Docket V06-1
Ex. 4-5

REPORT ON THE BROKEN CABLE SAFETY DEVICE USED ON THE PERSONNEL CAGE

Prepared by

The Engineering Subcommittee

of the

National Chimney Construction
Safety and Health Advisory Committee

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Nomenclature

Headache Ball:	Weight used to counteract hoist cable weight.
Headache Ball Restrainer:	Frame to prevent headache ball from striking top of cage.
Lift Bar:	Bar which links hoist line to safety clamps and springs.
Spring Rod:	Tension rod which transmits force of springs to lift bar.
Springs:	Steel alloy compression springs.
Spring Retainer:	Housing for spring protection.
Anchor Bar:	Bar to anchor springs for compression. May be part of personnel cage or bolt-on assembly for cage.
Vertical Supports:	Part of the anchor bar assembly. Cams pivot on this piece.
Clamp Body:	Steel plate bent into "U" shape, which provides surface against which safety cable can be clamped by the clamping cam.
Clamping Cam:	Stainless steel bar with hardened curved surface which wedges safety cable into clamp body.
Guide Cam:	Steel bar which keeps clamp body in proper position parallel to safety cable.
Roller Guides:	Nylon rollers to keep safety cables correctly positioned in the clamp body.
Down Side:	(Referring to hoist line) The vertical section of hoist line between the footblock and the cathead.
Footblock:	Fixed sheave located at chimney base routing the hoist line from the hoist to the cathead.

Nomenclature (continued)

Personnel Cage:	(Otherwise called cage) Personnel conveyance device which, when connected to the end of the hoist line, is used to transport personnel from ground level to the work level.
Cathead:	Horizontal beam element spanning chimney or grillage with two fixed sheaves providing overhead support and direction for the hoist cable.
Quick Release Device:	A link hooked in series to the hoist line, which can be remotely opened simulating a break in the hoist line.
Safety Cables:	(Otherwise called guide cables) Vertical cables suspended from the cathead or grillage providing backup support upon which the safety device catches when actuated. The cables also guide cage, preventing swaying and rotation of the mancage.

I. Introduction

This report describes the performance testing of a personnel cage safety system used in the construction of large chimneys. The investigation discussed in this report was conducted by the National Chimney Construction Safety and Health Advisory Committee.

The objective of this investigation is to demonstrate that the safety system, currently in use by member companies, will stop the personnel cage in the event of a failure in the hoisting system. This study uses two methods to achieve this objective, one a theoretical approach and the other a series of physical tests demonstrating the operation of the safety system.

Although the member companies do not have identical equipment, the basic principles and concepts described in this report are the same for all member companies. Configurations and dimensions of equipment may vary based on individual requirements.

II. Personnel Cage Safety System

II.1 Explanation of Safety System Operation

The purpose of the cage safety system (Figure 1) is to arrest the free fall of the cage if the main hoist line should fail. This is done by engaging a set of clamps on the two 1/2-inch diameter wire rope safety cables suspended from above. Figures 2 and 3 illustrate the actuation of the safety device.

In Figure 2, the safety system is shown during normal hoisting operation. The load in the hoist line is larger than the load in the springs. This causes the springs to compress; therefore the lift bar must move up in relation to the anchor bar. Note that the spring compression is limited by the spring retainer. This protects the spring from damage due to excessive compression. When the lift bar is raised, the clamping cam is rotated so that a space between the clamping cam and the clamp body is created for the safety cable to pass through. The personnel cage is then free to be raised or lowered.

In Figure 3, the hoist line has been broken. The actual load on the lift bar is a function of the dynamics of the hoist cable being overhauled. When the spring compression overcomes this load, the lift bar is forced down causing the clamping cam to rotate as shown. This rotation wedges the safety cable between the clamping cam and clamp body locking the cage to the safety cables.

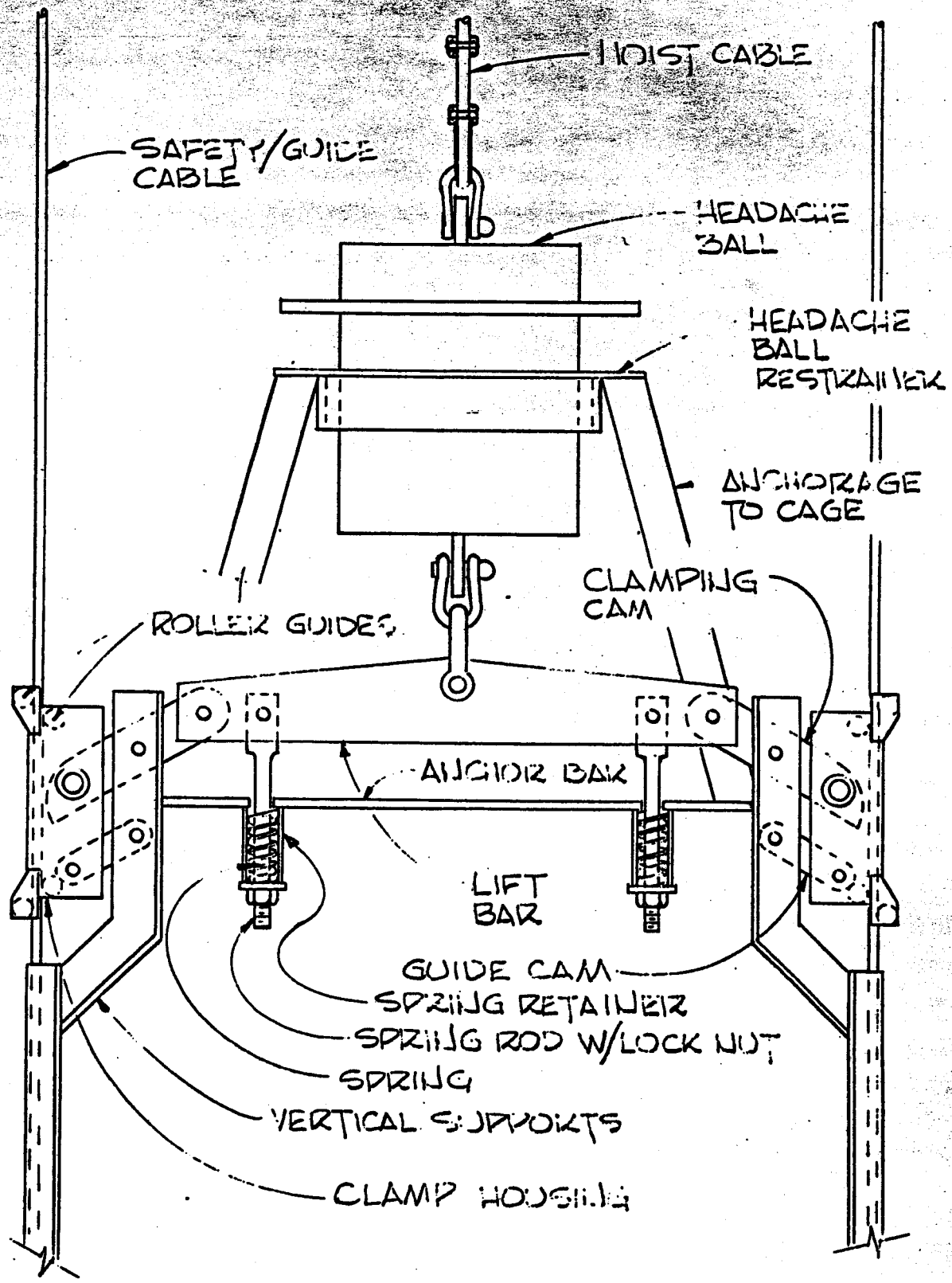

Figure 1

Example of a Personnel Cage Safety System

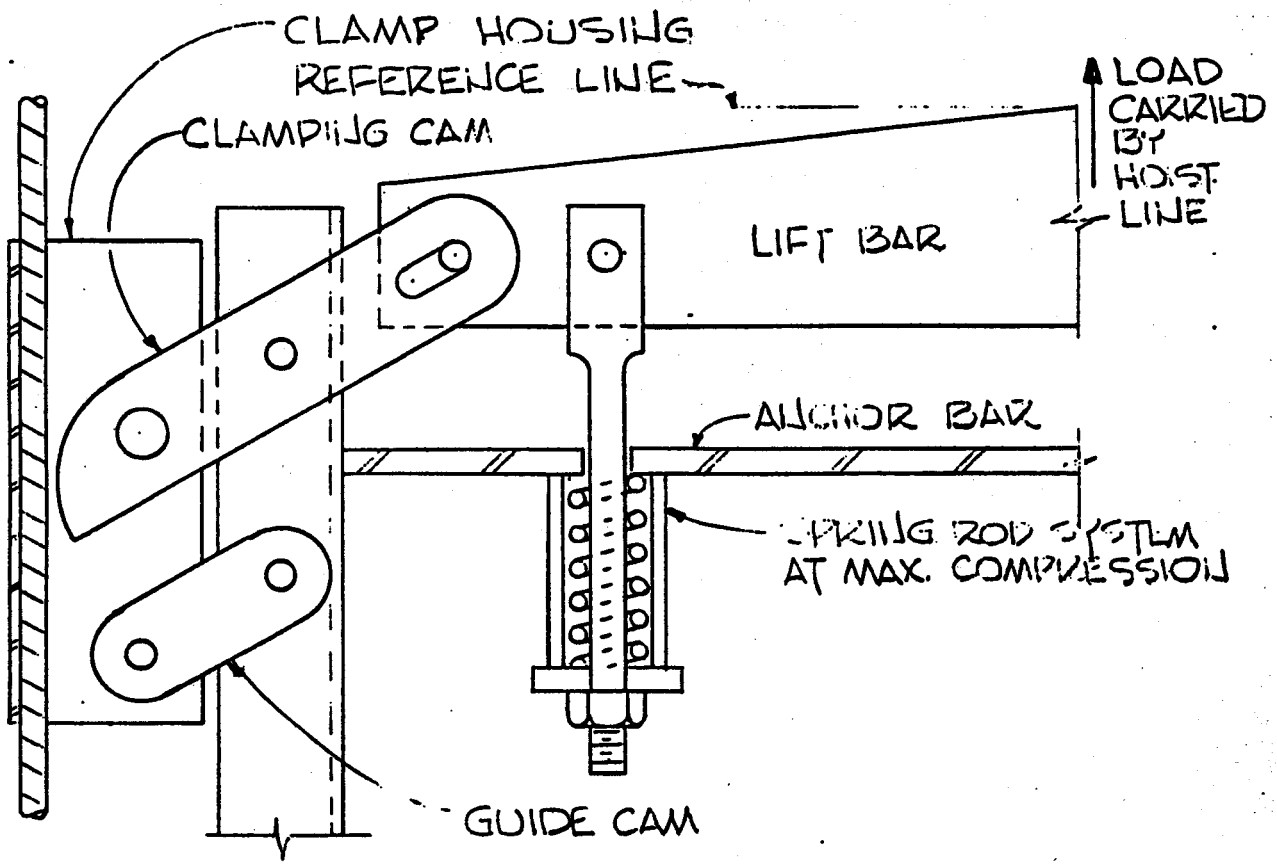

Figure 2

Safety System Position During Hoisting

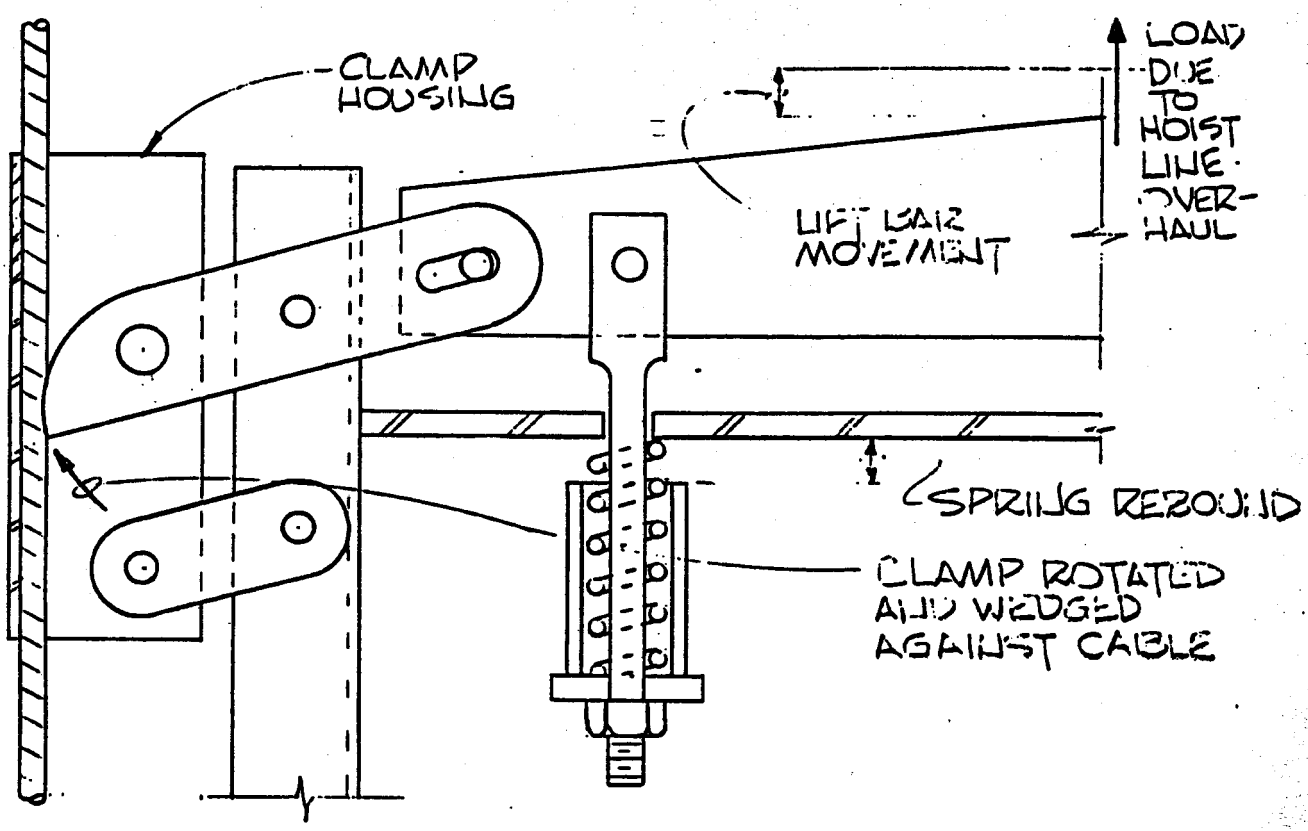

Figure 3

Safety System in Clamped Position

II.2 Headache Ball Restrainer

An example of a headache ball restrainer is shown in Figure 1. The headache ball restrainer prevents the headache ball from damaging the safety clamp mechanism and protects the personnel inside the mancage. The restrainer also prevents the headache ball from moving laterally and vertically with respect to the mancage.

II.3 Spring Force Calculation

II.3.1 Rigid Body Analysis

To adjust the broken cable safety device properly, the cage weight, passenger weight, headache ball weight, and cable weight must be considered. All these variables must be known in order to compute the spring force required for operation of the clamps. Pages 1 and 2 of Appendix A illustrate the derivation of the rigid body formula used to compute the spring force. Page 3 of Appendix A shows the calculation of the required spring force for the mancage used in this test program.

Rigid body analysis is more conservative than non-rigid body analysis, and therefore was used to determine the spring compression in the tests of this investigation.

II.3.2 Non-Rigid Body Dynamic Analysis

To describe more accurately what happens when a hoist cable breaks, a computer program was written. The program performs numerical integrations to determine the velocities, forces and accelerations of the personnel cage.

II.3.2 Non-Rigid Body Dynamic Analysis (Continued)

The program is general since the cable can be broken at any location. Any height, weight, area, or modulus of elasticity of cable can be used. Other variables include the weights of personnel cage and headache ball, and spring stiffness.

This analysis is called a time history structural analysis. Accelerations, velocities and displacements are computed for increments of time using the results from the previous time interval to initiate succeeding intervals until the program stops when the safety device engages. Because of the nature of the analysis, a very small time interval should be used (approximately 0.001 seconds). This program is described in Appendix B.

An example using the computer program is shown in Appendix B. This computer run simulates a 900-foot chimney corresponding to the field tests. Using the weight of the personnel cage as 2160 pounds and using calculations as defined in Appendix A, a spring compression of 1400 pounds was input into the program. The cable length and weight were also input. The field tests at Manchester, Ohio, demonstrated that the clamps engaged and stopped the personnel cage as predicted by the computer program.

II.4 Safety Guide Cable Tension

The safety guide cables are tensioned to minimize swaying and rotation of the personnel cage. The operation of the

II.4 Safety Guide Cable Tension (Continued)

safety device is independent of the guide cable tension. The magnitude of cage sway and rotation is a function of the cable's resistance to lateral motion. This lateral resistance is, in turn, a function of chimney height and cable tension. To maintain the same range of lateral resistance, the cable tension must increase as chimney height increases. However, it is reasonable to keep the same tension through the construction of any given chimney. In all cases a minimum of 200 pounds tension should be applied to the foundation end of each guide cable.

III. Experimental Investigation of the Personnel Cage Safety System

III.1 Statement of Approach

The objective of this experimental testing program was to examine the effectiveness of the personnel cage safety system in the event of any hoist line failure. Hoist line breaks were simulated both in a chimney simulation facility and in an existing chimney. Safety system performance was evaluated by monitoring:

a. Magnitude of loads in the safety cable

b. Safety device actuation

c. Accelerations in the personnel cage

III.2 Test at Chimney Simulation Facility (10, 11 June and 16 July 1980)

III.2.1 Test Facility

A test facility to perform static and dynamic tests has been established at the Pullman Power Products Warehouse in Kansas, City, Missouri. A steel tower was erected with 65 feet of vertical clearance for personnel cage travel (Figure 4). Personnel cage hoisting was provided by a ground-mounted single drum hoist. The hoist line was routed over a fixed footblock and two sheaves on the cathead. This arrangement is representative of construction equipment used in the field and can be used to model various chimney heights.

Chimney height and cable size were simulated by using an appropriately sized counterweight to represent cable on the down side of the hoist line. A quick-release device simulated cable break above the cage or between the footblock and hoist (Figure 5).

Occupant weight was simulated by using weights in the personnel cage. Vertical and horizontal accelerations in the cage were measured with an electric resistance accelerometer. Forces in the safety lines were measured with through-type strain gage load cells attached to the lines with strand chucks (Figure 6). Tension-link strain gage load cells were connected in line to measure force above the headache ball and above the counterweight in the hoist line (Figure 7). All load cells were electronically calibrated during setup. The accelerometer was calibrated using the 1 g (32 ft/sec^2) acceleration caused by gravity.

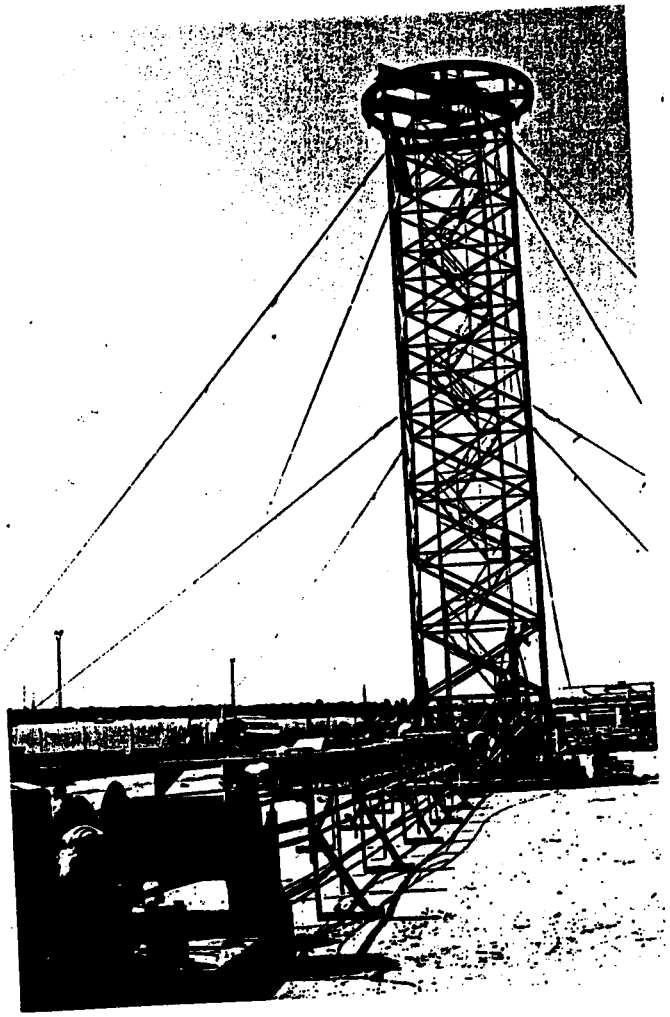

Figure 4 Kansas City Test Facility

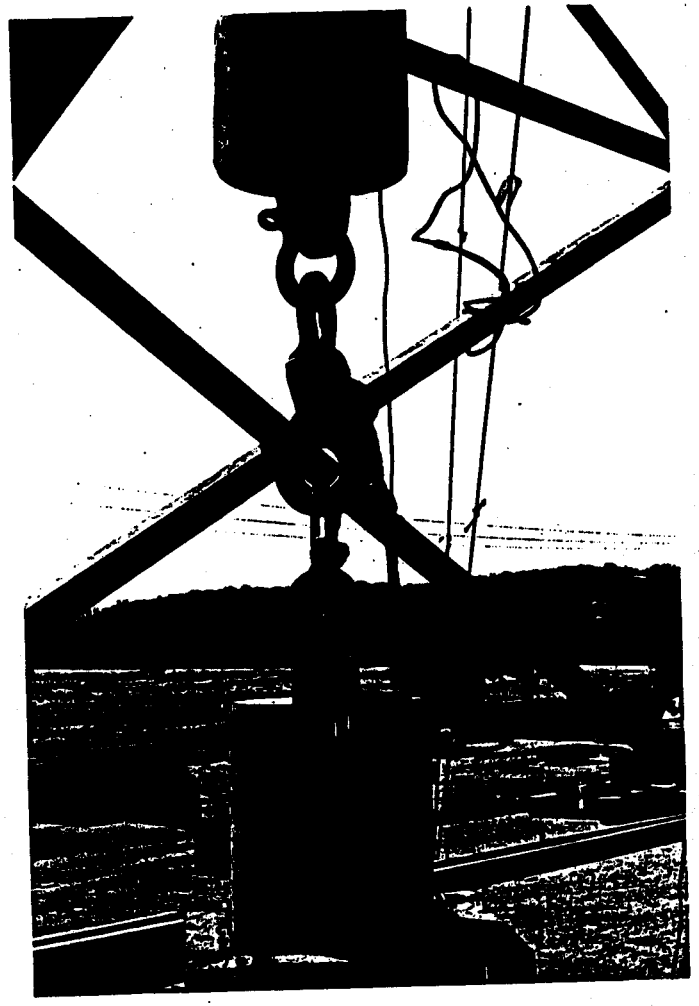

Figure 5 Quick Release Device Used to Simulate Cable Break

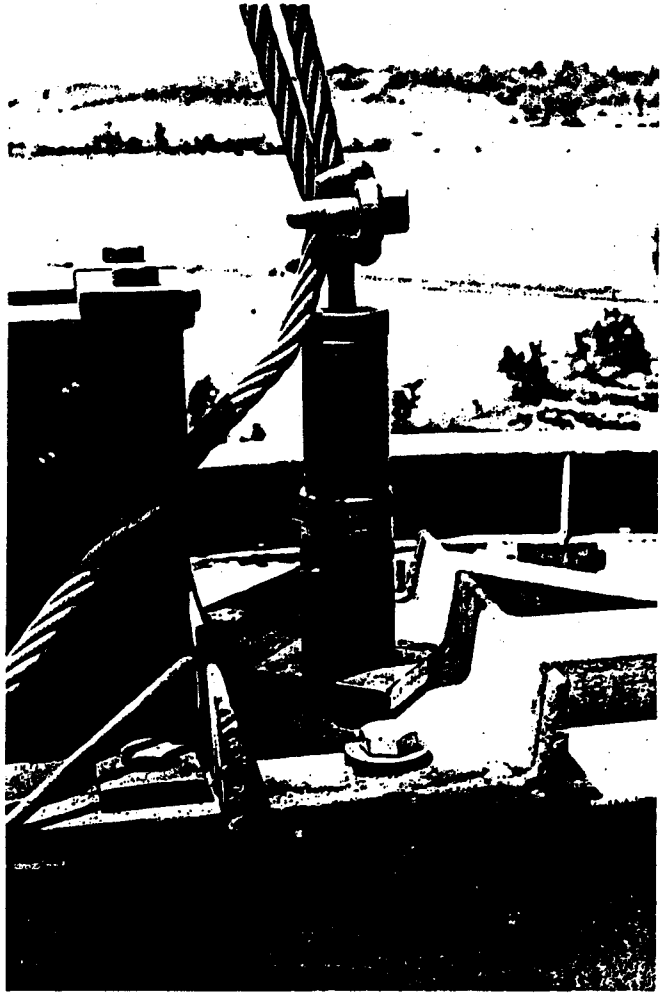

Figure 6 Safety Cable Load Cell Installation

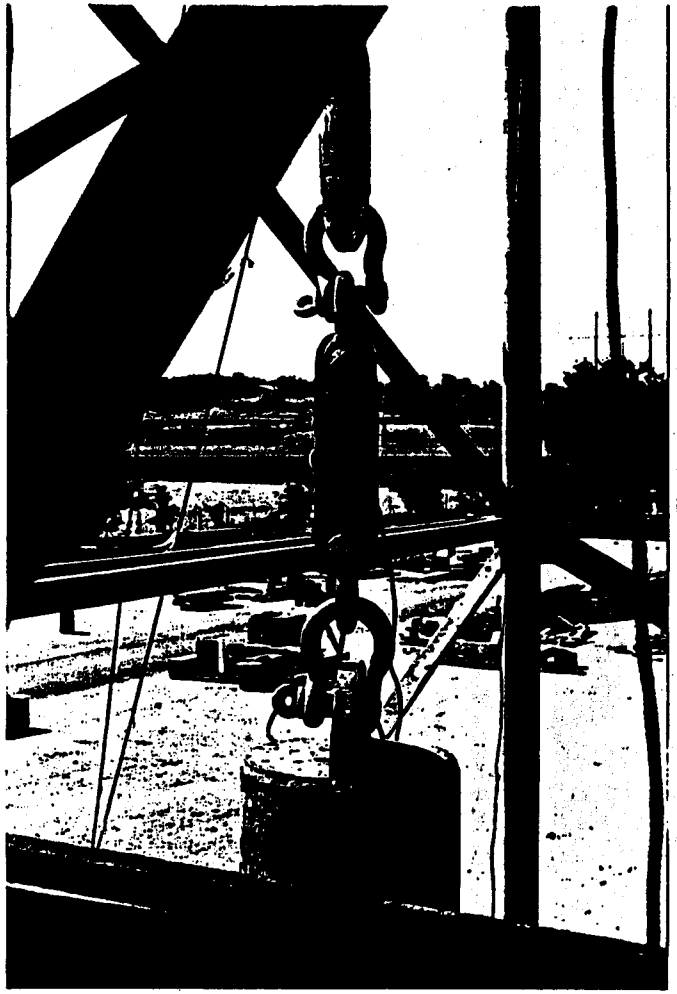

Figure 7 Hoist Line Load Cell

III.2.1 Test Facility (Continued)

A ground level instrument shelter contained power supplies, filters and amplifiers for the transducers mentioned above. Output was recorded on an oscillograph.

III.2.2 Procedure

A chimney height of 1000 feet was simulated by using a 900 pound counterweight to represent 1000 feet of 3/4 inch hoist line. A 600 pound headache ball was used above the personnel cage.

The springs on the safety device were adjusted using compression forces based on theoretical considerations as explained in Section II.3 of this report. Personnel cage tests were performed with the following simulated occupant weights:

Cable Break Between Footblock and Hoist

Stationary	Hoisting Down (about 250'/min)	Hoisting Up (about 250'/min)
Empty	Empty	Empty
800#	800#	800#

Cable Break Above Headache Ball

Stationary	Hoisting Down (about 250'/min)	Hoisting Up (about 250'/min)
Empty	Empty	Empty
-	400#	-
800#	800#	800#
-	1000#	-

III.2.2 Procedure (Continued)

In preparation for the field test, a 900 foot chimney was simulated. A 600 pound headache ball was used. The springs were initially adjusted using calculated values for a chimney 900 feet tall. The springs were then further adjusted by reducing the compression until the safety clamp would just engage during a static test with a break between footblock and hoist. This spring force reduction increased the severity of the test. This adjustment would not be made during normal personnel cage setup.

III.2.3 Results

Oscillograph plots of tests are included in Appendix C. A typical plot is shown in Figure 8. Up to five variables are recorded on each plot. Traces 1 and 2 are safety line loads, 3 is acceleration measured in the cage, and 4 and 5 are forces in the hoist line. When traces 1 and 2 are compared to 4 and 5, time can be measured from the initial load decrease in hoist line until the safety device catches on the safety line. This time is the actuation time for the safety device and typically ranges from 0.05 to 0.15 second.

Safety Cable Loads. The results of the 1000 foot chimney simulation are listed in Tables 1 and 2. Table 1 includes tests performed during the first test session (10, 11 June 1980). These tests were conducted primarily for demonstrative purposes and some data may be inconsistent since fewer variables were controlled than in subsequent tests. Table 2 includes tests

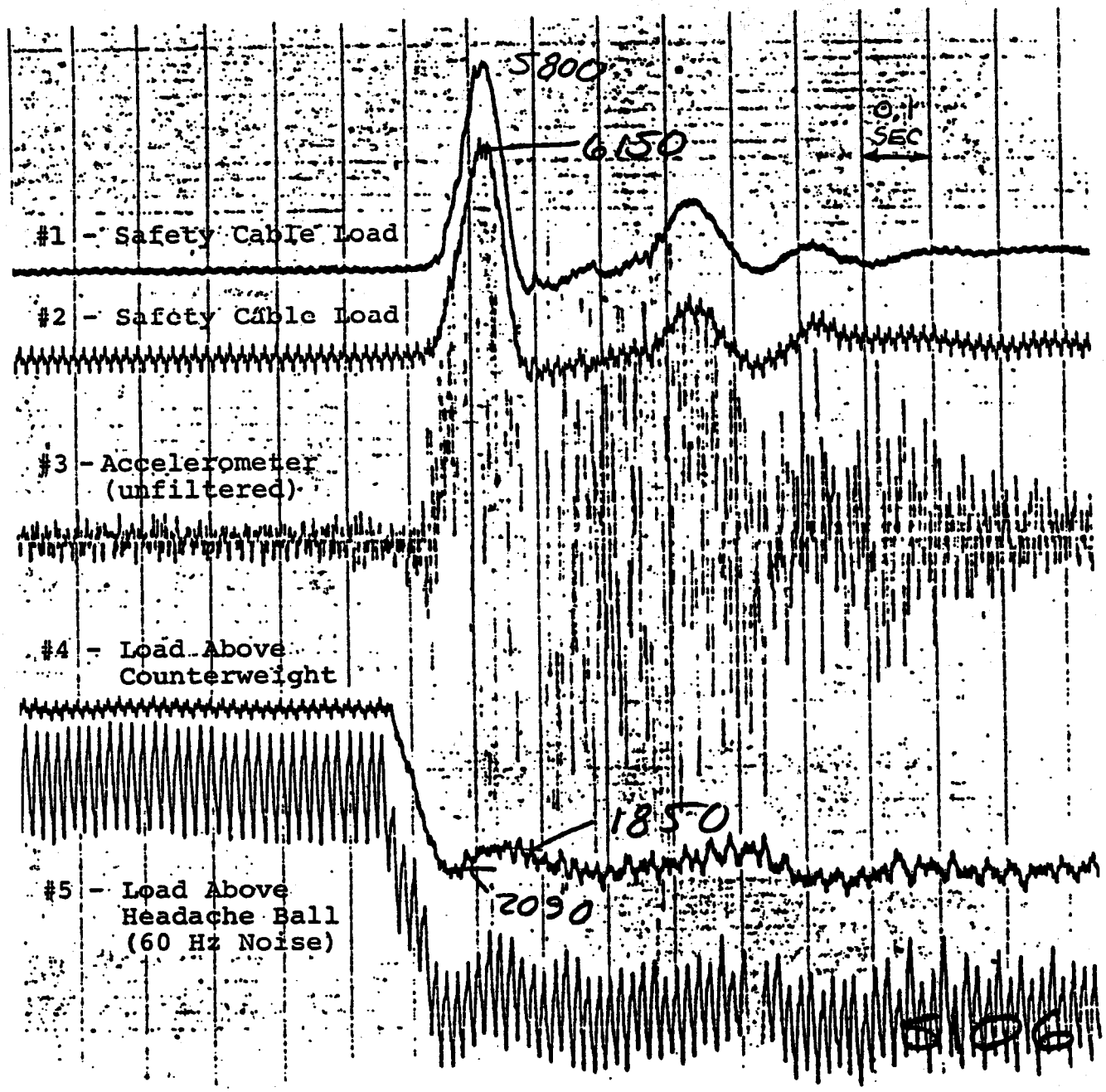

Figure 8 Detail of Typical Oscillograph Plot

Test#	Static, Hoist Up or Hoist Down	Break at	Cage Weight (lbs)	Ave. Max. Force In Safety Cables (lbs)	Safety Device Actuation
S101	static	hoist	2500	1400	worked
S102	down	hoist	2500	5100	worked
S103	down	hoist	2500	6880	worked
S104	down	hoist	2500	5940	worked
S105	up	ball	1960	1900	worked
S106	down	ball	1960	5975	worked
S201	static	ball	2760	4140	worked
S202	up	ball	2760	2340	worked
S203	down	ball	2760	9450	worked
S301	static	ball	2540	3300	worked
S302	up	ball	2540	1530	worked
S303	static	ball	1150	1290	worked
S304	static	ball	1150	1150	worked
S305	up	ball	1150	910	worked
S306	static	ball	1750	1800	worked
S307	up	ball	1750	1350	worked
S308	down	ball	1750	6120	worked
S309	static	ball	2550	3170	worked
S310	up	ball	2550	2590	worked
S401	down	ball	2550	8160	worked
S402	static	hoist	2550	1920	worked
S403	down	hoist	2550	6540	worked

Table 1

Kansas City Tests (10, 11 June 1980) - Preliminary Testing

Table 2

KANSAS CITY TESTS 7/16/80 - SIMULATE 1000' CHIMNEY

Cage Wt. - 2160#; Headache Ball Wt. - 600#

Test #	Static or Dynamic*	Break at	Load In Cage (lbs)	Ave. Max. Force In Safety Cables (kips)	Safety Device Actuation
S1	sta	cage	0	3.68	worked
S2	sta	cage	800	4.54	worked
S3a	dyn	cage	800	10.44	worked
S3b	dyn	cage	800	11.63	worked
S3c	dyn	cage	800	11.85	worked
S4a	dyn	cage	1000	11.95	worked
S5a	dyn	cage	400	9.75	worked
S5b	dyn	cage	400	10.11	worked
S6a	dyn	cage	0	9.09	worked
S6b	dyn	cage	0	9.33	worked
S7a	sta	hoist	0	1.62	worked
S8a	sta	hoist	800	2.59	worked
S8b	sta	hoist	800	2.68	worked
S8c	sta	hoist	800	2.72	worked
S9a	dyn	hoist	800	7.92	worked
S9b	dyn	hoist	800	8.60	worked
S9c	dyn	hoist	800	9.99	worked
S9d	dyn	hoist	800	10.15	worked
S9e	dyn	hoist	800	10.32	worked
S10a	dyn	hoist	0	5.53	worked
S10b	dyn	hoist	0	7.62	worked
S10c	dyn	hoist	0	6.89	worked
S10d	dyn	hoist	0	7.03	worked
S10e	dyn	hoist	0	8.35	worked

*Dynamic = Hoisting Down

III.2.3 Results (Continued)

performed during the second session (16 July 1980). Note that the highest loads occur in the safety cable when hoisting down and the cable breaks above the headache ball. This configuration was tested with three dissimilar personnel cages and the results are plotted in Figure 9. The results are consistent and indicate that a properly adjusted safety device will produce predictable loads in the safety cables.

Analysis of the data plotted in Figure 9 yields the following linear relationship between safety cable force (F) and weight of personnel cage (including occupants and headache ball):

$$F = 3.01W + 645.4$$

This is a conservative estimate of the highest force imparted to the safety cables since this simulation is more severe than most field cases.

Stationary and hoisting up tests with cable break above the headache ball caused lower forces in the safety cables than in the hoisting down tests (Figures 10 and 11).

In all cases tested, cable break between the footblock and hoist caused lower safety cable forces than the corresponding tests with cable break above the headache ball.

Safety Device Actuation. To confirm the safety device actuation, various tests were performed. The worst case for safety device actuation occurred when the cable break is between the footblock and the hoist. In all the tests performed at the test facility, the safety device actuated properly when the springs were correctly adjusted.

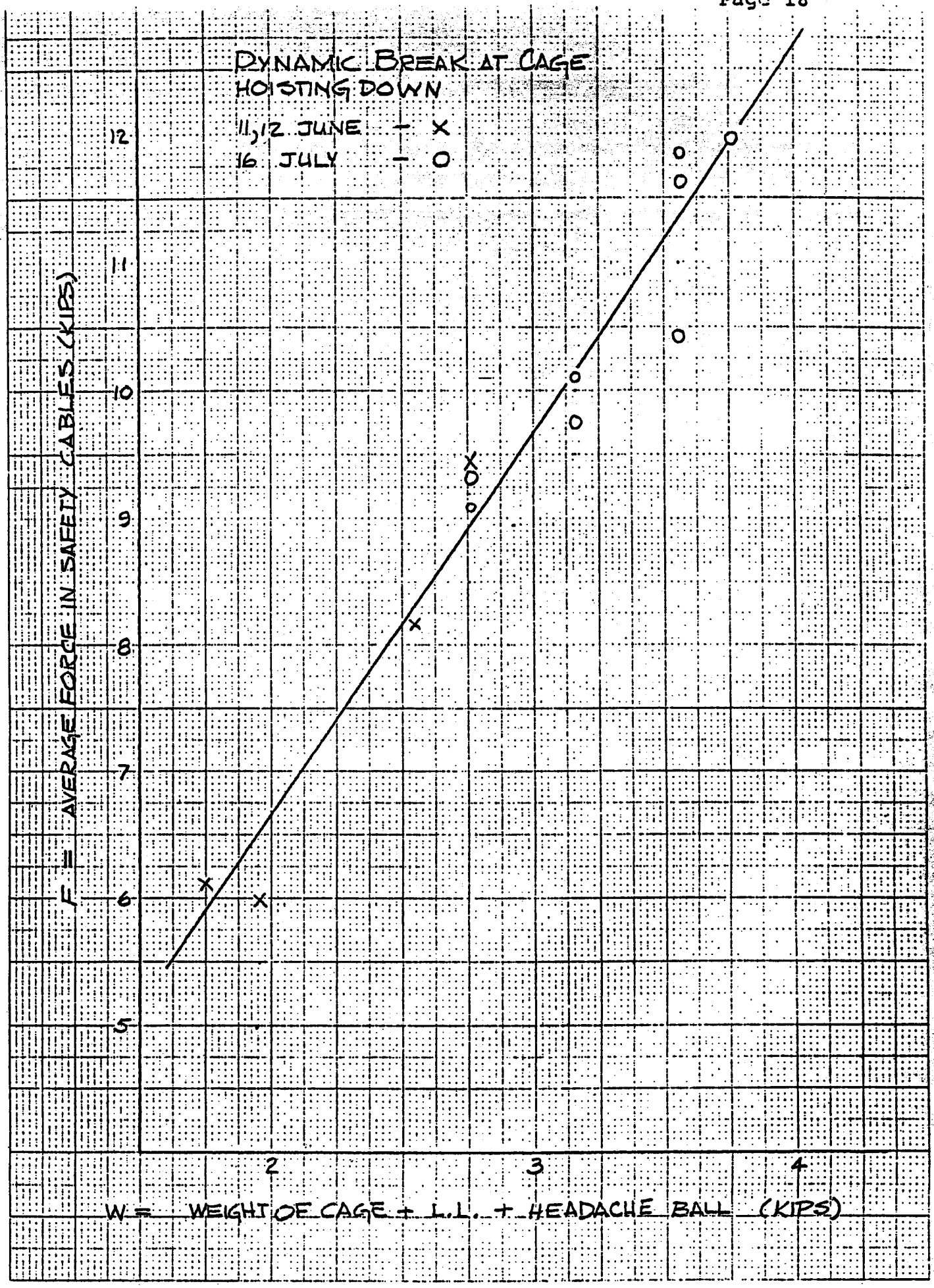
DYNAMIC BREAK AT CAGE
HOISTING DOWN
11,12 JUNE — X
16 JULY — O
F = AVERAGE FORCE IN SAFETY CABLES (KIPS)
12
11
10
9
8
7
6
5
2
3
4
W = WEIGHT OF CAGE + L.L. + HEADACHE BALL (KIPS)

Figure 10

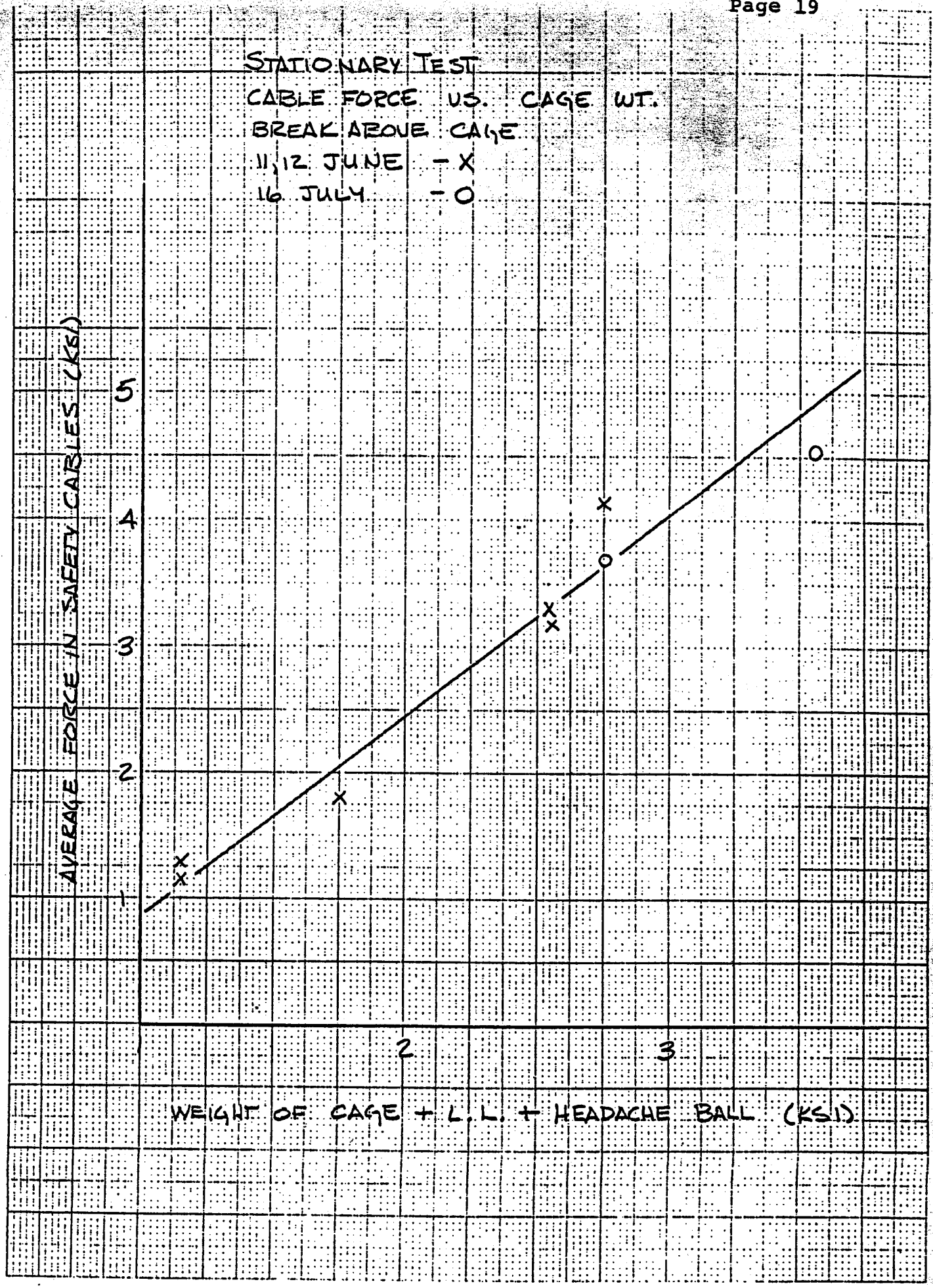

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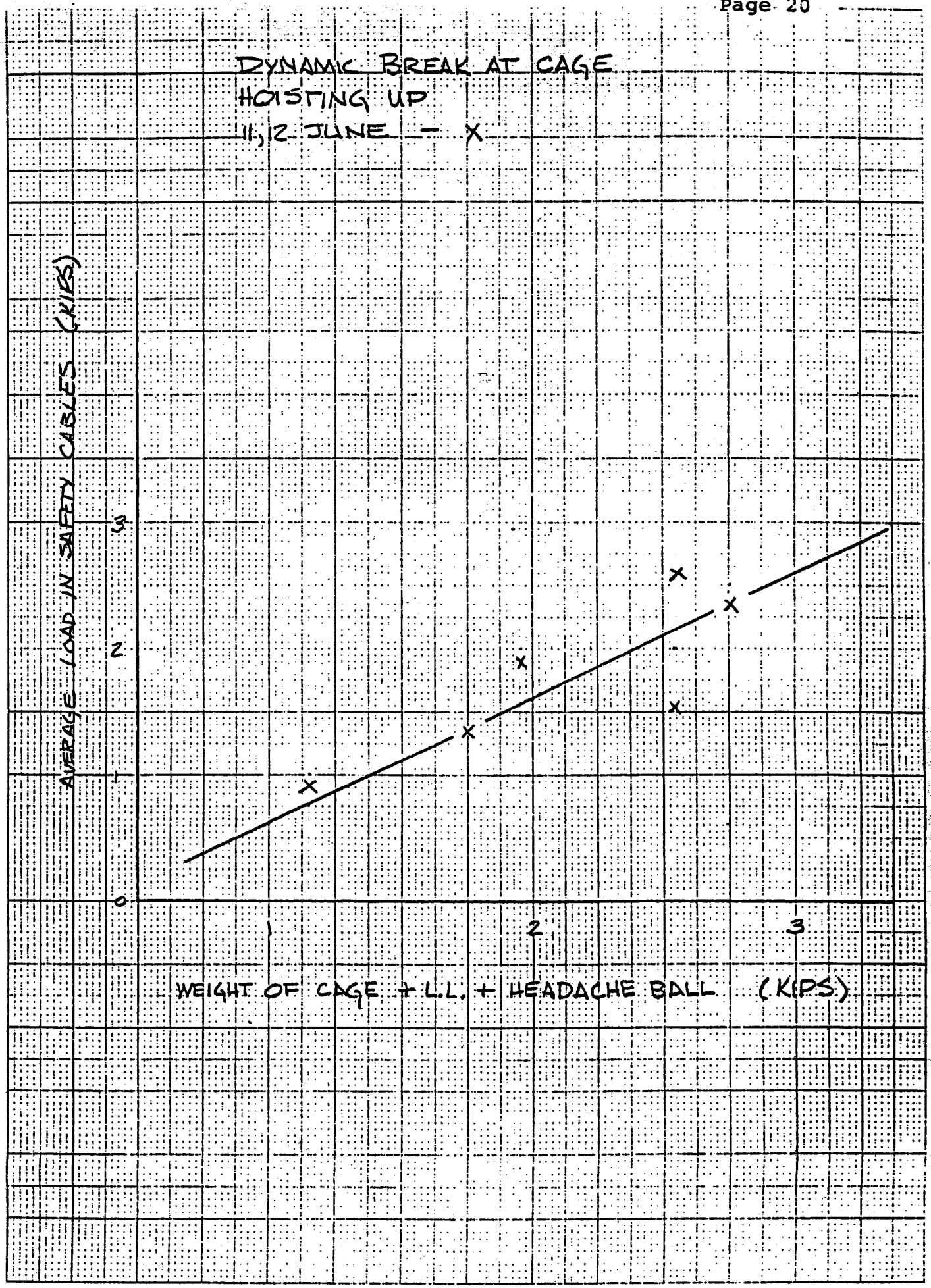
Figure 11



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III.2.3 Results (Continued)

Accelerations. High frequency (greater than 100Hz) accelerations (5-10 g) obscured nearly all usuable data from tests on 10, 11 June. The high frequency acclerations were caused by stiff components of the personnel cage roof where the accelerometer was mounted. During testing on 16 July a two-stage low-pass filter was used to screen out high frequency signals.

The highest sustained acceleration (longer than 0.1 second duration) was 1.45 g. This value was recorded in numerous tests and is a good estimate of maximum sustained acceleration in a personnel cage with a properly adjusted safety system.

Clamping Cam. The clamping cam has a hard alloy facing on the end which engages the cable. Radial cracks have been found in the facing on new, unused cams. During testing, cracks were observed on some of the cams, both before use and after repeated operation of the safety system. Three cams were submitted to Pullman Power Products Williamsport Metallurgical Lab for further investigation. A full report on this investigation is contained in Appendix D. This report concludes that the cracking is not detrimental to repeated operation of the safety device.

900 Foot Chimney Simulation. Results of the 900 foot chimney simulation are listed in Table 3.

Test #	Static, Hoist Up or Hoist Down	Break at	Cage Weight (lbs)	Ave. Max. Force In Safety Cables (lbs)	Safety Device Actuation
FS1a	static	hoist	800	2490	worked
FS1b	static	hoist	800	2500	worked
FS1c	static	hoist	800	2620	worked
FS2	down	hoist	800	9530	worked
FS3	up	hoist	800	5040	worked

Table 3

Kansas City Tests (16 July 1980) - Simulate 900' Chimney

Cage Wt. - 2160#; Headache Ball Wt. - 600#

III.3 Field Tests (12 August 1980)

III.3.1 Facility

Field tests were performed at a 900 foot chimney under construction by Rust Chimney Division. Personnel cage hoisting was accomplished with a ground-mounted single drum hoist. The hoist line was routed over a fixed footblock and two sheaves on the cathead. This setup is similar to that used by all member chimney companies during construction. A quick-release device was used to simulate a hoist line break above the cage or between the footblock and hoist.

Occupant weight was simulated by using weights in the personnel cage. Horizontal accelerations were measured with an electric resistance accelerometer. Forces in the safety lines were measured with through-type strain gage load cells attached to the lines with strand chucks. Load cells were electronically calibrated during setup. The accelerometer was calibrated using the 1 g acceleration caused by gravity.

Power supplies, amplifiers, filters and oscillograph were set up on the workdeck near the top of the chimney.

III.3.2 Procedure

The cage prepared at the Kansas City chimney simulation facility on 16 July 1980 was used in the field test. Personnel cage tests were performed with the following simulated occupant weights:

III.3.2 Procedure (Continued)

Cable Break Between Footblock and Hoist,
Personnel Cage Near Ground Level

Stationary	Hoisting Down (about 250'/min)
Empty	Empty
800#	800#

Cable Break Between Footblock and Hoist,
Personnel Cage Near Cathead

Stationary
800#

III.3.3 Results

Safety Cable Loads. Oscillograph plots of the field tests are listed in Appendix C. The results of the field tests at the 900 foot chimney are listed in Table 4. The loads in the safety cables were equal to or less than in the simulations for all cases except the static case with the personnel cage near the cathead. In this case the safety cable loads were higher than similar simulations but lower than the critical dynamic (hoisting down) case.

Safety Device Actuation. The safety device was set up with minimum spring compression as described previously (III.2.2). The safety device actuated properly for all field tests.

Accelerations in the Personnel Cage. The maximum horizontal acceleration perpendicular to the safety device was

Test #	Static or Dynamic	Break at	Cage at	Load In Cage (lbs)	Ave. Max. Force In Safety Cables (kips)	Safety Device Actuation
FA1a	static	hoist	ground	0	1.65	worked
FA1b	static	hoist	ground	0	1.30	worked
FA3	dyn	hoist	ground	0	2.41	worked
FA4a	dyn	hoist	ground	800	2.73	worked
FA4b	dyn	hoist	ground	800	3.33	worked
FB1	static	hoist	top	0	2.85	worked
FB2a	static	hoist	top	800	4.54	worked
FB2b	static	hoist	top	800	4.24	worked
FB2c	static	hoist	top	800	4.80	worked
FB3	dyn	hoist	top	0	8.24	worked
FB4	dyn	hoist	top	800	8.95	worked
FC1	static	cage	top	800	5.39	worked

Table 4

FIELD TESTS 8/12/80 - 900' RUST CHIMNEY NEAR MANCHESTER, OHIO

Cage Wt. - 2160#; Headache Ball Wt. - 600#

III.3.3 Results (Continued)

3.4 g. This occurred once at approximately 40 Hz. The next greatest acceleration was 0.4 g at approximately 5-10 Hz.

The maximum horizontal acceleration parallel to the safety device was 2 g. This also occurred at a relatively high frequency of 40-60 Hz. The highest recurring acceleration was 0.8 g at approximately 5-10 Hz.

During the horizontal acceleration tests and many other tests, the cage shimmed with negligible high frequency lateral displacements. The only appreciable lateral movements were slow oscillations, typically 1-2 Hz, with corresponding accelerations less than 0.05 g.

III.4 Discussion

The dynamic testing provided a severe environment for transducers and instrument wires. Load cells and accelerometers were damaged and instrument wires were frequently broken. This explains those oscillograph plots with interrupted or unusual output.

III.4.1 Safety Cable Loads

Safety cable loads have been accurately measured for various simulated hoist line breaks at the Kansas City facility and in the field. These measurements are shown in Table 1 (Page 15) for the Kansas City tests and in Table 2 (Page 16) for the field tests. As expected, the dynamic tests (hoisting down) lead to greater safety cable forces.

III.4.1 Safety Cable Loads (Continued)

Two aspects of these results may appear inconsistent. First, from Table 4 (Page 25) the safety cable forces for a break at the hoist were higher when the personnel cage was near the cathead than when the cage was near the foundation (compare tests FA1 with test FB1 - see Appendix C). When the personnel cage is near the foundation, however, the hoist-side cable merely counterbalances the weight of the cage-side cable.

The calculations in Appendix E show that the safety cable forces are a function of the cage weight (W), the stiffness of the safety cables (k), the clamp actuation time (t_o) and the initial velocity of the cage (v_o). In particular, the forces are larger when the frequency of the system is larger.

The combined stiffness of the two safety cables is

$$k = \frac{2AE}{L}$$

so that a longer cable yields a lower stiffness. Comparing the stiffness of 20 feet of cable with that of 900 feet of cable,

$$k_{20} \doteq 12{,}800 \text{ lb/in}$$

$$k_{900} \doteq 285 \text{ lb/in}$$

The frequency of the safety cable-cage system near the cathead and foundation are

$$\omega_T = \frac{12{,}800\ g}{2760 - 900} = 51.6 \text{ rad/sec}$$

$$\omega_B = \frac{285\ g}{2760} = 6.32 \text{ rad/sec}$$

III.4.1 Safety Cable Loads (Continued)

Even though the effective mass to be stopped is smaller near the cathead, the much higher frequency of that system can lead to larger safety cable forces.

The second apparent inconsistency occurred in the static test for a break above the personnel cage. Since no hoist cable is being overhauled, the test facility results and field results should be identical. The safety cable forces observed in the field are higher when comparing Test S2 from Table 1 with Test FC1 from Table 2. This discrepancy is explained by the difference in frequency. At the test facility, the personnel cage was approximately 50 feet below the cathead so that the stiffness of the safety cable system was

$$k_{50} = 5100 \text{ lb/in}$$

Therefore, the frequency of the field system was higher than the frequency of the test facility system. The forces measured in the field for this test were higher than the forces measured at the test facility.

III.4.2 Safety Device Actuation

The safety device actuated properly for all tests in which it was adjusted as detailed in Section II.3.1 of this report. A stationary test with cable break at the footblock was used to verify proper actuation of the safety device.

III.4.3 Accelerations in the Personnel Cage

Accelerations occurring at high frequencies have such short durations that they result in small velocities and displacements. Throughout all field and simulation tests, the highest accelerations occurred at high frequencies and would not be detrimental to personnel in the cage.

III.5 Endurance Testing

III.5.1 Procedure

In this series of tests, the 2160 pound cage was statically tested with break above the 600 pound headache ball. The safety device was adjusted as detailed in Section II.3.1 of this report. This session was composed of four sets, each set consisting of 36 drop tests for a total of 144 tests. The vertical personnel cage position was determined by measuring cage location before and after each test. The clamps were removed and examined for wear after each set.

III.5.2 Results

Test results are tabulated in Appendix F. No noticeable clamp wear was detected throughout the testing. The safety device actuated properly in each of these tests.

IV. Conclusions

1. A procedure is presented for calculating the spring force required for safety device actuation.

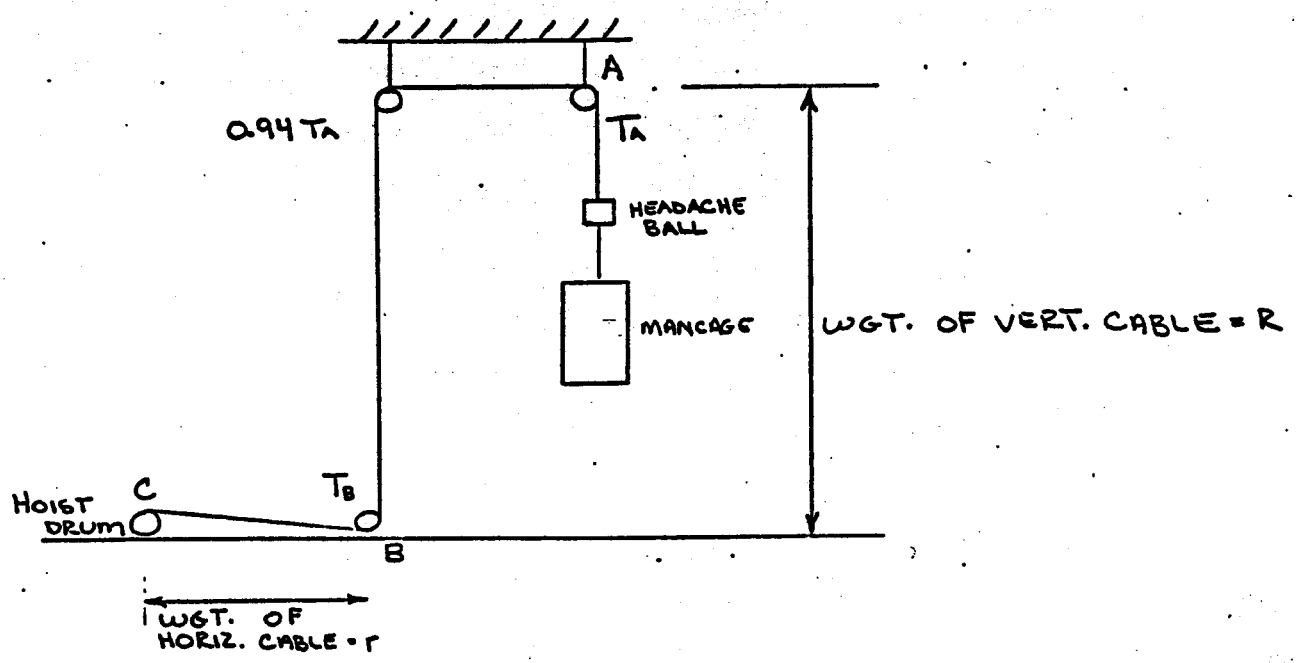
2. The existing safety device, when properly adjusted, will engage the safety lines and stop the descent of the personnel cage when the hoist line breaks.

3. The accelerations inside the personnel cage during an emergency stop are not severe enough to be detrimental to occupants.

4. Throughout this program, the personnel cage safety system was reliable and perfomed the function for which it was intended.

Appendix A

Rigid Body Analysis for Proper Spring Compression Force



LET:

W_C = WGT. OF CAGE
W_P = WGT. OF PASSENGERS
W_H = WGT. OF HEADACHE BALL

$\Big\}\ W = W_C + W_P + W_H$

R = WGT. OF VERT. HOIST LINE
r = WGT. OF HORIZ. HOIST LINE
T_A = TENSION IN HOIST LINE AT A
T_B = TENSION IN HOIST LINE AT B
a = ACCELERATION OF CAGE AND HOIST LINE

ASSUME
1. CABLE BREAKS AT HOIST DRUM, PT. C
2. CAGE IS AT TOP OF TRAVEL
3. 3% FRICTION LOSS AT EACH SHEAVE

THEN :

1) $W - T_A = \frac{W}{g} a$

2) $.94\,T_A - R - 1.03\,T_B = \frac{R}{g} a$

3) $T_B = \frac{r}{g} a$

$.94 \times$ 1) $.94W - .94T_A = .94\frac{W}{g} a$

2) $.94T_A - R - 1.03\frac{r}{g} a = \frac{R}{g} a$

$$.94W - R = (.94W + R + 1.03r)\frac{a}{g}$$

$$a = \frac{(.94W - R)\,g}{.94W + R + 1.03r}$$

FROM 1) $T_A = W - \frac{W}{g} a = W\left(1 - \frac{a}{g}\right)$

$\therefore$ EFFECTIVE WGT DURING FALL $= \left(1 - \frac{a}{g}\right) \times$ ACTUAL WGT

$$f = 1 - \frac{a}{g} = 1 - \frac{(.94W - R)}{.94W + R + 1.03r} = \frac{.94W + R + 1.03r - .94W + R}{.94W + R + 1.03r}$$

$$\longrightarrow f = \frac{2R + 1.03r}{.94W + R + 1.03r}$$

$\therefore$ FORCE ON SPRINGS DURING FALL $= f \times$ (WEIGHT OF CAGE + PASSENGE

COMPUTE SPRING FORCE REQUIRED FOR OPERATION OF MANCAGE SAFETY CLAMPS

HOIST CABLE TO BE 3/4" DIA. 6X19 FIBER CORE .9 #/FT.

CAGE WGT W_C = 2160#
PASSENGERS W_P = 800#
HEADACHE BALL W_H = 600#

$\Big\}$ W = 3560# $\quad W_{C_1} = W_C + W_P$

MAX. WGT. OF CABLE TO OVERHAUL = 900# = R
WGT OF CABLE FROM BLOCK TO HOIST = 90# = r

ASSUME 3% FRICTION PER SHEAVE

$$f = \frac{2R + 1.03r}{.94W + R + 1.03r} = \frac{2 \times 900 + 1.03 \times 90}{.94 \times 3560 + 900 + 1.03 \times 90} = .44$$

REQUIRED SPRING FORCE = $W_{C_1} f$ = 2960# x .44 = 1302#

∴ USE 1400# INITIAL COMPRESSION

USE 1½" ϕ x 8" WITH 443 #/IN SPRING CONSTANT

SPRING DEFLECTION = 1400#/2x443 = 1.58"

∴ INITIALLY COMPRESS EACH SPRING 700# IE 1 9/16"

Appendix B

Non-Rigid Body Dynamic Analysis

The Fortran program presented in Appendix B.3 has been developed to compute the time history data for the model depicted by Figures No. 1 and No. 2 of Appendix B.1. More specifically, after the user specifies:

1. the number of concentrated mass points desired along the lengths of cable XL1 and XL3,

2. DELT, the time increment (in seconds) at which the time history data is to be compiled,

3. SMAX, the maximum relative displacement (in feet) to be allowed between concentrated weights W(1) and W(2),

4. COUNT, the maximum number of iterations at which the time history computations are to be permitted,

5. TPRINT, the time increment (in seconds) at which the time history data is to be outputted,

6. FLIMIT, the specified constant force (in pounds) at the downside end of the support cable,

and

7. VERT, a positive value for the case W(LIMIT) is assumed to be hanging (i.e., Figure No. 2 of Appendix B.1 applies),

the program:

I. Starts by computing (at the time of release):

   a. NF=the number of concentrated mass points on the mancage side of the cable,

   b. NB=the number of concentrated mass points along the cable length XL3,

   c. LIMIT=the total number of concentrated mass points in the system,

   d. PRINT=the total time (in seconds) at which the first iterative time history data is to be listed,

II. Then reads in:

   a. WTCABLE=the weight (in lbs. per foot) of the support cable,

   b. WTCAGE=the mancage dead weight (in pounds),

   c. WTPASS=the mancage load (in pounds),

   d. WTBALL=the weight (in pounds) of the headache ball above the cage,

   e. W(LIMIT)=the weight (in pounds) of the weight at the end of the downside of the support cable,

and

the lengths of support cable XL1, XL2, and XL3.

III. Computes the weights (in pounds) of all the mass points, W(J), in the system; where

a. W(1) = WTCAGE + WTPASS

b. W(2) = WTBALL

c. for all $2 < J \leq NF$,

W(J) = the product of XL1 and WTCABL divided by XNF

d. for all $NF < J < LIMIT$,

WJ = the product of XL3 and WTCABL divided by XNB

IV. the computes (in slugs) the, respective, masses W(J) of the concentrated weights W(J)

V. then computes F(1, J); the initial or static forces (in pounds) in the system just before release. That is:

a. for $1 \leq J \leq NF$,

$$F(1,J) = \sum_{I=1}^{J} W(I)$$

b. for $NF < J < LIMIT$

$$F(1,J) = F(1,NF) - \sum_{I=NF+1}^{J} W(I)$$

c. for J = LIMIT F(I, J) = FLIMIT

VI. Then computes the initial velocities, accelerations and displacements of each of the concentrated mass points, under the assumption that the system was at rest and the backside cable was quickly released from the weight W(LIMIT). More specifically, by defining for each of the J mass points:

a. VEL(1, J) = the starting velocity (in feet per second) at the beginning of any time increment, T.

b. ACCEL(1, J) = the starting acceleration (in feet per second squared) at the beginning of any time increment, T.

c. DISP(1, J) = the starting displacement (in feet) at the beginning of any time increment, T.

the program assumes initially

a. for the J mass points that:

VEL(1,J) = 0.0
DISP(1,J) = 0.0

b. for all J < LIMIT

ACCEL(1,J) = 0.0

and

c. for J = LIMIT

i. for VERT > 0

$$ACCEL(1,J) = \frac{F(1,J-1) - W(J) - F(1,J)}{M(J)}$$

ii. for VERT ≤ 0

$$ACCEL(1,J) = \frac{F(1,J-1) - F(J)}{M(J)}$$

VII. If the above initial conditions are not acceptable to the user, the program allows at this point the capability to override these values. More specifically, following the input instructions given in Appendix B.2, the user can use the input variables XINIT, XJ, VELORG, ACCORG, and SORG to assign any specified values for initial VEL(1,J), ACCEL(1,J), and DISP(1,J) for for any J mass point. When assigning such values, the user must keep in mind that the programmed sign convention is such that all velocities, accelerations, and displacements consistent with a counter-clockwise movement of Figure No. 1 of Appendix B.1 are positive. For example, if the mancage were moving upward at a constant velocity at the time of release, this would require a negative VELORG to be assigned to all the J mass points.

VIII. At this point the program expects to read in values for

a. SPRCAB = the spring constant (lbs. per foot) desired between W(1) and W(2),

b. SPRSET=the initial spring force (in pounds) between W(1) and W(2),

c. ECABLE=the modulus of elasticity (in pounds per square inch) of the support cable,

d. ACABLE=the cross-section area (in square inches) of the support cable,

e. FRICT(1)=the frictional loss as the cable passes over Support A (i.e., a dimensionless decimal fraction),

f. FRICT(2)=the frictional loss as the cable passes over Support B(i.e., a dimensionless decimal fraction),

g. FRICT(3)=the frictional loss as the cable passes over Support C(i.e., a dimensionless decimal fraction).

IX. At this point, the cable spring constants (i.e. AE/L, in pounds per foot) are computed. That is:

a. for K(1), the program assigns the specified value for SPRCAB

b. for $1 < J < NF$: $$K(J) = \frac{ACABE\ (ECABLE)}{[XL1/(XNF+1)]}$$

c. for $J = NF$: $$K(J) = \frac{ACABLE\ (ECABLE)}{[XL1/(XNF+1] + XL2 + [XL3/(XNB+1)]}$$

and

d. for $NF < J < LIMIT$: $$K(J) = \frac{ACABLE\ (ECABLE)}{[XL3/(XNB + 1)]}$$

X. At this point the program has been written to assign the initial cable forces to an array FO(J). These are the forces associated with the spring constants K(J) just prior to the instant of release.

XI. The program then computes and prints out ACRIT, the critical acceleration (in feet per second squared) at which the weights W(1) and W(2) will no longer be assumed to move, simultaneously, together. It computes this value as:

$$ACRIT = \frac{W(1) - FO(1)}{M(1)}$$

XII. Then for each of the concentrated mass points, the program, then, lists its, associated, computed W(J), M(J), FO(J) and K(J) values.

XIII. When the program reachs this point of the analysis, it is ready to begin the compiling of the time history data. To accomplish this, the following variables are used:

a. TIME = used to accumulate the total time (in seconds) from the moment of release,

b. ACOUNT = a counter that keeps track of the number of iterations in order to assure the value specified for COUNT is not exceeded,

c. CHECK = a variable used to indicate whether or not ACRIT has been reached. That is once ACRIT has been reached, CHECK will be assigned a value of 1.0 to indicate that in all further interations it will no longer be assumed that W(1) and W(2) move, simultaneously, together.

d. T = a variable used to give the time increment at which the next iteration or time history data is to be compiled.

e. VEL(2,J) = the computed velocity (fps) for M(J) at the end of the time increment T,

f. DISP(2,J) = the computed total displacement (feet) for M(J) at the end of the time increment T,

g. ACCEL(2,J) = the computed acceleration (feet per second squared) for M(J) at the end of the time increment T.

h. F(2,J) = the cable force (in pounds) between M(j) and M(J+1) at the end of the time increment, T.

i. ACHECK = is the acceleration to be assigned to W(1) and W(2) as long as ACRIT is not reached.

j. DIFF = the fraction difference between ACHECK and ACRIT computed as:

$$\frac{\text{ACHECK} - \text{ACRIT}}{\text{ACRIT}}$$

k. F1 = 1 − FRICT(1)

l. F2 = 1 − FRICT(2)

m. F3 = 1 − FRICT(3)

n. DIFS = the relative displacement (in feet) between W(1) and W(2) computed as W(2) displacement minus W(1) displacement.

More specifically, after beginning by setting:

```
TIME    = 0.0
ACCOUNT = 0.0
CHECK   = 0.0
T       = DELT
```

the following programmed steps are repeated:

STEP A: Checks to see if ACOUNT exceeds the specified value for COUNT. If it does, then the analysis is ended; otherwise the analysis proceeds to STEP B.

STEP B: For each of the concentrated J masses, the velocities and displacements at the end of T are computed as:

$$VEL\ (2,J) = VEL\ (1,J) + \left[ACCEL(1,J) * T\right]$$

$$DISP(2,J) = DISP(1,J) + \left\{\left[VEL(1,J) * T\right] + \left[0.5*ACCEL(1,J) * T^2\right]\right\}$$

STEP C: For all mass point $J \leq NF$, the cable forces at the end of T are computed as:

$$F(2,J) = FO(J) - \left\{K(J)* \left[DISP(2,J+1) - DISP(2,J)\right]\right\}$$

STEP D: Checks to see how many mass points have been specified on the backside of the cable. More specifically, if $(NB \leq 0)$ then STEP E is skipped.

STEP E: When $(NB > 0)$, then for $(NF < J < LIMIT)$ the cable forces are then, also, computed as described in STEP C; however, none of these F(2,J) are permitted to go below zero (i.e., compression not permitted).

STEP F: The force F(2,LIMIT) is set equal to specified value for F(LIMIT).

STEP G: The program then checks to see if ACRIT has been reached. That is, if the variable CHECK is greater than zero (0.0) at this point, the analysis is rooted to STEP L. Otherwise, the analysis proceeds to STEP H.

STEP H: Here the program computes the acceleration ACHECK as:

$$\frac{W(1) + W(2) - F(2,2)}{M(1) + M(2)}$$

STEP I: The program then compares ACHECK to ACRIT. If ACHECK is not greater than ACRIT, then both accelerations ACCEL(2,1) and ACCEL(2,2) are assigned the value computed for ACHECK and the analysis process to STEP M. Otherwise, STEP J is next.

STEP J: At this point if CHECK is greater than zero (0.0), the analysis is rooted to STEP L. Otherwise, STEP K is next.

STEP K: Here the value DIFF is computed, and as long as it is greater than 0.001, then T is reduced by 1/2 and the analysis returns to STEP A. Otherwise, it is assumed that DIFF is small enough to assume that ACRIT has been reached and the variables:

1. CHECK is set equal to one (1.) and

2. T is reset to DELT for all further iterations.

The analysis is then rooted to STEP L.

STEP L: Here the accelerations for W(1) and W(2) at the end of the time increment are computed, separately as:

$$ACCEL(2,1) = \frac{W(1) - F(2,1)}{M(1)}$$

$$ACCEL(2,2) = \frac{W(2) + F(2,1) - F(2,2)}{M(2)}$$

and the analysis is rooted to STEP M.

STEP M: Then the accelerations for the remaining mass points on the mancage side of the support cable (i.e., for $3 \leq J \leq NF$) are computed as:

$$ACCEL(2,J) = \frac{W(J) + F(2,J-1) - F(2,J)}{M(J)}$$

STEP N: Then on the backside of the support cable, the program computes the cable forces as either:

1. When $(NB \leq 0)$, $J = (NF + 1) = LIMIT$ and

   i. for $VERT \leq 0$

$$ACCEL(2,J) = \frac{F(2,NF) * F1 * F2 * F3 - F(2,J)}{M(J)}$$

   ii. for $VERT > 0$

$$ACCEL(2,J) = \frac{F(2,NF) * F1 * F2 - W(J) - F(2,J)}{M(J)}$$

or

2. When $(NB > 0)$

   a. for $J = (NF + 1)$

$$ACCEL(2,J) = \frac{[F(2,NF) * F1 * F2] - W(J) - F(2,J)}{M(J)}$$

   b. for $(NF + 2) \leq J \leq LIMIT$

$$ACCEL(2,J) = \frac{F(2,J-1) - W(J) - F(2,J)}{M(J)}$$

   c. for $J = LIMIT$

      i. for $VERT \leq 0$

$$ACCEL(2,J) = \frac{[F(2,J-1) * F3] - F(2,J)}{M(J)}$$

      ii. for $VERT \geq 0$

$$ACCEL(2,J) = \frac{F(2,J-1) - W(J) - F(2,J)}{M(J)}$$

STEP O: Here the counter, ACOUNT, is increased by one (1) and the clock, TIME, is increased by the time increment, T. This gives, respectively, the identification number and time of the current iteration. If at this point in the analysis, the iteration is the first (i.e., ACOUNT = 1), then before proceeding to STEP P, the program will list for each of the J mass points its initial or starting velocities, displacements, cable support force, and accelerations, respectively, in units of (feet per second), (feet), (pounds), and (feet per second squared).

STEP P: Here the program checks to see if T equals DELT and TIME is less than PRINT. If both these conditions are true, then the analysis proceeds, directly, to STEP T; otherwise, STEP Q is next.

STEP Q: Here for each iteration the program gives a table listing at the end of the time increment:

1. Total clock time (in seconds) from the moment of release.

2. The relative displacement (in feet) between W(2) and W(1).

3. And for each of J mass points, its:

   a. Velocity (in feet per second)

   b. Total displacement (in feet).

   c. Support cable force (in pounds).

   and

   d. Acceleration (in feet per second squared)

STEP R: At this point, if T equals DELT, the PRINT time check variable is increased to the next time period by the interval amount TPRINT, before going to STEP S.

STEP S: Here the program checks to assure that DIFS does not continue past the value specified for SMAX. More specifically, if at this point DIFS is greater than SMAX, the analysis is ended. Otherwise, the analysis proceeds to STEP T.

STEP T: Here the program gets ready to begin the next iteration by setting all, required, period compiled data to their, respective, next period beginning values. That is here before going back to STEP A and reiterating the program sets

```
VEL(1,J)   = VEL(2,J)
DISP(1,J)  = DISP(2,J)
ACCEL(1,J) = ACCEL(2,J)
F(1,J)     = F(2,J)
```

for all the J mass points.

Appendix B.1

Mancage Model Assumed

MANCAGE MODEL ASSUMED:

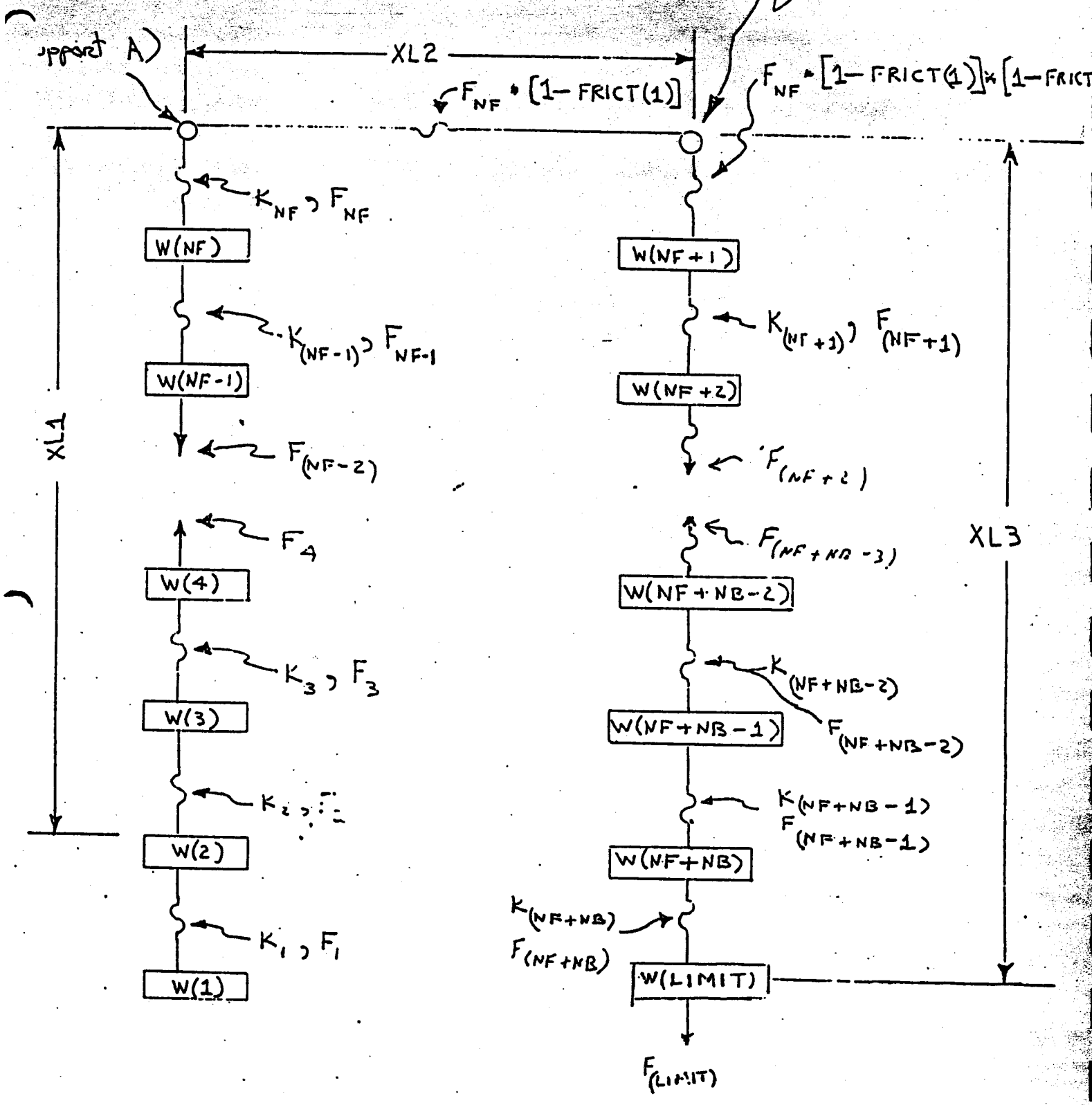


FIGURE 2

CASE: VERT > 0.0

CARD OR RECORD TYPE	INPUT DATA FOR THE MANCAGE ANALYSIS							
1	TITLE AND/OR RUN DESCRIPTION							
2	XNF	XNB	DELT	SMAX	COUNT	TPRINT	FLIMIT	VERT
3	WTCABL	WTCAGE	WTPASS	WTBALL	W(LIMIT)	XL1	XL2	XL3
4	XINIT							
5	XJ	VELORG	ACCORG	SORG				
	⋮							
6	SPRCAG	SPRSET	ECABLE	ACABLE	FRICT(1)	FRICT(2)	FRICT(3)	

FIELD	I	II	III	IV	V	VI	VII	VIII
COLUMNS	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80

Note: All data on record types 3 through 6 have been formatted as "REAL" (ie. decimal point) variables

Appendix B.2

Input Dataset and Definition of Input Variables

DESCRIPTION OF INPUT VARIABLES

XL1 = at the time of release, the length of cable (in feet) between the headache ball above the mancage and the vertical support A.

XL2 = the distance (in feet) between (Support A) and (Support B).

XL3 = the distance (in feet) between (Support B) and (Support C) or when no (Support C) is assumed it is the length (in feet) of cable hanging from (Support B) at the time of release.

XNF = the number of concentrated mass points to be specified as making up the cable length XL1.

XNB = the number of concentrated mass points to be specified as making up the cable length XL3.

DELT = the specified (in seconds) time increment at which the time history iterative computations are to be completed.

SMAX = maximum allowed relative displacement (in feet) between weights W(1) and W(2).

COUNT = the maximum number of iteration or time history computations to be permitted.

WTCABL = the weight per foot (i.e. lbs. per foot) cable

WTPASS = the weight (in pounds) of the load in the mancage.

WTBALL = the weight (in pounds) of the headache ball above the mancage.

W(LIMIT) = the weight (in pounds) of the headache ball on the backside of the mancage cable.

XINIT = a variable that allows the user to input an initial or starting velocity, acceleration and/or displacement to any of the concentrated weights or mass points specified. That is, if:

a. XINIT $\leq$ 0.0, then no Number 5 cards or record types are required.

b. if XINIT $>$ 0.0 then one Number 5 card or record type is required for each unit specified for the variable XINIT. For example, if a value of 4.0 is specified in Field I of the Type 4 record, then four Type 5 records will be required for a successful run.

Description of Input Variables
Page Two

XJ = the mass point for which the initial values VELORG, ACCORG and SORG are being specified.

VELORG = the initial velocity (in feet per second) being specified for the mass specified by XJ on the given Type 5 record.

ACCORG = the initial acceleration (in feet per second square) being specified for the mass specified by XJ on the given Type 5 record.

SORG = the initial displacement (in feet) being specified for the mass specified by XJ on the given Type 5 record.

SPRCAG = the spring constant (in lbs. per foot) desired between the mancage and its headache ball

SPRSET = the F_1 force (in pounds) between the mancage and its headache ball as they move simultaneously together (i.e., their relative displacement is zero).

ECABLE = the Modulus of Elasticity (in lbs. per sq. inch) of the cable.

ACABLE = the cross-sectional area (in sq. inches) of the cable.

FRICT(1) = the friction loss (i.e., a dimensionless decimal fraction) assumed lost by the cable passing over (Support A).

FRICT(2) = the friction loss (i.e., a dimensionless decimal fraction) assumed lost by the cable passing over (Support B).

FRICT(3) = the friction loss (i.e., a dimensionless, decimal fraction) assumed lost by the cable passing over (Support C).

TPRINT = the time increment (in seconds) at which the iterative time history data is to be outputed.

FLIMIT = a constant force (in pounds) that can be specified. If the force is a tension, it should be inputed as a positive quantity.

Appendix B.3

Copy of Fortran Source Program

```
C A PROGRAM FOR ANALIZING THE MANCAGE
      DIMENSION W(100),FO(100),FRICT(3),TITLE(20)
      DIMENSION VEL(2,100),DISP(2,100),ACCEL(2,100),F(2,100)
      REAL M(100),K(100),PRINT
      INTEGER ACOUNT
      READ(5,99) TITLE
   99 FORMAT(20A4)
      WRITE(6,98) TITLE
 98   FORMAT(//,1X,20A4,//)
  100 FORMAT(8F10.4)
C     COMPUTING  THE LIMIT OF MASS POINT ARRAYS
C
      READ(5,100) XNF,XNB,DELT,SMAX,COUNT,TPRINT,FLIMIT,VERT
C      NOTE; IF VERT IS ASSIGNED A POSITIVE VALUE PULLEY #3  DOES NOT
C       EXIST, AND W(LIMIT) IS  ASSUMED TO BE HANGING.
C
      NF=XNF+2
      NB=XNB
      LIMIT= NF + NB +1
      PRINT = TPRINT
C
C COMPUTING WEIGHTS (IN POUNDS) WITH
C       WTCAGE = WEIGHT OF THE MAN CAGE
C       WTPASS = WEIGHT OF PASSANGERS
C       WTBALL = WEIGHT OF HEADACHE BALL
C       WT(LIMIT) = WEIGHT OF BACKSIDE CABLE WEIGHT
C       XL1 = INITIAL FRONTSIDE  LENGTH OF CABLE ATTACHED TO MANCAGE
C       XL2 = INITIAL TOPSIDE  LENGTH OF CABLE
C       XL3 = INITIAL BACKSIDE  LENGTH OF CABLE ATTACHED TO ANCHORAGE
      READ(5,100) WTCABL,WTCAGE,WTPASS,WTBALL,W(LIMIT),XL1,XL2,XL3
      W(1) = WTCAGE + WTPASS
      W(2) = WTBALL
      IF(XNF.LE.0.0) GO TO 4000
      DO 400 J=3,NF
  400 W(J) = (WTCABL*XL1)/XNF
 4000 CONTINUE
      IF(NB.LE.0) GO TO 4010
      N1=NF+1
      N2=LIMIT-1
      DO 401 J=N1,N2
  401 W(J)= (WTCABL *XL3) / XNB
 4010 CONTINUE
C
C  COMPUTATION OF MASSES
      DO 402 J = 1 , LIMIT
  402 M(J) = W(J)  / 32.2
C
C COMPUTATION OF THE STATIC (I.E., JUST BEFORE RELEASE) FORCES IN POUNDS
      F(1,1) = W(1)
      SUM = W(1)
      DO 403 J=2,NF
      SUM = SUM + W(J)
  403 F(1,J) = SUM
      SUM = 0.0
```

```
      IF(NB.LE.0) GO TO 4040
      N1=NF+1
      N2=LIMIT-1
      DO 404 J=N1,N2
      SUM =SUM + W(J)
  404 F(1,J) = F(1,NF) - SUM
 4040 CONTINUE
      F(1,LIMIT) = FLIMIT
C
C  ASSIGNING INITIAL VELOCITIOES, ACCELERATIONS AND MOVEMENTS
C       A. FIRST, AS IF THE SYSTEM WAS AT REST AND THEN QUIKCKLY LET GO A
C          BACKSIDE END
      DO 405 J=1,LIMIT
      VEL(1,J)=0.0
      DISP(1,J)=0.0
      ACCEL(1,J)=0.0
  405 CONTINUE
      ACCEL(1,LIMIT) =( F(1,LIMIT-1) - F(1,LIMIT) ) / M(LIMIT)
      IF(VERT .GT. 0.0)  ACCEL(1,LIMIT) =
     1  ( F(1,LIMIT-1)-W(LIMIT)-F(1,LIMIT) ) / M(LIMIT)
C     B. NOW ALLOWING FOR AN OVER RIDE OF THE ABOVE VELOCITIES, ACCELERA
C        AND DISPLACEMENTS
      READ(5,100) XINIT
      IF (XINIT.LE.0.0) GO TO 407
      L = XINIT
      DO 406 I=1,L
      READ(5,100) XJ,VELORG,ACCORG,SORG
      J=XJ
      VEL(1,J)=VELORG
      ACCEL(1,J)=ACCORG
  406 DISP(1,J)=SORG
C
C
C COMPUTATION OF THE CABLE SPRING CONSTANTS, K(J), IN LBS PER FOOT.
  407 READ(5,100) SPRCAG,SPRSET,ECABLE,ACABLE,FRICT(1),FRICT(2),FRICT(3)
      K(1) =SPRCAG
      SPRCAB= (XL1/(XNF+1)) / (ACABLE*ECABLE)
      DO 500 J=2,NF
  500 K(J)=SPRCAB
      SPRCAB= (XL2) / (ACABLE*ECABLE)
      K(NF) = K(NF) + SPRCAB
      SPRCAB= (XL3/(XNB+1)) / (ACABLE*ECABLE)
      K(NF) = K(NF) + SPRCAB
      IF(NB.LE.0) GO TO 5011
      N1=NF+1
      N2=LIMIT-1
      DO 501  J=N1,N2
  501 K(J)=SPRCAB
 5011 CONTINUE
      DO 5012 J=2,N2
 5012 K(J) = 1.0 /K(J)
C
C ASSIGING NON STRECHED CABLE FORCES , FO(J)
      FO(1)=SPRSET
```

```
      N2= LIMIT-1
      DO 502 J=2,N2
  502 FO(J) = F(1,J)
C
C COMPUTATION OF ACRIT, THE ACCELERATION AT WHICH W(1) AND W(2) BEGIN TO
C NO LONGER MOVE TOGEHER AS ONE UNIT.
      ACRIT = ( W(1)- FO(1) ) /M(1)
      WRITE(6,85) ACRIT
   85 FORMAT(' ','  ACRIT = ',F12.6,'-FEET PER SECOND',
     1/,1X,'POINT    WEIGHT(LBS)   MASS(SLUGS)   FORCE FO(LBS',
     23X,' K (LBS PER FT)')
      N2=LIMIT-1
      DO 84 J=1,N2
   83 FORMAT(' ',2X,I3,3X,F10.3,3X,F10.3,3X,F10.3,3X,F10.3)
   84 WRITE(6,83)J,W(J),M(J),FO(J),K(J)
      WRITE(6,83)LIMIT,W(LIMIT),M(LIMIT),FO(LIMIT)
C
C BEGINING OF THE TIME HISTORY COMPUTATION WITHTHE CLOCK SET AT TIME=0.0
C
      TIME =0.0
      ACOUNT=0
      CHECK=0.0
      T=DELT
  599 IF(ACOUNT.GT.COUNT) GO TO 99999
      DO 600 J=1,LIMIT
      VEL(2,J) = VEL(1,J) +  ACCEL(1,J)*T
      DISP(2,J) = ( VEL(1,J) + 0.5*ACCEL(1,J)*T ) * T
      DISP(2,J) = DISP(1,J)  +  DISP(2,J)
  600 CONTINUE
      DO 601 J=1,NF
  601 F(2,J) = FO(J) - K(J)*( DISP(2,J+1) - DISP(2,J) )
      IF(NB.LE.0) GO TO 603
      N1=NF+1
      N2=LIMIT-1
      DO 602 J=N1,N2
      F(2,J) = FO(J) - K(J)*( DISP(2,J+1) - DISP(2,J) )
  602 IF( F(2,J).LE.0.0) F(2,J) =0.0
  603 F(2,LIMIT) =  FLIMIT
      IF(CHECK.GT.0.0) GO TO 6101
      ACHECK= ( W(1)+W(2)-F(2,2) )  /  ( M(1)+M(2) )
      IF(ACHECK.GT.ACRIT) GO TO 610
      ACCEL(2,1)=ACHECK
      ACCEL(2,2)=ACHECK
      GO TO 614
  610 IF(CHECK.LE.0.0) GO  TO  611
 6101 ACCEL(2,1)= ( W(1)-F(2,1) ) / M(1)
      ACCEL(2,2)= ( W(2)+F(2,1)-F(2,2) ) / M(2)
      GO TO 614
  611 DIFF=( ACHECK - ACRIT ) /ACRIT
      IF(DIFF.GT.0.001) GO TO 613
      CHECK =1.0
       T=DELT
      GO TO 6101
  613 T=0.5*T
```

```
      GO TO 599
C
C COMPUTATION OF THE REMANINIG ENDING PERIOD ACCELERATIONS
  614 IF(XNF.LE.0.0) GO TO 616
      DO 615 J=3,NF
  615 ACCEL(2,J)= ( W(J)+F(2,J-1)-F(2,J) ) / M(J)
  616 J=NF+1
      F1 = 1 - FRICT(1)
      F2 = 1 - FRICT(2)
      F3 = 1 - FRICT(3)
      ACCEL(2,J)  = F(2,NF)*F1*F2 - W(J) - F(2,J)
      IF((NB.LE.0).AND.(VERT.LE.0.0))ACCEL(2,J)=F(2,NF)*F1*F2*F3-F(2,J)
      ACCEL(2,J) = ACCEL(2,J)/M(J)
      IF(NB.LE.0) GO TO 6181
      IF(NB.LE.1) GO TO 618
      N1=NF+2
      N2=NF+NB
      DO 617 J=N1,N2
  617 ACCEL(2,J)=( F(2,J-1) - W(J) - F(2,J) ) / M(J)
  618 ACCEL(2,LIMIT)=( F(2,LIMIT-1)*F3-F(2,LIMIT) ) / M(LIMIT)
      IF(VERT .GT. 0.0)  ACCEL(2,LIMIT) =
     1  ( F(2,LIMIT-1)-W(LIMIT)-F(2,LIMIT) ) / M(LIMIT)
 6181 ACOUNT = ACOUNT + 1
      TIME = TIME + T
      IF(ACOUNT.GT.1) GO TO 1000
      WRITE(6,1101)
 1101 FORMAT(' ',' THE INITIAL OR STARTING VALUES WERE:',/,1X,
     1' ------------------------------------',/,1X,
     2'POINT   VELOCITY    DISPLACEMENT     FORCE     ACCELERATION',/,
     31X,'-----   --------    ------------     -----     ------------')
      J=1
      WRITE(6,11031)J,VEL(1,1),DISP(1,1),ACCEL(1,1)
11031 FORMAT(' ',2X,I3,2X,F10.4,2X,F10.4,15X,F10.4)
      DO 1102 J=2,LIMIT
 1102 WRITE(6,1103)J,VEL(1,J),DISP(1,J),F(1,J),ACCEL(1,J)
 1103 FORMAT(' ',2X,I3,2X,F10.4,2X,F10.4,2X,F10.3,3X,F10.4)
 1000 DIFS= DISP(2,2) -DISP(2,1)
      IF ( (T.EQ.DELT).AND.(TIME.LT.PRINT) ) GO TO 2000
      WRITE(6,1104) TIME,DIFS
 1104 FORMAT(//,' TIME =',F14.8,' SECONDS AND (S2-S1)= ',F14.8,/,1X,
     1' ------------------------------------',/,1X,
     2'POINT   VELOCITY    DISPLACEMENT     FORCE     ACCELERATION',/,
     31X,'-----   --------    ------------     -----     ------------')
      J=1
      IF(CHECK.LE.0.) WRITE(6,11031)J,VEL(2,1),DISP(2,1),ACCEL(2,1)
      IF(CHECK.GT.0.)WRITE(6,1103)J,VEL(2,1),DISP(2,1),F(2,1),ACCEL(2,1)
      DO 1105 J=2,LIMIT
 1105 WRITE(6,1103)J,VEL(2,J),DISP(2,J),F(2,J),ACCEL(2,J)
       IF(T.EQ.DELT) PRINT = PRINT + TPRINT
      IF(DIFS.GT.SMAX)  GO TO 99999
C
C REINITIALIZING FOR THE START OF THE NEXT TIME PERIOD
 2000 DO 700  J=1,LIMIT
      VEL(1,J) = VEL(2,J)
```

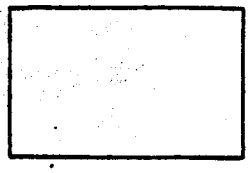
```
02170          DISP(1,J) = DISP(2,J)
02180          ACCEL(1,J) = ACCEL(2,J)
02190          F(1,J) = F(2,J)
02200      700 CONTINUE
02210          GO TO 599
02220    99999 STOP
02230 C        DEBUG INIT,SUBCHK
02240          END
END OF DATA
```

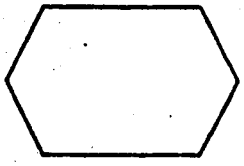
Appendix B.4

Program Flowchart

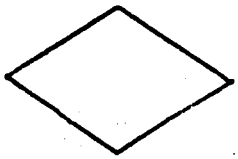
DEFINITION OF SYMBOLS

a. = INPUT/ØUTPUT

b.  = PRØCESS

c.  = PREPARATIØN

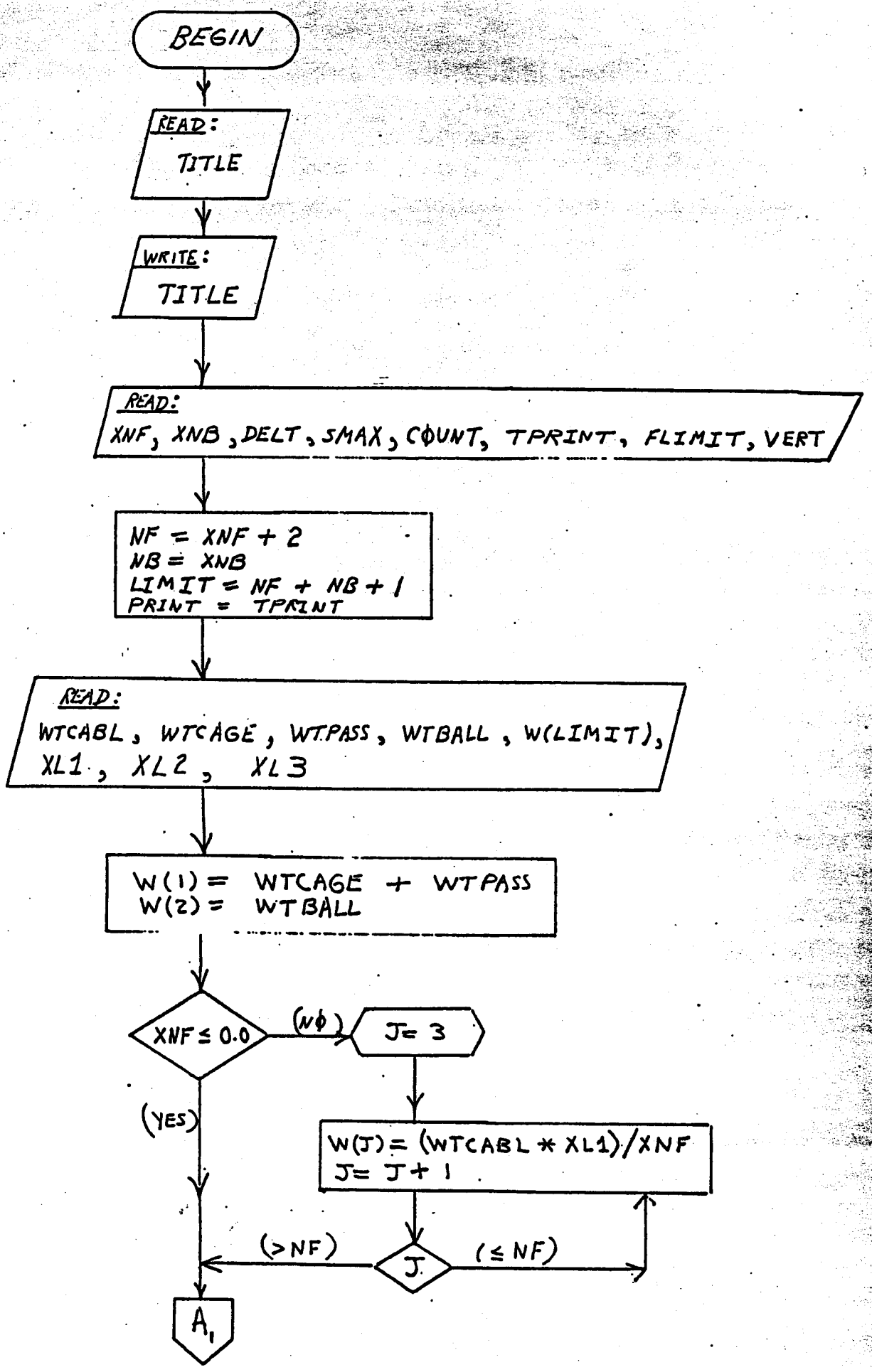
d. = INTERRUPT

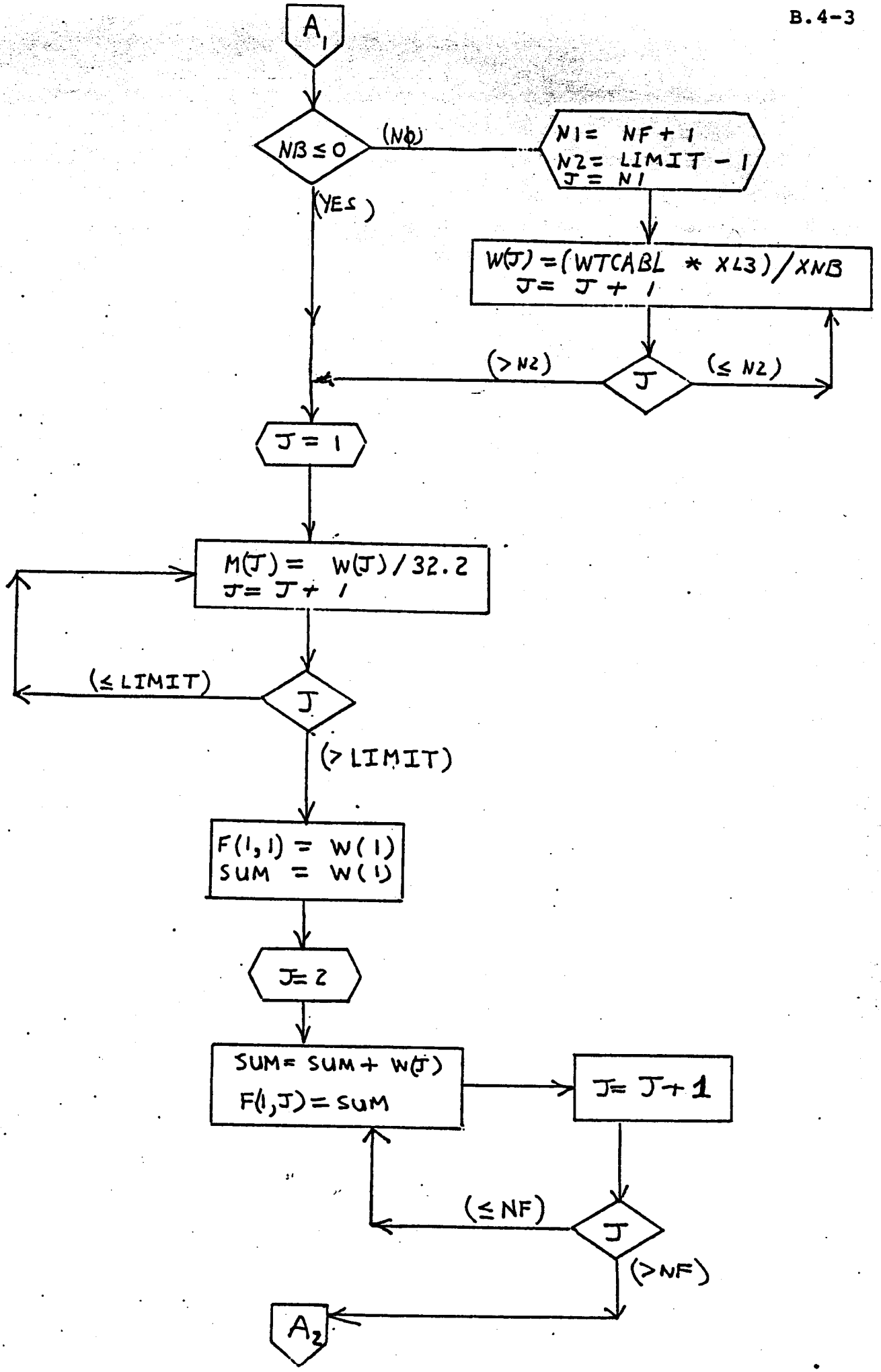
e.  = DECISIØN

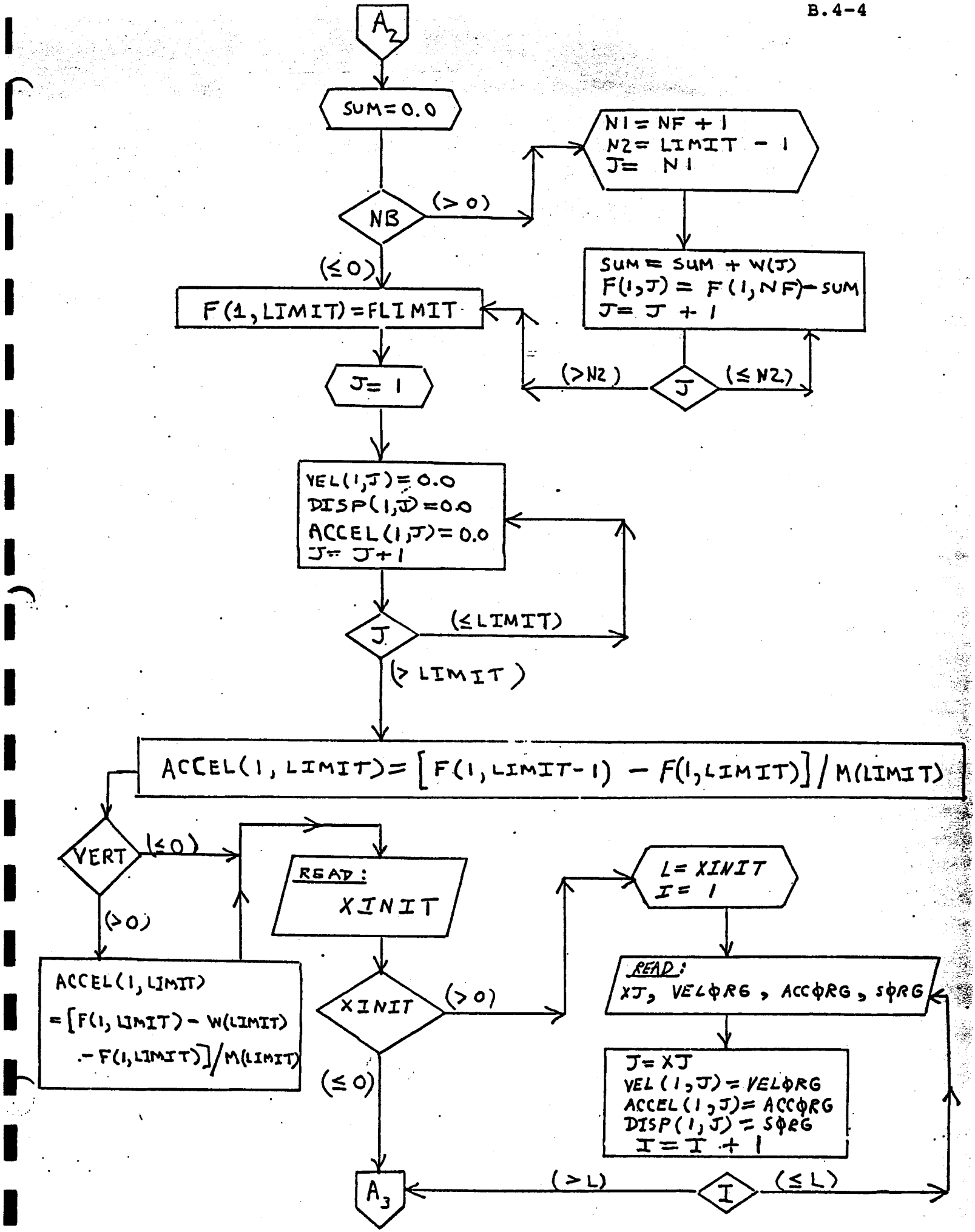
f. = CØNNECTØR

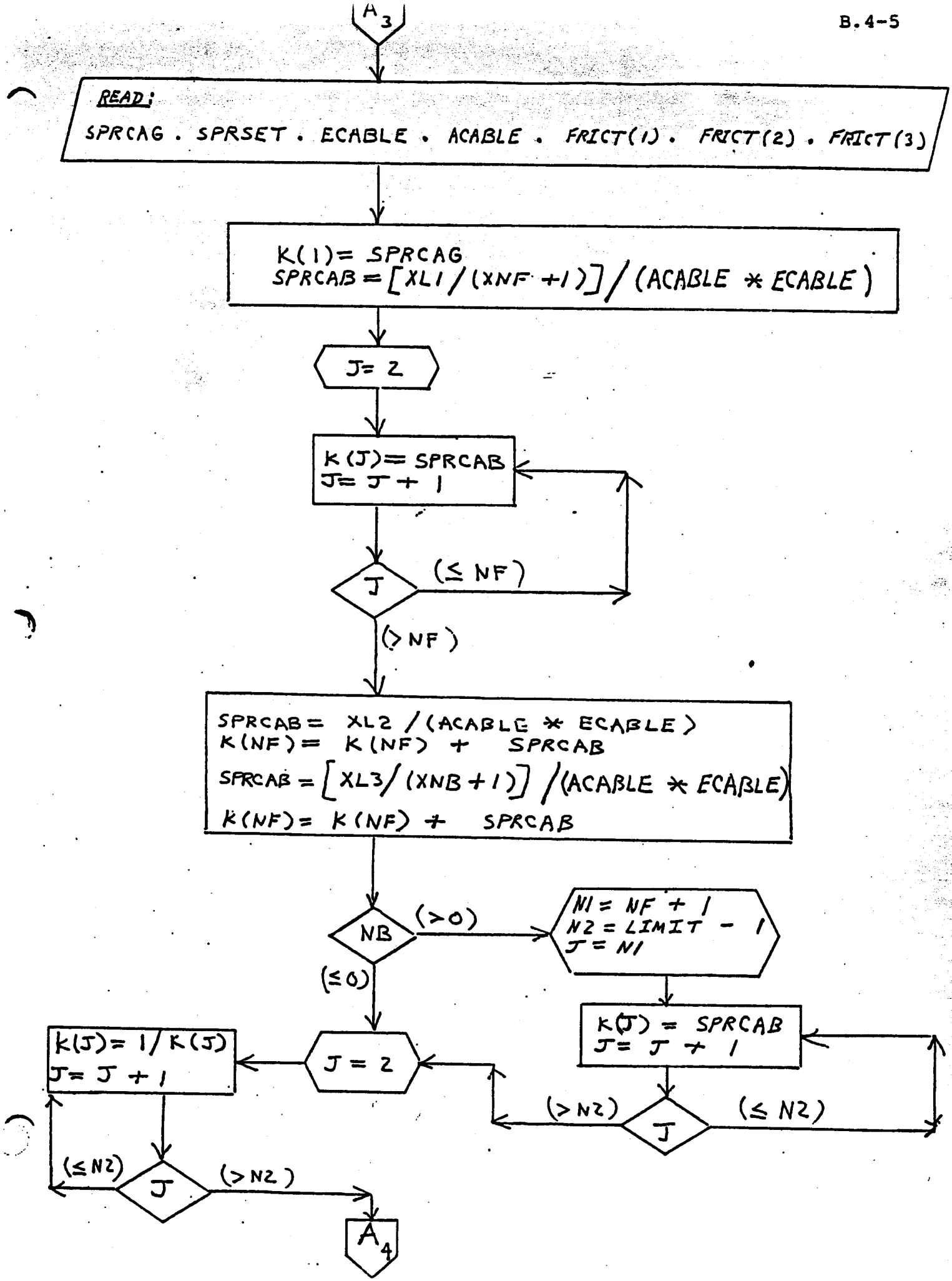
g. = ØFFPAGE CØNNETØR

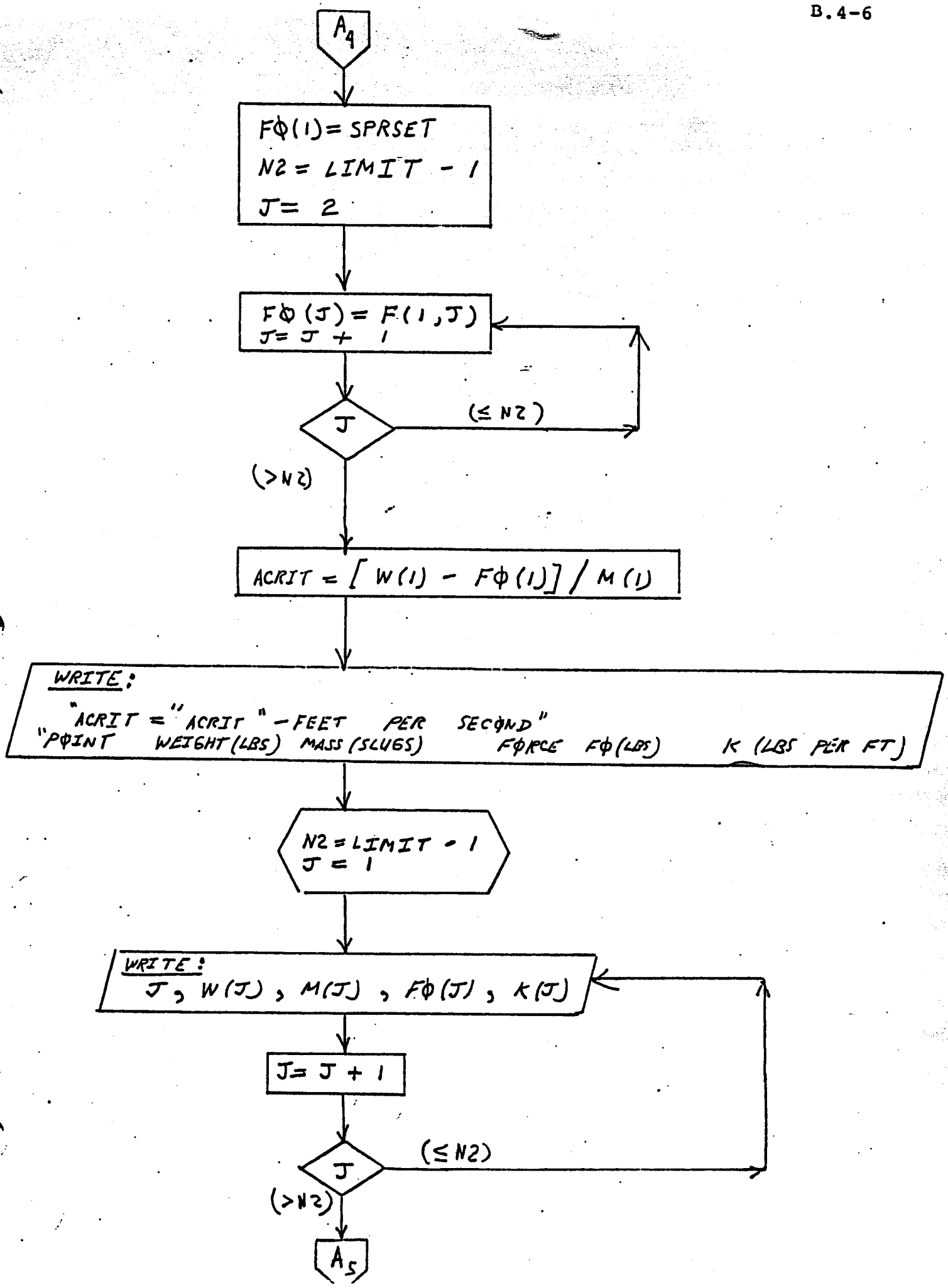
Ø = letter "OH"
O = numera zero
* = multiplication ; / = division
I = letter "i"
1 = numeral one

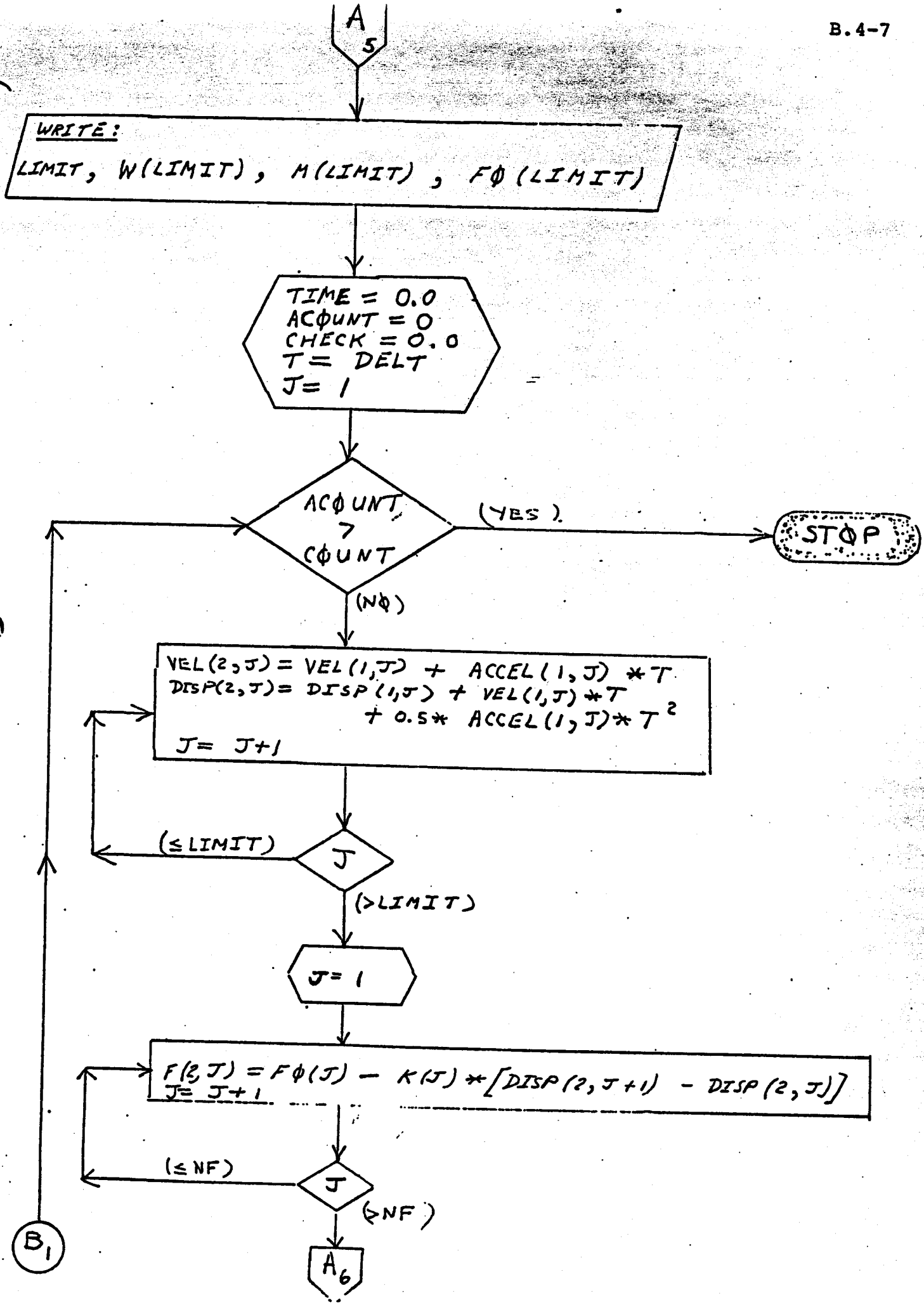

BEGIN
READ:
TITLE
WRITE:
TITLE
READ:
XNF, XNB, DELT, SMAX, CØUNT, TPRINT, FLIMIT, VERT
NF = XNF + 2
NB = XNB
LIMIT = NF + NB + 1
PRINT = TPRINT
READ:
WTCABL, WTCAGE, WTPASS, WTBALL, W(LIMIT),
XL1, XL2, XL3
W(1) = WTCAGE + WTPASS
W(2) = WTBALL
XNF ≤ 0.0
(NØ)
J = 3
(YES)
W(J) = (WTCABL * XL1)/XNF
J = J + 1
(>NF)
J
(≤ NF)
A1

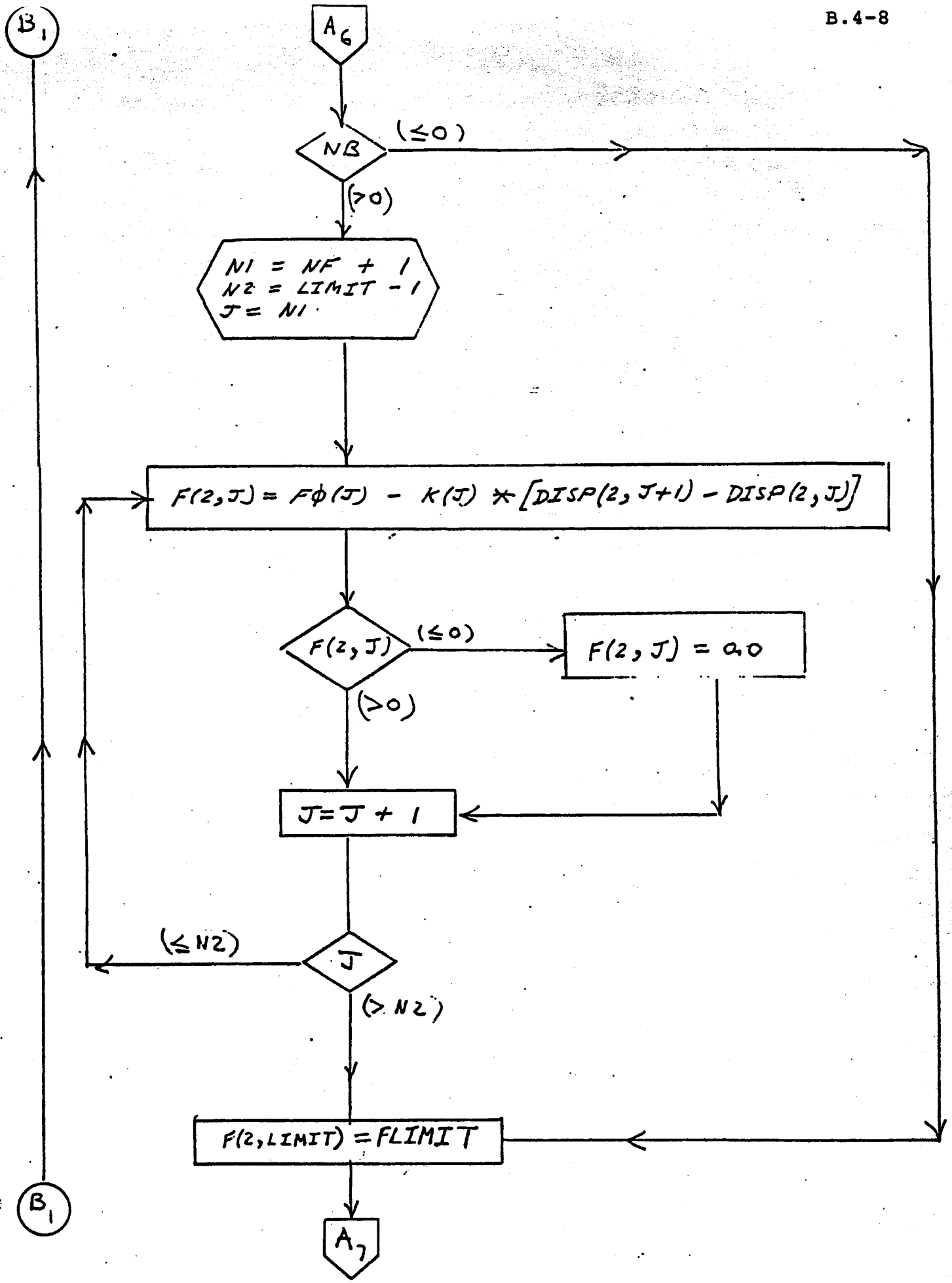

A1
NB ≤ 0
(NO)
N1 = NF + 1
N2 = LIMIT - 1
J = N1
(YES)
W(J) = (WTCABL * XL3)/XNB
J = J + 1
(> N2)
J
(≤ N2)
J = 1
M(J) = W(J)/32.2
J = J + 1
(≤ LIMIT)
J
(> LIMIT)
F(1,1) = W(1)
SUM = W(1)
J = 2
SUM = SUM + W(J)
F(1,J) = SUM
J = J + 1
(≤ NF)
J
(> NF)
A2

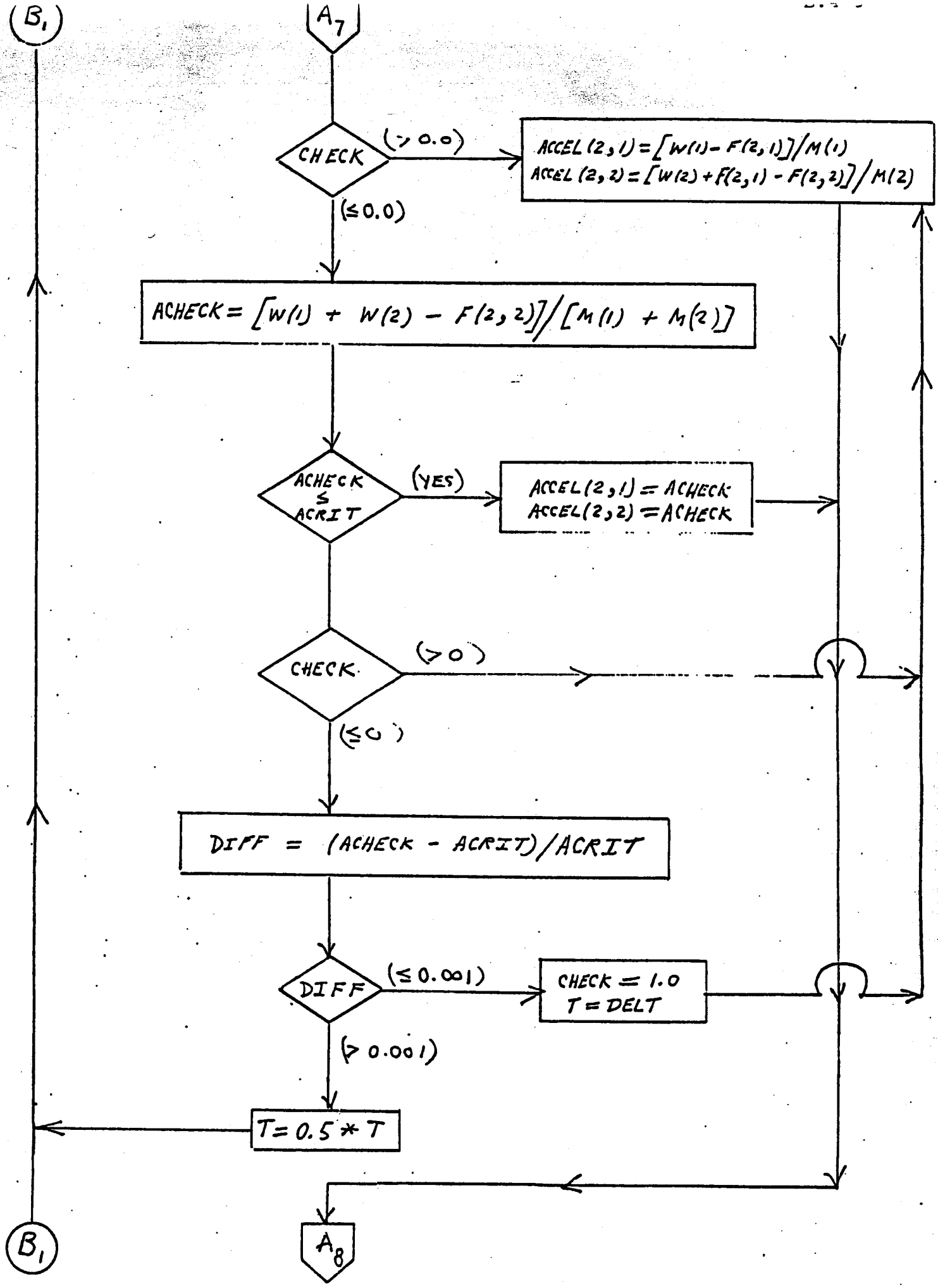

A2
SUM=0.0
NB
(> 0)
(≤ 0)
N1 = NF + 1
N2 = LIMIT - 1
J = N1
SUM = SUM + W(J)
F(1,J) = F(1,NF) - SUM
J = J + 1
J
(> N2)
(≤ N2)
F(1, LIMIT) = FLIMIT
J = 1
VEL(1,J) = 0.0
DISP(1,J) = 0.0
ACCEL(1,J) = 0.0
J = J + 1
J
(≤ LIMIT)
(> LIMIT)
ACCEL(1, LIMIT) = [F(1, LIMIT-1) - F(1,LIMIT)] / M(LIMIT)
VERT
(≤ 0)
(> 0)
ACCEL(1, LIMIT)
= [F(1, LIMIT) - W(LIMIT)
- F(1,LIMIT)] / M(LIMIT)
READ:
XINIT
XINIT
(> 0)
(≤ 0)
L = XINIT
I = 1
READ:
XJ, VELØRG, ACCØRG, SØRG
J = XJ
VEL(1,J) = VELØRG
ACCEL(1,J) = ACCØRG
DISP(1,J) = SØRG
I = I + 1
I
(> L)
(≤ L)
A3

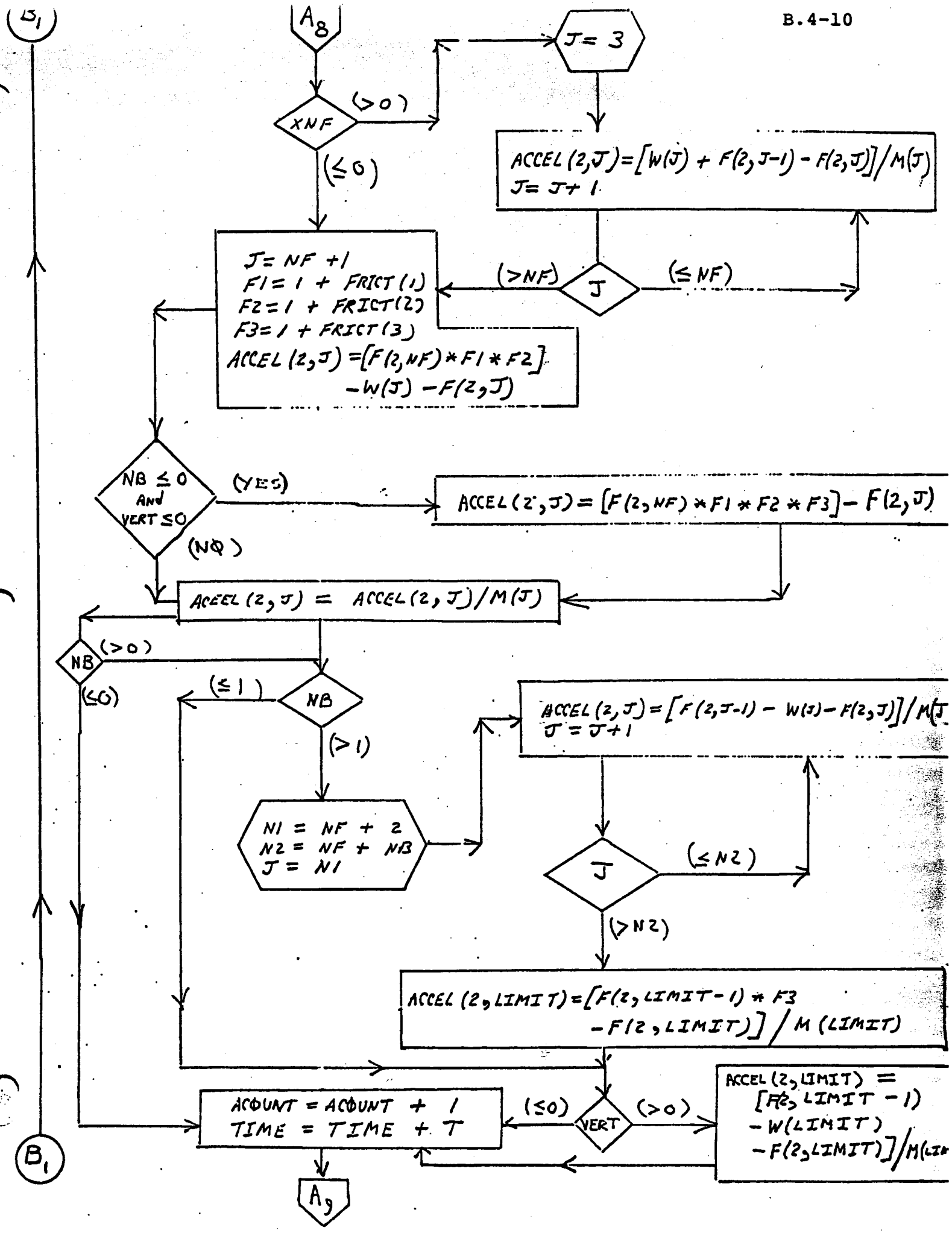

A3
READ:
SPRCAG . SPRSET . ECABLE . ACABLE . FRICT(1) . FRICT(2) . FRICT(3)
K(1)= SPRCAG
SPRCAB = [XL1 / (XNF +1)] / (ACABLE * ECABLE)
J= 2
K(J)= SPRCAB
J= J + 1
J
(≤ NF)
(> NF)
SPRCAB = XL2 / (ACABLE * ECABLE)
K(NF) = K(NF) + SPRCAB
SPRCAB = [XL3 / (XNB + 1)] / (ACABLE * ECABLE)
K(NF) = K(NF) + SPRCAB
NB
(>0)
(≤0)
N1 = NF + 1
N2 = LIMIT - 1
J = N1
K(J) = SPRCAB
J = J + 1
J
(> N2)
(≤ N2)
J = 2
K(J)= 1/ K(J)
J= J + 1
J
(≤ N2)
(> N2)
A4

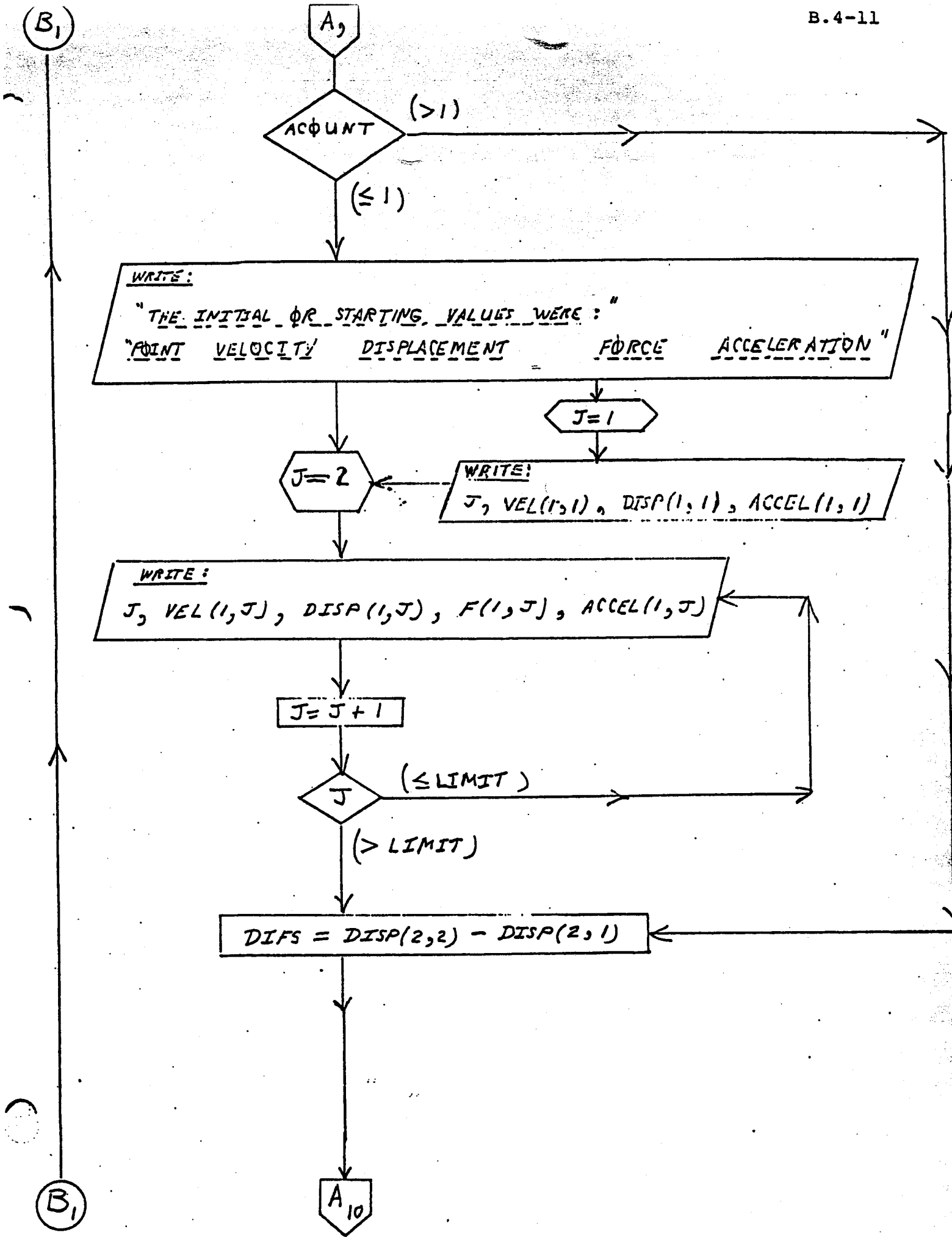

A4
FΦ(1) = SPRSET
N2 = LIMIT - 1
J = 2
FΦ(J) = F(1,J)
J = J + 1
J
(≤ N2)
(>N2)
ACRIT = [W(1) - FΦ(1)] / M(1)
WRITE:
"ACRIT = " ACRIT " - FEET PER SECOND"
"PΦINT WEIGHT (LBS) MASS (SLUGS) FΦRCE FΦ (LBS) K (LBS PER FT)
N2 = LIMIT - 1
J = 1
WRITE:
J, W(J), M(J), FΦ(J), K(J)
J = J + 1
J
(≤ N2)
(>N2)
A5

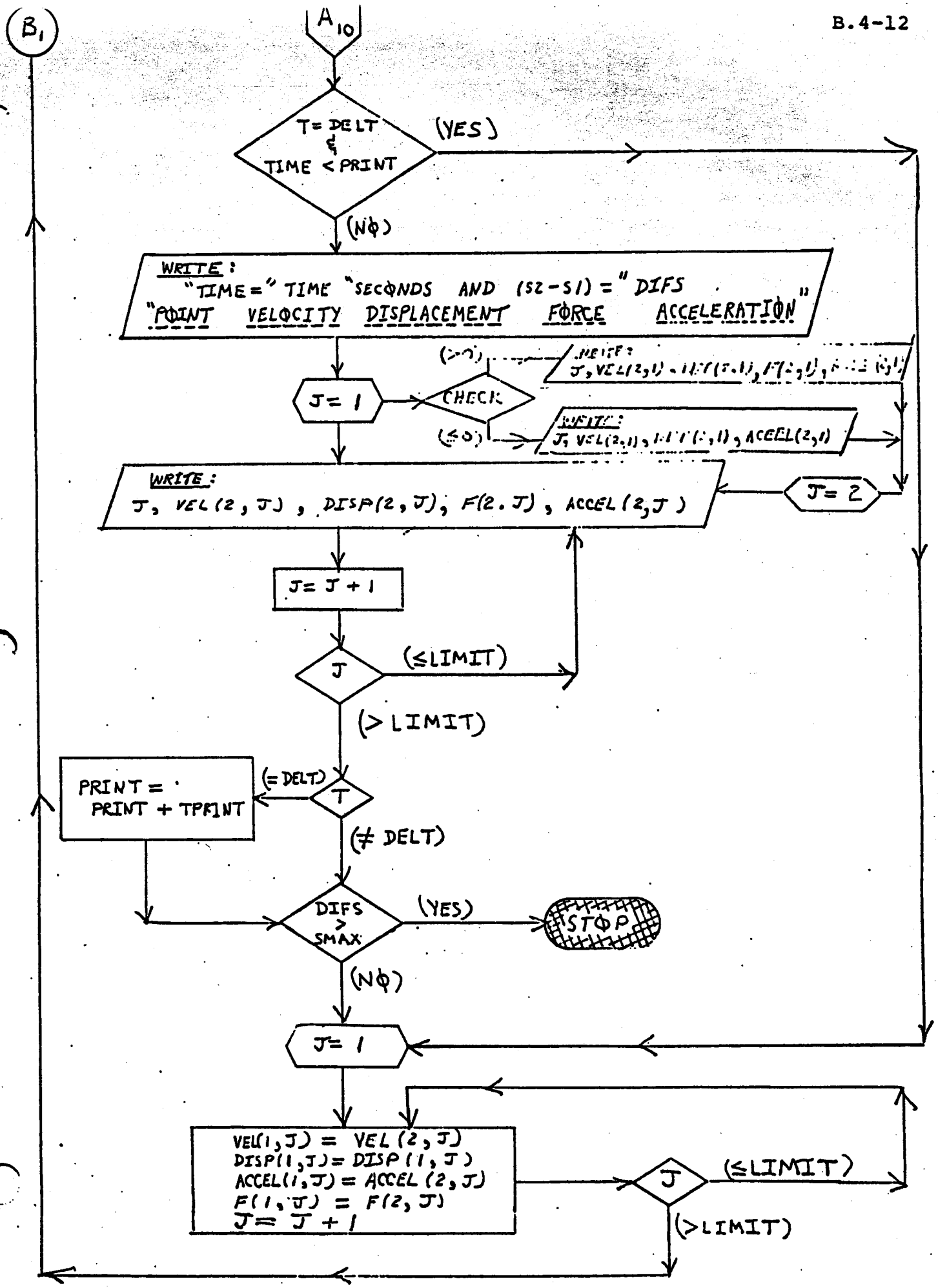

A5
WRITE:
LIMIT, W(LIMIT), M(LIMIT), FØ(LIMIT)
TIME = 0.0
ACØUNT = 0
CHECK = 0.0
T = DELT
J = 1
ACØUNT > CØUNT
(YES)
STØP
(NØ)
VEL(2,J) = VEL(1,J) + ACCEL(1,J) * T
DISP(2,J) = DISP(1,J) + VEL(1,J) * T + 0.5 * ACCEL(1,J) * T²
J = J+1
(≤ LIMIT)
J
(> LIMIT)
J = 1
F(2,J) = FØ(J) − K(J) * [DISP(2,J+1) − DISP(2,J)]
J = J+1
(≤ NF)
J
(> NF)
B1
A6


B1
A6
NB
(≤0)
(>0)
N1 = NF + 1
N2 = LIMIT - 1
J = N1
F(2,J) = FΦ(J) - K(J) * [DISP(2,J+1) - DISP(2,J)]
F(2,J)
(≤0)
F(2,J) = 0.0
(>0)
J=J + 1
J
(≤N2)
(>N2)
F(2,LIMIT) = FLIMIT
B1
A7


B1
A7
CHECK
(> 0.0)
ACCEL (2,1) = [W(1) - F(2,1)]/M(1)
ACCEL (2,2) = [W(2) + F(2,1) - F(2,2)]/M(2)
(≤ 0.0)
ACHECK = [W(1) + W(2) - F(2,2)]/[M(1) + M(2)]
ACHECK ≤ ACRIT
(YES)
ACCEL(2,1) = ACHECK
ACCEL(2,2) = ACHECK
CHECK
(> 0)
(≤ 0)
DIFF = (ACHECK - ACRIT)/ACRIT
DIFF
(≤ 0.001)
CHECK = 1.0
T = DELT
(> 0.001)
T = 0.5 * T
B1
A8


B1
A8
XNF
(>0)
(≤0)
J= 3
ACCEL (2,J)=[W(J) + F(2,J-1) - F(2,J)]/M(J)
J= J+ 1
J
(>NF)
(≤NF)
J= NF +1
F1= 1 + FRICT (1)
F2= 1 + FRICT(2)
F3= 1 + FRICT (3)
ACCEL (2,J) =[F(2,NF)*F1*F2]
-W(J) -F(2,J)
NB ≤ 0 AND VERT ≤0
(YES)
(NO)
ACCEL(2,J)= [F(2,NF)*F1*F2*F3]- F(2,J)
ACCEL (2,J) = ACCEL(2,J)/M(J)
NB
(>0)
(≤0)
(≤1)
NB
(>1)
N1 = NF + 2
N2 = NF + NB
J = N1
ACCEL (2,J)=[F(2,J-1) - W(J)-F(2,J)]/M(J
J = J+1
J
(≤N2)
(>N2)
ACCEL (2,LIMIT)=[F(2,LIMIT-1)*F3
-F(2,LIMIT)] / M (LIMIT)
ACOUNT = ACOUNT + 1
TIME = TIME + T
(≤0)
VERT
(>0)
ACCEL (2,LIMIT) =
[F(2,LIMIT -1)
-W(LIMIT)
-F(2,LIMIT)]/M(LI
A9
B1


B1
A9
ACØUNT
(>1)
(≤1)
WRITE:
"THE INITIAL ØR STARTING VALUES WERE :"
"ØINT VELOCITY DISPLACEMENT FØRCE ACCELERATION"
J=1
WRITE:
J, VEL(1,1), DISP(1,1), ACCEL(1,1)
J=2
WRITE:
J, VEL(1,J), DISP(1,J), F(1,J), ACCEL(1,J)
J=J+1
J
(≤LIMIT)
(>LIMIT)
DIFS = DISP(2,2) - DISP(2,1)
B1
A10


B1
A10
T = DELT & TIME < PRINT
(YES)
(NΦ)
WRITE:
"TIME =" TIME "SECONDS AND (S2 - S1) =" DIFS
"POINT VELOCITY DISPLACEMENT FORCE ACCELERATION"
J = 1
CHECK
(>0)
(≤0)
WRITE:
J, VEL(2,1), DISP(2,1), ACCEL(2,1)
J = 2
WRITE:
J, VEL(2,J), DISP(2,J), F(2,J), ACCEL(2,J)
J = J + 1
J
(≤LIMIT)
(> LIMIT)
PRINT = PRINT + TPRINT
(= DELT)
T
(≠ DELT)
DIFS > SMAX
(YES)
STOP
(NΦ)
J = 1
VEL(1,J) = VEL(2,J)
DISP(1,J) = DISP(1,J)
ACCEL(1,J) = ACCEL(2,J)
F(1,J) = F(2,J)
J = J + 1
J
(≤LIMIT)
(>LIMIT)

Appendix B.5

Sample Analysis

Input File

```
MANCHESTER, OHIO
0.0       5.        .0005     .073      600.      .01       0.
.71       2160.     800.      600.      57.       10.       10.       900.
0.
5316.     1772.     13500000. .1543     .03       .03
```

Output File

MANCHESTER, OHIO

ACRIT = 12.923514-FT/SEC/SEC

POINT	WEIGHT(LBS)	MASS(SLUGS)	FORCE FO(LBS)	K(LB/FT)
1	2960.000	91.925	1772.000	5316.000
2	600.000	18.634	3560.000	12253.235
3	127.800	3.969	3432.200	13887.000
4	127.800	3.969	3304.400	13887.000
5	127.800	3.969	3176.600	13887.000
6	127.800	3.969	3048.800	13887.000
7	127.800	3.969	2921.000	13887.000
8	57.000	1.770	0.000	

THE INITIAL OR STARTING VALUES WERE:

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	0.0000	0.0000	2960.000	0.0000
2	0.0000	0.0000	3560.000	0.0000
3	0.0000	0.0000	3432.200	0.0000
4	0.0000	0.0000	3304.400	0.0000
5	0.0000	0.0000	3176.600	0.0000
6	0.0000	0.0000	3048.800	0.0000
7	0.0000	0.0000	2921.000	0.0000
8	0.0000	0.0000	0.000	1650.1088

TIME = .01000000 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.0008	.0000	1772.000	.2607
2	.0008	.0000	3531.175	.2607
3	.4717	.0024	3464.110	38.8803
4	.0239	.0001	3305.176	7.8443
5	.0004	.0000	3176.328	.2641
6	.0125	.0000	3020.052	7.1747
7	.8374	.0021	1869.991	257.5650
8	14.5953	.0778	0.000	1056.3807

TIME = .02050000 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.0069	.0000	1772.000	.9724
2	.0069	.0000	3452.498	.9724
3	.6868	.0088	3540.285	-1.3429
4	.1897	.0010	3317.511	23.9291
5	.0275	.0001	3156.055	8.4800
6	.4444	.0016	2605.892	106.4169
7	5.9080	.0335	0.000	624.3706
8	19.5527	.2681	0.000	0.0000

TIME = .03050000 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.0200	.0002	1772.000	1.6501
2	.0200	.0002	3377.571	1.6501
3	.5094	.0151	3582.356	-31.9709
4	.4596	.0042	3345.542	27.4667
5	.2875	.0013	2993.323	56.5437
6	2.5041	.0145	1580.419	323.7900
7	11.0138	.1202	0.000	365.9963
8	19.5527	.4637	0.000	0.0000

TIME = .04050000 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.0384	.0005	1772.000	1.9888
2	.0384	.0005	3340.123	1.9888
3	.1564	.0184	3547.090	-33.0951
4	.7093	.0101	3325.782	23.5598
5	1.3780	.0086	2481.056	180.6339
6	6.5958	.0587	473.588	473.5940
7	13.2954	.2441	0.000	87.1234
8	19.5527	.6592	0.000	0.0000

TIME = .05050000 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.0584	.0009	1772.000	1.9639
2	.0584	.0009	3342.874	1.9639
3	-.0561	.0187	3432.622	-3.5192
4	1.0376	.0186	3091.420	53.7681
5	3.9766	.0340	1591.297	345.7652
6	11.1407	.1481	0.000	368.7372
7	13.3513	.3784	0.000	-32.2000
8	19.5527	.8547	0.000	0.0000

TIME = .06050000 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.0775	.0016	1772.000	1.8876
2	.0775	.0016	3351.311	1.8876
3	.1410	.0186	3232.884	49.0613
4	2.0101	.0330	2473.329	159.1746
5	7.9414	.0928	658.842	424.9713
6	13.6694	.2742	0.000	133.7993
7	13.0293	.5103	0.000	-32.2000
8	19.5527	1.0502	0.000	0.0000

TIME = .07050000 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.0978	.0025	1772.000	2.3374
2	.0978	.0025	3301.582	2.3374
3	.9702	.0236	2879.234	124.8731
4	4.3283	.0634	1509.169	312.9964
5	11.8634	.1927	91.147	325.0792
6	14.2287	.4149	0.000	-9.2348
7	12.7073	.6390	0.000	-32.2000
8	19.5527	1.2458	0.000	0.0000

TIME = .08050000 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.1282	.0036	1772.000	4.1428
2	.1282	.0036	3101.979	4.1428
3	2.6752	.0410	2275.612	223.6055
4	8.0132	.1243	526.401	408.5245
5	14.0807	.3243	0.000	100.4301
6	13.8284	.5556	144.686	-68.6545
7	12.5075	.7648	0.000	4.2545
8	19.5527	1.4413	0.000	0.0000

TIME = 09050000 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.1872	.0051	1772.000	8.3448
2	.1872	.0051	2637.409	8.3448
3	5.3675	.0804	1431.019	312.2262
4	11.9328	.2245	0.000	328.3541
5	14.2261	.4672	83.352	-53.2009
6	13.0214	.6900	262.073	-77.2299
7	12.7209	.8907	0.000	33.8308
8	19.5527	1.6368	0.000	0.0000

TIME = .09712500 SECONDS AND S2-S1 = 0.00000000

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.2556	.0066	1772.000	12.9051
2	.2556	.0066	2133.220	12.9051
3	7.5109	.1230	838.380	326.7754
4	13.6448	.3098	0.000	179.0351
5	13.7860	.5601	196.622	-81.7401
6	12.5922	.7747	257.914	-47.6430
7	12.9502	.9757	0.000	32.7831
8	19.5527	1.7664	0.000	0.0000

TIME = .10012500 SECONDS AND S2-S1 = .00000931

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.2883	.0073	1771.951	12.9241
2	.3007	.0073	1896.062	25.5393
3	8.3291	.1431	629.828	315.9289
4	14.0437	.3449	0.000	126.4891
5	13.5686	.5948	236.807	-91.8650
6	12.4859	.8065	241.940	-33.4934
7	13.0295	1.0086	0.000	28.7584
8	19.5527	1.8159	0.000	0.0000

TIME = .11012500 SECONDS AND S2-S1 = .00164170

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.4178	.0108	1763.273	13.0185
2	.8318	.0125	764.459	85.8030
3	10.9455	.2406	0.000	172.1401
4	14.4713	.4888	19.792	-37.1867
5	12.5129	.7254	328.127	-109.8870
6	12.4036	.9305	139.945	15.2136
7	13.2023	1.1399	0.000	3.0601
8	19.5527	2.0114	0.000	0.0000

TIME = .12012500 SECONDS AND S2-S1 = .01041911

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.5499	.0157	1716.612	13.5260
2	1.9962	.0261	-452.460	148.6069
3	11.0940	.3535	0.000	-153.1428
4	13.7523	.6306	309.803	-110.2567
5	11.8043	.8462	269.026	-21.9260
6	12.6330	1.0556	47.364	23.6489
7	13.1126	1.2717	0.000	-20.2662
8	19.5527	2.2069	0.000	0.0000

TIME = .13012500 SECONDS AND S2-S1 = .03237531

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.6904	.0218	1599.893	14.7958
2	3.7025	.0542	-1322.168	189.0172
3	8.3360	.4527	0.000	-385.6158
4	12.3918	.7617	487.267	-154.9699
5	11.9924	.9645	145.419	53.9307
6	12.7764	1.1828	10.150	1.8819
7	12.8535	1.4016	0.000	-29.6427
8	19.5527	2.4024	0.000	0.0000

TIME = .14012500 SECONDS AND S2-S1 = .07134656

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	.8483	.0295	1392.722	17.0494
2	5.6276	.1009	-1516.114	188.3075
3	4.0637	.5151	0.000	-437.4577
4	10.8912	.8779	394.743	-131.6580
5	12.5793	1.0874	81.235	46.7903
6	12.6969	1.3103	16.699	-15.9397
7	12.5587	1.5287	0.000	-27.9926
8	19.5527	2.5980	0.000	0.0000

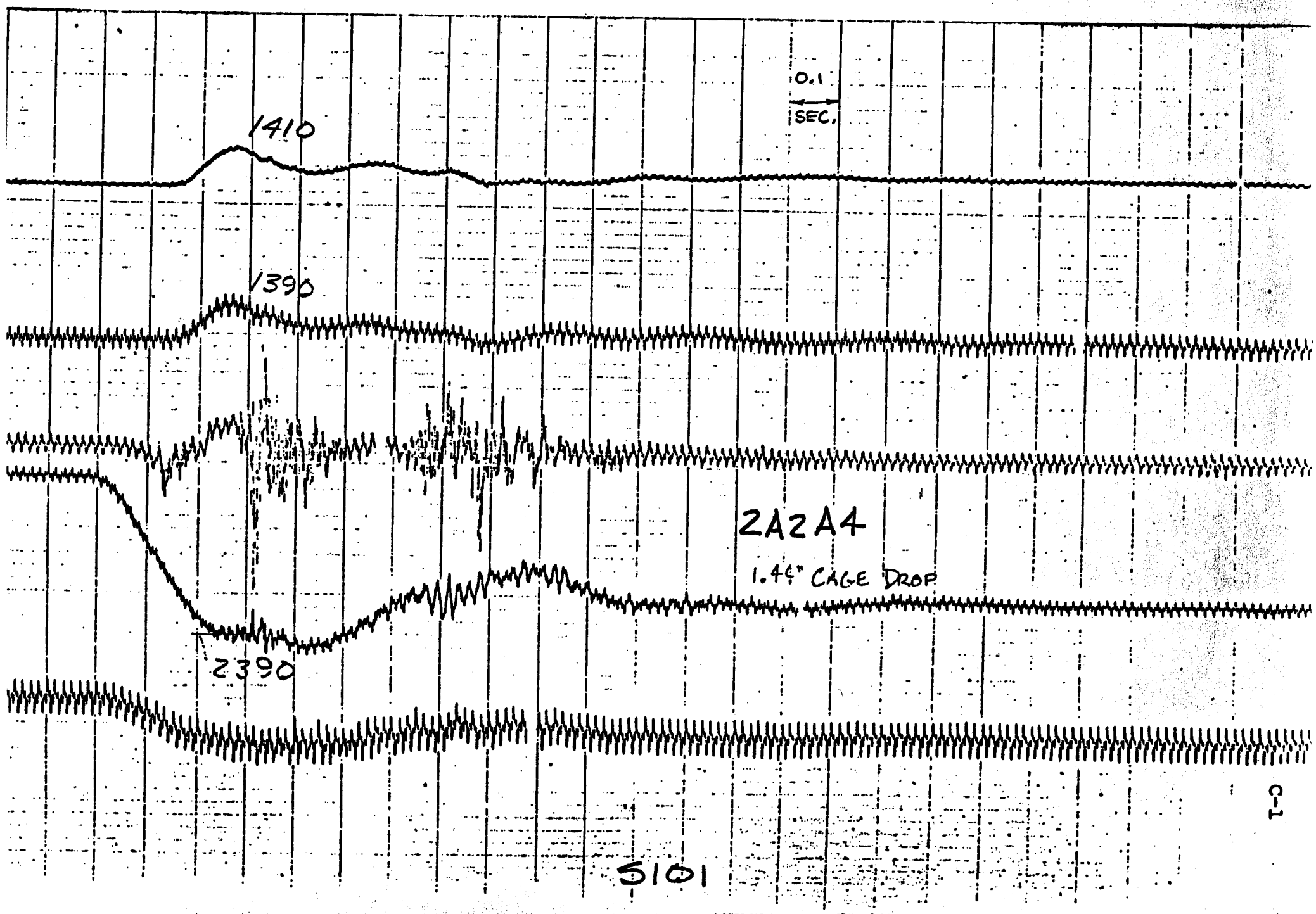
TIME = .15012500 SECONDS AND S2-S1 = .12711928

POINT	VELOCITY	DISPLACEMENT	FORCE	ACCELERATION
1	1.0333	.0389	1096.234	20.2748
2	7.3290	.1660	-966.550	142.9027
3	.2353	.5354	0.000	-290.5591
4	9.9351	.9814	67.511	-49.2099
5	12.6799	1.2145	94.019	-38.8789
6	12.5162	1.4364	41.890	-19.0657
7	12.3069	1.6530	0.000	-21.6456
8	19.5527	2.7935	0.000	0.0000

-END OF FILE-

Appendix C

Oscillograph Plots



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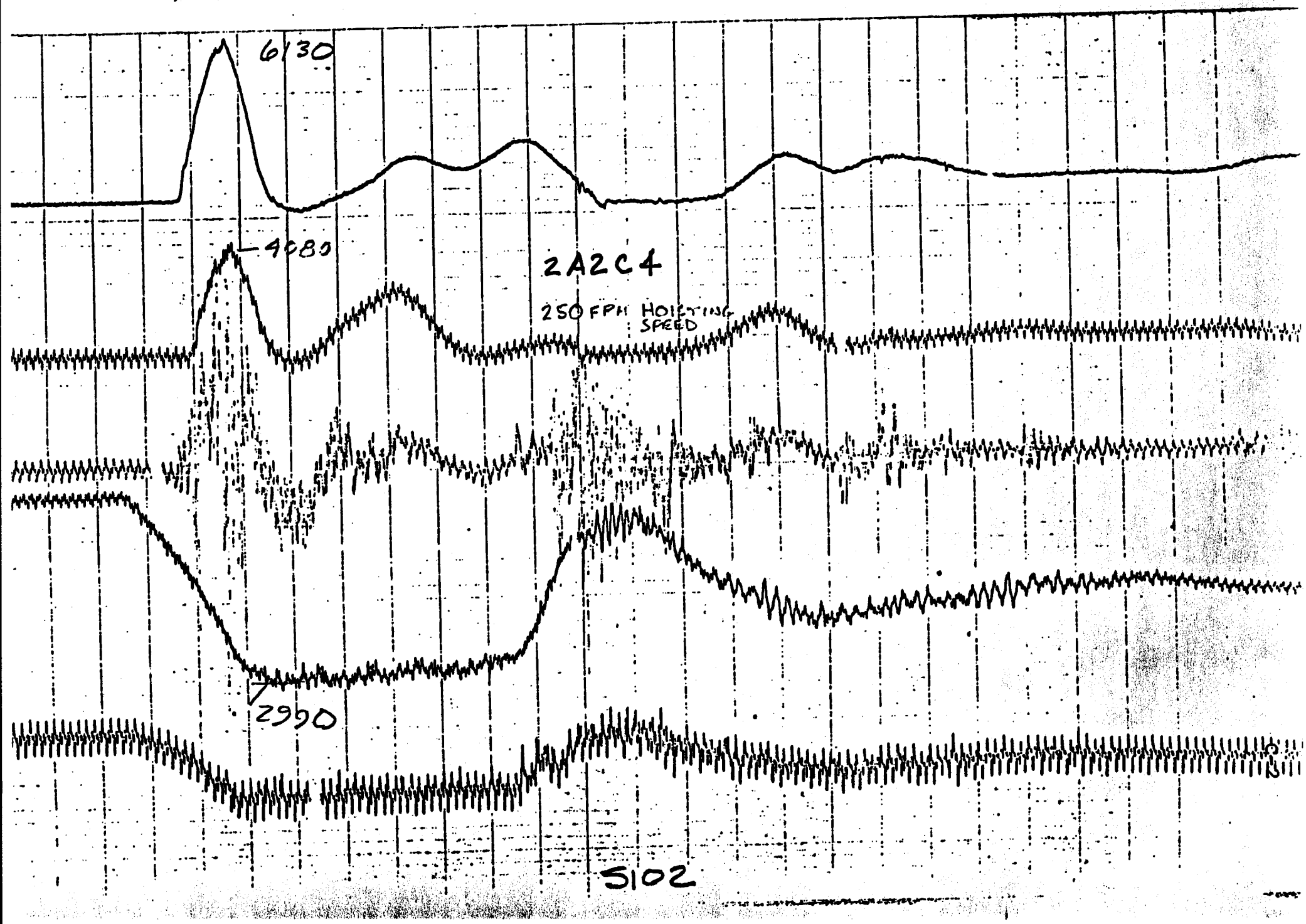
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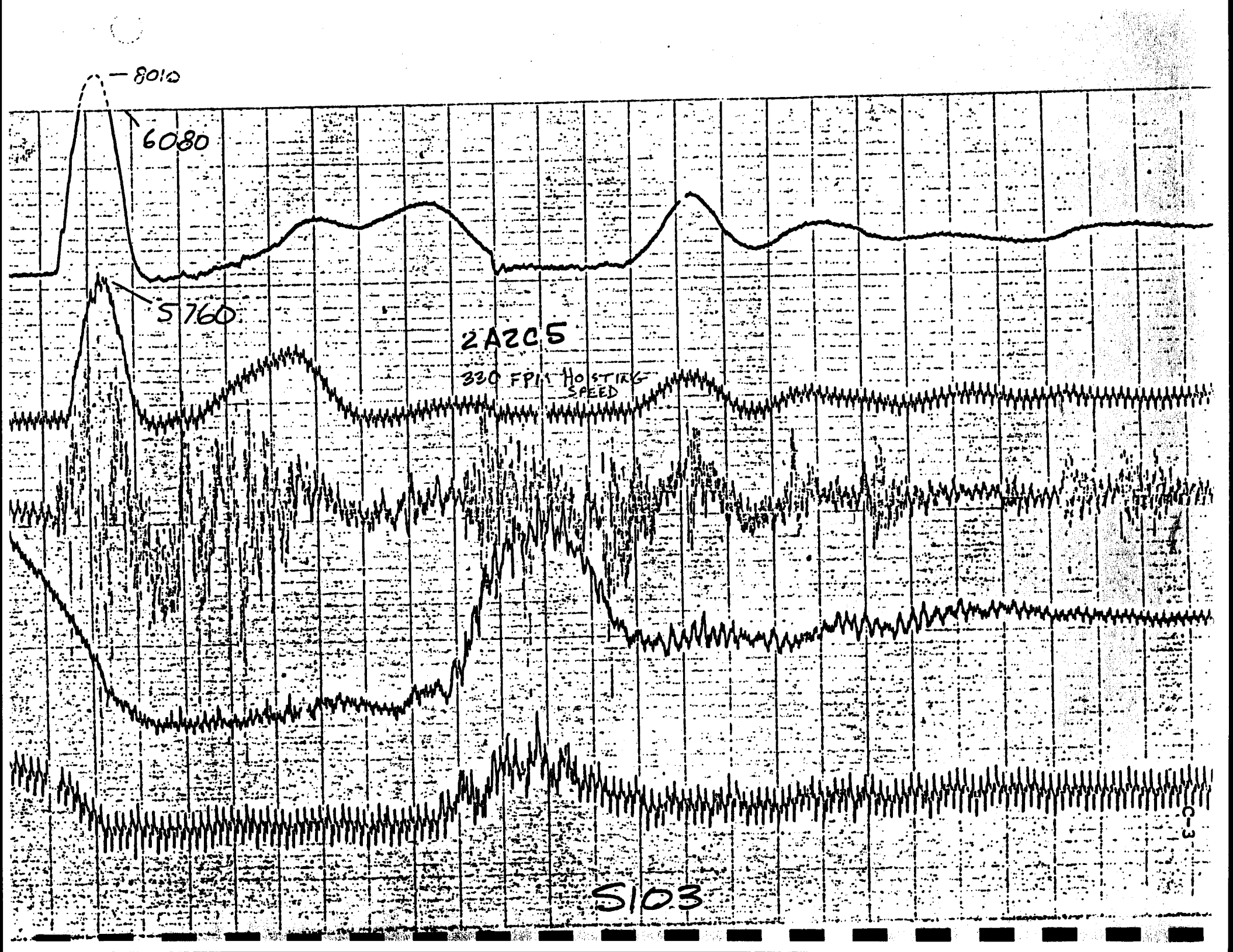
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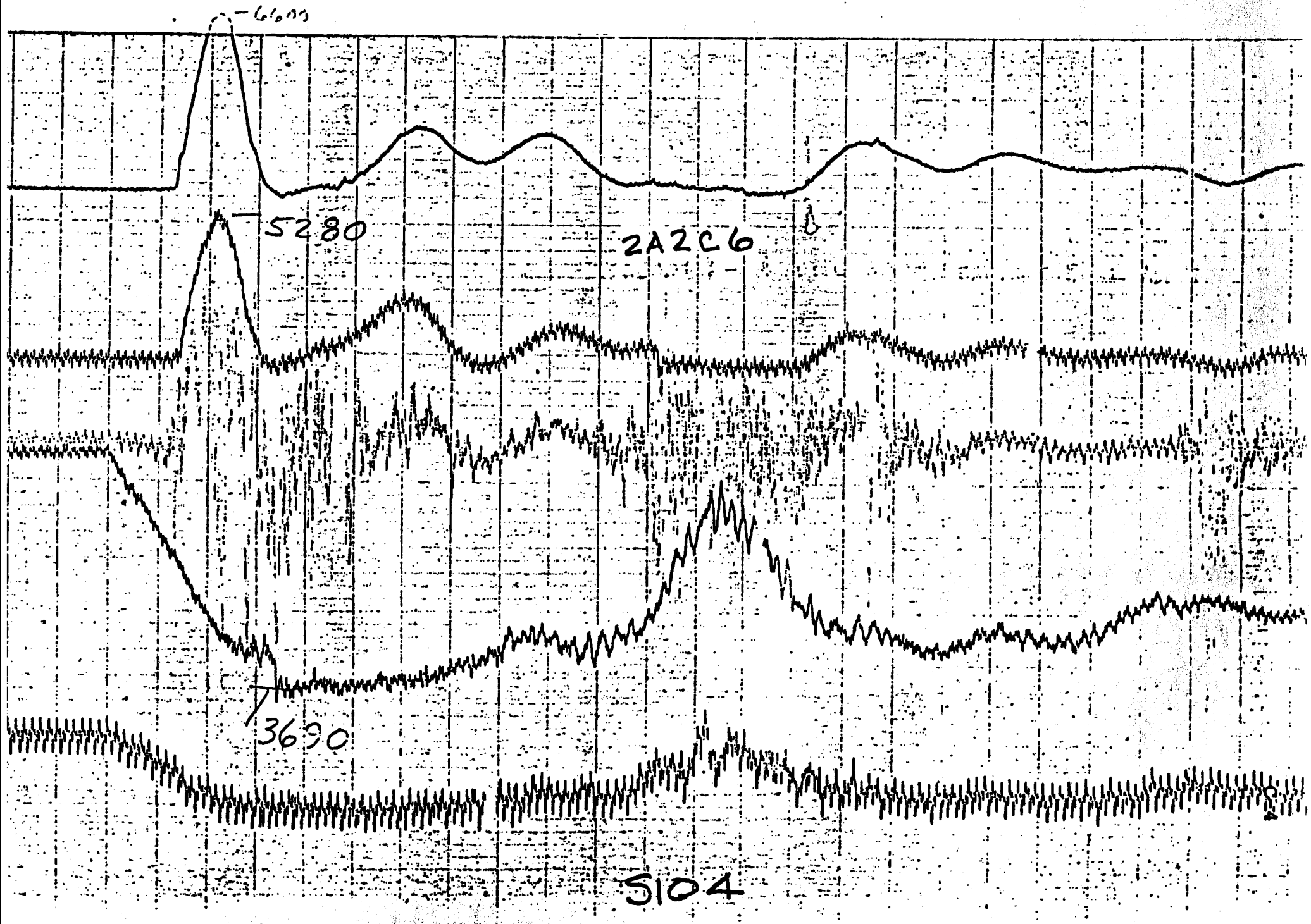
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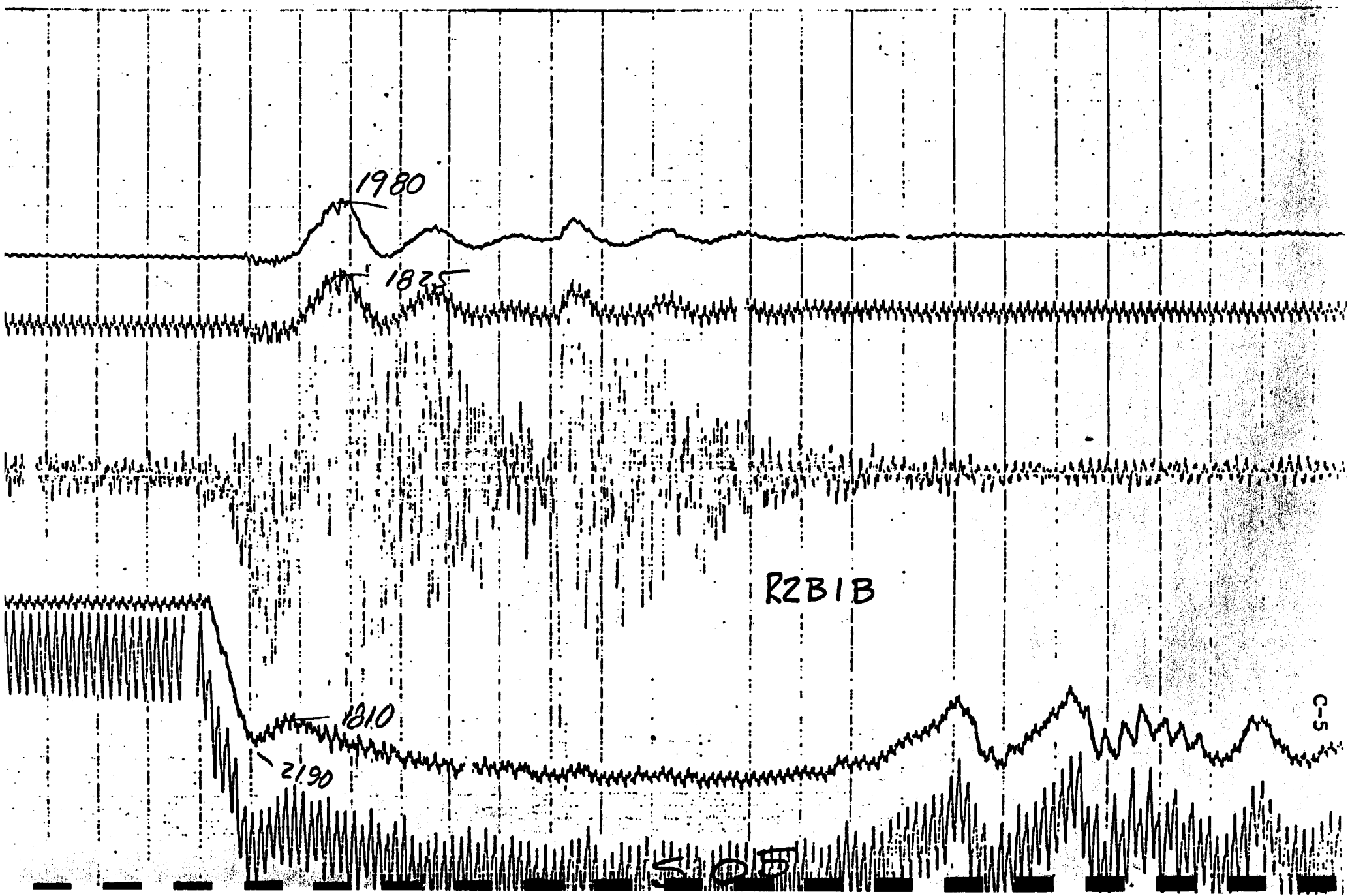
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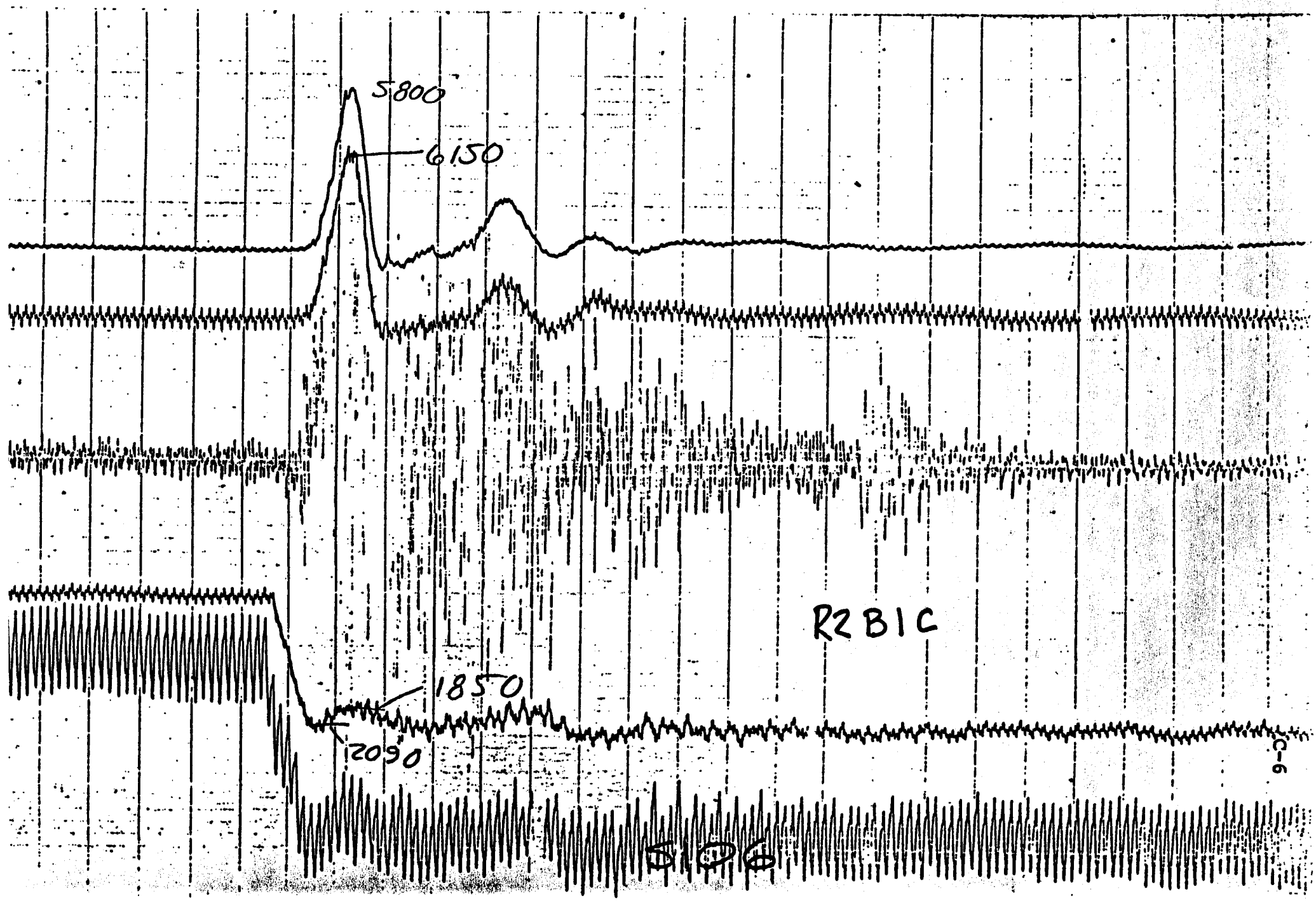
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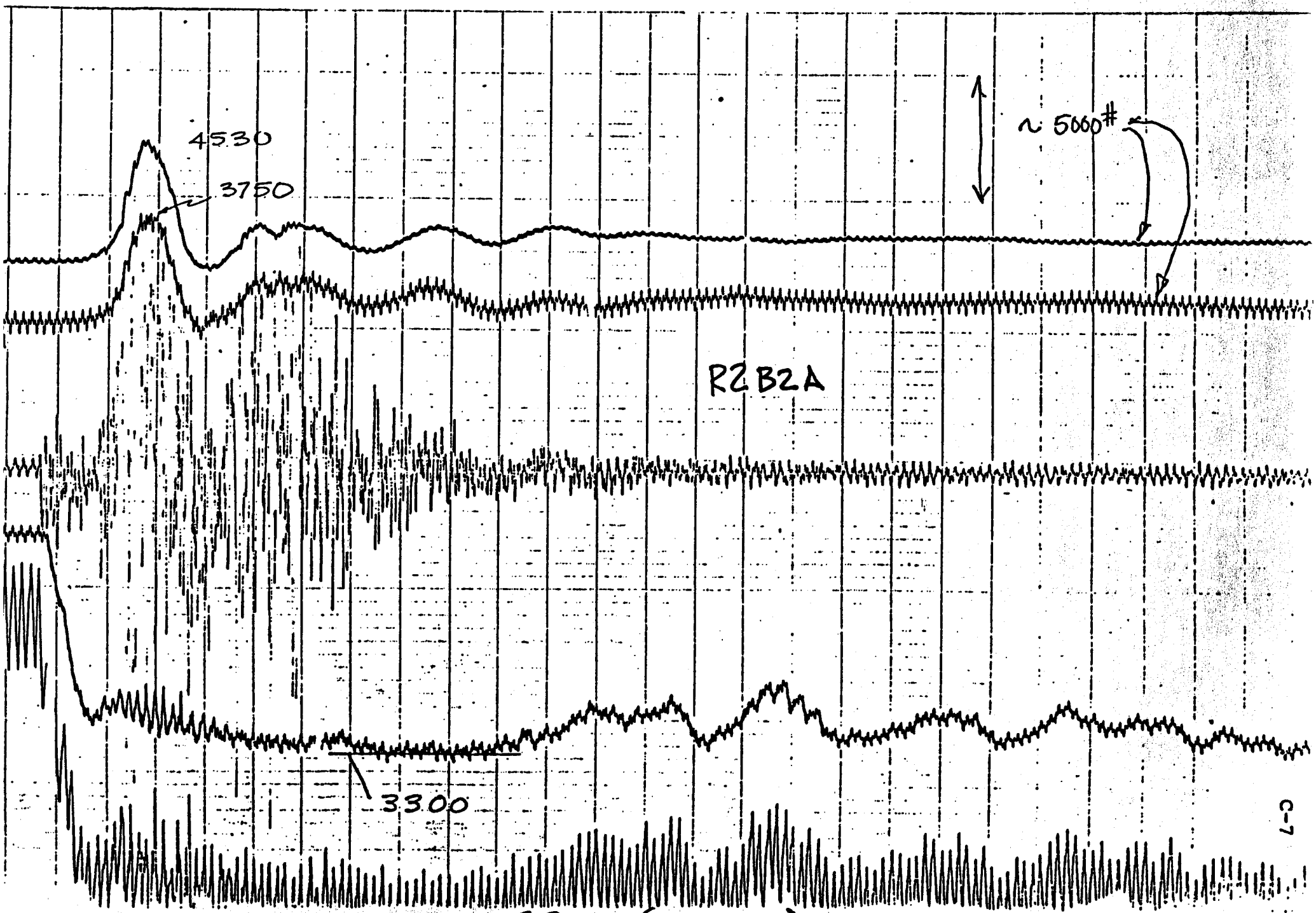

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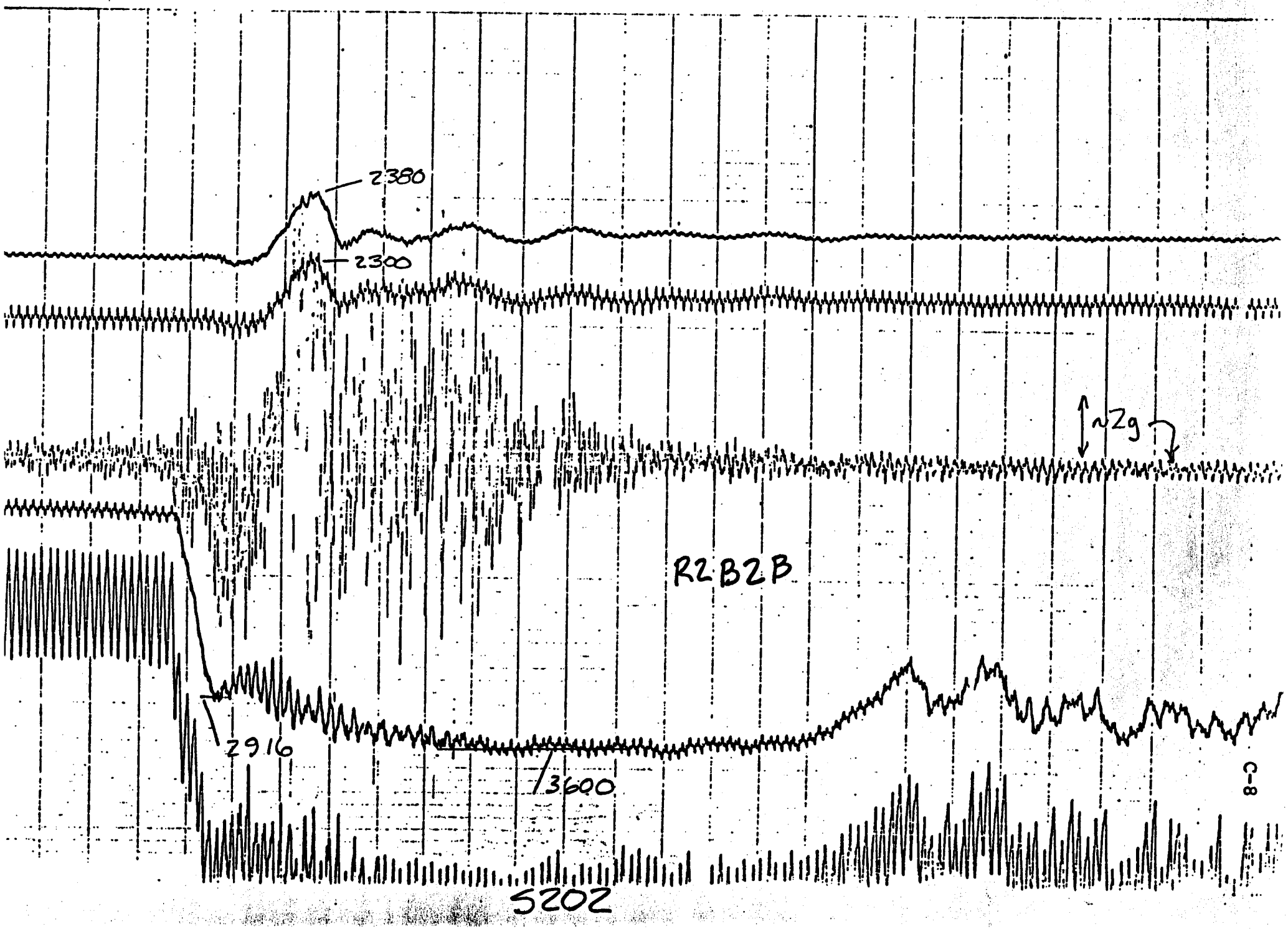
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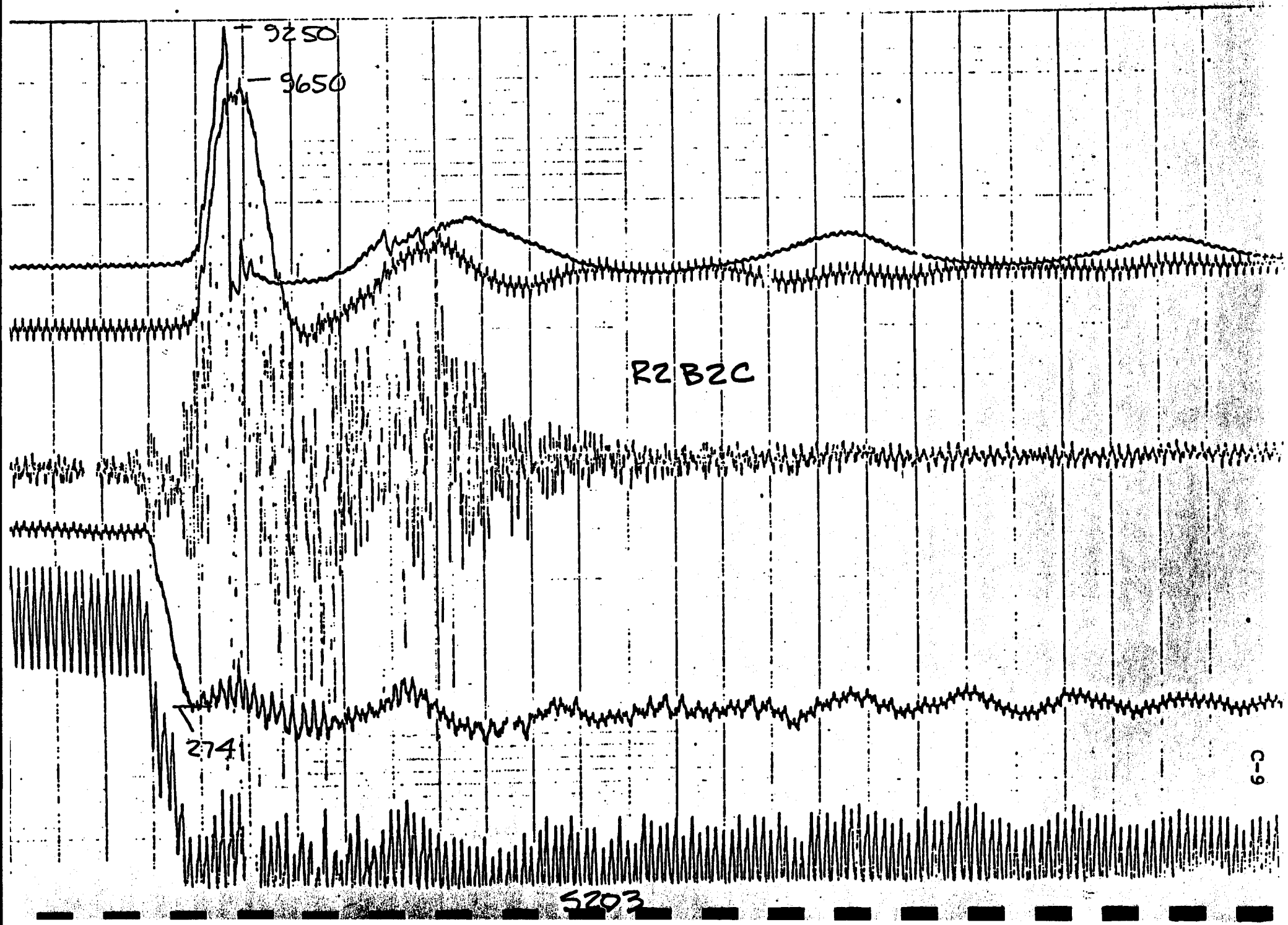
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— 9650
R2 B2C
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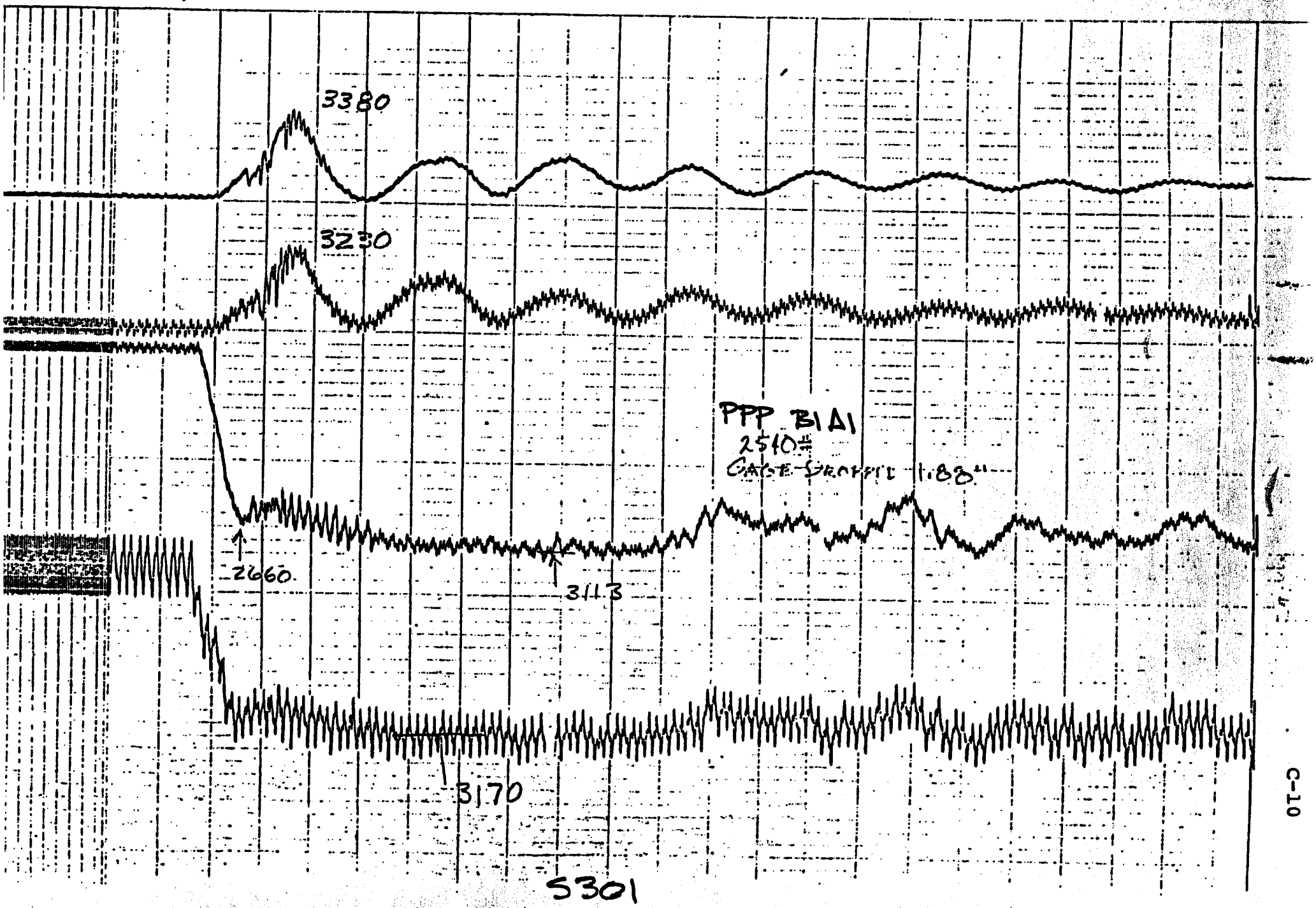
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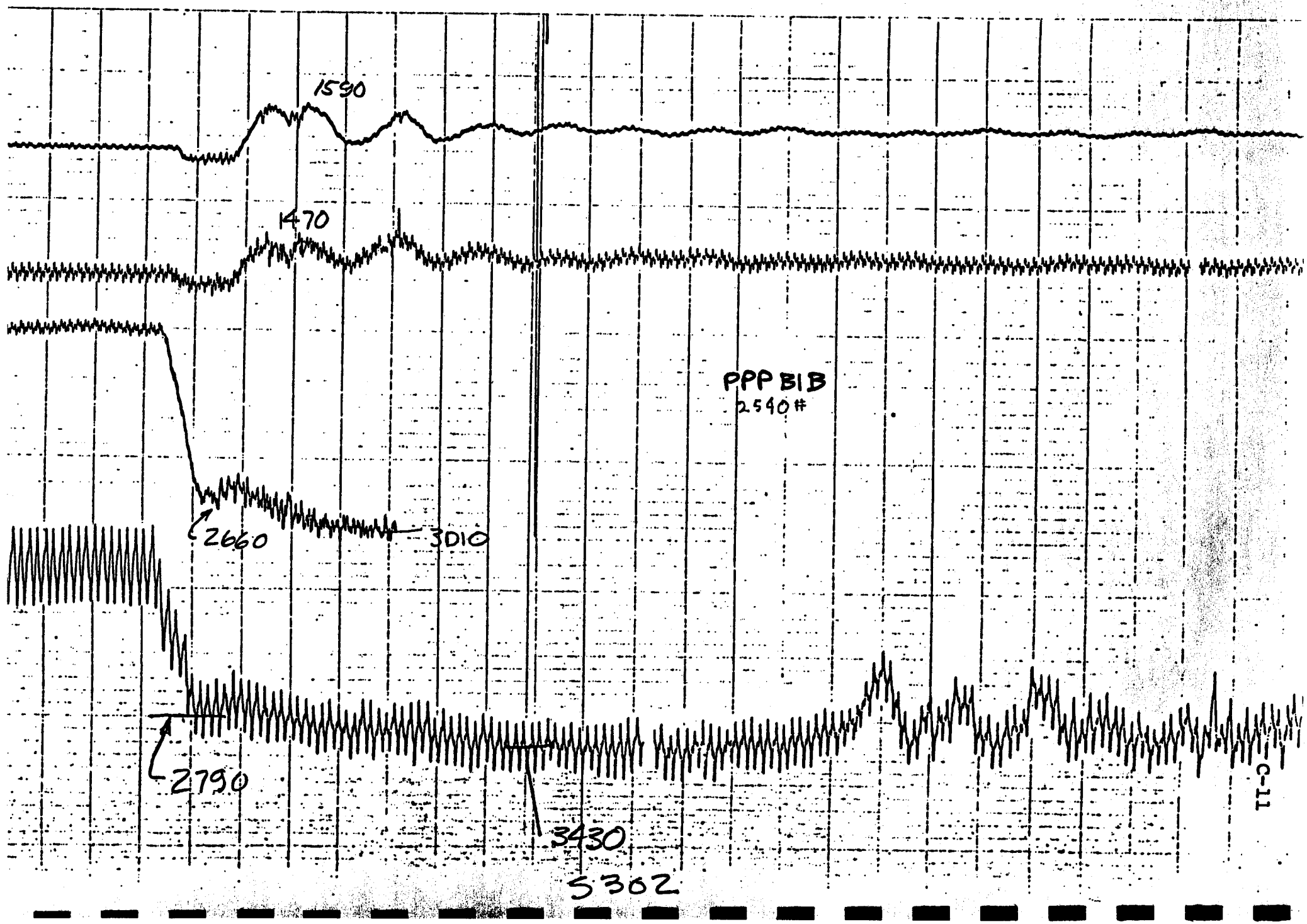
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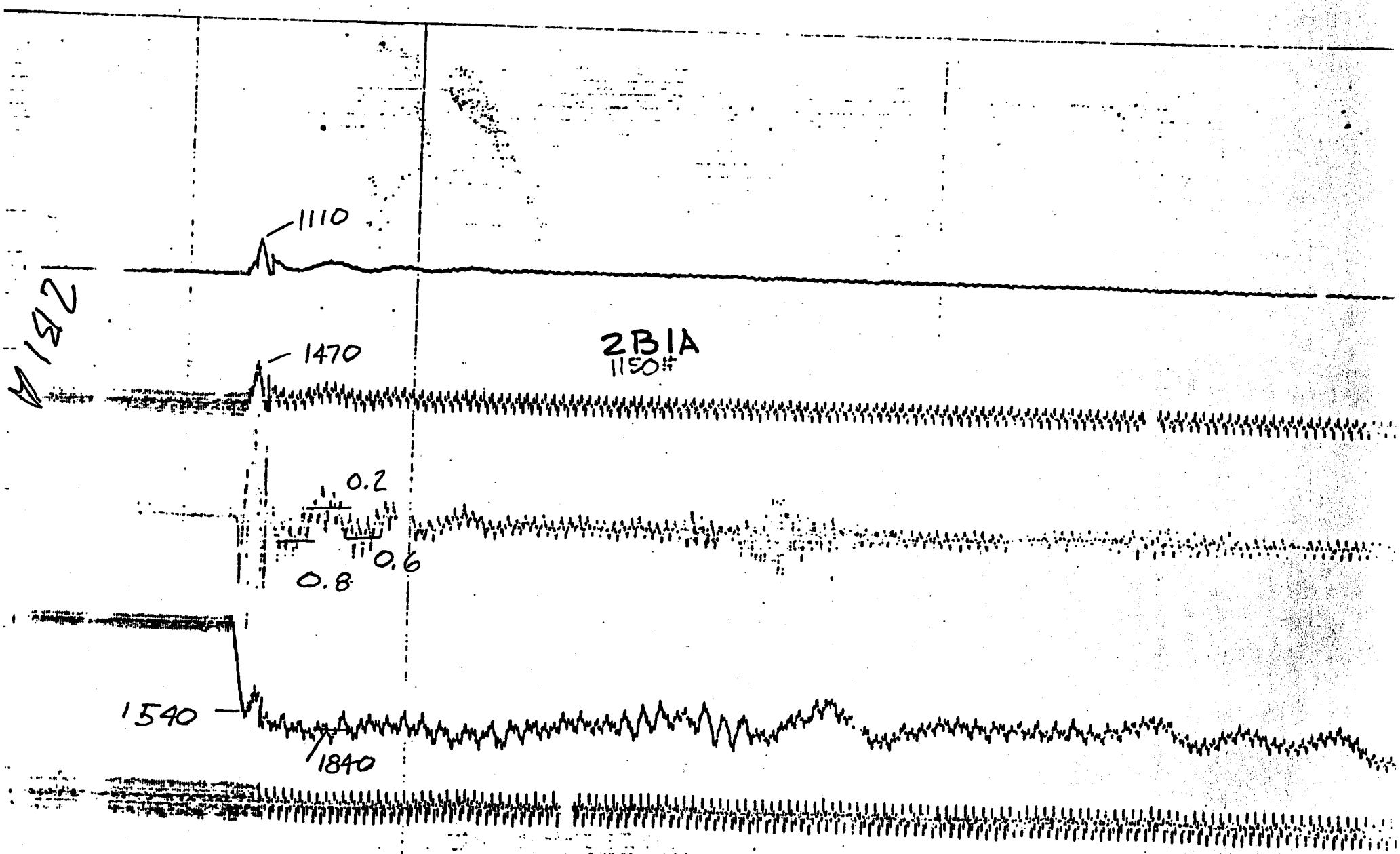

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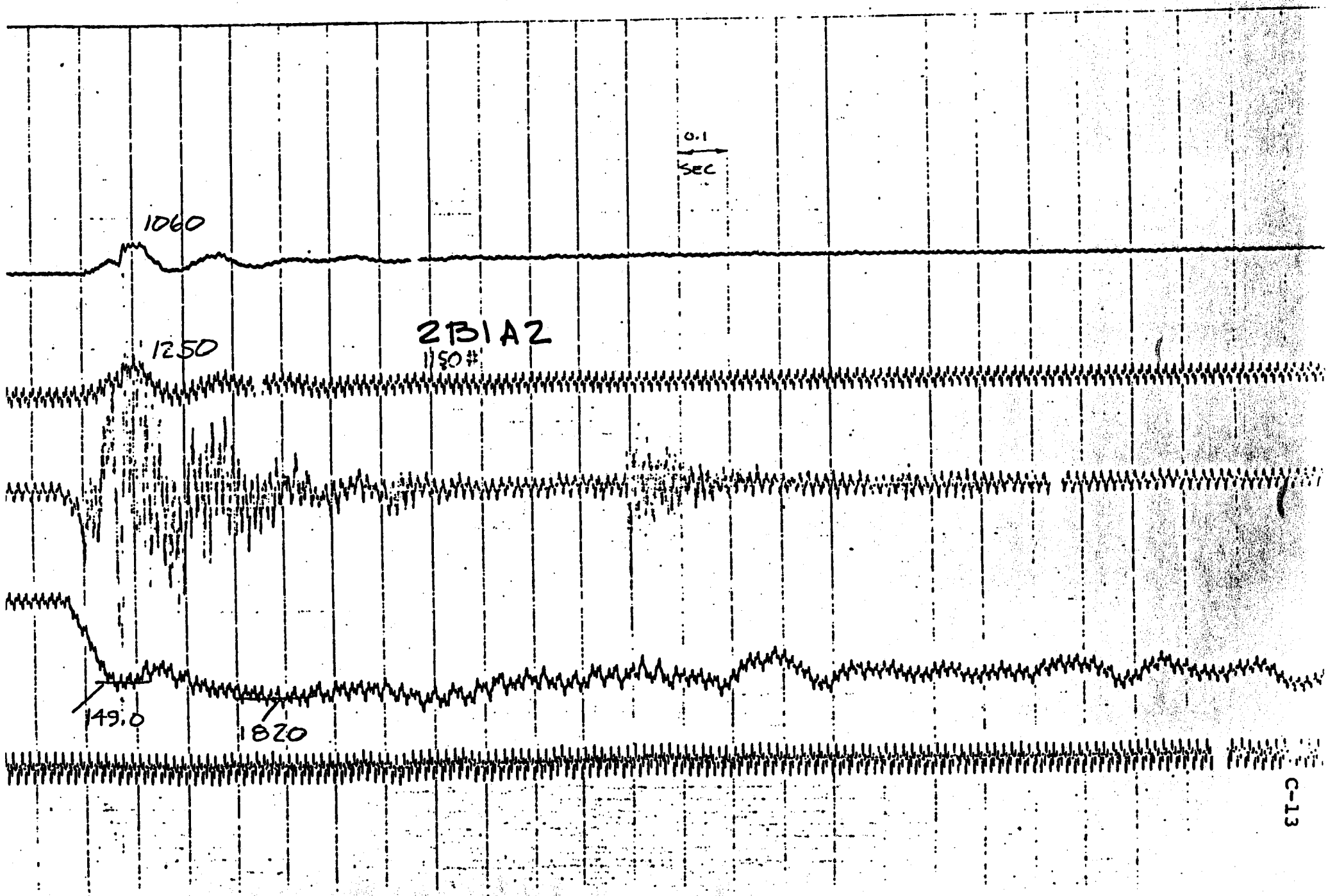
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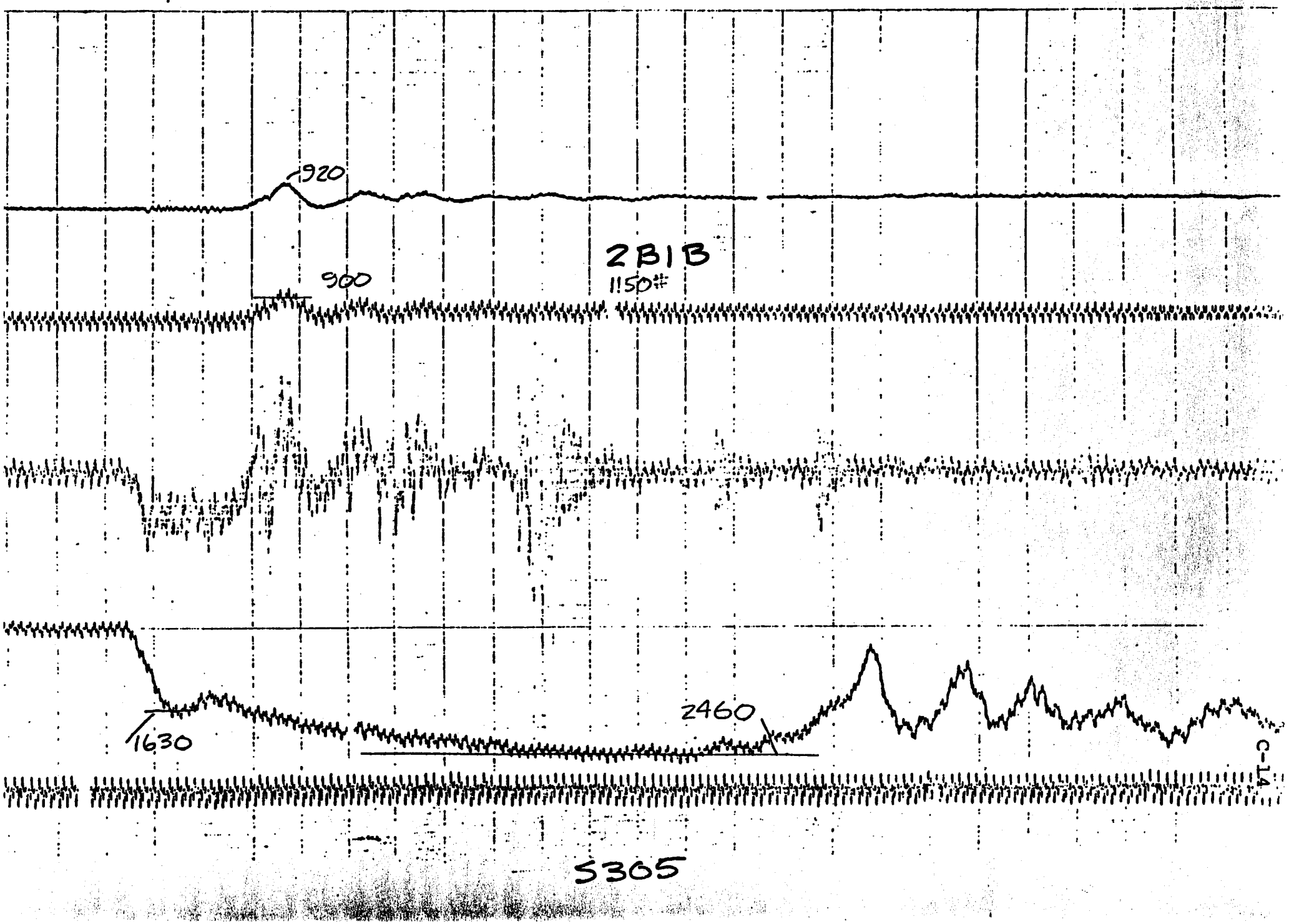
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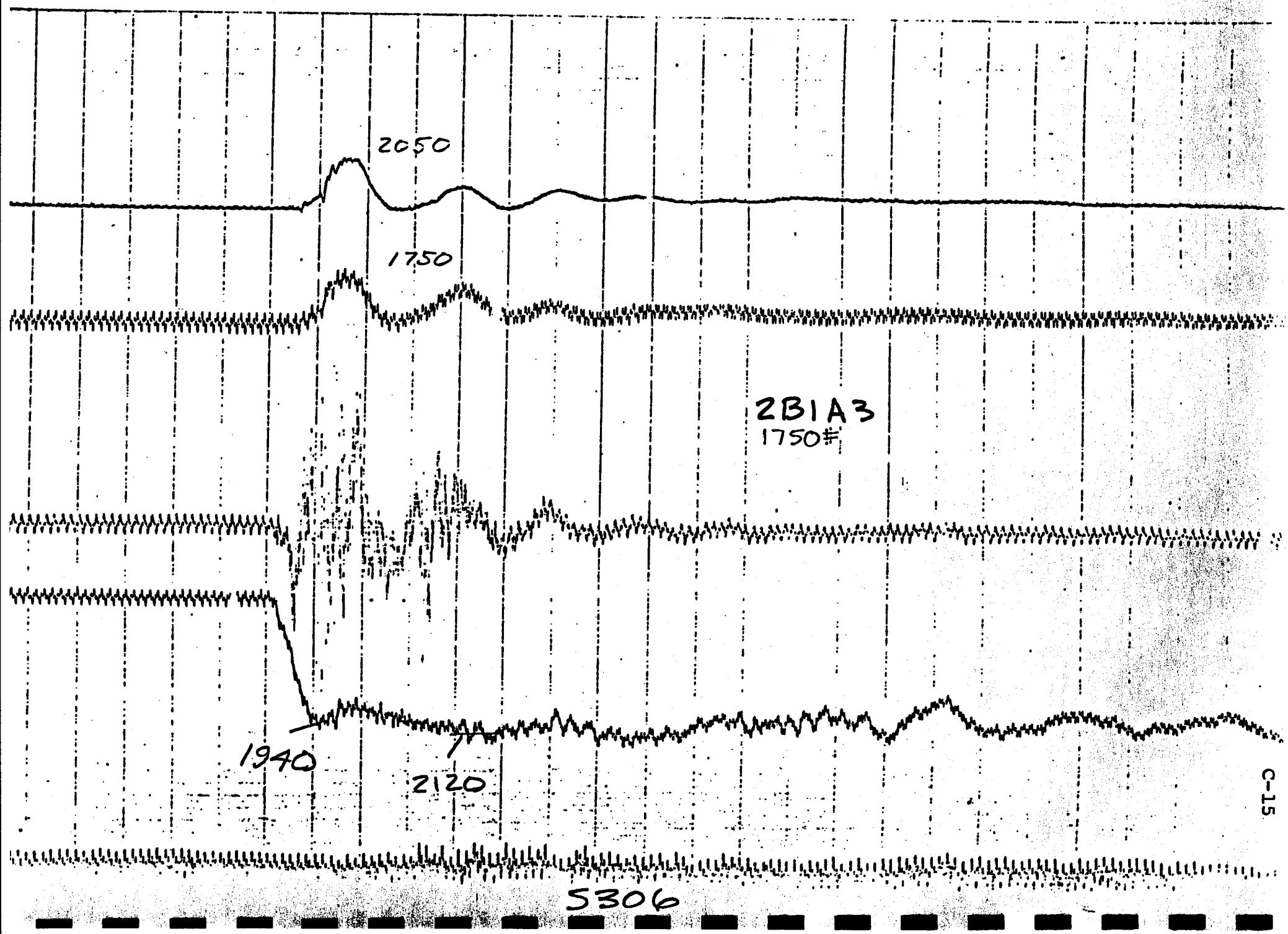
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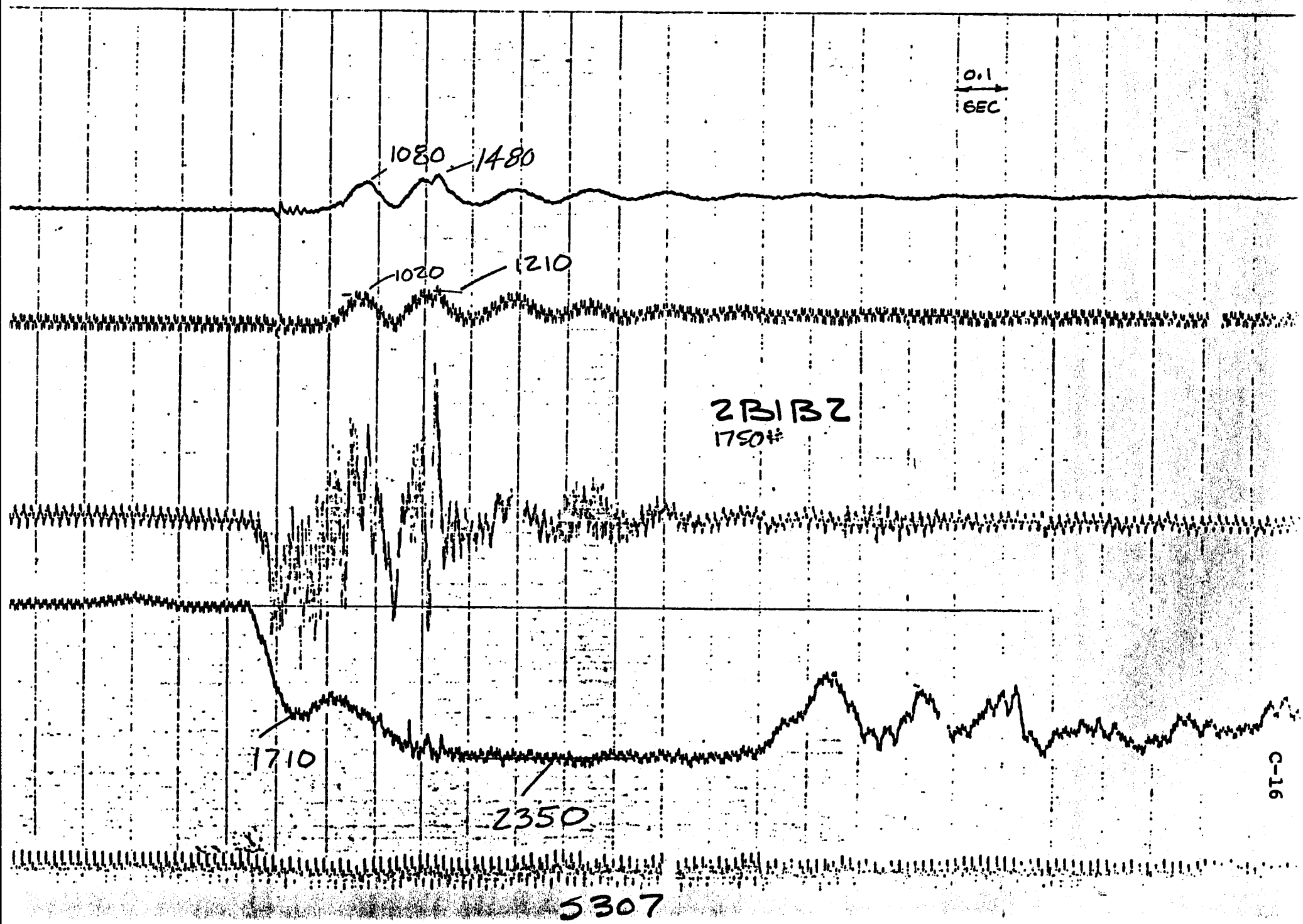
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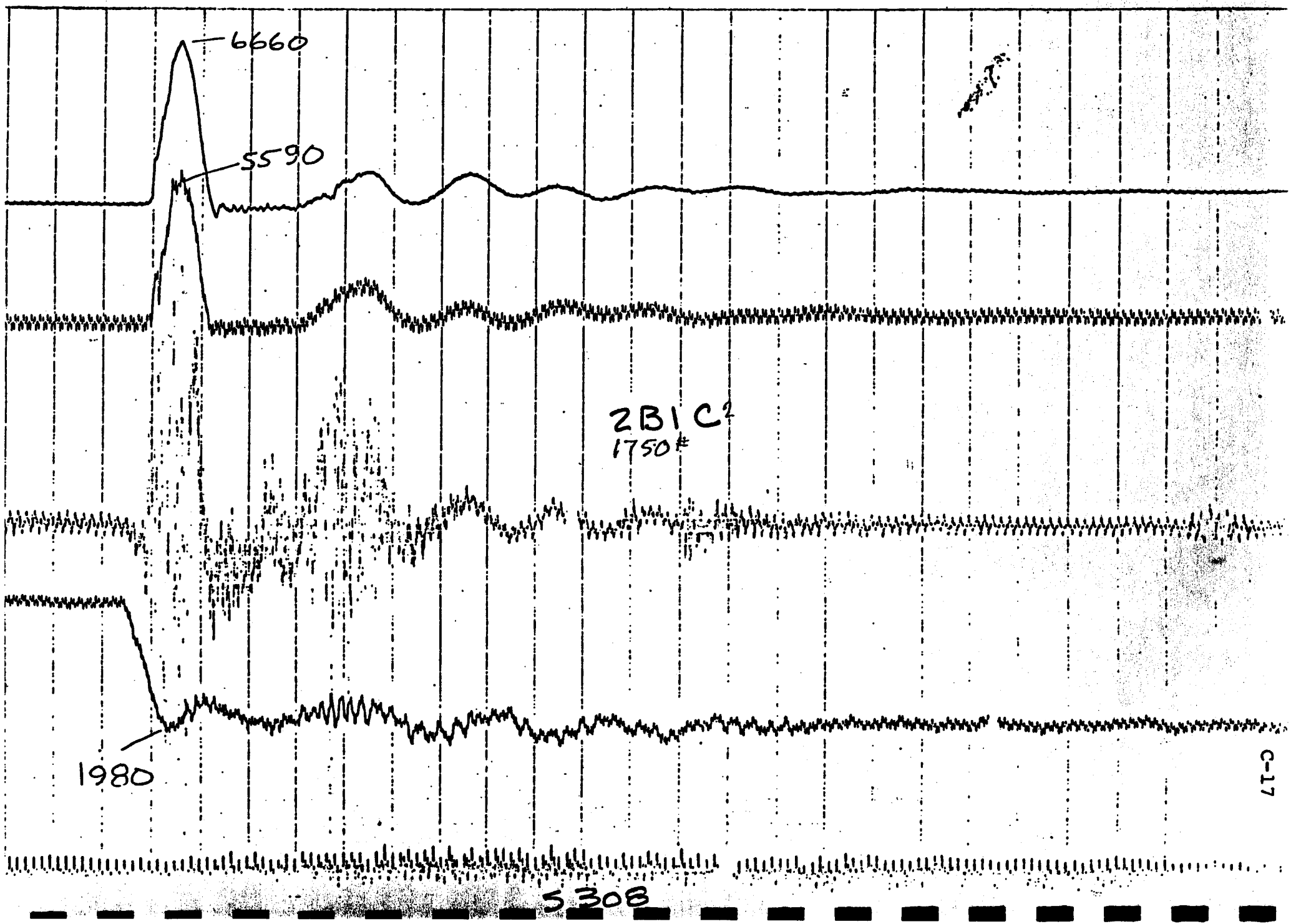
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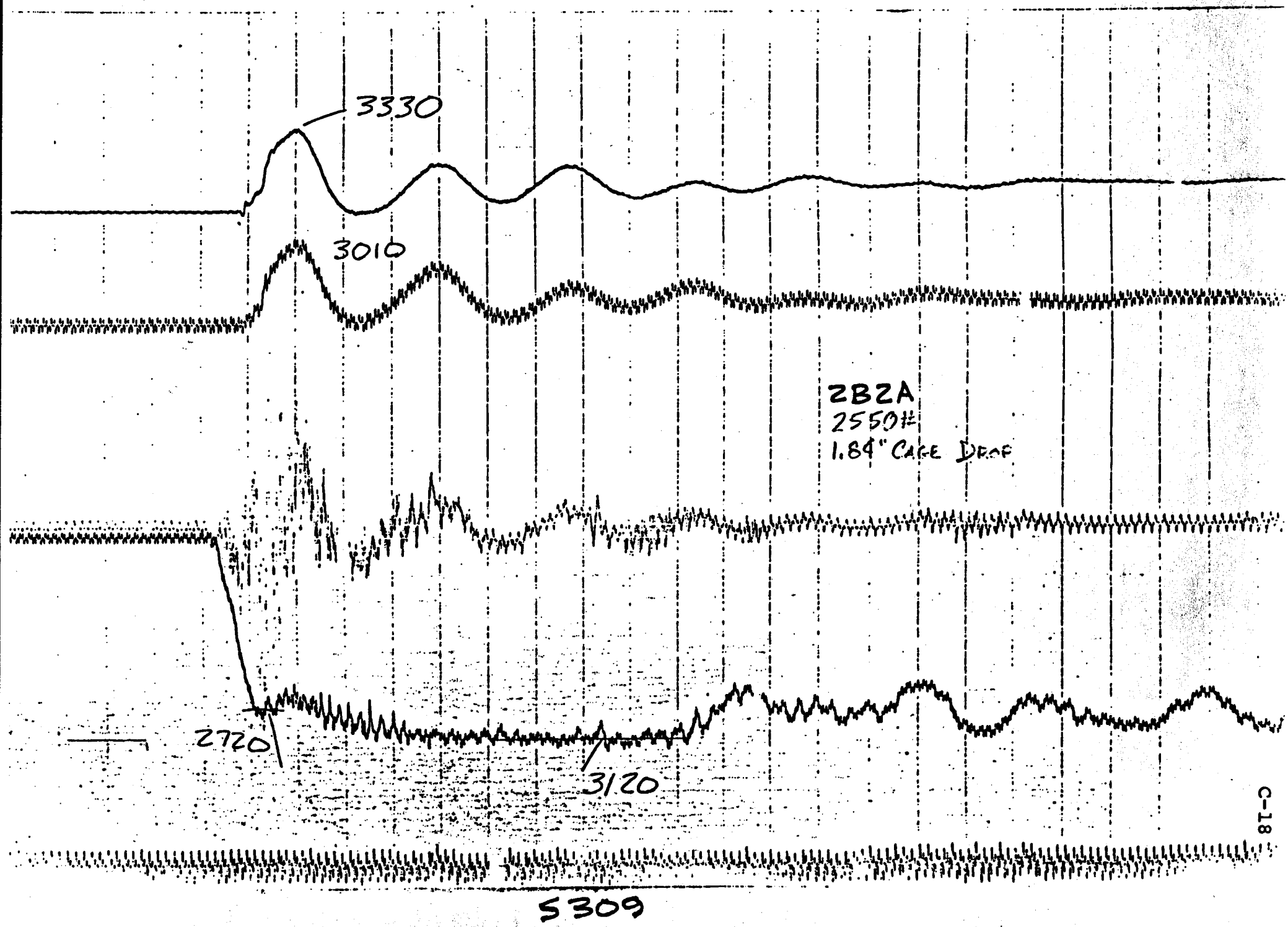
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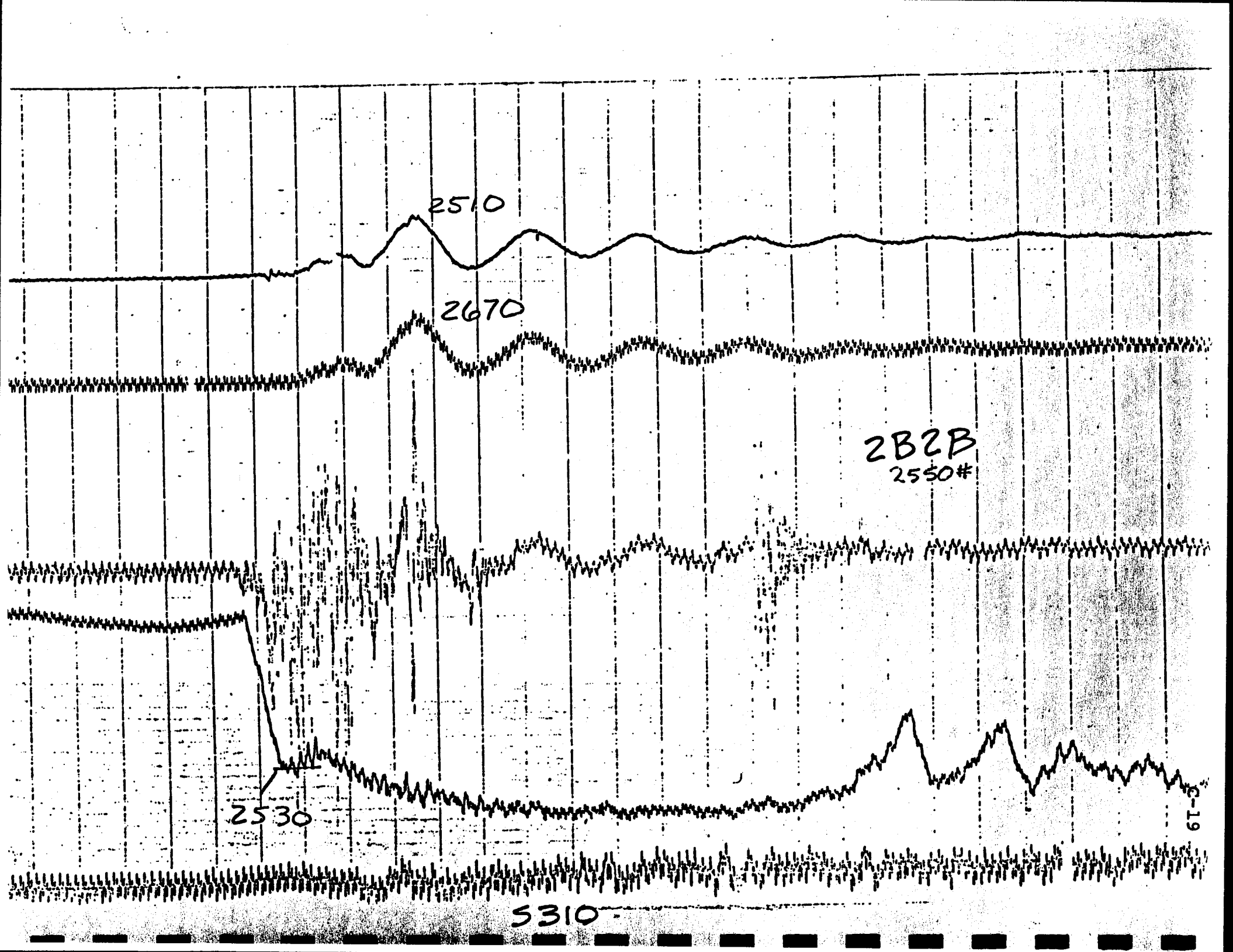
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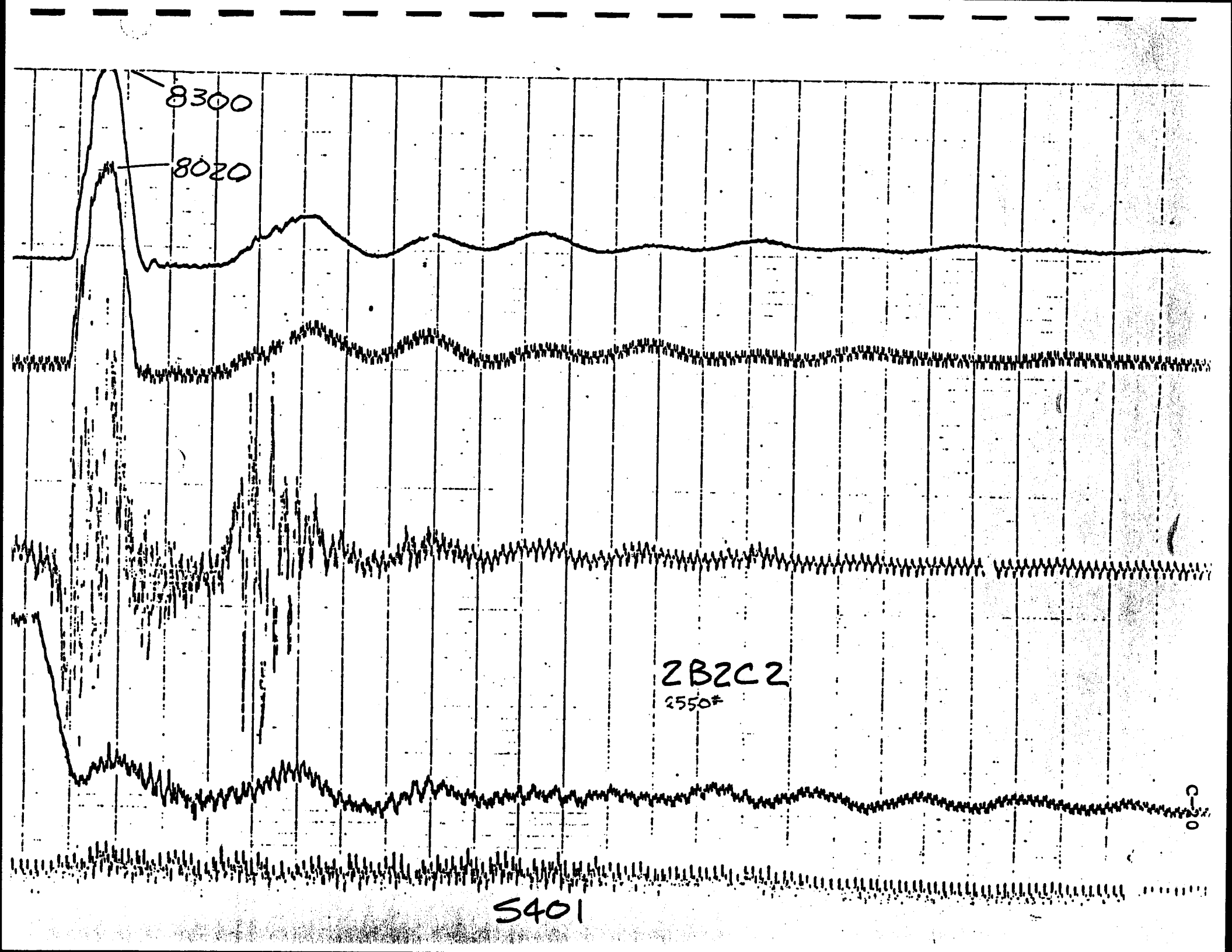
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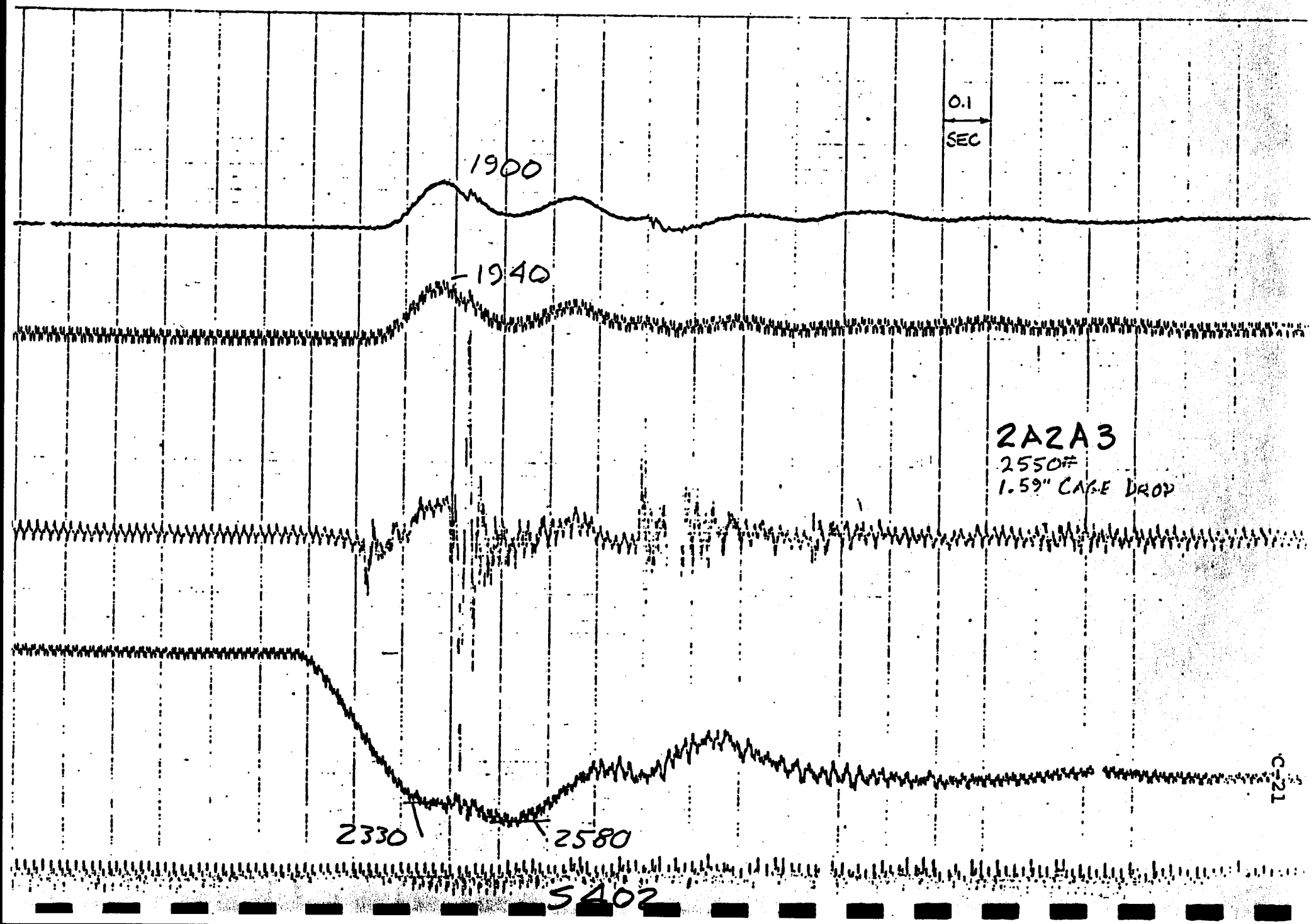

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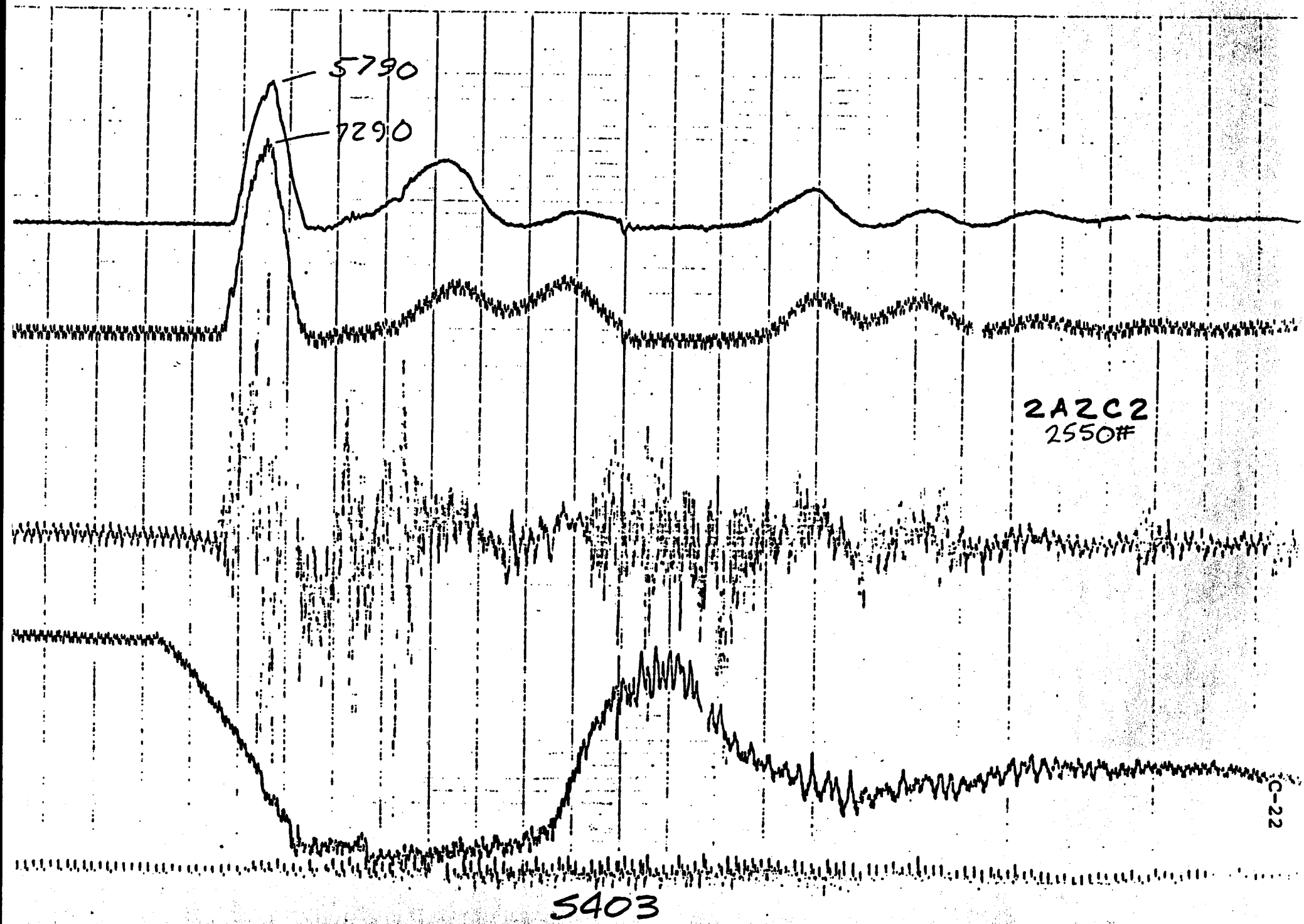
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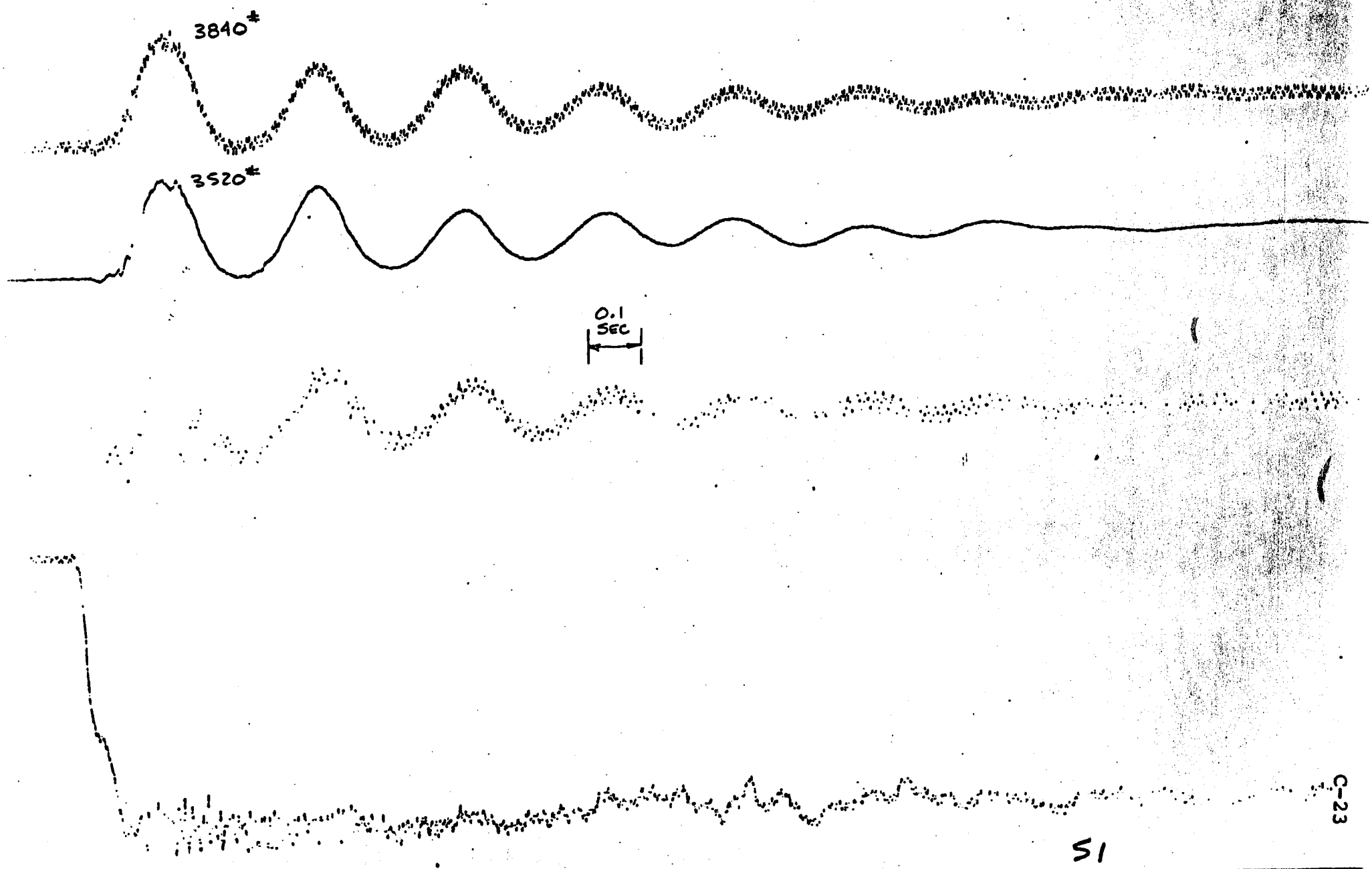
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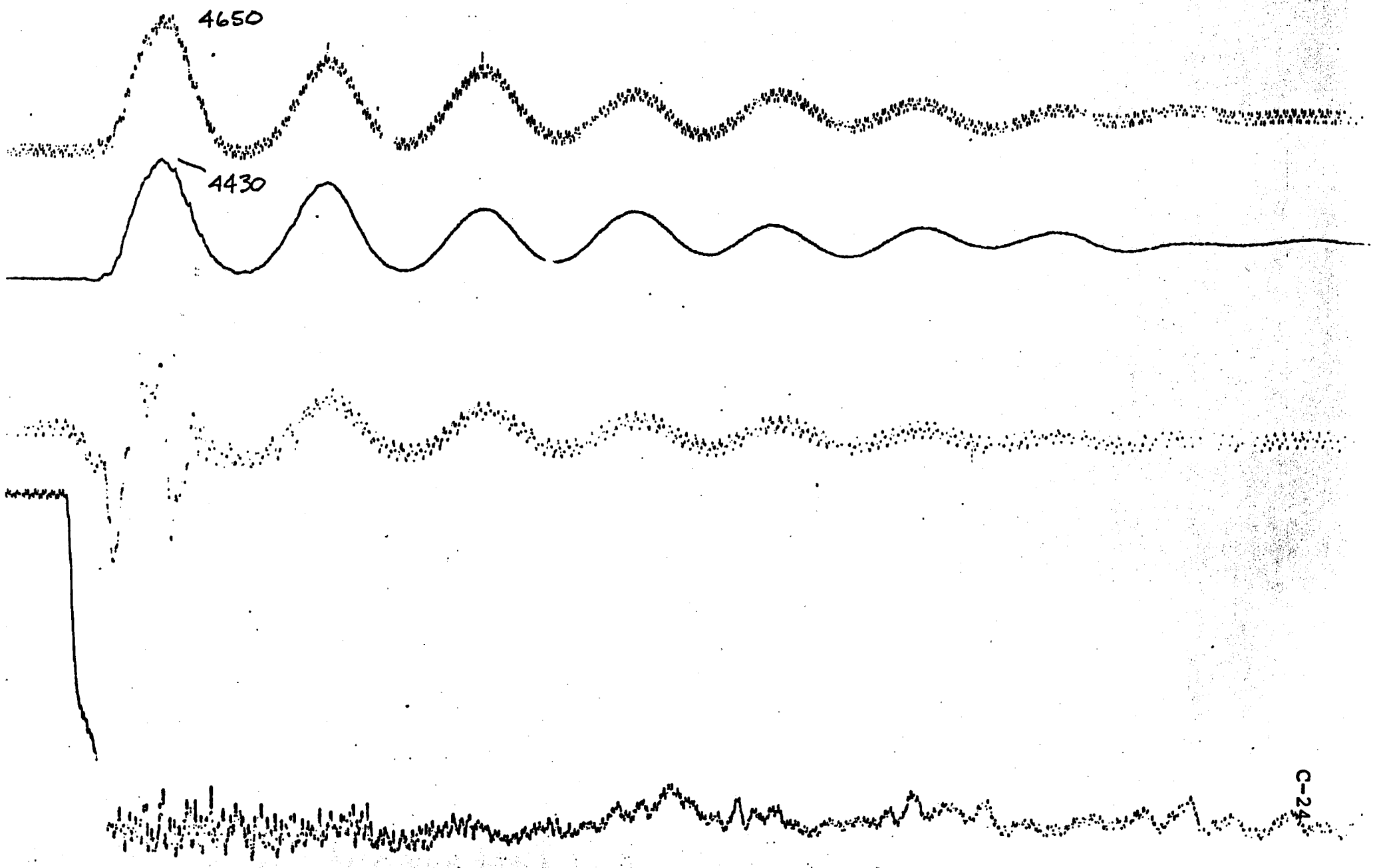
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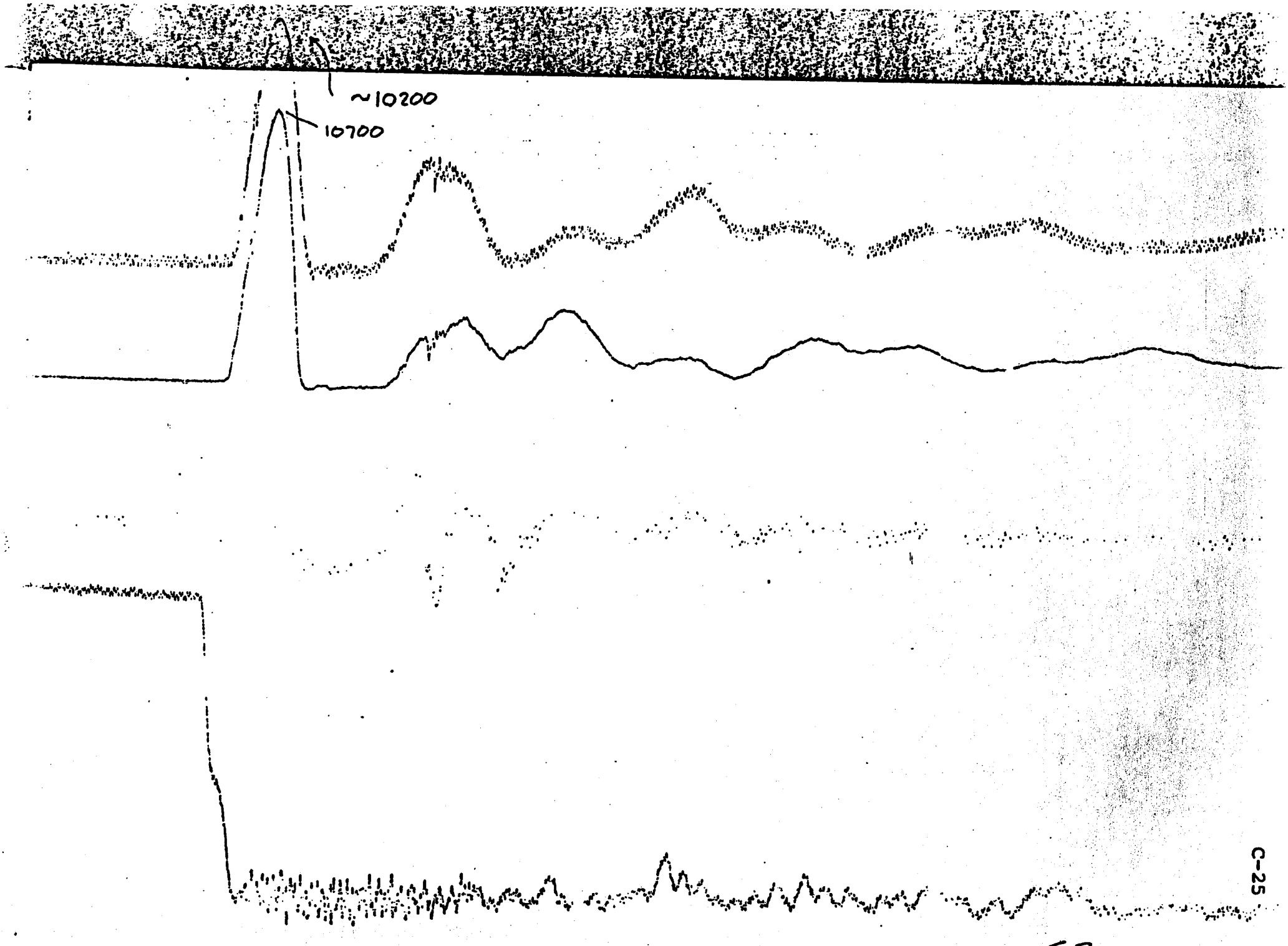

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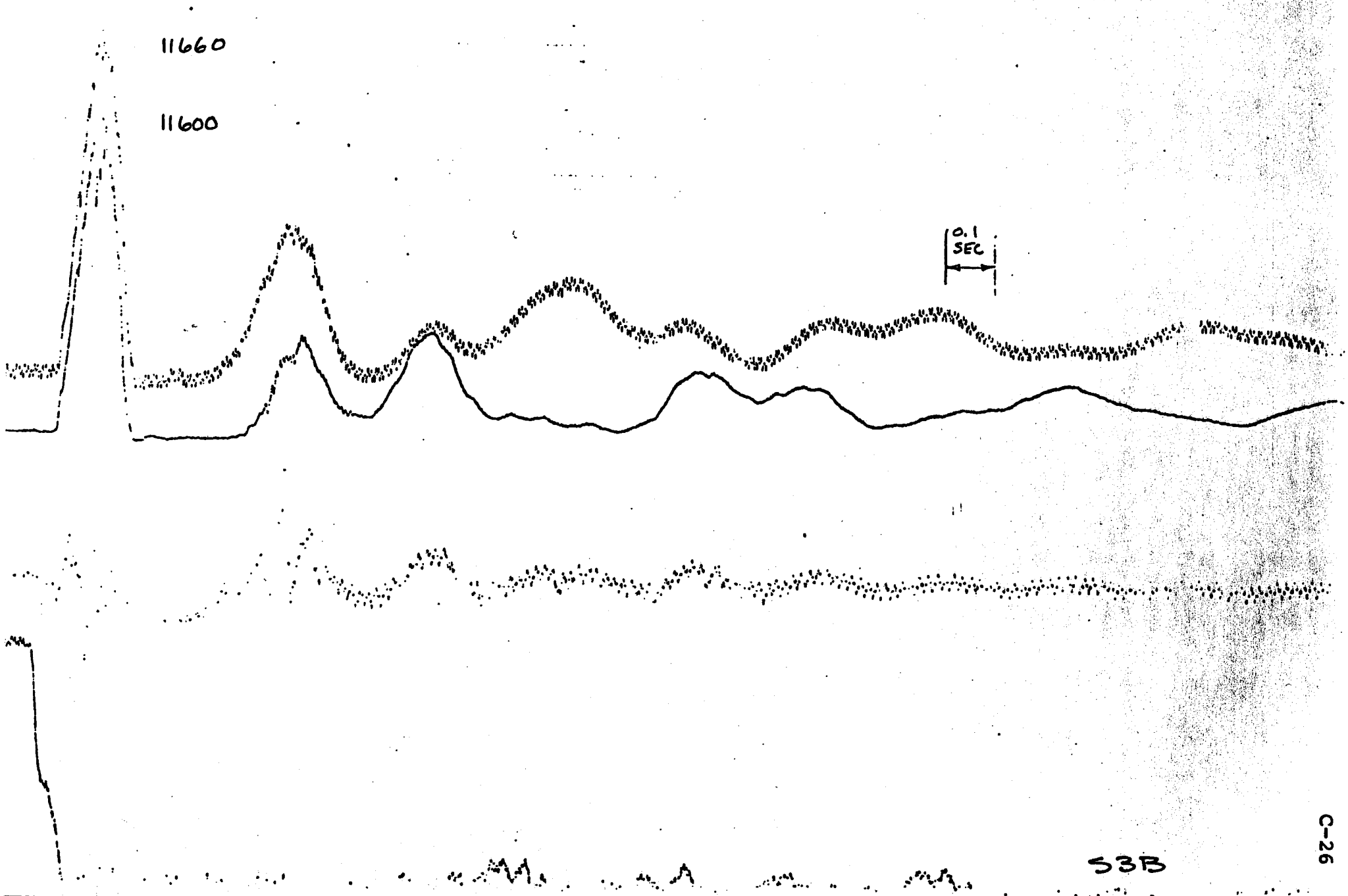
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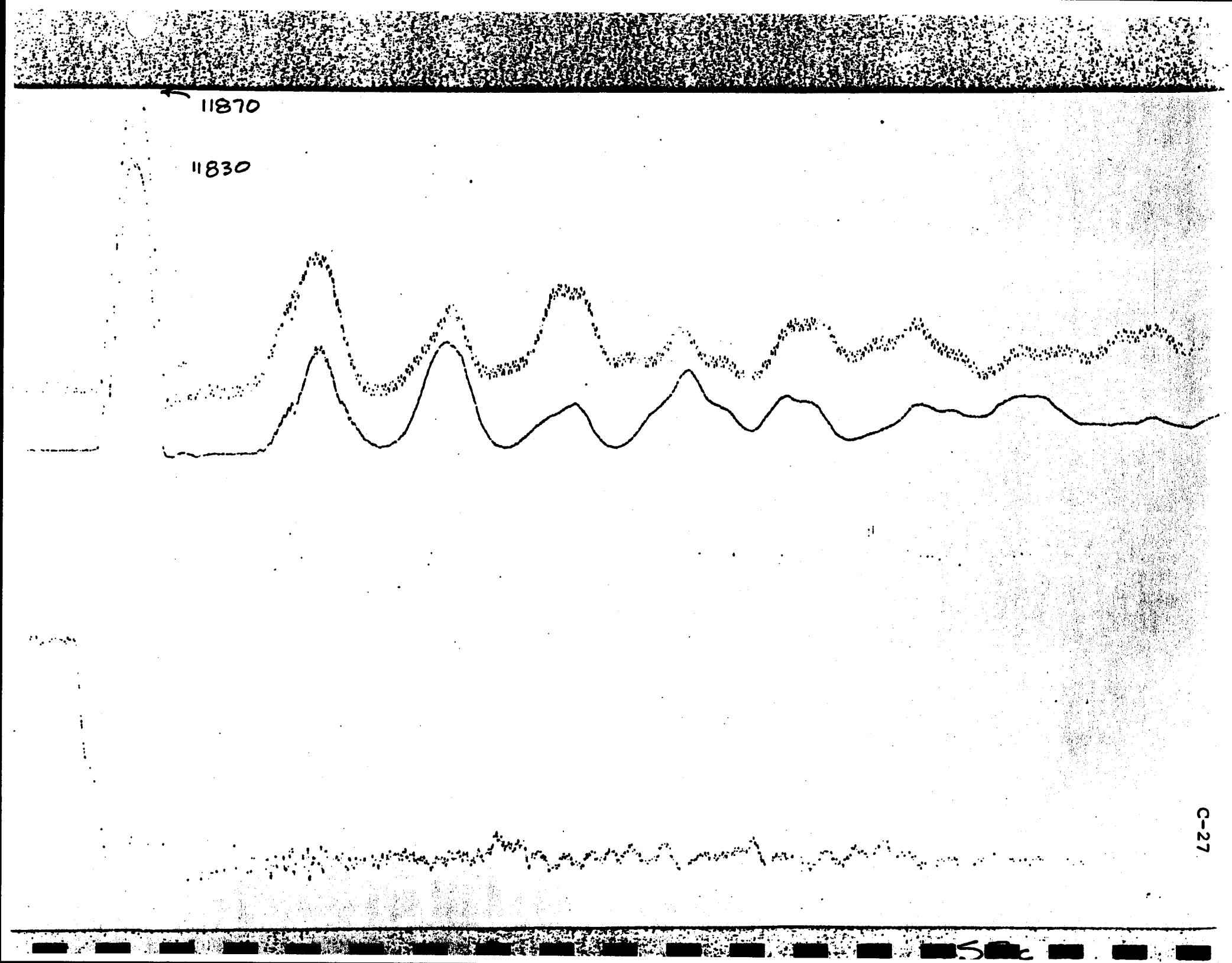
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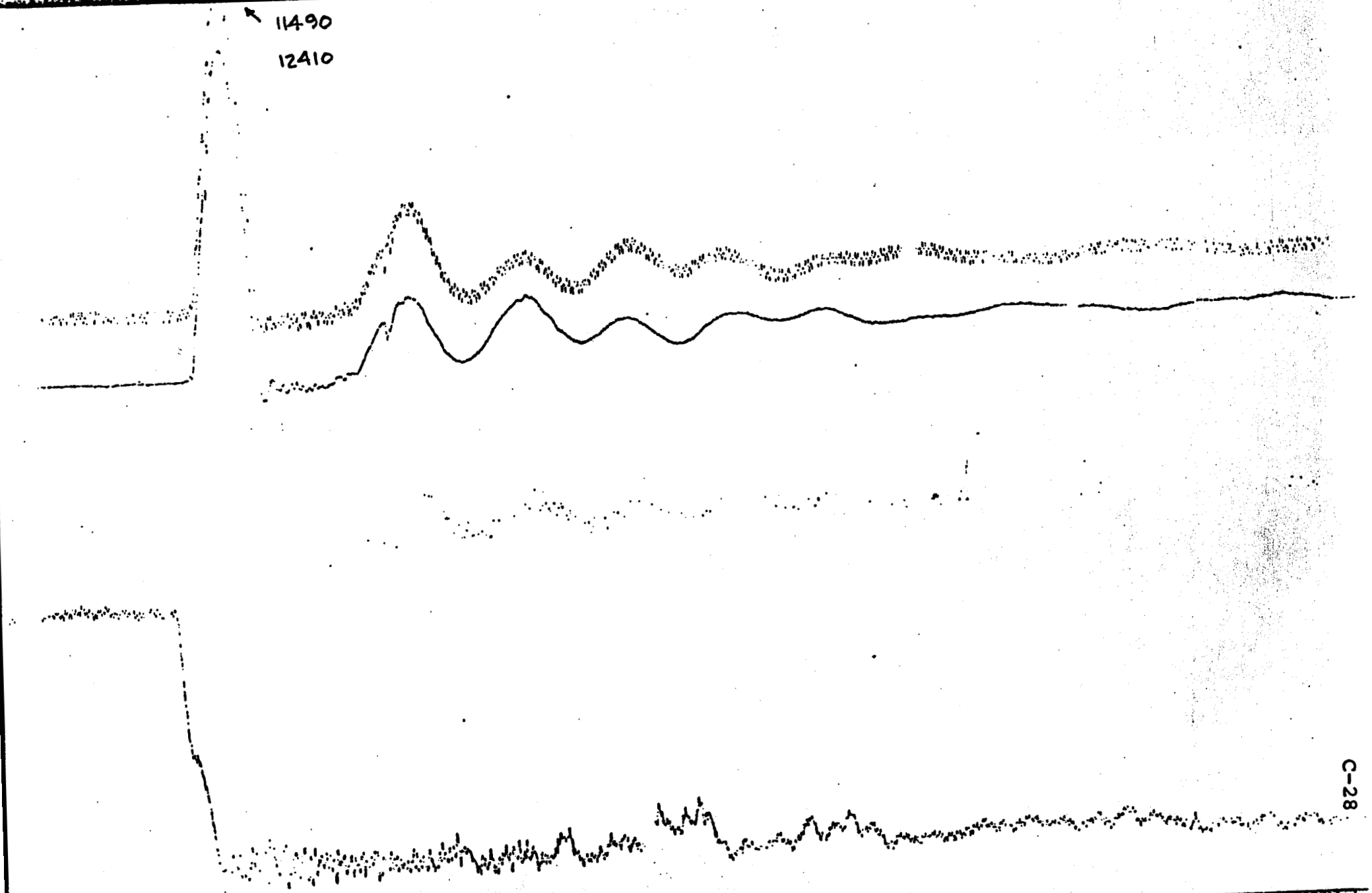

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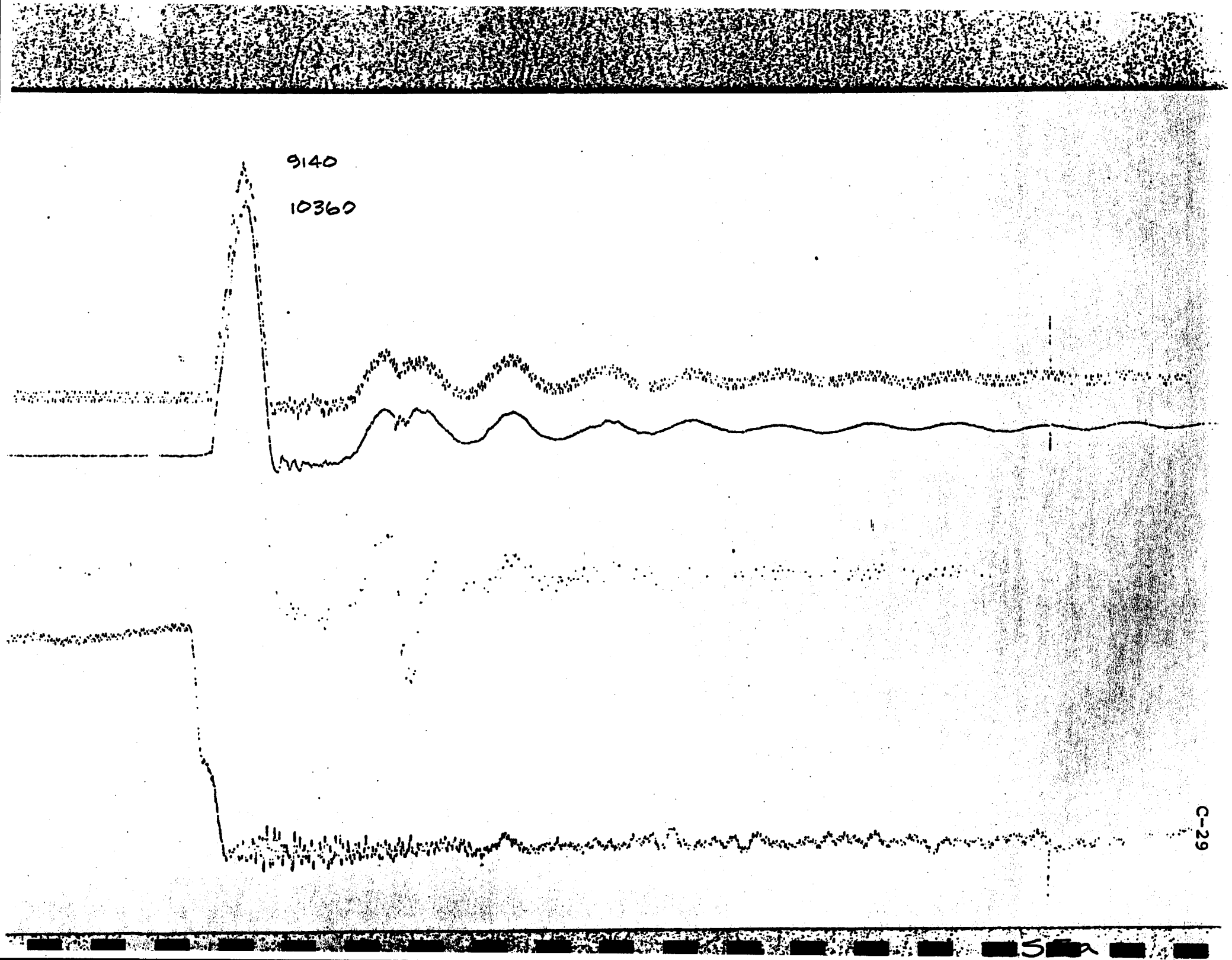
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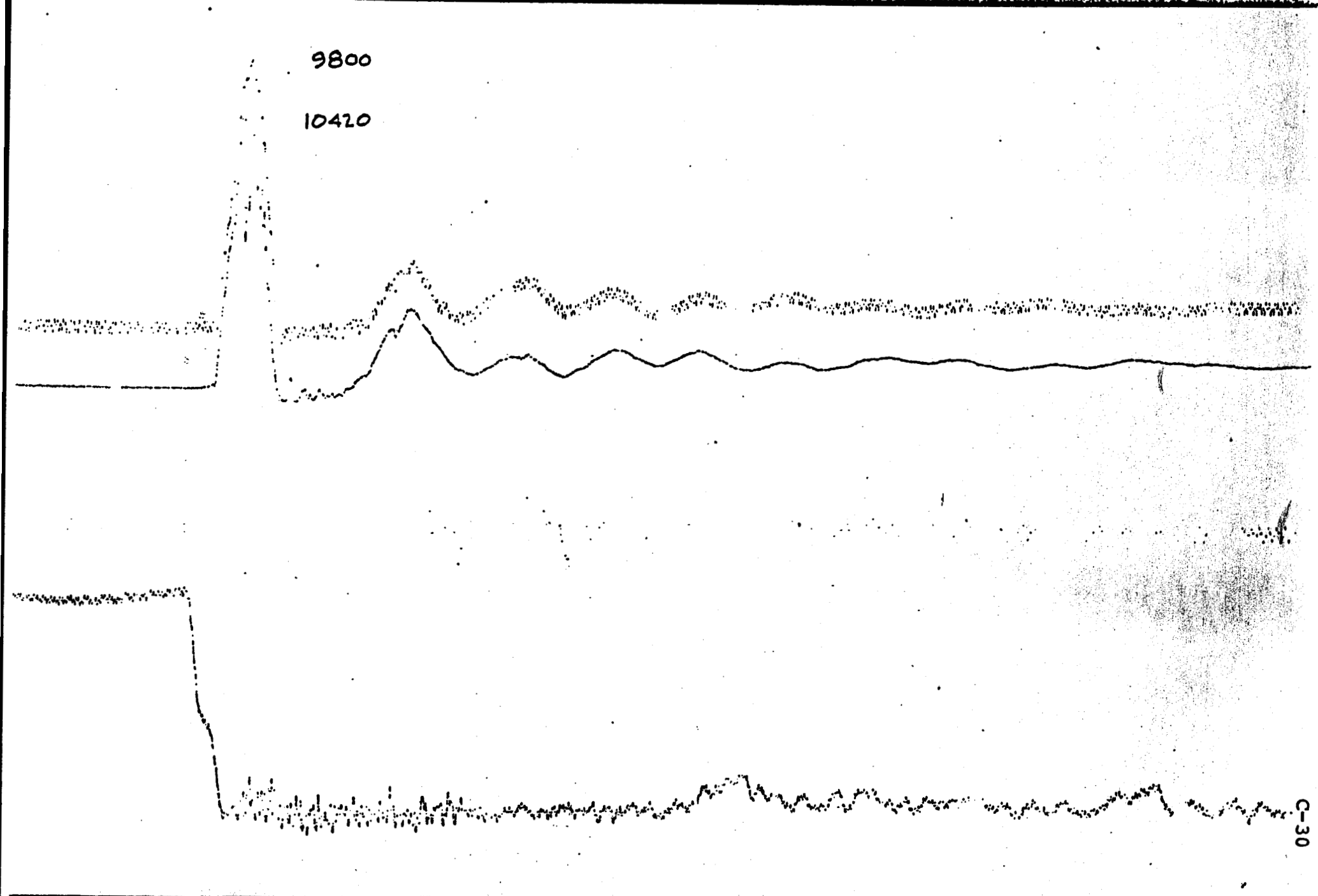

C-30

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8370

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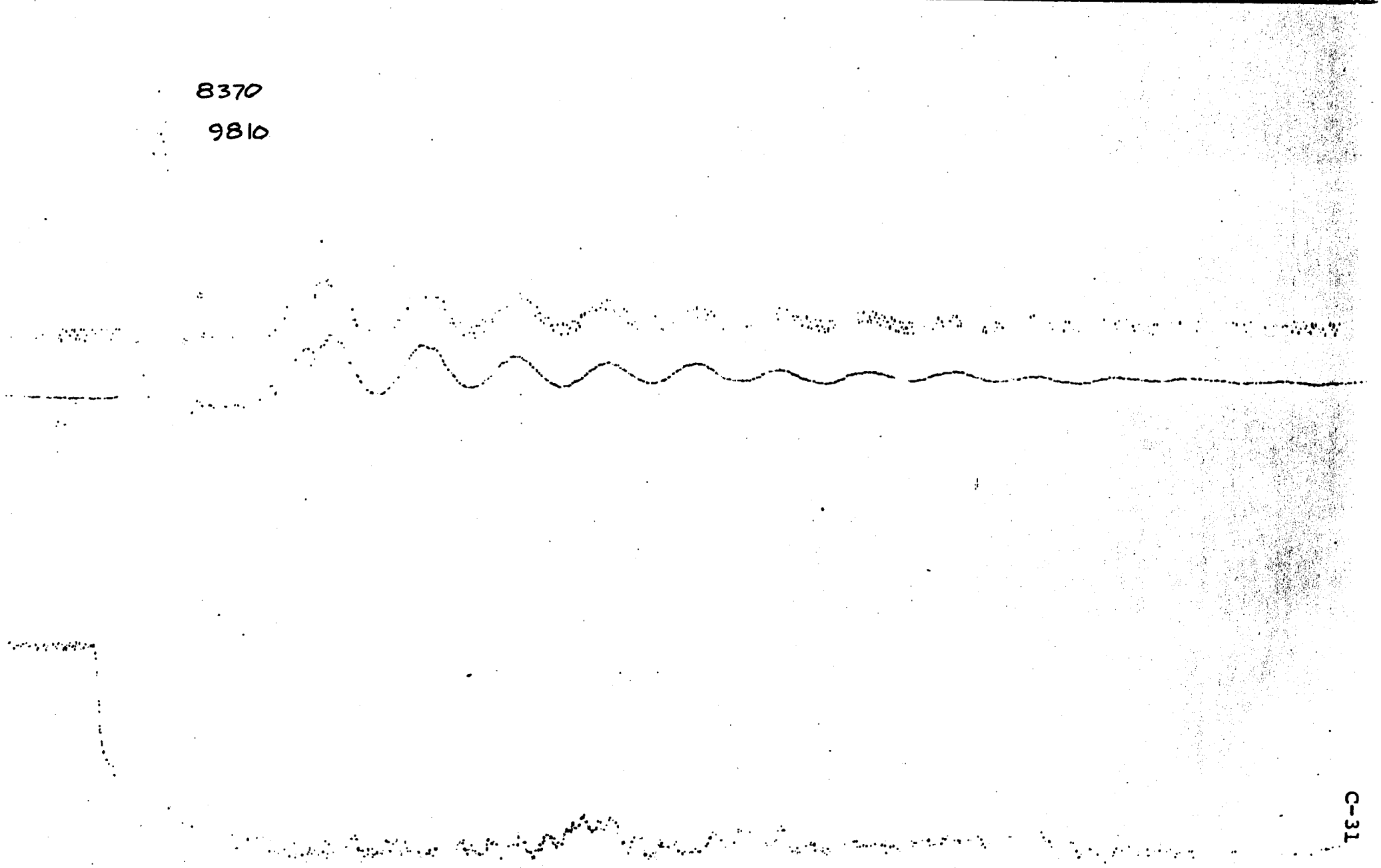

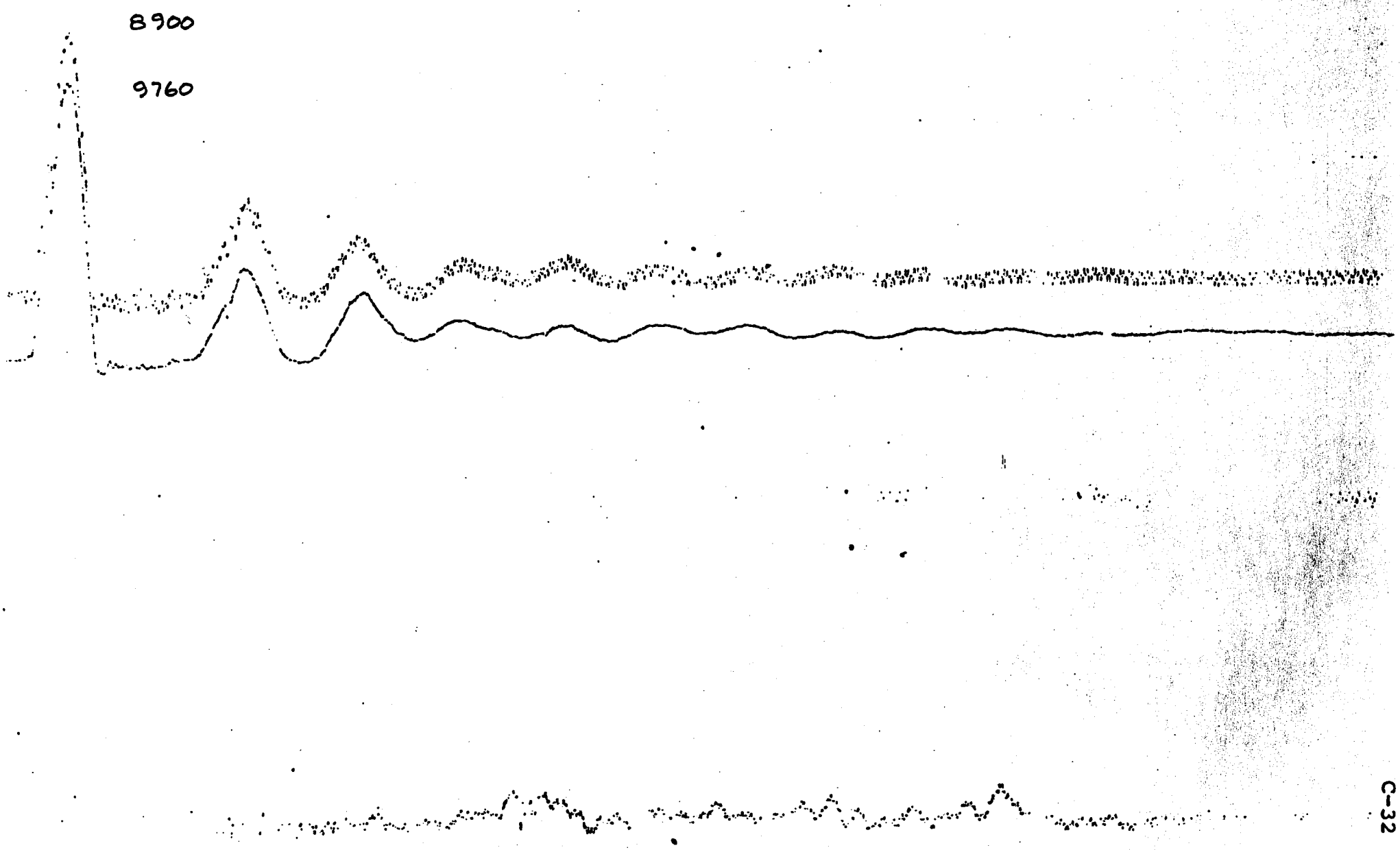

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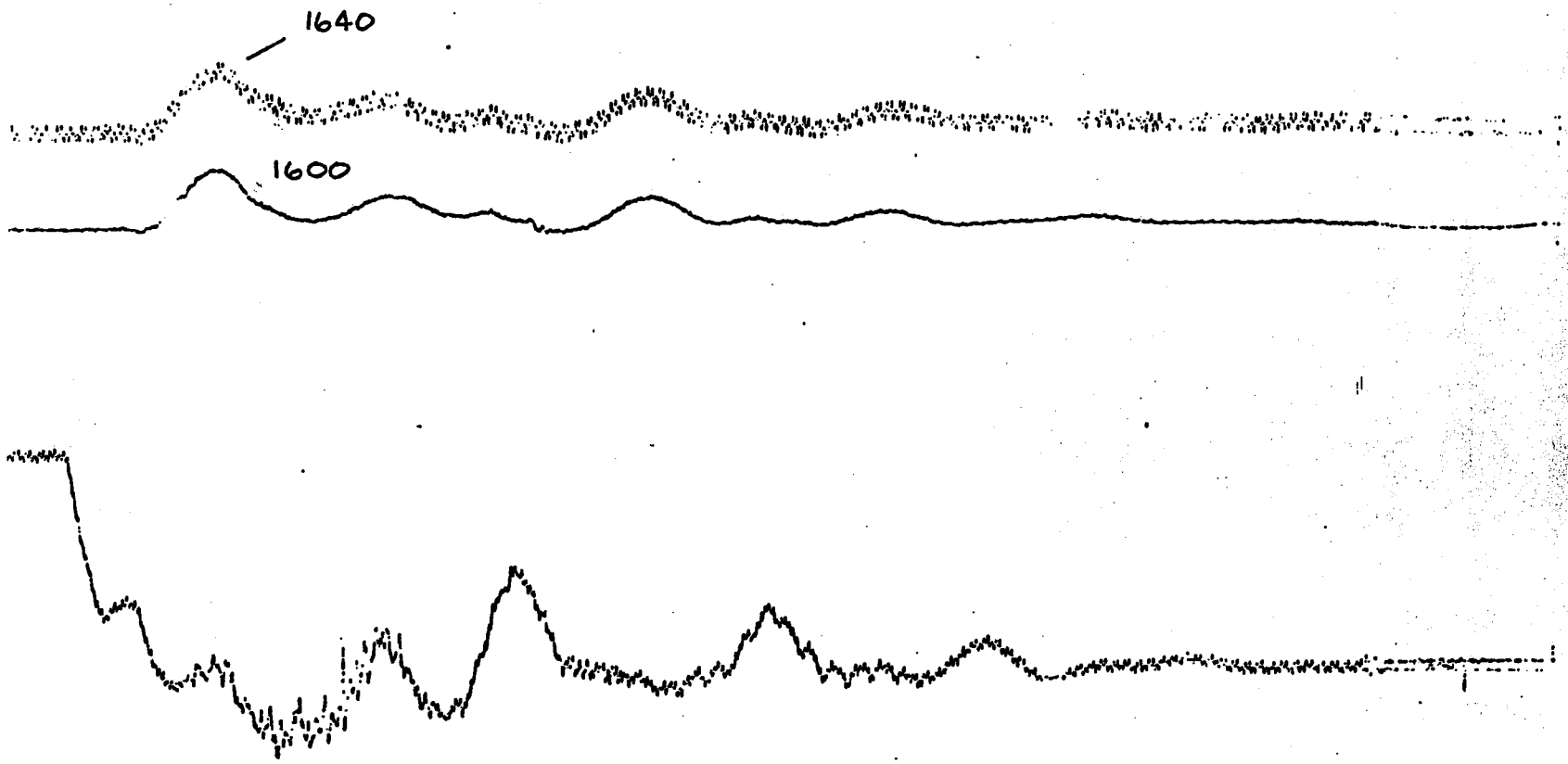
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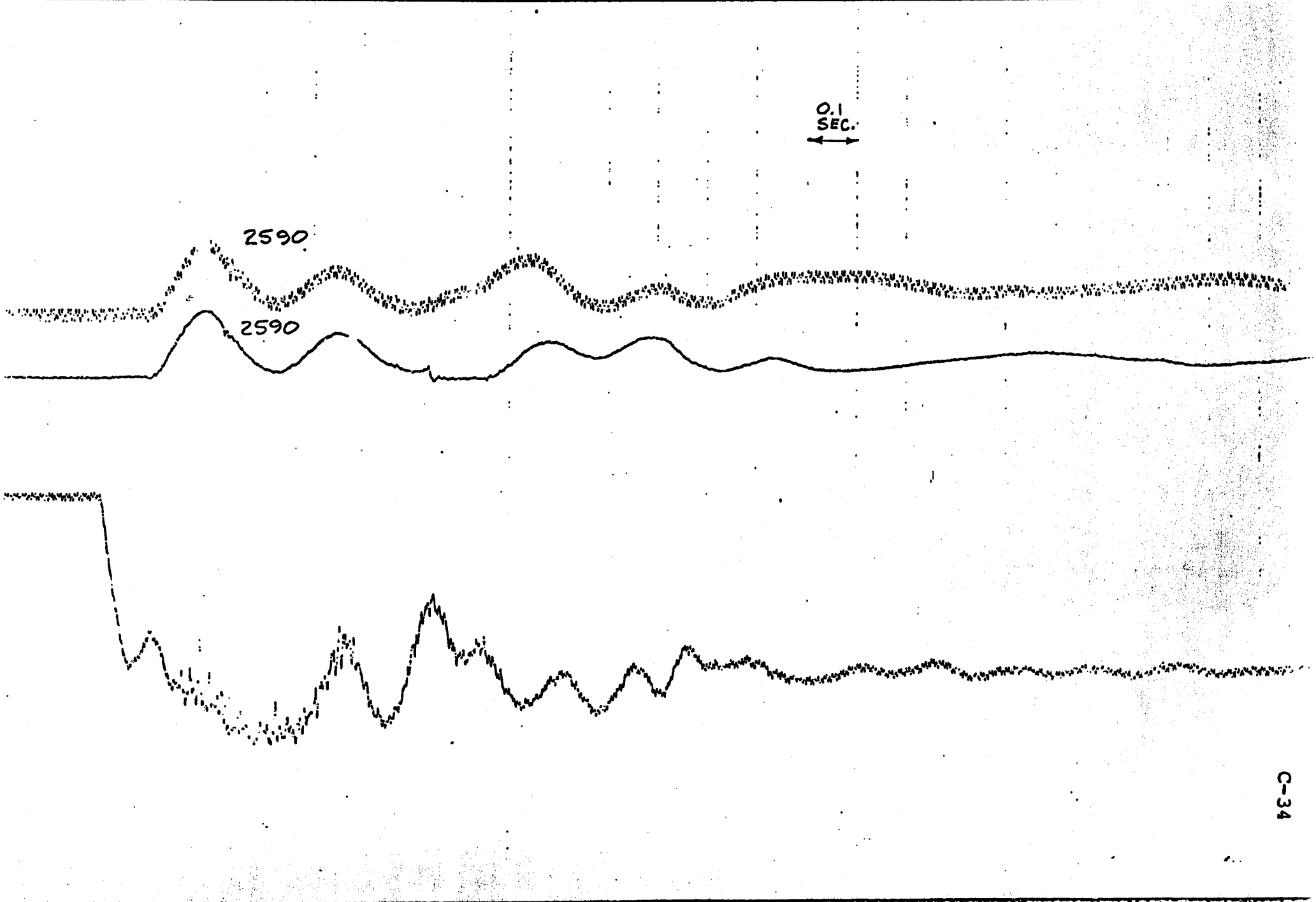

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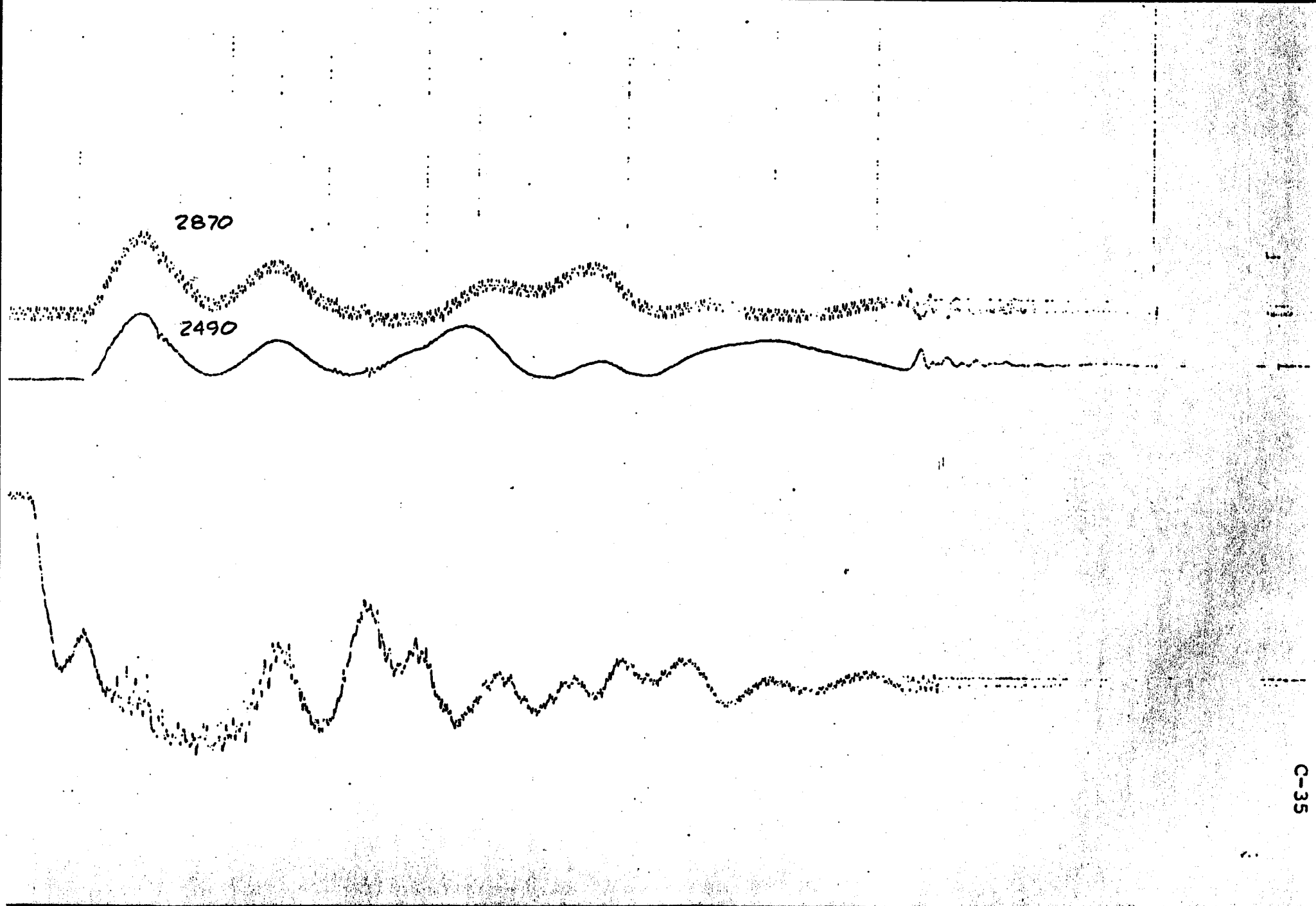
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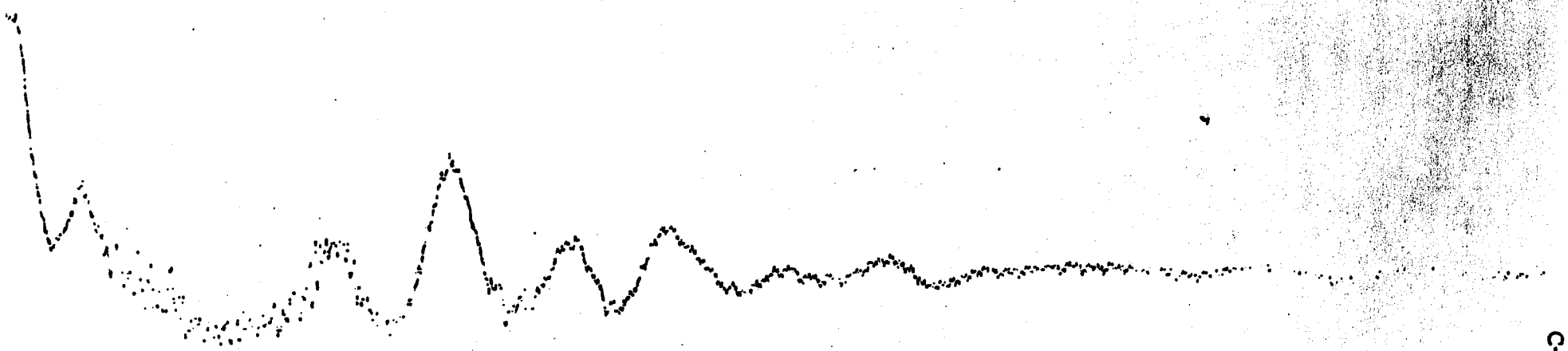

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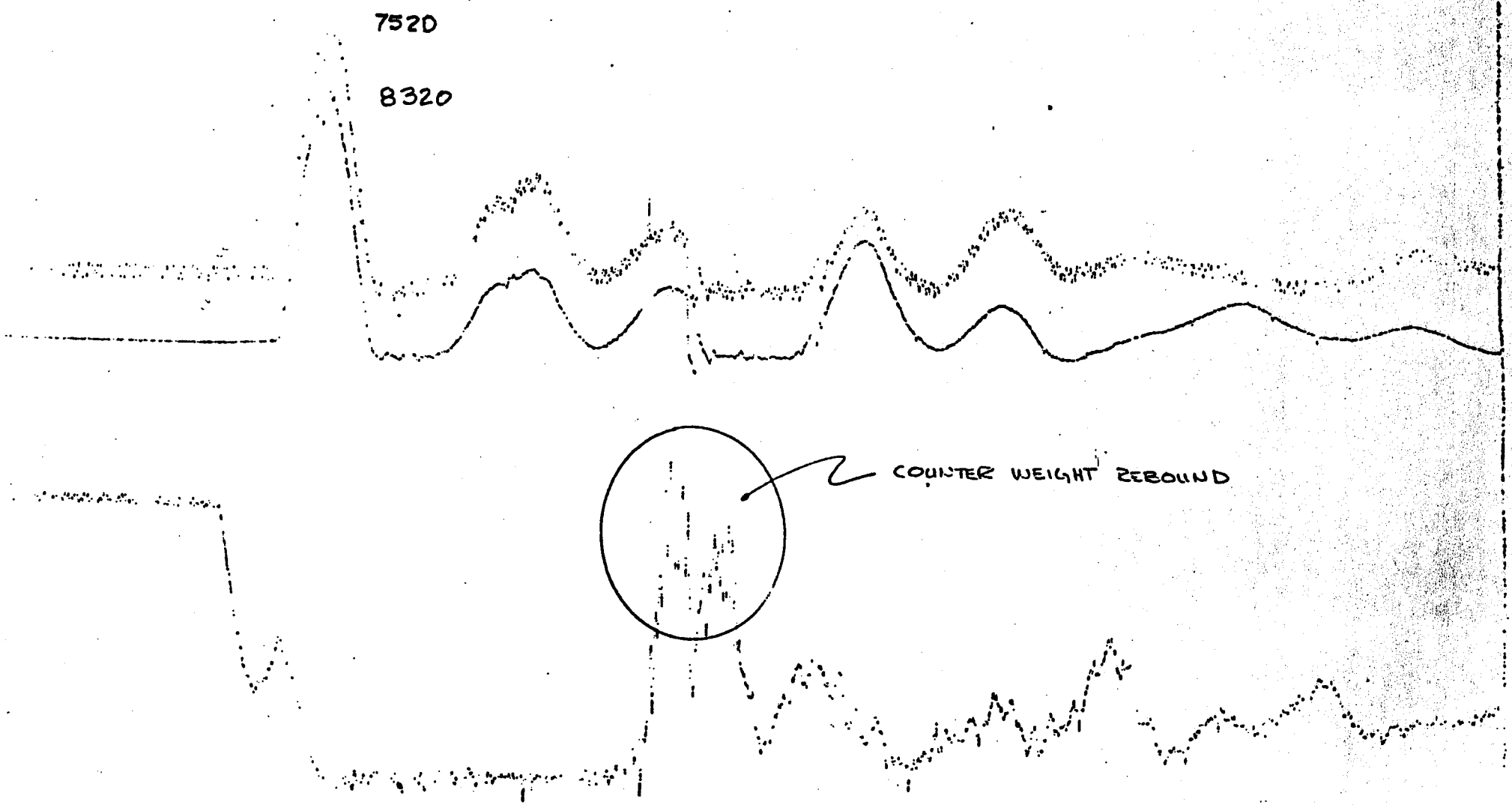
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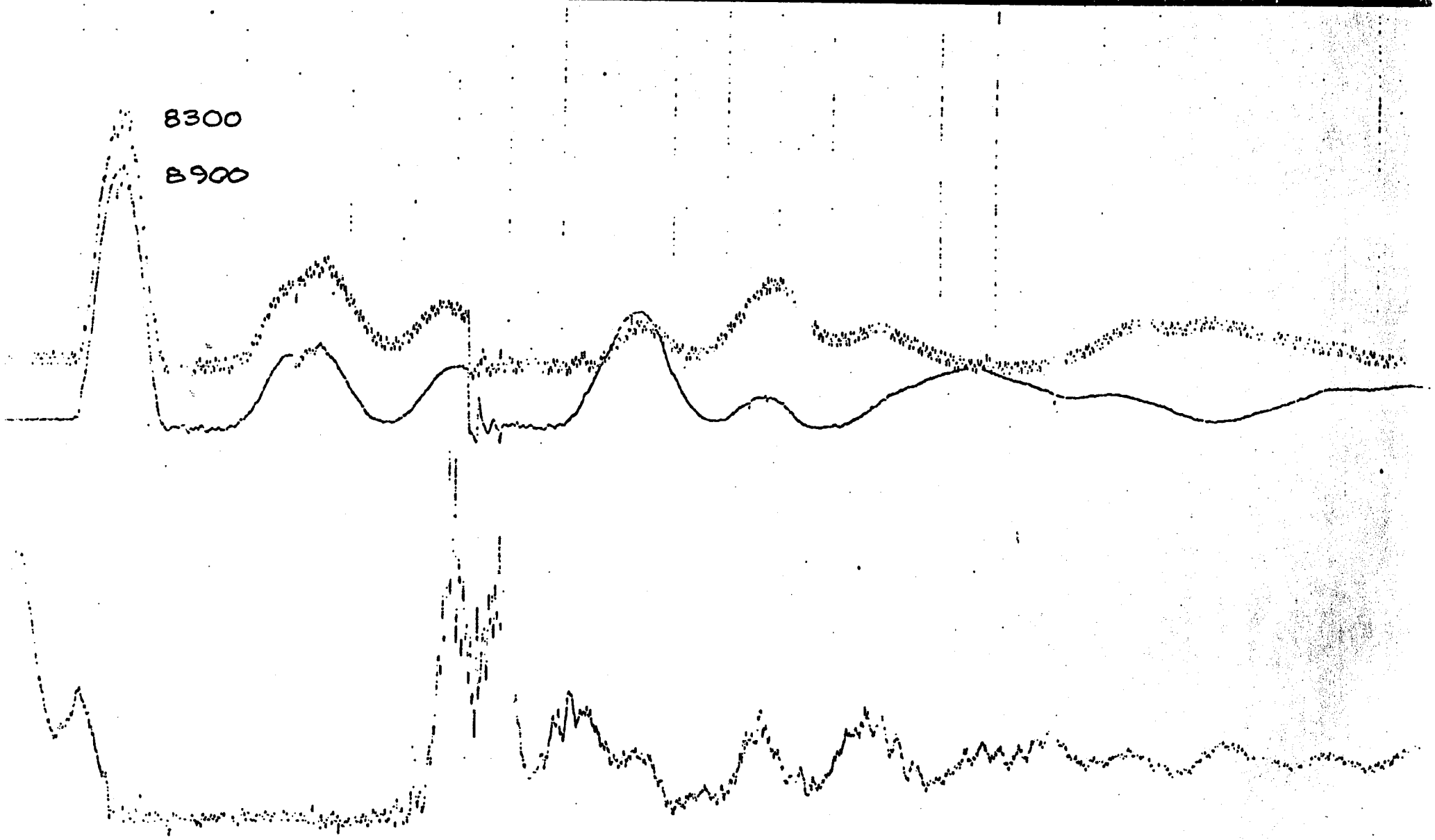

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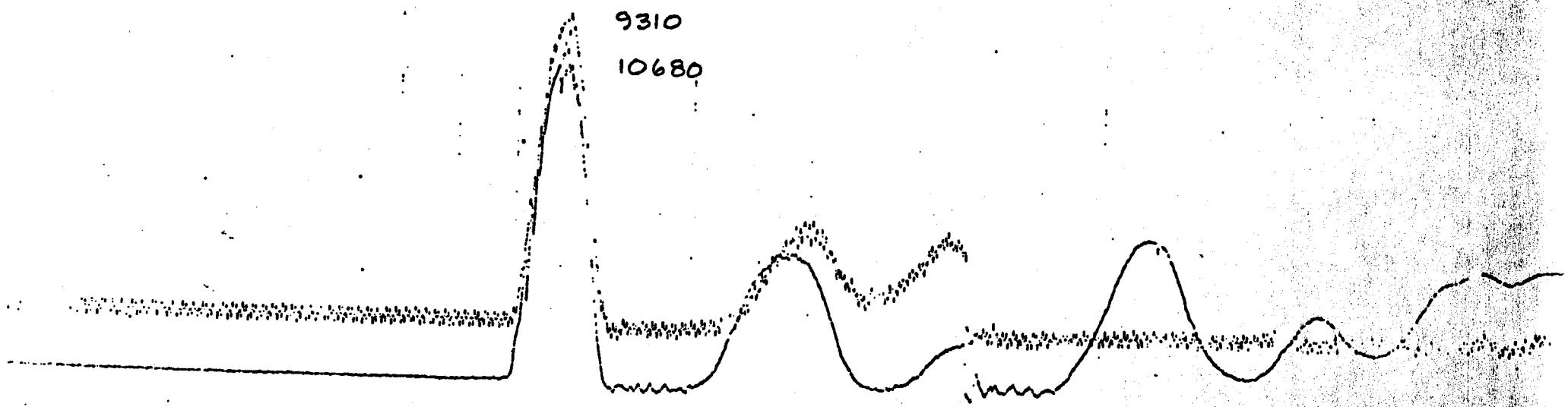
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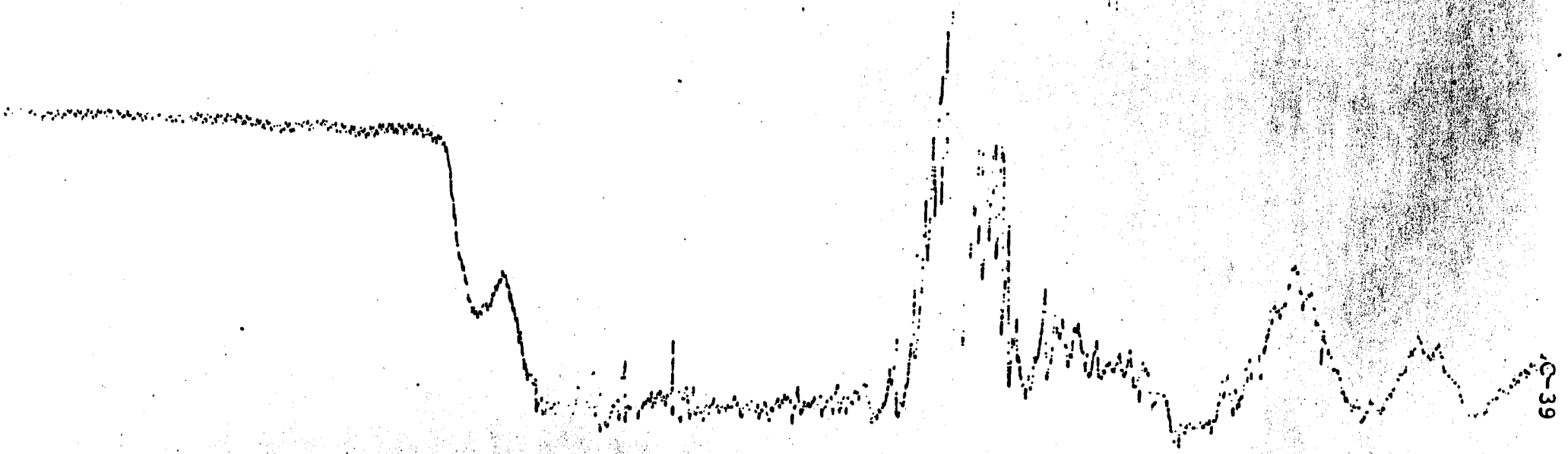

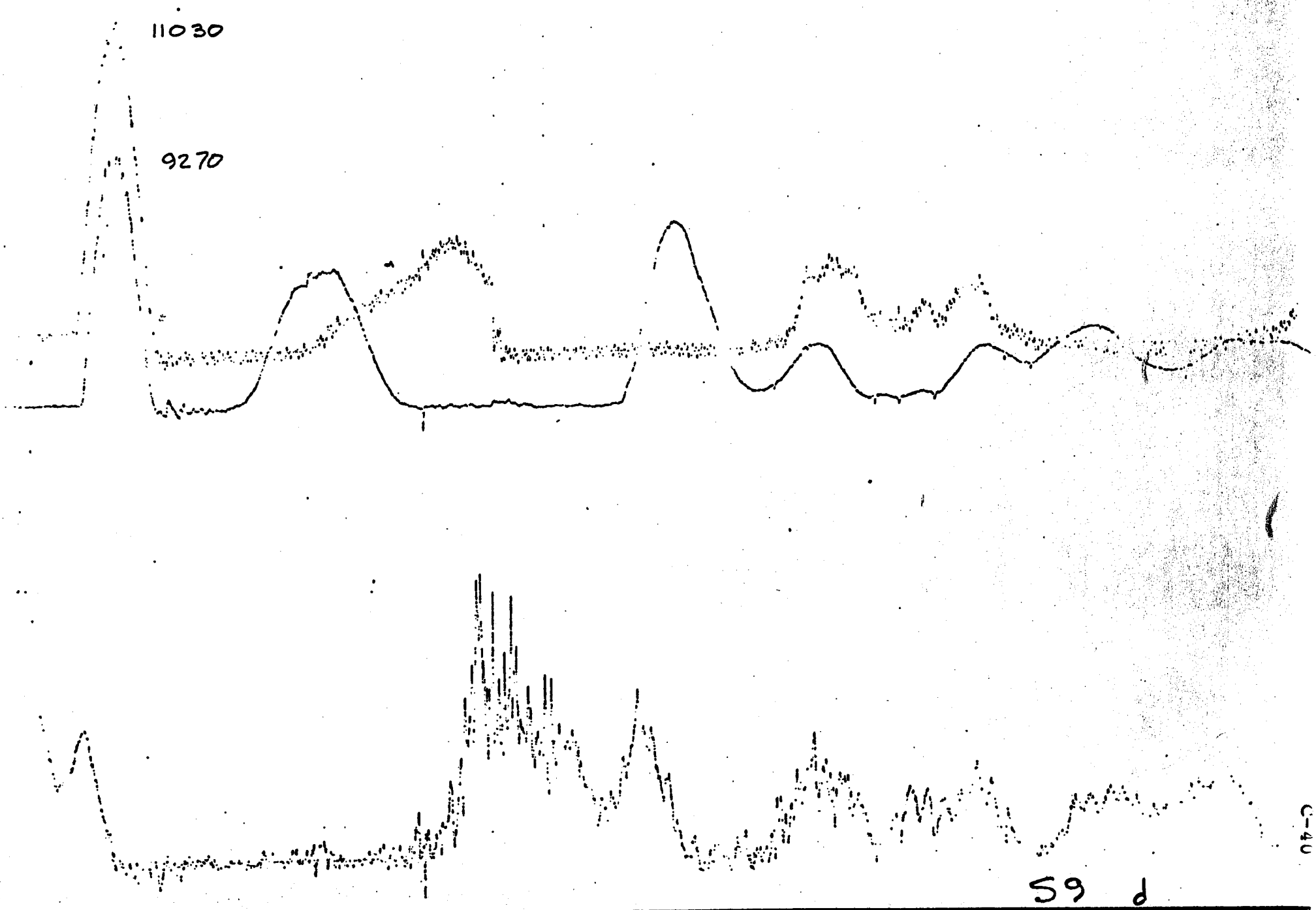
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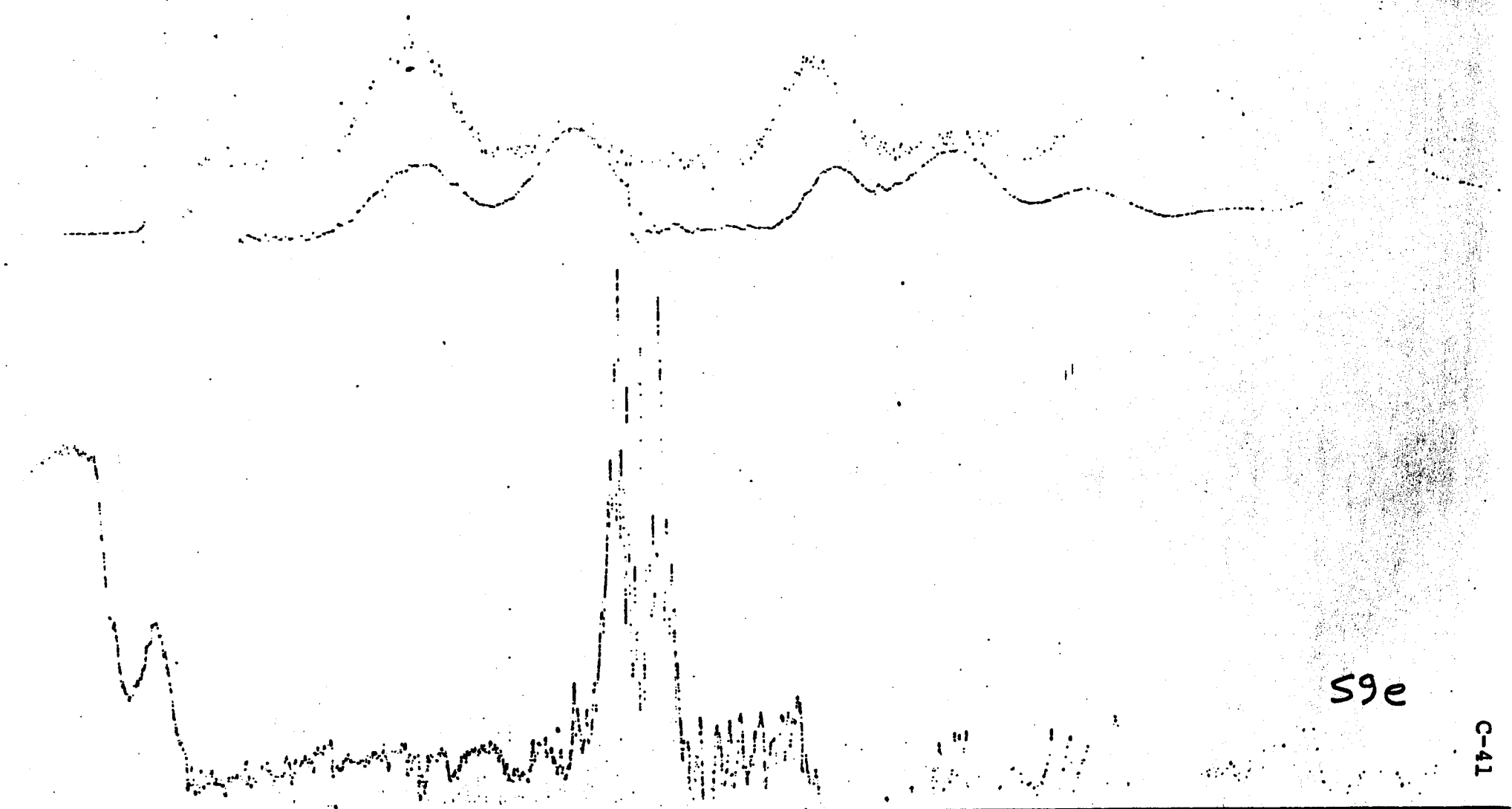

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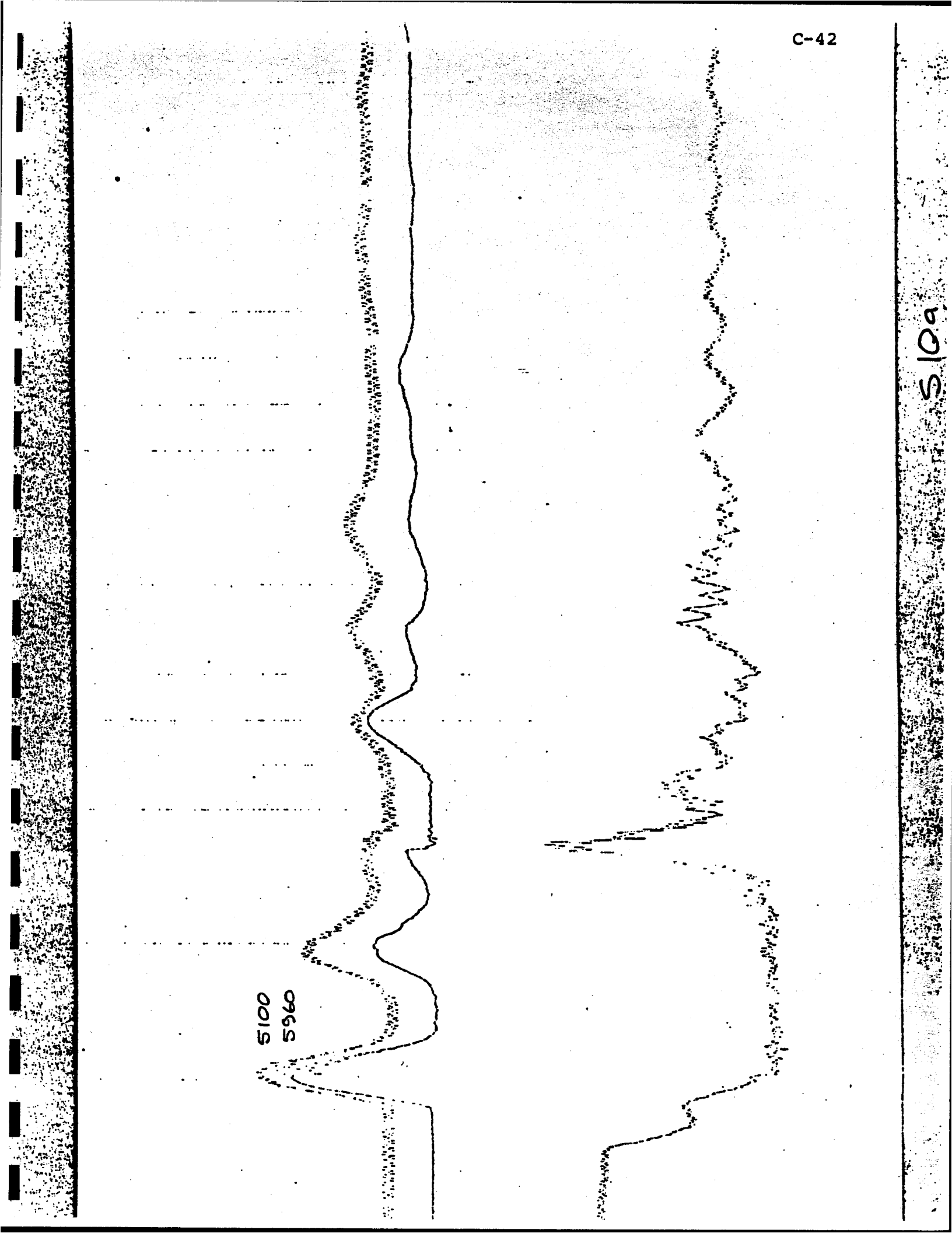
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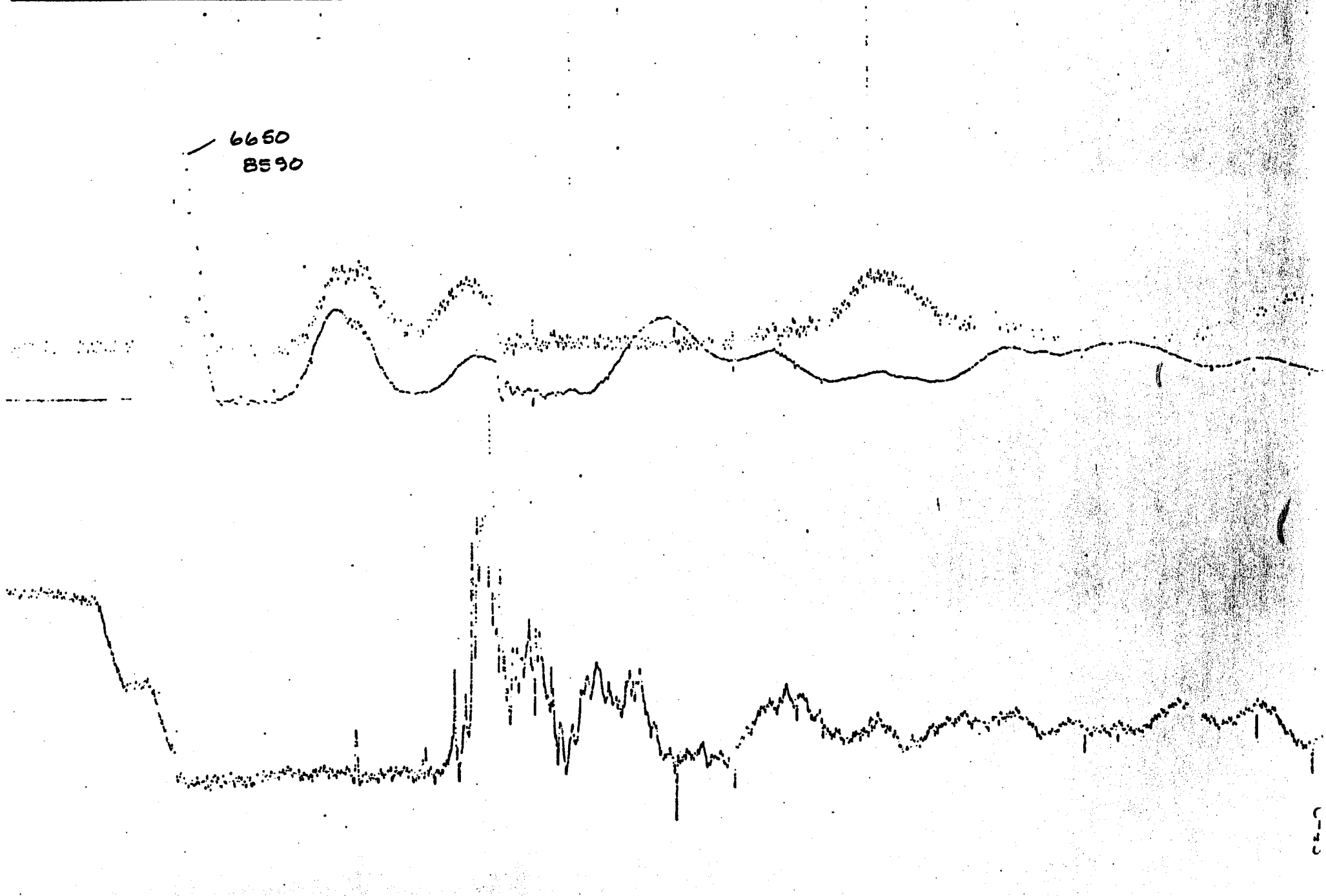
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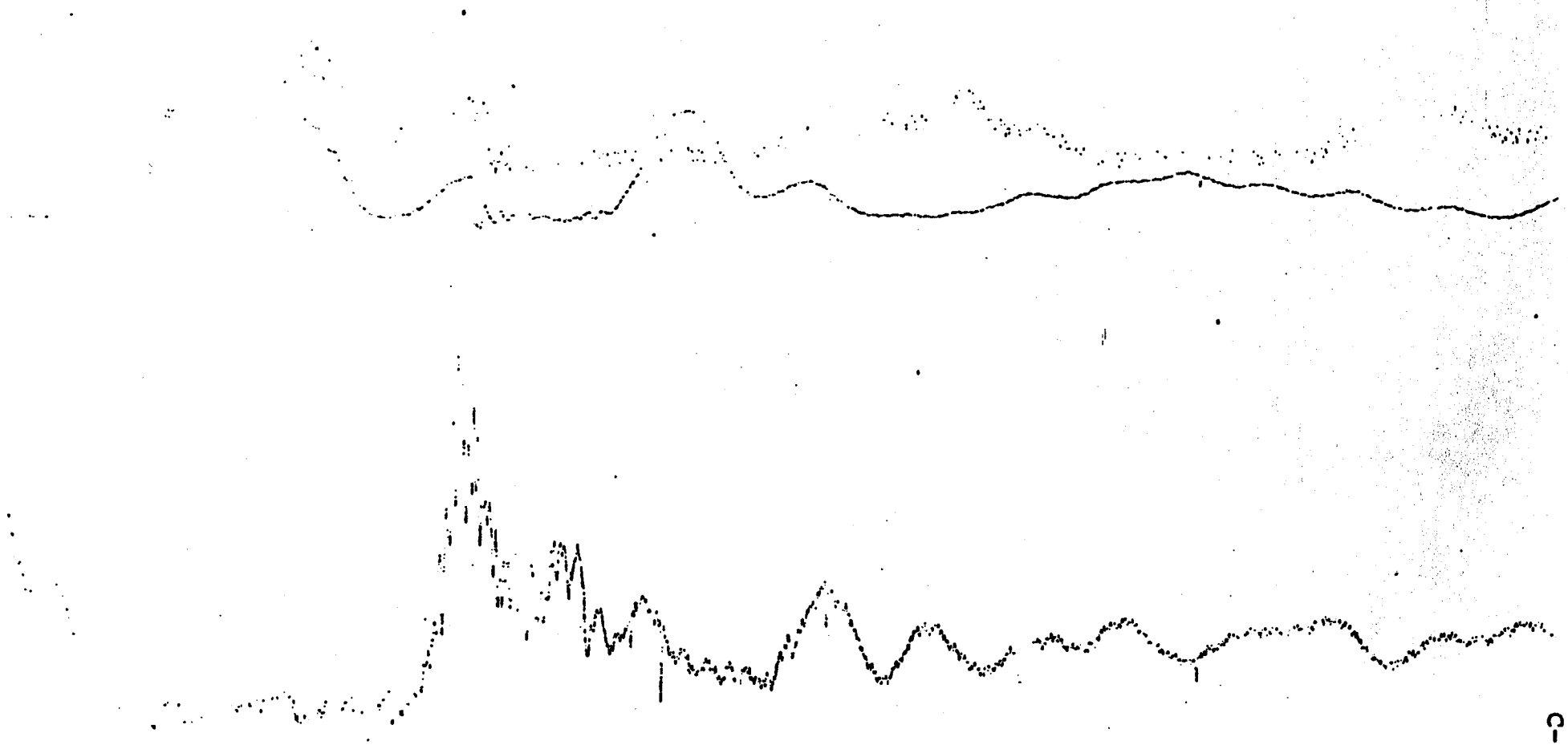

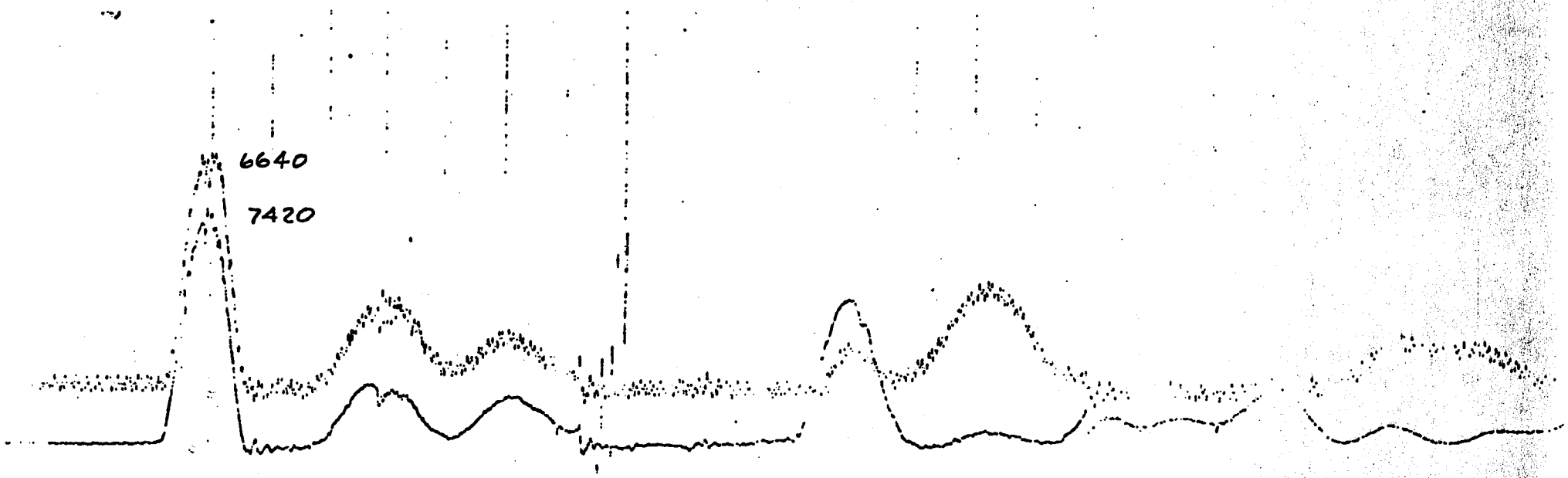

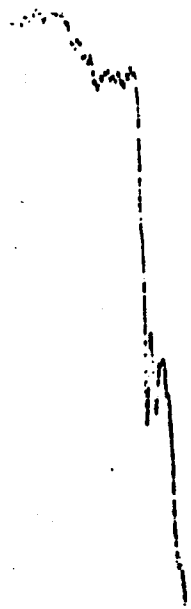

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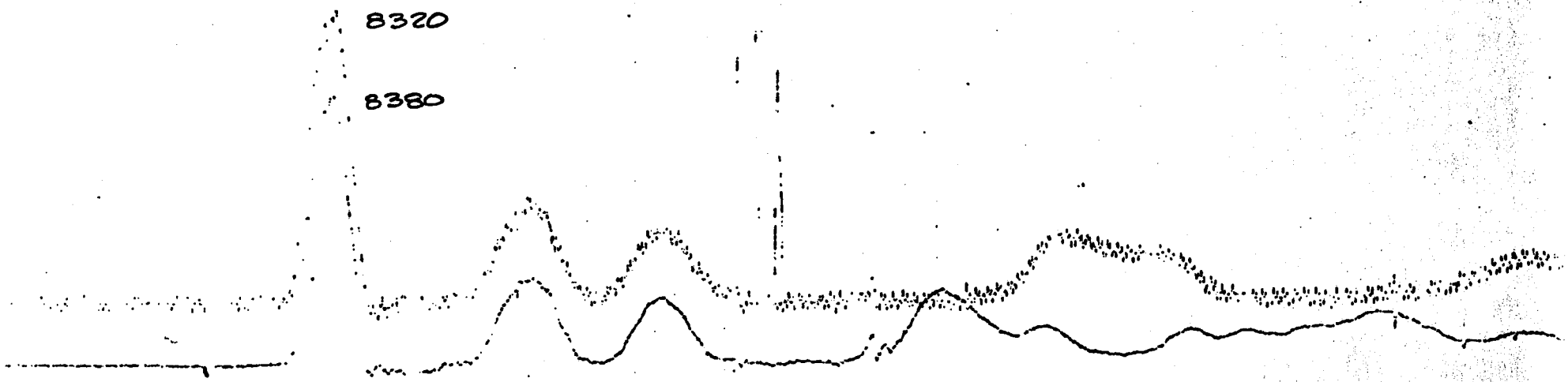

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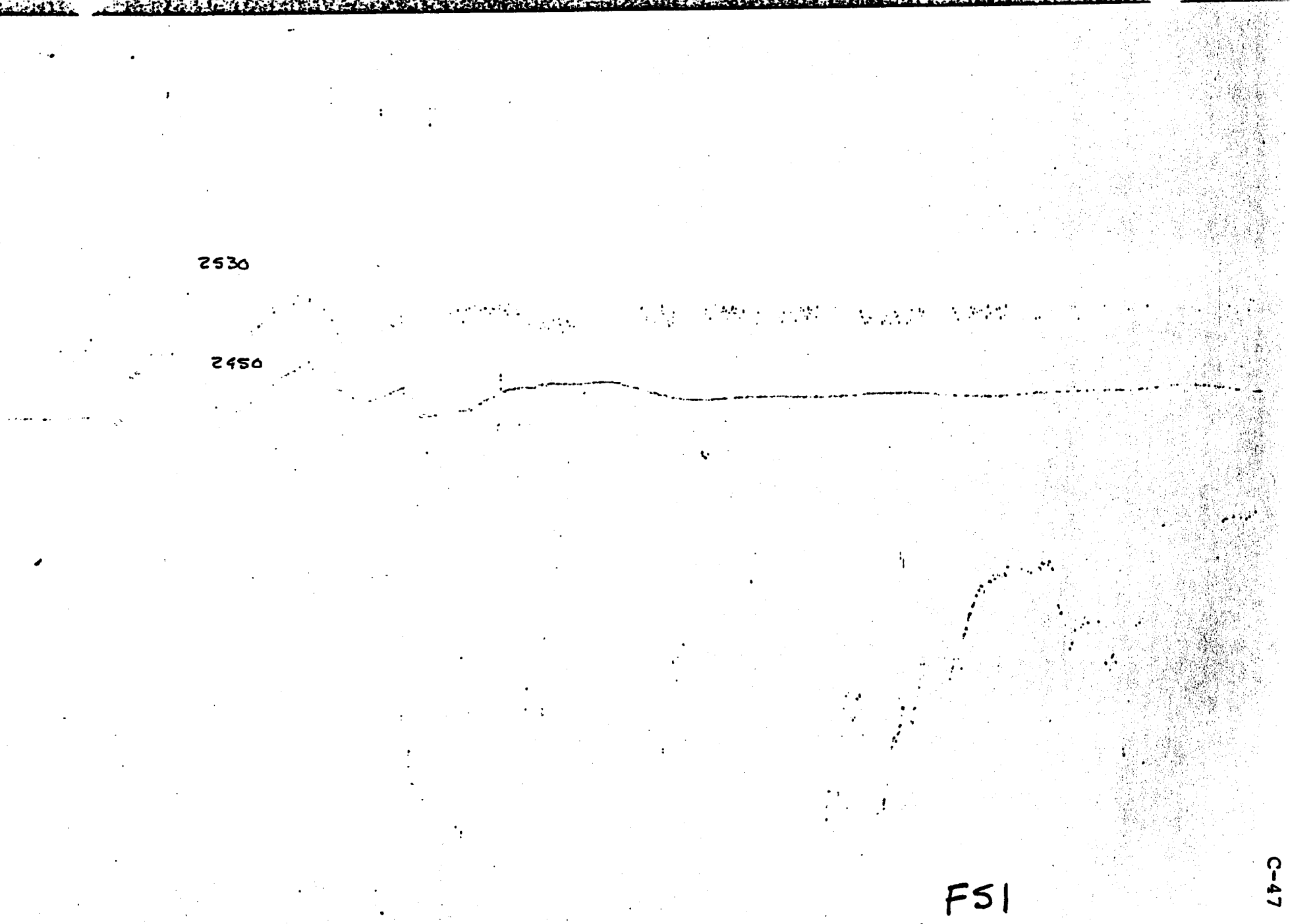
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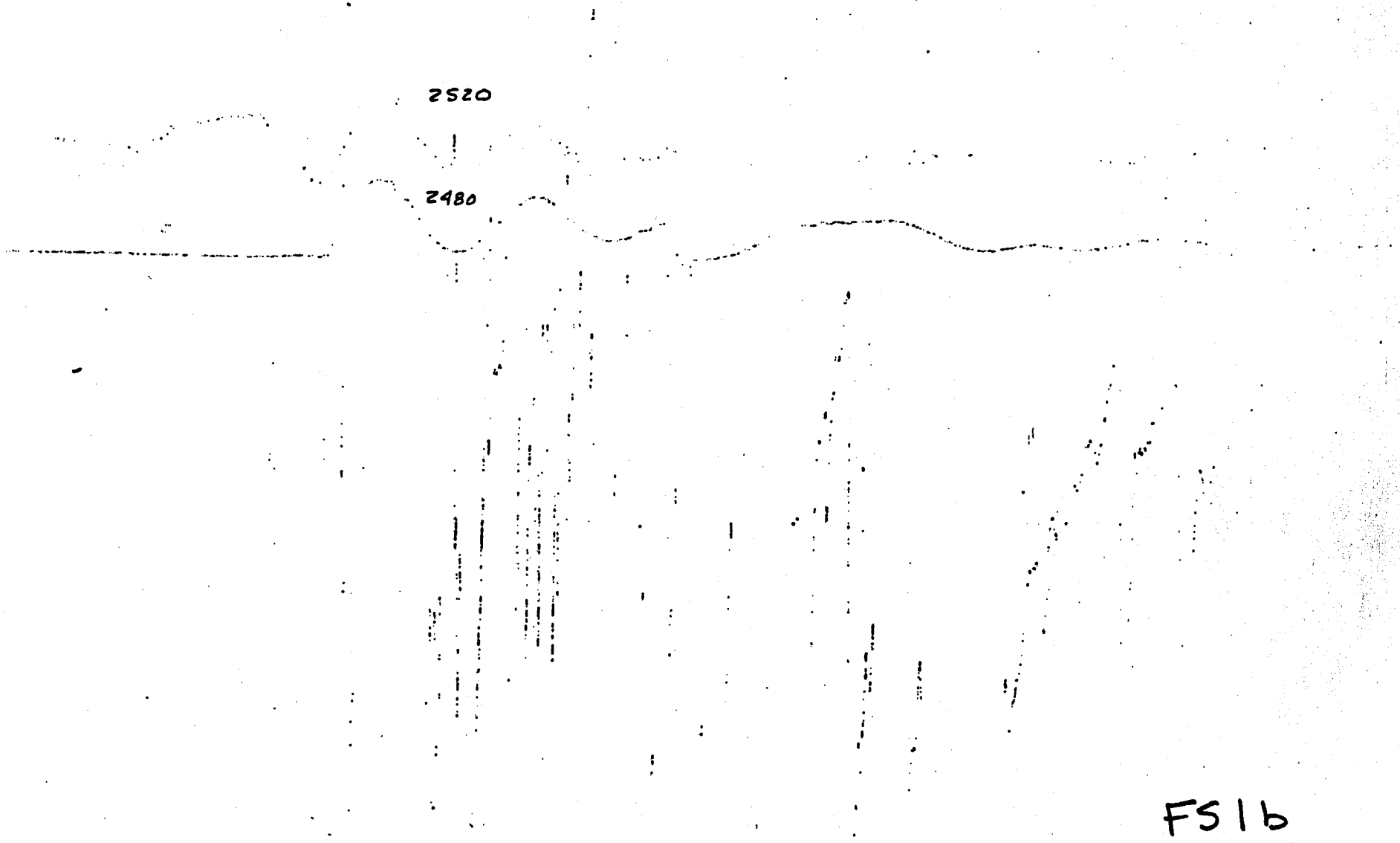

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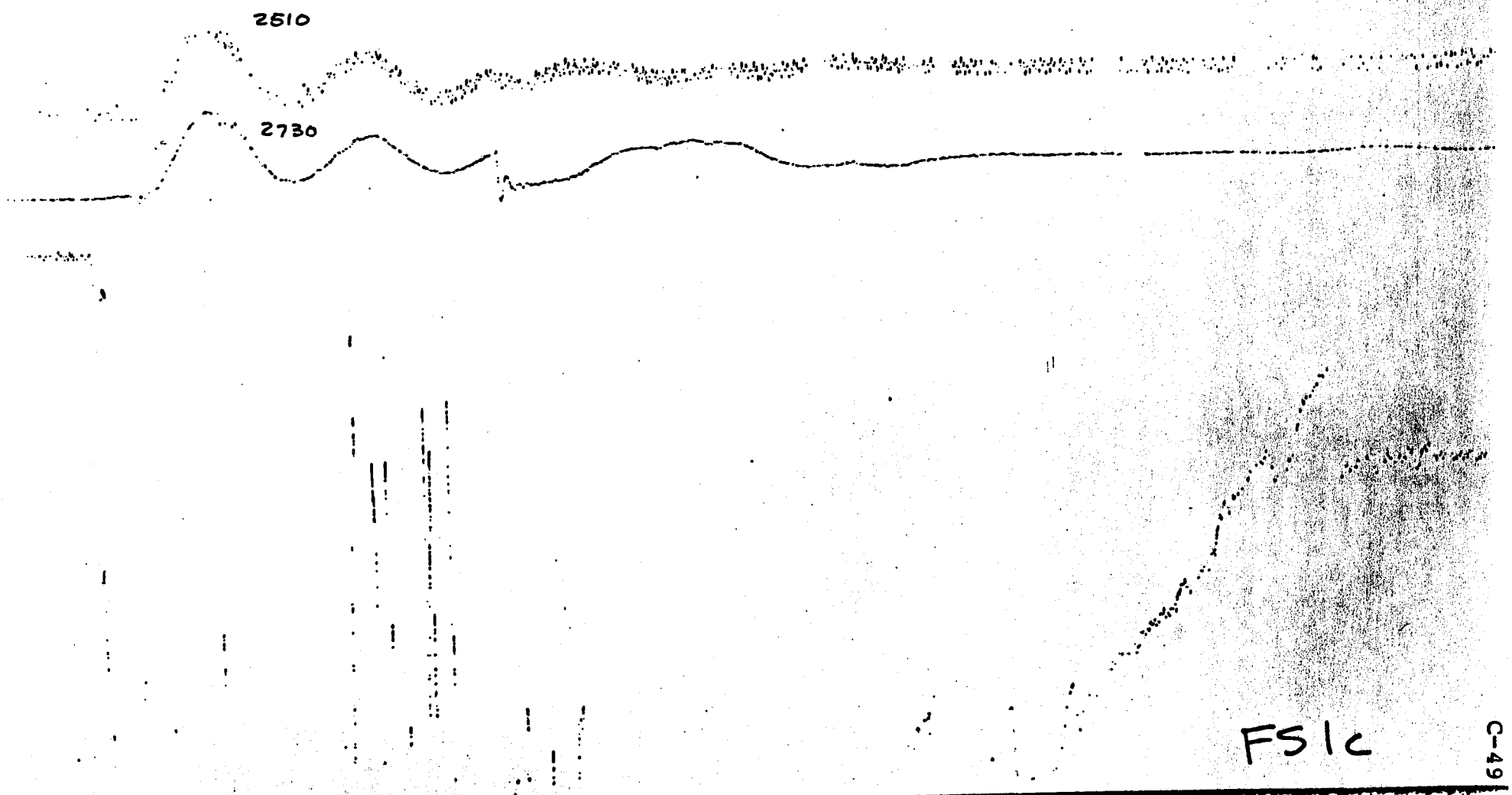
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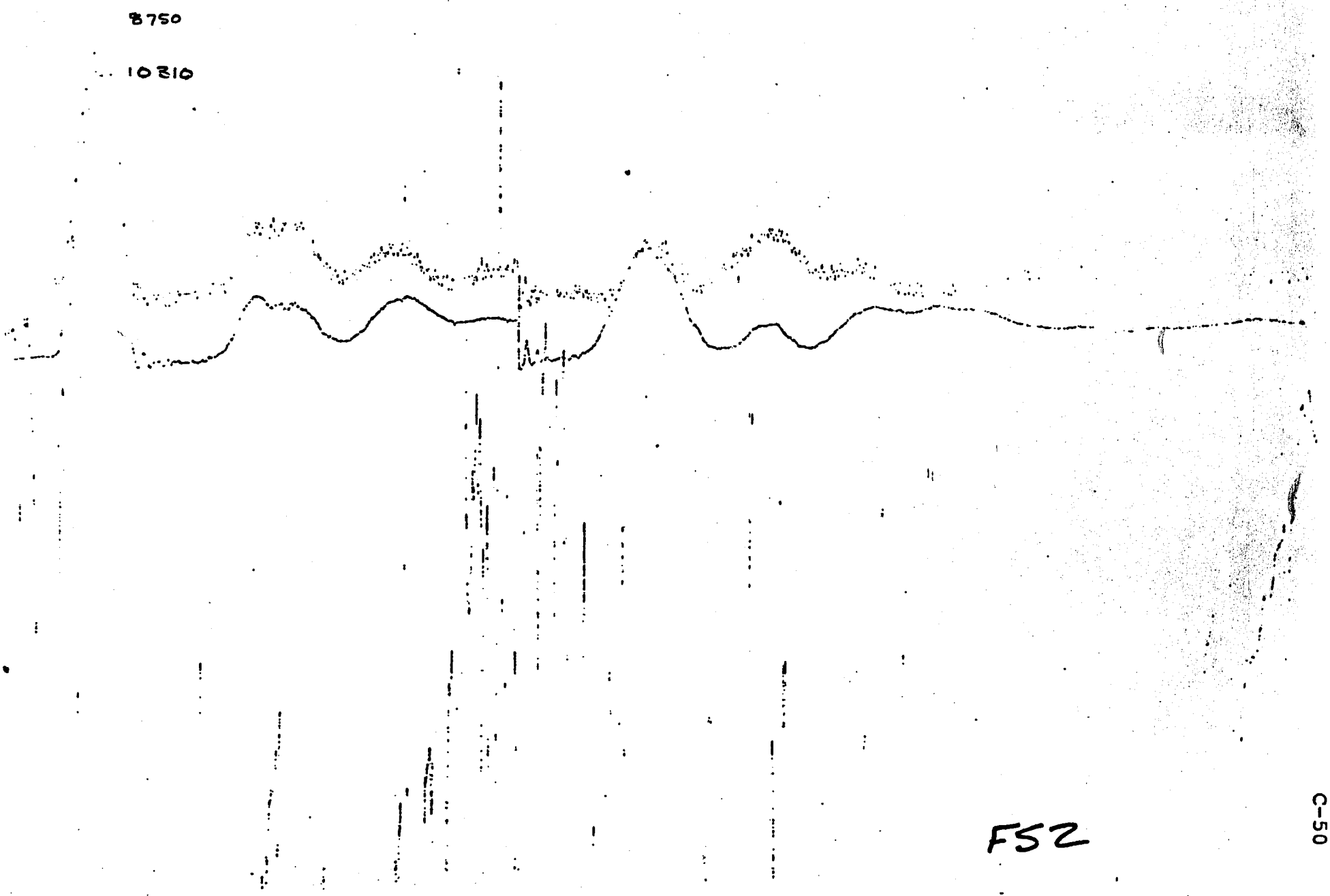
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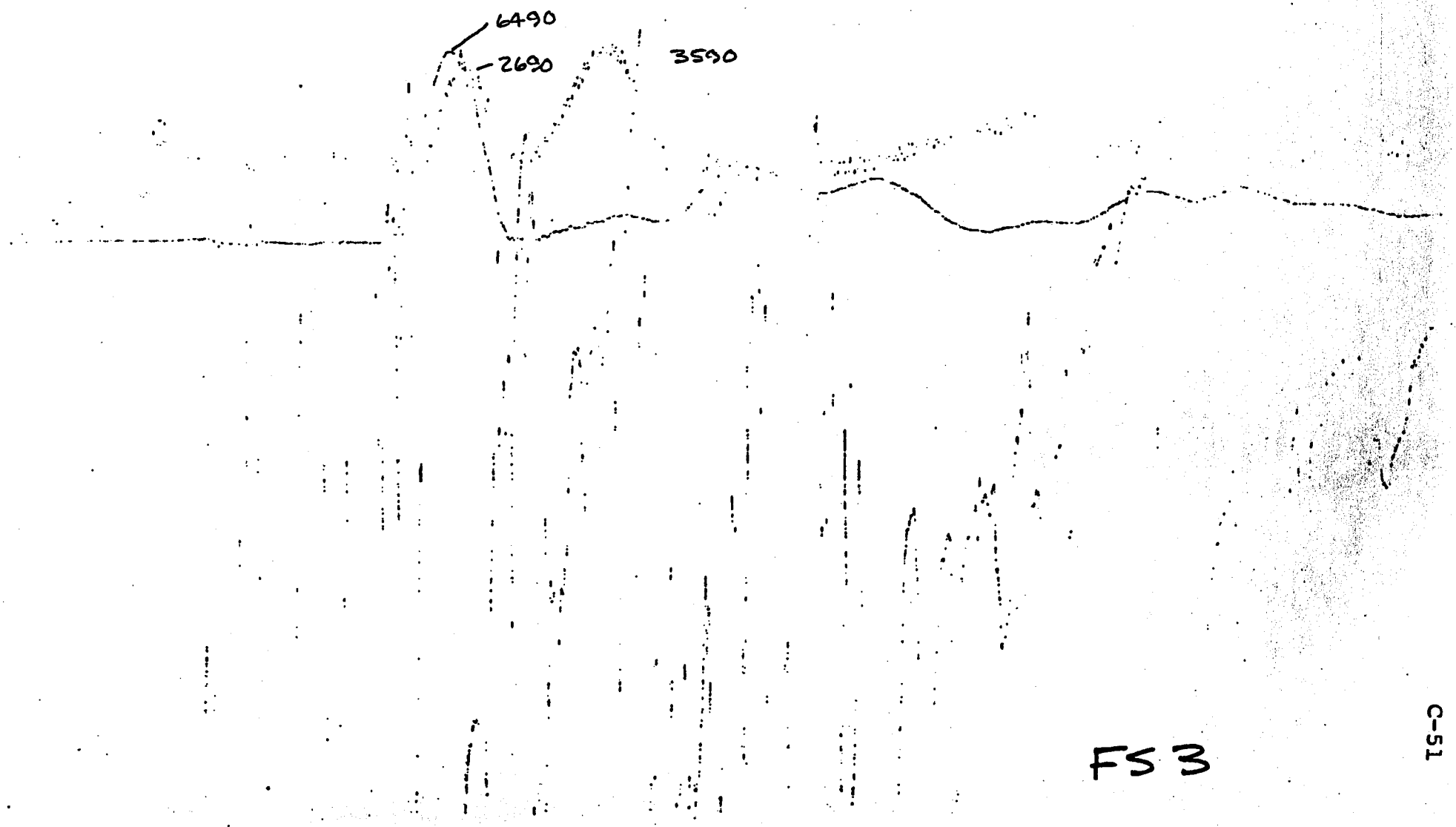

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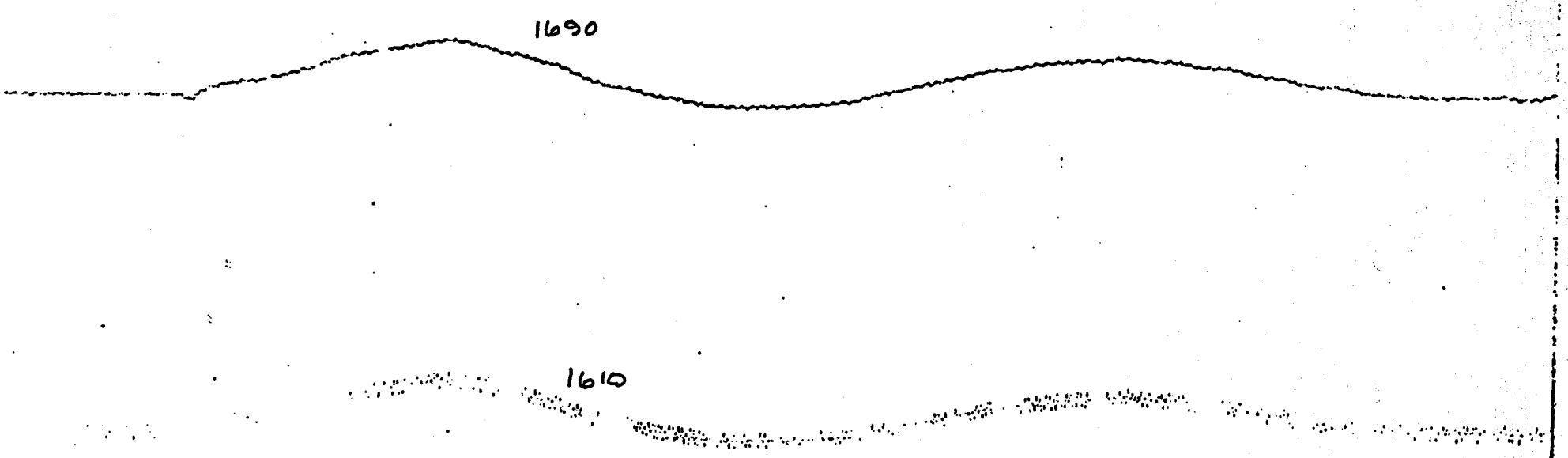


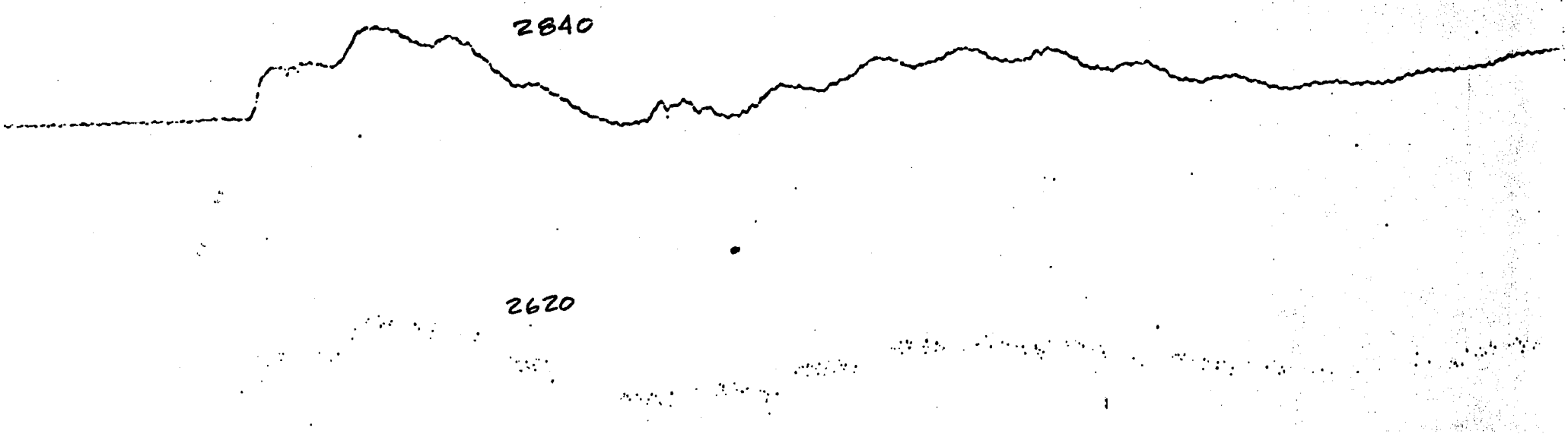
Slates drop bottom empty

2600

2220

cage @ Bottom
empty, going down

FA 3



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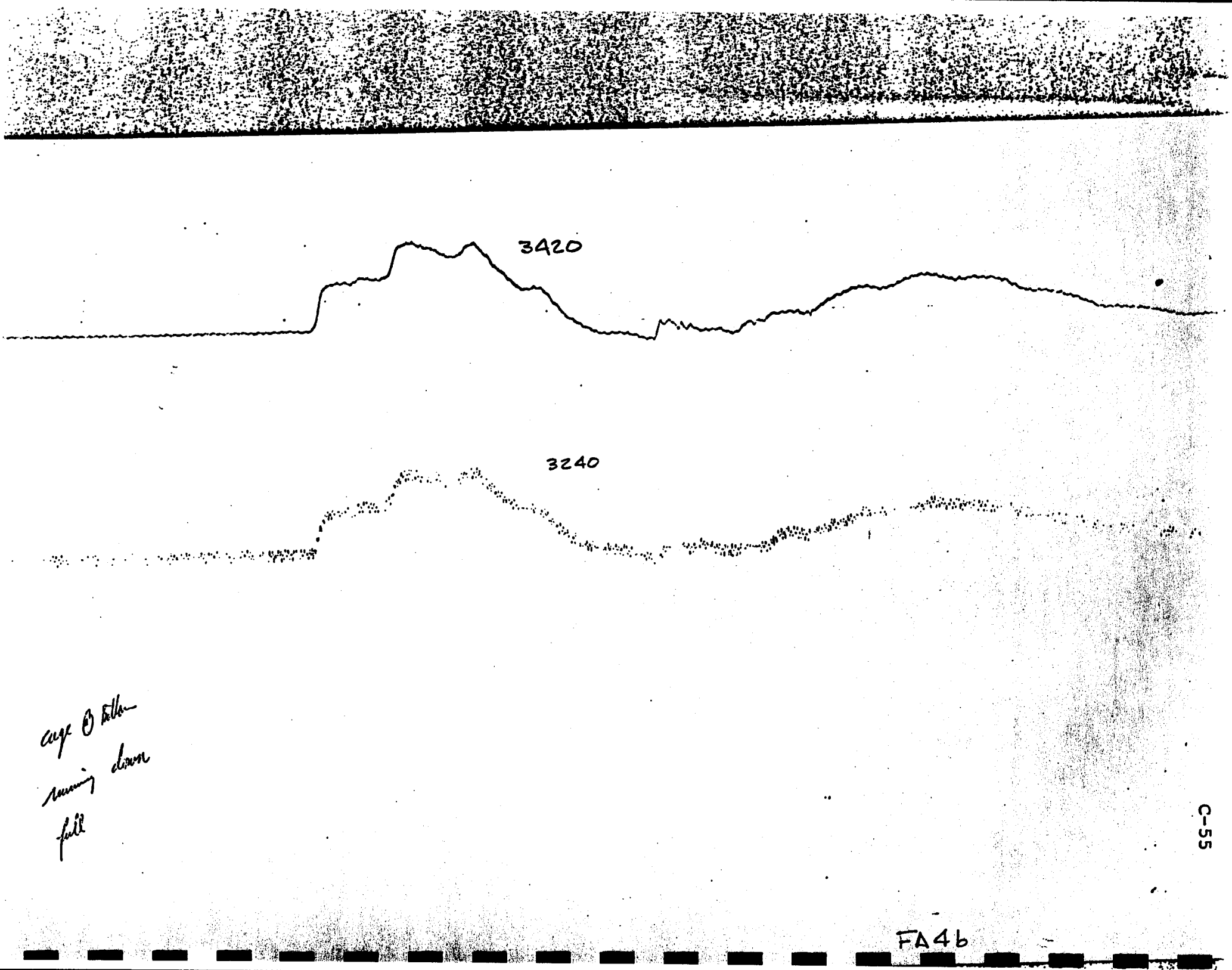
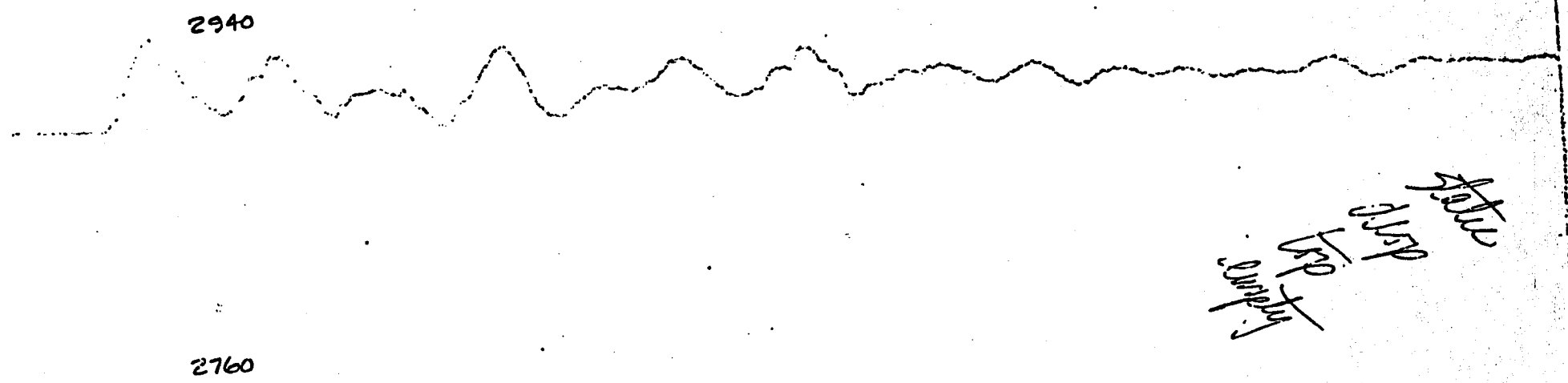


cage @ bottom
running down
full



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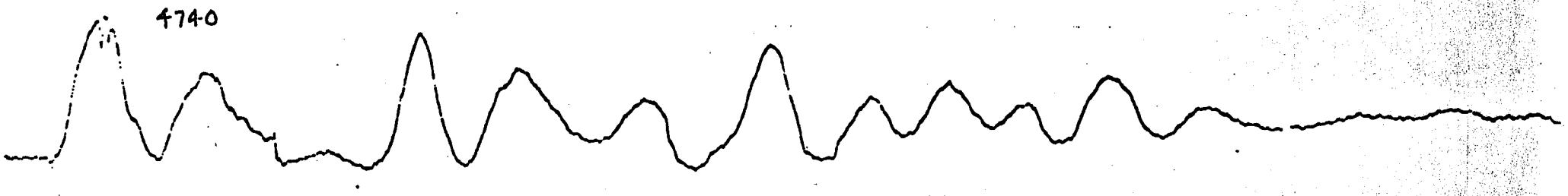

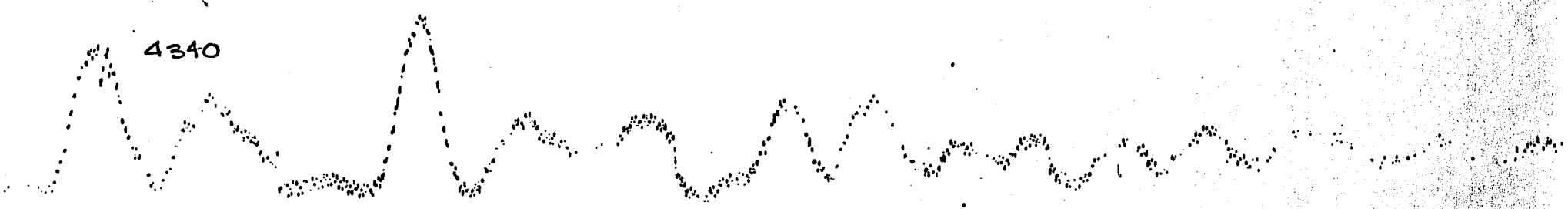

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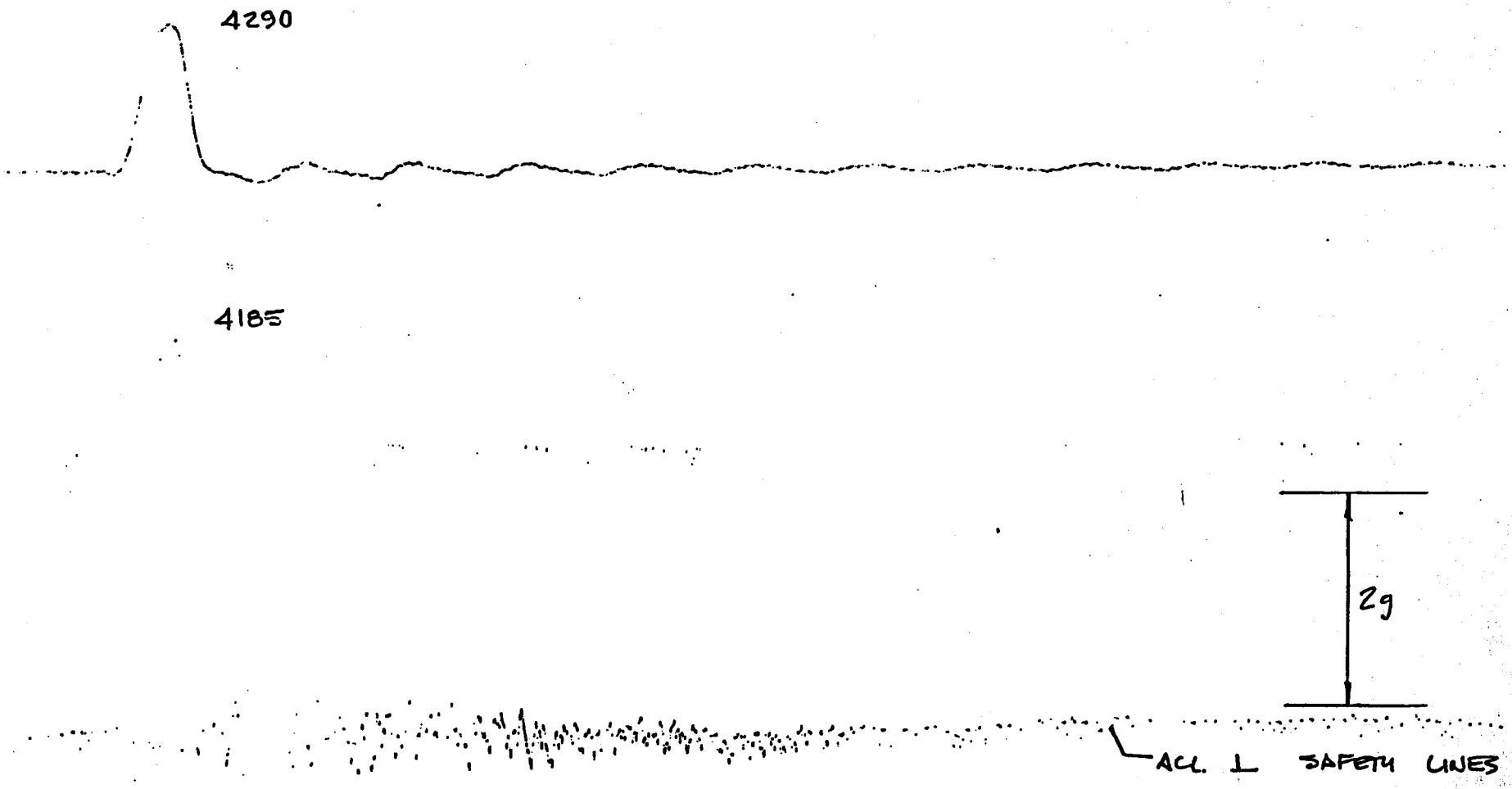

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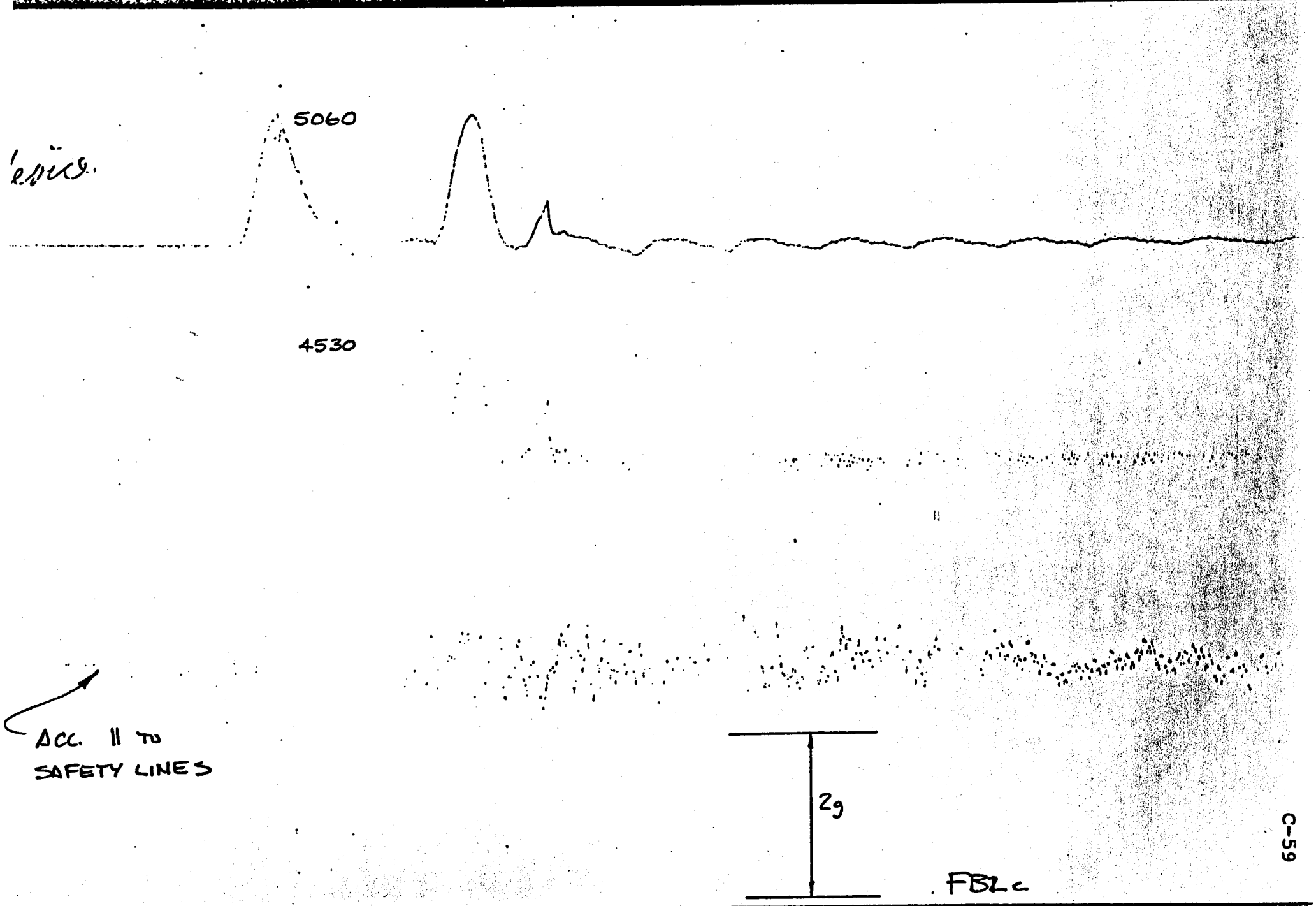
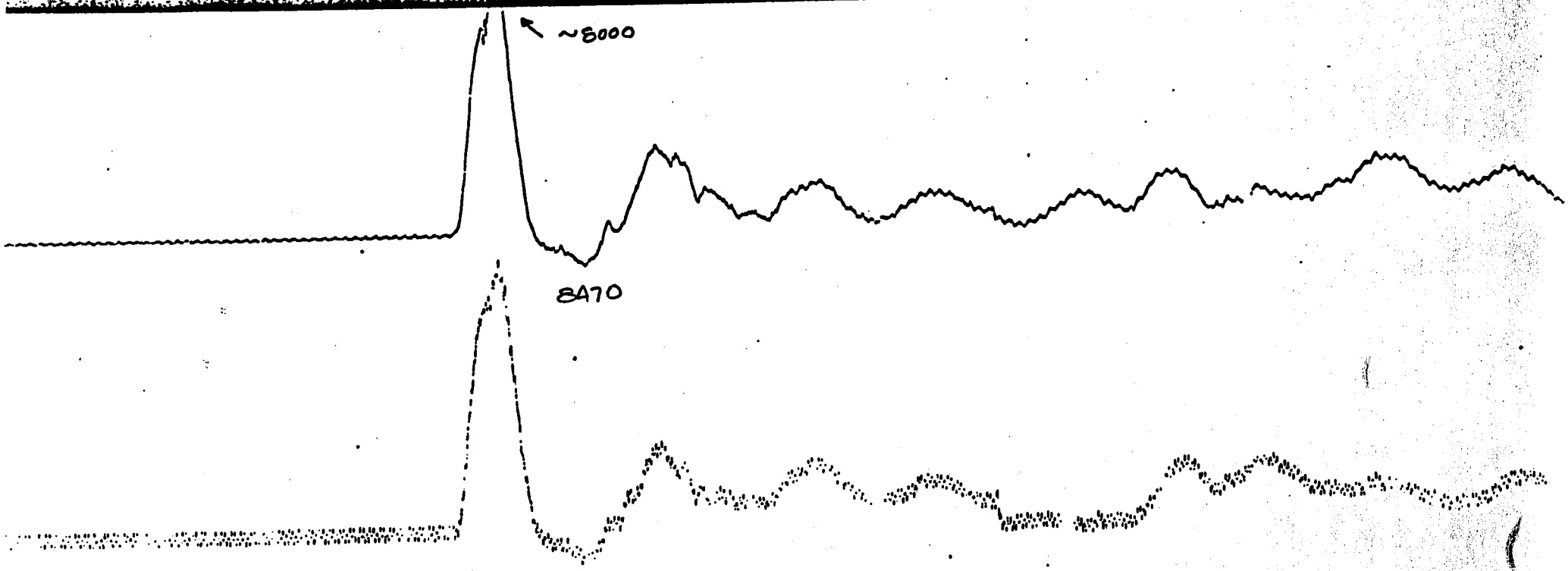

5060
4530
ACC. ∥ TO
SAFETY LINES
2g
FBLc



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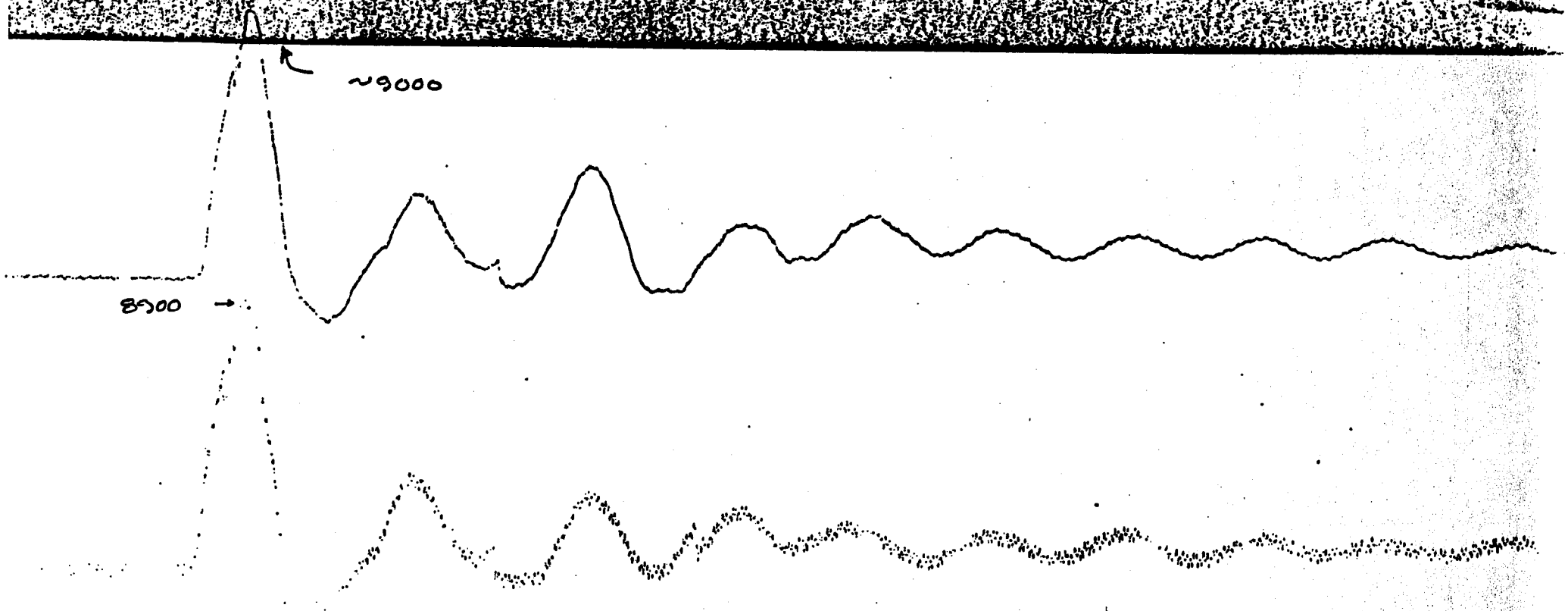
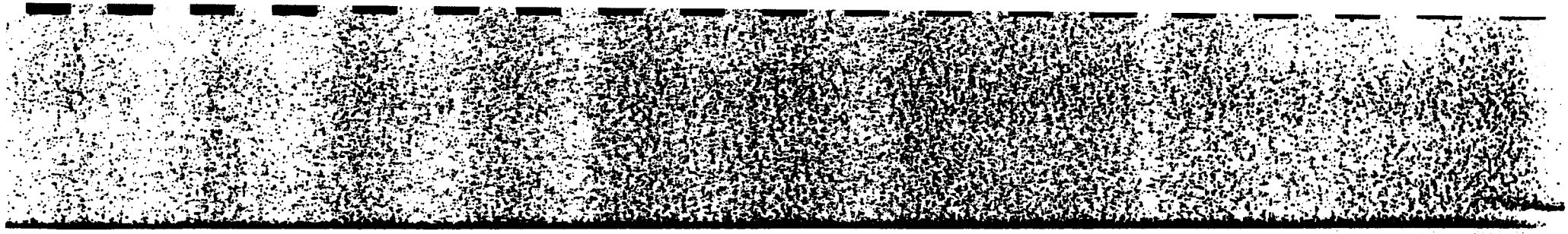
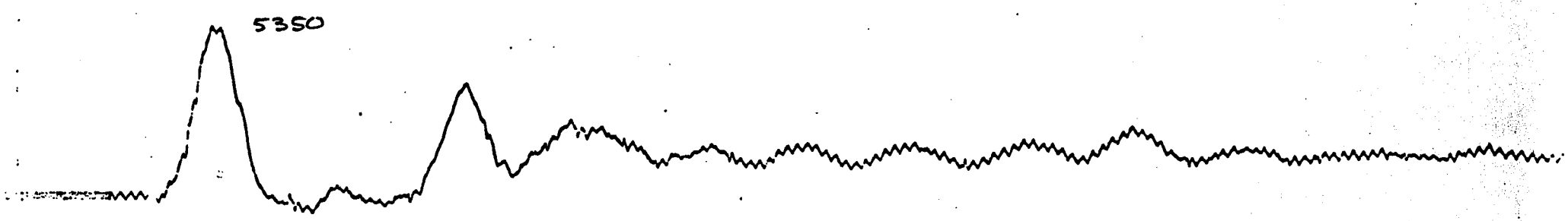
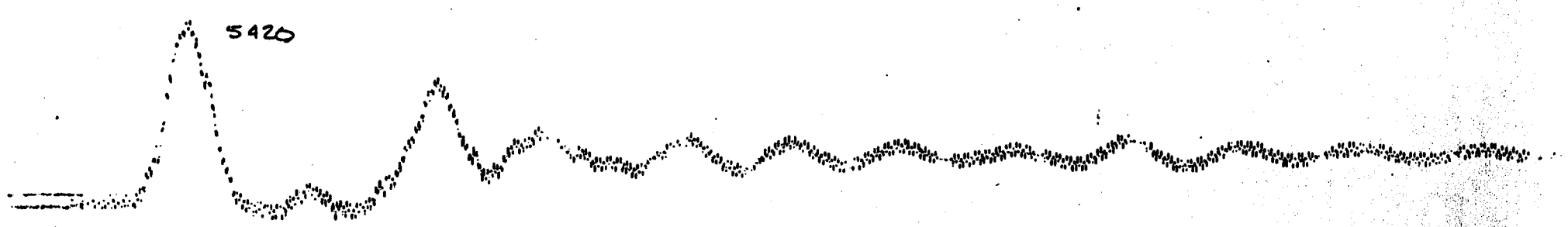


Stop
going down
fill

FB4







FC1

Appendix D

Metallurgical Report on Clamping Cams

TO R. W. Snook DATE July 10, 1980

FROM E. F. Gerwin

SUBJECT Metallurgical Examination - Crack Indications
Mancage Safety Clamps - Manufactured by (ITT)
Meyer Industries

References: (1) Meyer Industry Installation Operating Instruction Manual; Cracked Cable Safety Device, Inclusive of Skematic Sketch.

(2) R. Porthouse (PPP) memo to E. F. Gerwin (July 3, 1980) Transmitting Three (3) Separate Clamps

Three clamps as received (ITT skecth Ref I, Part No. 50613) consisted of a cam plate noted to be Type 304 S. S. (1/2" x 2 1/4" x 10"), which on one (working) end contained a weld metal "build up" composed of a hard facing alloy (unknown composition); about 1/4" thick on a 2 1/2" radius.

Visual Examination showed radial cracks existing in the hard facing alloy in all 3 clamps. Their radial length varied from full depth, to partial relative to the 1/4" hard face thickness; also on subsequent examination by microscopic means internal cracking evidence was observed which did not meet the outside surface. In no case however, did any of the crack evidence extend into the Type 304 base plate.

Initially the crack indications were discovered after on site safety tests were made; Numbered Cam #1 after 6 actuations; numbered #2 and #3 after 144 actuations (Reference 2 above).

The PPP Williamsport Metallurgical Lab chose Nos. #1 and #3 for examination by microscopic means. No. 1 contained notable "opened", radial crack through the hard faced thickness; No. 3 (and as well No. 2) contained multiple "hair-line" cracks at the outside surfaces.

Incidental with these examinations the hardness of the hard facing alloy was explored. The Rockwell Hardness was found to range from Rc 32 to 38 (BHN-300-352) not exceptionally high hardness, but apparently adequate for the intended service. The Manufacturer's Standard is not known. Evidence was discovered which shows that hardness checks were probably made and were consistent with PPP findings.

The results of microscopic examinations are shown in the attached series of photomicrographs (Fgis. 1 - 4 incl.).

TO: R. W. Snook DATE July 10, 1980

SUBJECT: Metallurgical Examination - Crack Indications
Mancage Safety Clamps - Manufactured by (ITT) Meyer Industries

Fig. 1 (Cam No. 1) shows the bond or fusion zone at the type 304 S.S. interface. It demonstrates a good metallurfical fusion, and penetration between the S.S. and the hard facing weld build up composition.

Fig. 2 (Cam No. 1) shows the crack opening at the surface (b) and the terminal (a) at the bond line. It is significant that there is no evidence of propagation into the 304 S.S. base plate.

Fig. 3 (Cam No. 3) shows the character of the hairline cracks discovered in this piece in the hard facing alloy. The radial depth in this case was about 90 mil (a-b, b-b).

Fig. 4 (a) (Cam No. 3) shows an internal crack in the hard facing alloy at about "mid" thickness which did not meet the outside surface. For the record Fig. 4 (b & c) is a 400 magnification of the crack pattern discovered. This is essentially the pattern of all the cracks observed in the microscopic examination.

DISCUSSION OF RESULTS

The crack pattern (as noted) describes the phenomenon which is variously known, relative to cast metal, as interdendritic or coring which takes place at the on set of solidification and attendant shrinkage. It is, as shown, characteristically intergrannular and in the case of this (unknown) hard facing composition, through the eutetic carbide precipitates at the dendritic grain boundaries.

It is therefore inherent (more or less) in the deposition process, and is augmented by variations in heat-input; deposition rates and to a very large extent by cooling rate at the melt pool. It also may vary widely from one composition to another and from chemical segregation in any one composition.

It is not entirely unavoidable especially in relatively thin cladding process effected by weld deposition.

The important consideration for the intended service (in this case particularly) is that "spalling off" of the clad is not a direct result. There was no evidence of this discovered in any of the samples submitted. It is believed that the good fusion, and coalescence at the boundary region (304 S.S. to weld deposit) will inhibit (if not prohibit) this occurence. Also significant is the fact that due to the customary toughness inherent in the 304 S.S. plate that the radial cracking discovered would not propagate this boundary.

TO: R. W. Shook

SUBJECT: Metallurgical Examination - Crack Indications
Mancage Safety Clamps - Manufactured by (ITT) Meyer Industries

PAGE NO. Three

As stated above, avoidance of this type of cracking is not always possible. On resolution is careful post welding inspection by aided means i. e., dye penetrant inspections and excavation and weld repair of discovered surface checking or cracking.

CONCLUSIONS AND RECOMMENDATIONS

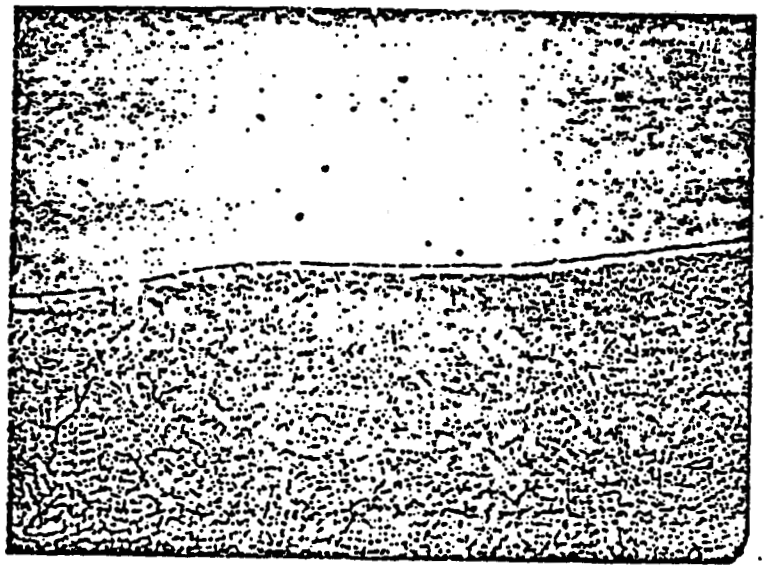
1. Cracking as noted stems from the welding process employed; it is not due to the service or testing experience.

2. The vendor (manufacturer) should be admonished to use precautionary process measures to minimize the occurrence; and to use post welding inspection and repair procedures which will mitigate the possibility of these prior service cracks.

E. F. Gerwin / dhs

EFG:dhs

Attachments



< 304 SS.

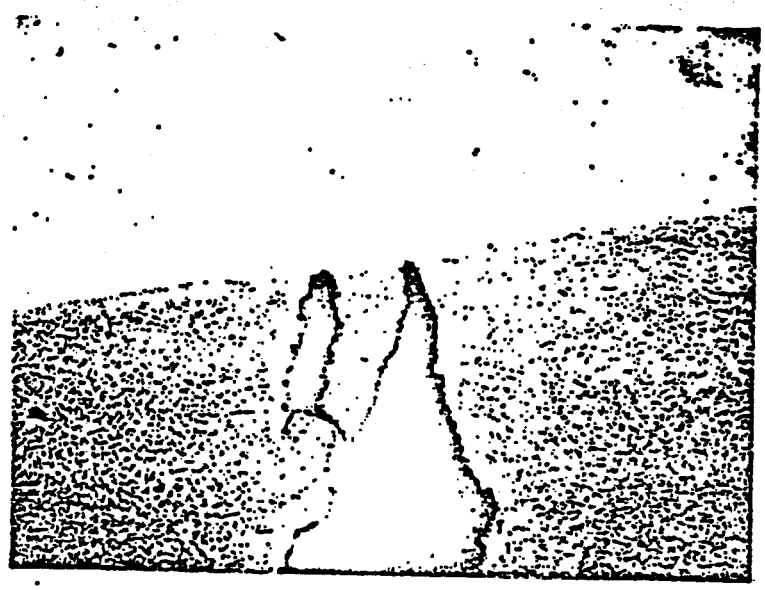
< Hard Face Alloy clad

Etch: Elec. Chromic 50X Mag.

Typical Fusion Zone

Manage Clamp No. 1.

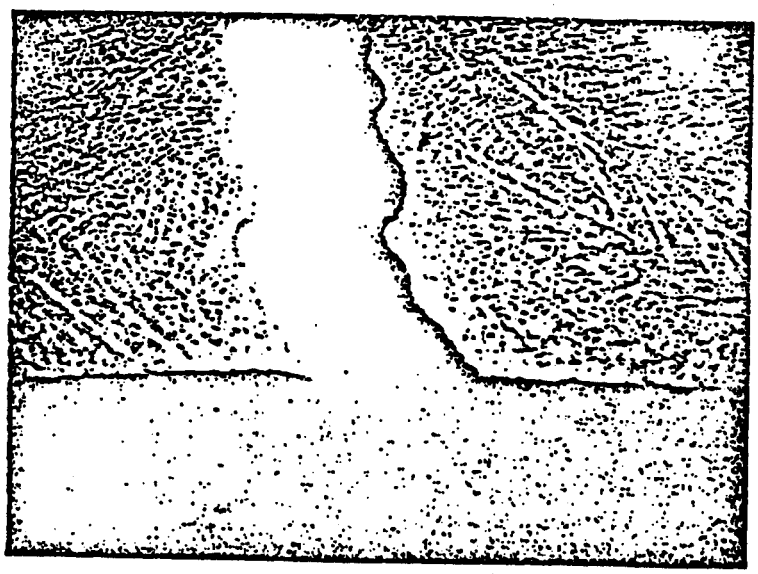
Fig. 1.



Terminal Crack
in 304 S.S. Base

Etch: Elec. Chromic 50x Mag.

(a)



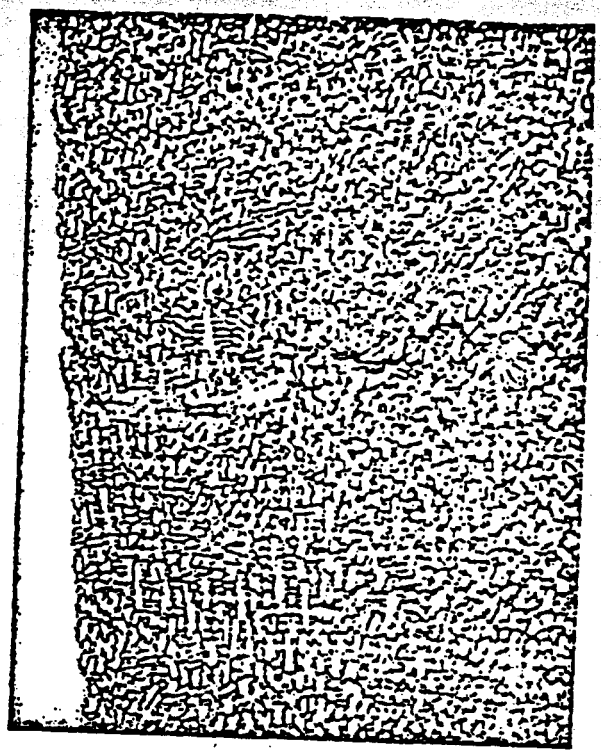
open crack
at outside surface
(b) to (a)

Etch: Elec. Chromic 50x Mag.

(b)

Manyage Clamp No.

FIG. 2.



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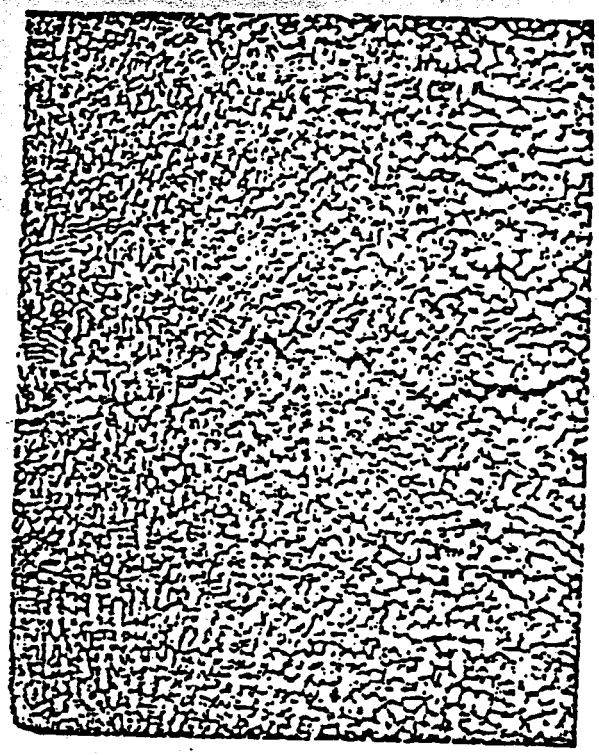
(a)



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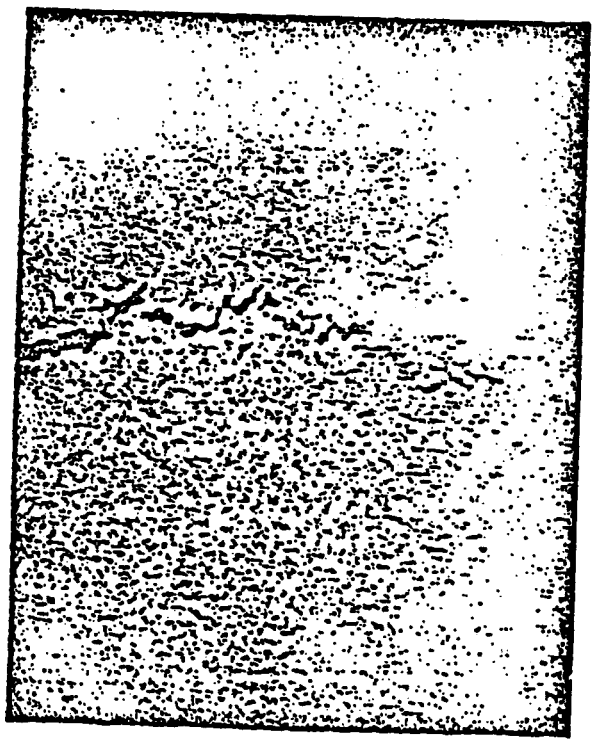
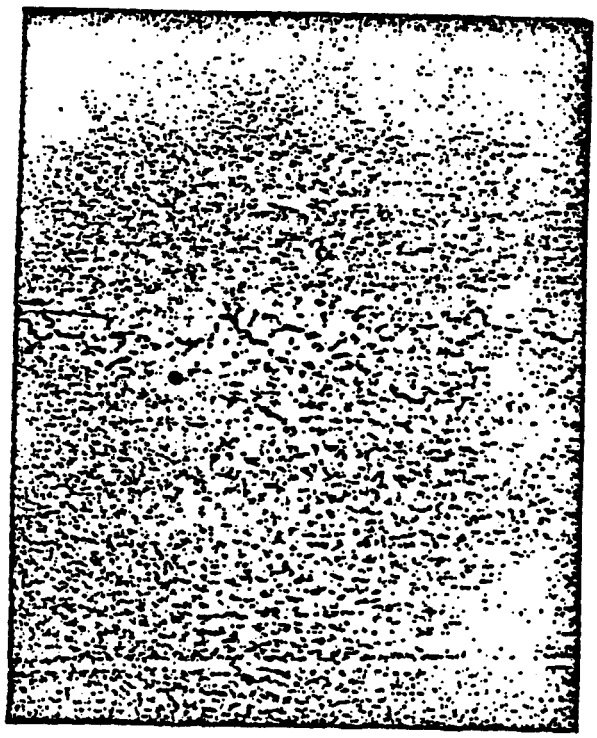
(b)

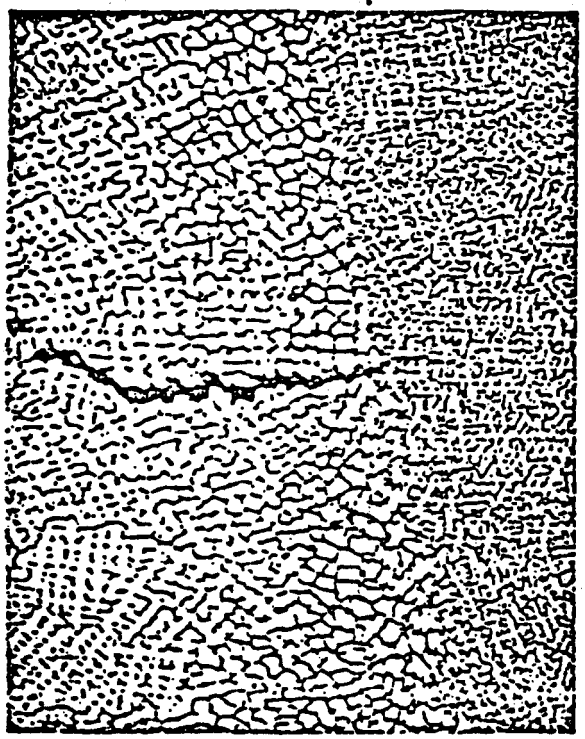


Unetched 50x Mag.
(a-a)



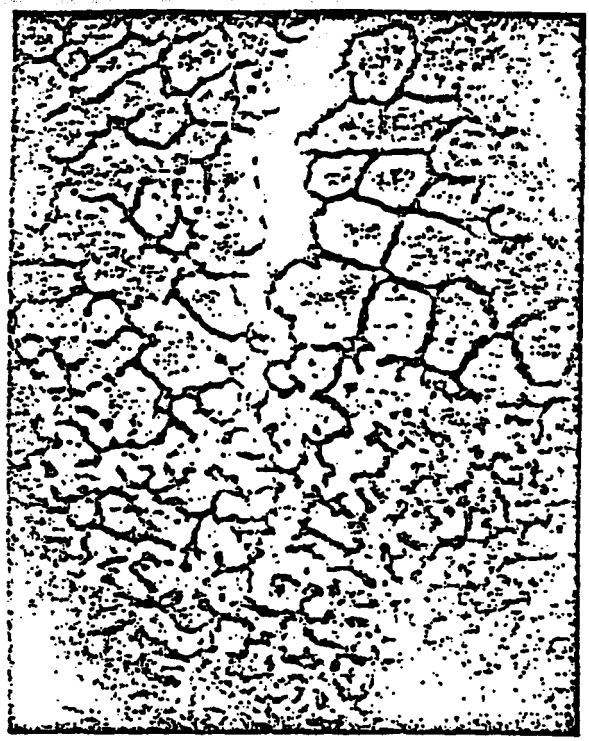
Unetched (b-b) 50x Mag.

Manage Clamp No. 3.
Fig 3.



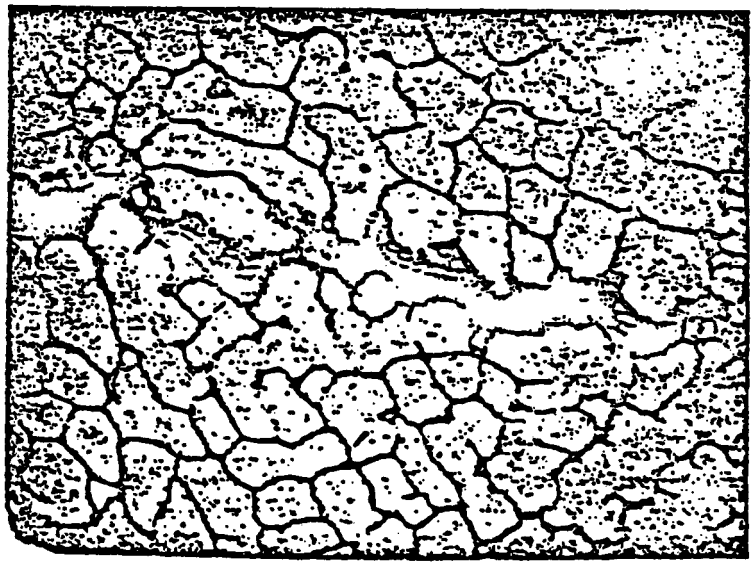
Etch: Elec. Chromic 50X Mag.

(a)



400X Mag.

(b)



400X Mag.

(c)

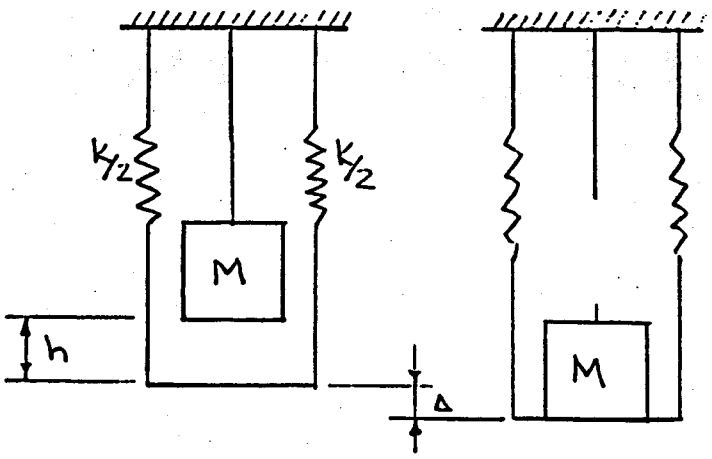
Massage Clamp No. 3.

FIG. 4.

Appendix E

Stiffness Effects of Safety System Components

Static Test - Break at Cage - Cage Near Top



Initial State

Maximum Deflection

The velocity at both states is 0; so kinetic energy is 0.

Total Energy

State 1: $Mg(h+\Delta) = W(h+\frac{F}{k})$

State 2: $\frac{1}{2}k\Delta^2 = \frac{1}{2}\frac{F^2}{k}$

$$F^2 - 2WF - 2kWh = 0$$

$$F = W + \sqrt{W^2 + 2kWh}$$

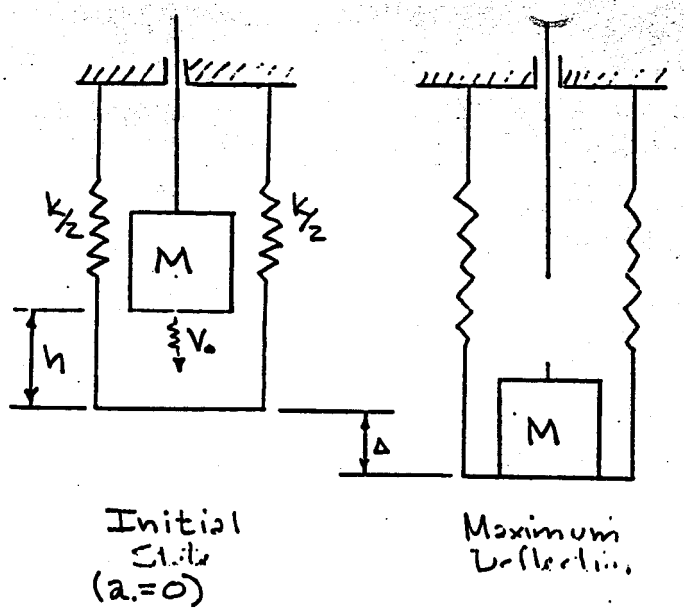
$$F = W + \sqrt{W^2\left(1 + 2\frac{k}{Mg}h\right)}$$

$$F = W\left[1 + \sqrt{1 + 2\omega^2\frac{h}{g}}\right] \qquad \text{where } \omega^2 = \frac{k}{M}$$

$$\boxed{F = W\left[1 + \sqrt{1 + (\omega t_0)^2}\right]} \qquad \text{where } h = \frac{1}{2}gt_0^2$$

Note: $\min F = 2W$

Dynamic Test - Break at Cage - Cage Near Top



Velocity at maximum deflection is 0.

Total Energy

State 1: $Mg(h+\Delta) + \frac{1}{2}Mv_o^2 = W\left(h+\frac{F}{k}\right) + \frac{1}{2}W\frac{v_o^2}{g}$

State 2: $\frac{1}{2}k\Delta^2 = \frac{1}{2}\frac{F^2}{k}$

$$F^2 - 2WF - 2kWh - Wk\frac{v_o^2}{g} = 0$$

$$F = W + \sqrt{W^2 + 2kWh + Wk\frac{v_o^2}{g}}$$

since $\omega^2 = \frac{k}{m}$ and $h = \frac{1}{2}gt_o^2 + v_o t_o$

$$F = W\left[1 + \sqrt{1 + \omega^2\left(t_o^2 + \frac{2v_o t_o}{g} + \frac{v_o^2}{g^2}\right)}\right]$$

$$\boxed{F = W\left[1 + \sqrt{1 + \omega^2\left(t_o + \frac{v_o}{g}\right)^2}\right]}$$

Appendix F

Endurance Testing Results

Table F.1 - Endurance Testing

Set 1 - 6/30/80

Test #	Cage Height Before Drop (inches)	Cage Height After Drop (inches)	Safety Device Actuation
E101	43 3/4	42 1/2	worked
E102	52 7/8	51 3/4	worked
E103	55 7/8	54 5/8	worked
E104	43 7/8	42 1/4	worked
E105	46 1/2	45 3/8	worked
E106	66 3/4	65 1/2	worked
E107	75 3/8	74 1/8	worked
E108	70 1/4	68 7/8	worked
E109	75 1/2	74 3/8	worked
E110	32 1/8	30 3/4	worked
E111	37	35 7/8	worked
E112	41 3/4	40	worked
E113	48 5/8	47 1/2	worked
E114	57 7/8	56 1/2	worked
E115	69 1/4	67 7/8	worked
E116	75 5/8	74 1/4	worked
E117	28 7/8	27 1/2	worked
E118	35 5/8	34	worked
E119	42 5/8	41 3/4	worked
E120	50 1/4	49	worked
E121	61 1/4	60	worked
E122	69 1/4	67 7/8	worked
E123	74 7/8	73 1/4	worked
E124	31	29 5/8	worked
E125	37 7/8	35 3/4	worked
E126	43 1/8	42 1/8	worked
E127	50 1/2	49 1/8	worked
E128	56 1/2	55 1/4	worked
E129	63 1/2	62 1/2	worked
E130	71 1/2	70 1/4	worked
E131	78 1/2	77 3/8	worked
E132	26 3/4	25 1/8	worked
E133	35 1/4	34	worked
E134	41 5/8	40 1/8	worked
E135	46 3/8	44 7/8	worked
E136	51 1/2	50	worked

Table F.2 - Endurance Testing

Set 2 - 6/30/80

Test #	Cage Height Before Drop (inches)	Cage Height After Drop (inches)	Safety Device Actuation
E201	22	20 1/2	worked
E202	30 3/4	29 5/8	worked
E203	37 3/4	36 1/4	worked
E204	46	44 7/8	worked
E205	52 7/8	51 1/2	worked
E206	60 3/4	59 1/2	worked
E207	70 1/2	69 1/4	worked
E208	77 1/4	76 3/8	worked
E209	29 1/2	25 3/8	worked
E210	30 3/8	28 7/8	worked
E211	37 1/2	35 7/8	worked
E212	45 1/2	44 1/4	worked
E213	53 3/4	51 3/4	worked
E214	58 7/8	57 1/2	worked
E215	64 1/4	62 5/8	worked
E216	69 3/4	68 3/8	worked
E217	76 1/4	74 7/8	worked
E218	27 1/4	25 1/2	worked
E219	31 3/4	30 1/8	worked
E220	36 1/2	34 7/8	worked
E221	41 3/4	40	worked
E222	45 7/8	43 7/8	worked
E223	50 3/4	48 7/8	worked
E224	57 3/4	56 1/4	worked
E225	67 3/8	65 3/4	worked
E226	72 1/8	70 1/2	worked
E227	72 1/2	70 3/4	worked
E228	25 1/2	24	worked
E229	30 3/4	28 7/8	worked
E230	36 5/8	34 1/2	worked
E231	43 1/4	41 3/8	worked
E232	51 1/2	49 1/2	worked
E233	59 1/2	57 7/8	worked
E234	64 1/2	62 1/2	worked
E235	68 3/8	66 7/8	worked
E236	72 1/2	70 1/4	worked

Table F.3 - Endurance Testing

Set 3 - 6/30/80

Test #	Cage Height Before Drop (inches)	Cage Height After Drop (inches)	Safety Device Actuation
E301	37 7/8	35 7/8	worked
E302	44 7/8	43 1/8	worked
E303	48 1/2	46 3/4	worked
E304	53 1/2	51 3/4	worked
E305	63 1/8	61 1/4	worked
E306	69 1/2	67 1/2	worked
E307	73 7/8	71 7/8	worked
E308	24 3/4	22 3/4	worked
E309	31 1/2	29 7/8	worked
E310	35 3/8	33 1/2	worked
E311	42 1/8	40 1/4	worked
E312	48 1/8	46 3/4	worked
E313	53 1/2	51 7/8	worked
E314	61 3/8	59 5/8	worked
E315	69 3/8	68	worked
E316	73 1/4	71 3/4	worked
E317	20 5/8	18 5/8	worked
E318	29 1/4	27 3/4	worked
E319	35	33 3/4	worked
E320	48 1/8	46 1/2	worked
E321	57 7/8	51 1/8	worked
E322	58 7/8	57 3/8	worked
E323	69 1/2	64 7/8	worked
E324	72 5/8	71 1/8	worked
E325	74 3/4	73 3/8	worked
E326	23 1/4	21 1/4	worked
E327	25 1/8	23 1/4	worked
E328	34 3/4	33	worked
E329	44 1/4	42 1/8	worked
E330	46 3/4	44 3/4	worked
E331	50 1/4	48 5/8	worked
E332	54 5/8	52 1/2	worked
E333	60 1/2	58 7/8	worked
E334	66 3/4	65 1/4	worked
E335	75 3/8	73 3/8	worked
E336	56 1/2	54 3/4	worked

Table F.4 - Endurance Testing

Set 4 - 7/01/80

Test #	Cage Height Before Drop (inches)	Cage Height After Drop (inches)	Safety Device Actuation
E401	56 1/4	54 5/8	worked
E402	58 1/4	56 1/2	worked
E403	57 1/2	55 5/8	worked
E404	34 1/2	32 5/8	worked
E405	37 1/2	35 3/4	worked
E406	45	43 1/2	worked
E407	53 1/8	51 1/4	worked
E408	58	56	worked
E409	61 1/8	59 1/2	worked
E410	69 3/4	67 3/4	worked
E411	46 5/8	44 3/4	worked
E412	32 1/8	30 1/8	worked
E413	43 1/4	41 3/8	worked
E414	50 7/8	48 7/8	worked
E415	45 1/8	43 1/4	worked
E416	60 1/4	58 1/2	worked
E417	70 7/8	69	worked
E418	28 1/8	26 1/2	worked
E419	51 1/4	49 3/8	worked
E420	60	58 1/4	worked
E421	66 7/8	65 1/8	worked
E422	44	42 1/8	worked
E423	38 1/8	35 7/8	worked
E424	46 3/4	44 3/4	worked
E425	65 1/8	63 1/4	worked
E426	30 1/8	28 1/2	worked
E427	37 1/8	35 1/2	worked
E428	53 1/8	51 1/4	worked
E429	26 5/8	24 5/8	worked
E430	59 5/8	57 7/8	worked
E431	32 7/8	30 7/8	worked
E432	38 1/2	36 3/8	worked
E433	51	49	worked
E434	53 1/4	51 3/8	worked
E435	31 5/8	30	worked
E436	49 1/2	48 1/8	worked

OTV

March 9, 1981

Mr. Robert N. Martin, Chairman
National Chimney Construction Safety
and Health Advisory Committee
Pullman Power Products
1575 North Universal Avenue
Kansas City, Missouri 64120

Dear Mr. Martin:

The following observations/questions were made by our engineering staff in the Office of Construction Standards concerning your report on the broken cable safety device used on the personnel cage:

1. Since the body of the report implies that there were failures, under what conditions did failure occur?

2. What forces, including lateral motion, were experienced at the floor of the cage?

3. What type of steel wire rope was used?

4. Tables in the body of the report are not clear.

5. Procedures for adjusting the safety device are not detailed. Also, how is this adjustment maintained and how quickly is it out of adjustment when used?

6. How is the 200 lb. tension, or adequate tension, maintained in the safety cables at the foundation ends for long lengths.

7. Computer printout does not give unit of measure, i.e., force, distance, etc.

8. What corrective actions have been taken to eliminate the deep cracks in the safety device (see metallurgical report on clamping cams in Appendix D)?

9. The computer program is missing the mathematical formula in the computer presentation that was used to develop this program.

Sincerely,

James J. Concannon
Director
Office of Variance Determination