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Performance Testing of Explosion Relief Panels Manufactured by C/S Construction Specialties Limited

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DIVISIONAL REPORT MRL 90-20 (TR)

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by

E.E. Dainty[1], D. Hamel[2], G. Lobay[3], R. Olson[4], W. Vincent[5]

ABSTRACT

Explosion vent panels, which are used to release a potentially damaging sudden buildup of internal pressure generated by a gas or dust explosion in a building or other structure, were assessed for performance. Prototype panels measuring about 30" x 30" were mounted on one of the ends of a cylindrical enclosure having an internal volume of approximately 65 ft^3. The enclosure was filled with an explosive methane-air mixture (8% methane-air), then ignited. Various panel constructions were assessed in terms of ability to prevent excessive overpressures.

KEYWORDS: Explosion Venting, Explosion Pressure Relief, Venting of Deflagrations, Damage Limiting Construction

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[1] Technician, Canadian Explosive Atmospheres Laboratory, CANMET

[2] Technician, Canadian Explosive Atmospheres Laboratory, CANMET

[3] Certification Officer, Canadian Explosive Atmospheres Laboratory, CANMET

[4] C/S Construction Specialties Ltd., New Jersey

[5] C/S Construction Specialties Ltd., Mississauga, Ontario

INTRODUCTION

This report describes work carried out on a collaborative basis with C/S Construction Specialties Ltd., of Mississauga, Ontario, a manufacturer of Explovent explosion venting systems used for damage-limiting construction in buildings.

In a typical gas or dust explosion, the rapid combustion of the fuel produces quantities of expanding hot gases which, if the explosion occurs in an enclosed space such as a building, quickly increases the internal pressure. If this rapid internal pressure buildup is not released, severe structural damage to the building may result. Damage may begin to occur in unprotected buildings at pressures on the order of 100 pounds force per square foot[6], i.e. less than 1 psi.

In general, explosion vent panels are intended to provide a means for pressure relief, so that explosion pressures generated inside a building from an explosion are reduced as much as possible. This can greatly reduce the potential damage to the building that would have otherwise resulted from the explosion, and accordingly is often used as a loss prevention (or reduction) measure.

Explosion venting panels provide an area of "least resistance" in a given installation, and are designed to be the first device to open in the protected structure, thereby releasing the rising internal pressure in the building in the event of an explosion. A suitable amount of explosion venting surface area must be provided, relative to the volume of the structure being protected, and must be located where it would best provide the required explosion pressure relief. In many cases, the application of the explosion vent panel requires a suitable degree of weather protection to minimize building heat loss through conduction and infiltration. In addition, the venting panel must mechanically operate satisfactorily under the dynamic conditions of an explosion, which is the focus of this report.

Under some circumstances, a vacuum within an enclosure can be experienced immediately after the explosion. This occurs as a result of the expulsion of large quantities of gas from the enclosure, and rapid cooling of the gases within. The negative pressure inside the enclosure will equilibrate to the pressure of the atmosphere surrounding the enclosure, the rate depending on how well the enclosure is sealed. In order to minimize this effect, Explovent panels are fitted with hold open mechanisms to allow air external to the enclosure to reenter in as unrestricted a manner as possible. If a hold open mechanism were not used or if one were used but did not operate effectively, an explosion

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[6] All references to explosion pressures in this report are in terms of gauge pressure (i.e. referenced to normal atmospheric pressure).

vent panel could open as the result of an explosion, but shortly thereafter be drawn shut by an ensuing vacuum in the building. This in turn could contribute to an implosion of the structure if the vacuum was not effectively relieved.

Two sources of information for explosion vent design are:

> "Venting of Deflagrations", National Fire Protection Association (NFPA) Guide 68 (1988 edition);
>
> "Damage Limiting Construction", document 1-44 published by Factory Mutual Inc., February 1968 edition.

Appendix B shows a sample calculation of venting area, using the method specified in NFPA Guide 68, for the explosion test chamber used to produce the results in this report.

The C/S Construction Specialties Ltd. Explovent Panels use a calibrated latch mechanism to hold the panel closed, also allowing it to open at a predetermined pressure. When customer specified, units are equipped with a hold-open device. C/S Construction Specialties Ltd. recommends that a hold-open device be used.

The panels all generally consist of a 30" x 30" (nominal) single panel, hinged either at the top or the bottom. In addition to the magnetic latch used to hold the panel closed under normal conditions, a hold open mechanism is provided, which holds the panel open once released. A shock absorbtion system is provided to absorb the kinetic energy of the panel as it opens. A variety of panel materials are available for various applications.

The objectives of the work undertaken were:

- confirm the overall function and durability of the Explovent explosion relief system, with particular attention to the magnetic latch release mechanism, the panel hold open restraint hardware, and the panel core materials;
- determine the effect of different panel materials on explosion venting performance;
- to check the operation of the field test equipment to be used in conjunction with the magnetic latch mechanism;
- determine the relationship between the static release pressure of the latch mechanism, and the pressures measured during an explosion;

- perform a preliminary explosion test on an explosion relief louvre;
- determine what changes would have to be made to the CANMET explosion test instrumentation to accommodate the measurement of extremely low explosion pressures;

METHOD

The chamber used for all explosion tests was cylindrical, measuring approximately 47" diameter by 67" long, constructed from fabricated steel. One end of the enclosure was closed off by a fabricated steel end. The panel under test was fitted to a plywood carrier which allowed the panel assembly to complete the test enclosure (see Fig. 1). Although all obvious openings in the enclosure were sealed for the tests, no attempt was made to make it completely air tight.

The test gas used in all cases was a mixture consisting of 8% methane (C.P. grade), and 92% air. Gas concentrations for each test were verified by a Beckman non-dispersive infrared laboratory analyzer, calibrated with gas produced by a custom built high accuracy calibration gas generator.

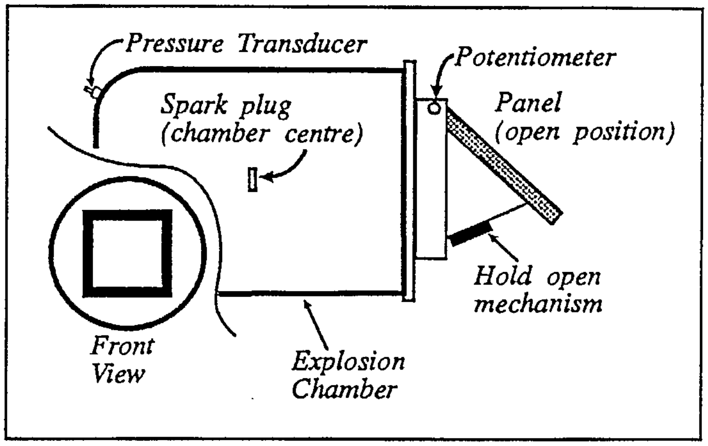


Figure 1 - Test Chamber

The gas was ignited by means of an automotive spark plug located in the approximate centre of the chamber.

In a typical test, 100% methane was injected into the enclosure, and mixed with the air in the chamber by a continuously running mixing fan. Because the enclosure was not air tight, the methane that was added to the enclosure did not raise the pressure inside the enclosure above normal atmospheric pressure. The slowly rising gas concentration was monitored with the infrared gas analyzer, and when the required concentration was reached, the mixing fan was turned off, and the gas was ignited.

Explosion pressures in the chamber were monitored by means of a piezoelectric pressure transducer, connected to a signal conditioning charge amplifier via a low noise teflon insulated coaxial cable, and a digital chart recorder. All the charts produced by the recorder as a result of the tests conducted are reproduced in Appendix A. A potentiometer was attached to the panel so that its angular position during a test could be recorded on the chart recorder. Most of the tests were recorded on video.

Figure 2 shows a typical explosion pressure vs. time curve, along with angular panel position, where the panel operated normally (i.e. stayed open after the explosion).

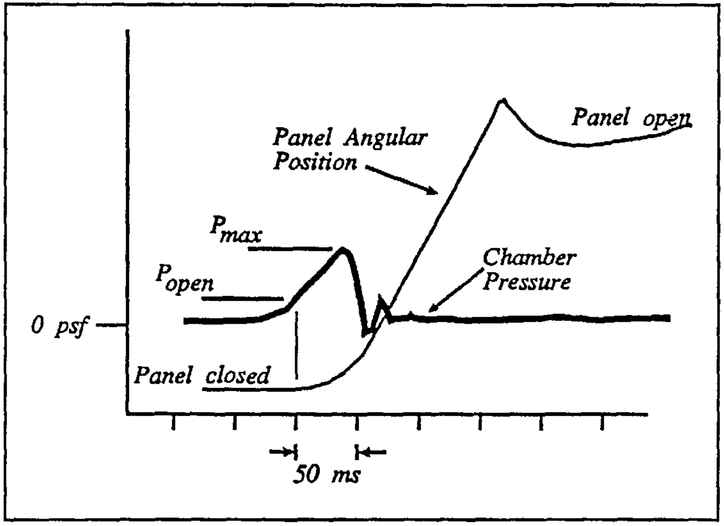


Figure 2 - Pressure vs. Time (typical)

The pressure transducers were dynamically calibrated before each series of tests on a dynamic pressure calibrator. The dynamic pressure transducer calibrator consists of a small compressed air reservoir connected to a three way electric solenoid valve. The pressure transducer is installed downstream from the solenoid valve. The air pressure in the reservoir is precisely known by means of a pressure gauge, which has been calibrated with a dead weight tester, which in turn provides calibrations traceable to NBS. The valve serves to expose the transducer to the pressure in the reservoir for a fraction of a second, thereby subjecting it to a pressure pulse of known amplitude. This system is preferable to methods of static calibration which can introduce drift errors.

The pressure transducer was located at the rear of the test chamber, opposite to the end where the panel was located. This location was carefully selected to minimize dynamic effects on the pressures being measured. Locating the pressure transducer near or on the Explovent panel would have exposed it to dynamic effects (i.e. Bernoulli effect) caused by the large volume of gas rushing through the Explovent panel opening, with a tendency to reduce recorded pressures. It would also have been exposed to more heat, flame and vibration in a location close to the panel, all of which would tend to detract from the pressure information being recorded.

With ignition in the centre of the chamber, and the test mixture being nonturbulent, spherical development of the flame front from the ignition point is likely. The explosion pressure front would accordingly reach the front and rear of the test chamber simultaneously, and allow the pressure transducer to "see" approximately the same pressure profile as the panel, at least until the panel started to open, whereupon the dynamic effects would come into play.

All pressure transducers, whether they are piezoelectric or strain gauge types, have temperature coefficients which contribute to measurement errors. These errors can be minimized in quasi steady state situations; the worst cases involve pressure measurements being made during severe temperature changes, such as during explosions. Transducers must be thermally isolated as much as possible from the medium, yet not have their dynamic response impaired by the thermal isolation method.

In the case of the Explovent tests, the transducer was mounted in a teflon bushing which provided a thermal break between the transducer enclosure and the steel test chamber. The bushing also served to isolate the transducer electrically from the chamber, which helped to minimize transient electrical effects caused by the spark ignition system. The transducer measuring surface was also fitted with an ablative coating. This consisted of a layer of silicone sealant, which provided additional thermal isolation between the medium and the transducer diaphragm.

A total of 53 explosion tests were conducted. Table 1 below indicates the distribution of testing. Note that the table does not include the louvre tests.

Panel Material	**Number of Tests**			
	P_{set} = 15 psf	P_{set} = 23.5 psf	P_{set} = 25 psf	P_{set} = 35 psf
16 mm Lexan Thermoclear glazing	8		6	9
16 mm Polygal glazing	2			2
½" honeycomb paper core with a .032" thick aluminum skin on each side		4		6
2" honeycomb paper core with a .032" thick aluminum skin on each side	2			4
2" AF545 fiberglass insulated core with a .032" thick aluminum skin on each side	3			2

Table 1 - Test Distribution

Also, a number of hold open catch mechanisms were evaluated in the testing.

RESULTS AND DISCUSSION

In general, the Explovent panels performed their intended task. The panels opened, and relieved the pressure in the explosion chamber. Each test consistently subjected the panel to a blast of heat and flame from the enclosure, as can be seen on the videotaped tests.

It is well known that enclosures of similar size and shape to the test chamber used for these experiments, but with no explosion relief installed, will (assuming the chamber is a pressure vessel capable of withstanding the explosion) generate explosion pressures on the order of 80 psi (11,520 psf) or more.

The maximum pressure reached during any test was 80.6 psf or 0.56 psi. Using the method for vent area calculation as specified in NFPA Guide 68 (see Appendix B), the required vent area was 17.3 ft^2. Due to space limitations on the test chamber the actual vent area was 5.7 ft^2. This demonstrates that even with a vent area much less than the recommended value, the Explovent system was fully effective.

When opening, the panels showed the considerable amount of kinetic energy involved produced a tendency for top hinged panels to bounce back and reclose from the fully open position. The hold open mechanism had to be able to prevent the panel from reclosing in spite of this rebound effect as well as the effect of the momentary vacuum produced in the enclosure. Some of the latch mechanisms tested were unable to resist these forces, and in those cases, allowed the panel to slam shut immediately after the explosion. In those cases, a significant vacuum condition occurred in the test chamber at the moment of closing. Other catch mechanism designs performed well, preventing the panel from closing after the explosion.

Appendix A contains reproductions of all pressure vs. time curves for the tests carried out. As can be seen from the data of the first seven explosions, difficulties were still being experienced with the instrumentation, which accounts for the discontinuities and drift of the pressure trace for those tests. Some curves are missing due to failure of the pressure recording equipment to trigger automatically at the time of the explosion. The data from all curves has been tabulated in Table 2.

Test No. 7 (see Appendix A) shows a test of a panel with an inadequate latch design in which the panel reclosed after the explosion.

Figure 3 shows a pressure vs. time curve for a coal dust-air explosion, illustrating the similarity between coal dust explosions and methane-air explosions. These curves also illustrate the maximum explosion pressures which are typically reached in unvented enclosures, assuming they are capable of withstanding the explosion.

Because the duration of the explosion was short, the effects of heat on the five types of panel material showed little or no adverse effect. After several explosions, the Polygal panels showed some minor heat warpage that did not in any way affect the operation of the panel. The other panel materials, after all the tests were completed, showed no effects from the heat at all.

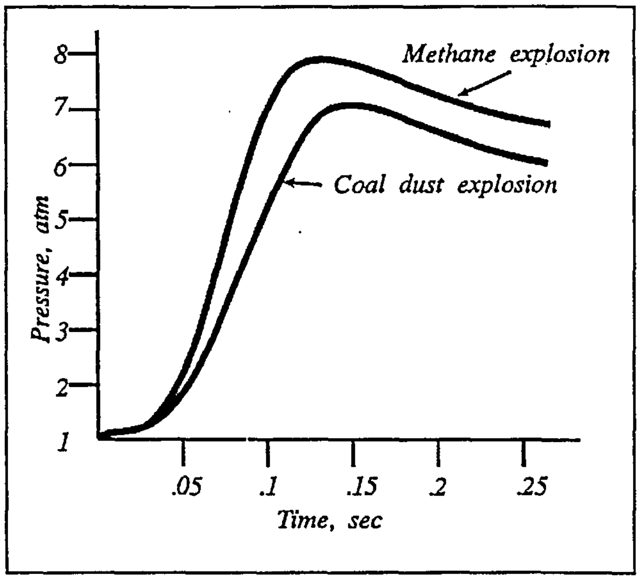


Figure 3 -Coal Dust and Methane Explosions Compared

All the panels were equipped with weatherstripping which did after a few tests lose its effectiveness in some areas of the panel through exposure to heat and flames from the explosions. For top hung panels, the worst damage was to the weatherstripping at the bottom of the panel, which is where the flames from the explosion impinged directly on the material. This did not affect the operation of the units as explosion vents.

The release mechanism was calibrated to release at a predetermined pressure. The panel release pressure was checked by means of a portable hydraulic apparatus which enabled field testing of the panels. The static release loads were set within ± 10% of their design values. Checks made during the tests indicated that the set points were maintained.

Table 2 shows the results obtained during the tests. The following are the tabulated variables.

P_{set}	is the designed opening pressure, in psf, for the panel. In Table 2, P_{set} was determined by converting the opening force of the panel as measured by the panel calibration apparatus. The relationship between P_{set} and the force applied at the latch by the calibration apparatus to release the panel is explained in Appendix C.
P_{open}	is the explosion pressure in the test chamber when the latch of the panel has just released, and the panel has begun its outward swing. It is interpreted on the Appendix A curves as the first

movement from baseline of the panel position trace on the chart.

P_{max} is the maximum explosion pressure in the chamber, obtained for each test using the indicated panel.

*** cal *** indicates that the pressure transducer was calibrated dynamically at this point in the series of tests, using the dynamic pressure transducer calibration apparatus described above.

Table 2 - Test Results

Test No.	Panel Type	Hinged at...	P_{set} (psf)	P_{open} (psf)	$\frac{P_{open}}{P_{set}}$	P_{max} (psf)	$\frac{P_{max}}{P_{set}}$
*** cal ***							
1	½" honeycomb	top	23.5				
2	½" honeycomb	top	23.5			80.6	3.4
3	½" honeycomb	top	23.5	10.4	.44	41.6	1.8
4	½" honeycomb	bottom	23.5	18.2	.77	52	2.2
*** cal ***							
5	½" honeycomb	top	34.9	7.8	.22	74	2.1
6	½" honeycomb	bottom	34.9	23.4	.67	65	1.9
7	½" honeycomb	top	34.9	45.5	1.3	73	2.1
8	½" honeycomb	top	34.9	36.4	1.04	65	1.9
*** cal ***							
9	½" honeycomb	top	34.9	33.8	.97	54.6	1.6
10	½" honeycomb	bottom	34.9	28.6	.82	72.8	2.1
11	2" AF545 insulation	top	15	10.4	.69	46.8	3.1
12	2" AF545 insulation	bottom	15			36.4	2.4
13	2" AF545 insulation	bottom	15	10.4	.69	48.1	3.2
14	2" AF545 insulation	top	35.3	18.2	.52		
*** cal ***							
15	2" AF545 insulation	bottom	35.3	5.2	.15	39	1.1
16	Lexan	top	15.6	7.8	.5	48.1	3.1
17	Lexan	bottom	15.6	7.8	.5	36.4	2.3
*** cal ***							
18	Lexan	top	35.6	5.2	.15	67.6	1.9
19	Lexan	bottom	35.6	10.9	.31	63.7	1.8
20	2" honeycomb	top	15.6	5.2	.33	44.2	2.8
*** cal ***							

Table 2 - Test Results

Test No.	Panel Type	Hinged at...	P_{set} (psf)	P_{open} (psf)	$\frac{P_{open}}{P_{set}}$	P_{max} (psf)	$\frac{P_{max}}{P_{set}}$
21	2" honeycomb	bottom	15.6	10.4	.67	41.6	2.7
22	2" honeycomb	top	36.4	7.8	.21	49.4	1.4
23	2" honeycomb	bottom	36.4	11.7	.32	57.2	1.6
24	Polygal	top	15	5.7	.38	52	3.5
25	Polygal	bottom	15	10.4	.69	41.6	2.8
26	Polygal	top	35.9	7.8	.22	57.2	1.6
27	Polygal	bottom	35.9	13	.36	57.2	1.6
28	Explosion Louvre	bottom				36.4	
29	Explosion Louvre	bottom				52	
30	Explosion Louvre	top				57.2	
*** cal ***							
31	Explosion Louvre	bottom				41.6	
32	Explosion Louvre	top				54.6	
33	2" honeycomb	top	35.9				
34	2" honeycomb	top	35.9	13	.36	80.6	2.9
35	Lexan with standard shock	top	15	16.4	1.09	53.3	3.6
36	Lexan with standard shock	top	15	13	.87	48.1	3.2
37	Lexan with standard shock	top	15	15.6	1.04	41.6	2.8
38	Lexan with standard shock	bottom	15	15.6	1.04	35.1	2.3
39	Lexan with standard shock	bottom	15	18.2	1.21	39	2.6
40	Lexan with standard shock	bottom	15	15.6	1.04	40.3	2.7
*** cal ***							
41	Lexan with standard shock	top	24.7	13	.53	62.4	2.5
42	Lexan with standard shock	top	24.7	15.1	.61	59.8	2.4
43	Lexan with standard shock	top	24.7	18.2	.74	59.8	2.4
44	Lexan with standard shock	bottom	24.7	26	1.05	50.7	2.1
45	Lexan with standard shock	bottom	24.7	20.8	.84	49.4	2.0
46	Lexan with standard shock	bottom	24.7	15.6	.63	49.4	2.0
47	Lexan with standard shock	top	35.3	13	.37	46.8	1.3
48	Lexan with standard shock	top	35.3	15.6	.44	67.6	1.9
49	Lexan with standard shock	top	35.3	13	.37	71.5	2.0
50	Lexan with standard shock	top	35.3	15.6	.44	63.7	1.8
51	Lexan with standard shock	bottom	35.3	15.6	.44	57.2	1.6
52	Lexan with standard shock	bottom	35.3	6.5	.18	65	1.8
53	Lexan with standard shock	bottom	35.3				
54	No panel - 2 mil plastic (diaphragm only)					26	

There were three main panel release settings, these being approximately 15 psf, 25 psf, and 35 psf.

The curves shown in Figures 4 and 5 are plots of the <u>average values</u> obtained at the three main values of P_{set} for the panels.

P_{max} vs. P_{set} is shown in Figure 4. As expected, the maximum explosion pressure in the protected structure increases with increasing panel release pressure.

Test no. 54 was conducted only with a 2 mil (.002") plastic sheet over one end of the explosion chamber. With only this thin diaphragm covering the end of the chamber, the measured explosion pressure was 26 psf.

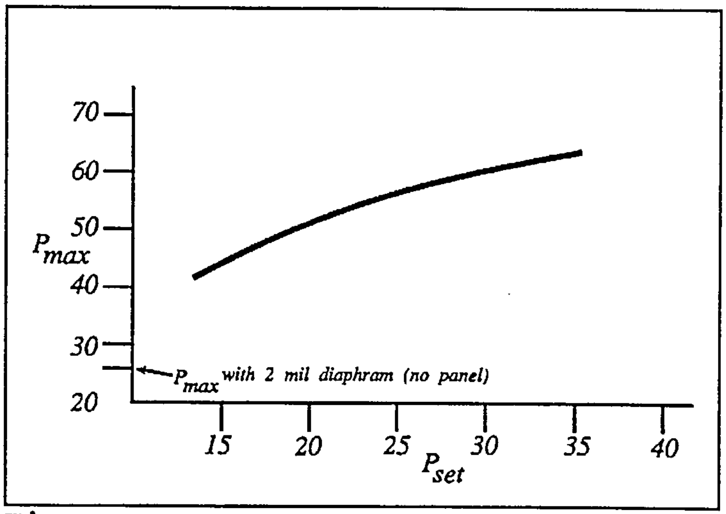


Figure 4 - P_{max} vs. P_{set}

Figure 5 illustrates that the pressure at which the panel just begins to open (P_{open}) was less than the predetermined opening pressure of the panel (P_{set}).

Instrumentation to indicate angular position for the louvres tested was not installed, so it was not possible to determine P_{open} for those units. Observation of the tests did indicate very good performance from the louvres, in that they appeared to open very quickly, and kept P_{max} to levels at least as low as those obtained with the panels.

CONCLUSIONS

The Explovent panels performed as expected, inasmuch as the ultimate explosion pressure in the protected vessel was greatly reduced through the operation of the panels, compared to what they would have been in an unprotected enclosure. Compared to a simple 2 mil plastic diaphragm installed across the open side of the test chamber, the Explovent panels offered only about two to three times as much resistance to opening as the plastic.

The results in these tests indicate that the explosion panels open at a lower pressure in an explosion situation than they do when checked statically (see Fig. 5). Additional experimental work would have to be carried out to confirm this data.

One explanation might be that it is the amount of energy transferred to the panel in a given time that determines whether the panel will open. Considering the simple case of hitting the panel with a hammer in an unsuccessful attempt to open it, the momentary force applied to the panel by the hammer blow would be far in excess of the static opening force for the panel. This indicates that whether or not the panel will open involves more than a simple relation to the static opening force.

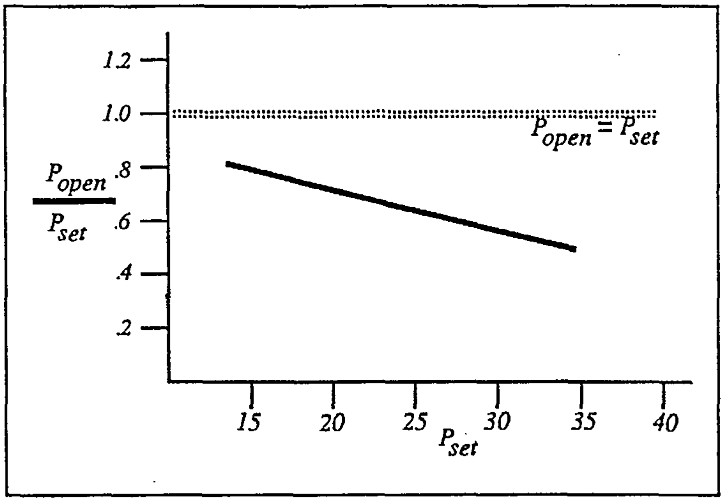


Figure 5 - P_{open}/P_{set} vs. P_{set}

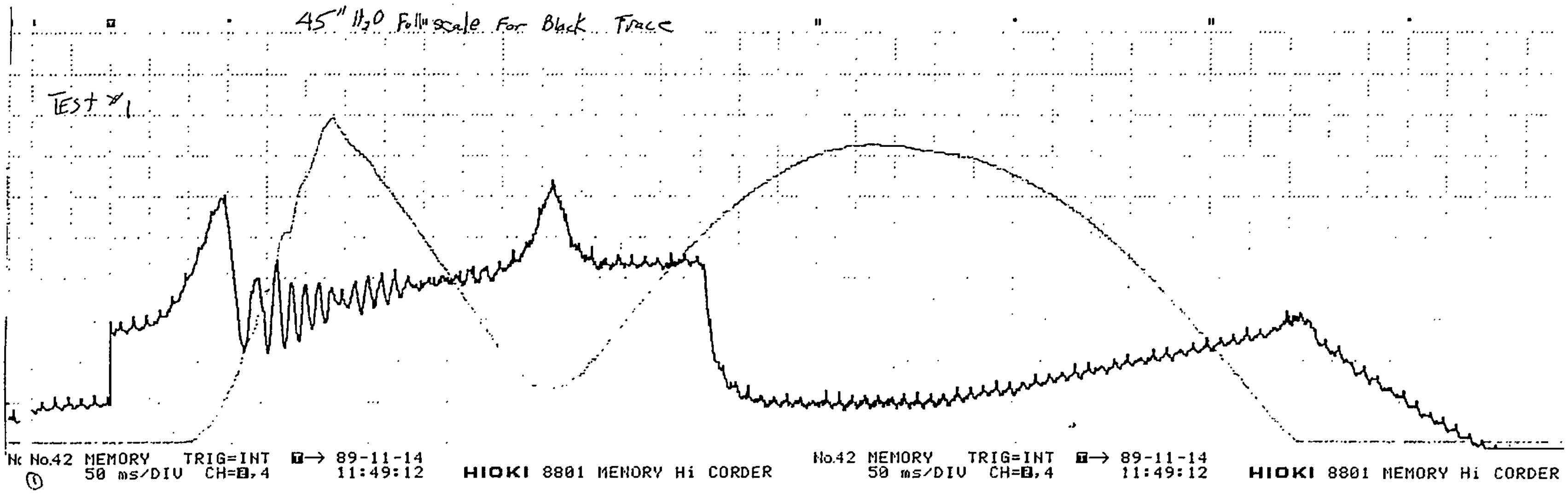
It is interesting to note that for all panels, each opens with a brief period of acceleration, then continues at virtually a constant velocity until the panel reaches the end of its travel, and is stopped by the hold open mechanism.

The hold open mechanism for top-hinged panels requires a robust design which is capable of resisting forces which tend to reclose the panel once it has just opened from the force of an explosion.

All the panel materials tested were well able to withstand the heat effects produced by the explosions.

Appendix A

Individual Pressure vs. Time Curves for Explovent Explosion Tests



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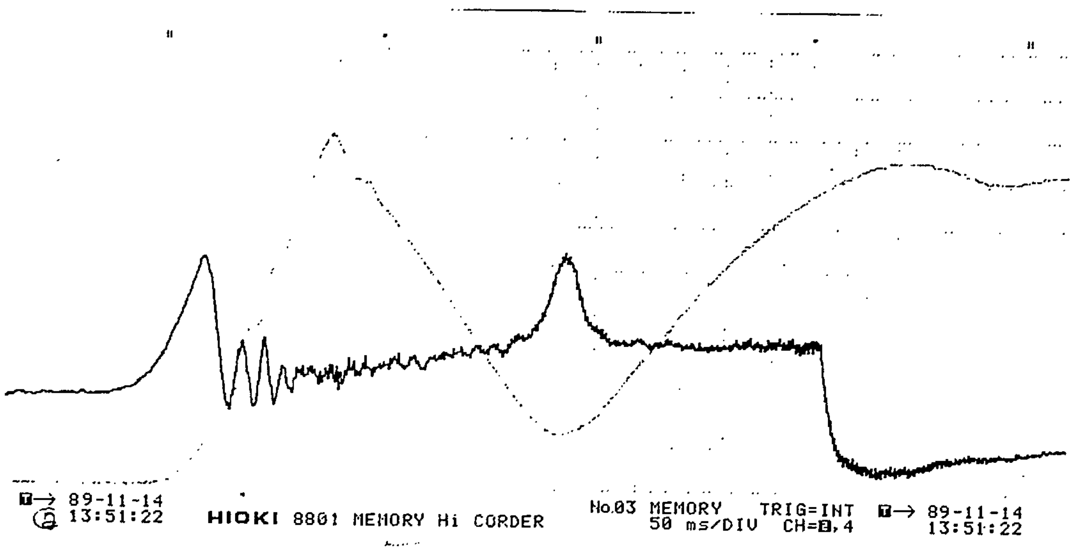

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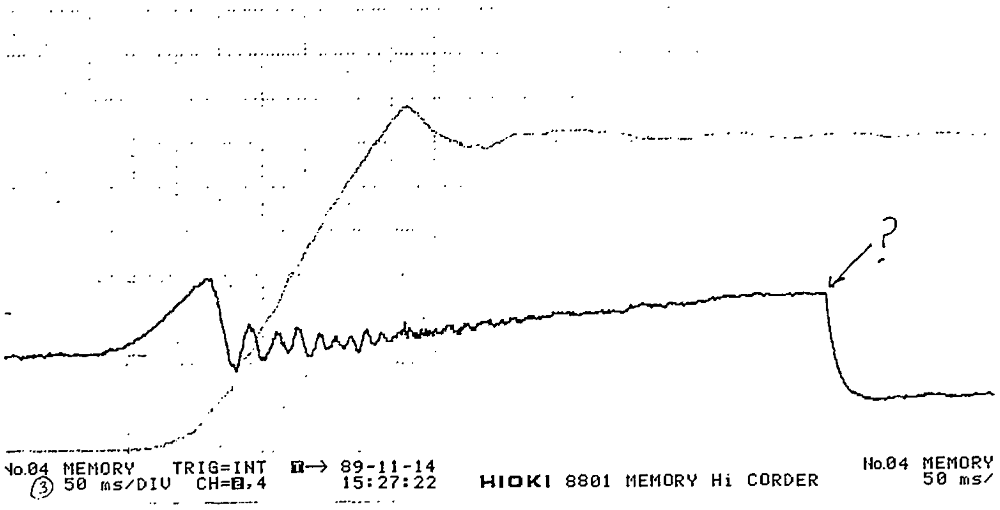

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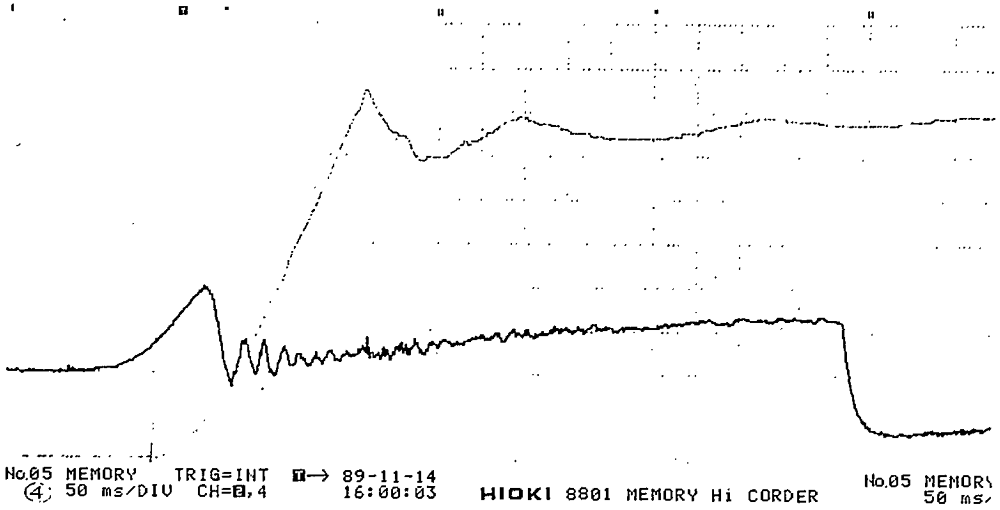

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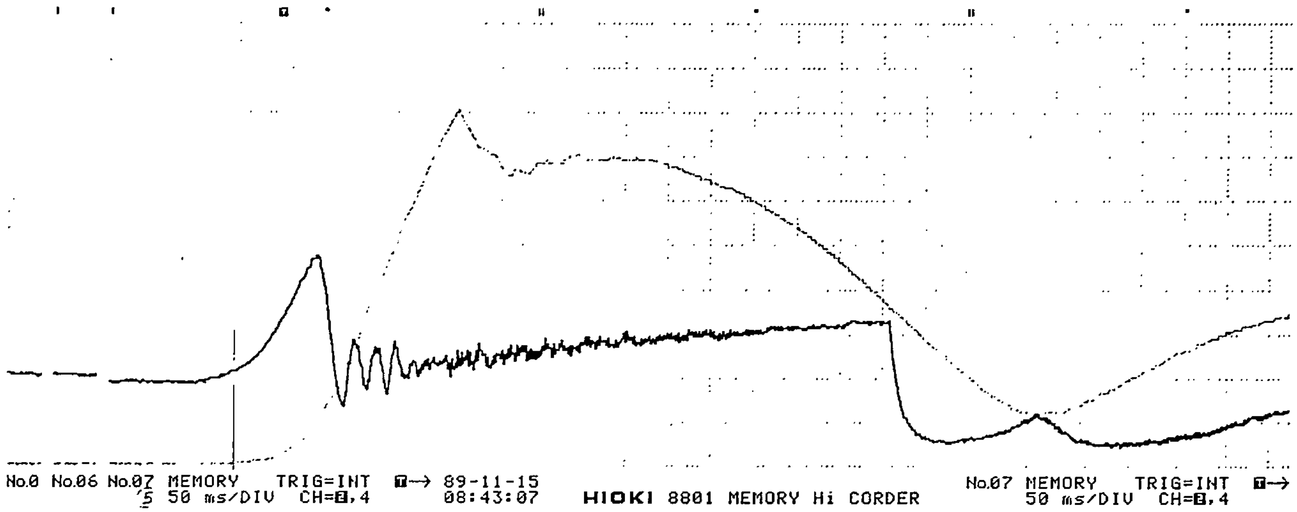

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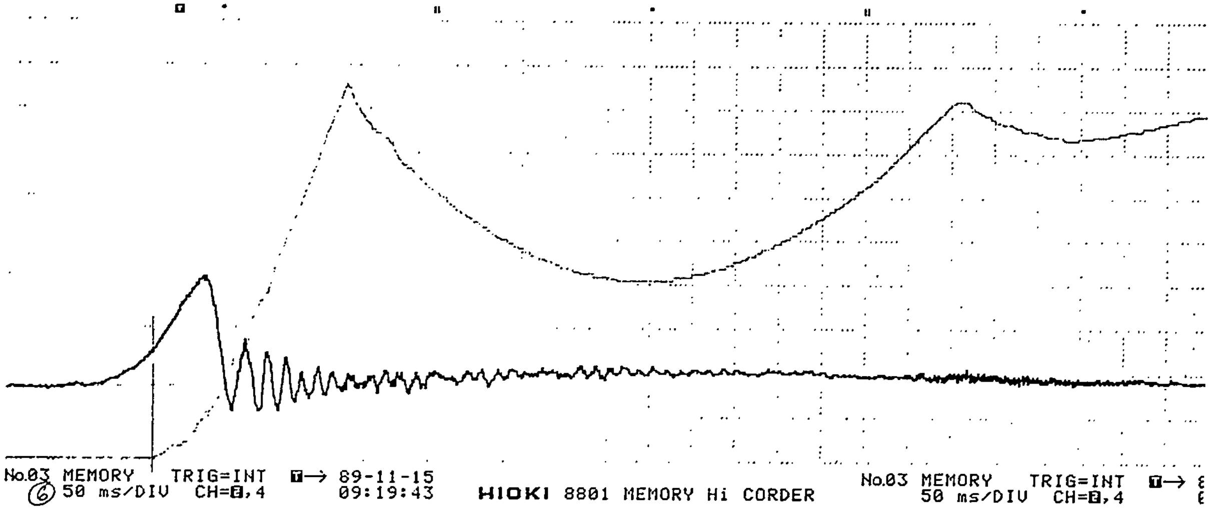

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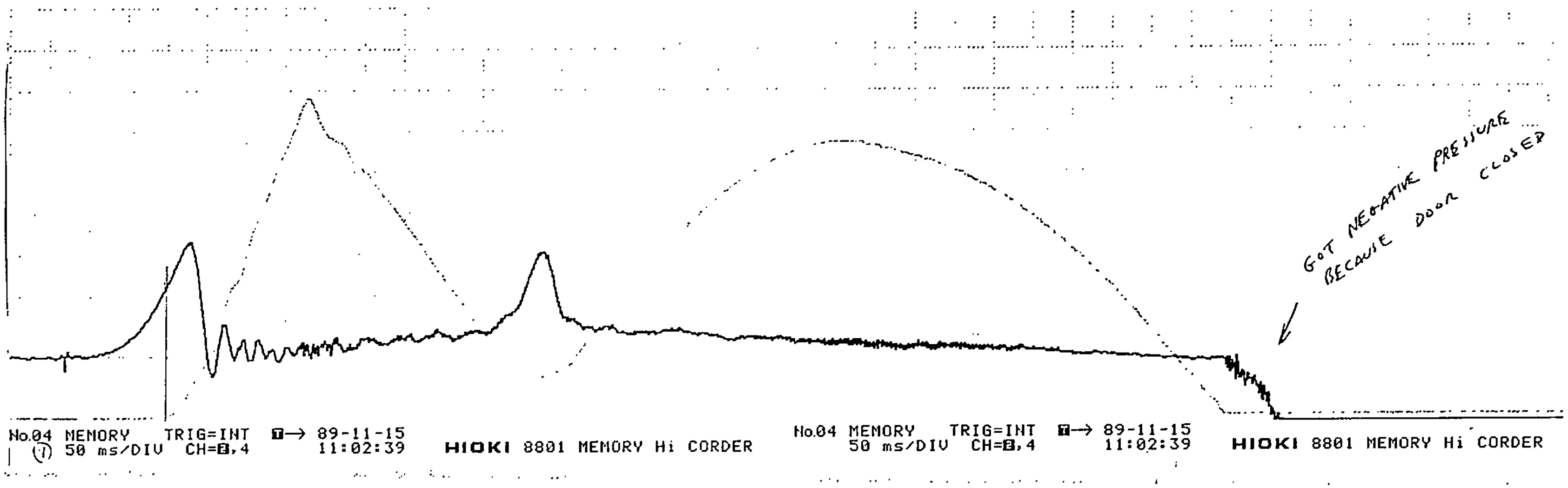

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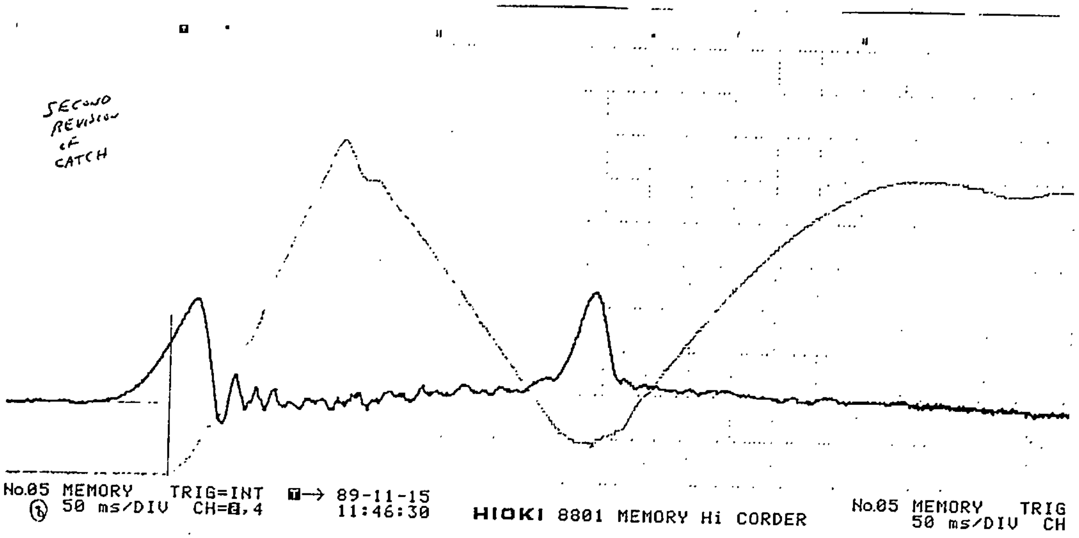

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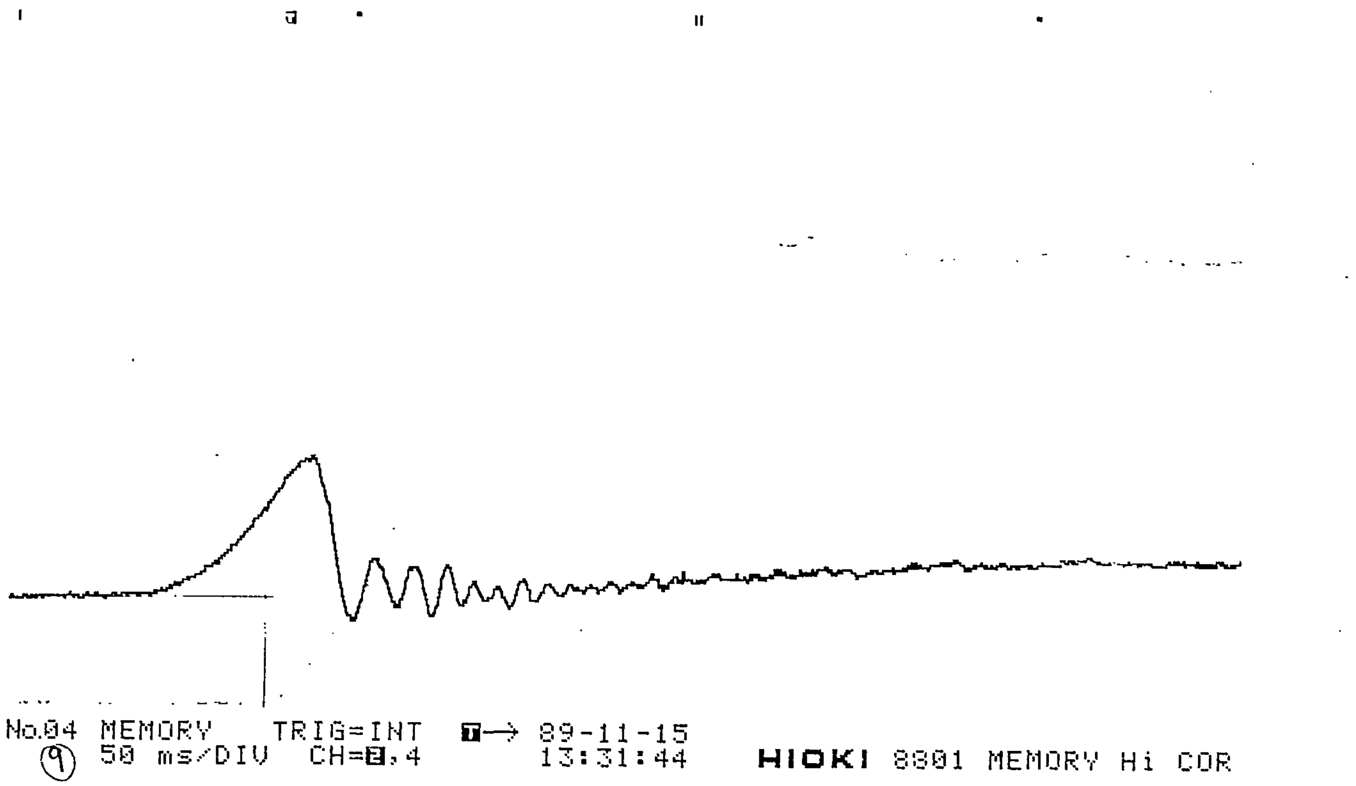

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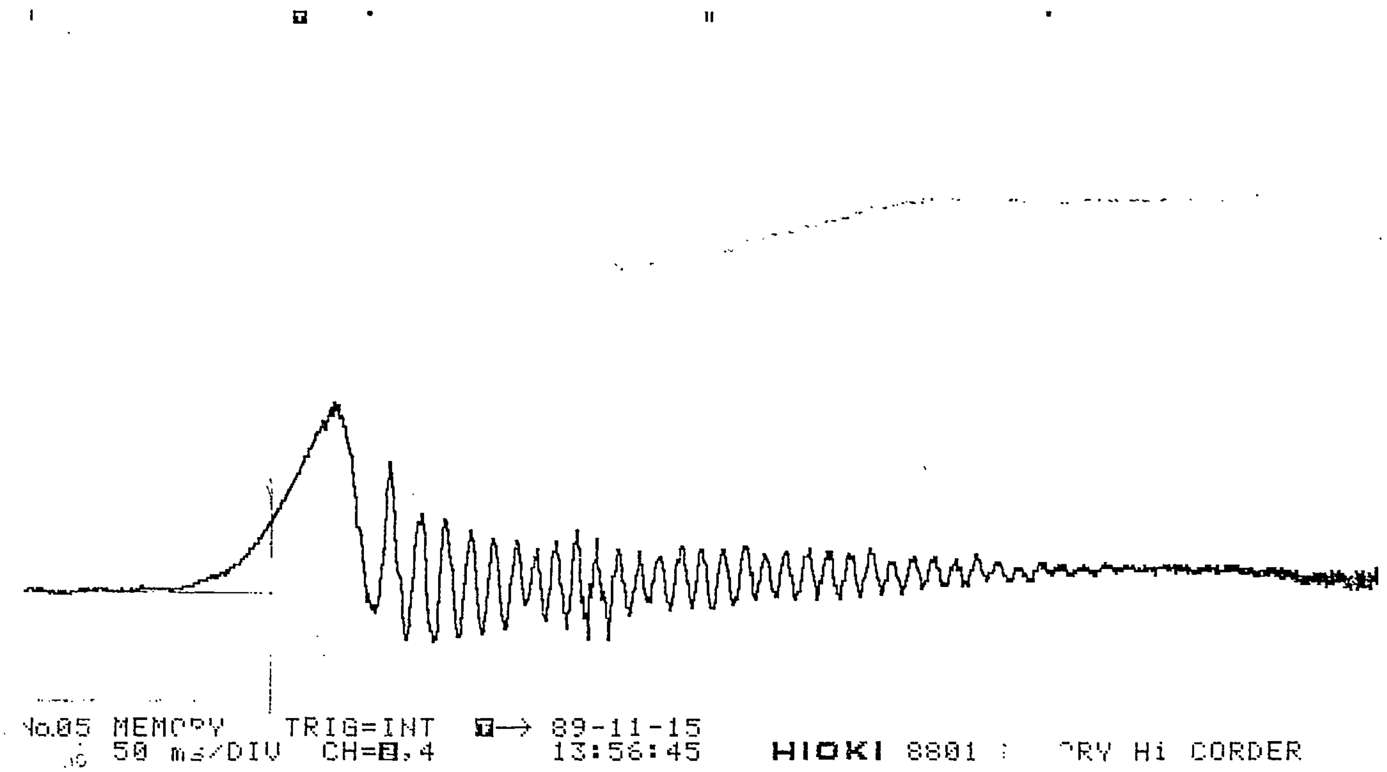

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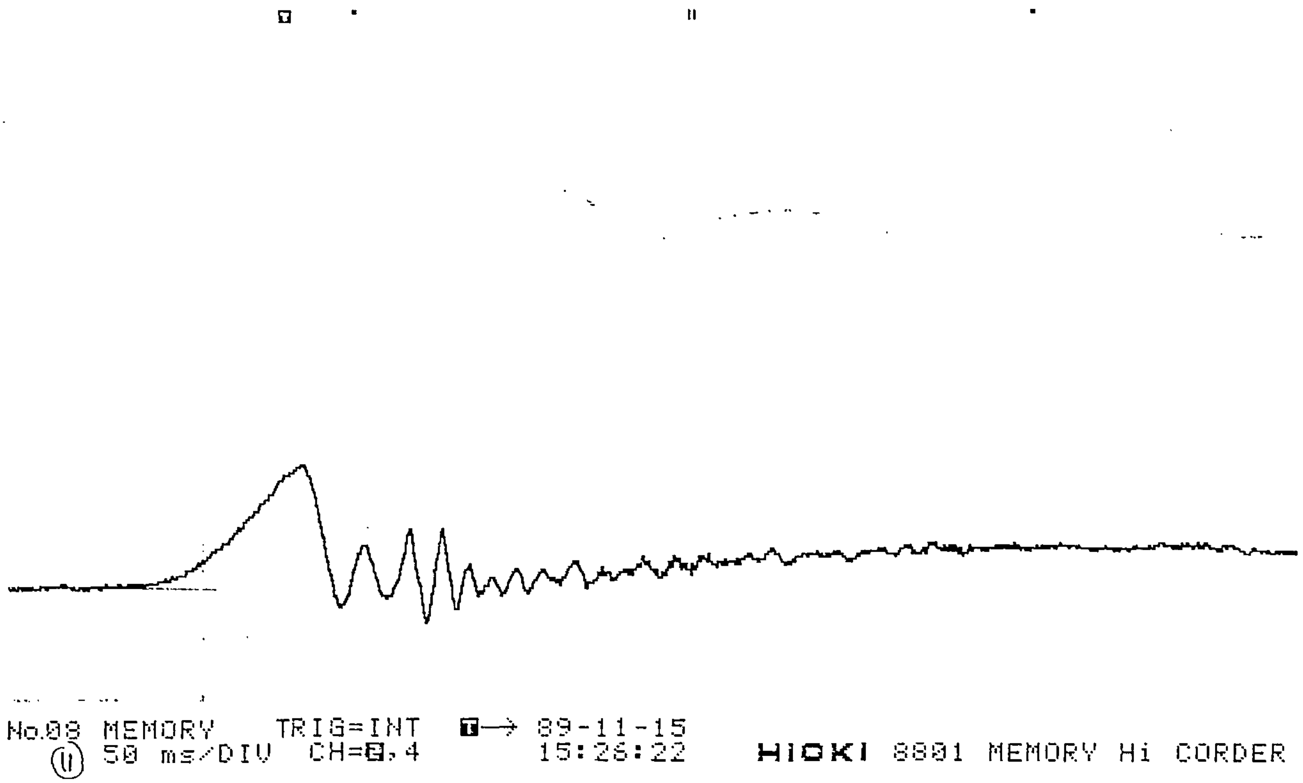

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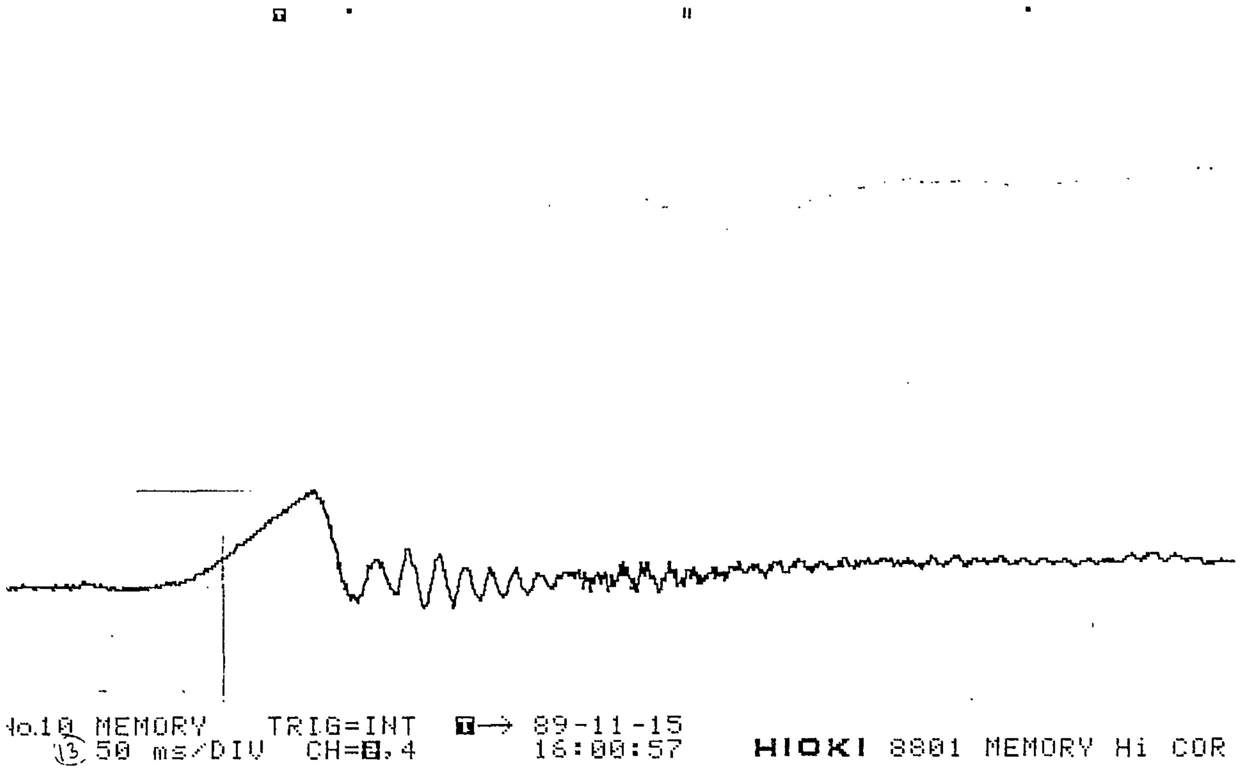

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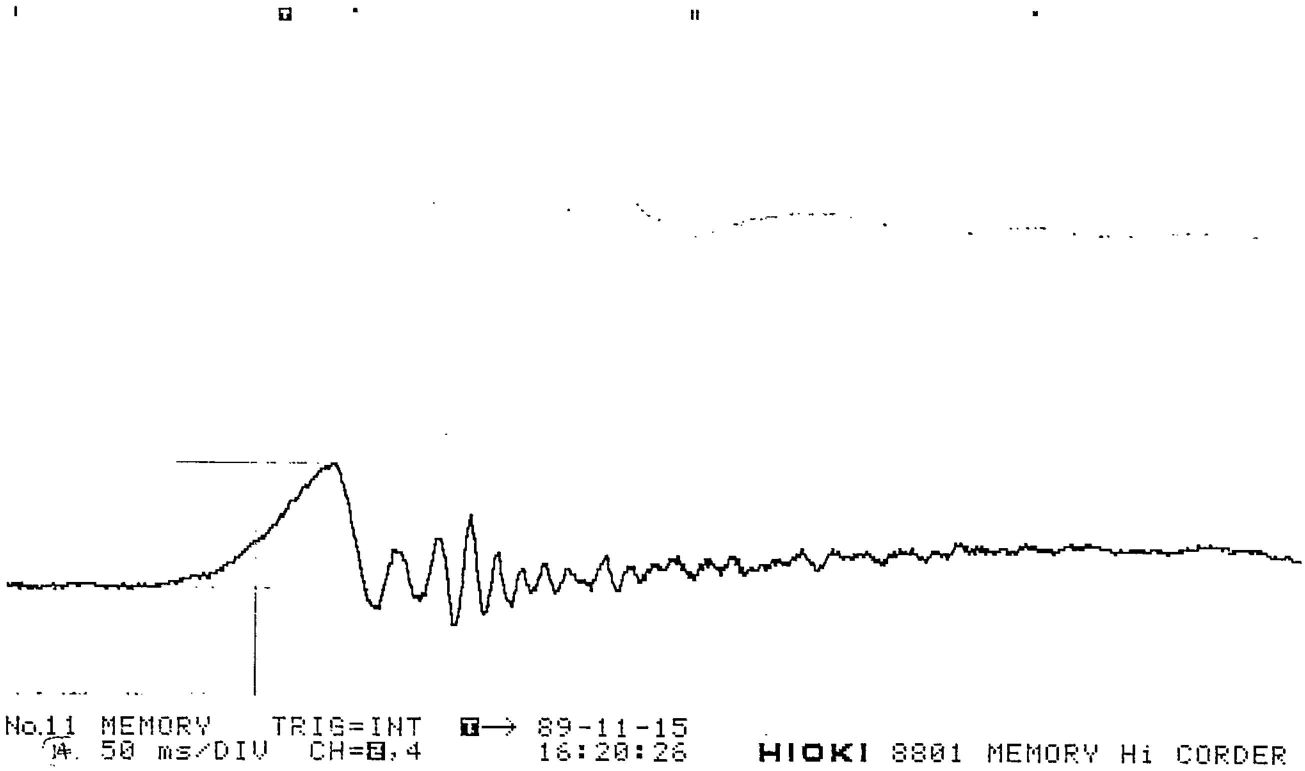

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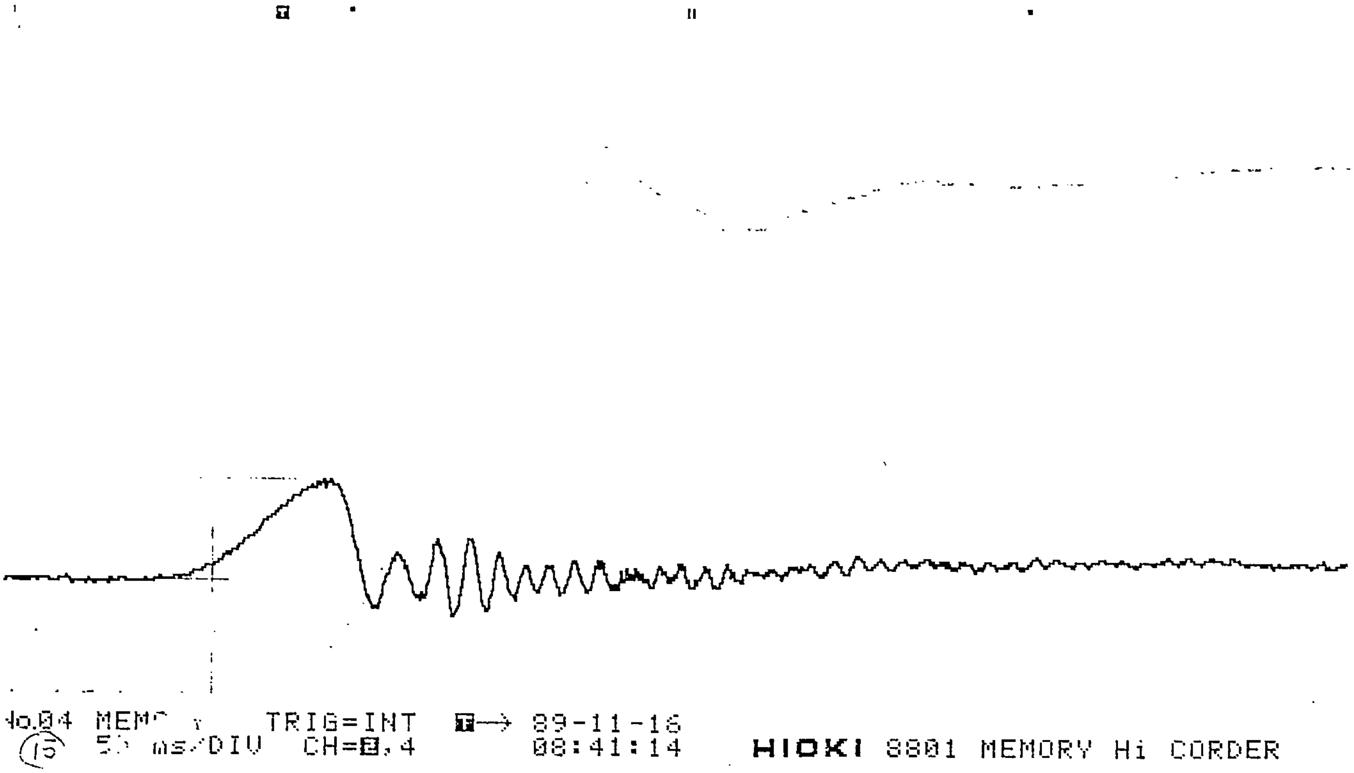

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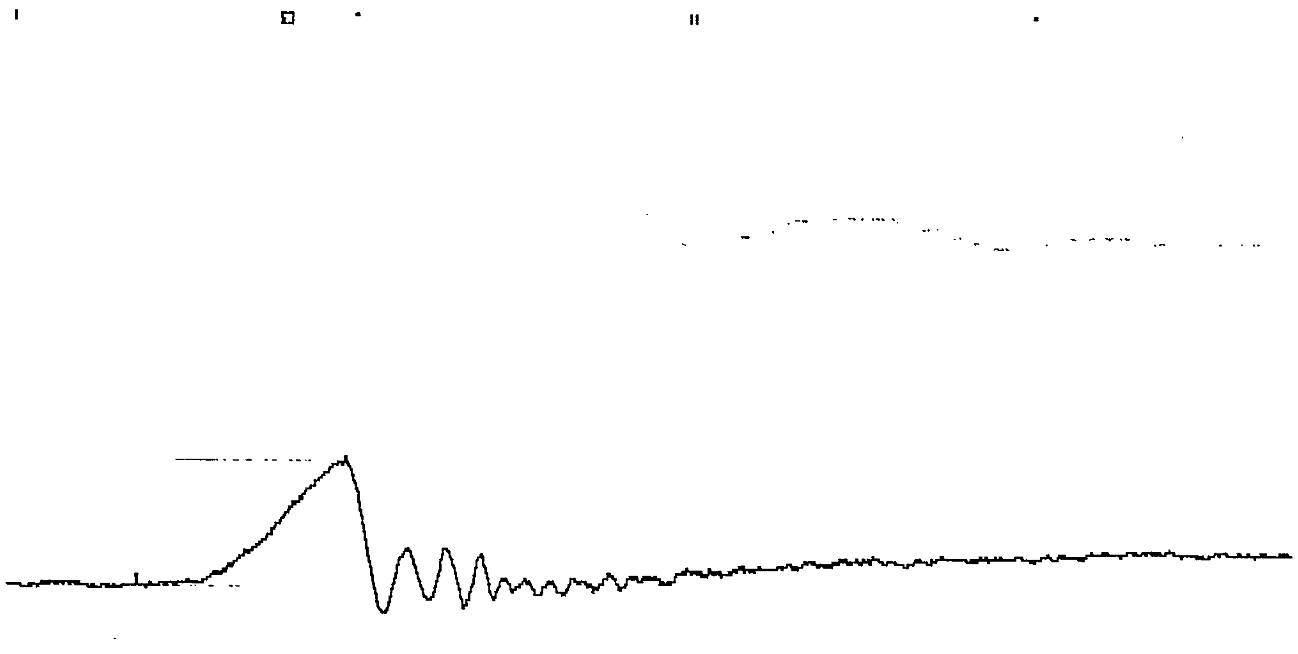

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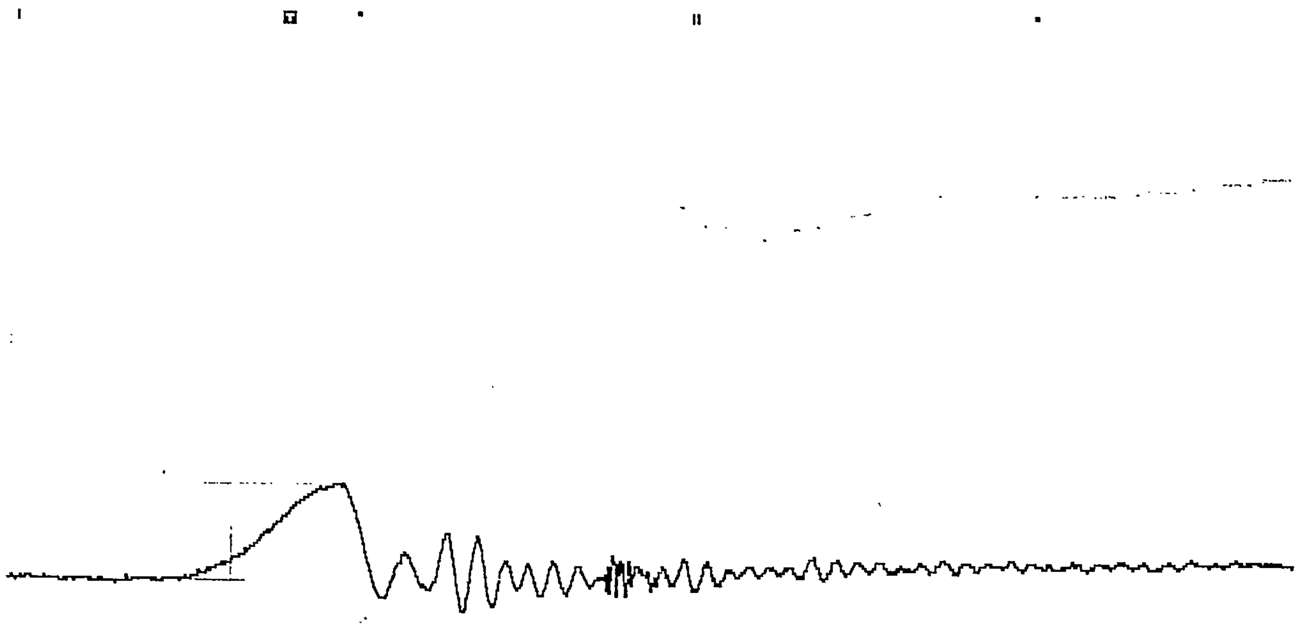

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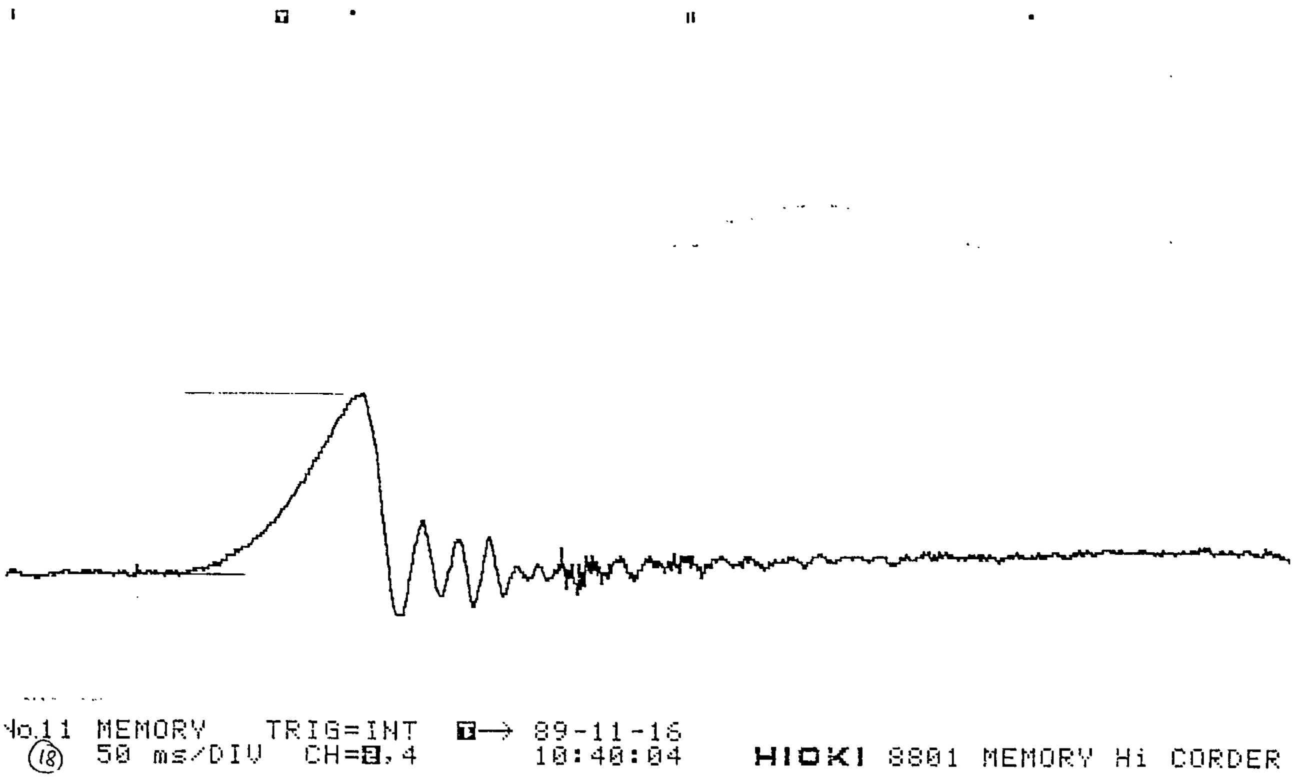
(17) 50 ms/DIV CH=2,4 09:52:56 **HIOKI** 8801 MEMORY Hi CORDER

Figure No. 17



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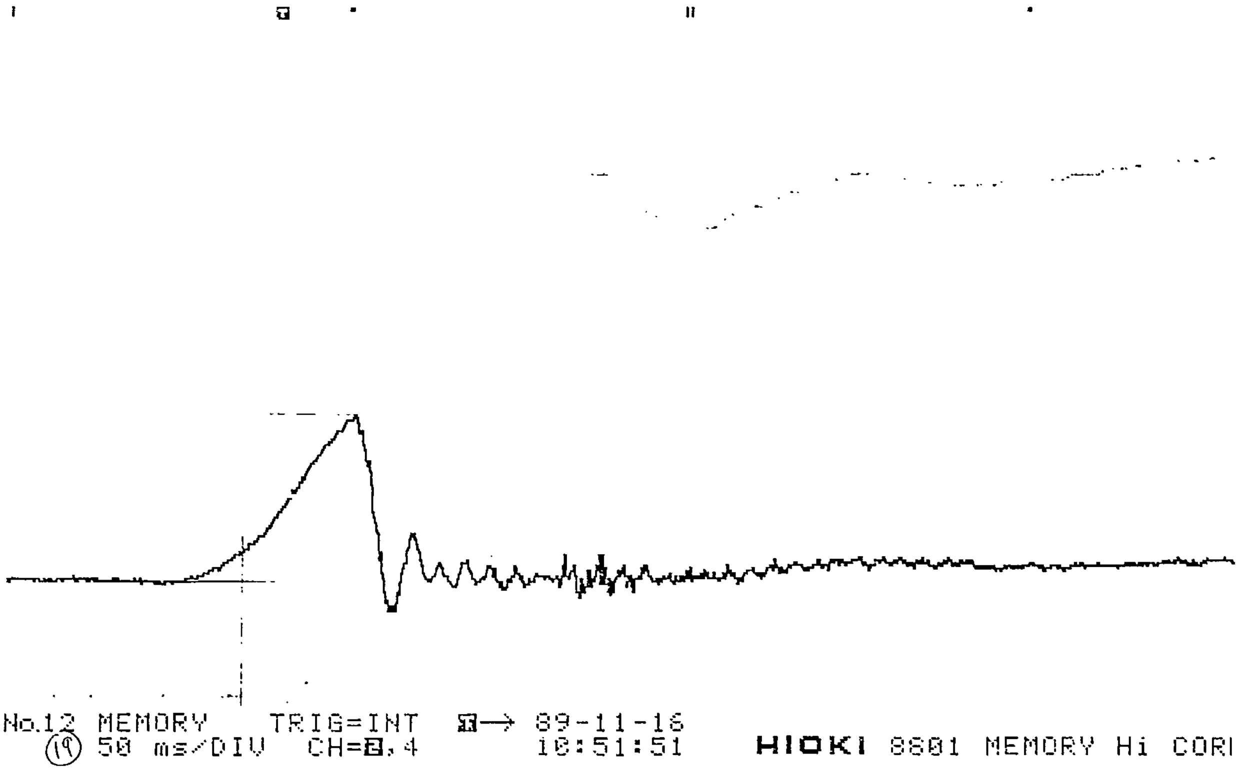

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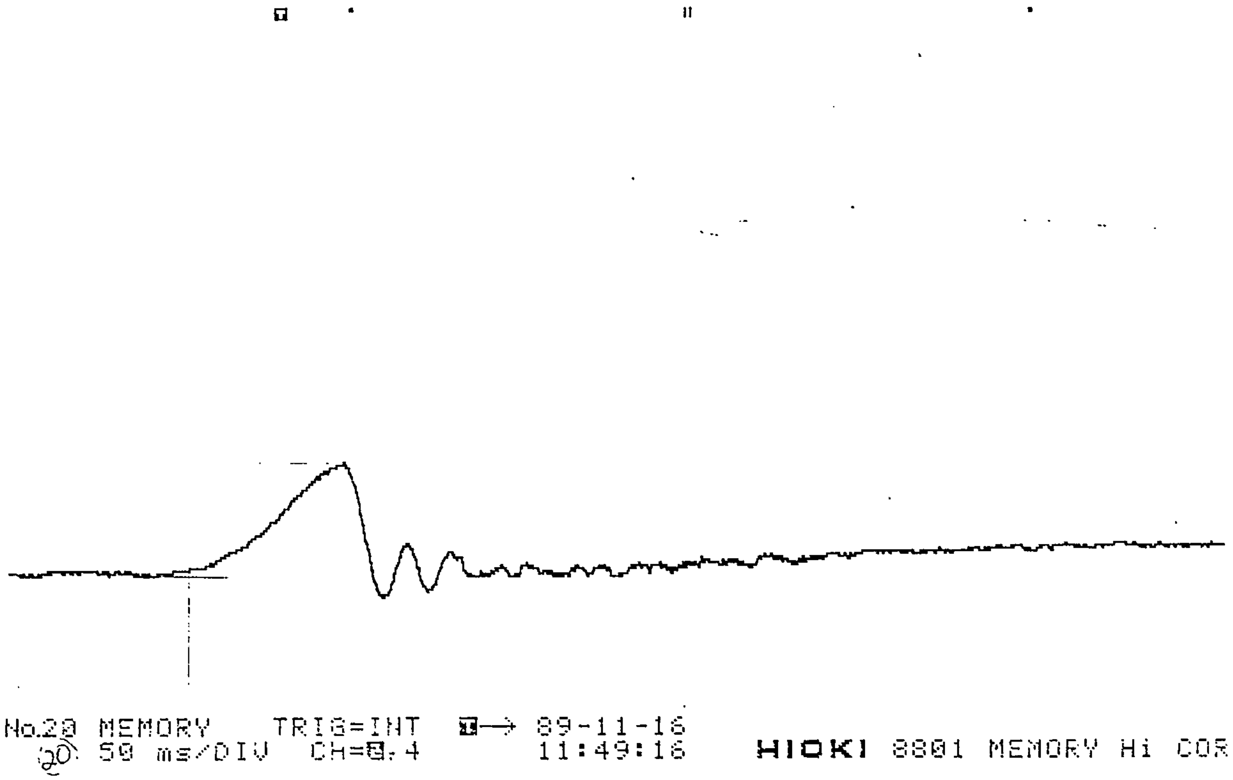

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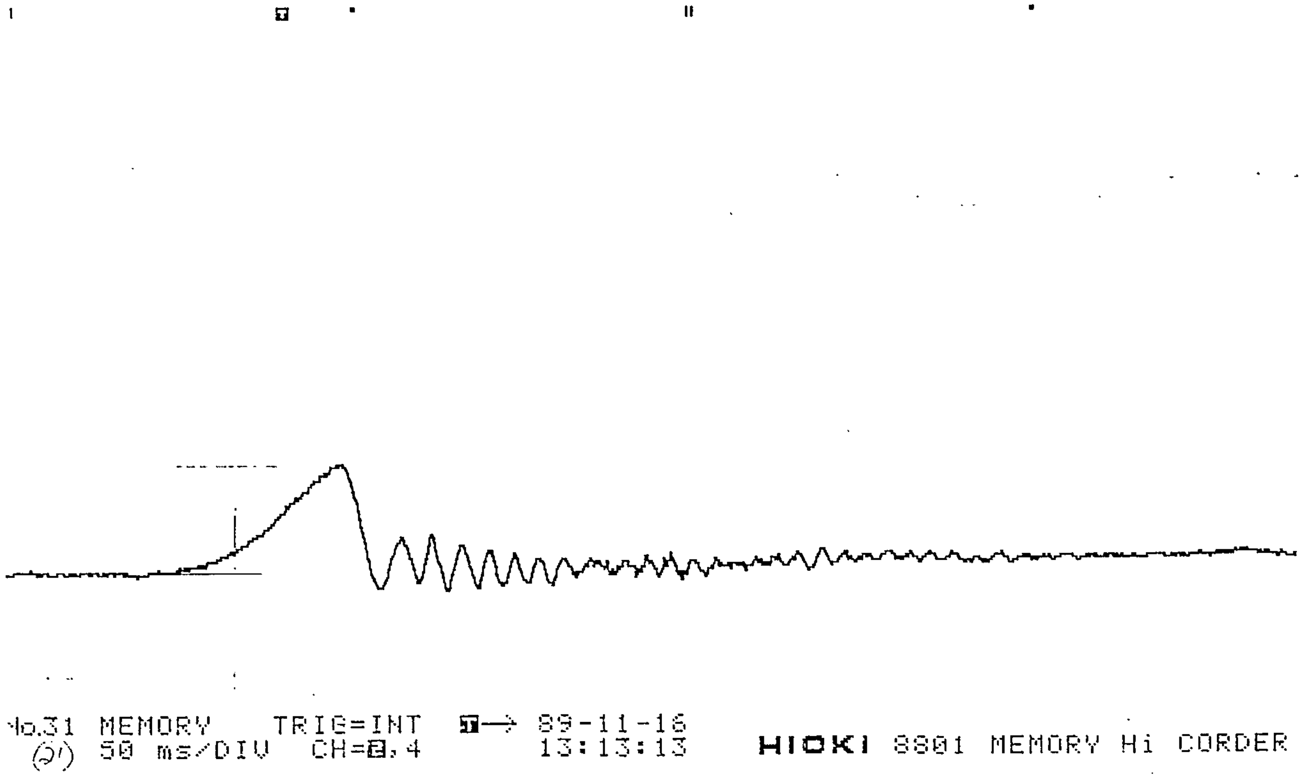

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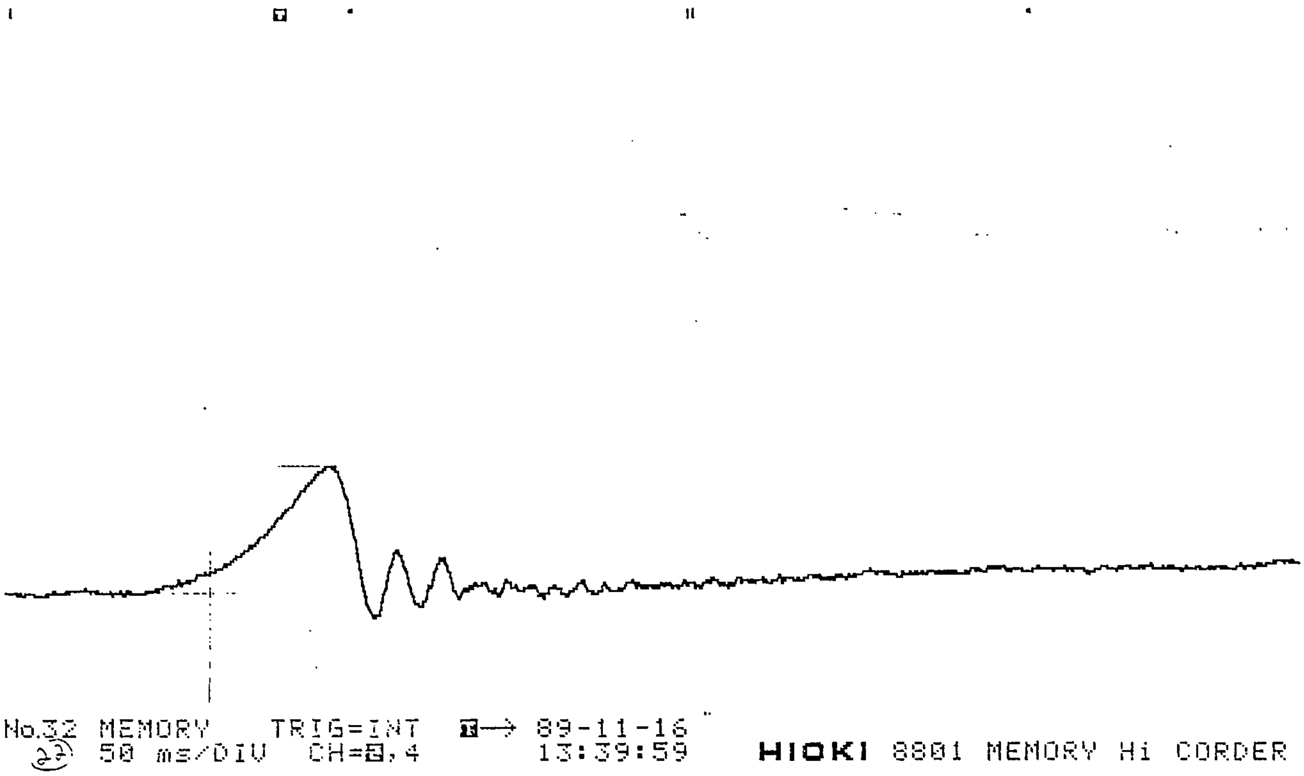

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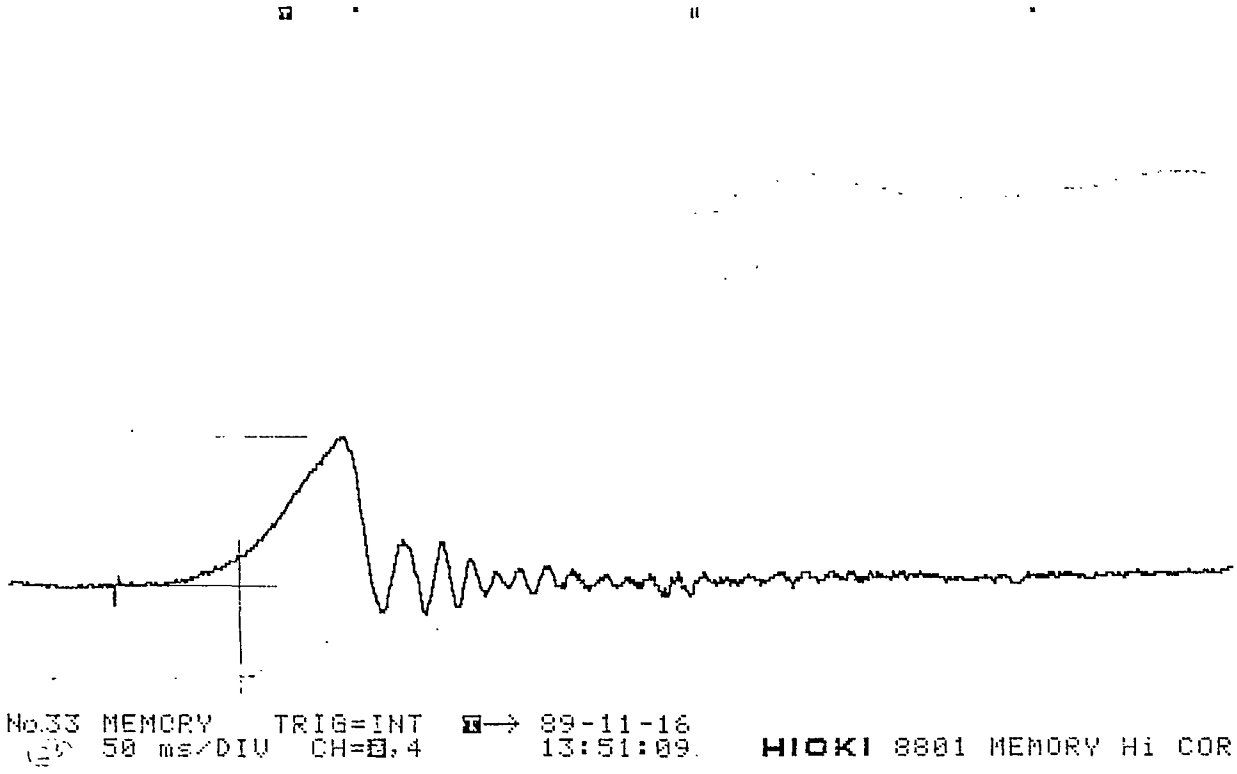

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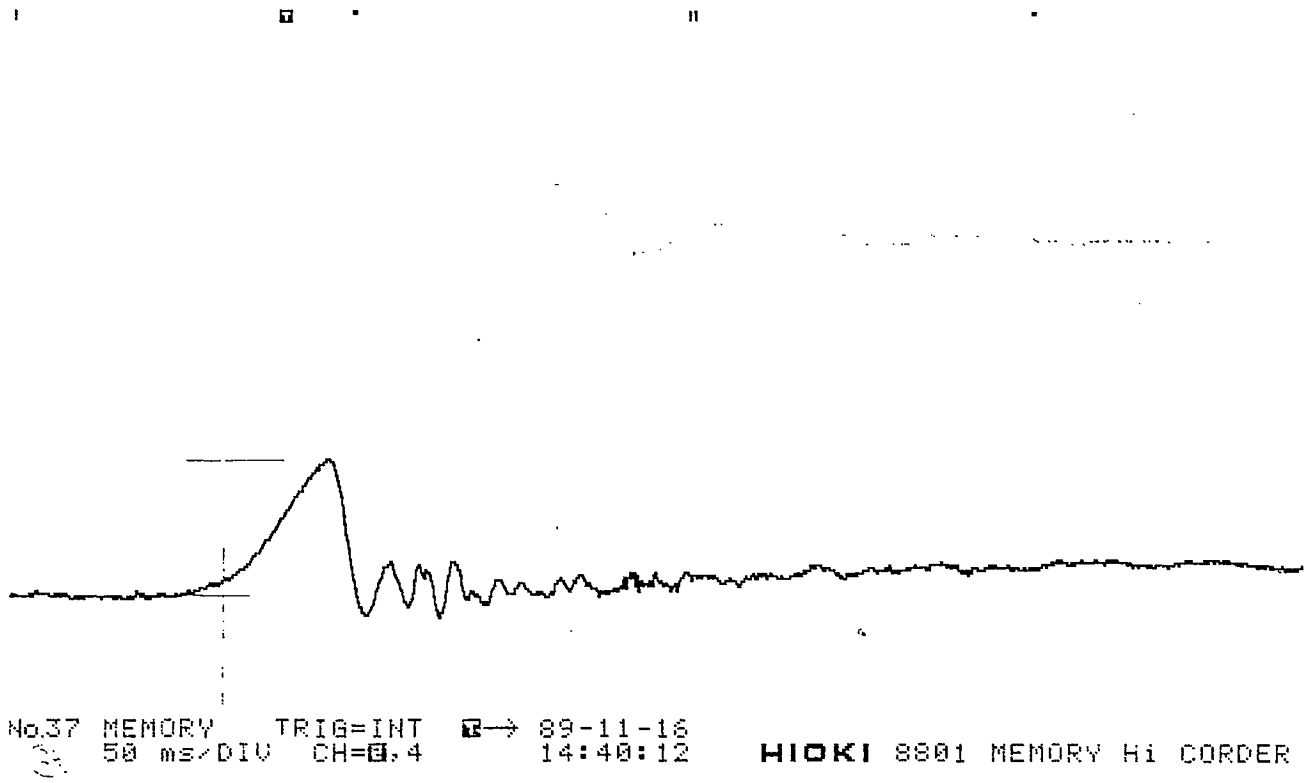

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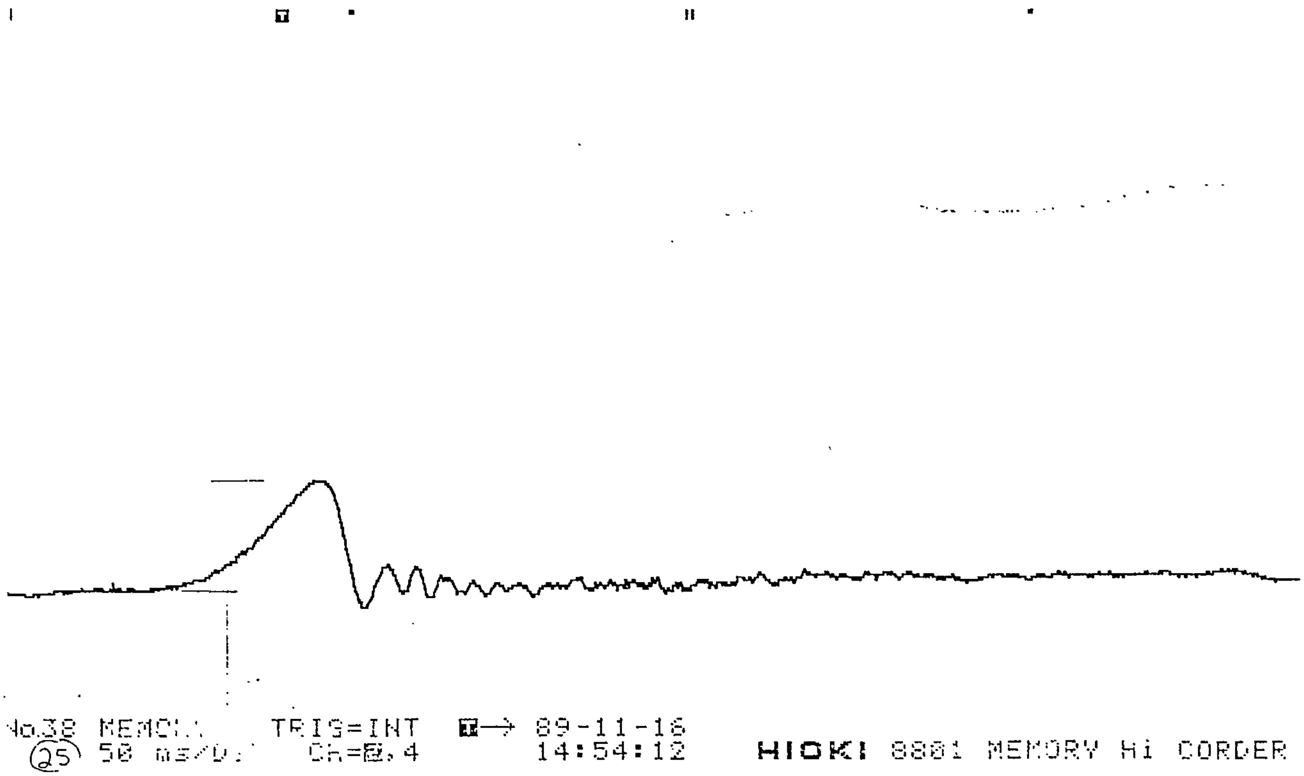

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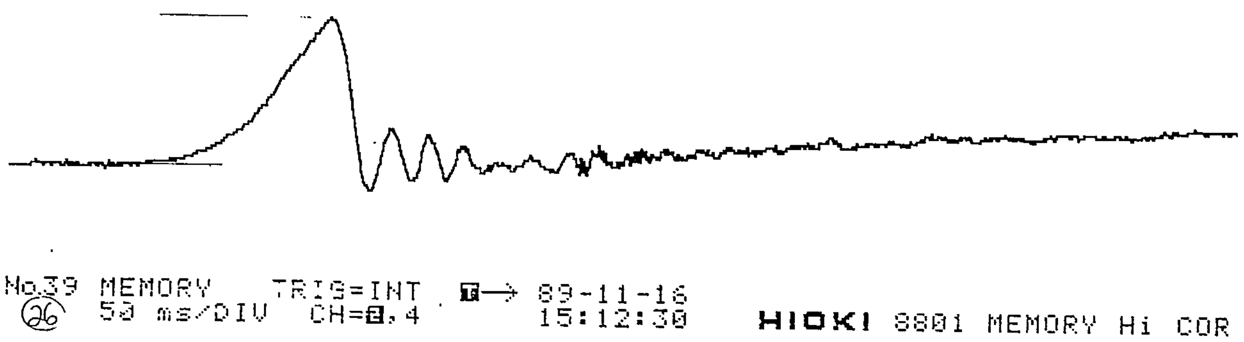

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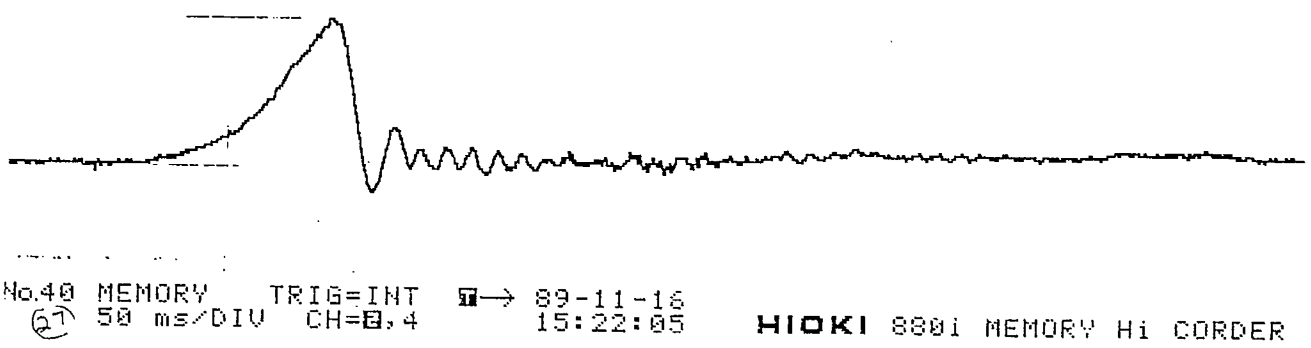

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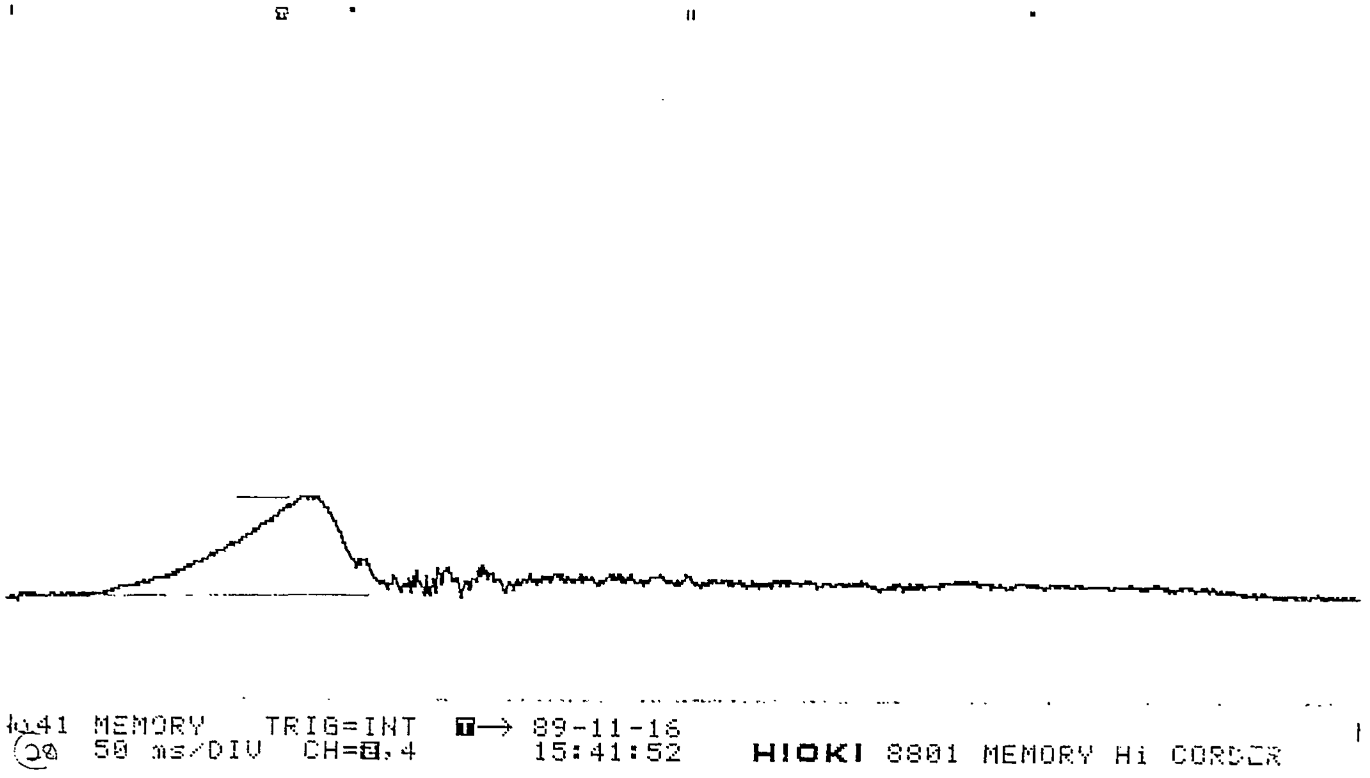

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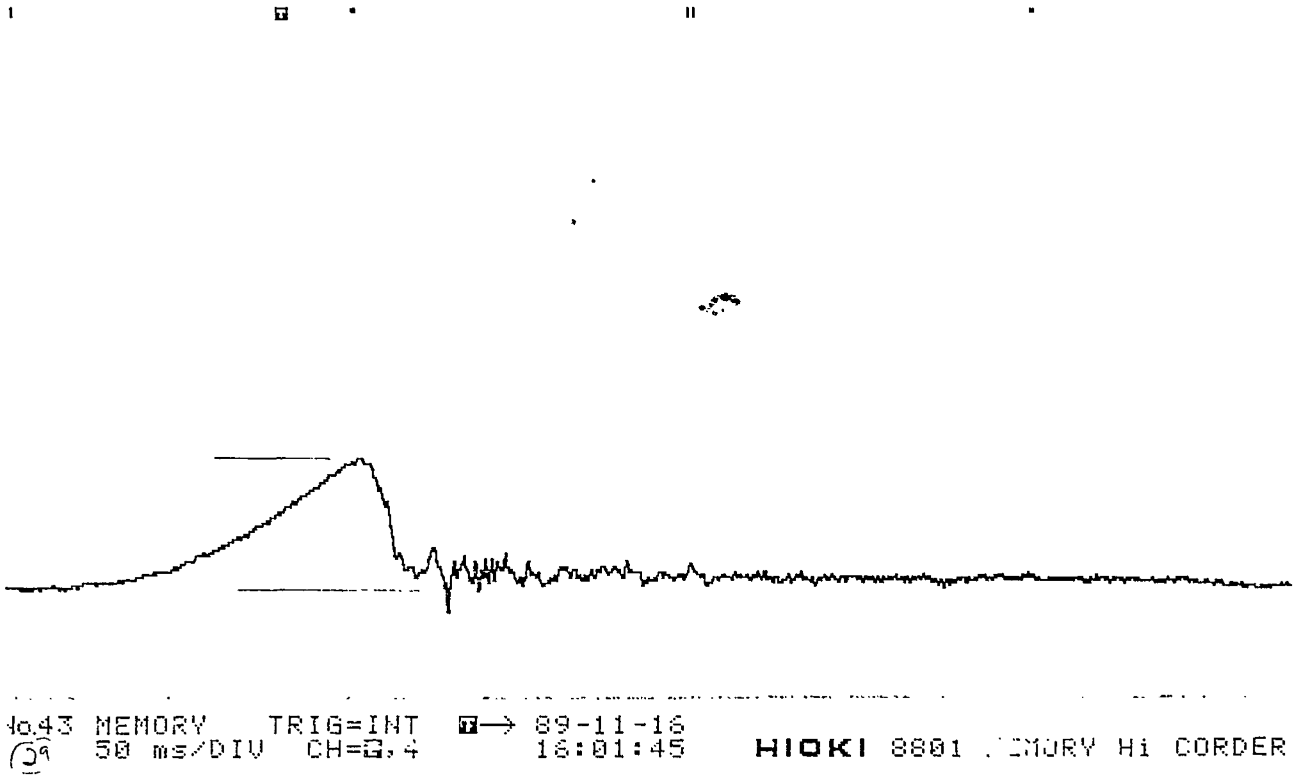

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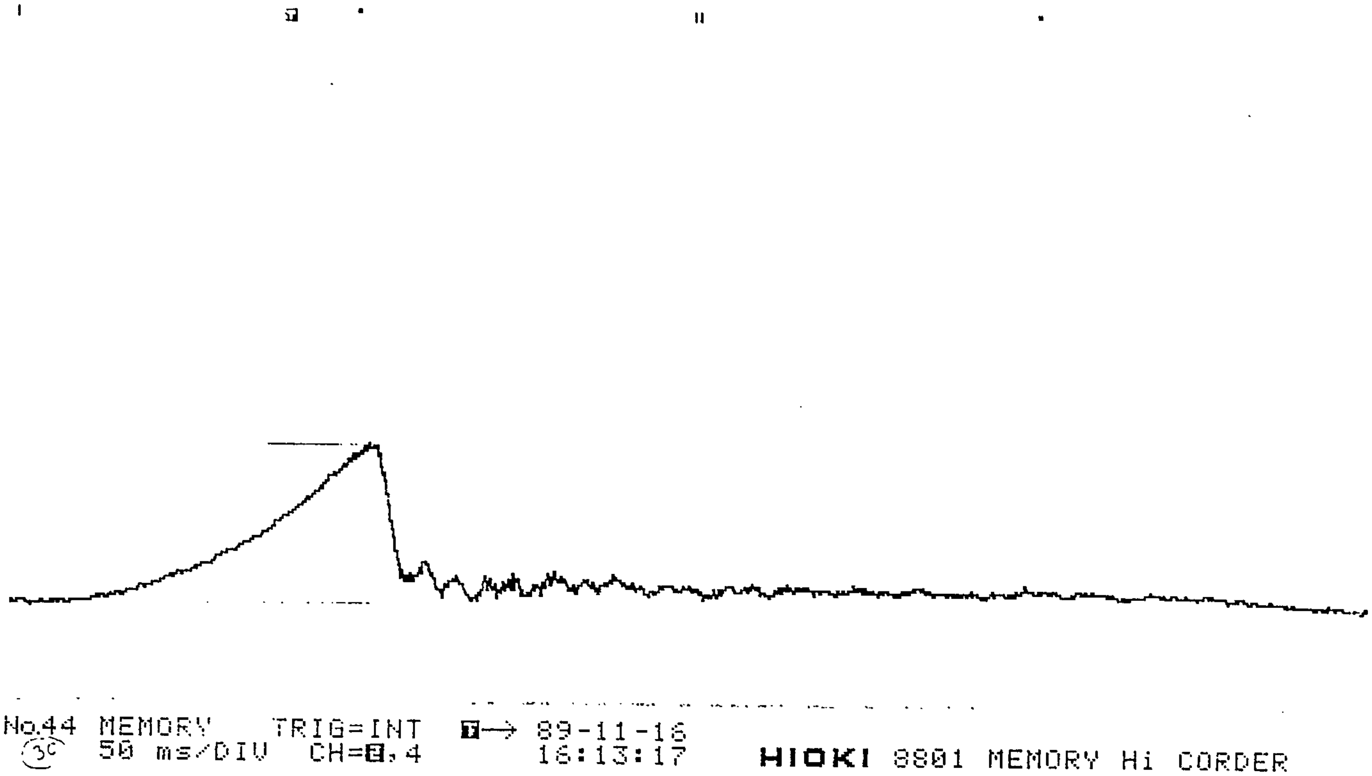

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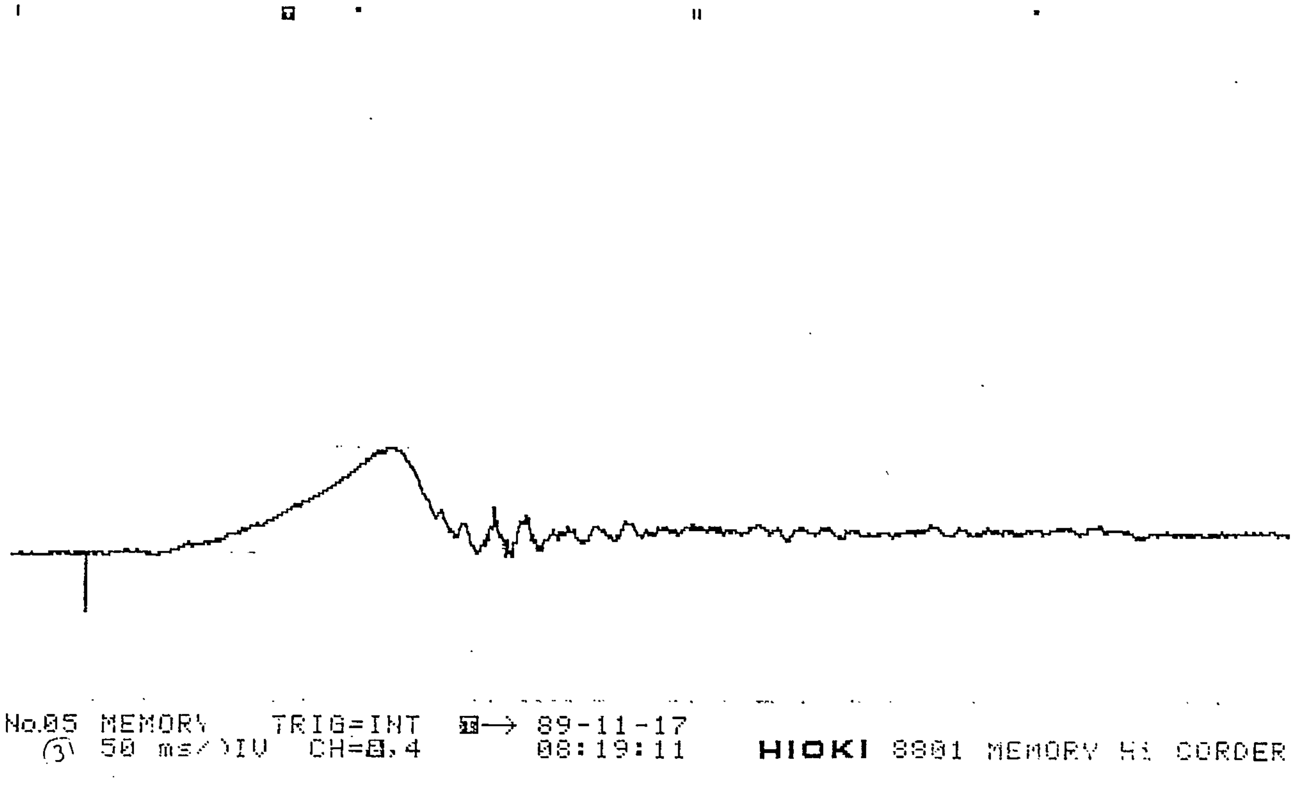

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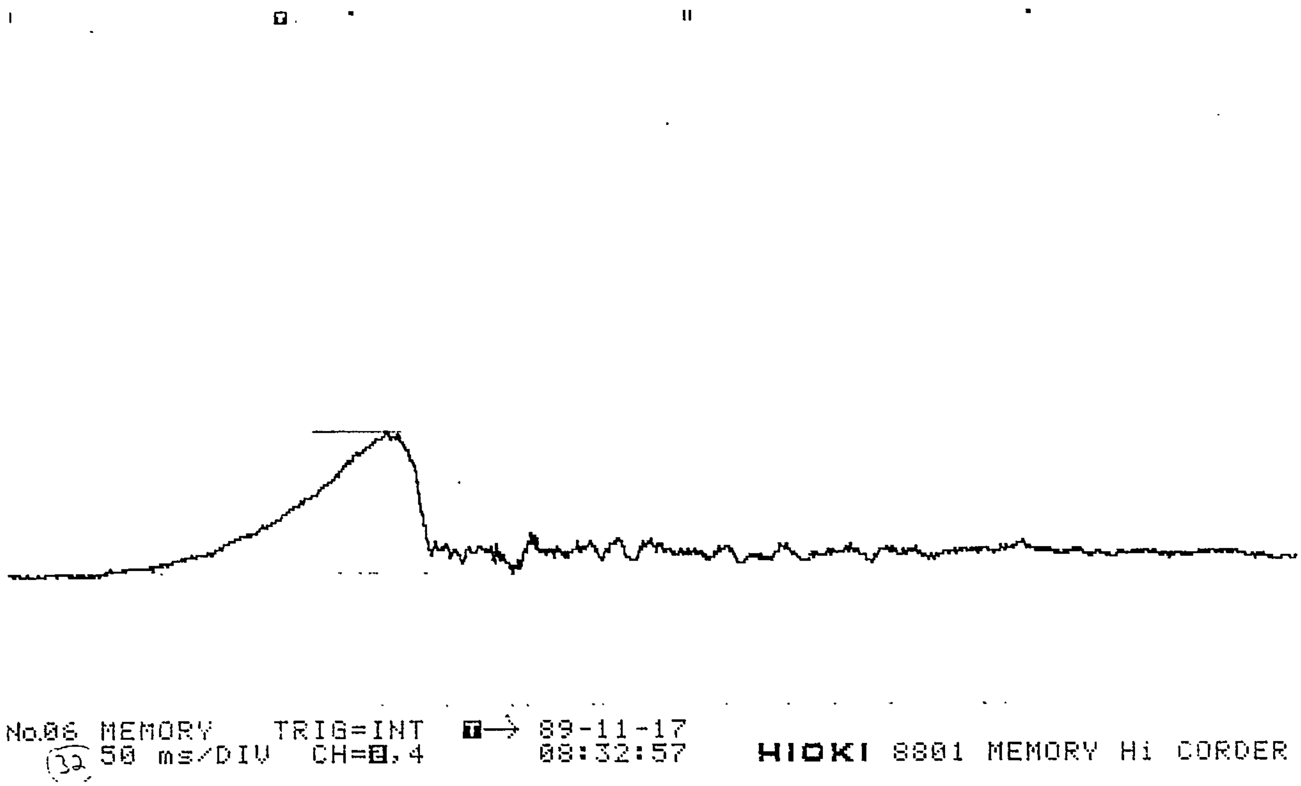

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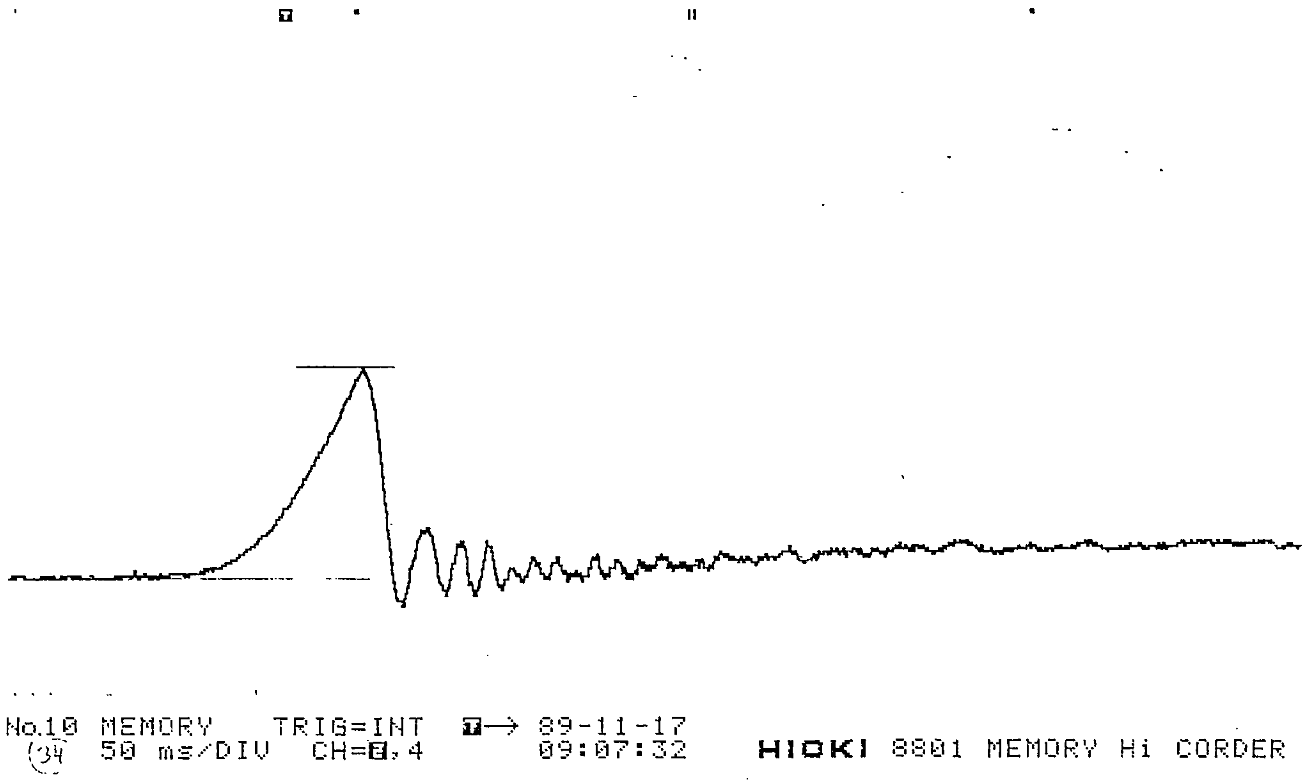

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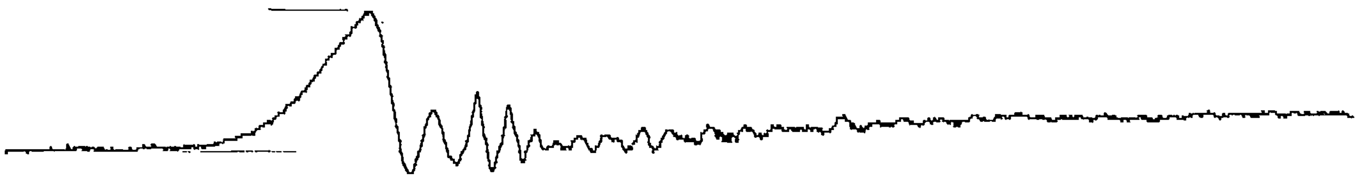
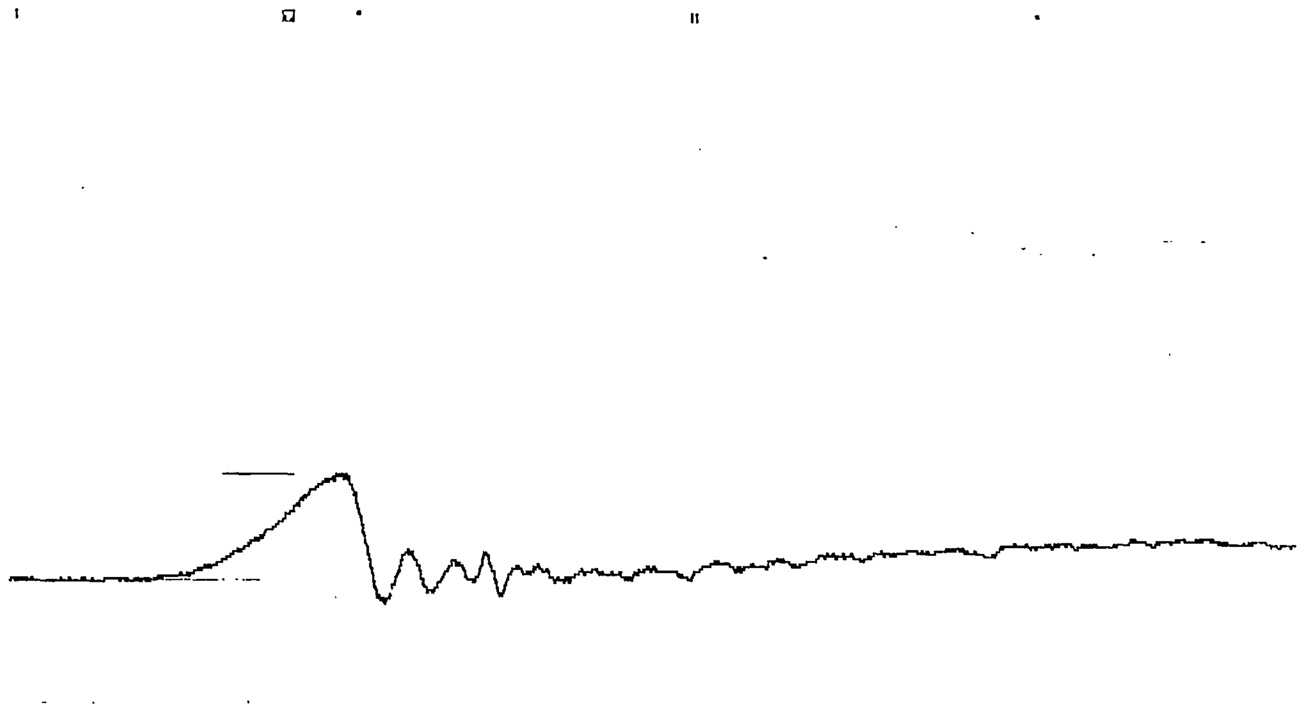


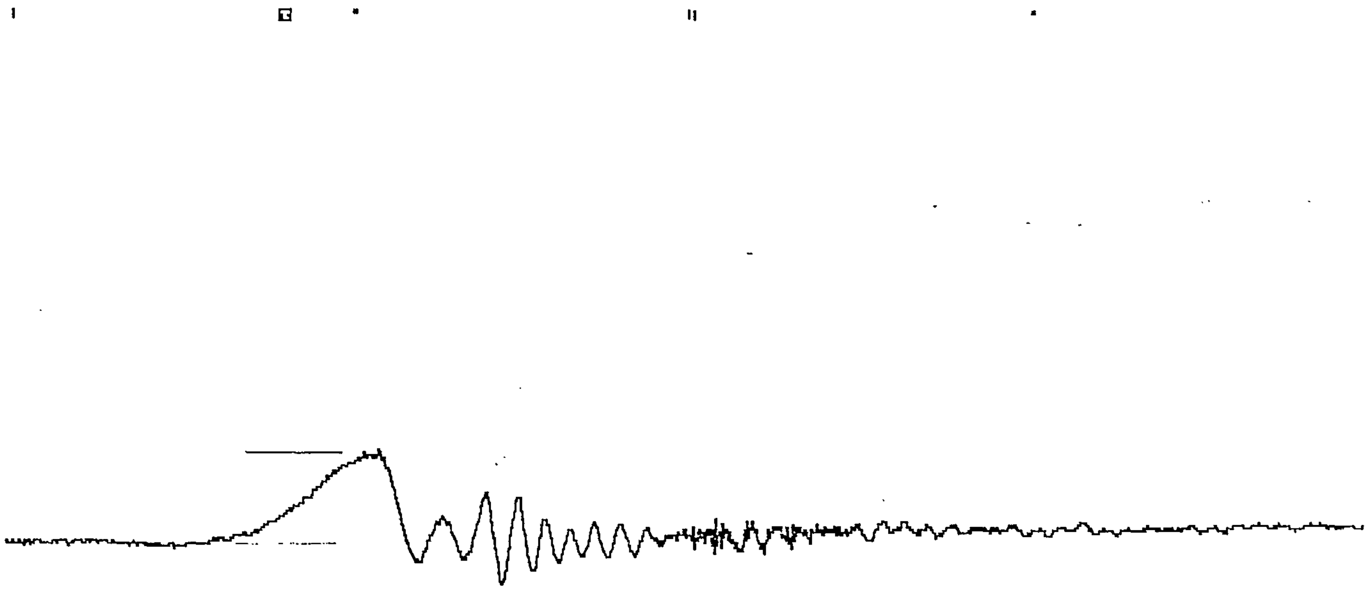
Figure No. 35

Figure No. 36



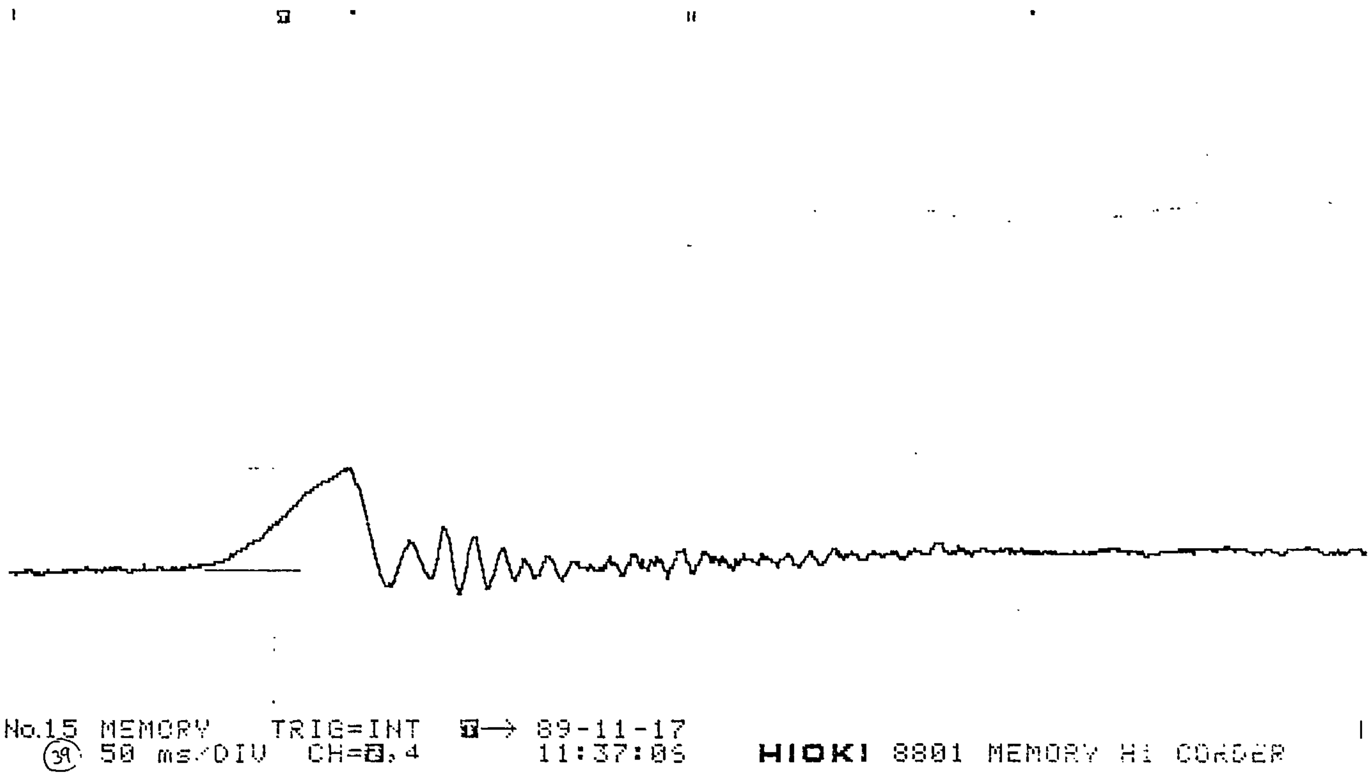
No.13 MEMORY TRIG=INT T→ 89-11-17
㊲ 50 ms/DIV CH=3,4 11:00:59 **HIOKI** 8801 MEMORY Hi CORDER

Figure No. 37



No.14 MEMORY TRIG=INT T→ 89-11-17
㊳ 50 ms/DIV CH=3,4 11:15:25 **HIOKI** 8801 MEMORY Hi CORDER

Figure No. 38



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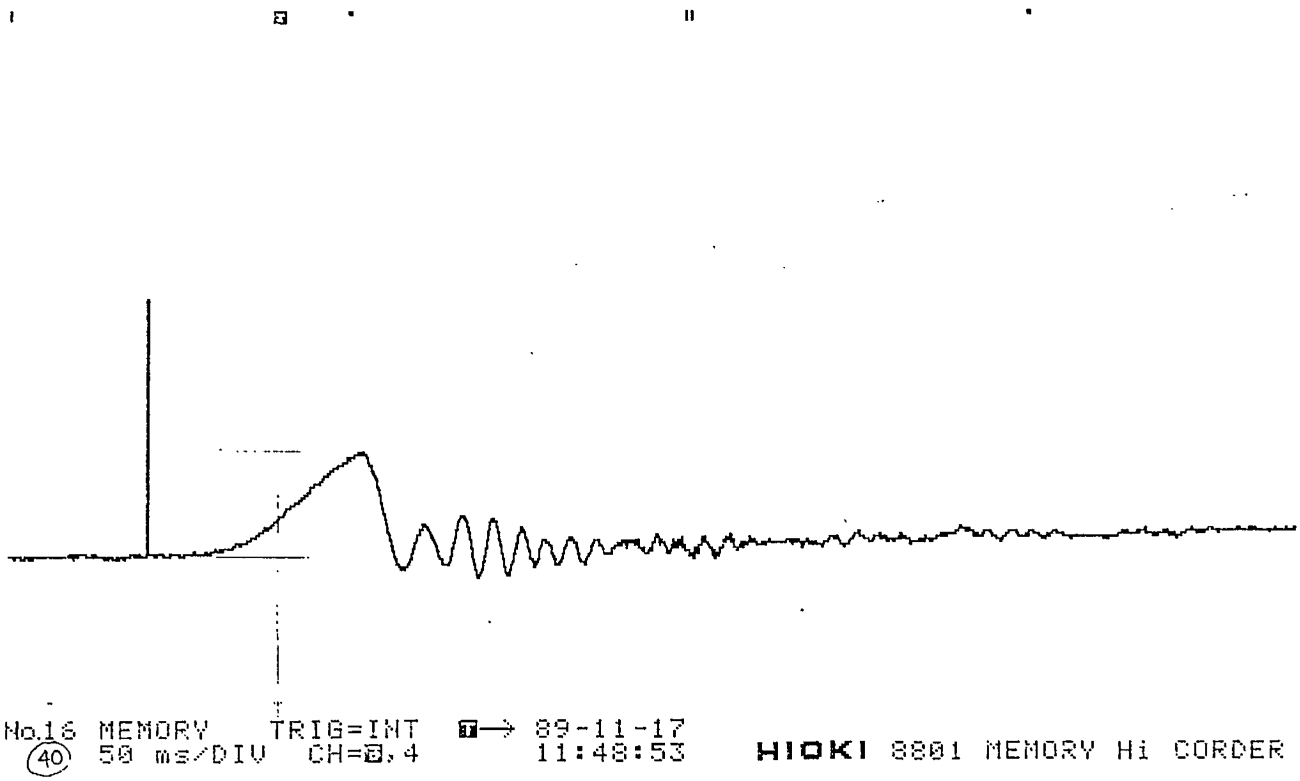
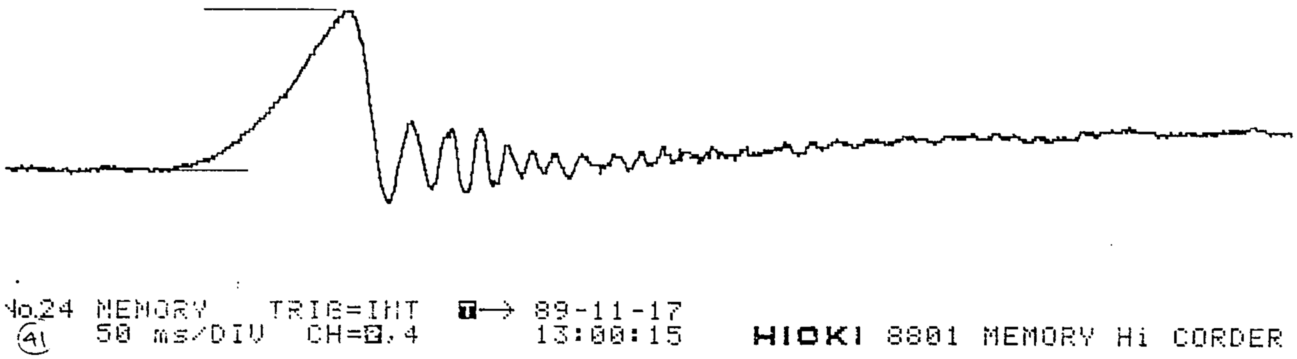


Figure No. 40

No 7



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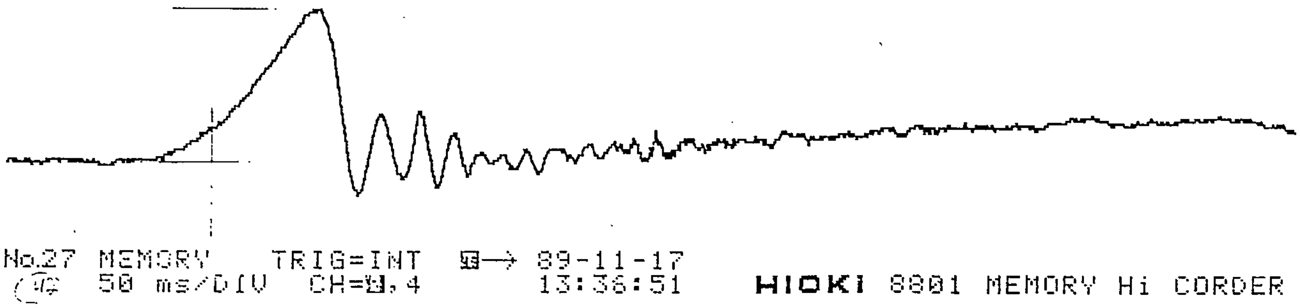

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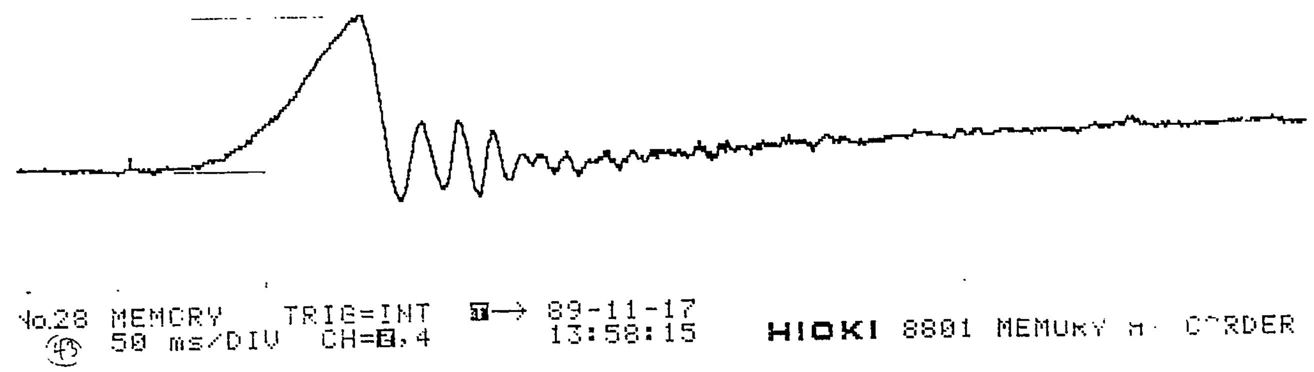

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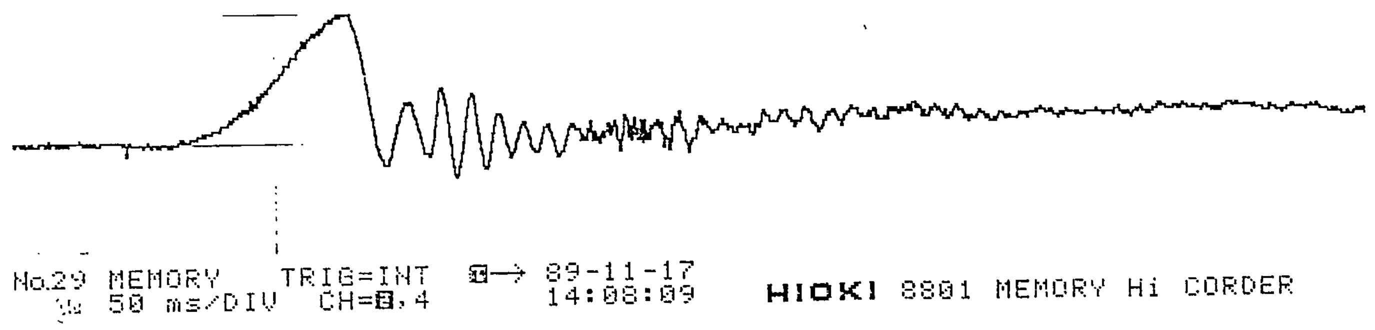

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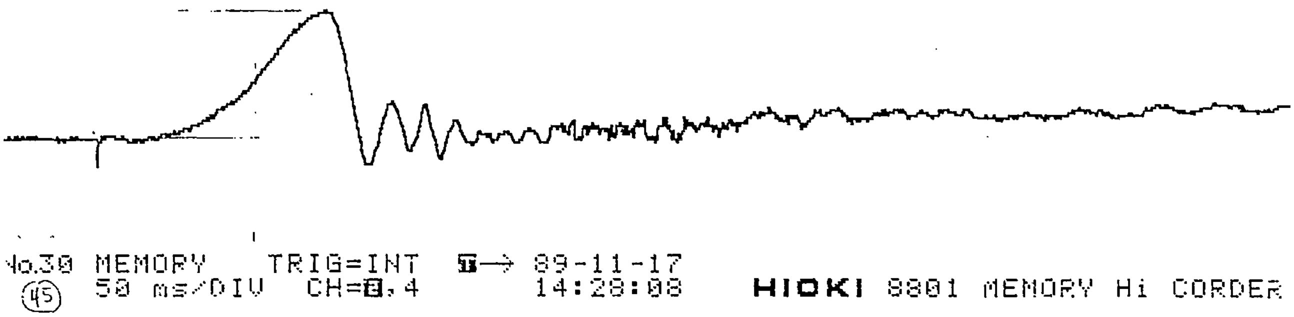

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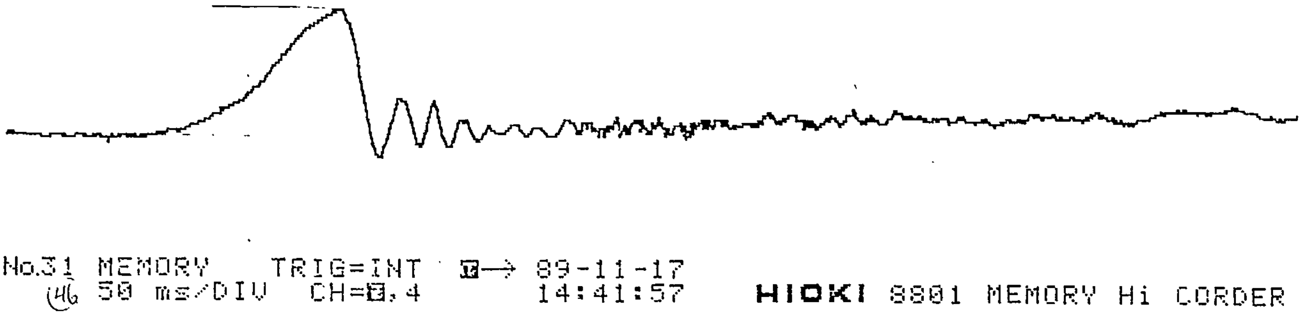

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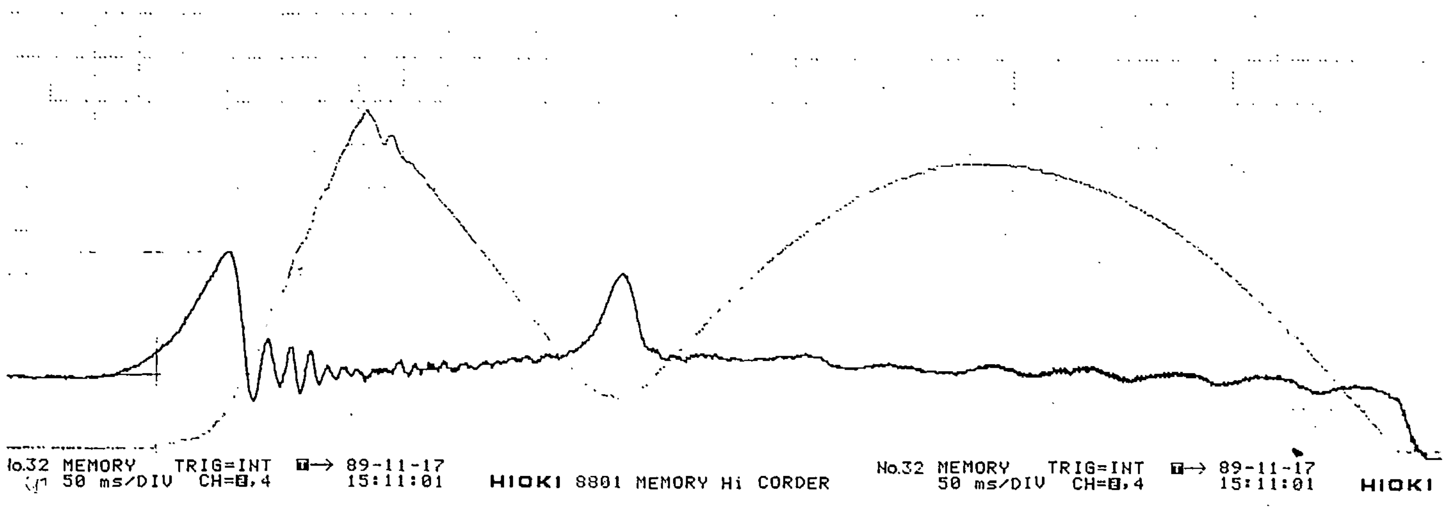

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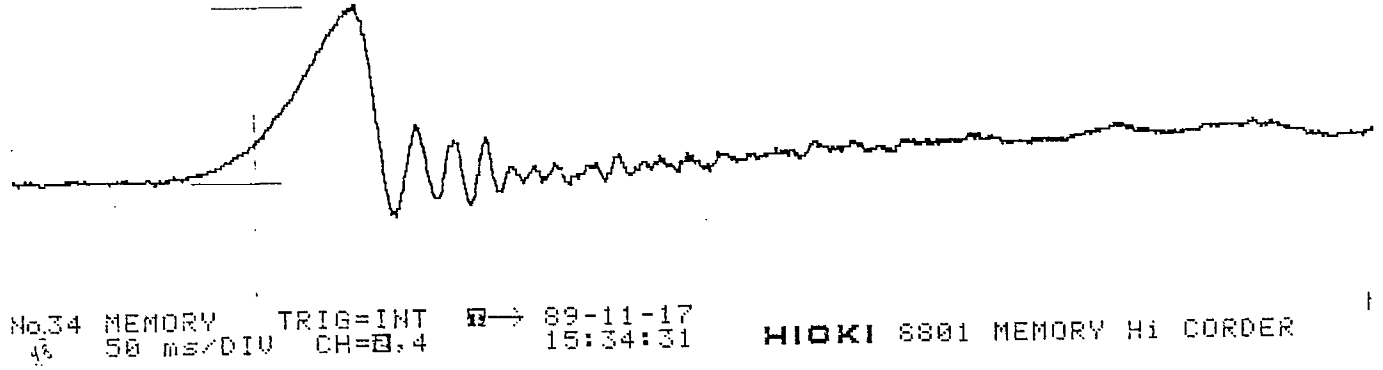

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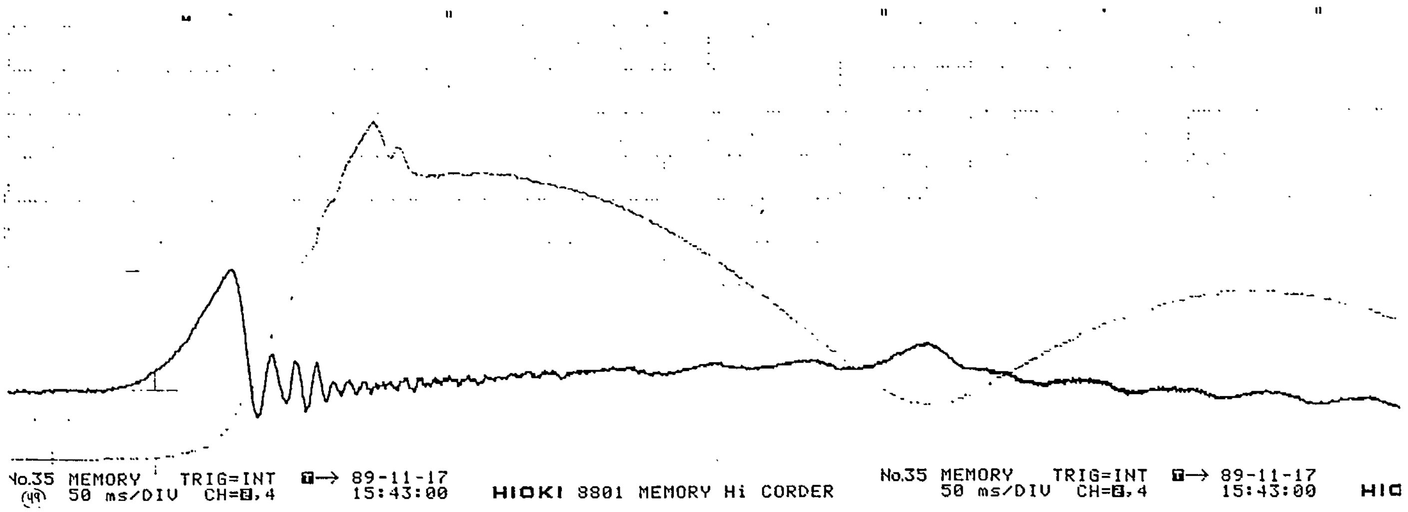

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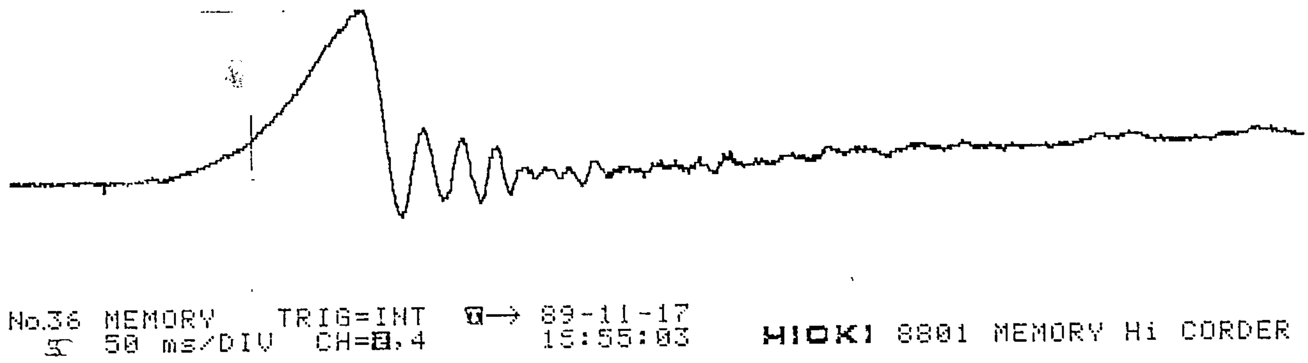

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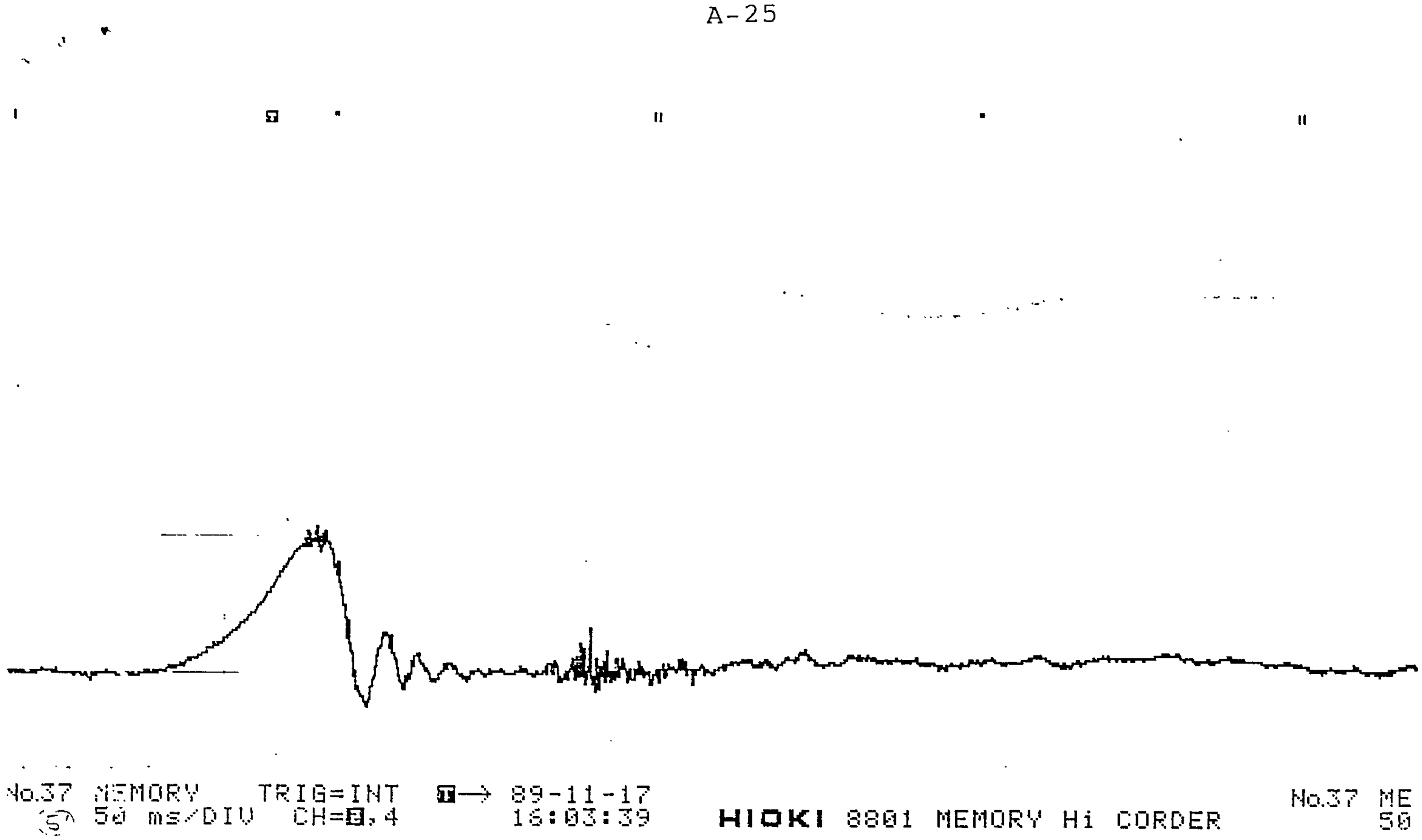

Figure No. 51

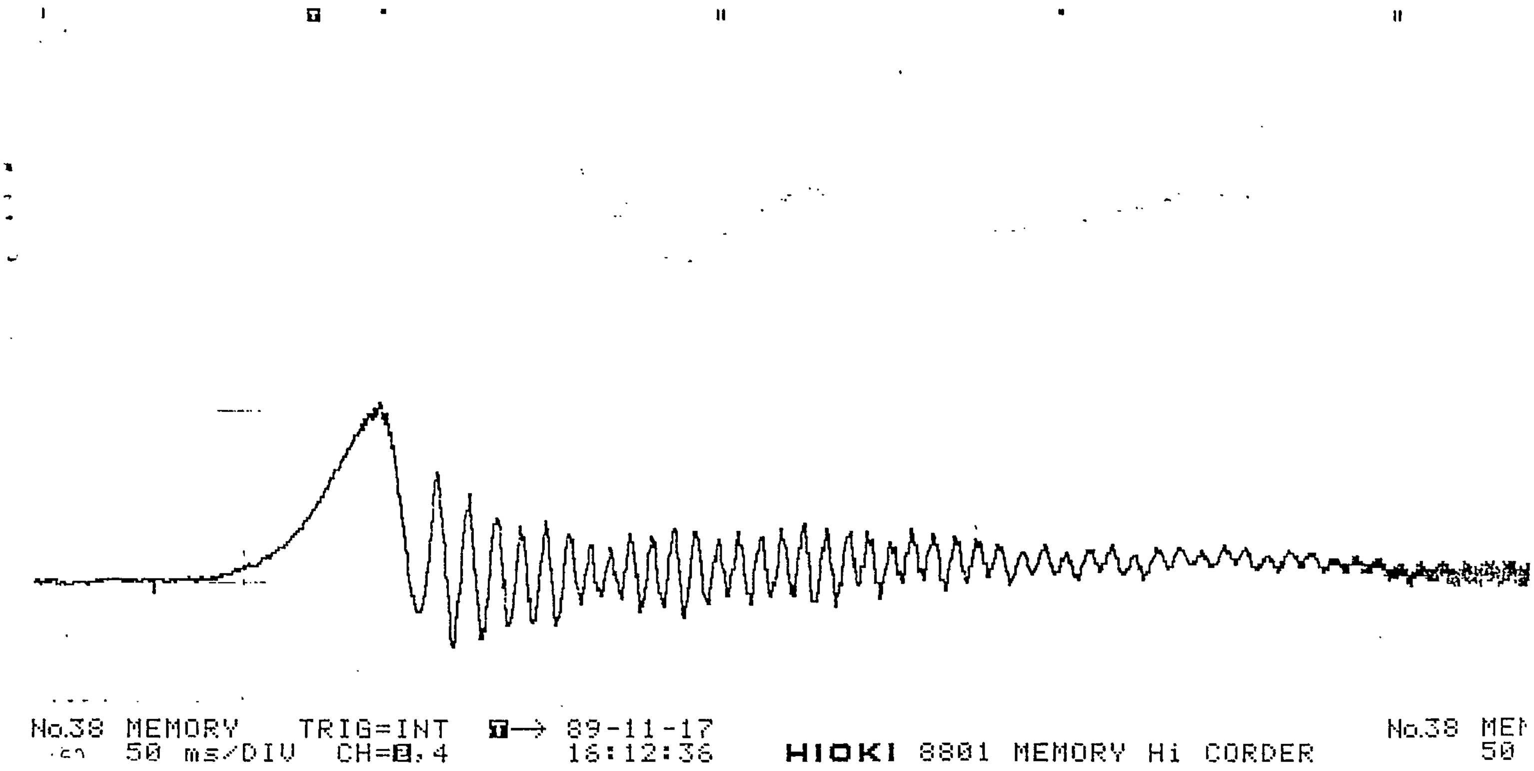

Figure No. 52

Appendix B

Calculation of Venting Area for the Canadian Explosive Atmospheres Laboratory Explosion Test Chamber

This calculation uses the method specified in NFPA Guide 68 (page 68-13).

According to NFPA Guide 68, the vent area is calculated using the following formula:

$$A_v = \frac{CA_s}{(P_{red})^{1/2}} \qquad \ldots(1)$$

where

A_v = vent area
C = venting equation constant
A_s = internal surface area of enclosure
P_{red} = maximum internal overpressure that can be withstood by the weakest structural element

The test chamber is cylindrical, having a length of 65" and a diameter of 48 3/8". Simple surface area calculations yield the value $A_s = 92.59$ ft^2.

From table 4-3 in NFPA Guide 68, C = 0.14 for methane.

Referring to Table 2 of this paper, the maximum explosion pressure measured during any of the tests was 80.6 psf (0.56 psi). Assigning this value to P_{red} allows the calculation of the vent area required by the NFPA guide to limit the pressure to 80.6 psf.

Substituting the assigned values into the above equation yields $A_v = 17.3$ ft^2. This calculated value is much higher than the actual venting area (6.109 ft^2) that was used during the tests.

Appendix C

Relationship Between Latch Load and Panel Release Pressure

This Appendix demonstrates the relationship between the calibration method used to determine the amount of force required to release the Explovent panel latch, and the amount of explosion pressure (in psf) that would be required to open the panel. That is, if force F is applied at the latch to open the panel, what would be the equivalent calculated explosion pressure required to open the panel?

With reference to Figure 6, which is a schematic representation of a side view of the panel, the explosion pressure can be considered as an equivalent amount of force P being applied to a point at the centre of the exposed portion[7] of the panel. This is the minimum amount of explosion force required to open the panel. For this case, the exposed panel surface area is 6.109 ft^2. If an explosion of P_{set} psf occurs (the minimum amount of explosion pressure required to just release the panel), then we have

$$P = P_{set} \cdot 6.109 \quad (2)$$

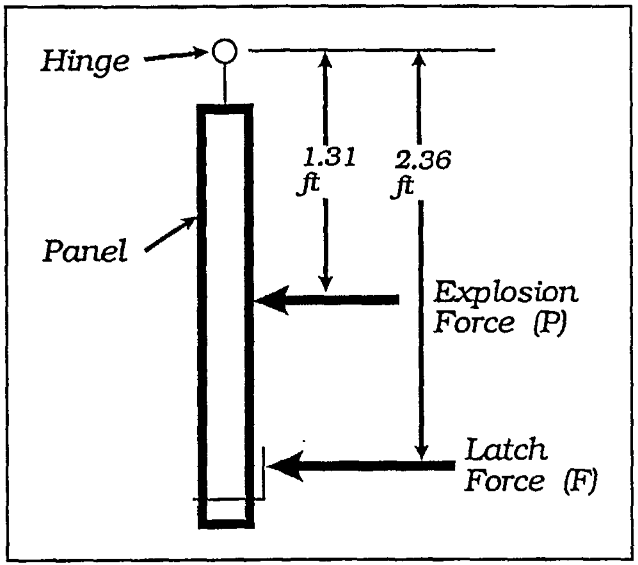

Figure 6 - Points of Application of Panel Forces

For the purposes of this discussion, we have assumed that the theoretical value P_{set} equals the actual explosion pressure to release the panel, P_{open}.

Also, the minimum amount of force F required to open the panel at the latch when using the calibration apparatus is shown in Figure 6.

Forces P and F are equivalent forces, in that they can be considered as being in equilibrium and are acting on a lever (i.e. the panel) which has the fulcrum (i.e. the hinge) located

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[7] Some portions of the panel are not exposed to the explosion due to the weatherstripping and other mechanical components.

at one end of the panel. For a lever to be in equilibrium, the forces are in balance and are acting through their respective distances to the fulcrum. Accordingly, we can write

$$F \cdot 2.36 = P \cdot 1.31 \qquad \ldots(3)$$

or we can substitute eq.(2) into eq.(3) and obtain

$$F \cdot 2.36 = P_{set} \cdot 6.109 \cdot 1.31 \qquad \ldots(4)$$

Simplifying and rearranging yields the desired relation:

$$F = P_{set} \cdot 3.43 \qquad \ldots(5)$$

where P_{set} is the minimum calculated explosion pressure, in psf, required to release the panel, and F is the minimum force applied by the calibration apparatus at the latch to release the panel. As can be seen in the results, the explosion pressure measured during the explosion tests required to relase the panel, P_{open}, is less than P_{set}.