This report summarizes the static component tests of the Boydbolt Fasteners. The detailed procedure is covered in BSR 2448 (ATR-105). Copies of the detailed test data will be supplied on request.

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1.0 Summary

The Boydbolt Verification Static Tests have been conducted to examine the installation procedure and seek out any design weaknesses, both of which may be contributing to the current problems of:

a) high spindle release forces

b) loss of bolt preload.

Nine different static tests were conducted in this test program. The details are covered in Section 3.0.

Typical test hardware and test set-ups are shown in Section 4.0, Test Information. This section also describes the purpose, scope, and results of each test.

Test conclusions are covered in Section 5.0. Stated briefly, they are:

a) Fastener release torque is within specification

b) Bolt spring force is constant at no load condition

c) "Wipe-out" torque under preload is 40-50 in-lb

d) Spindle depression depth to release balls varies greatly

e) Hardened spindle bolt is superior to regular spindled bolt

f) Creep of mylar insulation material under load is insignificant

g) Boydbolt assembly is structurally sound

h) ESNA nut life is limited

i) Preload torque level should be reduced

j) CS1011 spring should be replaced with CS1014 spring (left hand spiral).

Recommendations are noted in Section 6.0. They are:

a) Replace CS1011 spring with CS1014

b) Rework CA2773 bolts to hardened spindle configuration

c) Reduce preload torque to 44 ±2 in.-lb

d) Design a positive location installation tool

e) Inspect hardware prior to each installation

f) Limit ESNA nut usage to five installations

g) Train selected personnel for Boydbolt installation and inspection.

h) Preload torquing should be a one man operation

2.0 Introduction

The Boydbolt assemblies have experienced two problems which are very critical to the ALSEP Program. These problems are:

1) Spindle release forces that exceed the 20 lb limit.

2) Loss of preload in the bolt after dynamic testing.

These static tests have been conducted to examine the installation procedure and to seek out any basic weaknesses of the Boydbolt design. Dynamic tests will be conducted at the system level subsequent to the static tests.

3.0 Description of Test Program

This test program covered static component tests only, which are designed to provide basic technical information that could be used to improve Boydbolt installation procedures.

The tests conducted in this static test program are listed below:

Test No.	Test Title
6.1	Preload Torque Effects
6.2	Spindle Spring Life
6.3	Lock Spline Brinelling
6.5	Spindle Depression Depth
6.6	Bolt Torque Effects on Spindle Force
6.7	Insulation Effects on Fastener Pre-Load
6.8	Bolt Head Socket Wipe-Out Strength
6.9	ESNA Nut Static Load
6.10	ESNA Nut Life

The procedural details of these tests are covered in BSR 2448 (ATR-105), ALSEP BOYDBOLT FASTENER DESIGN VERIFICATION TEST PROGRAM. Test No. 6.4, Temperature Effects, was not conducted because the estimated cost was excessive for the data that was being sought.

4.0 Test Information

The typical Boydbolt assembly that was used for these tests is shown in Figure 4.1. The following items are shown:

ESNA nut (modified) — SP1015

Spring — CS1011

Bolt — CA2773

Nut plate — CA2774

The Fastener guide (2335931) and special washer (BSX 8205) that were used under the ESNA nut and spring are not shown, but can be seen in subsequent figures.

Two types of bolts were used for this test series, the CA2773-14 and the CA2773-14-1. The former has a regular spindle of Rockwell C42-46 hardness, and the latter has a hardened spindle of Rockwell C56-60 hardness. For reference, hardness of the balls is Rockwell C58-62.

Figures 4.2 and 4.3 show the test setup for test Nos. 6.1 through 6.7. Washer, BSX 8205, is visible under the ESNA nut in Figure 4.2. The Short Torque Tool Assembly that was used to torque the Boydbolt fastener assemblies is shown in Figure 4.4.

Testing information for the nine static tests are covered in the following paragraphs.

Test No. 6.1 Preload Torque Effects

Purpose: To determine the effect of preload level, in terms of preload torque, on the torque level required to release the fasteners.

Scope: Six Boydbolt assemblies (3 with regular spindles, 3 with hardened spindles) were tested by varying the preload torque from 35 to 65 in.-lb and measuring the corresponding fastener release torque for each preload torque value.

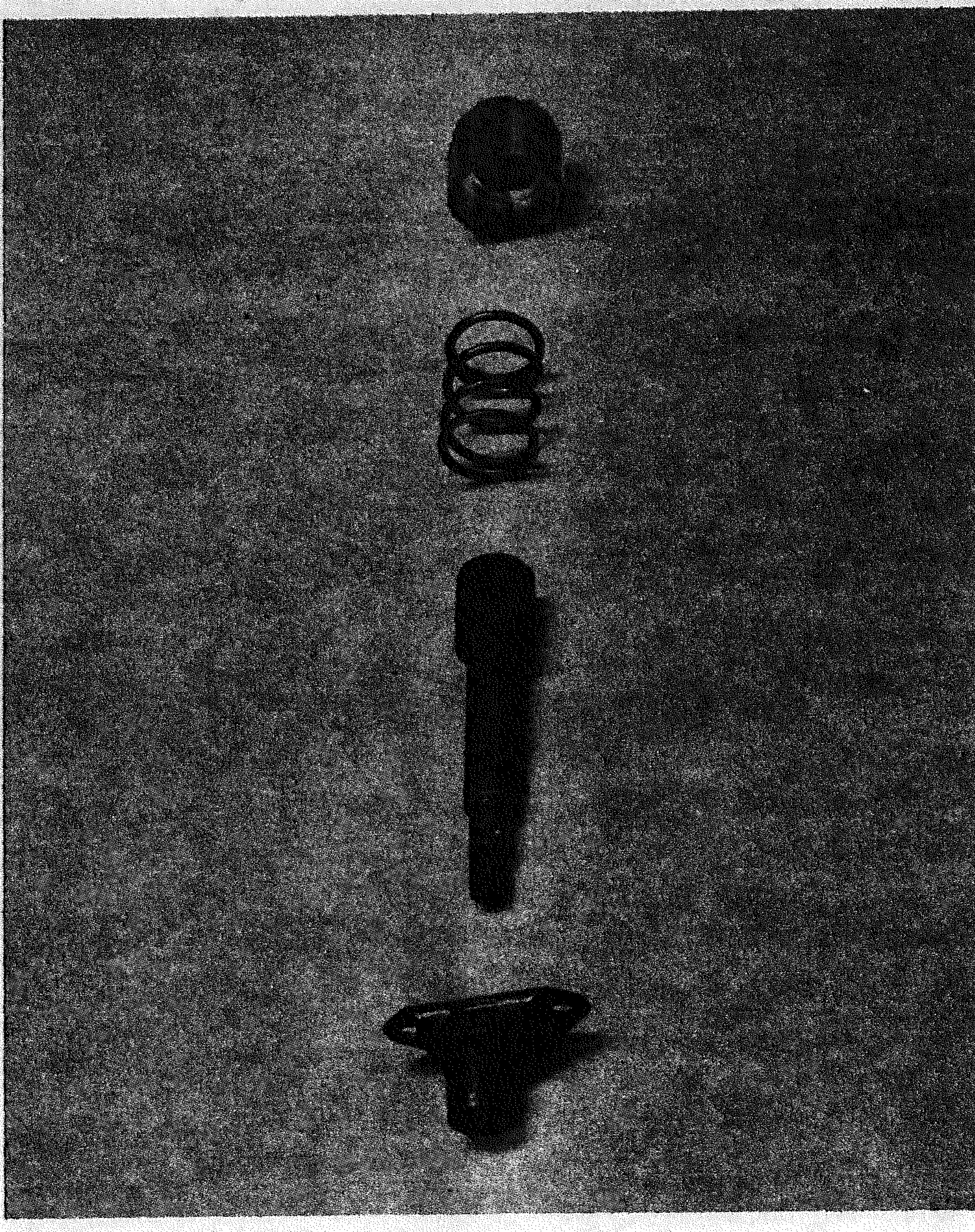

Figure 4.1 Boydbolt Assembly Components.

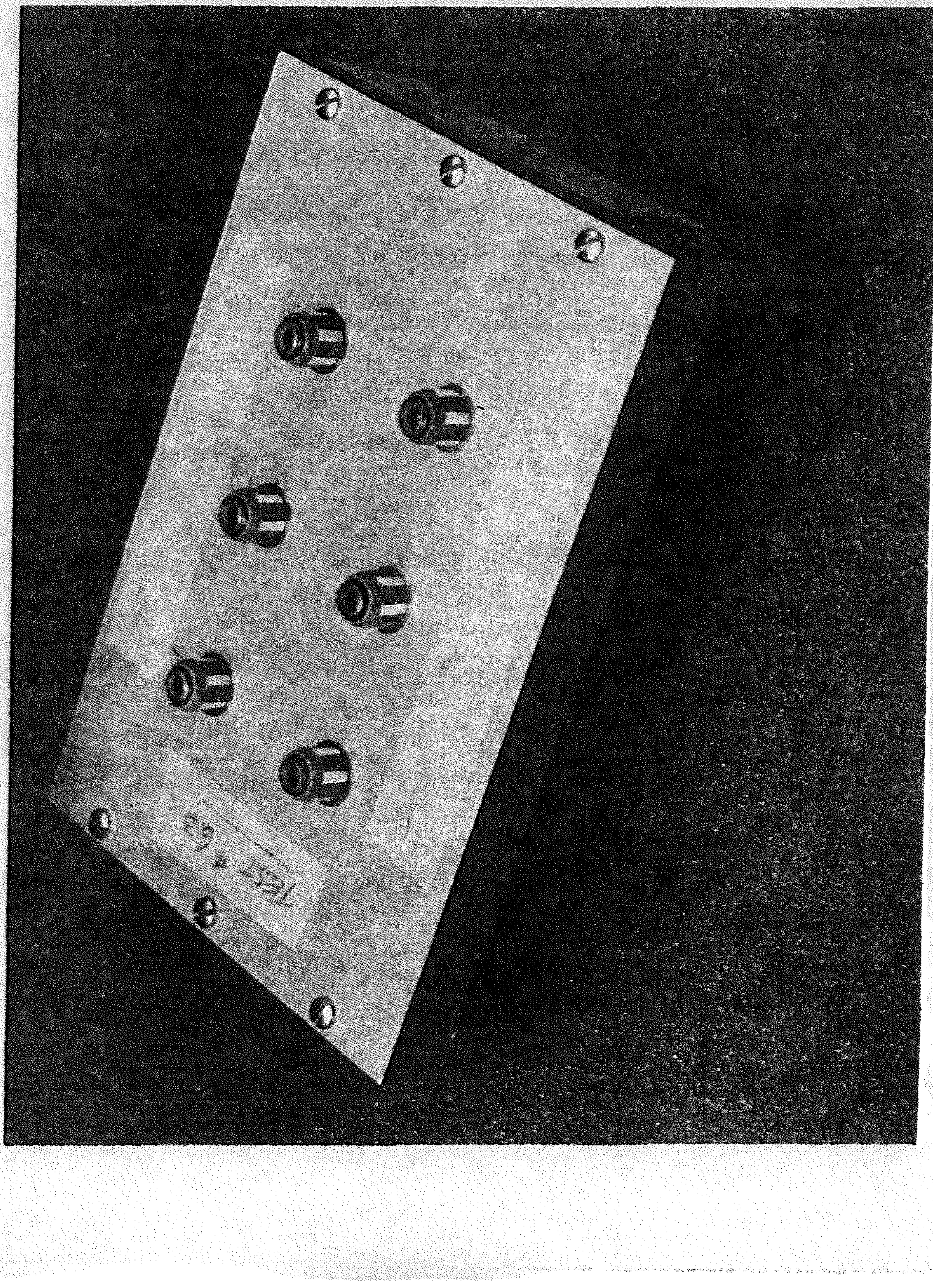

Figure 4.2 Test Set-up, Tests nos. 6.1 through 6.7, Top View.

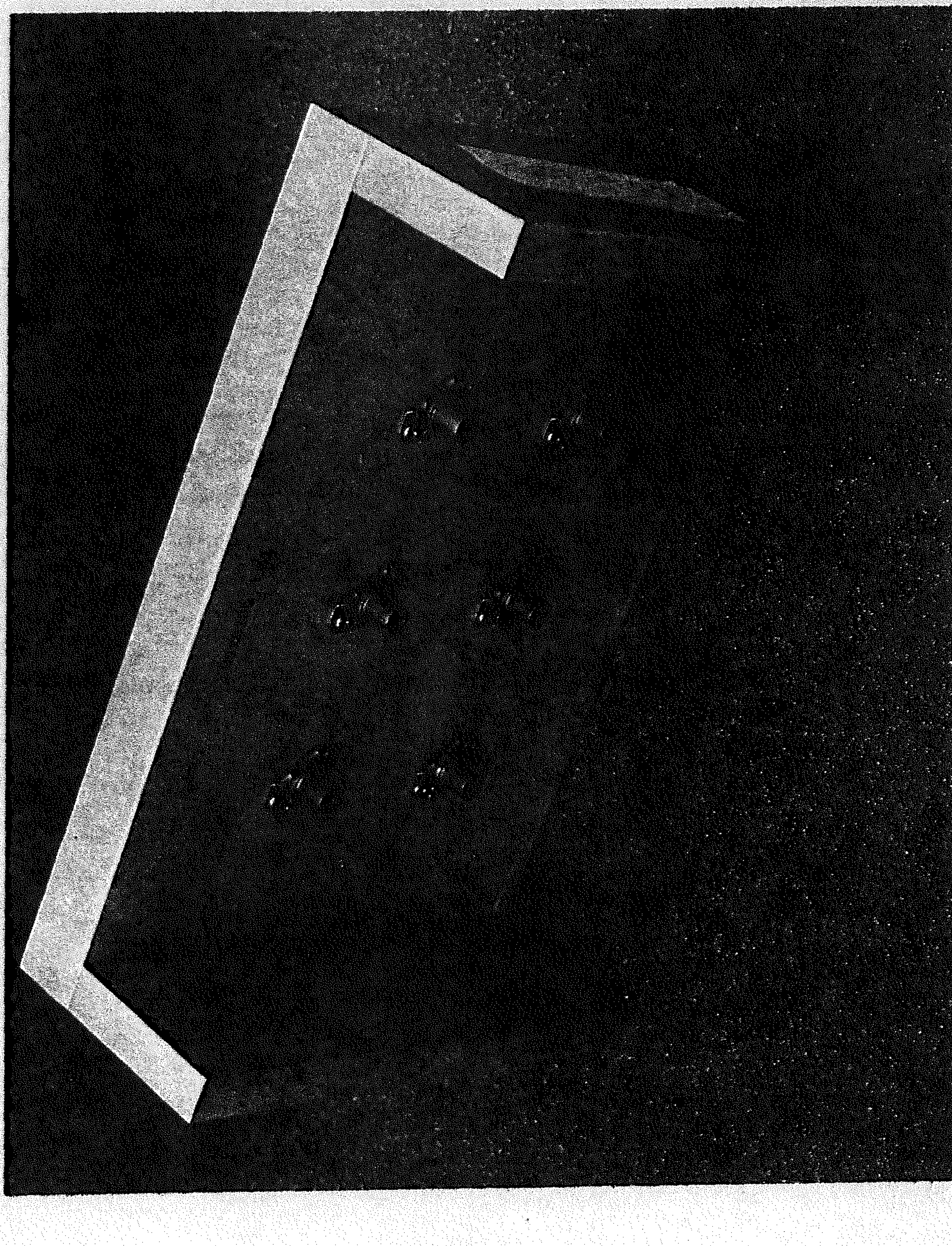

Figure 4.3 Test Set-up, Test nos. 6.1 through 6.7, Bottom View.

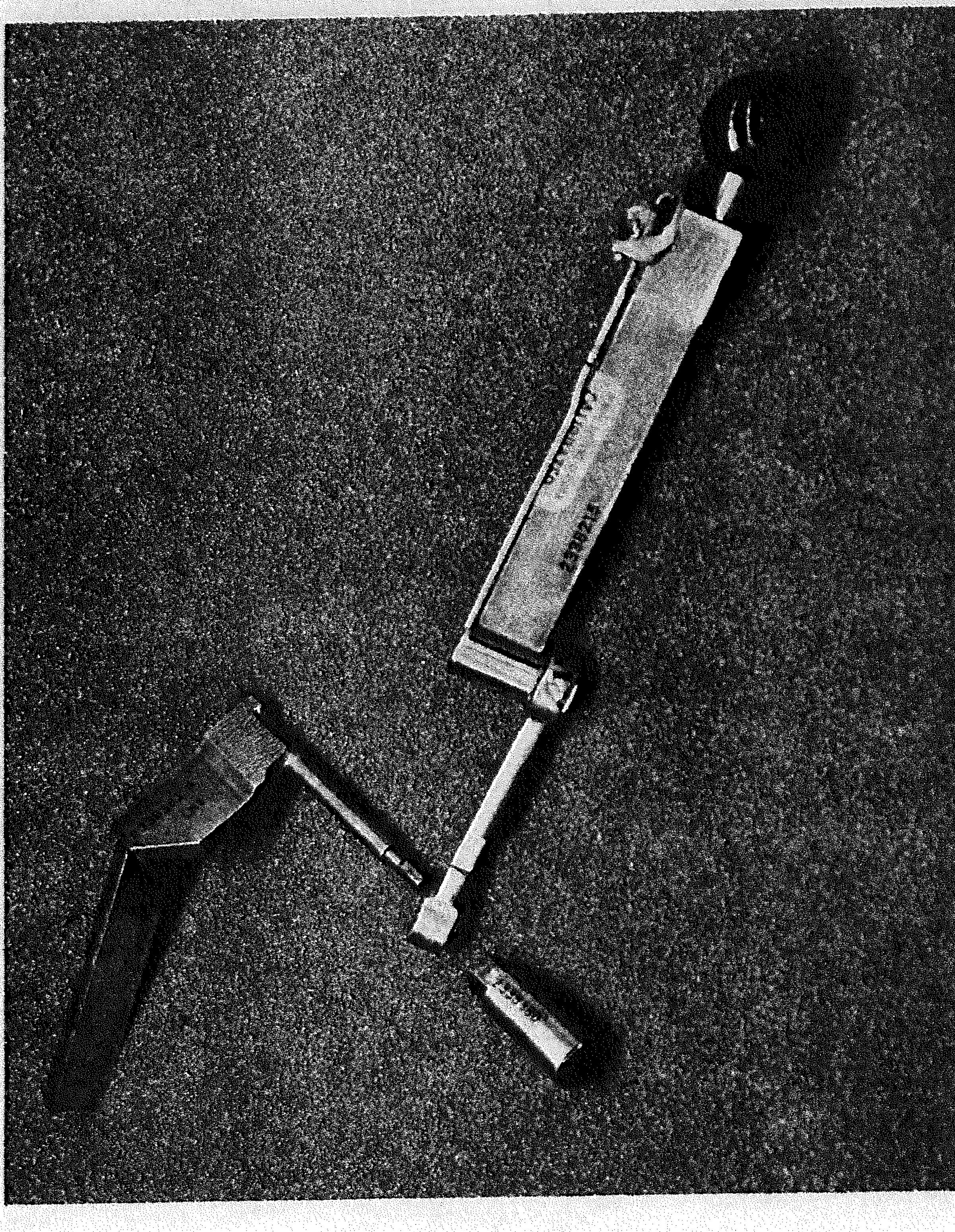

Figure 4.4 Boydbolt Torque Tool Assembly, Short.

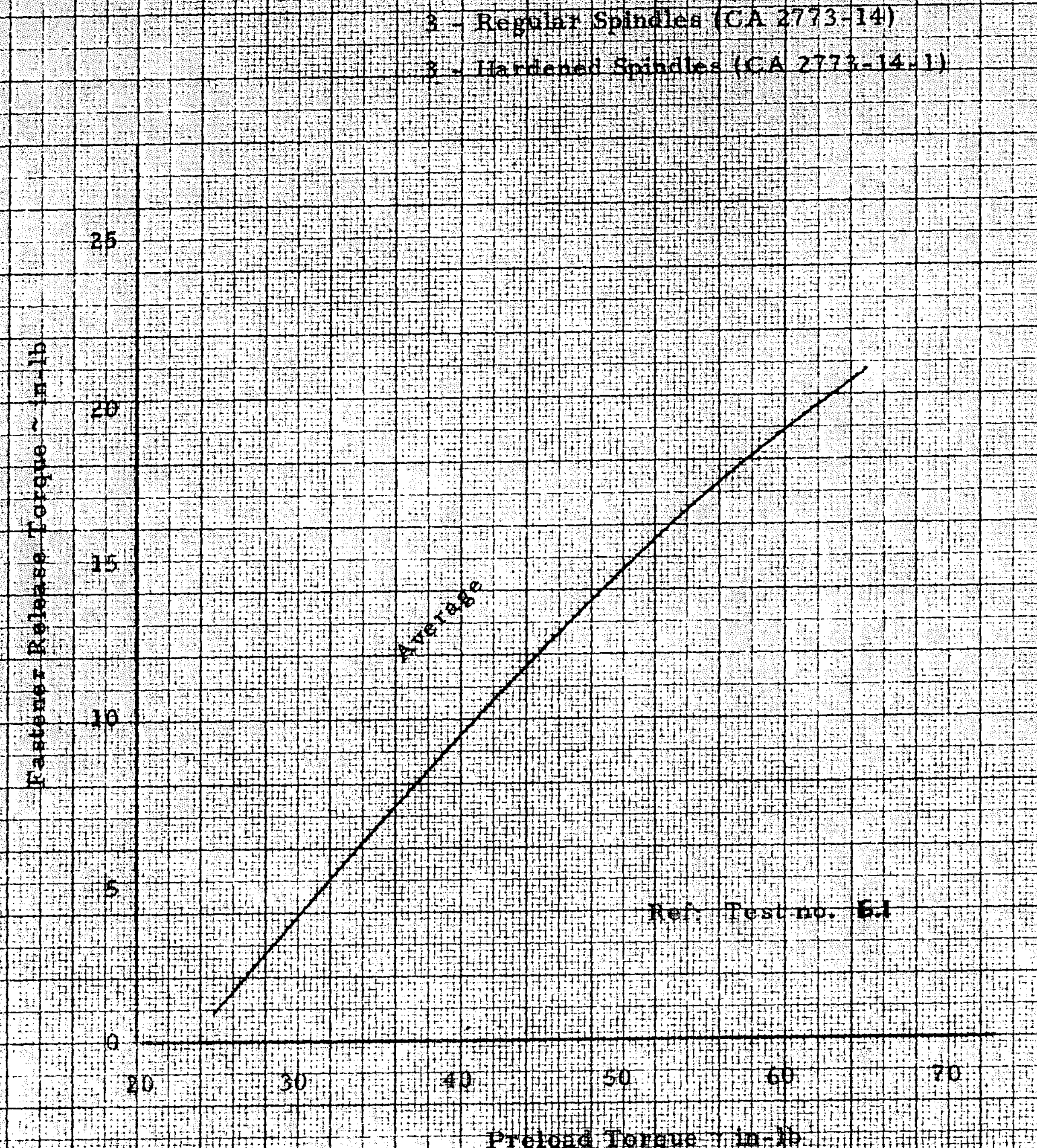

Figure 4.5 Fastener Release Torque versus Preload Torque

Results: The averaged curve for the six test assemblies is shown in Figure 4.5. In general, the data is linear up to 55 in.-lb of preload torque, and the hardened spindles exhibit slightly lower release torque than regular spindles. The average fastener release torque for the specified 55 in.-lb preload torque is 18 in.-lb.

Test No. 6.2 Spindle Spring Life

Purpose: To determine the life expectancy of the Boydbolt spindle spring in terms of the number of depressions before spring failure.

Scope: Six Boydbolt assemblies were tested (same hardware from Test No. 6.1). The spindle spring (internal to the bolt) was cycled by depressing the spindle with the Force Measuring Tool. Testing of each Boydbolt assembly was limited to 1000 cycles. The test set-up is shown in Figure 4.6.

Results: No degradation of spindle spring rate was found after 1000 cycles. The spring force at full deflection averaged 3 lbs.

Test No. 6.3 Lock Spline Brinelling

Purpose: To determine the integrity of the nut plate lock splines and the maximum permissible CCW torque which can be applied to the bolt before excessively damaging the lock splines.

Scope: CCW torque was applied to each bolt in increasing levels of 5 in.-lb (without depressing spindle) until the spline was "wiped-out". Six complete Boydbolt assemblies were used for one test series. An additional six bolts (CA 2773) and nut plates (CA 2774) were used for the second test series. Of these 12 bolts tested, three used in the first test had hardened spindles.

Results: Figure 4.7 shows the "wipe-out" torque values for each Boydbolt fastener assembly tested. Fastener assembly Nos. 1-6 were loaded to approximately 500 lbs, while fastener assembly Nos. 7-12 had no preload. The values below the data points indicate the dimension across the bolt balls in the extended position and the diameter of the "land region" between the locked and unlocked splines. It should be noted that the "wipe-out" values for assembly Nos. 5 and 6 are probably high since the diametrical values

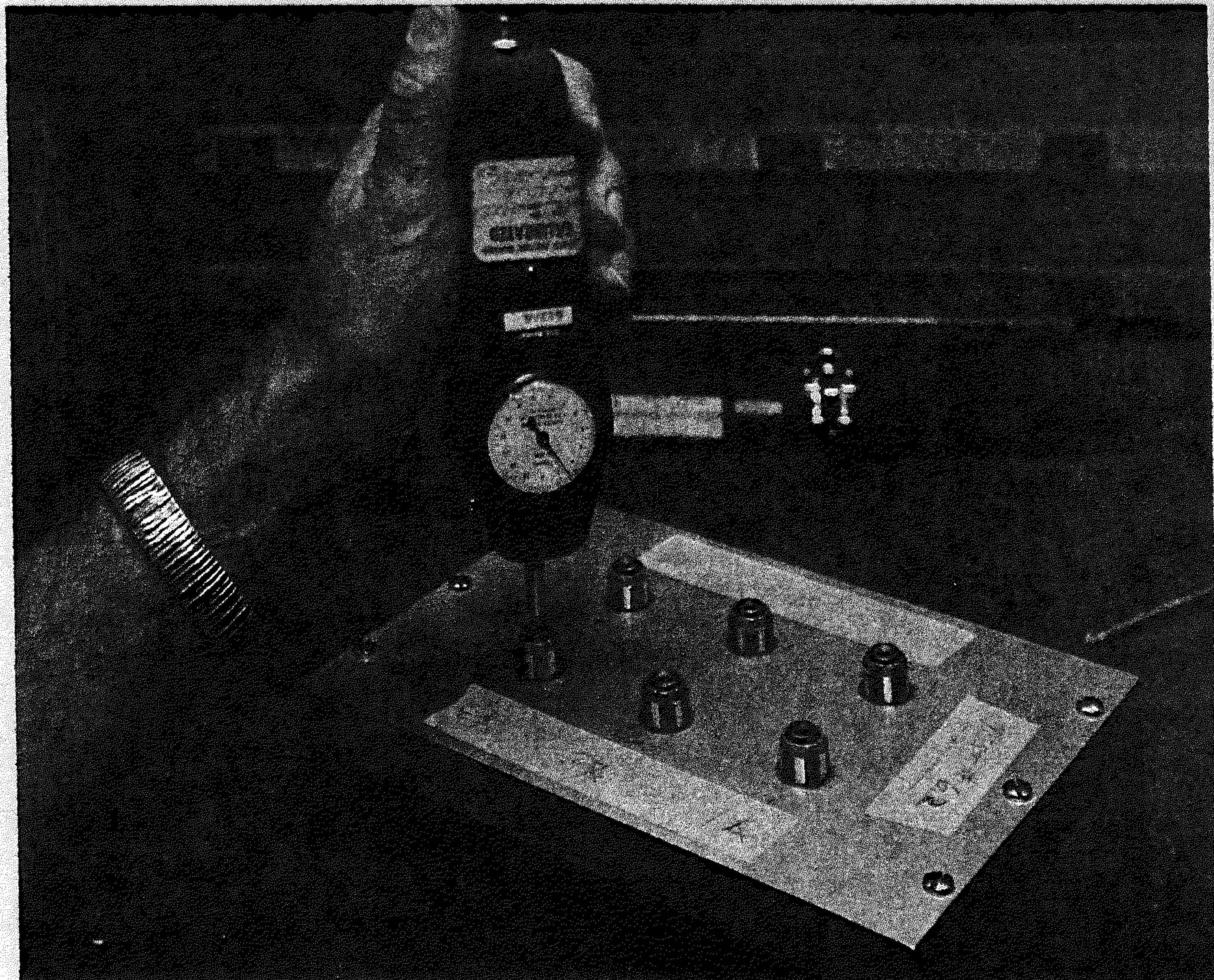

Figure 4.6 Spindle Release Force Measurement (Ref: Test no. 6.2)

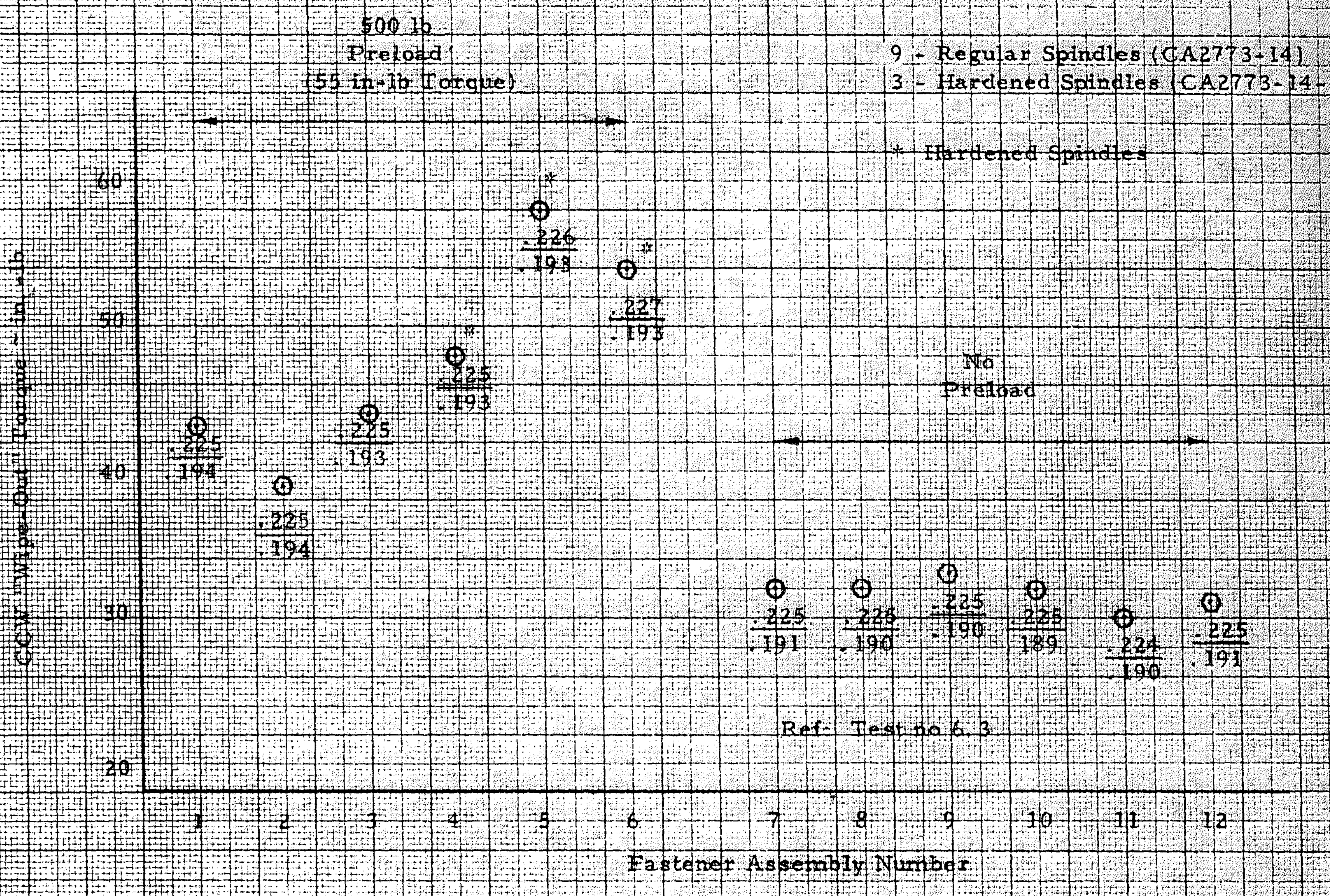

Figure 4.7 Counterclockwise Torque "Wipe Out" Data Plot.

of .226 and .227 increase the interference between the balls and the land region of the nut plate. In general, "wipe-out" of the nut plate land region occurred as follows:

a) Without fastener preload at 30-32 in.-lb for bolts with regular spindles.

b) With 55 in.-lb of fastener preload torque

1) at about 42 in.-lb for bolts with regular spindles

2) at about 50 in.-lb for bolts with hardened spindles.

Figures 4.8, 4.9 and 4.10 show photos (10 times size) of hardware used in this test. Figure 4.8 shows a typical ball brinell mark on the nut plate locking spline edge that occurred during a normal repeated preload installation. Figure 4.9 shows a typical "wipe-out" of the nut plate (No. 6) land region. Figure 4.10 shows a closeup of bolt No. 6 ball and interrupted thread region.

Test No. 6.5 Spindle Depression Depth

Purpose: To determine the amount of spindle depression required by the UHT tool to accomplish unlocking of the fasteners for release.

Scope: A depth gauge was used to measure the spindle depression distance required to retract the balls .001 inch on each side of the bolt.

Results: Thirty (30) bolts were examined. Spindle depression depth required to start retraction of balls varied from .016 to .038 inches.

Test No. 6.6 Bolt Torque Effects on Spindle Force

Purpose: To determine the spindle depression force as a function of the bolt ball loading by the lock splines, in terms of the CCW bolt torque.

Scope: Six (each) bolts (CA 2773) and nut plates (CA 2774) were used for this test. One hardened spindle bolt was available for this test. CCW torque was applied in 5 in.-lb increasing increments. Spindle depression force was measured during each torque increment.

Figure 4.8 Typical Ball Brinell on Nut Plate Locking Spline Edge During Normal Preload Installation.

Figure 4.9 Nut Plate no. 6 (Test no. 6.3) Showing "Wiped Out" Region Between Splines.

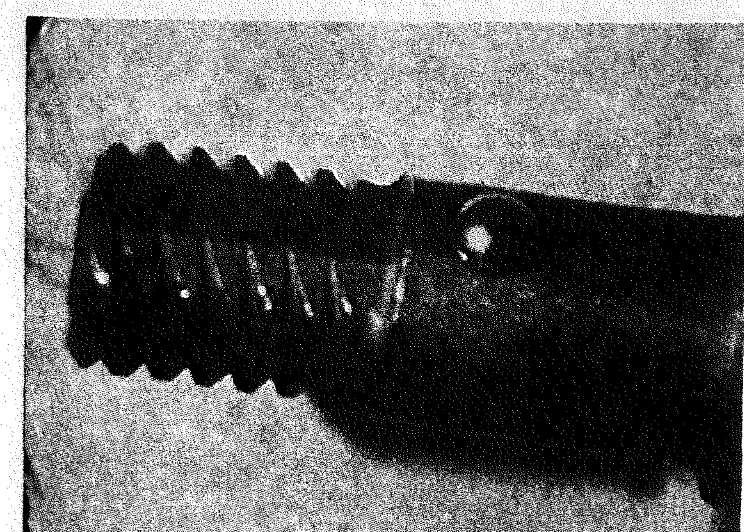

Figure 4.10 Bolt no. 6 (Test no. 6.3) Reference Figure 4.9

Results: The setup for this test is shown in Figure 4. 11. The test data is plotted in Figure 4. 12. Tests on the regular spindle bolts were repeated two times, while the test on the hardened spindle bolt was done six times. The results can be summarized as follows:

a) Bolts with regular spindles: Spindle would not release without exceeding the specified 20 lb force limit when a CCW torque of 5 in. -lb was applied, following a torque load of 10 in. -lb.

b) Bolts with hardened spindles: Spindle released repeatedly at 20 lb for a CCW torque of 15 in. -lb.

Test No. 6. 7 Insulation Effect on Fastener Preload

Purpose: To determine the possible change in fastener preload with time as a result of the presence of insulation material between the structures being clamped.

Scope: Six Boydbolt assemblies were tested in combination with 40 sheets of . 00025 in. thick mylar. The data required was the preload torque remaining on each fastener after the specified storage period.

Results: The setup for this test is shown in Figure 4. 13. An additional test was run using the test set shown in Figure 4. 14. The results of these tests were:

a) No creep in the mylar insulation material was observed in 7 days on the six assemblies shown in Figure 4. 13.

b) A load drop from 500 to 488 lb was measured in a 30 hour period on the single bolt test. This test was repeated once, with a similarly small load drop experienced.

Test No. 6. 8 Bolt Head Socket Wipe-Out Strength

Purpose: To determine the strength of the bolt head socket in terms of the maximum CCW torque which may be applied to the socket by the UHT tool tip, inserted only to top of raised spindle, before the double-hex is wiped out.

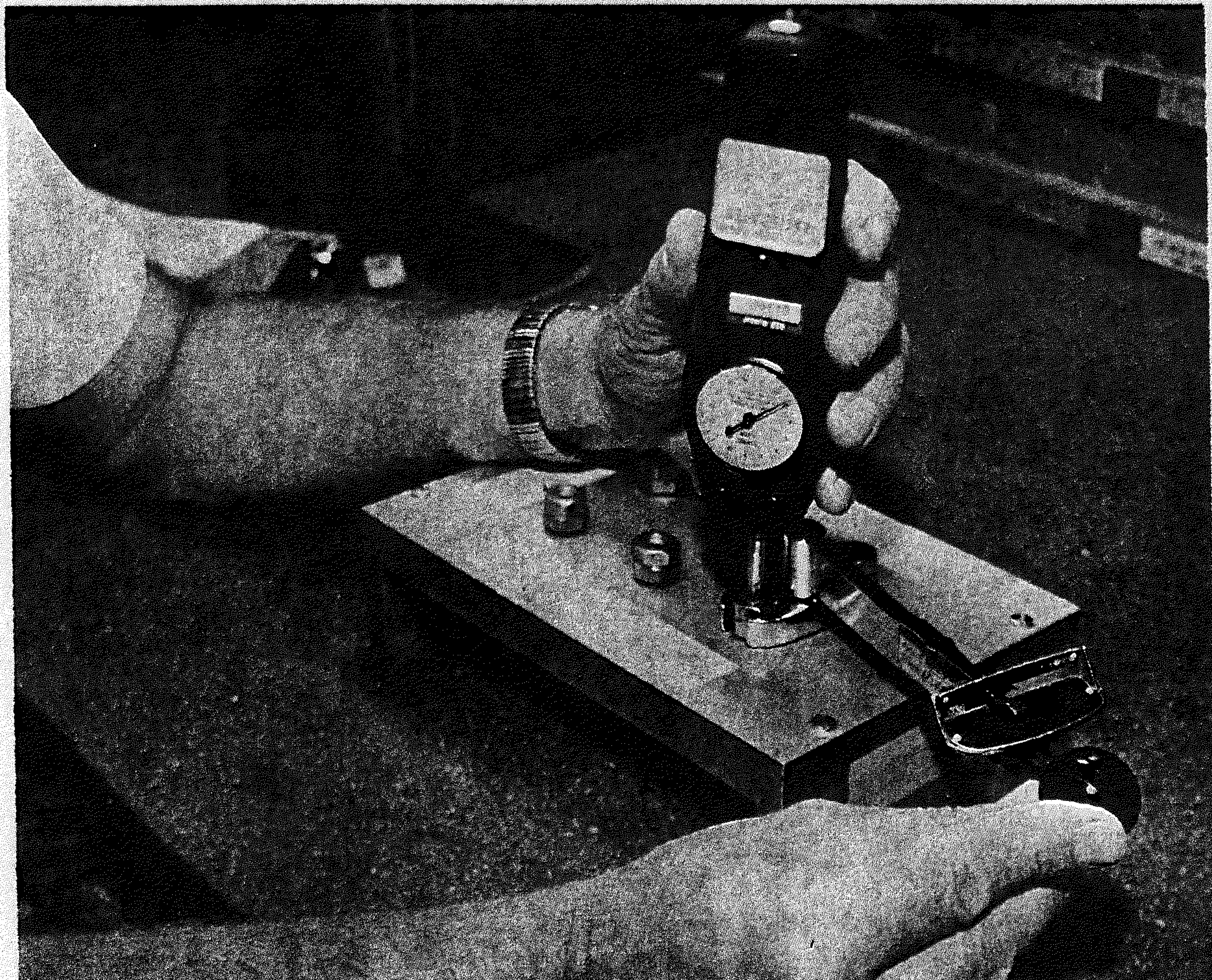

Figure 4.11 Spindle Release Force Test Set-up. (Ref. Test no. 6.6)

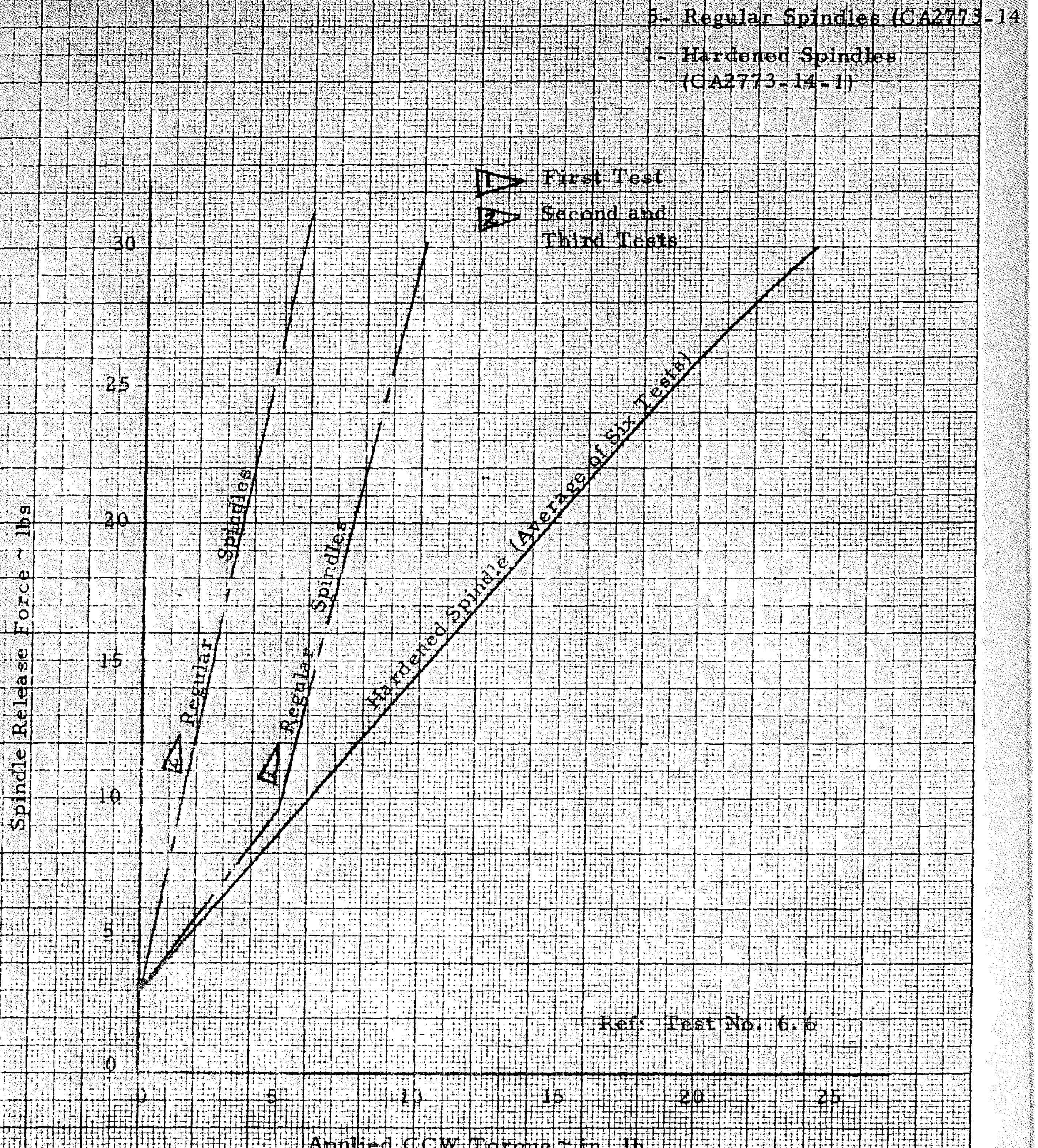

Figure 4.12 Spindle Release Force versus Applied CCW Torque

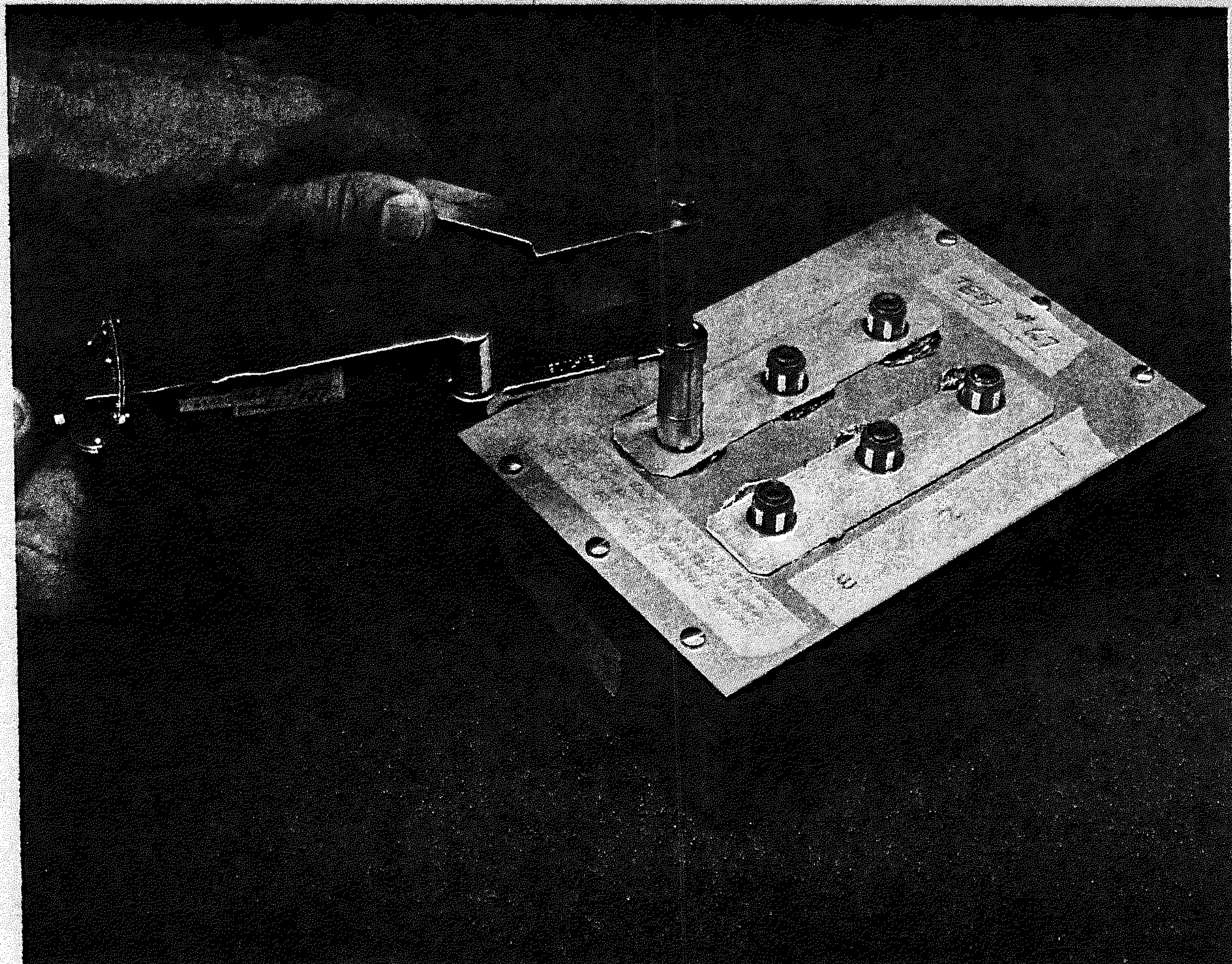

Figure 4.13 Insulation Effects Setup. (Test no. 6.7)

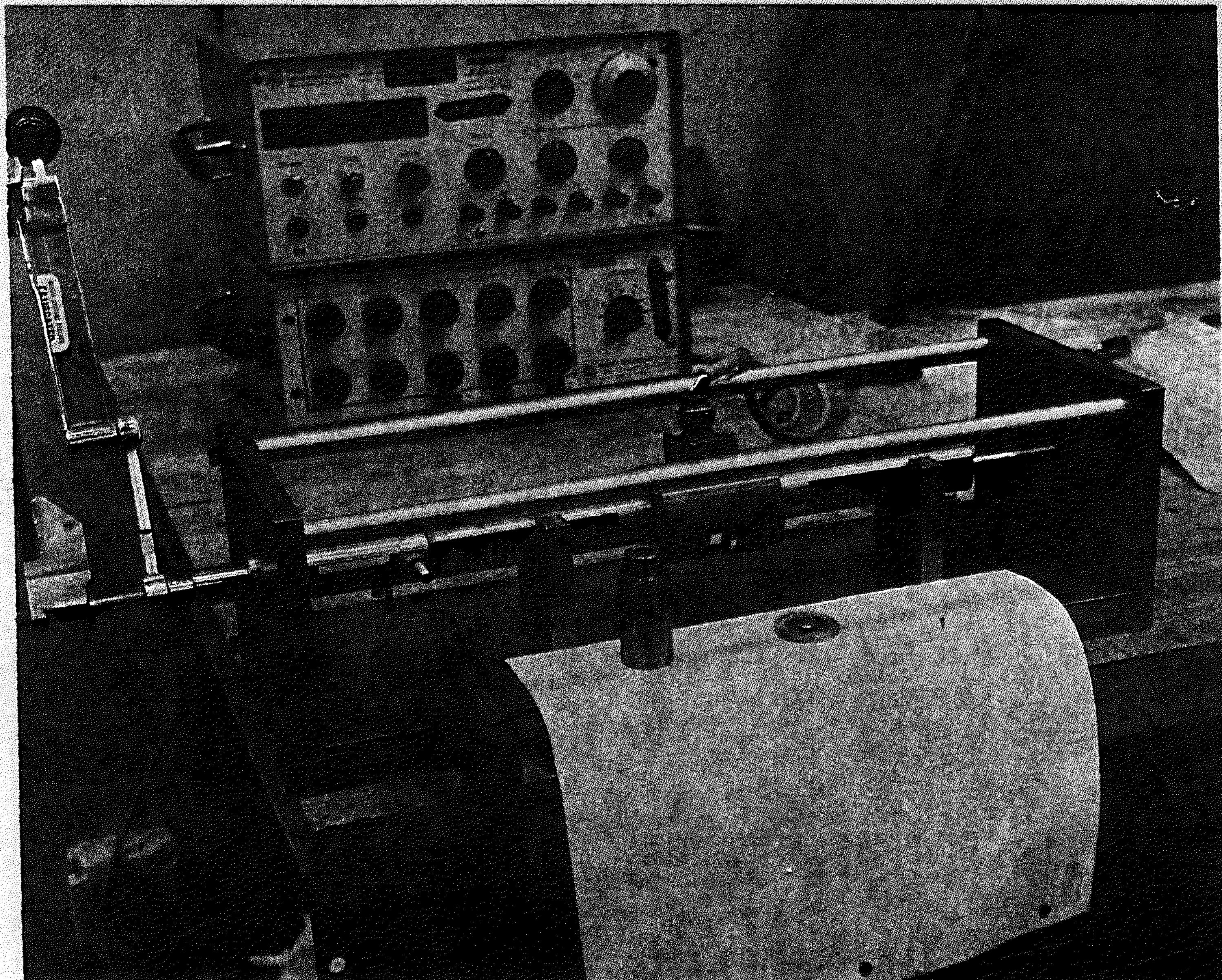

Figure 4. 14 Boydbolt Static Load and ESNA Nut Life Test Setup.
(Test nos. 6. 9 and 6. 10)

Scope: One bolt (CA 2773) was used. The data required is the torque reading at wipe-out of the double-hex. This data is for comparison with that from test No. 6.3 for torque to wipe out splines.

Results: The bolt head double-hex socket did not "wipe-out". The simulated UHT tool tip "wiped out" at 52 in.-lb.

Test No. 6.9 ESNA Nut/Boydbolt Static Load Test

Purpose: To determine maximum static load capabilities of the ESNA nut (SP1015), bolt (CA 2773-14) and nut plate (CA 2774), and to observe the mode of failure.

Scope: Four Boydbolt assemblies were used. The ESNA nut/bolt combination was loaded incrementally until it yielded structurally. The data required was the tensile load required to produce failure. Identification of the mode of failure from visual inspection and examination of the dimensional data taken were test requirements.

Results: The setup of the test is shown in Figure 4.14. The ESNA nut did not fail, or yield sufficiently to cause a loss in preload. The interrupted threads of the nut plate and the bolt did yield at loads above 1000 lbs (ref. Figure 4.16). The weakest member of the Boydbolt assembly was the interrupted 10-32 thread of the bolt. Of the four assemblies tested, 1050 lbs was the lowest failure load (by yielding). The data is tabulated below:

Test Assy No.	No. of Threads Engaged	Yield Failure Load (lbs)
1	3	1050
2	4	1070
3	4 2/3	1370
4	4	1200

Test No. 6.10 ESNA Nut Life on Micro-sealed Bolt Thread

Purpose: To determine the changes in applied torque vs. fastener preload as a function of the number of uses of the same ESNA nut.

Scope: A CA 2773 bolt and eight ESNA nuts were used. Static loads were applied repetitively by torquing the ESNA nut, in increments of 100 lb, to 600 lb maximum. Each assembly was cycled nine times. The data required was the preload torque vs. tensile preload for each sequential use of the same ESNA nut.

Results: The test setup is the same as used for test No. 6.9, and is shown in Figure 4.14. The test data was fairly repetitive through eight cycles. ESNA aluminum and steel nuts exhibit about the same life characteristics. ESNA nut preload torque versus static load is shown in Figure 4.15. The average ESNA nut torque required for bolt preload of the Boydbolt assembly is:

Torque (in. -lb)	Load (lb)
18-21	0
45	500
55	700

The frictional torque of the ESNA nut locking insert alone (without the CS1011 Spring installed) was about 20 in. -lb for the first cycle, and then reduced to approximately 15 in. -lb for subsequent installations.

Additional Problem: During the application of preload on these tests, it was noted that the CS1011 Spring (under ESNA nut) would unwind occasionally and the squared end would lodge under the edge of the ESNA nut. This condition is very undesirable from the standpoint of concentrated loading and possible loss of preload during vibration. Winding the spring in the opposite direction would solve this potential problem source.

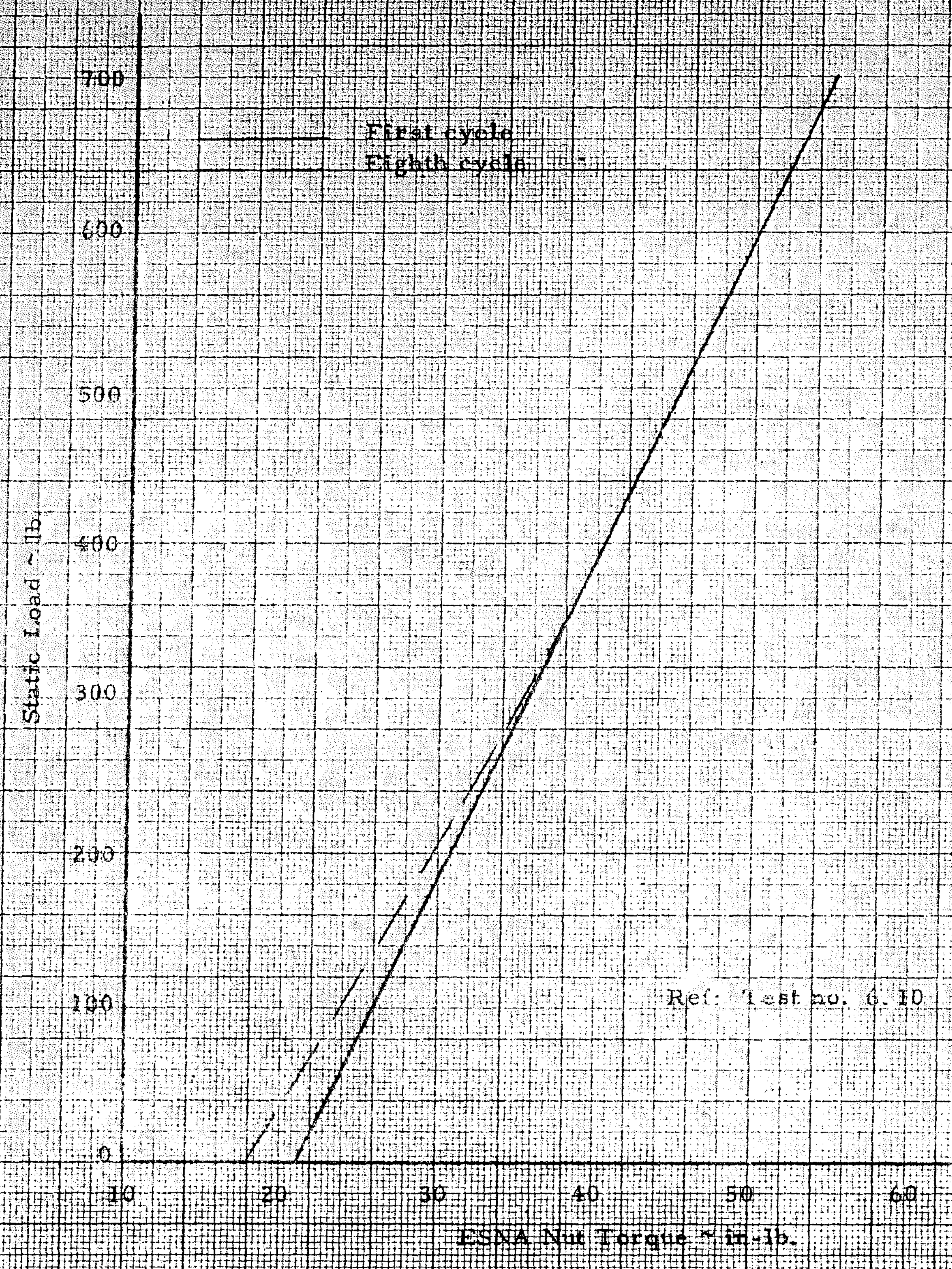

Figure 4.15 Boydbolt Static Load versus ESNA Nut Torque

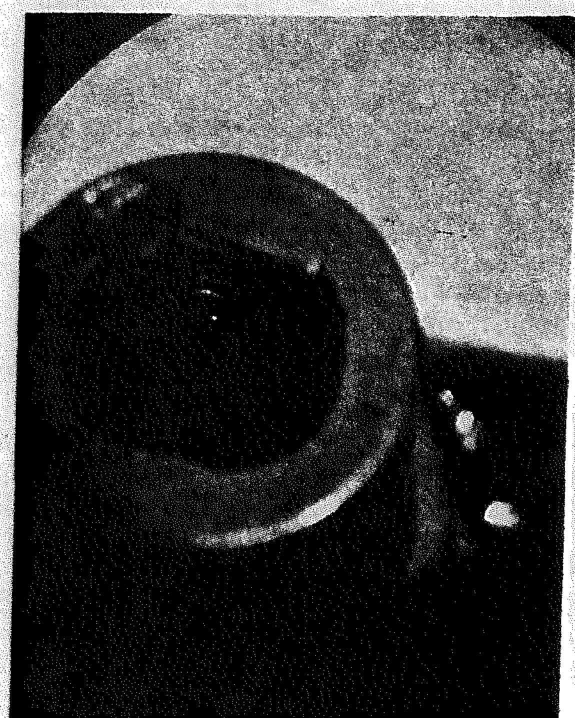

Figure 4.16 Nut Plate Thread Damage. (Ref. Test no. 6.9)

5.0 Conclusions

Conclusions from an examination of test results are as follows:

Test No. 6.1

Fastener release torque is well within the specified 30 in. -lb limit.

Test No. 6.2

Bolt spring force is predictable at about 3 lbs for full deflection at no load condition.

Test No. 6.3

1) Care must be taken during installation not to severely damage the locking spline land area that could be caused by an inadvertent CCW torque in the range of 30-40 in. -lb.

2) "Wipe-out" torque with the hardened spindle configuration would tax the astronaut's capability in the event that spindle depression must be bypassed.

Test No. 6.5

The variation in spindle depression depth is considerable. The requirements of the Boydbolt Installation Requirements and Procedures document (2335975) to check spindle position with ±.003 inches is a reasonable procedure.

Test No. 6.6

The bolt with a hardened spindle is far superior to the regular spindle bolt relative to spindle release force for a given CCW torque that tends to lock the spindle. Apparently the regular spindles are being brinelled, and thus "lock up", and require extremely high forces to release the spindle.

Test No. 6.7

The creep in the mylar insulation material is minimal. No significant loss of preload should be attributed to this effect. No re-torquing is required after the initial preload torque is measured.

Test No. 6.8

It is doubtful if the use of this method would be very successful, since the tool tip would soon become useless, and the torque level required is above the present limit of the astronaut's capability (30 in.-lb). However, it should be noted that this problem should not occur with the hardened spindle configuration.

Test No. 6.9

The Boydbolt assembly using the aluminum ESNA nut is structurally sound, and no basic changes are required. However, (1) care should be taken to get the maximum number of threads engaged, and (2) the specified preload torque should be applied smoothly and accurately, so as not to approach a tensile load that would initiate yielding of the interrupted threads.

Test No. 6.10

The preload torque versus bolt preload is a function of a number of "full" uses of the ESNA nut. The number of cycles of the ESNA nut should be limited, and should not exceed eight. The preload torque level should be reduced to a level nearer the 500 lb preload.

Additional Problem

Since this condition of the spring unwinding under the edge of the ESNA is possible, and virtually impossible to inspect (inside the fastener guide), this source of loss of preload should be eliminated by replacing the spring with a similar spring wound in the opposite direction.

6.0 Recommendations

The two major problems that are plaguing the Boydbolts are high spindle depression forces and loss of bolt preload. The recommendations for solving these problems are as follows:

1. Replace the present CS1011 spring with the CS1014 spring that is wound in the opposite direction (left-hand spiral).
2. Rework all CA2773 bolts to the hardened spindle configuration (Rockwell C-56 to 60) noted in Revision D of the CA2773 drawing.
3. Reduce preload torque level to 44 $\pm$2 in. -lb.
4. Design a special tool that will furnish a positive indication of the location of the Boydbolt balls in the locking spline.
5. Inspect bolts and ESNA nuts prior to each installation. Limit ESNA nut usage to five installations.
6. Train and certify selected personnel for Boydbolt assembly installation and inspection.
7. Preload torquing operations should be changed to a one man procedure.