77

DESIGN AND SIMULATION OF EVA TOOLS FOR FIRST SERVICING MISSION OF HST

By

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CONTENTS

ABSTRACT

The Hubble Space Telescope (HST) was launched into near-earth orbit by the Space Shuttle Discovery on April 24, 1990. The payload of two cameras, two spectrographs, and a high-speed photometer is supplemented by three fine-guidance sensors that can be used for astronomy as well as for star tracking. A widely reported spherical aberration in the primary mirror causes HST to produce images of much lower quality than intended. A Space Shuttle repair mission in January 1994 installed small corrective mirrors that restored the full intended optical capability of the HST.

The First Servicing Mission (FSM) involved considerable Extra Vehicular Activity (EVA). Special EVA tools for the FSM were designed and developed for this specific purpose. In an earlier report, the details of the Data Acquisition System developed to test the performance of the various EVA tools in ambient as well as simulated space environment were presented. The general schematic of the test setup is reproduced in this report for continuity. Although the data acquisition system was used extensively to test a number of fasteners, only the results of one test each carried on various fasteners and the Power Ratchet Tool are included in this report.

Design and Simulation of EVA Tools
For
First Servicing Mission of HST

1. Introduction

The performance of EVA tools in the space environment can be predicted by testing these tools in vacuum and in temperature extremes in space. The performance of EVA tools is based on various benchmarks such as maximum attainable torque, frequency response, and the life of the tools. Of these various benchmarks, torque and speed can be measured by torque transducers and encoders. The data acquisition system designed to test the EVA tools makes use of these two sensors. However, the data acquisition system can be easily modified to incorporate other analog and digital signals with few modifications.

2. The Data Acquisition System:

The block diagram of the data acquisition system is shown in Fig. 1. The torque/angle transducer #8241 has built-in strain gages and an encoder to generate analog and digital signals corresponding to torque and speed of the EVA tool being tested. These signals are taken to the GSE 290 Data-Stat, a meter which displays torque as well as angle of rotation, and to a plug-in data acquisition board. This is accomplished by cable #299210-6E080 and a parallel connection cable as shown in Fig. 1. The power to the GSE 290 Data-Stat is supplied through an A/C adapter. The cable carrying the transducer signals to the data acquisition board in a PC is connected to terminal blocks. Two such terminal blocks are used in this system. One is for analog signals which require signal conditioning, and the other is for TTL compatible digital signals which are directly connected to the data acquisition board through a feed-through terminal block, a feed-through panel and the SCXI-1340 MIO-16 cable #776574-40. The analog signals from the torque transducer are connected to the data acquisition board through the SCXI-1300 terminal block, SCXI-1110 multiplexure-signal conditioner and SCXI-1340 MIO-16 cable. The SCXI-1100 multiplexure-signal conditioner has low pass and high pass filters. The analog signals are conditioned in the form of noise isolation, voltage scaling and signal amplification. An application software package based on NI-DAQ (National Instrument Software System) is developed to control data acquisition functions for the PC based data acquisition boards.

The various cable connections for the torque transducer and encoder connector (Bendix-9219) to the data acquisition board connector AT-MIO-16F are shown in Fig. 2.

3. Computer Program:

An application program (PRT.BAS) developed for testing EVA tools, and particularly the Power Ratchet Tool, is based on a NI-DAQ software system supplied by

National Instruments. The application software has the capability to generate sequential data files and to compute torque, angle and speed at pre-programmed torque speed characteristics of the tool. The sequential steps to run this application are shown in Appendix-I.

4. Torque/Angle Tests:

Tests were conducted on COPE (Contingency ORU Protective Enclosure) cover fasteners at various torque loadings. The locations of these fasteners are shown in Fig. 3. These fasteners were fastened and unfastened at three settings; 2 Ft. Lbs, 5 Ft. Lbs. and 10 Ft. Lbs. The torques measured on GSE Datastat are tabulated in Table 1. The torque angle readings measured by the Data Acquisition System are shown in Appendix-II. The Power Ratchet Tool was also tested at various torque and speed profiles. The results of these tests are shown in Appendix-III. As a reference point, the programmed torques (desired torque) at these settings are given in the graphs showing the measured torques.

5. Observations:

Although the application software package, "PRT.BAS" was developed for testing the Power Ratchet Tool, it can also be used for other applications requiring measurement of torques and rpm as well as the ultimate torque capacities of various fasteners. The following observations can be made concerning the torque/angle tests.

The datastat readings were found to be more accurate. The reasons for this being that the datastat records only peak torque reached beyond a set threshold. The threshold for the sensor used in this test set-up is 2.5 Ft. Lbs. As soon as the torque level rises beyond 2.5 Ft. Lbs., only peak torque is recorded along with the corresponding angle reading. The torque angle readings are sampled at a rate of 3.6 KHz. In contrast to datastat, the data acquisition system records every torque and angle reading (as we were interested in examining the torque angle loading cycle of the system). Some time is lost in analog to digital data conversion. This results in missing some readings. Our tests showed that the limit to which this system can measure the data without missing any peaks, is 1.1 KHz. If we were to measure the torque/angle data like the datastat does, (recording only peak readings), the accuracy would have been much better. The reason for this being that in this case we could sample the data as fast as 1 MHz.

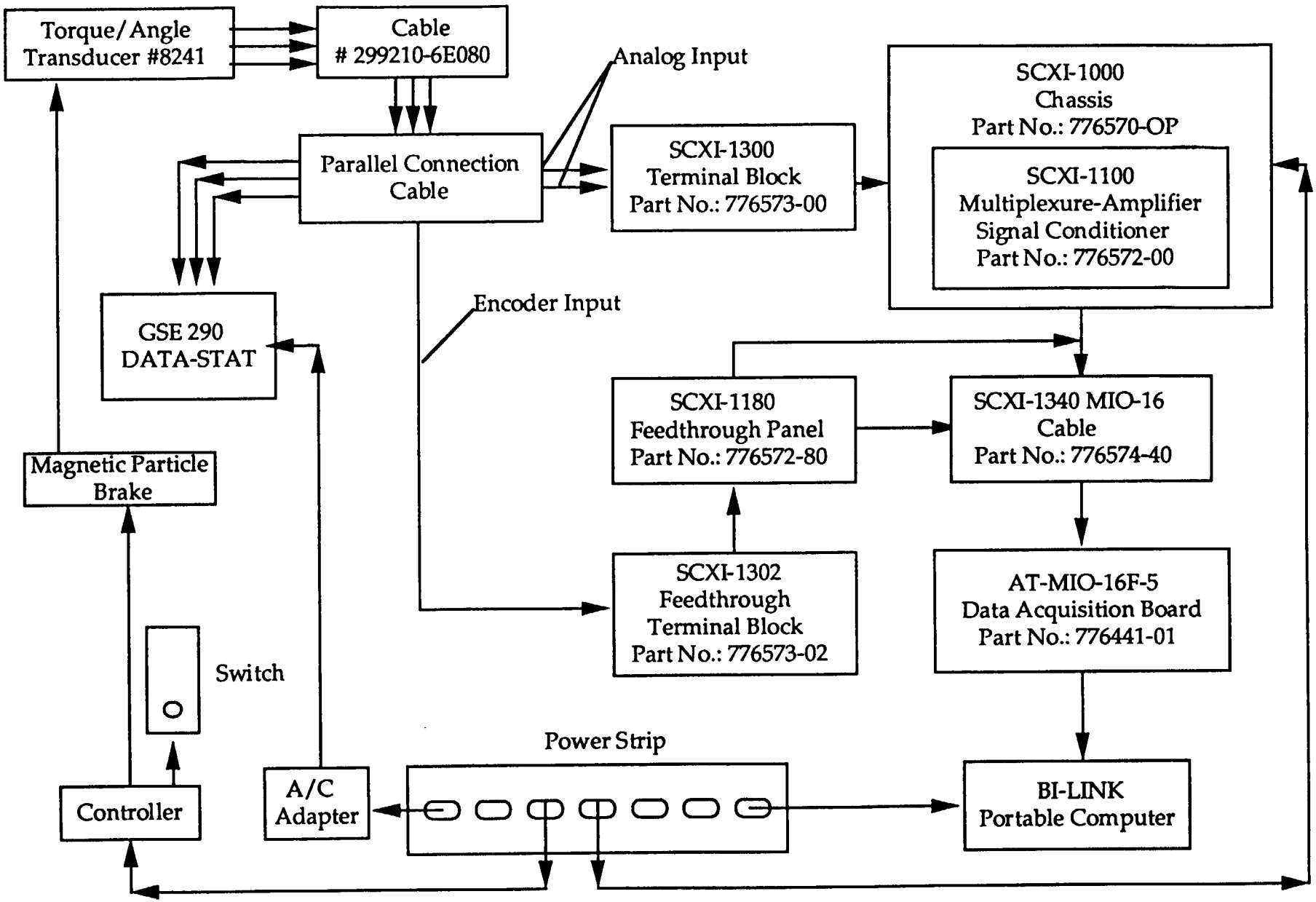


Fig. 1Data Acquisition System

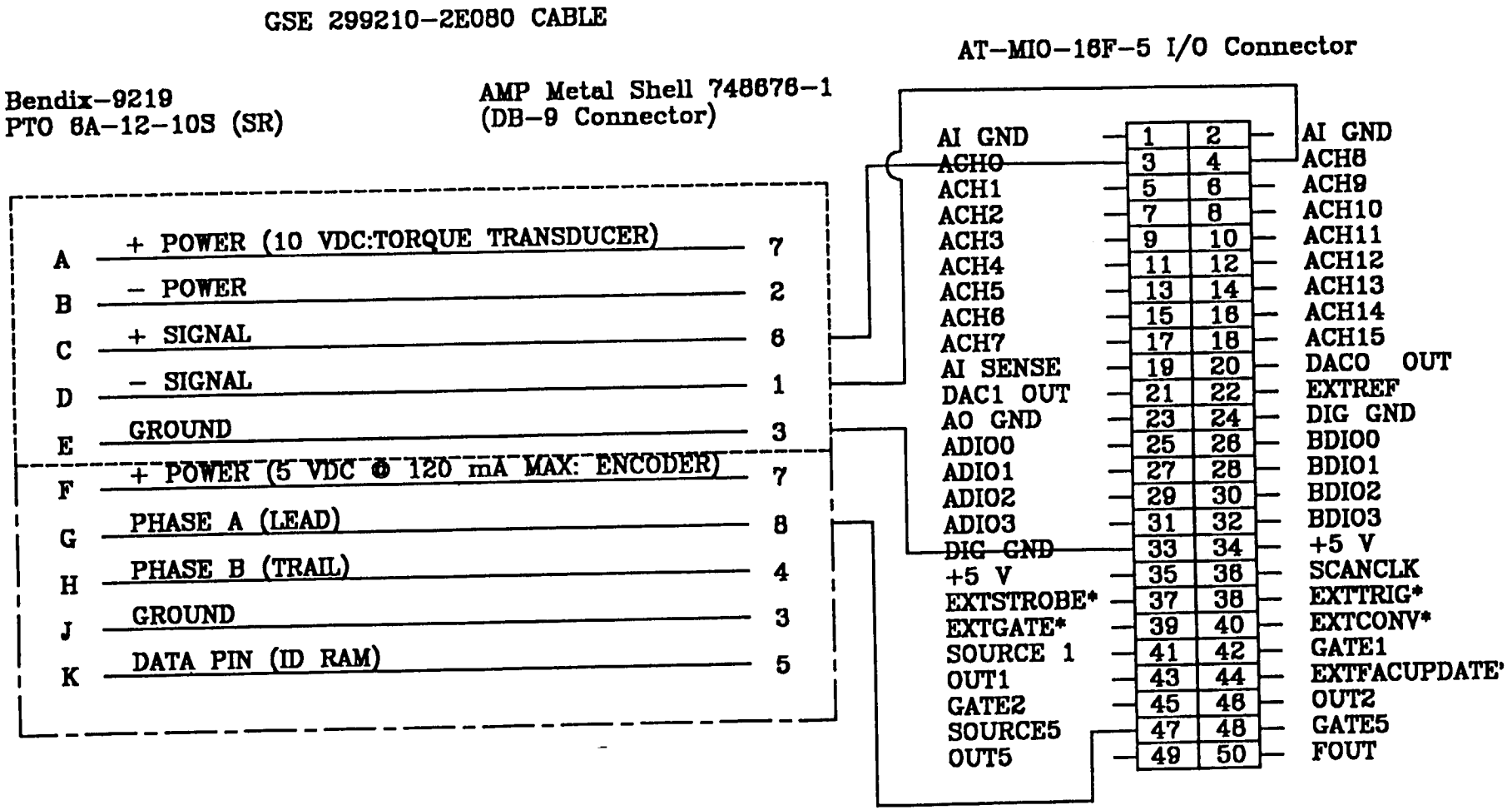
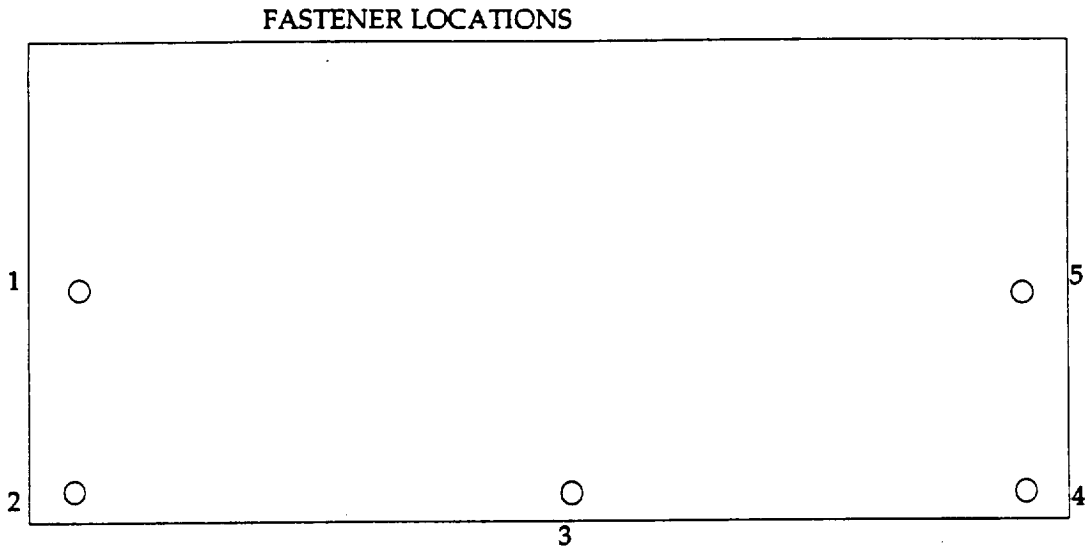


Fig. 2 AT-MIO 16-F-5 I/O Connector



FASTENTER NO.	MTL SETTING (Ft.Lbs)	FASTEN (Ft.Lbs)	UNFASTEN (Ft.Lbs)
1	2	2.1	1.6
	5	4.6	3.2
	10	9.3	5.8
2	2	1.9	1.6
	5	5.1	4.7
	10	9.3	8
3	2	2.3	1.65
	5	4.8	3.8
	10	8.9	7.7
4	2	2.3	1.8
	5	4.8	3.9
	10	9.7	6.8
5	2	2.3	1.3
	5	5.1	3.2
	10	8.9	5.9

Fig. 3 COPE Fastener Locations

APPENDIX - I

GUIDELINES FOR PC BASED DATA ACQUISITION

Notes: 1. User response is underlined.
2. Comments are in *(Italics)*.
3. Symbol ↓ Stands for Return Key
4. For Any Software Bugs Call Dipak Naik (301-474-0832 OR 286-1324)

HARDWARE SETUP:

1. Power On:
   a. Computer
   b. SCXI 1000 (Signal Conditioning Module)
   c. GSE Data-Stat
2. The CAPS LOCK and The NUM LOCK Keys On The Computer Keyboard Should be "ON"

SOFTWARE SETUP:

1.
(All The Executable File For Data Acquisition Are In VBDOS Directory. Key-In Following Command To Switch To VBDOS Directory.)

C:\> CD VBDOS↓
C:\> VBDOS>

2.
C:\>VBDOS>PRT↓ *(Run PRT.EXE)*

3.
DATA STORAGE FILE NAME? EVA272↓ *(Input Data Storage File Name)*

4.
EXEL FILE NAME? EVA272↓ *(Input Exel File Name)*

****
The Transducer Must Be Unloaded To Scan Initial Offsets
****

5.
If Transducer Is Unloaded Hit 'Y'? Y↓
(1. Before Responding To Above, Hit Any Key On GSE:Data-Stat If If Displays "Press any key to continue".
2. Enter 'Y' If Transducer is unloaded. Else Unload It and Then Hit 'Y'. User Will Get 5 Chances To Unload The Transducer. After That The Program Will Terminate.)

Initial Offset of Set-up Is = 0.00007324 Volts
****
Data Will Be Stored In EVA2721.DAt
Data For Cricket Graph Will Be In EEX2721.DAT
After Quitting The Program, Rename The Data Files
****
(File Extensions 1.DAT Will Be Automatically Added To The User File Names Entered Earlier In Step 2 and 3.. The Numeric Extension Will Change By An Increment of One For Every Iteration For Data Acquisition Hereafter.)

6.
Record Comments/Titles If Any:? A1 CW TORQUE/ANGLE↓
(Title For Data Being Acquired)

7.
Total time in seconds for data acquisition:? 30↓
(a. 15 Seconds For Speed Measurement
b. 30 Seconds For Torque/Angle Measurements)

8.
READINGS PER SECOND SHOULD BE LESS THAN: 33
READINGS PER SECOND:? 20↓
(a. 1Reading Per Second For Speed Measurement
b. 30 Readings Per Second For Torque/Angle Measurements)

9.
(At This Point Software Is All Set To Collect The Data. The Magnetic Particle Brake Switch Will Be "ON". The Brake Controller Knob Will Be In Its Zero Position.)

Hit Any Key If Ready To Go:?↓

(If The Measurement Is Of Speed (RPM), Then User Notes Down The RPM Displayed On The Computer Screen. If The Measurement Is Of TORQUE/ANGLE Then The User Gradually Stalls PRT By Turning The Brake Controller Knob In Clockwise Direction. For The Present Application User Will Stall PRT 3 Times In Succession In 30 Seconds. All The Pertinent Data Will Be Displayed In Real Time As Is Shown In Step 10.)

10.
scanning channels for data.....
****
Reading No. = 15
****
Controller Pulse = 8
****

RPM (Average) = 26.666
****
Degrees = 475
****
Torque (Ft.Lbs) = 7.896
****
Peak Torque (Ft.Lbs) = 10.666
****

11.

The Above Readings Are Taken In 30 Seconds
Starting at 03:30:28 And Ending At 03:30:58

(General Information Is Displayed)

12.

MAX (Ft.Lbs)	MIN(Ft.Lbs)	MAX(Degrees)	RPM
10.666	0.216	576	26.666

(The Information Above Displayed Shows Either Peak Or Maximum Valued Attained During The Data Acquisition)

13.
(Hit Return (↓) To Display The Torque/Angle Graph For The Data Collected. Hit Return (↓) To Quit The Torque/Angle Graph.

14.

Hit 'Y' To Redisplay The Graph: Y↓

(Hit Y↓ AND ↓ To Display The Torque/Angle Graph Again For The Data Collected, N↓ To Proceed Further.

15.

(Hit Return (↓) To Quit The Torque/Angle Graph For The Data Collected).

16.

(The Software Will Close All Data File: EVA 2721.DAT And EEX 2721.DAT And Automatically Generate EVA2722.DAT and EEX2722.DAT For Next Cycle Of Data Acquisition.)

17.
****
Hit 'Y' to Continue
****

Y↓

(Hit 'Y' To Continue. If User Accidentally Hits Any Other Key System Will Respond As Follows)

18.

Are You Sure?*+#@??

N↓

(Hit 'N' To Continue)

19.
Go To Step 6.

Else

20.
(If User Responds By N↓ In Step 17, OR Y↓ In Step 18. Then System Will Respond As Follows.

21.
****
Hit 'Y' to Restart
****

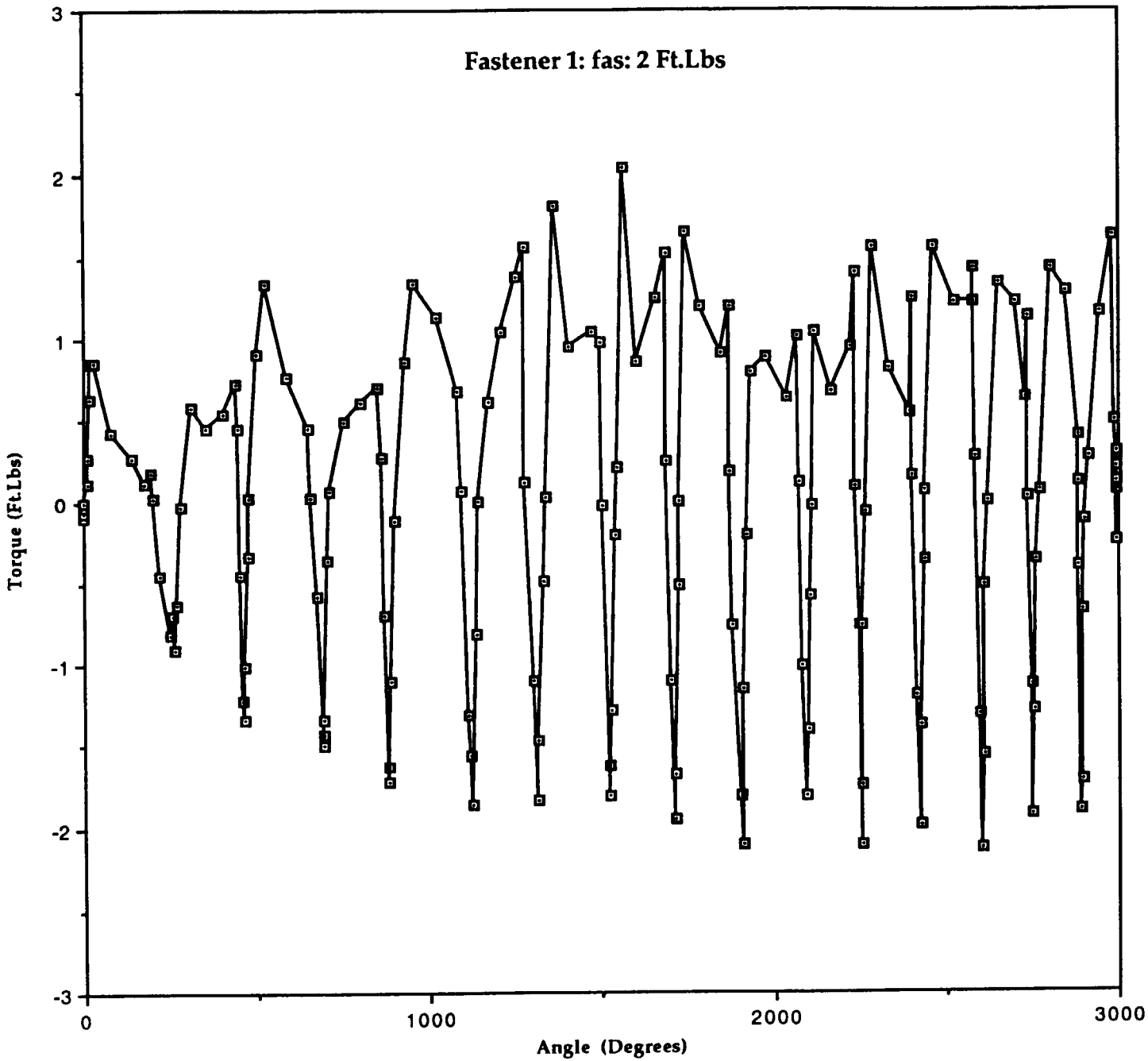
22.
Y↓ *(To Restart. Go To Step 3)*

Else

N↓ *(To Terminate The Program.)*
Bye!

(Insert A Blank Floppy Disc In Drive B And Copy All Data Files By Keying-In Following Commands. After Each Command, Files Being Copied Will Be Displayed On The Computer Screen)
C:\> VBDOS> COPY EVA272*.* B:↓
C:\> VBDOS> COPY EEX272*.* B:↓

APPENDIX - II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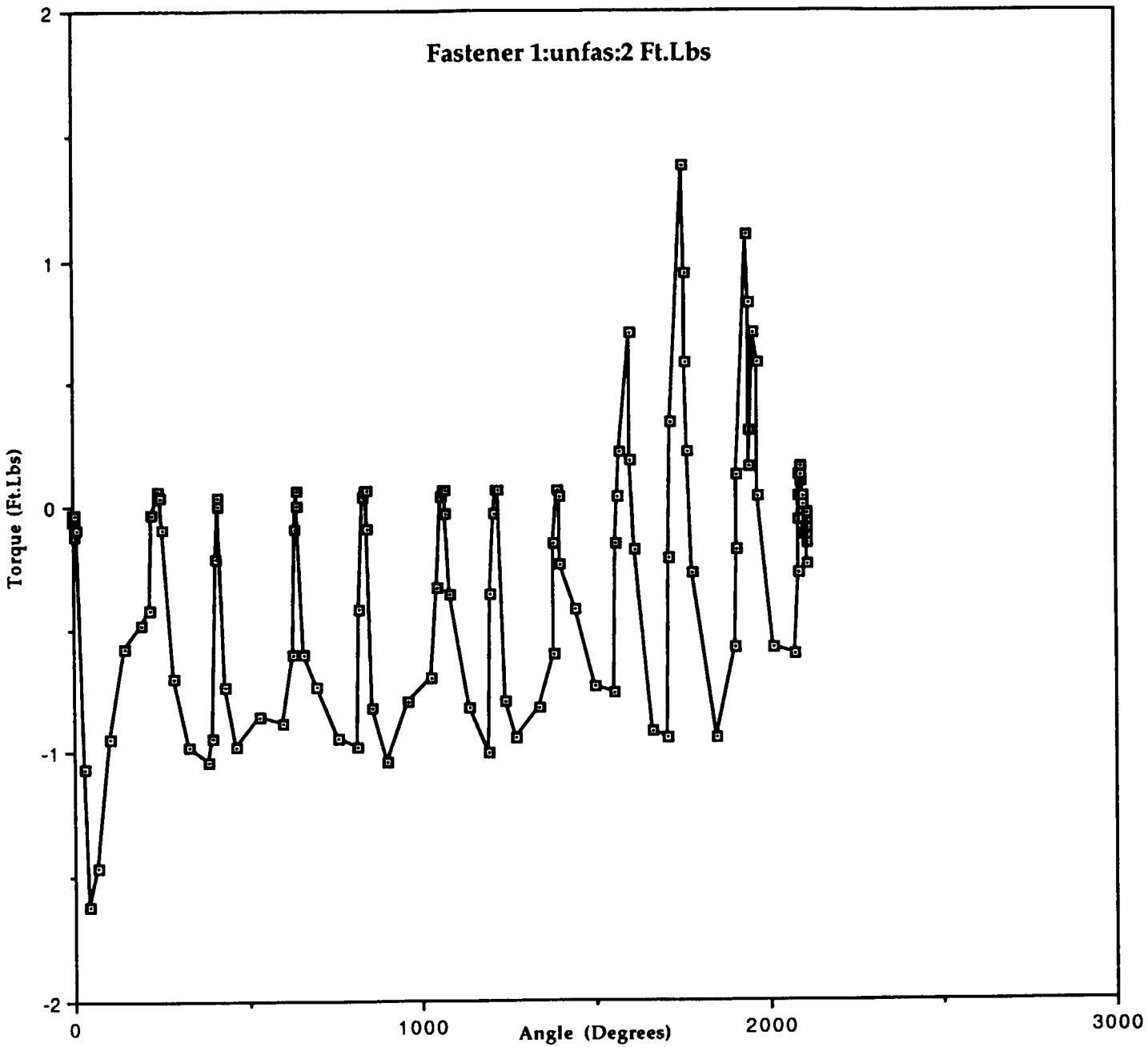
-1
-2
-3
0
1000
2000
3000
Angle (Degrees)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-1
-2
0
1000
2000
3000
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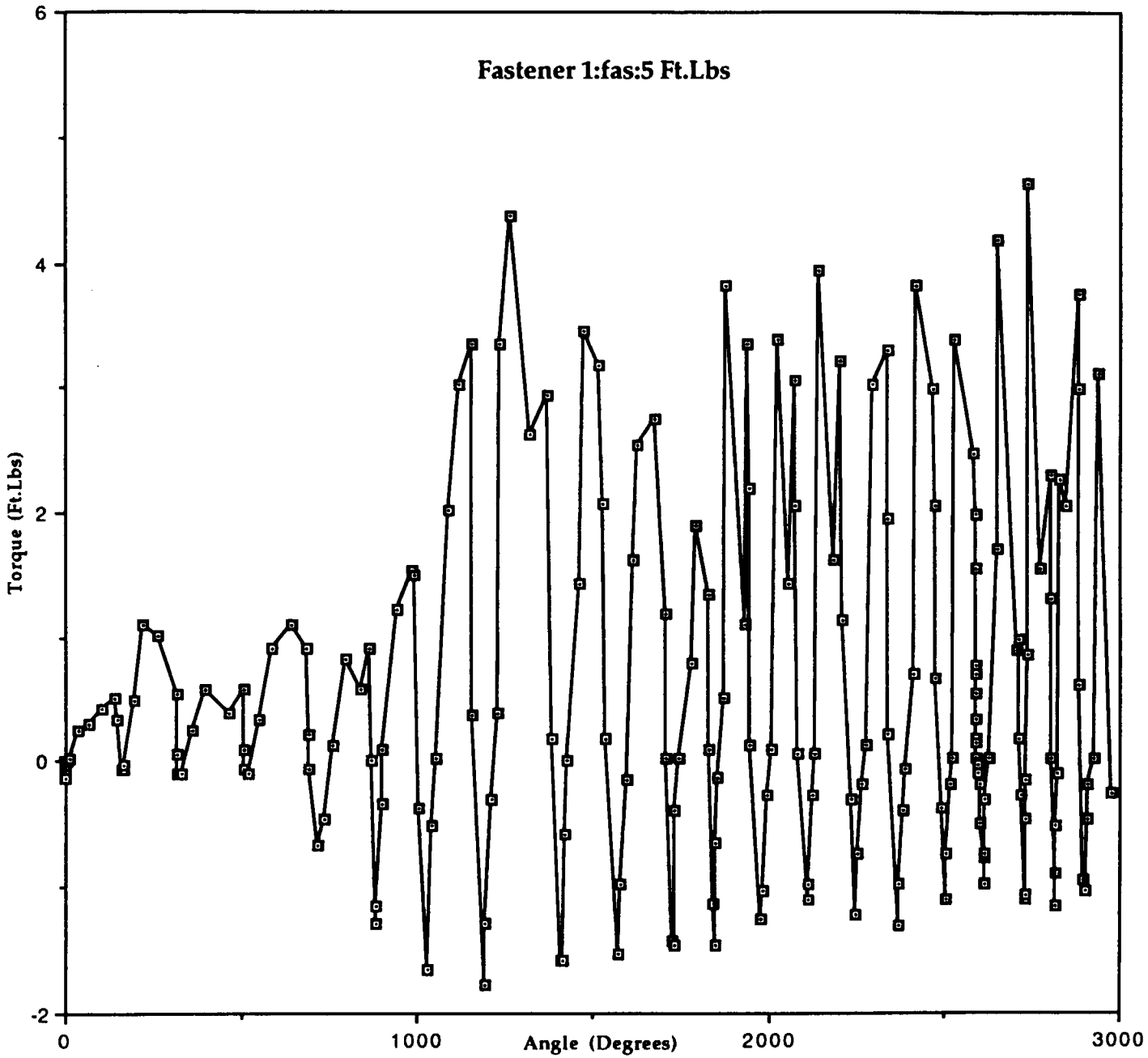
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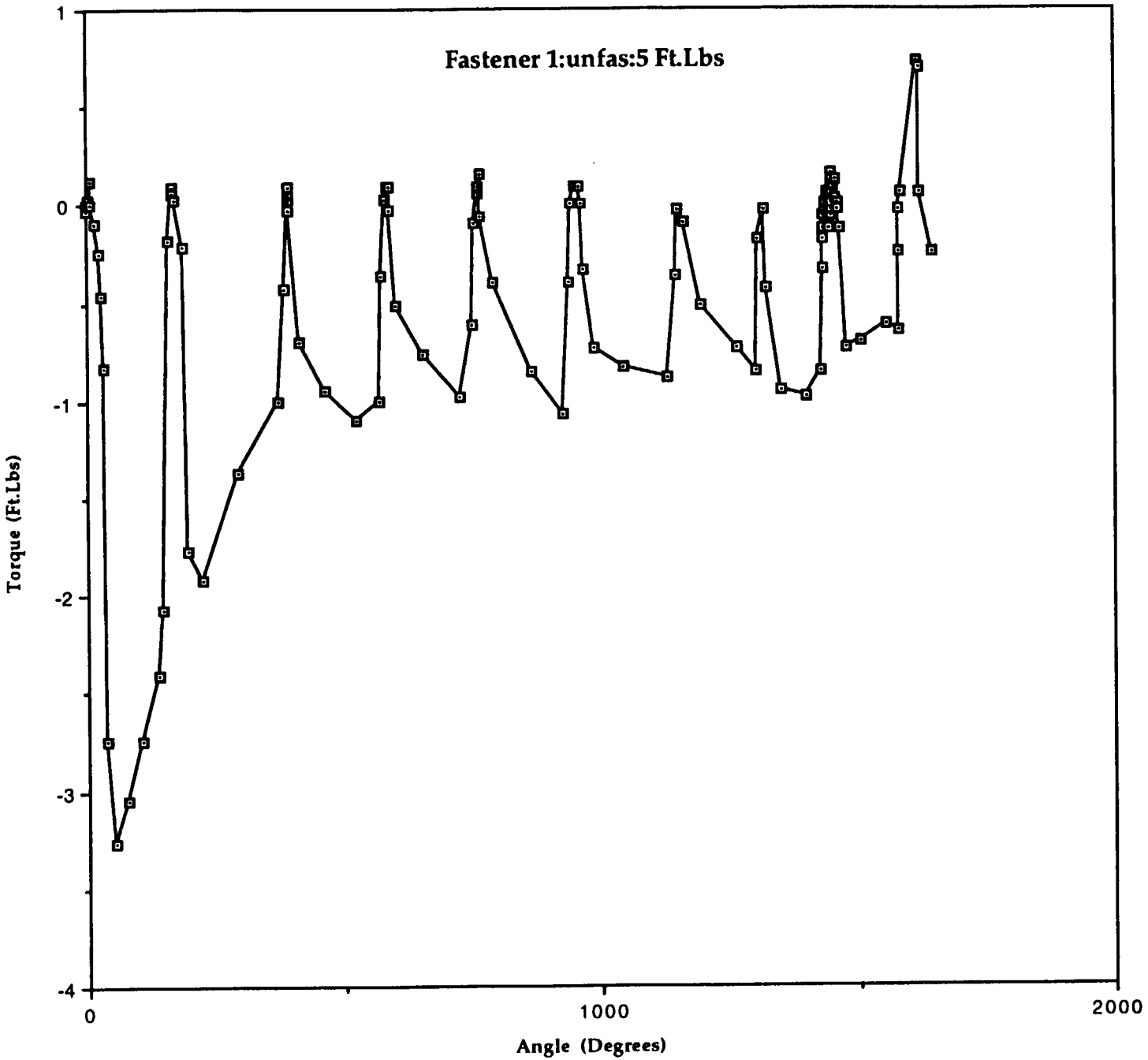
4
2
0
-2
0
1000
2000
3000
Angle (Degrees)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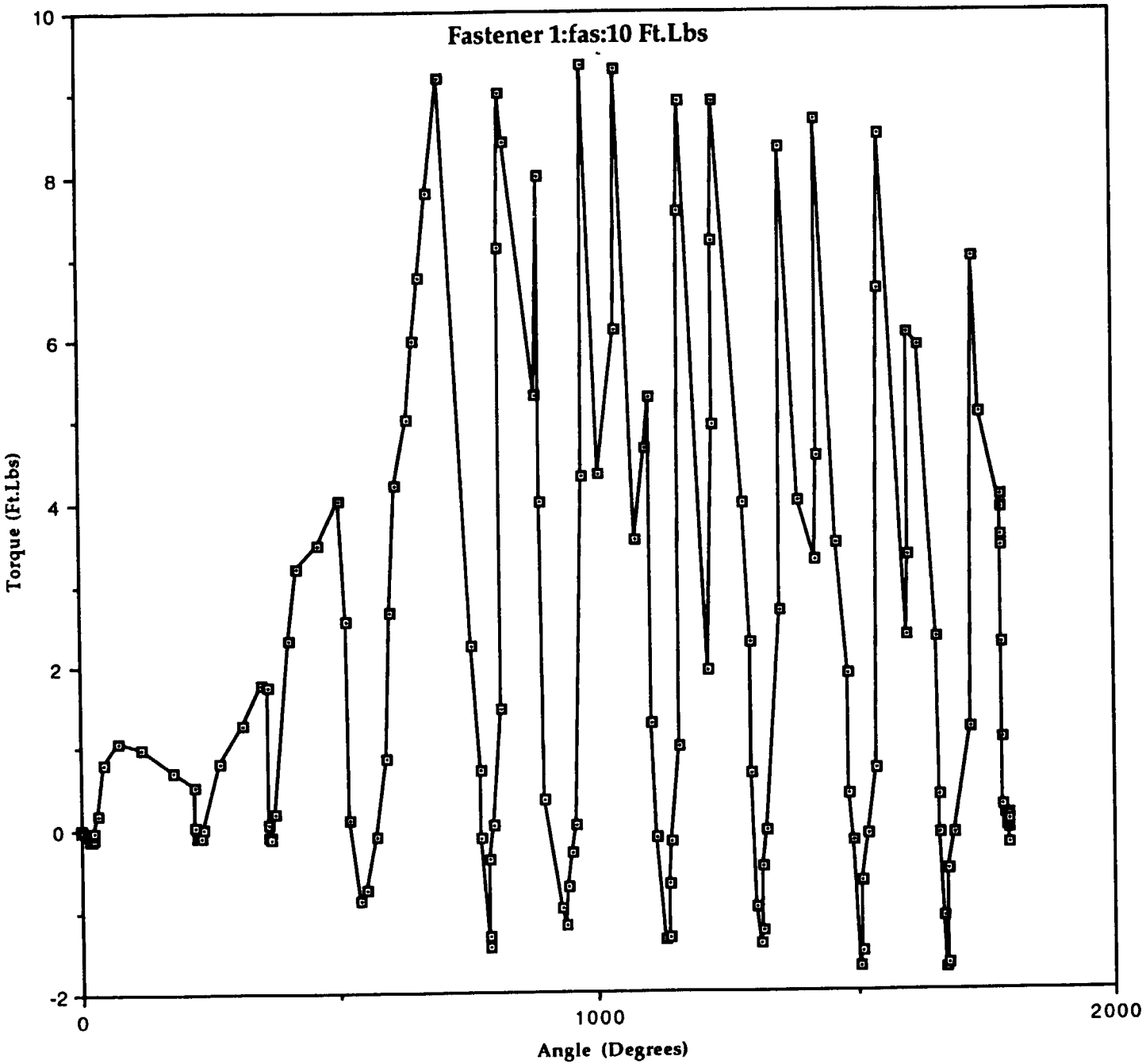
Torque (Ft.Lbs)
1
0
-1
-2
-3
-4
0
1000
2000
Angle (Degrees)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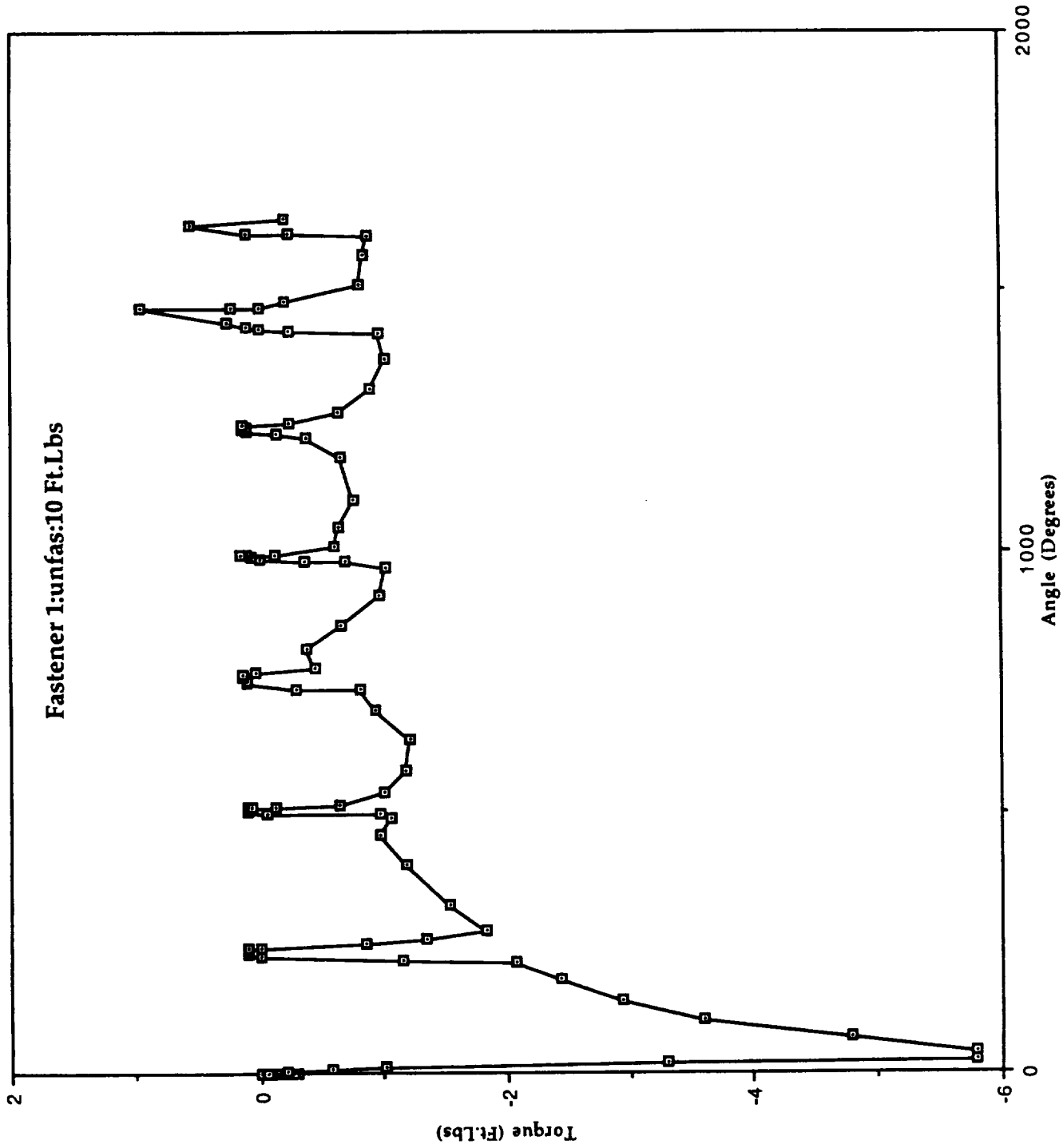
Torque (Ft.Lbs)
10
8
6
4
2
0
-2
0
1000
2000
Angle (Degrees)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Torque (Ft.Lbs)
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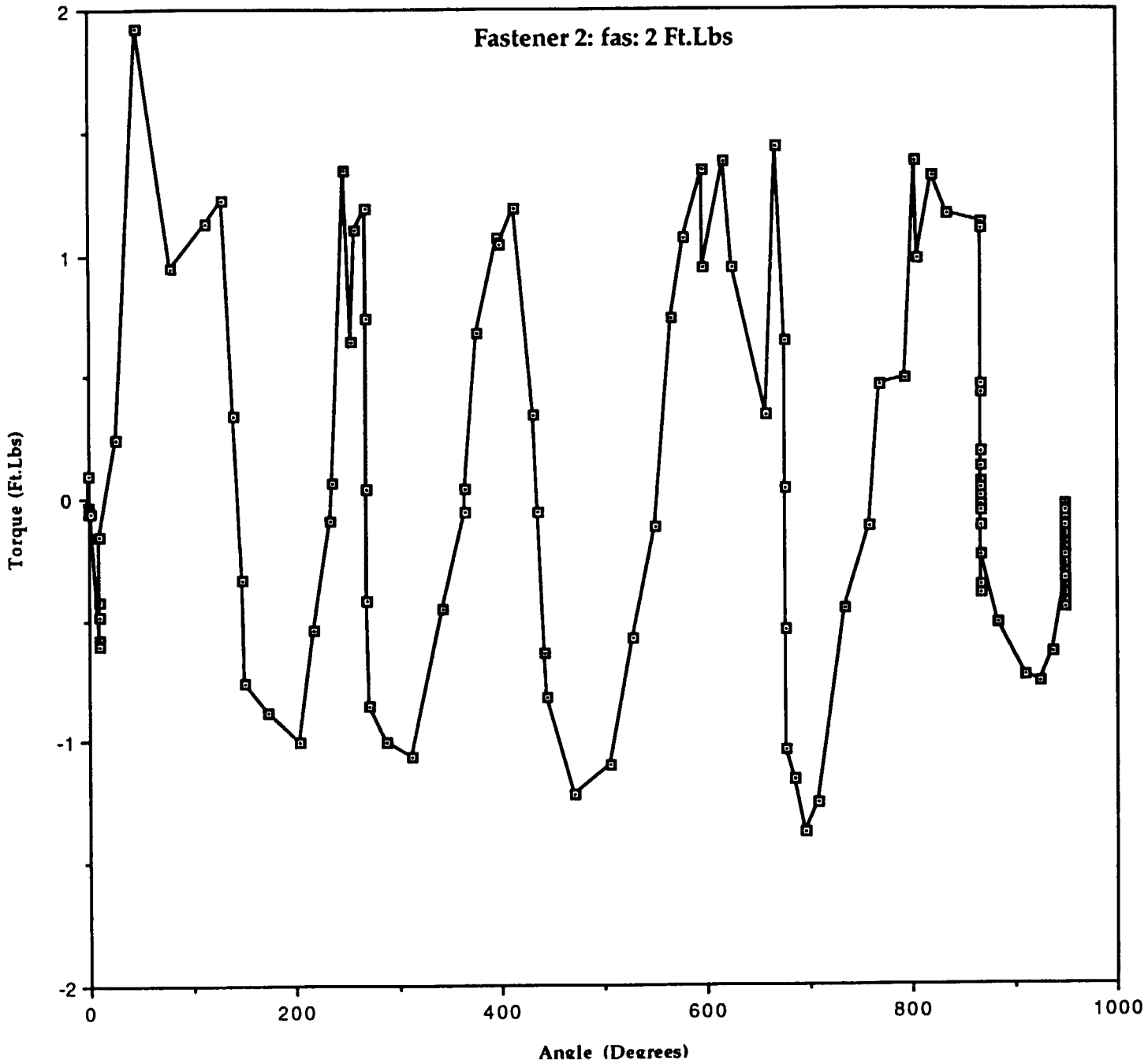
0
-2
-4
-6
0
1000
2000
Angle (Degrees)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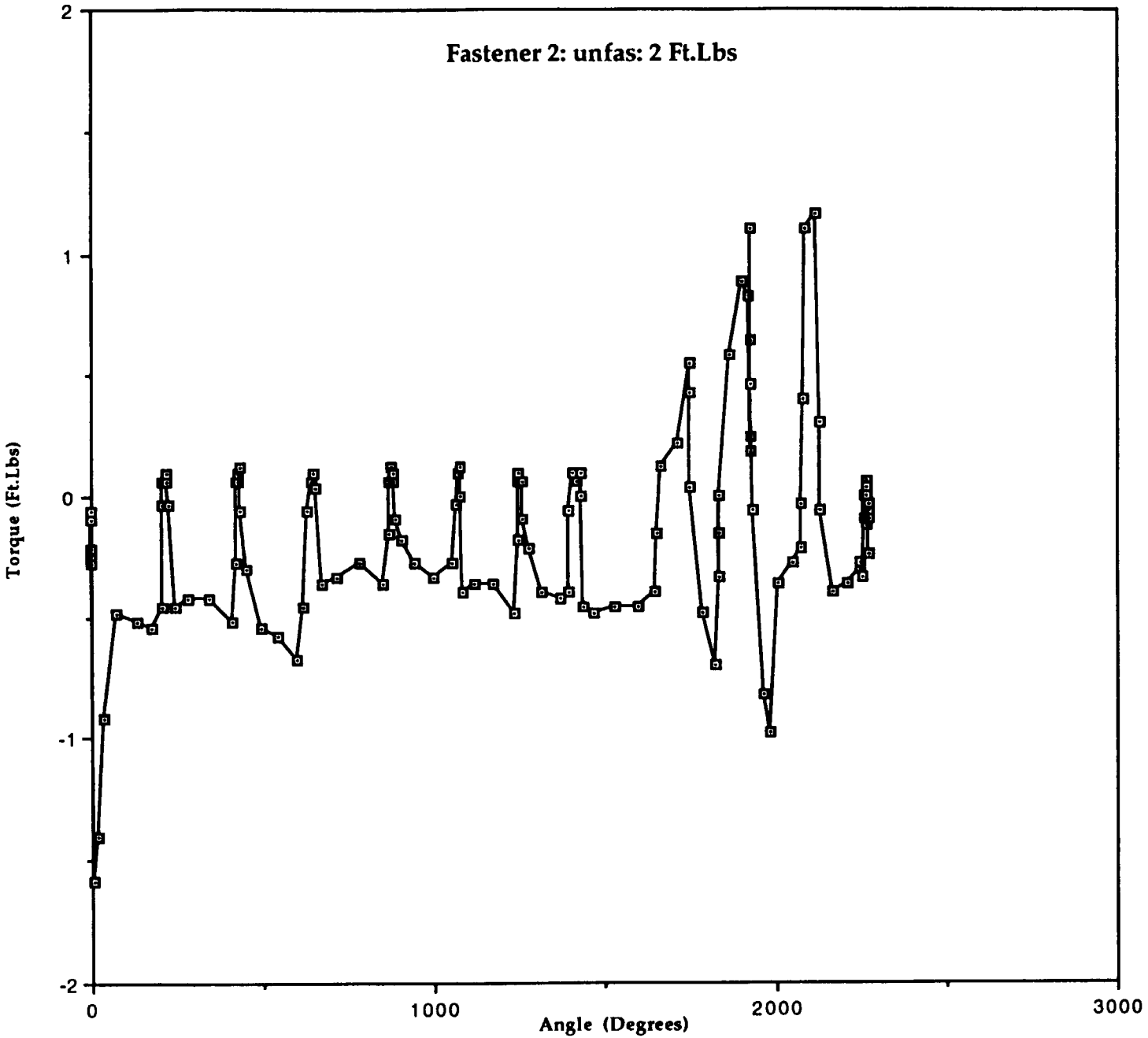
0
-1
-2
0
200
400
600
800
1000
Angle (Degrees)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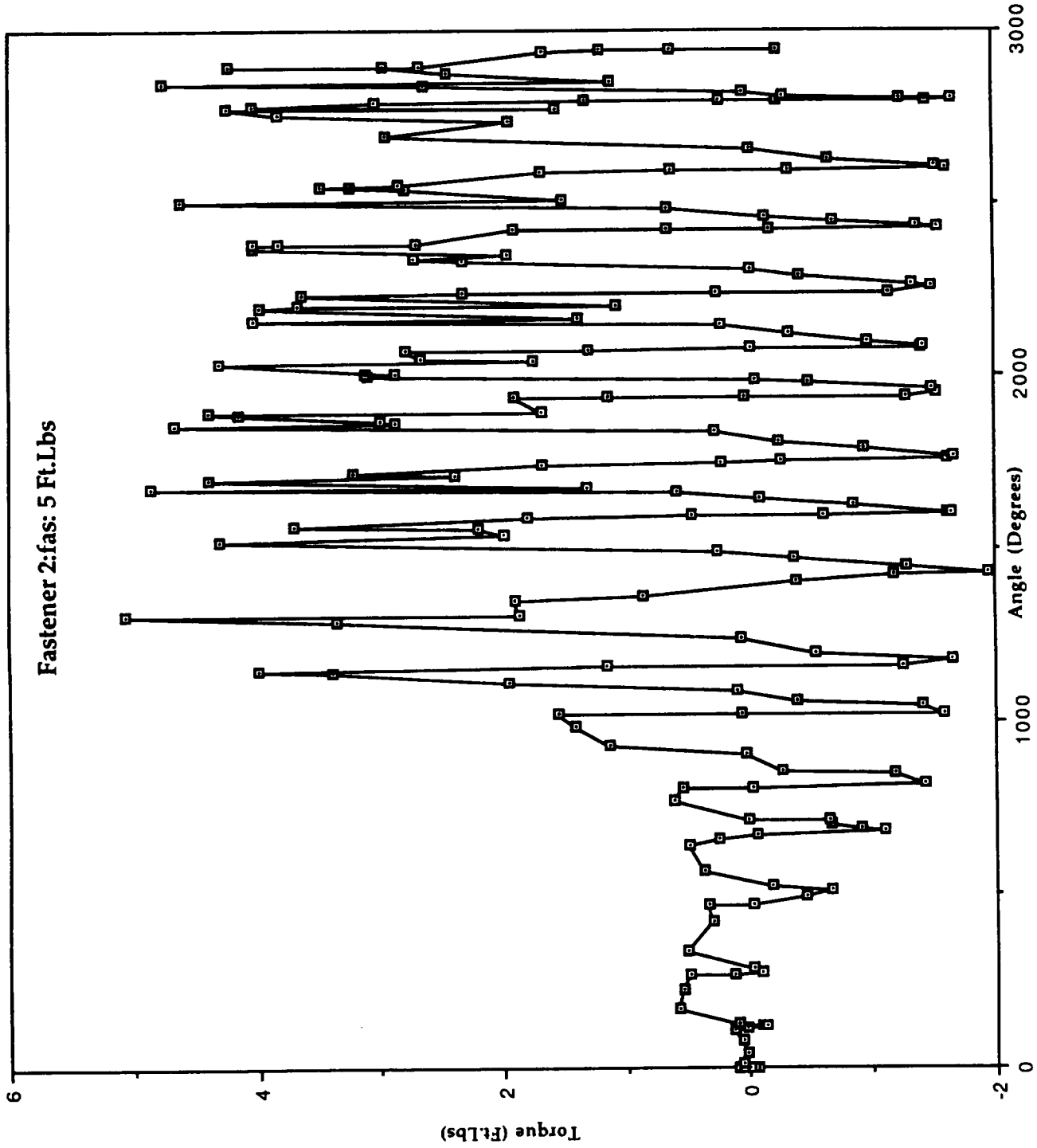
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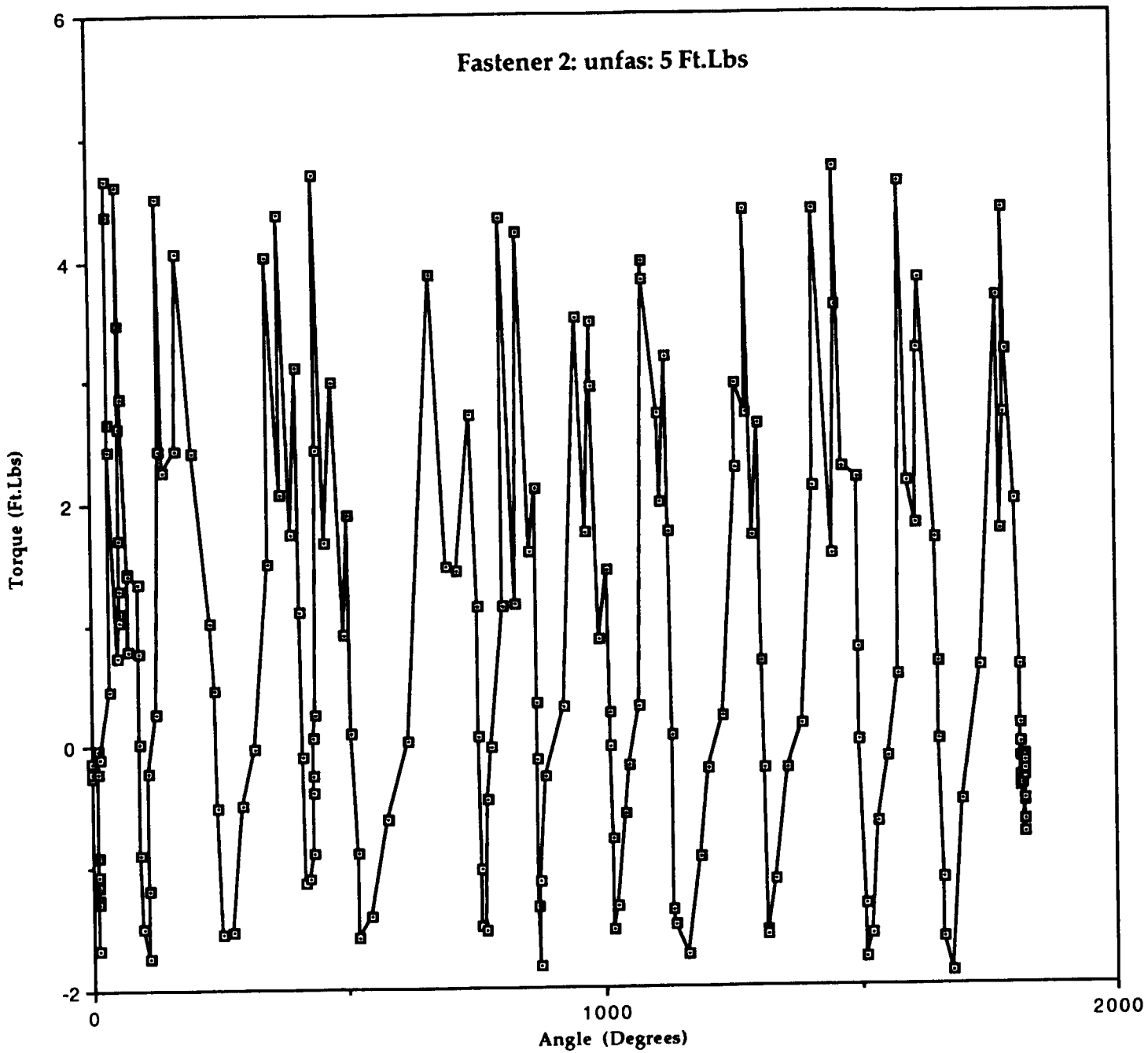
0
-2
0
1000
2000
3000
Angle (Degrees)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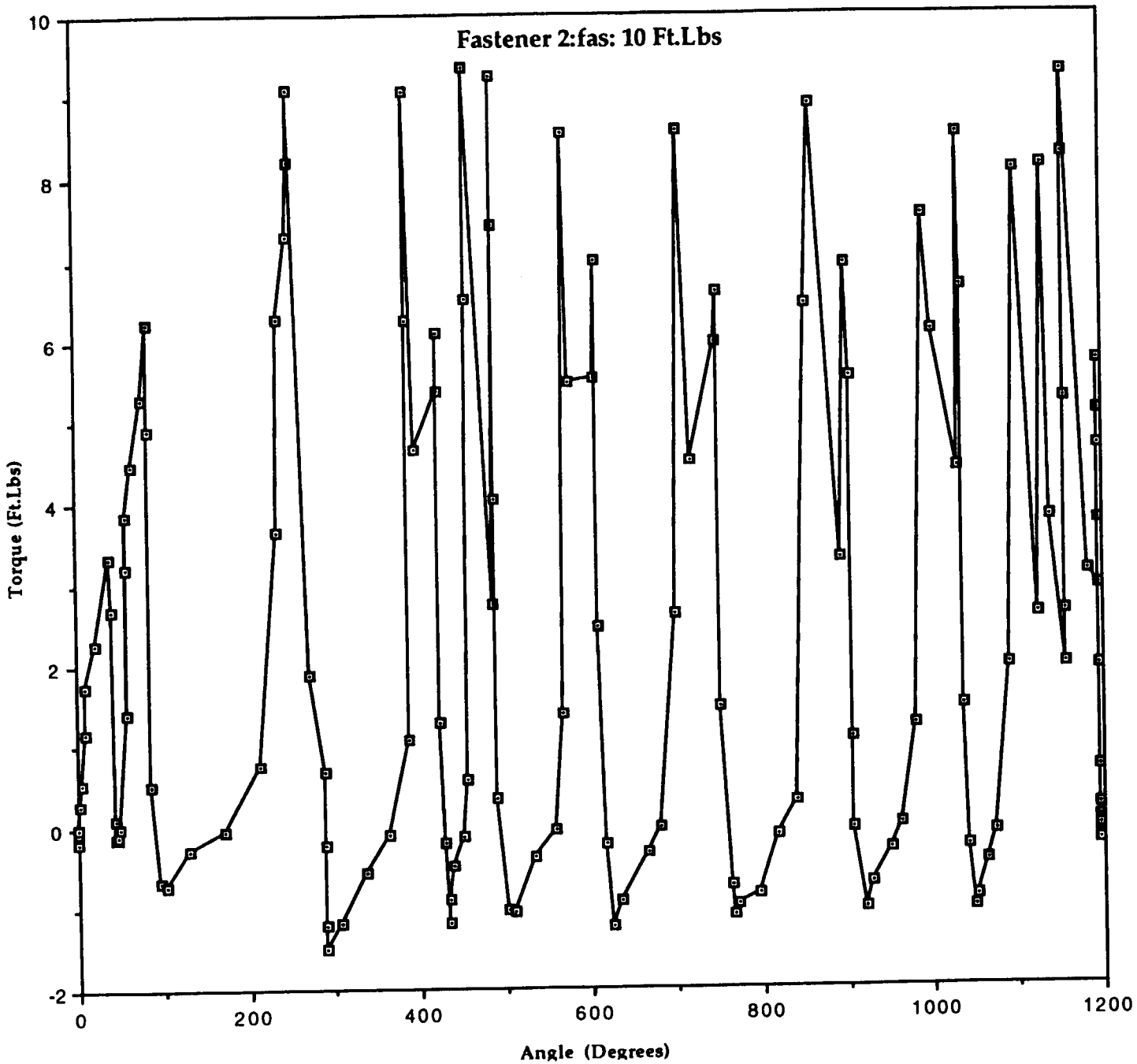
6
4
2
0
-2
0
1000
2000
Angle (Degrees)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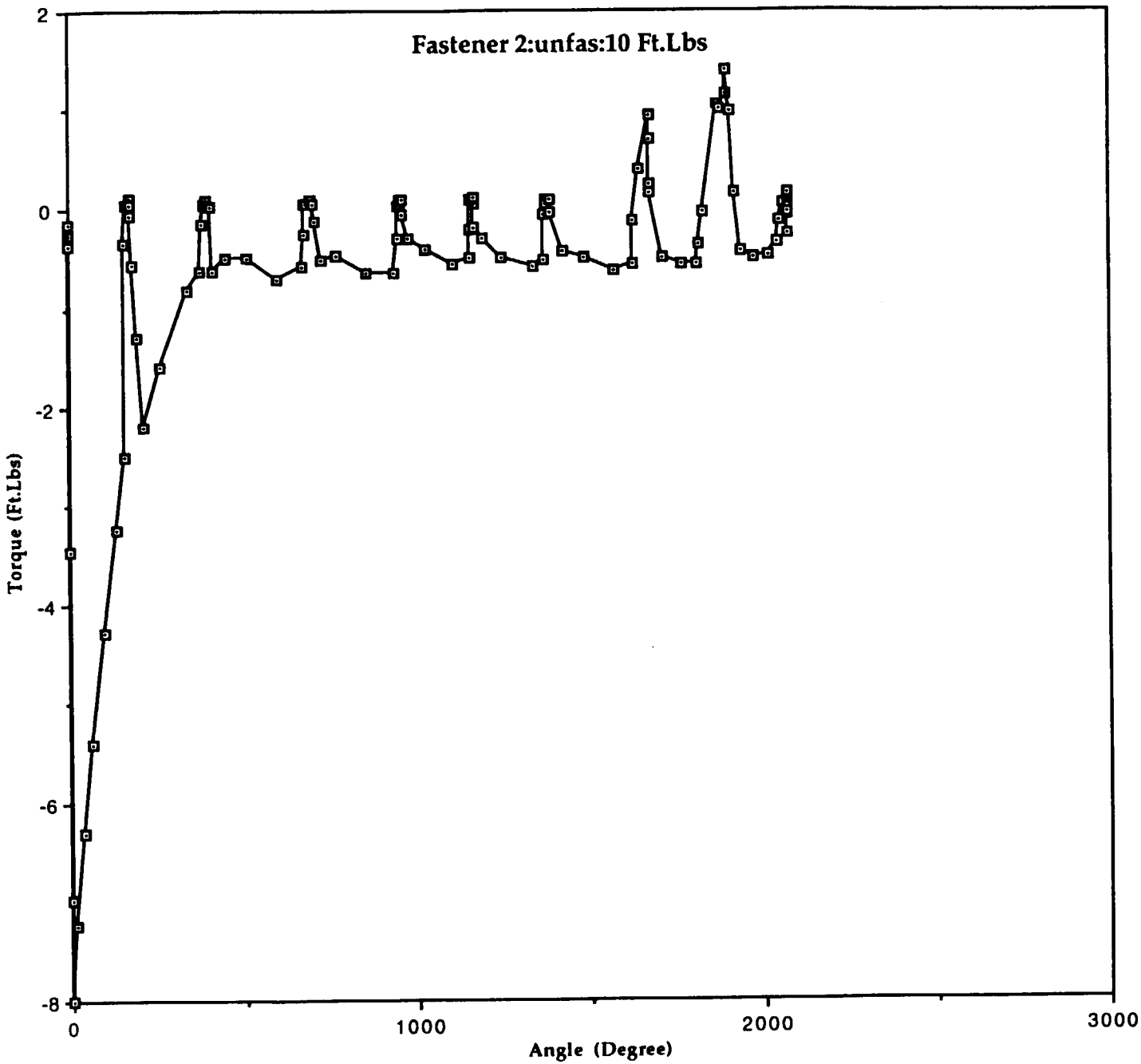
6
4
2
0
-2
0
200
400
600
800
1000
1200
Angle (Degrees)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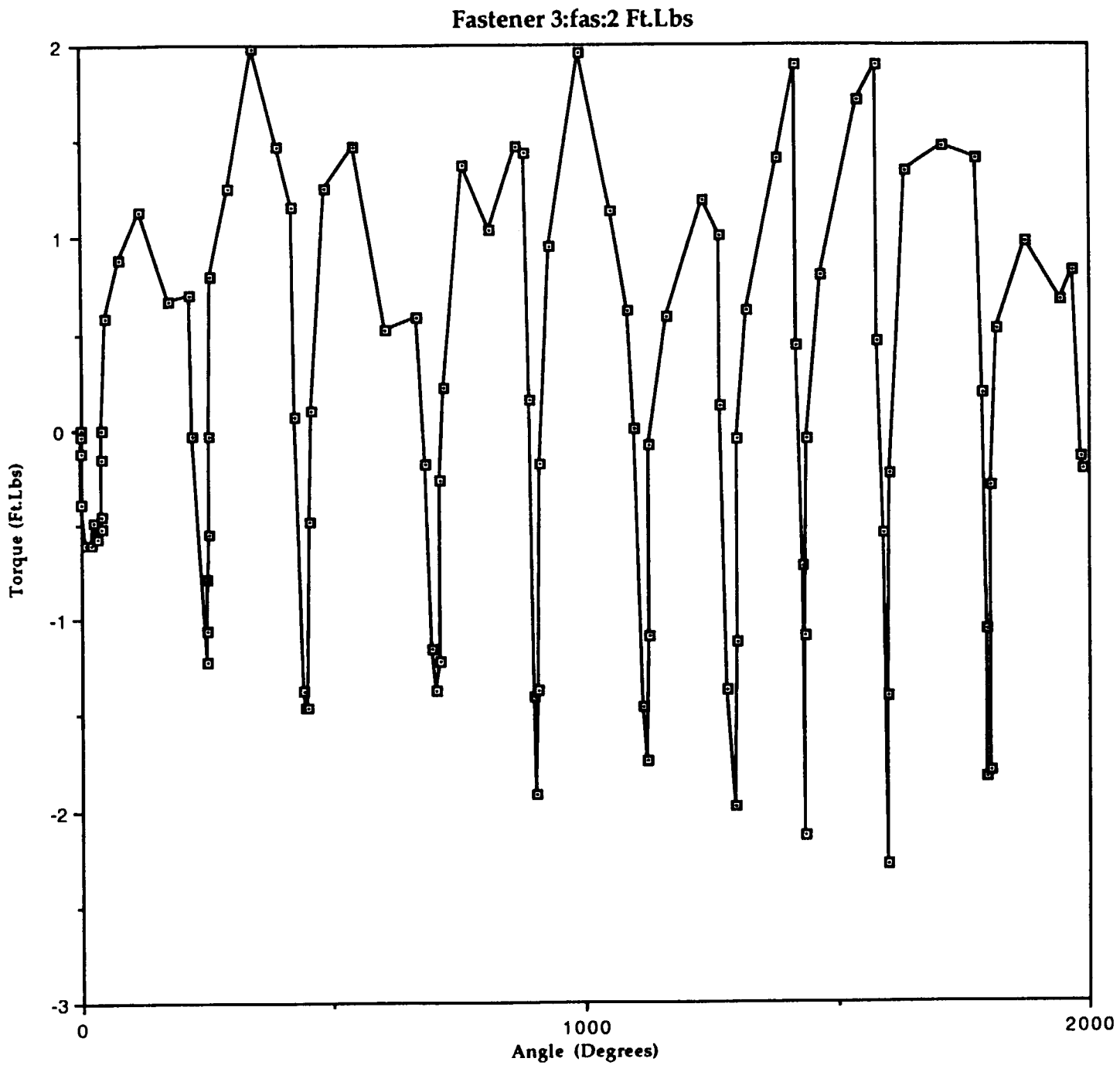
Angle (Degree)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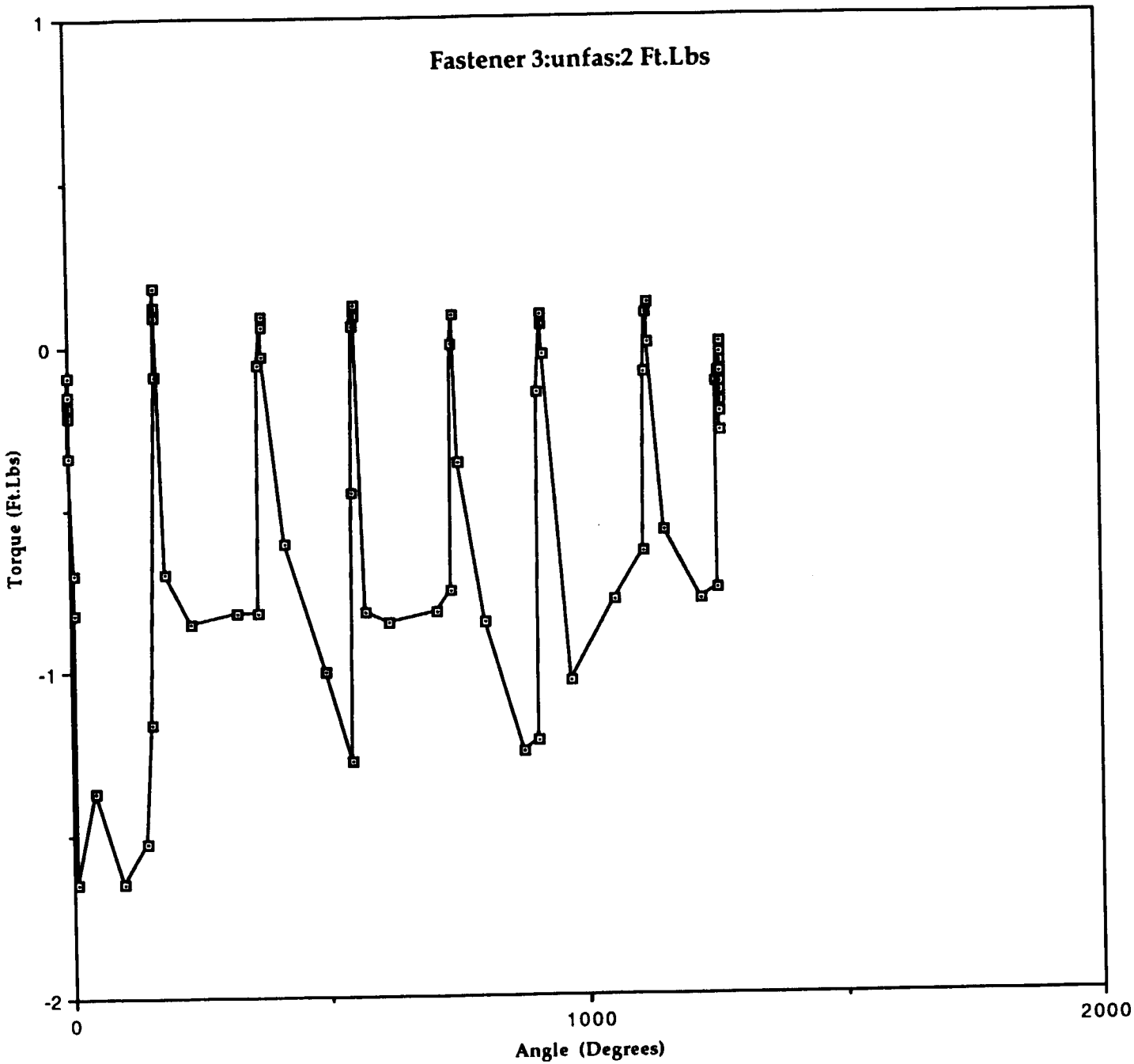
Angle (Degrees)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-2
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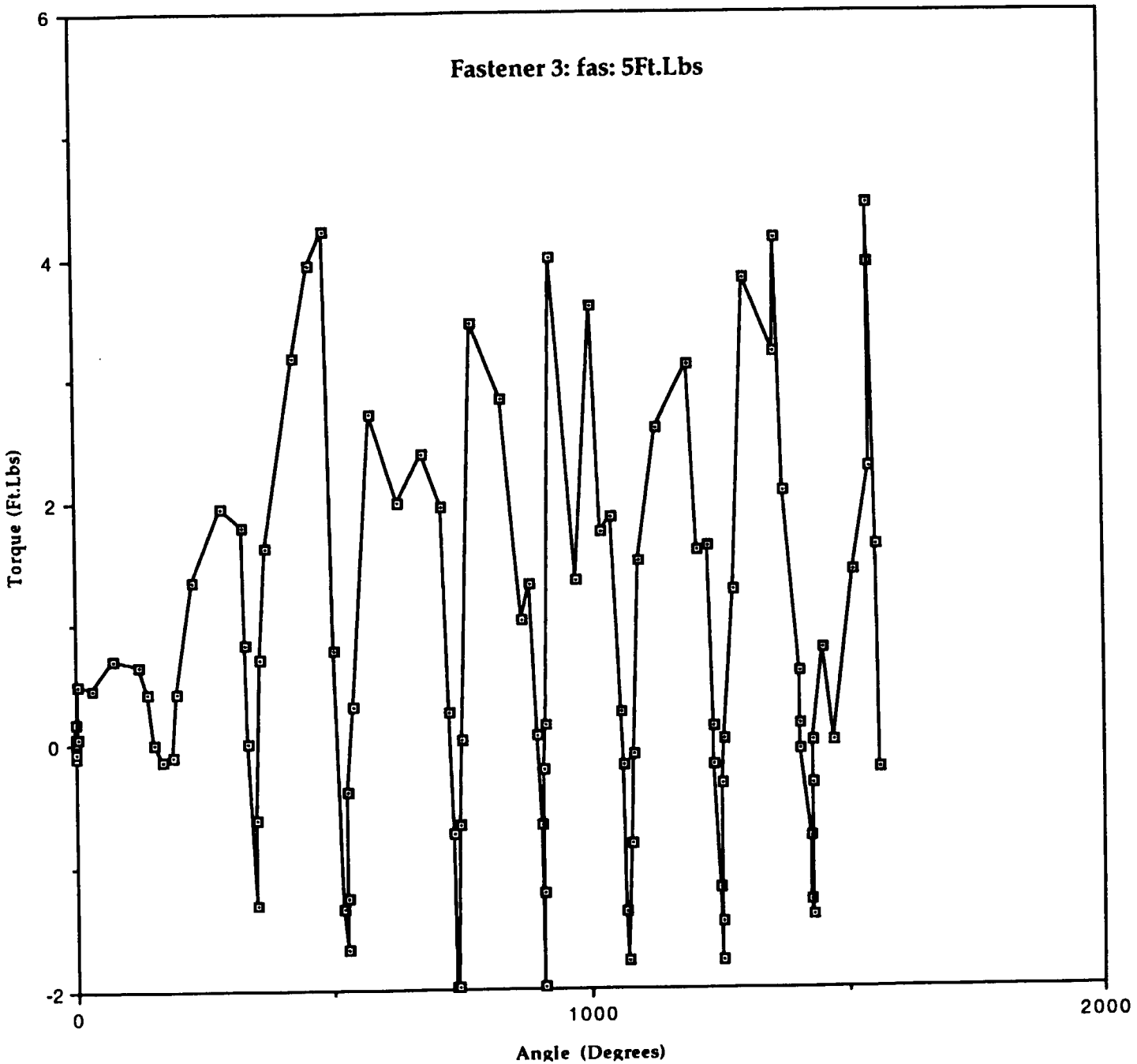
Angle (Degrees)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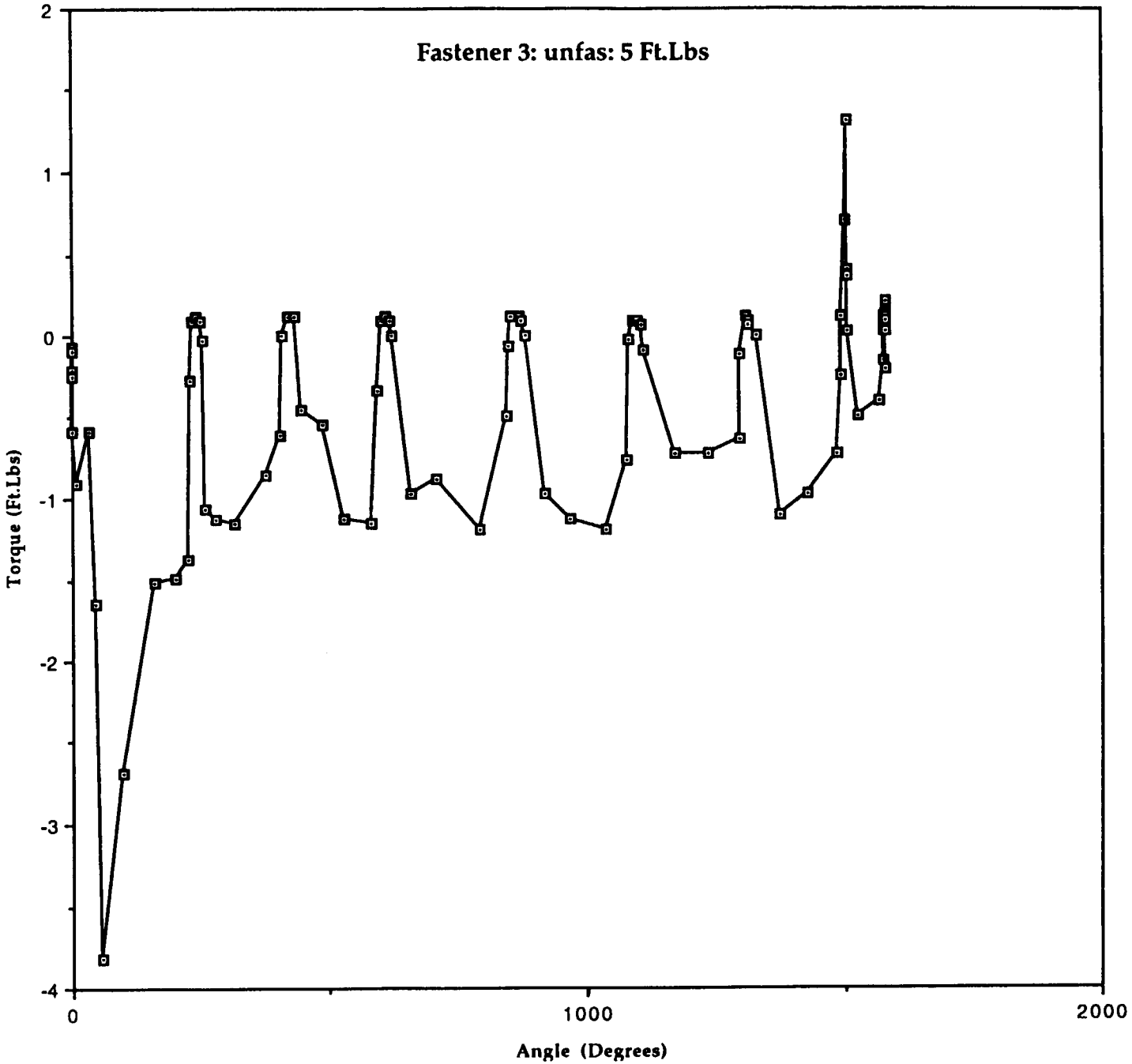
6
4
2
0
-2
0
1000
2000
Angle (Degrees)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-3
-4
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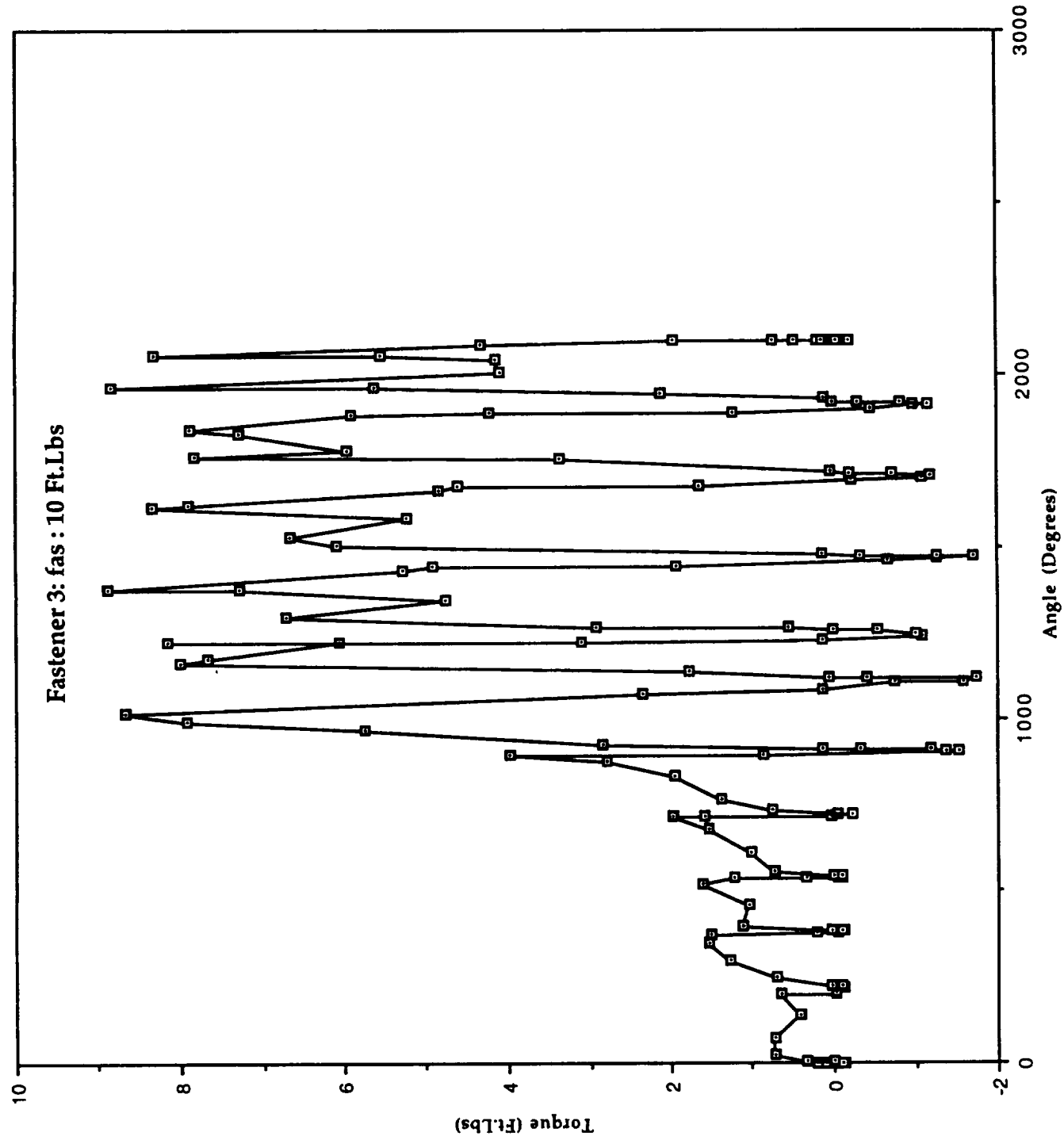
1000
2000
Angle (Degrees)


Fastener 3: fas : 10 Ft.Lbs
Torque (Ft.Lbs)
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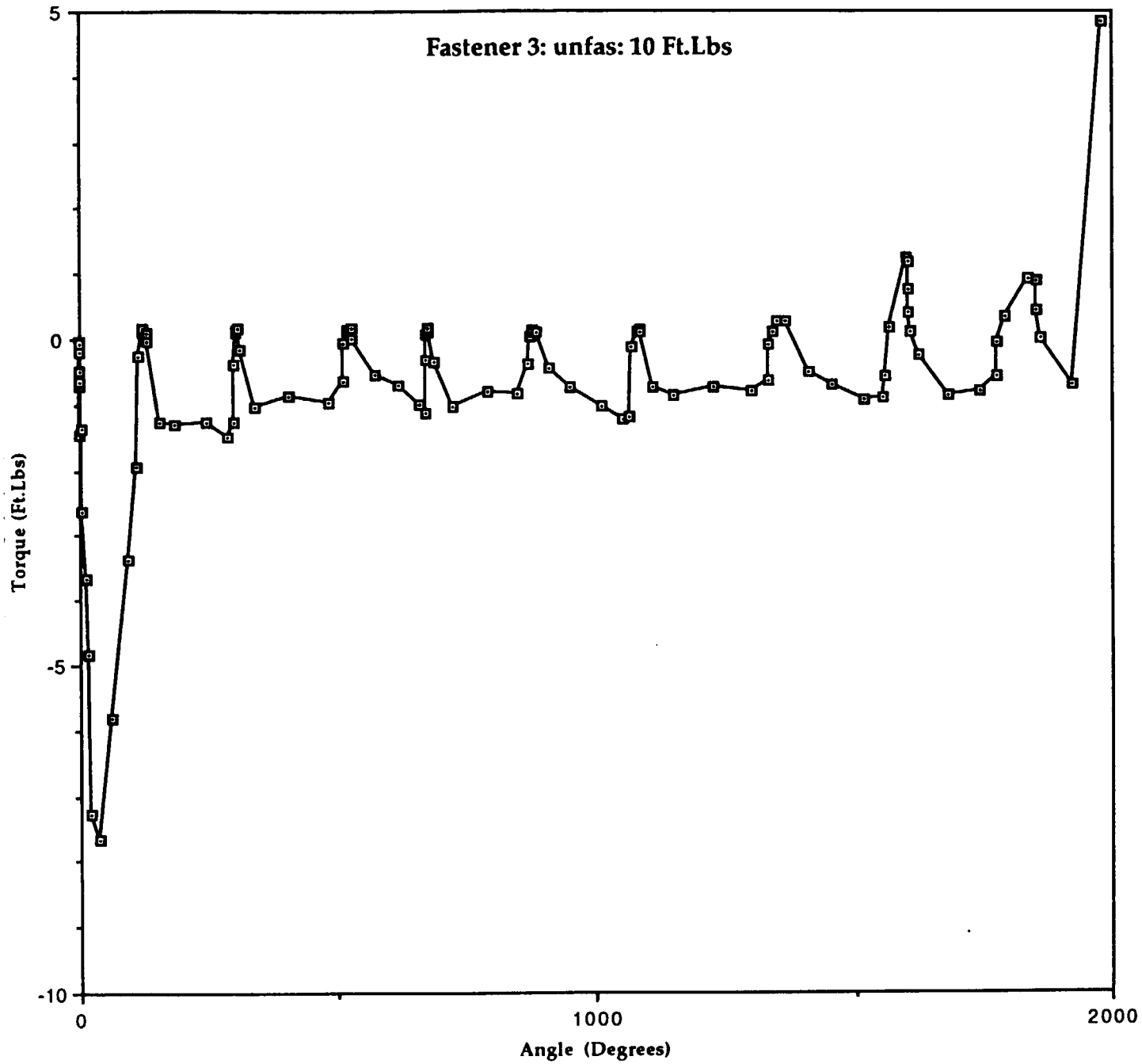
8
6
4
2
0
-2
0
1000
2000
3000
Angle (Degrees)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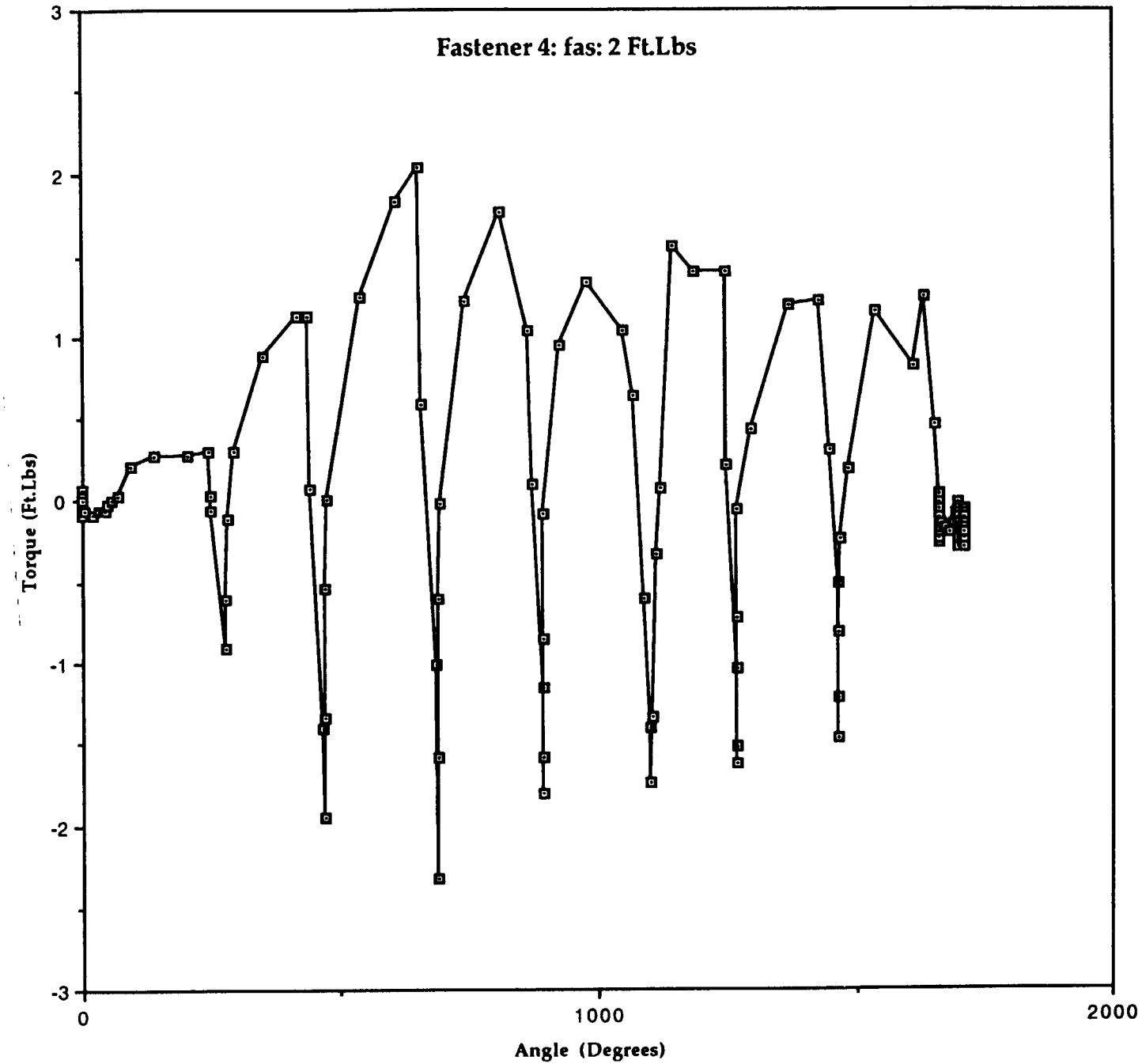
0
-5
-10
Torque (Ft.Lbs)
0
1000
2000
Angle (Degrees)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Torque (Ft.Lbs)
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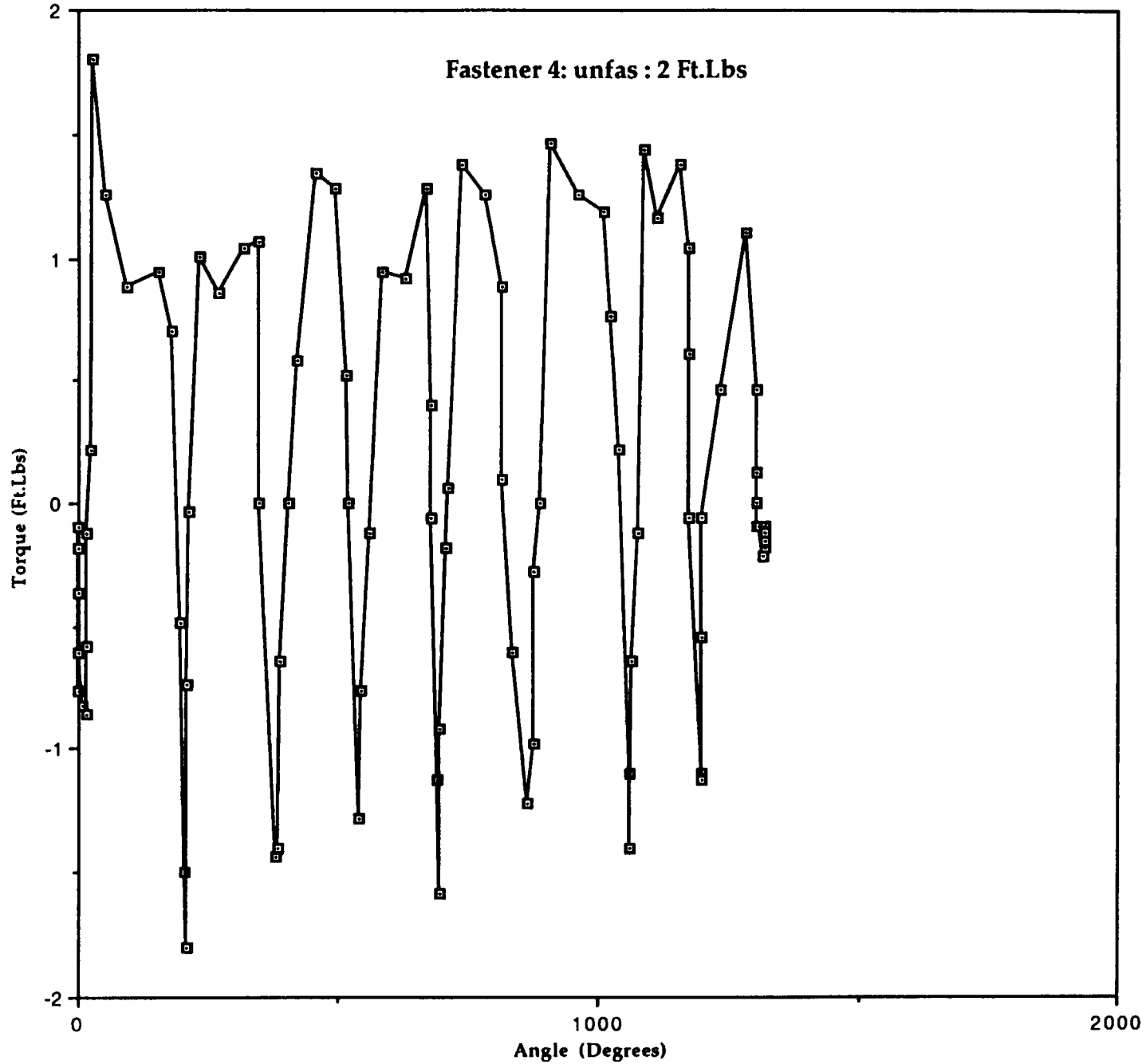
1
0
-1
-2
-3
0
1000
2000
Angle (Degrees)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Torque (Ft.Lbs)
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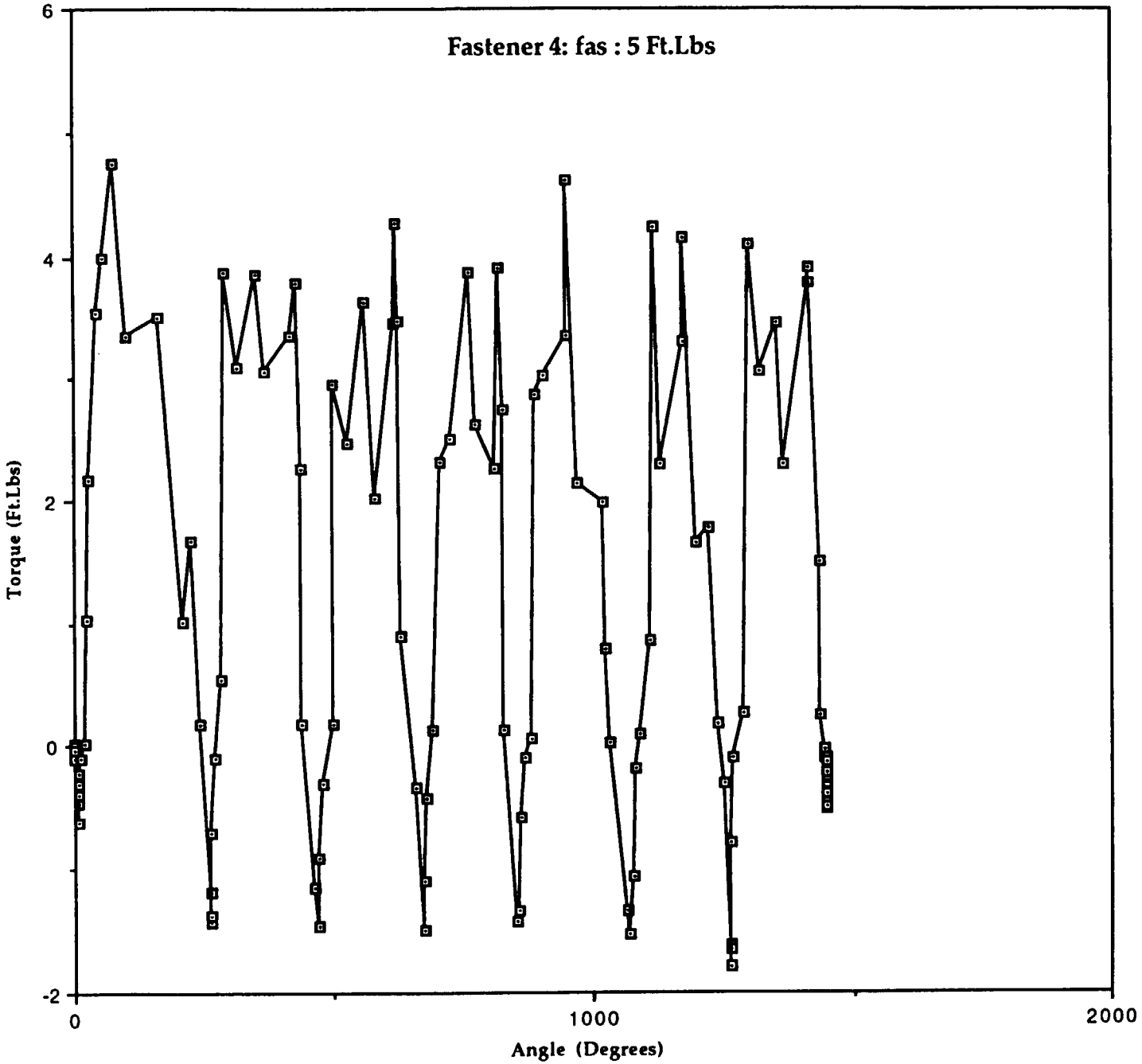
1
0
-1
-2
0
1000
2000
Angle (Degrees)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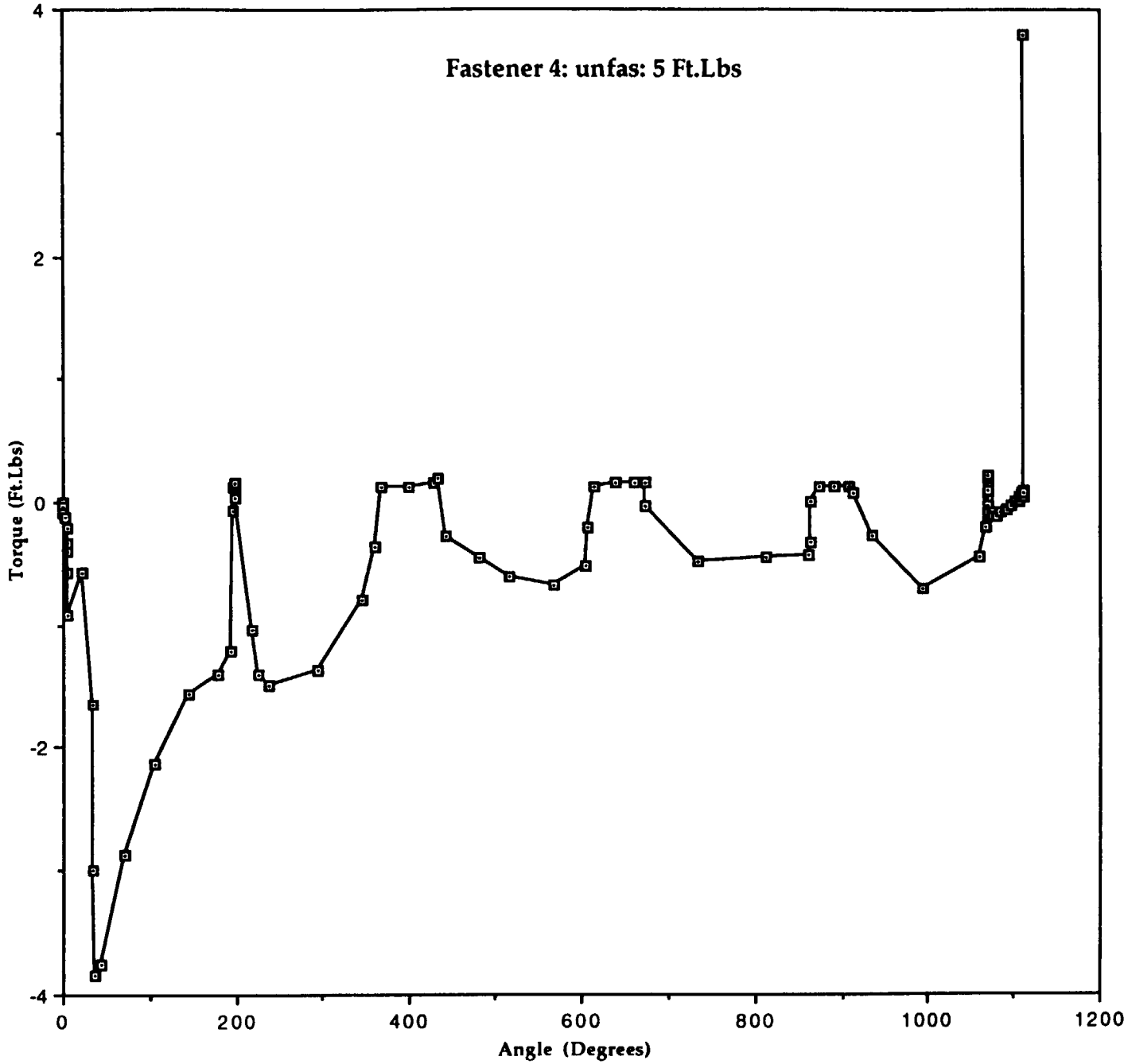
Torque (Ft.Lbs)
6
4
2
0
-2
0
1000
2000
Angle (Degrees)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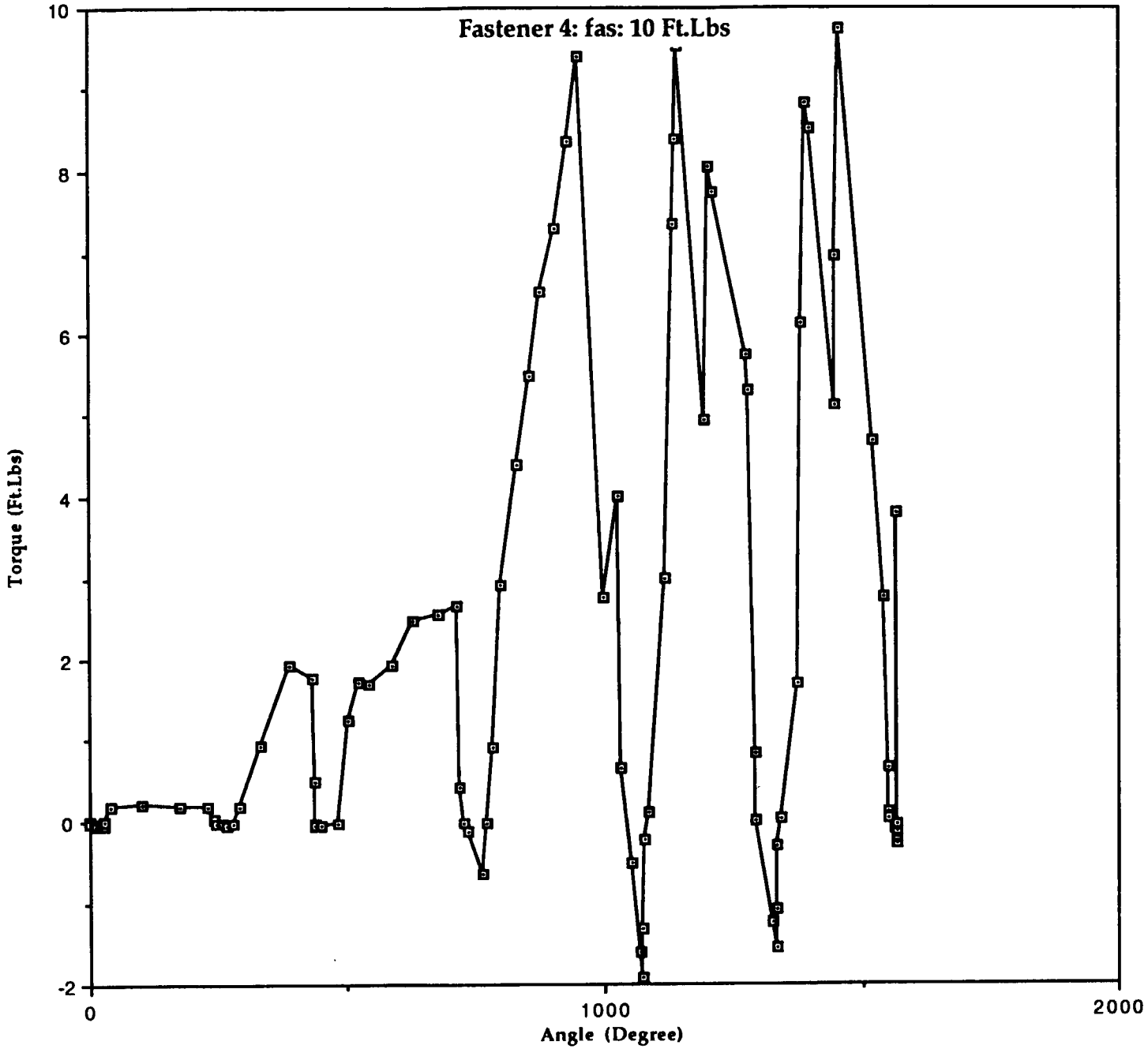
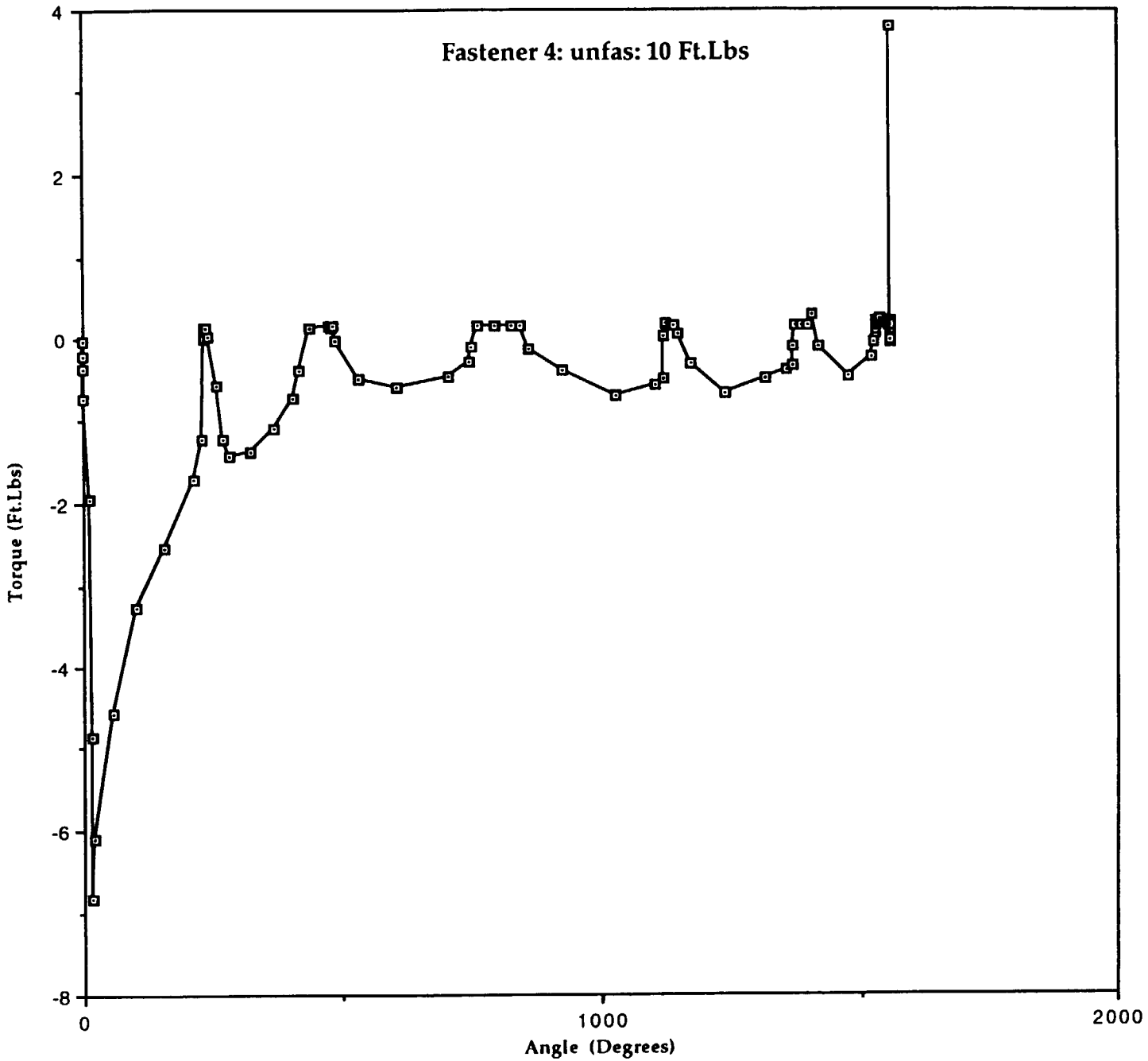
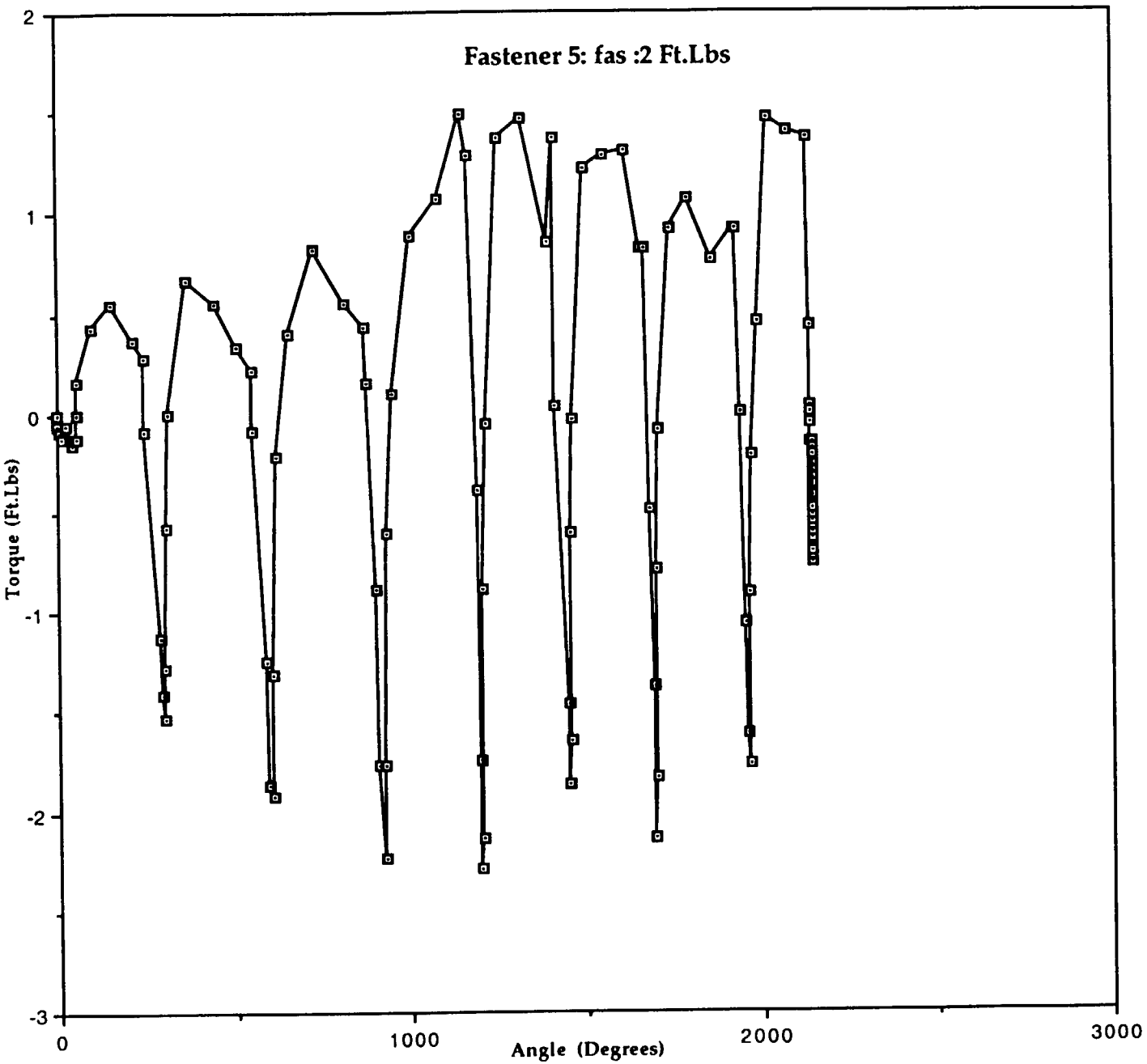
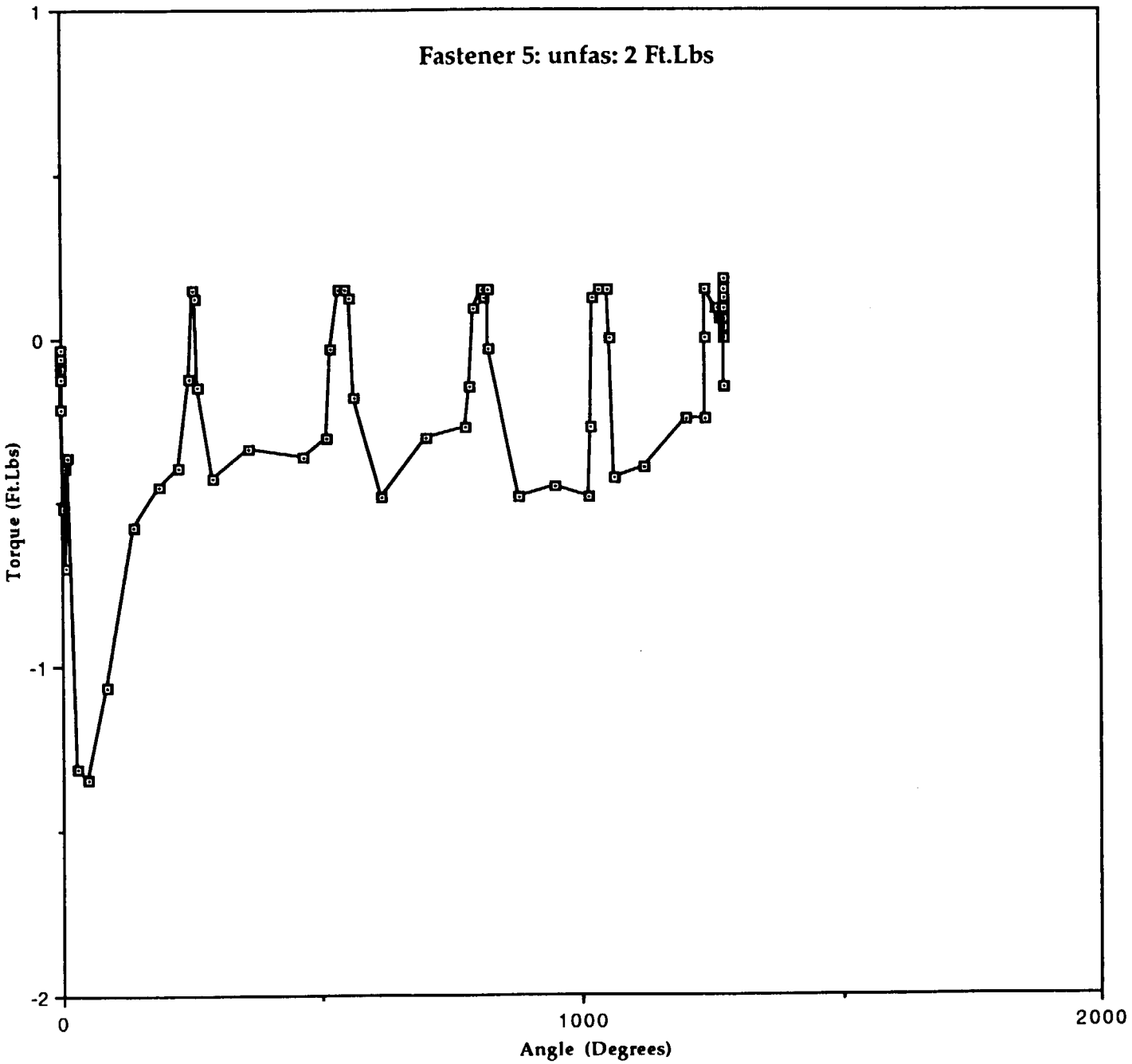
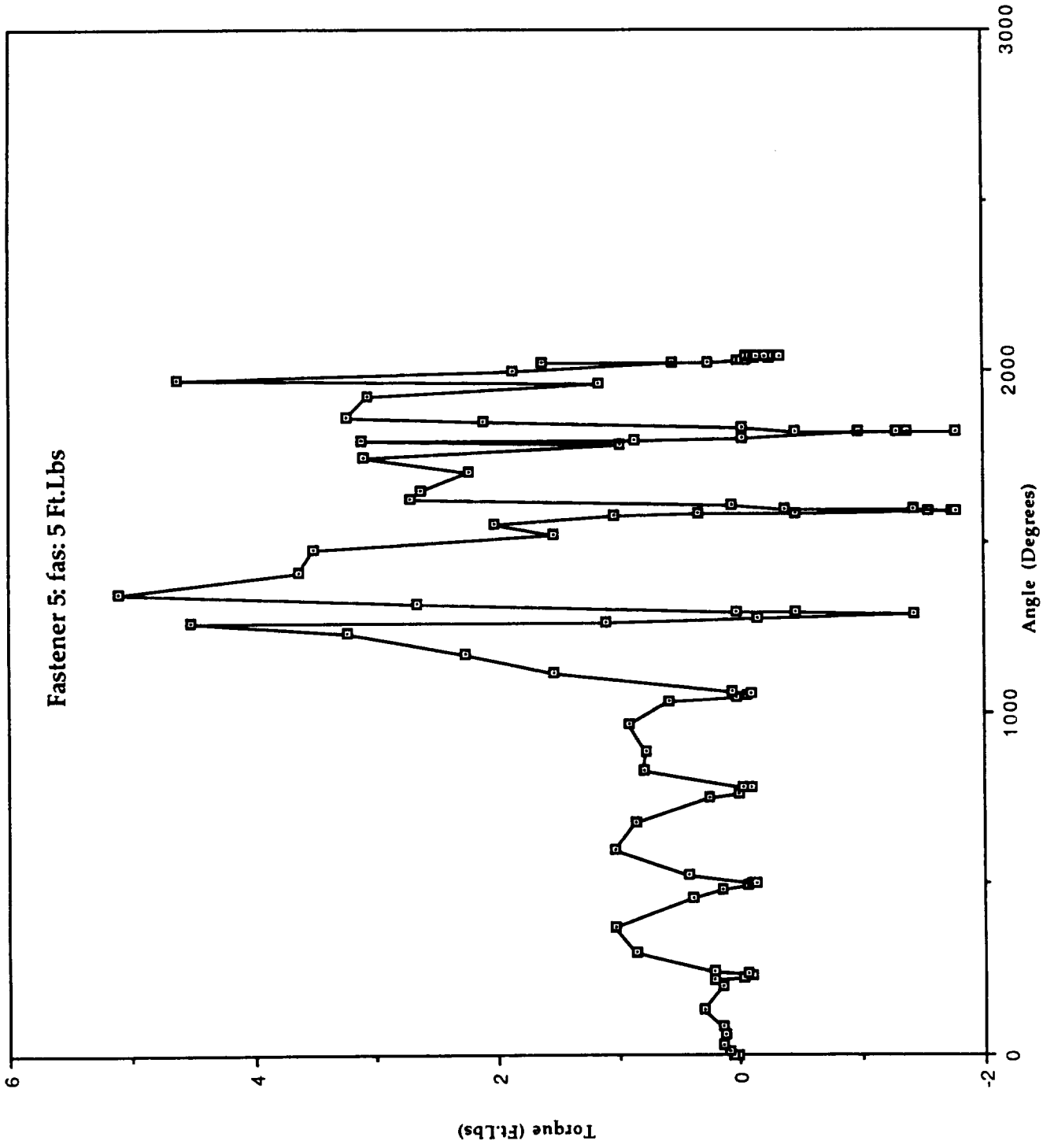
Torque (Ft.Lbs)
4
2
0
-2
-4
0
200
400
600
800
1000
1200
Angle (Degrees)

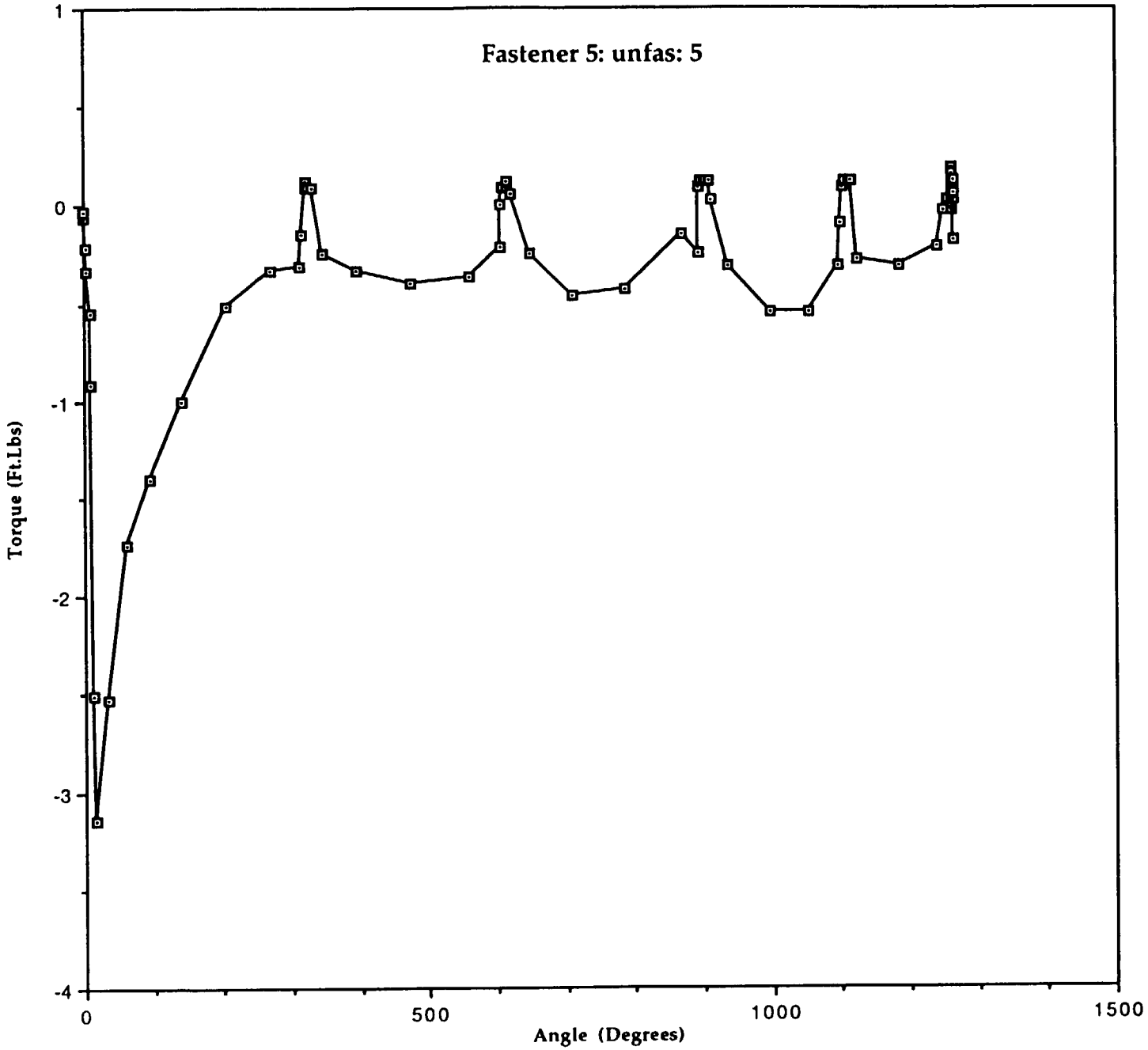

Fastener 4: fas: 10 Ft.Lbs
Torque (Ft.Lbs)
10
8
6
4
2
0
-2
0
1000
2000
Angle (Degree)

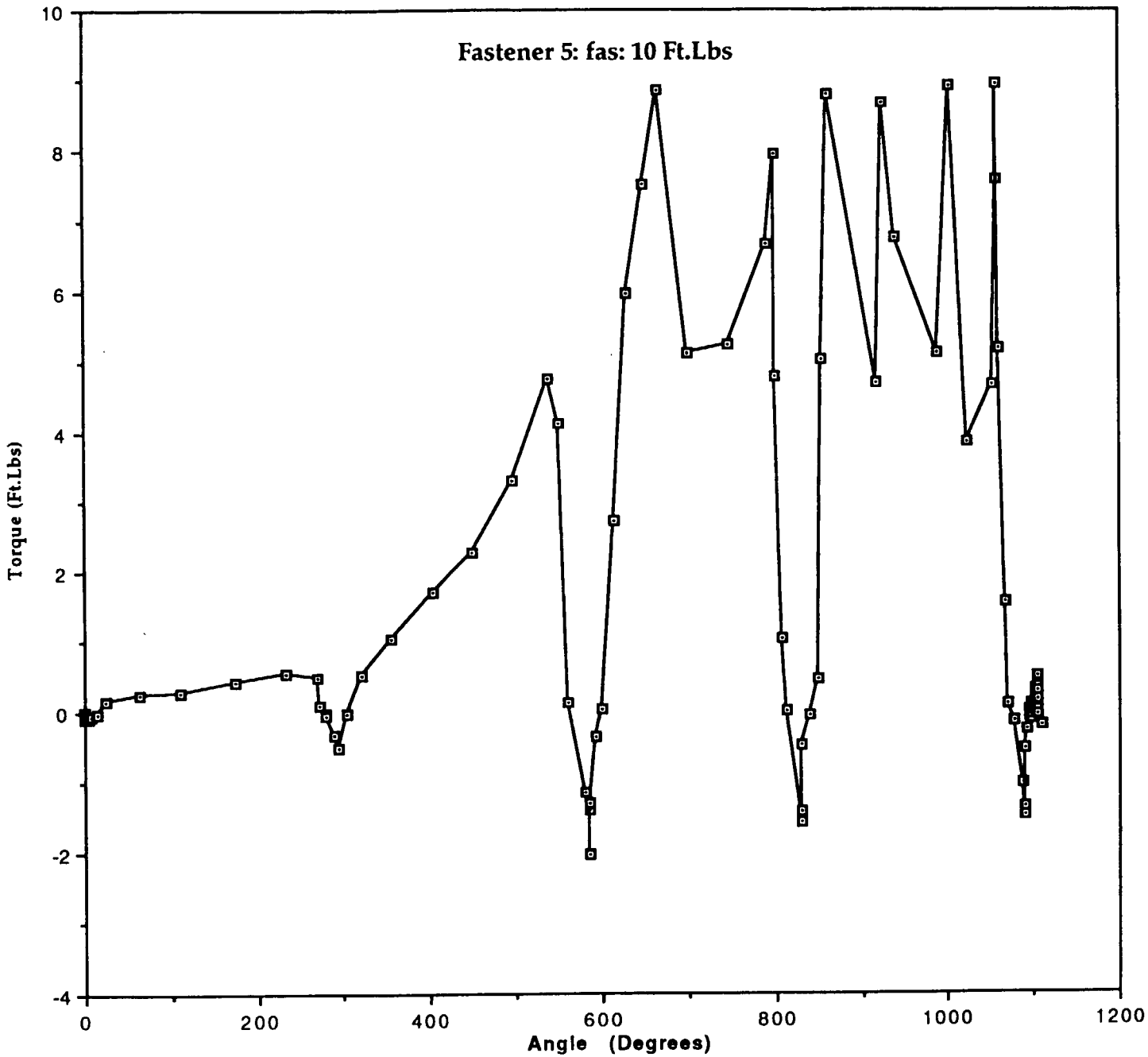

Fastener 4: unfas: 10 Ft.Lbs
Torque (Ft.Lbs)
4
2
0
-2
-4
-6
-8
0
1000
2000
Angle (Degrees)

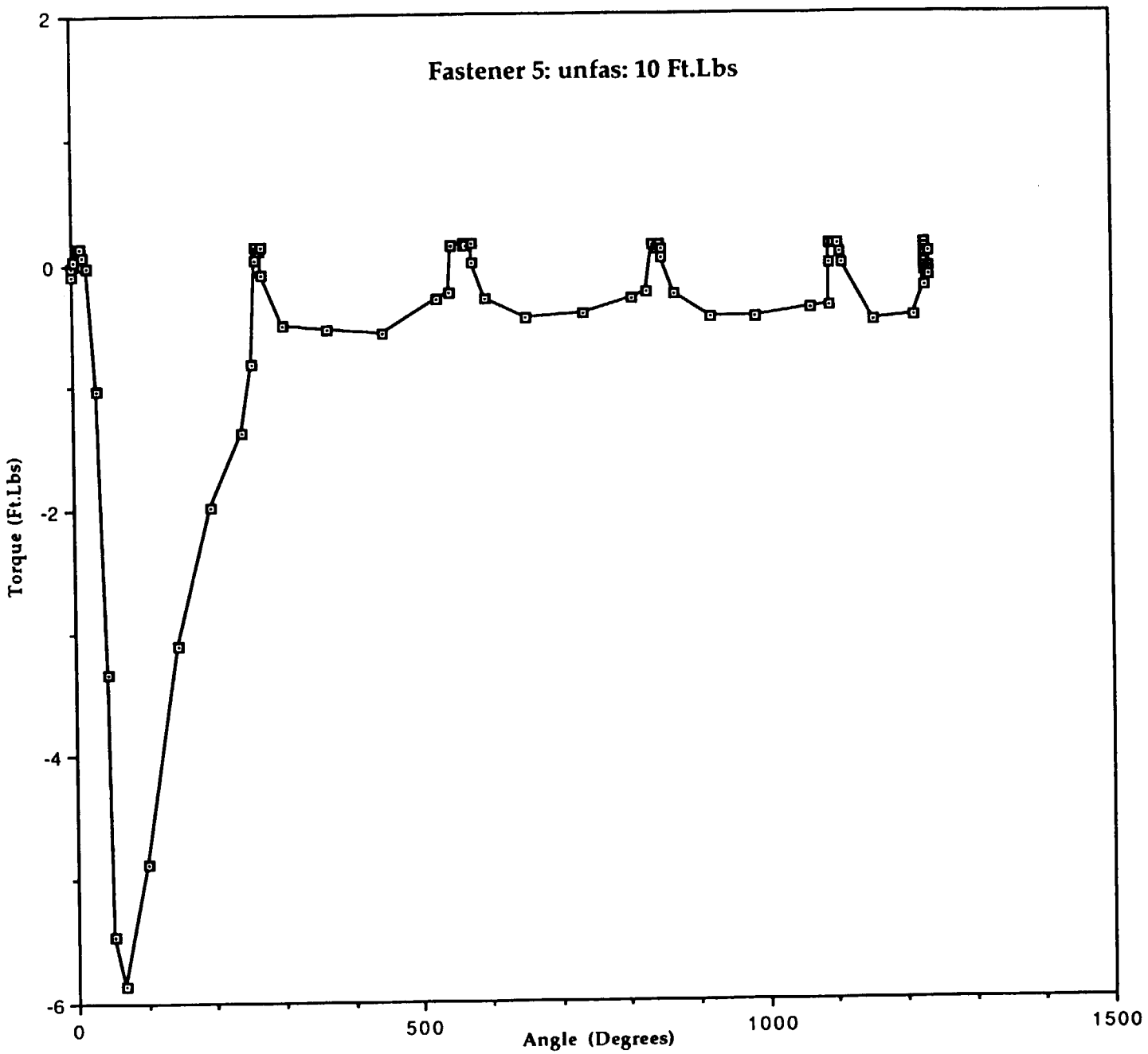

Fastener 5: fas :2 Ft.Lbs
Torque (Ft.Lbs)
2
1
0
-1
-2
-3
0
1000
2000
3000
Angle (Degrees)


Fastener 5: unfas: 2 Ft.Lbs
Torque (Ft.Lbs)
1
0
-1
-2
0
1000
2000
Angle (Degrees)


Fastener 5: fas: 5 Ft.Lbs
Torque (Ft.Lbs)
6
4
2
0
-2
0
1000
2000
3000
Angle (Degrees)


Fastener 5: unfas: 5
Torque (Ft.Lbs)
1
0
-1
-2
-3
-4
0
500
1000
1500
Angle (Degrees)

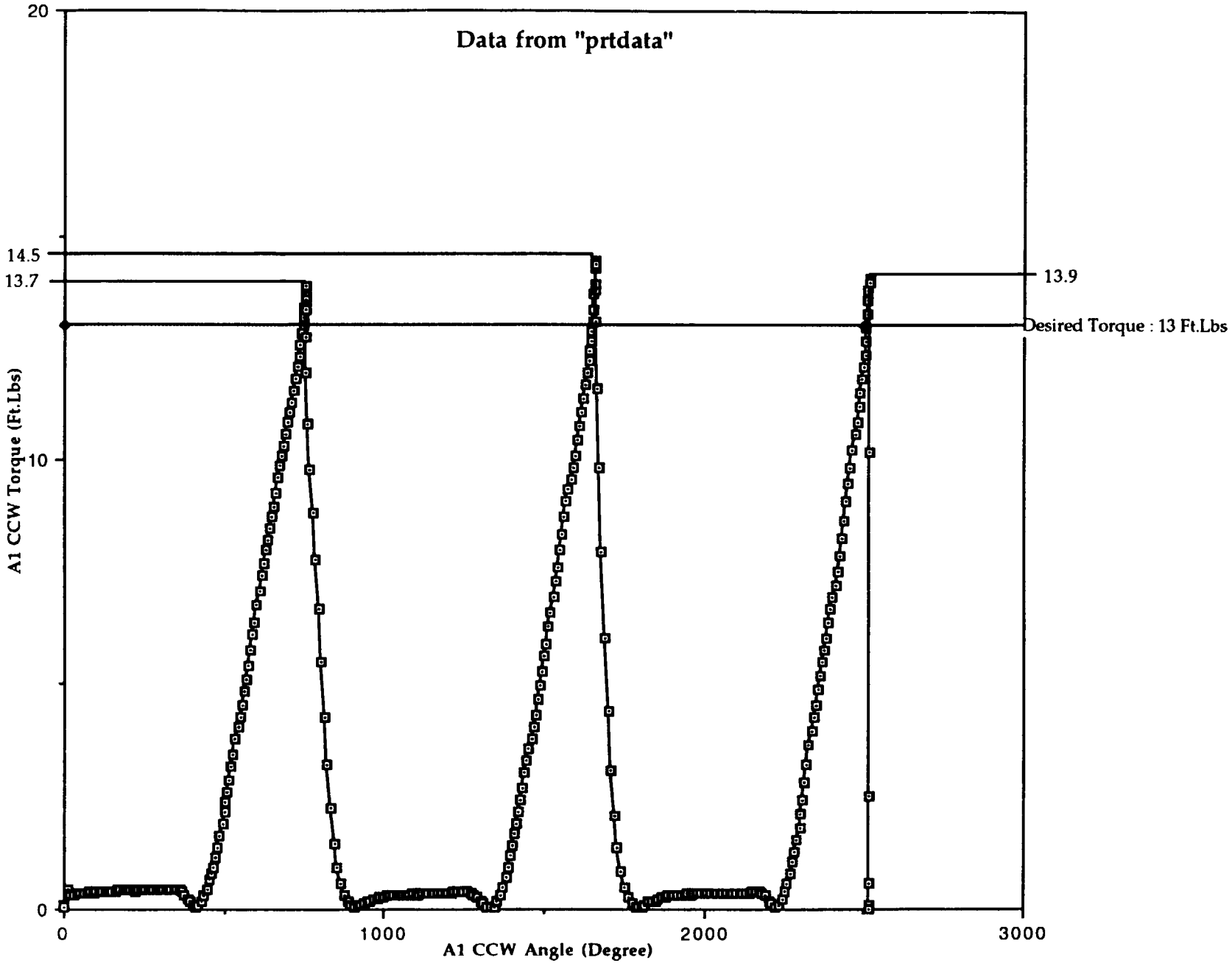

Fastener 5: fas: 10 Ft.Lbs
Torque (Ft.Lbs)
Angle (Degrees)
10
8
6
4
2
0
-2
-4
0
200
400
600
800
1000
1200

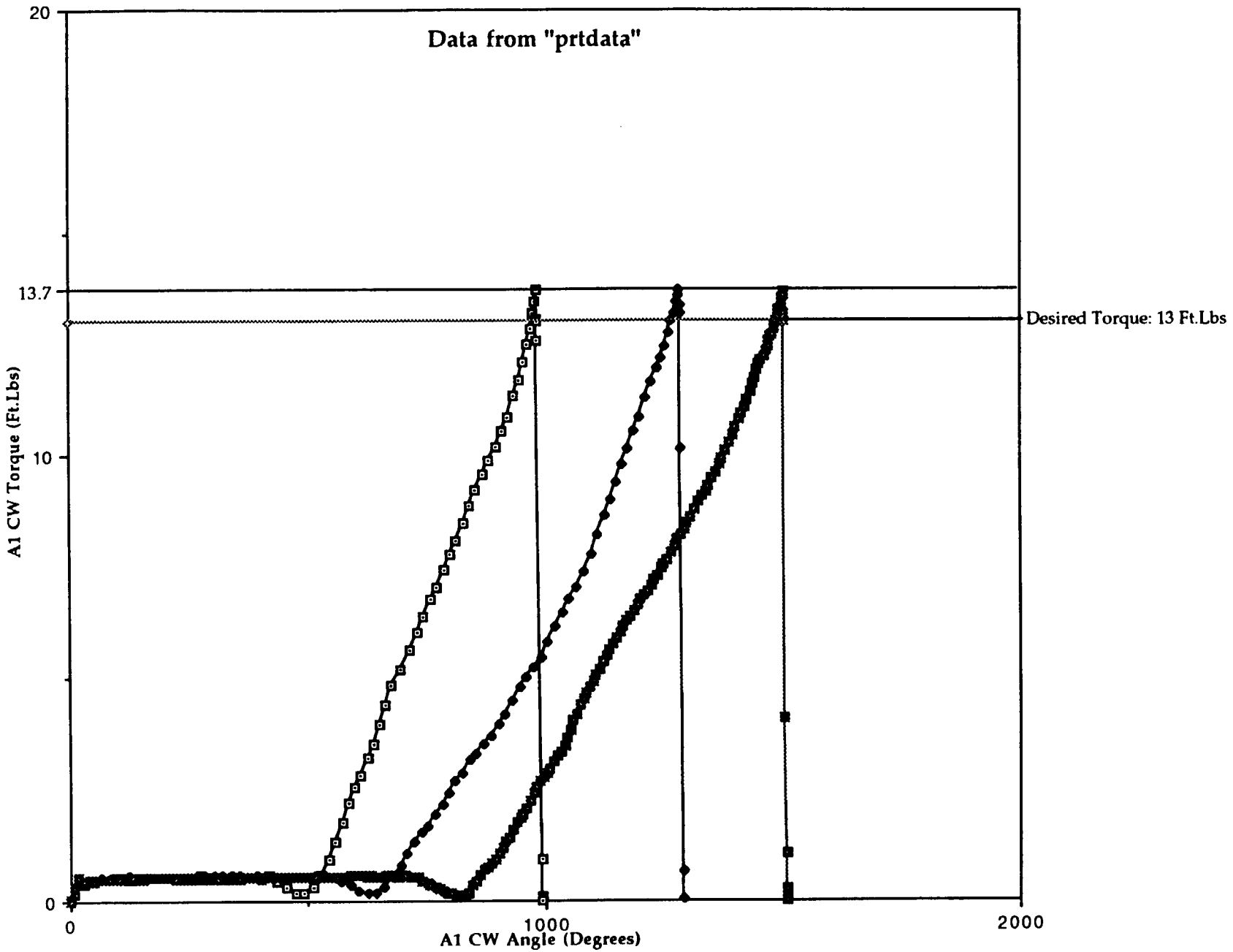

Fastener 5: unfas: 10 Ft.Lbs
Torque (Ft.Lbs)
2
0
-2
-4
-6
0
500
1000
1500
Angle (Degrees)

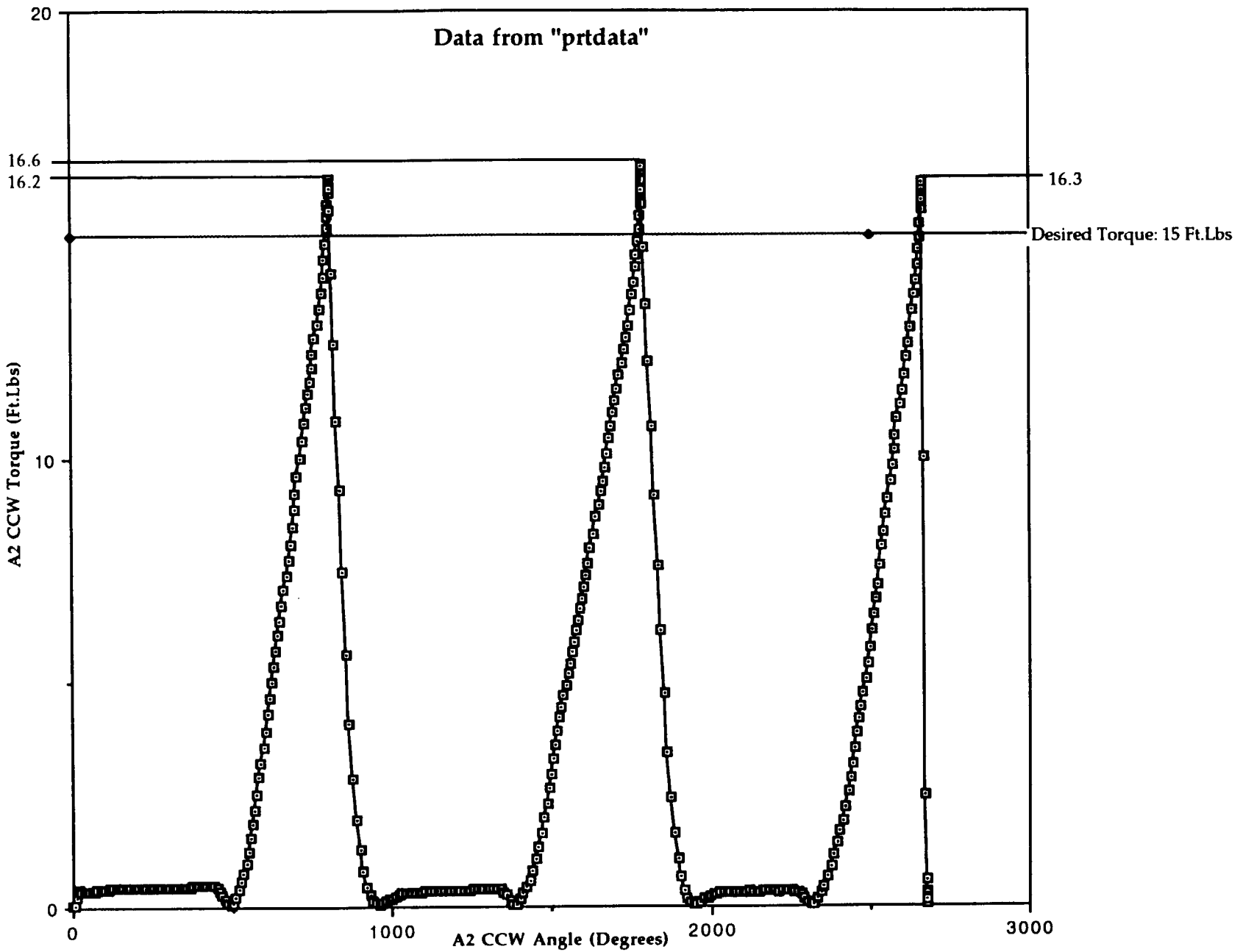
APPENDIX - III

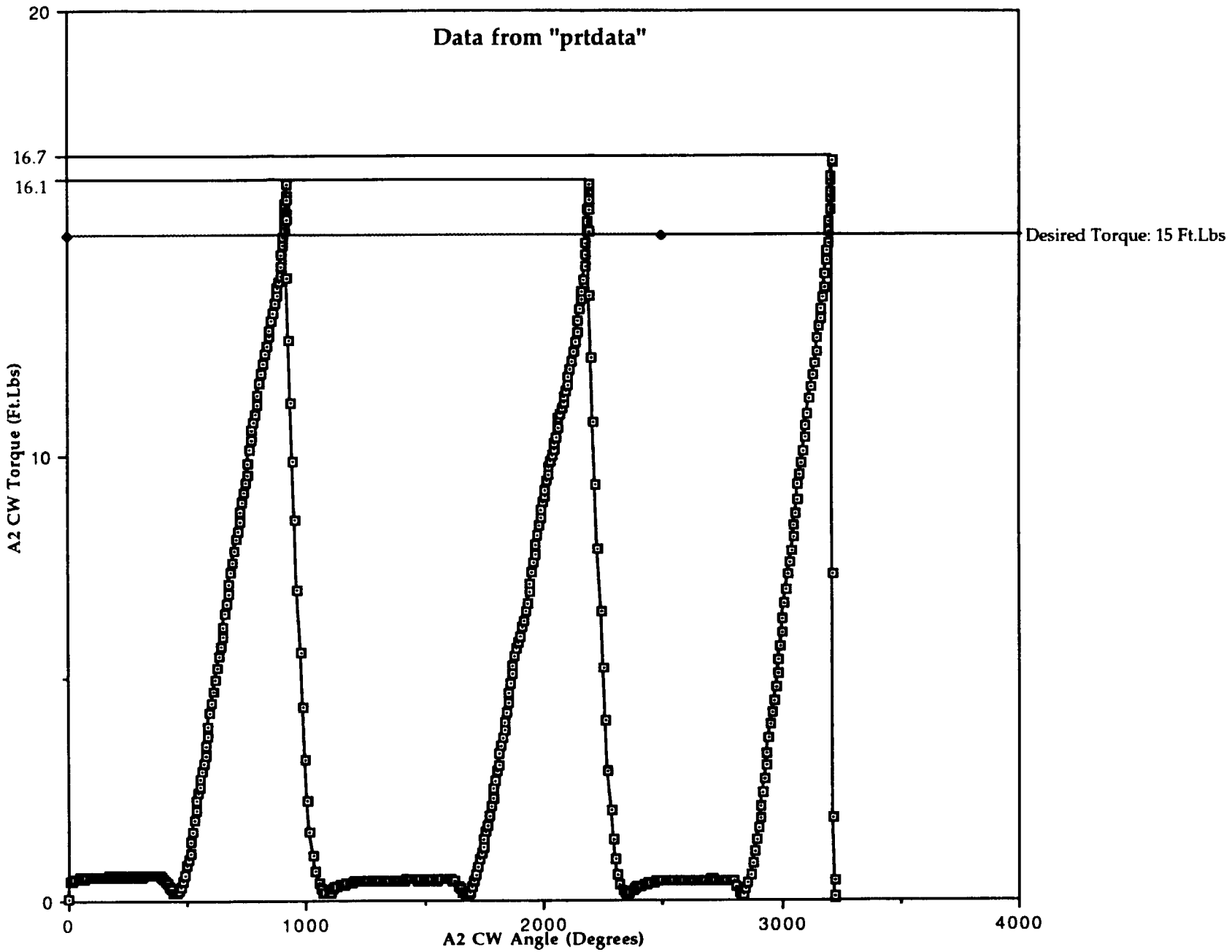
						AVG.	AVG.	AVG.	AVG.	RPM	AVG.	RPM	AVG.
PROF.	PROG.	GSE	COMP	GSE	COMP	GSE	COMP	GSE	COMP	CW	RPM	CCW	RPM
SETTG.	TOR.	(CW)	(CW)	(CCW)	(CCW)	(CW)	(CW)	(CCW)	(CCW)		(CW)		(CCW)
		0.7	1.1	1.5	1.6					13.33		10	
B1	2	0.8	1.46	0.8	1.1	0.80	1.34	1.03	1.27	13.33	13.33	10	10.00
		0.9	1.46	0.8	1.1					13.33		10	
		1.4	2.4	1.8	2.2					20		20	
B2	3	1.9	2.43	1.9	2.3	1.70	2.38	1.90	2.33	20	20.00	20	20.00
		1.8	2.3	2	2.5					20		20	
		4.9	4.7	5.2	4.8					33.33		33.33	
B3	5	5	4.8	5.6	4.7	5.07	4.70	5.43	4.93	33.33	33.33	33.33	33.33
		5.3	4.6	5.5	5.3					33.33		33.33	
		7.4	6.8	7.7	7					33.33		33.33	
B4	7	7.7	7	7.8	7.3	7.47	6.93	7.80	7.20	33.33	33.33	33.33	33.33
		7.3	7	7.9	7.3					33.33		33.33	
		9.9	9.44	10	9.7					33.33		33.33	
B5	9	10.1	9.4	10.1	9.3	9.97	9.31	10.03	9.53	33.33	33.33	33.33	33.33
		9.9	9.1	10	9.6					33.33		33.33	
		11	10.45	11.2	10.7					33.33		33.33	
B6	10	11	10.61	11.2	10.6	11.00	10.59	11.37	10.67	33.33	33.33	33.33	33.33
		11	10.7	11.7	10.7					33.33		33.33	
		12.4	11.7	12.4	11.7					33.33		33.33	
B7	11	12.3	11.8	12.3	11.6	12.43	11.87	12.40	11.70	33.33	33.33	33.33	33.33
		12.6	12.1	12.5	11.8					33.33		33.33	
		14.8	13.7	14.7	13.7					30		30	
A1	13	14.8	13.7	14.8	14.5	14.80	13.70	14.87	14.03	30	31.11	33.33	32.22
		14.8	13.7	15.1	13.9					33.33		33.33	
		17.1	16.1	17.1	16.2					30		30	
A2	15	16.9	16.1	17.3	16.6	17.07	16.30	17.20	16.37	33.33	32.22	33.33	32.22
		17.2	16.7	17.2	16.3					33.33		33.33	
		19.7	18.4	20	19.3					33.33		33.33	
A3	17	19.6	18.6	20.1	19.3	19.77	18.57	20.00	19.30	33.33	33.33	33.33	33.33
		20	18.7	19.9	19.3					33.33		33.33	
		22.1	20.8	22.1	20.7					30		30	
A4	19	22.8	21.7	22	20.8	22.30	21.10	22.07	20.77	33.33	32.22	33.33	32.22
		22	20.8	22.1	20.8					33.33		33.33	
		24.3	23	24.5	23.33					33.33		33.33	
A5	21	24.1	23.2	24.4	23.1	24.20	23.30	24.43	23.34	33.33	33.33	33.33	33.33
		24.2	23.7	24.4	23.6					33.33		33.33	
		24.2	25.7	26.8	26.1					33.33		33.33	
A6	23	26.6	25.3	26.9	25.8	25.77	25.57	26.90	25.95	33.33	33.33	33.33	33.33
		26.5	25.7	27	****					33.33		33.33	
		29.4	27.8	29.3	27.8					33.33		33.33	
A7	25	29.2	28.03	29.1	27.9	29.23	28.11	29.23	28.20	33.33	33.33	33.33	33.33
		29.1	28.5	29.3	28.9					33.33		33.33	
**** MISSED THE READING													

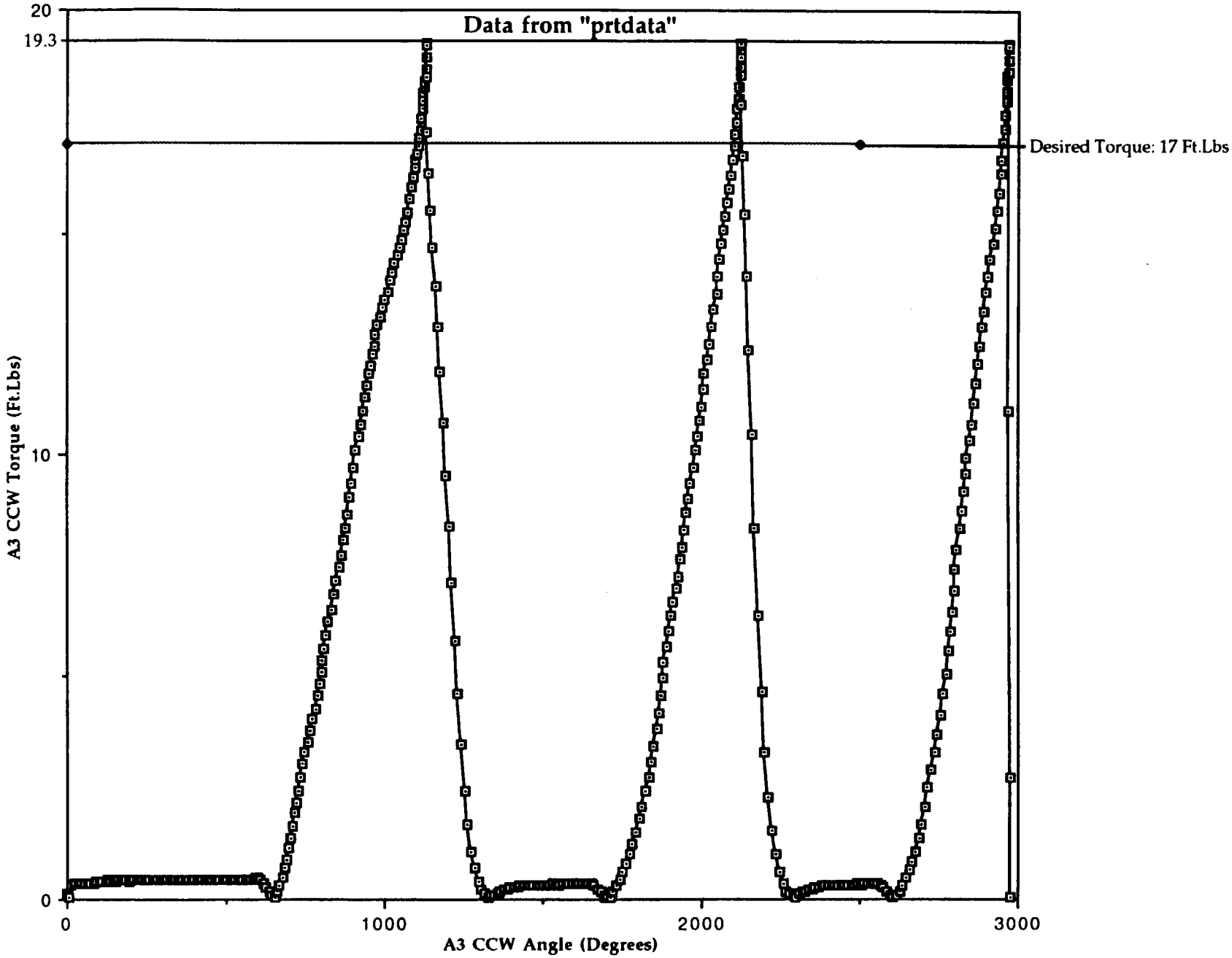
						AVG.	AVG.	AVG.	AVG.	%ERR	%ERR	%ERR	%ERR
PROF.	PROG.	GSE	COMP	GSE	COMP	GSE	COMP	GSE	COMP	GSE	COMP	GSE	COMP
SETTG.	TOR.	(CW)	(CW)	(CCW)	(CCW)	(CW)	(CW)	(CCW)	(CCW)	(CW)	(CW)	(CCW)	(CCW)
		14.8	13.7	14.7	13.7								
A1	13	14.8	13.7	14.8	14.5	14.80	13.70	14.87	14.03	13.85	5.38	14.36	7.95
		14.8	13.7	15.1	13.9								
		17.1	16.1	17.1	16.2								
A2	15	16.9	16.1	17.3	16.6	17.07	16.30	17.20	16.37	13.78	8.67	14.67	9.11
		17.2	16.7	17.2	16.3								
		19.7	18.4	20	19.3								
A3	17	19.6	18.6	20.1	19.3	19.77	18.57	20.00	19.30	16.27	9.22	17.65	13.53
		20	18.7	19.9	19.3								
		22.1	20.8	22.1	20.7								
A4	19	22.8	21.7	22	20.8	22.30	21.10	22.07	20.77	17.37	11.05	16.14	9.30
		22	20.8	22.1	20.8								
		24.3	23	24.5	23.33								
A5	21	24.1	23.2	24.4	23.1	24.20	23.30	24.43	23.34	15.24	10.95	16.35	11.16
		24.2	23.7	24.4	23.6								
		24.2	25.7	26.8	26.1								
A6	23	26.6	25.3	26.9	25.8	25.77	25.57	26.90	25.95	12.03	11.16	16.96	12.83
		26.5	25.7	27	****								
		29.4	27.8	29.3	27.8								
A7	25	29.2	28.03	29.1	27.9	29.23	28.11	29.23	28.20	16.93	12.44	16.93	12.80
		29.1	28.5	29.3	28.9								
		0.7	1.1	1.5	1.6								
B1	2	0.8	1.46	0.8	1.1	0.80	1.34	1.03	1.27	-60.00	-33.00	-48.33	-36.67
		0.9	1.46	0.8	1.1								
		1.4	2.4	1.8	2.2								
B2	3	1.9	2.43	1.9	2.3	1.70	2.38	1.90	2.33	-43.33	-20.78	-36.67	-22.22
		1.8	2.3	2	2.5								
		4.9	4.7	5.2	4.8								
B3	5	5	4.8	5.6	4.7	5.07	4.70	5.43	4.93	1.33	-6.00	8.67	-1.33
		5.3	4.6	5.5	5.3								
		7.4	6.8	7.7	7								
B4	7	7.7	7	7.8	7.3	7.47	6.93	7.80	7.20	6.67	-0.95	11.43	2.86
		7.3	7	7.9	7.3								
		9.9	9.44	10	9.7								
B5	9	10.1	9.4	10.1	9.3	9.97	9.31	10.03	9.53	10.74	3.48	11.48	5.93
		9.9	9.1	10	9.6								
		11	10.45	11.2	10.7								
B6	10	11	10.61	11.2	10.6	11.00	10.59	11.37	10.67	10.00	5.87	13.67	6.67
		11	10.7	11.7	10.7								
		12.4	11.7	12.4	11.7								
B7	11	12.3	11.8	12.3	11.6	12.43	11.87	12.40	11.70	13.03	7.88	12.73	6.36
		12.6	12.1	12.5	11.8								
**** MISSED THE READING													

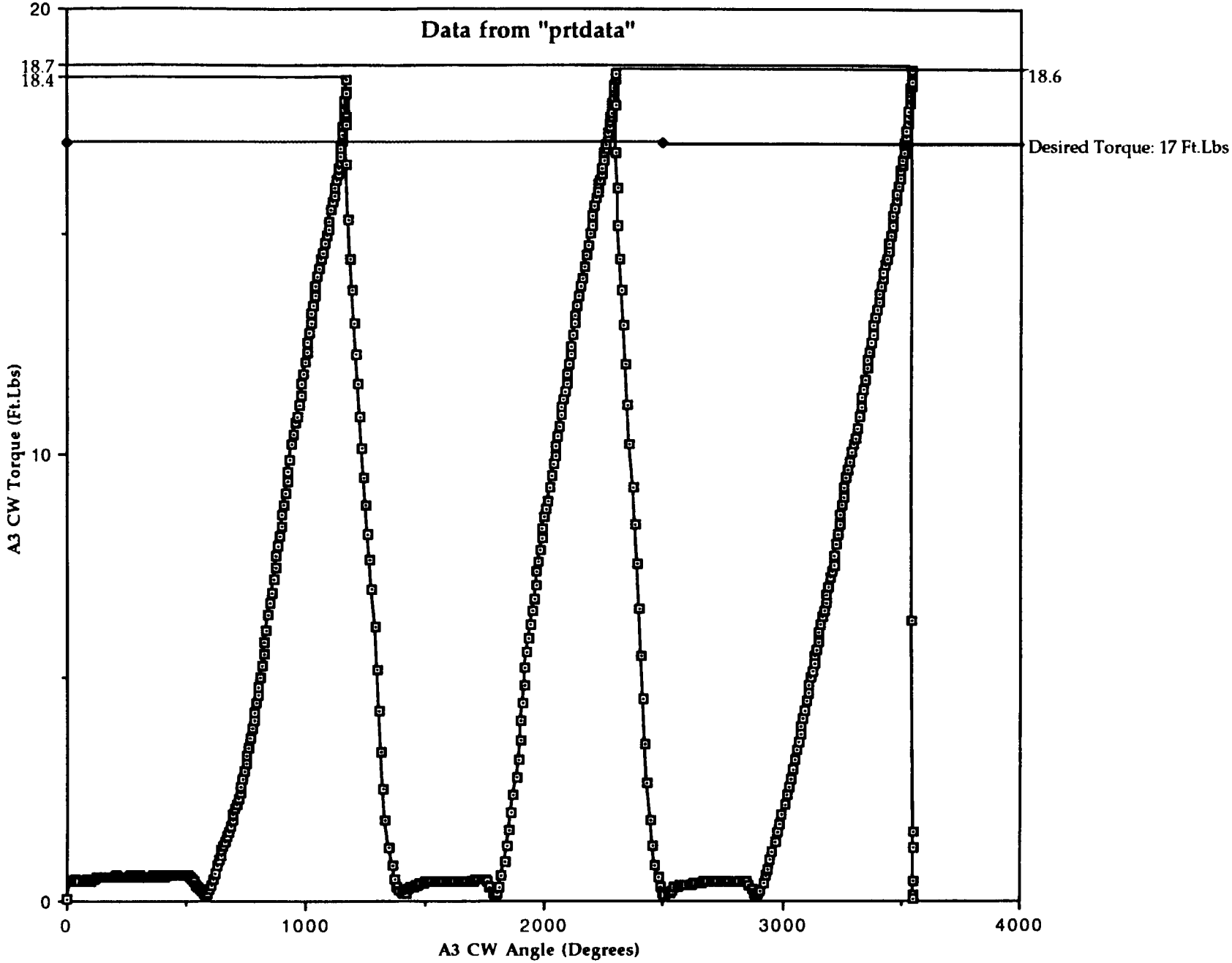

Data from "prtdata"
20
14.5
13.7
10
0
A1 CCW Torque (Ft.Lbs)
13.9
Desired Torque : 13 Ft.Lbs
0
1000
2000
3000
A1 CCW Angle (Degree)

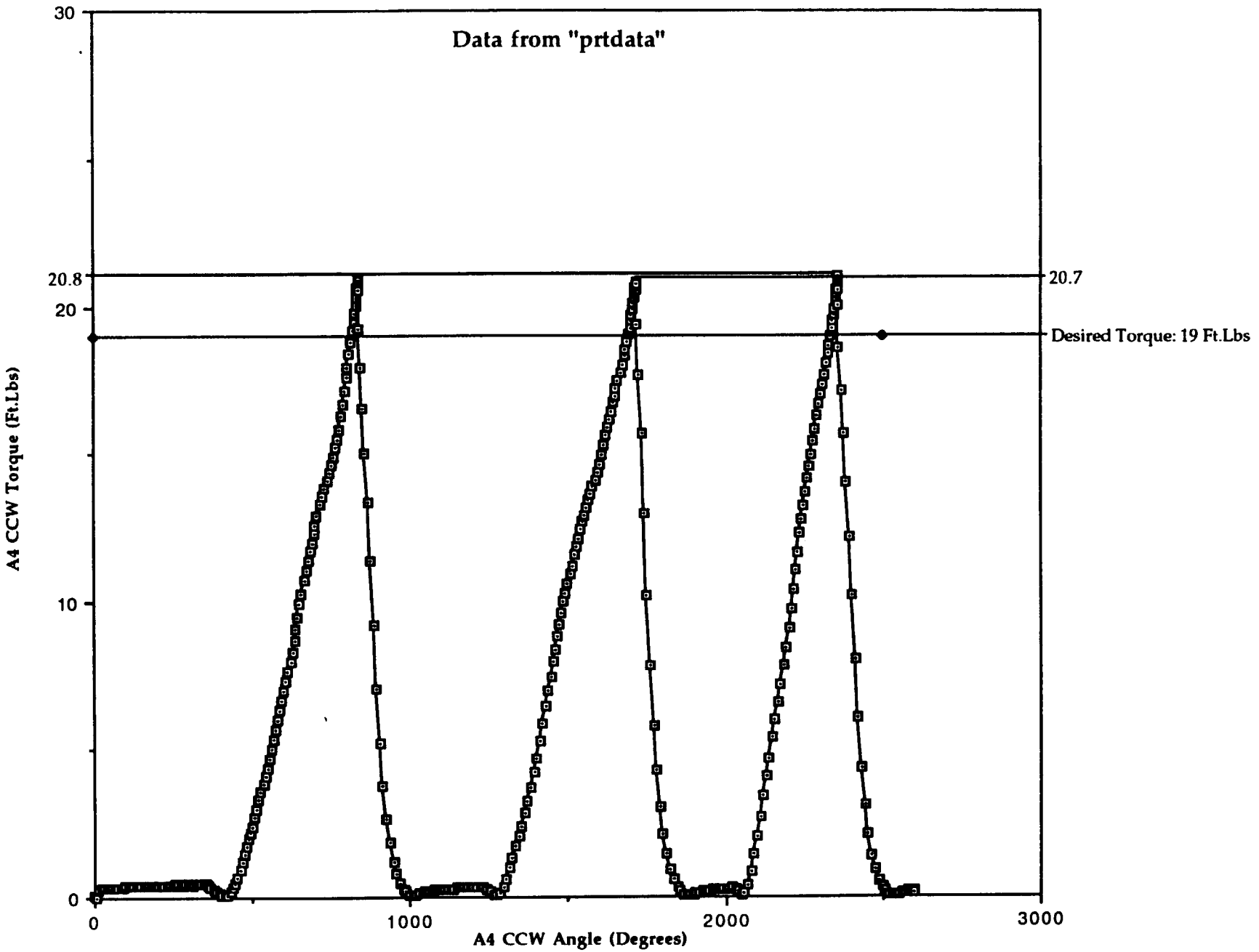

Data from "prtdata"
20
13.7
10
0
A1 CW Torque (Ft.Lbs)
Desired Torque: 13 Ft.Lbs
0
1000
2000
A1 CW Angle (Degrees)

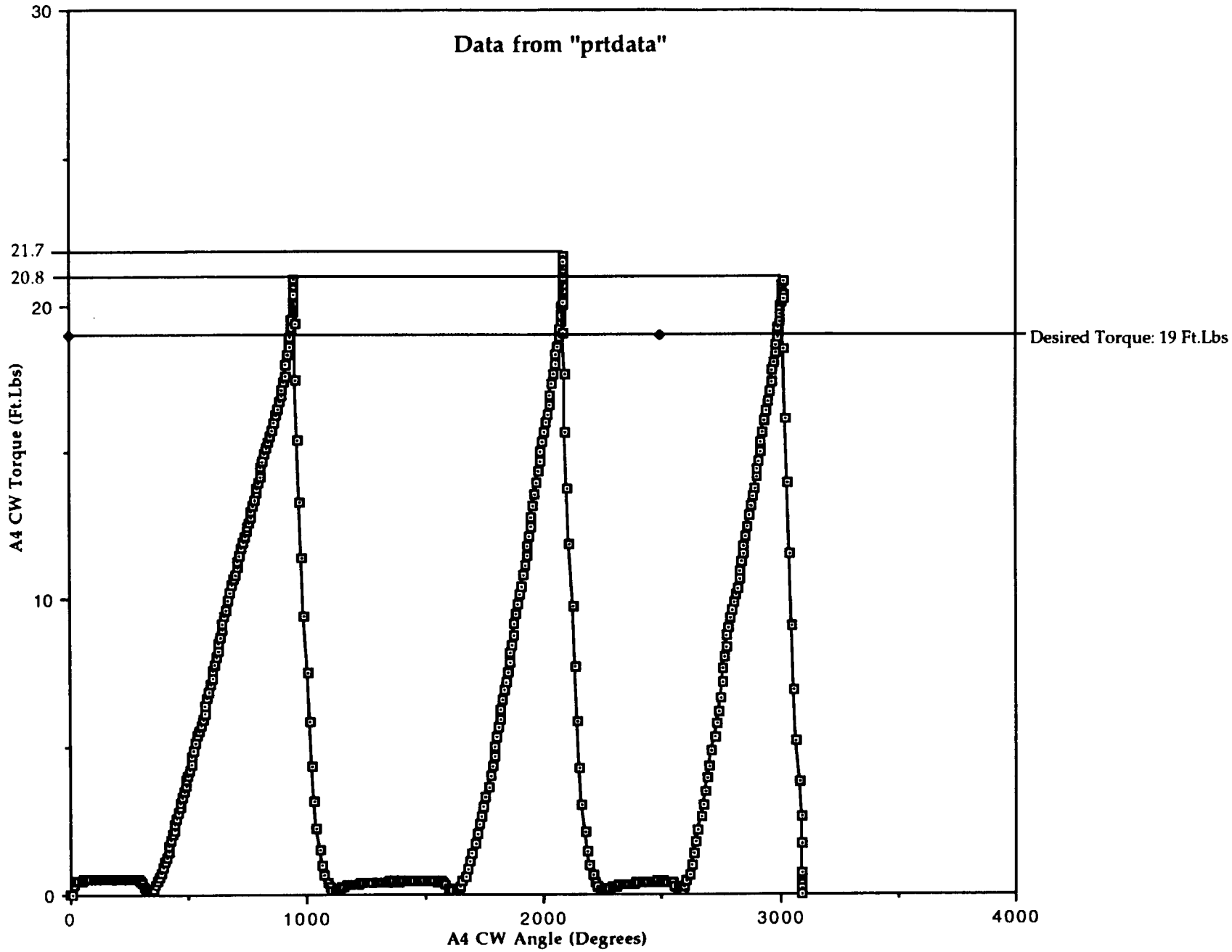

Data from "prtdata"
20
16.6
16.2
16.3
Desired Torque: 15 Ft.Lbs
10
0
A2 CCW Torque (Ft.Lbs)
0
1000
2000
3000
A2 CCW Angle (Degrees)

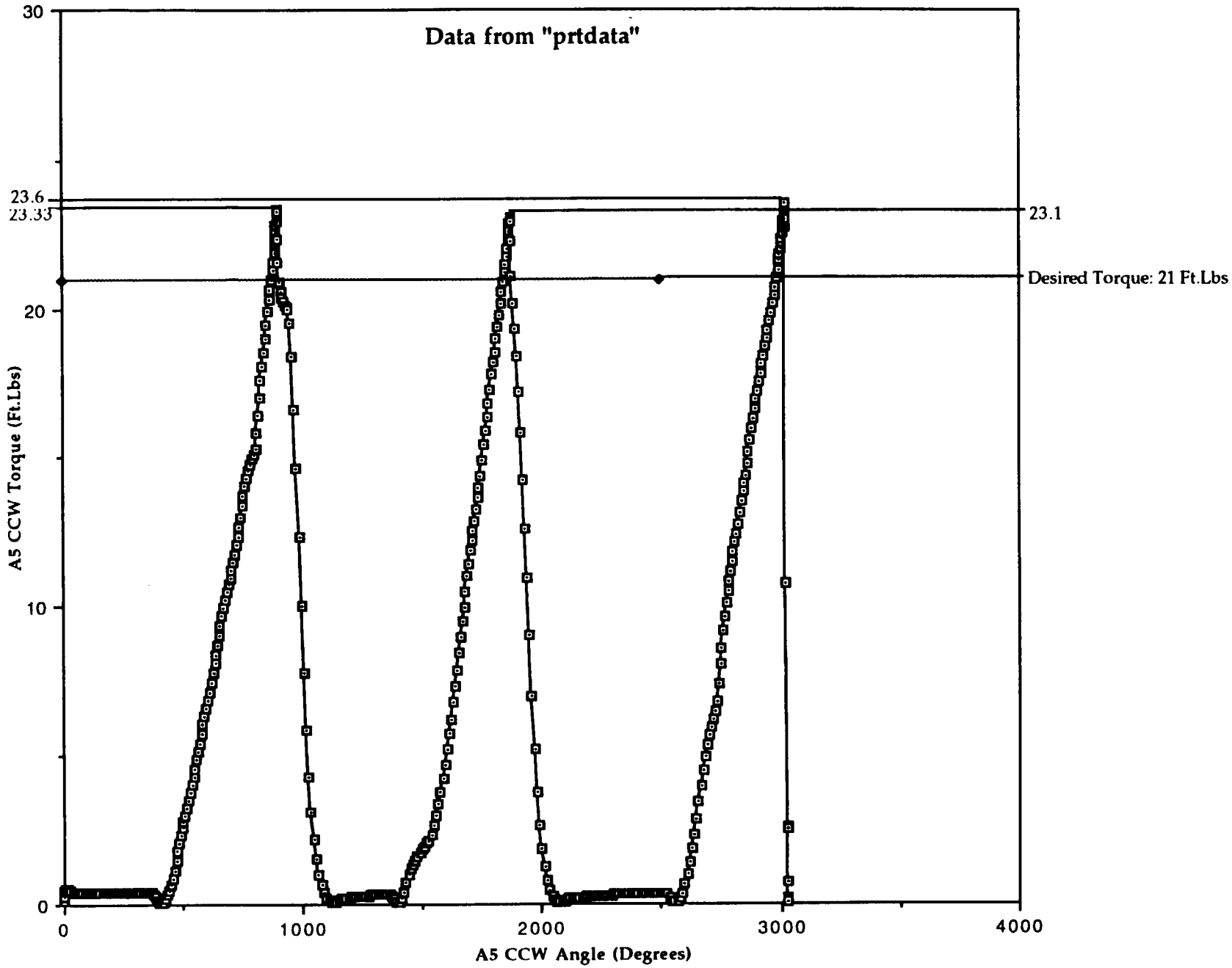

Data from "prtdata"
20
16.7
16.1
10
0
A2 CW Torque (Ft.Lbs)
Desired Torque: 15 Ft.Lbs
0
1000
2000
3000
4000
A2 CW Angle (Degrees)

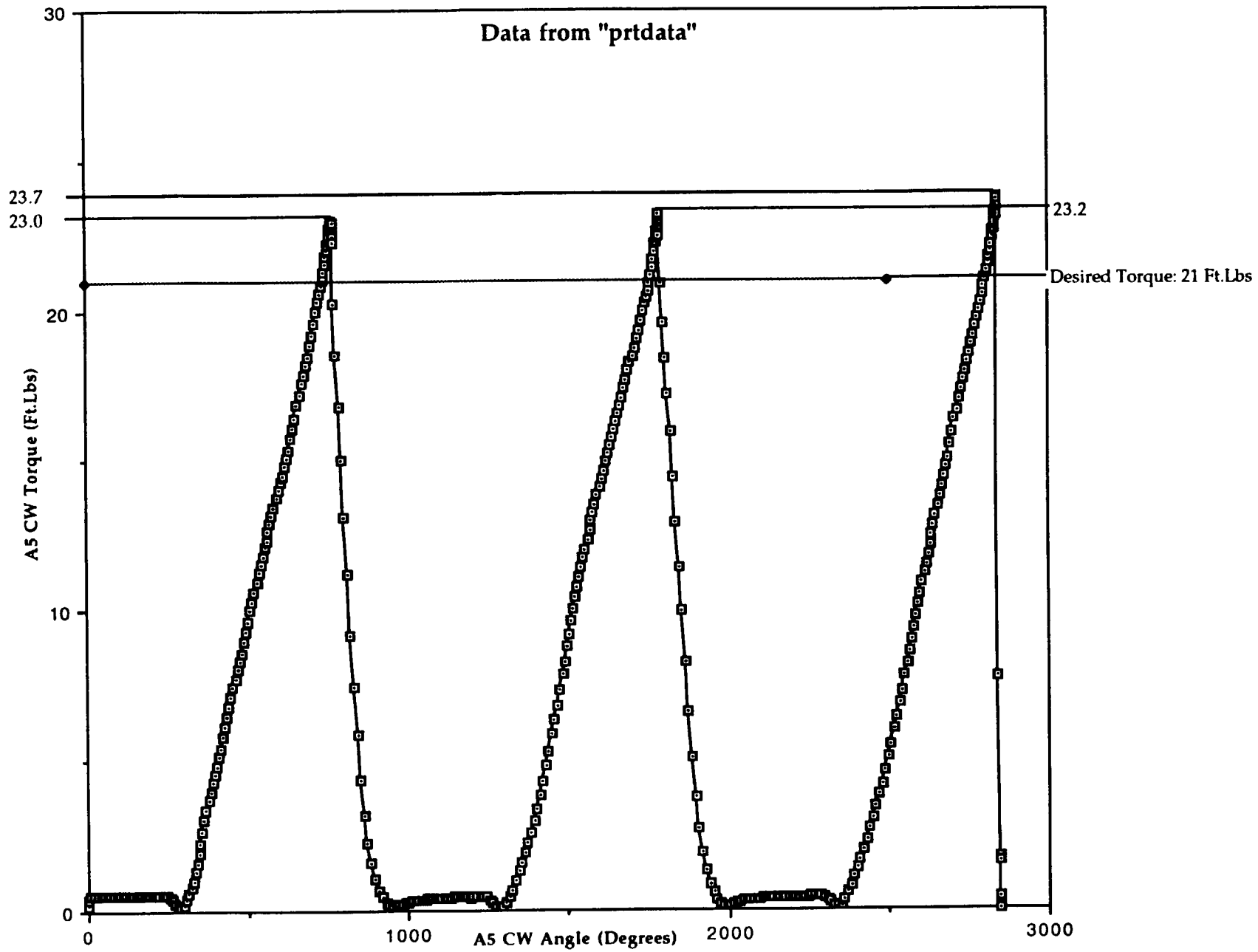

Data from "prtdata"
20
19.3
10
0
A3 CCW Torque (Ft.Lbs)
0
1000
2000
3000
A3 CCW Angle (Degrees)
Desired Torque: 17 Ft.Lbs

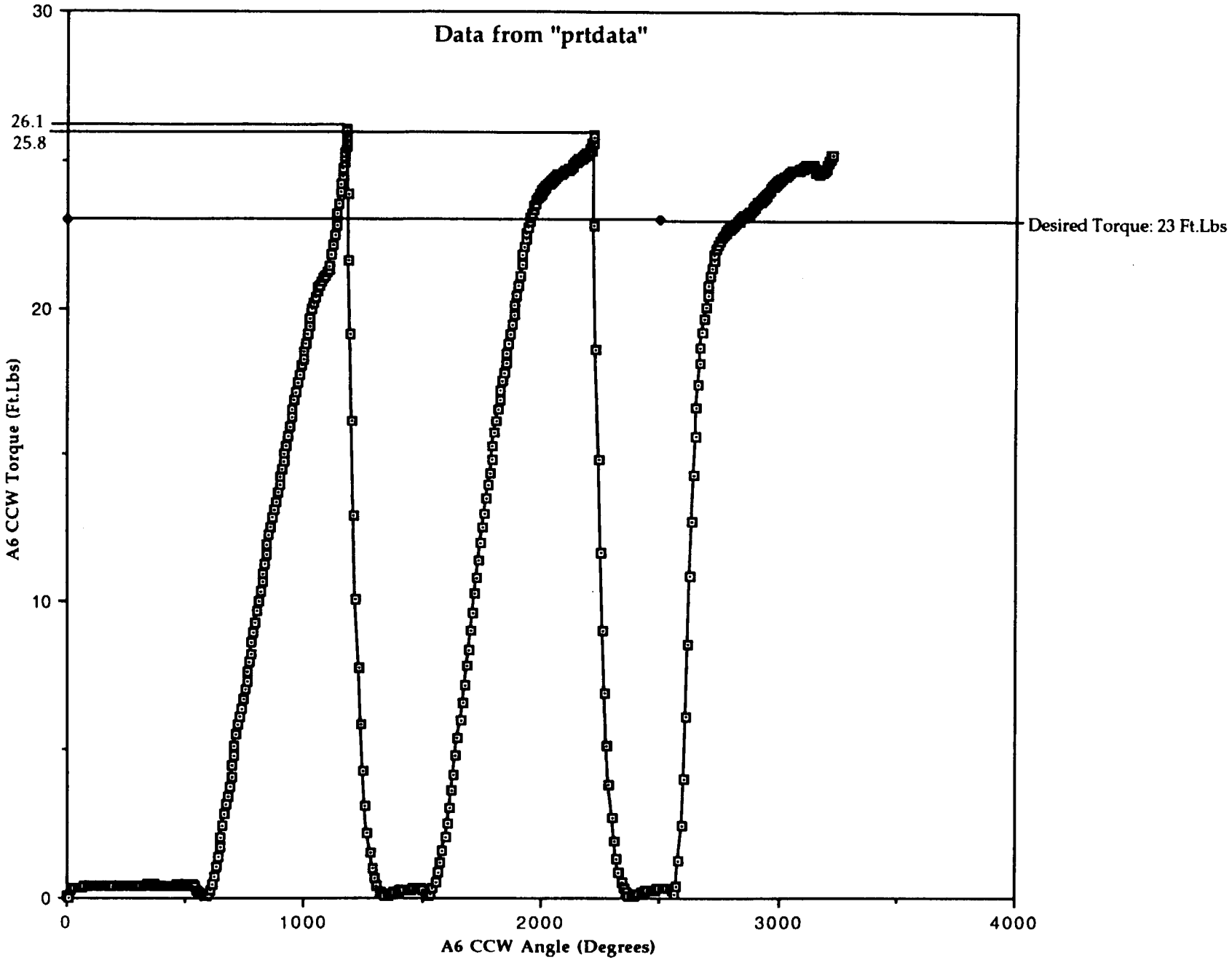

Data from "prtdata"
20
18.7
18.4
10
0
18.6
Desired Torque: 17 Ft.Lbs
A3 CW Torque (Ft.Lbs)
0
1000
2000
3000
4000
A3 CW Angle (Degrees)

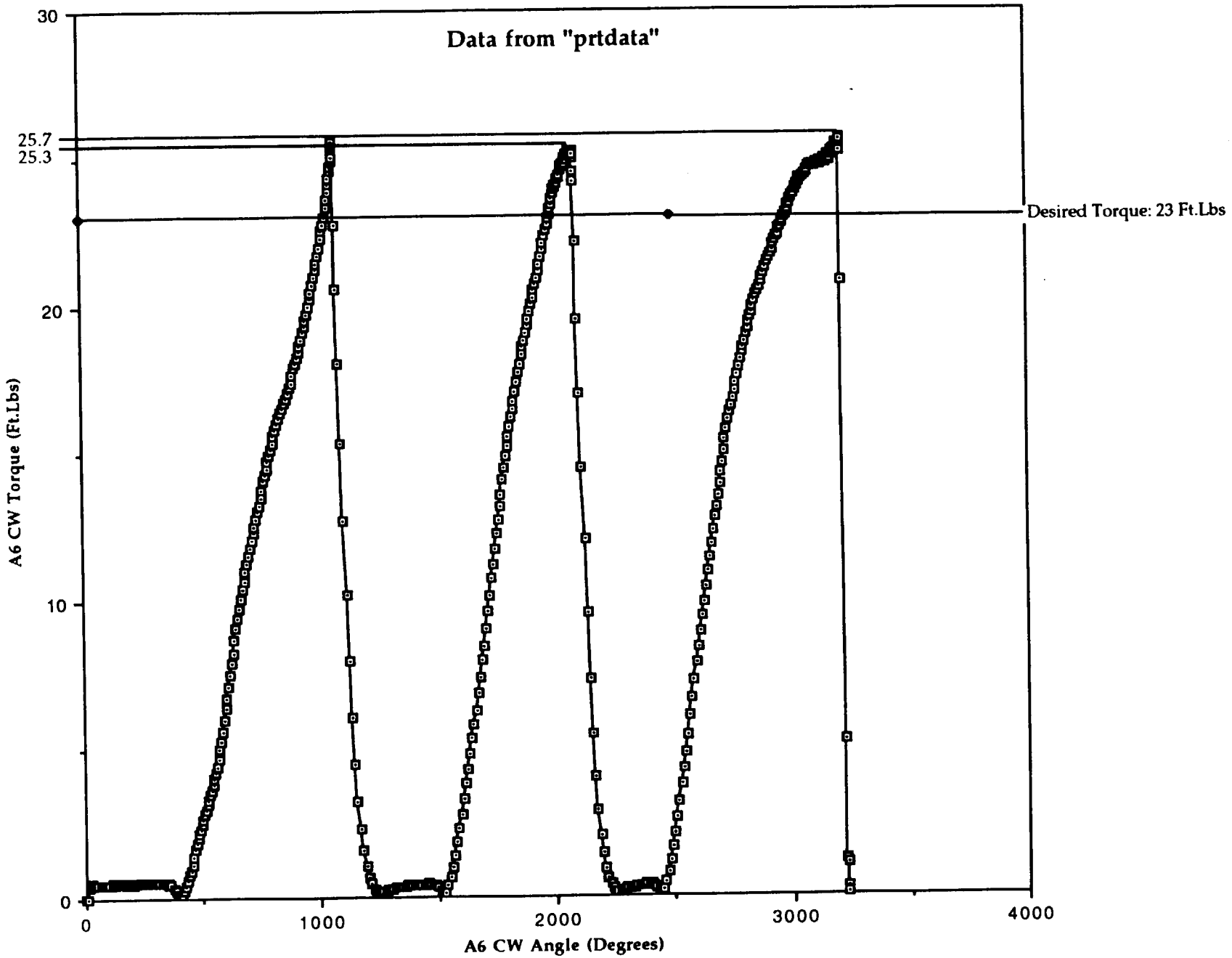

Data from "prtdata"
30
20.8
20
10
0
20.7
Desired Torque: 19 Ft.Lbs
A4 CCW Torque (Ft.Lbs)
0
1000
2000
3000
A4 CCW Angle (Degrees)

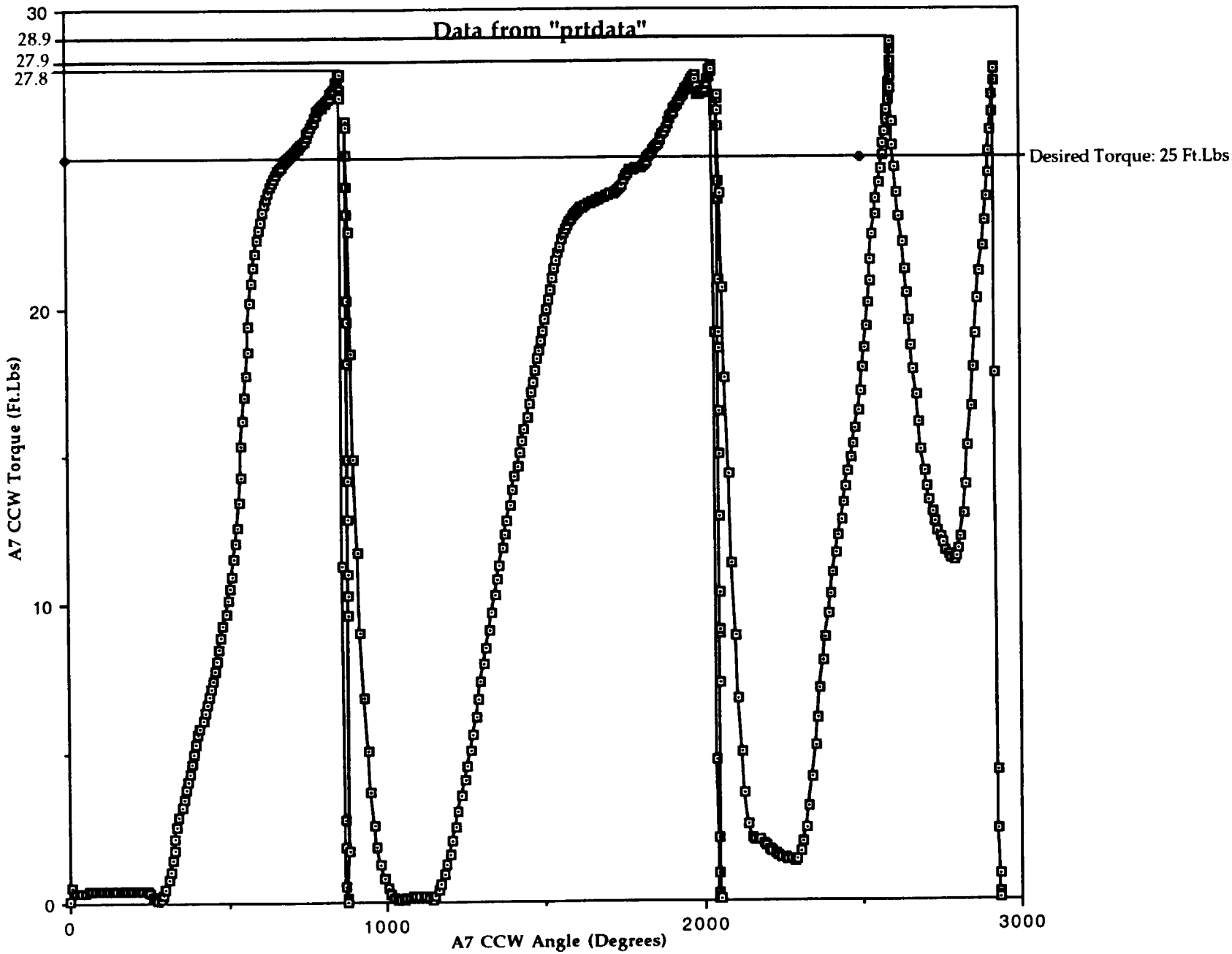

Data from "prtdata"
30
21.7
20.8
20
10
0
A4 CW Torque (Ft.Lbs)
Desired Torque: 19 Ft.Lbs
0
1000
2000
3000
4000
A4 CW Angle (Degrees)

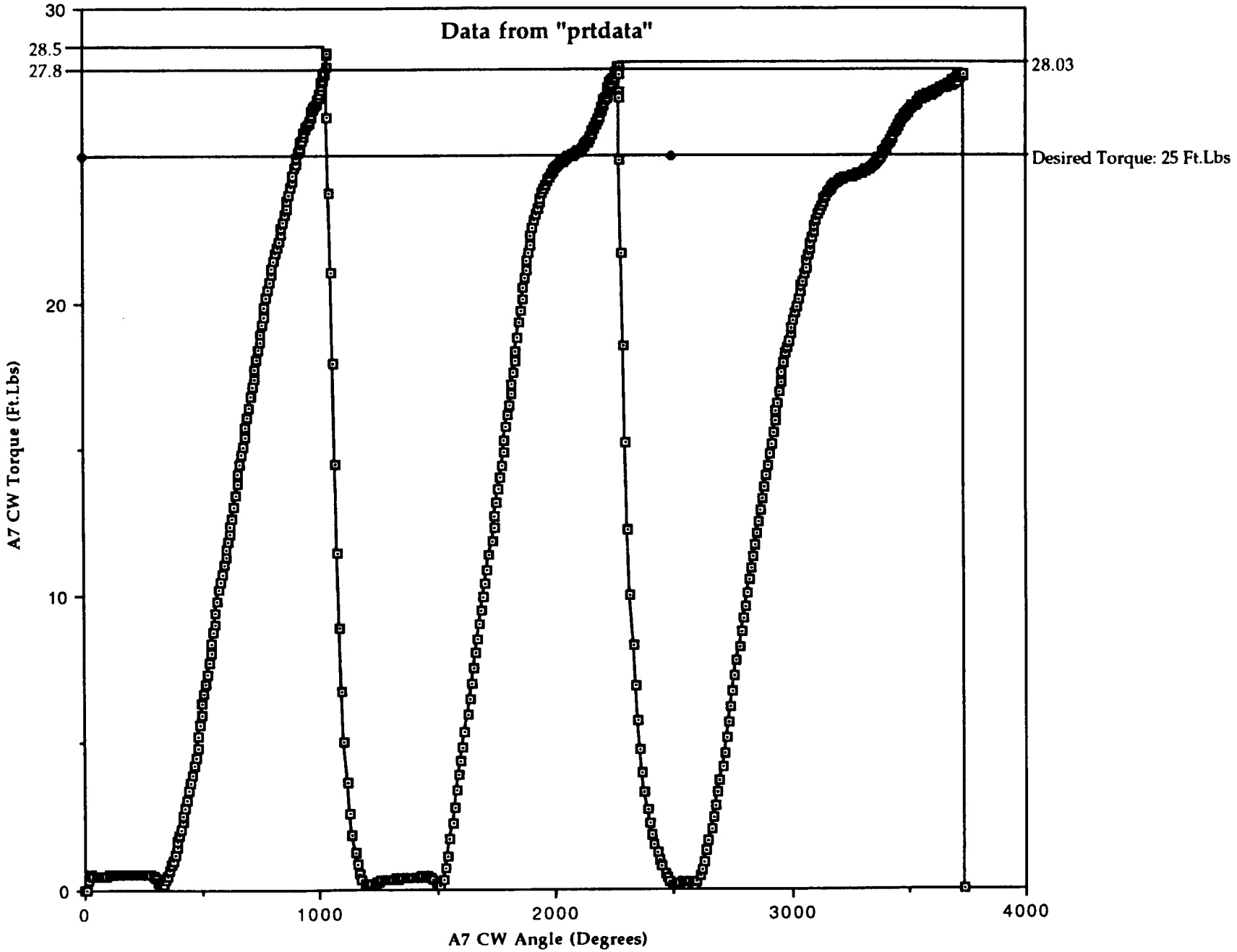

Data from "prtdata"
30
23.6
23.33
20
10
0
23.1
Desired Torque: 21 Ft.Lbs
A5 CCW Torque (Ft.Lbs)
0
1000
2000
3000
4000
A5 CCW Angle (Degrees)

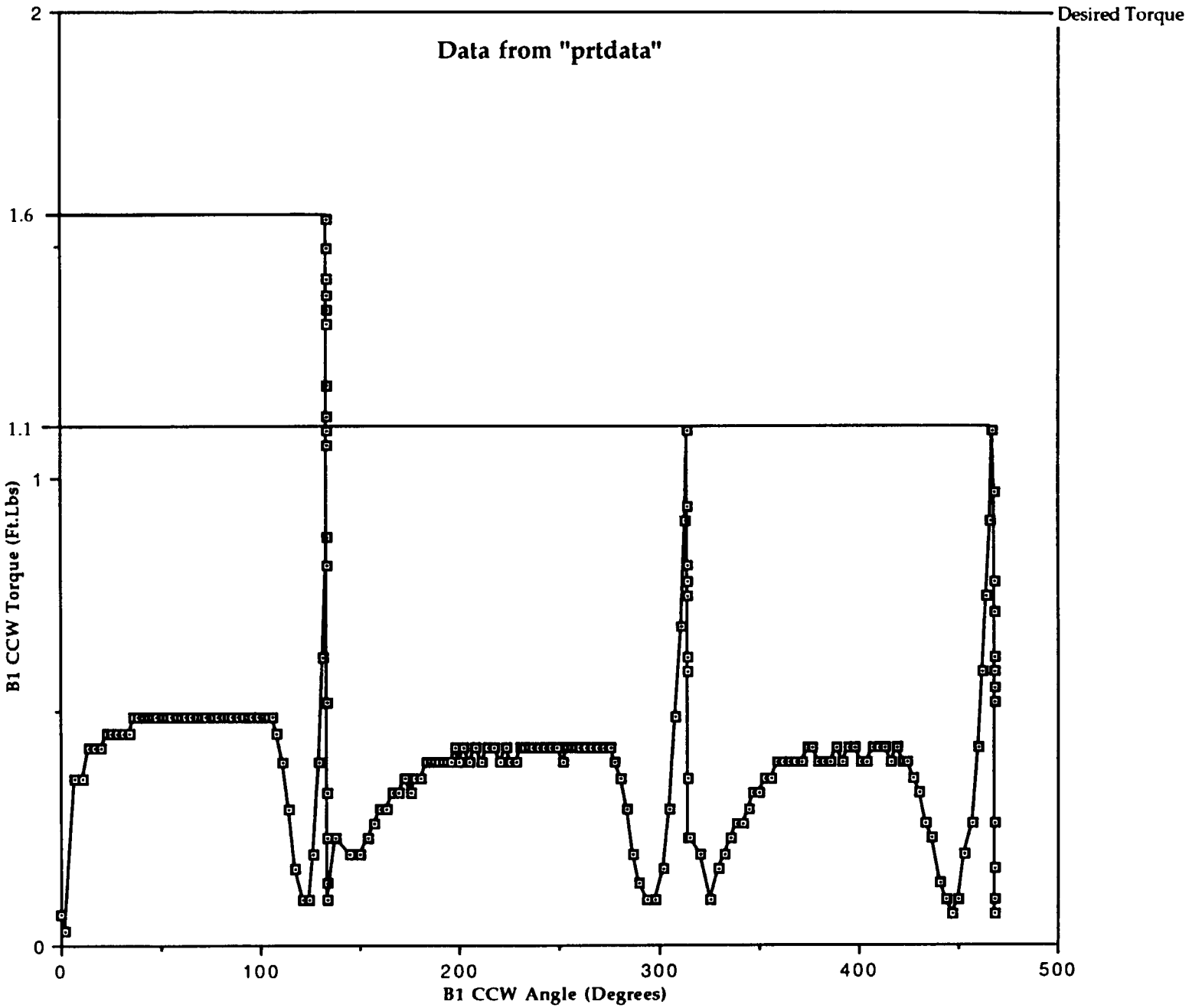

Data from "prtdata"
30
20
10
0
23.7
23.0
23.2
Desired Torque: 21 Ft.Lbs
A5 CW Torque (Ft.Lbs)
0
1000
2000
3000
A5 CW Angle (Degrees)

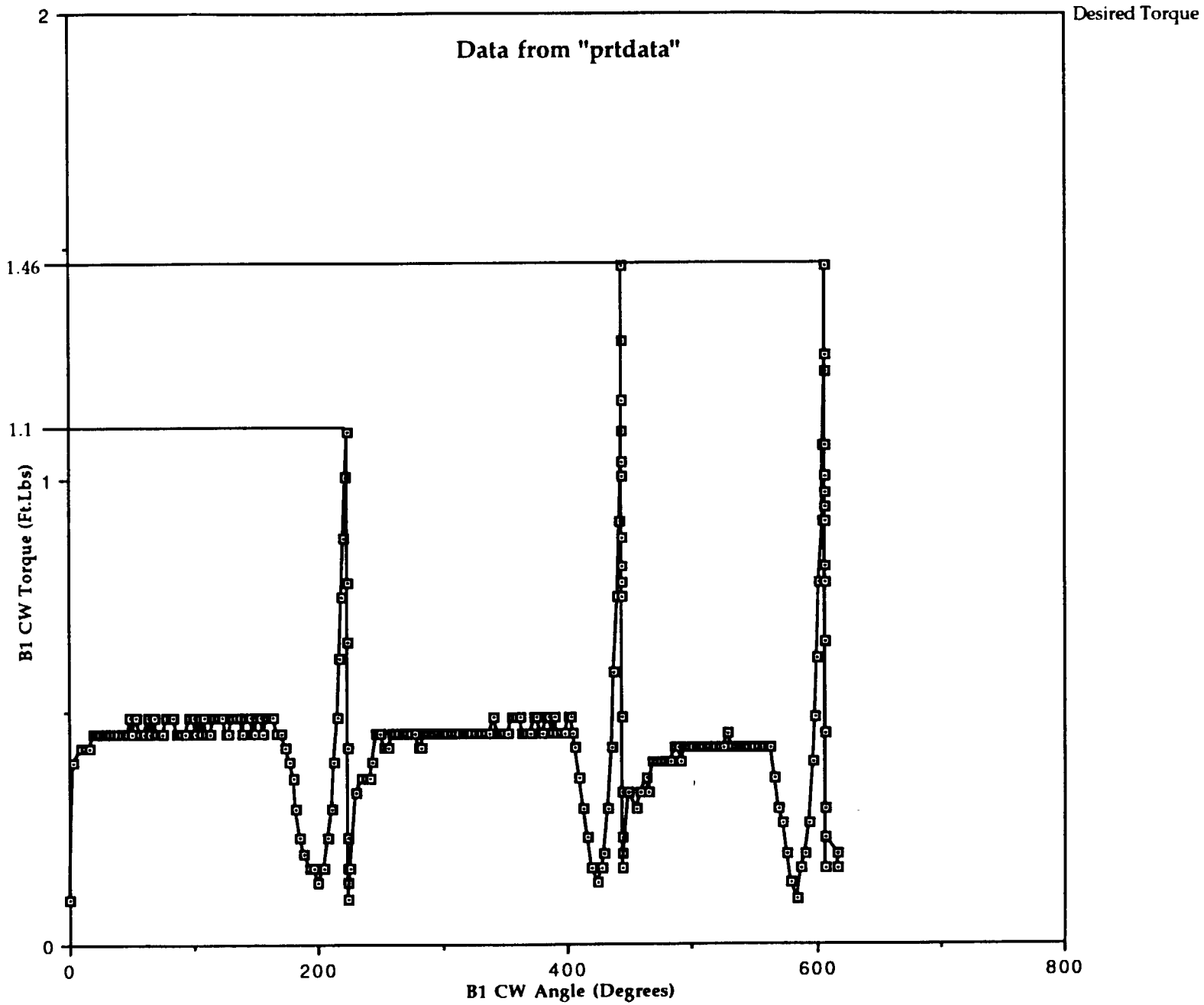

Data from "prtdata"
30
26.1
25.8
20
10
0
A6 CCW Torque (Ft.Lbs)
Desired Torque: 23 Ft.Lbs
0
1000
2000
3000
4000
A6 CCW Angle (Degrees)

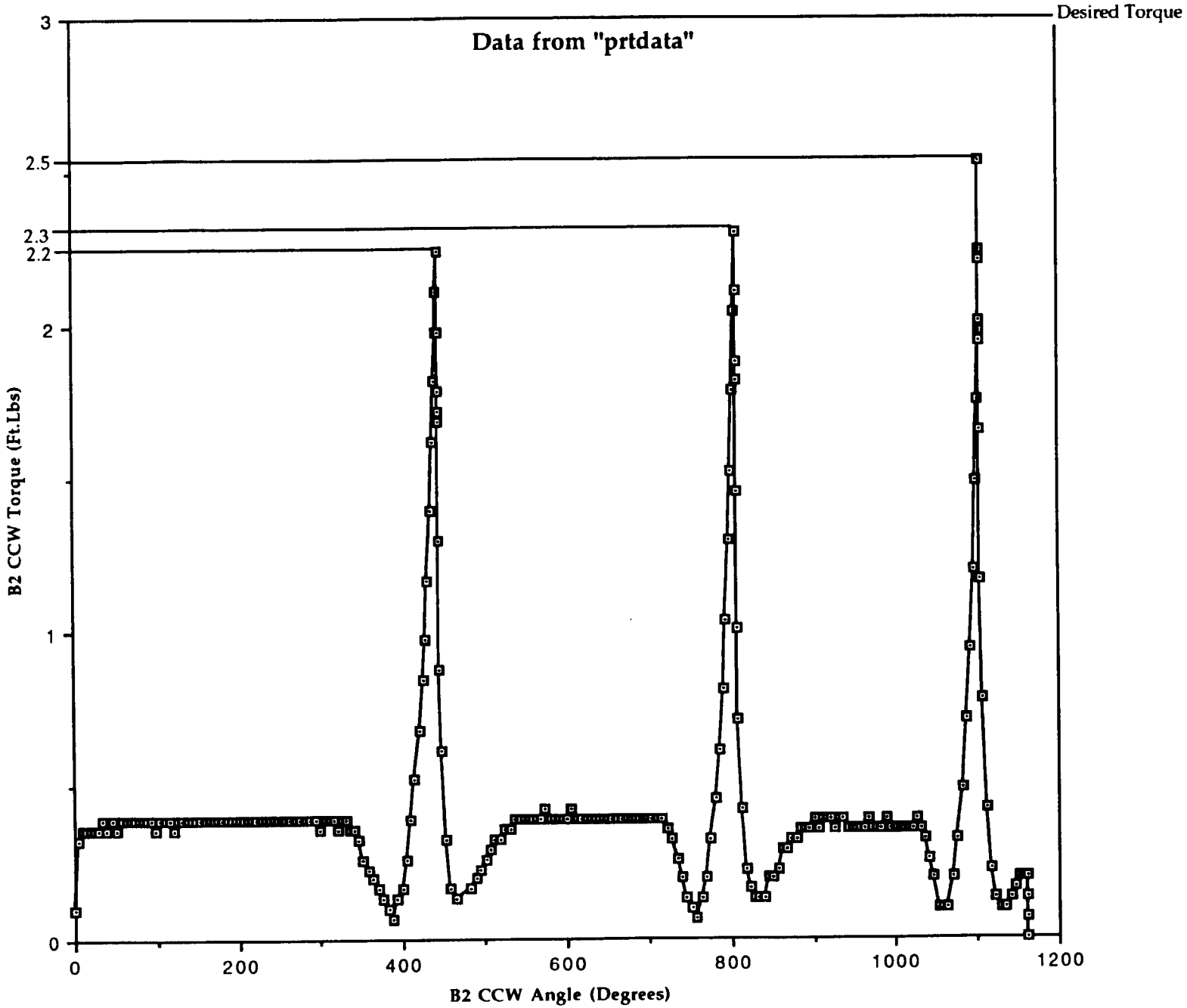

Data from "prtdata"
30
25.7
25.3
20
10
0
0
1000
2000
3000
4000
A6 CW Torque (Ft.Lbs)
A6 CW Angle (Degrees)
Desired Torque: 23 Ft.Lbs

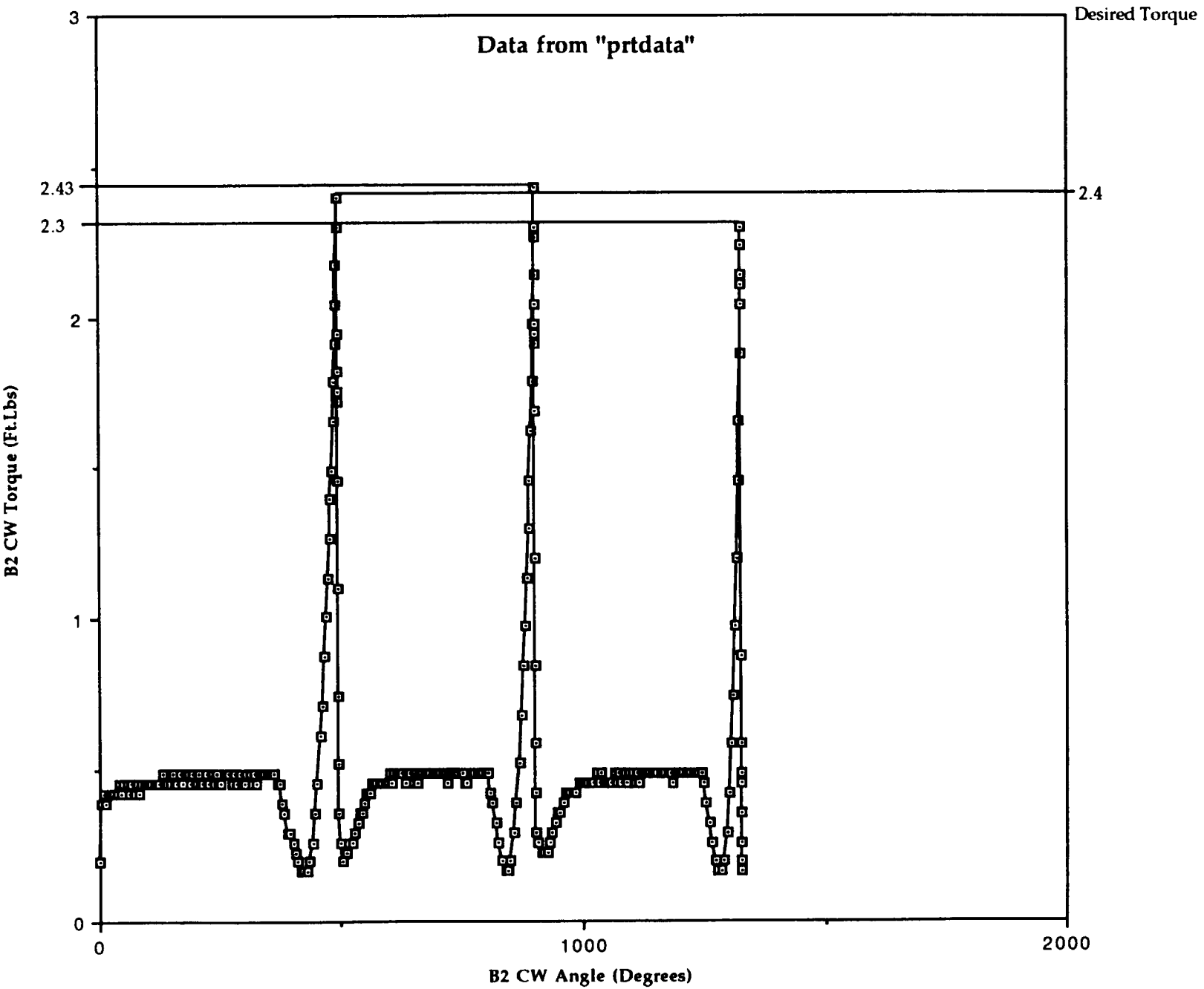

Data from "prtdata"
30
28.9
27.9
27.8
20
10
0
0
1000
2000
3000
A7 CCW Torque (Ft.Lbs)
A7 CCW Angle (Degrees)
Desired Torque: 25 Ft.Lbs

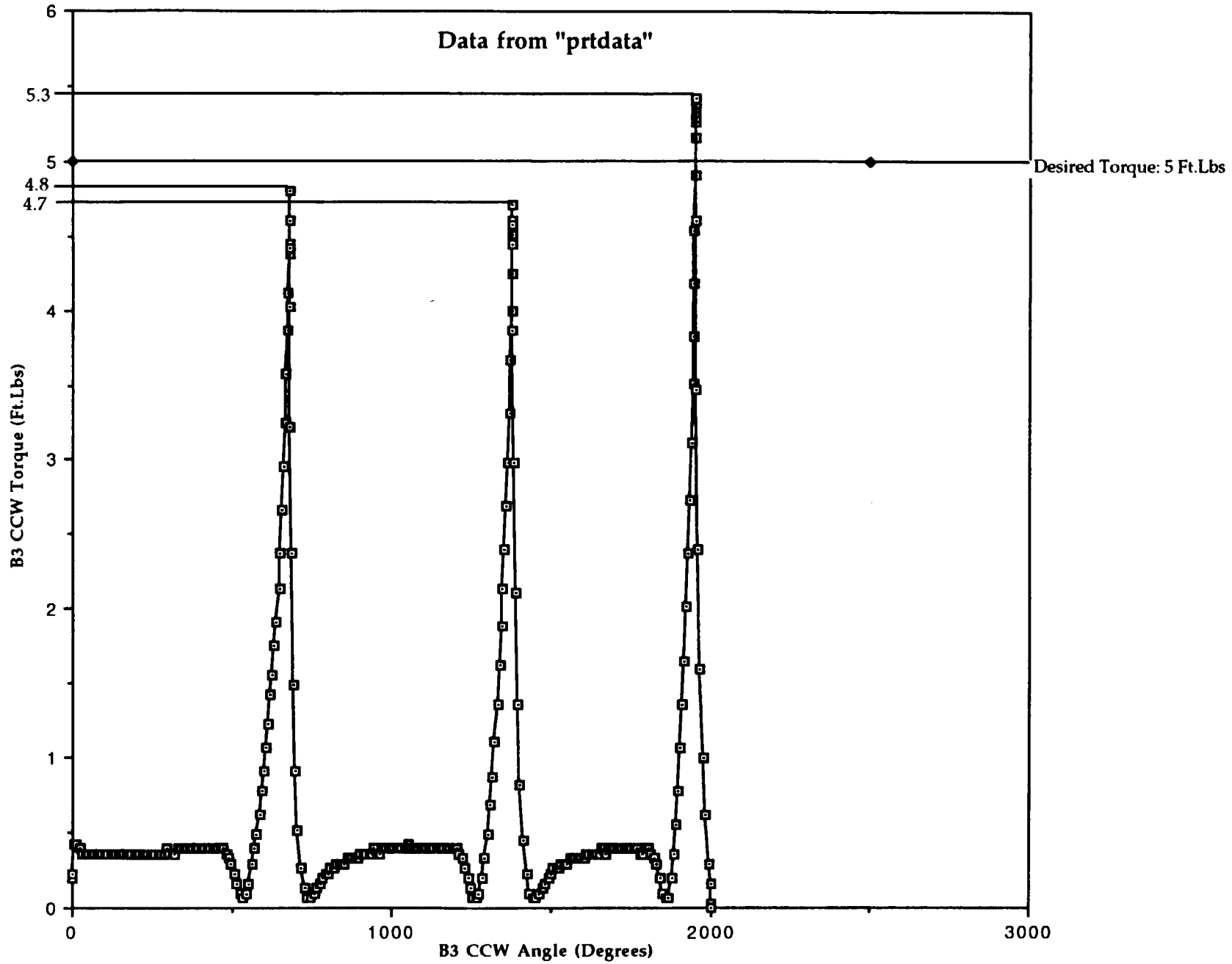

Data from "prtdata"
30
28.5
27.8
20
10
0
28.03
Desired Torque: 25 Ft.Lbs
A7 CW Torque (Ft.Lbs)
0
1000
2000
3000
4000
A7 CW Angle (Degrees)


Data from "prtdata"
Desired Torque
2
1.6
1.1
1
0
B1 CCW Torque (Ft.Lbs)
0
100
200
300
400
500
B1 CCW Angle (Degrees)

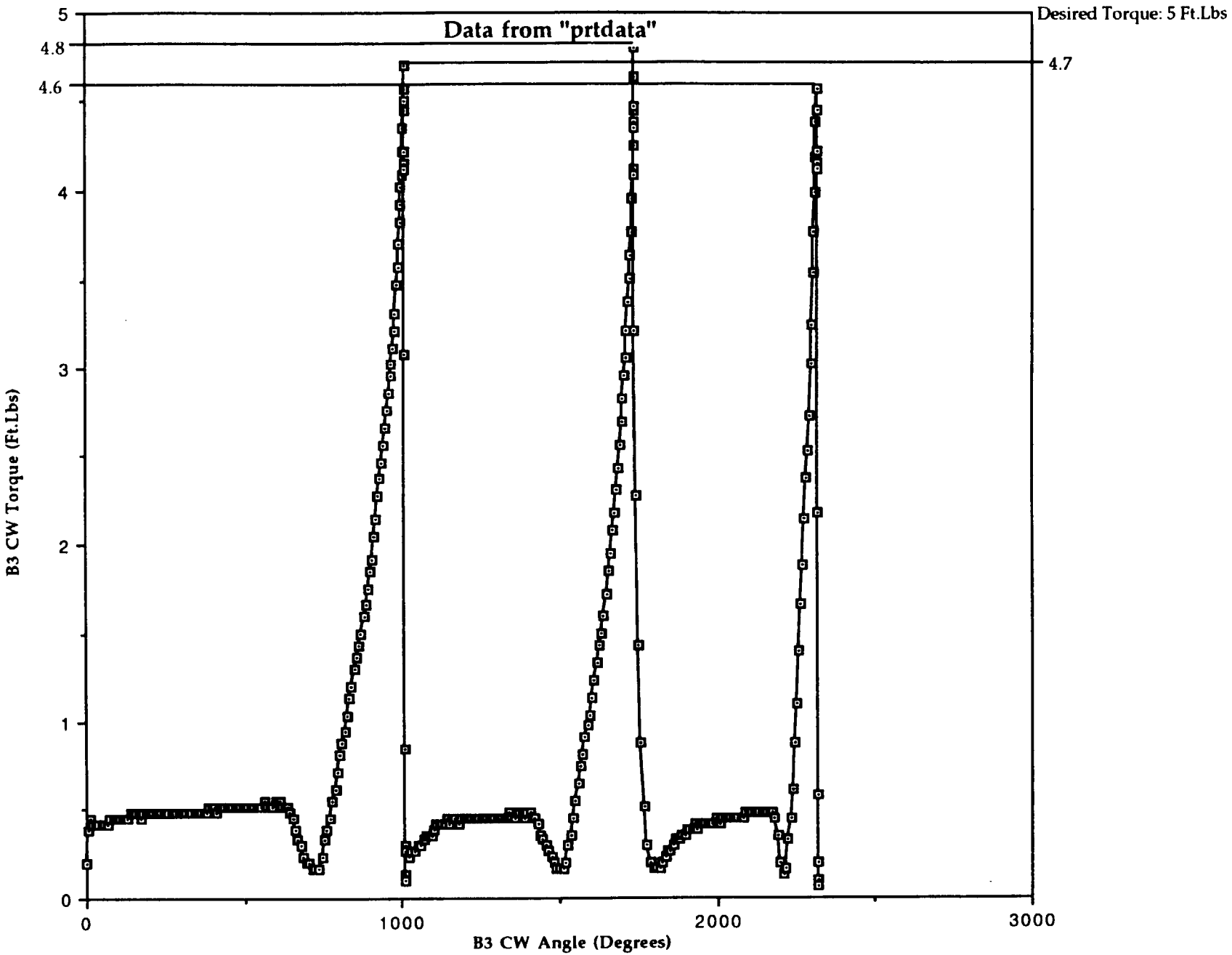

Data from "prtdata"
Desired Torque
2
1.46
1.1
1
0
B1 CW Torque (Ft.Lbs)
0
200
400
600
800
B1 CW Angle (Degrees)

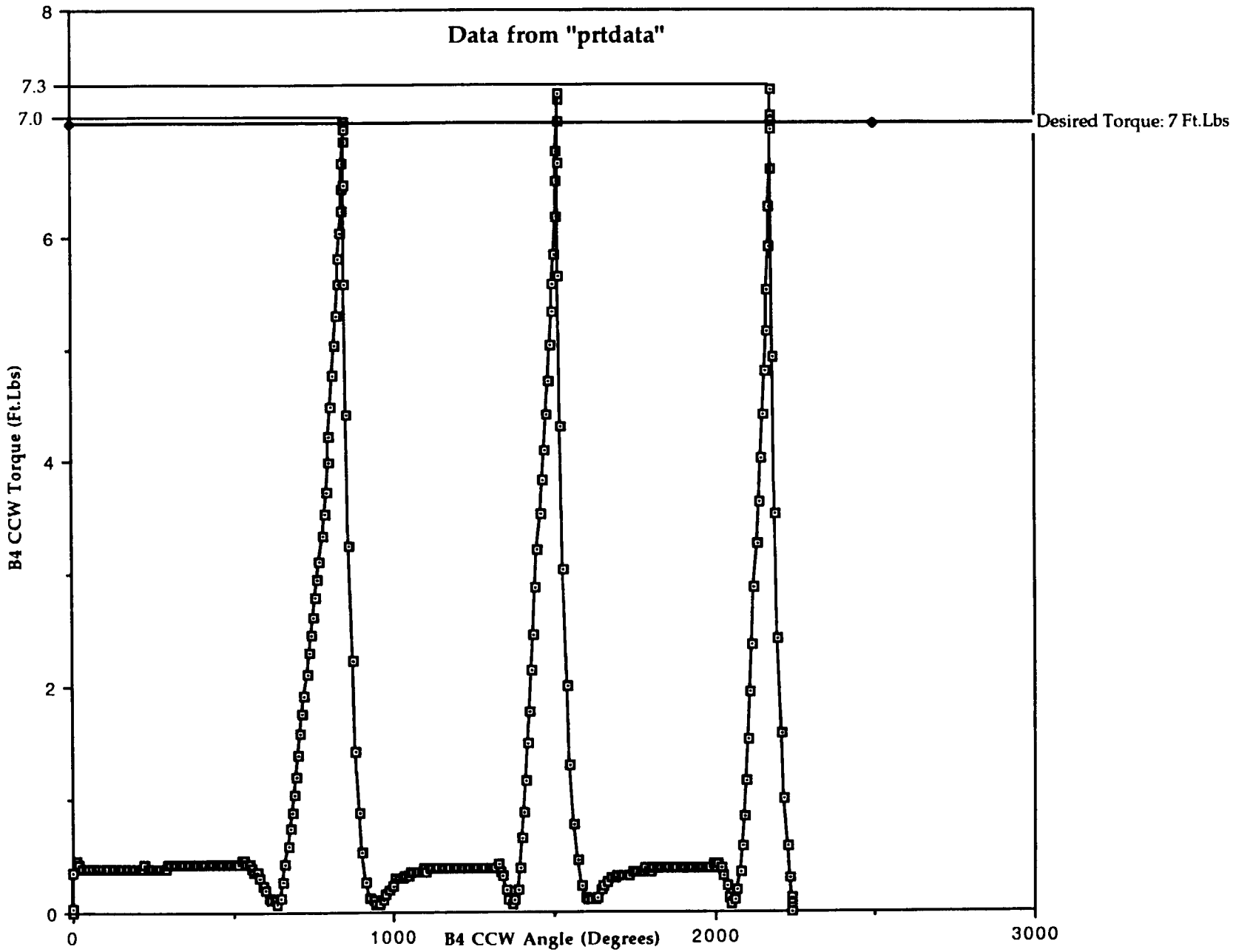

Data from "prtdata"
Desired Torque
3
2.5
2.3
2.2
2
1
0
B2 CCW Torque (Ft.Lbs)
0
200
400
600
800
1000
1200
B2 CCW Angle (Degrees)

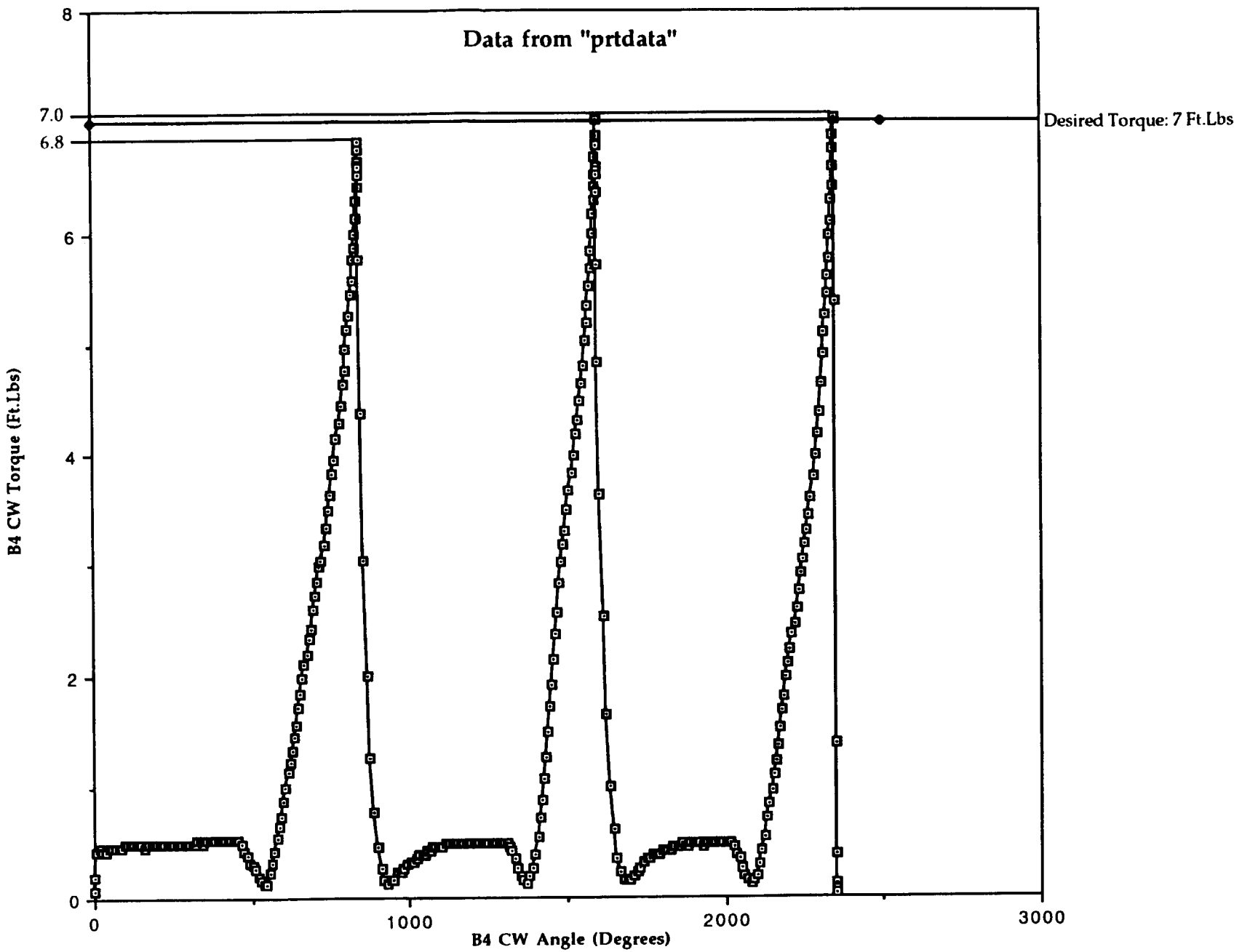

Data from "prtdata"
Desired Torque
2.4
3
2.43
2.3
2
1
0
B2 CW Torque (Ft.Lbs)
0
1000
2000
B2 CW Angle (Degrees)

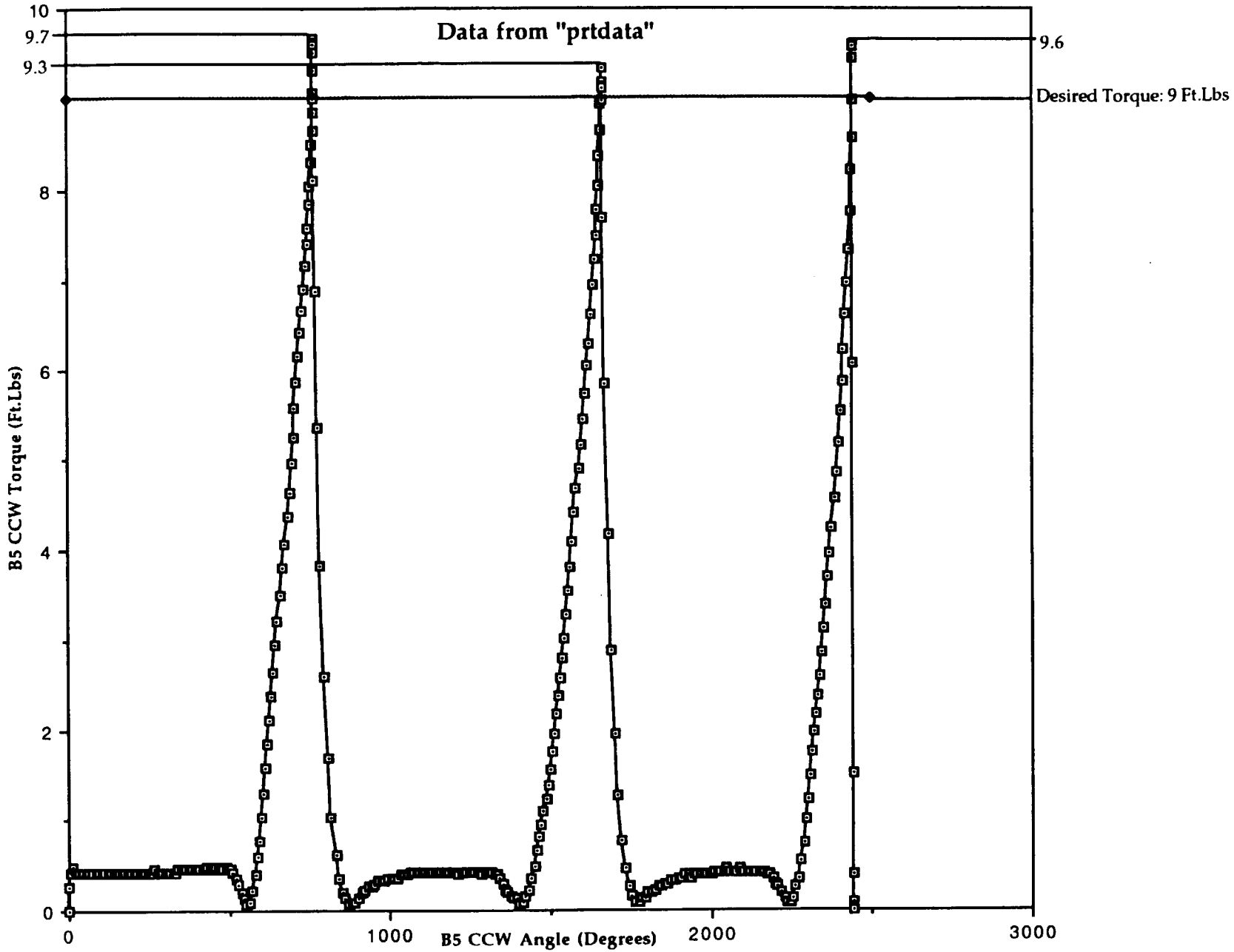

Data from "prtdata"
6
5.3
5
4.8
4.7
4
3
2
1
0
0
1000
2000
3000
B3 CCW Torque (Ft.Lbs)
B3 CCW Angle (Degrees)
Desired Torque: 5 Ft.Lbs

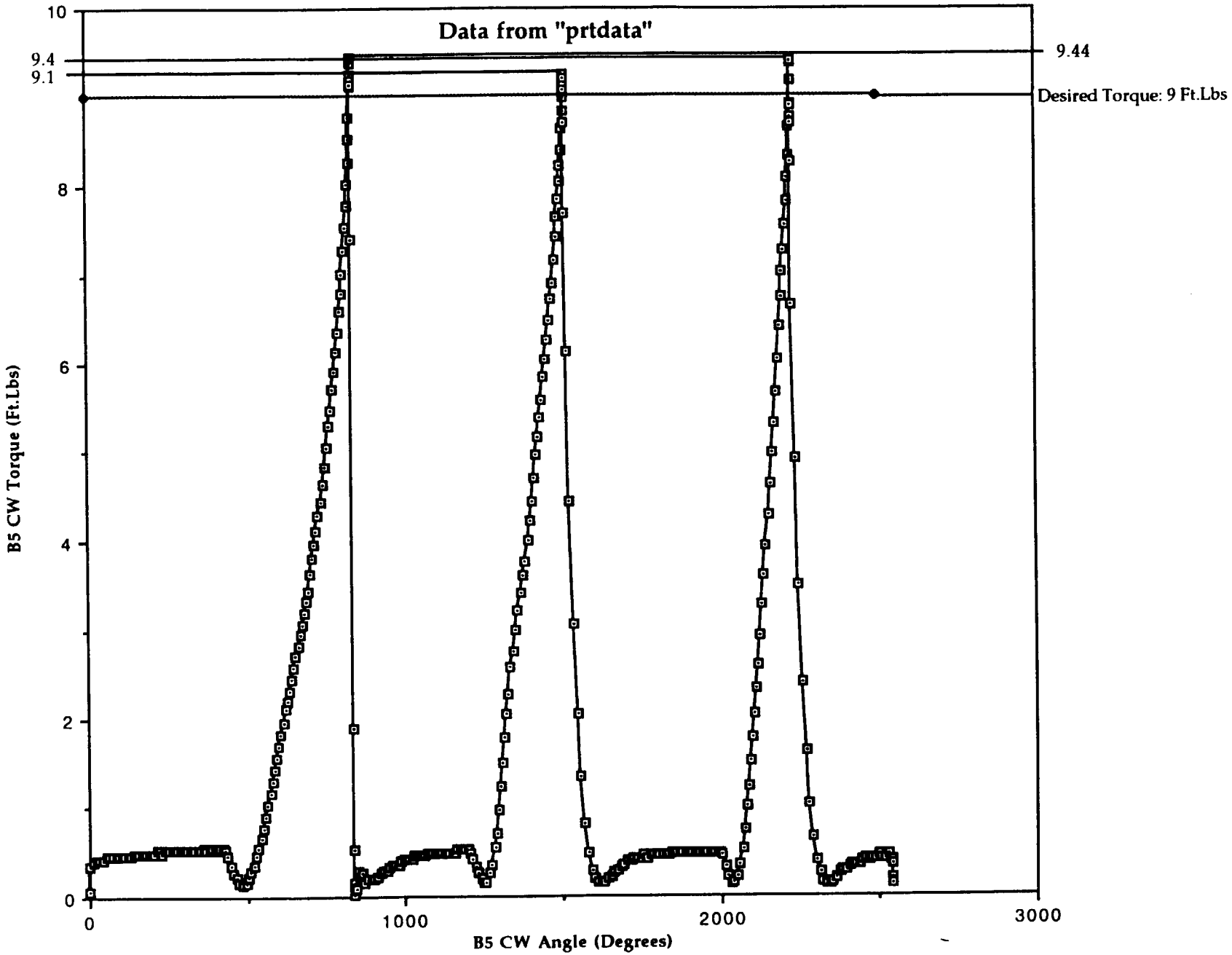
09

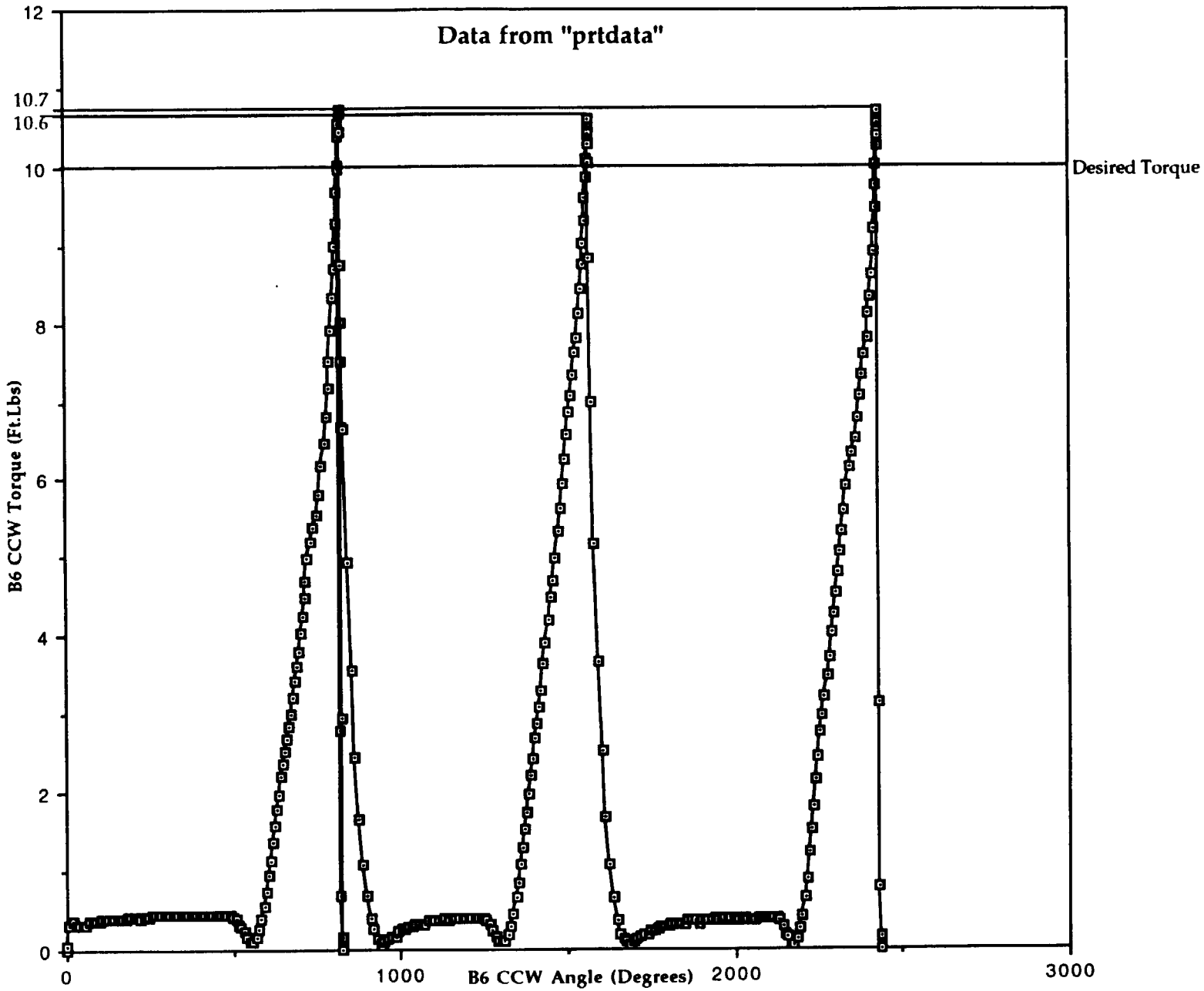

Data from "prtdata"
Desired Torque: 5 Ft.Lbs
4.7
5
4.8
4.6
4
3
2
1
0
B3 CW Torque (Ft.Lbs)
0
1000
2000
3000
B3 CW Angle (Degrees)

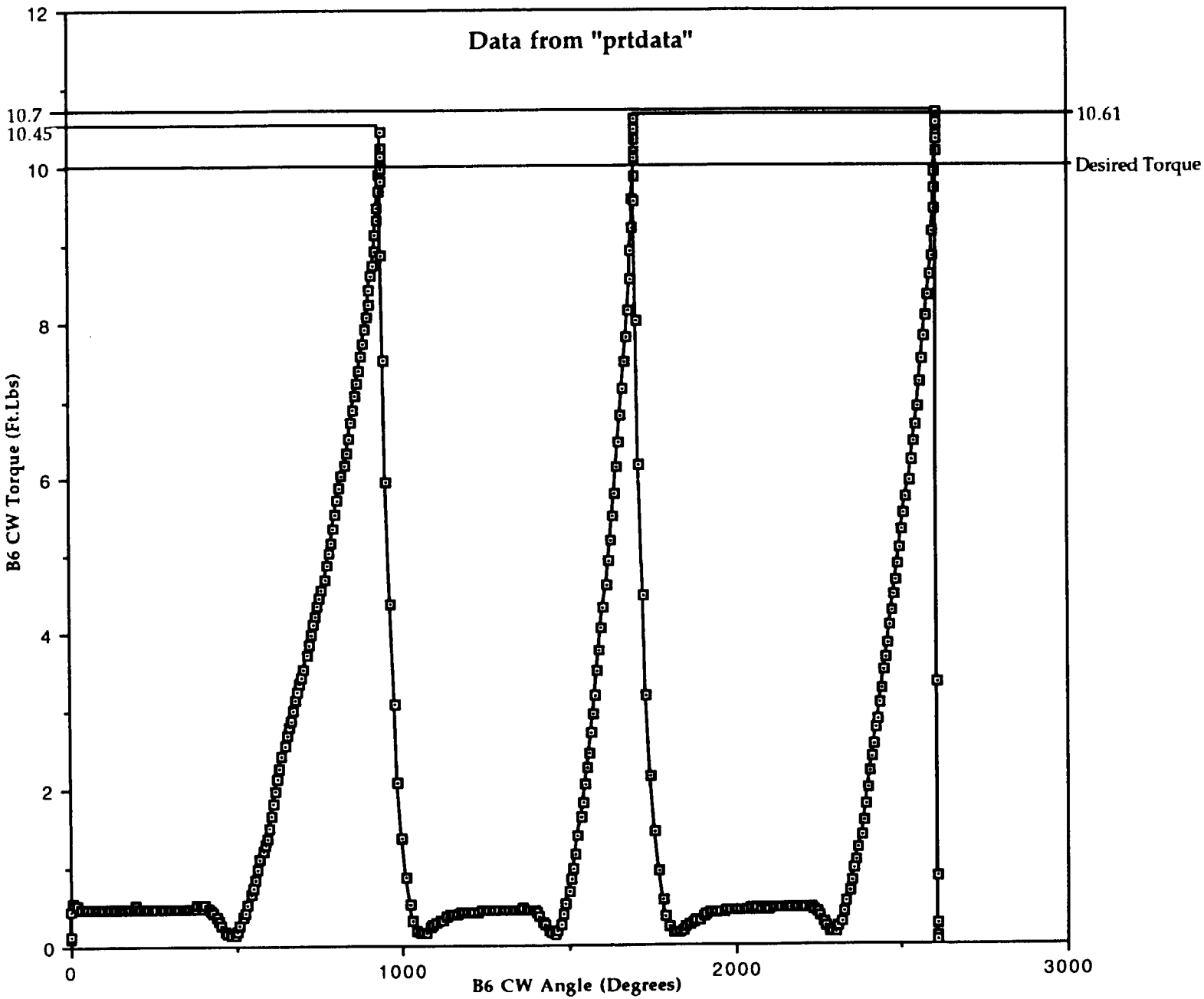

Data from "prtdata"
8
7.3
7.0
6
4
2
0
Desired Torque: 7 Ft.Lbs
B4 CCW Torque (Ft.Lbs)
0
1000
2000
3000
B4 CCW Angle (Degrees)

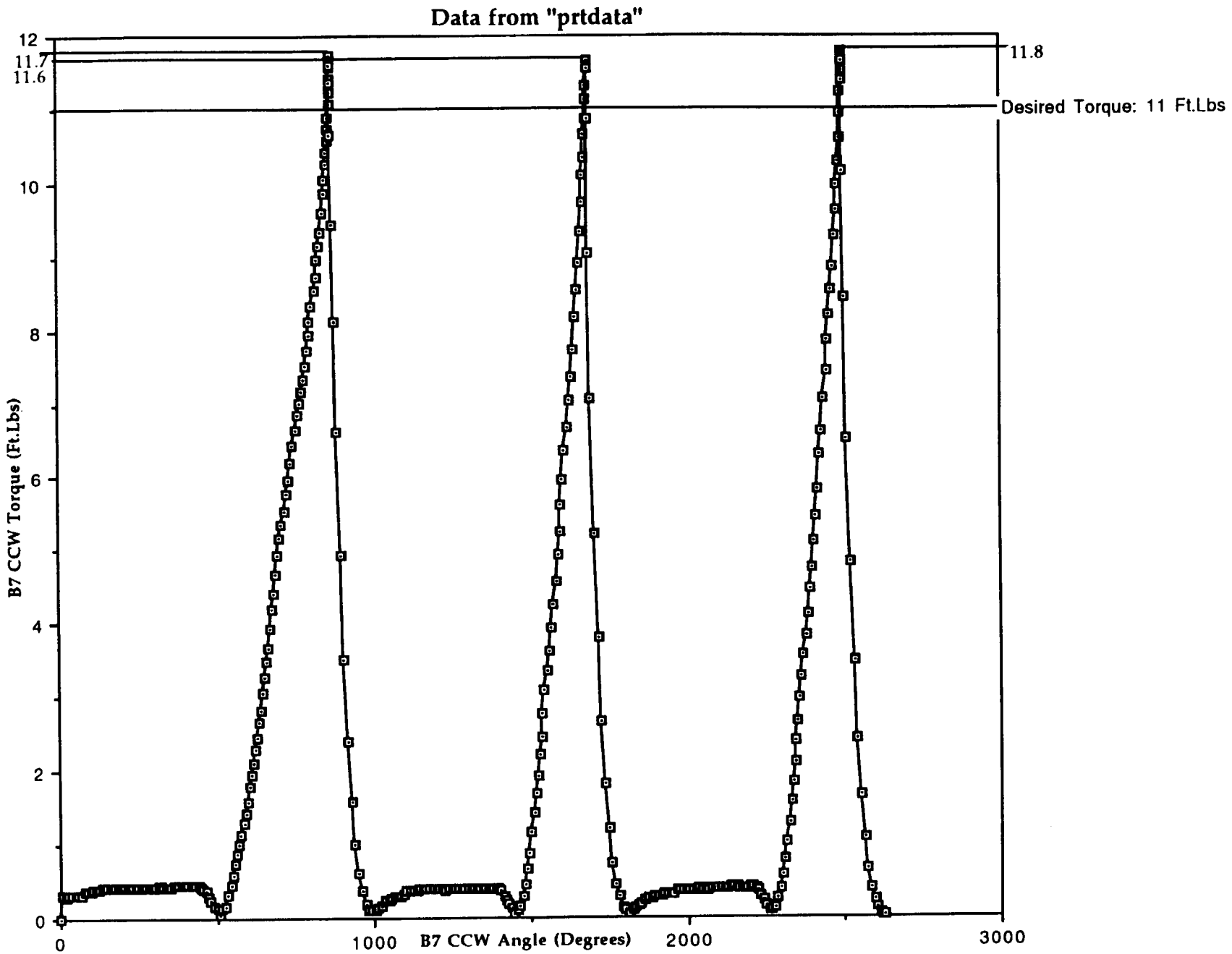

Data from "prtdata"
Desired Torque: 7 Ft.Lbs
B4 CW Torque (Ft.Lbs)
B4 CW Angle (Degrees)
8
7.0
6.8
6
4
2
0
0
1000
2000
3000

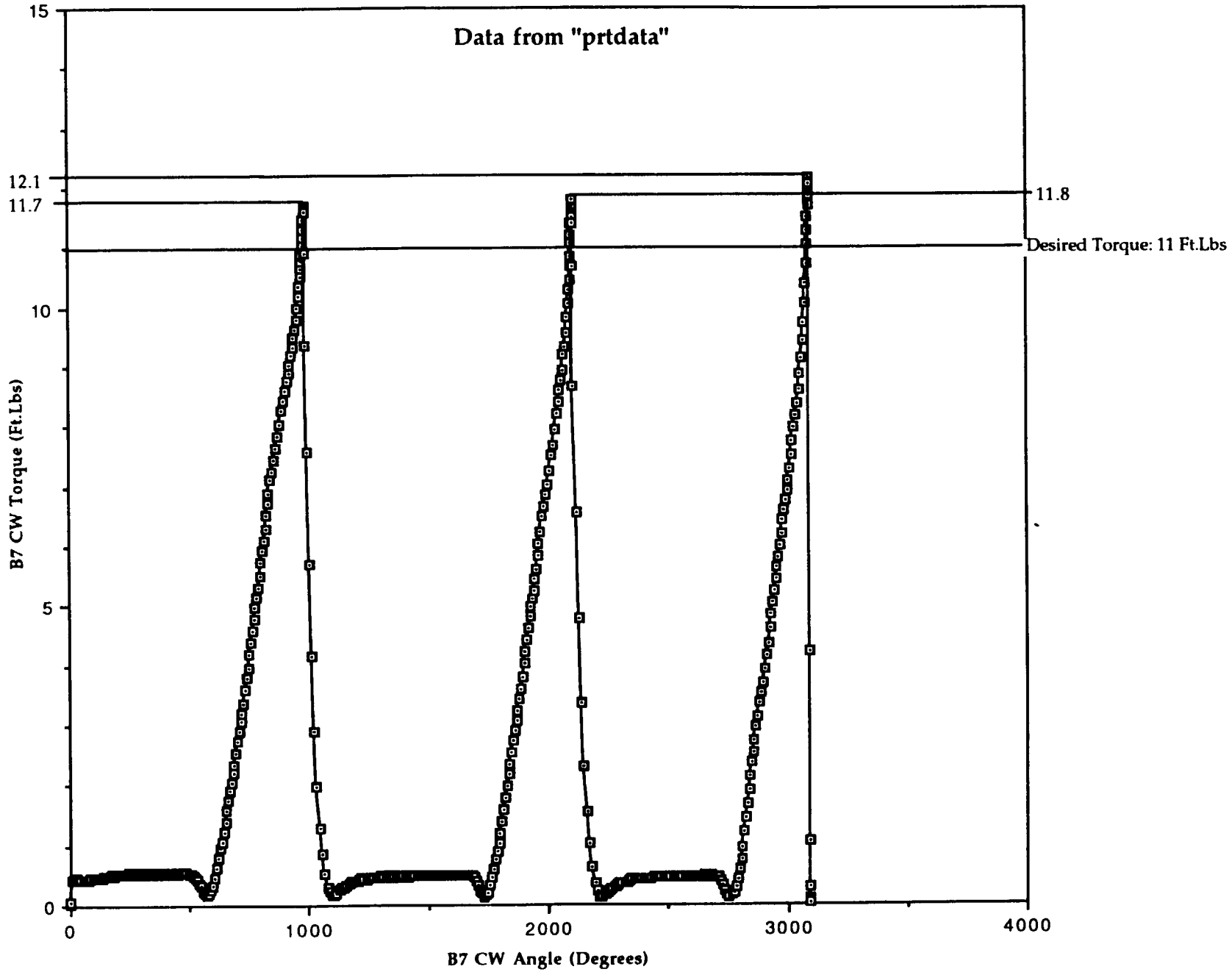

Data from "prtdata"
10
9.7
9.3
9.6
Desired Torque: 9 Ft.Lbs
8
6
4
2
0
B5 CCW Torque (Ft.Lbs)
0
1000
2000
3000
B5 CCW Angle (Degrees)

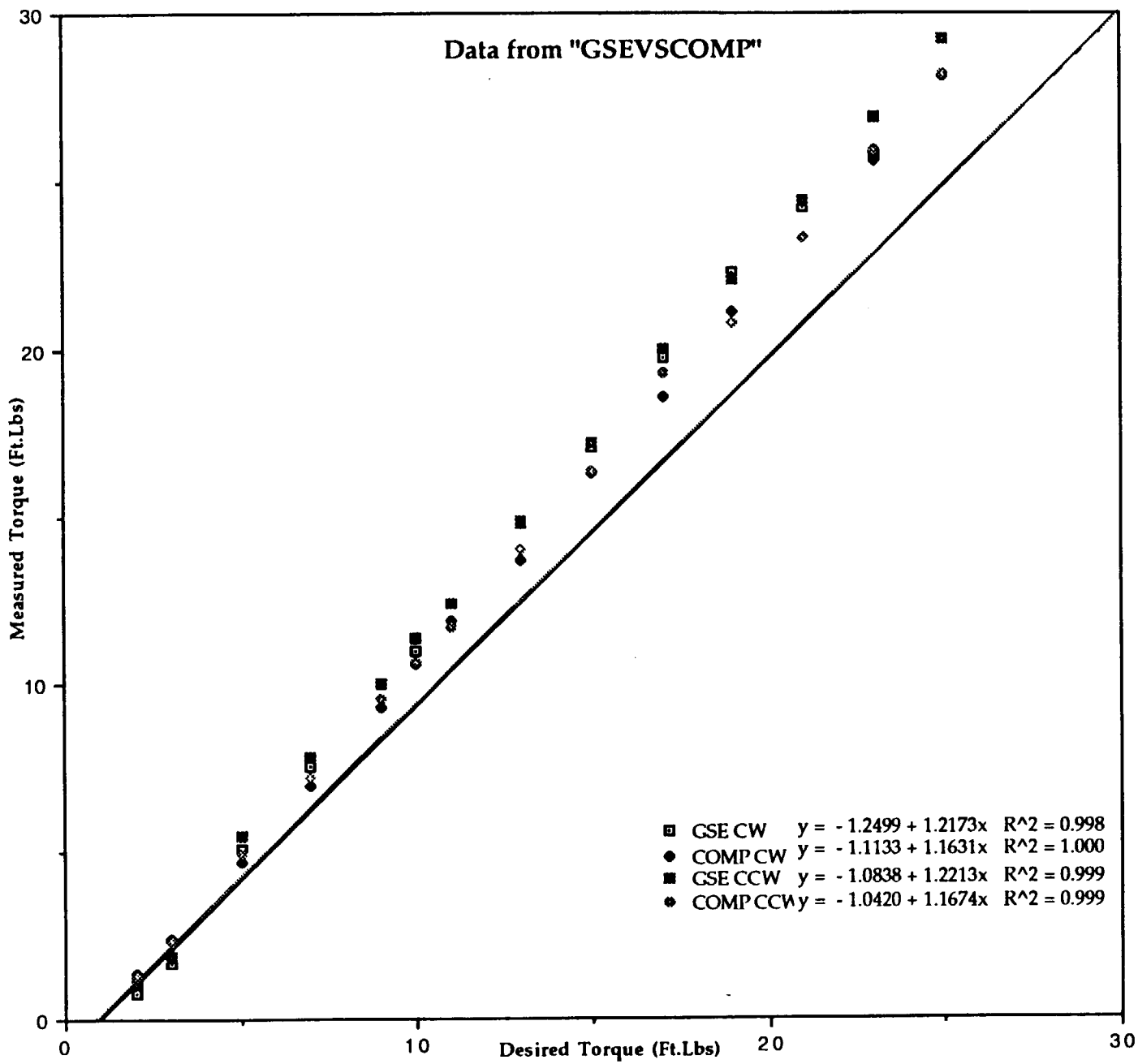

Data from "prtdata"
9.44
9.4
9.1
Desired Torque: 9 Ft.Lbs
10
8
6
4
2
0
0
1000
2000
3000
B5 CW Torque (Ft.Lbs)
B5 CW Angle (Degrees)

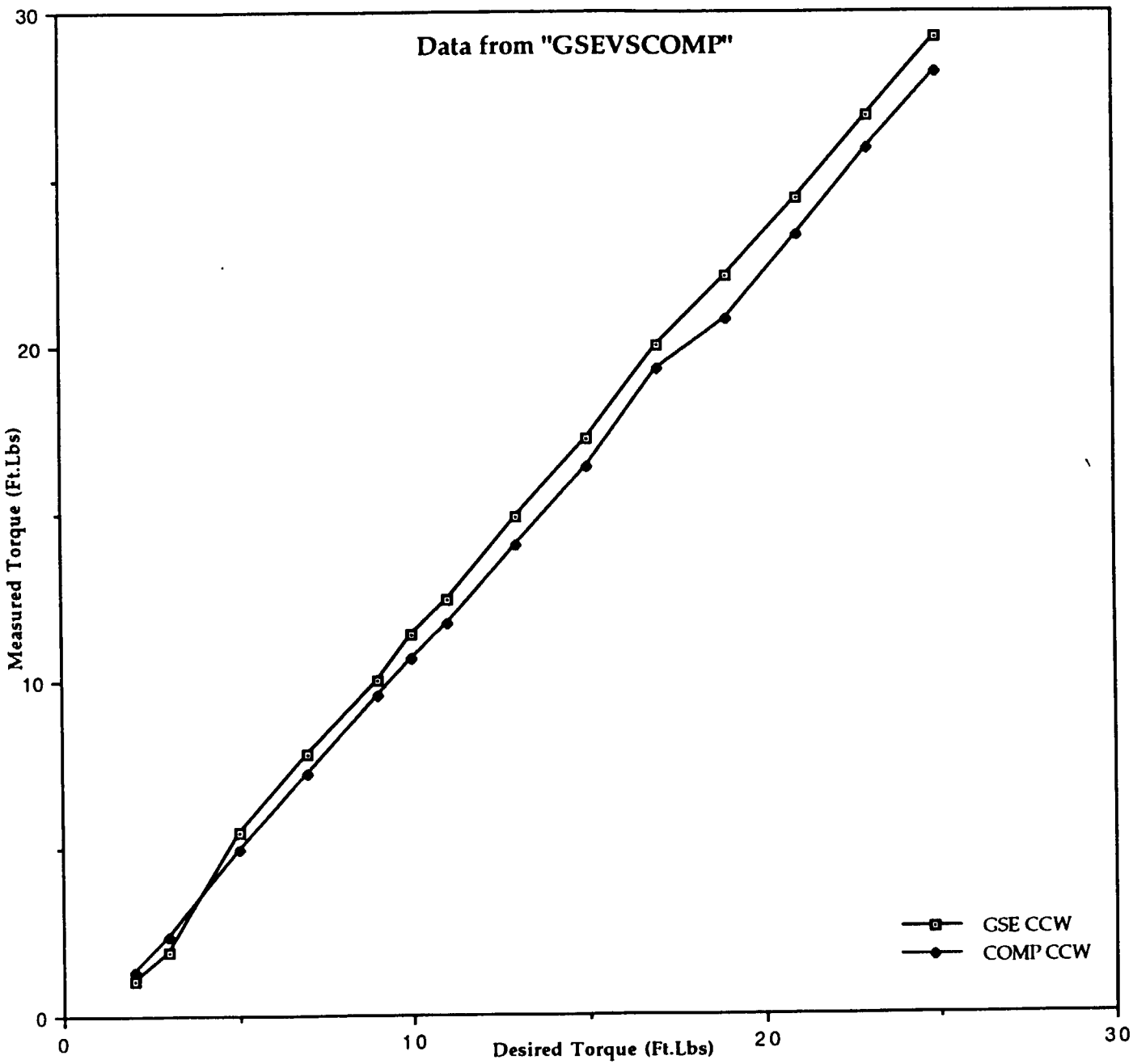

Data from "prtdata"
12
10.7
10.6
10
8
6
4
2
0
Desired Torque
B6 CCW Torque (Ft.Lbs)
0
1000
2000
3000
B6 CCW Angle (Degrees)

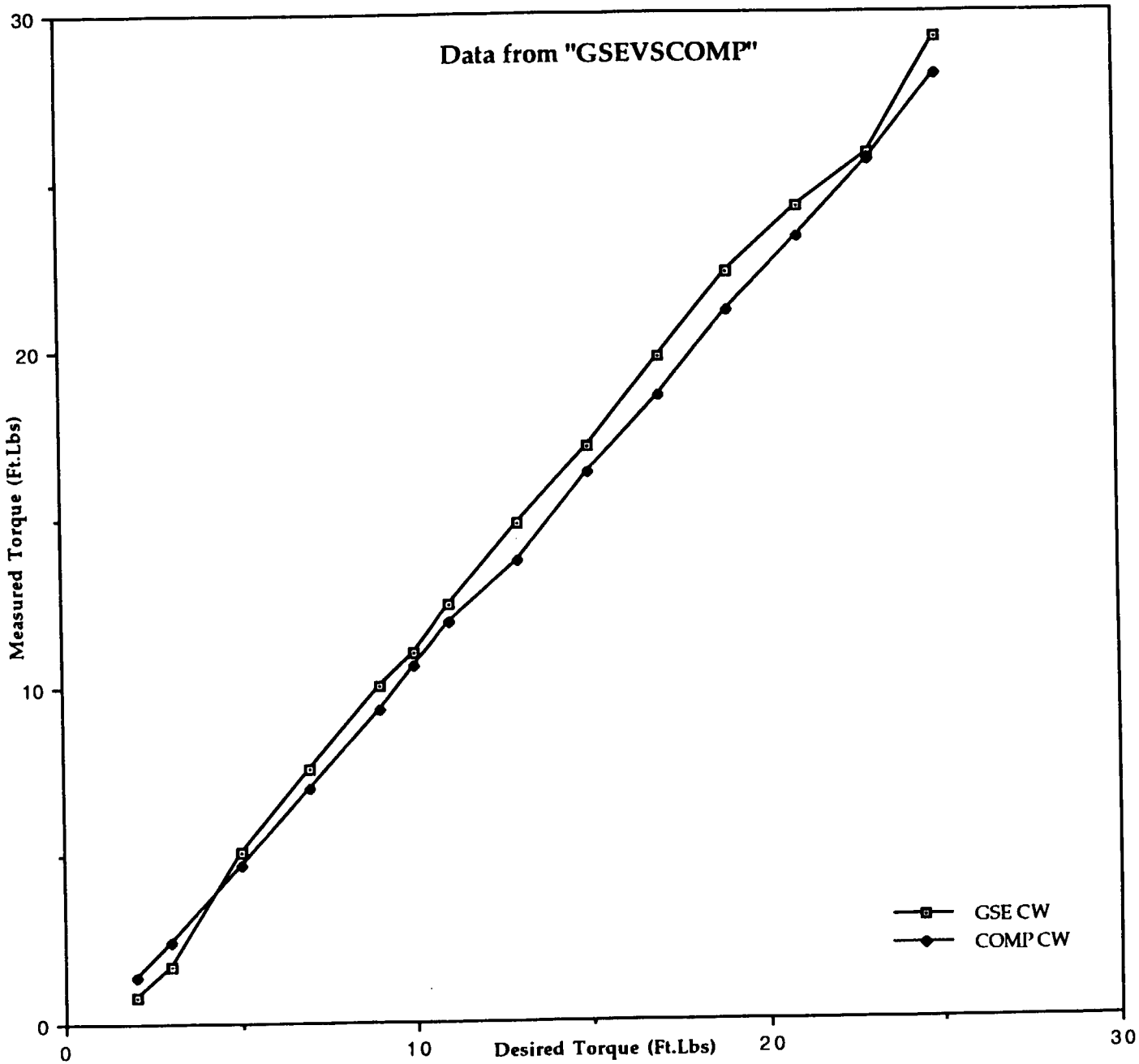

Data from "prtdata"
12
10.7
10.45
10
8
6
4
2
0
10.61
Desired Torque
B6 CW Torque (Ft.Lbs)
0
1000
2000
3000
B6 CW Angle (Degrees)

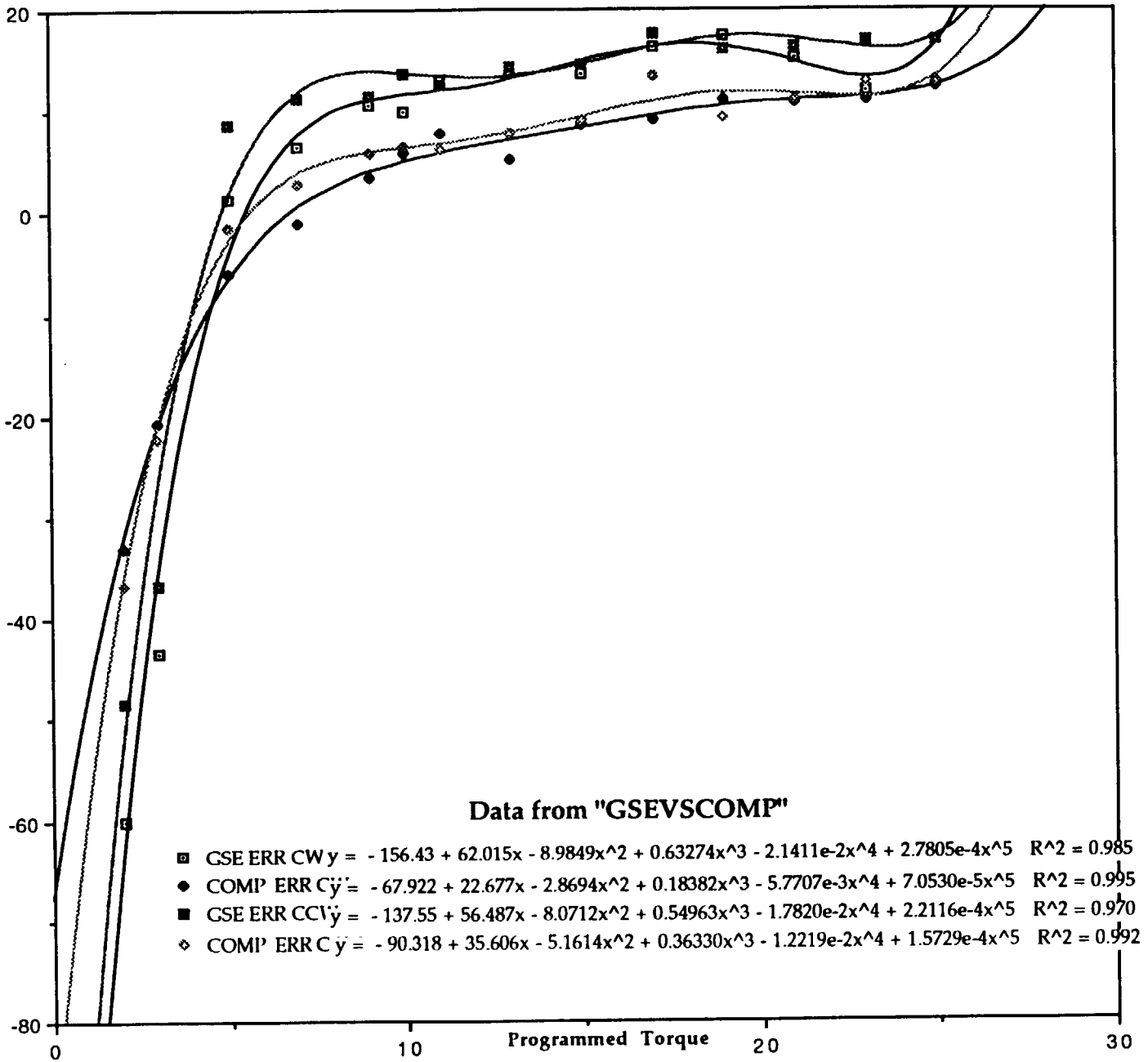

Data from "prtdata"
12
11.7
11.6
11.8
Desired Torque: 11 Ft.Lbs
10
8
6
4
2
0
B7 CCW Torque (Ft.Lbs)
0
1000
B7 CCW Angle (Degrees)
2000
3000


Data from "prtdata"
15
12.1
11.7
10
5
0
11.8
Desired Torque: 11 Ft.Lbs
B7 CW Torque (Ft.Lbs)
0
1000
2000
3000
4000
B7 CW Angle (Degrees)


Data from "GSEVSCOMP"
Measured Torque (Ft.Lbs)
Desired Torque (Ft.Lbs)
0
10
20
30
GSE CW y = - 1.2499 + 1.2173x R^2 = 0.998
COMP CW y = - 1.1133 + 1.1631x R^2 = 1.000
GSE CCW y = - 1.0838 + 1.2213x R^2 = 0.999
COMP CCW y = - 1.0420 + 1.1674x R^2 = 0.999


Data from "GSEVSCOMP"
Measured Torque (Ft.Lbs)
Desired Torque (Ft.Lbs)
0
10
20
30
GSE CCW
COMP CCW


Data from "GSEVSCOMP"
Measured Torque (Ft.Lbs)
Desired Torque (Ft.Lbs)
0
10
20
30
GSE CW
COMP CW


20
0
-20
-40
-60
-80
0
10
20
30
Programmed Torque
Data from "GSEVSCOMP"
GSE ERR CW y = - 156.43 + 62.015x - 8.9849x^2 + 0.63274x^3 - 2.1411e-2x^4 + 2.7805e-4x^5 R^2 = 0.985
COMP ERR CW y = - 67.922 + 22.677x - 2.8694x^2 + 0.18382x^3 - 5.7707e-3x^4 + 7.0530e-5x^5 R^2 = 0.995
GSE ERR CCW y = - 137.55 + 56.487x - 8.0712x^2 + 0.54963x^3 - 1.7820e-2x^4 + 2.2116e-4x^5 R^2 = 0.970
COMP ERR CCW y = - 90.318 + 35.606x - 5.1614x^2 + 0.36330x^3 - 1.2219e-2x^4 + 1.5729e-4x^5 R^2 = 0.992