INTERIM REPORT

Accession No. ______________

Contract Program or Project Title:	Integration of NDE Reliability and Fracture Mechanics Fin. No. B2289
Subject of this Document:	April, 1980 Monthly Report
Type of Document:	Monthly Report
Author(s):	F.L. Becker and others
Date of Document:	5/27/80

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Prepared for
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

INTERIM REPORT

NRC Research and Technical
Assistance Report

8006250 342

INTEGRATION OF NONDESTRUCTIVE EXAMINATION RELIABILITY AND FRACTURE MECHANICS*

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SUMMARY

Major accomplishments during the past quarter have included:

- Measurements have been performed which define the influence of flaw aspect ratio, the ineffectiveness of current code requirements for beam overlap and indicate that use of Appendix 3 of the 1977 Edition of the ASME Code will result in a sensitivity decrease of 5 to 16 dB compared to requirements of the 1974 Summer-1975 Edition of the Code.

- Preparation for the Round Robin Inspections to be initiated in July are proceeding satisfactorily. However, receipt of A106 carbon steel pipe samples has delayed progress. Initial Round Robin tests will proceed without the A106 pipe, with that part of the test matrix being completed at a later date.

INTRODUCTION

The progress and accomplishments of the past quarter are described below by task.

TASK 6: SAMPLE FABRICATION

Sample preparation for the Round Robin Inspections, Task 8, are in progress. The six, 10 inch schedule 80S and the two 27.5 inch ID centrifugally cast stainless steel pipes have been welded. The two 33-1/4 O.D. A106 carbon steel pipes have been delivered and are being welded. Welding and cladding of the A106 pipes are expected to be completed by June 6, 1980. Cracking of the 10 inch schedule 80 and

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centrifugally cast stainless pipes has been initiated.

Technique development for thermal fatigue cracking of the welded pipe samples has now been completed. Thermal fatigue cracks of the desired sizes have been produced in 10 inch schedule 80S, 27.5 inch centrifugally cast stainless steel and 26 inch schedule 160 A106 carbon steel welded pipe samples. Initially, there was a concern that flaws of the required depth (1.0 to 1.25 inch) could be grown in the two heavy wall pipes. This problem was solved by enlarging the diameter of cooling nozzle from 1.25 to 2.5 inch. The larger nozzle requires a longer cycle time of 90 seconds, as compared to approximately 40 seconds for the smaller nozzle.

TASK 7: MEASUREMENT AND EVALUATION

Efforts this quarter were directed toward definition of the influence of flaw aspect ratio on ultrasonic response, the adequacy of the 10% scan overlap requirement of ASME Section XI, Appendix III and comparisons of side drilled holes and end-mill notches as calibration reflectors. As expected, flaws of aspect ratio .5 (depth/length) of unacceptable depths, were not detectable using the calibration sensitivity specified by Appendix III. The 10% beam overlap was also found to be inadequate to assure acceptable coverage. Comparisons of side drilled holes, used for calibrations of inspections performed to the 1974 Summer 1975 Addenda of the ASME Code, and 10% notches required by the 1977 Winter 1978 Revision of the Code were performed. The initial conclusion of this study is that inspections performed to 1977 Code are from 5 to 16 dB (depending on transducer and pipe size) less sensitive than inspections performed to the 1974 Code.

Aspect Ratio

All flaw geometry results reported to date were acquired from inspection of machined flaws having aspect ratios of roughly 0.2. (As of this report, aspect ratios are given as depth/length as in Table IWB-3514-3.) To investigate the effect of changing flaw length, normal vertical flaws were fabricated in the same depth range (40-300 mil) with aspect ratios of 0.5 and 0.1. The flaws with aspect ratio 0.1 are saw cuts, and the 0.5 aspect ratio (semicircular) flaws are EDM slits; all are fabricated in C 6 inch thick 304 stainless steel bars.

The new flaws were inspected using a selection of transducers and beam paths. The beam paths were 45° 1/2V, full V, and 3/2 V, and 60° 1/2 V. The transducers, selected to be representative of units used in the field and to provide a variety of beam patterns, were three 2.25 MHz pulse echo units with crystal diameters 1/4 inch, 1/2 inch and 1 inch, and a 1.5 MHz dual transducer with two 3/8 inch square crystals which were used only at 45°.

Table IWB-3514-3 of Section XI requires that flaws of aspect ratio 0.5 and depth 12.5% throughwall be detected. Flaws of this aspect ratio should be the hardest to detect because they have the smallest area for a given depth. Figure 1 presents the results of 1/2 V 45° inspection of the flaws of aspect ratio 0.5 using the four search units listed. Note that at 12.5% throughwall depth (75 mils), only the 1 inch transduc. fails to exceed 50% DAC. However, none exceed 100% DAC (reporting level).

At shallow depths, small crystals give better responses because the flaw is smaller than the sound beams. At 300 mil flaw depth, the responses are reversed; the response of the small transducers has reached or nearly reached an upper plateau as the flaw size begins to exceed the beam size, while the response of the 1 inch transducer (large beam size) is still rising with depth. The same trends occur with aspect ratios 0.2 and 0.1, indicating a trade-off between small flaw and large flaw detectability when selecting a search unit.

Figures 2 and 3 show the response of the 1/4 inch unit for 1/2 V inspection at 45° and 60° of normal vertical flaws of all three aspect ratios. Note that in both cases, at depths of 200 mils or more, aspect ratio ceases to make a difference, meaning that even the 0.5 aspect ratio flaws are longer than the horizontal dimension of the acoustic beam. At smaller depths, the semicircular flaws have significantly less response than the 0.2 and 0.1 aspect ratio flaws. Also, we see another large flaw-small flaw detectability trade-off, this time between 45° and 60° inspections.

The large flaw response for the 1/2 inch transducer (Figures 4 and 5) shows the same features; at 300 mil depth, the influences of depth and aspect ratio are disappearing. The small flaw responses show more difference between flaws of 0.1

and 0.2 aspect ratio, simply because the beam is now wide enough for the flaw length difference to matter. No large flaw-small flaw detectability trade-off between 45° and 60° inspection is observed for this transducer; in fact, responses for the two beam angles are about the same for all depths and aspect ratios.

Only the 1 inch unit (Figures 6 and 7) is still responding to depth and aspect ratio increases at 300 mils depth, because it has the largest beam size. For both beam angles, detectability is good for large flaws and poor for small flaws. Small flaw detectability is marginally better at 60° than at 45°.

Scan Overlap

Paragraph III-2410 of Section XI, Appendix III, requires that scans must overlap by a minimum of 10% of the transducer dimension, measured perpendicular to the scan path. This minimum requirement was evaluated by measuring how far apart scans could be made while assuring that the flaw response would exceed a specified recording level. This experiment was performed for the 60 mil vertical flaws of 0.5 and 0.2 aspect ratio. The same transducers and beam paths (excepting full V 45°) used for the aspect ratio study were also used here.

The signal is maximized at the desired beam path, and then the transducer is moved perpendicular to the beam direction (sideways) until the signal drops to a certain level relative to DAC, where the transducer position is recorded. The positions of responses 6, 14 and 20 dB below DAC were recorded on both sides of the position of maximum signal, thus defining the maximum scan separation for a certain detectability level. For example, if in a particular test, the positions which result in a signal 14 dB below DAC are 0.5 inch apart, then adjacent scans must be separated by no more than a half inch to assure detection of this flaw with a 20% DAC criterion.

The results are shown in Table 1. The maximum allowable separation between adjacent scans is expressed in percent of the crystal dimension. Where a dash appears instead of a number, the maximum flaw signal is below the detection criterion. When the separation in percent of crystal size is less than 90, the

TABLE 1. Required Inspection Coverage for Detection of 10% Throughwall Flaws

Transducer	Beam path	angle	Aspect Ratio = 0.5 -6dB	-14dB	-20dB	Aspect Ratio = 0.2 -6dB	-14dB	-20dB
1/4" 2.25 MHz	1/2V	45°	36	96	128	100	144	176
	3/2V	45°	--	152	228	92	176	224
	1/2V	60°	--	72	112	60	108	140
1/2" 2.25 MHz	1/2V	45°	--	38	68	40	76	100
	3/2V	45°	--	56	88	46	84	110
	1/2V	60°	--	28	54	--	60	84
1" 2.25 MHz	1/2V	45°	--	--	47	--	50	75
	3/2V	45°	--	--	45	--	53	78
	1/2V	60°	--	--	59	--	53	81
3/8"x3/8"(2) dual 1.5 MHz	1/2V	45°	--	72	96	53	101	128
	3/2V	45°	--	109	176	67	147	184

% crystal dimension

the Section XI scan overlap criterion of 10% is inadequate. It can be seen at a glance that this is often the case. In fact, for the 1 inch transducer 10% overlap is never sufficient.

Table 1 also indicates that the required overlap for a given detectability cannot be defined by a single number that will apply to all search units and beam paths. The numbers in the table will also change with pipe wall thickness and curvature. The obvious inference is that this procedure could become part of calibration. Since the smallest surface-connected defect Section XI requires the inspector to detect is a semicircular flaw with depth 12.5% of wall thickness, one might calibrate on this reflector. The recording level for inspection indications would be set a few decibels below a DAC thus established, to allow for the fact that the surface of a service defect would not be so ideal a reflector as the machined surface of the calibration reflectors. The added value of this semicircular calibration reflector would be the capability of measuring the necessary scan overlap for each inspection. This measurement is neither complex nor time-consuming, and provides assurance of complete coverage.

Side-Drilled Holes Versus Notches

Recent acceptance by NRC of ASME Section XI Code through Winter of 1978, has raised a question as to the adequacy of the inspection sensitivity which is defined in Appendix III of Section XI. Previously most piping inspections were performed or calibrated using the side-drilled holes specified by ASME Section V, Article 5, whereas Appendix III requires the use of surface-connected notches. A program has been initiated to define the difference in inspection sensitivity produced by these two calibration techniques. Limited data is available at this time, however, there is a clear trend indicating less sensitive inspections result from notch calibrations.

At present, we have data from a 20 inch O.D. schedule 80 standard and from 0.6 inch thick flat plate standards (representative of 10 inch schedule 80 pipe). The 20 inch standard has I.D. and O.D. 10% notches and a t/4 SDH; the 0.6 inch flat plates have a t/2 SDH and notch depths 5%, 10%, 20% and 30% through wall. The flat plate SDH and 10% notch comparison appeared in a previous report. In this report, Table 2 compares 4 notch depths to a SDH in 0.6 inch metal. Table 3 compares 10% notches to SDH for the 20 inch O.D. standard.

TABLE 2. Ultrasonic Response of End-Mill Notches Relative to a Side-Drilled Hole DAC, in Decibels, for a Flat Plate

Transducer	Notch Depth	1/2 V Path	Full V Path	3/2 V Path
1/4" 2.25 MHz	5%	+ 6.5	+ 8	+ 8
	10%	+ 9.5	+12	+12
	20%	+11	+14	+15
	30%	+12	+16	+16.5
1/2" 2.25 MHz	5%	+ 4.5	+ 4	+ 5
	10%	+ 9	+ 8	+ 9
	20%	+12	+12	+12
	30%	+14	+14	+14.5
1" 2.25 MHz	5%	+ 2.5	+ 1	+ 2
	10%	+ 5	+ 5	+ 4.5
	20%	+ 9	+ 8	+ 9
	30%	+10.5	+10	+11

TABLE 3. Ultrasonic Response of a 10% End-Mill Notch Relative to a Side-Drilled Hole DAC, in Decibels, for a 20" Schedule 80 Pipe Standard

Transducer	1/2 V Path	Full V Path	3/2 V Path
1/4", 2/25 MHz	+ 7	+10	+10
1/2", 2.25 MHz	+ 8	+11	+11
1", 2.25 MHz	+13	+16	+16

Conclusion

In inspecting machined flaws of aspect ratios 0.5, 0.2, and 0.1, it is seen that the semicircular flaws (aspect ratio 0.5) are usually much lower in response than the longer flaws, expecially at low depth. This points out the fallacy of calibrating on a reflector of (usually) effectively infinite length, when Section XI also requires that very short flaws of approximately the same depth be detected. Figure 1 indicates that while three out of the four transducers used produced indications higher than 50% DAC from the minimum rejectable semicircular flaws, two of the three were just barely above 50% DAC. Since a service defect would not have the ideal reflecting surfaces of the machined flaws, one has to conclude that the same size flaw grown in service would probably not be detected by these transducers. Thus, inservice, only the 1/4 inch transducer would have detected the rejectable 75 mil semicircular flaw with a 50% DAC recording criterion.

Investigation of scan overlap requirements shows that the 10% Section XI scan overlap is often insufficient to provide coverage with even a 20% DAC recording criterion. Also, it shows that no single number can define the necessary overlap for all situations, leading to the suggestion that measurement of overlap requirement become part of calibration.

Finally, investigation to date of the relationship of SDH and notches as calibration reflectors has produced as many questions as answers, but acquisition of an ample data base is foreseen in the very near future.

TASK 8: ROUND ROBIN INSPECTIONS

Preparation for the Round Robin Inspections scheduled for initiation in July, are proceeding. Review of the procedures sumbitted by the test teams are in progress as a part of finalizing the Round Robin test protocol. The "Search Unit Tracking and Recording System" (SUTARS) has been ordered and is scheduled for delivery June 1, 1980. The SUTARS will be used to automatically record test data for later error analysis. Negotiations with EPRI for use of intergranular stress corrosion samples are proceeding. We expect to be able to use at least four of these pipes for the Round Robin tests.

Definition of the statistical test matrix and analysis procedures have been completed. Randomization of flaw locations has also been completed to allow initiation of sample cracking procedures. The statistical analysis procedures will supply information pertaining to correct flaw identification as well as the false rejection probability.

As a result of the late delivery of the 33-1/4 inch A106 carbon steel pipe and a strike involving the welding contractor for this sample, the schedule for these samples has been delayed. These samples will not be available for the initial one or two teams. These teams will be called back at a later time to complete the test matrix. It is expected that the A106 samples will be available by mid-July.

FUTURE PLANS

Primary emphasis in the coming quarter will be placed on completion of cracking for the available samples, definition of the Round Robin test protocol and contractual negotiations. Measurement of side-drilled hole and notch calibration sensitivities is in progress and should be completed during the coming quarter.

LIST OF FIGURES

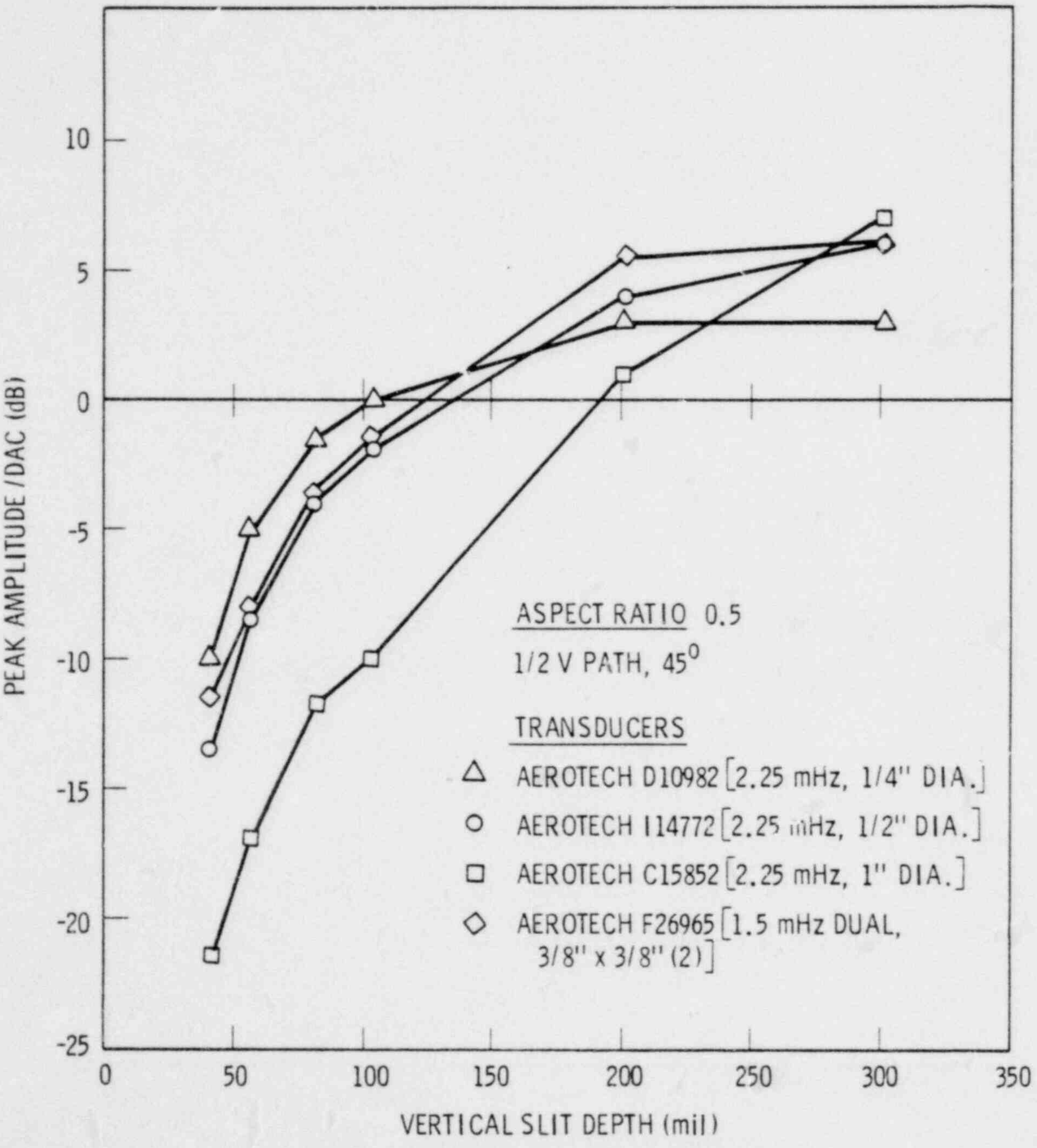

Figure 1: Ultrasonic Response from .5 Aspect Ratio Notches in .6 Inch Thick Stainless Steel Plate Using 1/4, 1/2 and 1.0 Inch Diameter, 2.25 MHz Transducers.

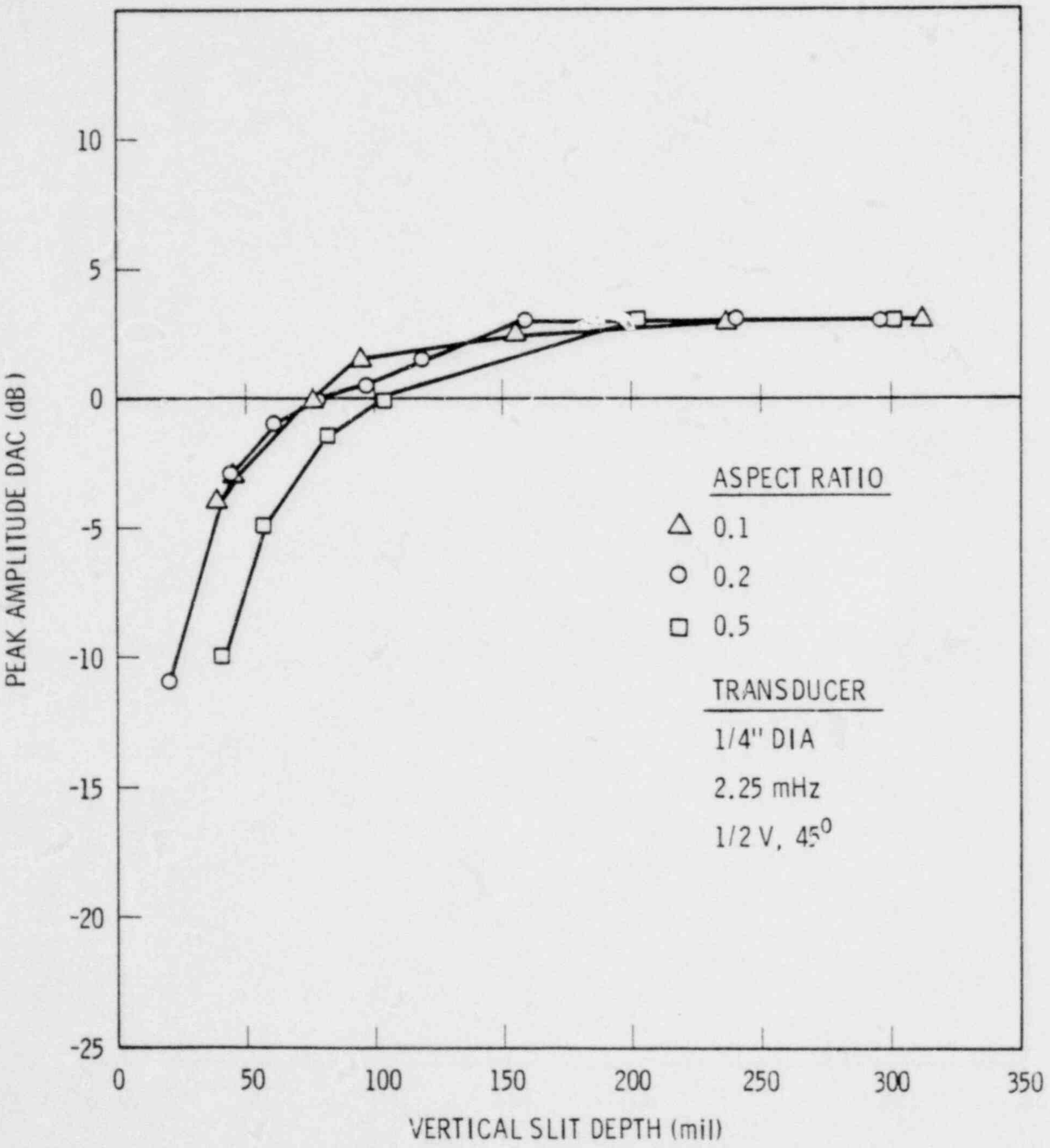

Figure 2. Ultrasonic response from 0.1, 0.2 and 0.5 Aspect Ratio Notches Using 1/4 Inch Diameter, 2.25 MHz Transducer for 45° Incidence.

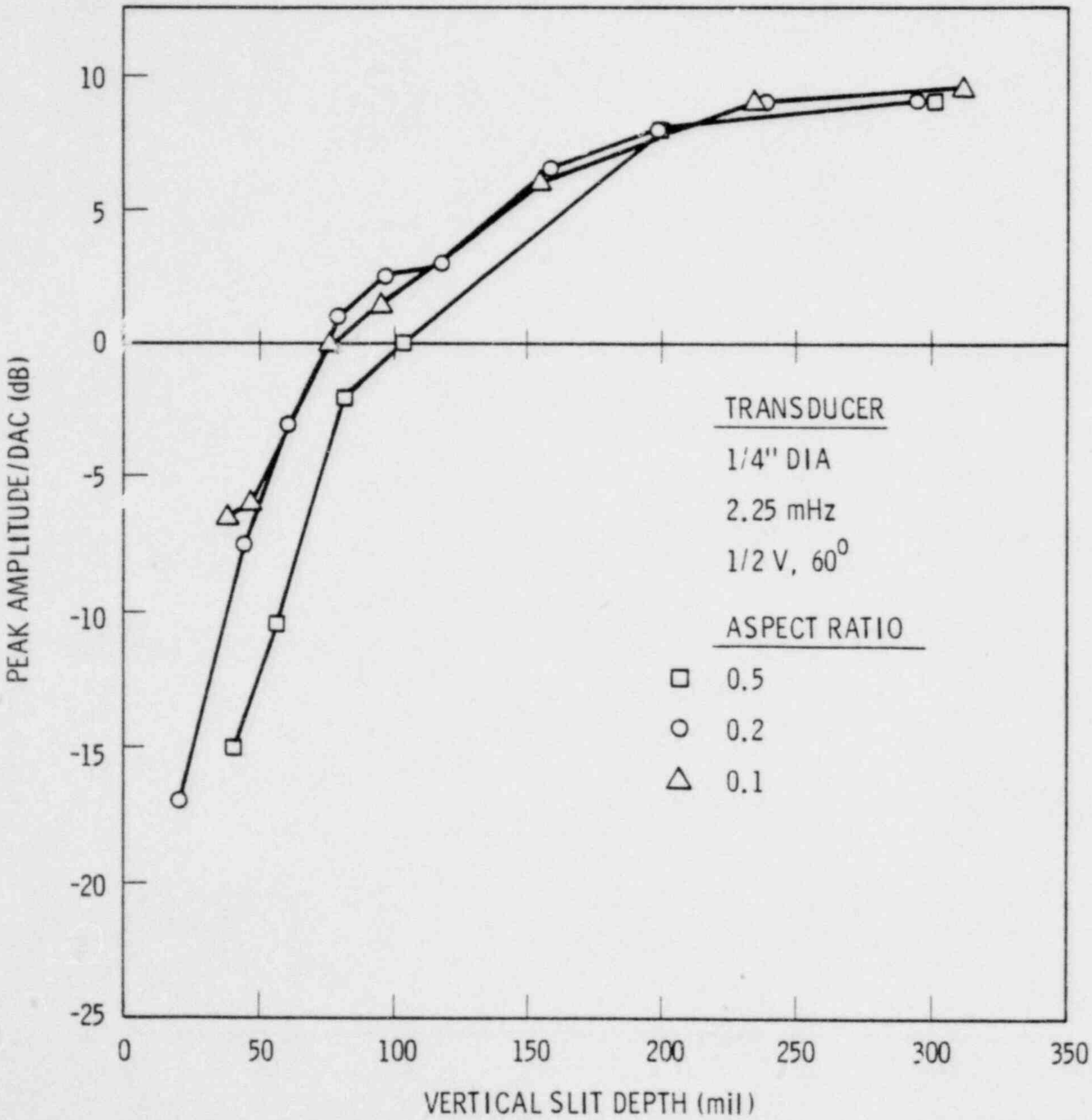

Figure 3: Ultrasonic Response from 0.1, 0.2 and 0.5 Aspect Ratio Notches Using 1/4 Inch Diameter, 2.25 MHz Transducer for 60° Incidence.

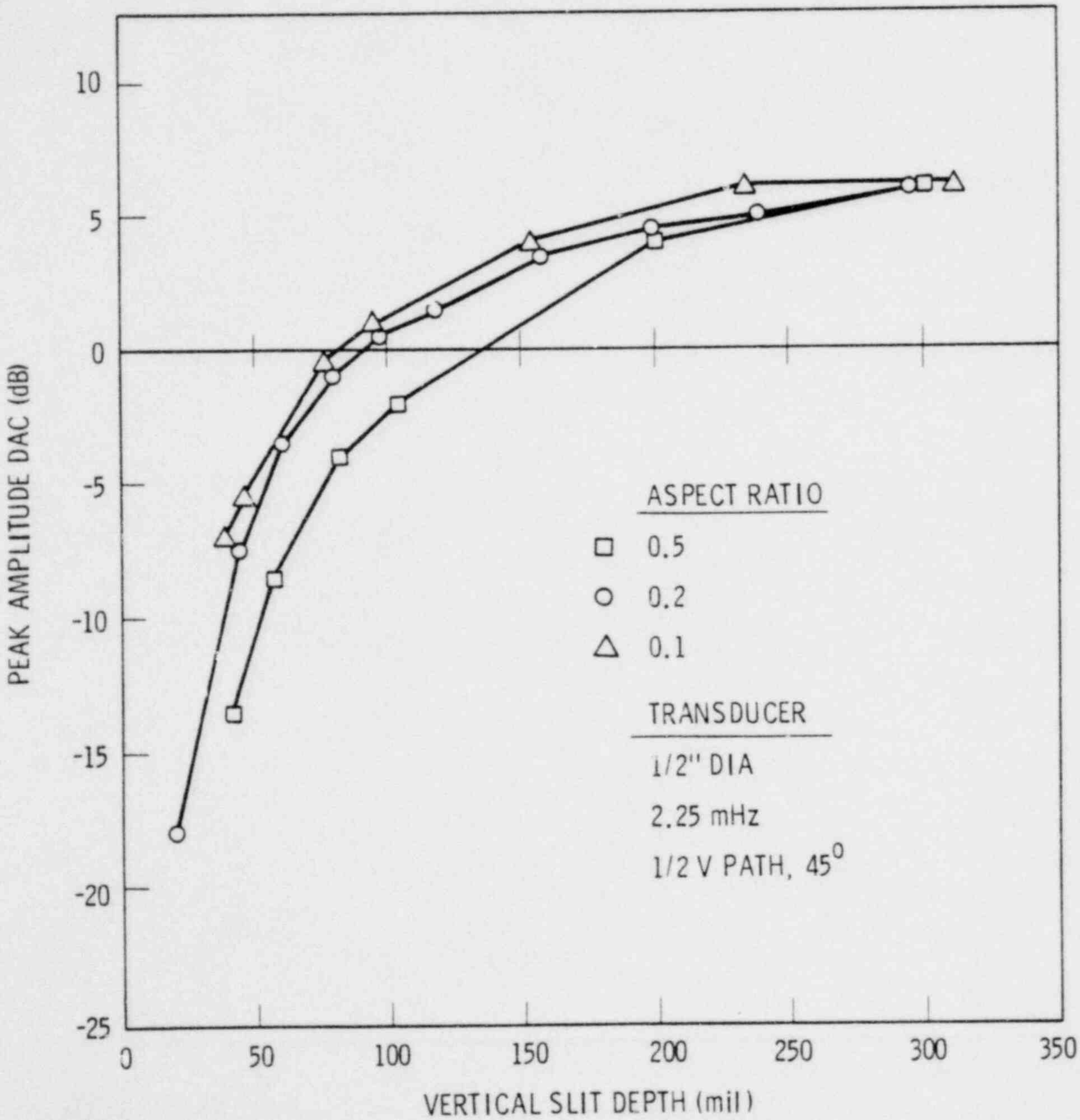

Figure 4: Ultrasonic Response from 0.1, 0.2 and 0.5 Aspect Ratio Notches Using 1/2 Inch Diameter, 2.25 MHz Transducer for 45° Incidence.

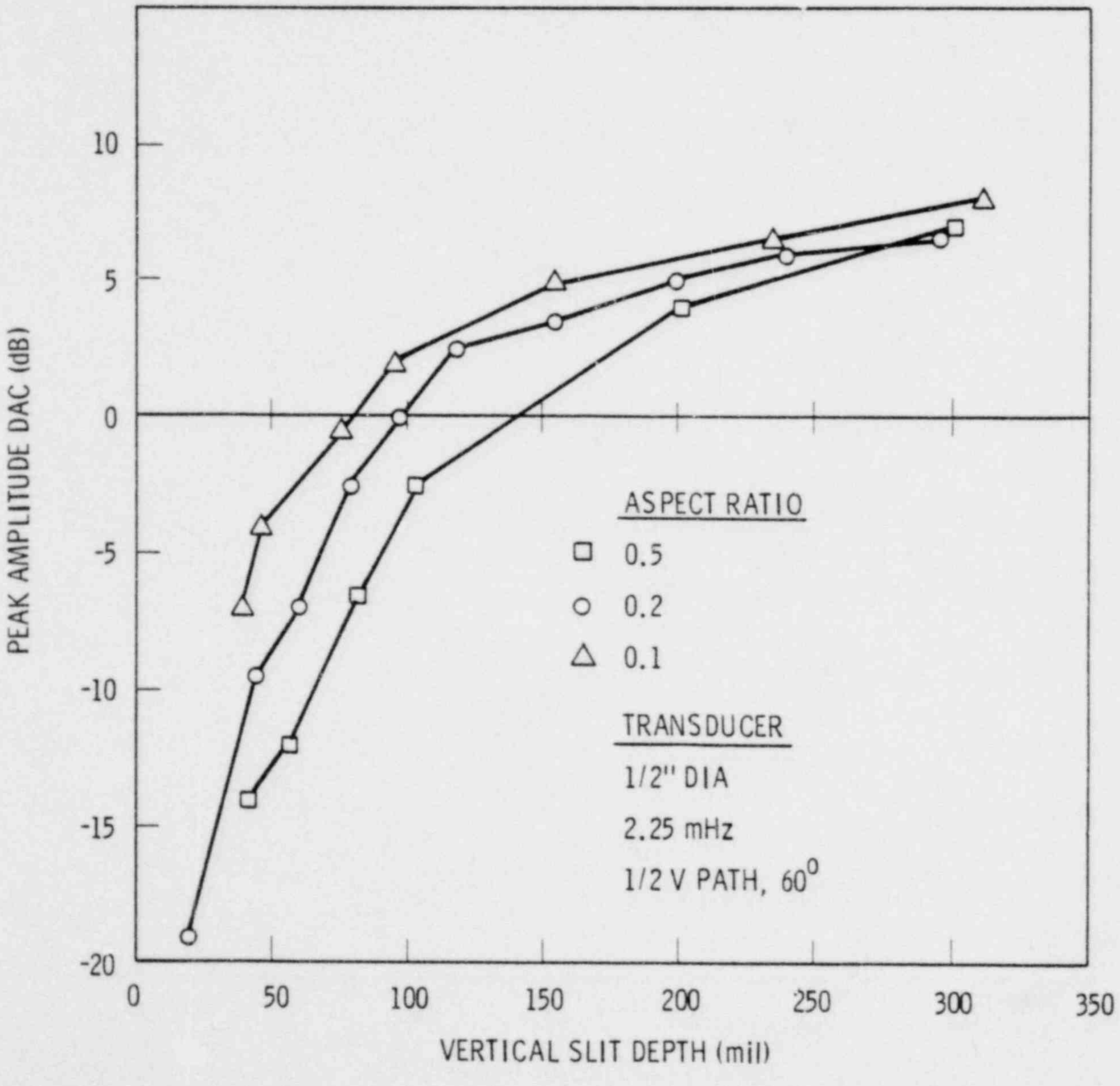

Figure 5: Ultrasonic Response from 0.1, 0.2 and 0.5 Aspect Ratio Notches Using 1/2 Inch Diameter, 2.25 MHz Transducer for 60° Incidence.

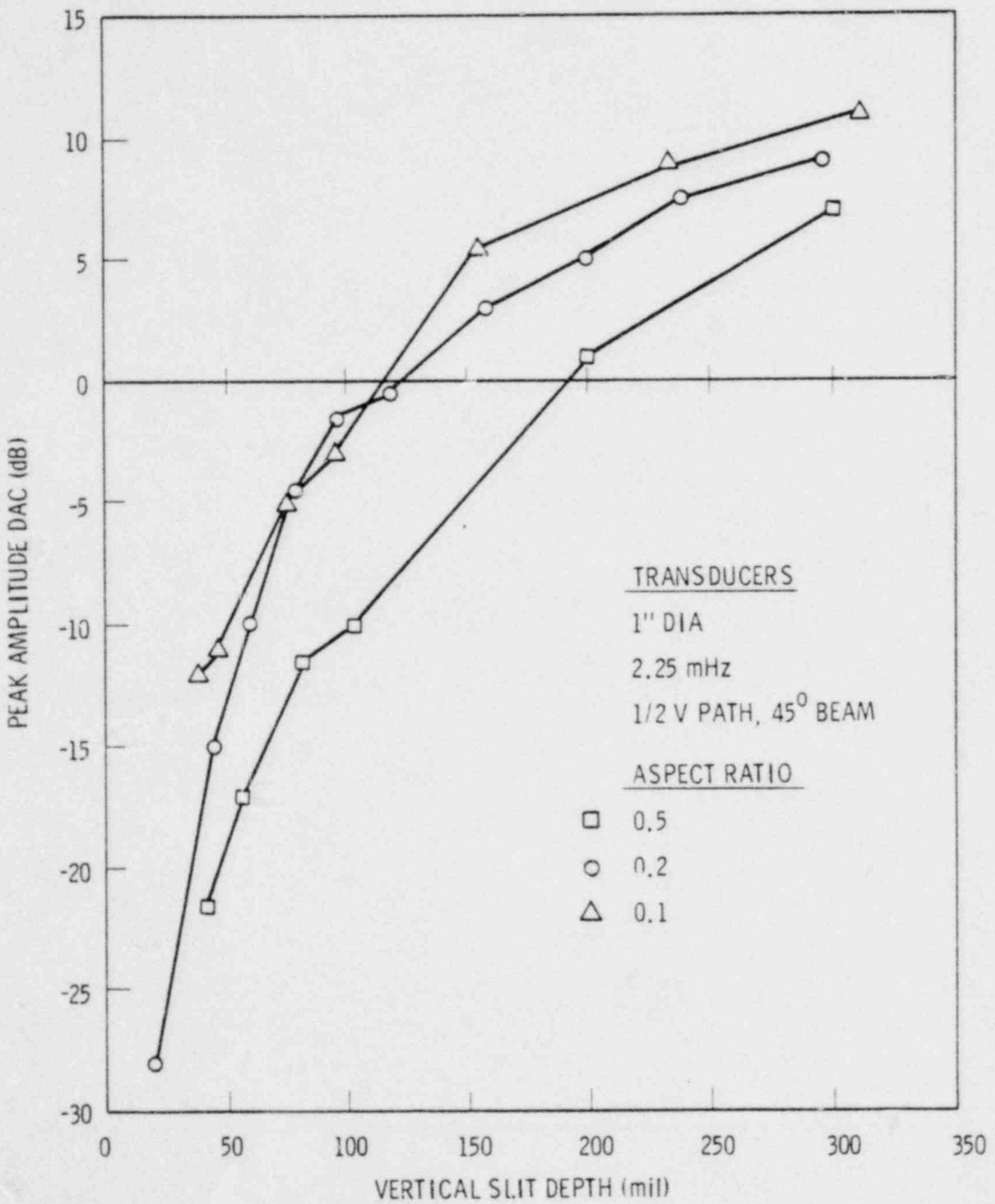

Figure 6: Ultrasonic Response from 0.1, 0.2 and 0.5 Aspect Ratio Notches Using a 1.0 Diameter Transducer for 45° Incidence.

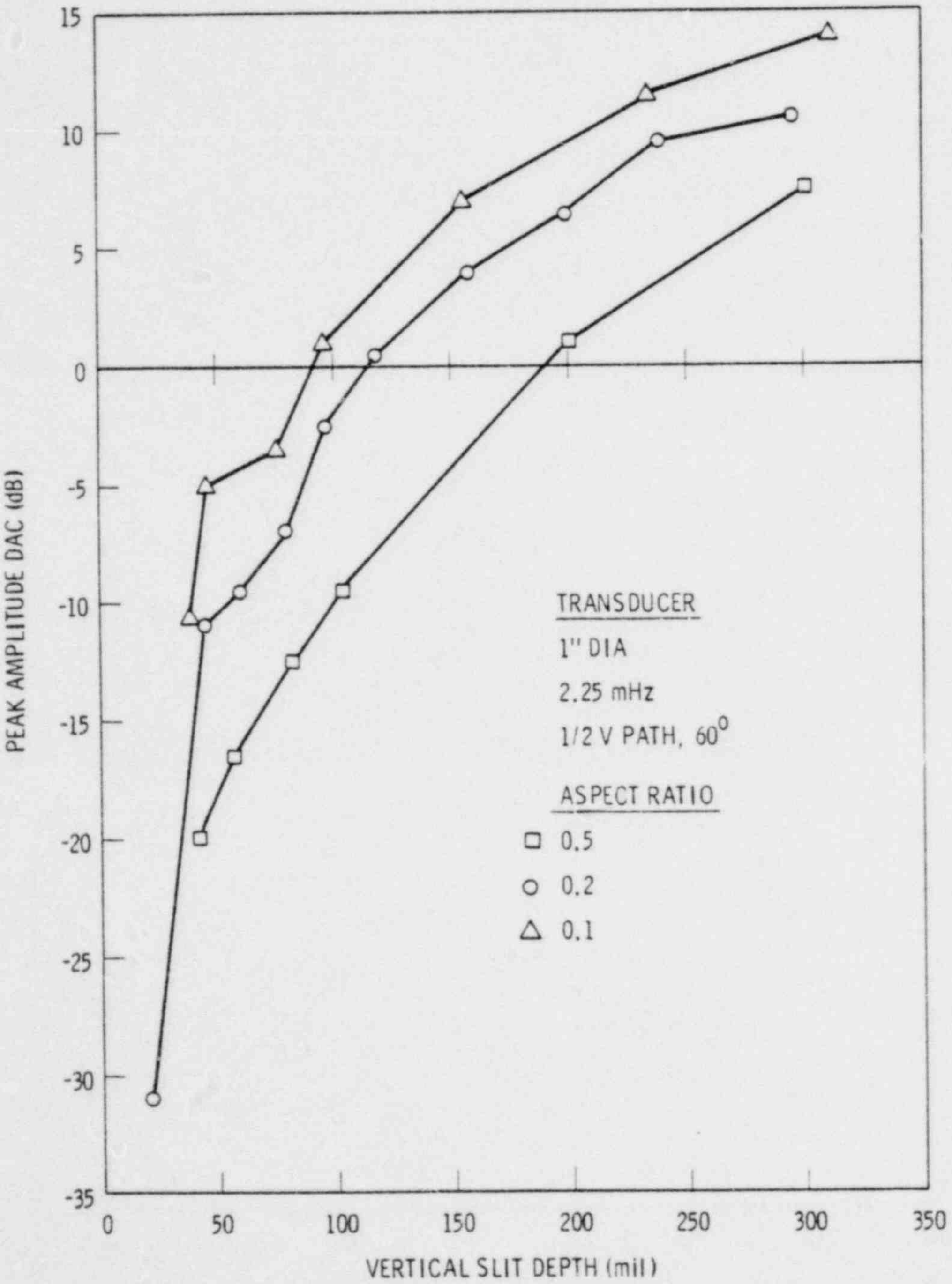

Figure 7: Ultrasonic Response from 0.1, 0.2 and 0.5 Aspect Ratio Notches Using a 1.0 Inch Diameter Transducer for 60° Incidence.

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