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Engineering and Equipment

MASTER

STRAIN GAGE TEST AT THE THREADED CLOSURE
ON A THIRTY-INCH PRESSURE VESSEL

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Y-12 PLANT
Oak Ridge, Tennessee

UNION
CARBIDE

UNION CARBIDE CORPORATION
NUCLEAR DIVISION

Operating the

OAK RIDGE GASEOUS DIFFUSION PLANT • OAK RIDGE NATIONAL LABORATORY
OAK RIDGE Y-12 PLANT • PADUCAH GASEOUS DIFFUSION PLANT

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Oak Ridge, Tennessee
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ABSTRACT

A study has been made utilizing the strain-gage measurement method to determine the stresses experienced by the internal threaded areas of the closure on a 30-inch pressure vessel at the Y-12 Plant.

This test was performed to gain information that can be used for: (1) determining the maximum stress levels at operational pressures, (2) estimating the useful operational life of the vessel at various stress levels, (3) making a comparison with photo-elastic studies that were obtained on models of a vessel of very similar design, and (4) estimating the operational pressure parameters of the proposed alterations to the vessel.

Measurements were obtained by utilizing metal-film gages having a gage length of 0.050 inch and a width of 0.044 inch. These gages were secured in the root of the threads with Eastman 910 cement. Measuring accessibility was attained using enameled wire of Size 34 AWG, spot cemented into the root of the thread. Conventional strain readout instrumentation was used.

The highest strains measured were obtained in the thread closest to the internal pressurized area. These values were approximately 3470 microinches/inch.

Results of the test indicate that reliable information can be obtained by this strain-measuring technique provided the installation of the gages and lead wires is given close attention.

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INTRODUCTION

Pressure vessels (isostatic presses) in the Y-12 Plant have operated within a large range of pressure levels and have been capable of pressing a wide variety of materials.

When a change in the mode of operation of a pressure vessel is contemplated, it is generally necessary to review all of the parameters that can affect the operation of the vessel. Any proposed test or operation must fall within the design capabilities of the equipment.

In order to evaluate the capabilities of the pressurizing equipment, it is necessary to obtain information concerning the stresses to be expected in the proposed use of the equipment.

The application of strain gages and strain-gage techniques to obtain actual strain readings at critical areas under load conditions is one way of arriving at a definition of stress conditions and the life expectancy of the equipment.

The most critical area of the vessel in question (a 30-inch-ID pressure vessel) is located in the roots of the wall threads in the lower plug assembly of the vessel.

Since the original installation of the vessel, there has been a considerable advance in strain-gage technology. Consequently, there are now very small strain gages and special cements that can be used to obtain the actual strain in the thread-root areas under actual load conditions.

This study was designed to determine the stresses that occurred at the root of the internal threads of the closure on an existing 30-inch pressure vessel.

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SUMMARY

Strain-gage measurements were made at the root of the top three internal threads of the bottom closure on a 30-inch-ID pressure vessel at pressures up to the operational levels (zero to 22,500 psi).

A preliminary study was made prior to the actual test in order to work out wiring and gage installation problems. This study was made by utilizing the proposed gages and wire with a model of the thread area to be encountered on the test.

The test was performed to gain information that can be used for: (1) determining the maximum stress levels at operational pressures, (2) an estimation of the useful operational life of the vessel at various stress levels, (3) making a comparison with photo-elastic studies that were obtained on models of a vessel of very similar design, and (4) estimating the operational pressure parameters of the proposed alterations to the vessel.

Measurements were obtained by utilizing metal film gages having a gage length of 0.050 inch and a width of 0.044 inch. These gages were secured in the root of the threads with Eastman 910 cement. Measuring accessibility was attained using enameled Size 34 AWG wire, spot cemented into the root of the thread. The measuring equipment consisted of two Baldwin SR-4 strain indicators (a Model M and a Model N) and two ten-channel switching and balancing units (a Budd Company Model SW 1 and a Baldwin Model 225).

The highest strains measured were obtained in the thread root closest to the internal pressurized area. Recorded values were approximately 2940 microinches/inch. Applying the necessary correction factor of 1.18 gives a maximum strain of approximately 3470 microinches/inch.

The interpretation of these values has been given by Pohto and Sturm.^(a)

(a) Pohto, H. A. and Sturm, R. G.; Interpretive Report on the Fatigue Life of a 30-Inch ID Pressure Vessel with Threaded Closure; Union Carbide Corporation-Nuclear Division, Y-12 Plant, Oak Ridge, Tennessee; to be issued.

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PERFORMANCE OF THE TEST

EXPLANATION OF THE PROBLEMS

There was a desire to modify the operation of a 30-inch pressure vessel (isostatic press) and it was felt that more information was needed concerning the principal stresses in the vessel to arrive at a complete evaluation of the safety and life expectancy of the vessel.

The principal stresses in question were known to be at the roots of the wall threads in the lower plug assembly portion of the vessel. This is an area in which another pressure vessel failed while being operated at routinely higher pressures. Calculations based on material tests, external strain-gage tests, and results of photoelastic studies made at the time of the failure of the other vessel were available, but it was felt that more information was needed than had been obtained under the actual operating conditions.

The basic problem was how to obtain this additional information. From Figure 1 it can be seen that the assembled plug and mushroom do not offer ready access to the area in question. The only apparent possibility was to attempt to use a very small strain gage with very fine wire leads to get a circuit into the chamber immediately above the threads. From here it was hoped larger leads could be used and passed through the bleeder passages, down through the plug, and out the bottom to the indicating equipment.

Full advantage would have to be taken of the clearance between the mating threads, shown in Figure 2. This clearance was slightly greater than 0.10 inch, and this fact had a decided bearing on the size of the gage, the number of gages, and the size of the wire to be used.

Several essential conclusions were agreed upon after discussions between the consultant, Y-12 Engineering personnel, and representatives of the Y-12 Physical Testing Department. These points are enumerated in the sections that follow.

Type of Wire

Because the size of the wire leads would be a deciding factor in using up the space available, AWG 34 enameled copper wire would be used for the leads.

Number of Leads and Gages

Due to the diameter of the wire and the fact that the wire would have to be cemented into the root of the threads to make its exit into the cavity above the threads, it was decided a maximum of 40 leads could be used and therefore a total of 20 gages. This would give 10 locations of biaxial gages.

Figure 9
Presents the
Enlarged View

Figure 1. PRESSURE VESSEL ASSEMBLY.

Type of Gage

The gage to be used would be one which would have a grid length of approximately 0.050 inch and be as small physically as practical. Here, again, the major consideration was the area available in which to install the gage. A review of the

Figure 2. THREAD CROSS SECTION DETAIL.

literature on commercially available gages indicated that the Budd C6-1X1-M50 metal film gage would be suitable for the installation.

Location of Gages

In order to obtain the most information possible, the gages would be located in the first three threads from the top of the threaded area (see Figure 1). It was felt the first thread was most critical so there should be five gage locations here. Of the five gage locations remaining, three would be located in the second thread and two in the third thread.

Installation Procedure

The general procedure to be followed during installation is:

1. Cement gages in place with Eastman 910 cement.
2. Attach AWG 34 lead wires to the gage.
3. Cement lead wires into the root of the thread, passing over succeeding gages and picking up additional leads until all 40 leads made their exit into the chamber above the threads.
4. Attach leads to the terminals mounted in the cavity.
5. Attach AWG 22 lead wire to the terminals, allowing plenty of length to reach the outside of the vessel.
6. Insert the plug into the vessel until approximately three turns are required to completely close it. This distance would leave approximately 4.5 inches for working into the cavity over the top of the plug.
7. At this point the external lead wires would be wound around the plug in such a manner as to unwind it into the cavity as the plug was inserted the rest of the way into the vessel. Also, at this point, the leads would be directed out through the plug by way of the bleeder openings (4 each, 90 degrees apart) and cemented in place.
8. Complete the installation of the plug and perform the tests. At this point, the problems of installation and testing were turned over to the Physical Testing Department for completion.

PRELIMINARY STUDIES

The first action on the part of the Physical Testing Department was to conduct a complete review and discussion of the proposed tests with the personnel who would be responsible for procuring the materials, making the installation, and conducting the tests.

Because of the inaccessability of the test area, small size of the gages, generally unusual nature of the tests to be made, and lack of experience with very small gages on the part of the technicians who would be installing the gages, it was decided to study closely a number of the apparent problems before attempting the tests. To provide the necessary study and training, a mockup of one thread was made and a number of practice gages were installed.

Even though the working conditions were much better in the laboratory than they would be in the vessel, this training period provided very valuable experience in using the cements, handling the gages, connecting the leads, and in the general use of the tools for this type of installation. Figures 3 and 4 show a "student" practicing some of the techniques to be used in the actual test.

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Figure 3. WORKING ON THE PRACTICE RING.

Placement of the gage posed one of the major problems of installation. This difficulty existed because of the double inside radius curve into which the gage had to fit. A tape-transfer method was worked out which, with some experience, allowed an application of both gages (circumferential and longitudinal) at the same time. Clear, cellophane tape was used for placing the gages. First, the tape was cut to the narrowest possible width to minimize wrinkling when pressed into the two curved surfaces. Then, once the gage was in place and accurately located in the root of the thread, standard tape transfer attachment techniques were used.

Attaching the gage leads was recognized as another major problem. The gage terminals were only approximately 0.018-inch wide by 0.030-inch long with approximately a 0.005-inch separation between them. This restriction made the solder job

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Figure 4. TOOLS AND MATERIALS FOR GAGE INSTALLATION.

very difficult. One set of leads (longitudinal) had to leave the terminals at almost right angles due to the small clearance from the plug thread and inaccessibility due to the recess of the thread root, and the lead attachment was difficult. Figure 5 shows the arrangement that had to be made.

Suitable soldering equipment and protection from excessive heat on the gage were the first problems which had to be solved in conjunction with the lead attachment. Available standard soldering pencils and accessories were not suitable for this work mainly because the smallest available tip was too large and its mass allowed it to attain and hold too high a temperature. Several soldering methods were tried before it was decided to use a form of a modified commercial tip with a standard 23 1/2-watt heater and standard pencil holder. The end was cut from a copper pyramid tip that was 1/4 inch in diameter. An offset tip fashioned from 1/16-inch-diameter silver brazing wire, approximately 1 1/4 inches long, was brazed to the flat surface remaining on the copper tip. This arrangement provided enough heat at the tip to allow the solder to flow in the small area necessary for proper tinning and joining of lead, but the heat was dissipated rapidly enough so that the terminal did not get too hot. Also, the mass of the copper portion of the tip held the heat close to the small tip so

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Figure 5. ENLARGED VIEW OF AN INSTALLED GAGE JUST PRIOR TO LEAD ATTACHMENT.

there was rapid heat recovery at the point. A tip of this design is shown near the center of Figure 4.

Another problem connected with the gage lead attachment was the small wire size which must be used for leads. It was desirable to use the largest diameter which could possibly be used, but this seemed to be controlled largely by the size of the gage terminals and the clearance between them. Tests indicated that the best results could be obtained by using AWG 40 varnished coil wire between the gage terminal and a Number 2 glass-epoxy-laminate-backed terminal cemented adjacent to the gage. This lead was approximately 0.2-inch long. The Number 2 terminal had to be cemented right in the root of the thread and the rigidity of the backing caused some problems. It was learned that care must be exercised to prevent the backing on the terminal from breaking. The AWG 36 lead attachment to this terminal presented no problem.

In connection with the glass-epoxy backed terminals it was learned, from tests run on standard bars, that exposure to oils and with very slight pressure the copper terminal strip would separate from the backing. Since there was a great possibility of

oil exposure during tests on the vessel, plans were made to ensure that complete moisture proofing was attained by using oil-resistant materials. Tests proved that a coat of Budd GW-1 waterproofing compound over the entire gage and its terminals, followed by two thin coats of four-pound cut shellac, did a good job of protecting the gages and terminals.

During all of these experimental tests, one fact became quite apparent. There was only about 0.1 inch of clearance between the root of the wall thread and the tip of the plug thread, and some gages would have to occupy this space with as many as thirty six AWG 34 enameled leads over them.

Still another major problem was concerned with data reduction and how it might be affected by the large resistance of the small-diameter leads. Calculations indicated that the lead and gage resistance would be between 128 and 145 ohms. It was decided to put the leads in three groups, with a length suitable for the greatest length of each of the three threads where gages were to be installed. Based on this decision, a pair of test gages were installed on a standard flexure test bar. One gage was connected with a short length of AWG 22 leads; the other with AWG 34 leads. The AWG 34 leads were 65 feet in length. This arrangement would simulate the leads used for gages in the second thread and would have a resistance in about the middle of the calculated span for all three threads. The actual resistance of the AWG 34 leads turned out to be 138.7 ohms, while the gage with the AWG 22 leads measured 123.3 ohms. Both gages had AWG 40 leads to connect the gage terminal to the Number 2 terminal adjacent to the gage.

The two gages were connected to a Baldwin Type M, SR 4 indicator through a Budd SB-1 switch and balancing unit. Dummy resistors equal to the total gage and lead resistance were used to complete one arm of a half bridge circuit for each gage.

The gages were first checked to get an indication of their stability under these conditions. As was suspected, the long, small-diameter leads had considerable instability. These leads were located in a room-temperature environment whereas on the actual test they would not be. Therefore, much better stability could be expected since most of the instability appeared to be from temperature variation.

Finally, a quick check was made for gage sensitivity. Because the sensitivity appeared to be quite good, a series of comparison readings were taken. The gages had been located at a point on the bar that should give a strain indication of 1000 micro-inches per inch for full deflection of the bar. The measurements from the gage with AWG 22 leads indicated its accuracy to be very close, but the other gage was reading low. Readings were then made through a range of 2000 microinches per inch and the approximate percent of loss of sensitivity calculated. This loss was in the range of 6 - 7 percent. However, it was felt that this was very good, and reliable data could be obtained under these conditions. Satisfactory preparations had now been made and work began on the vessel itself.

INSTALLATION OF THE GAGES

Figure 6 shows the arrangement that was used for positioning the technician in the bottom opening of the vessel. By adjusting the platform, the work could progress from a sitting position at about desk height. Also shown is the microscope illuminator with its strong, permanent-magnet base. This device provided proper lighting for the very fine and close work necessary for installing the gages.

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Figure 6. INSTALLING GAGE IN THE PRESSURE VESSEL.

The areas selected in each thread for the gage locations are shown in Figure 7. Each surface was prepared by sanding with Size 240 grit paper, cleaned by flushing with acetone, and then neutralized with Budd GA-1B neutralizer.

A suitable number of gages were trimmed, accurately located in proper biaxial respect to each other, and transferred to suitable widths of clear cellulose tape. These gages were then temporarily taped in place on a Teflon sheet to provide for easy removal and installation at the proper time.

After the surface preparation was completed, the tape with its gage set was removed from the Teflon sheet and inverted, the plastic backing removed from the gages, and

Figure 7. GAGE LOCATIONS IN THE THREE TEST THREADS. (Odd Numbers are Longitudinal Gages; Even Numbers are Circumferential Gages)

the back surface of each gage polished lightly with a very fine scouring powder. After this, the gages were dusted free of the scouring powder and taped in place in the root of the thread just as they would be when completely installed. Next, one end of the tape was lifted so that the gages were turned back into the thread with their under side exposed. In this position Budd GA-1A accelerator was applied to the back of the gages and allowed to dry. This treatment was followed by the application of a bead of Eastman 910 cement. The cement was placed in the thread of the pressure vessel just in front of the tape-thread surface interface. A soft gauze pad was used to carefully position the tape in place and to apply slight pressure during the cementing action. Finally, the tape was quickly and very carefully peeled away leaving the gages cemented securely in place.

The second step in the installation process was the cementing in place of the Number 2 terminal strips adjacent to either side of the gages. A typical installation is shown in Figure 5. These terminals were cemented in place one at a time by treating the back of each glass-epoxy laminate with accelerator and, when dried, placing them in position in the cement-coated thread root with tweezers. After being placed in position, the terminal was pressed firmly in place with the end of a cotton swab. This work completed the cementing and left the terminal securely in place.

The next phase of the gage installation involved tinning and soldering the leads. The terminals were first tinned with a very thin coat of solder. This operation was accomplished by first allowing a small amount of rosin-core solder to flow onto the tip of the soldering iron and then transferring the solder to the gage terminal by touching it with the tip of the iron. The only fluxing acid used other than the rosin core in the solder was a small amount of standard solder paste and then only when it seemed the gage terminals were extremely resistant to tinning.

After the terminals were tinned, a short ($\sim 0.2''$, AWG 40 varnished coil wire) connecting lead was attached between the gage terminal and the Number 2 terminal strip adjacent to the gage, also shown in Figure 5. The wire was cut to the proper length and the varnish coating removed for a very short distance back on either end. These exposed ends were then well tinned, exercising care to prevent the accumulation of excessive amounts of solder on the wire. After the leads were tinned, the soldering tip was cleaned of all excess solder, and the leads were attached using a "dry" iron and only the solder on the tinned lead and previously tinned terminal. This procedure provided a suitable amount of solder for a good electrical connection but reduced considerably the hazard of an electrical short across the very narrow clearance between the gage terminals.

Following the attachment of these leads, a set of AWG 36 enameled leads were soldered to the Number 2 terminal and cemented at approximately 2-inch intervals around the root of the thread until the lead emerged into the cavity above the threads. These leads were measured, cut, and spooled in these groups prior to beginning the lead installation. They were again spooled in such a way that the lead attachment could begin with the last gage in the lowest thread and continue around the thread cementing the leads down and attaching the next set of leads as each gage was reached. The gage leads were cut so that all gages in each of the threads would have equal leads. As each successive gage was reached while cementing the leads in place, the leads for that gage were attached and the bundle of leads passed over the top of the water-proofed installation, as shown in Figure 8. Four leads from the gage were added to the bundle and the cementing operation continued. It should be noted here that as the lead attachment was completed at each gage, the entire gage and terminals were made moisture proof with Budd GW-1 water-proofing compound.

Cementing the leads into the root of the thread presented certain problems; namely, to get a cement that would set rapidly and yet have sufficient strength to hold the lead securely in place. Using Eastman 910 cement alone was unsatisfactory, but a suitable technique was worked out by putting a bead of "910" cement in the root of the thread, pressing the bundle of leads into it, and then applying an excessive amount of GA-1A accelerator on top of the wires and cement. The accelerator caused a very rapid reaction in the cement and yet the wires were held securely in place. This procedure allowed the work to move along rapidly.

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Figure 8. TYPICAL LEAD AND GAGE INSTALLATION. (View of All Three Threads)

As the leads were brought into the cavity above the threads they were grouped into four groups, each group terminating in a different quadrant of the vessel. For termination at this point, Number 6 terminal strips were cemented in place and the leads soldered to them. After termination of these leads, resistance measurements were made across the gage and from gage to ground (vessel). These measurements were made to the nearest 0.10ohm and appear in Columns 4 and 7 of Table 1. Prior to these measurements, periodic tests were made that employed a multitester for the purpose of checking for complete short circuits or openings.

The only indication of trouble in any gage was in Gage 8 where there was an indication of a partial short across this gage. By removing the leads from the gage, thoroughly cleaning the terminals, and then resoldering the leads to the terminals, the trouble was eliminated.

After completing the tests, all leads, terminals, and gages were painted with two coats of four-pound cut shellac. After the shellacking was completed, the entire thread area was checked with a male thread gage to be sure that proper clearance was maintained. All areas were cleaned where excessive moisture-proofing compound or shellac might interfere with the insertion of the plug. An interesting note here is

Table 1
GAGE AND LEAD RESISTANCE MEASUREMENTS

1	2	3	4	5	6	7
Gage Number(1)	Cable Number(2)	Color	Resistance Through Gage (ohms)			Resistance to Ground
			At the Junction of the AWG 36 and AWG 22 Lead Wires	End of "Long" Cable	End of "Short" Cable	
1	1	Green	126.9	130.4	129.7	∞ (3)
2	1	White	127.6	131.1	130.3	∞
3	2	Yellow	127.4	130.3	129.6	∞
4	2	Brown	127.5	131.0	130.2	0.5 megohms
5	3	Red	127.4	130.9	130.2	∞
6	3	Blue	127.4	130.9	130.2	∞
7	4	White	127.1	130.4	129.7	∞
8(4)	4	Green	127.3	130.6	129.9	∞
9	4	Blue	128.1	131.4	130.8	∞
10	4	Red	127.7	131.1	130.4	∞
11	2	Blue	134.2	137.7	137.1	∞
12	2	Red	133.7	137.3	136.6	∞
13	3	Green	133.9	137.4	136.7	∞
14	3	White	134.5	137.8	137.1	∞
15	4	Yellow	133.7	137.1	136.4	∞
16	4	Brown	134.5	137.8	137.2	∞
17	1	Red	141.3	144.8	144.2	∞
18	1	Blue	141.2	144.7	144.1	∞
19(5)	3	Yellow	141.7	145.2	126.0	∞
20	3	Brown	141.6	145.1	144.4	∞
C1	1	Yellow	127.5	131.1	130.4	∞
C2	2	White	136.0	139.6	139.0	∞
C3	1	Brown	143.4	147.0	146.4	∞

(1) Gage Type - Budd Metal Film C6-1x1 - M50; Factor - 2.0; Resistance - 120.0 ohms.

(2) Cable 1 - Terminated in SW Quadrant; Cable 2 - Terminated in NW Quadrant; Cable 3 - Terminated in NE Quadrant; Cable 4 - Terminated in SE Quadrant.

(3) ∞ = > 9 megohms.

(4) This gage shorted at the gage terminal but was cleared up later.

(5) This gage apparently partially shorted but cleared up before test was started. Measured 144.6 ohms.

that at some points, particularly at the first or top thread, the clearance was so small that it could only be observed with the aid of optical magnification.

Three dummy (temperature-compensating) gages had been previously prepared by attaching a gage on each of three separate pieces of 1/8 by 2 by 6-inch steel. These gages had leads that were cut the same length as each of the three lengths used for the gages. The dummy gages were located at the top of the cavity above the threads and held in place by cementing them to the vessel by a bead of cement at only one end of the mounting steel. The gages were then taped over to insure that they stayed

in place. The leads from these gages were also soldered to Number 6 terminals cemented in place with the others.

The next phase of the installation was the attachment of the external leads. The leads consisted of six-pair, stranded, unshielded, AWG 22 cables. These cables were insulated with a plastic which was resistant to the oil being used in the vessel. Shielding was omitted due to space requirement. Four of the cabled leads were required for the tests.

The leads were properly identified by cable number and pair number and then soldered to the Number 6 terminals. As the connections were made, proper gage identification and lead number were recorded.

After soldering, the leads were trimmed from the terminals and cemented to the pressure vessel using the same techniques that were employed in the root of the threads. After all leads and cables were secured to the vessel wall, all leads and terminals in the cavity from the thread up were covered with two-inch plastic tape and the tape covered with two coats of shellac.

Following completion of the cable attachment the cables were pulled to the top of the vessel and preparations were made for inserting the vessel plug. At this point another resistance check was made and the resistances recorded to the nearest 0.1 ohm. The readings are shown in Column 5 of Table 1.

The plug was inserted until there were three threads remaining to be turned into the vessel. At this point approximately three inches of working space remained between the seating face of the plug and the end of the vessel.

At this point the technician entered the vessel from the top side and, working through the space at the top of the plug, wound three turns of the four cables onto the portion of the plug extending into the cavity region. This winding was arranged in a way that would allow the cable to wind into the cavity as the remaining three turns were taken on the plug.

After making the three turns around the plug, each cable was cemented into the half-round seat in the top of the plug and fed down through the 0.5-inch-diameter bleeder hole to the outside below the plug.

It was necessary to take the cables to the outside at this time because the bleeder holes were in the portion of the plug which seats against the end of the vessel and becomes inaccessible as the pad portion of the plug enters the vessel. This may be seen more clearly by looking at Figure 9.

After this was completed, the plug was turned another $1\frac{1}{2}$ turns. During this movement of the plug, one cable rolled out over the face of the plug. This was not an unexpected problem so after much work and fishing into the cavity with the aid of mirrors, all of the cables were once more located in the cavity area.

Figure 9. PLUG MATING TO THE END OF THE PRESSURE VESSEL.

An attempt was now made to complete the insertion of the plug, but it could not be inserted completely. Calculations indicated that the plug lacked approximately 0.2 inch from achieving a complete seat against the end of the vessel. Since the thickness of one cable when slightly compressed was about 0.2 inch it was assumed a cable had once again worked over the top of the plug.

At this point some measurements were made and it was determined that the mushroom would properly seal without inserting the plug any further. Thus, it appeared that the tests could be made without further attempts to completely insert the plug.

Resistance measurements were once more made across the gages and to ground as a check against the readings prior to starting installation of the plug. All readings were identical and there was no indication of openings or short circuits (see Column 5, Table 1).

The cables were now ready to be extended to an area adjoining the vessel room and connected to the indicating equipment.

Before connecting the leads to the indicating equipment they were made as short as possible by removing an equal length from every lead. Final resistance measurements were made at this time to provide additional insurance against the existence of open or short circuits. There was trouble in one gage, apparently a partial short, but this cleared up of its own accord before the tests were started. These measurements are recorded in Column 6 of Table 1.

CONDUCTING THE TEST

The pressure-strain gage test was performed with commercially available equipment that consisted of two Baldwin SR-4 strain indicators (a Model M and a Model N) and two 10-channel switching and balancing units (a Budd Company Model SW 1 and a Baldwin Model 225).

In order to obtain data over a wide pressure range, strain-gage readings were made in the following sequence: (1) zero strain readings at zero pressure; (2) readings at 5000 psi; (3) readings at 10,000 psi; (4) zero strain readings at zero pressure; (5) readings at 5000, 10,000, and at every 2000 psi up through 20,000 psi, and then at 21,000 and 22,500 psi; and (6) zero readings after return to zero pressure.

During the performance of the test it was noted that the strain-gage factor had been incorrectly set on the strain indicators. After the test was completed a calibration test was made to obtain a correction factor for this error. This factor was obtained by using strain gages of the same type mounted on a calibration bar and obtaining data using the correct and incorrect gage factors.

In a similar manner a factor was obtained that could be used to correct the results from the effects of the small-diameter and long-lead wires. (Refer to the Appendix for the correction data.)

RESULTS AND CONCLUSIONS

The largest strain readings at an internal pressure of 22,500 psi was about 3000 micro-inches per inch. Table 2 gives the strains recorded from each gage at the various pressure levels. The test was considered very satisfactory, since reliable readings were obtained on all of the installed gages. This means that the data obtained can be applied and used toward a better stress analysis of the vessel. Further, it will contribute to a better definition of the operating parameters, including the life expectancy of the vessel.

Table 2
 RECORDED STRAIN LEVELS ON THE THIRTY-INCH PRESSURE VESSEL
 (All Readings Are in Microinches Per Inch)

Gage Number	Pressure Level (psi)														Maximum Corrected
	Zero	5,000	10,000	Zero	5,000	10,000	12,000	14,000	16,000	18,000	20,000	21,000	22,500	Zero	
1	0	220	480	20	250	470	580	680	760	860	950	1000	1060	- 10	1250
2	0	10	20	30	- 20	20	30	30	40	50	50	40	40	- 10	47
3	0	920	1490	10	860	1500	1740	2020	2190	2430	2660	2770	2940	- 30	3470
4	0	0	20	20	- 20	10	30	30	40	40	40	50	40	- 10	47
5	0	510	1080	10	530	1070	1320	1600	1780	2010	2260	2370	2540	0	2995
6	0	10	30	20	0	30	40	50	60	50	60	60	60	- 10	70
7	0	560	1130	10	590	1130	1400	1710	1870	2110	2380	2500	2670	- 10	3150
8	0	60	90	70	0	80	90	100	100	110	110	110	110	0	130
9	0	960	1400	- 10	990	1400	1590	1760	1880	2020	2170	2240	2340	- 20	2760
10	0	- 20	10	- 10	- 10	20	10	20	30	40	40	40	40	0	47
11	0	- 25	60	0	- 120	60	170	310	410	530	660	720	820	0	970
12	0	- 10	30	- 10	10	40	40	50	50	60	60	60	70	0	83
13	0	580	840	- 10	620	860	960	1070	1150	1250	1350	1400	1470	0	1735
14	0	- 10	20	- 10	10	40	40	50	50	60	60	60	70	0	83
15	0	- 510	- 480	- 10	510	530	560	610	630	660	700	710	740	- 5	875
16	0	- 40	20	- 10	20	30	30	40	40	50	50	50	60	0	70
17	0	450	790	0	470	790	910	1050	1130	1250	1380	1430	1500	- 10	1770
18	0	20	50	0	20	40	50	50	50	60	70	70	70	- 10	83
19	0	340	600	0	350	600	710	830	900	1000	1100	1135	1190	- 10	1400
20	0	0	30	0	0	30	30	40	40	50	50	55	50	- 10	60

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APPENDIX

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CORRECTION FACTORS

Test bars were used to develop the correction factors for error due to the incorrect gage factor and error due to the high resistance of the leads. The gage-factor correction was developed as described in the paragraph that follows.

A gage was installed on a standard deflection bar with leads and installation simulating those in the pressure test. Comparison readings were made of the true factor of 2.00 and the erroneous factor of 2.15. The following values were recorded:

	<u>Gage Factor 2.15</u>		<u>Gage Factor 2.00</u>	
	<u>Reading</u>		<u>Reading</u>	
	<u>First</u>	<u>Second</u>	<u>First</u>	<u>Second</u>
Zero	8970	8965	8800	8800
Load	9950	9930	9860	9850
Strain (μ inches/inch)	980	965	1060	1050
Average Strain (μ inches/inch)	973		1055	

$$\text{Gage Factor Correction} = \frac{1055}{973} = 1.08.$$

The correction factor for lead resistance was developed in a manner similar to that just described except in this case two gages mounted on the same test bar were compared. One gage was installed to simulate the gages on the vessel having a greater resistance and one simulated a condition of insignificant lead resistance. The following values were recorded:

	<u>Low Resistance (123.3 ohms)</u>		<u>High Resistance (138.7 ohms)</u>	
	<u>Load 1</u>	<u>Load 2 (doubled)</u>	<u>Load 1</u>	<u>Load 2 (doubled)</u>
Zero	8,990	9,000	8,980	8,980
Load	10,060	11,160	9,960	10,940
Strain (μ inches/inch)	1,070	2,160	980	1,960

$$\frac{1070}{980} = 1.092 \text{ Factor for Load 1} \quad \frac{2160}{1960} = 1.102 \text{ Factor for Load 2}$$

$$\text{Average Correction Factor for Lead Resistance} = 1.097.$$

$$\text{Correction for Gage Factor Error and Lead Resistance} = 1.097 \times 1.08 = 1.18.$$