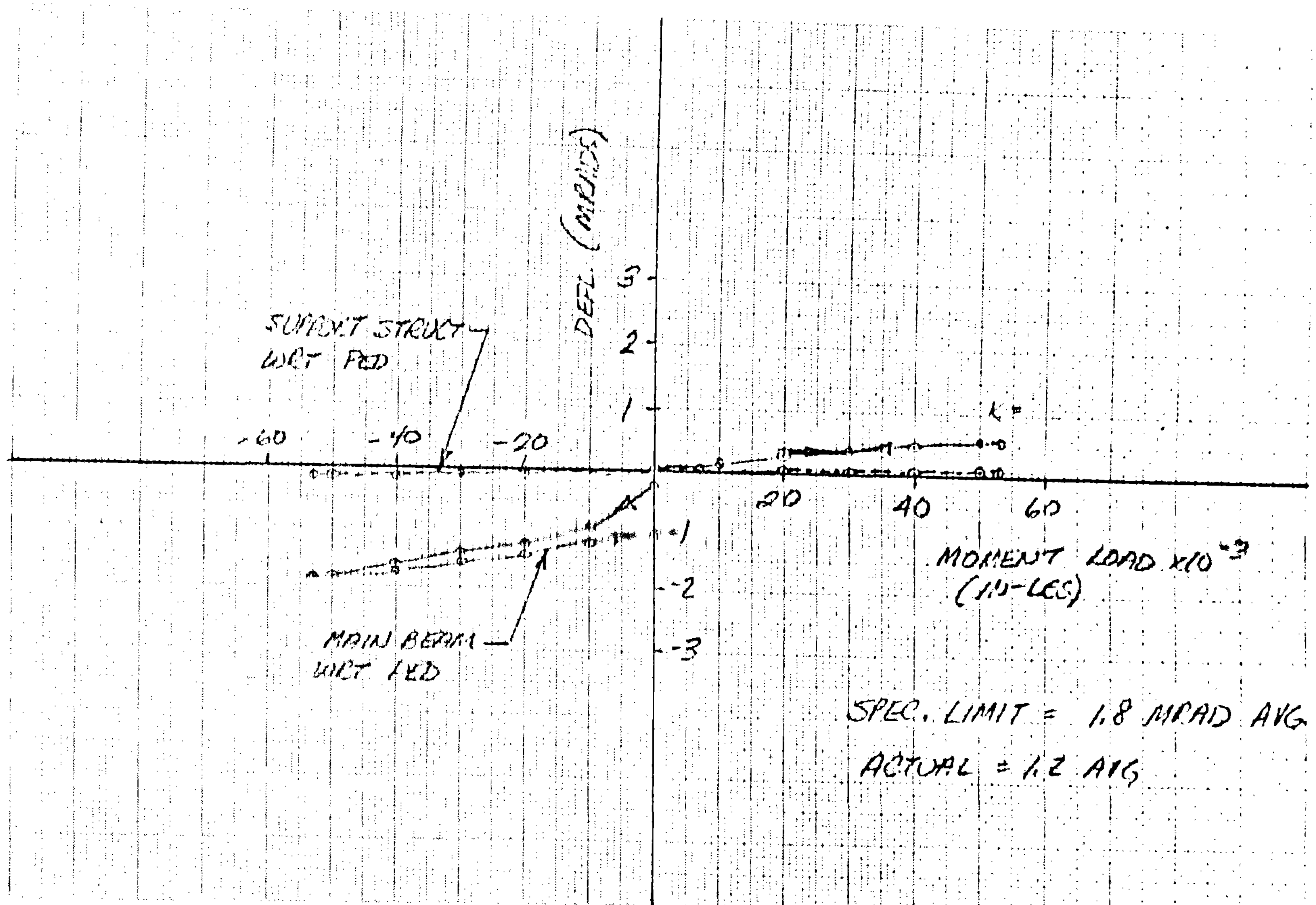
FIGURE 11

MINI-LEVEL SETUP FOR DEFLECTION READINGS



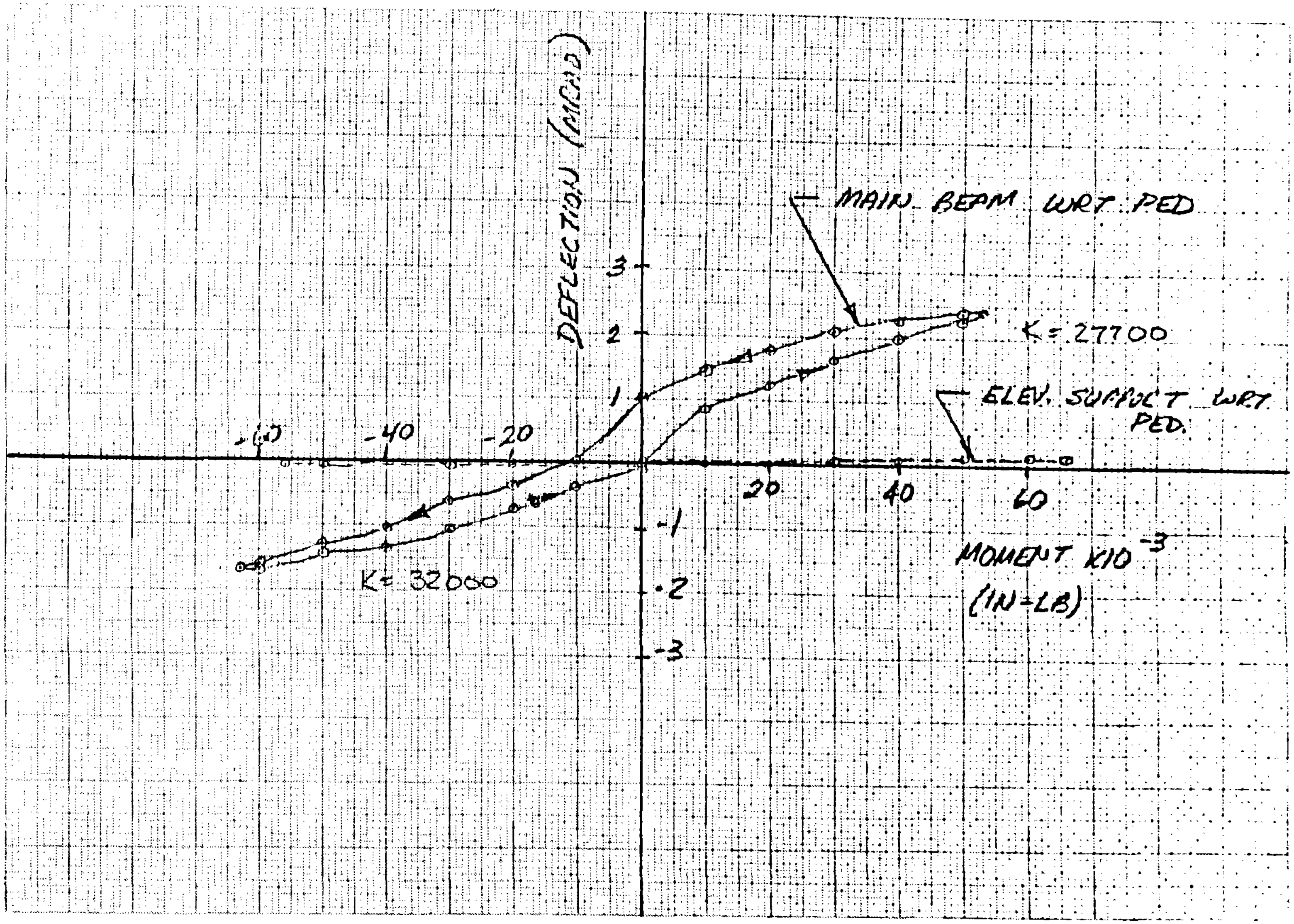
ELEV. DRIVE MAX. OP. HYSTERESIS @ 0° 1T53864 ⍝ 3.3.5
7-26-80

FIGURE 12



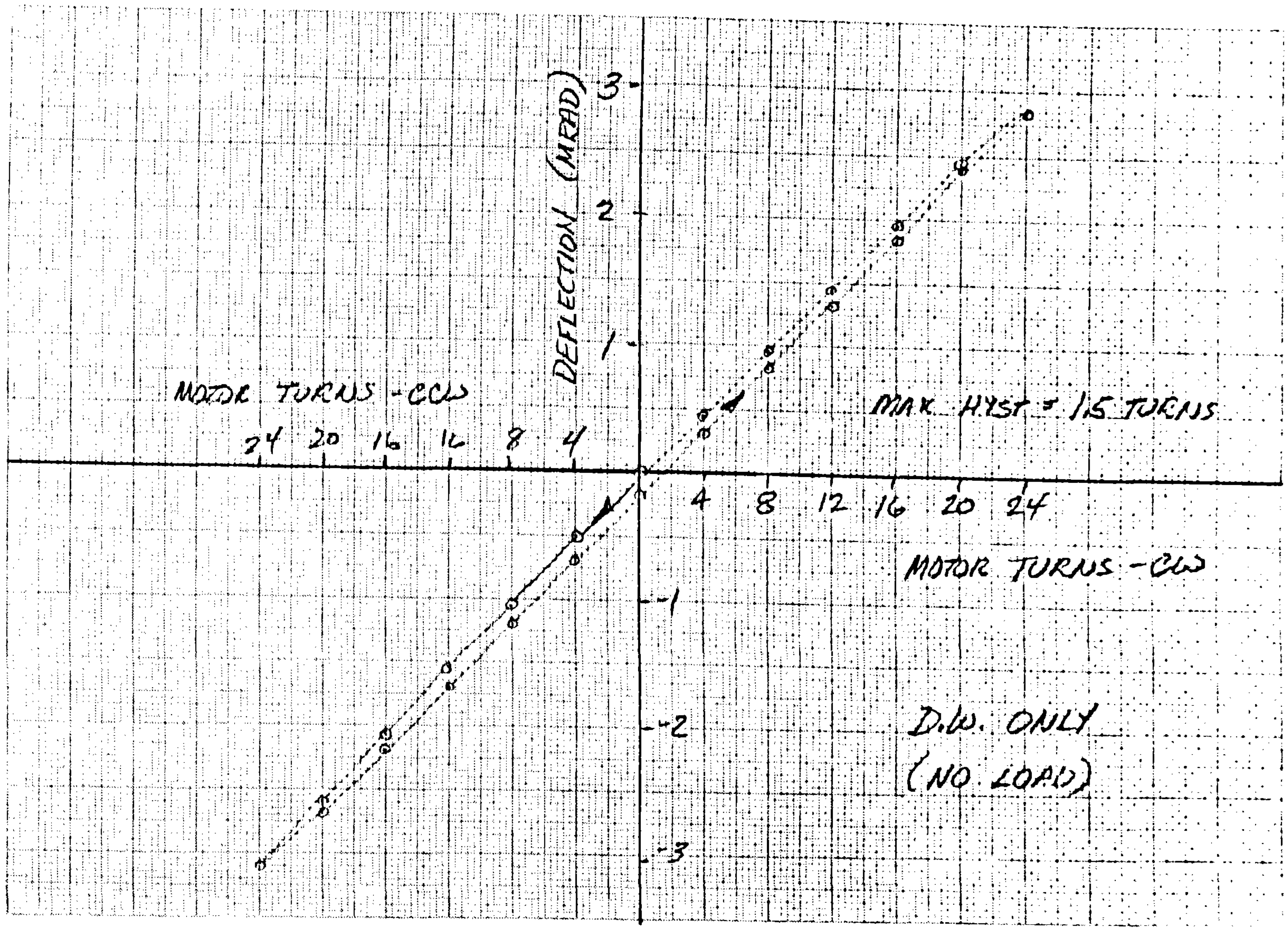
ELEV. DRIVE MAX. OP. HYSTERESIS @ 40° IT53864 ¶ 3.3.5
7-30-80

FIGURE 13



ELEV. DRIVE MAX OR HYSTERESIS @ 90° (.0?? SHIM) 1753864 ¶3.3.5 7-28-80

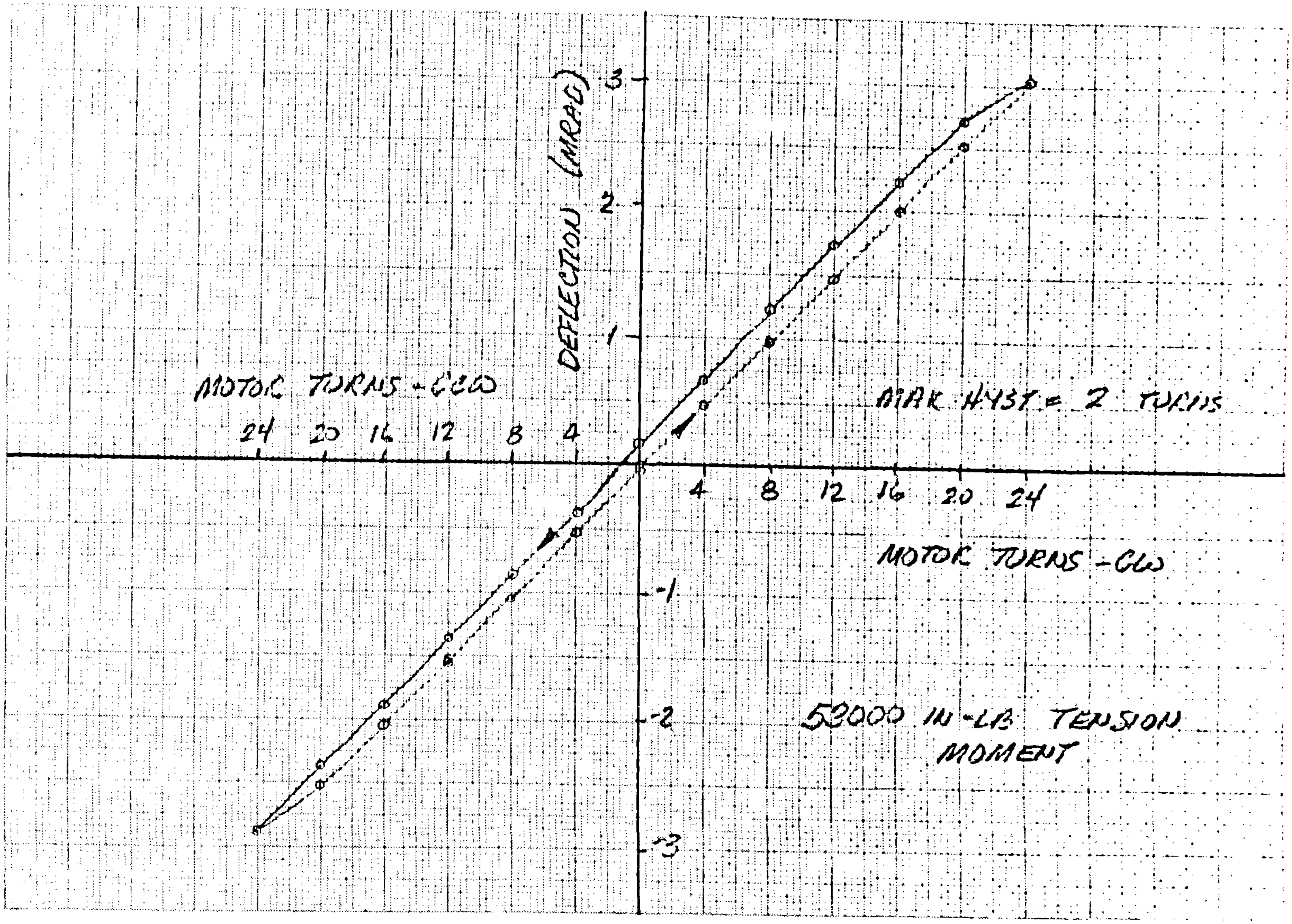
FIGURE 14



ELEV. DRIVE INPUT HYSTERESIS

7-30-80

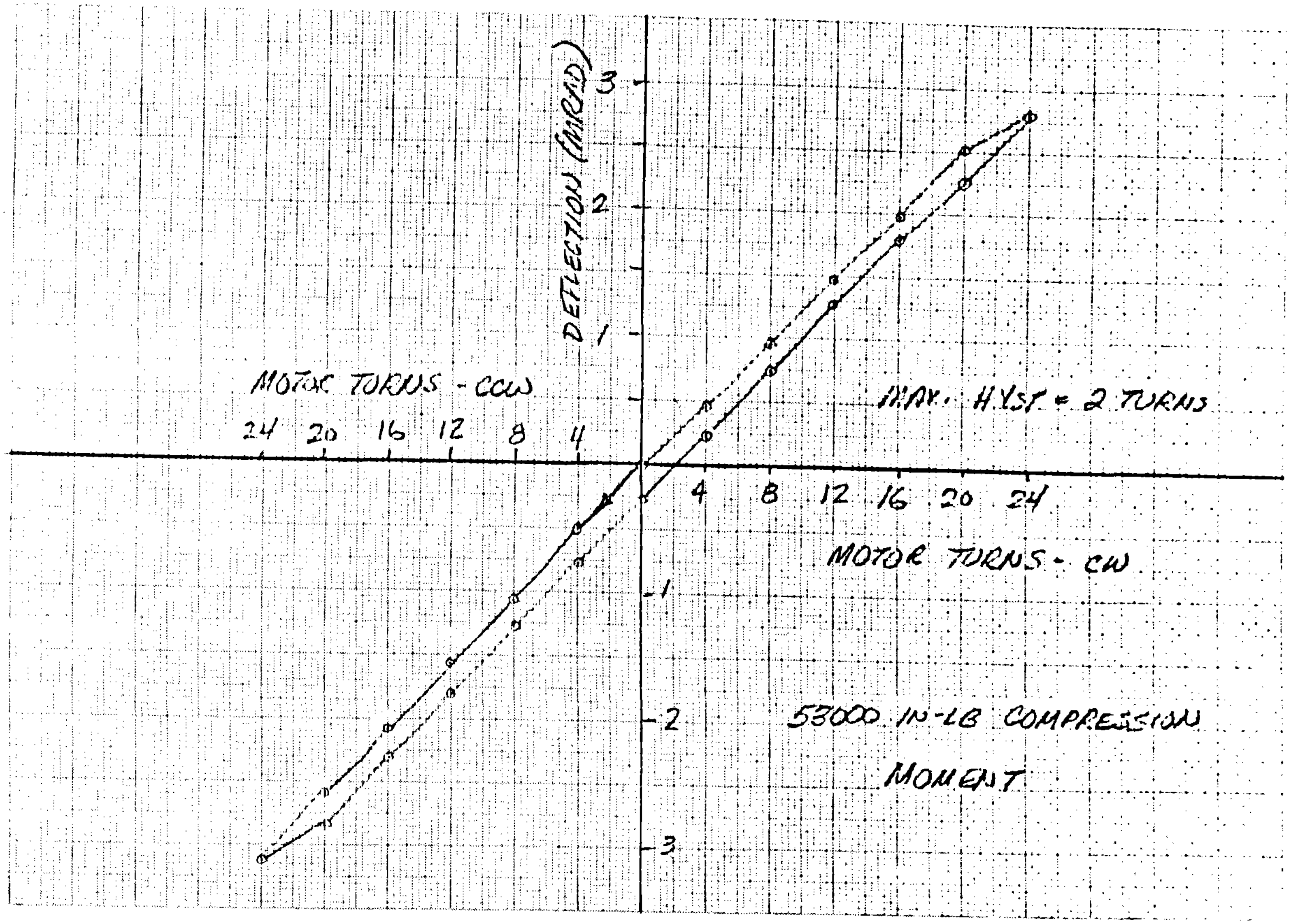
FIGURE 15



ELEV DRIVE INPUT HYSTERESIS (.063 SHIM)

IT53864 ¶3.3.5b
7-30-80

FIGURE 16



ELEV. DRIVE INPUT HYSTERESIS
(.06? "SHIM")

IT53864 # 3.3.5 b
7-30-80

FIGURE 17

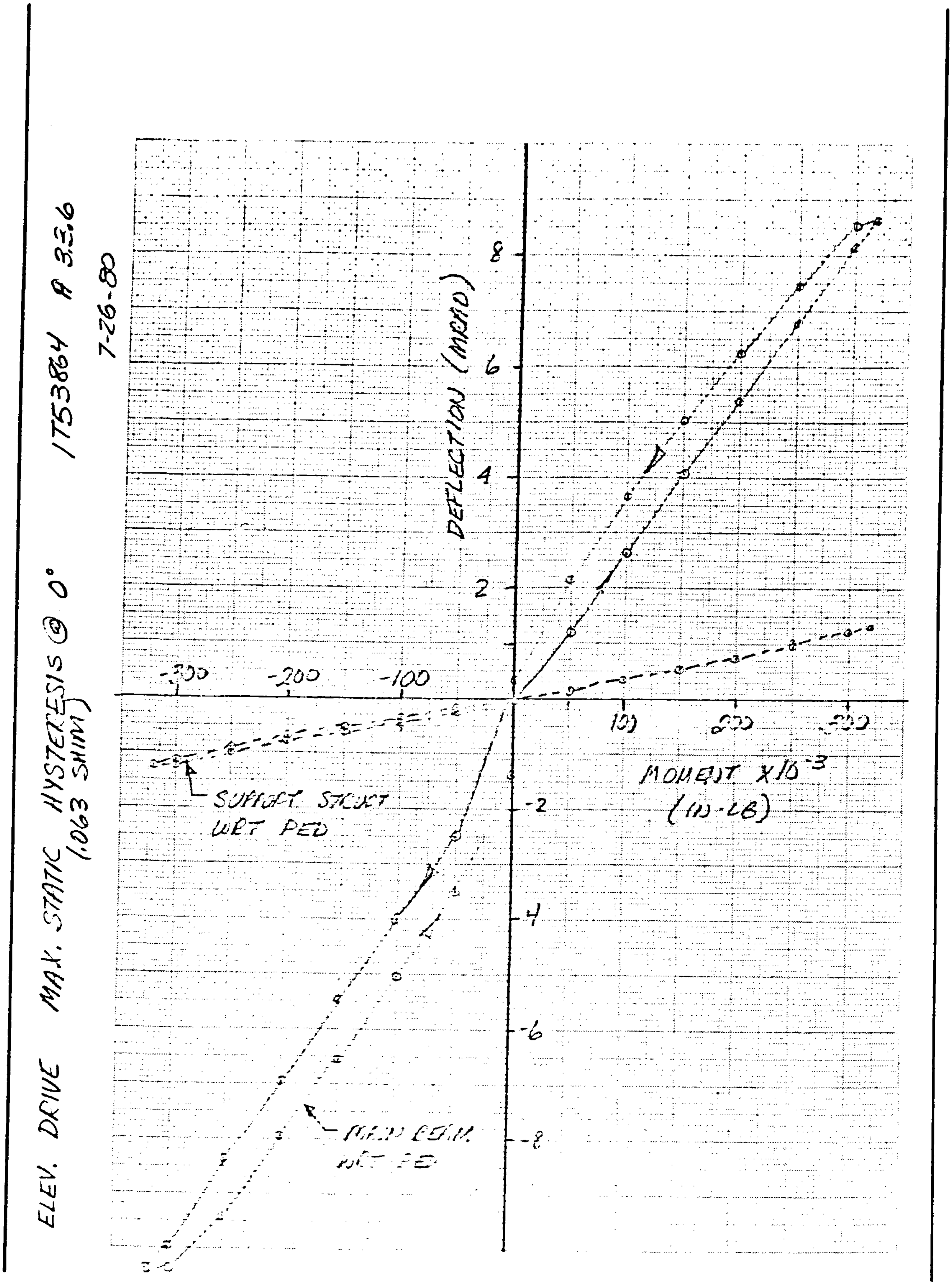

ELEV. DRIVE MAX. STATIC HYSTERESIS @ 0°
(.063 SHIM)
7-26-80
DEFLECTION (MRAD)
8
6
4
2
-2
-4
-6
-8
-300
-200
-100
100
200
300
MOMENT X10^{-3}
(IN-LB)
SUPPORT STRUCT
WRT PED

FIGURE 18

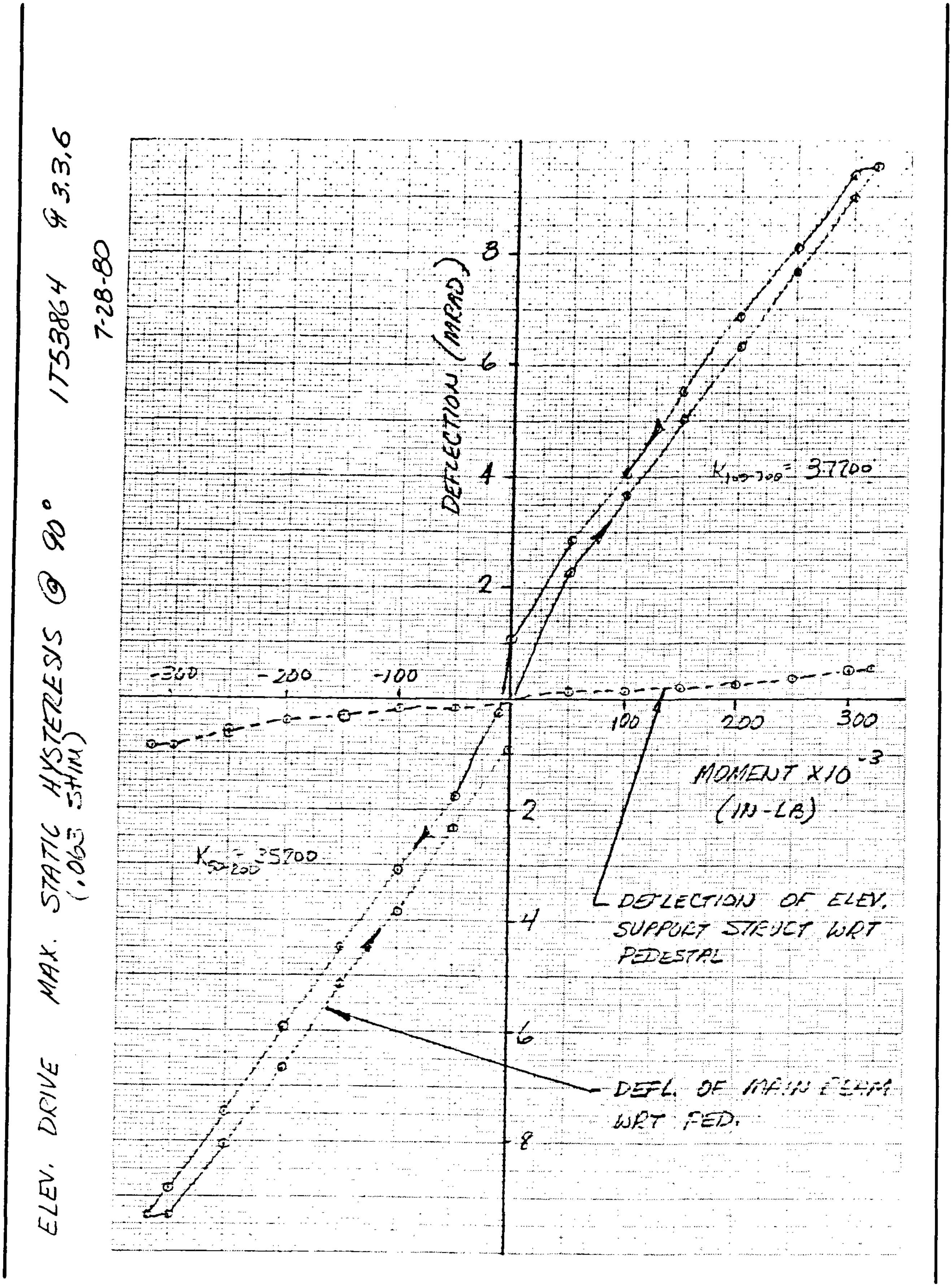

ELEV. DRIVE MAX. STATIC HYSTERESIS @ 90°
(.063 SHIM)
1T53864 # 3.3.6
7-28-80
DEFLECTION (MRAD)
8
6
4
2
2
4
6
8
-300
-200
-100
100
200
300
MOMENT X10^-3
(IN-LB)
K100-300 = 37700
K50-200 = 35700
DEFLECTION OF ELEV. SUPPORT STRUCT WRT PEDESTAL
DEFL. OF MAIN BEAM WRT PED.

FIGURE 19

2.5 System Gain Characteristics

The elevation drive gain characteristics were derived analytically and a test was planned to verify the results. A tri-axial accelerometer was mounted on the main beam with 2 channels of output available to determine the elevation angle. The main beam was initially set to its horizontal reference point using the SK 1D22475-1ATP1 #1 tool and then elevation data was recorded each 500 motor revolutions. Problems arose with the test setup and it was discovered that the data was unreliable and inconsistent. Since time did not permit troubleshooting of the electronics, the test was terminated.

3.0 Azimuth Drive Tests

Azimuth drive testing was accomplished to determine starting torque, efficiencies, max operating hysteresis and max static hysteresis. All external loads were applied with hydraulic cylinders and deflection readings about the azimuth axis obtained using a transit and target. Moment CW-CCW reference is looking down on the specimen.

3.1 Starting Torque

Moments were applied to simulate the maximum operating load for the azimuth drive and a torque wrench used to measure the motor breakout torque. Voltage was applied to the motor and increased until breakout occurred. A summary is presented below.

Load (In-Lb)	Breakout Torque (In-Oz)		Breakout Voltage	
	With	Against	With	Against
80,900 CW	75-80	165-225	138	148
80,900 CCW	20-25	90-165	137	148

These values are very low and well within the capabilities of the 1/4 HP motor selected for the azimuth drive.

3.2 Efficiencies

For this test, the azimuth drive output member was loaded to 80,900 in-lbs. The load was maintained while the motor was driven against the load and with the load for 20 seconds. An electrical power meter monitored the voltage, current and power to the motor and a counter on the motor monitored the number of turns. These data were recorded for CW and CCW loads and then repeated at 40,000 in-lb load. The data were reduced and are presented in Figure 9.1 with a summary below.

Load	Efficiency
40,000 in-lb	8.8%
80,900 in-lb	12.2 - 13.8%

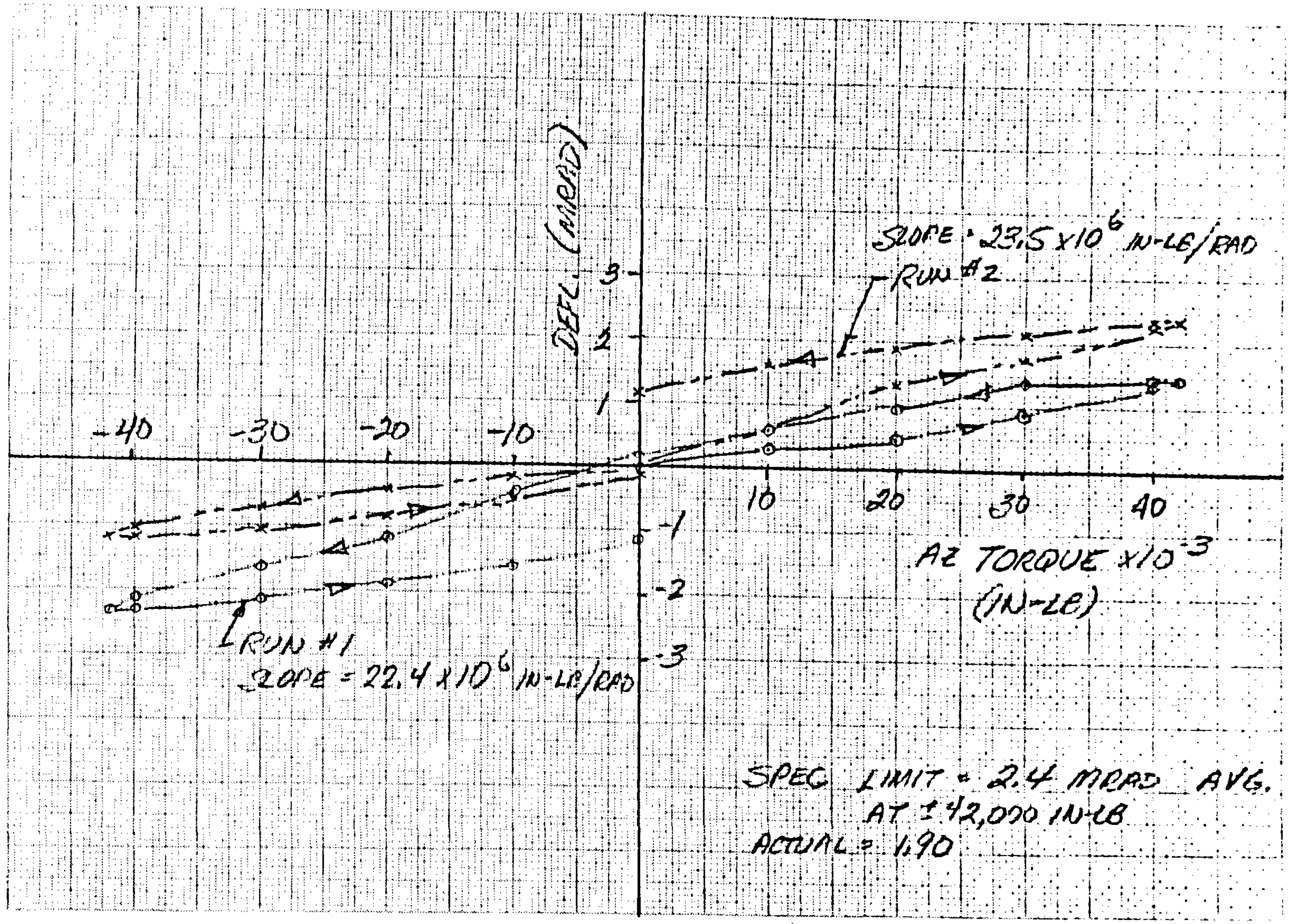
3.3 Operating Load Hysteresis

The azimuth drive unit was loaded incrementally to ± 42,000 in-lb and deflection readings were taken using a transit mounted on the drive centerline. This loading condition simulated max operational loads resulting from a 27 mph wind. The data are shown in Figure 20 and the average deflection is 1.90 mrad. 2.40 mrad is the design maximum for this condition.

Another indication of azimuth drive hysteresis and sensitivity measured was the input hysteresis characteristics. These data were generated by manually rotating the motor shaft and monitoring the output rotation of the harmonic drive using the transit.

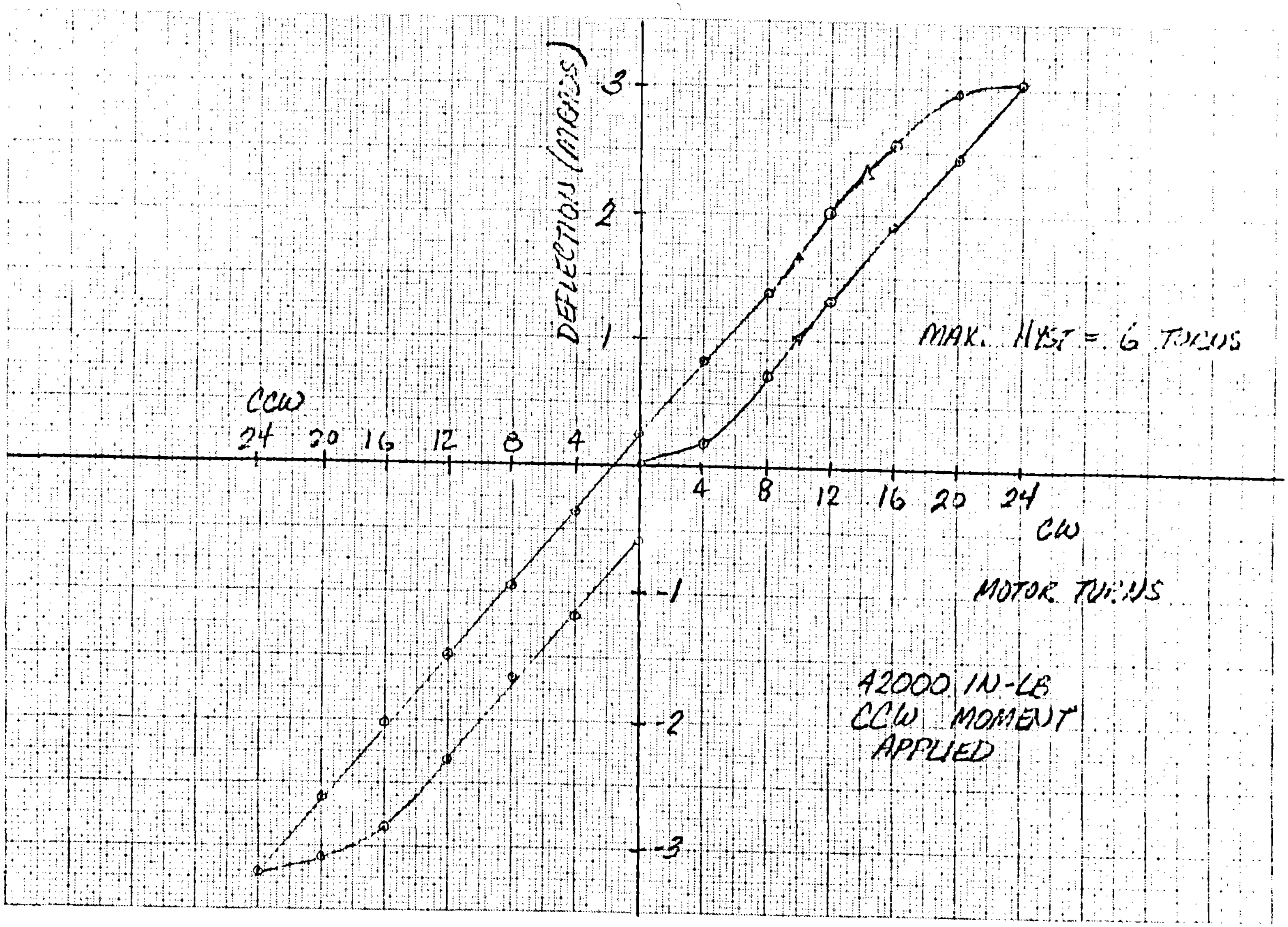
This test was run at loads of 42,000 in-lb CW and CCW, and at the no load condition. Figures 21 through 23 give the results of these tests which show an input dead band of 8 motor turns. The control system design budget for azimuth drive backlash was 0.14 mrads which was recognized as optimistic. 0.14 mrads equates to 1.0 motor turn. Eight motor turns was excessive and it was determined that the control system could not tolerate this potential positioning error. In an effort to troubleshoot the problem, a hysteresis test was run at a low external moment (± 5,000 in-lb). These data are shown in Figure 24 and indicate 0.4 mrad bandwidth at this low level. Further troubleshooting determined visually that there was little or no backlash between the motor and the harmonic drive wave generator. All of this evidence pointed to a problem of excessive friction in the wire race bearing causing the circular spline (output drive member) to bind up.

The wire race bearing had been shimmed early in the test program to a tight condition to minimize deflections. It was now evident that this had an adverse effect on the drive input hysteresis and a median ground has to be reached where deflection is traded for acceptable friction and hysteresis. The rework and retest effort required to correct this problem is reported in Section 4.0 of this report.



AZ DRIVE TORQUE HYSTERESIS - 27 MPH WIND 1753864 # 3.4.4a
(.063 SHIM) 7-25-80

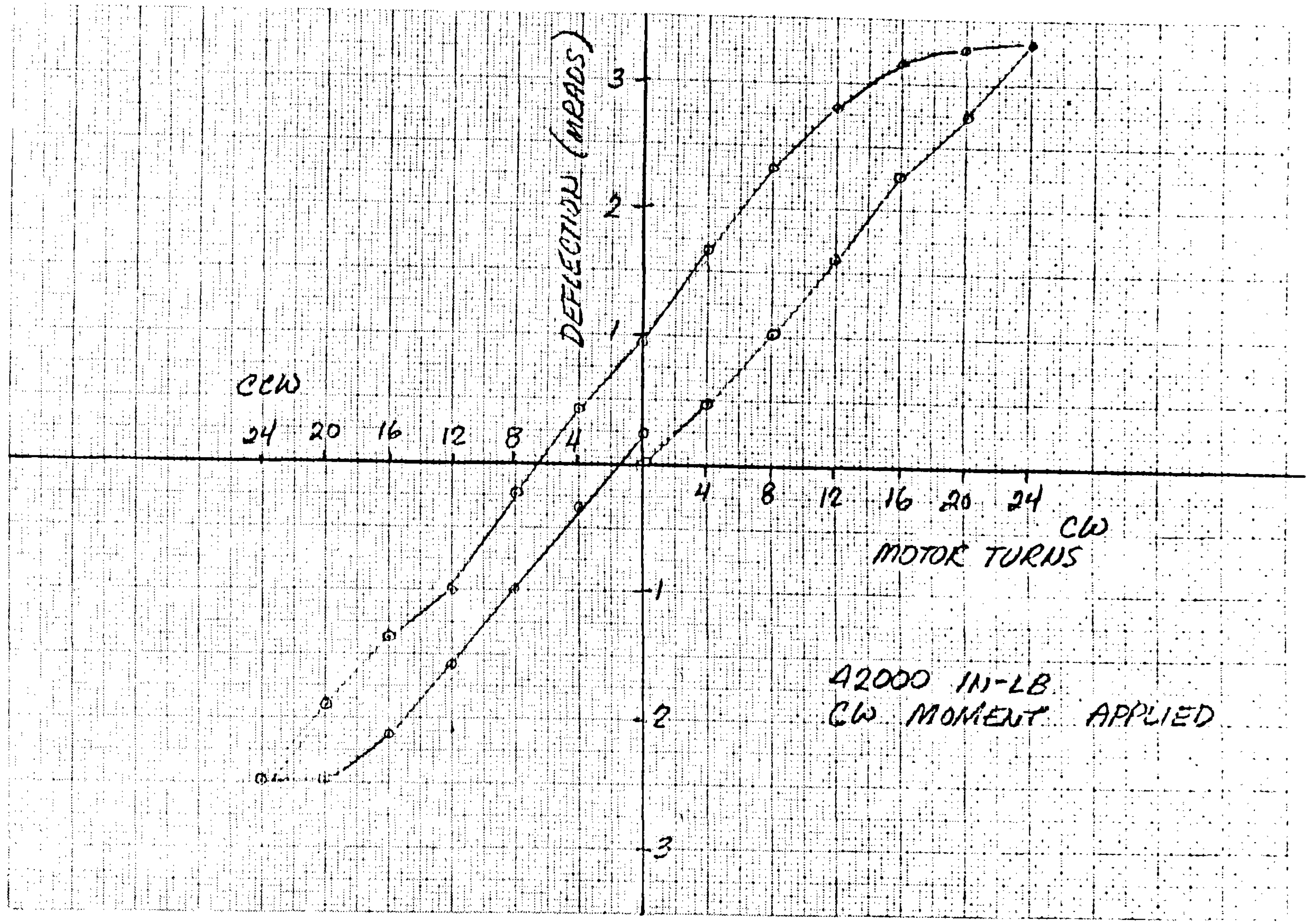
FIGURE 20



AZIMUTH DRIVE HYSTERESIS
(.033 SHIM)

IT53864 # 3.4.4 b
7-22-80

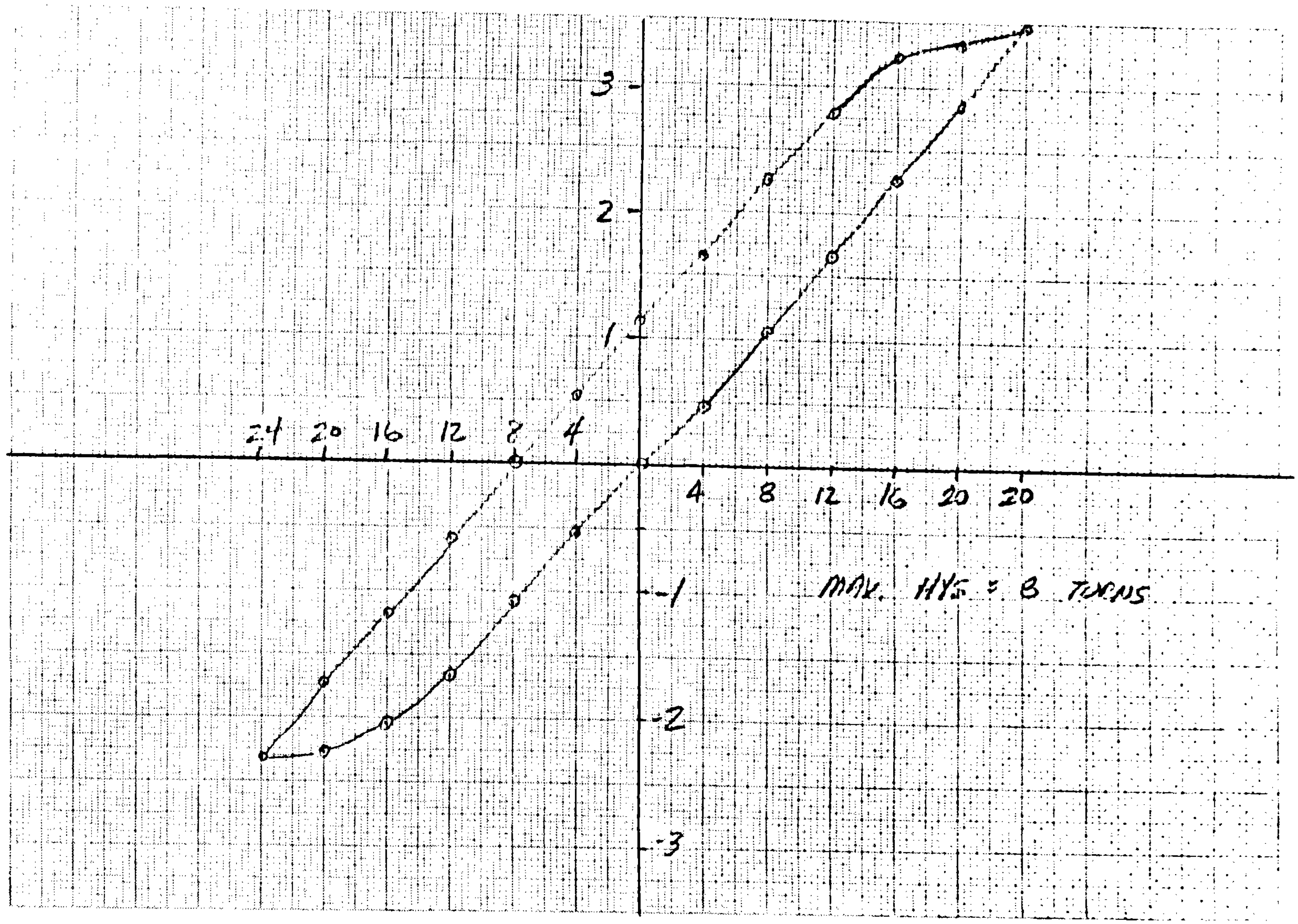
FIGURE 21



AZIMUTH DRIVE HYSTERESIS
(.013 SHIM)

1753864 A 3.4.4 b
7-22-80

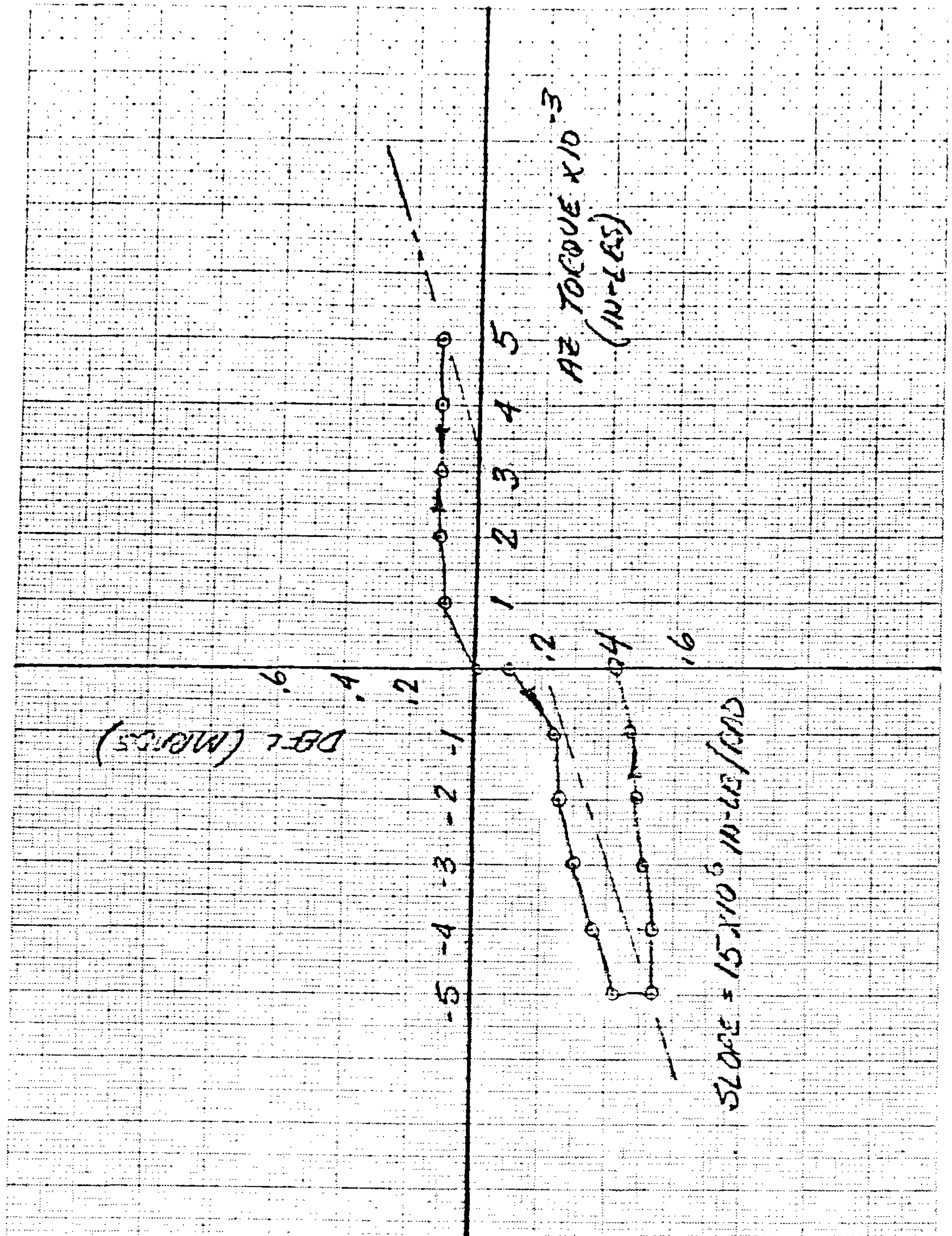
FIGURE 22



AZ DRIVE INPUT (.062 SHIM) HYSTERESIS NO-LOAD

7-24-80

FIGURE 23



AZIMUTH 500 IN-LB HYSTERESIS

7-26-80

FIGURE 24

3.4 Max Static Load Hysteresis

With the problem identified in the preceding section, it was decided to complete the testing with the specimen prior to any rework. Load vs. deflection readings were taken at moment loads up to ± 144,000 in-lbs and are plotted in Figure 25. During this test effort, it was discovered that 75 ft-lb torque on the NAS 1308-15 pedestal bolts was insufficient to prevent movement of the drive unit on the pedestal. The torque on these bolts was increased to 120 ft-lb and this solved the problem. This design change was incorporated into the 1D22457 assembly drawing.

3.5 Reduction Ratio

Using the transit and target as the origin, the number of motor turns for one complete revolution was determined to be 43,254. This is the reduction ratio expected for the harmonic drive mounting configuration (162:1 for the helicon gear set and 267:1 for the harmonic drive).

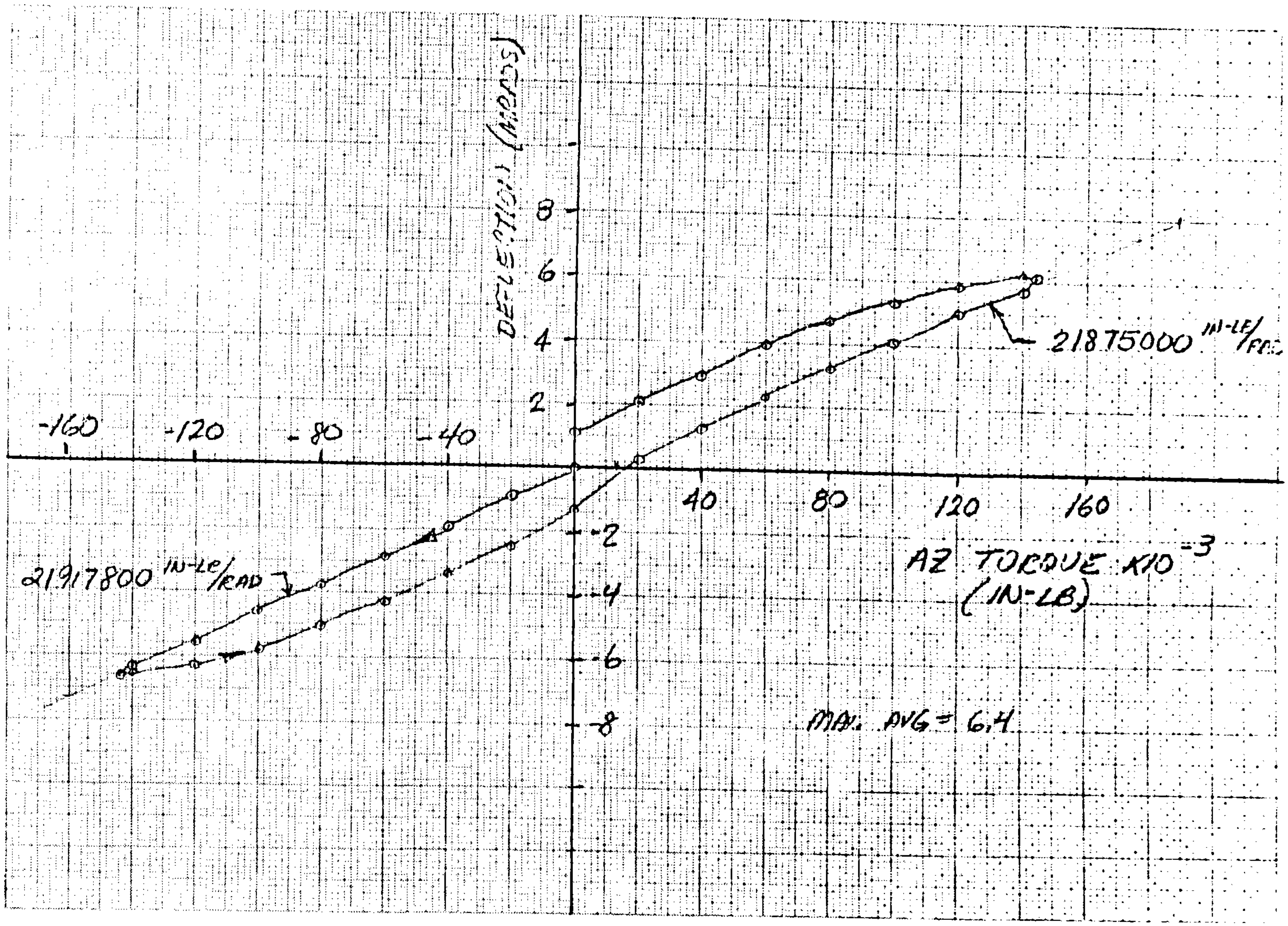
4.0 Drive Unit Rework and Retest

As a result of the excessive friction noted in the azimuth drive hysteresis test, a decision was made to reshim the wire race bearing. This was necessary to reduce the dead band on the azimuth drive input hysteresis. The azimuth drive unit was partially disassembled and the bearing shim pack increased from 0.063" to 0.065" by adding one of the shim laminates removed earlier. It was anticipated that this would reduce the hysteresis without causing an unacceptable increase in the elevation drive compliance.

Some of the preceding tests were rerun to verify acceptable performance following rework. Startup torque and efficiency tests were not repeated since the rework would have insignificant effect.

4.1 Azimuth Drive Input Hysteresis - Retest

Following the rework, the first test accomplished was to check the input drive hysteresis at the azimuth motor. This test was run at no load and at 42,000 in-lb CCW moment by counting motor turns and monitoring the



AZ. DRIVE MAX STATIC LOAD HYSTERESIS # 9.4.5 1T53864
PED. BOLTS TORQUED TO 120 FT-LB (.063 SHIM) 7-25-80

FIGURE 25

rotation of the output drive. The data are presented in Figures 26 and 27, and show a reduction in total dead band from 8 turns in previous testing to 2.5 turns following this rework. This condition is acceptable and indicates reduced friction in the output stage of the harmonic drive.

4.2 Azimuth Drive Hysteresis, 27 mph Wind - Retest

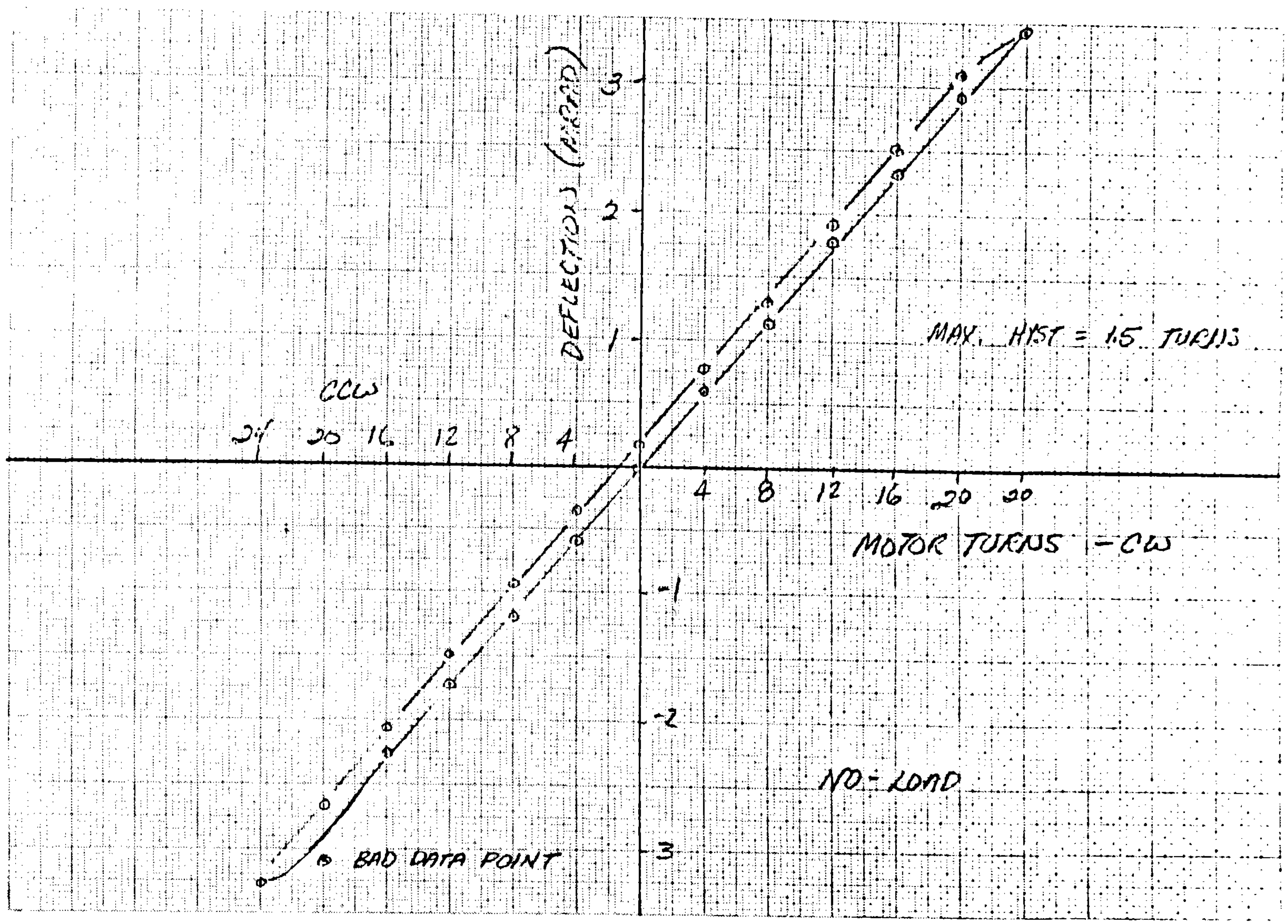
Load vs. deflection readings were taken at intervals up to ± 42,000 in-lb which simulates the 27 mph max operating wind load. The data are shown in Figure 28 and indicate no significant change in average deflection due to reshimming. The test data show an average deflection of 1.70 mrad, with the spec limit being 2.4 mrad.

4.3 Azimuth Drive Max Static Load Hysteresis - Retest

Load vs. deflection readings were taken at intervals up to azimuth loads of ± 144,000 in-lb and are presented in Figure 29.

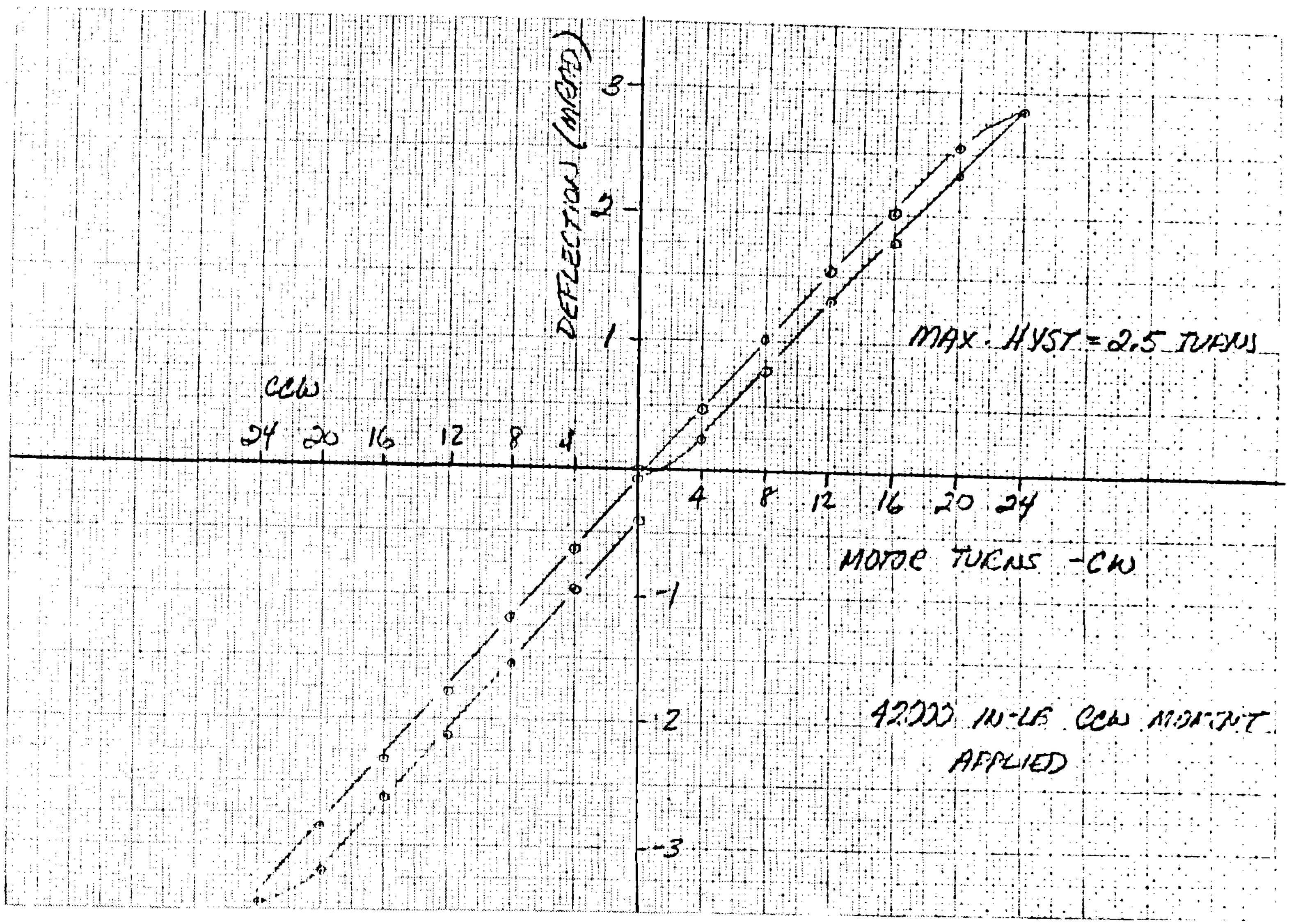
4.4 Elevation Drive Hysteresis - Retest

Elevation drive operating and max static hysteresis tests were repeated following the rework. The max operating hysteresis test was accomplished at 40° elevation angle and the max static test at 0°. Results of these tests are presented in Figures 30 and 31. The hysteresis at the max operating load increased from 1.2 mrad to 1.6 mrad due to the reshimming, but was still within the 1.85 mrad limit.



AZ. DRIVE INPUT HYSTERESIS (.065" SHIM) IT53864 ¶3.4.4 b 8-1-80

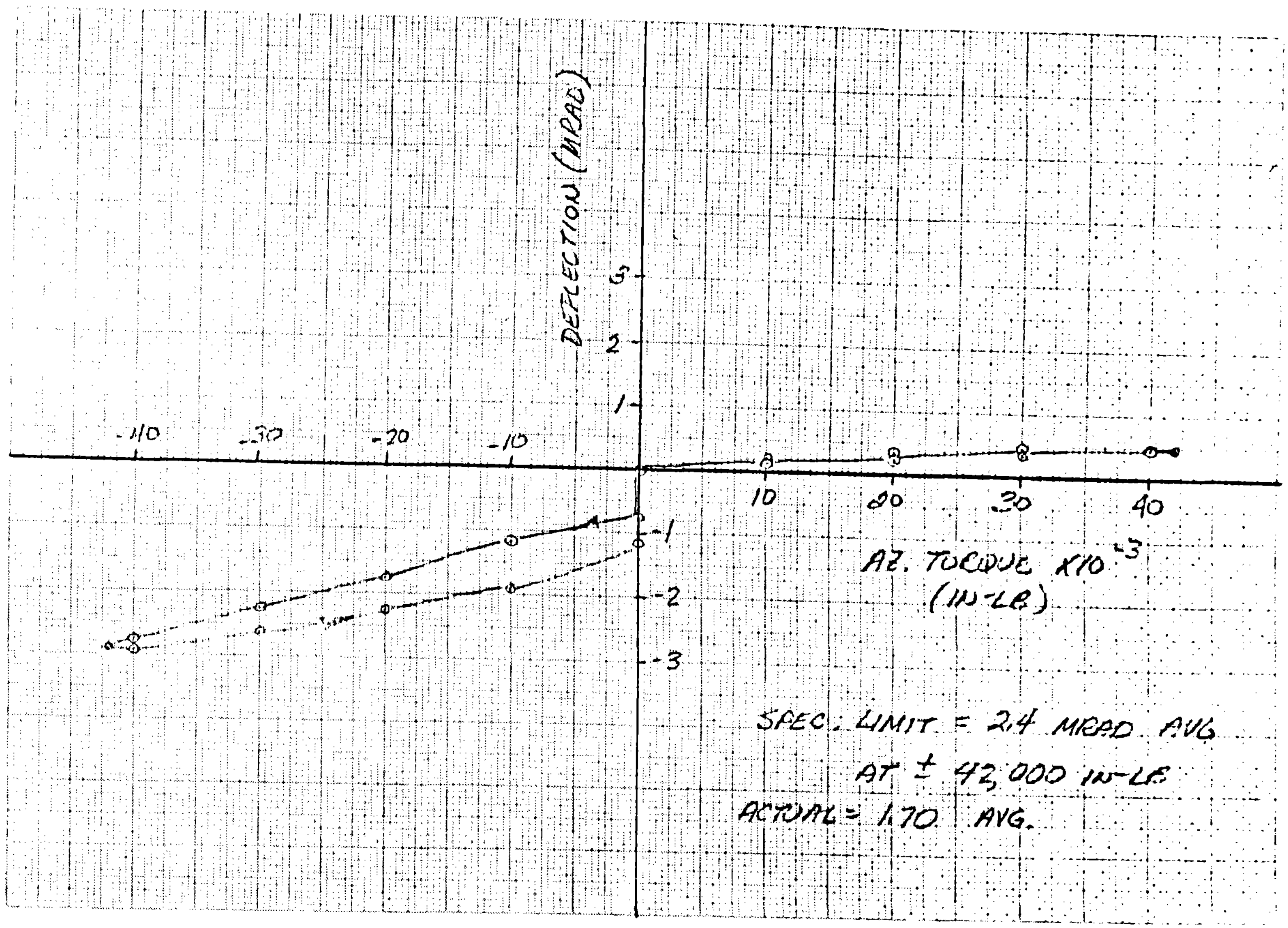
FIGURE 26



AZ. DRIVE INPUT HYSTERESIS (.035" SHIM)

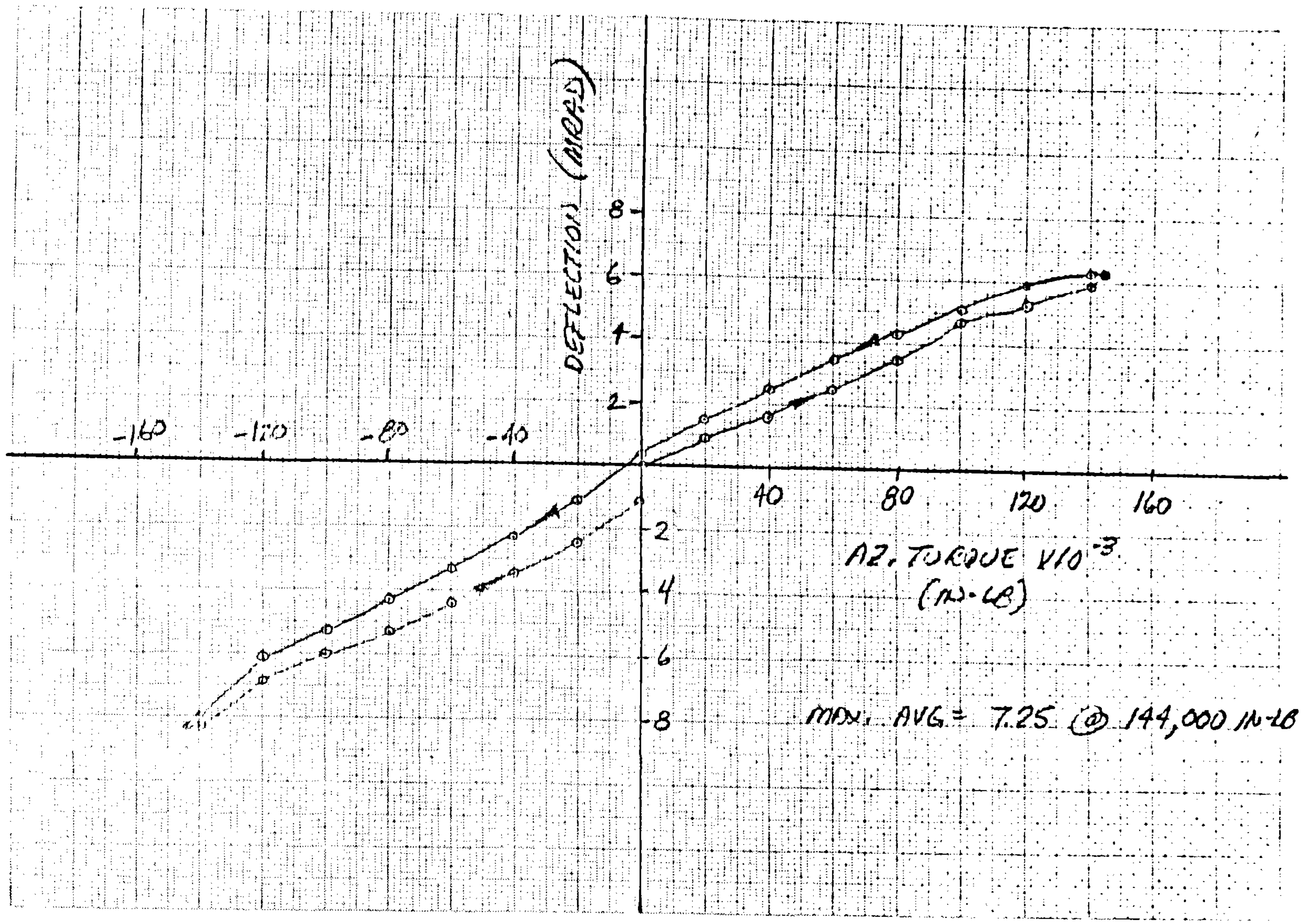
1753864 ¶3.4.4 b
8-1-80

FIGURE 27



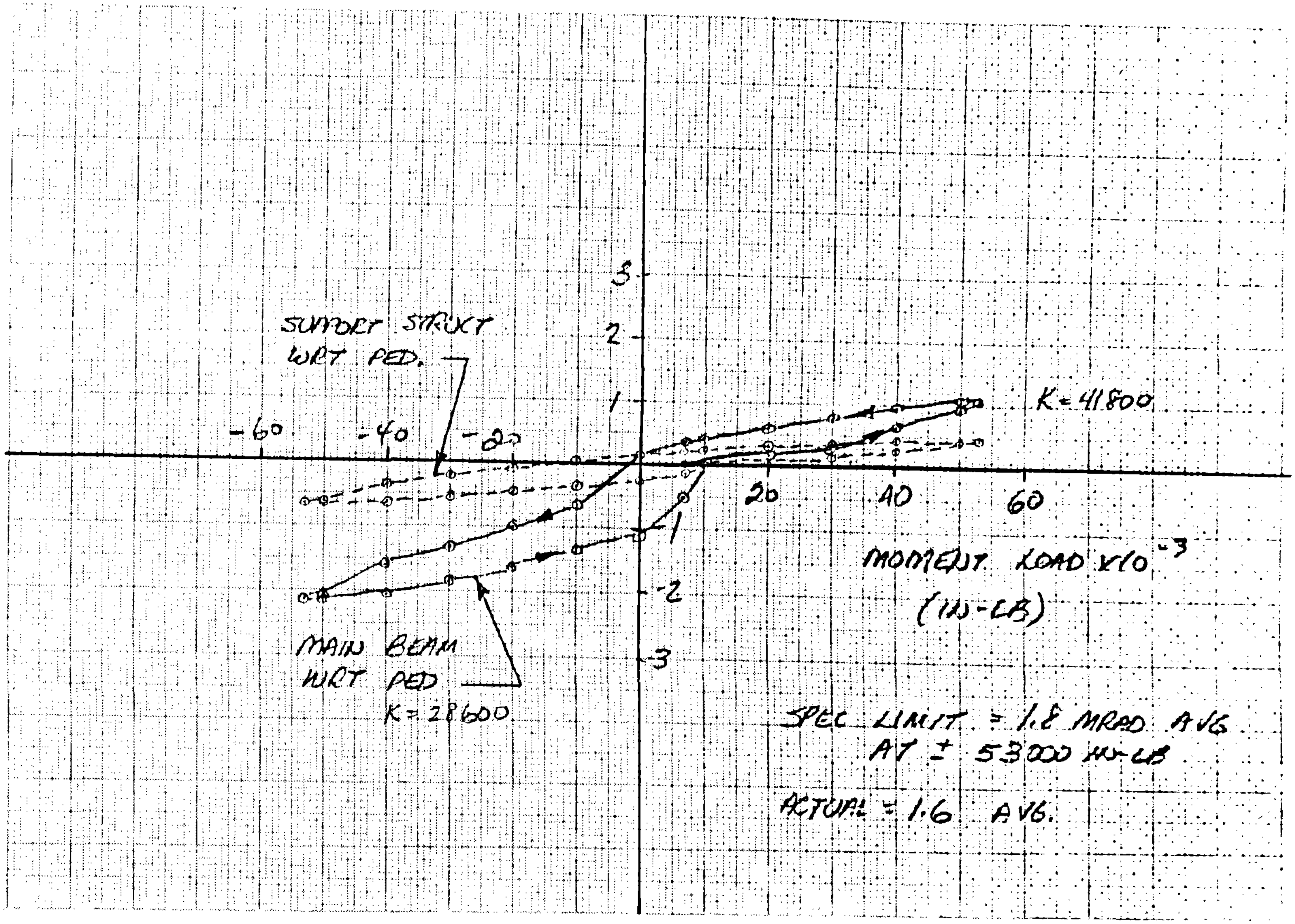
AZ. DRIVE TORQUE HYSTERESIS -27 MPH WIND (.065" SHIM) 1T53864 ℞ 3.4.4 a 8-1-80

FIGURE 28



AZ. DRIVE MAX STATIC LOAD HYSTERESIS (.065" SHIM) #3.4.5 ITS3864 3-1-80

FIGURE 29



ELEV. DRIVE, MAX. OF HYSTERESIS @ 40° (.065" SHIM)   IT53864 # 3.3.5 8-1-80

FIGURE 30

E.L.V. DRIVE MAX STATIC HYSTERESIS @ 0°
(.065" SHIM)

1753864 # 3.3.6
8-4-80

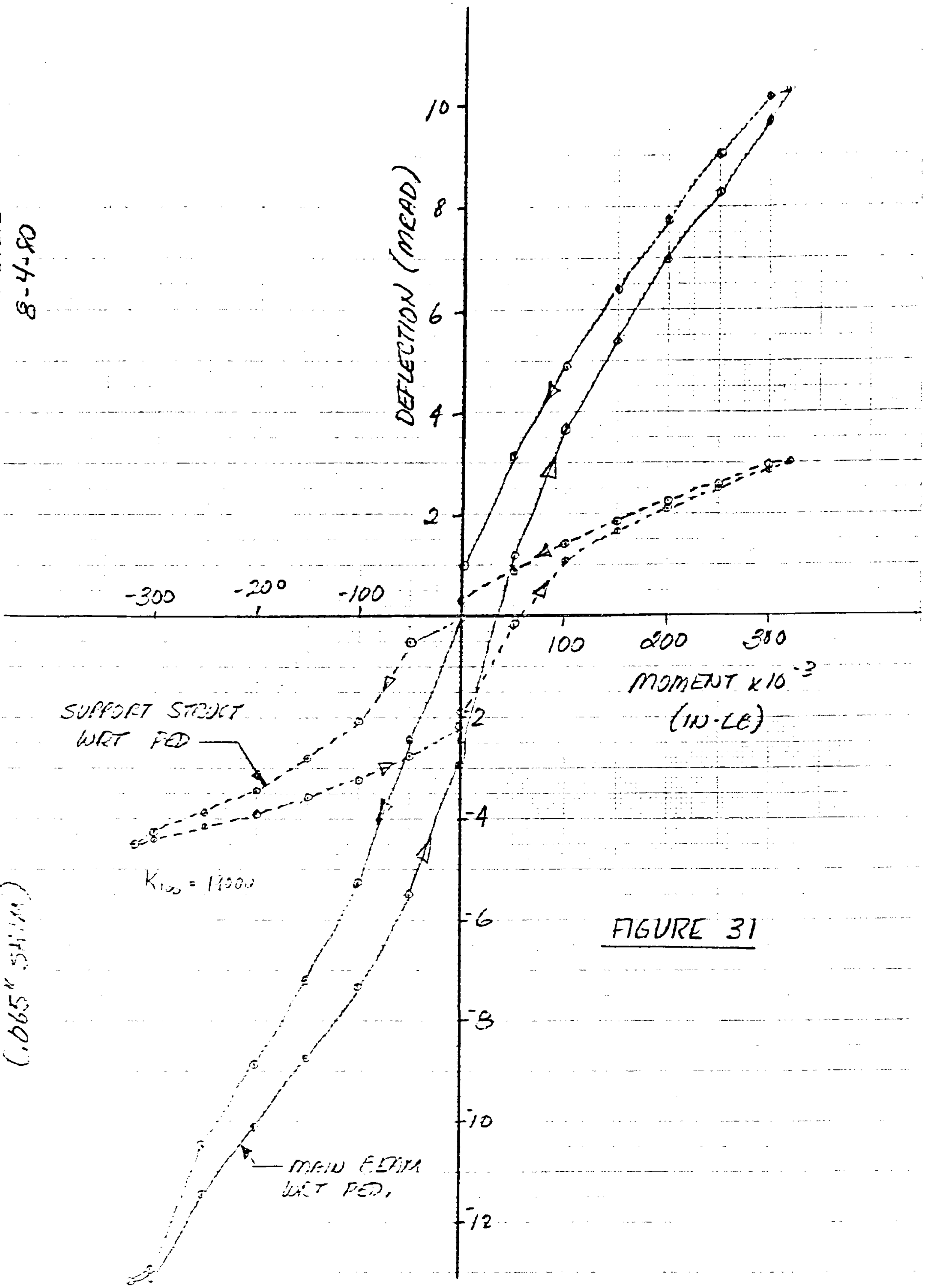


FIGURE 31

CONCLUSIONS

Based on the preceding test results, the following conclusions are offered.

A. Testing of the 1D22436-1 drive unit has demonstrated the integrity of the design concept, and performance of the assembly meets all specified requirements. A summary of drive performance is given in Figure 4.

B. The 1/3 HP motor selected for the elevation jack will provide sufficient torque margin for all operating conditions.

C. The range of size for the wire race bearing shim which will produce acceptable compliance without excessive friction is small. The current shimming method is subject to error depending on bolt friction and is not sufficient to exclude excessive bearing friction.

D. Current system oil seals are acceptable based on no leakage noted during the test program.

E. The drive system structural integrity was proven by the inadvertent application of a 60% overload in the elevation axis.

F. The wire race bearing has demonstrated satisfactory performance for use in the heliostat drive application. This conclusion reinforces test results documented in TM A3-228-AAMO-TM80-Solar-1, "Design Evaluation Test Report, 1D22490-1 Wire Race Bearing, Solar Energy Program".

RECOMMENDATIONS

The 1D22475-1 drive unit is recommended for use on the 2nd Generation Heliostat with the following change.

A new shim procedure is recommended for installation of the wire race bearing. The existing procedure does not allow for variations in the bearing retainer bolt friction and does not guard against excessive bearing friction. The initial preload on the bearing bolts used when measuring for shim size should be increased which would reduce the sensitivity of the procedure to variations in bolt friction. Also, following buildup of the 1D22494 drive unit, an input drive hysteresis check would determine if WRB friction is excessive indicating improper shimming.

It is possible that a 1/4 HP electric motor would provide satisfactory performance for the elevation drive. It is recommended that this hardware change be investigated as a means of reducing heliostat power requirements.