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EVALUATION OF BATHYTHERMOGRAPH MODELS OC-1C/S AND OC-2C/S.(U)

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EVALUATION OF BATHYTHERMOGRAPH MODELS OC-1C/S AND OC-2C/S

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253 550

THE PROBLEM

Evaluate preproduction samples of surface-vessel bathythermograph models OC-1C/S and OC-2C/S for compliance with specifications.

RESULTS

The sample models do not meet the existing specification requirements. Required design changes could easily be made.

RECOMMENDATIONS

1. Amend the equipment Contract Specification (MIL-B-15237B) to bring the requirements into more realistic conformance with the permitted design.
2. Improve the pressure elements to increase the bellows life and decrease the materials hysteresis and piston rod sticking.
3. Eliminate linear temperature error variation.
4. Eliminate interference of stylus and carriage.
5. Make grid lines not more than 0.002 inch wide.

ADMINISTRATIVE INFORMATION

This report covers work from May 1957 to 27 December 1957 and was approved for publication 24 January 1958. The work was done by members of the Engineering Division under BUSHIPS Problem ST-102 (NEL T1-46) assigned to the Navy Electronics Laboratory by BUSHIPS letter T1-46, Ser 848b-187 dated 8 June 1955.

The equipments were manufactured by the Triumph Manufacturing Company, Chicago 50, Illinois, under BUSHIPS Contract NObsr-64711, and were received at NEL on 27 December 1956. (Work loads then existing did not permit starting the evaluation until May 1957.) The same models were previously manufactured by Wallace and Tiernan, Inc., under BUSHIPS Contract NObsr-52104 and NObsr-63349.

The evaluation was conducted in accordance with Contract Specification MIL-B-1537B of 26 November 1954 and Military Specification MIL-E-16400 (SHIPS) of 1 May 1953.

The author acknowledges the advice and assistance of L. E. Weinert, T. G. Thompson, H. G. Kiner, and H. E. Sprecklemeyer.

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INTRODUCTION

This report covers testing of preproduction samples of bathythermograph (BT) Models OC-1C/S (200-ft) and OC-2C/S (450 ft), made by the Triumph Manufacturing Company, Chicago, Illinois, under Contract NObsr-64711. These two BT's, as well as Model OC-3C/S (900 ft), previously have been made by Wallace and Tiernan, Inc., under Contracts NObsr-52104 and NObsr-63349.

The general features of BT's are well known. The instrument is intended to make a permanent record of ocean temperature as a function of depth below the surface. A detailed explanation of the instrument is given in the instruction book.[1]

EVALUATION RESULTS

The applicable section or paragraph number of the Contract Specification (MIL-B-1537B of 26 November 1954) is shown in parentheses after the title of each test, unless otherwise indicated.

General Inspection

The equipments were inspected to assess their condition, as received, for compliance with Contract Specification MIL-B-15237B of 26 November 1954 and the general provisions of Military Specification MIL-E-16400 of 1 May 1953; and for similarity to the description in the instruction book. The samples match the description in the instruction book except for the stylus points and the direction in which the capillary helix is wound.

CONDITION AS RECEIVED

Two preproduction sample BT's and their accessories were received. The BT's consisted of one OC-1C/S (PP-1) and one OC-2C/S (PP-2). The accessories consisted of one mounted calibration grid for each BT, three swivels, one slide viewer, and 24 slides in an improvised box. The instruments were each mounted on eight Barry C1015-T4 shock mounts and some hair excelsior and sponge rubber. The mounting was much too stiff, since the capacity of the mounts was about 100 pounds compared to 26 pounds for the BT. There was no cushioning for endwise motion, and the instruments had dented the boxes on the ends. The pen lifters did not support the pens when the BT's were received. The pens were probably unsupported when shipped from the factory and should definitely be supported during transit.

WEIGHTS AND DIMENSIONS (3.3.1, 3.6.4, 3.6.5, 3.6.5.3, AND 3.6.8.1)

The weights and dimensions of the instruments conform to the specification.

FASTENERS

The samples use more varieties of fasteners than are needed. Both fillister and round head No. 10-32 screws are used on the body tube. The tail fins use No. 8 screws. Screws of two different heads are also used on the thermal and temperature elements for no apparent reason. Screw varieties should be minimized for simplicity of repair and smaller parts inventory.

SWIVELS AND SHACKLES (3.6.4, 3.6.8.10, AND 3.6.8.11)

The swivels and shackles conform to the specification except that the spare swivel jams under load and will not rotate. The jamming is due to excessive swagging of the swivel rivet. The production swivels should be checked for free action.

NOSE SLEEVE (3.6.4.1)

The sleeve weights as measured were 5½ pounds each, which is the minimum allowed by the specification. The sleeve weight is borderline and should be watched on the production models. Heavier sleeves would have increased the insufficient depths attained in the sea trials. The sleeves are secured by two setscrews that are so short they do not tighten on the nose, but merely engage shallow, oversize, flat counterbores on the nose piece by only one turn. The loose sleeves promote vibration in the BT during shipment and handling. Longer setscrews should be used and the counterbores should be deeper.

NOSEPIECE

The slotted screw that secures the swivel to the towing pin has a flush head the same diameter as that of the shank. Removal of the screw would be difficult when it is corroded. A fillister head screw should be used or the present screw should be longer so that the slotted head will protrude.

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[1] *Instruction Book for Bathythermographs OC-1C/S, OC-2C/S, and OC-3C/S (Bureau of Ships, NavShips 92, 127) 14 December 1953.*

PORTS

One or more additional ports are needed to drain the space between the nose piece and the base of the pressure element, which was found to stay full of water after the sea trials. The port in the stem of the thermal element casting that permits flow of water past the bourdon is ⅛ inch in diameter in the samples, but should be enlarged in size or number to promote circulation inside the instrument and reduce temperature lag.

MARKINGS

The temporary name and serial tags are aluminum and unsuitable for service. The only other marks that were found are on the sides of the pressure elements where they cannot be seen on the installed element. The BT's were mixed during the sea trials because of the lack of markings. Marks giving the model and serial numbers should be made on the thermal elements, pressure elements, and body tubes to prevent mixing of parts and thus affecting the calibration. All marks should be visible without removing the thermal or depth elements.

THERMAL ELEMENT (3.6.3.1)

1. The end of the stylus protrudes beyond the scriber and interferes with the piston head on both samples before the pressure stop operates. The stylus should not extend beyond the point, and the carriage should not protrude above the surface of the slide between 30°F and 90°F where the arc of the stylus carries it near the piston head.

2. The stylus points consist of brass studs with conical alloy points. The radii of curvature of the points are several thousandths of an inch. In the various tests the points gave traces about 0.002 inch wide, which were sharp enough for 0.1°F accuracy except when smoke would stick to the point. It is doubtful if alloy points will remain sharp enough in service. The jeweled phonograph needles used in the Wallace and Tierman models would be preferable.

3. During the transient response test it was noticed that the PP-1 stylus did not have plane motion, but undulated toward and away from the graph paper. Bourdon tubes with such behavior should be either corrected or rejected, since such motion requires increased stylus point force which increases the hysteresis and does not comply with the specification. It is also very important to be sure that the stylus moves in a mean plane that is parallel to the slide. This should be done by rotating the thermal element, not the pressure element carriage.

4. The bourdon is connected to the stern of the capillary helix. The stern connection requires extra tubing which is poorly ventilated and impairs the transient response. The bourdon should connect to the forward end of the helix. This matter is discussed in connection with the transient response test.

5. The helix has been wound toward the rear of its form, probably because the protective fin cage is too small for the form at the forward end. The helix should be wound toward the front in order to give better ventilation and allow a shorter winding form. The change will require relieving each fin at least ⅛ inch each. The fins already rub on the capillary helix in the samples.

6. The capillaries have some bends and mild kinks between the helices and bourdons that should be avoided in the production models.

7. In one sample the capillary tube to the bourdon tube is not bent to lie in its slot between the body tube and thermal element casting. When the BT is being assembled the tube can be nicked if it does not lie in the slot.

8. The bourdon axis does not have slotted ends for easy adjustments. The vee slots for receiving the rod are not shallow enough to insure repeated tightening.

9. The two rods that support the pen lifter are a force fit in the tail piece casting. Better quality control can be achieved by using threads, since they cannot unscrew in this application.

10. The plug at the stern of the capillary cage should be soldered in place to improve durability.

11. The twelve riveted straps in the capillary cage have been bent over a sharp edge. They should be bent over a rounded edge to avoid nicks and increase the bend radius.

PRESSURE ELEMENT

1. The temperature-reference pins on the carriages are ¼ inch longer than needed and one of them is so near the edge of the carriage that the hole has broken out of the edge and the protruding pin has been filed down. The holes should be drilled at least 1/16 inch from the edge with slanted direction to prevent the pins from breaking out. A little nick can be filed in the pin to prevent the slide from climbing up the slide.

2. The stock numbers are on the side of the element, but should be on the base for visibility in the assembled BT.

3. Protective paint should be applied to the solder joints of the bellows, the evacuation tube, and pen lifter adjustment to prevent corrosion of the solder. There was noticeable corrosion during the tests.

SLIDES (3.6.8.1)

The slides conform to the specification. They are described more fully in the General Discussion.

GRIDS (3.6.8.2)

1. The layout of both the PP-1 and PP-2 grids is good. However, the PP-1 (fig. 1) must be considered unacceptable because the lines, which vary in width from 0.0025 to 0.0045 inch, are much too wide for reading to 0.1°F. The calibration trace is nearly hidden. Wide grid lines can be caused by wide harp lines, shadows, or overexposure.

The PP-2 grid (fig. 2) is satisfactory; its lines are thin (0.002 inch and less) as a result of underexposure. In the interest of accuracy, it is preferable to err on the thin side rather than the thick, and underexposure is a means to this end. However, the grid-making apparatus should be improved to make thinner lines without underexposure. The names of the grid units should be applied to both axes when there is room.

2. The PP-2 grid came loose during use, probably as a result of insufficient cement. It was recemented with very thin shellac, but came loose again. Better cements, such as epoxy resins, should be used, rather than cement.

3. The screws for mounting the grid holders to the viewer are missing. They should accompany each mounted grid. The countersunk holes on the grid holders require both flathead and fillister head screws. The countersinks should require only one type of head.

4. The temperature reference eccentrics do not seat flush with the grid holder as they should, and contact the slides on only about 0.02 inch of their thickness. This criticism also applies to the groove under the depth reference edge. The groove can be reduced from 0.02 to about 0.005 inch in thickness and still relieve the grid.

Calibration Tests

TEST PROCEDURE

The BT's were separately tested while suspended nose down with tail fins and nose removed. The water in the calibration tank was heated by an immersion heater, cooled by a closed heat exchanger, and agitated by a pump, with all units inside the tank. The pressure was controlled by needle valves from a tank of compressed nitrogen.

The temperature was measured to 0.02°F by a platinum resistance thermometer and a calibrated Mueller-type Wheatstone bridge.

Pressures below 100 psig were measured by a mercury manometer to 0.2 psi. Pressures above 100 psig were measured to 0.5 psi by a dead-weight gage with balance beam and motor-driven weighing piston. The manometer was corrected for temperature. The pressures corresponding to ocean depths at the slide carriage were calibrated for 29.92-inch barometer, gravity at 45 degrees latitude, and sea water at 35 per cent salinity and 55°F (0.4450 psi per foot of depth).

PP-1 TEST (3.5, 3.5.1, 3.6.3.3, AND 4.2.2)

The two tests of the PP-1 produced traces similar to figure 3. Both tests were interrupted by failures of two successive immersion heaters. Figures 4 and 5 show that the temperature and depth errors exceed the specification limits of 1 per cent of full depth and 0.2°F between 34°F and 90°F. The average errors for the two tests vary by 0.3°F and 1.5 feet of water. The stylus probably suffered a change of adjustment between tests. The pen lifter operated at 60 feet as required by the specification.

Temperature hysteresis was measured by approaching given temperatures from values 1°F lower and 1°F higher at the same pressures. In nine of twelve cases the hysteresis was 0.09°F, and the maximum value was 0.13°F, meeting the 0.1°F requirement. The temperature hysteresis was largely caused by stylus friction on the slide and consequent stylus flexure. Pressure hysteresis, similarly measured, was satisfactory, being 1 per cent of full depth or less in six out of six cases.

PP-2 TEST (3.6.2.3)

The bourdon tube was adjusted before the initial calibration check was made in order to put the 60°F point in the middle of the smoked slide. The adjustment was an error because it changed the average temperature error and also because 64°F or higher should be centered on the slide to comply with the 28° to 100°F requirement.

After the adjustment the calibration was checked from the trace of figure 3 and another trace, and plotted in figure 6. (The slide and grid were not properly aligned when figure 3 was taken.) Test No. 1 was conducted with increasing temperature and Test No. 2 with decreasing temperature. The plot shows the average error after correcting for the 3°F adjustment. The original temperature calibration did not meet the specification because the error varied over a span of 1.2°F between 30° and 90°F. The depth errors were 2 feet and less, meeting the 1 per cent limit of 4.5 feet. The pen lifter operated at 60 feet. Hysteresis data were not obtained during calibration because of the close test scheduling. The sea trials and pressure-element tests give some hysteresis information, and the vertical spread of the points in figure 6 indicates the variation of temperature error for repeated measurements.

ANALYSIS OF CALIBRATION TESTS

The calibration errors in the as-received condition were caused by changes in transit, the factory calibration, and variable behavior of the BT's. The errors can be grouped as "zero" (average) errors, linear errors, and random errors.

The average temperature and depth errors for the PP-1 were probably increased during transit, as was shown by the 0.6°F calibration shift caused by shock and vibration tests in a previous evaluation.[2] Such simulated transit and handling tests were contemplated for the present samples, but were dropped to save time.

It is important to note that the effective weight of the moving parts of the PP-1 element is sufficient to cause a 2.8-foot depth error merely by inverting the element. This fact suggests that the depth errors of figure 5 are greater by 1.4 feet because the sample BT's were calibrated in the nose-down position instead of the horizontal towing position. If this correction is applied, the PP-1 depth calibration in figure 5 meets the 1 per cent requirement.

The factory calibration errors appear as systematic variations over the grid range. Figures 4 and 6 show similar slopes, indicating calibration error. The vertical line segments indicate isothermal traces on the temperature calibration plots. The isotherms read from 0.1 to 0.2 higher at full depth than at sea level in four out of seven cases for PP-1 and six out of seven cases for PP-2. This was probably caused by stylus flexure. The slope of figure 5 suggests a linear calibration error. The systematic errors are more serious than the average errors because they change the shape of the traces and cannot easily be corrected.

The scattering of points in figures 4, 5, and 6 is due to calibration errors and variable BT behavior such as materials hysteresis, vibration, friction, and compliance. In figures 4 and 6, the spread of points at any given temperature prevents 0.1°F accuracy for the samples regardless of the calibration.

Bathythermograph calibration performance is sensitive to the excellence of the grid, smoke coating, stylus point, stylus motion, and carriage-stylus alignment. The information gathered on these interrelating factors during the various tests appears in the report of inspection of the components and in the General Discussion.

Sea Trials (3.3, 3.3.2, and 3.6.1.2)

The BT's were lowered by free-wheeling winches from booms 12 feet above the water at 13 knots, the highest available speed. The BT's were required to tow and dive smoothly up to 20 knots and obtain a permanent visual record.

The depths reached were similar to those of table 1-1 of the instruction book.[1] The PP-2 sample dived as deep as 410 feet at 13 knots with 1100 feet of *line out* (fig. 2).

The BT's were interchanged on the first two lowerings because of a lack of identification markings. The PP-1 dived to about 400 feet, receiving an overpressure test in excess of the 250 feet (125 per cent) specified, but not in excess of what it can be expected to receive in service. The stylus went off the bottom of the slide on this occasion. Although the PP-1 passed the test at the time, troubles developed during the pressure element tests. The PP-1 showed about 4°F difference between the up and down traces, which was found to be caused by an accidental bend in the stylus during reassembly after the thermal response tests, resulting in excessive pressure on the slide and much stylus flexure.

The traces of figure 2 have about 0.3°F hysteresis. The trace of decreasing depth is marred by stylus

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[2] G. D. Shipway *Evaluation of Modified Preproduction Model Surface-Vessel Bathythermographs OC-1C/S, -2C/S, and -3C/S (Wallace and Tiernan, Inc.); Service Test Report* (Navy Electronics Laboratory, Report 304) 11 April 1952.

vibrations excited from the ship, cable, and currents of water around and through the BT. Figure 2 is representative of a BT in good working order.

Temperature Element Tests

TRAVEL (3.6.2 AND 3.6.2.3)

The specification requires the stylus to cover the full slide length (1.75 inches) from 28°F to 100°F. The sample elements cover only 1.3 inches as computed from the calibration grids. It is desirable to increase the travel to at least 1.6 inches in order to reduce temperature errors by about 20 per cent. The travel can be increased by using 8 feet more capillary tubing, by enlarging its inside diameter only 10 per cent, or by using a more responsive bourdon tube. The present capillary length is 42 feet, which meets the specification.

TRANSIENT RESPONSE (3.4.1)

The tests were conducted with the element mounted between a movie camera and a piece of graph paper. The camera recorded stylus position to 0.005 inch at a synchronous speed of 24 frames per second. The specification requires that the stylus shall move smoothly through two-thirds of the travel in less than ½ second when shifted rapidly from water at 85°F to 40°F.

The first test was designed to obtain rapid temperature change by stabilizing the capillary in a 40°F beaker and then dropping the beaker and flooding the element with a hose of water at 85°F. The order was reversed according to the specification because a large supply of 40°F water was not available. Three trials of each element were made, and the exponential plots were obtained. The best performance for each element was 0.7 second at 2/3 travel. The test was then re-run, using two beakers and the 85°F water first. The times at 2/3 travel ranged from 0.35 to 0.43 second for PP-1 and 0.38 to 0.50 second for PP-2.

The difference between the hose and the beaker tests might be due to inadequate flooding by the hose. The hose test was intended to simulate service conditions closely, and when it is perfected will give a more realistic test than the two beakers.

The two tests also differed in the manner of applying the temperature change in relation to the connection of the bourdon to the helix. The bourdon on the sample elements is connected to the after end of the helix. The xylene is therefore set in motion more rapidly when a beaker is placed over the after end than when the helix is flooded forward to aft. The sample construction does well in the beaker test but will not work as well in service because the temperature change will hit the forward end of the helix first. The bourdon should be connected to the forward end of the helix.

Pressure Element Tests

The pressure elements were tested base down in a water-filled tank at room temperature. Pressures were measured to 0.2 per cent of depth by the manometer. The slide-holder position was measured to 0.001 inch by a traveling microscope through ports in the chamber.

TRAVEL (3.6.1.1)

The travel was measured from zero to full depth. The PP-1 moved 0.693 inch and the PP-2 moved 0.689 inch. The travel of both elements is within the requirement of 0.67 to 0.73 inch.

TRANSIENT RESPONSE (3.4.2)

The transient response of both elements was checked by venting the gas in the system from full to zero depth through a solenoid valve. Full travel occurred in less than 1 second, meeting the requirement of 2/3 travel in 5 seconds. Later inspection confirmed that the piston rod bushings are vented to the bellows chamber to prevent transient pressure differences in the element.

PP-1 HYSTERESIS

The loop hysteresis, consisting of piston-rod friction and materials hysteresis, was found by measuring the positions of the slide holders from a slight vacuum to full depth and back to sea level. The point hysteresis, consisting almost entirely of piston-rod friction, was found by approaching given pressures from depths both lesser and greater by one or two feet of water. The data also determined the linearity.

Figure 7 shows the loop plots, which give the departures of the data from a straight line fit. The curves of increasing and decreasing pressure show four points where the element appears to have jammed. The element was also seen to jump about 0.01 inch (1.5 per cent of full travel) on two occasions during the test between 10- and 40-foot depths. A jump of 0.01 inch corresponds to a 2.6-pound breakaway force. A later examination showed that the spiral groove on the piston rod would catch on the edges of the bushings if a small lateral force was exerted, such as might be expected from a slight eccentricity of the spring. (It is almost impossible to make the spring force concentric with the piston rod.) The snagging of the groove might have caused the peaks of the curves. If the peaks are ignored, the loop hysteresis assumes a regular shape with a maximum of 1.3 per cent. The loop hysteresis is excessive.

The point friction was measured at the same pressures as the loop hysteresis and was less than 0.5 per cent, or 0.25 per cent each way, corresponding to a 0.4-pound drag. The bushing friction during an ocean drop would be smaller because the pressure would vary smoothly instead of stepwise, as it did in the test. The point friction values were unaffected by snagging of the piston rod spiral because the observed friction values were smaller than the pressure changes that were used to produce them, and therefore the element was not snagging on the spiral.

PP-1 LINEARITY

The standard BT calibration grid uses equally spaced arcs of constant pressure. In order to calibrate the BT to 1 per cent of full depth, the pressure element must be sufficiently linear to allow fitting a straight line to the data to 1 per cent or better. Nonlinearity of the element is the result of materials hysteresis and variable spring and bellows compliances.

The curves in figure 7 show that the hysteresis and compliance variation opposed each other during the trace of increasing depth, causing it to be quite straight (within 0.6 per cent and better) and the trace of decreasing depth to be noticeably curved (within 1.3 per cent). Therefore, readings of either increasing depth or of an average of increasing and decreasing depths will best meet the 1 per cent requirement.

PP-2 HYSTERESIS

A full-depth loop test was made on the element, but the readings extended to only 44 per cent of full depth, which was the limit of the manometer. The curves appear in figure 8 and are similar to figure 7. The point friction was not measured. The maximum loop hysteresis is about 0.50 per cent. Abnormal friction shows only on the curve of increasing depth and is about 0.3 per cent. The element was not seen to jump during the test.

OVERPRESSURE STOP

The overpressure stop was checked after the PP-1 stylus left the slide during the sea trials. The slide carriage positions were measured at full depth and at maximum travel. Both elements overtraveled about ⅛ inch before hitting the stops. The overtravel is excessive because the stylus can leave the slide (as it did in the PP-1 sea trials) if the calibration grid is located low on the slide. The overtravel need not be large because the element is not likely to shorten during its life.

ACCELERATED LIFE AND OVERPRESSURE (4.2.3, 3.3.3, and 3.6.1.2)

The specification requires the elements to withstand 100 full depth pressure cycles and 125 per cent of full depth pressure without permanent deflection or other damage. The PP-1 sample was accidentally dropped to 200 per cent of full depth pressure during the sea trials. The excessive pressure did not cause failure at the time. During the life test the bellows cracked at the 23rd cycle, and the element filled with water. The element had received about 35 cycles in previous tests, giving 60 cycles at failure in addition to those received at the factory. The test was continued to the 43rd cycle to make the cracks more obvious. The cracks found were on the second and sixth outer folds from the base, as shown in figure 9.

The PP-2 failed the overpressure test, which was run before the life test. The pressure used was only 122 per cent of full depth. The element slowly filled with water through a fatigue crack on the third outer fold from the base. The element had received about 35 cycles in previous tests. The leak was no doubt incipient before the test, and would have happened during the life test.

ANALYSIS OF PRESSURE ELEMENT TESTS

The PP-1 element has more abnormal piston friction and hysteresis than the PP-2 element because the stiffer spring of the latter overrides the defects. If the ordinate of figure 8 is multiplied by 450/200 to correct for the spring, the values for PP-2 are still somewhat less than those for PP-1. The results indicate that most of the loop hysteresis is in the bellows.

The abnormal piston friction is apparently caused by the spiral groove catching on the bushing edges. The groove appears to be intended for lubrication and its need is doubtful. The snagging can be reduced by increasing the pitch of the groove and rounding the edges of the bushings. The latter step is desirable regardless of the groove.

The accelerated life and overpressure tests disclosed cracks on the outer folds of the bellows nearest the bases of the elements. The outer folds have a much sharper bend radius than the inner ones and therefore fail first. The rough and grainy appearance of the outer folds shows that the metal has been excessively deformed and is metallurgically unsatisfactory. The bellows appear to have been hydraulically formed, resulting in crimped outer folds. The base bellows might have failed because they were heat treated more severely than the others during soldering of the base.

GENERAL DISCUSSION

The equipment specification (section 3.5) requires greater temperature accuracy than the present BT design can give. The required temperature accuracy is one part in 600 (0.1°F equals 0.0017 inch on slide), while the pressure accuracy is only one part in 100 (0.007 inch on slide). The BT design is so primitive and environmentally sensitive that the pressure accuracy can barely be obtained and the temperature accuracy is not practical. Such accuracy is not necessary for sonar applications and is required only for research work. However, it is not practical to require high accuracy of all the BT's so that a few can be used for research.

The equipment specification (sections 3.3.3, 3.6.1.2, 3.6.2.4) requires overpressure tests at 125 per cent of full depth, but the requirement does not apply equally well to all three models. The 200-foot model is readily lowered deeper than 250 feet when towed, and can be confused with the 450-foot model, as happened during the sea trials of this problem. The requirement is about right for the 450-foot model because it is not easily lowered below 570 feet when towed, and is not readily confused with the 900-foot model. The requirement is too severe for the 900-foot model because few winches have enough cable to meet it and full depth is unlikely during towing. The tests should be approximately as follows: 200-foot model, 500 feet; 450-foot model, 600 feet; 900-foot model, 1000 feet. The temperature elements should all be tested to 1000 feet of water.

There are good reasons for a lighter slide coating than the 10 to 20 per cent light transmission thickness recommended by section 3.6.8.1. A thick coating requires a sharper stylus to obtain a thin trace because of the finite stylus point curvature. If the stylus is too dull for the coating, the smoke will build up in front of the stylus, hindering it and frequently producing a very wide trace. The smeared traces of figure 3 show what can happen, although this case was aggravated by the antifreeze in the calibration water. A thick coating requires more skunk oil, which makes buildup more likely. Also, a thick coating tends to flake like a thick coat of paint. A thin coating has the advantages of a sharper trace, less hysteresis because of less friction, and less buildup. The thin coating reduces the contrast for photography. However, it is much better to get a fair photo of a good record than to get a good photo of a poor record. The best coating is the thinnest that meets minimum requirements for reading and photographing.

The evaluation engineer usually finds room for improvements that cannot be included in the procurement. For example, the sample temperature elements passed the transient response test but had insufficient travel and showed time lag in the sea trials. Increased travel and decreased time lag can be obtained by using 50 feet or more tubing instead of 42, and by winding the capillary so that both ends are connected to the bourdon tube. The hysteresis which is common in BT's can be much reduced merely by shaping the stylus to make it more rigid in its control of the stylus point without stiffening it for the pen lifter.

The sliding sleeve can be modified to make the BT more reliable by cutting a hole in it to provide automatic relieving of the pen lifter port. In the present method* the sleeve is shoved aft, covering the pen lifter port, cocking the lifter and dropping the stylus. Then the sleeve is pulled forward 2 inches to expose the lifter port and allow the lifter to operate. If a hole is cut in the sleeve, the pen lifter will be cocked as the sleeve is pushed and the port will then be relieved automatically as the hole appears at the end of the sleeve travel.

Future bathythermograph evaluations will be aided by receipt of the slides from which the factory grids are made.

CONCLUSIONS

The poor bellows endurance, abnormal friction, and large hysteresis of the pressure elements are the most serious faults of the samples, and *must* be corrected before the BT's can be considered acceptable.

* See ref. 1, p. 3-1, para. 7.

The samples also do not meet the specifications on a number of less vital points which should be corrected before acceptance. The samples will meet the requirements of specifications MIL-B-1537B and MIL-E-16400 after adoption of the required changes listed in the Recommendations section following.

RECOMMENDATIONS

Required Changes

CALIBRATION

1. Improve the temperature calibration to eliminate the variation of temperature error with temperature shown by figures 4 and 6.

2. Make the calibration grid from an average of pips of both increasing and decreasing temperature and depth, in order to minimize hysteresis errors. It would be much better to make a grid from an average of two calibration slides, one of increasing temperature and depth and the other of decreasing temperature and depth, than to calibrate from only one slide and check with a second slide, as prescribed by section 4.2.2 of the specification.

MISCELLANEOUS

1. Inspect swivels to eliminate those that do not operate freely under load.

2. Weigh nose sleeves and reject any weighing less than 5½ pounds.

3. Use longer setscrews for the nose sleeve and deeper counterbores for the nosepieces to eliminate loosely secured sleeves.

4. Place permanent identification marks on nosepieces, forward face of pressure element, thermal element, and body tube. Marks should indicate model number, depth range, and manufacturer. All marks should be visible without removing indicating elements.

THERMAL ELEMENT

1. Eliminate projection of stylus beyond the stylus point to prevent interference with carriage.

2. Inspect stylus motion to eliminate elements whose motion is so nonplanar that stylus-point force cannot be kept within established limits between 28°F and 90°F. Inspect parallelism of stylus motion and slide surface. Adjust them by rotating the thermal element, not the pressure-element carriage.

3. Connect the bourdon tube to the forward end of the capillary.

4. Relieve each protective fin ⅛ inch or more to avoid rubbing on capillary tubing. Wind the capillary as far forward as the protective fins allow.

5. Use a rounded edge for bending the twelve straps in the protective fin cage to increase the bend radius and avoid scoring the surface.

6. Increase the travel between 28°F and 100°F to at least 1.6 inches, as required by section 3.6.2.3 of the specification.

PRESSURE ELEMENT

1. Use temperature-reference pins on the carriage that scarcely protrude above the slides. Avoid breaking-out of the carriage edge when drilling the holes for the pins.

2. Apply protective paint to the solder joints of the bellows, evacuation tube, and pen lifter plunger adjustment to prevent solder corrosion.

3. Eliminate the abnormal piston rod friction found in the hysteresis tests. This can be done by increasing the pitch of the spiral groove or eliminating the groove, and rounding the bushing edges.

4. Reduce the overpressure travel to about 0.05 inch.

5. Study and eliminate the causes of bellows failure.

6. Reduce the nonlinearity of the pressure elements to 1 per cent or less on the traces of decreasing depth, and reduce the loop hysteresis to 1 per cent or less.

GRIDS

1. Make grid lines 0.0015 inch wide or less, except for the periodic heavier lines, which should not exceed 0.003 inch in width. Improve the grid-making apparatus to give the thin lines without extreme underexposure.

2. Cement the grids in the holders more securely. Use a better cement than shellac.

3. Countersink the grid holders for only one type of screwhead.

4. Supply screws with each grid holder.

5. Seat the temperature eccentrics not farther than 0.01 inch from the grid holder.

6. Relieve the edge of the grid holder that overhangs the shallow side of the grid not more than 0.01 inch.

Desirable Changes

The following modifications are not required by the specifications but are recommended for consideration in present and future procurements.

MISCELLANEOUS

1. Use fewer sizes of screw threads and only one head type for each thread size.

2. Use towing fin screw with slotted head that sticks out of the fin.

3. Drill at least two ports on body tube between nosepiece and forward end of pressure element. Increase porting in aft end of thermal element casting to increase circulation past bourdon tube.

4. Put a hole in the sliding sleeve to automatically expose the pen lifter catch port when the sleeve is pushed aft.

THERMAL ELEMENT

1. Use a stylus point made of a tough, hard, corrosion-resistant material that can be fractured or finely ground to produce a point of lasting sharpness. Materials such as tungsten carbide are promising.

2. Avoid kinks and extra bends in the capillary tubing. Bend the capillary to lie in its slot in the body casting.

3. Put screwdriver slots in the ends of the bourdon axis rod. Make the journals for the rod shallow enough to permit repeated tightening.

4. Use threaded rods for mounting the pen lifter assembly on the body casting.

5. Connect both ends of the capillary tube to the bourdon.

Pressure Element

1. Remove metal from the carriage between 30°F and 90°F where the arc of the stylus carries it near the carriage at zero depth.

2. Administer overpressure tests according to the recommendations in the General Discussion.

Slides

Use as light a smoke coating on the slides as can be photographed by the standard procedures. Avoid excessively greasy smoke and excess skunk oil.

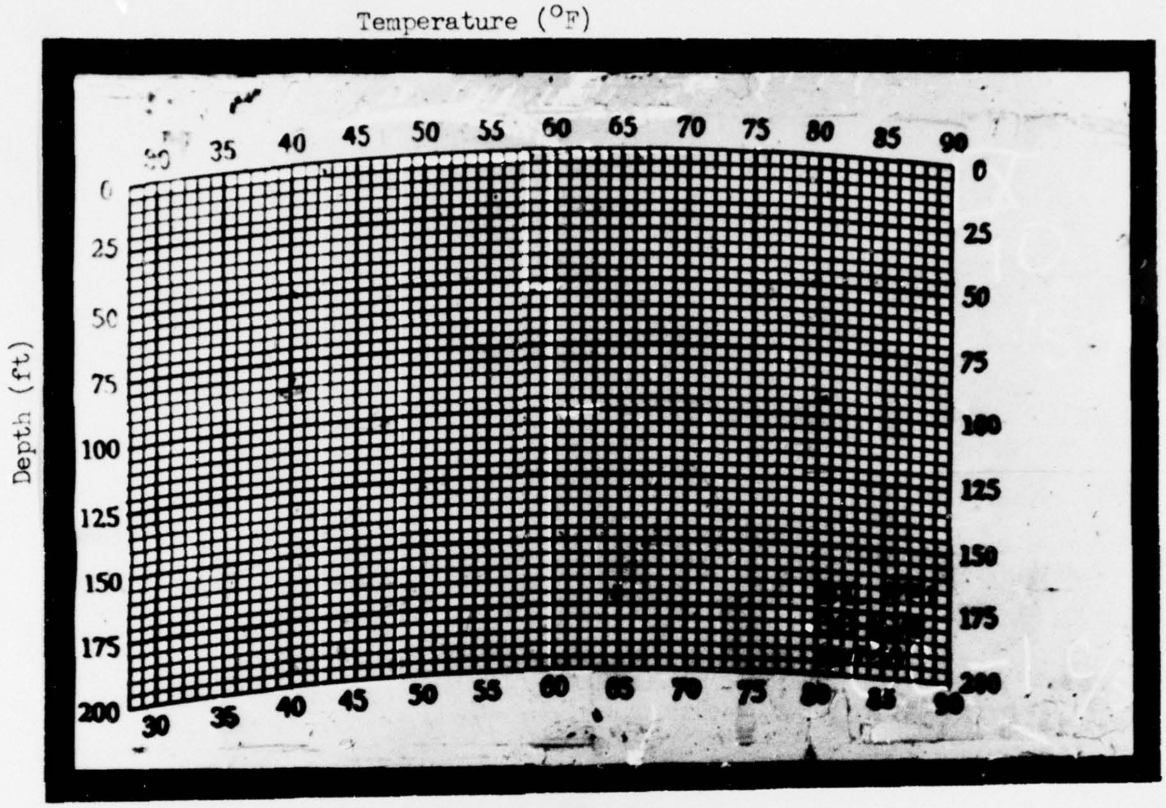


Figure 1. PP-1 Calibration trace.

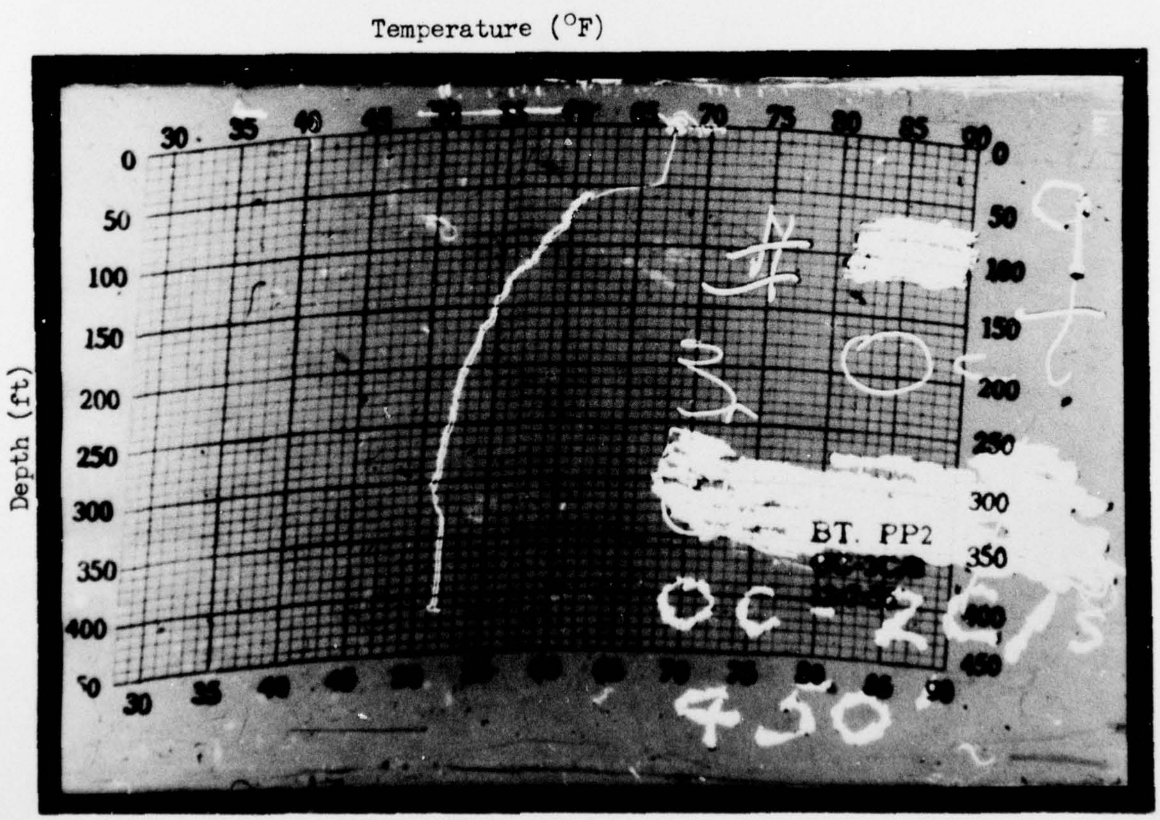


Figure 2. PP-2 Sea trial trace.

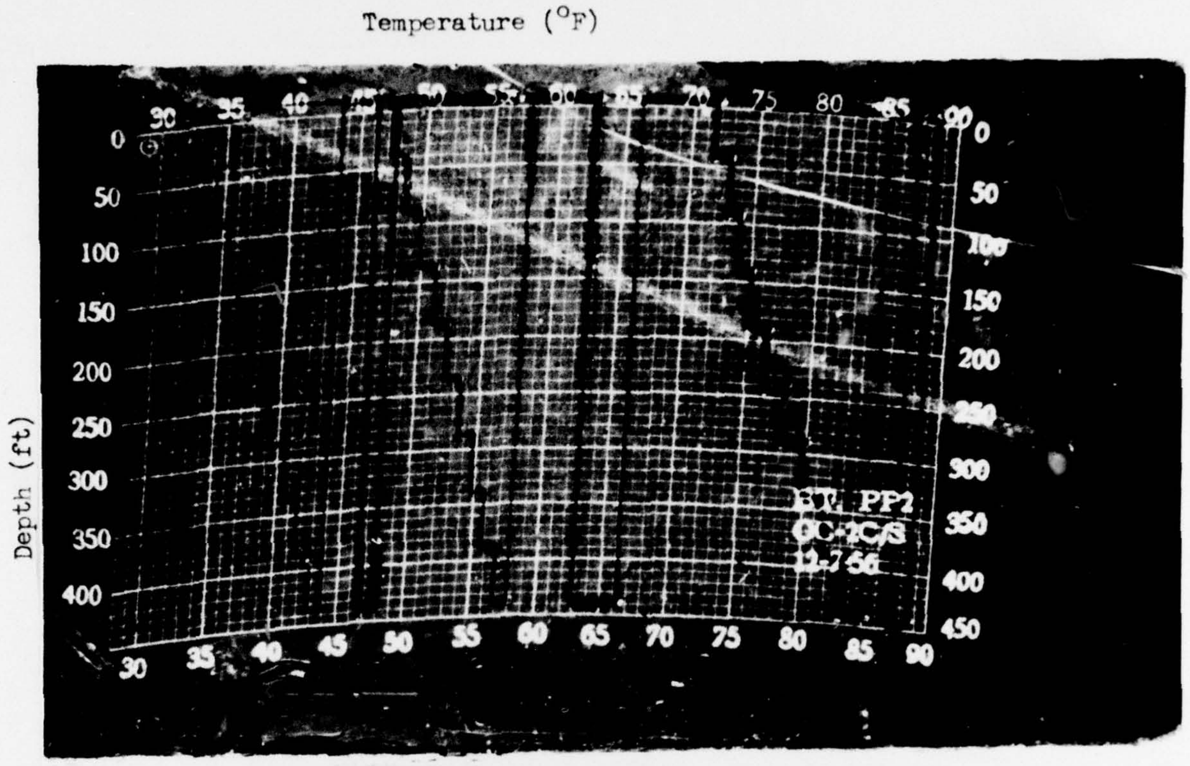
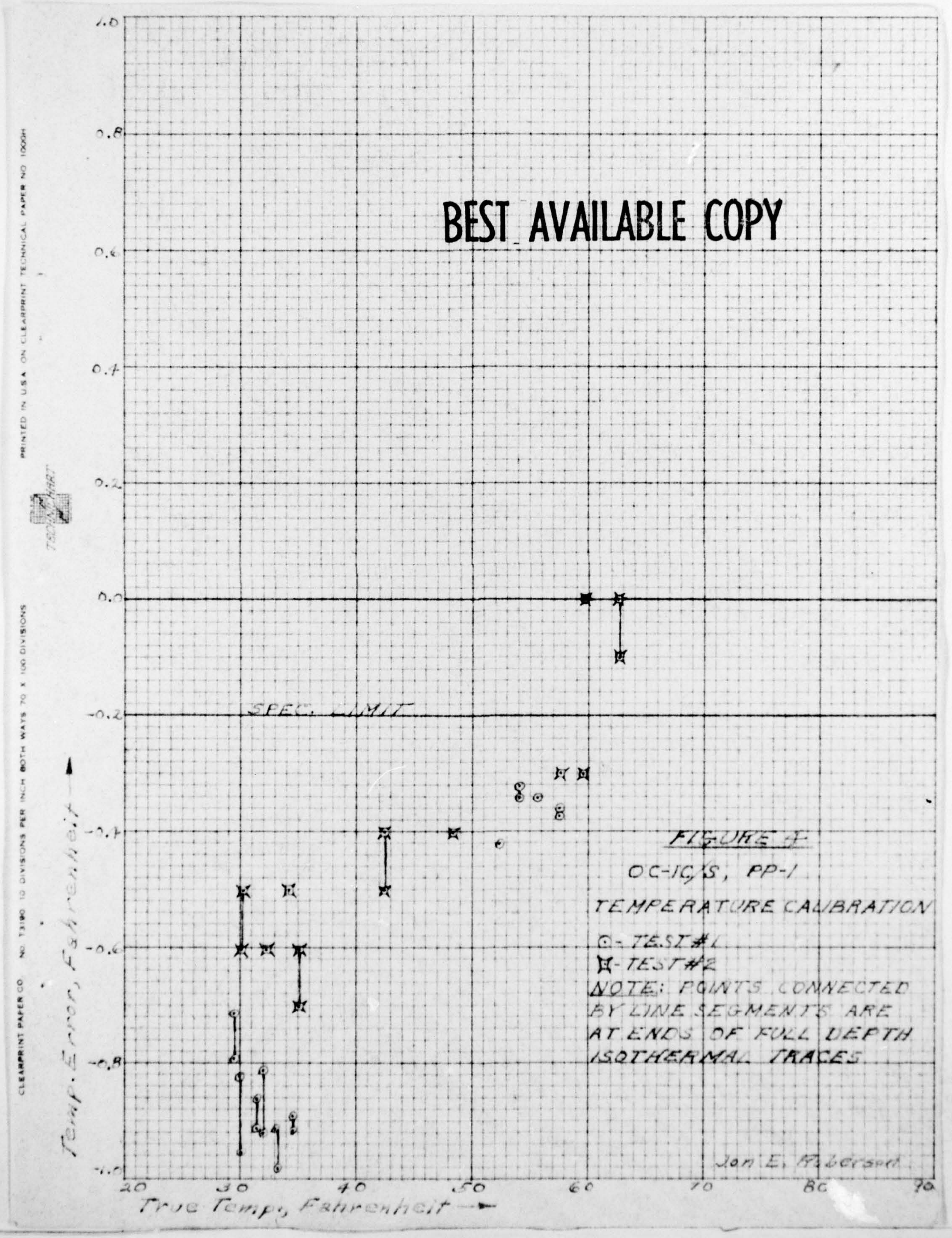
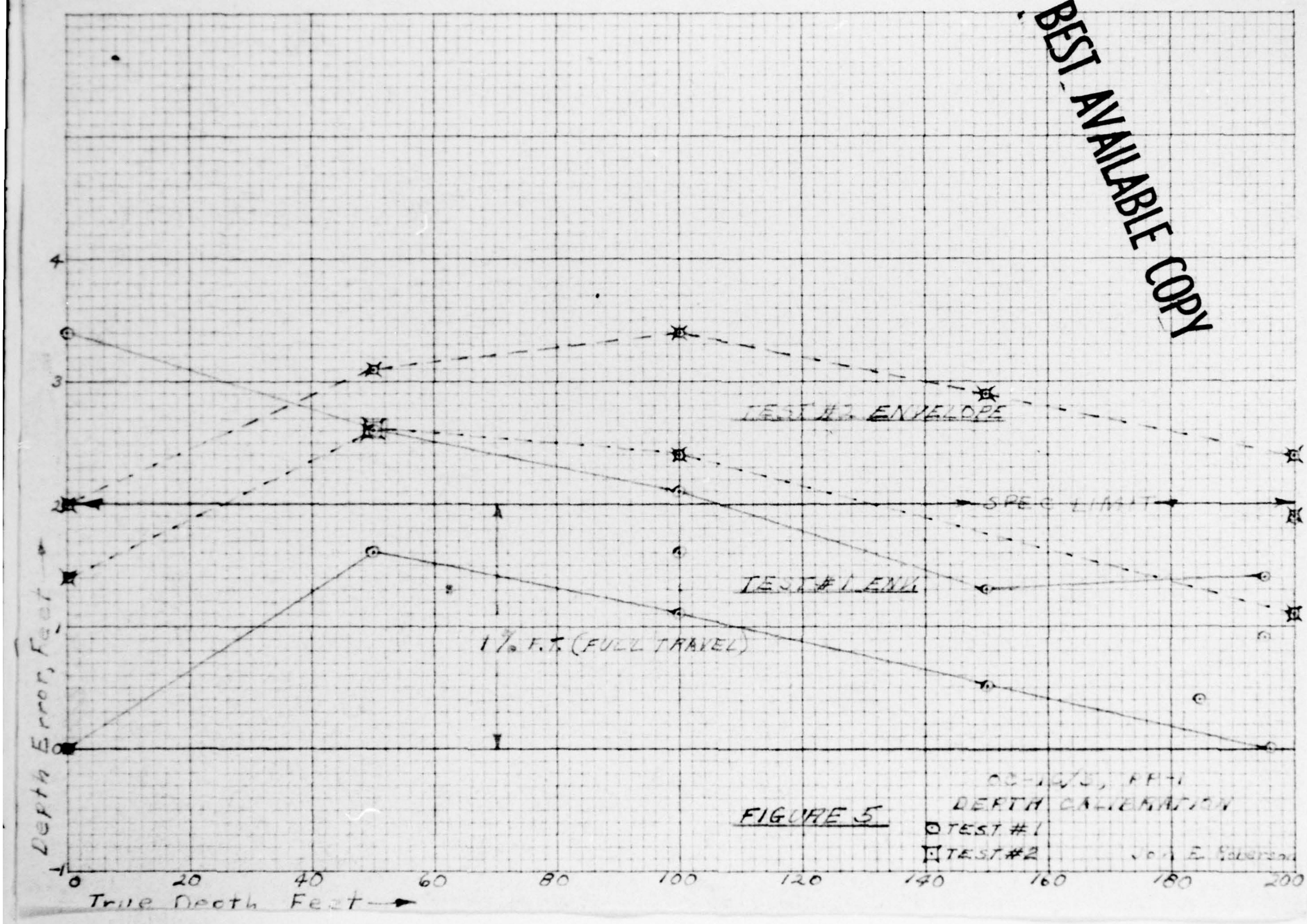


Figure 3. PP-2 Calibration trace


1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
SPEC. LIMIT
20
30
40
50
60
70
80
90
Temp. Error, Fahrenheit
True Temp, Fahrenheit
FIGURE 4
OC-IC/S, PP-1
TEMPERATURE CALIBRATION
⊙ - TEST #1
⌘ - TEST #2
NOTE: POINTS CONNECTED BY LINE SEGMENTS ARE AT ENDS OF FULL DEPTH ISOTHERMAL TRACES
CLEARPRINT PAPER CO. NO. T3190 10 DIVISIONS PER INCH BOTH WAYS 70 X 100 DIVISIONS PRINTED IN U.S.A. ON CLEARPRINT TECHNICAL PAPER NO. 1000H



TEST #2 ENVELOPE
SPEC LIMIT
TEST #1 ENV.
1% F.T. (FULL TRAVEL)
DEPTH CALIBRATION
TEST #1
TEST #2
FIGURE 5
Depth Error, Feet
True Depth Feet
0
20
40
60
80
100
120
140
160
180
200
-1
0
1
2
3
4

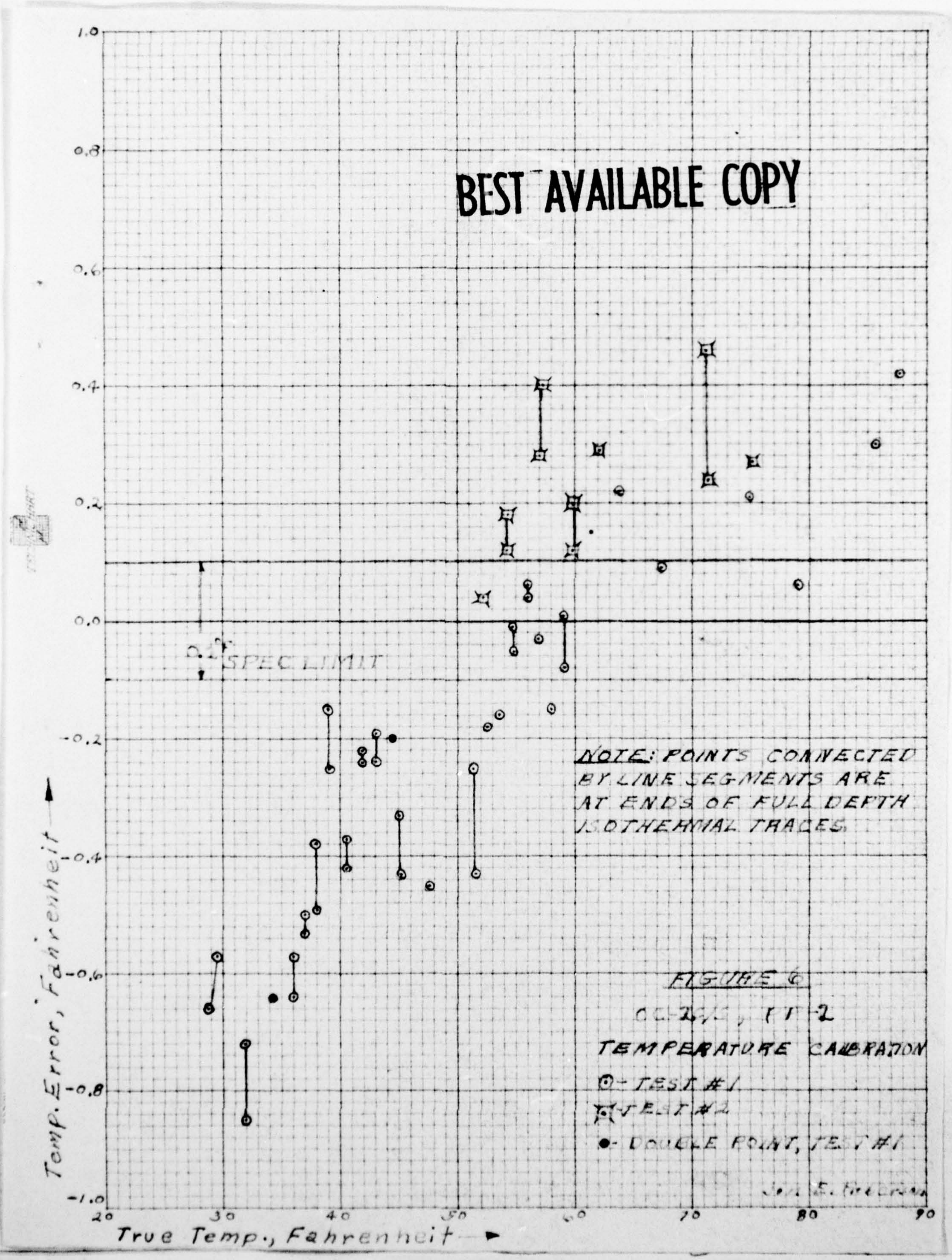


FIGURE 6

TEMPERATURE CALIBRATION

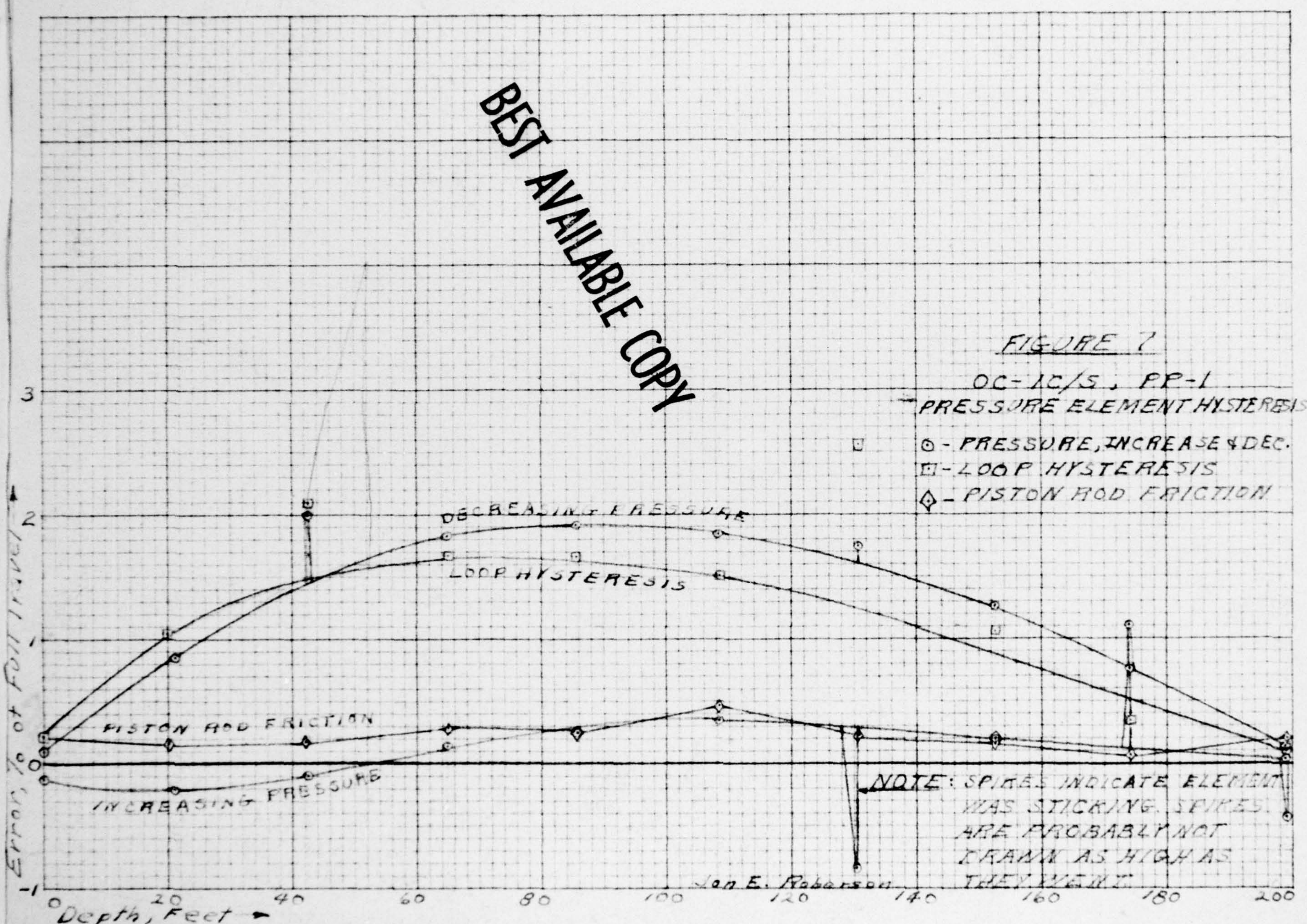


FIGURE 7
OC-1C/S, PP-1
PRESSURE ELEMENT HYSTERESIS
⊙ - PRESSURE, INCREASE & DEC.
⊡ - LOOP HYSTERESIS
◇ - PISTON ROD FRICTION
DECREASING PRESSURE
LOOP HYSTERESIS
PISTON ROD FRICTION
INCREASING PRESSURE
NOTE: SPIKES INDICATE ELEMENT WAS STICKING. SPIKES ARE PROBABLY NOT DRAWN AS HIGH AS THEY WENT.
Jan E. Roberson
Error, % of Full Travel
Depth, Feet
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200

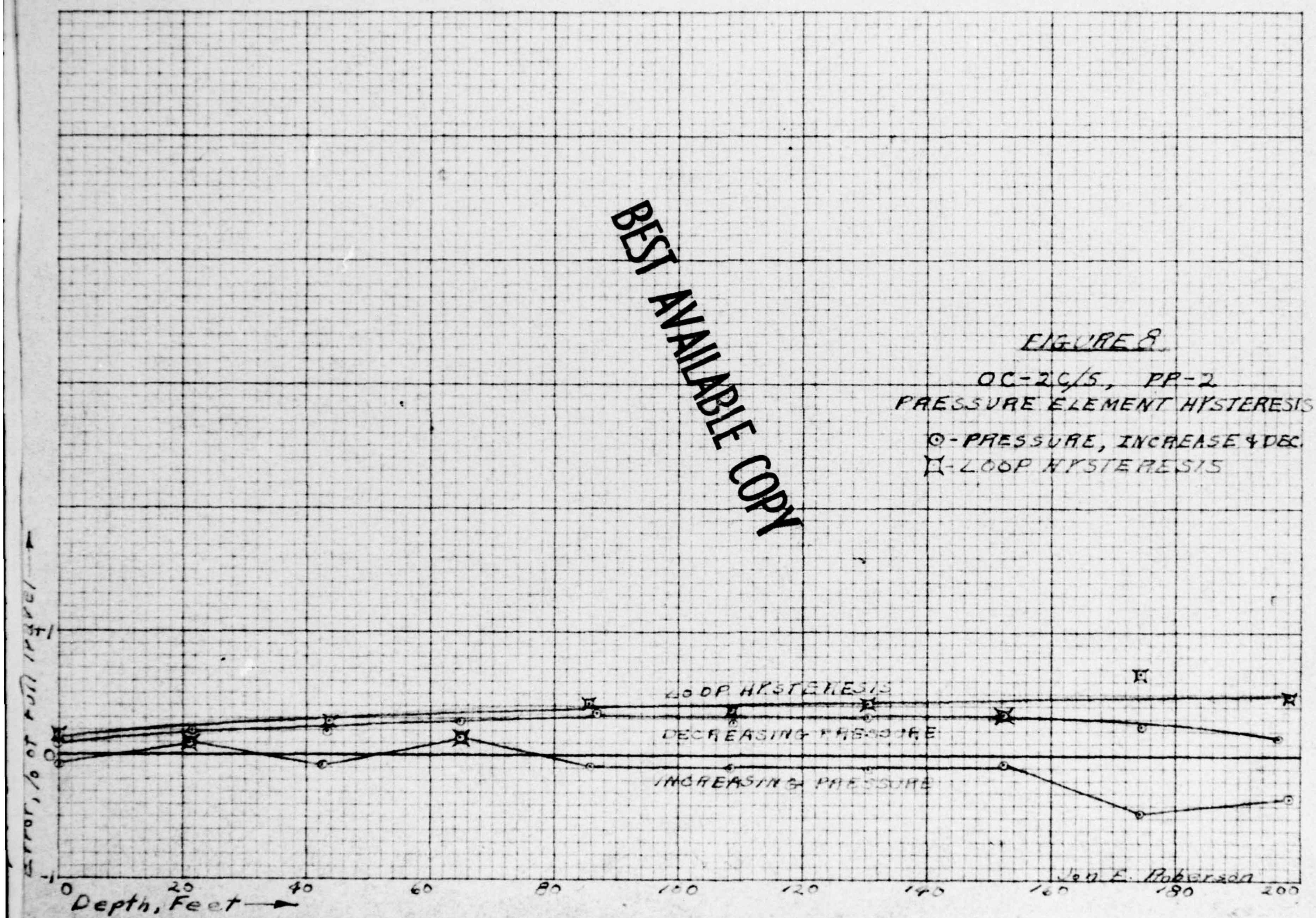


FIGURE 8
OC-2C/S, PP-2
PRESSURE ELEMENT HYSTERESIS
⊙-PRESSURE, INCREASE & DEC.
⌑-LOOP HYSTERESIS
LOOP HYSTERESIS
DECREASING PRESSURE
INCREASING PRESSURE
Error, % of Full Travel
+1
0
-1
Depth, Feet
0
20
40
60
80
100
120
140
160
180
200
Jon E. Roberson

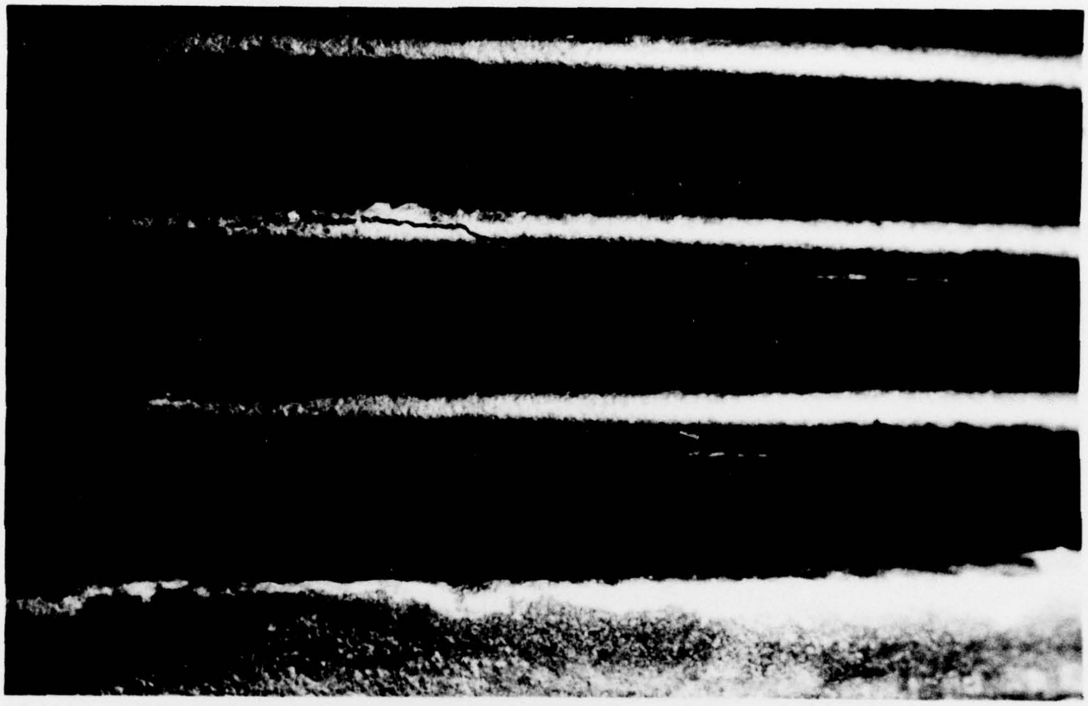


Figure 9. PP-1 Bellows crack.