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A STUDY OF THE APPLICABILITY OF ACOUSTIC EMISSION TO PRESSURE VESSEL TESTING

B. H. SCHOFIELD

LESSELLS AND ASSOCIATES, INC.

TECHNICAL REPORT AFML-TR-66-92

NOVEMBER 1966

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AIR FORCE MATERIALS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by B.H. Schofield, Senior Project Engineer, Lessells and Associates, Inc., Waltham, Massachusetts, under USAF Contract No. AF33(657)-8562. This contract was initiated under Project 7360, "The Chemistry and Physics of Materials," Task No. 736002, "Nondestructive Methods." The work was administered under the direction of the Metals and Ceramics Division with Mr. H.W. Kamm, MAMD, Project Engineer.

This report covers work from 15 March 1965 to 15 March 1966. The manuscript was submitted by the author in March 1966.

The author wishes to acknowledge the assistance of Mr. Frank Ranstrom in the conduct of these experiments and to Mr. D. Leone for preparation of data, both of Lessells and Associates, Inc.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

W. J. Trapp

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ABSTRACT

This report describes a series of experiments designed to assess the practical capability of acoustic emission to indicate stress and/or deformation in a structure, as well as to offer a means of assessing structural integrity. The tests were conducted on split ring samples and specimens of cylindrical form internally pressurized. The integrity of the cylindrical vessels was altered by inserting machined notches of various shapes at predetermined locations on the vessel surface. Specimens were fabricated from 4130 steel and 6061 aluminum. The studies were extended to tests in which the surface of the specimens was coated with a brittle film. This was done to provide an artificial source of high acoustic energy which conceivably could offer an alternate method comparable in reliability with the metal induced emission and one which would be much less susceptible to the environmental disturbances.

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I. INTRODUCTION

This report describes the effort relating to the development of the practical use of acoustic emission in assessing the structural integrity and stress state of a structure. In the specific instance the program concerns internally pressurized vessels and is a direct extension of the preliminary studies of Reference 1.

The occurrence of acoustic emission during the deformation of a metal suggested the possibility of employing the phenomenon as a nondestructive tool to monitor structures relative to their physical integrity and perhaps as a measuring technique with regard to stress or deformation. The methods used to observe and study the acoustic emission have been comprehensively discussed in previous publications.[2, 3, 4*] In this preceding work it was determined that the emission is induced by inelastic (plastic) deformation which can, of course, exist on a very local as well as a gross scale within a given structure. With respect to structural integrity, in the usual case it is the unpredictable local deformation which is of specific interest. Local discontinuities or defects within the structure material can result in premature local plastic deformation. Hence, it is evident that under appropriately controlled conditions their presence could be detected by the acoustic method. In addition, the previous experiments indicated that the amplitude of the emission, neglecting strain rate and volume effects, is dependent on the stress level at which it is produced; the higher the stress level the greater acoustic energy or higher amplitude. This characteristic proffers the possibility of establishing a correlation between emission and stress. These two aspects of emission application, i.e., defect detection and stress/deformation measurement, were investigated in the subject program.

In pursuit of the stated goals the majority of the effort concerned observance of the primary, deformation induced, emission from the structure material. Vessel integrity was varied by artificially inserting defects into the structure while the emission-stress relation was studied under different states of induced stress using standard strain gage instrumentation. A secondary phase of the study concerned a modified acoustic technique.

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* Refers to References

In the usual primary acoustic emission method the extremely low energy of the emission necessitates signal amplification of the order of 10^6. From the view that in many instances the local environment would preclude such sensitivity, an alternate acoustic method was investigated. The technique is similar in principle, although it is a marked departure from the physical premises distinguishing the primary acoustic emission. In the alternate method brittle-type coatings are applied to the surfaces of the structure. These coatings crack locally under strain thereby producing an acoustic pulse. The coating serves as the source of the acoustic signal rather than the structural material. The advantage gained is that the acoustic energy of a crack pulse is orders of magnitude greater than that associated with primary metal emission. Hence, a high signal to noise ratio is obtained, greatly reducing the required amplification.

Two different epoxy coatings were used in these experiments; the significant difference between them is the different threshold strain level at which cracking occurs. The composition of the coatings was also markedly different. The latter was done with the expectation that the crack pulse characteristics of the two coatings would differ in detail and thereby offer a means of discrimination. If extant, the characteristic signal would provide a means of physically locating the emission source by selectively positioning the different coatings on the structure. It should be noted, however, that the coating method has two shortcomings which should be kept in mind when considering this particular technique. Obviously, the coating is only responsive to the conditions on the surface of the structure where the coating exists. Further, as in the case of the pressure vessels, the coating is applied to the external surface only and hence would not necessarily respond to anomalies on the inside surface.

Two structural materials were used in the subject investigations; 4130 steel and 6061 aluminum.

II. EXPERIMENTAL PROCEDURE

The arrangement for the split ring tests preceding the pressure vessel tests is shown in Figure 1 along with a detail of the test specimen. As here indicated, motion of the ram produced bending deformation in the reduced section of the sample. Strain gages were mounted on the specimens at the reduced section as well as on the adjacent heavier section to provide a measure of deformation rate which was varied over a substantial range, as high as 1000 microinches per inch per second. The acoustic transducers were mounted on the flat and on the edge of the specimen close to the reduced portion. Control of the deformation rate was accomplished by adjustment of a needle valve which connected the hydraulic cylinder to an hydraulic accumulator. The valve and accumulator do not appear in the figure. The motion of the ram piston was measured by a slide wire transducer.

The strain gage and linear ram motion were recorded on a chart oscillograph, while the acoustic emission was recorded on the dual channel magnetic tape unit. The reduced section of the specimens was varied to provide different total volumes of deformed metal. This was done by changing both the thickness and width of the section to provide data on the effect of participating volume of material. Precaution was taken to prevent the occurrence of apparatus noise by isolating all parts with teflon washers and spacers. The split ring specimen was welded to its mounting base to further assure that surface friction motions would not interfere.

The experimental setup for the pressure vessel tests is shown schematically in Figure 2 and photographically in Figure 3. The test enclosure was used to contain the hydraulic fluid at failure and was not intended as an acoustic isolator or shield. The test cylinder was instrumented with strain gages, usually two, and two piezoelectric transducers. The piezoelectric transducers were held against the cylinder by an elastic band. A thick layer, about 1/16 inch, of silicone grease was between the transducer and the specimen surface. Internal pressure was measured by a strain gage pressure transducer and monitored visually.

Strain gage and pressure data were recorded on the chart oscillograph. In addition, the amplified acoustic emission from one of the two transducers was transmitted through a sound level meter to the chart oscillograph. In this way the data on the magnetic tape could be accurately correlated against the physical measurements.

Figure 4a shows the geometric form of the steel pressure vessels, all 4130 steel. Also depicted are the several types of defects artificially inserted into the vessel surface. In some instances, such as Figure 4c, Longitudinal-Type Defect, two defects were put into the surface. (See also photographs of the cylinders, Figures 7-14.) In almost all cases the strain gages were circumferentially oriented in the central part of the cylinder, except when a defect was present, in which case the strain gage was located adjacent to the defect at the high stress region. See Table I for details on defects and strain gages.

Figures 5 and 6 show the aluminum cylinder geometry and the steel circumferential stress specimen, respectively. The latter contains an insert which carries the axial load, sealing being accomplished by O-rings.

The coatings for the cylinders were of two types. One was the standard "Stresscoat" which was sprayed onto the cylinder surface. The second type was an epoxy casting compound, Stycast 3020, made by the Emerson-Cuming Company. The latter was brushed onto the surface while rotating the specimen continuously in a machine lathe. The coatings were applied to as-received cylinders and also to defect cylinders for a comparison of sensitivity.

Pressurization of the cylinders was accomplished by the system depicted in Figure 2. The double hydraulic ram method permitted reasonable isolation of the specimen from the motor driven hydraulic pump. The lower ram is connected to the cylinder and the system completely filled with oil. By driving the lower ram with the upper ram, the cylinder was gradually pressurized. Rate of pressurization was controlled by the needle valve to the upper ram. In the majority of tests, pressurization was uninterrupted from the onset to failure. However, in a few cases repetitions of the pressure range were imposed to examine the effect of prior loading on the emission characteristics.

III. EXPERIMENTAL RESULTS

The experimental results for the split ring tests provided some insight into the data obtained in the subsequent cylinder tests. They did not, however, provide the desired data on the nature of the emission under varying stress levels and strain rates due to the paucity of emission. The lack of emission introduced a new aspect into the experimental program and although a negative result, does offer additional knowledge concerning the nature of induced acoustic emission.

Both steel and aluminum specimens were tested in the split ring form. Neither material exhibited any high frequency type emission of physical significance, particularly the 6061 aluminum. The alteration of strain rate, up as high as 1000 μin/in sec had little influence; essentially no evidence of emission being observed. Some burst-type activity was observed with the 4130 steel specimens, but this was erratic and did not correlate with either stress or deformation.

The actual recorded data for most of the test cylinders are shown in Appendix A. The curves show strain gage data, internal pressure and acoustic emission response. Except where noted, the strain data represents the nominal circumferential strain at the vessel center; see Table I for instrumentation details.

Cylinder No. 1, an as-received, no artificial defect specimen, exhibited the type of emission response previously observed in the preliminary studies of Reference 3. The salient difference is the presence of the relatively high peaks just prior to the general rise in amplitude. In the original tests[1] these premature emission indications were absent for the as-received cylinder, the general rise to peak amplitude at gross deformation being the first significant emission. It can be seen that the high amplitude rise is similar in form to the sudden change in the strain rate shown in the lower curve. The change to the higher strain rate lags the rise in emission by a slight period. The rate of change of the pressure is more closely related to the emission change, but even here there is a slight time lag; the emission rise being the first indication of a physical change occurring in the structure. Following the peak emission amplitude there is a gradual, although somewhat erratic, decrease in emission energy until just immediately prior to fracture the final acoustic peak occurs. Cylinder No. 6, an as-received cylinder, exhibited a very high emission amplitude almost immediately upon loading and Cylinder No. 7, also as-received, a premature, fairly high amplitude preceding the rapid rise to maximum level at yielding. The strain gages on Cylinders No. 1 and No. 6 show substantial strain levels as well as a clear indication of plastic yielding. These gages were circumferentially located at the vessel center. In the case of Cylinder No. 7 the strain gages are positioned at the juncture between the hemispherical head and the cylindrical portion of the shell. The much lower strain in this region and the lack of plastic deformation indication are evident.

In the repeated loading tests on the as-received Specimens No. 6 and No. 7, the emission response showed a tendency to increase gradually and more regularly to the maximum level. Some irregularities are evident in the gradual rise of the emission. However, there is no sudden increase to the maximum level at the onset of loading as observed in many cases. The initial loading did not entirely eliminate emission in subsequent loadings over the same range as might have been expected from the previous experiments showing emission irreversibility.

Cylinder No. 4 was also stressed in several cycles and exhibited an emission pattern similar to the above. In this case the cylinder contained a spot-type defect, the influence of which would seem to have been eliminated in the first loading. It should be noted, however, that for the same internal pressure level the emission energy as expressed by the amplitude level is greater for the third cycle than the second cycle.

Cylinders No. 3 and No. 8, both thinned wall specimens, show emission response similar to the as-received cylinder except that the pressure level at which the amplitude change occurs is much lower, as expected. Again, there is the premature rise prior to that associated with the gross yielding. The energy of this premature emission (amplitude level and period of sustainment) is noticeably greater for the thin vessel than for the thicker specimen. In contrast, the total emission during plastic deformation up to fracture is much greater for the thicker vessel. In Figure 3 of Appendix A it can be seen that Strain Gage No. 1 was located fairly close to the region of final fracture. Gage No. 2 was 180° around from No. 1.

The defect cylinders show a premature emission in every instance (see especially No. 2, No. 5 and No. 9, Appendix A), but in many cases a high amplitude level is sustained almost immediately upon loading. See No. 4, No. 10, and No. 11. The maximum amplitude level of the emission is fairly uniform for all specimens including those without defects as well as those with defects.

The presence of the defect did not result in an emission response which was characteristic of a specific form of defect. In every case of a specimen with a defect there was either a premature occurrence of limited acoustic energy or a rapid increase in emission at the onset of loading. These defects varied not only in shape, as previously noted, but where similar in form the locations were different. Cylinders No. 4 and No. 5, for example, contain defects of identical shape, yet the emission response varies from a rather rapid rise at onset of loading in the former to a premature lower level emission in the latter. The specific emission behavior for the different defects can be seen in the charts of Appendix A, Cylinder Nos. 2, 4, 5, 9, 10, and 11.

The results from the o-ring type specimens are also presented in the Appendix. Only the circumferential stress exists in these specimens and the emission behavior is essentially the same as for the defect and as-received cylinders. The o-ring type specimens did not contain any artificial defects.

Charts No. 24 and No. 25 contain the data recorded for the aluminum specimens. The pattern of the emission from these cylinders is a marked departure from that of the 4130 steel. A rather meager amount of emission, particularly for the second cylinder, Chart No. 25, is exhibited at the onset of loading and this decreases very rapidly such that essentially no emission is evident during the gross deformation of the cylinder. This lack of emission confirms the results observed in the split ring tests. Neither cylinder contained artificial defects. Examination of the vessels following the tests showed the cylinders were plastically deformed over the entire cylindrical section, although the final deformation and fracture region was confined to a relatively small local area. This is shown in the photograph of Figure 13. The amount of general permanent deformation can also be observed from the strain gage curves. This data shows that the strain gages were remote from the final failure region.

The emission results for the coated cylinders are shown in the Appendix A, Charts 21, 22, and 23. These cylinders were not instrumented with strain gages in order to insure a uniform, uninterrupted coating. The presence of a strain gage would induce a stress concentration acting much the same as an artificial defect in the cylinder. Nominal stress was obtained simply by calculation using the internal pressure data.

Cylinder A exhibits a marked change in the acoustic pulses from the elastic to plastic range, there being no pulses until general plastic deformation occurs. This cylinder was in the as-received condition. Again, there is the decrease in emission as deformation proceeds. Cylinder B, which contained a longitudinal-type defect, exhibited acoustic response immediately upon loading as did Cylinder C with a similar defect, but a different type coating. The no-defect cylinder to correspond with C, i.e., surfaced with Stresscoat, was inadvertently damaged in test and did not produce decipherable information.

IV. DISCUSSION

As noted in Section III, the experimental results from the split ring tests did not provide emission data which could be correlated with stress or deformation. The lack of emission in these tests is considered to be a result of the manner of deformation. In all previous testing the applied load was the controlled variable rather than deformation as in these tests. Consequently, in the former experiments local or general plasticity occurred in avalanches of appreciable acoustic energy. In the split ring apparatus strain avalanches are precluded, since the system is strain controlled. Although the 6061 aluminum showed some evidence of emission in the subsequent pressure vessel tests, the above conclusion is supported by the prolific emission exhibited by the 4130 steel cylinders when internally pressurized.

The split ring tests point out an important consideration relative to application of the technique in that the system under test must permit deformation instability on a local scale. This is somewhat equivalent to the yield drop of a tensile test. It is not entirely clear why this anomaly exists, considering the rather high strain rates imposed in the ring tests. It had been thought that the emission produced by the deformation instability was a direct consequence of a high strain rate in addition to material volume, but unless the local strain rates associated with emission are considerably higher than 1000 μin/in/sec, it would appear another parameter is prerequisite. A second aspect emphasized by these tests as well as the vessel studies is the fact that certain materials, in this case the 6061 alloy, do not produce emission of significant energy. Separate bend tests on bar samples of the alloy further confirmed that detectable emission is not produced during plastic deformation. This is only the second material which has been encountered that did not produce acoustic pulses, the other being pure iron.[1]

A review of the steel pressure vessel data shows that the presence of defects can be detected by acoustic emission. The emission evidence is not as clear as would be desired, as seen in the tests on the as-received cylinders; for example, both Cylinders No. 2 and No. 6 exhibit the premature emission usually associated with the presence of a defect. Nevertheless, in every instance of a defect there is evidence of emission energy prior to the development of general yielding of the entire structure. It is conceivable that these cylinders contained fabrication defects, although examination of the cylinders after the tests did not reveal such.

The correlation between the occurrence of acoustic emission and the onset of plastic deformation induced by the defect is best shown in the test of Cylinder No. 2, Appendix A. Here Strain Gage No. 1

is located at the end of the notch defect while No. 2 is 180° around the cylinder in a no-defect area. Both internal pressure and strain on No. 2 gage are increasing linearly, whereas Gage No. 1 shows a sharp increase in strain and an increase in the amplitude of the emission corresponding to this strain increase. Cylinder No. 5 shows premature emission, but in this case no strain rate change adjacent to the defect. This defect was considerably smaller than that of Cylinder No. 2 and hence has less effect on the strain gage. The emission energy is also much reduced. Nevertheless, the emission does present an indication of defect presence, whereas the strain gage does not.

The variation in defect size and shape had little effect on the emission response. Cylinders which contained the small spot-type defect (Cylinder No. 4) showed emission response similar to that of cylinders containing the much larger longitudinal defect (Cylinder No. 2). Location of the defect on the cylinder appeared to show the primary effect as expected, i.e., the higher the stress state in the defect area, the earlier the emission in response. For example, considering Cylinders No. 4 and No. 5, the emission response in the former is most evident right from the beginning of loading. The defect in this cylinder is in the center of the vessel and in the second cylinder (No. 5) the defect is at the juncture between cylinder and hemispherical end head. Because of the local restraint in the latter position, local yielding is less than in No. 4 and slightly delayed relative to the internal pressure. It is clear that a defect, in order to be "seen" must induce local plastic deformation; hence, must be located in a stress field sufficient to induce the yielding. It also follows that the orientation of a defect relative to the stress field would be significant. It should be noted, nevertheless, that Cylinder No. 11 containing a circumferential notch exhibited substantial emission immediately upon loading, identical to that observed for an identical notch in the longitudinal direction.

The test results show that the size of defect cannot be reliably indicated by the energy of the emission since, as noted above, the stress field surrounding the defect is a vital influence. From an absolute sense, however, the data does show that the presence of a defect, around which some plastic deformation occurs, can be detected by observance of the emission. In this regard the applicability of the technique to pressure vessels would necessitate special methods to preclude false indications that may arise from the surrounding environment. A review of the subject data indicates that an acoustic amplitude greater than about three major chart divisions and continuing to show a definite increase in emission amplitude for a predetermined time period would be cause for cessation of loading and inspection. Undoubtedly, in every instance it would be desirable to establish, quite precisely, the characteristics of a prototype known to be defect free. The monitor technique would then apply to that stress region in which a defect-free structure does not exhibit emission. It is clear from the data charts that the extent of emission output during gross deformation is a function of the structure ductility. This is of no consequence with regard to nondestructive monitoring, since the latter is important in the useful stress region of the vessel which is generally below the gross yield condition.

The emission results for the coated cylinders were most encouraging and show a more distinct demarcation between cylinders with and without defects. Cylinder A, for example, was an as-received cylinder without defect, and exhibited no emission until gross deformation of the cylinder occurred. Cylinders B and C both contained the longitudinal-type defect. For the latter two specimens the acoustic pulses appear very shortly after initiation of loading rising to appreciable amplitude levels. It is to be recalled that the acoustic transducer gain was reduced by an order of magnitude in these tests; hence, the usual metal emission is not detected on the recording.

In the studies that were undertaken, which of necessity were somewhat limited, no obvious difference in the acoustic signals of the two types of coatings was ascertained. Nevertheless, with audio monitoring a definite qualitative difference in the sounds is perceptible, indicating a difference in frequency and amplitude content of the two signals. Furthermore, limited signal observations indicated a possible difference in the signal decay rates as well as maximum pulse energy, but again the quantitative analysis showed only a trend that was not conclusive at the present stage. It would appear that identification of pulse source relative to a particular coating might well necessitate parameter combinations. Another approach could, of course, investigate a greater variety of coating materials to see if certain ones exhibit characteristics peculiar or unique to that material.

The limitations of such coating, previously noted, would mitigate their overall effectiveness. An additional shortcoming, particularly for very large structures, would be the requirement of coating the surface of the structure. Nevertheless, there are undoubtedly instances where such a technique could be very effective and certainly cases where the entire structure need not be coated. For example, very thin structures where defects not on the coated surface would still show a stress influence or concentration on the coating. Also, structures which have critical regions, e.g., structural discontinuities, could be effectively investigated in these local regions by the coating method. In short, the acoustic-brittle coating technique shows definite promise as a nondestructive tool.

A review of the strain gage/emission data shows that there is little consistent correlation between the acoustics and the stress level. The quantitative measurement of stress would therefore not appear possible except in the specific instance of the yield stress. A clear example is shown by the charts for Specimen No. 4, Test 2 and Test 3 (Charts 5 and 6). Here it can be seen that in Test No. 3, for the same level of stress, the emission is higher than in the preceding loading of Test 2. A similar conclusion is obtained from an analysis of the pulse rate. For the latter the emission was transmitted through an electronic counter to a print-out tabulator. Although the emission pulse rate varies with stress and of course deformation, no consistent rate would be associated with an absolute stress level. It seems clear that even though the nominal strain rates appear comparable, there probably are considerable differences in a local sense and further, different volumes of materials are undoubtedly involved. Both items would have a strong influence on the observed emission pulse rate. The artificial coating method would appear to show greater promise regarding stress determination, assuming that such could be individually identified acoustically. Application to a specimen of several coatings varying in strain sensitivity would permit measurement of as many stress levels.

V. CONCLUSIONS AND RECOMMENDATIONS

The experimental results concerning primary acoustic emission show that, for purposes of nondestructive evaluation, the acoustic phenomena response is affected by the presence of certain defects and that this response can be detected. The subject results do show that a defect which exists on a structure under stress will induce detectable emission and with the addition of other techniques, i.e., triangulation, the position of such defects would be determinable. However, the results also demonstrate that the information obtained by this technique is not as definitive as had been desired; that the emission characteristic is not unique for a given defect. Further, some ambiguity existed due to the occurrence of premature emission in the as-received cylinders but the conclusion that premature emission occurs in other than defective vessels is not decisive inasmuch as the presumption of a sound specimen may be erroneous, although not evident. In every instance of a known defect an early acoustic indication was observed. It is clear that the existence of emission is positive evidence of active deformation in the specimen. The lack of emission might be considered inconclusive, but obviously not the actual occurrence. It follows that an anomaly of a type was present in the cylinders assumed to be structurally sound. The importance of the irregularity relative to the specimen performance remains in question. The results obtained suggest therefore that further studies should be made in which performance, possibly fatigue behavior, is determined in respect to the emission observed. In this way the emission significant to ultimate behavior would be separated from that resulting from an anomaly not determinant of performance. Such studies would obviously necessitate not only more precise knowledge of the physical condition of the specimen, but also the specific performance of the structure.

The direct measurement of stress utilizing acoustic emission is feasible in a limited sense, but from the view of practical applicability has serious shortcomings. Since acoustic emission exhibits a maximum amplitude and rapid rise thereto at the yield stress level, the phenomenon can detect the attainment of this single value. Due to the variety of acoustic energies associated with all other stress levels, i.e., lack of single value, the determination of any stress level other than the yield value does not appear feasible on the basis of the subject studies. The presence of emission on successive loadings of the specimen, i.e., the lack of irreversibility, precludes the determination of the previous stress level imposed on the vessel. For the same and additional reasons the quantitative degree of strain or deformation would also be impractical if at all possible. The method would nevertheless have definite value in monitoring complex structures under load for the occurrence of yielding which is undesirable and detrimental to the structure. Locating techniques, such as triangulation previously noted, could be used to locate the position of such yielding.

The brittle coating method would appear to be immediately applicable to the detection of defects in structures with the limitations noted in the body of this report. It is to be noted that only one type and size of defect was examined in the subject work, but in principle, the technique appears workable for any defect form; minimum size being the only question. The versatility of the properties of such coatings would permit considerable latitude in defect size. It is recommended that investigations relative to minimum defect size and detail acoustic characteristics be made to establish the scope of the coating method. Further, such an investigation should be accompanied by a manifest of specific practical applications where, considering the scope of the method, the method would be advantageous and so recommended.

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TABLE I

PRESSURE VESSEL SPECIMENS

Specimen No.	Material	Stress State (1)	Defect Type (2)	Defect Location (3)	STRAIN GAGE Location and Direction (4)		Remarks
					#1	#2	
1	4130	Biaxial	None	—	AC	—	
2	4130	Biaxial	4c	A	XC	AC	
3	4130	Biaxial	Thin Wall	—	AC	AC	
4	4130	Biaxial	4b	A	XC	AC	
5	4130	Biaxial	4b	B	XC	AC	
6	4130	Biaxial	None	—	—	AC	
7	4130	Biaxial	None	—	BA	BC	
8	4130	Biaxial	Thin Wall	—	BC	BA	
9	4130	Biaxial	4e	A	XC	AC	
10	4130	Biaxial	4c	A&B	XC(B)	XC(A)	Two Defects
11	4130	Biaxial	4d	A	AC	XA	
12	4130	Circum.	None	—	AC	AC	
13	4130	Circum.	None	—	AC	AC	
A	4130	Biaxial	None	—	—	—	Surface Coating
B	4130	Biaxial	None	—	—	—	Surface Coating
C	4130	Biaxial	None	—	—	—	Surface Coating
1A	6061	Biaxial	None	—	AC	AC	
2A	6061	Biaxial	None	—	AC	AC	

Notes: (1) Circum. = Circumferential stress only.
(2) See Figure 4.
(3) Location, A = Center of vessel
B = Junction of cylinder and hemi-head
(4) AC = Center of vessel, circumferential stress
BA = Discontinuity region, axial stress
X = Adjacent to defect, e.g., XC = Location, circumferential stress, etc.

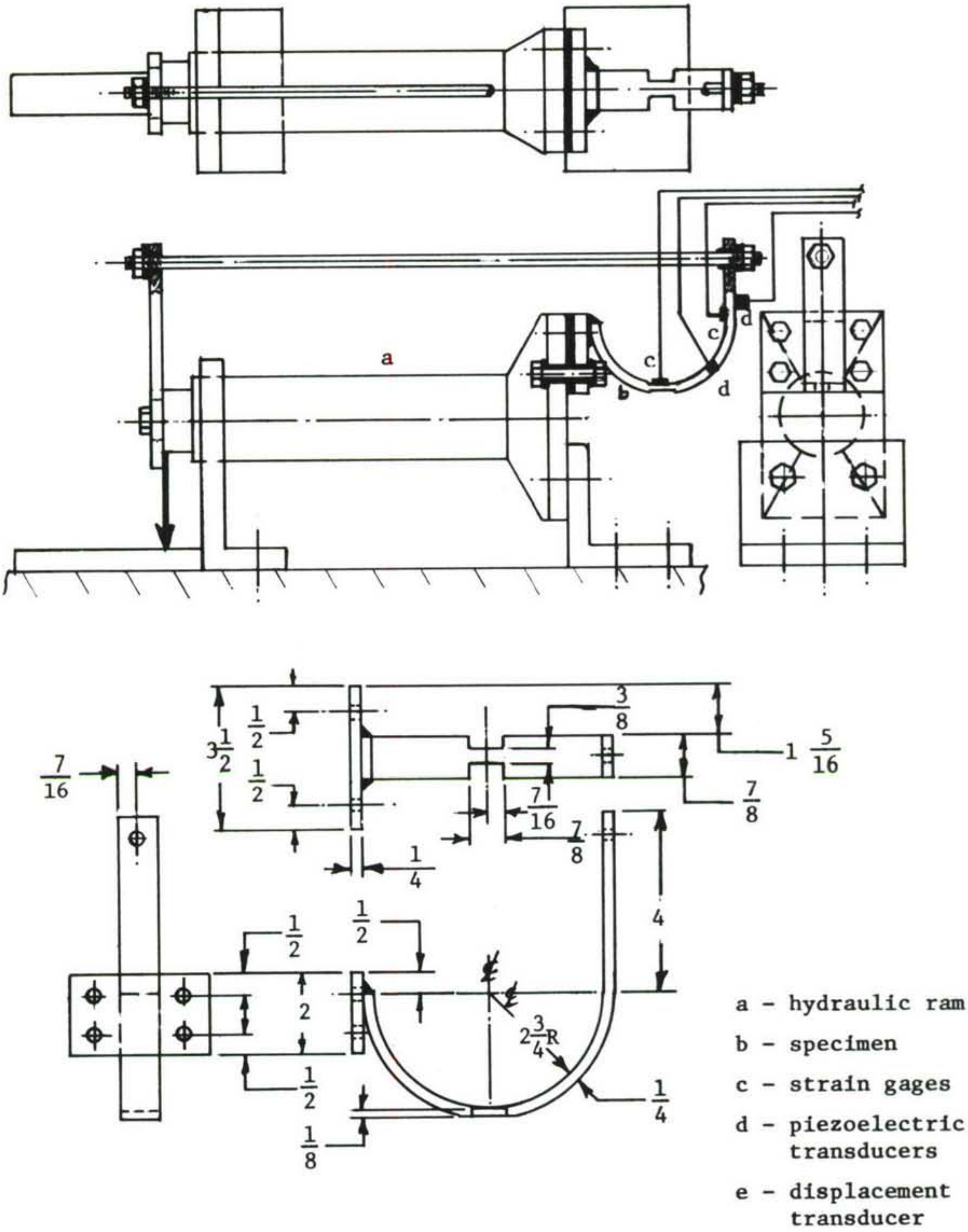
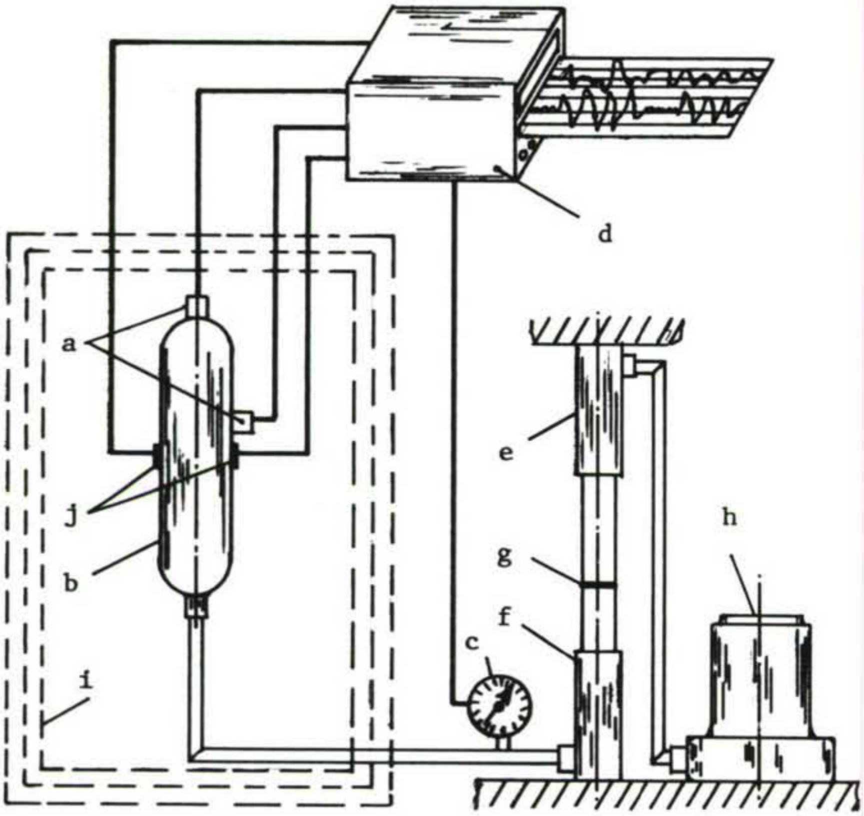


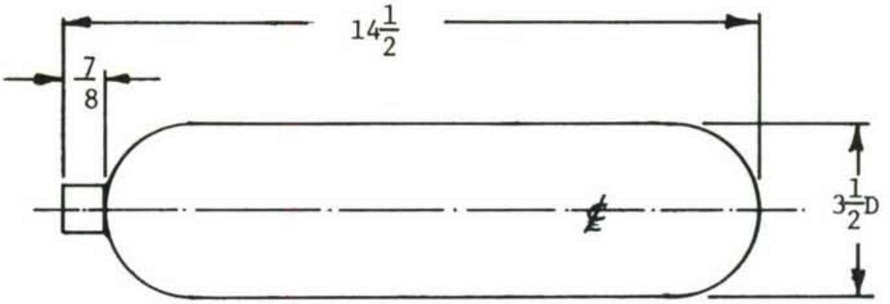
Figure 1. Split-Ring Test Arrangement and Test Specimen Geometry



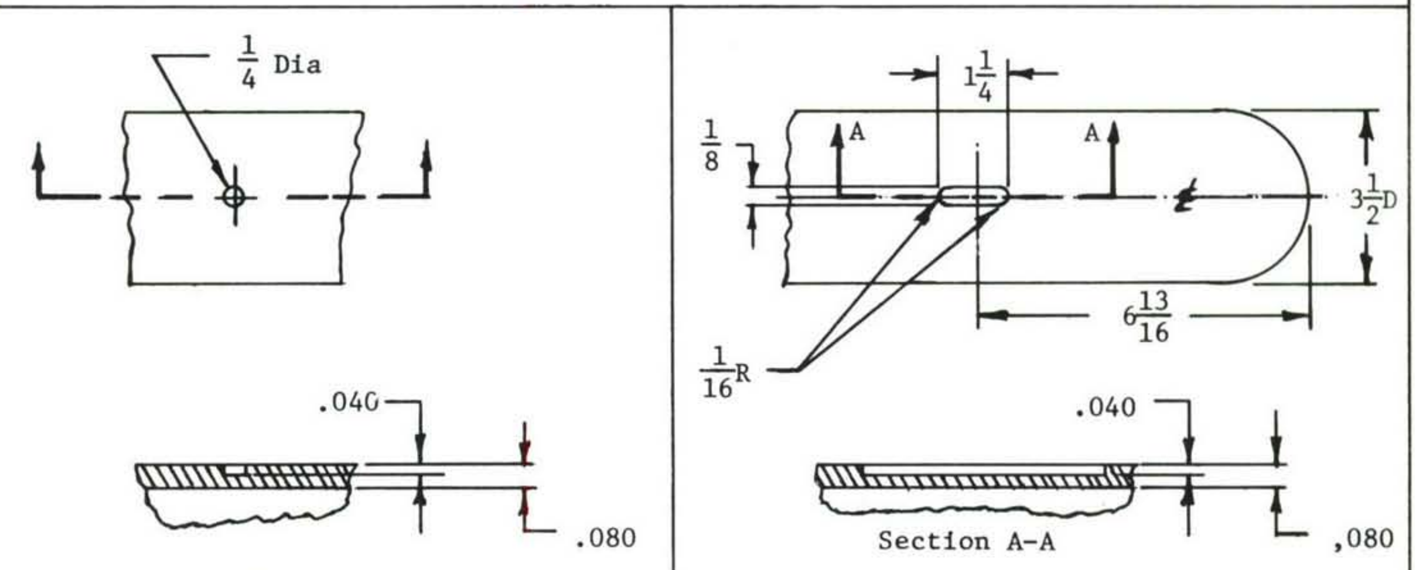
a - piezoelectric transducers
b - test specimen
c - pressure transducer
d - chart recorder
e - hydraulic ram
f - hydraulic ram
g - acoustic barrier
h - hydraulic pump
i - test enclosure
j - strain gages

Figure 2. Pressure Vessel Test Apparatus

Figure 3. Photograph of Test Vessel in Enclosure Showing Piezoelectric Transducers Attached

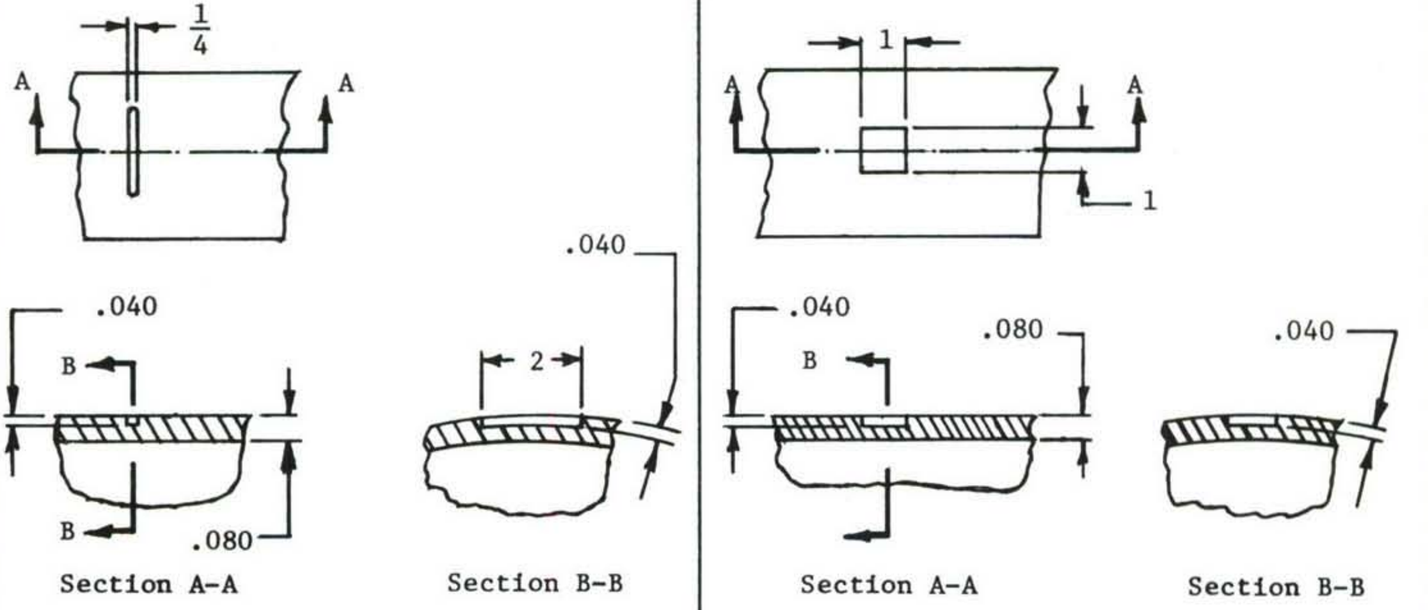


a. Pressure Vessel Dimensions



b. Spot-Type Defect

c. Longitudinal-Type Defect



d. Circumferential-Type Defect

e. 1" x 1" Type Defect

Figure 4. Steel Pressure Vessel Geometry and Types of Defects

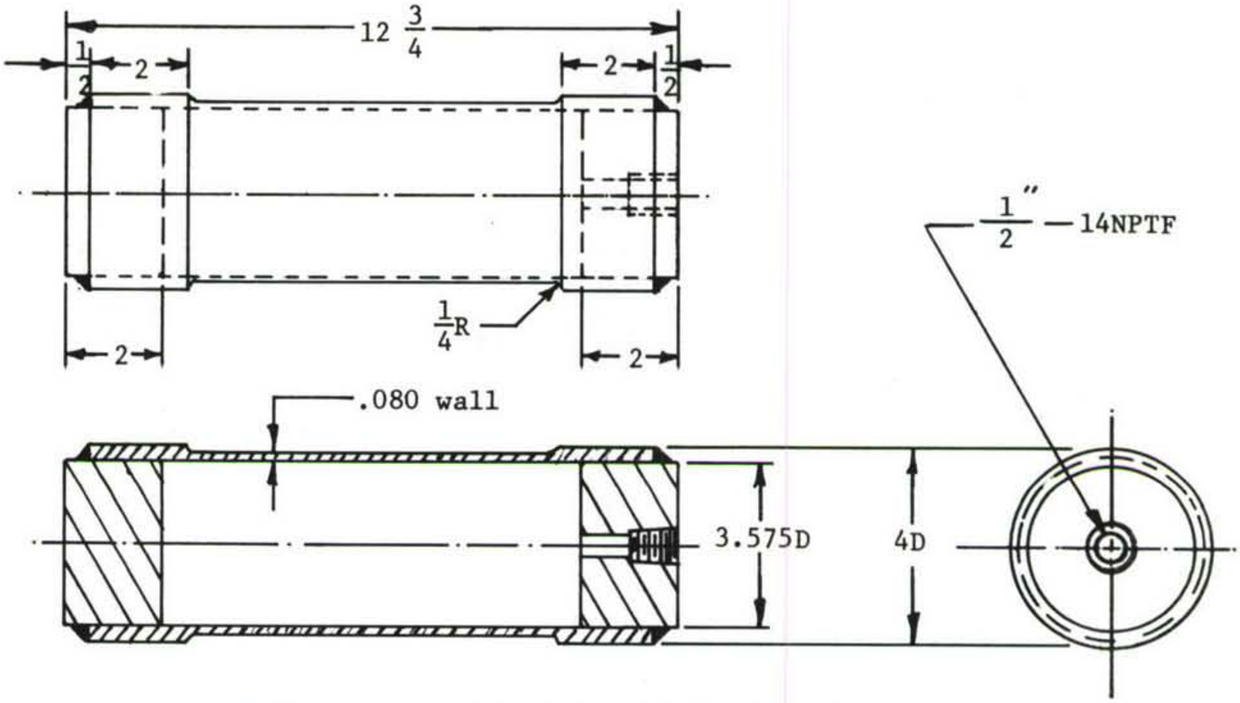


Figure 5. Construction of 6061 Aluminum Specimens

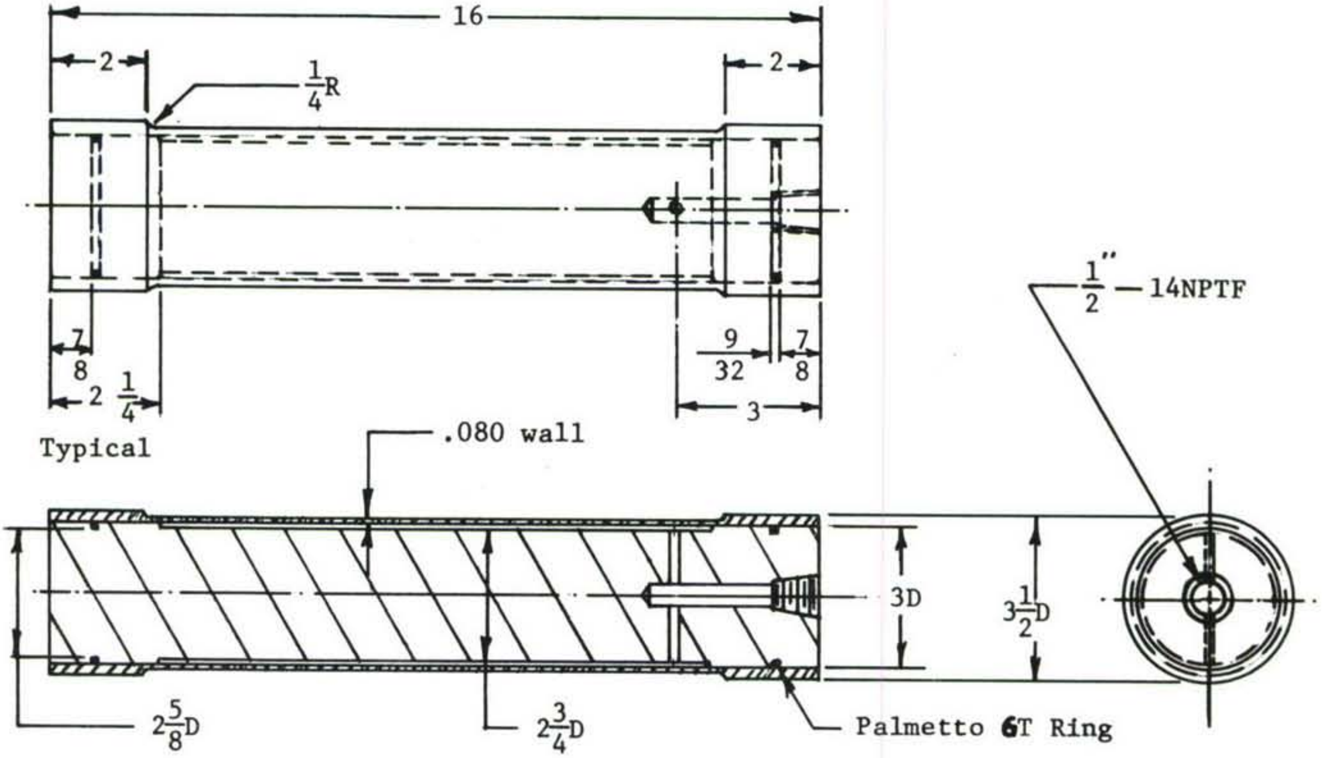


Figure 6. O-Ring Type Steel Pressure Vessel Geometry

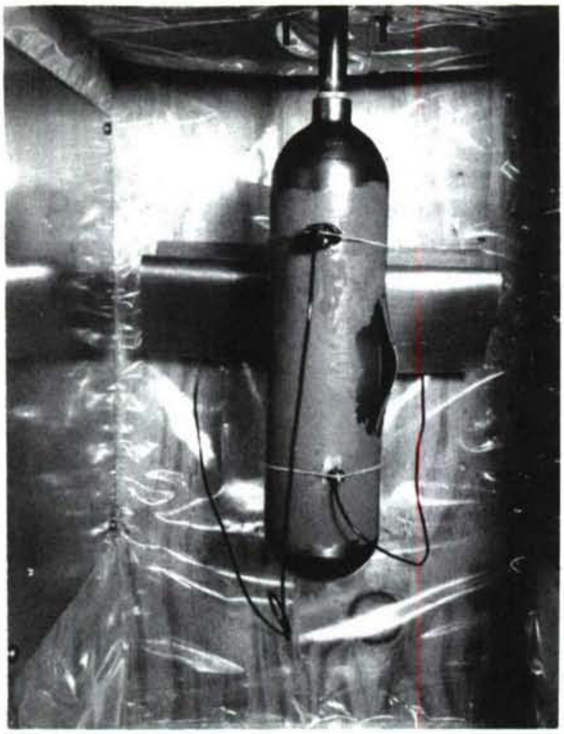
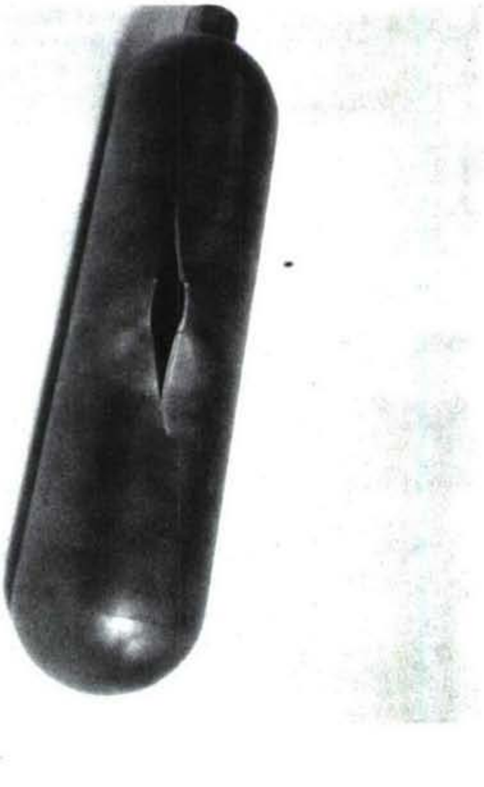


Figure 7. Close-up of Cylinder C in Test Enclosure Showing Two Piezoelectric Transducers Attached

Figure 8. Cylinder No. 2 Showing Fracture at Longitudinal Defect



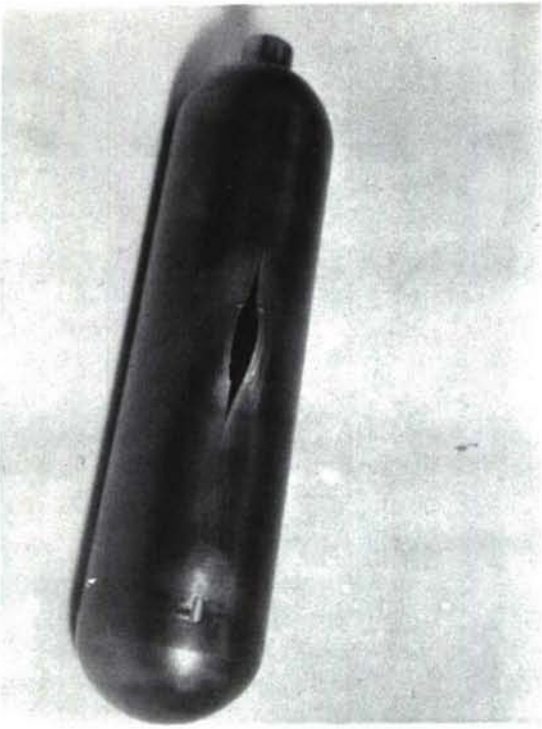


Figure 9. Cylinder No. 10 Showing Two Longitudinal Defects, Fracture at Center Defect

Figure 10. Cylinder No. 9 Fracture

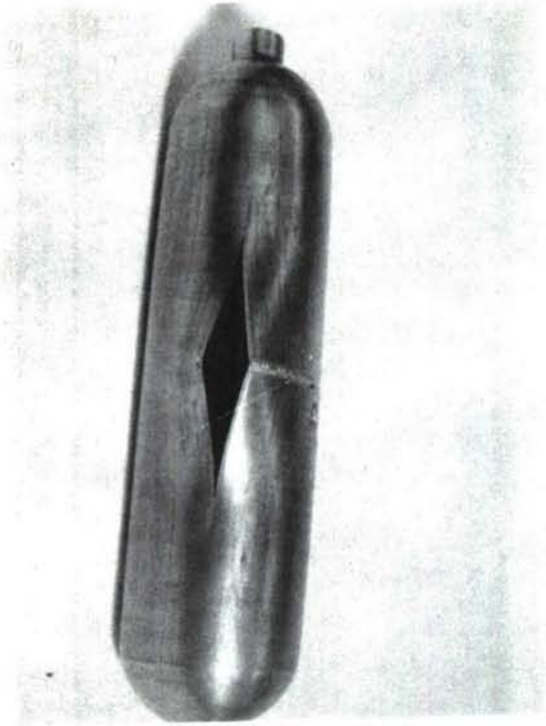


Figure 11. Cylinder No. 11 Showing Fracture at End of Circumferential Defect

Figure 12. Cylinder No. 12 Fracture

Figure 13. Cylinder No. 2, Aluminum Alloy 6061

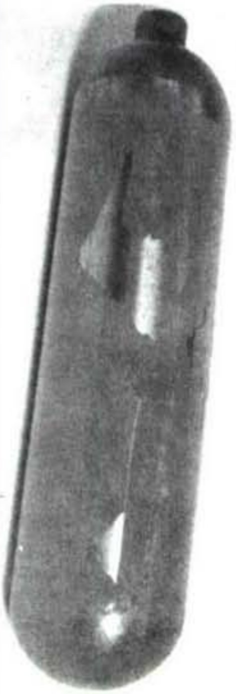


Figure 14. Cylinder A, Stycast Surface Coating

APPENDIX A

OSCILLOGRAPH CHART RECORDINGS

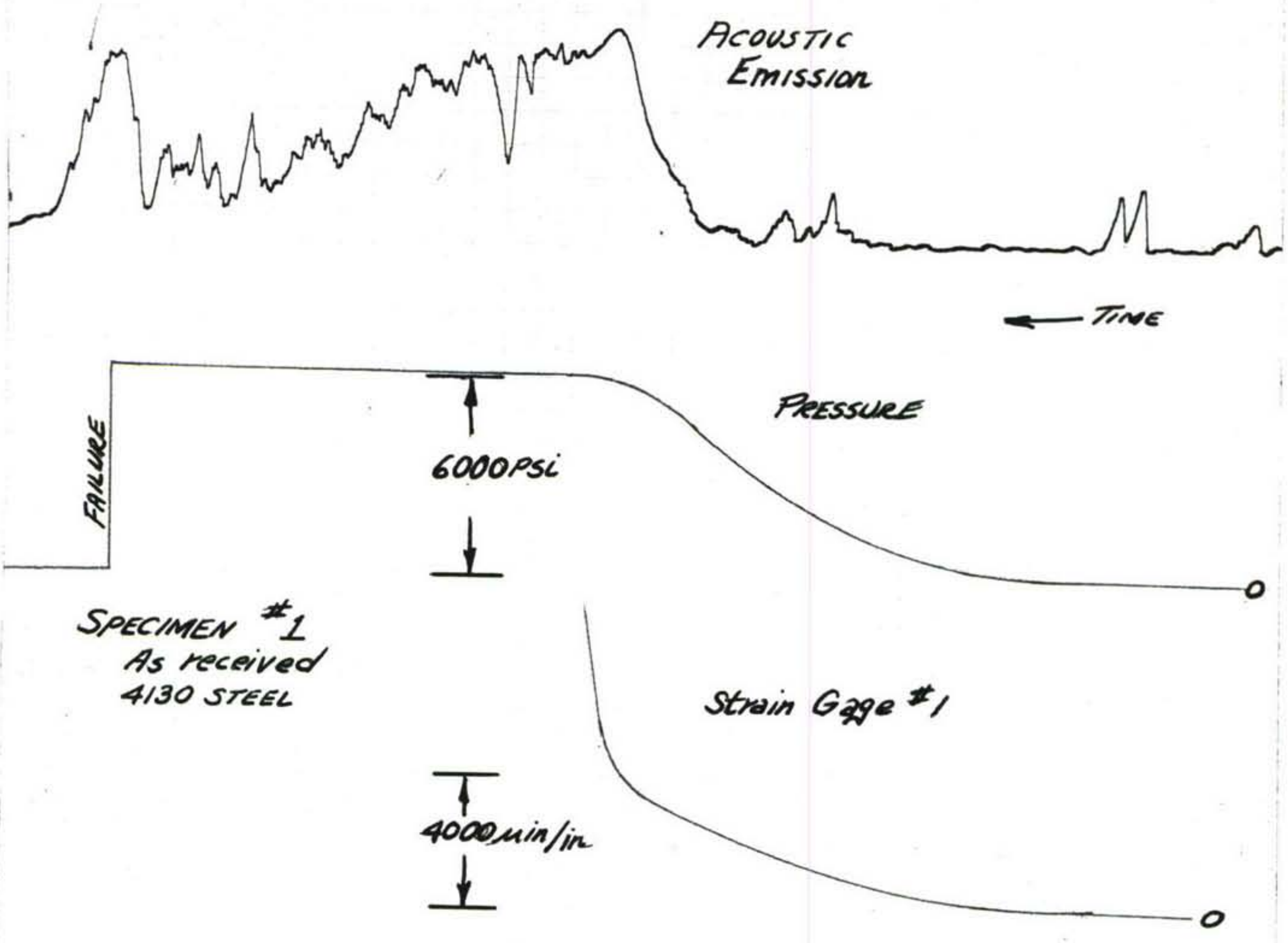


Chart 1. As-Received Cylinder No. 1, 4130 Steel

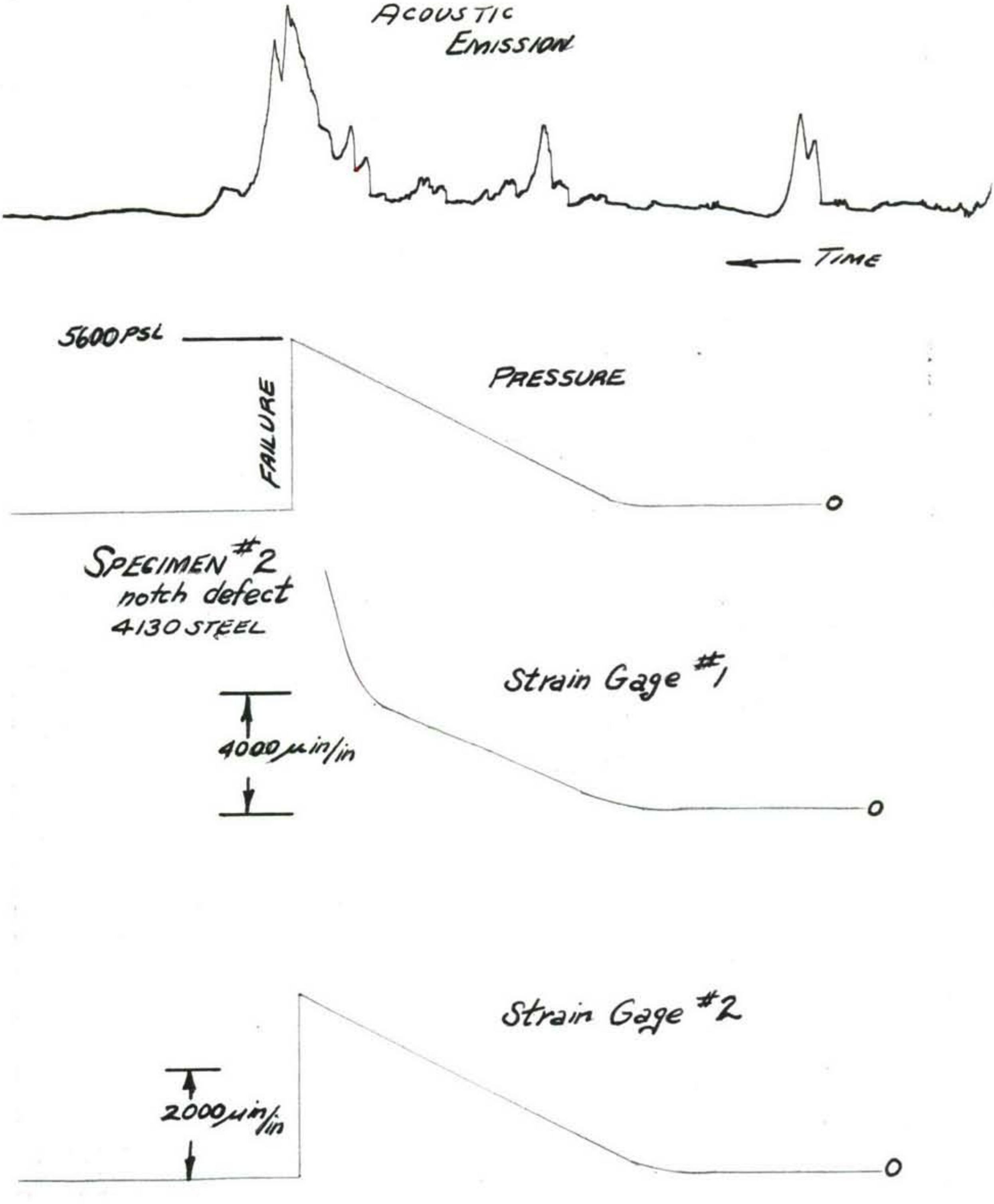


Chart 2. Cylinder No. 2, 4130 Steel, Notch Defect

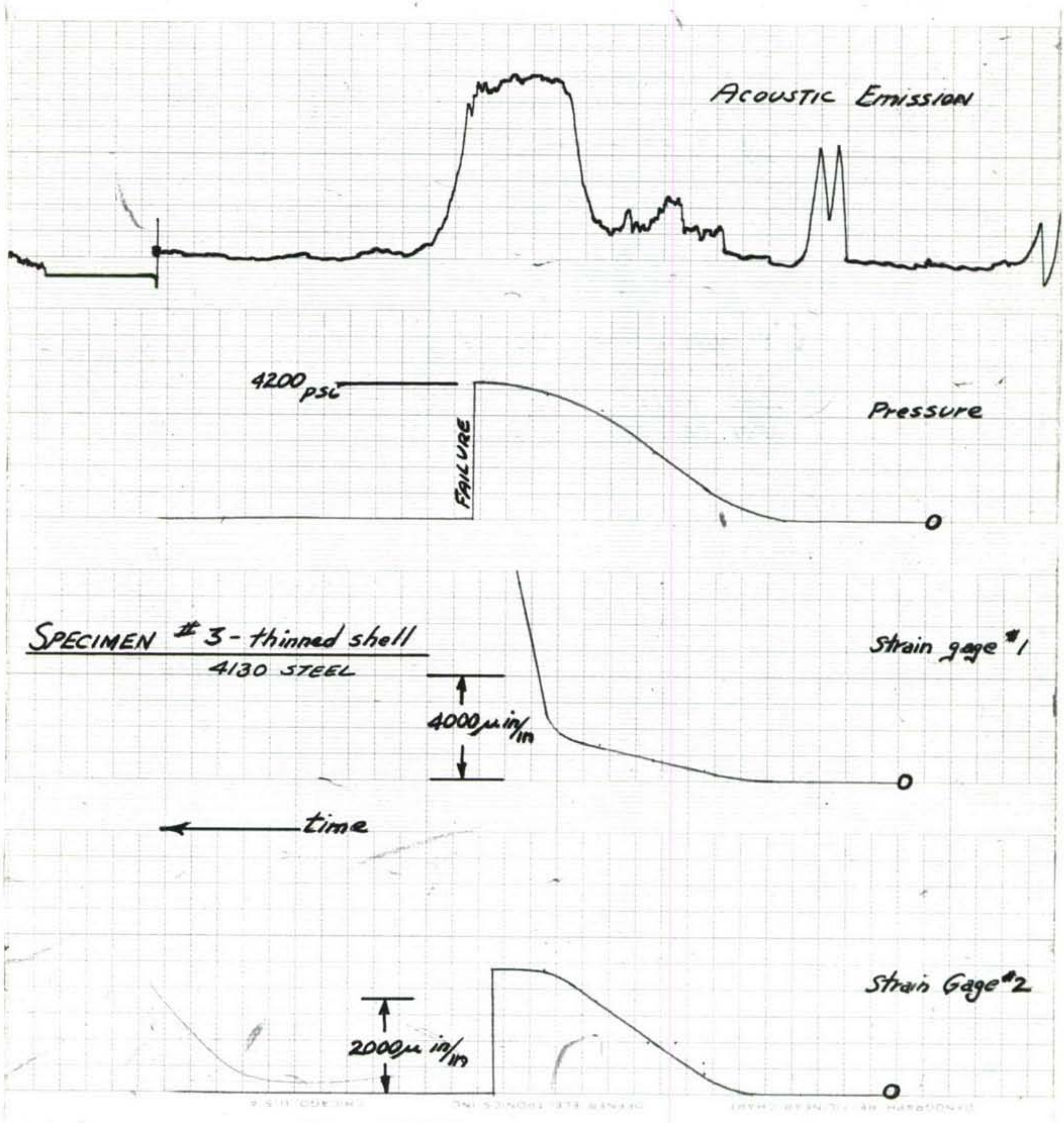


Chart 3. Cylinder No. 3, 4130 Steel, Thinned Wall

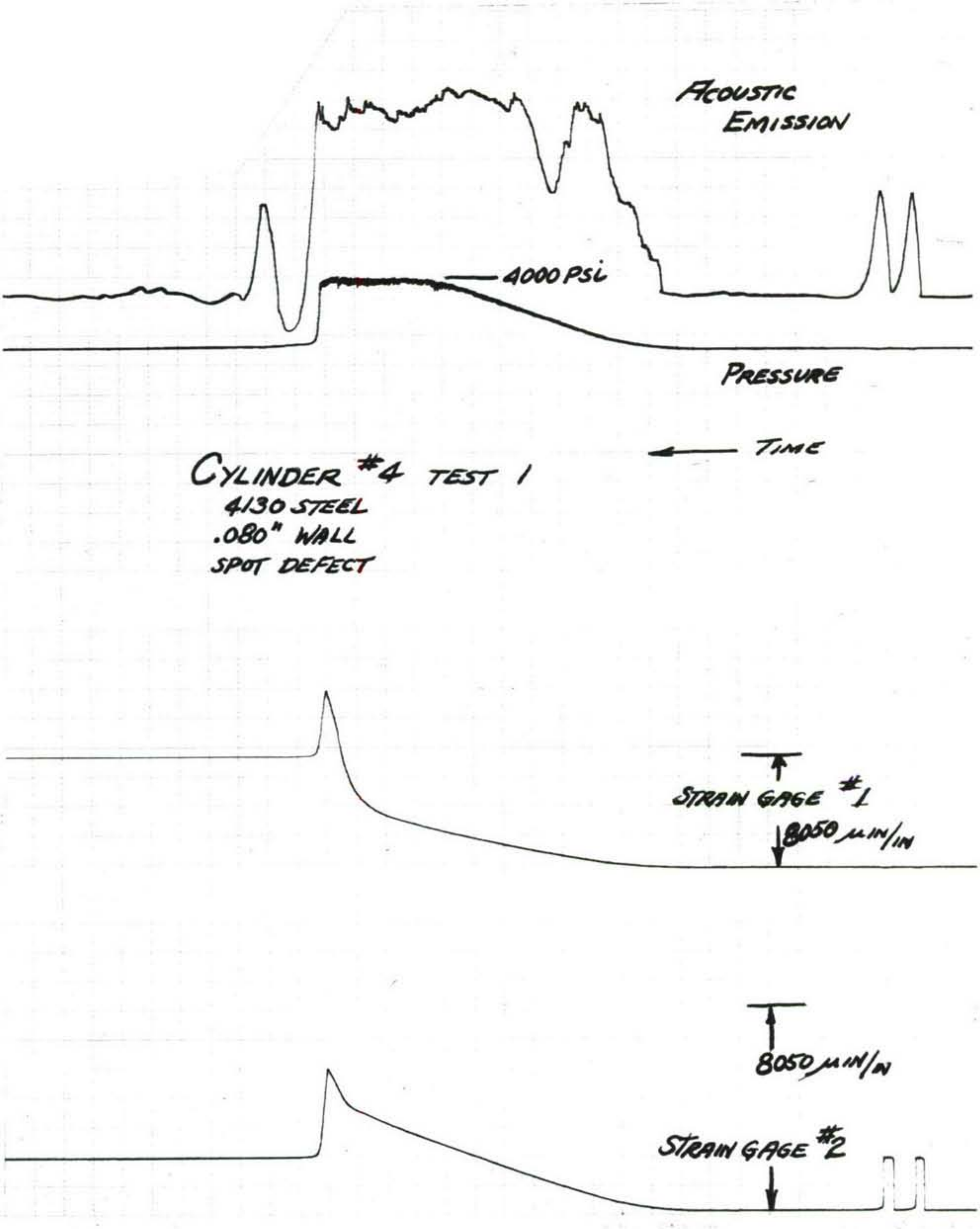


Chart 4. Test No. 1, Cylinder No. 4, 4130 Steel, Spot Defect

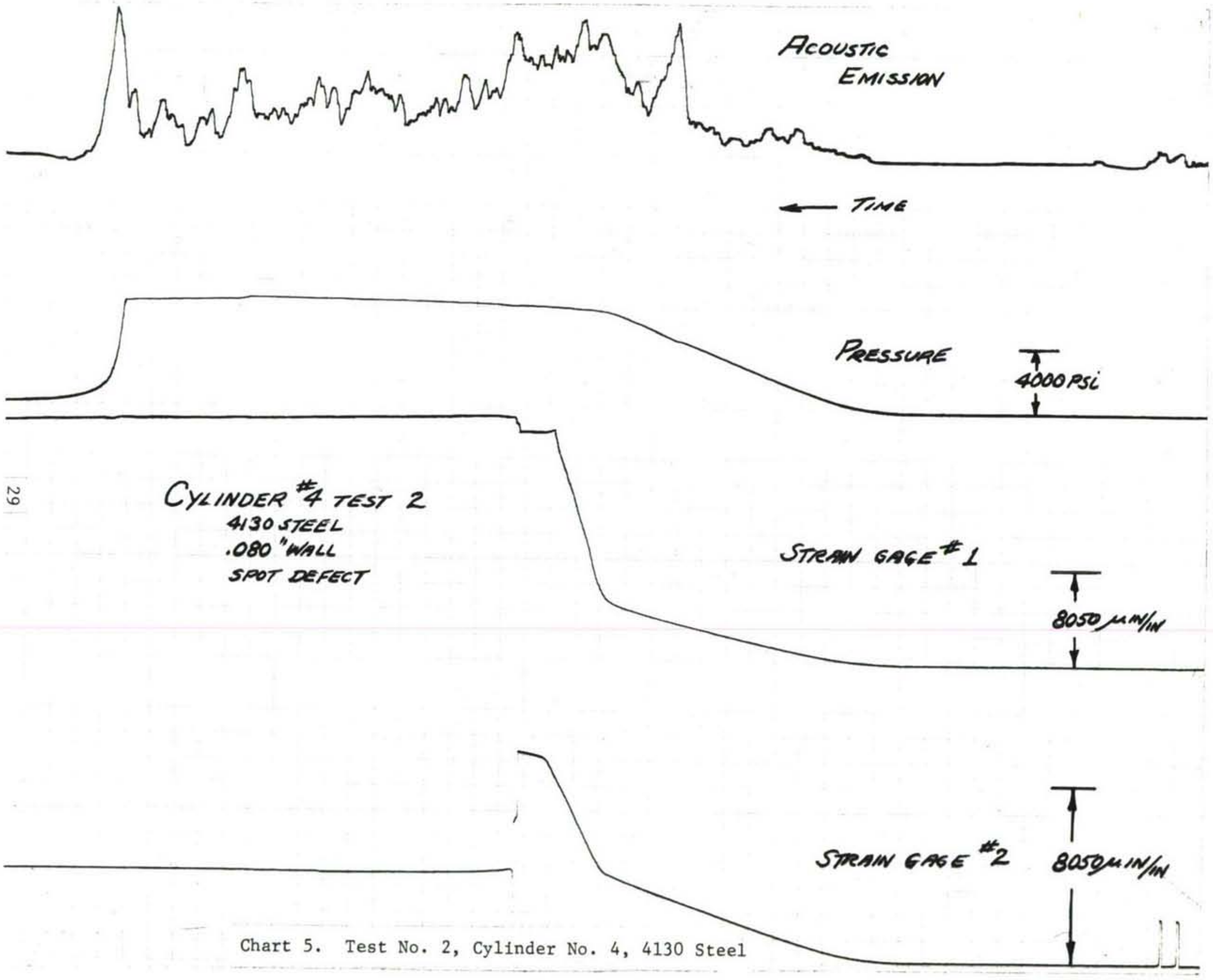


Chart 5. Test No. 2, Cylinder No. 4, 4130 Steel

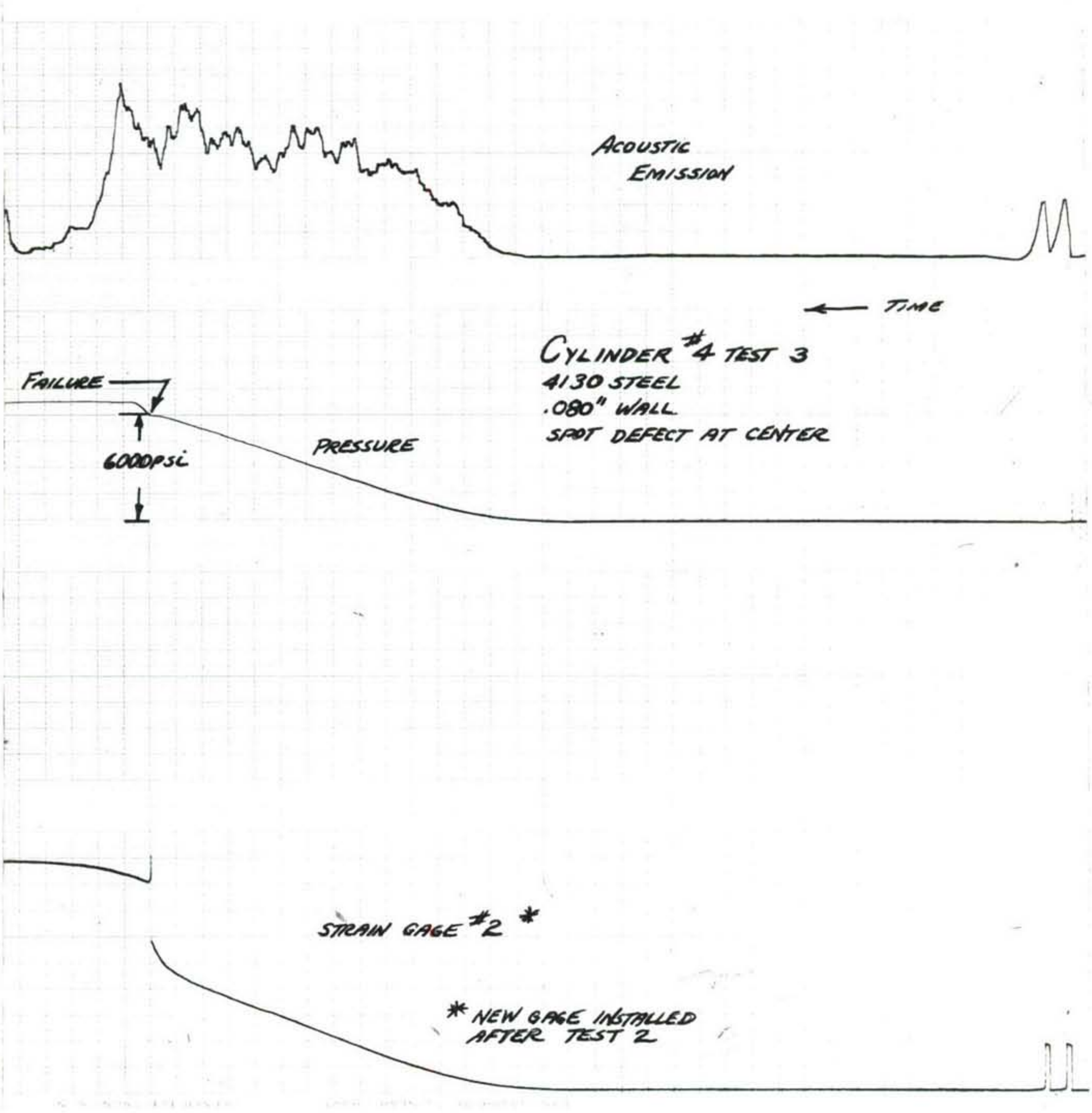


Chart 6. Test No. 3, Cylinder No. 4, 4130 Steel

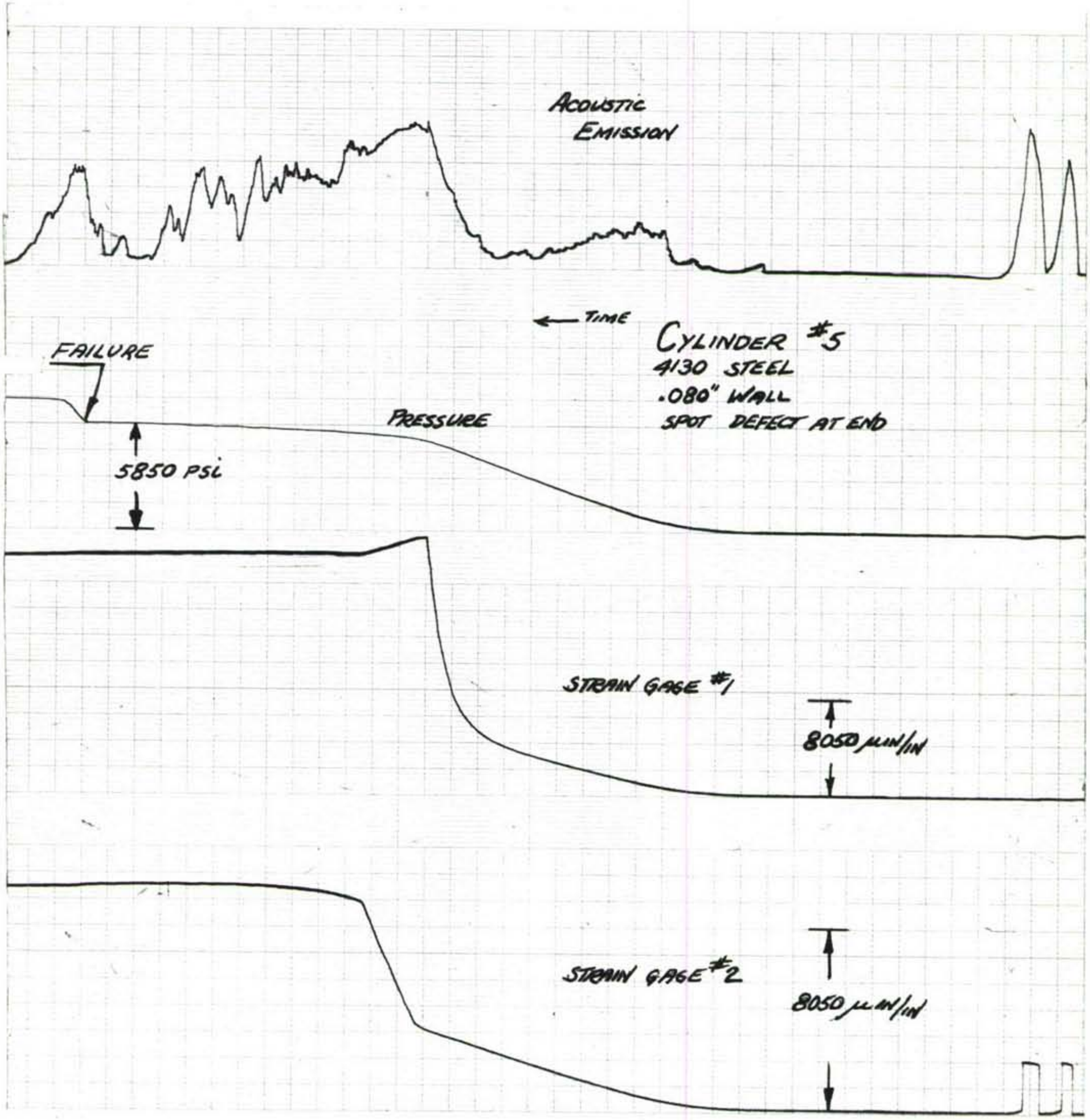


Chart 7. Cylinder No. 5, 4130 Steel, Spot Defect

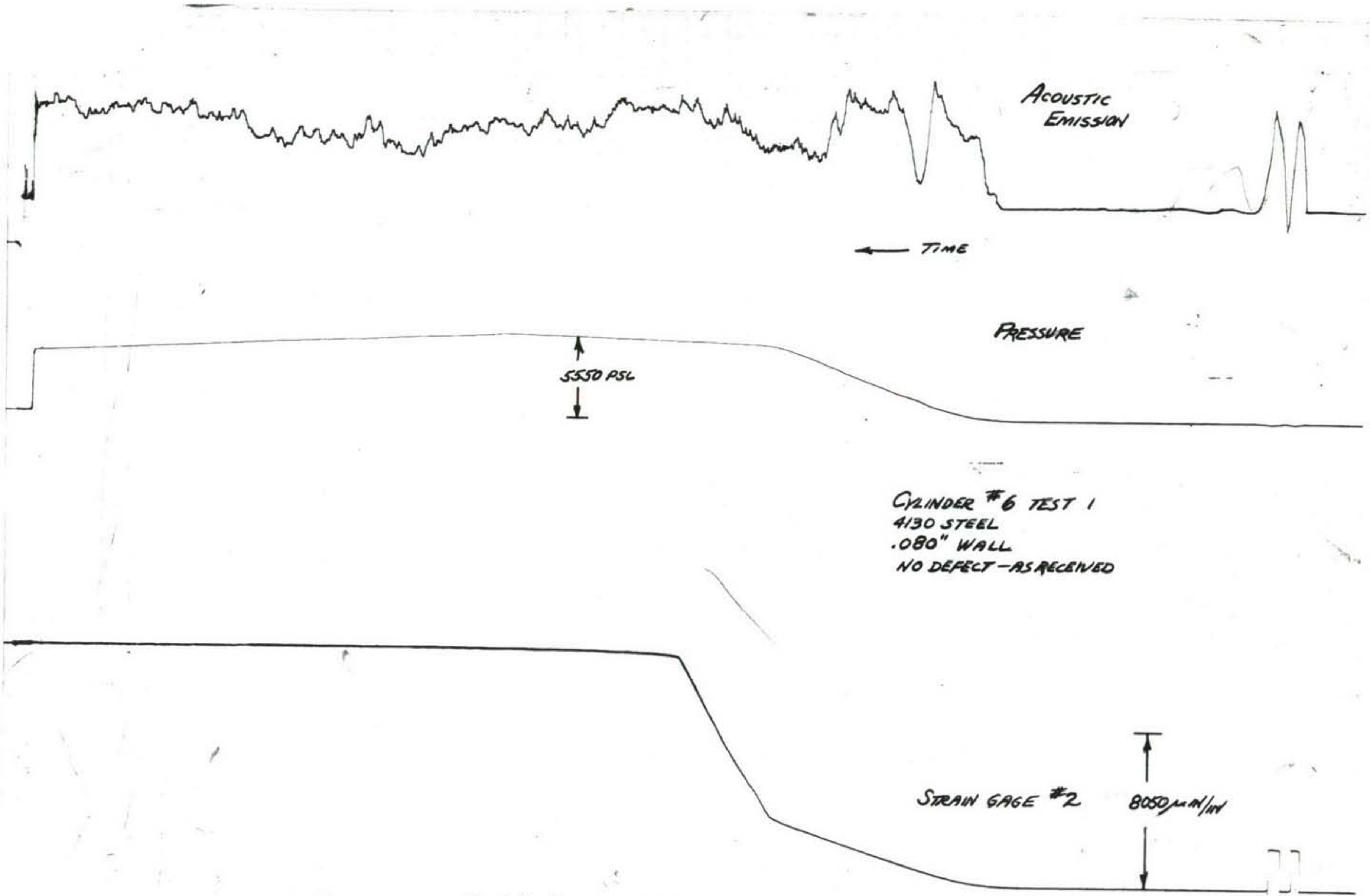


Chart 8. Test No. 1, Cylinder No. 6, 4130 Steel

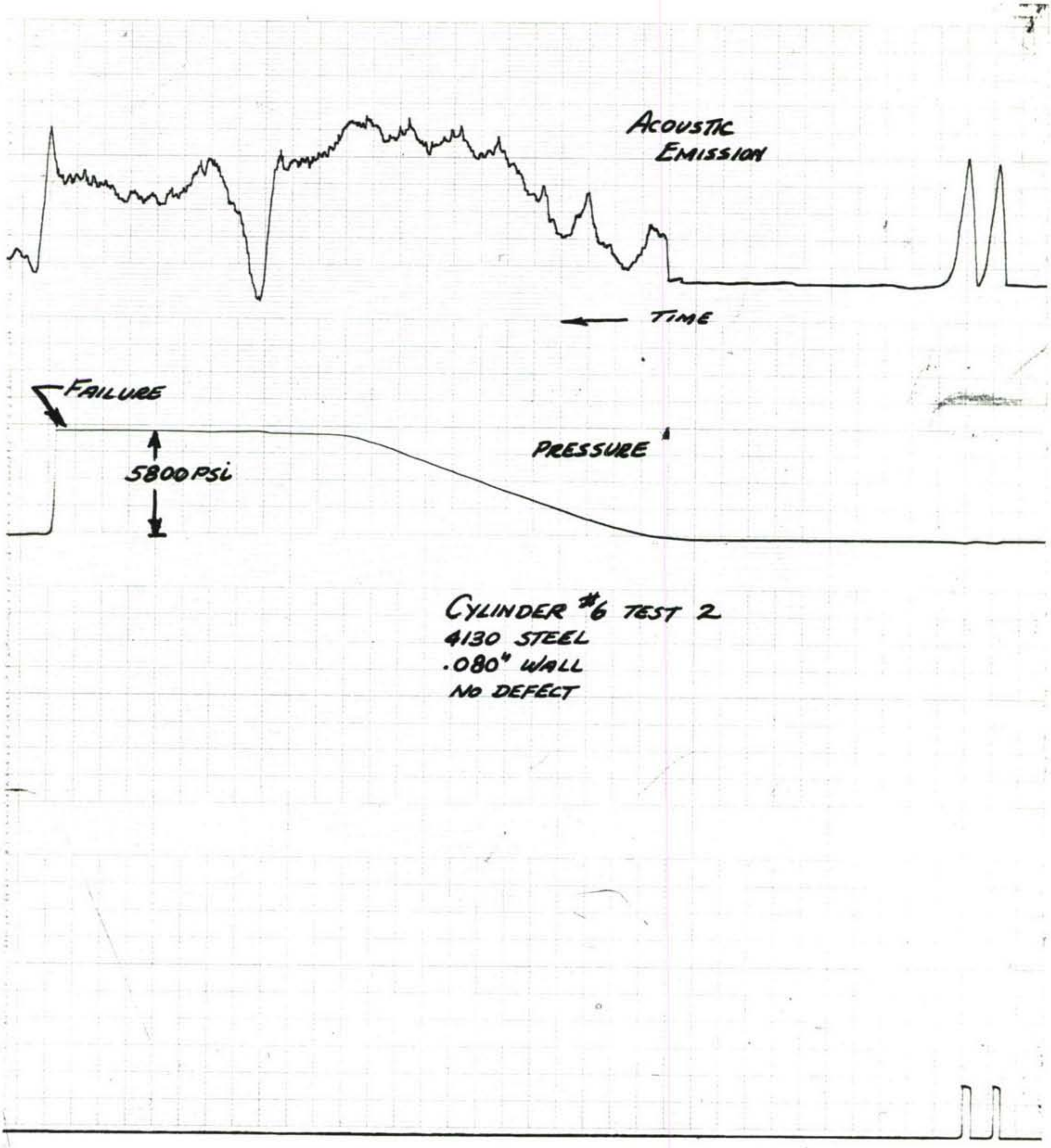


Chart 9. Test No. 2, Cylinder No. 6, 4130 Steel

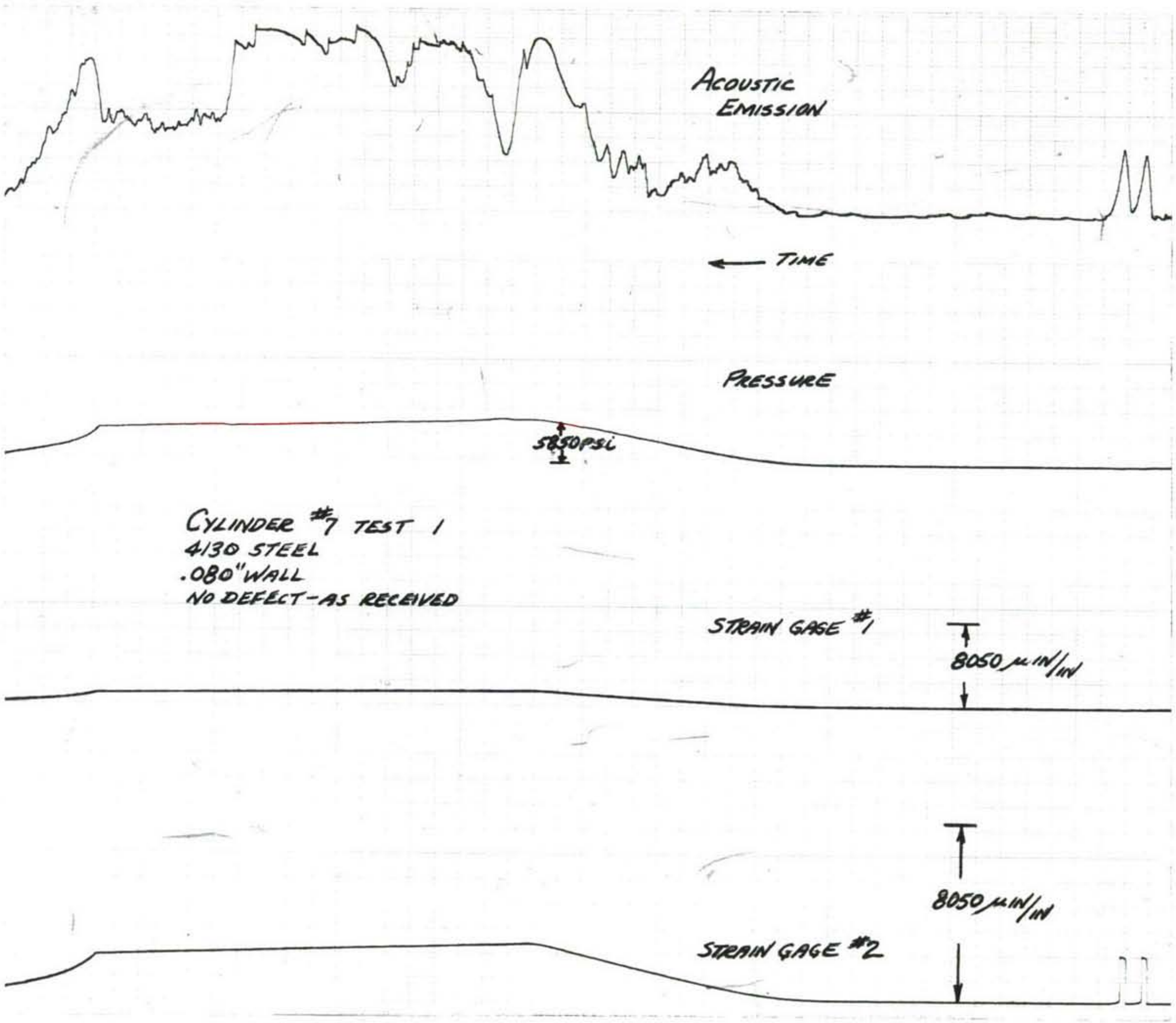


Chart 10. Test No. 1, Cylinder No. 7, 4130 Steel, As-Received

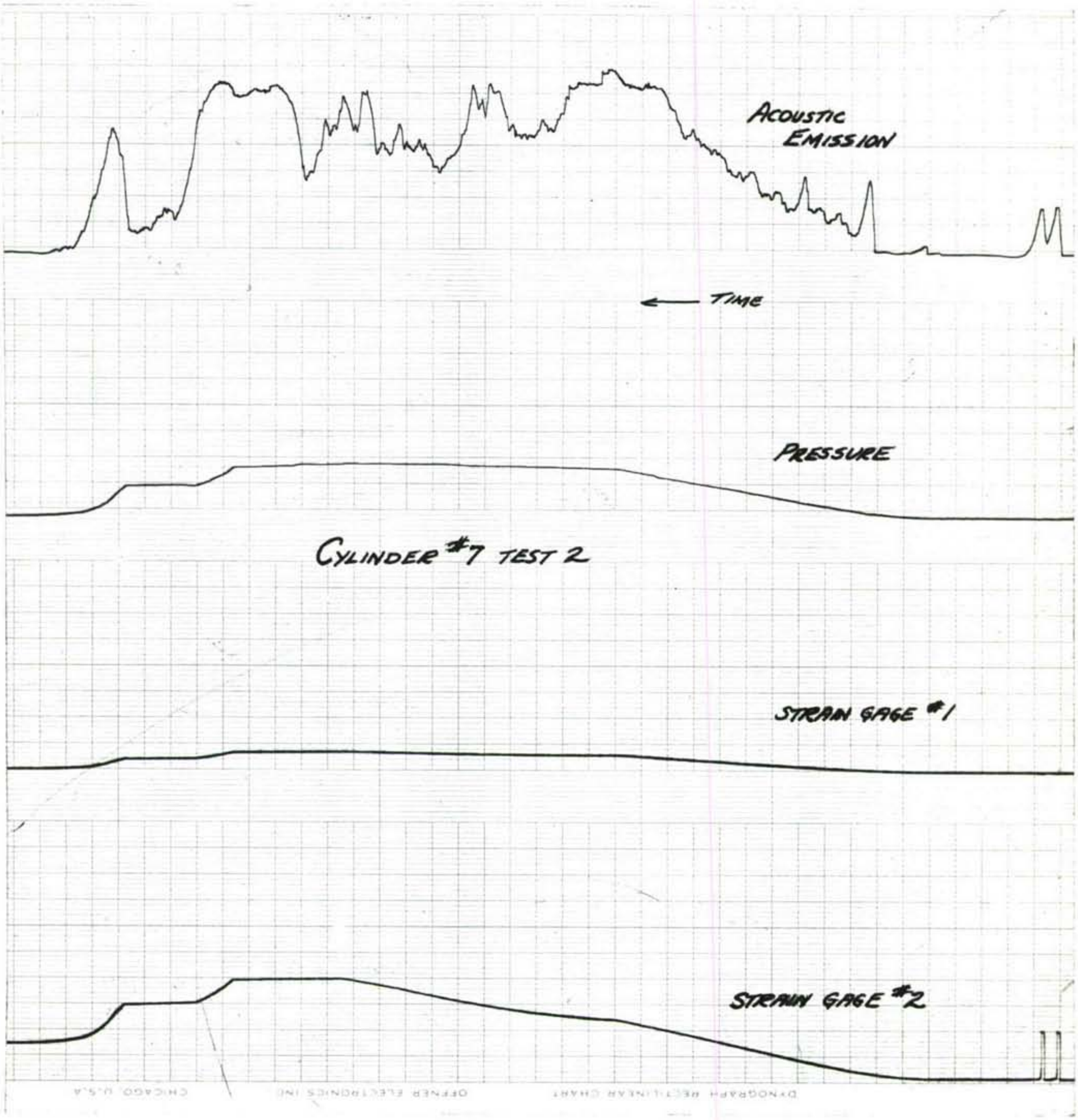


Chart 11. Test No. 2, Cylinder No. 7, 4130 Steel

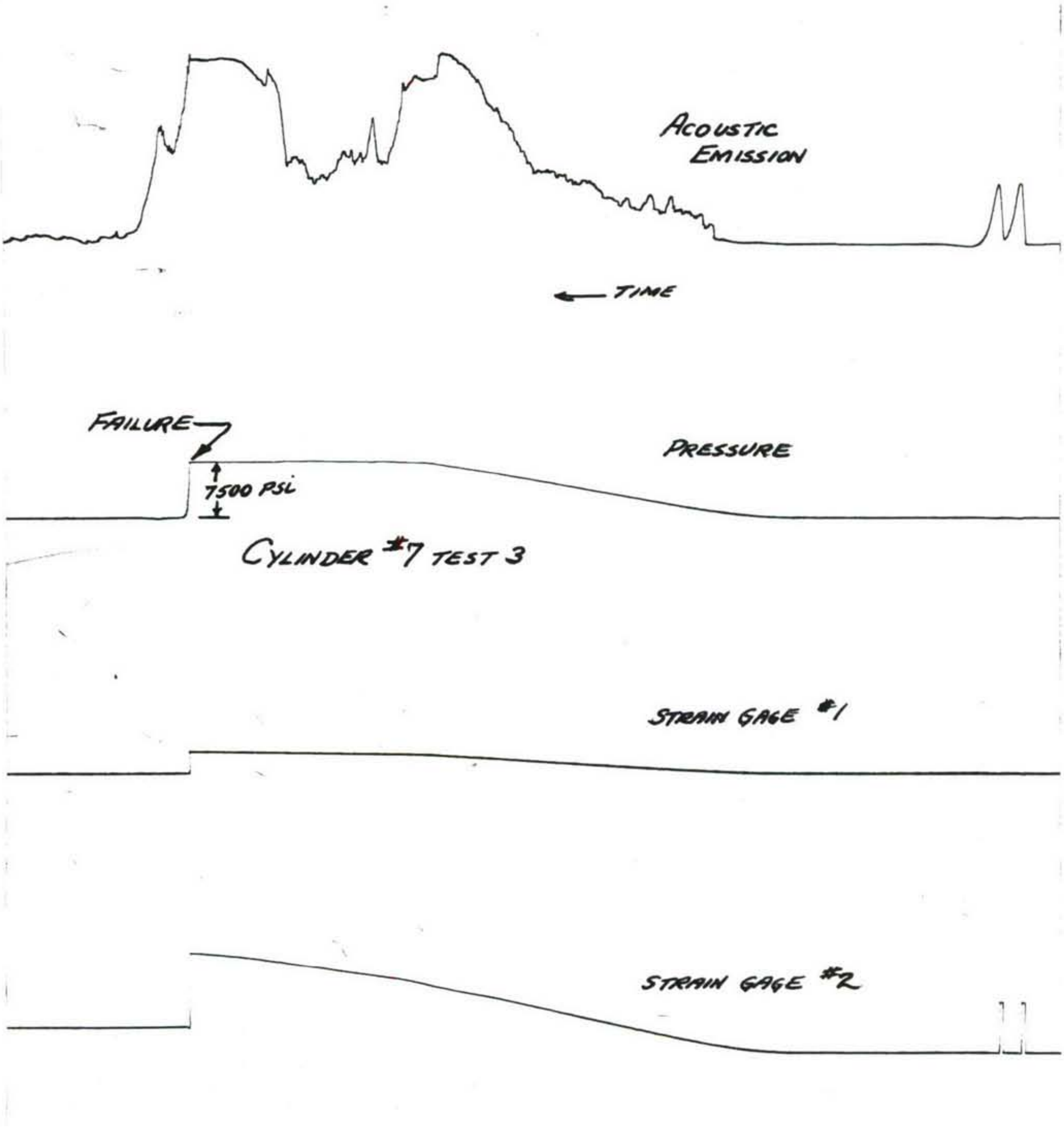


Chart 12. Test No. 3, Cylinder No. 7, 4130 Steel

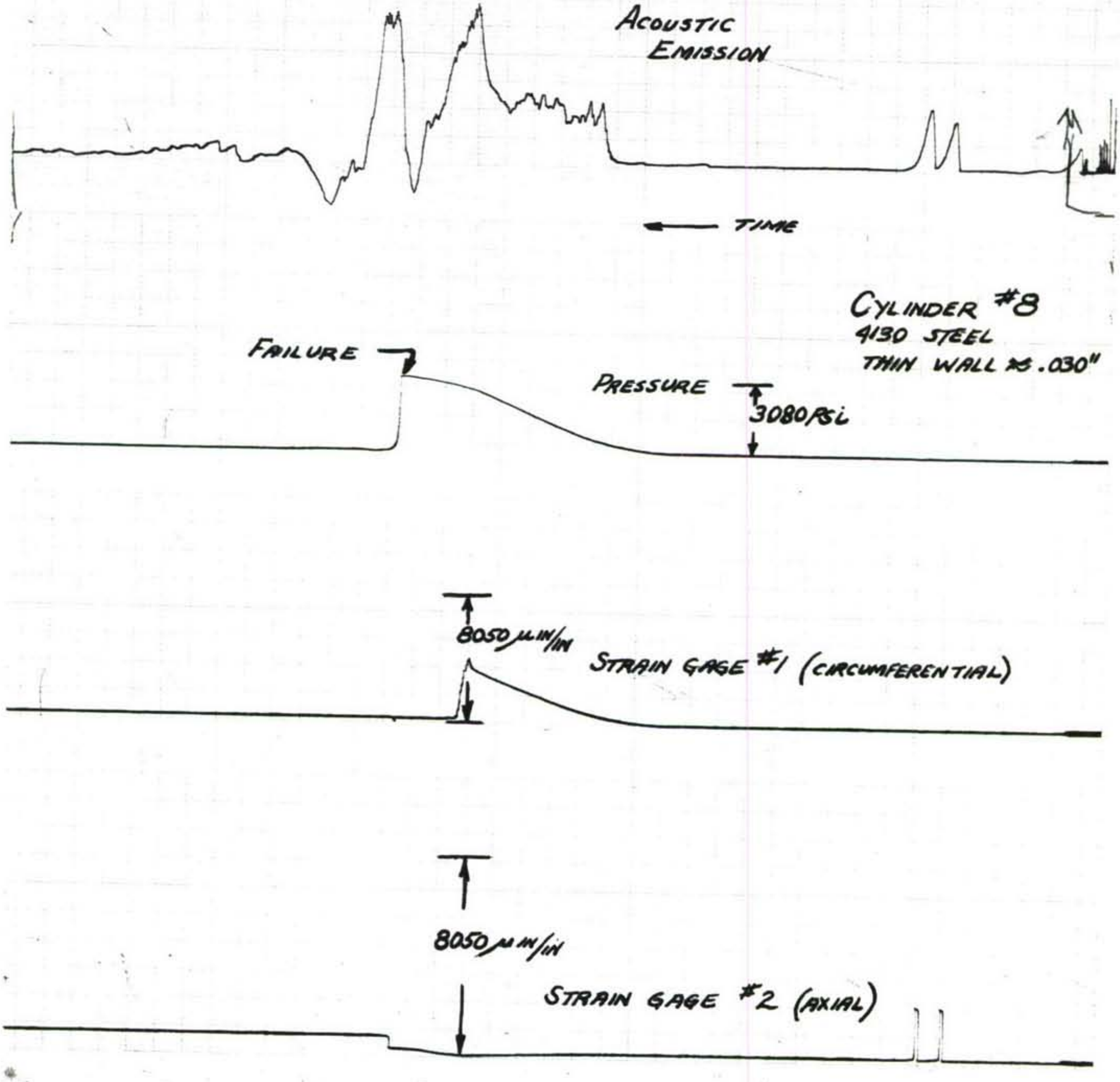


Chart 13. Cylinder No. 8, 4130 Steel, Thinned Wall

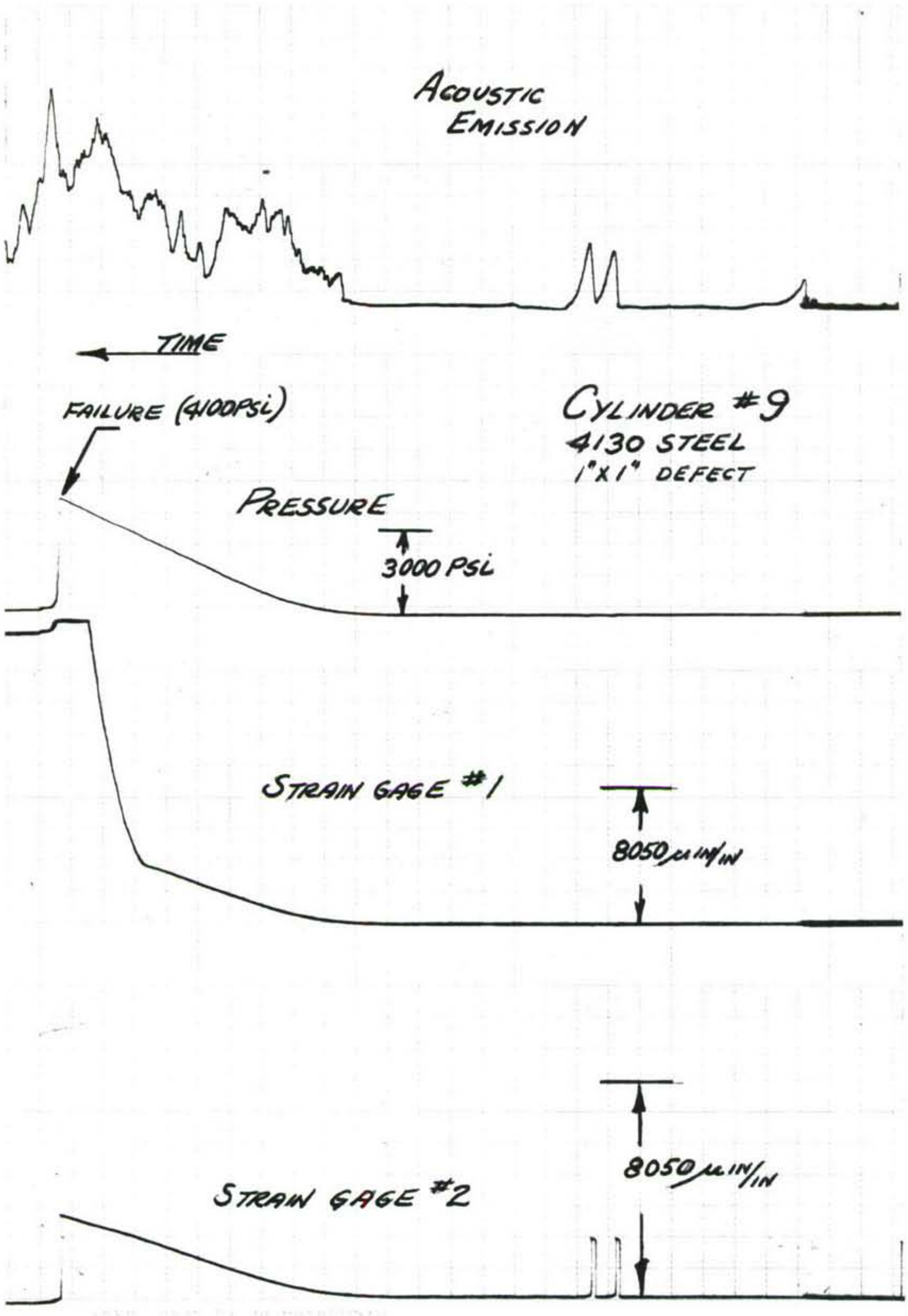


Chart 14. Cylinder No. 9, 4130 Steel, 1" x 1" Defect

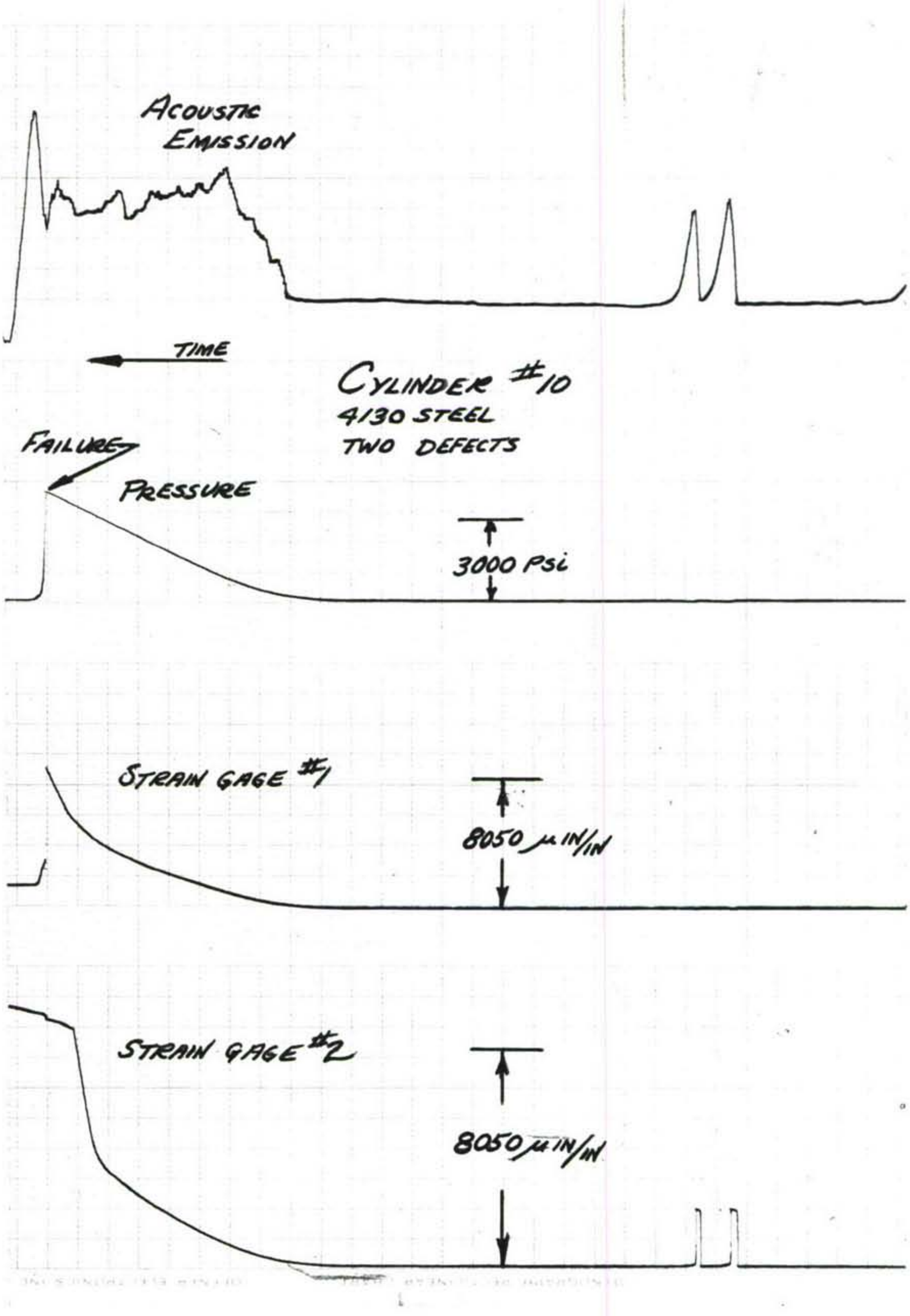


Chart 15. Cylinder No. 10, 4130 Steel, Two Longitudinal Defects

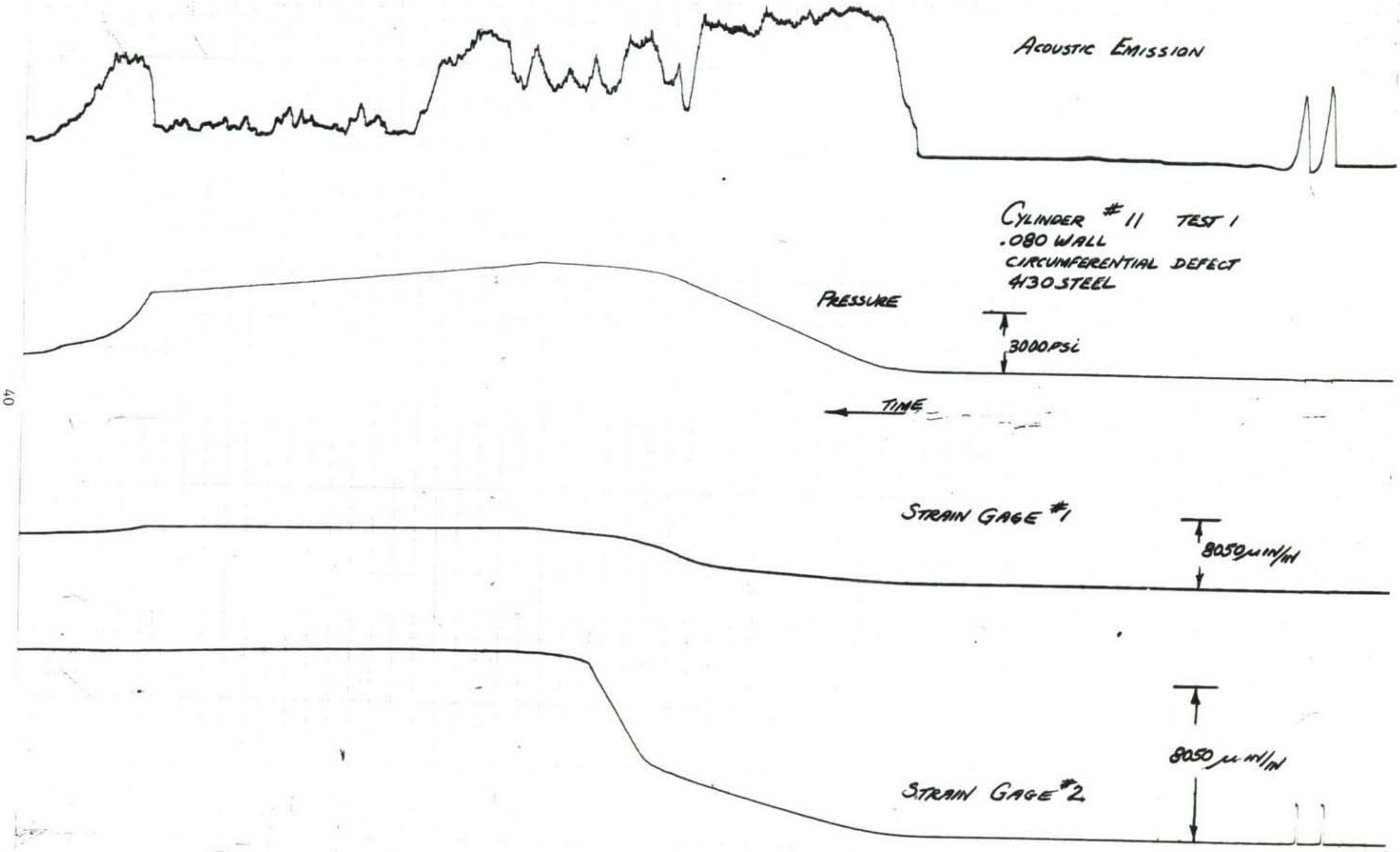


Chart 16. Test No. 1, Cylinder No. 11, 4130 Steel, Circumferential Defect

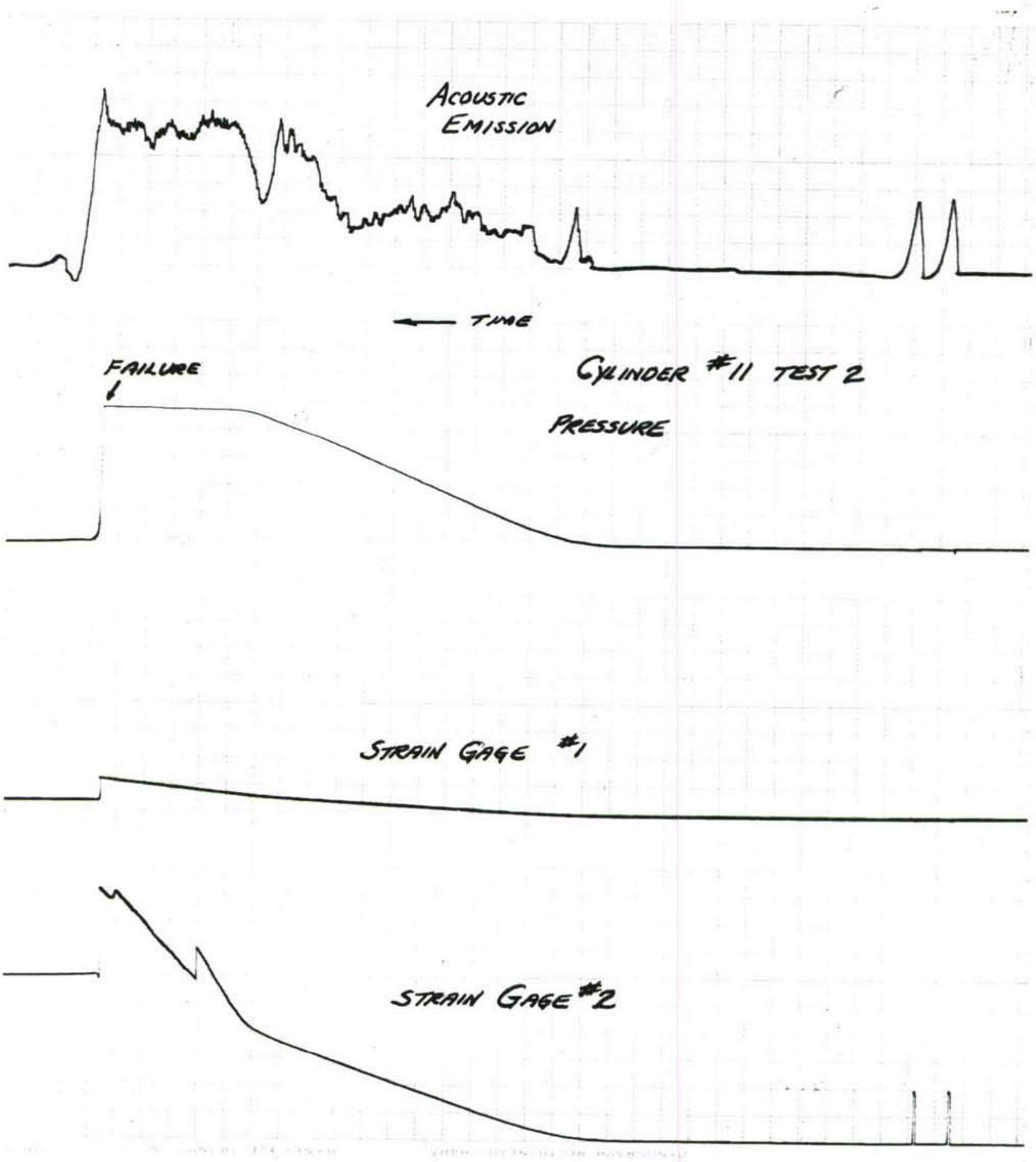


Chart 17. Test No. 2, Cylinder No. 11, 4130 Steel

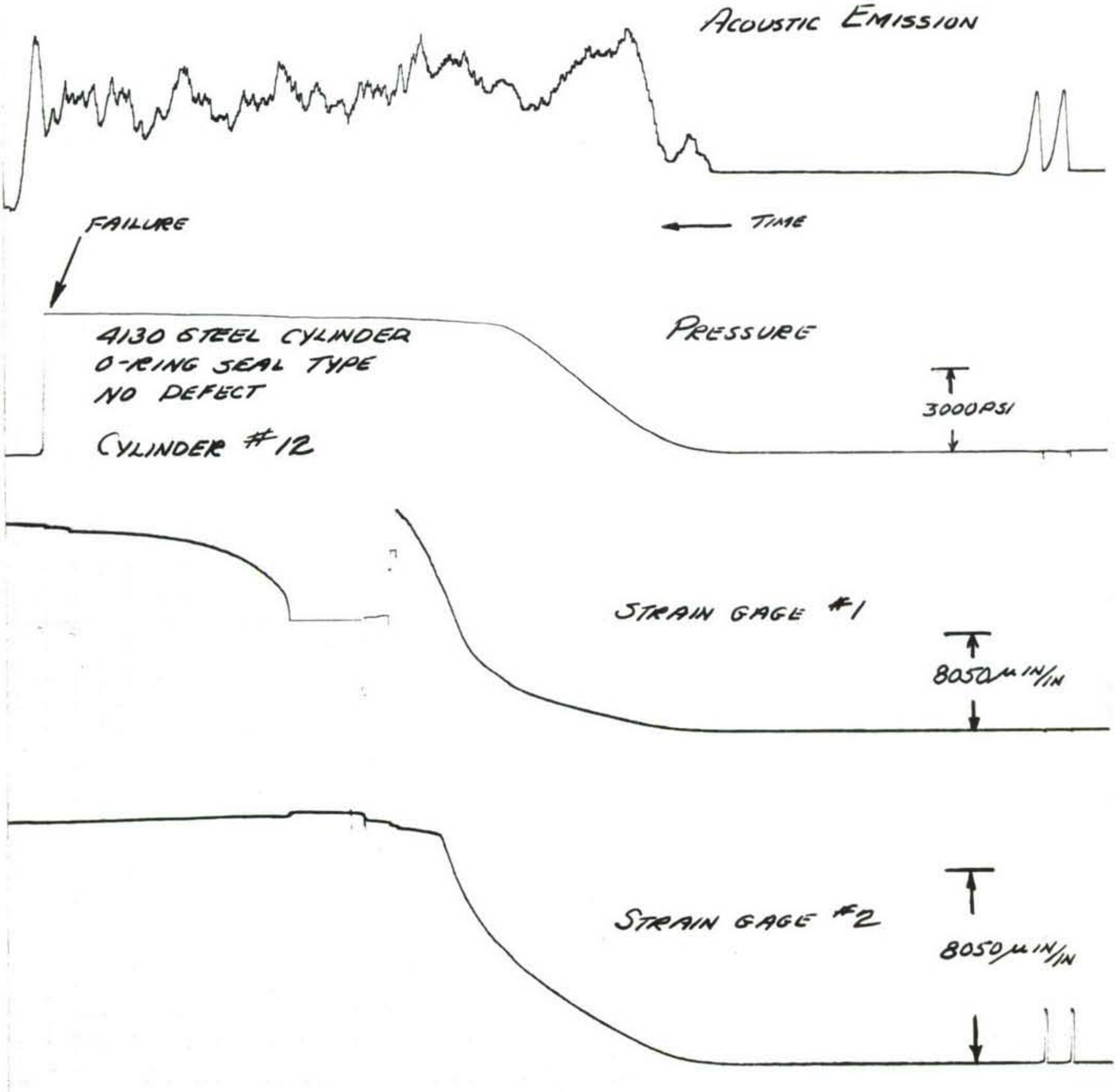


Chart 18. Cylinder No. 12, 4130 Steel, O-Ring Seal, No Defect

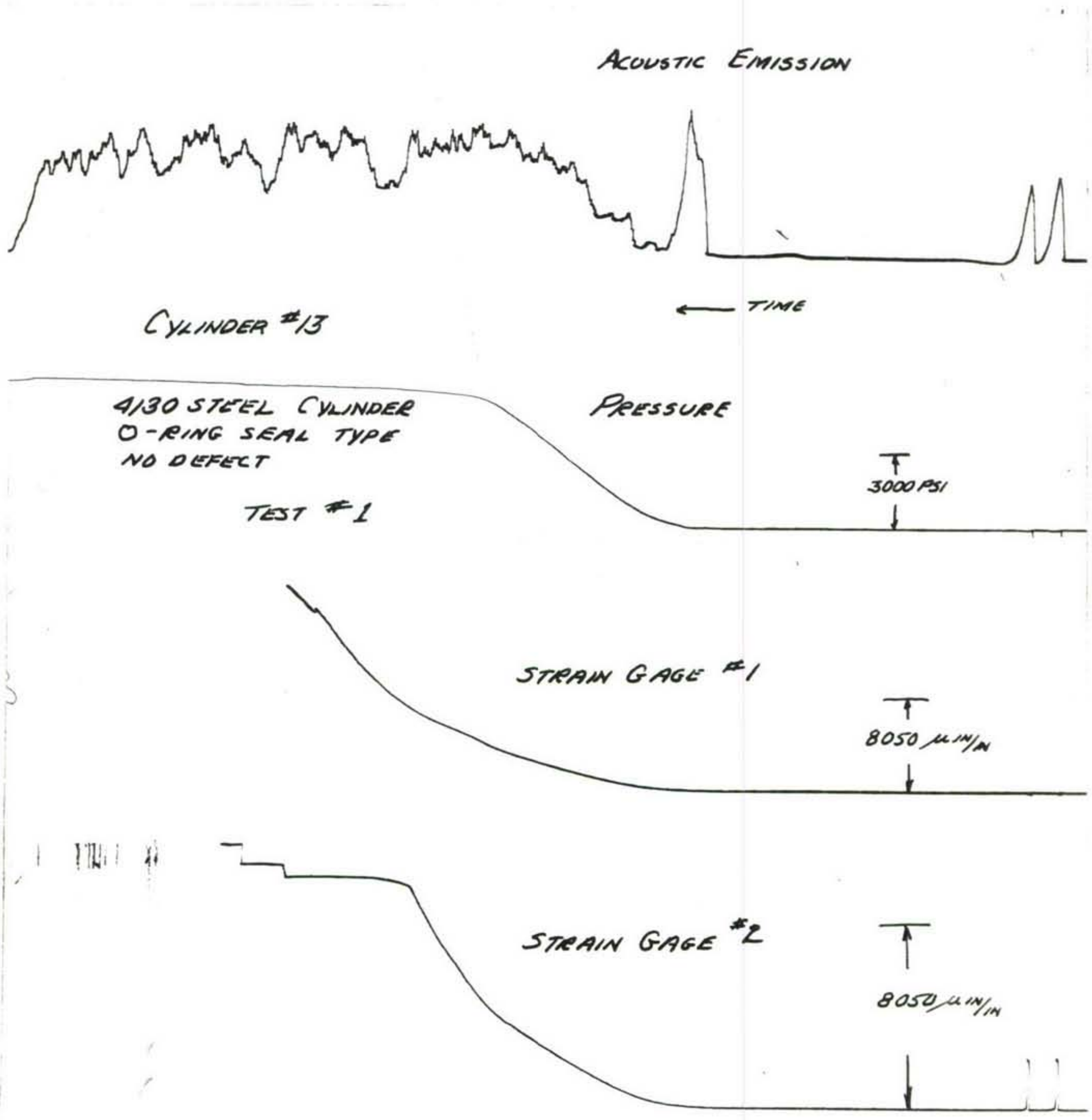


Chart 19. Test No. 1, Cylinder No. 13, 4130 Steel, O-Ring Seal, No Defect

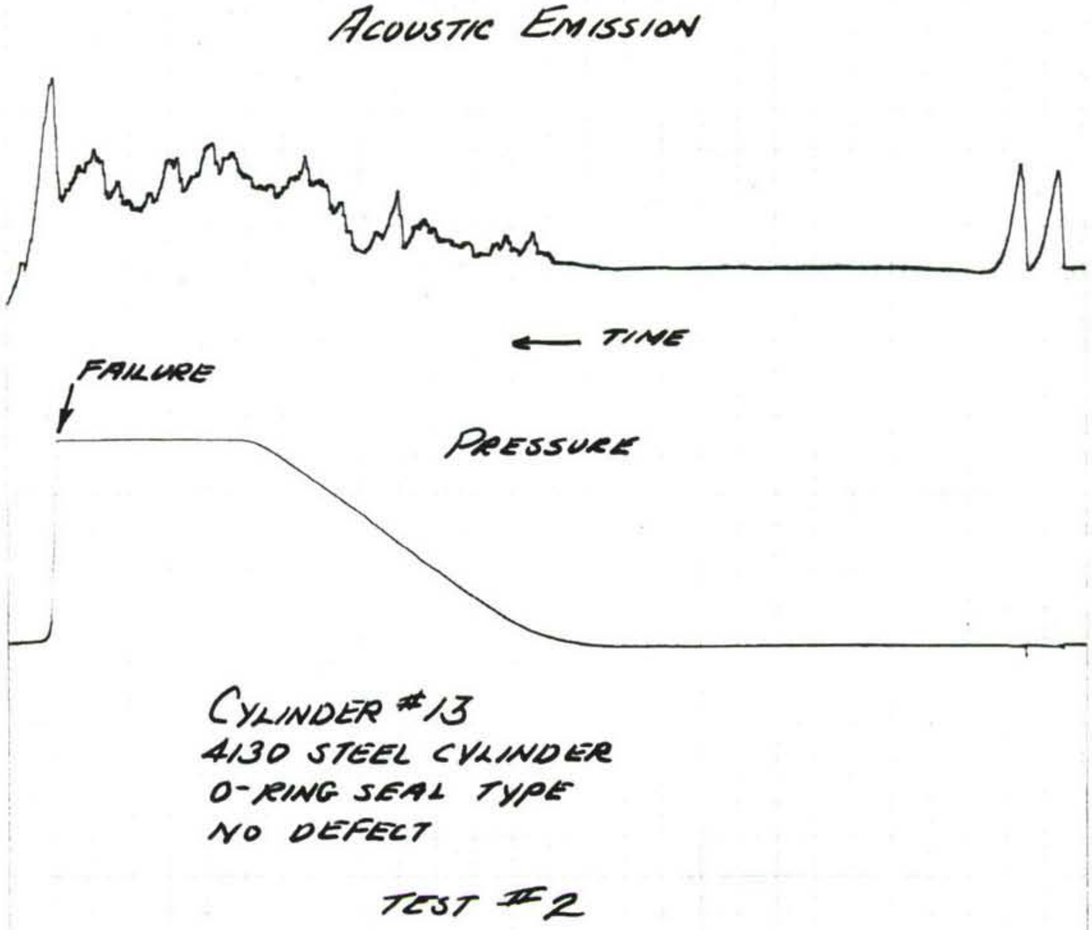


Chart 20. Test No. 2, Cylinder 13, 4130 Steel

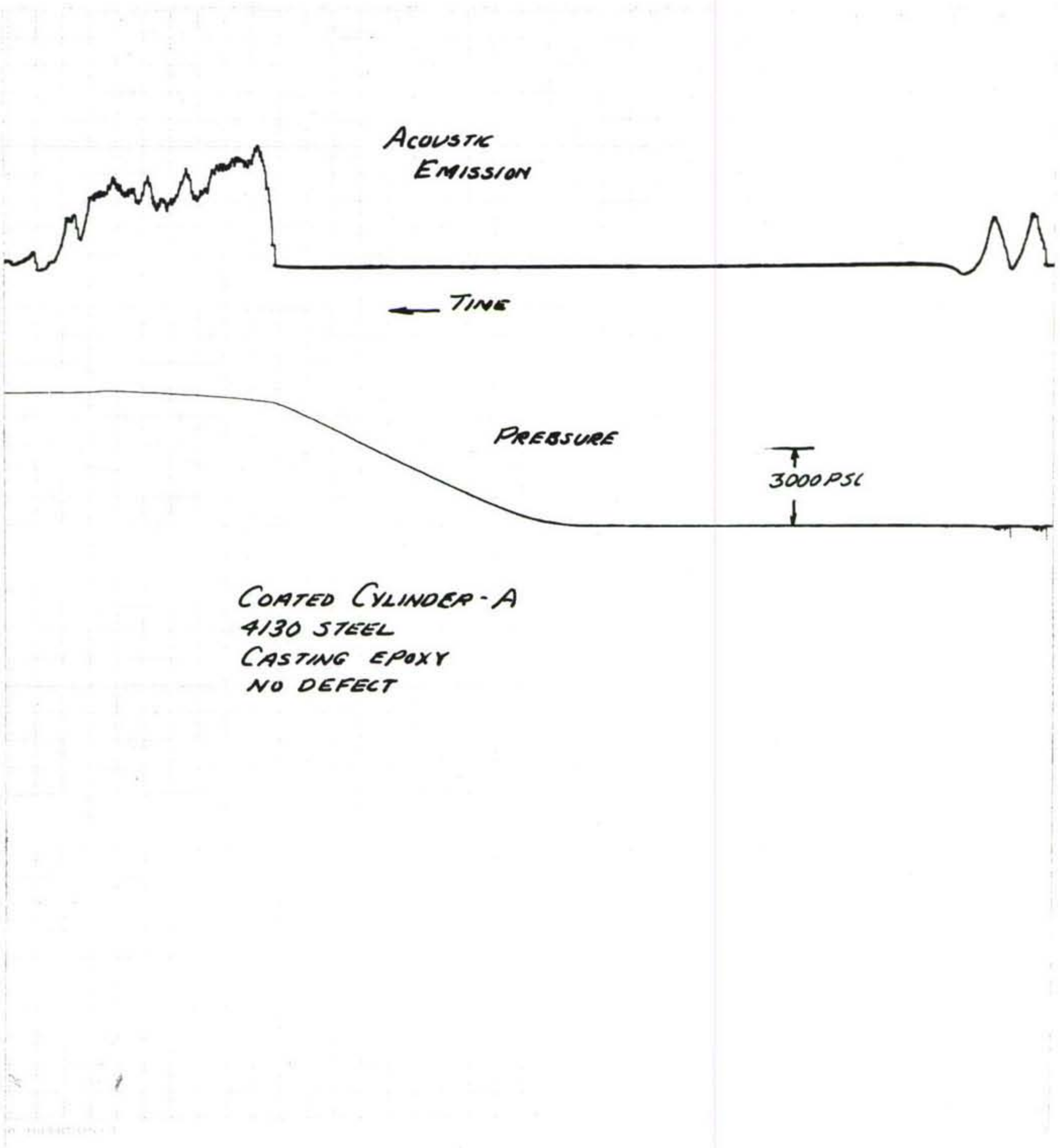


Chart 21. Coated Cylinder A, Casting Epoxy Coating, No Defect

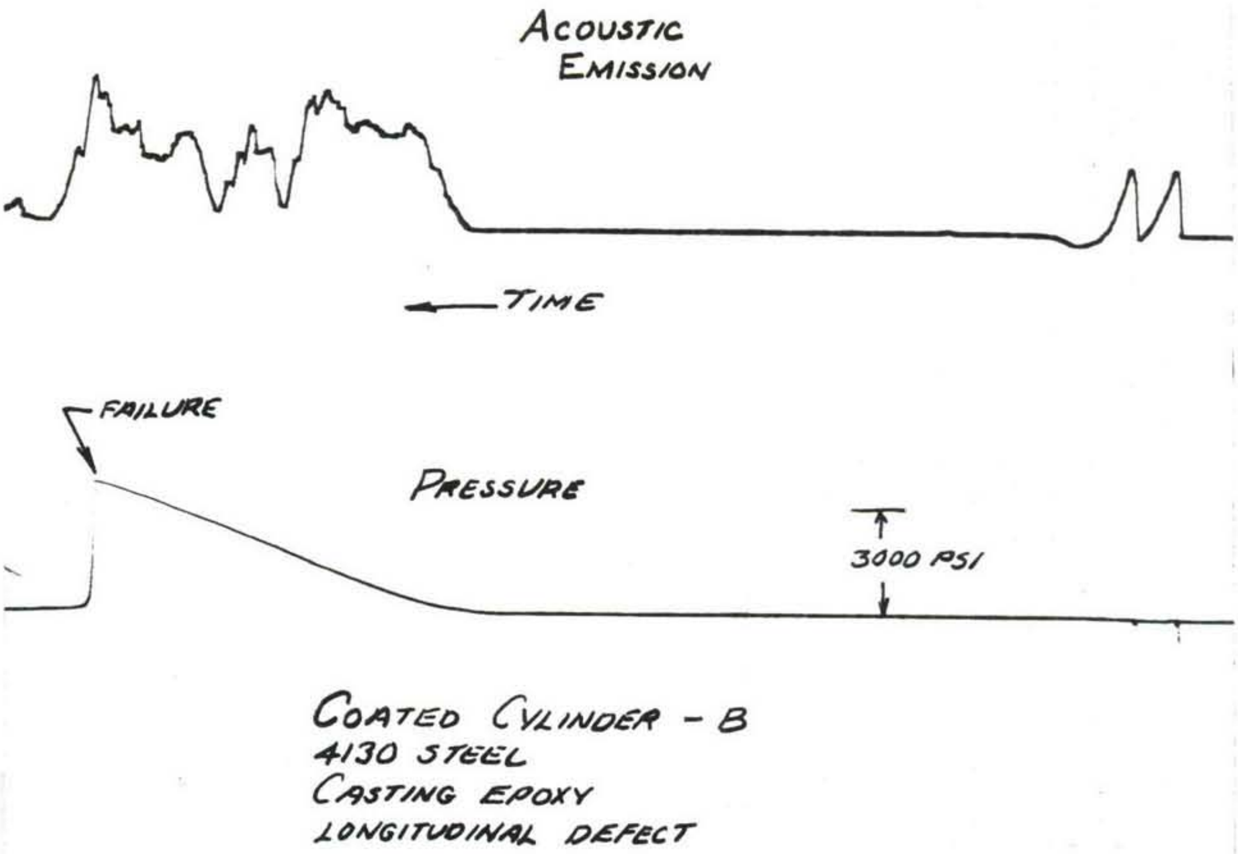


Chart 22. Coated Cylinder B, 4130 Steel, Casting Epoxy Coating, Longitudinal Defect

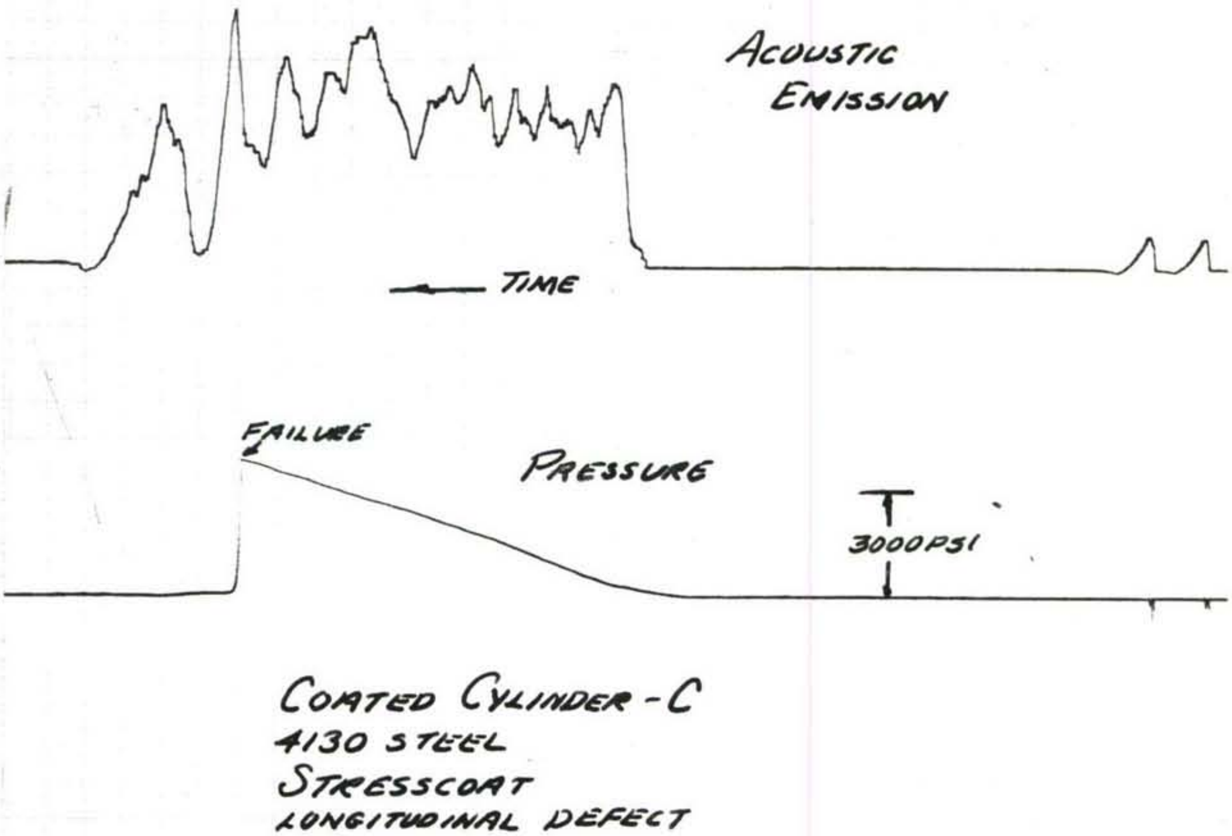


Chart 23. Coated Cylinder C, 4130 Steel, Stresscoat, Longitudinal Defect

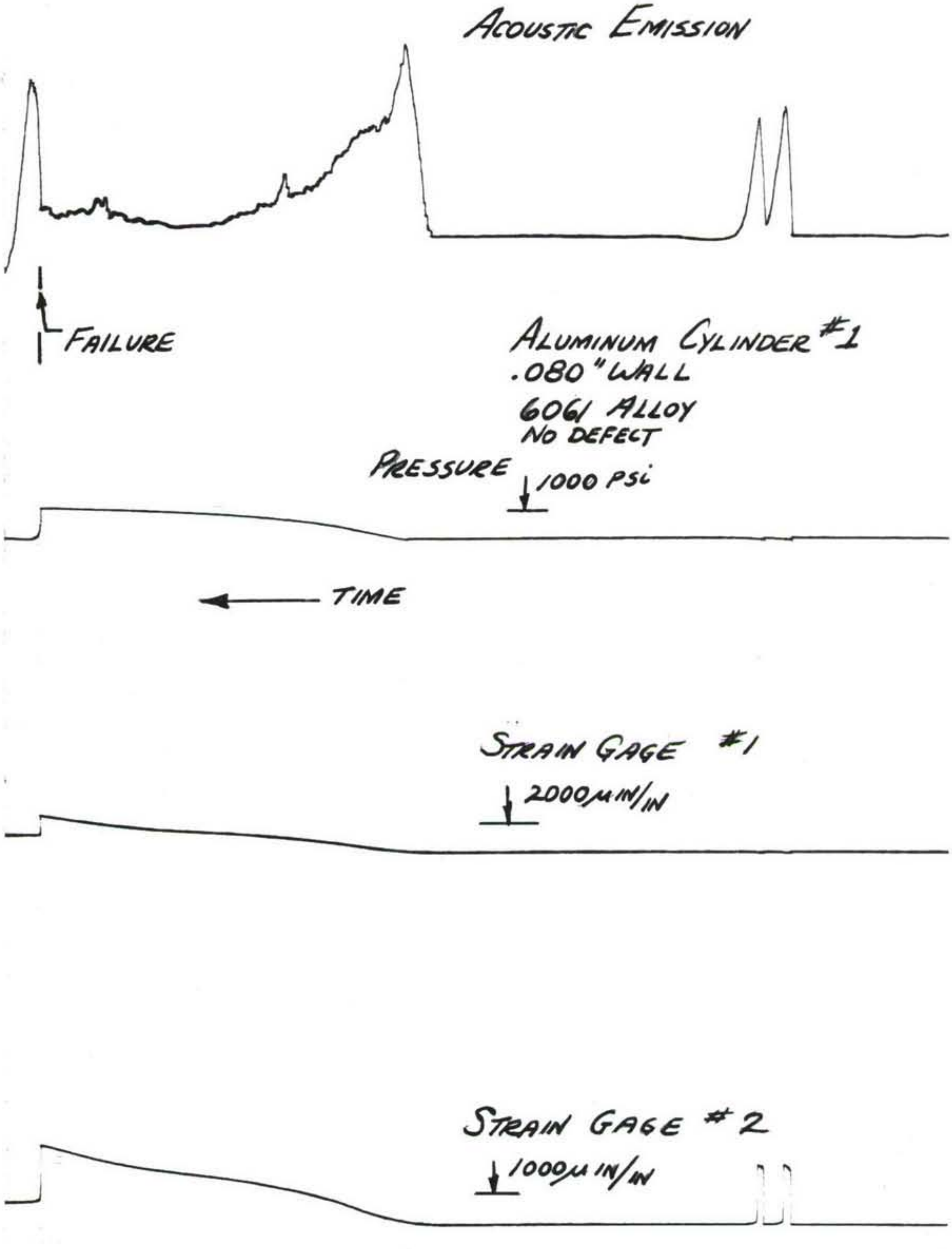


Chart 24. Aluminum Cylinder No. 1, 6061 Alloy, No Defect

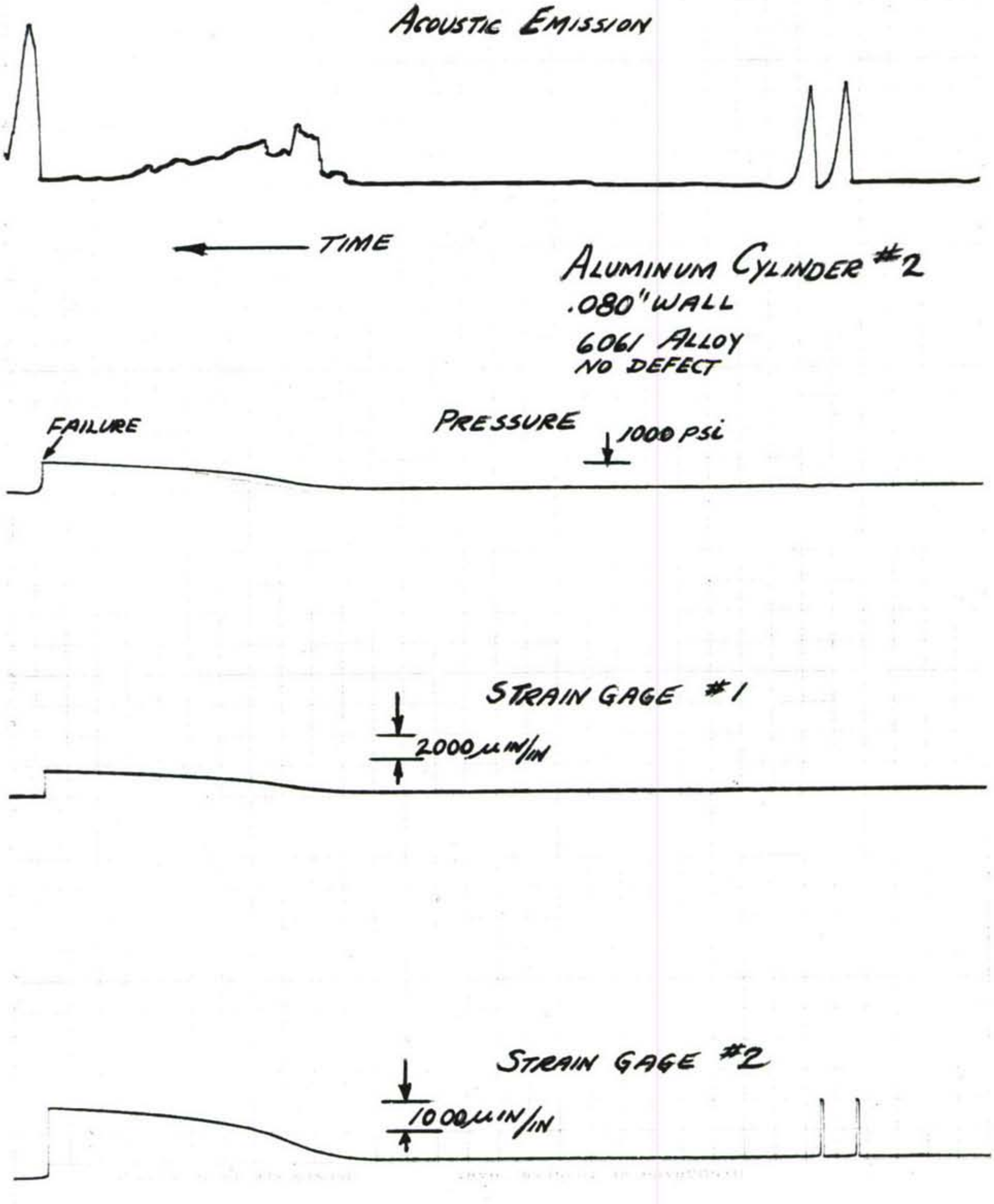


Chart 25. Aluminum Cylinder No. 2, 6061 Alloy, No Defect

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13. ABSTRACT

This report describes a series of experiments designed to assess the practical capability of acoustic emission to indicate stress and/or deformation in a structure, as well as to offer a means of assessing structural integrity. The tests were conducted on split ring samples and specimens of cylindrical form internally pressurized. The integrity of the cylindrical vessels was altered by inserting machined notches of various shapes at predetermined locations on the vessel surface. Specimens were fabricated from 4130 steel and 6061 aluminum. The studies were extended to tests in which the surface of the specimens was coated with a brittle film. This was done to provide an artificial source of high acoustic energy which conceivably could offer an alternate method comparable in reliability with the metal induced emission and one which would be much less susceptible to the environmental disturbances.

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