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SUPERSONIC MEASUREMENT OF WALL THICKNESS
IN DIESEL LINERS

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ABSTRACT

This report describes studies that have been made at the Naval Research Laboratory aimed at modifying the Sonigage so that it can be used to inspect thick materials with curved surfaces. Its application to the measurement of wall thickness in diesel cylinder liners is discussed in detail.

The report includes also a brief description of the Sonigage together with its theory of operation, and describes the results of measurements on 19 diesel cylinder liners at the Norfolk Naval Shipyard. Evidence of core-shifting was found in many cases. In two instances, core-shifting was so bad that the test indicated that the castings should be discarded. In two other instances, the wall thickness had been reduced to the one-quarter inch minimum allowable.

In the hands of a trained operator, the Sonigage can be successfully applied to the routine testing of diesel cylinder castings.

TABLE OF CONTENTS

		Page
	Abstract	2
I.	INTRODUCTION	4
II.	DESCRIPTION OF SONIGAGE	4
III.	ADAPTATION OF SONIGAGE FOR LINER INSPECTION	5
IV.	INSPECTION OF LINERS	7
V.	DATA AND GRAPHICAL PRESENTATION	8
VI.	DISCUSSION OF RESULTS	8
VII.	CONCLUSIONS	9

PLATES

I	Fig. 1	Sonigage	
	" 2	Sonigage Measuring .062" Sheet Steel	
II	Fig. 1	Sonigage Adapted to Liner Inspection	
	" 2	Duralumin Filler - Attached to Probe	
III	Fig. 1	Indication on .250" Steel Plate	
	" 2	Indication on .500" Steel Plate	
IV	Fig. 1	Indication on .375" Steel Plate	
	" 2	Indication over .365" Section of Liner (with Filler Thickness .400")	
V	Fig. 1	Indication over .450" Section of Liner (with Filler Thickness .485")	
	" 2	Indication over Rib of Section of Liner	
VI	Longitudinal Section View of Liner		
VII	A & B	Tabulation of Results of Tests	
VIII	A to I	Graphs of Results of Tests	

Supersonic Measurement of Wall Thickness in Diesel Liners

Refs: (a) BuShips ltr. to NRL S69-2(336) of 27 Nov. 1944.
(b) BuShips ltr. to NRL S69-2(334) of 8 Feb. 1946.

I INTRODUCTION

1. Reference (a) authorized the Naval Research Laboratory to investigate the Sonigage, as developed by the Research Laboratories Division, General Motors Inc., in order to ascertain its application to Naval problems. The Laboratory was further authorized to modify the device to satisfy specific requirements.

2. The Sonigage is a device for indicating the thickness of metal plates by setting them into resonant supersonic vibration. The device, as developed by General Motors, is particularly useful in testing relatively thin flat plates. However, in many naval applications it is necessary to make measurements on thick materials often with curved surfaces, as was the case in the measurements of wall thicknesses in diesel liners.

3. Investigations at NRL have led to the development of a technique of making relatively accurate measurements on thick materials having curved surfaces. Reference (b) requested NRL to examine a number of diesel cylinder liners at the Norfolk Naval Shipyard prior to the chrome-spraying process. Nineteen castings were investigated and good thickness indications obtained. There was evidence of core-shifting in many cases. In two cases, the tests indicated that core-shifting was so great that the units should probably be discarded; in two other instances, core-shifting had reduced the wall thickness to the minimum allowable amount ($1/4''$).

II DESCRIPTION OF SONIGAGE

4. The Sonigage used in these tests is shown in Plate 1, Fig. 1. It is equipped with two quartz crystal probes shown in the foreground. The larger is for use on steel in the thickness range .080 to .150 inches while the smaller probe covers the range .045 to .090 inches. The unit on the left contains an electronic oscillator which supplies power to the crystal probes in the frequency bands of 0.833 to 1.56 million cycles per second for the larger probe and 1.388 to 2.777 for the smaller. A motor-driven condenser sweeps either band thirty times a second. The horizontal sweep on the cathode-ray oscilloscope, shown on the right, is synchronized with the frequency sweep. Calibrating marker pips appear at each end of the horizontal sweep. These pips indicate the all-out and all-in position of the frequency sweeping condenser and are set to calibrating points on the scale.

5. If now the smaller probe with its quartz crystal, which resonates at a frequency slightly higher than those swept, is placed in contact with a steel plate .062" thick through a film of oil, a pip will appear on the scale as shown in Plate 1, Fig. 2. The plate is resonant at a frequency of 2.0165 million cycles. The pip on the screen is caused by the reaction on the oscillator as the quartz crystal changes its impedance rapidly near the resonant frequency.

6. The frequency at which resonance occurs in the material is determined by the relation $V = \frac{2ft}{N}$, where V is the bulk velocity of sound which has the value 250,000 in/sec for steel, f is the resonant frequency, t is the thickness in inches of the material, and N an integer which represents the order of the harmonics. Obviously, the wave length (λ) is given by the relation $2t/N$.

7. A quartz probe in general will cover a 2 to 1 range in thickness. To cover effectively the range of thicknesses from .025 to .300 inches, six or seven probes are needed if indications are to be limited to fundamental resonances. Since a directed supersonic beam is desired, the area of the quartz crystal must be greater for measuring thicker materials. The concentration of the beam is a function of the number of wavelengths across the crystal; thus for a given frequency the larger this area the sharper the beam will be.

III ADAPTATION OF SONIGAGE FOR LINER INSPECTION

8. The foregoing description applies to the Sonigage used for direct-reading indications (on a plane surface) at the fundamental resonant frequency. If the Sonigage, which is designed to cover thicknesses in steel of .045 to .090", is used on a thick sheet (such as .50") harmonics corresponding to several half waves will appear as multiple pips on the screen. Only those harmonics included in the band of frequencies swept will appear. A transparent scale has been designed to aid in interpreting these harmonics pips in terms of thickness. The scale is moved up or down until the series of pips falls on a sequence of the diagonal black lines corresponding to a series of harmonics.

9. Such a scale is made possible through the properties of standing waves. A plate of a given thickness may be set into resonant vibration at any integral number of half waves, such as $\frac{2}{2}$, $\frac{3}{2}$, $\frac{4}{2}$, etc. The frequencies where these resonances occur will likewise be 2, 3, 4, etc. times the single half-wave frequency. The relation between the resonant frequency, the order of the harmonic, and the thickness has been given in paragraph 6.

10. For illustration, the frequency swept with the Sonigage using the 1.38 to 2.77 megacycles range corresponds to a single half-wave coverage in steel of .045 to .090". Now if the probe is placed on a sheet of steel .250" thick, three pips will be observed on the screen. (See Plate III, Fig. 1) From the relation $y = \frac{2ft}{N}$ the half-wave frequency for .250" steel is .5 megacycles, which is below the sweep range. However, at 1.5, 2.0, and 2.5 megacycles, which are in the sweeping range, the corresponding $\frac{3}{2}$, $\frac{4}{2}$, and $\frac{5}{2}$ resonances will take place. These pips will occur at the scale positions for single half-wave thicknesses of .0833, .0625" and .050" respectively. In like manner points may be determined for other thicknesses.

11. It is apparent that the thicker the material the more pips will show on the screen. For a thickness of .500" the $\frac{6}{2}$ to the $\frac{11}{2}$ resonances will appear. (See Plate III, Fig. 2) The diagonal dark lines on the transparent scale indicate the various multiples or harmonics. The lower diagonal corresponds to the second harmonic. Plate III, Figs. 1 and 2 and Plate IV, Fig. 1, show the use of the scale in indicating the thickness of sheet steel samples.

12. The manner of judging thickness by use of this scale is well illustrated on Plate IV, Fig. 1. Here there appear to be six pips. Two of these, the one at the extreme left and the one at the extreme right (both rather small) are not pips caused by resonance, but are merely markers. Hence they are not considered. The transparent scale has already been slipped (up or down) to the proper position for reading. Pip one (just to the right of the first dotted vertical line) intersects a black diagonal line at a point slightly below .40 on the left hand scale; pip two intersects the next lower diagonal at approximately the same scale height; pip three the next lower diagonal; and pip four the diagonal still below. An imaginary horizontal line drawn through the four points of intersection, and read where it crosses the left hand scale, indicate a thickness of .375. From the different diagonal intersects, the harmonics indicated by the four pips received are the eighth, seventh, sixth, and fifth.

13. For the application of the Sonigage to curved surfaces, General Motors has recommended the fabrication of extra probes equipped with curved quartz crystals. This means that a crystal must be provided to fit each radius of curvature to be examined. Such a procedure is warranted if the volume of work on a particular curvature justifies the expense and complications of producing the required curved crystal. Since, the excellence of the Sonigage indication is a direct function of the fit between the crystal and the surfaces being examined, if the radius of curvature varies slightly between individual samples or groups of units, a prohibitively large number of crystals may be required.

14. In order to overcome these difficulties, the Naval Research Laboratory has been investigating the possibility of inserting a thin "filler" between the conventional flat face of the crystal and the curved surface of the work. To be generally useful, such a filler must be easy to fabricate, provide intimate contacts with both the crystal and the work, and give good sound transmission over the operating frequencies of the Sonigage. Following a study of several materials, duralumin was selected for intensive investigation.

15. One such filler (shown in Plate II, Fig. 2) has one flat surface for contact with the flat crystal of the probe while the opposite surface is cut to the radius of the surface to be inspected. A retaining ring keeps the filler in place on the probe. It is imperative for good transmission, that its thickness be less than a quarter wave length for the highest frequency in the band used. These fillers can be readily turned out on a lathe and may be lapped to meet slight variations in curvature, a procedure not practicable if a curved crystal were used.

16. Plate II, Fig. 1 illustrates the use of the probe, with filler attached, applied to the inner concave surface of a section of a diesel liner. Plate IV, Fig. 2 and Plate V, Figs. 1 and 2 show the indications on the screen over various regions of this casting. The observer must visualize the horizontal line through the points of intersection of the vertical axes of the pips, projected if necessary, to meet the diagonal lines. For the indications shown in Plate V, Fig. 1, these intersections would occur at a height indicating (on the left hand scale) a thickness of .485". Thicker areas such as over the reinforcing ribs are readily discerned by the increased number of harmonic indications shown in Plate V, Fig. 2.

17. The average thickness of the filler, .035", is accounted for in the data shown in Plate VII A and B, which show the actual estimated thickness.

IV INSPECTION OF LINERS

18. In accordance with Ref. (b), on 14 February 1946 the Sonigage was carried to Portsmouth, Va. and set up on a massive steel bed plate in the center of Machine Shop 31 at the Norfolk Naval Shipyard. The liners were mounted on a balancing stand to facilitate revolving them during inspection. The machined finish of the inner surface of the liners required buffing of the areas to be inspected. Initially some trouble was encountered in getting good reflections due to lack of intimate contact through the filler with the liner surface. Lapping of the flat surface of the filler with a hand tool and lapping of the filler to the liner improved the image in proportion to the nicety of contact. In general, a thickness indication could be obtained within a square inch area where inspection was desired. Accurate location of reinforcing ribs and thicker end boundaries was shown by the increased

number of pips on the screen. Owing to experience gained and to a more intimate contact of the probe with the liner, it was possible to inspect the last few liners in from fifteen to twenty minutes each. While a separate room free from dust would have facilitated inspection, the tests as made demonstrated the serviceability of the Sonigage operating under general shop conditions. It may be added that the Sonigage functioned normally when a cutting hammer was in use within twenty feet of the instruments.

V DATA AND GRAPHICAL PRESENTATION

19. The location of points on the liners which were checked with the Sonigage are shown in Plate VI. Five representative points along the bore were taken at 90-degree stations on the circumference. The 0-degree station was chosen at the point where the serial number was stamped on the liner. A tabulation of the data taken is shown in Plate VII A and B.

20. Two graphical presentations for each liner inspected are shown in Plate VIII A to I. The ordinate, which represents the thickness of the liner in inches, is common to each set of graphs. The minimum allowable thickness (.250") is indicated by a broken line drawn at this value. Each graph on the left is a circumferential presentation, the abscissa depicting the stations on the circumference. For a perfect liner, the five lines should be horizontal with the spacing between lines determined by the taper from A to B.

21. The graphs on the right are longitudinal presentations, the points along the abscissa corresponding to the longitudinal inspection points A, M, B, C, and D. In this presentation, a perfect liner should have all points falling on a straight diagonal line, the slope of which would indicate the amount of taper from A to D.

VI DISCUSSION OF RESULTS

22. An inspection of the graphs suggests the following classifications for the liners inspected:

<u>Condition</u>	<u>Liner Serial Number</u>
Good	3969
"	987P
"	3912
"	5025
"	3929
"	5024
"	763J
"	5011
"	3939

<u>Condition</u>	<u>Liner Serial Number</u>
Appreciable core shift	3977
" " "	4036
Pronounced core shift	3947
" " "	758J
" " "	1513
" " "	6989
" " "	5020
Minimum allowable wall thickness (1/4")	4035
" " " " "	3926
Less than minimum allowable wall thickness	3947
" " " " " "	6989

23. With the exception of liner 1513, sufficient energy was reflected from the water-jacket surface to obtain thickness measurements at the desired inspection points. This indicated a relatively homogeneous surface free from pronounced pitting or included sand areas which, if present, would have scattered the beam and resulted in weak or no reflected energy. Considerable difficulty was experienced in inspecting liner 5024 because a carbon deposit became mixed with the oil used as a contact medium. This was the only liner to give trouble of this nature. The accuracy of the data presented is approximately 10%.

VII CONCLUSIONS

24. As a result of the tests at the Norfolk Naval Shipyard, the following conclusions may be made:

- a) The Sonigage, using a filler to adapt the standard probe to a curved surface, can indicate the thickness of a diesel liner wall.
- b) An indication of the concentricity of bore, or degree of core shift, may be shown by a proper choice of inspection points.
- c) The Sonigage is electrically and mechanically reliable, performing faithfully under general shop conditions.
- d) The water-jacket surface of the diesel engine liner is sufficiently smooth to give reliable reflections of a supersonic beam in the frequency range 1.3 to 2.7 megacycles.

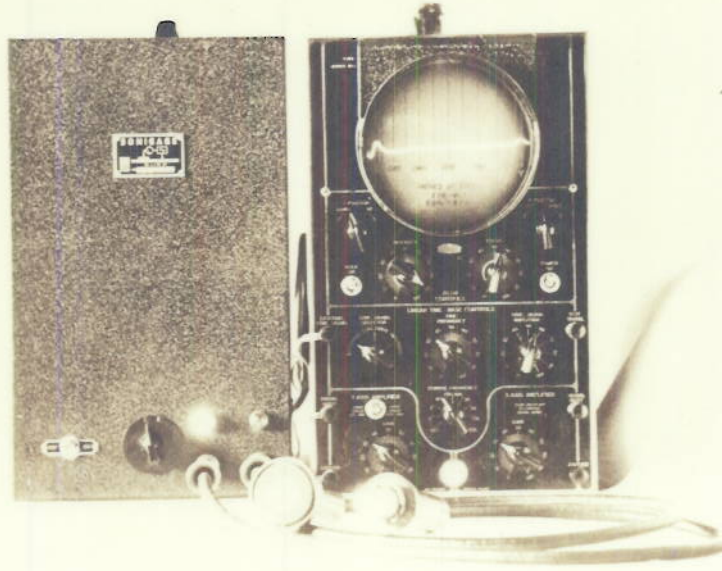


FIG. 1 SONIGAGE

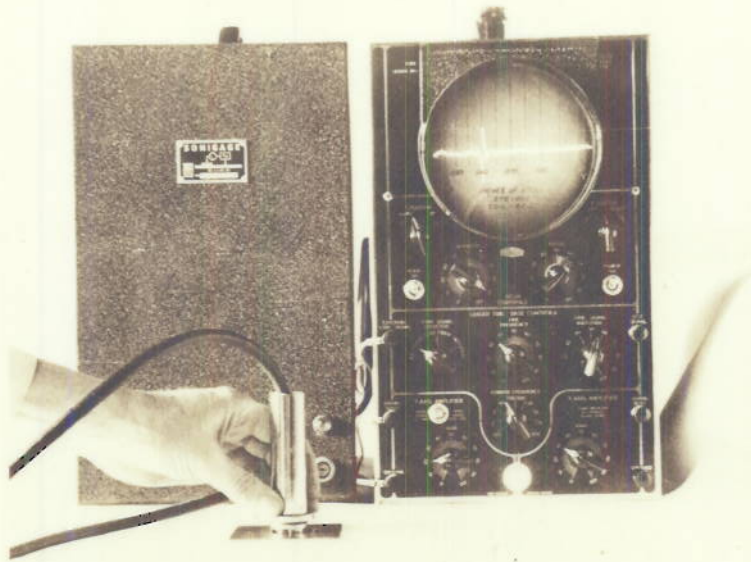


FIG. 2 SONIGAGE MEASURING .062" SHEET STEEL

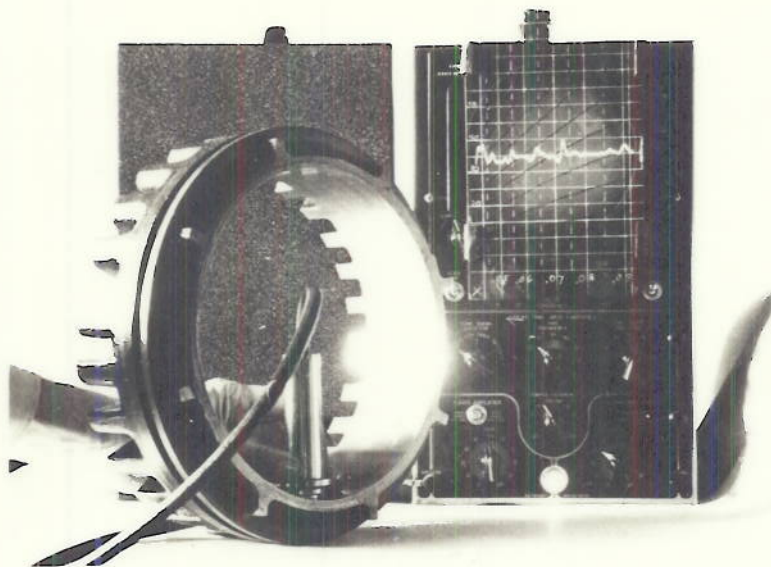


FIG. 1 SONIGAGE ADAPTED TO LINER INSPECTION



FIG. 2 DURALUMIN FILLER - ATTACHED TO PROBE

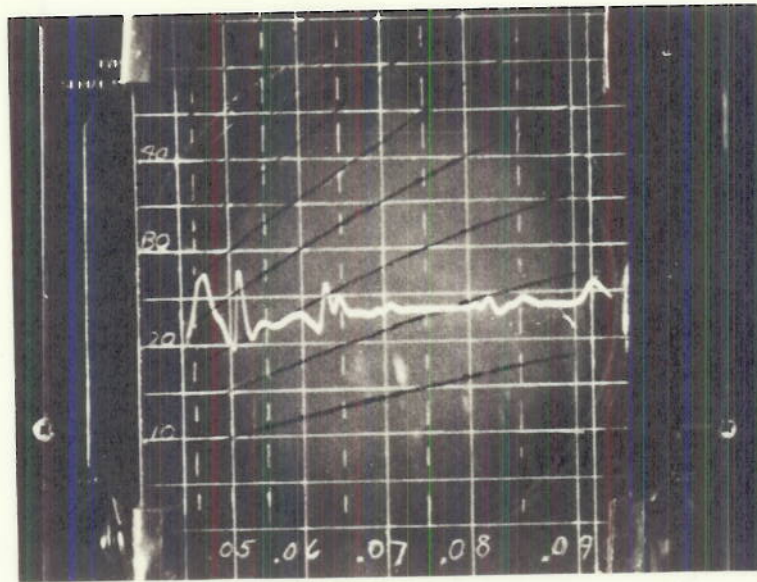


FIG. 1 INDICATION ON .250" STEEL PLATE

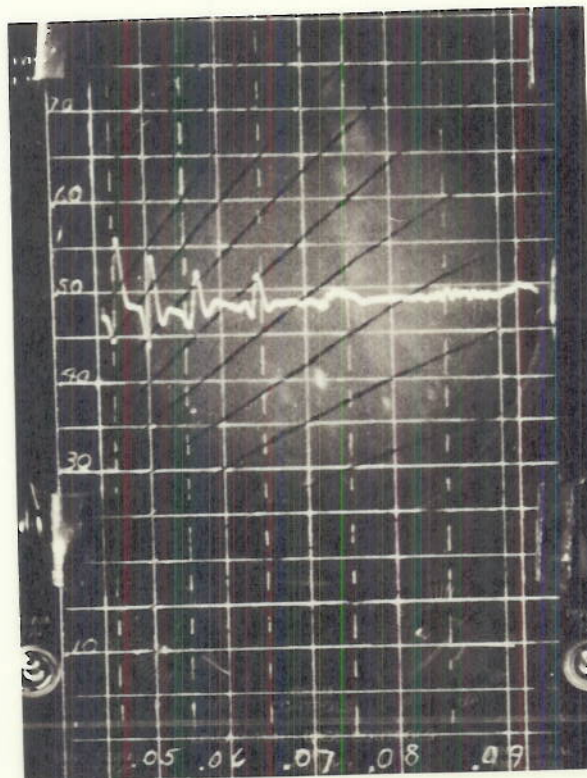


FIG. 2 INDICATION ON .500" STEEL PLATE

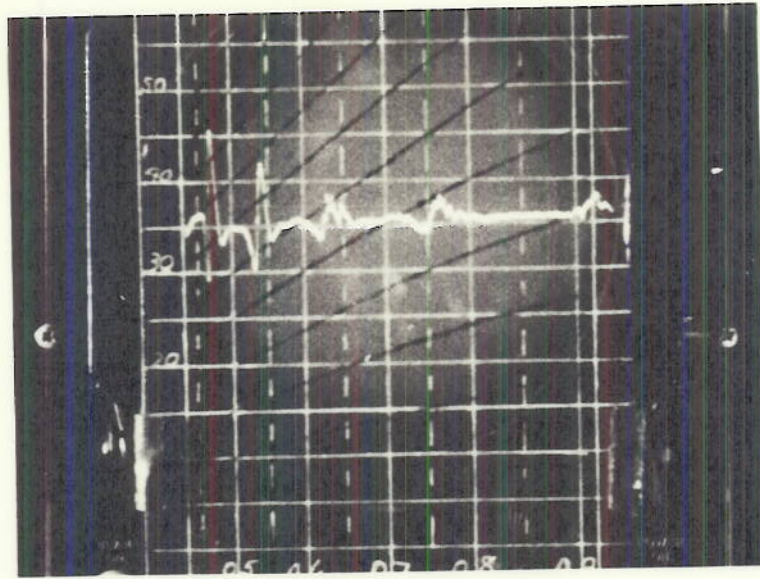


FIG. 1 INDICATION ON .375" STEEL PLATE

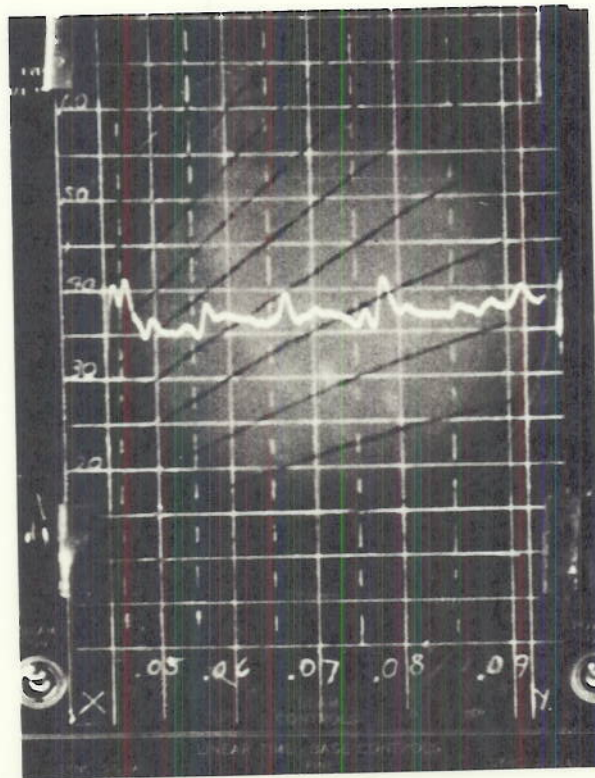


FIG. 2 INDICATION OVER .365" SECTION OF LINER
(WITH FILLER THICKNESS -.400")

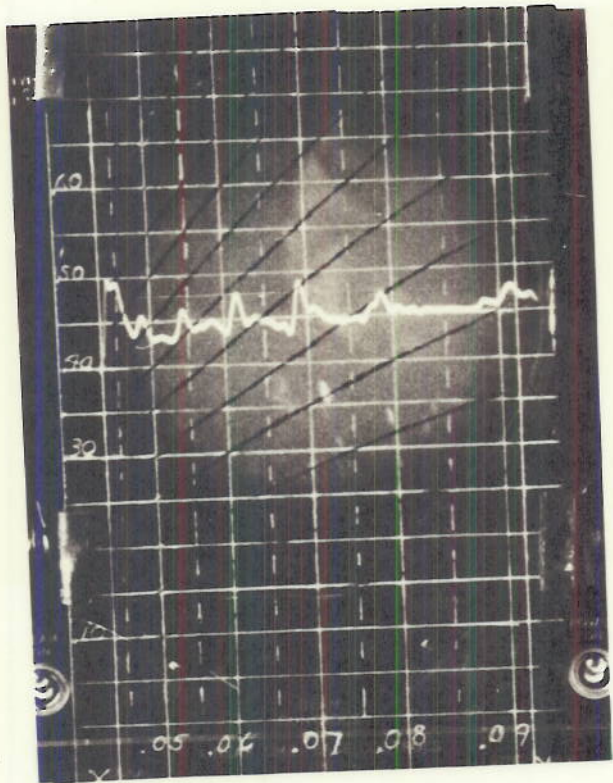


FIG. 1 INDICATION OVER .450" SECTION OF LINER
(WITH FILLER THICKNESS -.485")

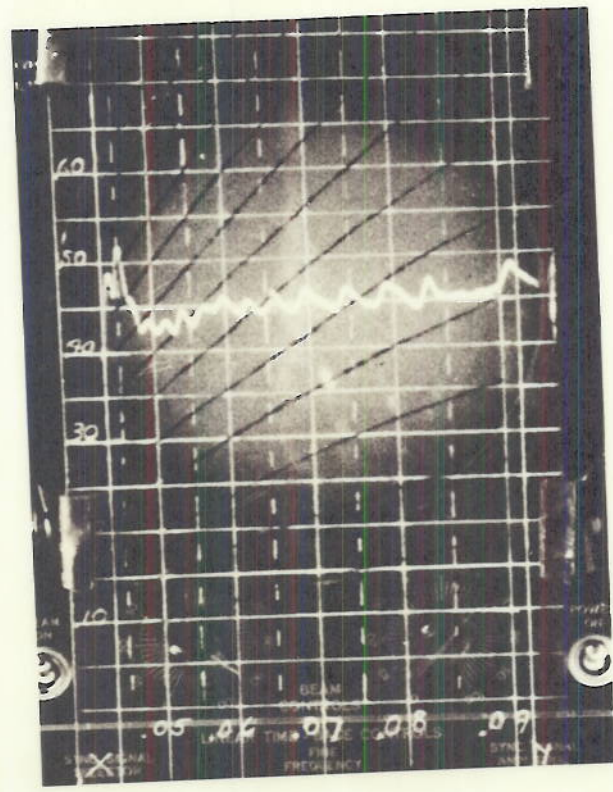
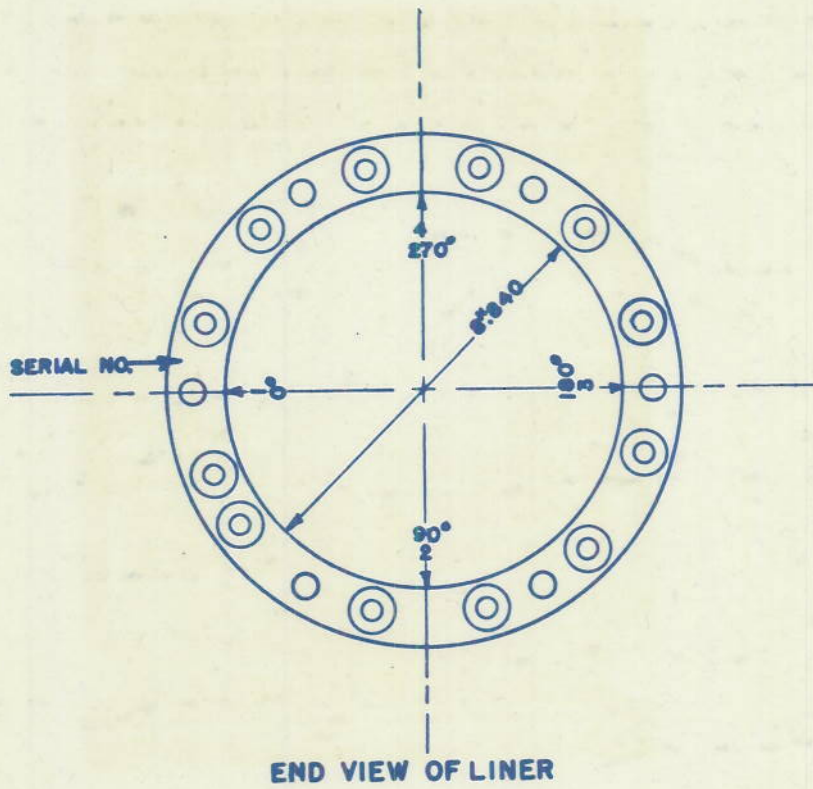
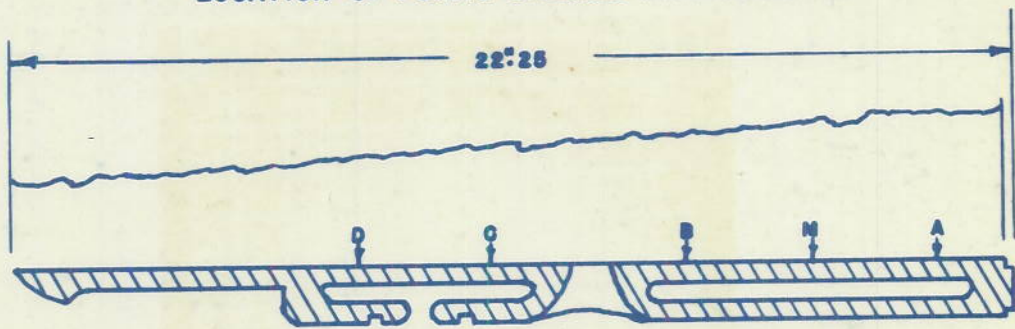


FIG. 2 INDICATION OVER RIB OF SECTION OF LINER

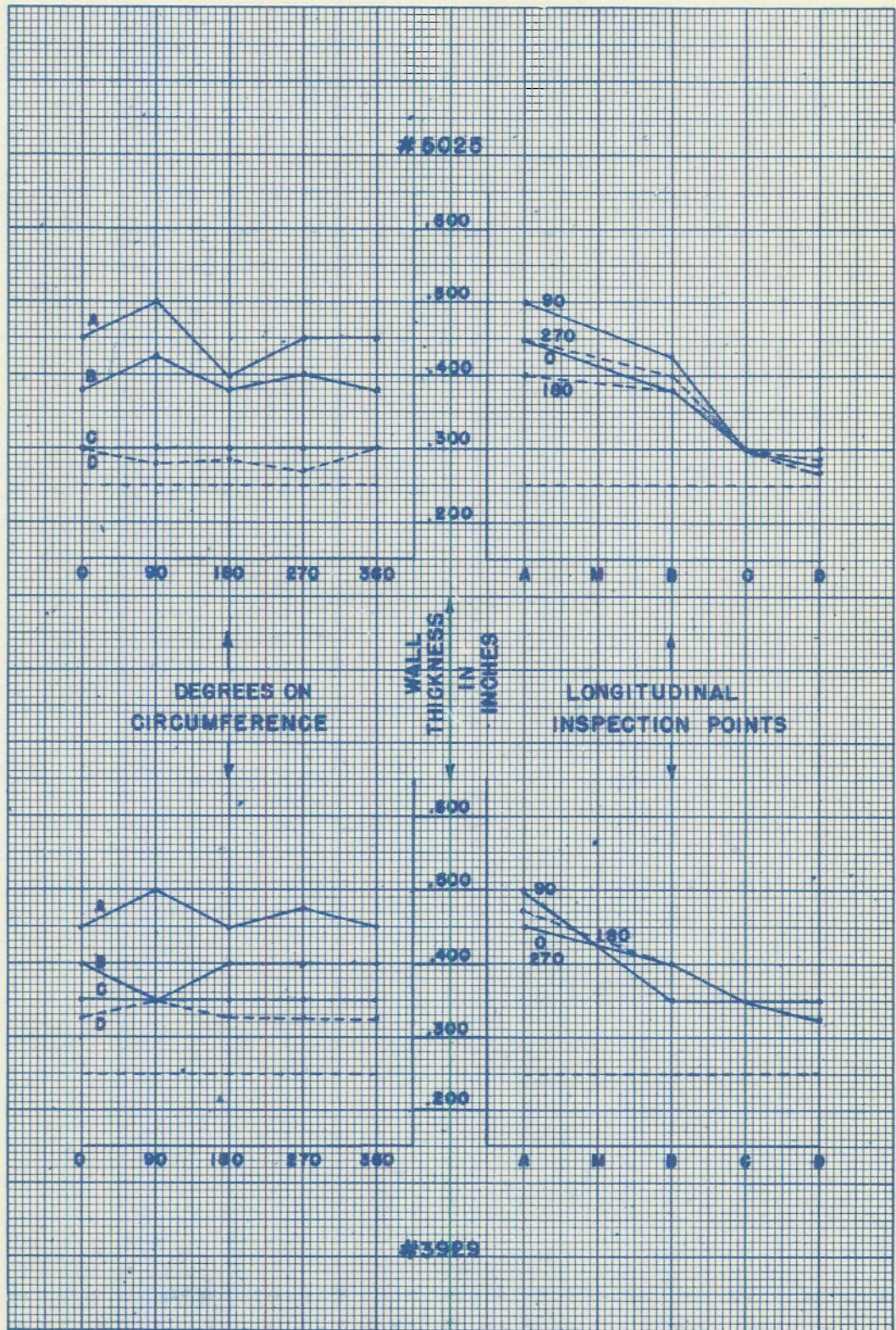


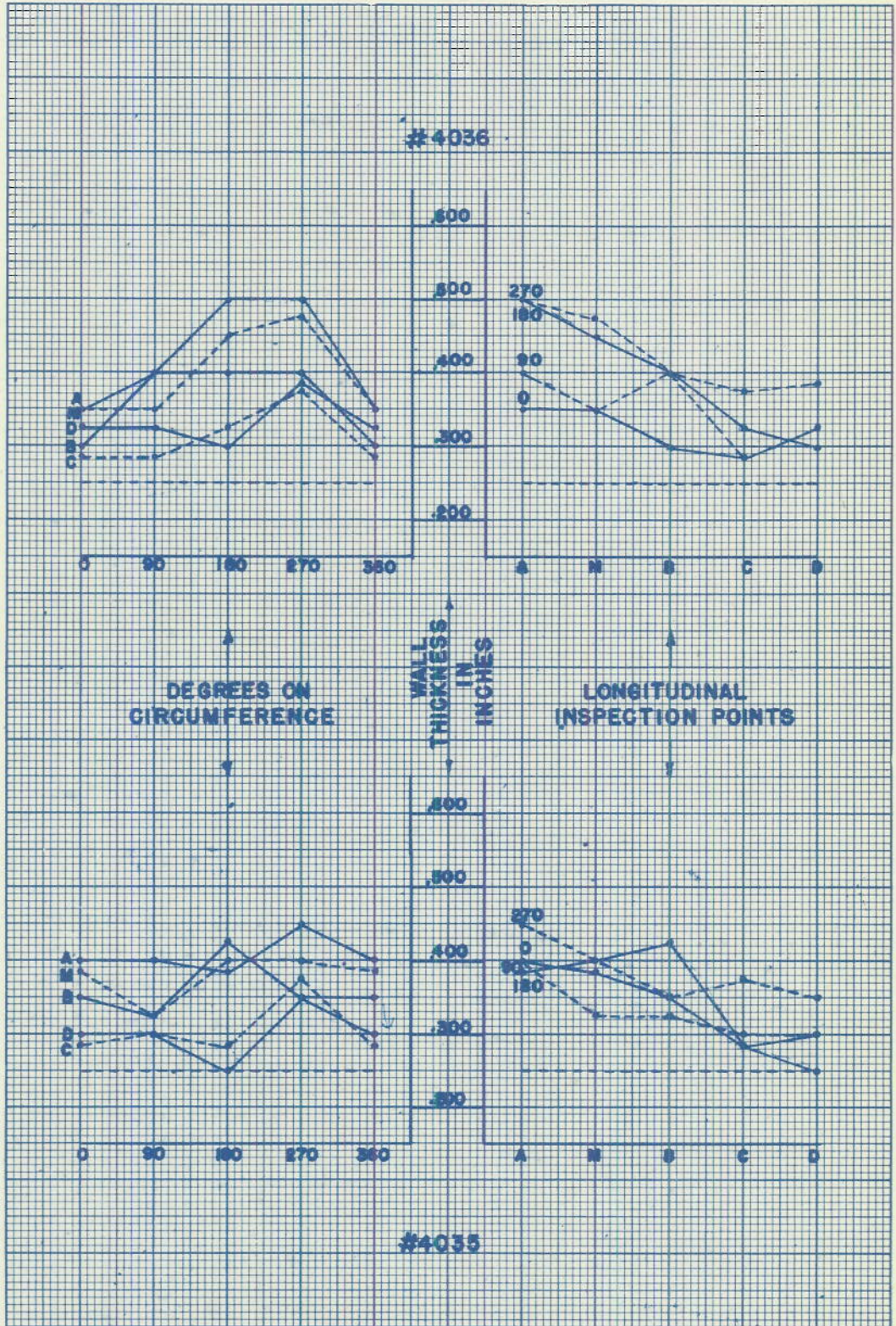
LOCATION OF POINTS CHECKED WITH SONIGAGE

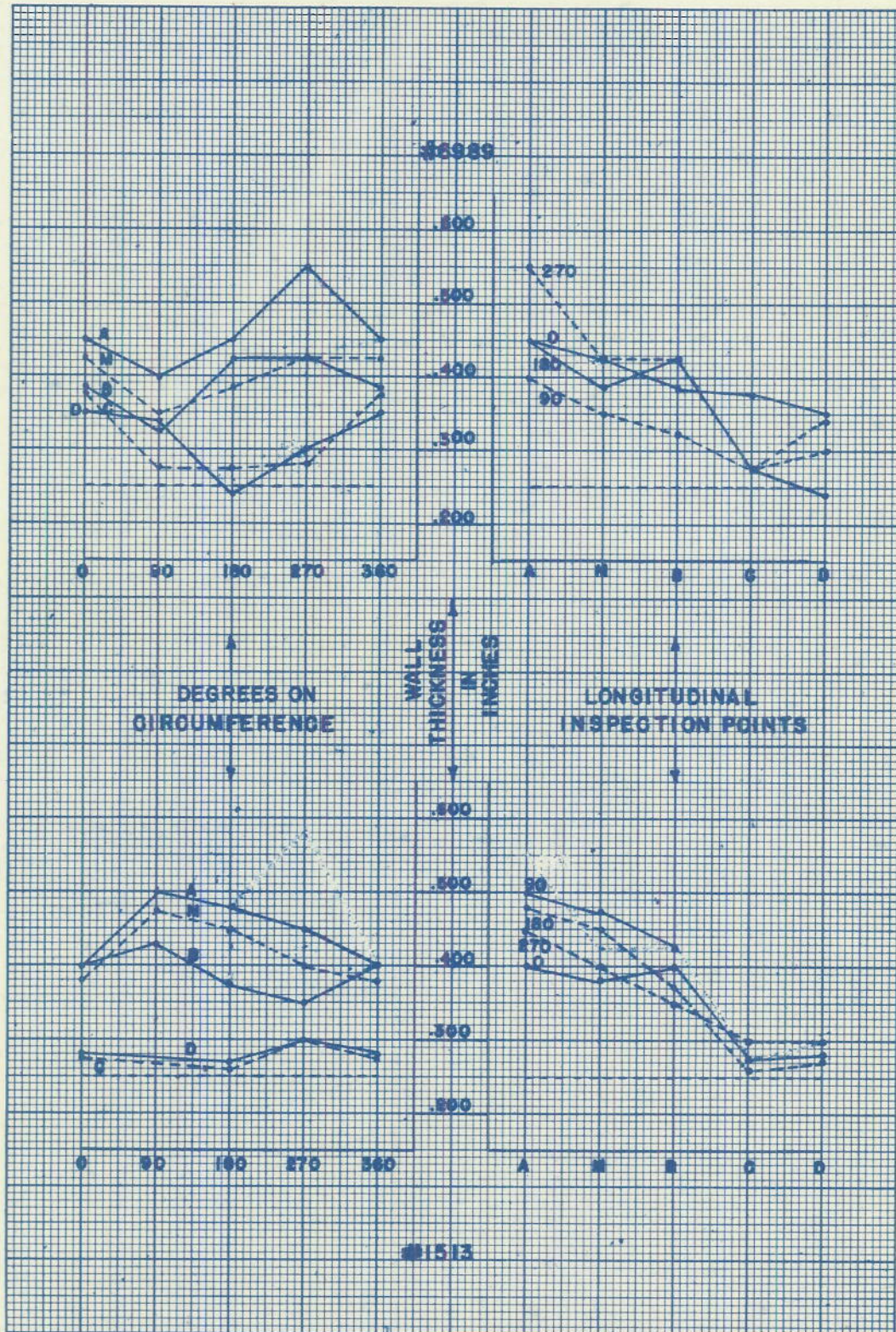


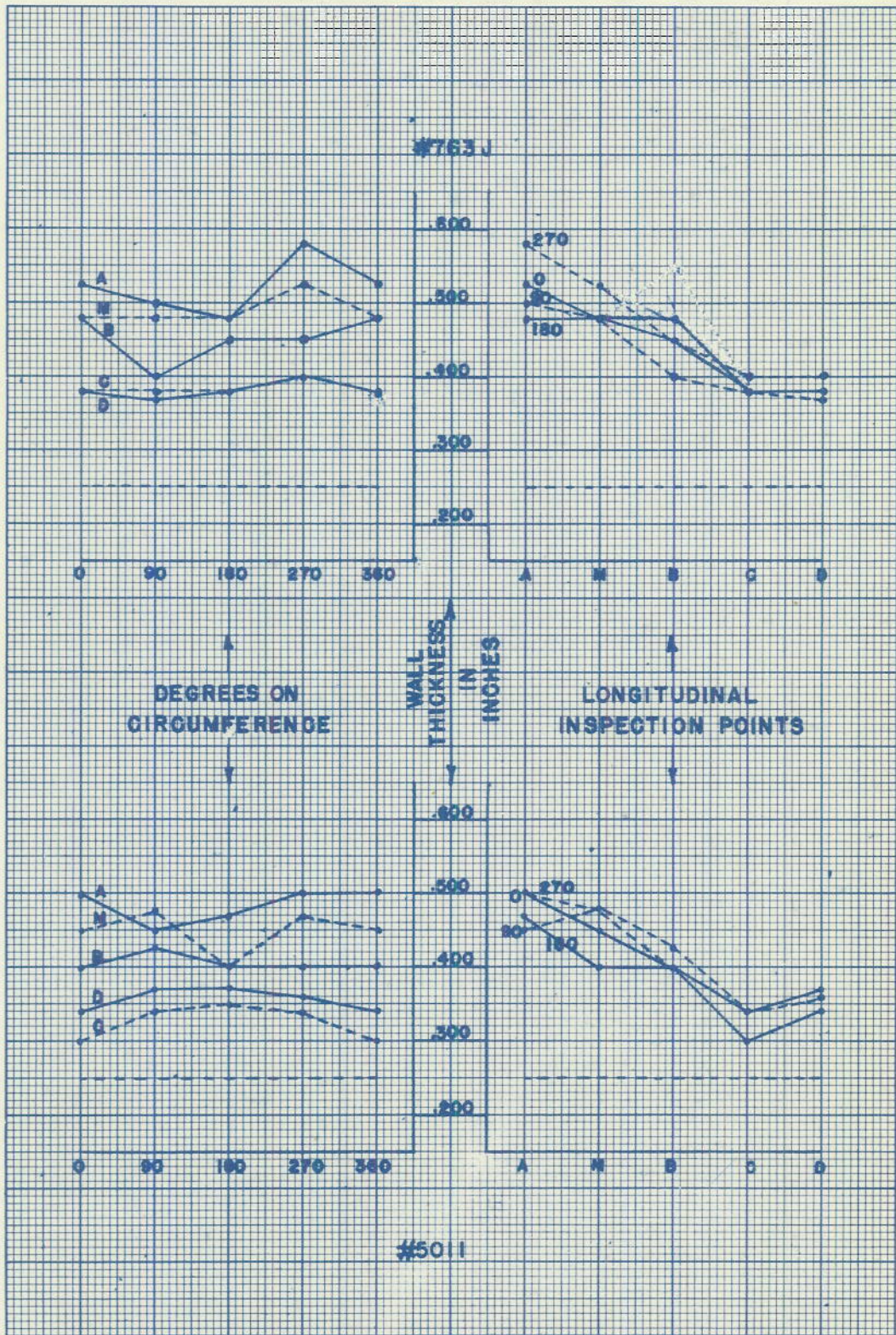
LINER SERIAL NUMBER	ORDER OF INSPECTION	DEGREES ON CIRCUM-FERENCE		LONGITUDINAL INSPECTION POINTS THICKNESS IN INCHES				
				A	M	B	C	D
7234	1			CHECKED	AT A EVERY 30°	0.475" TO	0.400"	
				CHECKED	AT B EVERY 60°	0.375" TO	0.300"	
5025	2	1	0	.450		.380	.300	.300
		2	90	.500		.425	.300	.280
		3	180	.400		.380	.300	.285
		4	270	.450		.400	.300	.270
3929	3	1	0	.450		.400	.350	.325
		2	90	.500		.350	.350	.350
		3	180	.450		.400	.350	.325
		4	270	.475		.400	.350	.325
4036	4	1	0	.350	.350	.300	.285	.325
		2	90	.400	.350	.400	.285	.325
		3	180	.500	.450	.400	.325	.300
		4	270	.500	.475	.400	.375	.385
4035	5	1	0	.400	.385	.350	.285	.300
		2	90	.400	.325	.325	.300	.300
		3	180	.385	.400	.425	.285	.250
		4	270	.450	.400	.350	.375	.350
6989	6	1	0	.450	.425	.385	.375	.350
		2	90	.400	.350	.325	.275	.340
		3	180	.450	.385	.425	.275	.240
		4	270	.550	.425	.425	.280	.300
1513	7	1	0	.400	.380	.400	.275	.280
		2	90	.500	.475	.425	No Indications	
		3	180	.480	.450	.375	.260	.270
		4	270	.450	.400	.350	.300	.300
763-J	8	1	0	.525	.480	.480	.380	.380
		2	90	.500	.480	.400	.380	.370
		3	180	.480	.480	.450	.380	.380
		4	270	.580	.525	.450	.400	.400
5011	9	1	0	.500	.450	.400	.300	.340
		2	90	.450	.475	.425	.340	.370
		3	180	.470	.400	.400	.350	.370
		4	270	.500	.470	.400	.340	.360

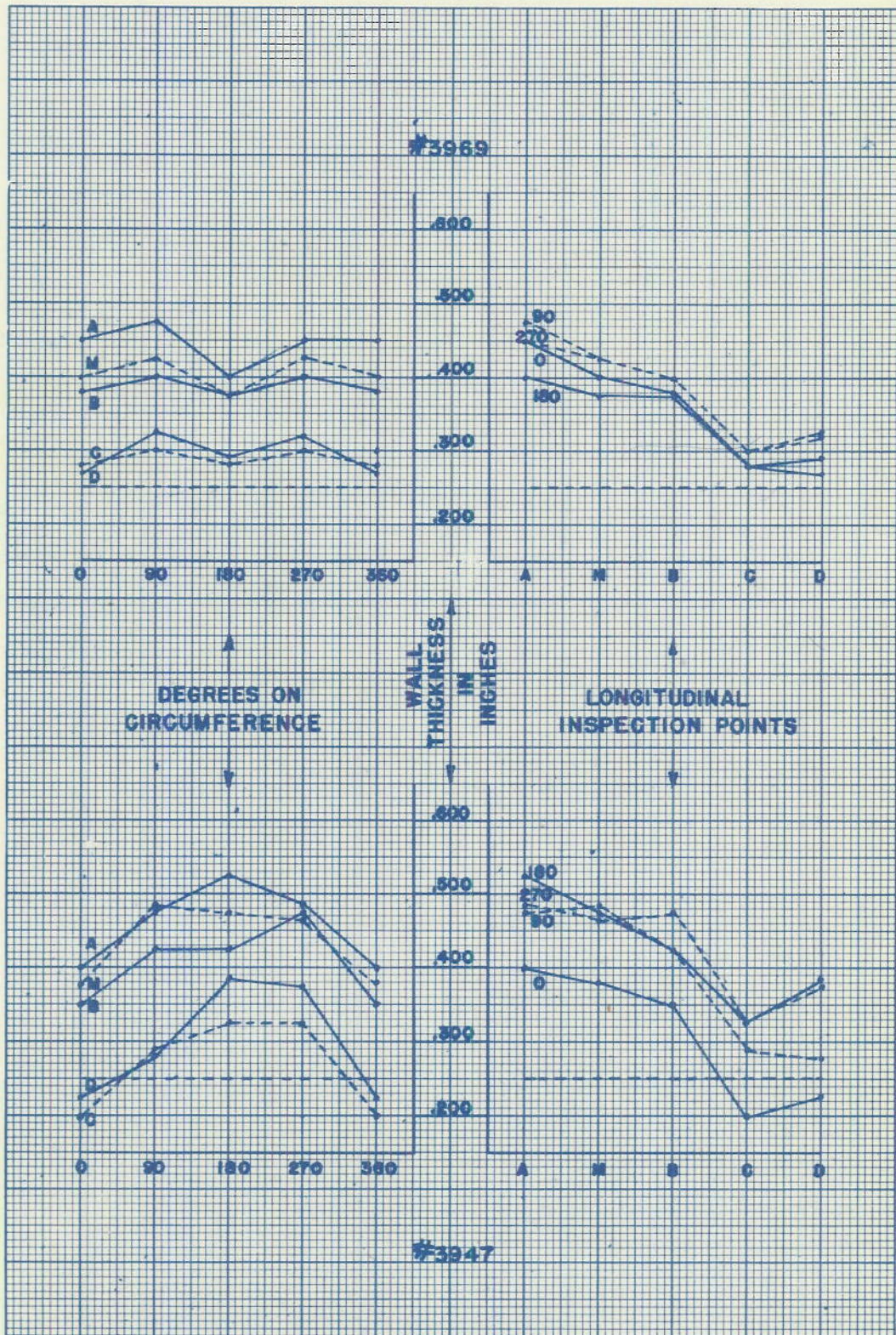
LINER SERIAL NUMBER	ORDER OF INSPECTION	DEGREES ON CIRCUM- FERENCE		LONGITUDINAL INSPECTION POINTS THICKNESS IN INCHES				
				A	M	B	C	D
3969	10	1	0	.450	.400	.380	.280	.270
		2	90	.475	.425	.400	.300	.325
		3	180	.400	.375	.375	.280	.290
		4	270	.450	.425	.400	.300	.320
3947	11	1	0	.400	.380	.350	.200	.225
		2	90	.475	.485	.425	.290	.280
		3	180	.525	.475	.425	.325	.385
		4	270	.485	.465	.475	.325	.375
987-P	12	1	0	.400	.410	.390	.300	.325
		2	90	.380	.380	.370	.320	.300
		3	180	.500	.425	.400	.320	.325
		4	270	.425	.400	.400	.300	.325
758-J	13	1	0	.380	.370	.340	.360	.380
		2	90	.480	.500	.450	.380	.380
		3	180	.525	.490	.440	.400	.380
		4	270	.520	.450	.480	.325	.380
3977	14	1	0	.380	.380	.370	.300	.330
		2	90	.480	.500	.480	.300	.320
		3	180	.480	.470	.450	.400	.380
		4	270	.450	.425	.420	.360	.380
3912	15	1	0	.470	.450	.425	.300	.325
		2	90	.500	.500	.480	.300	.300
		3	180	.470	.440	.420	.380	.370
		4	270	.450	.400	.400	.360	.380
5024	16	1	0	.440		.380	.280	.300
		2	90	.450	.440	.440	.270	.280
		3	180	.480	.460	.480	.360	.370
		4	270	.480	.460	.470	.320	.320
5020	17	1	0	.500	.480	.430	.370	.380
		2	90	.450	.440	.400	.330	.370
		3	180	.340	.300	.280	.380	.340
		4	270	.480	.450	.440	.310	.330
3939	18	1	0	.400	.370	.380	.280	.300
		2	90	.380	.360	.350	.280	.280
		3	180	.380	.370	.390	.260	.280
		4	270	.425	.420	.400	.320	.320
3926	19	1	0	.380	.325	.300	.270	.280
		2	90	.400	.380	.370	.300	.325
		3	180	.400	.390	.400	.250	.260
		4	270	.425	.400	.380	.325	.300

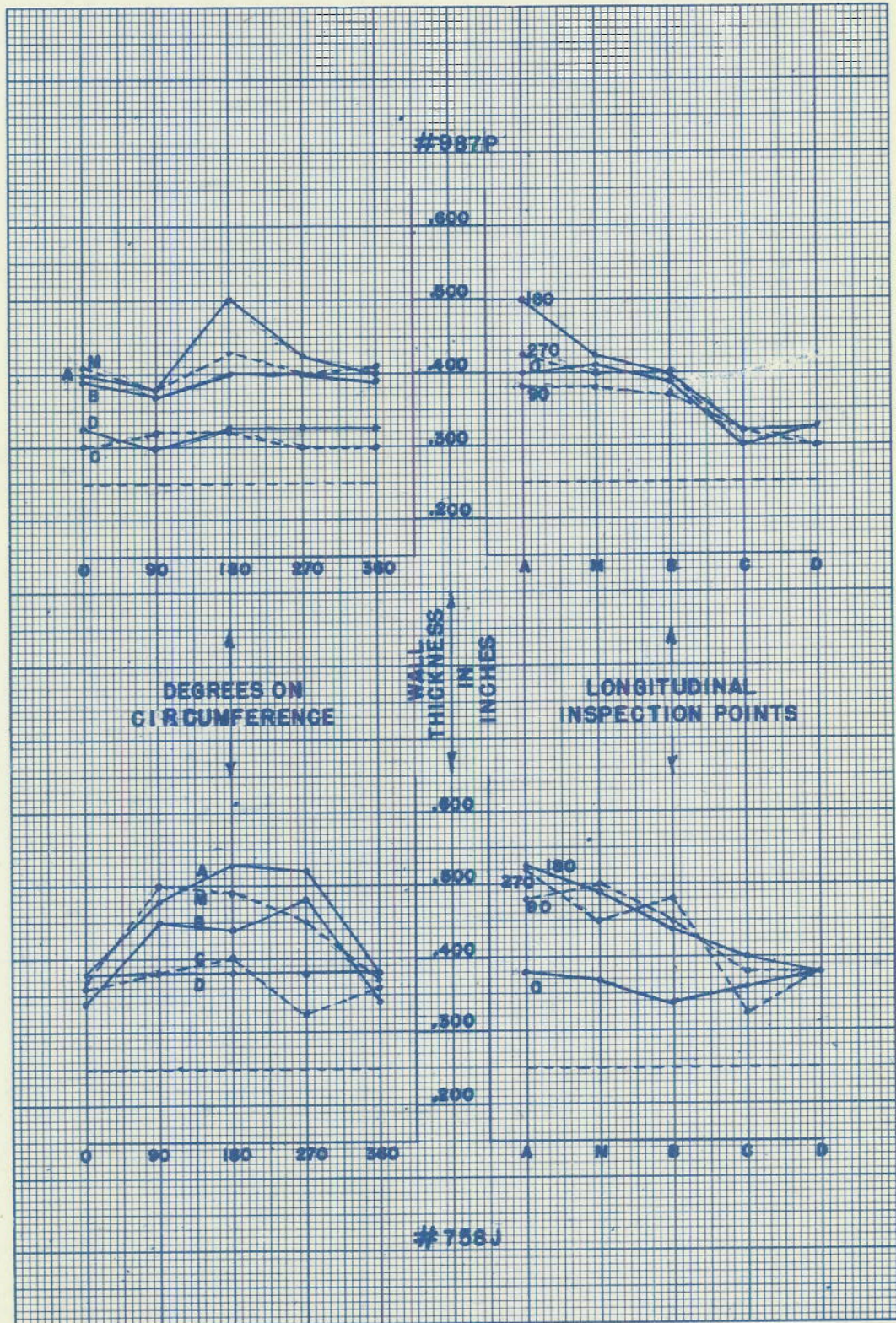




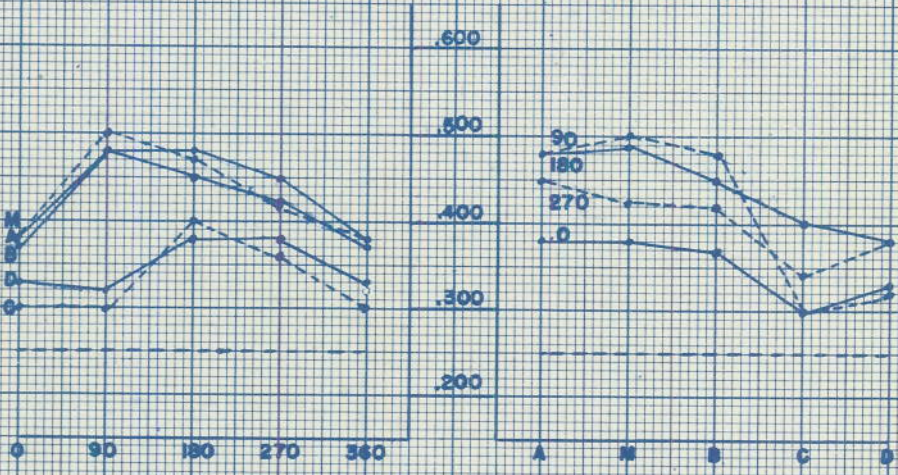








#3977



DEGREES ON CIRCUMFERENCE

LONGITUDINAL INSPECTION POINTS

#3912

